



Test Plan Water Tunnel Pump Model

Submitted to:

**Office of Naval Research
Ballston Tower One, 800 North Quincy Street
Arlington, VA 22217-5660**

**Dr. Paul Rispin, Program Manager
ONR Code 33X
703.696.0339
rispinp@onr.navy.mil**

**In fulfillment of the requirements for:
FY 2004 Cooperative Agreement No. N00014-04-2-0003
*Agile Port and High Speed Ship Technologies***

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

Classification: Unclassified

Prepared and submitted by:

**Center for the Commercial Deployment of Transportation Technologies
California State University, Long Beach Foundation
6300 State University Drive, Suite 220 • Long Beach, CA 90815 • 562.985.7394**

February 08, 2005

STATUS REPORT

**FY 04 PROJECT 7, PE 2.29
TASK NO. 7.2**

WATER TUNNEL PUMP MODEL TEST PLAN

System:

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

By:

CDI Marine Company
Systems Development Division
900 Ritchie Highway
Severna Park, MD 21146

For:

Center for the Commercial Deployment of Transportation Technologies
6300 State University Drive, Suite 332
Long Beach, CA 90815

CCDoTT Fiscal 2004 Sub-agreement: S07-291804CDI
Prime Agreement No.: N00014-04-2-0003

CCDoTT Project Director:

Stanley Wheatley
CCDoTT
6300 State University Drive, Suite 332
Long Beach, CA 90815

CDI Marine SDD Technical Manager:

John Purnell
CDI Marine Systems Development Division
900 Ritchie Highway, Suite 102
Severna Park, MD 21146

This material is based upon work supported by the Office of Naval Research, under Cooperative Agreement No. N00014-04-2-0003 with the California State University, Long Beach Foundation, Center for the Commercial Deployment of Transportation Technologies (CCDoTT).

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.

TABLE OF CONTENTS

	<u>PAGE</u>
1.0 Introduction.....	1
1.1 Pump Model Testing and Prototype Waterjet Propulsor Design Information	2
1.2 Functional Description of Test Program.....	3
1.3 Milestones	4
1.4 Participation and Definition of Responsibilities	5
1.5 Location.....	6
1.6 Schedule	6
1.7 Security	6
2.0 Master Test List.....	6
2.1 Test Description	7
2.1.1 Tunnel and Pump Model Checkout Tests.....	7
2.1.2 Performance Tests.....	7
2.1.3 Flow Surveys.....	7
2.1.4 Cavitation Tests	8
2.1.5 Cavitation Visualization Tests.....	9
2.2 Applicable Specifications	9
2.3 Test Parameters.....	9
2.4 Special Tests.....	9
2.5 Test Classification Categories	9
2.6 Test Objectives	9
2.7 Test Equipment	11
2.8 Support Equipment	11
2.9 Special Test Equipment	12
2.10 Approach	12
2.11 Instrumentation	16
2.12 Data Reduction and Analysis.....	18
2.12.1 Calculated and Recorded Parameters.....	18
2.12.2 Definitions of Parameters.....	19
2.12.3 Pump Characterization Curves	20
2.13 Government Test Facilities	22
3.0 Validation Procedures.....	22
4.0 References.....	22

LIST OF FIGURES

		<u>PAGE</u>
1	Test Program Functional Diagram	4
2	Test Schedule	5
3	Model Pump Assembly with Measurement Locations	15
4	Model Pump Performance Map	20
5	Cavitation Breakdown Characteristics	21
6	Pump Performance Verification	21

LIST OF TABLES

		<u>PAGE</u>
1	Test Conditions and Parameters	8
2	Preliminary Estimates for Model Design Point Operation	10
3	Model Instrumentation Requirements	16

QUANTITIES AND SYMBOLS

<u>Symbol</u>	<u>Definition</u>	<u>Units</u>
D_t	Impeller Tip Diameter	ft
g	Gravitational Constant	ft/sec ²
GPM	Flow Rate	gallons/min
ΔH	Pump Headrise	ft
K_p	Pump Power Coefficient	lbm-sec ² /ft ⁴
NPSH	Net Positive Suction Head	-
N_{SS}	Suction Specific Speed	-
ΔP	Pump Pressure Rise	lbf/ft ²
Q	Volume Flow Rate	ft ³ /sec
RPM	Shaft Speed	revs/sec
SHP	Shaft Horsepower	horsepower
T_Q	Shaft Torque	lbf-ft
T_S	Shaft Thrust	lbf
U_t	Impeller Tip Speed	ft/sec
V_{ax}	Axial Inflow Velocity	ft/sec
η_p	Pump Efficiency (Eta)	see section 2.12.2
λ	Impeller Inlet Hub to Tip Ratio	see section 2.12.2
ρ	Fluid Density	lbm-sec ² /ft ⁴
τ_u	Cavitation Coefficient	see section 2.12.2
Φ	Flow Coefficient (Phi)	see section 2.12.2
Ψ	Head Coefficient (Psi)	see section 2.12.2

Subscripts

0	Design Point Value
1 –6	Measurement Plane Locations
req	Required

Abbreviations

cfs	Cubic Feet Per Second
DPT	Differential Pressure Transducer
F	Degrees Fahrenheit
ft	Feet
in	Inches
lbf	Pounds Force
lbm	Pounds Mass
min	Minutes
psia	Absolute Pressure, lbf/in ²
psid	Differential Pressure, lbf/in ²
psf	Pressure, lbf/ft ²
revs	Revolutions
sec	Seconds

1.0 INTRODUCTION

The necessity of delivering time-critical cargo, both commercial and military, has driven future commercial and sealift ships to higher speeds than those currently available using today's technology. The need for high ship speeds of 45 to 50 knots and beyond will require the use of slender hullforms to reduce the ship's drag force and efficient propulsion systems in order to minimize the total installed power that will be required. Waterjets are the overwhelming choice for the propulsion system in these speed ranges due to the lack of appendage drag with an internal waterjet using a flush-mounted waterjet inlet, high propulsive efficiency due to the recovery of part of the ship's frictional drag by ingesting the low momentum boundary layer by the waterjet inlet, and the negative thrust deductions which have been measured on waterjet-propelled ships. These factors lead to higher propulsive efficiencies for waterjet-propelled ships at speeds starting around 25 knots.

Today's commercially available large waterjets, above the 5,000 to 10,000 horsepower range, are of the mixed-flow impeller type where the installation flange diameter is on the order of 70 to 85 percent larger than the inlet flow duct diameter by which waterjets are presently classified by manufacturers. The large flange diameter presents a very difficult integration with the slender hulls required for high-speed ships. Simply stated, there isn't sufficient beam available on the most optimum hullform, so the beam has to be increased to accommodate the number of mixed-flow waterjets required. This results in increased drag and, therefore, additional power must be installed. It is clear that a more compact waterjet system is needed for high-speed ships. The axial-flow waterjet is clearly the solution to this problem since its installation flange diameter is only about 15 to 20 percent larger than the inlet duct diameter.

For high-speed ships, the conflicting requirements of slender hulls and large amounts of installed power, with multiple waterjet units required to absorb that power, has led to the need for this development program on axial-flow waterjets. The coastal commercial ship mission, as identified in the High-Speed Sealift Technology Development Plan, was chosen as the baseline mission for conducting this analysis. The coastal commercial ship mission requires a 50-knot design speed, a range of 1500 nautical miles, and a payload of 1500 metric tons at a full performance wave height of 2.4 meters. This particular mission was one recommended by MARAD for the CDNSWC High-Speed Sealift Innovation Cell. The overall program consisted of a design trade-off study to determine the best hullform and propulsion machinery arrangement for the coastal commercial mission, development of a conceptual integrated hull and advanced axial-flow waterjet for this mission using advanced computational fluid dynamics analysis, development of details for model-scale designs for both a water tunnel test model and a self-propulsion model, and details for test plans for both the water tunnel and the self-propulsion evaluations. This report covers the development of the model water tunnel test plan.

The overall water tunnel test objective is to completely define the hydrodynamic and cavitation performance characteristics of an advanced-design axial-flow waterjet pump model. Measurements will be used to verify design predictions, provide off-design performance information, and yield details of the flow-field for use in understanding the behavior of the new pump design. Data will ultimately be scaled to the 7.5-foot (90-inch) diameter prototype machine and will be used to predict performance of an operational system of that size.

The axial-flow waterjet pump model is to be water tunnel tested to determine performance characteristics at design point and off-design operating conditions. Sufficient data are required to cover the full range of operating conditions anticipated for the primary full-scale waterjet propulsion installation as well as for other hull and mission variants. The waterjet pump design with a representative nozzle will be tested as a unit and may be characterized in terms of powering and thrust performance, with limits defined on suction pressures required to avoid performance degradation and cavitation damage. A broad range of test conditions is needed to assure that performance is fully defined and that any departures from predicted behavior are identified. Model data are ultimately to be used to predict full-scale performance through application of conventional scaling procedures. General information for pump model testing, along with details of the characteristics of the prototype waterjet pump design to be tested, are also presented.

1.1 Pump Model Testing and Prototype Waterjet Propulsor Design Information

Uniform inflow tests are needed to define pump characteristics in general terms and to match the design assumptions as closely as possible. Boundary layer flows could be eliminated using suction or other means in the approach duct wall, but the added complexity and expense of such a system is not warranted since real installations all have developed boundary layer flow as well as flow non-uniformities caused by inlet system geometries and the ingested flow energy distributions. The best situation for the model test approach flow is one in which a fully-developed turbulent axial-flow velocity profile is presented to the impeller, which is essentially free of any radial or tangential components and without significant circumferential variation in pressures and velocities. This profile should be established at a reasonable distance upstream of the impeller leading edge plane and verified by flow-field measurements. The presence of an upstream rotating shaft is typical of most waterjet pump designs and should be considered in the modeling effort to the extent practical. A stationary concentric tube is sometimes used to minimize rotational flow interactions due to the shaft, but this requires supporting struts that cause additional concerns such as axial non-uniformities. An open shaft with a diameter of about 20 percent of the inlet tip diameter is typical of most waterjet installations and probably causes the least difficulty in terms of flow-field interference and departure of test approach flow conditions from those used in the design process. For model tests, this arrangement is satisfactory and can be fairly readily duplicated in different test facilities. However, the chosen water tunnel test facility features a rear drive shaft arrangement. In order to simulate a rotating shaft effect, the inlet nose of the rotor will be extended and installed with a parallel length of about one-half the rotor diameter, which will then be elliptically tapering with a ratio of 3:1 to provide a smooth transition region forward of that.

Conditions at the pump exit are particularly important in waterjet pump modeling because the stator housing and nozzle are usually designed as a unit. Either S-shaped or Pelton-type nozzles are used in specific designs, and the measurement of performance of the pump-nozzle combination is of importance in model testing. Modeling of a Pelton-type nozzle is not generally possible unless a free-jet water tunnel configuration can be provided. This arrangement requires maintaining sub-atmospheric jet exit conditions to enable full characterization of model performance at reduced tip speeds. In addition, the Pelton-type nozzle has a vena contracta associated with its exit flow, which adds to the difficulty of flow measurements since the location of the vena contracta is not easily determined. An equivalent S-shaped nozzle will be used for model testing to reduce the complexity of the overall testing. The S-shaped nozzle, with its parallel exit throat, makes its exit an ideal location to measure nozzle exit conditions since radial flow contributions are significantly minimized, if not totally eliminated, at that location. The rear-drive water tunnel arrangement presents some compromises in testing in which modeling of the nozzle and hub must be adjusted to account for the presence of the drive shaft. In these cases, pump performance data loses some accuracy, and efforts must be made to estimate interaction effects and losses that may be attributed to the presence of the shaft and the recontouring of the exit housing and hub. Nozzle losses may be determined by energy measurements made at both the stator blade exit plane and nozzle exit. It would be desirable that an exit tube with a straight section be fitted to the nozzle, followed by a conical diffuser section configured to avoid exit duct cavitation during low suction head testing. The final exit tube, fitted to the diffuser exit, would continue downstream as far as practical, ending where necessary with a plug-type or other low-loss valve which exits to the tunnel.

The tunnel configuration features an inlet bellmouth or entry tube and duct of sufficient length to provide a fully developed turbulent-flow axial-velocity profile that should essentially eliminate non-uniformities and any measurable radial or tangential velocities other than those induced by shaft nose rotation. This test plan covers uniform inflow tests of a waterjet pump model, which includes an S-shaped nozzle designed to represent the full-scale nozzle as much as possible, with the stator hub shape and the outer nozzle contour geometry not being modified until a slight distance downstream of the stator blade trailing edge location to accommodate the rear drive shaft.

The pump model will be manufactured to assure that geometries and surface finishes will adequately represent the full-scale machine. This means that tolerances should be scaled as the overall scale ratio wherever possible. Some relaxation of this requirement is generally allowed for surface finish so that special finishing and polishing may be avoided. Measurements of geometries and surface finishes are

desired to assure model accuracy and allow corrections to be made to performance data for extrapolation to full-scale. Problem areas in model manufacturing generally involve reproducing thin blade leading and trailing edges, and care is required to avoid adding excess material to these critical regions. Other problems often involve scaling of hydrodynamic clearances, usually caused by assembly requirements and shaft bearing design constraints. Providing scaled blade tip clearances is a particularly important goal, since this dimension can significantly affect performance.

Prototype pump design point parameters:

Impeller diameter:	90 in.
Nozzle diameter:	58.4 in.
Maximum power:	57,330 SHP
Shaft speed:	406.9 RPM
Flow rate:	2405.9 cfs
Headrise:	184.2 ft. seawater
Suction specific speed:	15,005 (maximum value)

Model design point parameters:

Impeller diameter:	7.50 in.
Nozzle diameter (unblocked):	4.87 in.
Shaft speed (target):	2440 RPM
Shaft speed (acceptable):	2000 RPM
Maximum power:	50 SHP
Flow rate (target):	8.35 cfs
Headrise (target):	46 ft. freshwater
Suction specific speed (design point):	12,730

Target shaft speed is determined on the basis of one-half the prototype design tip speed. Power, flow rate, and headrise values are determined using the target values of shaft speed.

1.2 Functional Description of Test Program

The selected water tunnel facility is the 24" diameter water tunnel located at the Carderock Division, Naval Ship Warfare Center. The personnel possess the required capabilities for developing a complete model performance data set. The water tunnel is suitable in terms of powering, flow and pressure ranges required. Instrumentation is complete, including a highly capable Laser Doppler Velocipede (LED) system to characterize and define internal flow-fields. The functional diagram for conduct of the testing program is shown in Figure 1.

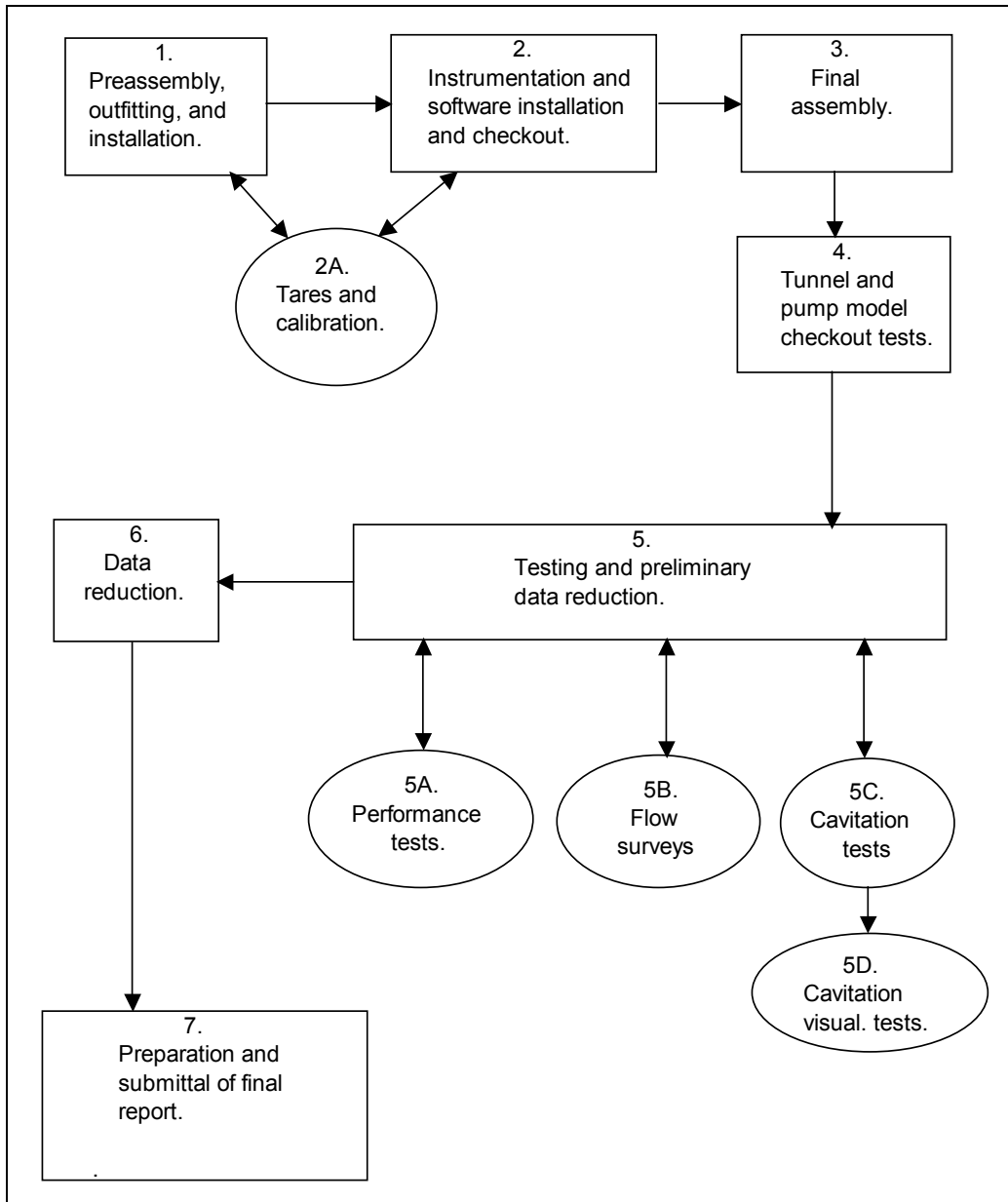


Figure 1. Test Program Functional Diagram

1.3 Milestones

The schedule for the test program completion is provided here for the general guidance of the testing organization. Total time to complete all model tests, reduce and correlate data, and submit the testing data report is of importance since additional review of the data and extrapolation of that data to full-scale will still need to be done. A milestone chart is given in Figure 2 for general reference, with activities numbered as identified in the functional diagram of Figure 1.

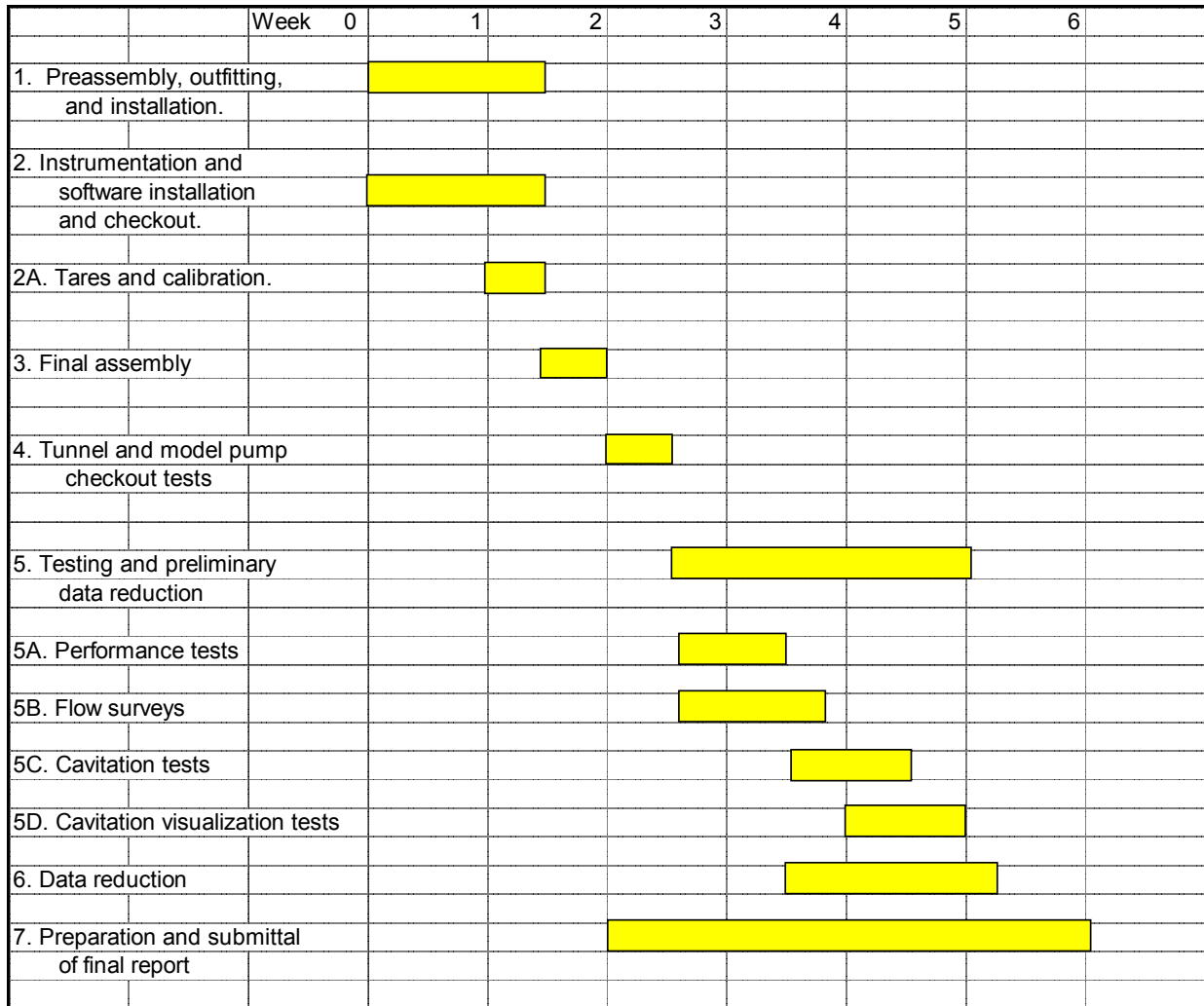


Figure 2. Test Schedule

1.4 Participation and Definition of Responsibilities

This actual testing program will be conducted under a Lead Test Engineer from the testing organization at CDNSWC, with the mutual review of a Technical Manager who will be a representative of CDI Marine SDD. Design of the model test facility fixtures and special components will be accomplished by the testing organization. Instrumentation will be provided by the testing organization in accordance with general specifications as listed in this test plan. The test assembly, special fixtures, components, and instrumentation will be reviewed with CDI Marine SDD prior to the conduct of tests. The special fixtures and components shall be representative of, or include, the following as appropriate:

- Stub 2" shaft piece No. 8 on Reference 4
- A-frame support as shown on Reference 5
- Inlet tube piece No. 7 on Reference 3
- Tunnel mounting plate piece No. 1 on Reference 3
- Flange adapter plate piece No. 2 on Reference 3
- 8" PVC flange assembly piece No. 4 & 5 on Reference 3
- Inlet bellmouth piece No. 3 on Reference 3
- Exit diffuser
- Exit throttling device

Shaft housing bearings
Shaft housing
Strut support
Strut clamp
Struts

The waterjet pump model will be provided by CDI Marine SDD and will include the rotor, stator and shroud assembly, or basically the components enclosed within and including the pump shroud. The interfaces between the pump assembly and mechanical design parts of the tunnel assembly (shaft couplings, piping connections and assembly support pads) will be coordinated by CDI Marine SDD with the testing activity. The test operations will be conducted under the supervision of the Lead Test Engineer from CDNSWC. Other engineers and technicians required during the testing will be provided by the testing organization as necessary.

1.5 Location

Testing will be performed at Carderock Division, Naval Surface Warfare Center in West Bethesda, MD. The test facility will be the 24-inch Variable Pressure Water Tunnel that has been recently modified and outfitted to accommodate appropriately sized waterjet pump models for performance testing and flow-field measurements. Similar types of testing have been performed in this water tunnel and that experience should be of benefit to the presently planned testing.

1.6 Schedule

Testing and test reporting will be completed within a general time period of six weeks (see the Milestone Chart, Figure 1). Considerable scheduling flexibility exists in terms of testing sequence and accomplishment of data reduction/report preparation activities. Model accessibility assures efficient servicing of mechanical components and installing or replacing instrumentation if required. The performing activity is expected to have a reasonable inventory of spare parts and instrumentation-related items on hand to prevent any appreciable delays in completion of the program. The testing facility will assure that critical personnel are available to address and correct any unforeseen problems and to complete the test program within a reasonable scope of the allotted time period.

1.7 Security

Model components and design data provided to the testing activity are the property of CCDoTT as entrusted to CDI Marine SDD. Hardware must be stored and handled in such a manner as to avoid damage or loss, and design data entrusted to the testing organization are not to be disclosed to any person or activity outside the testing organization. No physical measurements other than those needed for assembly and/or servicing are to be made unless authorized by CDI Marine SDD. Test data are to be provided exclusively to CDI Marine SDD and are not to be disclosed in any form to other persons or organizations unless written permission is first obtained.

2.0 MASTER TEST LIST

Required tests are as follows:

- Tunnel and Pump Model Checkout Tests
- Performance Tests
- Flow Surveys
- Cavitation Tests
- Cavitation Visualization Tests

2.1 Test Description

2.1.1 Tunnel and Pump Model Checkout Tests

This initial test series requires careful data evaluations to be performed continuously, with special attention given to linearity of measured torque, thrust and headrise values as appropriate functions of shaft speed. Initial (checkout) test runs must be made at low and gradually increasing shaft speeds to assure that the pump model operation is free of unusual levels of vibration, that there are no indications of problems with impeller to housing contact, and that other mechanical components function properly (i.e. bearings, seals, etc.). During this phase of initial testing, the upper shaft speed limit of the test setup will be established if it is felt prudent not to go to the original shaft speed objectives. It is most important to get the data, which can then be scaled to predict performance at other shaft speeds. Proper functioning of all instrumentation and controls will be verified in these initial tests.

2.1.2 Performance Tests

Performance tests are to be conducted to define the noncavitating performance characteristics of the model. Performance maps will be constructed using measured values of shaft speed, torque, flow rate, and integrated values of total headrise developed by the pump. Headrise will be determined by pressure and velocity surveys made at the inlet, rotor/stator gap, and the discharge flow plane locations as specified. Data will be taken over a range of flow coefficients for each of three shaft speeds to ensure the absence of data nonlinearities or anomalies. For each series, the shaft speed will be maintained at a constant given value and flow rate will be adjusted incrementally by varying the water tunnel circulation pump speed and flow resistance through the model. To vary the flow resistance, an exit-throttling device that consists of a PVC flange will be installed behind the diffuser which has holes for holding rods. The rods will be put in to bring the flow coefficient to a minimum value, then the water tunnel circulation pump will be ramped up to force additional flow through the inlet duct into the model waterjet test pump tube to reach higher flows. Rod configurations can be adjusted, as appropriate, to provide the required data point range. RPM, torque, energy rise, and mass flow measurements will be made in accordance with the testing requirement details given in Table 1.

The maximum shaft speed is determined as that required to operate at approximately one-half the prototype impeller design tip speed. If the test facility driveline needs to be speed limited, a value of not less than 2000 RPM is desired for this maximum shaft speed condition. Suction pressures will first be maintained at values established to assure that cavitation will have no significant effect on pump performance. Other tests will be run to measure performance at calculated suction pressures representing full-scale operation at the design point value of NPSH and the minimum NPSH for off-design operation. Data maps will be presented in nondimensional form, as defined in Sections 2.12.3 and 2.12.4. Data will be tabulated in both dimensional and nondimensional form.

2.1.3 Flow Surveys

These surveys are to be performed to characterize the impeller inflow velocity and energy profiles, determine the total energy rise or fall across the pump impeller and the stator/nozzle, define the degree of rotation in the nozzle exit flow, and to measure performance. Survey data are required to complete the performance maps covered above. Surveys between the rotor and stator are to be made so that rotor and stator/nozzle performance may be determined separately. Sections 2.10 and 2.12 cover detailed testing and data presentation requirements.

Table 1
Test Conditions and Parameters

Test Series	Flow Coefficient Ratio, ϕ / ϕ_0	Shaft Speeds, RPM		Net Positive Suction Head, Feet of Water
		Preferred	Minimum	
5A. Performance	0.70 to 1.20 (preferred) (0.025 to 0.05 steps)	2440 2100 1700	2000 1700 1400	a) 45+
	0.90 to 1.05 (minimum) (0.025 steps)			
	0.92, 0.96, 1.0, 1.04	2440	2000	b) Design point NPSH* c) Minimum operating NPSH*
5B. Flow Surveys	0.70 to 1.20 (preferred) (0.10 steps)	2440	2000	a) 45+ b) Design point NPSH* c) Minimum operating NPSH*
	0.90 to 1.05 (minimum) (0.05 steps)			
	0.70, 1.0, 1.20 (preferred) 0.90, 1.0, 1.05 (minimum)	2100	1700	d) Design point NPSH*
5C. Cavitation		2440 2100	2000 1700	a) 45+ to below 3% breakdown**
	0.92, 0.96, 1.0, 1.04	2440	2000	a) Inception b) Design point NPSH* c) Minimum operating NPSH* d) 3% breakdown**
5D. Cavitation Visualization	0.92, 0.96, 1.0, 1.04			

* Refers to model pump design predicted performance numbers to be provided by CDI Marine SDD with pump model components.

** To be determined during conduct of cavitation tests. A value of 70% of design point NPSH should be used as an initial estimate.

2.1.4 Cavitation Tests

Tests will be carefully conducted to determine the effect of gradually decreasing suction pressure on pump headrise and shaft power, with flow rate maintained at a constant value. Suction pressure is to be decreased to the point at which total headrise is reduced to 3% below the noncavitating value. Pump performance at this point is defined as breakdown performance. Further reduction in suction pressure is established to define performance below breakdown and to assure data repeatability. Tests are to be run at the design point flow as well as at 8% and 4% below, and 4% above, design flow. Complete maps are to be made at the highest shaft speed, with several points run at reduced speeds to verify accuracies. Conditions and data presentation requirements are defined in Sections 2.10 and 2.12.

2.1.5 Cavitation Visualization Tests

These tests are to be conducted using video camera or other applicable photo techniques to observe blade row cavitation at normal and reduced suction pressures. Of particular importance is the determination of location and the extent of tip vortex cavities at design-point operation as well as at several reduced pressure conditions. Viewing and recording of cavitation structures and events is to be accomplished during conduct of the cavitation tests covered in Sections 2.10 and 2.12.

2.2 Applicable Specifications

Specifications are provided in the following subsections. No government or military specifications are cited for this test program.

2.3 Test Parameters

Table 1 summarizes the complete set of test conditions for all testing series. There are two ranges of test conditions shown, with the preferred range being the desired test range objective. The minimum test range would indicate the narrowest range at which data would be obtained due to unforeseen circumstances not allowing the full range to be covered. Preliminary testing will establish the appropriate range of flow and RPM that can be accomplished to provide the most complete data set possible.

2.4 Special Tests

All testing requirements are covered in Section 2.1.

2.5 Test Classification Categories

Referring to Figure 1, the functional areas of these tests are:

4. Tunnel and Pump Model Checkout Tests: Mechanical, electrical, electronic, and hydrodynamic functional checks preceding conduct of the test program.
5. Testing and Preliminary Data Reduction.
- 5A. Performance Tests: Measurements of hydrodynamic performance of the model under noncavitating suction conditions.
- 5B. Flow Surveys: Measurements of flow pressure and velocity distributions in the model inlet, exit, and between-stage locations. Determination of integrated flow rates and flow rate calibration curve.
- 5C. Cavitation Tests: Measurements of hydrodynamic performance of the model at reduced suction static pressures.
- 5D. Cavitation Visualization Tests: Visual observation and recording of cavitation on model blade and ducting surfaces.

2.6 Test Objectives

The overall test objective is to define the hydrodynamic and cavitation performance characteristics of an advanced-design axial-flow waterjet pump model. Measurements will be used to verify design predictions, provide off-design performance information, and yield detailed flow-field data for use in understanding behavior of the new pump design. Data will ultimately be scaled to the 7.5-foot diameter prototype machine and used to predict performance of an operational system of that size.

- a. Success/failure criteria. Approximate performance predictions will be used to guide the testing activity in establishing test conditions. No failure or success criteria will be established or applied by the testing activity in measuring model pump performance.
- b. Baseline data. Design point predicted flow rate, headrise, shaft torque, and shaft thrust will determine baseline values for these quantities. Approximate values for these quantities are to be determined, using information provided in Table 2, once RPM values for testing have been established. Table 1 gives RPM goals and minimum objective values for conduct of the test program.

Table 2
Preliminary Estimates for Model Design Point Operation

Parameter	Symbol	Estimated Value	Equation
Shaft speed, RPM	RPM	2440	—
Flow rate, cfs	Q	8.35	$Q = 3.4 \times 10^{-3} (\text{RPM})$
Total headrise, feet of water	ΔH	46	$\Delta H = 7.7 \times 10^{-6} (\text{RPM}^2)$
Shaft torque, lbf – in	T_Q	1291	$T_Q = 1.84 \times 10^{-4} (\text{RPM}^2) / \eta_p$
Shaft thrust, lbf	T_S	570	$T_S = 9.6 \times 10^{-5} (\text{RPM}^2)$
Shaft horsepower	SHP	50	$\text{SHP} = 2.92 \times 10^{-9} (\text{RPM}^3) / \eta_p$
Flow coefficient (tip)	ϕ_0	0.375	—
Power coefficient	K_P	0.36	$K_P = 10^7 (\text{SHP}) / (\text{RPM}^3) D_t^5$
Net positive suction head, feet	NPSH	27	$\text{NPSH} = 4.16 \times 10^{-6} (\text{RPM}^2)$
Off-Design			
Estimated minimum net positive suction head required	NPSH_{req}	20	$\text{NPSH}_{\text{req}} = 3.1 \times 10^{-6} (\text{RPM}^2)$

- c. Duration. Each test condition must be maintained for a length of time that is adequate to assure steady-state pump model and tunnel operation, and sufficient to assess proper functioning of all instrumentation. Simultaneous recording of all data must be assured where possible, and care taken to prevent drifting of critical conditions during flow visualization recording activities.
- d. Quantity. The preferred range of data points should completely define the performance of the pump model and provide for adequate scaling of data to the prototype propulsion pump. Using the minimum acceptable range of flow coefficients given in Table 1, the number of points is reduced, but will be adequate to give a good representation of the pump performance over the expected core operating range of the prototype propulsion pump. Table 1 lists the conditions to be established for each category of required tests.

2.7 Test Equipment

- a. Description. The 24-inch Variable Pressure Water Tunnel, located at Carderock Division, Naval Surface Warfare Center in West Bethesda, MD, described in Ref. 2, is capable of meeting the model test program requirements. The tunnel will be fitted with downstream throttling rods to facilitate establishment of the large number of test flow conditions needed for developing head-flow maps and other required data sets. The tunnel features a model drive motor that includes shaft torque and thrust dynamometry. Specifications for the drive system indicate adequate shaft speed and powering margins for the pump model.
- b. Nomenclature. Major tunnel components are as follows:
 1. Tunnel Drive Motor
 2. Tunnel Ducting
 3. Convergent Approach Duct
 4. Test Section
 5. Pump Model
 6. Pump Model Drive Shaft
 7. Pump Model Drive Motor
 8. Tunnel Duct Diffuser Section

The tunnel test section encloses the suspended pump model components described below:

- 5-1. Inlet
 - 5-2. Inlet Duct
 - 5-3. Housing
 - 5-4. Impeller
 - 5-5. Stator
 - 5-6. Nozzle
 - 5-7. Exit Duct and Diffuser
 - 5-8. Exit Throttling Device (to be fitted)
- c. Serial Numbers. These are available from the testing activity for items as appropriate. Components that have been specially fabricated for the tunnel and pump model are not necessarily assigned serial numbers. Inventory Control Number listings can be made available as appropriate.

2.8 Support Equipment

- a. Description. Precise control systems for the drive motor are essential for establishing and maintaining required test conditions. These are described in Reference 1. Measurements of model drive shaft torque, thrust and speed are made using a dynamometer system described in that reference. Other support equipment is provided to control dissolved air in the circulated

water and to precisely control static pressure at the model test section entry, as described in Reference 1.

- b. Nomenclature. Support equipment nomenclature is as follows:
 - 1. Tunnel Drive Motor Control System
 - 2. Model Drive Motor Control System
 - 3. Model Torque and Thrust Dynamometer
 - 4. De-aeration System
 - 5. Air Content Measurement System (Van Slyke or equivalent)
 - 6. Static Pressure Control System
- c. Serial Numbers. These can be made available by the testing activity for all but items (4) and (6) above. Inventory Control Number listings can be made available where required.
- d. Calibration Constants. All calibration information can be made available by the testing activity.
- e. Calibration Procedures. This information can be made available by the testing activity.
- f. Operating Instructions. Operating instructions for support equipment are included in facility manuals and other internal documentation used by the testing activity.

2.9 Special Test Equipment

- a. Description. Special components are required to mount the pump model in the water tunnel test section and to interface components for connections with the model impeller, housing and nozzle. An exit duct diffuser section and/or throttling device are required to adjust pump load conditions and avoid cavitation in the downstream region, depending on the test conditions.
- b. Nomenclature. Special equipment nomenclature is as follows:
 - 1. Shaft Adaptor and Impeller Drive Assembly
 - 2. Exit Duct and Diffuser
 - 3. Discharge Throttling Device
- c. Date Required. These components will need to be available at the start of the test program (see the milestone chart, Figure 2).

2.10 Approach

Referring to Figure 1, tests will be conducted according to the practices and procedures appropriate to specific requirements for each type of data set. These are detailed for Milestones 4 – 5D (Figures 1 and 2) in the following subsections. In all cases, data will be provided wherever possible to CDIM-SDD engineers during testing for preliminary evaluation.

- 4. Tunnel and Model Pump Checkout Tests. Initial checkout tests are to be made to assure that the tunnel equipment and model are functioning satisfactorily. Test procedures are as follows:

Establish tunnel test section static pressure at about one atmosphere or higher for initial tunnel and model checkout tests. Operate tunnel drive motor at several low RPM values. Record shaft speed, water temperature, static pressures at tunnel test section and other selected locations, and initial dissolved air content. Operate de-aerating system, as appropriate, and establish a desired level of dissolved air using the Van Slyke measurements. Increase tunnel drive motor RPM and check functioning of all tunnel systems and instrumentation.

Rotate model pump at low speed and check for impeller tip/housing contact and indications of motor, shaft or bearing problems. Increase speed incrementally, monitoring pressures in the model inlet and downstream ducting, approximate flow rate, torque and shaft thrust. Compare recorded quantities with predicted values. Establish a constant RPM in the lower range (1000-1500 RPM) and run for 5-10 minutes with continuous monitoring and recording of model pressures, flow rate, torque, thrust and tunnel data. Compare data to predictions and correct any malfunctions in mechanical equipment and instrumentation if noted. Repeat at two higher RPM values (up to 1500-2560 RPM, as appropriate) and compare data for linearity. Return to lower shaft speeds to check for data repeatability.

Establish several reduced test section pressures and observe performance of model and tunnel components. Check functioning of instrumentation and tunnel components, particularly regarding air leaks and indications of unstable operation such as flow surging and high vibration levels.

Perform upstream flow-field surveys using LDV and/or probe traverses at an appropriate distance upstream of the impeller to establish the inlet flow field. Provide pertinent data to CDIM-SDD engineers for evaluation and analysis regarding any needed changes in hardware, instrumentation or testing procedures.

- 5A. Performance Tests. Determinations of pump performance at static pressures sufficient to avoid significant blade surface cavitation are made in this series of tests. Operating performance is also measured at the design point NPSH and at the predicted minimum operating NPSH values. Maps of headrise, flow rate, and efficiency are constructed and verified by maintaining several constant shaft speeds and varying pump flow rate through systematic adjustment of exit duct area and/or variation of the tunnel circulation pump speed. Table 1 gives the range of parameters for these tests. Procedures are as follows:

Establish a tunnel test section absolute static pressure of 45 ft of water or higher. Operate the model pump at the minimum selected rotational speed and adjust flow rate to cover the required range of flow coefficients by incrementally changing exit area and/or tunnel circulation pump speed. Measure and record shaft torque, RPM, thrust, flow rate and integrated developed head. Calculate pump efficiency using flow rate, developed headrise, RPM and torque measurements. Plot reduced data and evaluate measured characteristics using baseline design point performance estimates for comparison. Repeat this test series at the intermediate and high shaft speed conditions.

After appropriate de-aerating and recording of tunnel conditions, establish a tunnel test section static pressure giving the design point NPSH calculated for the selected highest shaft speed (see Tables 1 and 2). Repeat (see above) performance measurements at that speed. Use flow coefficients given in Table 1. Then repeat this test at a tunnel test section static pressure giving the minimum operating NPSH calculated at the highest selected shaft speed. Measure, record, reduce, and plot data as above.

- 5B. Flow Surveys. Flow-field velocity and static pressure measurements are needed to determine flow rates, allow precise determinations of total energy in pump upstream and downstream flows, and to provide information on the impeller and stator blade row performance. The traversing LDV system will be used to fully define the velocity fields at three axial planes, with multiple locations at each plane, and traversing Kiel and/or pitot-static probe measurements will provide static pressure distributions and dynamic pressure correlations. A fixed Kiel or pitot-static probe located in the model exit duct will provide single-measurement flow rate data after calibrations are made using the detailed flow-field survey measurements. Figure 3 shows survey plane and pressure tap locations. Flow survey test procedures are as follows:

Set model RPM at the selected maximum value. Establish and maintain tunnel test section NPSH at 45 feet of water or greater. Establish the minimum flow coefficient value (Table 1) and

make LDV surveys, traversing radially across the ducting along several radial axes at each of the three survey planes to effectively cover any circumferential variations due primarily to the stationary stator blades. Make Kiel and/or pitot-static probe surveys at the traverse locations for correlation with laser velocity measurements and to determine static pressure distributions. Measure and record total pressure at the fixed-position pitot-static and/or Kiel probe, and record wall static pressures at that plane. Check pitot-static probe data by making traverses at each of the three planes using the Kiel probe.

Repeat this series of tests at each of the listed flow coefficients. Compare the integrated flow rate data obtained at each measurement plane, and develop calibration curve for the single-point measurement probe mounted in the exit duct. This curve is to be used in determining flow rates in the conduct of all tests in the test program, with checks made against LDV surveys at selected test conditions. Run calibration tests at the intermediate shaft speed for three flow coefficients to verify flow calibration curve.

Repeat above surveys at a maximum shaft speed, maintaining tunnel pressures at the design point and minimum operating NPSH values. Check flow calibration curve.

Repeat above procedures at an intermediate shaft speed and design point NPSH for three flow coefficients. Check flow calibration curve.

- 5C. Cavitation Tests. These tests are conducted by systematically reducing suction pressure while maintaining a constant flow rate and shaft speed, recording pump headrise and torque, and plotting these data against NPSH. Procedure is as follows:

De-aerate tunnel and record tunnel conditions. Establish maximum shaft speed condition and the lowest flow coefficient (Table 1). With NPSH set at 45 feet of water or greater, commence testing and record pump headrise and torque at successively reduced NPSH points. Continue until headrise is reduced by approximately 3%, and then continue incrementally reducing NPSH until headrise has dropped to ~10% below the initial (noncavitating) value or lower. Then raise NPSH incrementally until headrise has recovered to the noncavitating value. In order to maintain constant flow rate during these tests, continuous adjustment of the downstream throttling device and/or tunnel circulation pump speed is required. Repeat this test at each of the remaining flow coefficient values given in Table 1.

Repeat the above test series at the intermediate shaft speed value given in Table 1.

Early in this test series, repeat at least one of the cavitation tests run at the maximum shaft speed value, maintaining tunnel dissolved air content at a level of some 50 – 100% greater than established for the above tests. The purpose is to discern any possible effects on performance caused by air content and to allow actions to be taken to correct for air content in the cavitation performance characterizations, if necessary.

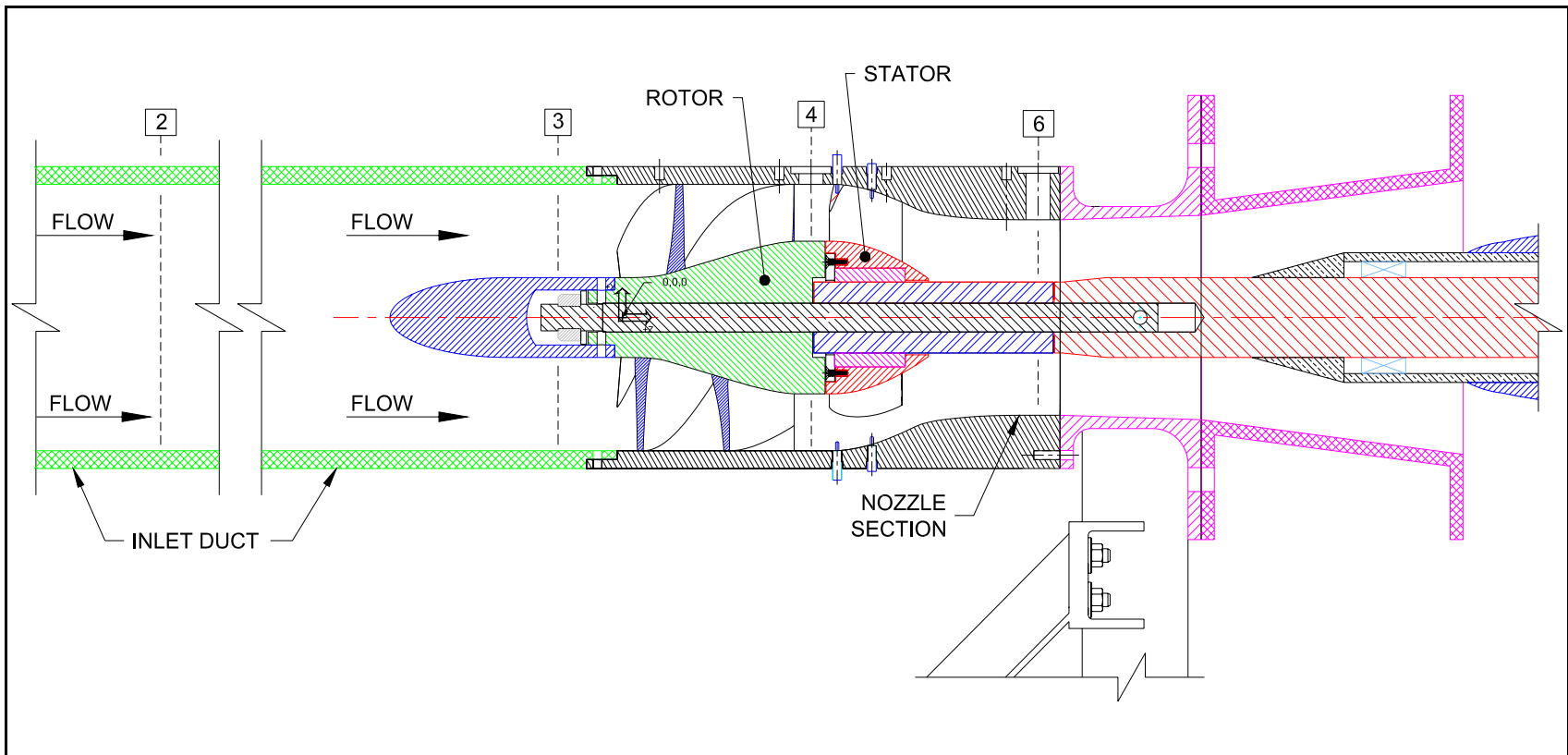


Figure 3. Model Pump Assembly with Measurement Locations

- 5D. Cavitation Visualization Tests. These tests are conducted using stroboscopic and photographic techniques to view and record cavitation at various locations in the model pump. The transparent shroud housing the impeller and stator allows viewing of the impeller and stator blade surfaces, flow channels, and the hub and tip regions of the impeller and stator. Incipient visual cavitation, normally occurring at impeller blade tip regions, will be detected by stroboscopic illumination techniques and recorded. Procedures are as follows:

De-aerate tunnel and operate model pump at the highest selected shaft speed. Establish and maintain test section NPSH at 45 feet of water or greater and the lowest flow coefficient given in Table 1. Gradually reduce the NPSH while observing impeller and stator blade flows using the stroboscope. Record the NPSH at which a steady cavitation pattern is first observed on one or more blade locations. Make photographic recordings. Reduce test section pressure to establish the design point NPSH, and make photographic recordings of cavitation on blades or within flow channels. Further reduce NPSH to the minimum operating value and to the 3% breakdown value, repeating recordings of cavitation patterns in each case.

The above tests should be repeated for the remaining three flow coefficients given in Table 1.

Throughout this cavitation test series, tunnel dissolved air content should be monitored and maintained at a constant level. Inception tests should be checked at three or more values of dissolved air content to allow corrections to be made for air content effects if needed.

2.11 Instrumentation

Data must be sufficient to define pump performance, cavitation characteristics, and limits on the operational envelope that may be dictated by performance degradation and/or damage potential due to cavitation. Basic instrumentation requirements and measurement ranges are summarized in Table 3. Measurement locations are shown in Figure 3.

Table 3

Model Instrumentation Requirements

Measurement	Plane	Axial Location	Circumferential Location	Instruments	Required Range	Notes
2-1 Inlet static pressure	2	1 duct diameter from inlet (approx.)	8 wall taps, equally spaced, 1/16-1/8 inch diameter	Differential pressure transducers (DPTs) (8)	0-10 psid (0-35 psia)	Averaged (referenced to est section static)
2-2 Inlet dynamic pressure	2		Top quadrant of duct	Pitot-static and DPT	0-10 psid (0-35 psia)	Option: see 6-4
3-1 Duct static pressure	3	1 duct diameter from impeller blade leading edge plane	8 wall taps, equally spaced, 1/16-1/8 inch diameter	8 DPTs	0-10 psid (0-35 psia)	Averaged (referenced to test section static)
3-2 Duct flow-field static and dynamic pressure/flow angle survey	3		Traverse at 4 locations, equally spaced	3-hole wedge and 3 DPTs and/or Kiel probe	0-10 psid (0-35 psia)	6 radial locations or more between shaft and housing (referenced to test section static)
3-3 Duct flow-field LDV survey	3			Laser Doppler apparatus	0-35 fps	LDV practice to fully define velocity field
4-1 Impeller exit flow-field velocities, pressures, and angles	4	Midway between blade rows	Traverse at 1 location	3 or 5-hole wedge and/or Kiel probe and 3 or 5 DPTs	0-20 psid (0-65 psia)	6 radial locations or more between hub and housing (referenced to test section static)

Measurement	Plane	Axial Location	Circumferential Location	Instruments	Required Range	Notes
4-2 Impeller flow-field LDV survey	4			Laser Doppler apparatus	0-60 fps	LDV practice to fully define velocity field
6-1 Nozzle exit static pressure	6	In the nozzle exits straight section	8 wall taps equally spaced, 1/16-1/8 inch diameter, mid-channel from stators	8 DPTs	0-25 psid (0-60 psia)	Averaged (referenced to test section static)
6-2 Nozzle exit static and total pressures	6	In the nozzle exits straight section	Traverse across several locations to cover complete stator channel	3-hole wedge or Pitot-static probe and/or Kiel probe, and DPTs	0-25 psid (0-65 psia)	12 diametral locations or more (referenced to test section static)
6-3 Nozzle exit LDV survey	6	In the nozzle exits straight section	Minimum of 1 stator channel	Laser Doppler apparatus	0-75 fps	LDV practice to fully define flow-field
6-4 Nozzle exit dynamic pressure	6	In the nozzle exits straight section	Top quadrant of duct	Pitot-static probe and/or Kiel probe, and DPT	0-25 psid (0-65 psia)	1/3 radius from wall (approx.) Option: see 2-2

Basic instrumentation includes absolute and differential pressure transducers (DPTs), fixed and traversing pressure probes for local flow-field pressure measurements, traversing LDV for flow-field velocity measurements, shaft dynamometer, temperature sensors, and air content measuring system. Suitable electronics must be provided for signal detection, processing, and recording. Overall pump performance is determined by measuring shaft input power and added energy rates in the through-flow. The energy added to the flow is determined by measurements made in the upstream duct and in the pump nozzle. Parameters to be measured and types of sensors are listed below:

- (0-1) Visualization system: Illumination, video camera, and stroboscopic light source to enable viewing and recording of cavitation on blading and within flow channels.
- (0-2) Shaft speed: Counter to measure RPM (may be integral part of dynamometer).
- (0-3) Shaft torque: Dynamometer.
- (0-4) Shaft thrust: Load cell to measure thrust (may be integral part of dynamometer).
- (0-5) Barometric pressure: Periodic measurements as required.
- (1-1) Water temperature: Thermocouple measurement, used primarily for vapor pressure calculations needed in cavitation tests.
- (1-2) Water air content: Determinations of dissolved air using a Van Slyke or equivalent apparatus. Use for making corrections to vapor pressure calculations needed in cavitation tests.
- (1-3) Tunnel test section static pressure: Absolute pressure. Also use as reference pressure for pump model static pressure measurements. 1 DPT, referenced to atmosphere.
- (2-1) Model inlet static pressure: 8 wall taps, pressure averaged. 1 DPT, using tunnel test section reference pressure.
- (2-2b) Model inlet dynamic pressure: Optional fixed-position Kiel and/or pitot-static probe for calibrated single-point flow rate determinations. 1 DPT. Kiel probe referenced to averaged wall tap pressure (2-1).

- (3-1) Model duct static pressure: 8 wall taps, pressure averaged. 1 DPT, using tunnel test section reference pressure.
- (3-2) Duct flow-field static and dynamic pressure: 3-hole wedge or pitot-static probe, yaw angle measurement range $\pm 10^\circ$ and/or Kiel probe. 3 DPTs, referenced to tunnel test section static pressure.
- (3-3) Duct flow-field velocities and angles: Detailed 2-dimensional flow measurements using LDV system.
- (4-1) Impeller exit flow-field velocities, pressures and angles: 3-hole wedge or 5-hole probe and/or Kiel probe. Yaw angle range $\pm 90^\circ$. Pitch angle range $\pm 15^\circ$ for optional 5-hole probe. 3 or 5 DPTs, referenced to tunnel test section static pressure.
- (4-2) Impeller exit flow-field velocities and angles: Detailed 2-dimensional flow measurements using LDV system.
- (6-1) Nozzle exit static pressure: 8 wall taps, pressure averaged. 1 DPT, referenced to tunnel test section static pressure.
- (6-2) Nozzle exit static and total pressures: Pitot-static or 3-hole wedge probe option and/or Kiel probe. 3 DPTs, referenced to tunnel test section static pressure.
- (6-3) Nozzle exit flow-field velocities and angles: Detailed 2-dimensional flow measurements using LDV system.
- (6-4) Nozzle exit dynamic pressure: Optional fixed position Kiel or pitot-static probe. 1 DPT. Kiel probe referenced to averaged wall taps at 6-2.

2.12 Data Reduction and Analysis

Approximately 30 channels of data will be measured, processed, and recorded for pump performance and cavitation testing. A digital system is required, using appropriate sampling rates and real time averaging to assure accuracies. Electronic signals are sent to a data reduction system, and sensor calibration data applied to each signal to compute physical quantities (rates, forces and pressures). Additional data reduction is accomplished using PC programs developed to convert multiple channels of information into quantities defining the pump performance. Refer to Section 2.11 and Table 3 for a listing of measured data to be recorded.

2.12.1 Calculated and Recorded Parameters

Basic parameters to be calculated and recorded based on measured data are:

Pump flow rate: This is determined using the calibrated inlet bellmouth as well as traverse data from planes 3 and/or 6. The axial component of the probe dynamic pressure is processed using incremental area summations to yield average flow rates. Integrated flow rates measured at both planes are checked against one another to ensure accuracy. LDV traverses at these two planes are integrated in similar fashion and computed flow rates checked against the probe traverse calculated flow rates. The bellmouth will be planned as the primary flow measurement device for all tests.

Pump headrise: Determined using traverse data from both planes 3 and 6. Local total pressures are multiplied by the local incremental mass flow rate and summed over each plane, giving the fluid power at each plane. The difference in power calculated in this manner between planes 6 and 3 is then divided by the integrated mass flow to give the pump headrise.

Pump fluid power: Determined using traverse data from both planes 3 and 6. Local total pressures are multiplied by the local incremental mass flow rate and summed over each plane, giving the fluid power at each plane. The difference in power calculated between planes 6 and 3 is defined as the power added to the fluid by the pump model. Care should be taken to consider circumferential and radial velocity non-uniformities if flow surveys find them to be significant. Total integrated flow rate must be checked against calibrated bellmouth measurements in all cases.

Impeller fluid power: Determined using traverse data from both planes 3 and 4. Local total pressures are multiplied by the local incremental mass flow rate and summed over each plane, giving the fluid power at each plane. The difference in power calculated between planes 3 and 4 is defined as the power added to the fluid by the impeller. Total integrated flow rate is checked against bellmouth measurements in all cases.

Shaft power: The tunnel drive shaft dynamometer provides shaft torque measurements. Power is determined using this and the shaft speed measurement. Before testing, tests are run with no impeller to correct for frictional drags on the drive shaft and radial bearing assembly.

Net Positive Suction Head (NPSH): The total flow energy measured at plane 3 is calculated using the survey data at that plane. Measured integrated fluid power is then divided by the measured integrated mass flow to give total average suction head, and the fluid vapor pressure component subtracted to give NPSH.

Flow-fields: Circumferential and axial components of flow velocity are measured by LDV surveys at planes 3, 4 and 6. Radial velocities cannot be measured with the LDV setup, as it would require an additional unit mounted inside the pump to get the radial component, which is not feasible. However, radial velocity components are very minimal at these three survey planes. Recorded data are provided as part of the overall pump performance characterization data set.

Visual recordings of cavitation: Video recordings are to be provided to allow viewing of flow cavities in the relative reference frame. Recordings are to be made using stroboscopic illumination techniques.

2.12.2 Definitions of Parameters

Performance characterization will generally be in the nondimensional terms defined as follows:

Flow coefficient	$\Phi = V_{ax} / U_t$
Head coefficient	$\Psi = 2g \Delta H / U_t^2$
or	$\Psi = 2 \Delta P / \rho U_t^2$
Power coefficient	$K_p = 10^7 (\text{SHP}) / (\text{RPM}^3) D_t^5$
Efficiency	$\eta = 9.545 (g \rho Q \Delta H) / T_Q (\text{RPM})$
Cavitation coefficient	$\tau_u = 2g \text{NPSH} / U_t^2$
Suction specific speed	$N_{ss} = (\text{RPM}) (\text{GPM}^{1/2}) / \text{NPSH}^{3/4}$
Design point flow coefficient	$\Phi/\Phi_0 = V_{ax} U_{t0} / V_{ax0} U_t$
Design point head coefficient	$\Psi/\Psi_0 = U_{t0}^2 \Delta H / U_t^2 \Delta H_0$

The dimensional expression for axial velocity at the impeller blade leading edge is:

$$\text{Axial velocity} \quad V_{ax} = 4Q / \pi D_t^2 (1 - \lambda^2)$$

2.12.3 Pump Characterization Curves

Sample data plots are given in Figures 4 – 6. Plotted data are as follows:

Figure 4. Φ , Ψ , and K_p plotted against Φ/Φ_0
 RPM = 2440
 NPSH = 45 ft of water (or higher).

This plot is to be repeated for two reduced RPM values (see Table 1).

Abbreviated data sets are to be plotted for the design point NPSH and for the minimum operating NPSH values.

Figure 5. Ψ plotted against τ_u for 4 values of Φ/Φ_0
 RPM = 2440

This plot is to be repeated for one reduced RPM value (Table 1).

Figure 6. Φ , Ψ , and K_p plotted against RPM

This plot is to be made for the purpose of verifying test data linearity. Data trends or inconsistencies will generally show instrumentation or test facility-related problems, should any exist. Repeat for 3 additional values of Φ/Φ_0 .

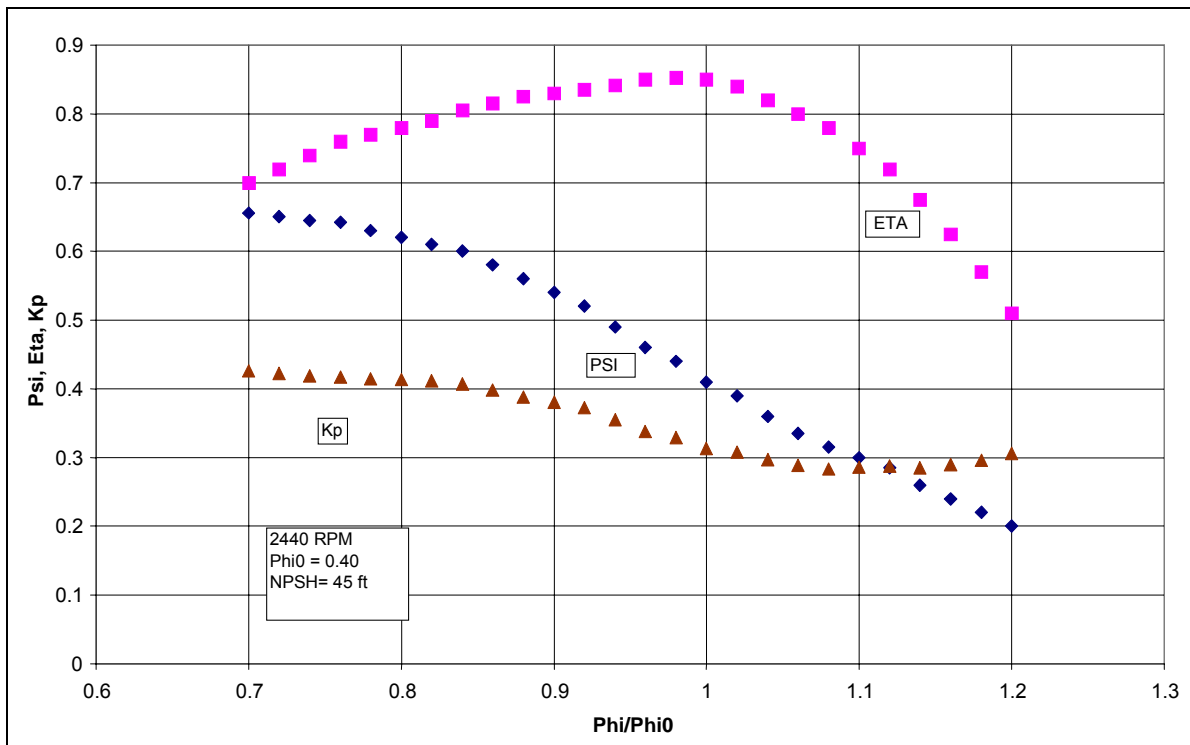


Figure 4. Model Pump Performance Map

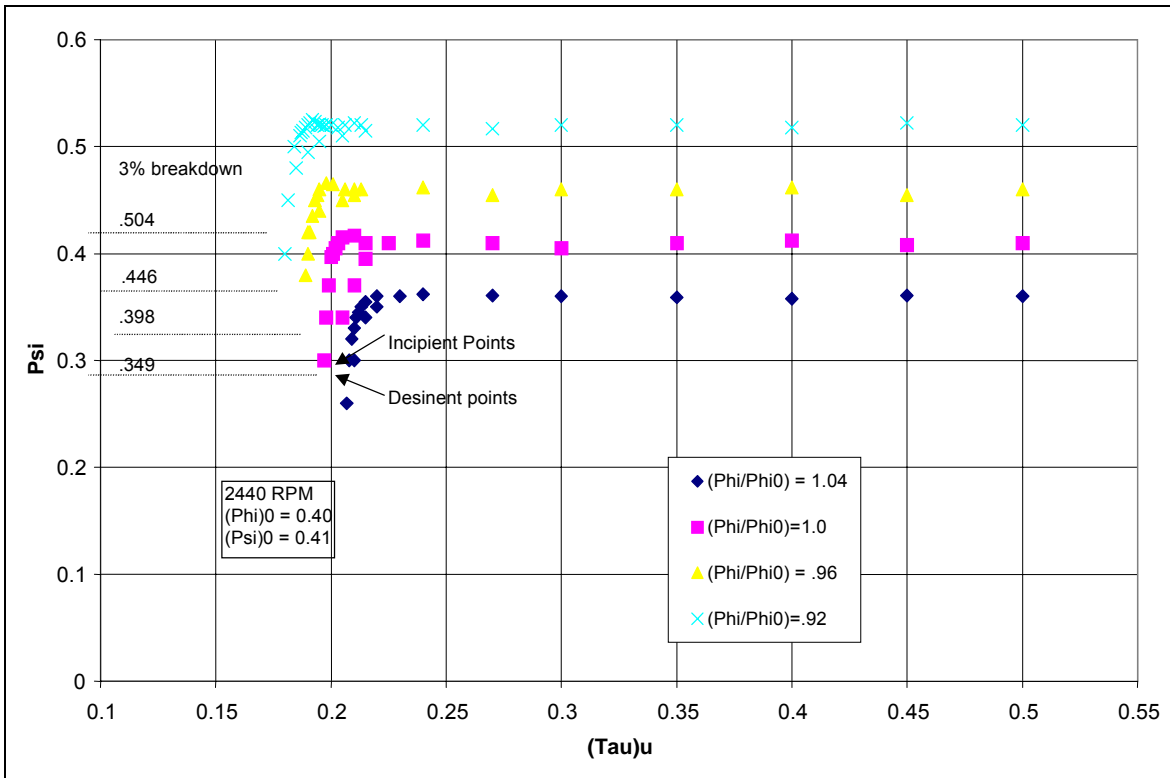


Figure 5. Cavitation Breakdown Characteristics

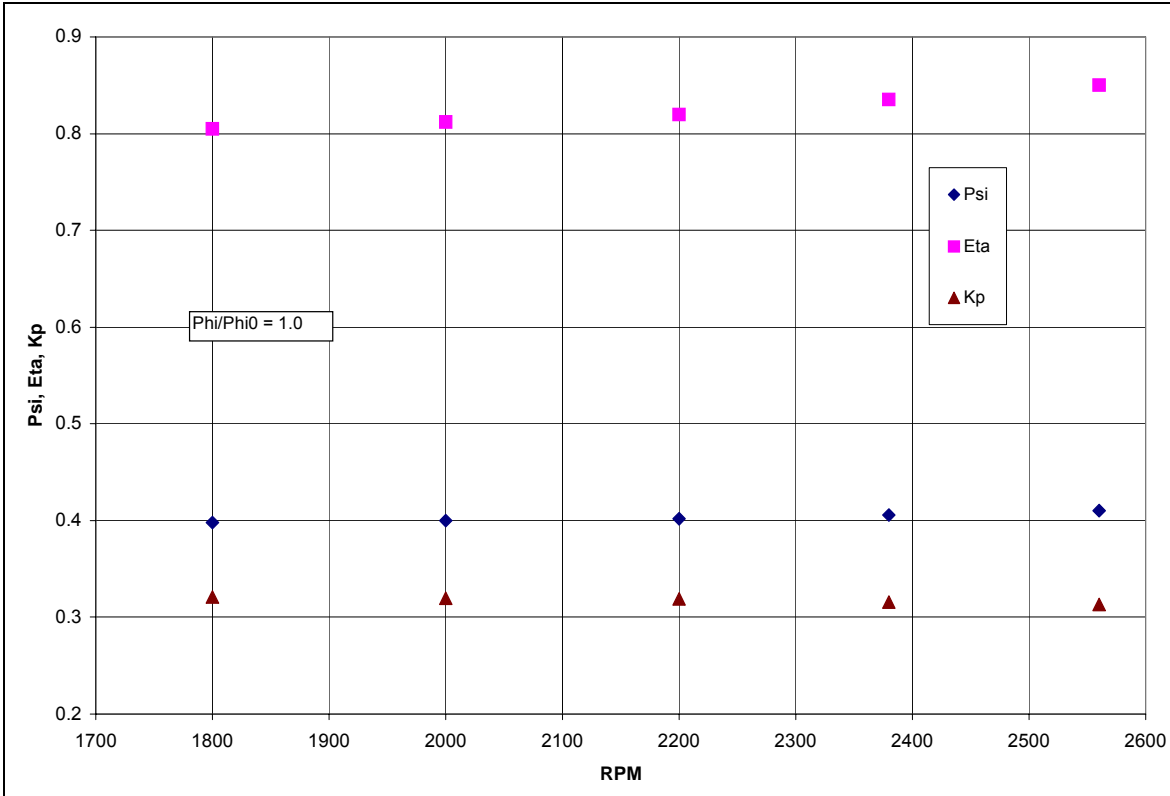


Figure 6. Pump Performance Verification

2.13 Government Test Facilities

The 24-inch water tunnel facility is located at the David Taylor Model Basin, CDNSWC, West Bethesda, MD. References 1 and 2 describe the facility in detail.

3.0 VALIDATION PROCEDURES

Data verification is provided using standard techniques to assure accuracy of selected instrumentation and data-taking procedures. The basic requirements are:

Selection of accurate instrumentation: Specifications of transducers, load cells, LDV sensors, and other items must assure accurate linearity and repeatability. The testing activity must provide instrumentation data that traces accuracies to appropriate standards and lists specifications for nonlinearity and repeatability characteristics, as appropriate. The testing activity is responsible for providing error analyses for each instrumentation subsystem and for overall accuracies and levels of confidence in measuring flow rates, pressures, and all other key quantities.

Control of test conditions: Care in measuring and maintaining conditions such as water temperature, air content, tunnel flow rates, and test section static pressures is of importance in assuring data validity and repeatability. Corrections for temperature and air content are particularly important in characterizing and defining cavitation inception and breakdown characteristics.

Care and consistency in conducting tests: Testing conditions must be stable for each measurement and adequate checks made to assure that mechanical systems and instrumentation are functioning properly.

Specific testing to assure data validity: A sufficient number of tests must be run to assure and demonstrate data repeatability. Data plots are required to demonstrate linearity of all mechanical and electronic systems (see Figure 6), and tests to determine the effects of dissolved air on cavitation parameters must be made. These involve cavitation inception determinations made at two or more levels of dissolved air, as measured by the Van Slyke apparatus, with temperature corrections.

4.0 REFERENCES

1. Brownell, W.F. "Two New Hydrodynamics Research Facilities at the David Taylor Model Basin", DTMB Report 1690, December 1962.
2. Miller, M.L. "Experimental Determination of Unsteady Propeller Forces", Proceedings of the Seventh Symposium on Naval Hydrodynamics, Rome, August 1968.
3. NSWC drawing E50-4263-3.
4. NSWC drawing E50-4263-4.
5. NSWC drawing E50-4263-5.