



## **STATUS REPORT ON MODEL FINAL ARRANGEMENTS**

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*Waterjet Self-Propulsion Model Test for Application to a High-Speed Sealift Ship***

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**MODEL ARRANGEMENT**

**FY 05 PROJECT 05-6, PE 2.33  
TASK NO. 5.1**

**WATERJET SELF-PROPULSION MODEL ARRANGEMENT**

**System:**

Arrangement for the Self-Propulsion Model Tests for Application to a High-Speed Sealift Ship  
Utilizing Advanced Axial-Flow Waterjets

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Task 5.1: Towing Tank and Model Arrangements

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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 report 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.

## TABLE OF CONTENTS

	<b><u>PAGE</u></b>
1.0 Introduction .....	1
1.1 Waterjet Model Testing and Prototype Waterjet Propulsor Design Conditions .....	1
1.2 Location.....	3
2.0 Model Hull .....	3
2.1 Model Hull Scaling .....	3
2.2 Model Waterjets .....	5
2.3 Hull Model .....	5
3.0 Hull Outfitting.....	6
4.0 Summary.....	7
5.0 References.....	7

## LIST OF FIGURES

	<b><u>PAGE</u></b>
1 Froude Number as a Function of Ship Wetted Length and Speed.....	4
2 Froude Number as a Function of Model Wetted Length and Speed .....	4
3 Bow Quarter View of the Wave-Piercing Catamaran-Type Hull .....	5
4 General Arrangement of the Self-Propulsion Model Hull.....	6
5 General Arrangement of the Model Waterjet Pump Assembly .....	7

## LIST OF TABLES

	<b><u>PAGE</u></b>
1 Prototype Design Point Parameters.....	2
2 Single-Side Hull Model Preliminary Froude-Scaled Parameters .....	2

## QUANTITIES AND SYMBOLS

Symbol	Definition	Units
Fr No	Froude number	—
g	Gravitational constant	ft/sec <sup>2</sup>
L <sub>w</sub>	Wetted length	ft
V <sub>0</sub>	Ship or model design velocity	ft/sec

### Abbreviations

RPM	Revolutions per minute
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## **1.0 INTRODUCTION**

A 17.5 to 1 scale self-propulsion model of a single catamaran-type sidehull will be tested to determine powering characteristics at design 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. A model size on the order of 18 feet or more is necessary to provide accurate data based on the experience of the towing tank engineers. Testing will be performed at the Naval Surface Warfare Center, Carderock Division on the Towing Tank Carriage No. 1. Two scaled waterjet inlets will be incorporated with the hull using appropriately sized waterjet-type pumps for the self-propulsion aspects.

### **1.1 Waterjet Model Testing and Prototype Waterjet Propulsor Design Conditions**

The great body of towed model test data and experience with open propeller designs has resulted in a generally high degree of confidence in predicting full-scale performance with open propellers. However, waterjet model testing is relatively new, and the body of test data and testing experience is a small fraction of the propeller database. Towing tank tests of waterjet propulsors and ship hulls present a unique challenge to engineers and experimenters because of interaction effects normally absent, or of far less importance, in propeller installations. For these reasons, the fundamentals of waterjet model testing have been the subject of growing attention and study in recent years with considerable progress being made. The development of the momentum flux method of estimating powering characteristics and interaction effects<sup>1,2</sup> has allowed model testing to be performed with a higher degree of confidence than before, and the data and experience base is steadily expanding. While the overall waterjet characterization capabilities remain somewhat limited relative to open water and towed model propeller testing, prediction techniques are improving. The development of a database with a significant quantity of model to full-scale data correlations is a matter of importance in improving levels of confidence in predicting waterjet system performance.

Self-propulsion towed model tests can require installation of multiple small-scale waterjet pumps and inlets since typical high-speed, full-scale designs usually require multiple propulsor units to absorb the large amounts of power that are required. Accurately scaled waterjet inlets are necessary for modeling the inlet-hull interactions and their impact on performance. The expense and degree of manufacturing difficulty usually prevents producing accurately modeled pumps for towed model testing, and Froude-scaled testing conditions prevent model operation at cavitation and Reynolds numbers that can approximate full-scale values for these critical parameters. Thus, separate water tunnel testing of larger-scale pump models are normally performed to adequately define critical powering characteristics and cavitation limits of the waterjet pump design. The extrapolated data obtained in both water tunnel and towed model tests then constitutes a complete data set characterizing the overall performance of the combined hull and propulsor.

Therefore, for towed waterjet model testing, model pumps only need to produce the required headrise and flow rate with reasonably representative jet energy and momentum characteristics. Representative pumps with thicker blade sections are acceptable since pump performance measurements are not critical. Rapid prototyping can be used to fabricate the waterjet inlets and waterjet pump parts. Rapid prototyping will produce the accurately scaled waterjet inlet that is desired. Rapid prototyping will provide a representative waterjet pump, which can be fabricated fairly quickly and cheaply, that will meet the model head and flow requirements and can operate at the loads and torque of the model with the available types of material.

The full-scale prototype catamaran design conditions are listed below in Table 1 with the waterjet performance requirements. The corresponding scaled requirements for the single self-propulsion model hull are listed in Table 2. The final model scale was established at 17.5 to 1 and that will be further discussed in the following sections.

**Table 1**  
**Prototype Design Point Parameters**

Hull length:	346.5 feet
Payload (with 2 hulls):	1000 long tons
Number of propulsors per hull:	2
Design speed:	40 knots
Speed at minimum payload:	45 knots
Impeller diameter:	59.1 inch
Nozzle diameter:	38.2 inch
Maximum power per shaft:	12,069 SHP (9,000 kW)
Maximum shaft speed:	492 RPM
Flow rate per shaft:	822.5 cubic feet per second
Headrise:	116 feet of seawater
Suction specific speed (design value):	11,000

**Table 2**  
**Single-Side Hull Model Preliminary Froude-Scaled Parameters**

Hull length:	19.8 feet
Number of propulsors:	2
Design speed:	16.14 feet/second
Maximum speed:	18.16 feet/second
Impeller diameter:	3.375 inches
Nozzle diameter:	2.18 inches
Shaft speed:	2056 RPM
Maximum power per pump:	0.573 Shaft horsepower
Flow rate per pump:	0.64 cubic feet per second

## 1.2 Location

Testing will be performed at Naval Surface Warfare Center, Carderock Division in Bethesda, MD. The test facility is Towing Carriage No. 1 outfitted to meet the special measurement needs of waterjet self-propulsion testing. Testing will be performed using experienced personnel from the Seakeeping Division (Code 5500) at NSWC, Carderock Division.

## 2.0 MODEL HULL

The model hull will be representative of a large-size catamaran-type craft based on a pair of stern-mounted waterjets in each hull. Since the main point of interest in these tests is looking at and determining the interaction-type effects between the hull and waterjet inlet, only a single hull will be used for the testing to reduce complexity and, consequently, the overall expenses. The bottom of the hull is symmetrical about the hull centerline so that everything forward of the waterjet inlets would be the same, but mirror-imaged, about the hull centerline. The hull will have a pair of waterjet inlets at the stern that are also mirror images of each other about the hull centerline. Using two pumps with opposite rotation to each other would then represent a mirroring of the pumps about the hull centerline. Since the model tests are conducted in a straight-ahead condition, both pumps would be expected to have near identical performance. This would allow for full instrumentation and measurements on one pump to be indicative of what is happening on the other pump, with some measurements taken on the second pump to assure consistency.

### 2.1 Model Hull Scaling

The objective with the model testing is to have the model design point at a Froude Number that is the same as the design point for the larger craft that is being modeled. Froude Number relates hull wetted length ( $L_w$ ) and ship speed ( $V_o$ ) by:

$$FroudeNumber (Fr No) = \frac{V_o}{(gL_w)^{1/2}} \quad (1)$$

where  $V_o$  is ship design velocity in feet per second and  $L_w$  is the ship's wetted length in feet with the gravitational constant,  $g$ , in feet per second squared. Equation (1) is plotted in Figure 1 over a range of ship wetted lengths and different ship speeds, with the Froude Number for the prototype design point, from above, noted on the figure at a value of Froude Number approximately 0.639. Figure 2 is a plot similar to Figure 1, but uses a range of representative model wetted lengths and speeds. The line of constant Froude Number of 0.639 is highlighted in Figure 2, which is the prototype ship value from above to which the model needs to be equal. For a minimum model wetted length of 18 feet, model speeds of 9 knots or more are required. The final selected model wetted hull length was at about 19.8 feet. This allowed proper hull model speeds and size that were also within the capabilities of Carriage No. 1 at NSWC, Carderock Division. Carriage No. 1 generally has better availability, which would allow a little potential leeway in the testing schedule for unexpected circumstances. The 19.8-foot model wetted length was a 17.5 to 1 scale ratio of the prototype ship and its model design towing speed will be 9.56 knots.

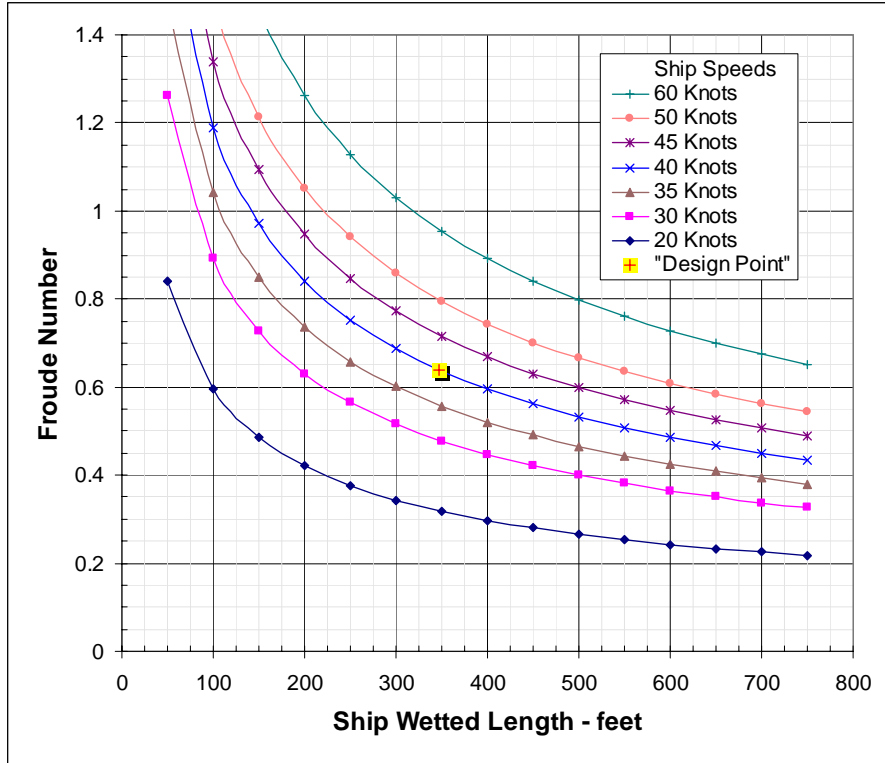


Figure 1. Froude Number as a Function of Ship Wetted Length and Speed

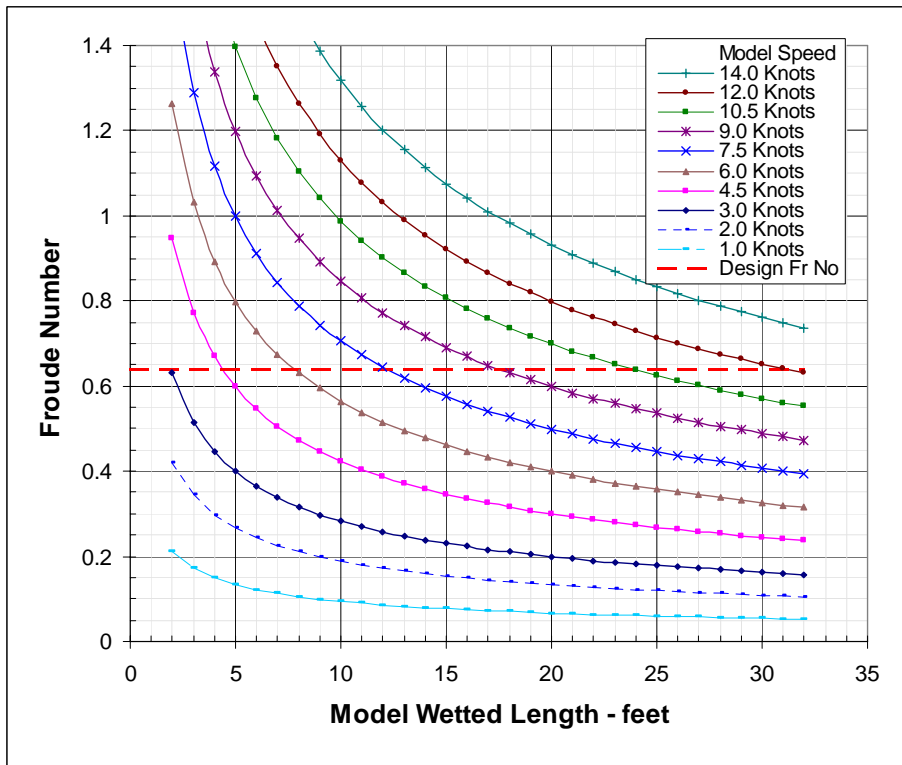


Figure 2. Froude Number as a Function of Model Wetted Length and Speed

## 2.2 Model Waterjets

For the self-propulsion tests, scaled representative waterjet inlets will be incorporated in the model hull. The waterjet pump does not necessarily need to be modeled, but a pump is needed that will develop the scaled flow rate through the model waterjet inlets so that the hull-inlet interactions that are of interest can be measured for appropriate scaling. Scaled model axial-flow waterjets will be fabricated for the setup. The scaled axial pumps will move the proper flow rates and will be representative of the full-scale waterjet pump, but because the blade thickness becomes too thin to scale at model scale, the blades were given constant thickness blades built on the representative axial pump camber surface. The waterjet pump will include both an impeller and stator blade rows with a scaled nozzle for the arrangement.

Rapid prototyping will be used to fabricate the model inlets and the model pumps. This allows accurate components to be made rather quickly and at reasonable cost compared to any other possible alternatives. At the model-scale requirements, stresses and loads are within the capability of available rapid prototyping material, which is a form of nylon-based material.

## 2.3 Hull Model

The catamaran hull that will be evaluated has a wave-piercing bow with a length-to-beam ratio between 18 and 19. Figure 3 shows a bow quarter view of the basic catamaran hull. Figure 4 shows the general arrangement of the model catamaran hull in the cut-away with the block gage and pitch pivot mounted to a strongback. Two waterjets with inlets will be located aft, each with their own drive motor.

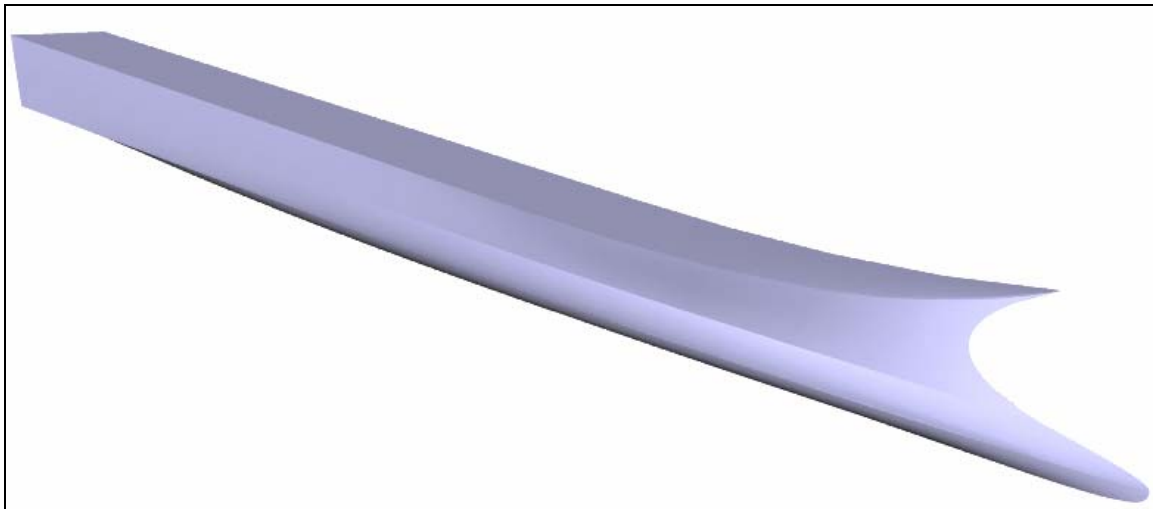


Figure 3. Bow Quarter View of the Wave-Piercing Catamaran-Type Hull

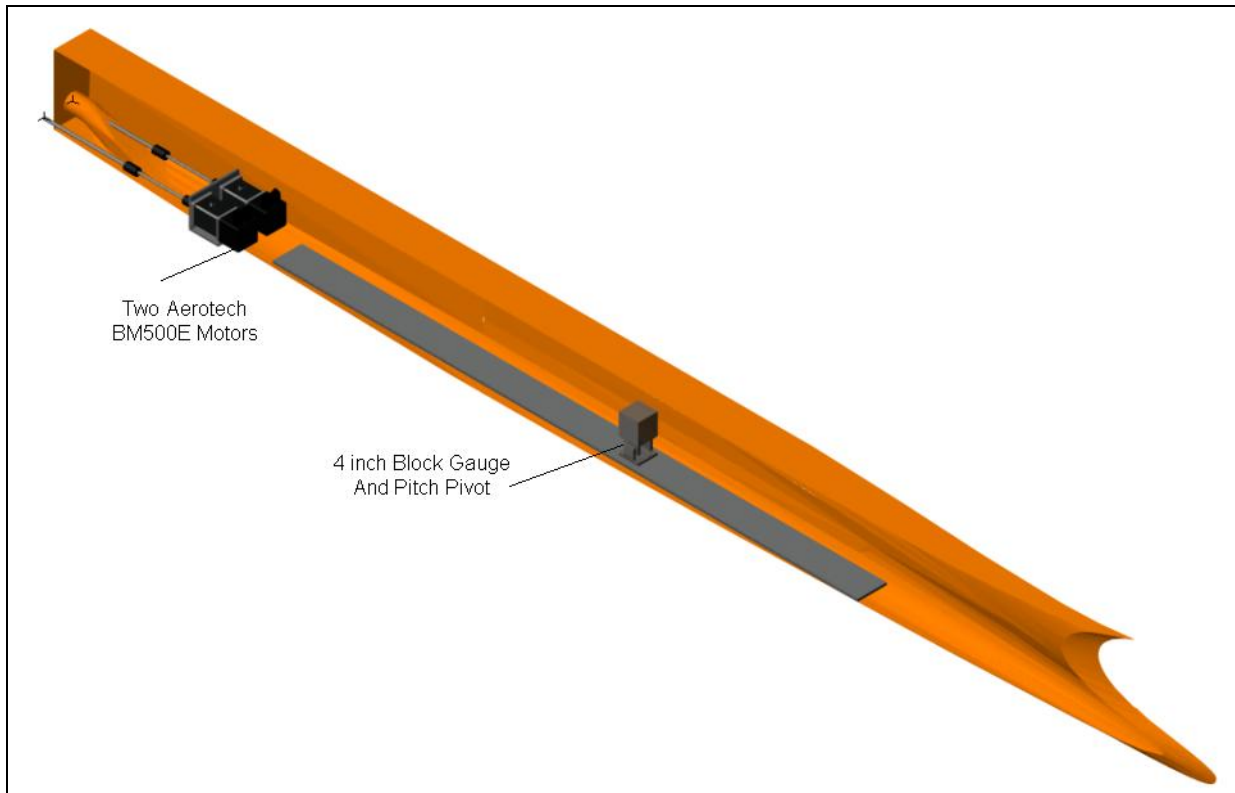


Figure 4. General Arrangement of the Self-Propulsion Model Hull

The model hull will be laid up and constructed in a mold from fiberglass layers. The hull will be built in halves and then joined along its length to form the complete hull. The two rapid prototype waterjet inlets will be fabricated and include a small portion of the hull that surrounds the inlets. The inlets will be attached in the hull mold and the model hull will be constructed around the inlets to incorporate them as part of the model hull. A prior procedure for installing the inlets has been to construct the entire hull and then cut out holes in the hull to locate and install the inlets, which requires additional time and effort. Two Brother's Boatworks, Inc. of Severna Park, Maryland is fabricating the model hull and proposed this inlet installation procedure.

### 3.0 HULL OUTFITTING

The main components to be placed in the hull are the waterjet inlets, the pump drive motors, and the block gauge/pitch pivot. A strongback will first be installed in the hull. The strongback will be a long slender aluminum plate (approximately 10 feet long x 6 inches wide x ½ inch thick) which gives strength and stiffness to the model and provides a solid mounting surface for items such as the block gauge apparatus. Bags of metal shot will be used for ballast in the model as they can be adapted to fit virtually any space and/or location and can be easily adjusted as conditions require. Final instrumentation arrangements and their locations will be determined as appropriate when the model is received at NSWCCD and the major components installed.

The model waterjet pumps will be assembled after the model hull is received. The inlets will already be installed in the model hull, but the impeller, driveline assembly, and stator/nozzle must be mounted and aligned with the inlet. Figure 5 shows a basic schematic of a general arrangement for the waterjet pump assembly and the driveline which is similar to the expected arrangement. There is a saddle on the inlet to which a stuffing tube will be attached, allowing the drive shaft to pass through to drive the impeller. A bushing mounted in a heat sink in the stator hub will hold the back end of the shaft and align the impeller in the inlet. The heat sink serves as a backup item to dissipate bearing heat if the surrounding water fails to provide adequate cooling for the model pump arrangement. A backstop, just forward of the stuffing

tube, serves as a thrust bearing surface to take and transmit the shaft thrust of the impeller. A flexible shaft coupling will connect the pump drive shaft to the motor drive shaft and can take some minor misalignment to simplify the installation arrangement.

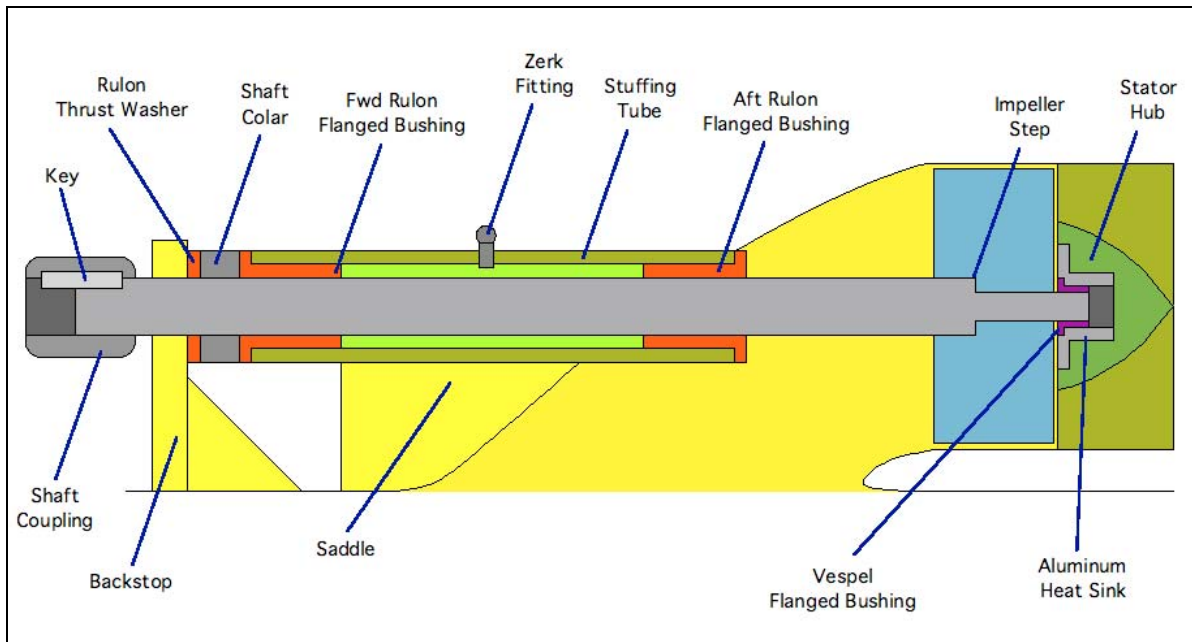


Figure 5. General Arrangement of the Model Waterjet Pump Assembly

#### 4.0 SUMMARY

The molds in which the model hull will be fabricated have been completed and fabrication of the model in the molds is nearing completion. When the model halves are joined and support structures installed, the model will be delivered to Naval Surface Warfare Center, Carderock Division on or about 22 May 2006. At that time, outfitting and instrumentation of the model hull for the testing phase will begin.

#### 5.0 REFERENCES

1. 21<sup>st</sup> International Towing Tank Conference (ITTC) Waterjet Group Report, (1996).
2. Quality Manual of the 22<sup>nd</sup> ITTC Special Committee on Waterjets (1999).