Resistance, self-propulsion and wake survey tests of the Contract Design (Model OCRE911) of DND Joint Support Ship

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TITLE
RESISTANCE, SELF-PROPULSION AND WAKE SURVEY TESTS OF THE CONTRACT DESIGN (Model OCRE911) OF DND JOINT SUPPORT SHIP

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SUMMARY
This report describes experiments carried out on a 1:29.78 scale fully appended model of the Contract Design of the Joint Support Ship (JSS) in the Oceans, Coastal and River Engineering (OCRE) Towing Tank in June/July 2012. The purpose of these experiments was to evaluate performance of this revised design of the JSS in terms of its resistance, propulsion and wake survey characteristics. Revised design featured modifications to bulbous bow and stern region to correct deficiencies observed in the Preliminary Design of the JSS.

Appended Resistance: Resistance coefficient is essentially the same as that of the preliminary design up to ten knots, is slightly higher (about 2%) at 10 knots and then becomes steadily less at all speeds above 10 knots. Maximum reduction in resistance coefficient is 12.5% and occurs at 20 knots (Froude number (Fr) = 0.244). Full scale effective power shows a similar trend.

Propulsion: Propulsion tests showed that Contract Design represents an improvement over Preliminary Design in terms of Delivered Power (PD) and propeller revolutions. As was the case with Appended Resistance, there was little difference below 10 knots. Above 10 knots, PD for Contract Design versus Preliminary Design decreases steadily. The maximum percentage reduction in Delivered Power is 24% at 19 knots. Ship propulsion efficiency coefficients for this design confirm trends shown by the improvements in PD and propeller revolutions

Wake Survey: Wake Survey shows improved flow particularly into the upper portion of the propeller disk for the Contract Design when compared to the Preliminary Design.

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LIST OF ABBREVIATIONS

AP	aft perpendicular
cm	centimetre(s)
CADD	Computer Aided Design and Drafting
DC	direct current
deg.	degree(s)
deg. C	degrees Centigrade
DND	Department of National Defence
DVD	Digital Video Disc
DWL	design water line
FP	forward perpendicular
FS	full scale
GDAC	General Data Acquisition and Control
GEDAP	General Data Analysis Package
Hz	Hertz
ITTC	International Towing Tank Conference
JSS	Joint Support Ship
kg	kilogram(s)
LBP	length between perpendiculars
LCB	longitudinal center of buoyancy
m	metre(s)
mm	millimetre(s)
MS	model scale
N	Newton(s)
NRC	National Research Council
QA	quality assurance
s	second(s)
t	tonne(s)
T1, T2	start, end time
Vr	radial velocity
Vt	tangential velocity
Vs	free stream velocity
Vx	axial velocity
Vy	horizontal velocity
Vz	vertical velocity

LIST OF SYMBOLS – RESISTANCE EXPERIMENTS[1]

Symbol	Definition
∇	volumetric displacement, m^3
υ_M	kinematic viscosity water for the model test facility, m^2/s
υ_S	kinematic viscosity water for the ship, m^2/s
ΔC_T	blockage correction
Δk	increase in form factor due to appendages
θ_V	dynamic trim due to forward speed effects, deg.
ρ_M	water density for the model test facility, kg/m^3
ρ_S	water density for the ship, kg/m^3
A	submerged cross sectional area of tank, m^2
A_V	projected frontal area of ship above the waterline, m^2
c	constant in Prohaska's method
C_A	incremental resistance coefficient for model-ship correlation
C_{AA}	air resistance coefficient
C_{FM}	frictional resistance coefficient for the model
C_{TM}	total resistance coefficient for the model
C_{FM15}	frictional resistance coefficient for the model at 15°C
C_{FS}	frictional resistance coefficient for the ship
C_R	residuary resistance coefficient
C_{TM15}	total resistance coefficient for the model at 15°C
C_{TS}	total resistance coefficient for the ship, N
C_W	Wave making resistance coefficient
F	measured tow force, N
F_r	Froude number for the ship and model
g	gravitational acceleration (standard IOT value 9.808 m/s^2)
h	tank water depth, m
k	form factor
k_S	mean hull surface roughness, m
L_M	model length on waterline, m
L_S	ship length on waterline, m
$_nn$	exponent in Prohaska's method
P_E	effective ship power, W
R	measured resistance, N
R_{TM}	total resistance for the model, N
R_{TS}	total resistance for the ship, N
Re_M	Reynolds number for the model
Re_S	Reynolds number for the ship
S_M	wetted surface area of the model, m^2
S_S	wetted surface area of the ship, m^2
V_M	model speed, m/s
V_S	ship speed, m/s
V_{KN}	ship speed, knots
z_V	Sinkage at centre of gravity due to forward speed effects, m

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[1] Note IOT uses ITTC Symbols Version 2002.

LIST OF SYMBOLS – PROPULSION EXPERIMENTS

Symbol	Definition
ρ_M	water density in the test facility kg/m^3
C_A	incremental resistance coefficient for model-ship correlation
D	model propeller diameter, m
F	measured tow force, N
F_D	skin friction correction in propulsion test, N
F_P	tow force in bollard test, N
g	gravitational acceleration (standard IOT value 9.808 m/s^2)
F_r	Froude number for the ship and model
J	advance coefficient for model in propulsion test
J_{bol}	dimensionless propeller rate of rotation for bollard tests
K_{FD}	skin friction correction coefficient in propulsion test
K_{FP}	tow force coefficient in bollard test
K_Q	propeller torque coefficient
K_T	propeller thrust coefficient
K_{TD}	duct thrust coefficient
L_M	model length on waterline, m
n	model propeller rate of rotation, rps
Q	model propeller torque, Nm
T	model propeller thrust, N
T_D	model duct thrust, N
V_M	model speed, m/s

LIST OF SYMBOLS – SHIP POWERING

Symbol	Definition
β	Appendage scale factor
λ	Model scale factor
υ_M	Kinematic viscosity water for the model test facility, m^2/s
ν_O	Kinematic viscosity of water during the propeller open water experiments, m^2/s
υ_S	Kinematic viscosity water for the ship, m^2/s
ΔC_T	Blockage correction
Δk	Increase in form factor due to appendages
η_D	Propulsive efficiency
η_H	Hull efficiency
η_O	Propeller open efficiency
η_{OS}	Propeller open efficiency for full-scale propeller
η_R	Relative rotative efficiency
ρ_M	Water density for the model test facility, kg/m^3
ρ_S	Water density for the ship, kg/m^3
A	Submerged cross sectional area of tank, m^2
A_V	Projected frontal area of ship above the waterline, m^2
$c_{0.7}$	Ship propeller blade chord at 0.7 radius, m
$(c_{0.7})_{model}$	Model propeller blade chord at 0.7 radius, m
C_A	Incremental resistance coefficient for model-ship correlation
C_{AA}	Air resistance coefficient
C_{DM}	Model propeller section drag coefficient
C_{DS}	Ship propeller section drag coefficient
C_{FD}	Skin friction correction coefficient in propulsion test (Based on V_M and S_M)
C_{FM}	Frictional resistance coefficient for the model
C_{FM15}	Frictional resistance coefficient for the model at 15°C
C_{FMP}	Frictional resistance coefficient for the model at the propulsion test temperature
C_{FS}	Frictional resistance coefficient for the ship
C_R	Residuary resistance coefficient
C_{TM}	Total resistance coefficient for the model
C_{TM15}	Total resistance coefficient for the model at 15°C
C_{TMP}	Total resistance for the model at the propulsion test temperature
C_{TS}	Total resistance coefficient for the ship
D_M	Model propeller diameter, m
D_S	Ship propeller diameter, m
F_D	Skin friction correction in self propulsion test, N
F_r	Froude number for the ship and model
F_P	Pull force for the ship, N
g	Gravitational acceleration (standard IOT value 9.808 m/s^2)
h	Tank water depth, m

LIST OF SYMBOLS – SHIP POWERING (Cont'd.)

Symbol	Definition
J_{bol}	Dimensionless propeller rate of rotation for bollard tests
J_O	Advance coefficient in propeller open water test
J_{OS}	Advance coefficient for full-scale propeller in open water
J_{OA}	Advance coefficient for alternative propeller in open water
J_P	Advance coefficient for model in propulsion test
k	Form factor
k_P	Full-scale propeller blade roughness, m
k_S	Mean ship hull surface roughness, m
K_{FD}	Skin friction correction coefficient in propulsion test (Based on D_M and n_M)
K_{QO}	Propeller torque coefficient in open water test
K_{QOA}	Propeller torque coefficient for an alternative propeller in open water
K_{QOS}	Propeller torque coefficient for full-scale propeller
K_{QP}	Propeller torque coefficient in propulsion test
K_{TO}	Propeller thrust coefficient in open water test
K_{TDO}	Duct thrust coefficient in open water test
K_{TOA}	Propeller thrust coefficient for an alternative propeller in open water
K_{TDOA}	Duct thrust coefficient for an alternative propeller in open water
K_{TOS}	Propeller thrust coefficient for full-scale propeller
K_{TDOS}	Duct thrust coefficient for full-scale propeller
K_{TP}	Propeller thrust coefficient in propulsion test
K_{TDP}	Duct thrust coefficient in propulsion test
L_M	Model length on waterline, m
L_S	Ship length on waterline, m
n_M	Model propeller rate of rotation, rps
n_O	Maximum propeller rate of rotation in open water test, rps
n_S	Ship propeller rate of rotation, rps
N_S	Ship propeller rate of rotation, RPM
$P_{0.7}$	Ship propeller pitch at 0.7 radius, m
P_D	Delivered ship power, W
P_E	Effective ship power, W
Q_S	Ship propeller torque, Nm
R_{nco}	Propeller Reynolds number based on chord at 0.7 radius
Re_M	Reynolds number for the model
Re_S	Reynolds number for the ship
R_{TM}	Total resistance for the model, N
R_{TS}	Total resistance for the ship, N
S_{BK}	Wetted surface area of bilge keels for the ship, m^2
S_M	Wetted surface area of the model, m^2
S_S	Wetted surface area of the ship, m^2
t	Thrust deduction fraction
$t_{0.7}$	Maximum propeller blade thickness at 0.7 radius, m
t_P	Average test temperature for propulsion tests °C
t_O	Average test temperature for propeller open water tests °C
t_R	Average test temperature for resistance tests, °C
T_S	Ship propeller thrust, N

LIST OF SYMBOLS – SHIP POWERING (Cont'd.)

Symbol	Definition
V_{KN}	Ship speed, knots
V_M	Model speed, m/s
V_S	Ship speed, m/s
w_T	Taylor wake fraction
w_{TS}	Ship Taylor wake fraction
Z	Number of propeller blades

LIST OF SYMBOLS – WAKE SURVEY

Symbol	Definition
P	Dynamic Pressure Parameter
$Pcal$	Empirical Dynamic Pressure Parameter
Q	Yaw-Plane Parameter
R	Pitch-Plane Parameter

EXECUTIVE SUMMARY

This report describes experiments carried out on a 1:29.78 scale fully appended model of the Contract Design of the Joint Support Ship (JSS) in the Oceans, Coastal and River Engineering (OCRE) Towing Tank in June/July 2012. The purpose of these experiments was to evaluate performance of this revised design of the JSS in terms of its resistance, propulsion and wake survey characteristics. Revised design featured modifications to bulbous bow and stern region to correct deficiencies observed in the Preliminary Design of the JSS.

Experiments were also done on the Planar Motion Mechanism (PMM) at this time to assess the controls-fixed directional stability of the JSS. These results of those experiments will be reported under separate cover.

Summary Results

Appended Resistance: This design represents an improvement on the preliminary design of the JSS across almost the entire speed range. Resistance coefficient is essentially the same as that of the preliminary design up to ten knots, is slightly higher (about 2%) at 10 knots and then becomes steadily less at all speeds above 10 knots. Maximum reduction in resistance coefficient is 12.5% and occurs at 20 knots (Froude number (Fr) = 0.244). Full scale effective power shows a similar trend. Maximum reduction in effective power is 17% and occurs at 19 knots.

Propulsion: Propulsion tests showed that Contract Design represents an improvement over Preliminary Design in terms of Delivered Power (PD) and propeller revolutions. As was the case with Appended Resistance, there was little difference below 10 knots. Above 10 knots, PD for Contract Design versus Preliminary Design decreases steadily. The maximum percentage reduction in Delivered Power is 24% at 19 knots. A brief summary is shown below in tabular format.

Speed [knots]	Delivered Power [kW]			Propeller Revolutions [RPM]		
	Contract	Preliminary	Contract-Prelim	Contract	Preliminary	Contract-Prelim
10	1610	1592	18	63.5	63.5	0.0
15	4404	5529	-1125	90.3	96.1	-5.8
18	7902	10377	-2475	109.8	118.2	-8.4
19	10011	13147	-3136	118.2	127.3	-9.1
20	12865	16422	-3557	128.2	136.8	-8.6
21	16106	20140	-4033	137.5	146.3	-8.8

Ship propulsion efficiency coefficients for this design confirm trends shown by the improvements in PD and propeller revolutions.

Wake Survey: Wake Survey shows improved flow particularly into the upper portion of the propeller disk for the Contract Design when compared to the Preliminary Design.

RESISTANCE, SELF-PROPULSION AND WAKE SURVEY TESTS OF THE CONTRACT DESIGN (Model OCRE911) OF DND JOINT SUPPORT SHIP

1.0 INTRODUCTION

This report describes experiments carried out on a 1:29.78 scale model of the contract design for a DND Joint Support Ship (JSS), designated OCRE911, in the National Research Council St. John's (NRCSJS) Towing Tank in June 2012. The Systems Requirements Document (SRD) for the JSS specifies that the design comply with several performance requirements regarding speed, sea-keeping and manoeuvrability. The purpose of these experiments was to confirm the power needed and the dynamic stability characteristics of the Contract Design of the JSS.

This document includes background information on the project, a description of instrumentation, facilities used, test program, data analysis procedures and discussion of the results. This report describes the appended resistance, self-propulsion and wake survey experiments conducted in the Towing Tank between June 1 and June 7, 2012. This report is a contractual deliverable to DND published in partial fulfillment of the NRCSJS obligations included in the Letter of Agreement between DND and the National Research Council (NRC) dated April 5, 2012.

2.0 BACKGROUND

BMT Fleet Technology (BMT) is developing the design of this vessel for the JSS Project Office. BMT is the project's Engineering, Logistics and Management Services (ELMS) contractor. Construction of up to three new vessels is planned and they are intended to replace the following existing ships: HMCS Protector, HMCS Provider and HMCS Preserver

The following three series of tests were carried out to satisfy goals of this phase of the project:

- Appended resistance experiments were carried out to derive the resistance of the model through the water over a speed range equivalent to 5 to 21 knots full scale. The condition tested represents estimated end of life condition - 8.2 m draught level trim.
- Self propulsion experiments were carried out to derive delivered power required to propel the model through the water at speeds equivalent to 5, 8 10, 15, 18, 20 and 21 knots.
- Wake survey experiments were carried out to assess flow through the propeller disc at speeds equivalent to 15 and 20 knots full scale.

3.0 DESCRIPTION OF THE NRCSJS TOWING TANK

NRCSJS Towing Tank has dimensions of 200 m by 12 m by 7 m. Flexible side absorbers can be deployed along the entire length of the tank to minimize the time between runs. The 85 t tow carriage, capable of speeds up to 10 m/s, is used to accommodate models for a wide range of test types carried out in calm water and waves. A 4,000 kg lift capacity moveable overhead crane is available over half of the tank length.

At the west end of the tank is a dual flap hydraulic wave board capable of generating regular waves up to 1 m. in height and irregular waves with a signification wave height of 0.5 m. Waves are absorbed by a parabolic corrugated surface beach with transverse slats at the east end of the tank.

Additional information on the Towing Tank is provided in Appendix A.

4.0   DESCRIPTION OF PHYSICAL MODEL OCRE911

Model IOT911 is a 1:29.77 scale, nominally 6 m long, representation of the contract design of the Joint Support Ship fabricated using a polystyrene foam core with ¾" plywood and Renshape[TM] for areas requiring reinforcement as described in NRCSJS's model fabrication standard provided in Reference 1. Foam was milled to conform to the desired hull geometry using NRCSJS's Liné milling machine. For this series of experiments, the model was complete up to the deck at 15.25 m full scale. This height corresponds to the Replenishment at Sea (RAS) deck. The model was then painted with three coats of polyurethane yellow.

Renshape[TM] inserts were included in the hull to add reinforcement in way of the hull penetrations and in way of the location of the bilge keels. A removable rudder was fabricated. A lateral bow tunnel thruster was included in the model. A rudder post and stern tube were embedded in the hull.

A pull point, consisting of an eye bolt fixed to the transom on the longitudinal centerline, was designed to accommodate a longitudinal force nominally 3 cm above the base of the transom for daily verification of integrity of the resistance load cell. A total of 14 milled surfaces capable of accommodating trim hooks were included along the main deck provide flexibility when verifying model attitude in the tank. Lifting lugs were included on the model to avoid using lifting straps and thereby potentially defacing the marking scheme or damaging the bilge keels. The lugs provide attachment points for the bi-filar suspension used to verify the yaw gyradius of the model. Body plan, profile drawing and plan view are provided in Figures 1 and 2. Sketches of the as fitted rudder and bilge keels are included as Figures 3, 4 and 5. Dimensions of the appendages are given in Table 1. Cylindrical stud turbulence stimulators were fitted to the bow and bulb as per NRCSJS Standard (Reference 1) and shown in Figure 6.

Standard markings were included on the model as described in NRCSJS model construction standard (Reference 1). In addition, to assess the wave profile on the hull, tick marks corresponding to 1.0 m waterline spacing were placed at each station marked on the hull. Three tick marks were drawn above the 8.2 m waterline and two below as shown in Figure 7.

Photographs of model OCRE911, as installed in the Towing Tank, are given in Figures 8 and 9.

The model was tested in the following displacement conditions:

CONDITION 1: nominally 23929 m^3 volume displacement, level trim at 8.2 draught full scale. This is the condition set for appended resistance experiments done with bilge keels fitted but without rudder.

CONDITION 2: nominally 23948 m^3 volume displacement, level trim at 8.2 draught full scale. This is the condition set for self-propulsion experiments with bilge keels and rudder fitted to model.

CONDITION 3: nominally 23929 m^3 volume displacement, model is held captive at trim and sinkage values that correspond to mean trim and sinkage at speeds equivalent to 15 and 20 knots measured during the appended resistance experiments.
At 15 knots, dynamic sinkage and trim were 4.5 mm and –0.07 degrees, respectively.
At 20 knots, dynamic sinkage and trim were 8.8 mm and –0.13 degrees, respectively.
These are the conditions set for wake survey experiments.

Hydrostatics for the ship and model at these conditions, model and propeller dimensional quality assurance and flotation quality assurance measurements can be found in Appendix B.

The model was mounted to the medium tow post gimbal and permitted freedom to roll, pitch and heave about a pivot point situated on the longitudinal centerline at the model LCB – nominally 86.99 m forward of the AP and 4.46 m full scale above baseline. NRCSJS standard procedure would attempt to place the pivot of the gimbal along the shaft line but this was not possible in this model. This tow point position was used for all displacement/trim conditions. A provision was included for installation of a yaw restraint grasshopper mount at Station 1.5, nominally 2.1 m forward of the tow point.

A flat bed wooden cart was fabricated to transport the model.

5.0 DESCRIPTION OF INSTRUMENTATION AND DATA ACQUISITION SYSTEM

This section describes instrumentation and calibration methodology used for each parameter measured on model OCRE911. Standard NRCSJS sign convention described in Reference 2 was followed where:

> Trim Angle – positive bow up
> Sinkage – positive down
> Roll Angle – positive starboard down
> Tow Force – positive forward

5.1 Standard Resistance and Self-Propulsion Test Instrumentation

Tow force was measured using a 50 lb S-type load cell while model sinkage, heel and trim were measured using the tow post mounted yo-yo potentiometer and two gimbal rotary potentiometers respectively. Water temperature was periodically measured using a hand-held digital thermometer submerged at the nominal mean draft depth of the model.

In addition to standard resistance test instrumentation, the model was also fitted with a pair of Shaevitz LSOC gravity-referenced inclinometers oriented to measure trim and heel angle, and sinkage at the FP and AP was measured directly using a pair of yoyo potentiometers.

An R-250 Kempf & Remmers thrust-torque dynamometer was fitted to inboard end of the shaft to measure the propeller thrust and torque.

Load cells (resistance, verification pull and thrust) were calibrated by applying a series of static weights over the desired measuring range. Torque was calibrated using static weights applied to the end of a torque arm. All NRCSJS calibration weights are verified on precision digital scales. At the beginning of the resistance test, a series of in-line loads were applied to the model stern pull point and the output from the resistance load cell compared to a 50 lb S-type load cell attached to the stern pull point to verify that the acceleration stops in the gimbal were not attenuating measured resistance.

Rudder angle was measured at the rudder shaft using a Vishay Spectrol Model 132 Single Turn Precision Potentiometer. This device was mounted to the aft coaming and attached to the rudder shaft with a flexible coupling.

Shaft speed was measured using an Allegro A3422 Hall-Effect, Direction-Detection Sensor combined with a Maxim 525 digital-to-analog converter.

Model was propelled using an Aerotech motor controlled by a Soloist CP single-axis digital servo controller. Rudder was controlled using an SSPS-105 precision electro-mechanical servo. This was programmed to give a slew rate of 7.5 deg/second, full scale (40.9 deg/s model scale).

Sinkage (heave) displacement sensors were calibrated using a dedicated apparatus whereby the yoyo potentiometer cable was attached to a flat plate such that the cable could be adjusted in discrete increments a known distance from the sensor.

Rotary potentiometers and Shaevitz inclinometers used to measure pitch (trim) and roll (heel) angle were calibrated using a digital inclinometer.

Carriage speed is verified periodically by setting up two proximity switches on the towing tank rails at a measured distance apart with companion switches on the tow carriage linked by cable to the carriage data acquisition system. Tow carriage is operated at a constant speed between the two switches and time between activating the switches recorded on the carriage data acquisition system - thus providing an accurate measure of the mean towing carriage speed. Carriage speed calibration range for these tests was -0.65 to 5.65 m/s.

5.2   Wake Survey Test Instrumentation

Pressure Transducers: Wake survey pressures were measured using Honeywell Model KZ Differential, 1 psi, pressure transducers. These sensors were calibrated by varying a head of water acting on the transducer. A pyramidal type five-hole Pitot tube probe is used and oriented as shown in Figure 10. Pressures are measured differentially between four outside holes and the common centre hole. The centre hole is ground perpendicular to the axis of the probe. Four outside holes (top, bottom, port and starboard) are ground at 45 degrees to the center axis. Top and bottom holes are sensitive to pitch while the port and starboard holes are sensitive to yaw angle. The average of the four outside holes is used to calculate dynamic pressure.

Pitot tube probe was previously calibrated by fixing the probe at intervals of 5 degrees of pitch and roll angles over ±40 degrees matrix range. At each combination of angles, Pitot tube pressures were measured for a range of forward speeds. Differential pressure coefficients between each of the outside pitot tubes and the center tube were calculated and non-dimensionalized by carriage speed. Finally three coefficients were then calculated at each combination of angles. Coefficient *R*, sensitive to pitch angle, is the difference between top and bottom pressure coefficient. Coefficient *Q*, sensitive to yaw angle, is the difference between port and starboard pressure coefficient. *Pcal*, dynamic pressure parameter, is the average of the four outside Pitot tube pressure coefficients. Three tables of values for pitch, yaw and *Pcal* are then interpolated for a finer grid of *P* versus *R* coefficients.

List of signals is presented in Table 2 and the instrumentation calibration information is given in Appendix C.

5.3   Control Hardware and Software

Remote control system consisted of a shore-based component and a model-based component connected using an RS-232 link. Shore-based component was a personal computer (PC) that was equipped with software that permitted the operator to control shaft speed and rudder angles using a mouse to adjust the respective sliders. The software has a number of programmable buttons that can be programmed to set a specific shaft speed and rudder angle. Command stream used a proprietary packet protocol developed by NRCSJS.

Model-based component of remote control consisted of a microcontroller computer with embedded firmware, which received the command stream and translated it into necessary signals to articulate the model. This microcontroller unit was designed and fabricated at NRCSJS.

5.4   Data Acquisition System

Model based data acquisition system used for this test consisted of two "8-channel high speed signal conditioners" (HSC8). These HSC8 units include input radio frequency rejection, low temperature drift amplification, selectable filtering, a very stable sensor excitation reference and signal offset adjustment. Inputs can accommodate current, voltage and resistive signals. These HSC8's were designed, developed and fabricated at NRCSJS. High-speed signal conditioner was designed for field or trials measurements. Data from this system has been observed to have a low base noise. Other components in this model's acquisition system consisted of a National Instruments 32-channel NI USB-6218 and a computer running NRCSJS's standard data acquisition system and software described in Reference 3. Carriage-based signals were acquired using hardware and software described in Reference 3. All acquired analog DC signals were low pass filtered at 10 Hz, amplified as required and digitized at 50 Hz.

6.0   DESCRIPTION OF THE EXPERIMENTAL SET UP

Towing tank was configured as follows for these experiments:

   Water Depth: Fixed at nominally 7 m.

Model Towing Arrangement: Model was towed toward the west end of the Towing Tank using the medium tow post/gimbal shown in Figure 11. A yaw restraint is fitted forward of the tow post.

Pull Point: Pull point apparatus used to carry out daily verification of resistance was installed on outboard edge at east end of the towing carriage. This enabled loading of a standard series of weights to the gimbal load cell at the beginning and end of every test day during the resistance and self propulsion tests. Applied load was verified using a waterproof in-line load cell.

Wake Suppression Strategy: Side Beaches described in Reference 4 were deployed along the length of north and south side of tank to suppress model wake generated wave.

Wake Survey Positioning Stage Setup: Model was held captive by an apparatus mounted to the tow post and the model as shown in Figure 12. Pitot tube probe is moved to various locations within the flow using an X-Y positioning stage (Figure 13) mounted on the stern of the model (Figure 14). Pitot tube is attached to the positioning stage by a faired strut. Two Soloist motor controllers each connected to a DC servomotor are used to drive the X-Y stage. Controllers were mounted on the test frame adjacent to the model stern. A dedicated Python program, operating on a Windows operating system, enabled automated point selection and the ability to program desired points, controlling the positioning stage.

7.0   DESCRIPTION OF THE TEST PROGRAM

7.1   Appended Resistance Experiments

Appended resistance experiments were carried out as per NRCSJS standard resistance procedure (Reference 5) from 5 to 21 knots full scale (0.471 to 1.980 m/s model scale) with repeat runs included for data verification. For lower forward speeds, more than one speed could be acquired for each run down the tank. Data was acquired for the 8.2 m full scale level trim condition (CONDITION 1) as described in Section 4.0. The model was appended with bilge keels and thruster tunnel was open with a device fitted to simulate the blockage of the thruster.
The resistance test plan is given Table 3 and the annotated Run Log for all tests in the Towing Tank can be found in Appendix D.

7.2   Flow Visualization Experiments

Throughout calm water experiments, an above water photo system consisting of two digital still cameras was mounted fore and aft of the model and photos of wave profile on the hull taken at all speeds in the test matrix. Framing of the image was set so that the forward camera captured from bow to Station 6 while the aft camera captured from Station 4 to transom, resulting in Stations 4, 5 and 6 being visible in both cameras. Digital imagery was copied to a DVD as ANNEX A. The

Run Log contained in ANNEX A was expanded to include hyperlinks to facilitate finding images of the experiments.

Digital imagery for the tests corresponding to speeds of 15 and 20 knots full scale was digitized using KeyCreator, a computer aided design and drafting program, to assess wave profile along the hull

7.3 Self-Propulsion and Overload Experiments

Self-propulsion experiments were carried out in accordance with IOT Standard Procedure (Reference 6) for speeds of 5, 8, 10, 15, 18, 19, 20, and 21 knots full scale. Model was set to test displacement condition and appended with rudder and bilge keels.

Shaft friction torque values were determined as described in Section 4.2.6 of Reference 6 for twelve values of shaft speed evenly spaced from ten percent below to ten percent above the estimated shaft speed range for the experiment. Shaft friction torque was determined with model stationary and propeller replaced with a cylindrical dummy hub of the same weight. Shaft friction experiments were carried out before and after the self-propulsion experiments. Test program for shaft friction torque evaluation is given in Table 4.

In-situ bollard tests were carried out at the beginning and end of the test day as described in Section 4.2.7 of Reference 6 to verify integrity of the propulsion signals. Model was moved to the center of the Towing Tank and, with the propeller fitted, the shaft speed increased in eight steps from 2 to 12.5 rps. Test program for the in-situ test is given in Table 4.

Self-propulsion tests were carried out as described in Section 4.3 of Reference 6 using a range of five approximately evenly spaced propeller speeds for each forward speed to cover a range of tow force from ship self propulsion – 0.0004 to ship self-propulsion point +0.0012, where values of – 0.0004 and +0.0012 are incremental resistance coefficients for ship/model correlation (C_A).

Nominal Tow Force $F_D = (C_{FM} – (C_{FS} + C_A)) * 0.5 * \rho_M * V_M^2 * S_M$

Test program for self-propulsion experiments is given in Table 5. It usually required several iterations of shaft speed to successfully acquire data for the desired tow force range.

Overload experiments were carried out at speeds of 5, 8, 10, 15 and 18 knots full scale with shaft speed increased in multiple steps from 2.6 to 14 rps. Test program for the overload test is outlined in Table 4.

7.4 Wake Survey Experiments

Wake survey data was acquired in the propeller plane for one model displacement condition, CONDITION 3 as described in Section 4.0, at two forward speeds of 15 and 20 knots full scale (1.414 and 1.885 m/s model scale). The model was clamped fully captive at desired model attitude corrected by the dynamic trim angle and sinkage as measured at 15 and 20 knots during

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appended resistance tests (-0.07 deg. trim, 4.5 mm sinkage CONDITION 3a, -0.13 deg. trim, 8.8 mm sinkage CONDITION 3b). Rudder was removed for these experiments to avoid interference with the Pitot tube probe. Interference between Pitot tube probe and overhanging stern section aft of propeller disk was avoided by setting mechanical stops limiting vertical travel of the probe. Wake survey was carried out at five concentric radii about the centre of the propeller disk with the Pitot tube velocity probe aligned with the propeller shaft rake angle. Data was acquired for an equal angular spacing of 15 degrees from 0 to 360 degrees at each radius for a total of 120 points. Dwell at each point was nominally ten seconds and typically data for four to six points could be acquired per run depending on carriage speed.

Propeller diameter is 5.70 m full scale and hub diameter was assumed to be equal to diameter of the hull shaft bossing, 1.6 m full scale. Pressure data was acquired to derive three velocity components (axial, tangential and radial) from 35 to 110% of propeller diameter. The previous model of the JSS had shown that it was difficult to get reliable flow measurements at 30% of propeller diameter. Nominal radii where data were measured are listed as follows:

	Model Scale Measurement Radius (m)	Full Scale Measurement Radius (m)	% of Prop Radius	Comment
Radius #1	0.0335	0.9975	35%	Just outside bossing
Radius #2	0.0479	1.425	50%	50% Propeller Radius
Radius #3	0.0670	1.995	70%	70% Propeller Radius
Radius #4	0.0861	2.565	90%	90% Propeller Radius
Radius #5	0.1053	3.135	110%	110% Propeller Radius

At the beginning of the wake survey test program free stream tests were performed on the Pitot tube probe. Probe was mounted on the carriage test frame, away from the model and run at two forward speeds (1.5 m/s and 2.0 m/s). Pressures were measured and non-dimensional velocities calculated for each test. Average velocity measured was then used to finely adjust wake survey. Pitot tube probe was then mounted on the X-Y positioning stage and the probe moved as far down and out on the stage. Test runs were then performed at two forward speeds before, midway and at the end of the wake survey test program. These tests confirmed repeatability and consistency of the wake survey. Results of free stream tests, away from and in vicinity of model, are given in Table 6.

8.0   ONLINE DATA ANALYSIS PROCEDURE

An analysis of the preliminary data was carried out on the Tow Tank carriage workstation throughout the test program to verify integrity of the acquired data. Carriage operator was responsible for viewing time series data for all acquired data using SWEET software described in Reference 7. In addition, the following data analysis was carried out during the experiments:

8.1   Flow Visualization

The digital images of the model were reviewed after every run to ensure adequate clarity and integrity. No analysis per se was carried out on the acquired images during the experiment.

8.2 Appended Resistance

Data were acquired in GDAC format (*.DAQ files) described in References 8 and 9 and converted to GEDAP format described in Reference 10 prior to carrying out an online data analysis on the Towing Tank carriage workstation during the test to verify the integrity of the acquired data. Resistance online data analysis is described as follows:

- Basic resistance channels (forward speed, tow force, sinkage and trim) were plotted on the screen in time domain. Start and end times (T1, T2) were interactively selected for initial tare segment as well as for each steady state segment. There was more than one steady state segment if more than one forward speed was acquired during a single run up the tank – a common situation for low forward speeds.
- The following four plots are displayed on the same screen:
    - Trim (degrees) vs. Froude Number
    - Sinkage (mm) vs. Froude Number
    - Resistance (N) vs. Froude Number
    - Total Resistance Coefficient for the Model ($C_{TM}*10^3$) vs. Froude Number for the acquired points as well as a comparison curve where:

$$C_{TM} = \frac{R_{TM}}{0.5\rho_M S_M V_M^2}$$

- Total Resistance Coefficient for Model ($C_{TM}*10^3$) vs. Froude Number for acquired points as well as a comparison curve was then displayed - the entire plot displayed on a single screen provides greater visual resolution. Included on this plot is Total Resistance Coefficient for Model (acquired)/ Total Resistance Coefficient for Model (comparison) vs. Froude Number – a normalized curve to accentuate deviation from comparison curve. Normalized curve represents a deviation from the standard resistance analysis procedure described in Reference 5 but was included to facilitate comparison of resistance of Model OCRE911 ballasted to CONDITION1 to the resistance measured with Model 907 (JSS Preliminary Design) at a similar test condition.
- Run Designation, Acquire Time, and mean values of Carriage Speed (m/s), Resistance (N), Sinkage (mm) and Trim (degrees) computed over each steady state time segment were output in tabular form for all runs completed for the given model configuration up to the given run.
- The user exercises an option to print the tables and plots on a local tow carriage laser printer.

The comparison curve used for the CONDITION 1 experiments was derived from resistance measured with Model IOT 907 in November 2011. This data was converted to model scale C_{TM} versus Froude number for tank temperature measured at the start of the test.

The tables and plots output from the online data analysis are provided in Appendix E.

8.3 Self-Propulsion and Overload Experiments

Data were acquired in GDAC format (*.DAQ files) described in References 8, 9 and converted to GEDAP format described in Reference 10 prior to carrying out an online data analysis on the Towing Tank carriage workstation during the test to verify integrity of acquired data. Self-propulsion online data analysis had three separate components and is described as follows:

Part 1: Shaft Friction Torque Analysis (as per Section 4.2.6 of Reference 6): Shaft friction torque was acquired as per the test plan outlined in Table 4 before and after self-propulsion experiment.

- Data transformations were made to ensure that all shaft torque and speed channels were converted to positive values.
- Shaft torque and speed were plotted on the screen in the time domain. Start and end times (T1, T2) were interactively selected for each of ten steady state shaft speed data segments.
- Mean value statistics were computed for each steady state shaft speed and torque time segment and stored in an ASCII (***.PNT) file.
- The user was required to interactively fit a spline curve through the shaft torque vs. shaft speed plot. These spline curves were then output in GEDAP format files.

Once, both, before and after self-propulsion experiment shaft friction analysis was completed, a routine was run to average two friction curves and output a plot of shaft torque vs. shaft speed that include the:

- initial friction points;
- final friction points;
- initial friction spline curve;
- final friction spline curve; and
- average friction spline curve.

The user exercises an option to print this final average shaft friction plot on a local carriage laser printer.

It is initial shaft friction spline curve that is used during online analysis while average before and after shaft friction spline curve is used in offline self-propulsion analysis. An example shaft friction torque and speed time series plot and the average spline curve fitted through the shaft friction data are given in Appendix F.

Part 2: In situ (Bollard) Tests (as per Section 4.2.7 of Reference 6): in situ (bollard) data was acquired as per the test plan outlined in Table 4 at start of each self-propulsion test day.

- Although the carriage is stationary during this test, any noise on this channel was removed by replacing the acquired carriage speed channel with a zero value channel (i.e. where carriage speed $Y = 0.0X + 0.0$).
- A data transformation was made to ensure tow force is a positive value.

- Channels shaft torque, shaft thrust, shaft speed, tow force and carriage speed were plotted on the screen in time domain. Start and end times (T1, T2) are interactively selected for initial tare segment as well as each of the steady state segments.
- Basic statistics (minimum, maximum, mean and standard deviation) were computed for each selected time segment in model scale units for shaft torque, shaft thrust, shaft speed, tow force and carriage speed (carriage speed was always zero). Mean values were stored in an ASCII (***.PNT) file while all statistics were stored in a separate ASCII (***_STAT.PNT) file.
- Quality of data was evaluated by plotting mean values of shaft thrust and torque (without correction for shaft friction torque) vs. shaft speed[2]. Quality data was expected to comprise straight lines with the value of shaft torque extrapolated to zero rps approximately equal to the friction torque.
- A plot of tow force vs. shaft thrust was then generated. Quality data should comprise straight lines that extrapolate to ~zero.
- The user exercises an option to print these plots on a local tow carriage laser printer.

The time series plot of shaft torque, shaft thrust, shaft speed, and tow force, plot of shaft thrust and torque vs. shaft speed[2], as well as a plot of tow force vs. shaft thrust for the pre- and post-test in-situ checks are included in Appendix F.

Part 3: Initial Analysis of Overload and Self-Propulsion Test Data (as per Section 4.4.6 of Reference 6): Overload data was acquired as per the test plan provided in Table 4 while self-propulsion data was acquired as per the test plan given in Table 5.
- A data transformation was made to ensure tow force is a positive value.
- Channels shaft torque, shaft thrust, shaft speed, tow force and carriage speed were plotted on the screen in time domain. Start and end times (T1, T2) were interactively selected for initial tare segment as well as for each of the steady state segments. Note that only carriage speed, shaft thrust and tow force channels were tared with shaft rotating slowly (0.1 rps) prior to the carriage being accelerated to the desired nominal forward speed.
- Basic statistics (minimum, maximum, mean and standard deviation) were computed for each selected time segment in model scale units for shaft torque, shaft thrust, shaft speed, tow force and carriage speed. A value for shaft torque corrected for the mean initial shaft friction was computed for the relevant shaft speed.
- The following non-dimensional coefficients were then computed:

Advance Coefficient:
$$J = \frac{V_M}{nD}$$

Skin Friction Correction Coefficient:
$$K_{FD} = \frac{F_D}{\rho_M n^2 D^4}$$

Propeller Thrust Coefficient:
$$K_T = \frac{T}{\rho_M n^2 D^4}$$

Propeller Torque Coefficient:
$$K_Q = \frac{Q}{\rho_M n^2 D^5}$$

- • Mean value for each tare segment of shaft torque (not actually used to tare torque), shaft thrust, shaft speed, tow force and carriage speed was stored in an ASCII (***_TARE.PNT) file. Water temperature input for each run was stored in an ASCII (***_WATER.PNT) file. Basic statistics for shaft torque, shaft thrust, shaft speed, tow force and carriage speed were stored in a separate ASCII (***_STAT.PNT) file. The following mean values were stored in an ASCII (***.PNT) file:
  - - carriage speed;
  - - tow force;
  - - shaft speed;
  - - shaft thrust;
  - - shaft torque;
  - - shaft torque – corrected for initial friction torque;
  - - shaft Advance Coefficient (J);
  - - shaft Thrust Coefficient (K_T);
  - - shaft Torque Coefficient (K_Q);
  - - Skin Friction Correction Coefficient (K_{FD});
- • Average values of shaft Thrust Coefficient (K_T), shaft Torque Coefficient ($10K_Q$) and Skin Friction Correction Coefficient (K_{FD}) were plotted against Advance Coefficient (J) for the given nominal carriage speed.
- • Since propeller open water data was available for the propeller P106R (results described in Section 9.0), as further verification discrete values of torque coefficient (K_Q) were plotted versus the thrust coefficient (K_T) combined with data from the propeller open water experiment. Quality data is assumed to entail agreement between the acquired self-propulsion data and propeller open water data within ~ ±10%.
- • Run Designation, Acquire Time, Carriage Speed (m/s), Tow Force (N), Shaft Speed (rps), Shaft Thrust (N) and Shaft Torque (N-m) data was output in tabular form for all runs completed for the experiment up to the given run.
- • The user was given the option of printing the tables and plots on a local tow carriage laser printer.

An example time series plot of the shaft torque, shaft thrust, shaft speed, tow force and carriage speed for one carriage speed (1.885 m/s – 20 knots) as well as the tabular output, plots of initial propulsion analysis, comparison of propulsion parameters to the propeller open water data for all speeds tested are provided in Appendix F. In addition, the initial overload analysis for one carriage speed (0.942 m/s – 10 knots) that includes the tabular output and comparison of propulsion parameters to the propeller open water has been included in Appendix F.

8.4   Wake Survey

At the end of each run, raw pressures were displayed on the Tow Tank carriage workstation and steady state time segments for each of the radius and angle locations acquired were interactively selected. An example plot of raw differential pressures, measured as probe position is varied, is given in Figure 15. Average measured pressures were then non-dimensionalized by carriage speed (i.e. the nominal free stream velocity). From the non-dimensional pressures, coefficients

for *Q* (yaw angle), *R* (pitch angle) and *P* (dynamic pressure) were calculated. Using Pitot tube probe calibration table described in Section 5.2, yaw, pitch and *Pcal* were interpolated from coefficients *Q* versus *R*. Resultant velocity was calculated as the square root of the ratio of measured dynamic pressure, *P*, over dynamic pressure, *Pcal*.

Axial, horizontal, vertical, tangential and radial velocity components were then computed from the resultant velocity and pitch - yaw angles. Velocity component versus radial angle plots for each radius and axial vector contour plot with resultant Y/Z velocity quivers are available for review at the end of each carriage run. Example online analysis plots are given for radial angle plot (Figure 16) and contour plot (Figure 17) for the wake survey done at 20 knots.

The coordinate system is orientated with x-axis along the propeller shaft axis positive from bow to stern, Y-axis is positive to starboard and z-axis is positive upwards. Tangential velocity is positive clock-wise and radial velocity is positive towards propeller centreline. Position angle is measured clockwise positive from top centre position and radius is measured positive from centreline. Tables and plots of results of two wake surveys performed are given in Appendix G.

9.0 PROPELLER OPEN WATER DATA

Propeller open water data was acquired on IOT stock propeller P106R in the Towing Tank in April 2012. Standard IOT test and data analysis procedures were used (Reference 11) and the results of the propeller open water data analysis are provided in Appendix H including:

- Example of online analysis at one shaft speed
- Shaft friction analysis for the propeller open water apparatus;
- Plot of propeller thrust coefficient in open water (K_{TO}), propeller torque coefficient in open water ($10K_{QO}$) and propeller open water efficiency (η_O) vs. advance coefficient in open water (J_O).
- Table of polynomial coefficients to fitted lines for thrust coefficient (K_{TO}) and torque coefficient ($10K_{QO}$) vs. advance coefficient (J_O). A table of discrete values derived from the fitted lines is also provided in the same table. [2]

10.0 OFFLINE DATA ANALYSIS

The following data analysis was carried out after completion of the experimental program to generate the final data products:

10.1 Flow Visualization

The interpretation process for the flow visualization images is described as follows:

The above water digital images of the model were imported into KeyCreator and the height of wave profile at each station calculated using design waterline and reference grid marked on the

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[2] Propeller open water symbols are included in List of Powering Symbols at the beginning of this report.

model. The results of this analysis are shown in Figure 18 and Table 7. Images used for this analysis can be found in Appendix I.

10.2   Appended Resistance Experiments

The following data analysis was carried out to assess the appended hull resistance using IOT Standard Resistance Procedure described in Reference 5. Within Reference 5, effective power is estimated using both the ITTC`57 Method described in Reference 12 and the ITTC`78 Method described in Reference 13.

- Run Designation, Acquire Time, Carriage Speed (m/s), Resistance (N), Sinkage (mm) and Trim (degrees) values were output in tabular form for all runs carried out for a given model appendage configuration.
- The user exercises an option to interactively fit and save a spline through the C_{TM} vs. F_r curve.
- The model resistance coefficients were then plotted vs. Froude Number and $\log_{10}R_{eM}$. Coefficients plotted include C_{TM}, blockage corrected C_{TM} (towing tank blockage corrected using Scott's Method (Reference 14), C_{FM} and $(1 + k) *C_{FM}$ where $(1+k)$ is the Prohaska form factor computed during the bare hull resistance experiments carried out on model IOT907 and described in Reference 15.
- A table of model resistance coefficients corrected to standard conditions (15 °C) was generated including F_r, $10^{-6}R_{nM}$, 10^3C_{TM15}, and 10^3C_{FM15}.
- A plot of effective power vs. ship speed (knots) using ITTC `78 methodology was generated.
- A table of ship resistance and effective power using ITTC `78 prediction method was provided for the ship in salt water and including tank blockage correction using Scott's Method (Reference 14). The table included: V_S (knots), P_E (kW), R_{TS} (kN), F_r, $10^{-8}R_{nS}$, 10^3C_{TS}, 10^3C_{FS} and 10^3C_R. A Prohaska form factor $(1 + k)$ of 1.148, correlation allowance C_A of $3.475*10^{-4}$ and air resistance allowance C_{AA} of $5.08*10^{-5}$ was used.
- A plot of effective power vs. ship speed (knots) using the ITTC '57 methodology was generated.
- A table of ship resistance and effective power using ITTC `57 prediction method was provided for the ship in salt water and including tank blockage correction using Scott's Method (Reference 14). The table includes: V_S (knots), P_E (kW), R_{TS} (kN), F_r, $10^{-8}R_{nS}$, 10^3C_{TS}, 10^3C_{FS} and 10^3C_R. A correlation allowance C_A of 0.0002 was used as per IOT standard for ships the length of the Joint Support Ship.
- A plot comparing results of predicted effective power (P_E) vs. ship speed (V_S) using both ITTC `57 and ITTC `78 methodology was provided that included ITTC `78/ITTC `57 percent difference.
- The user then executed an option to interactively fit a spline through sinkage and trim data. Once splines were fit, a plot of non-dimensional sinkage in the form of $10^2Z_V/L_M$ and dynamic trim (θ_V) were plotted vs. Froude Number (both test data and lines smoothed through them).
- A table of sinkage and trim information was also generated and included: V_S (knots), F_r, $10^2Z_V/L_M$, and θ_V.

A plot comparing effective power (P_E) as predicted using the ITTC'78 method as derived in Towing Tank (November 2011) for Model 907 (preliminary design) and Model 911 (contract design) for the 8.2 m level trim displacement condition is given in Figure 19.

Standard tables and plots output for the appended resistance data acquired are provided in Appendix J.

10.3   Self-Propulsion and Overload Experiments

Once initial online propulsion analysis was completed and average shaft torque friction curve derived, the propulsion point file containing all self-propulsion and overload data was modified to extract data for shaft speeds that gave tow forces within the appropriate range of C_A as shown in Table 5. The offline analysis routine permits the user to interactively adjust polynomial curves of the following non-dimensional propulsion parameters for each nominal forward speed (5, 8, 10, 15, 18, 20 and 21 knots full scale):

K_T vs. J – thrust coefficient
$10K_Q$ vs. J – torque coefficient
K_{FD} vs. J – skin friction correction coefficient

Values of shaft thrust coefficient (K_T), shaft torque coefficient ($10K_Q$) and Skin Friction Correction Coefficient (K_{FD}) were plotted against Advance Coefficient (J) for the given nominal carriage speed. For the self-propulsion data, linear or quadratic fits were used. For the overloads, third order polynomials were fitted. Tables of the polynomial fits to the self-propulsion section of the data and the overload section were generated.

Plots of the average shaft friction torque curve acquired June 5th, final non-dimensional propulsion coefficients versus advance coefficient, and tables of polynomials for the seven speeds tested are provided in Appendix L.

Digital still images were acquired with cameras directed at the port bow and stern quarter and included in ANNEX A.

10.4   Powering Prediction

IOT Standard Ship Powering Procedure (Reference 16) was used to carry out a powering prediction for the JSS using ITTC'57 and ITTC'78 methodologies.

ITTC'57 Methodology
Initially, a program was run to create a file compiling the resistance coefficients corresponding to propulsion experiments. Inputs required include:

- File listing model speed and names of propulsion coefficient files created during offline analysis;

- ASCII file of propulsion data (***.PNT) created during online data analysis as described in Section 8.3, Part 3;
- File of appended resistance data created during offline resistance analysis (described in Section 10.2);
- File containing GEDAP format C_{TM} vs. F_r curve, smoothed and without correction for tank blockage, created during resistance offline data analysis;
- Incremental resistance coefficient for ship/model correlation C_A: 0.0002 (default);
- To assess effect of fouling, additional resistance files were generated using the following incremental resistance coefficient for ship/model correlation C_A: 0.0004, 0.0006 and 0.0008.

A ship power prediction was now carried out using the following input files/information:

- GEDAP format files with polynomials fit to the propulsion data for each ship speed tested;
- Propeller P106R open water data files;
- File of ITTC'57 resistance coefficients; and
- Default full scale propeller roughness ($3 * 10^{-5}$ m) – this input is not used for ITTC'57 computations.

Tables of ship powering data were then generated for each ship speed tested and incremental resistance coefficient for ship/model correlation, C_A, applied. These tables include ship speed (knots), nominal shaft speed (RPM), total delivered power (kW), shaft thrust (kN), shaft torque (kN-m) and total effective power (kW). Similarly, tables of propulsive efficiency data for each ship speed tested and C_A applied were generated. These tables include Taylor wake fraction (W_T), thrust deduction fraction (t), relative rotative efficiency (η_R), propulsive efficiency (η_D), hull efficiency (η_H), and propeller open efficiency (η_O). All powering and propulsive efficiency data are provided in Appendix L. Table 8 shows the powering prediction using ITTC'57 methodology at the default value of C_A. A plot illustrating variation of delivered power (P_D) and shaft RPM with ship forward speed for various values of C_A was provided (Figure 20). A plot of variation with speed of propulsion efficiency coefficients at the default value of C_A was provided (Figure 21).

ITTC'78 Methodology
Initially, a program was run to create a file compiling the resistance coefficients corresponding to the propulsion experiments. Inputs required include:

- File listing model speed and names of propulsion coefficient files created during offline analysis;
- ASCII file of propulsion data (***.PNT) created during online data analysis as described in Section 8.3, Part 3;
- File of appended resistance data created during offline resistance analysis (described in Section 10.2);
- File containing GEDAP format C_{TM} vs. F_r curve, smoothed and without correction for tank blockage, created during resistance offline data analysis;
- Prohaska Form Factor (1+k) = 1.148;

- Default hull surface roughness: $150 * 10^{-6}$ m;
- Nominal full scale projected ship frontal area above waterline assumed to be $0.5* Beam^2$ = 288.04 m^2;
- Incremental resistance coefficient based on hull roughness C_A: 3.475 x 10^{-4}; and
- Air resistance coefficient C_{AA} based on nominal projected frontal area: $5.08 * 10^{-5}$.

A ship power prediction was now carried out using the following input files/information:

- GEDAP format files with polynomials fit to propulsion data for each ship speed tested;
- Propeller P106R open water data files;
- File of ITTC'78 resistance coefficients; and
- Default full scale propeller roughness ($3 * 10^{-5}$ m).

A table of ship powering data was then generated for each ship speed tested that includes ship speed (knots), nominal shaft speed (RPM), total delivered power (kW), shaft thrust (kN), shaft torque (kN-m) and total effective power (kW). A table of propulsive efficiency data for each ship speed tested is also generated that includes Taylor wake fraction (W_T), thrust deduction fraction (t), relative rotative efficiency (η_R), propulsive efficiency (η_D), hull efficiency (η_H), and propeller open efficiency (η_O). Powering and propulsive efficiency data are also provided in Appendix L. Table 9 shows the powering prediction using ITTC'78 methodology. A plot illustrating variation of delivered power (P_D) and shaft RPM with ship forward speed was provided (Figure 22). A plot of variation with speed of propulsion efficiency coefficients at the default value of C_A was provided (Figure 23).

10.5 Wake Survey

No further analysis of the wake survey data beyond what was executed online is carried out other than adding appropriate labels to plots and compiling velocity components into tables. No fairing of the data was carried out. Standard tables and plots output for both displacement conditions acquired are provided in Appendix G.

10.6 Data Quality

The following measures were taken to ensure the integrity of the acquired resistance data:

ONLINE DATA ANALYSIS: Data were analyzed during test as described in Section 8.2. Any anomalies in the primary resistance channels were identified. Using the technique of plotting the acquired data against a comparison curve, it was possible to detect and address even minor problems immediately. If data from a given run was found to vary from what was expected by an unacceptable amount, the run was repeated. If variance persisted, the test was halted and an investigation carried out to determine the source of the problem.

REPEAT RUNS: Another method of monitoring data integrity, especially for critical primary resistance channels, involved executing a number of repeat runs. Several speeds were selected for repeats and embedded in the resistance curve test program. A comparison of mean values for

identical speed/model condition runs is provided in Table 10. Range, (maximum-minimum) in resistance parameters between comparison runs is also included.

In addition, prior to the actual appended resistance experiments, a series of repeat tests were done at a speed corresponding to 20 knots full scale to characterize variability of resistance measurement that could be expected with this size and type of model. Results of those tests are presented in Table 11. These tests illustrate the variability that occurs during normal tank testing. Variability displayed here in this ten point set is similar to that noted during embedded repeats. Precision, taken as twice the standard deviation, is 0.34 N or about 0.7% of the mean of ten samples.

DAILY PULLS TO CHECK RESISTANCE LOAD CELL: Every effort was made to verify integrity of the load cell used to measure resistance load as it was acknowledged that this was the single most critical acquired parameter. Resistance load cell was calibrated prior to test by suspending a series of known static weights from it. It was then installed in the model tow gimbal balance such that it remains horizontal with respect to the still waterline independent of model attitude. Mechanical stops were adjusted to prevent inertial carriage acceleration/deceleration induced forces from damaging the load cell. A series of in-situ longitudinal loads was applied to the stern of the model using a dedicated drag verification apparatus fitted on east side of towing carriage for this purpose. An S-type load cell with a waterproof coating was calibrated in a similar manner to model resistance load cell and attached to the pull point on the model just above the 8.2 m waterline. A steel wire was connected to the opposite end of this load cell and extended to the drag verification apparatus, which was aligned with the longitudinal centerline of the model. This wire passed over three low friction sheaves vertically up and over the west end of the carriage deck such that weights could be applied using a weight pan on the carriage deck. Height of post was vertically adjustable to ensure that the applied load was horizontal. Use of an inline load cell at model stern, while it adds an extra instrument to the process, mitigates unknown effects of friction in sheaves. In-situ checks were carried out on June 1st, 4th and 5th at start and end of each day of resistance and self-propulsion tests. Results of these checks are presented in Table 12. These tests show that the precision of the tow force measurement of the towing apparatus as configured for the resistance and self-propulsion tests is about 0.1%.

11.0   DISCUSSION

11.1   Flow Visualization – Wave Profile on Hull

Wave profile along the hull in calm water is well below the level of Replenishment at Sea (RAS) deck and there should be little risk of water on deck in calm water.

11.2   Appended Resistance

Figure 24 shows comparison of full scale effective power prediction for Contract Design versus Preliminary Design using ITTC'78 and ITTC'57 methods. Since no bare hull experiments were done with this design, the Prohaska 3-d form factor used is an estimate based on the experiments done with the preliminary design and reported in Reference 15. The value of 1+k used is 1.148 - lower than the NAVCAD prediction (Reference 17) or the value measured at GTO (Reference

18) - and thus, the effective power prediction is slightly higher or conservative. Using ITTC'57 methodology, the effective power required for the contract design is less than that required for the preliminary design at all speeds except near ten knots. Maximum improvement of 17.3 percent occurs at 19.25 knots and improvement is more than 15 percent at all speeds above 17.5 knots. Effective power is reduced by 1.1 and 1.8 MW to 5.9 and 8.7 MW at speeds of 18 and 20 knots, respectively. Similar trends were noted using ITTC'78 methodology.

11.3   Self-Propulsion

Figure 25 shows comparison of full scale delivered power prediction for Contract Design versus Preliminary Design using ITTC'57 method. Improvement of Contract Design over Preliminary is greater than the effective power prediction indicated. Above 15 knots, Contract Design requires 20% less delivered power than Preliminary Design and achieves a maximum reduction of 24% between 18 and 19 knots. Delivered power is reduced by 2.5 and 3.6 MW to 7.9 and 12.9 MW at speeds of 18 and 20 knots, respectively.

Shaft revolutions are reduced by about 8 RPM to 110 and 128 RPM at speeds of 18 and 20 knots, respectively. Maximum propulsive efficiency coefficients occur between speeds of 15 and 18 knots.

11.4   Wake Survey

Wake survey experiments show improved axial flow for Contract Design particularly in the +/-30 degree region at the top of the propeller. In upper portion of propeller disk, variation in axial flow into the propeller disk as characterized by the standard deviation of Vx/Vs component is much less for Contract Design. This improvement in flow contributes to an increase in thrust developed by the propeller at a given shaft speed and thus to a decrease in delivered power.

12.0   ACKNOWLEDGEMENTS

13.0   REFERENCES

1) "Construction of Models of Ships, Offshore Structures, and Propellers", IOT Standard Test Method GM-1, V10.0, October 18, 2007.

2) "Model Test Co-ordinate System & Units of Measure", IOT Standard Test Method GM-5, V6.0, November 29, 2004.

3) "Data Acquisition, Verification and Storage", IOT Standard Test Method GM-2, V1.0, January 20, 2000.

4) Harris, C. J.,"Use of Side Beaches in the 200m Towing Tank at the Institute for Marine Dynamics", Proceedings of the 22nd American Towing Tank Conference (ATTC), August 8 – 11, 1989, St. John's, NL.

5) "Resistance in Open Water", IOT Standard Test Method TM-1, V7.0, December 12, 2006.

6) "Model Propulsion in Open Water", IOT Standard Test Method TM-3, V6.0, December 12, 2006.

7) Web Site: https://segweb.iot.nrc.ca/trac/sweet

8) Miles, M.D., "Test Data File for New GDAC Software", NRC Institute for Marine Dynamics Software Design Specification, Version 3.0, January 2, 1996.

9) Miles, M.D., "DACON Configuration File for New GDAC Software", NRC Institute for Marine Dynamics Software Design Specification, Version 3.2, August 14, 1996.

10) Miles, M.D., "The GEDAP Data Analysis Software Package", NRC Institute for Mechanical Engineering, Hydraulics Technical Report #TR-HY-030, August 11, 1990.

11) "Propeller Open Water Tests", IOT Standard Test Method TM-2, V7.0, December 12, 2006.

12) Proceedings of 8th ITTC, Madrid, Spain, 1957.

13) Proceedings of 15th ITTC, The Hague, Netherlands, 1978.

14) Scott, J.R., "Blockage Correction at Sub-Critical Speeds", Trans. RINA, 1976, p. 169.

15) Pallard, R.L., Sullivan, M., "Resistance, Propulsion and Wake Survey Experiments of the Preliminary Design (Model IOT907) of the Joint Support Ship" National Research Council Canada – Ocean, Coastal and River Engineering Report OCRE-CTR-2012-21, July 2012.

16) "Prediction of Ship Powering", IOT Standard Test Method TM-4, V4.0, December 12, 2006.

17) "Propeller Calculations", BMT Fleet Technology Report, 5436EL-C-200-01, July 8, 2011.

18) "Intermediate Model Test Report", BMT Fleet Technology Report, WME - #384599-v1-5436-006-000346, April, 2012

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TABLES

Table 1 – Appendage Dimensions

Appendage Dimensions

Rudder	Model Scale		Full Scale	
Tip Chord	5.304	in.	0.135 m	4.01 m
Root Chord Along Hull	8.148	in.	0.207 m	6.16 m
Span	9.298	in.	0.236 m	7.03 m
Shaft CL Fwd of Transom	7.271	in.	0.185 m	5.50 m
Leading Edge Slope	3.3	deg.		
Section profile	NACA0015			

Bilge Keel	Model Scale		Full Scale	
Aft end of bilge keel wrt to transom	98.831	in.	2.510 m	74.75 m
Fwd end of bilge keel wrt to transom	146.43	in.	3.719 m	110.76 m
Bilge Keel Span	0.925	in.	0.023 m	0.700 m
Angle to Baseline	42.8	deg.		

Table 2 – List of Signals

Signal	Device	Calibrated Range		Measurement Range		Units	Test Type Req'd
		min	max	min	max		
Inline Load	S-Type Load Cell	0	392.32	-721	656	N	RES, SP
Tow Force	S-Type Load Cell	0	127.44	-159	129	N	RES,SP
FWD Trim	yoyo potentiometer	50	400	-541	517	m	RES,SP
AFT Trim	yoyo potentiometer	0	400	-837	764	m	RES,SP
Tow Post Sinkage	yoyo potentiometer	0	225	-280	233	mm	RES,SP
Tow Post Roll	Gimble RVDT	-16.3	13.5	-24	43	deg	RES,SP,WKS
Tow Post Trim	Gimble RVDT	-6.03	7.46	-12	9	deg	RES,SP,WKS
Carriage Speed	carriage instrumentation	-0.65	5.65	-1	6	m/s	RES, SP, FV, WKS
Tachogenerator		0.5	2	-11	11	m/s	RES,SP
Shaft Speed Magnetic	Allegro A3422 Hall-Effect Senson	4.16	20.09	-32	32	rps	SP
Shaft Spd Soloist	Motor Controller Output	-19.61	18.95	-24	24	rps	SP
Thrust	Kempf&Remmers R250	0	146.96	257	-338	N	SP
Torque	Kempf&Remmers R250	-4.9041	4.9041	-14	14	Nm	SP
Top	Delta Pressure Sensor	5	35	-94	92	cm H2O	WKS
Bottom	Delta Pressure Sensor	5	35	-91	95	cm H2O	WKS
Port	Delta Pressure Sensor	5	35	-91	95	cm H2O	WKS
Stbd	Delta Pressure Sensor	5	36	-93	93	cm H2O	WKS
XPos	yoyo potentiometer	-321	-21	-401	394	mm	WKS
Ypos	yoyo potentiometer	-342	-48	-411	381	mm	WKS
Model Heel (incl)	LSOC-14.5 Inclinometer	-14.9	14.8	-18	18	deg	RES,SP,WKS
Model Trim (incl)	LSOC-14.5 Inclinometer	-4.33	4.89	-8	8	deg	RES,SP,WKS
Rudder Angle	Vishay Spectrol	-33	34.2	-485	157	deg	n/a

Table 3 – Appended Resistance Test Plan

JSS Joint Support Ship **Model OCRE911**
Naval Task Group End of Life Loading Condition
Project: A1-001054 **Towing Tank**

Comment	Run	Speed No	VS [kts]	VS [m/s]	Vm [m/s]	Fr [-]
Roughup	1	12	15.00	7.717	1.416	0.184
Roughup	2	12	15.00	7.717	1.416	0.184
	3	1	4.75	2.444	0.448	0.058
	3	5	10.00	5.144	0.944	0.122
	3	10	13.88	7.143	1.311	0.170
	4	2	5.00	2.572	0.472	0.061
	4	6	10.62	5.462	1.002	0.130
	4	9	13.07	6.723	1.234	0.160
	5	3	8.00	4.116	0.755	0.098
	5	4	9.80	5.042	0.925	0.120
	5	8	12.25	6.303	1.157	0.150
	6	7	11.43	5.882	1.080	0.140
	6	14	16.34	8.404	1.542	0.200
	7	11	14.70	7.563	1.388	0.180
	7	13	15.52	7.983	1.465	0.190
	8	2	5.00	2.572	0.472	0.061
	8	3	8.00	4.116	0.755	0.098
	8	12	15.00	7.717	1.416	0.184
	9	16	18.00	9.260	1.699	0.220
	10	18	19.60	10.084	1.851	0.240
	11	20	20.42	10.504	1.928	0.250
	12	22	21.56	11.093	2.036	0.264
	13	23	22.05	11.343	2.082	0.270
	14	21	21.00	10.803	1.983	0.257
	15	19	20.00	10.289	1.888	0.245
	16	17	18.79	9.664	1.774	0.230
	17	15	17.15	8.824	1.619	0.210
	18		6.5	3.344	0.614	0.080
sch repeat 1	18		9	4.630	0.850	0.110
	18		10	5.144	0.944	0.122
sch repeat 2	19	5	10.00	5.144	0.944	0.122
	19	12	15.00	7.717	1.416	0.184
sch repeat 3	20	16	18.00	9.260	1.699	0.220
sch repeat 4	21	19	20.00	10.289	1.888	0.245

Table 4 – Test Plan for Shaft Friction, In-situ and Overload Tests

JSS Joint Support Ship   **Model   OCRE911**
Naval Task Group End of Life Loading Condition
Project: A1-001054   **Towing Tank**

Frictions	Insitu	Overload				
Vs [kts]	0	5	8	10	15	18
Vm [m/s]	0	0.471	0.754	0.943	1.414	1.697
Shaft Speed [rps]	Shaft Speed [rps]	Shaft Speed [rps]	Shaft Speed [rps]	Shaft Speed [rps]	Shaft Speed [rps]	Shaft Speed [rps]
2	2	2.6	4	5	7.5	10
3.5	3.5	3.5	4.5	6.5	8	10.5
5	5	5	5	7.5	8.5	11
6.5	6.5	6.5	6.5	8.5	9	11.5
8	8	8	8	9.5	9.5	12
9.5	9.5	9.5	9.5	10.5	10.5	12.5
11	11	11	11	11.5	11.5	13
12.5	12.5	12.5	12.5	12.5	12.5	13.5
14		14				14
15.5						
17						

Table 5 – Self Propulsion Test Plan

JSS Joint Support Ship   **Model   OCRE911**
Naval Task Group End of Life Loading Condition
Project: A1-001054   **Towing Tank**

Tow Force Estimate for Self Propulsion Test								
TempS	15	degC	nu_s	1.187E-06	m^2/s	rho_s	1025.88	kg/m3
TempM	18.3	degC	nu_f	1.05E-06	m^2/s	rho_f	998.28	kg/m3
VS [kts]	**VM [m/s]**	**ReS [-]**	**ReM [-]**	**CFS [-]**		**CFM [-]**	**CA [-]**	**F [N]**
5	0.471	4.01E+08	2.80E+06	1.720E-03		3.793E-03	-0.0004	1.77
5	0.471	4.01E+08	2.80E+06	1.720E-03		3.793E-03	0	1.48
5	0.471	4.01E+08	2.80E+06	1.720E-03		3.793E-03	0.0004	1.20
5	0.471	4.01E+08	2.80E+06	1.720E-03		3.793E-03	0.0008	0.91
5	0.471	4.01E+08	2.80E+06	1.720E-03		3.793E-03	0.0012	0.62
5	0.471	4.01E+08	2.80E+06	1.720E-03		3.793E-03		OVLD
8	0.754	6.41E+08	4.48E+06	1.619E-03		3.467E-03	-0.0004	4.12
8	0.754	6.41E+08	4.48E+06	1.619E-03		3.467E-03	0	3.39
8	0.754	6.41E+08	4.48E+06	1.619E-03		3.467E-03	0.0004	2.66
8	0.754	6.41E+08	4.48E+06	1.619E-03		3.467E-03	0.0008	1.92
8	0.754	6.41E+08	4.48E+06	1.619E-03		3.467E-03	0.0012	1.19
8	0.754	6.41E+08	4.48E+06	1.619E-03		3.467E-03		OVLD
10	0.943	8.02E+08	5.60E+06	1.573E-03		3.327E-03	-0.0006	6.74
10	0.943	8.02E+08	5.60E+06	1.573E-03		3.327E-03	0	5.02
10	0.943	8.02E+08	5.60E+06	1.573E-03		3.327E-03	0.0004	3.88
10	0.943	8.02E+08	5.60E+06	1.573E-03		3.327E-03	0.0008	2.73
10	0.943	8.02E+08	5.60E+06	1.573E-03		3.327E-03	0.0012	1.59
10	0.943	8.02E+08	5.60E+06	1.573E-03		3.327E-03		OVLD
15	1.414	1.20E+09	8.39E+06	1.496E-03		3.093E-03	-0.0006	14.16
15	1.414	1.20E+09	8.39E+06	1.496E-03		3.093E-03	0	10.30
15	1.414	1.20E+09	8.39E+06	1.496E-03		3.093E-03	0.0004	7.72
15	1.414	1.20E+09	8.39E+06	1.496E-03		3.093E-03	0.0008	5.14
15	1.414	1.20E+09	8.39E+06	1.496E-03		3.093E-03	0.0012	2.56
15	1.414	1.20E+09	8.39E+06	1.496E-03		3.093E-03		OVLD
18	1.697	1.44E+09	1.01E+07	1.463E-03		2.996E-03	-0.0008	21.65
18	1.697	1.44E+09	1.01E+07	1.463E-03		2.996E-03	0	14.23
18	1.697	1.44E+09	1.01E+07	1.463E-03		2.996E-03	0.0004	10.52
18	1.697	1.44E+09	1.01E+07	1.463E-03		2.996E-03	0.0008	6.80
18	1.697	1.44E+09	1.01E+07	1.463E-03		2.996E-03	0.0012	3.09
18	1.697	1.44E+09	1.01E+07	1.463E-03		2.996E-03		OVLD
20	1.885	1.60E+09	1.12E+07	1.445E-03		2.942E-03	-0.0004	21.74
20	1.885	1.60E+09	1.12E+07	1.445E-03		2.942E-03	0	17.16
20	1.885	1.60E+09	1.12E+07	1.445E-03		2.942E-03	0.0004	12.58
20	1.885	1.60E+09	1.12E+07	1.445E-03		2.942E-03	0.0008	7.99
20	1.885	1.60E+09	1.12E+07	1.445E-03		2.942E-03	0.0012	3.41
21	1.980	1.68E+09	1.18E+07	1.436E-03		2.918E-03	-0.0004	23.77
21	1.980	1.68E+09	1.18E+07	1.436E-03		2.918E-03	0	18.71
21	1.980	1.68E+09	1.18E+07	1.436E-03		2.918E-03	0.0004	13.66
21	1.980	1.68E+09	1.18E+07	1.436E-03		2.918E-03	0.0008	8.61
21	1.980	1.68E+09	1.18E+07	1.436E-03		2.918E-03	0.0012	3.55
19	1.791	1.52E+09	1.06E+07	1.454E-03		2.968E-03	-0.0004	19.80
19	1.791	1.52E+09	1.06E+07	1.454E-03		2.968E-03	0	15.66
19	1.791	1.52E+09	1.06E+07	1.454E-03		2.968E-03	0.0004	11.53
19	1.791	1.52E+09	1.06E+07	1.454E-03		2.968E-03	0.0008	7.39
19	1.791	1.52E+09	1.06E+07	1.454E-03		2.968E-03	0.0012	3.25

Table 6 – Wake Survey Free Stream Checks

Condition	File Name	Date	Time	Carriage Speed	Derived Velocity
Free Stream	CHECK_RUN_002	06-Jun-12	14:55	1.5	1.011
	CHECK_RUN_002	06-Jun-12	14:55	2	1.013
	CHECK_RUN_003	06-Jun-12	15:03	1.5	1.013
	CHECK_RUN_003	06-Jun-12	15:03	2	1.014
			Mean	1.75	1.013
			Std	0.29	0.001
Model 1.5 m/s	CHECK_RUN_006	06-Jun-12	16:33	1.5	0.964
	CHECK_RUN_007	06-Jun-12	16:54	1.5	0.965
	CHECK_RUN_008	07-Jun-12	8:16	1.5	0.971
	CHECK_RUN_009	07-Jun-12	12:29	1.5	0.970
	CHECK_RUN_010	07-Jun-12	12:50	1.5	0.970
	CHECK_RUN_011	07-Jun-12	16:46	1.5	0.963
			Mean	1.5	0.967
			Std	0	0.004
Model 2.0 m/s	CHECK_RUN_006	06-Jun-12	16:33	2	0.968
	CHECK_RUN_007	06-Jun-12	16:54	2	0.969
	CHECK_RUN_008	07-Jun-12	8:16	2	0.975
	CHECK_RUN_009	07-Jun-12	12:29	2	0.971
	CHECK_RUN_010	07-Jun-12	12:50	2	0.972
	CHECK_RUN_011	07-Jun-12	16:46	2	0.970
			Mean	2	0.971
			Std	0	0.002

Table 7 – Wave Profile Measurements

Summary of Wave Profile of Hull Measurements

Ship Speed **15 knots**
Model Speed 1.414 m/s

Wave Height on Hull [m. full scale]

Station	VS15F1	VS15F2	VS15A1	VS15A2	VS15	Range/2	St Dev
0	9.511	9.523			9.517	0.006	
1	8.776	8.767			8.772	0.005	
2	8.067	8.100			8.083	0.017	
3	8.023	8.085			8.054	0.031	
4	8.204	8.244			8.224	0.020	
5			8.218	8.216	8.217	0.001	
6	8.143	8.166	8.180	8.146	8.159	0.019	0.017
7			7.971	7.961	7.966	0.005	
8			8.052	8.033	8.042	0.009	
9			8.323	8.327	8.325	0.002	
10			8.667	8.659	8.663	0.004	

Ship Speed **20 knots**
Model Speed 1.885 m/s

Wave Height on Hull [m. full scale]

Station	VS20F1	VS20F2	VS20A1	VS20A2	VS20	Range/2	St Dev
0	11.724	11.748			11.736	0.012	
1	8.762	8.732			8.747	0.015	
2	7.873	7.829			7.851	0.022	
3	7.764	7.763			7.763	0.000	
4	8.398	8.398			8.398	0.000	
5			8.462	8.475	8.468	0.007	
6	7.948	7.976	8.035	8.016	7.994	0.044	0.039
7			7.783	7.797	7.790	0.007	
8			7.887	7.854	7.871	0.017	
9			8.404	8.438	8.421	0.017	
10			8.909	8.925	8.917	0.008	

Table 8 – Ship Powering Prediction – ITTC '57

Ship Powering Tables (ITTC 57)

Model: 911
Description: Joint Support Ship
Condition: 8.2 m Draught - Level Trim
Tank: Towing Tank

Propeller: P106R
Description: MCDV B-Screw
Condition: Deep Departure
Rotation: RIGHT

Test Date: 04-Jun-2012
Analysis Date: 11-Jun-2012
Project Number: 42_2517_16
Avg. Test Temperature: 18.2 °C
Standard Water Temperature: 15.0 °C

Correlation Allowance:

0.0002

Ship Powering Data

V_{KN}	F_r	N_s	P_D	T_S	Q_S	P_E
Knots		RPM	kW	kN	kN-m	kW
4.99	0.061	30.4	248	69.1	77.9	142
7.99	0.098	50.2	783	174.1	148.8	545
9.99	0.122	63.4	1605	280.4	242.0	1120
14.98	0.183	90.2	4385	534.3	464.1	3324
17.99	0.220	109.7	7883	785.3	686.0	5935
18.98	0.232	118.0	9961	913.7	806.3	7163
19.98	0.244	128.0	12804	1083.3	955.5	8735
20.99	0.257	137.4	16072	1269.5	1116.8	10736

Propulsive Efficiency Data

V_{KN}	F_r	W_T	t	η_R	η_D	η_H	η_O
Knots							
4.99	0.061	0.431	0.201	0.788	0.571	1.404	0.516
7.99	0.098	0.368	0.238	1.060	0.697	1.207	0.545
9.99	0.122	0.370	0.223	1.047	0.698	1.233	0.541
14.98	0.183	0.370	0.193	1.057	0.758	1.280	0.560
17.99	0.220	0.358	0.183	1.053	0.753	1.272	0.562
18.98	0.232	0.350	0.197	1.040	0.719	1.234	0.560
19.98	0.244	0.334	0.216	1.039	0.682	1.177	0.558
20.99	0.257	0.327	0.217	1.037	0.668	1.164	0.553

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Table 9 – Ship Powering Prediction – ITTC '78

Ship Powering Tables (ITTC 78)

Model:	911		Test Date:	04-Jun-2012
Description:	Joint Support Ship		Analysis Date:	06-Jun-2012
Condition:	8.2 m Draught - Level Trim		Standard Water Temperature: 15.0 °C	
Tank:	Towing Tank			

Propeller:	P106R
Description:	MCDV B-Screw
Condition:	Deep Departure
Rotation:	RIGHT

Ship Powering Data

V_{KN}	F_r	N_s	P_D	T_S	Q_S	P_E
Knots		RPM	kW	kN	kN-m	kW
4.99	0.061	30.0	233	66.1	74.2	136
7.99	0.098	49.8	741	169.7	142.2	530
9.99	0.122	62.8	1533	274.5	233.0	1095
14.98	0.183	89.7	4217	526.0	449.1	3271
17.99	0.220	109.3	7629	776.6	666.8	5866
18.98	0.232	117.5	9657	904.7	785.0	7089
19.98	0.244	127.5	12443	1074.5	931.8	8657
20.99	0.257	137.0	15634	1259.8	1090.1	10654

Propulsive Efficiency Data

V_{KN}	F_r	W_T	t	η_R	η_D	η_H	η_O
Knots							
4.99	0.061	0.426	0.198	0.783	0.583	1.398	0.533
7.99	0.098	0.369	0.240	1.066	0.715	1.205	0.557
9.99	0.122	0.371	0.224	1.048	0.714	1.233	0.552
14.98	0.183	0.370	0.193	1.058	0.776	1.282	0.572
17.99	0.220	0.359	0.184	1.054	0.769	1.272	0.574
18.98	0.232	0.350	0.197	1.041	0.734	1.235	0.571
19.98	0.244	0.334	0.216	1.039	0.696	1.177	0.569
20.99	0.257	0.328	0.217	1.037	0.682	1.165	0.564

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Table 10 – Repeatability of Selected Runs

Record Number	Carriage Speed m/s	Resistance N	Sinkage Meters	Trim Degrees	Total Resistance Coeff CTM
4	0.4702	3.41	0.0003	-0.0043	0.004830
14	0.4702	3.34	0.0007	-0.0056	0.004738
Mean	0.4702	3.38	0.0005	-0.0049	0.004784
Range	0.0000	0.06	0.0004	0.0013	0.000091
7	0.7534	8.01	0.0014	-0.0134	0.004421
15	0.7534	7.84	0.0013	-0.0136	0.004330
Mean	0.7534	7.92	0.0014	-0.0135	0.004375
Range	0.0000	0.17	0.0002	0.0002	0.000092
2	0.9422	12.42	0.0020	-0.0204	0.004386
28	0.9422	12.56	0.0016	-0.0198	0.004432
29	0.9422	12.62	0.0016	-0.0198	0.004454
Mean	0.9422	12.53	0.0017	-0.0200	0.004424
Range	0.0001	0.19	0.0004	0.0007	0.000068
16	1.4126	24.90	0.0045	-0.0676	0.003911
30	1.4124	24.94	0.0044	-0.0678	0.003918
Mean	1.4125	24.92	0.0044	-0.0677	0.003914
Range	0.0001	0.04	0.0001	0.0002	0.000007
17	1.6961	35.95	0.0067	-0.1104	0.003916
31	1.6961	36.15	0.0072	-0.1102	0.003939
Mean	1.6961	36.05	0.0069	-0.1103	0.003927
Range	0.0000	0.20	0.0005	0.0002	0.000022
23	1.8840	46.11	0.0088	-0.1317	0.004071
32	1.8838	46.43	0.0088	-0.1351	0.004101
Mean	1.8839	46.27	0.0088	-0.1334	0.004086
Range	0.0001	0.33	0.0000	0.0034	0.000030

Table 11– Data Variability for Ten Repeats at a Single Speed [VS= 20 knots]

	Carriage Speed (m/s)	Tow Force (N)	Tow Post Trim (deg)	Tow Post Sinkage (mm)	AFT Trim (mm)	FWD Trim (mm)	CTM [-]
	1.8839	46.38	-0.1268	9.16	1.33	16.51	0.004096
	1.8840	46.18	-0.1452	8.85	1.16	16.35	0.004078
	1.8839	46.18	-0.1365	9.12	1.43	16.62	0.004078
	1.8840	45.96	-0.1186	8.81	1.07	16.60	0.004058
	1.8839	46.02	-0.1257	9.11	1.43	16.46	0.004063
	1.8840	46.18	-0.1287	8.60	0.85	16.33	0.004078
	1.8840	46.25	-0.1137	9.26	1.58	16.66	0.004083
	1.8840	46.30	-0.1366	8.91	1.15	16.70	0.004088
	1.8840	46.42	-0.1164	9.03	1.29	16.49	0.004099
	1.8841	46.48	-0.1157	8.77	1.02	16.56	0.004104
Mean	1.8840	46.23	-0.1264	8.96	1.23	16.53	0.004082
St Dev	0.0001	0.17	0.0105	0.21	0.22	0.12	0.000015
Precision (2sd)	0.0001	0.34	0.0211	0.41	0.44	0.25	0.000029
StDev/Mean	0.00%	0.36%	-8.35%	2.29%	17.95%	0.75%	0.36%

Table 12 – X-Pull Summary

	Slope [N/N]	Percent Difference from Mean	Intercept [N]	StDev Residuals [N]	Max Error of Fit [N]	Comment
XPULL_001	1.00253	-0.01%	0.74	0.060	0.105	
XPULL_002	1.00316	0.05%	-15.59	0.078	0.129	Weight Pan Changed
XPULL_003	1.00239	-0.03%	-15.74	0.054	0.098	
XPULL_004	1.00186	-0.08%	-15.50	0.069	0.119	
XPULL_005	1.00272	0.01%	-15.23	0.093	0.159	
XPULL_006	1.00329	0.06%	-15.72	0.105	0.213	
Mean	1.00266			0.076	0.137	
StDev	0.00053			0.020	0.043	
Min	1.00186			0.054	0.098	
Max	1.00329			0.105	0.213	
StDev/Mean	0.05%					
Precision (2sd)	0.001053					

FIGURES
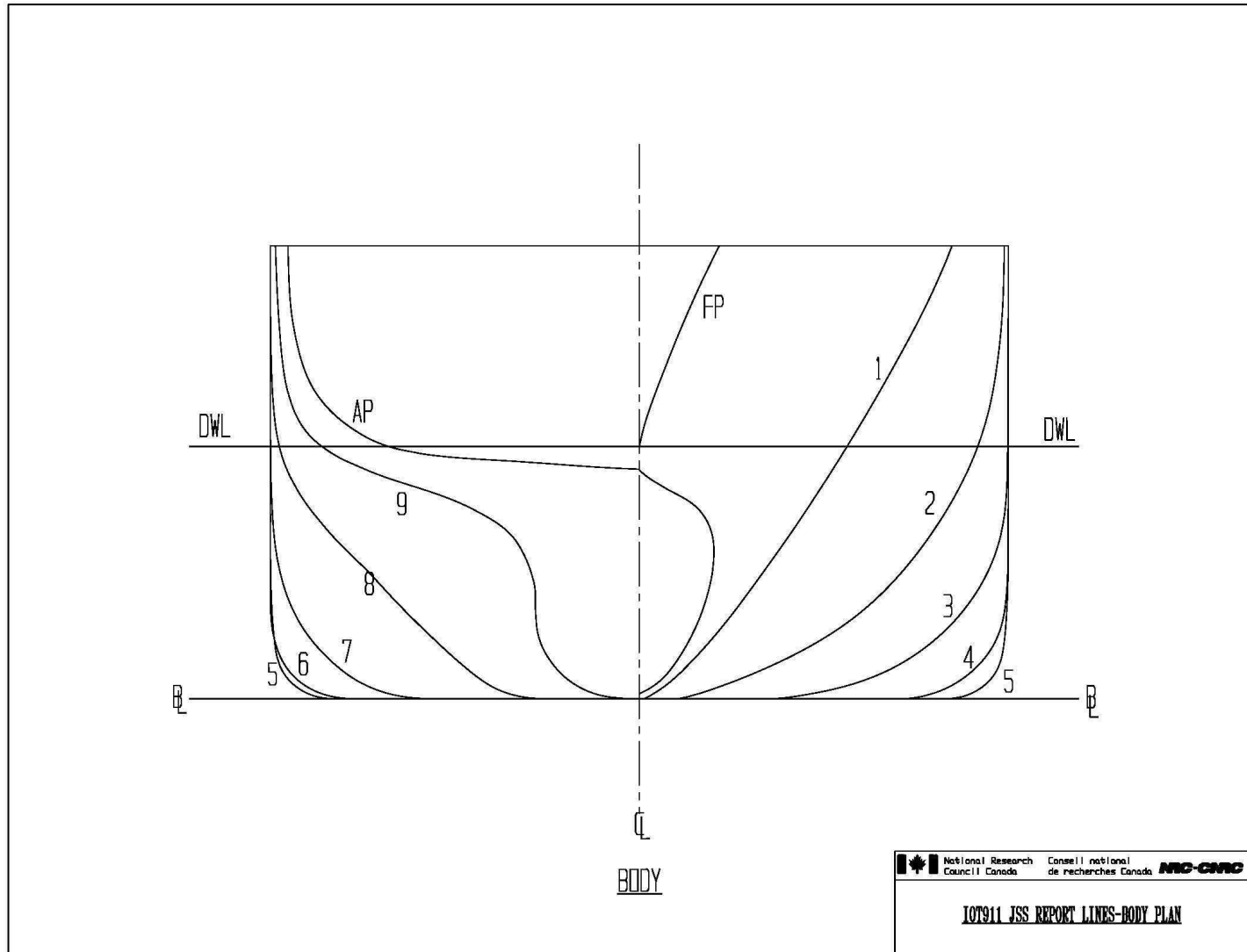
Figure 1 - OCRE 911 Body Plan
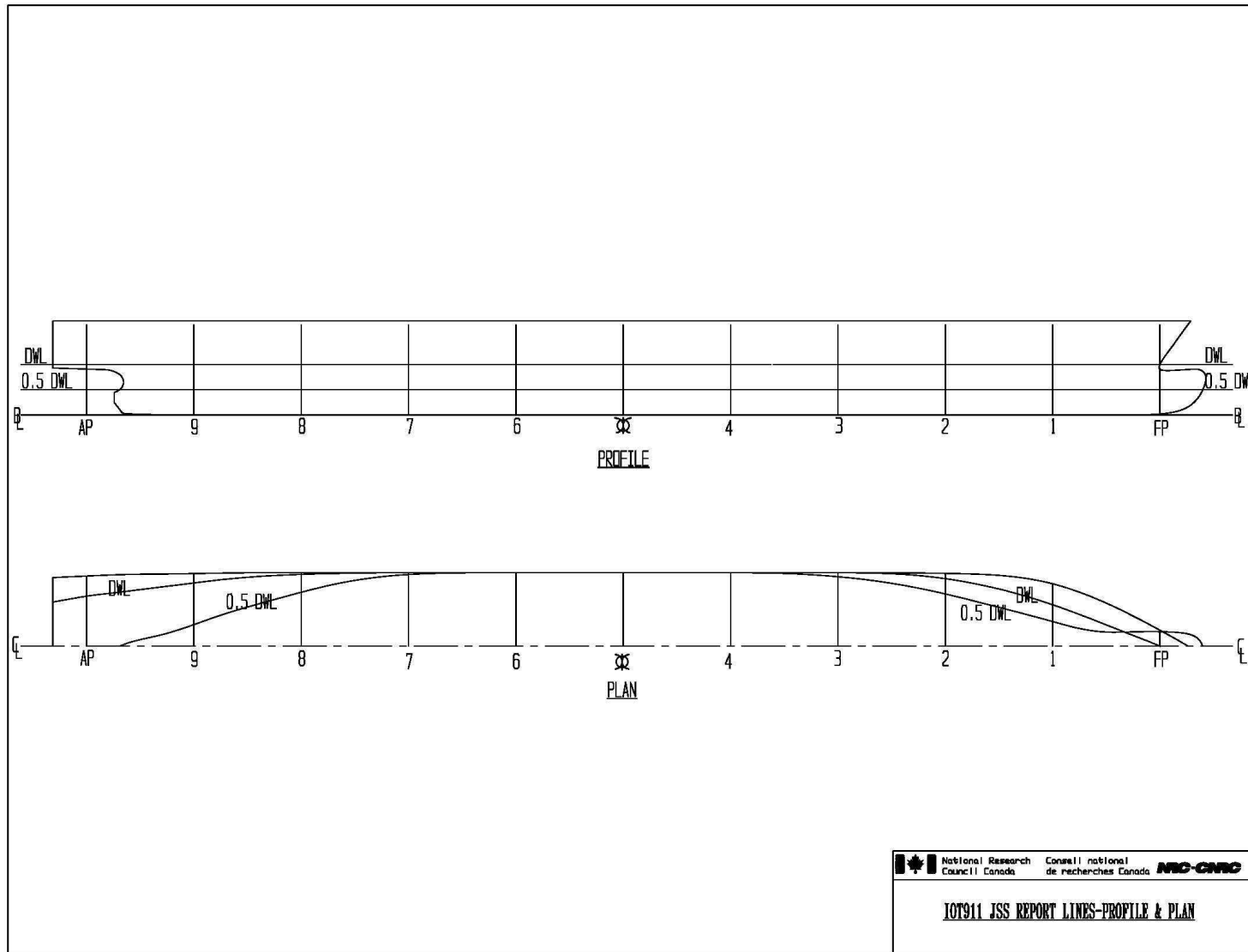
Figure 2 - OCRE 911 Profile and Plan
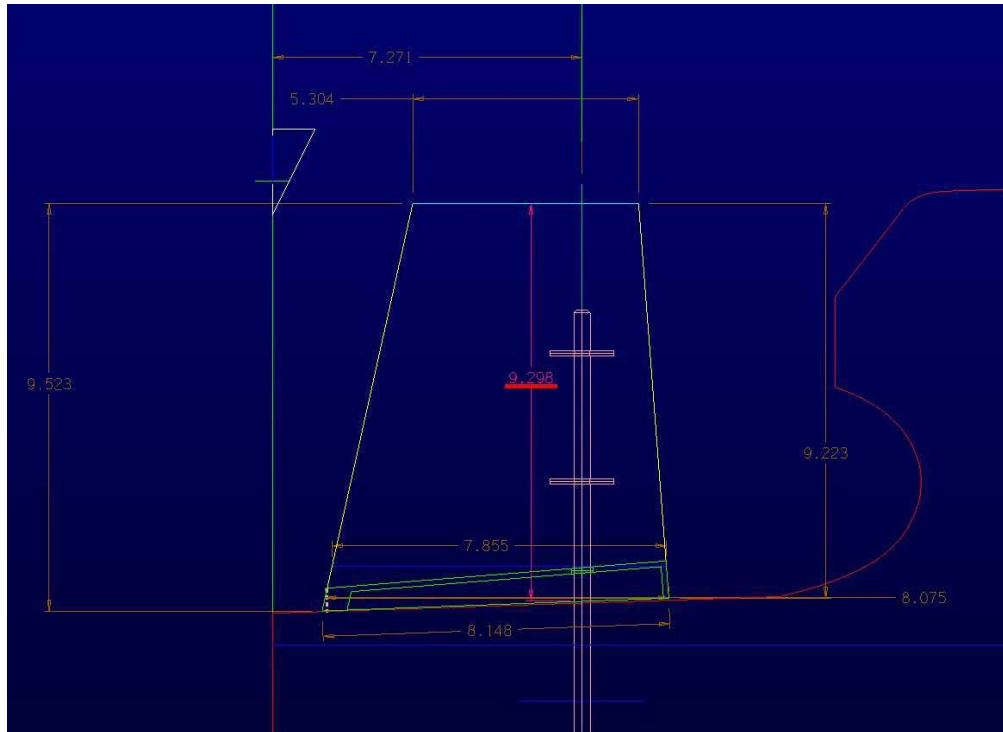
Figure 3 - OCRE 911 Rudder Details (model scale)
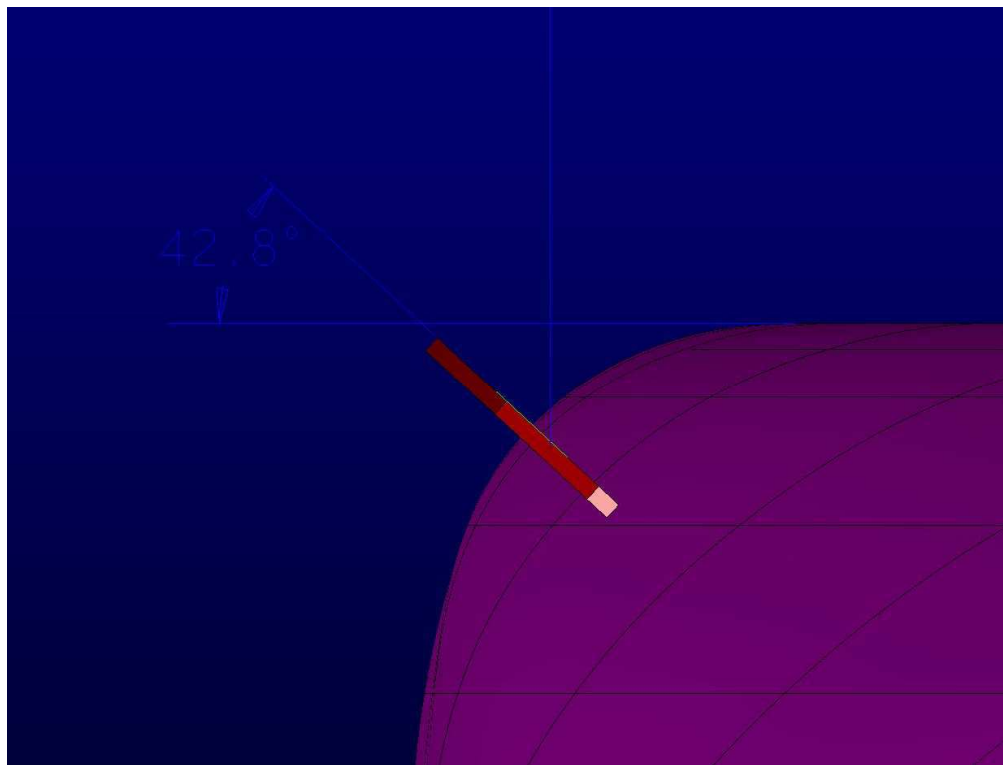
Figure 4 - OCRE 911 Bilge Keel Orientation
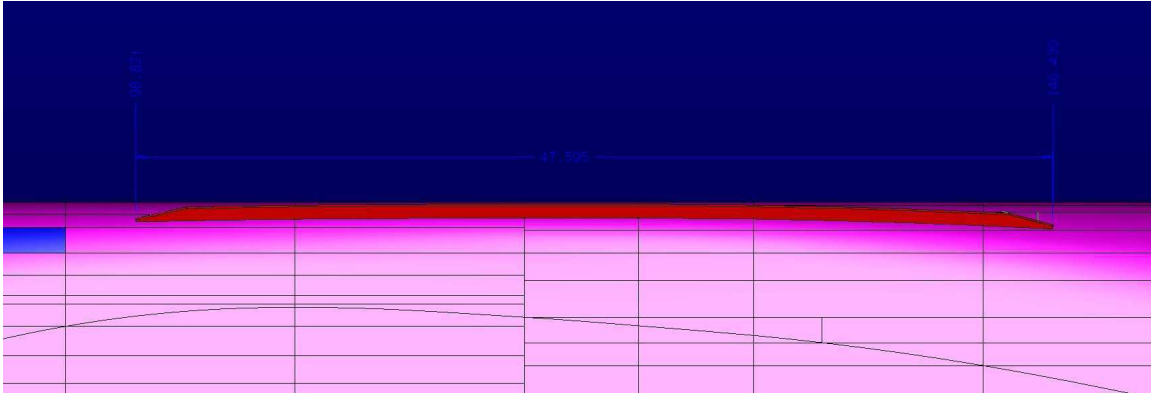
Figure 5 - OCRE 911 Bilge Keel Extent

Figure 6 - OCRE 911 Turbulence Stimulation
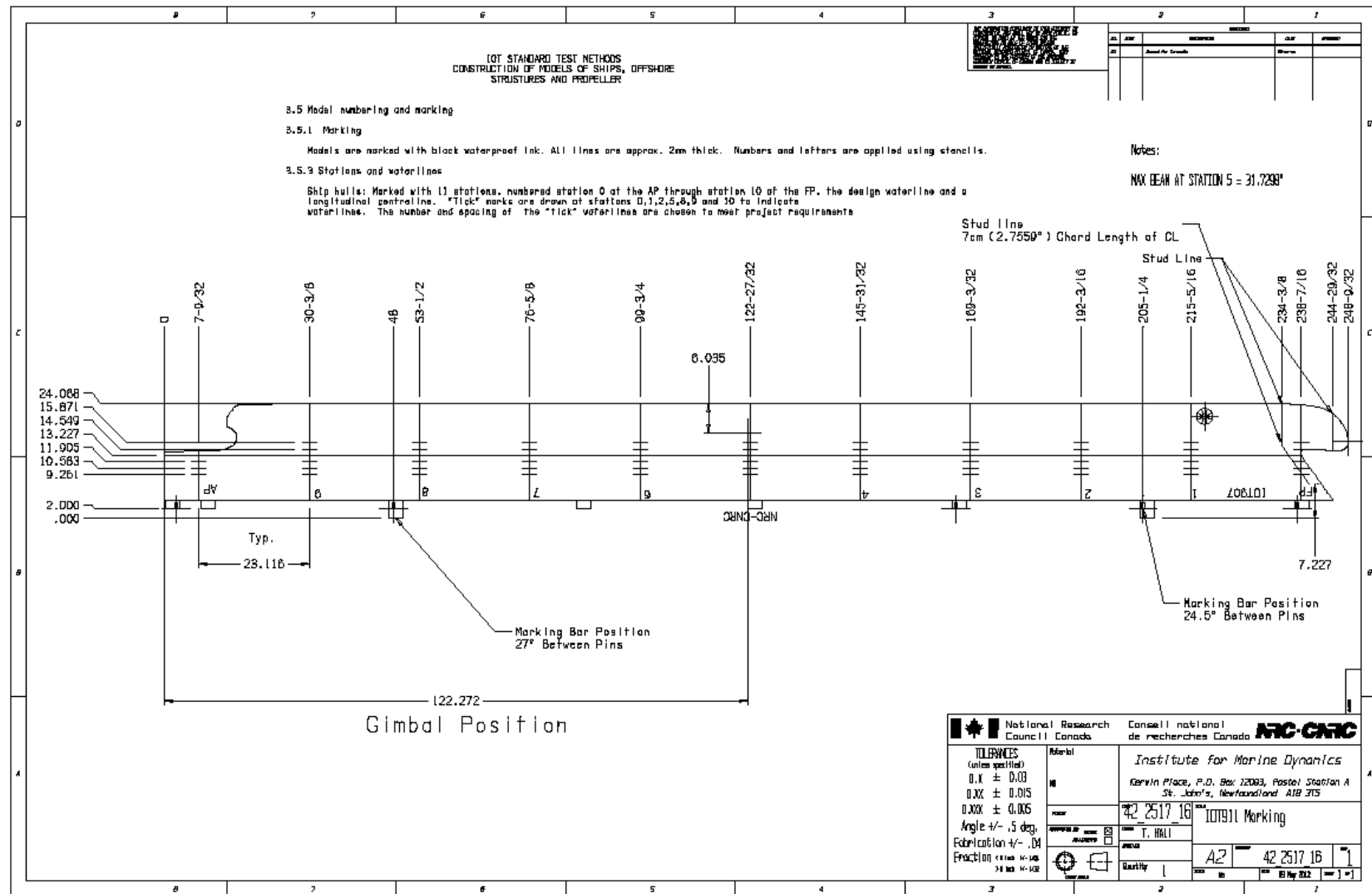
Figure 7 - OCRE 911 Model Marking Diagram
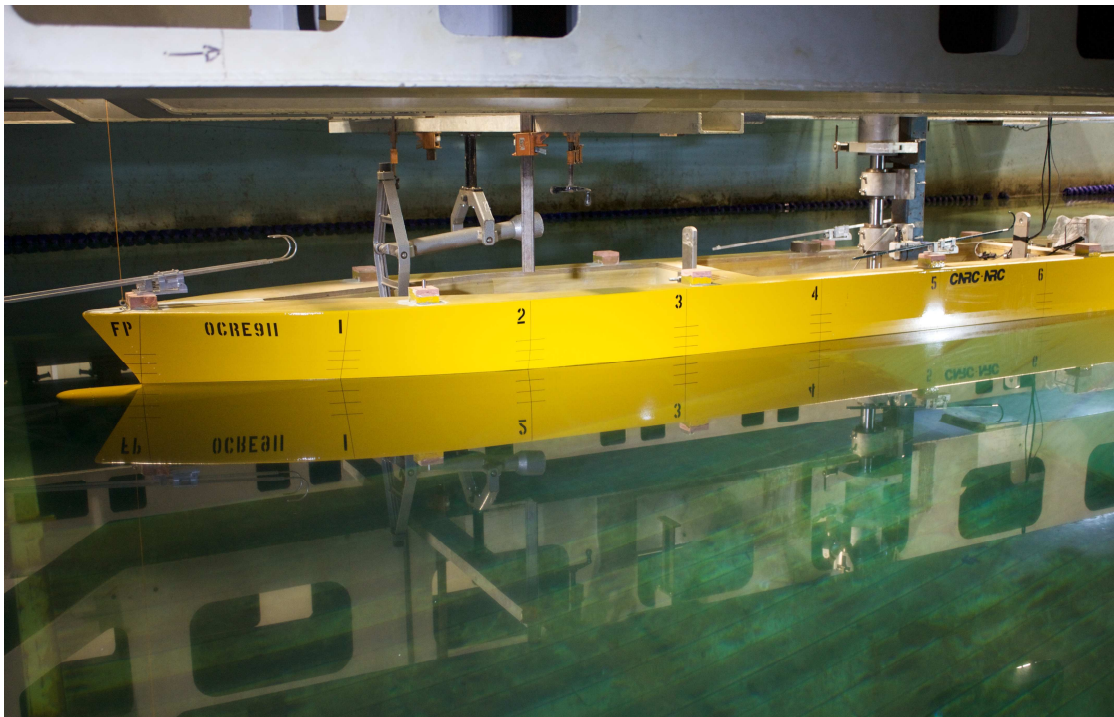
Figure 8 - OCRE 911 as installed in Towing Tank (bow view)
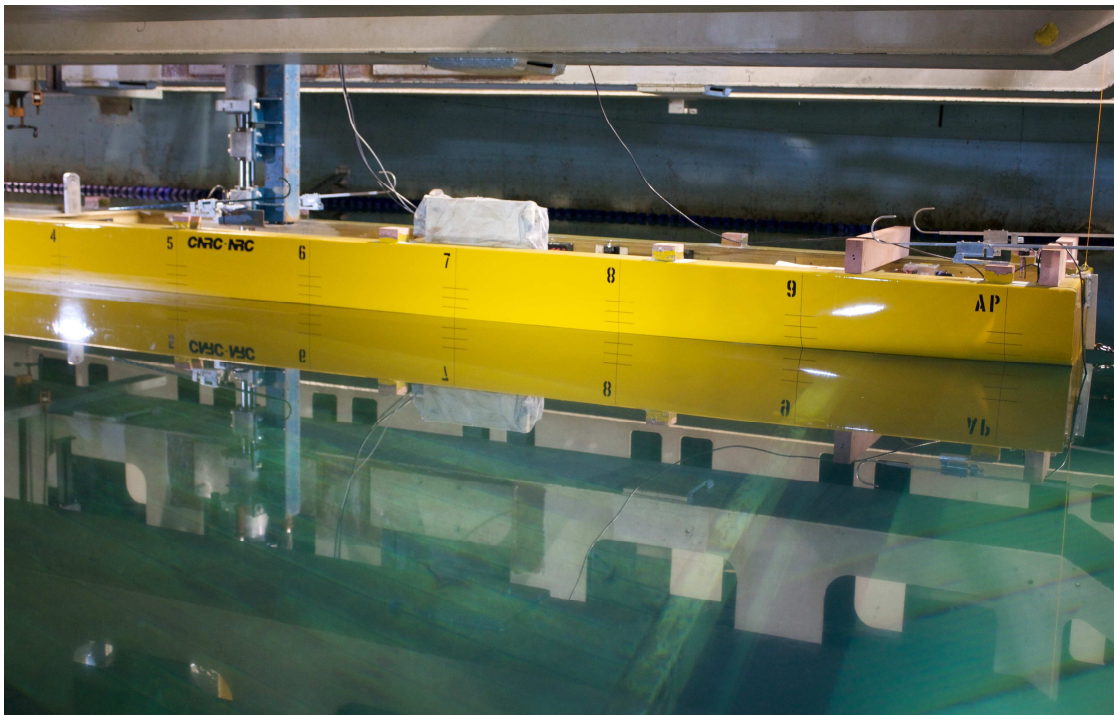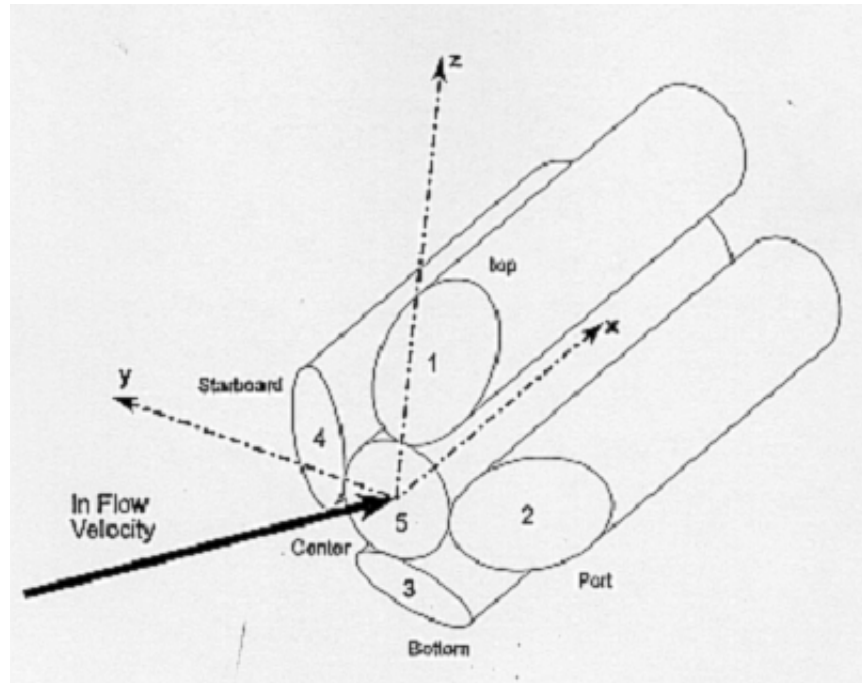

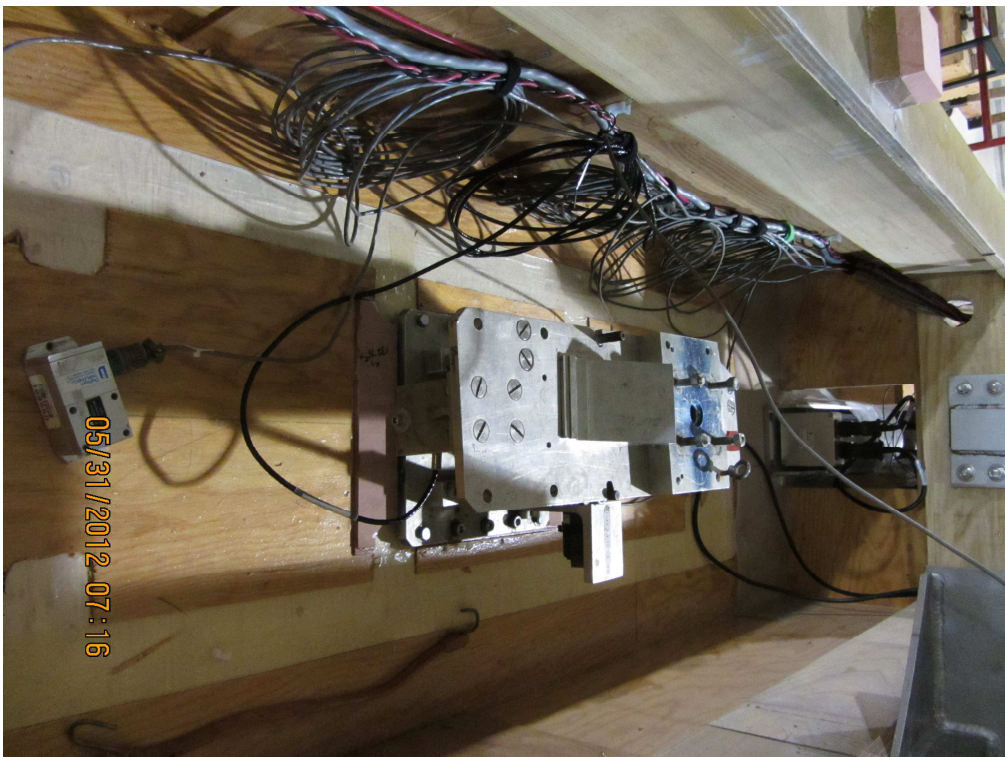**Figure 9 - OCRE 911 as installed in Towing Tank (stern view)**

Figure 10 - Wake Survey Five Hole Pitot Tube

Figure 11 - Medium Towing Gimbal
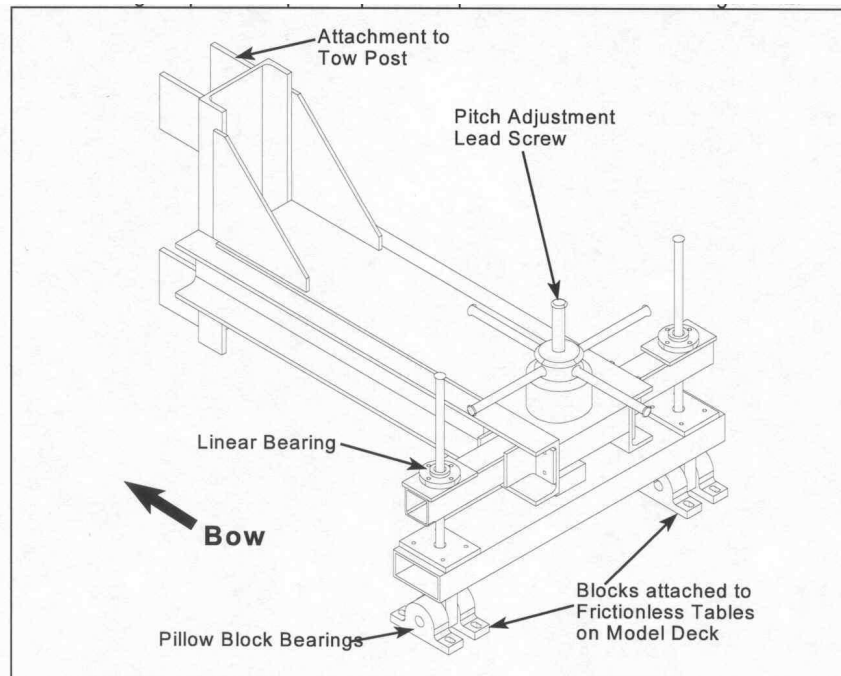
Figure 12 - Wake Survey Model Clamping Apparatus
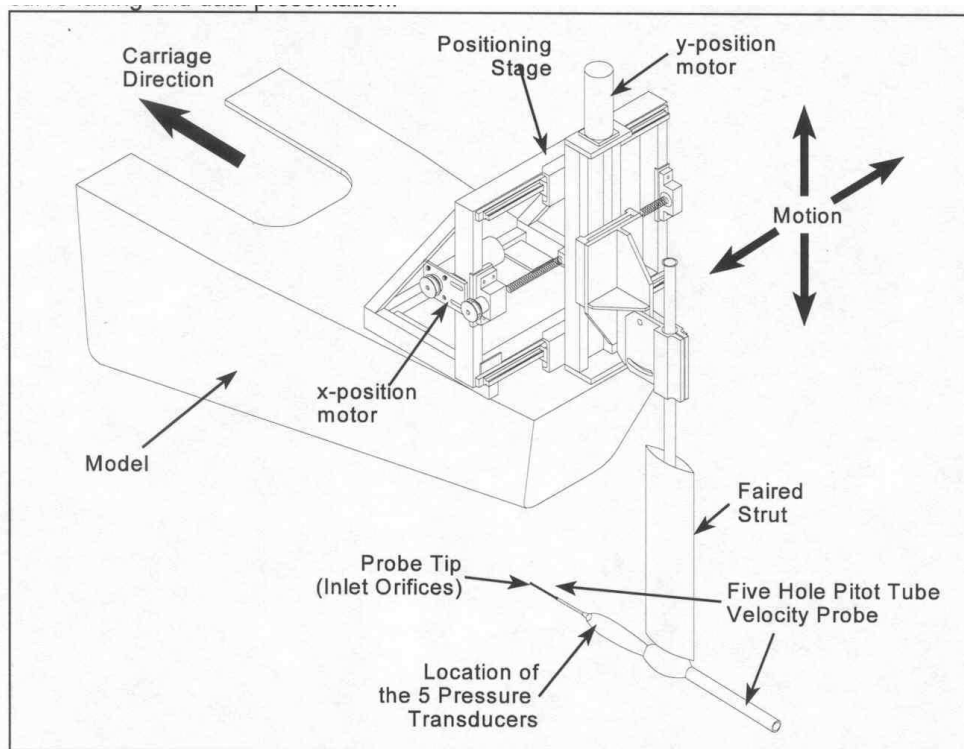
Figure 13 - Wake Survey Probe Positioning Apparatus
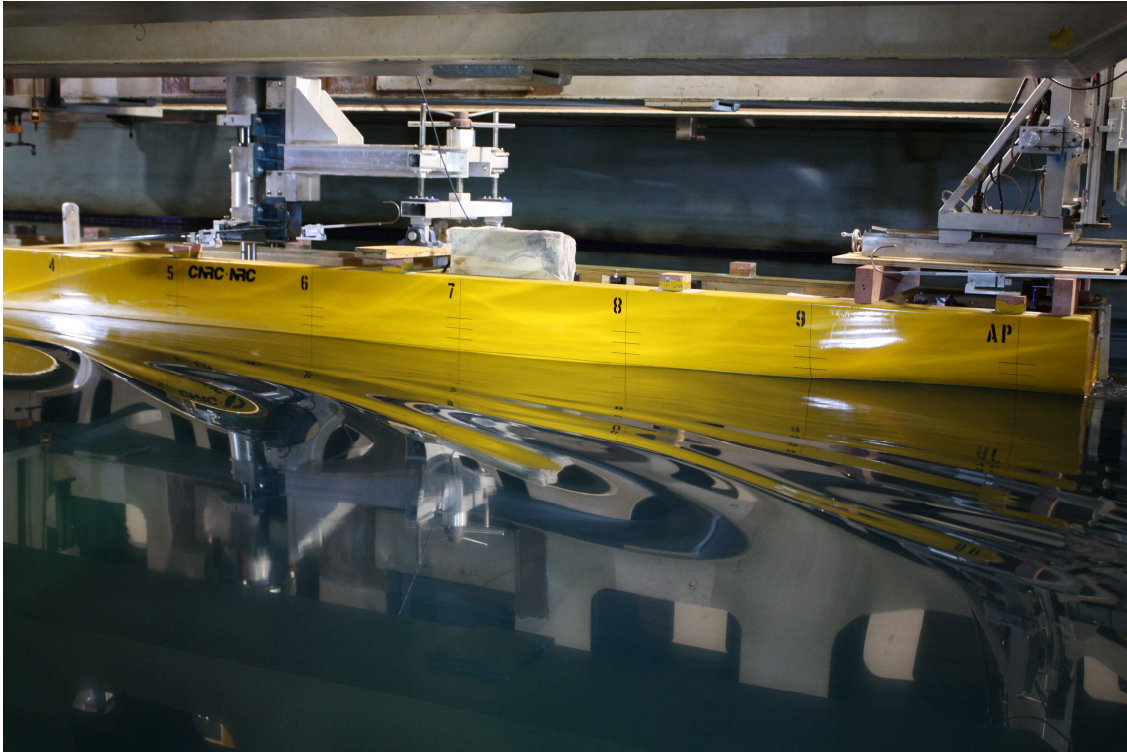
Figure 14 - OCRE 911 during 15-Knot Wake Survey
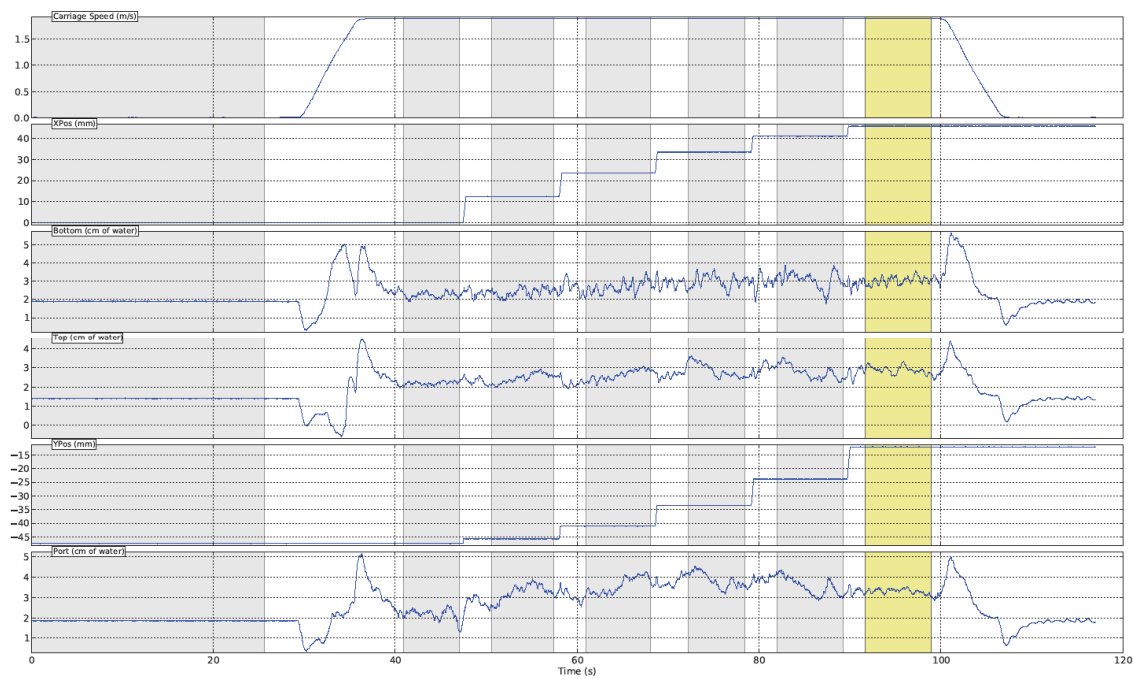
Figure 15 - Example of Differential Pressure Time History and Segment Selection
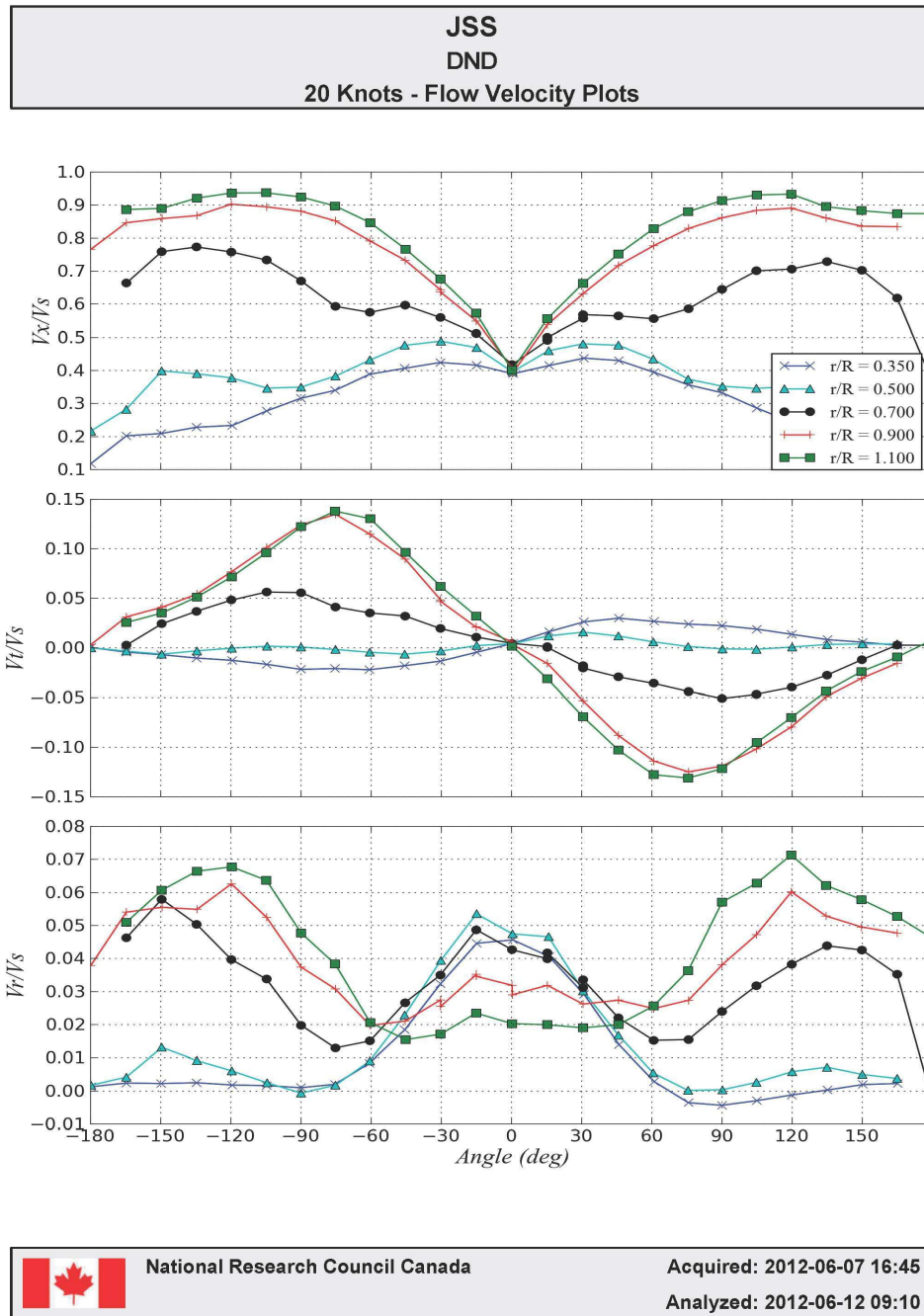
Figure 16 - Example of Axial, Tangential and Radial Flow versus Propeller Disk Angle
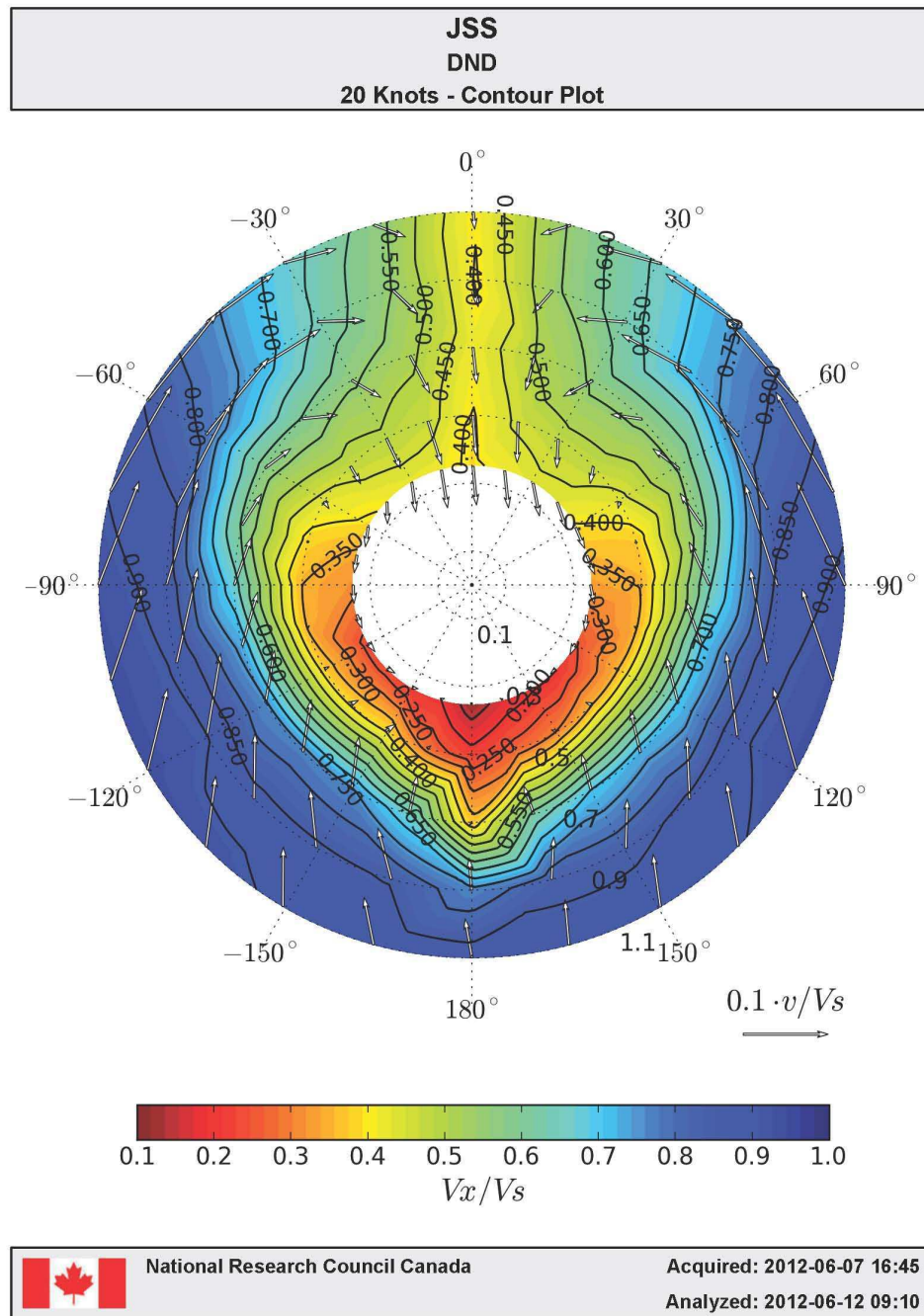
Figure 17 - Example of Contour Plot at Vs=20 knots

Wave Profile on Hull of JSS Contract Design
Model OCRE 911
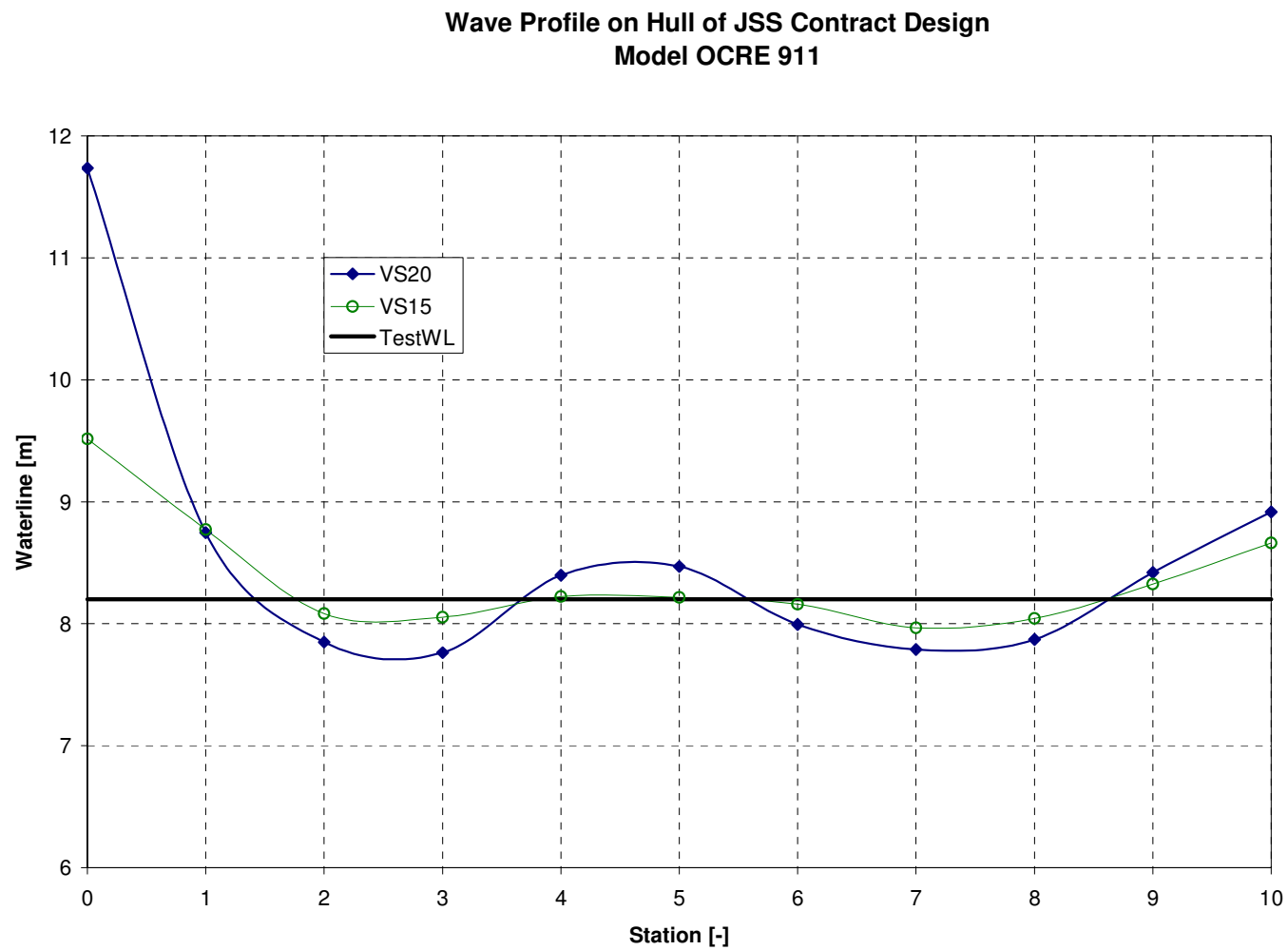
Figure 18 – Wave Profile on Hull at VS = 15 and 20 knots
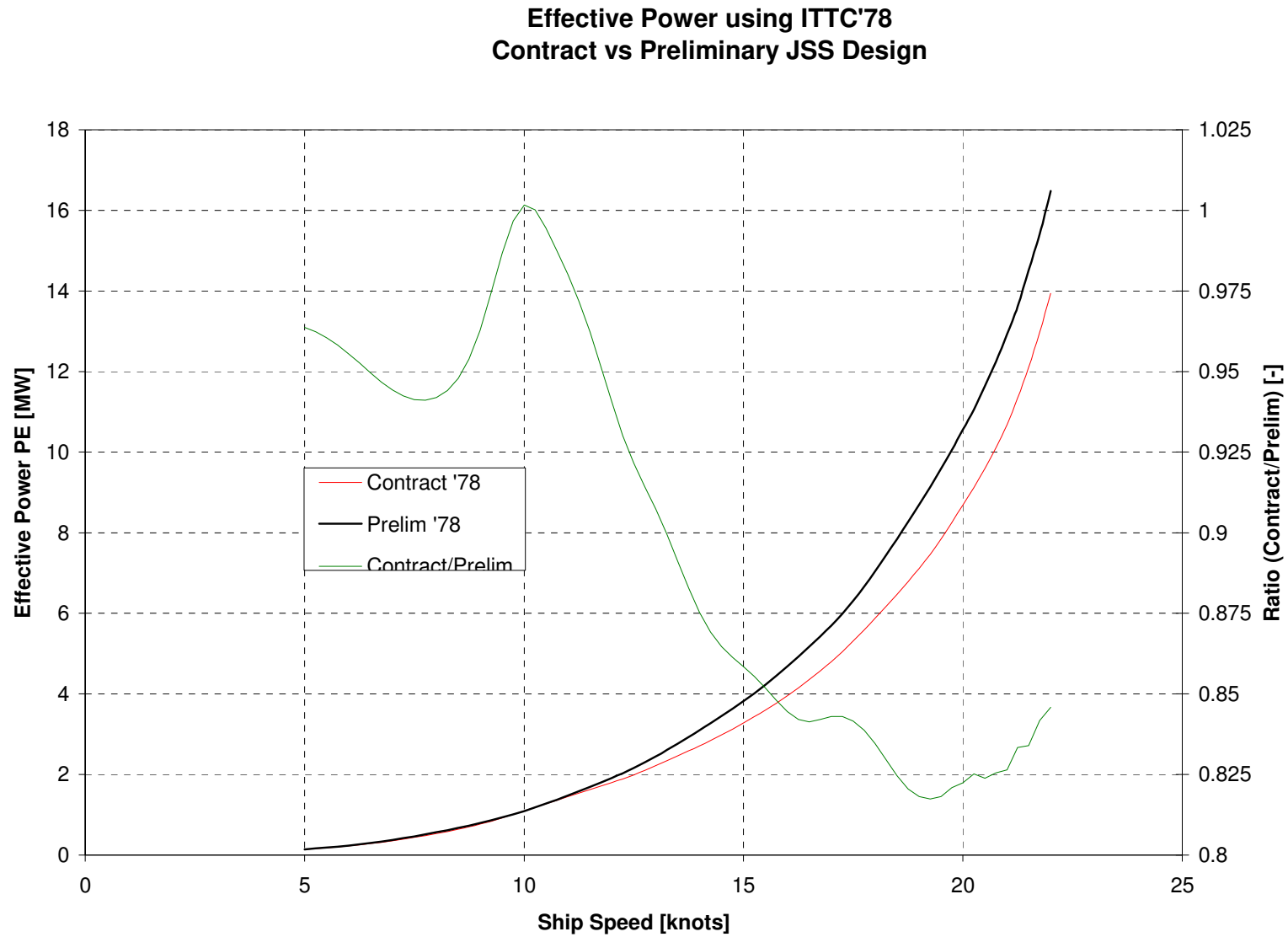
Figure 19 – Comparison of Effective Power Prediction for Contract and Preliminary Versions of the JSS using ITTC'78 Method
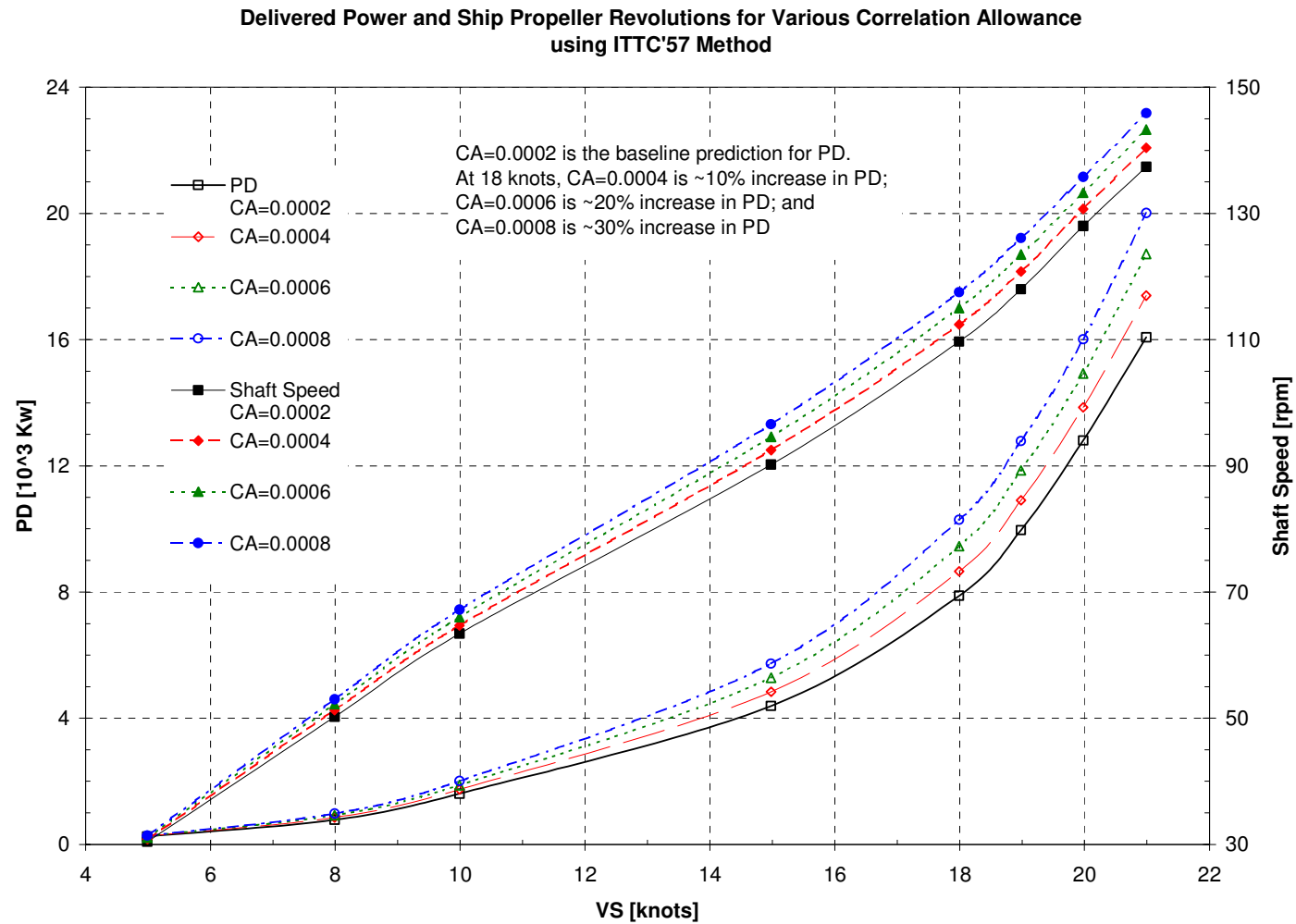
Figure 20 – Power and Shaft Revolutions for Various Correlation Allowances
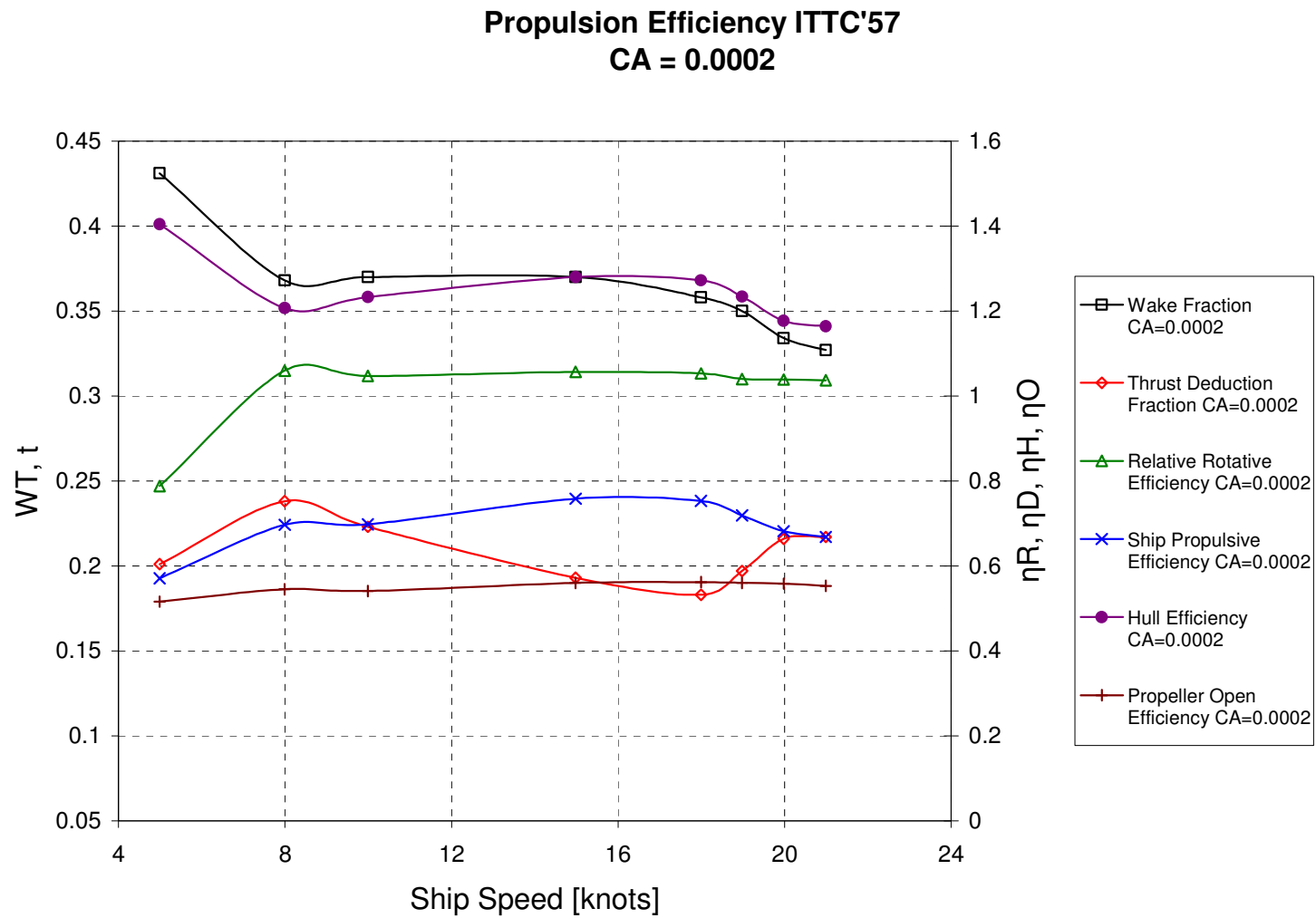
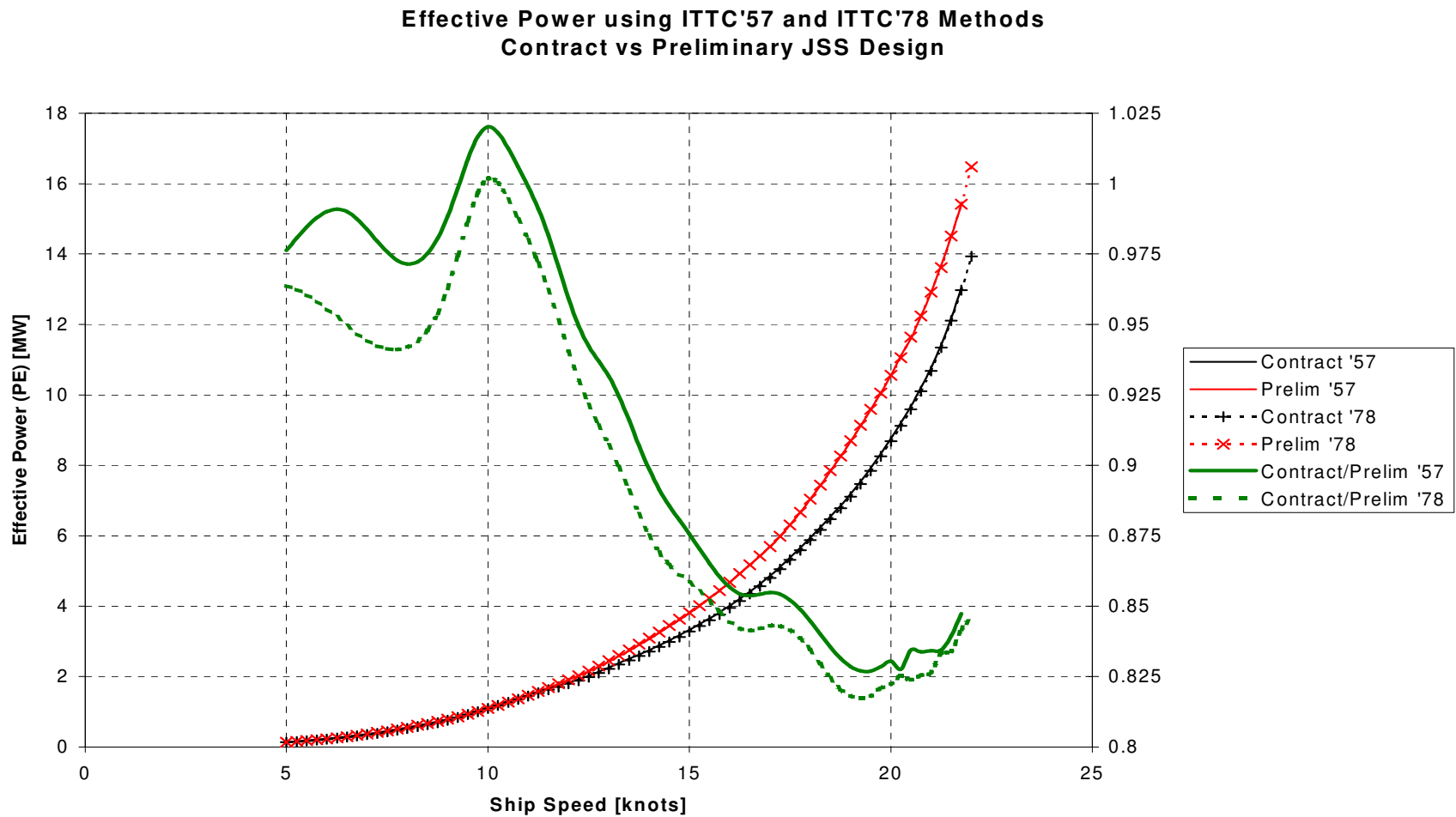**Figure 21 – Propulsion Efficiency Coefficients against Ship Speed using ITTC'57 Method**

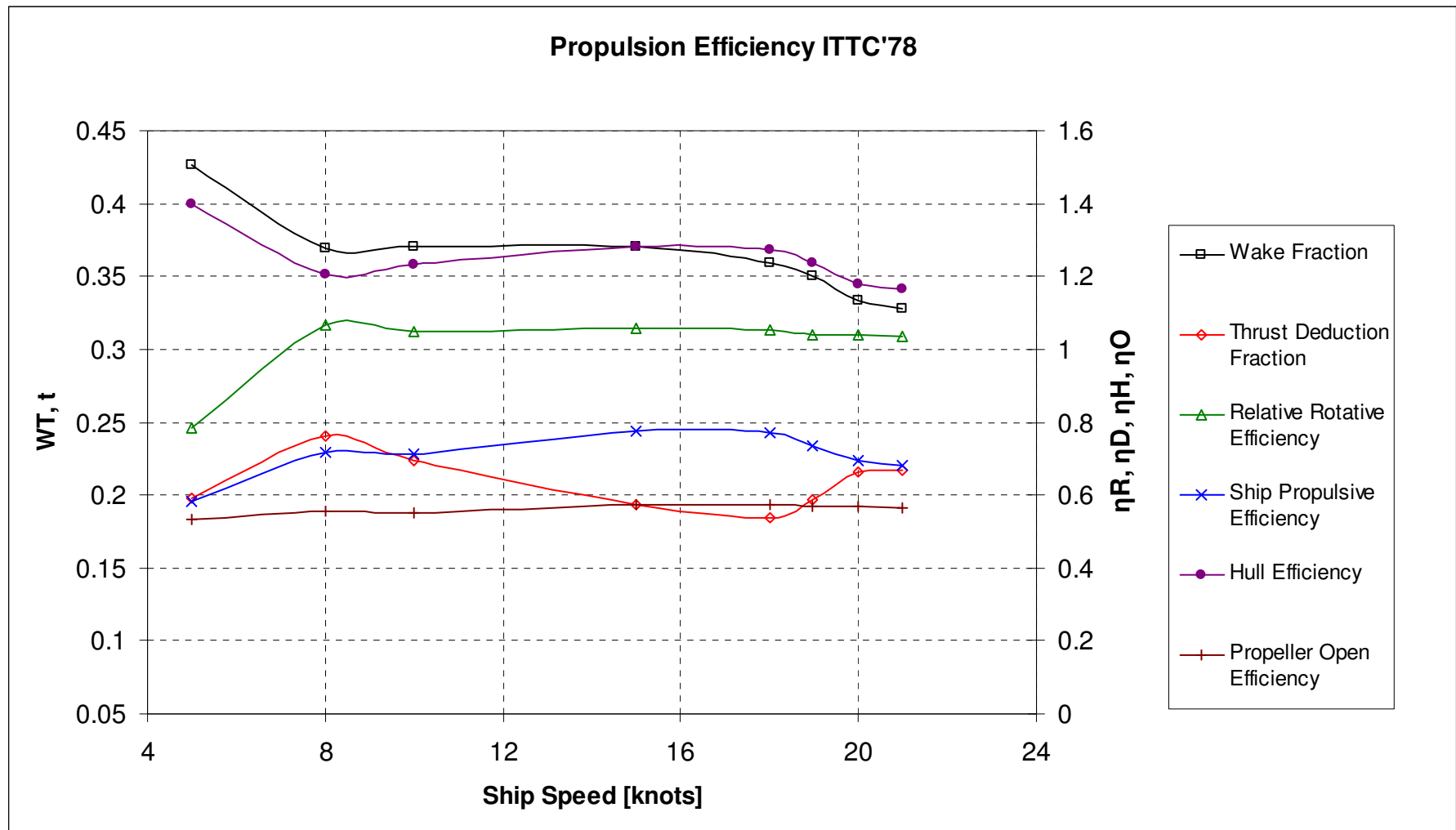**Figure 22 – Delivered Power and Shaft Revolutions using ITTC'78 Method**

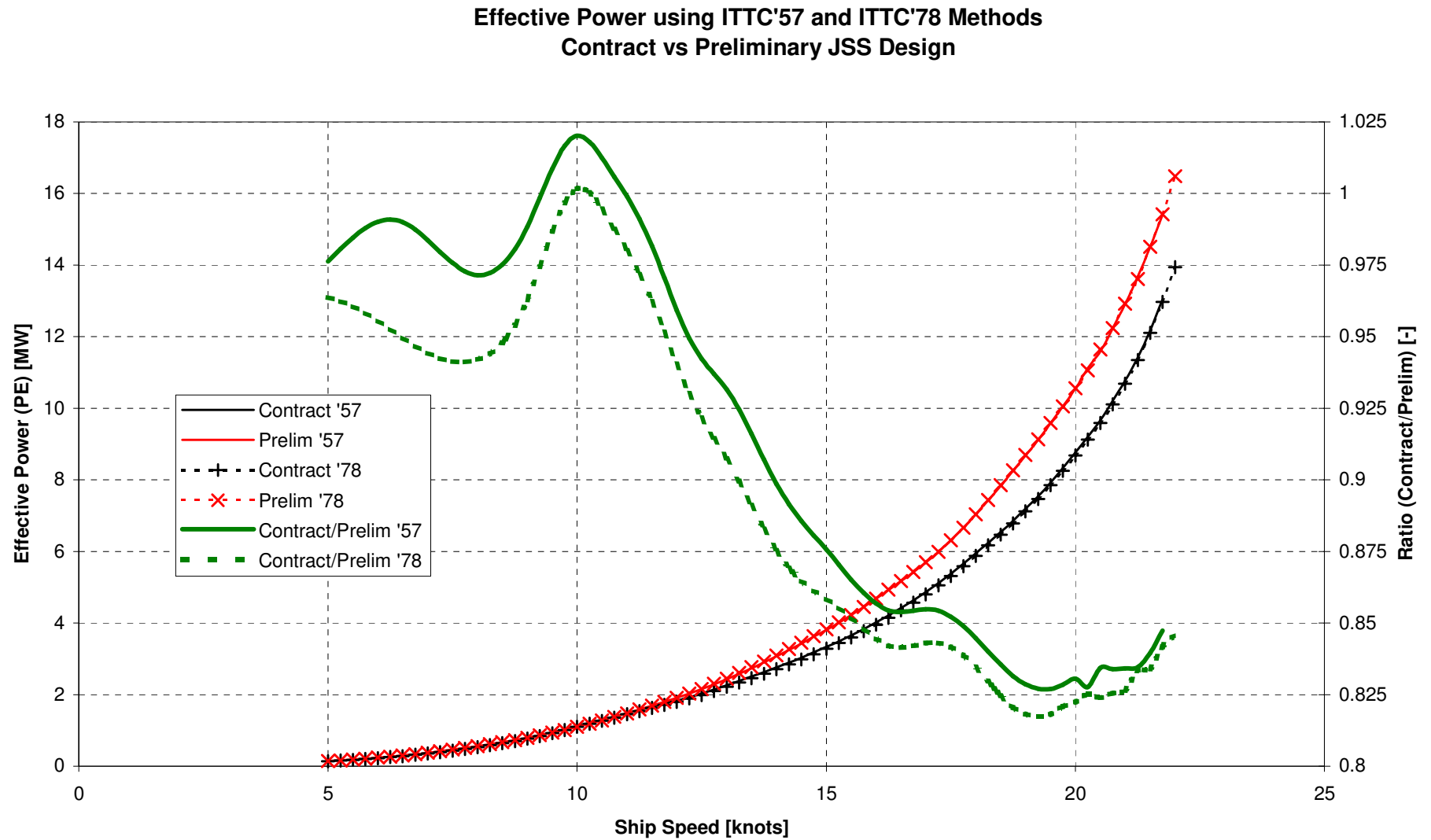**Figure 23 - Propulsion Efficiency Coefficients against Ship Speed using ITTC'78 Method**

Figure 24 – Comparison of Effective Power Predictions

Ship Powering Prediction
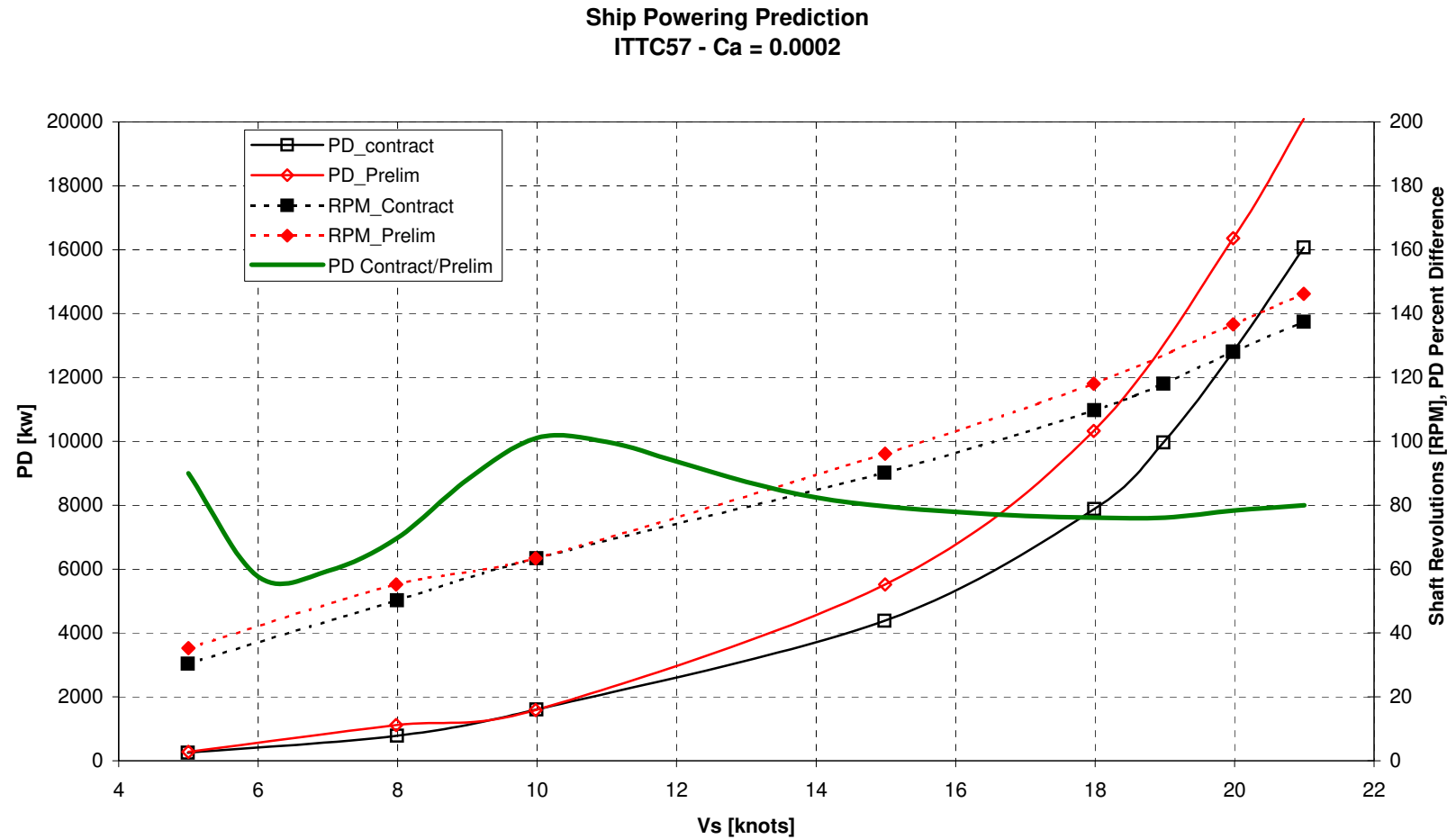**ITTC57 - Ca = 0.0002**

Figure 25 – Delivered Power and Shaft Revolution Comparison for Contract versus Preliminary Design