Description of propeller open water experiments carried out on warship propellers IOT 319L/R

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DESCRIPTION OF PROPELLER OPEN WATER EXPERIMENTS CARRIED OUT ON WARSHIP PROPELLERS IOT319L/R

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SUMMARY

This report describes propeller open water experiments carried out on a pair of stock Institute for Ocean Technology (IOT) five bladed warship propellers, designated IOT319L/R, in the IOT Tow Tank January 13, 2006. These propeller are normally fitted to a large scale warship model such as *HALIFAX* Class frigate model IOT691.

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D. Cumming, R. Pallard

April 2006

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LIST OF ABBREVIATIONS

DC	direct current
deg.	degree(s)
deg. C, °C	degree(s) Centigrade
CCW	counter clockwise
CW	clockwise
GDAC	General Data Acquisition and Control
GEDAP	General Data Analysis Package
Hz	Hertz
IOT	Institute for Ocean Technology (formerly Institute for Marine Dynamics)
kg	kilogram(s)
K&R	Kempf & Remmers
kW	kiloWatt(s)
m	metre(s)
mm	millimetre(s)
MARIN	Maritime Research Institute Netherlands
N	Newton(s)
P/D	pitch/diameter
QA	quality assurance
rps	revolution(s) per second
t	tonne(s)
T1, T2	start, end times

LIST OF SYMBOLS – PROPELLER OPEN WATER EXPERIMENTS[1]

Symbol	Definition
υ_M	kinematic viscosity of the water in the test facility, m^2/s
ρ_M	density of the water in the test facility, kg/m^3
η_O	open efficiency
$c_{0.7}$	model propeller blade cord at 0.7 radius, m
D	model propeller diameter, m
Fr	Froude number for the ship and model
g	gravitational acceleration (standard IOT value 9.808 m/s^2)
J_O	advance coefficient in propeller open water test
K_{QO}	propeller torque coefficient in open water test
K_{TO}	propeller thrust coefficient in open water test
K_{TDO}	duct thrust coefficient in open water test
n_O	propeller rate of rotation in open water test, rps
Q_O	propeller torque in open water test, Nm
R_{nco}	propeller Reynolds number
T_O	propeller thrust in open water test, N
T_{DO}	duct thrust in open water test, N
V_A	propeller speed of advance in open water test, m/s

[1] Note IOT uses ITTC Symbols Version 2002.

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DESCRIPTION OF PROPELLER OPEN WATER EXPERIMENTS CARRIED OUT ON WARSHIP PROPELLERS IOT319L/R

1.0 INTRODUCTION

This report describes propeller open water experiments carried out on a pair of stock Institute for Ocean Technology (IOT) five bladed warship propellers, designated IOT319L/R, in the IOT Tow Tank January 13, 2006. These propellers are normally fitted to a large scale warship model such as *HALIFAX* Class frigate model IOT691.

2.0 DESCRIPTION OF THE IOT TOWING TANK

The IOT Towing Tank has dimensions of 200 m by 12 m by 7 m with a dual-flap wavemaker fitted at one end capable of generating uni-directional regular waves up to 1 m in height or irregular waves up to a 0.5 m significant wave height. A wave absorber consisting of a parabolic beach is fitted at the opposite end. Flexible side absorbers can also be deployed along the entire length of the tank to minimize the time between runs. The 80 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 or waves. A 4,000 kg lift capacity moveable overhead crane is available over most of the tank length. Additional information on the Towing Tank is provided in Appendix A.

3.0 DESCRIPTION OF IOT PROPELLER OPEN WATER DYNAMOMETER

The IOT propeller open water dynamometer is used to determine the characteristics of model propellers in a homogeneous flow field and can be mounted in either the 200 m Towing Tank or Cavitation Tunnel. The IOT unit is a model H-39, fabricated by Cussons Technology Marine Research Systems Division in the U.K. Torque and thrust of the propeller are measured using separate full-bridge strain gage transducers in a streamlined body, which is an extension of the propeller shaft. The strain gages are temperature compensated and an effort has been made to minimize crosstalk. A schematic of the dynamometer is presented in Figure 1.

Rated Torque = ± 55 N-m
Rated Thrust = 1000 N
Maximum Shaft Speed = 50 rps
Power of the Drive Motor for Rated Torque @ 50 rps = 18 kW

4.0 DESCRIPTION OF PROPELLERS IOT319L/R

The propellers designated IOT319L/R are nominally 320.4 mm diameter 5 bladed adjustable pitch warship propellers fabricated by the Maritime Research Institute Netherlands (MARIN) several years ago. The MARIN designation for these propellers is 5687L/R and when received by IOT were is rather poor condition. The propeller hubs were bored out and a sleeve inserted such that they could be accommodated on the IOT

standard shaft diameter. The propellers were then set by IOT at the nominal design pitch of 31.012 degrees (P/D = 1.322). The QA information for these propellers is provided in Appendix B while a photograph of the propellers along with associated fittings is given in Figure 2.

5.0 DESCRIPTION OF INSTRUMENTATION AND DATA ACQUISITION SYSTEM

The experiments were carried out using the standard IOT propeller open dynamometer fitted to the tow carriage in the IOT Towing Tank.

All acquired analog DC signals were low pass filtered at 10 Hz, amplified as required and digitized at 50 Hz using IOT's standard data acquisition system and software described in Reference 1.

The signals measured and recorded during the propeller open water experiments are listed in the Table 1.

6.0 CALIBRATION PROCEDURE

The procedure used to calibrate each individual signal is described as follows using the standard IOT sign convention described in Reference 2.

Tow Carriage Speed: Carriage speed is calibrated 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. The tow carriage is operated at a constant speed between the two switches and the time between activating the switches recorded on the carriage data acquisition system – thus providing an accurate measure of tow carriage speed.

Shaft Speed: The shaft speed was measured using a pre-installed tachometer that provides an analog signal linearly proportional to shaft speed and was calibrated using a laser tachometer directed at a piece of reflective tape located on the drive shaft.

Shaft Thrust, Torque: In order to statically calibrate the propeller open water dynamometer; the device is mounted to a dedicated K&R calibration jig. To calibrate the thrust, the dynamometer was mounted with the sensing end pointed upward with a spreader bar and weight tray hanging from it. Static weights were added to the weight tray – 70 kg in total in 10 kg increments. To calibrate the torque, a lever arm with a weight tray mounted on one end, was mounted horizontally to the sensing end of the dynamometer. A torque clamp was added to the other end of the dynamometer to prevent the internal shaft from rotating. Static weights were added to the weight tray – 10 kg in 2 kg increments. The thrust was calibrated over a range of 0 to 700 N, while the torque was calibrated over a range of ± 50 N-m.

Instrumentation calibration results are presented in Appendix C.

7.0 TEST PROGRAM

The test program was carried out as per IOT's standard propeller open water test procedure (Reference 3). Due to the large size of the propellers, care was taken to ensure the loads on the propeller opens boat did not exceed maximum allowable values. The planned test program is provided in Appendix D. Shaft friction values were acquired with dummy hubs fitted at the beginning and end of testing for each propeller from 7 to 14 rps in 1 rps increments. The following three shaft speeds were planned:

For n_o = 8 rps – R_{nco} corresponds to 476747.
For n_o = 11 rps – R_{nco} corresponds to 655527.
For n_o = 13 rps – R_{nco} corresponds to 774713.

Due to excessive shaft vibration noted at bollard at a shaft speed of ~ 7.5 rps, it was decided to carry out experiments at 7 rps and 11 rps only – although it was necessary to omit low J_o values for the 11 rps speed. A Run Log for experiments carried out on both propellers is given in Appendix E.

8.0 DATA ANALYSIS PROCEDURE

The data were acquired in GDAC format (*.DAC files) described in References 4, 5. The data were converted to GEDAP format described in Reference 6 prior to carrying out an online data analysis on the Tow Tank carriage workstation during the test to verify the integrity of the acquired data. The online data analysis for each propeller is described as follows:

Online data analysis for each shaft friction run:

- The shaft torque and shaft speed were plotted on the screen in the time domain. Start and end times (T1, T2) are interactively selected for each steady state segment.
- Basic statistics (minimum, maximum, mean, standard deviation) were computed for each data segment.
- A plot of mean shaft torque vs. shaft speed was now displayed on the screen and the user required to interactively fit a spline curve through the data.
- A spline curve of mean shaft torque vs. shaft speed was now output to a GEDAP file.

Propeller open water data for 198.12 mm diameter 5 bladed adjustable pitch warship propellers IOT131 L/R (former MARIN propellers 4055L/R) acquired as described in Reference 7 was used as a source for the comparison curves (K_{TO} vs. J_O) and ($10K_{QO}$ vs. J_O) for the online analysis where:

$$J_O = \frac{V_A}{n_O D} \tag{1}$$

$$K_{QO} = \frac{Q_O}{\rho_M n_O{}^2 D^5} \tag{2}$$

$$K_{TO} = \frac{T_O}{\rho_M n_O{}^2 D^4} \tag{3}$$

Online data analysis for each propeller open water run:

- The shaft torque, shaft thrust, shaft speed and carriage speed are plotted on the screen in the time domain. Start and end times (T1, T2) are interactively selected for the 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.
- Basic statistics (minimum, maximum, mean, standard deviation) were computed for each data segment.
- A routine was executed where the nondimensional propeller coefficients: advance coefficient, J_O, torque coefficient, K_{QO}, and thrust coefficient, K_{TO}, were computed using the corrected averaged values of each relevant parameter. These dimensionless coefficients are calculated using equations 1 to 3 and mean values as well as dimensionless coefficients are output to an ASCII point [.PNT] file.
- A plot of the computed nondimensional propeller coefficients points were displayed on a screen (K_{TO} vs. J_O) and ($10K_{QO}$ vs. J_O) along with the designated comparison curves.
- Run Designation, Acquire Time, Carriage Speed (m/s), Shaft Speed (rps), Shaft Thrust (N), Shaft Torque (N-m) and Reynold's Number data was displayed in tabular form for all runs completed for the given model configuration up to the given time.
- The user exercises an option to print the table and plot on a local tow carriage laser printer.

The results of the online data analysis are provided in Appendix F.

After completion of the propeller open water experiment, the following offline data analysis is carried out:

Deriving the average shaft friction:

- A routine was run to compute the average shaft friction derived from friction runs carried out before and after each propeller open water shaft speed. The following files were required as an input:

  P1 = Initial raw friction points [*.PNT].

  P2 = Spline fitted curve of initial friction points [*SPL.001].

P3 = Final raw friction points [*.PNT].
P4 = Spline fitted curve of final friction points [*SPL.001].

- The shaft torque vs. shaft speed plot was displayed on the screen. Included on the plot is the following information:
  - The initial shaft friction points;
  - Initial spline curve fitted through initial friction points;
  - The final shaft friction points;
  - Final spline curve fitted through final friction points;
  - Average shaft friction curve.

The user exercises an option to print the plot on a laser printer.

To deriving the final propeller open water data taking into consideration the average shaft friction curve:

- The nondimensional propeller coefficients: advance coefficient, J_O, torque coefficient, K_{QO}, and thrust coefficient, K_{TO} data was extracted from the [.PNT] file;
- A four degree-of-freedom polynomial was fitted to the K_{TO} vs. J_O and K_{QO} vs. J_O data to create polynomial curve files in GEDAP format;
- The K_{QO} vs. J_O curve was now multiplied by 10 to create a $10K_{QO}$ vs. J_O curve file;
- A plot of the computed nondimensional propeller coefficients were displayed on a screen (K_{TO} vs. J_O) and ($10K_{QO}$ vs. J_O) along with the propeller efficiency in open water (η_O) where:

$$\eta_O = \frac{J_O K_{TO}}{2\pi K_{QO}} \tag{4}$$

- The polynomial coefficients to the fitted lines for K_{TO} and $10K_{QO}$ where:

$$f(J_O) = \sum_{i=0}^{n} B(i) Jo^i \tag{5}$$

were displayed in a table. In addition, the values for the fitted lines for J_O, K_{TO}, $10K_{QO}$ and η_O in J_O increments of 0.05 were displayed in the same table;

- The user exercises an option to print the table and plot on a laser printer.

The results of the offline data analysis are provided in Appendix G.

9.0 DATA QUALITY CONTROL

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

ONLINE DATA ANALYSIS: The data were analyzed during the test as described in Section 8.0. Using the technique of plotting the acquired data against a comparison curve, it was possible to detect and address even minor problems immediately. The

comparison curve for these tests was propeller open water data for a similar 5-bladed warship propeller. If the data from a given run was found to vary from what was expected by an unacceptable amount, then the run was repeated. If the variance persisted, the test was halted and an investigation carried out to determine the source of the problem.

REPEAT RUNS: As another method of monitoring data integrity, a number of repeat runs were embedded in the test program for the 7 rps tests. A table comparing mean values for identical carriage speed/shaft speed condition runs are provided in Table 2. The maximum difference between repeat run values of shaft torque and thrust is less than 0.5%.

10.0 ACKNOWLEDGEMENTS

Funding for these experiments was provided by the Department of National Defence. The authors would like to thank all IOT technical staff that assisted with acquiring this propeller open water data.

11.0 REFERENCES

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

3) "Propeller Open Water Tests", IOT Standard Test Method TM-2, V6.0, April 1, 2004.

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

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

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

7) Cumming, D, Molyneux, W.D.,"Description of Propeller Open Water, Resistance and Propulsion Experiments Carried out on HALIFAX Class Frigate Model IMD592", Institute for Marine Dynamics Test Report TR-2003-01, January 2003. **PROTECTED**

TABLES

LIST OF SIGNALS

Name	Units	Range	Acquire?	Sample Rate (Hz)	Critical Level	Device
Carriage Speed	m/s	0-5	Y	50	1	
Shaft Torque	N-m	0-54	Y	50	1	K&R H-39 Prop Opens Dyno
Shaft Thrust	N	0-980	Y	50	1	K&R H-39 Prop Opens Dyno
Shaft Speed	rps	0-15	Y	50	1	
Water Temp.	deg. C	0-20	N	N/A	1	Hand Held Temp. Probe

TABLE 1: LIST OF SIGNALS

Propeller IOT319L/R Open Water Experiments

January 13, 2006 **Towing Tank**

Propeller IOT319R Nominal Shaft rps: 7 rps

Carriage Speed (m/s)	Shaft Speed (rps)	Shaft Thrust (N)	% Diff. Shaft Thrust (N)	Shaft Torque (N - m)	% Diff. Shaft Torque (N - m)
0.68844	-7.00177	292.169	0.02%	-17.2095	-0.07%
0.68840	-7.00008	292.238		-17.2215	
2.07640	-7.00164	110.976	0.11%	-8.1914	-0.17%
2.07650	-6.99974	111.099		-8.2057	
Propeller IOT319L		Nominal Shaft rps: 7 rps			
0.68863	6.96634	293.134	0.12%	17.3363	0.29%
0.68910	6.96556	292.773		17.2868	
2.07637	6.96864	112.244	0.11%	8.3378	0.47%
2.07656	6.96795	112.124		8.2992	

TABLE 2: REPEAT RUNS

FIGURES

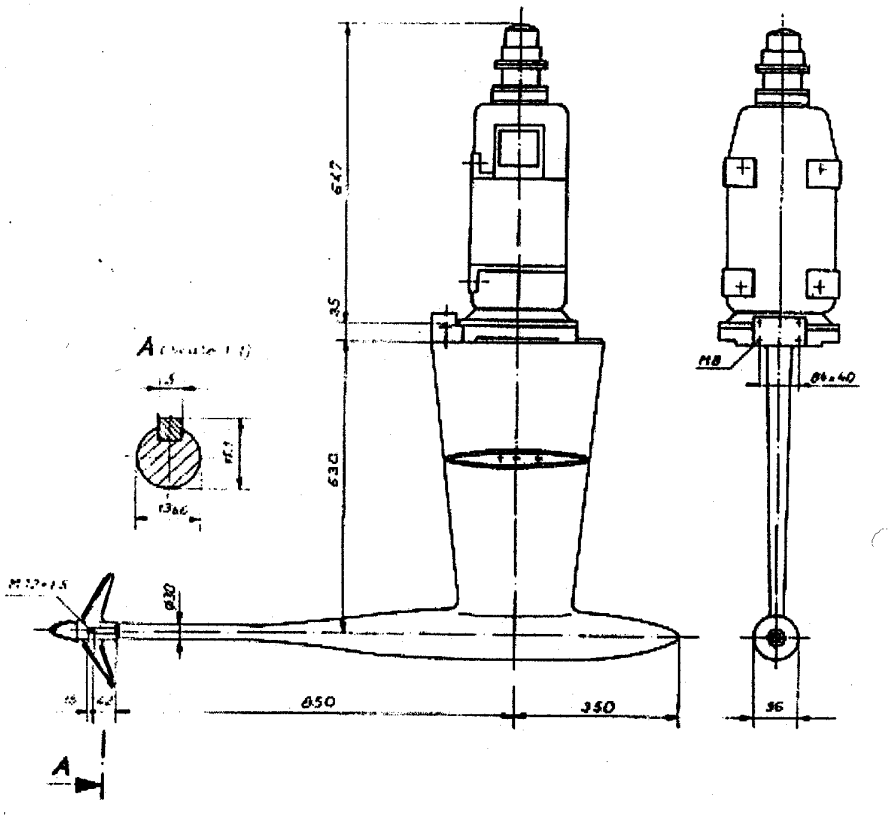


FIGURE 1: Schematic of IOT Propeller Open Water Dynamometer

FIGURE 2: Propellers IOT319L/R & Fittings

APPENDIX A

Description of IOT Towing Tank

Facilities

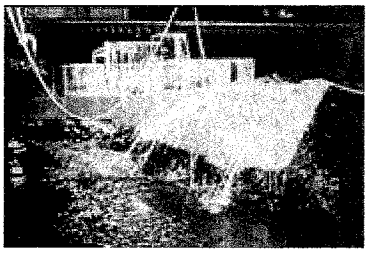
Commercial Services
Offshore Engineering Basin
Towing Tank
Ice Tank
Cold Rooms
Cavitation Tunnel
Other Facilities and Equipment

Printable version

Towing Tank

Description: rectangular tank 200m (656 ft) in length, 12m (39 ft) in width and 7m (23 ft) in depth, models are towed through still water or waves by a carriage spanning the width of the tank, model rigging is facilitated by two trim docks and a moveable overhead crane (4000 kg).

Carriage: single manned carriage with 8 wheel synchronous motor drive, test frame adjustable for model size, 80,000 kg mass, 746 kW power, speed range .001 m/s - 10.0 m/s, manual service carriage for wind and current generation.



Towing Tank

Play Video (.ram)
Free video player

Wave Generator: dual flap hydraulic wave board with digital computer control, regular or irregular waves program controlled, maximum wave height 1m (regular) or 0.5m significant (irregular).

Wave Absorber: parabolic corrugated surface beach with transverse slats, 20m long with 10.5 slope at water line, flexible side absorbers.

Current Generation: maximum surface current speed 0.3 m/s @ 10m from nozzles.

Wind Generation: 12 fan bank with gusting capability, maximum wind speed 12 m/s @ 10m from fans.

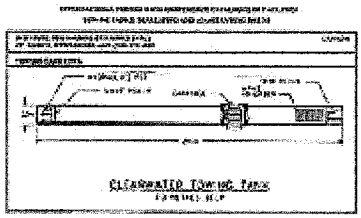
Model Size Range: ships models up to 12m in length, floating structures 0.5m - 4m diameter.

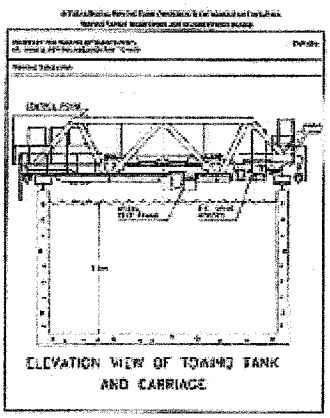
Instrumentation: force measurement, strain gauge load cells, capacitance and sonic wave probes, model position, Qualisys optical tracking, accelerometer arrays and motions package for model motions, propeller characteristics, open water propeller dynamometer, propulsion and control system for free-running models, under and above water video, transient recorders, and flow measurement.

Data Acquisition: A VMS and Windows NT based distributed client/server system using one or more IOtech DaqBoards, each with 256 channel capability at 100kHz aggregate.

Tests Performed:
(1) resistance and propulsion
(2) wake survey
(3) flow visualization
(4) propeller open water
(5) seakeeping
(6) floating and moored structures
(7) loads due to wind and current
(8) lift and drag
(9) dynamics of underwater vehicles

Schematic Diagrams (click to expand)





Date Modified: 2005-02-21 ▲ Important Notices

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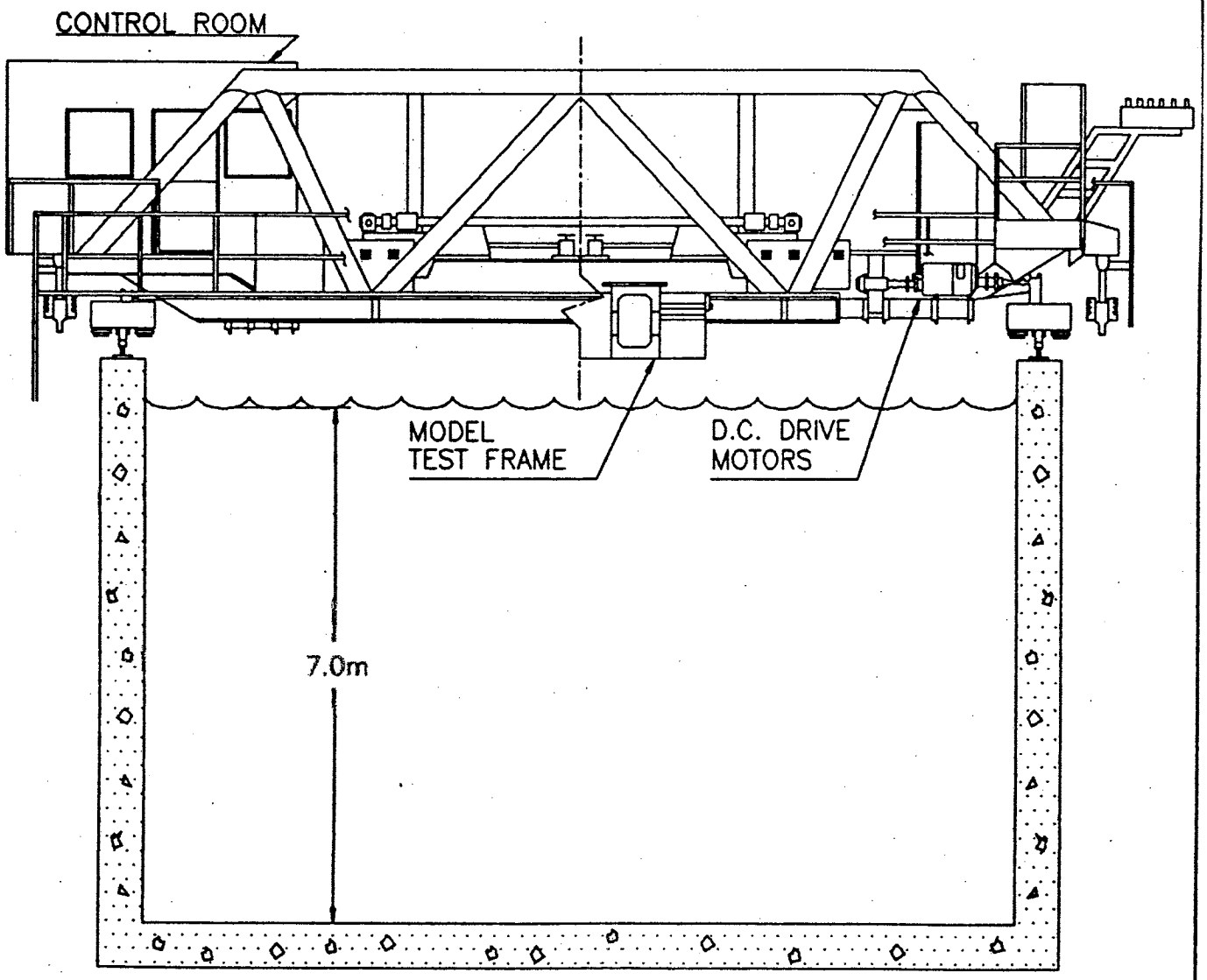
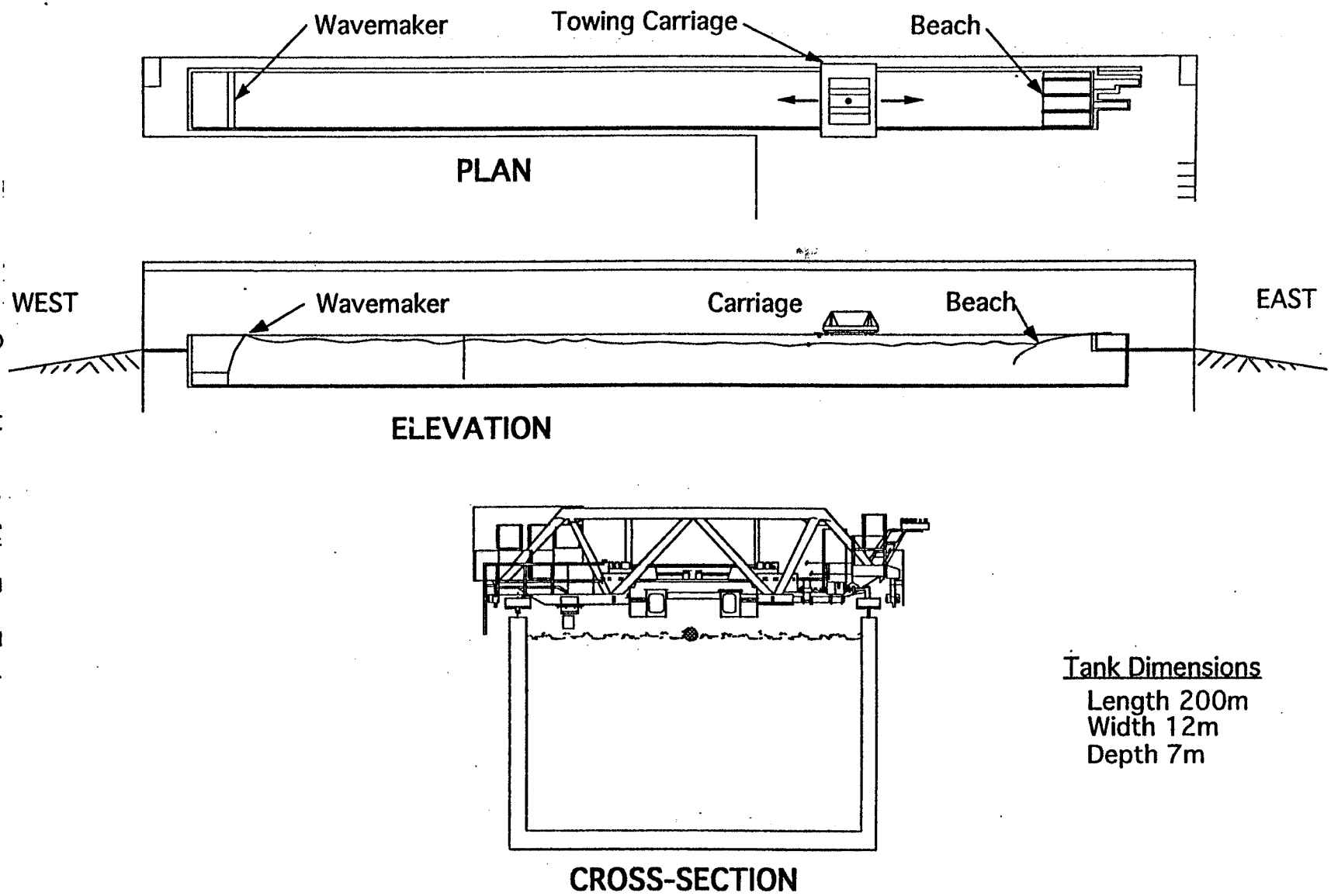
CANADA

TOWING TANK (1985)



ELEVATION VIEW OF TOWING TANK AND CARRIAGE



General Layout of the Tow Tank

APPENDIX B

QA Information for Propellers IOT319l/R

Propeller IOT319L/R QA Sheet							Jan. 2006						
NOTE: IOT319L/R were provided by MARIN (Marin Propeller No. 5687L/R)													
Procedure		1	enter the dia. In B11										
		2	enter the P/D ratio desired in F13										
		3	enter the rad ratio where the measurements are being taken in F15										
		4	the req'd angle will appear in F16										
		5	enter angles and heights for the blade being adjusted and get the full blade angle to match F16										
Outside Dia. as measured from blade 1	12.615	in.	320.421	mm									
				P/D	1.322								
		rad the pitch angle is req'd for			0.7								
Calculated Pitch Angle Req'd for a Specific P/D			angle req'd		31.01222	degrees	tolerance +/-		0.155061	degrees	31.16728		
											30.85716		
					4.415	7th rad	=D/2 * 0.7 (in.)		112.15 mm				
Pitch Measurement													
					height measured parallel to axis of prop shaft								
	IOT319L - Left Hand							**IOT319R - Right Hand**					
	angle (deg.)		height (in.)		pitch angle (deg.)			angle (deg.)		height (in.)		pitch angle (deg.)	
0 degree set at the trailing edge of blade one	2		-0.2962					358		-0.2976			
1	27		-1.518		-32.383			333		-1.522		32.438	
	52		-2.611		-29.568			308	352	-2.6118		29.496	
					-30.996	full blade #1						30.990	full blade #1
	74		-0.2888					70		-0.299			
5	99		-1.515		-32.476			45		-1.5254		32.480	
	124		-2.609		-29.591			20		-2.6174		29.546	
					-31.055	full blade # 2						31.036	full blade # 2
	146		-0.2904					142		-0.295			
4	171		-1.514		-32.421			117		-1.5206		32.463	
	196		-2.61		-29.636			92		-2.614		29.577	
					-31.049	full blade # 3						31.042	full blade # 3
	218		-0.3					214		-0.289			
3	243		-1.516		-32.260			189		-1.5138		32.447	
	268		-2.6062		-29.505			164		-2.6104		29.649	
					-30.902	full blade # 4						31.068	full blade # 4
	290		-0.2928					286		-0.2948			
2	315		-1.5158		-32.408			261		-1.5222		32.502	
	340		-2.6138		-29.681			236		-2.6118		29.492	
					-31.064	full blade #5						31.020	full blade #5
Average Pitch Measurement for all Blades (deg.)					-31.013							31.031	

Propeller IOT319L/R QA Sheet

	Blade Diameter Measurements								Gauge Block Heights for Pitch Setting				
		Left Hand			Right Hand					Left Hand			Right Hand
	1	12.624		1	12.624				1	0.735		1	0.75
	2	12.622		2	12.616				2	0.735		2	0.75
	3	12.614		3	12.602				3	0.735		3	0.75
	4	12.614		4	12.61				4	0.735		4	0.755
	5	12.614		5	12.618				5	0.735		5	0.76
		12.618	in.		12.614	in.							
		320.487 mm			320.3956 mm								

APPENDIX C

Instrumentation Calibration Results

Calibration of TOWDAS Channel 16 15:18 10 January 2006

Project: CPF STERN FLAPS **Facility:** CWT

Sensor: Opens Thrust **Model:** K&R Opens Dynamometer **Serial Number:** N/A

Programmable Gain: 1 **Plug-In Gain:** 500 **Filter Frequency:** 10.0 Hz

Data Point No.	Input Signal (volts)	Physical Value (N)	Fitted Curve Value (N)	Error (N)	
1	−0.674	96.92	97.39	0.46388	⇐ Maximum Error
2	−1.065	195.99	196.01	0.02074	
3	−1.448	292.91	292.52	−0.39621	
4	−1.842	392.04	391.68	−0.35938	
5	−2.228	488.96	488.81	−0.15814	
6	−2.621	587.72	587.81	0.09467	
7	−3.006	684.64	684.97	0.33435	
Maximum Error = 0.0789 % of Calibration Range.					

Definition of Calibration Curve

Polynomial Degree = 1 (Linear Fit)

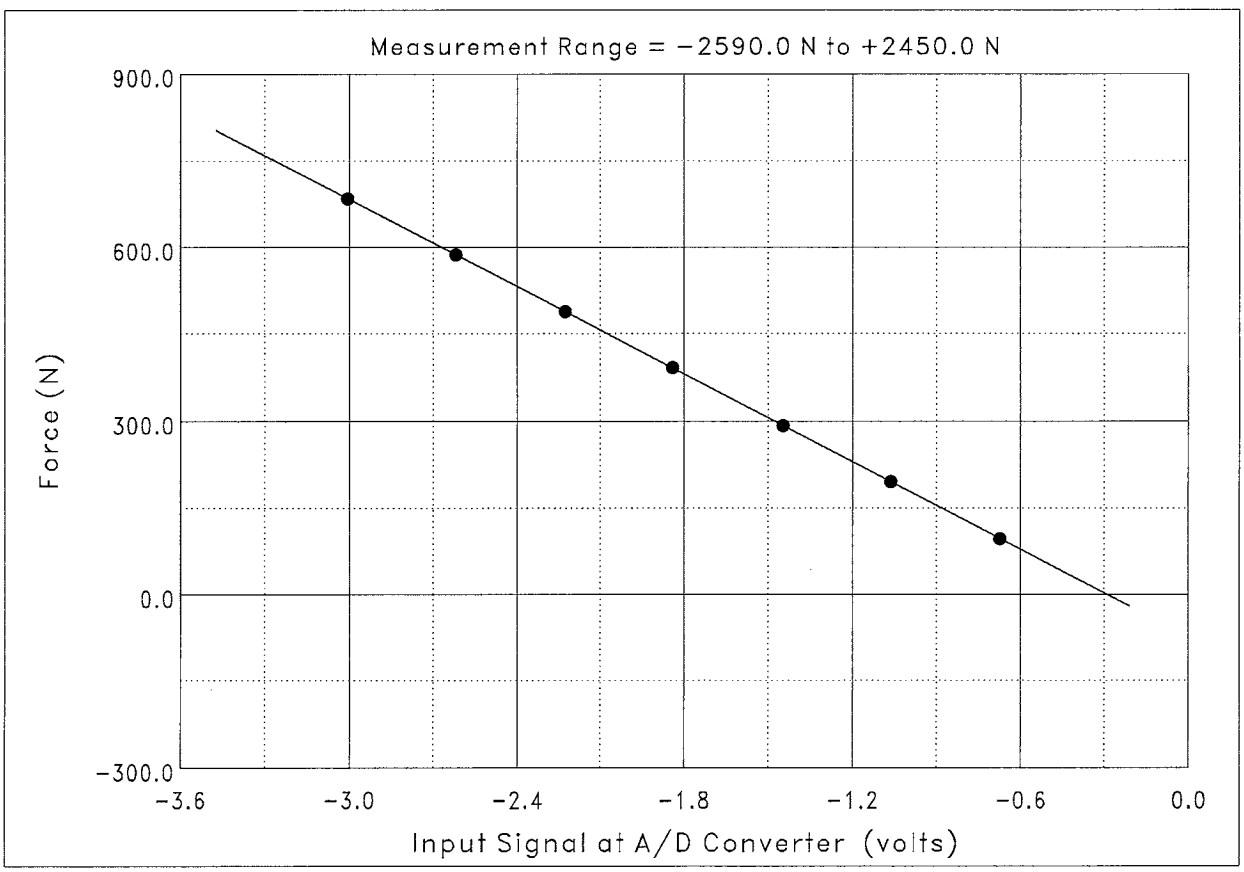
$$Y = C_0 + C_1 \cdot V$$

where $Y(t)$ = Force (N),

$V(t)$ = input signal at A/D converter (volts),

C_0 = −72.2472 N,

and C_1 = −251.864 N/volt.



Calibration of TOWDAS Channel 15 15:10 10 January 2006

Project: CPF STERN FLAPS **Facility:** CWT

Sensor: Opens Torque **Model:** K&R Opens Dynamometer **Serial Number:** N/A

Programmable Gain: 1 **Plug-In Gain:** 500 **Filter Frequency:** 10.0 Hz

Data Point No.	Input Signal (volts)	Physical Value (Nm)	Fitted Curve Value (Nm)	Error (Nm)	
1	−0.645	9.787	9.751	−0.035735	
2	−1.293	19.513	19.494	−0.018721	
3	−1.946	29.310	29.305	−0.004602	
4	−2.597	39.091	39.097	0.006199	
5	−3.243	48.800	48.813	0.012608	
6	0.652	−9.787	−9.749	0.037522	⇐ Maximum Error
7	1.301	−19.513	−19.499	0.013536	
8	1.953	−29.310	−29.305	0.004761	
9	2.604	−39.091	−39.091	0.000004	
10	3.251	−48.800	−48.816	−0.015568	
Maximum Error = 0.0384 % of Calibration Range.					

Definition of Calibration Curve

Polynomial Degree = 1 (Linear Fit)

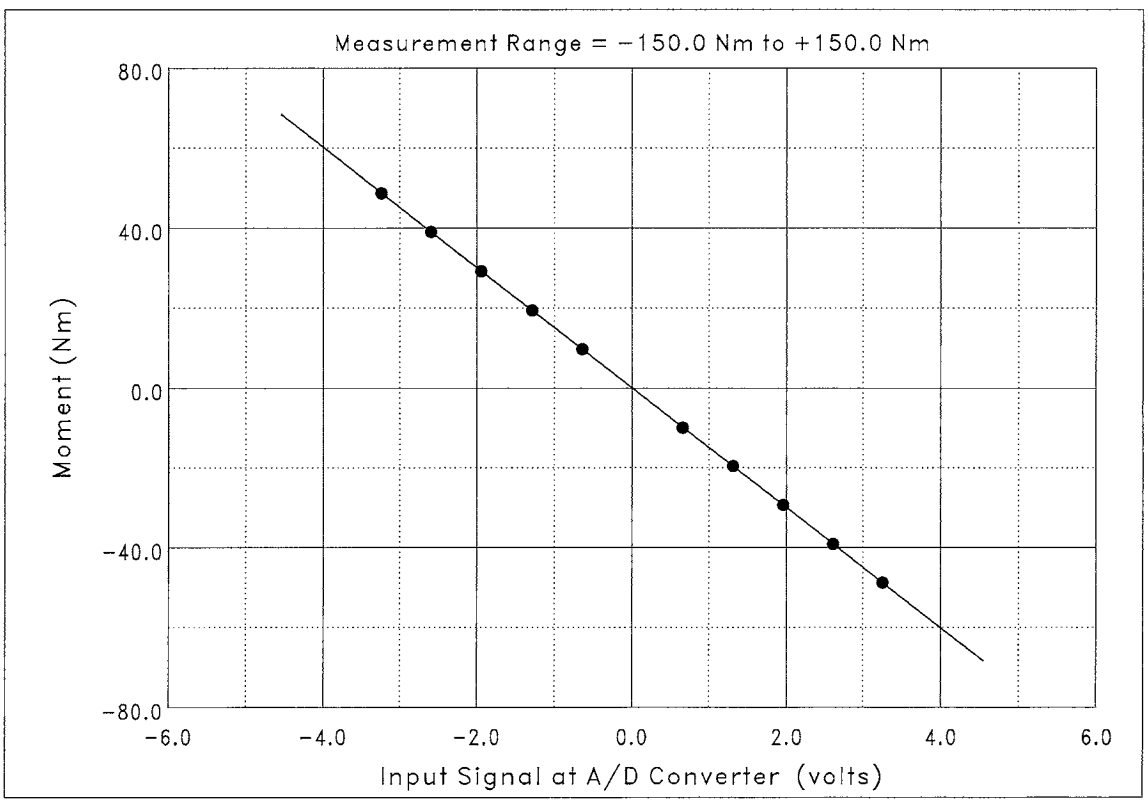
$$Y = C_0 + C_1 \cdot V$$

where $Y(t)$ = Moment (Nm),

$V(t)$ = input signal at A/D converter (volts),

C_0 = 0.0584519 Nm,

and C_1 = −15.0327 Nm/volt .



Calibration of TOWDAS Channel 2 — 21:01 12 January 2006

Project: CPF STERN FLAPS **Facility:** CWT

Sensor: Opens Speed **Model:** N/A **Serial Number:** N/A

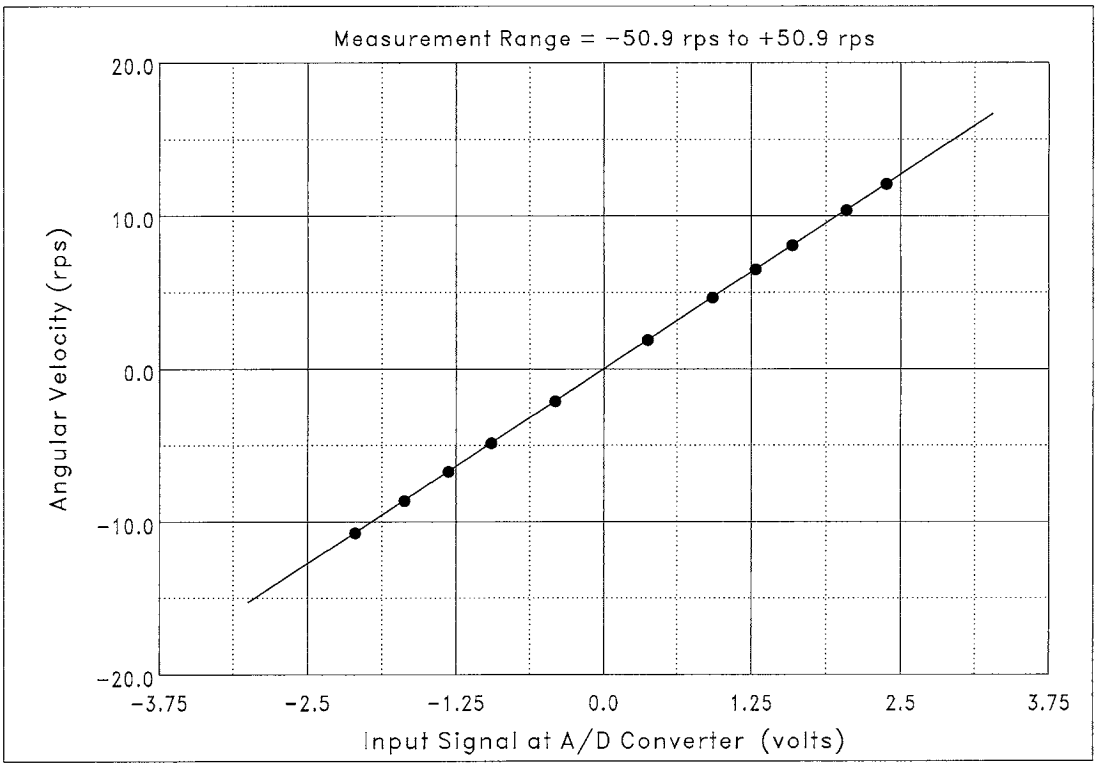
Programmable Gain: 1 **Plug-In Gain:** 1 **Filter Frequency:** 10.0 Hz

Data Point No.	Input Signal (volts)	Physical Value (rps)	Fitted Curve Value (rps)	Error (rps)	
1	0.373	1.891	1.894	0.0032988	
2	0.923	4.693	4.692	−0.0007958	
3	1.284	6.527	6.526	−0.0005331	
4	1.591	8.088	8.088	−0.0000820	
5	2.045	10.400	10.401	0.0008507	
6	2.381	12.108	12.109	0.0005455	
7	−0.413	−2.102	−2.106	−0.0038710	
8	−0.954	−4.853	−4.857	−0.0040221	⇐ Maximum Error
9	−1.316	−6.700	−6.699	0.0009403	
10	−1.690	−8.602	−8.600	0.0019312	
11	−2.104	−10.710	−10.708	0.0017357	
Maximum Error = −0.0176 % of Calibration Range.					

Definition of Calibration Curve
Polynomial Degree = 1 (Linear Fit)

$$Y = C_0 + C_1 \cdot V$$

where $Y(t)$ = Angular Velocity (rps),
$V(t)$ = input signal at A/D converter (volts),
C_0 = −0.00403288 rps,
and C_1 = 5.08728 rps/volt .



Calibration of TOWDAS Channel 33 — 12:22 13 January 2006

Project: CPF STERN FLAPS **Facility:** CWT

Sensor: Carriage Speed **Model:** N/A **Serial Number:** N/A

Programmable Gain: 1 **Plug-In Gain:** 1 **Filter Frequency:** 10.0 Hz

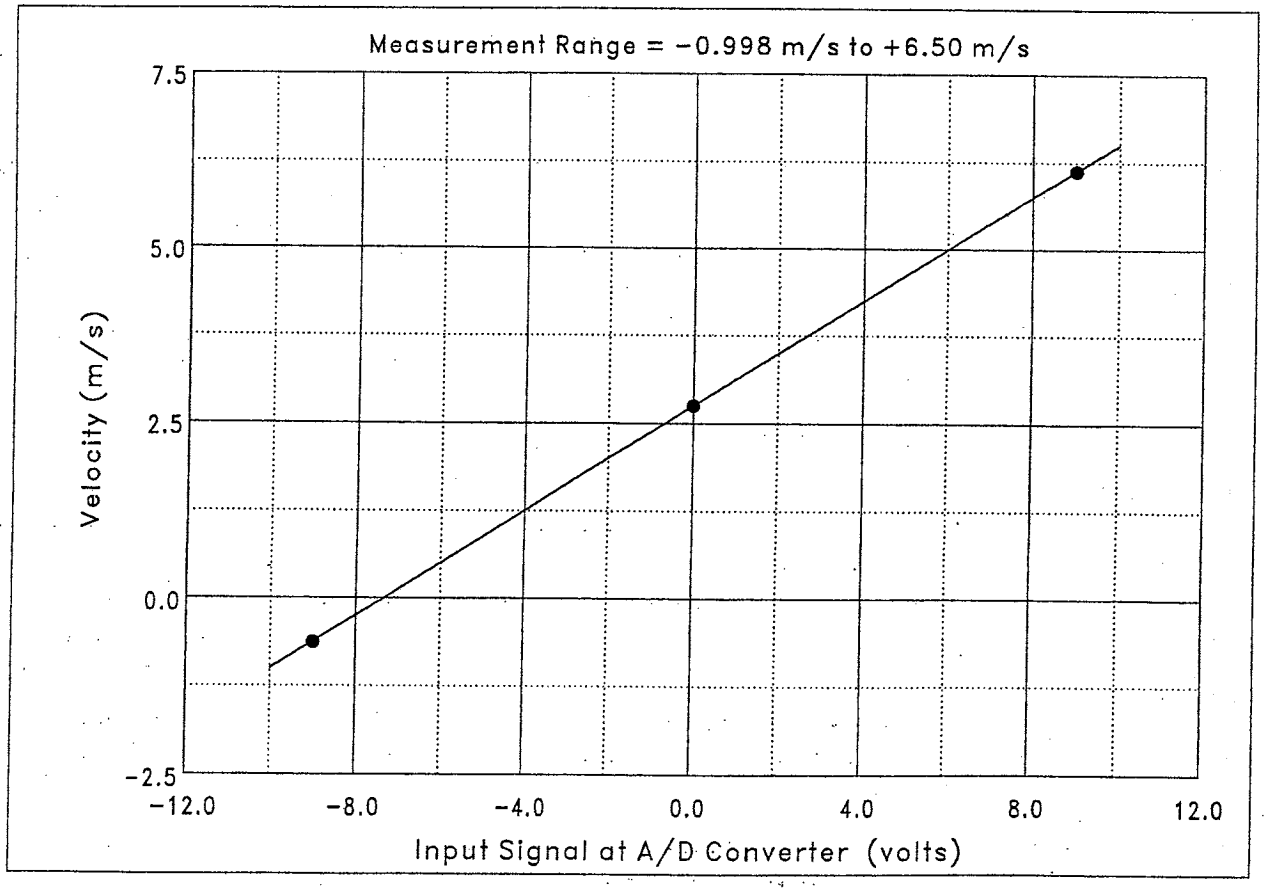
Data Point No.	Input Signal (volts)	Physical Value (m/s)	Fitted Curve Value (m/s)	Error (m/s)	
1	−0.002	2.7500	2.7500	0.000048399	⇐ Maximum Error
2	−9.006	−0.6250	−0.6250	−0.000024319	
3	9.002	6.1250	6.1250	−0.000023842	
Maximum Error = 0.000717 % of Calibration Range.					

Definition of Calibration Curve

Polynomial Degree = 1 (Linear Fit)

$$Y = C_0 + C_1 \cdot V$$

where $Y(t)$ = Velocity (m/s),
$V(t)$ = input signal at A/D converter (volts),
C_0 = 2.75062 m/s,
and C_1 = 0.374838 (m/s)/volt.



APPENDIX D

Test Program

Halifax Class Model Test Pro V2.0 May 18, 2005

Stern Flap Design & Development Project (Proj. #2104)

Propeller Open Water Experiments

Shaft Friction Torque:

Shaft friction torque to be determined as described in IOT Standard Procedure TM-2 Sect. 4.2.6.
Carry out shaft frictions with prop replaced by dummy hub at beginning & end of each shaft rps.

Run No.	rps MS	RPM FS
1	7	114.1
2	8	130.4
3	9	146.7
4	10	163.0
5	11	179.3
6	12	195.6
7	13	211.9
8	14	228.2

Propellers are 5 bladed warship propellers set at design pitch angle (31.01 deg.) , 320.42 mm dia.
Prop Number 319L/R Model Scale: 1: 13.5447
Experiments to be carried out on both L & R propellers - First Quadrant Only.

PROPELLER IOT319L/R TEST PROGRAM

Run #	J_O	No. 1: n = 8 rps Carriage Speed (m/s)	Comments	Run #	J_O	No. 2: n = 13 rps Carriage Speed (m/s)	Comments
1	0.09	0.23		1	0.09	0.37	
2	0.27	0.69		2	0.27	1.12	
3	0.45	1.15		3	0.45	1.87	
4	0.63	1.61		4	0.63	2.62	
5	0.81	2.08		5	0.81	3.37	
6	0.99	2.54		6	0.99	4.12	
7	1.17	3.00		7	1.17	4.87	
8	1.35	3.46		8	1.35	5.62	
9	1.44	3.69		9	1.44	6.00	
10	1.26	3.23		10	1.26	5.25	
11	1.08	2.77		11	1.08	4.50	
12	0.81	2.08	Repeat Run	12	0.81	3.37	Repeat Run
13	0.9	2.31		13	0.9	3.75	
14	0.72	1.85		14	0.72	3.00	
15	0.54	1.38		15	0.54	2.25	
16	0.36	0.92		16	0.36	1.50	
17	0.27	0.69	Repeat Run	17	0.27	1.12	Repeat Run
18	0.18	0.46		18	0.18	0.75	

NOTE: Preliminary calculations determine that the IOT Prop Opens Boat dyno can not accommodate the loads down to bollard for n > 11 rps!!!

Thus propose to acquire data for 8 rps and as much of the curve at 13 rps as possible without overloading or damaging the opens boat dyno.

Thus it is likely that the lower $J_o$values for 13 rps will be omitted and the curve extrapolated to derive the final K_T/K_Q curve. The sequence of runs will have to modified to ensure the instrumentation is not damaged.

PROPELLER IOT319L/R TEST PROGRAM

NOTE: - experiments are scheduled to be carried out in the IOT Towing Tank Jan. 2006.
- all experiments to be carried out as per IOT Standard Procedure TM-2, Sect.4.3 unless otherwise noted.
For n = 13 rps: Corresponds to 212 RPM on ship - or nominal max shaft speed.
For n = 8 rps: Corresponds to 130 RPM on ship - or nominal speed for just over 20 knots.
For n = 11 rps: Corresponds to 179 RPM on ship - or nominal speed for just over 26 knots.
May acquire curve for 11 rps if time permits.
- side beaches to be deployed for all runs.

IOT Standard Procedure for Propeller Open Water Tests TM-2, Sect. 4.3.1 requires that a third shaft speed be tested if the local Reynolds Number R_{nco} at 0.7 radius for either No. 1 or 2 above does not exceed $3 * 10^5$ with the tow carriage stationary.
0.7R = 320.42mm/2 * 0.7 = 112.147 mm
Radial Angle at 0.7R = 50 deg.
Chord length = 0.7R * angle = 112.147 mm * 50 deg. * pi/180 deg. = 97.87 mm assuming a circle
Chord length assuming a straight line (using Sine Law) = sin 50 * 112.147 mm/ sin 65 deg. = 94.79 mm
Assume chord length falls between these two values: $C_{0.7}$ = 96.33 mm = 0.09633 m
Assume a Kinematic Viscosity for Fresh Water at 15 deg. C (from ITTC Recommended Procedure 7.5-02-01-03 - (1999): V_M = 1.13902-6 m^2/s

For Shaft Speed No. 2: 13 rps:
$R_{nco} = C_{0.7} * 0.7 * pi * n_o * D/V_M$
= 774713

For Shaft Speed No. 1: 8 rps:
$R_{nco} = C_{0.7} * 0.7 * pi * n_o * D/V_M$
= 476747

Thus there is no requirement to test at a third shaft speed.

There will be a 5 minute wait time between runs thus this experiment should take about 7 hours for both props.

Maximum Loads on Opens Boat Cl Limit of K&R Opens Boat: Thrust = 980 N, Torque = 54 N-m

Assume max K_{TO} @ bollard is ~ 0.70, K_{QO} = 0.14 (from 1:21.92 scale data, TR-2003-01):

n_o (rps)	Thrust T_o (N)	Torque Q_o (N-m)
8	471.76	30.23
9	597.07	38.26
10	737.13	47.24
11	891.92	57.16
12	1061.46	68.02
13	1245.74	79.83

Where:
$T_o = K_{TO} * RHO_M * n_o^2 * D^4$
$Q_o = K_{QO} * RHO_M * n_o^2 * D^5$
V2.0 changes in blue font.
Will ask MARIN for open water data for these props. If we get this data, we will try to verify in IOT cav tunnel.
If data verifies OK, IOT will not carry out prop open water tests in Tow Tank.

PROPELLER IOT319L/R TEST PROGRAM

Run #	J_O	No. 3: n = 11 rps Carriage Speed (m/s)	Comments
1	0.09	0.32	
2	0.27	0.95	
3	0.45	1.59	
4	0.63	2.22	
5	0.81	2.85	
6	0.99	3.49	
7	1.17	4.12	
8	1.35	4.76	
9	1.44	5.08	
10	1.26	4.44	
11	1.08	3.81	
12	0.81	2.85	Repeat Run
13	0.9	3.17	
14	0.72	2.54	
15	0.54	1.90	
16	0.36	1.27	
17	0.27	0.95	Repeat Run
18	0.18	0.63	

APPENDIX E

Run Log

RUN LOG - Propeller Open Water Experiment on Propeller IOT319L/R

NRC - Propeller Open Water Experiment on IOT319R/L				
DATE	ACQ.TIME	FILENAME(.DAC)	RUN DESCRIPTION	COMMENTS
			Carriage Speed (m/s)	
12-Jan-06	21:00			Calibrate Ch. 2 - Opens RPS
12-Jan-06				Use test frame to raise and lower opens only
12-Jan-06				Centerline waterline of opens measured on NW side of carriage frame 903 mm
12-Jan-06				Testing depth for prop NW side of carriage frame 1383.6 mm
12-Jan-06	22:33	Opens_var_fric_001		CCW rotation
Propeller Open Water Experiments on IOT319R.				
13-Jan-06		friction_cw_001		Shaft friction run with dummy hub fitted.
				Prop 319R was installed and run up. It was noticed that the propeller is not dynamically balanced above 7.5 rps. Therefore it was decided to do a curve @7rps. Will install prop 319L after and determine its balance.
13-Jan-06		P319R_N7_001		Carriage speed not calibrated, recal
13-Jan-06	12:23	P319R_N7_002	0.23,0.69,1.15,1.61,2.08	
13-Jan-06	12:34	P319R_N7_003		carriage speed not plugged in, repeat runs
13-Jan-06	12:44	P319R_N7_004	0.23,0.69,1.15,1.61,2.08	Water Temp. = 16.2 deg. C
13-Jan-06	12:54	P319R_N7_005	2.54,3.0	
13-Jan-06	13:04	P319R_N7_006	3.46	
13-Jan-06	13:14	P319R_N7_007	3.69	
13-Jan-06	13:24	P319R_N7_008	3.23	
13-Jan-06	13:34	P319R_N7_009	2.31, 2.77	
13-Jan-06	13:44	P319R_N7_010	0.46,0.69,0.92,1.38,1.85,2.08	
13-Jan-06				Will do the 11 rps curve but will have to dial up the propeller while at speed. Will omit the very low J's due to vibration concerns. No bollards possible.
13-Jan-06	14:19	P319R_N11_001	2.22, 2.54	
13-Jan-06	14:29	P319R_N11_002	3.49	
13-Jan-06	14:39	P319R_N11_003	4.12	
13-Jan-06	14:49	P319R_N11_004	4.76	
13-Jan-06	14:59	P319R_N11_005	4.44	
13-Jan-06	15:09	P319R_N11_006	3.81	
13-Jan-06	15:19	P319R_N11_007	2.85, 3.17	
13-Jan-06				Remove prop 319R and do frictions with dummy hub installed in CW direction. Then do frictions in CCW direction for prop 319L
13-Jan-06	15:40	friction_cw_002		Shaft friction run with dummy hub fitted.

RUN LOG - Propeller Open Water Experiment on Propeller IOT319L/R

Propeller Open Water Experiments on IOT319L.				
13-Jan-06		friction_ccw_001		Shaft friction run with dummy hub fitted.
13-Jan-06	16:29	P319L_N7_001	0.23,0.69,1.15,1.61,2.08	
13-Jan-06	16:47	P319L_N7_002	2.54,3.0	Touch Roller Alarm at start - Try again
13-Jan-06	16:57	P319L_N7_003	3.46	Water Temp - 16.2 deg. C
13-Jan-06	17:08	P319L_N7_004	3.69	
13-Jan-06	17:18	P319L_N7_005	3.23	
13-Jan-06	17:28	P319L_N7_006	2.31, 2.77	
13-Jan-06	17:39	P319L_N7_007	0.46,0.69,0.92,1.38,1.85,2.08	
13-Jan-06	18:00	P319L_N11_001	2.22, 2.54	
13-Jan-06	18:10	P319L_N11_002	3.49	
13-Jan-06	18:20	P319L_N11_003	4.12	
13-Jan-06	18:30	P319L_N11_004	4.76	
13-Jan-06	18:40	P319L_N11_005	4.44	
13-Jan-06	18:50	P319L_N11_006	3.81	
13-Jan-06	19:00	P319L_N11_007	2.85, 3.17	
13-Jan-06	19:30	friction_ccw_002		Shaft friction run with dummy hub fitted.

NOTE:
- Propeller open water experiments carried out in IOT Tow Tank Jan 13, 2006 on 5 bladed adjustable pitch warship propellers IOT319L/R. Shaft speed 7 & 11 rps used.
- CW = clockwise, CCW = counterclockwise
- Nominal propeller pitch angle = 31.01 deg., nominal propeller dia. = 320.42 mm.
- All data stored in test directory TOW:[TEST_PJ2104.OPENS].
- Used propeller open water standard procedure TM-2 although omitted 13 rps from test plan due to vibration concerns.
- Used data from 5 bladed adjustable pitch warship propeller IOT131L/R for online data analysis comparison curve with nominal pitch angle 32.2 deg., nominal dia. = 198.36 mm.
- Both propellers started vibrating in bollard condition at ~ 7.5 rps.
- Propeller open water experiments carried out as part of Proj. 2104 - CPF Stern Flaps.

File Name Convention: P(prop #)_N(nominal shaft rps)_run number
Eg: P319R_N11_005

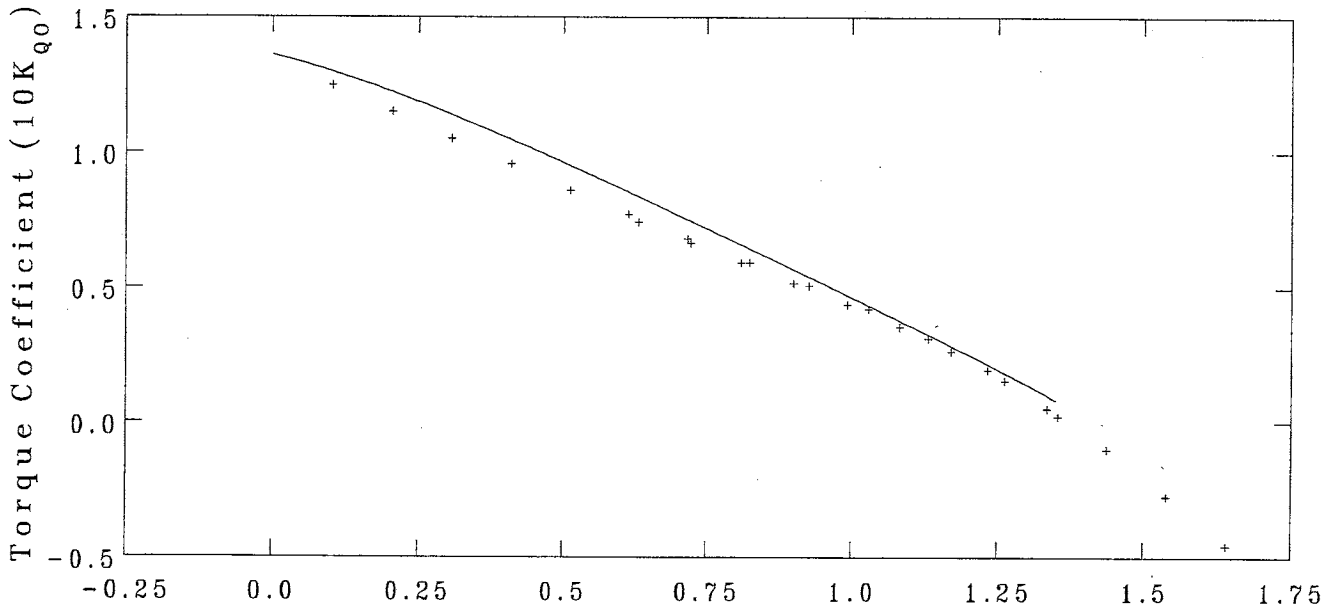
APPENDIX F

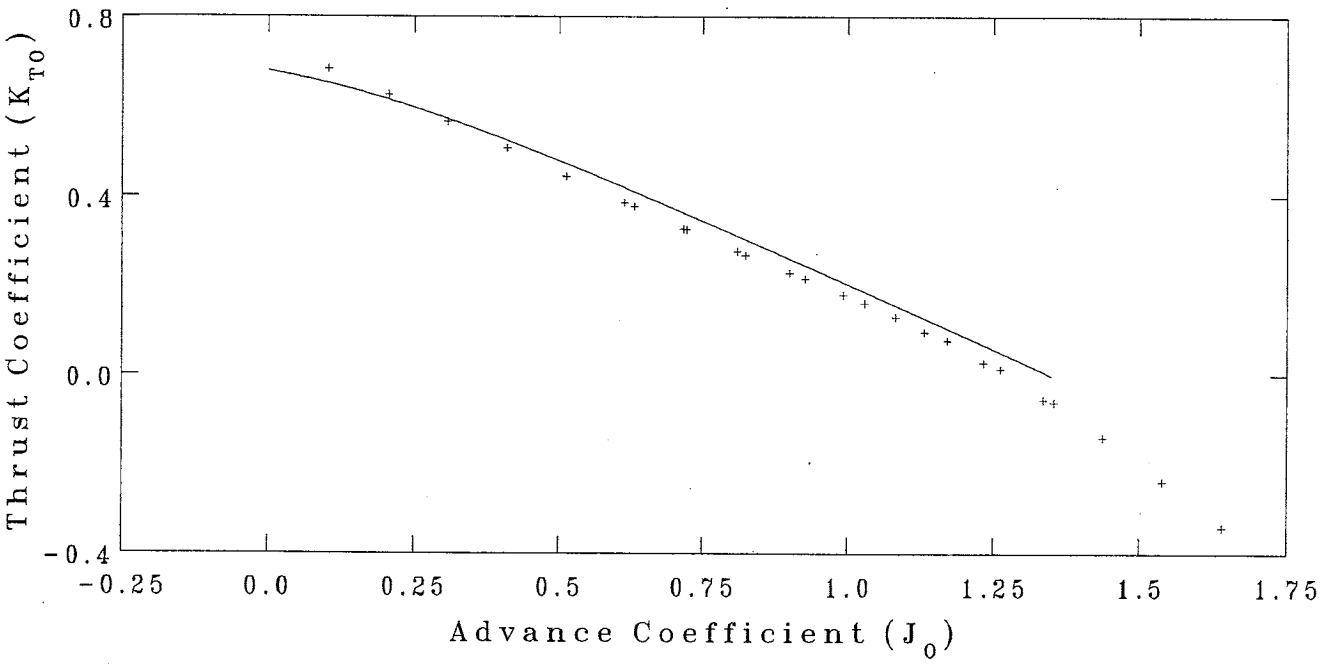
Online Data Analysis Results

Initial Analysis of Propeller Opens Experiments

Propeller: IOT319R
Description: WARSHIP PROPELLER
Condition: DESIGN PITCH
Rotation: RIGHT
Tank: Towing Tank
Avg. Test Temperature: 16.2°C

Test Date: 13-Jan-2006
Analysis Date: 13-Jan-2006
Project Number: PJ2104





—— Comparison curves

National Research Council Canada
Institute for Ocean Technology

Results of Propeller Open Water Experiments

Propeller: IOT319R
Description: WARSHIP PROPELLER
Condition: DESIGN PITCH
Rotation: RIGHT

Test Date: 13-Jan-2006
Analysis Date: 13-Jan-2006
Project Number: PJ2104

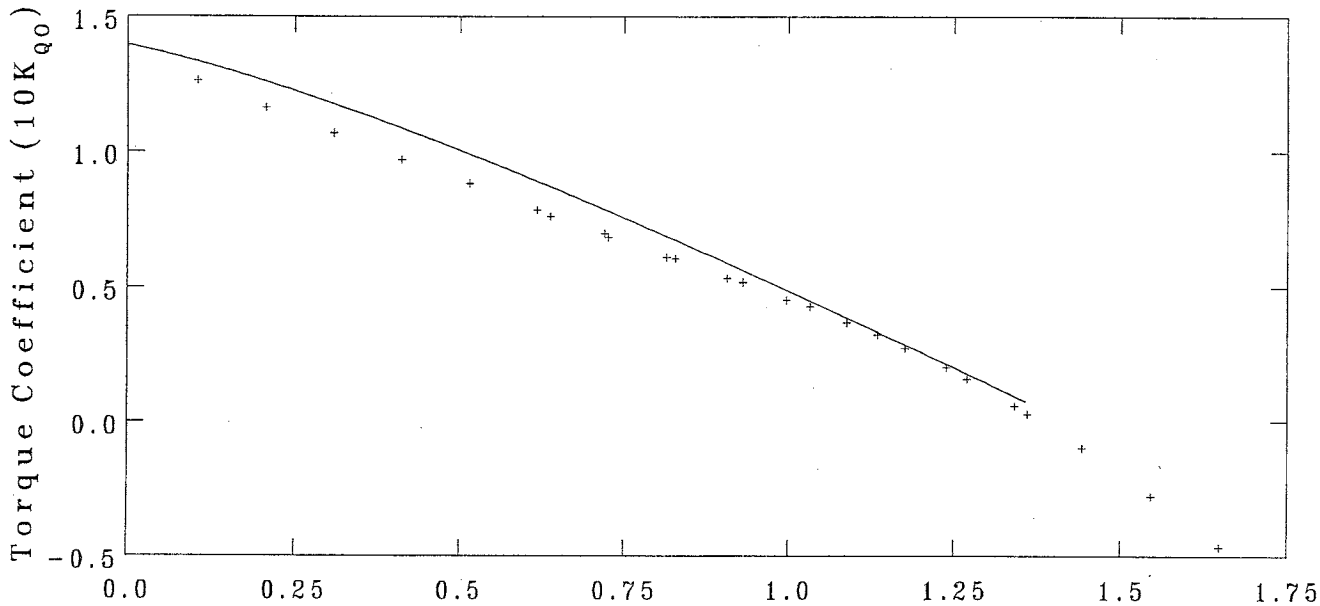
Tank: Towing Tank
Avg. Test Temperature: 16.2 °C

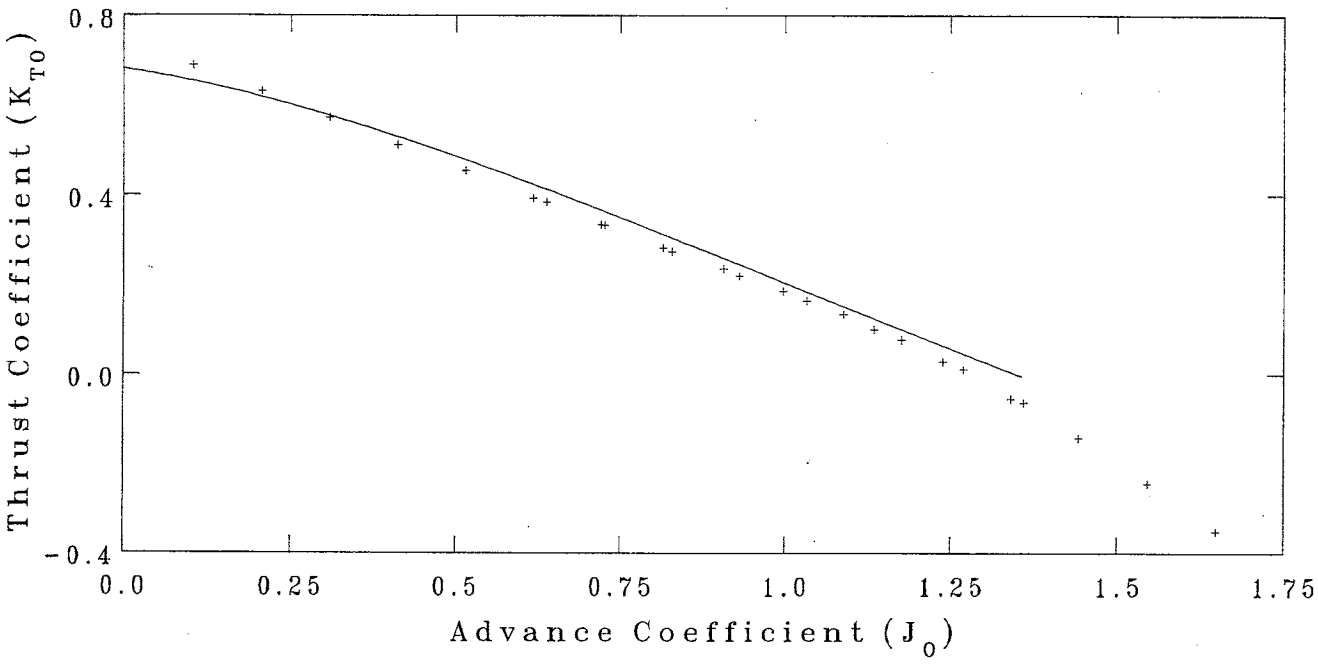
Run Designation	Time Of Day	Carriage Speed (m/s)	Shaft Speed (rps)	Thrust (N)	Torque (Nm)	$10^{-5}R_{nco}$
1	12:45:27	0.229	-7.001	352.79	20.458	5.660
2	12:45:46	0.688	-7.002	292.17	17.210	5.709
3	12:46:08	1.148	-7.001	229.23	14.035	5.805
4	12:46:29	1.607	-7.002	169.00	11.099	5.947
5	12:46:49	2.076	-7.002	110.98	8.191	6.135
6	12:56:21	2.535	-6.998	49.37	4.969	6.354
7	12:56:41	2.993	-6.997	-28.76	0.679	6.610
8	13:05:36	3.452	-7.000	-123.61	-4.704	6.900
9	13:15:54	3.682	-7.005	-177.30	-7.738	7.058
10	13:25:39	3.222	-6.997	-72.42	-1.795	6.750
11	13:35:41	2.306	-7.000	82.99	6.773	6.241
12	13:36:03	2.764	-7.000	13.86	3.053	6.480
13	13:45:37	0.459	-7.000	323.09	18.846	5.678
14	13:45:54	0.688	-7.000	292.24	17.222	5.708
15	13:46:11	0.918	-7.000	261.70	15.662	5.750
16	13:46:29	1.377	-7.000	199.19	12.582	5.869
17	13:46:46	1.847	-7.000	138.51	9.608	6.036
18	13:47:03	2.077	-7.000	111.10	8.206	6.133
19	14:20:24	2.216	-10.961	477.84	29.893	9.209
20	14:20:42	2.535	-10.957	411.20	26.649	9.314
21	14:29:53	3.483	-10.960	227.20	17.451	9.710
22	14:39:52	4.112	-10.960	96.78	10.453	10.028
23	14:50:02	4.750	-10.957	-78.18	0.687	10.390
24	15:00:01	4.431	-10.960	15.17	5.984	10.204
25	15:09:52	3.802	-10.961	163.27	14.075	9.866
26	15:19:42	2.843	-10.961	351.11	23.725	9.432
27	15:20:00	3.162	-10.963	289.74	20.688	9.566

Initial Analysis of Propeller Opens Experiments

Propeller: IOT319L
Description: WARSHIP PROPELLER
Condition: DESIGN PITCH
Rotation: LEFT
Tank: Towing Tank
Avg. Test Temperature: 16.2°C

Test Date: 13-Jan-2006
Analysis Date: 13-Jan-2006
Project Number: PJ2104





——— Comparison curves

National Research Council Canada
Institute for Ocean Technology

Results of Propeller Open Water Experiments

Propeller: IOT319L
Description: WARSHIP PROPELLER
Condition: DESIGN PITCH
Rotation: LEFT

Test Date: 13-Jan-2006
Analysis Date: 13-Jan-2006
Project Number: PJ2104

Tank: Towing Tank
Avg. Test Temperature: 16.2 °C

Run Designation	Time Of Day	Carriage Speed (m/s)	Shaft Speed (rps)	Thrust (N)	Torque (Nm)	$10^{-5}R_{nco}$
1	16:30:32	0.229	-6.966	352.13	20.499	5.631
2	16:30:53	0.689	-6.966	293.13	17.336	5.681
3	16:31:13	1.148	-6.967	231.89	14.239	5.779
4	16:31:33	1.607	-6.968	171.16	11.267	5.921
5	16:31:54	2.076	-6.969	112.24	8.338	6.110
6	16:49:23	2.535	-6.968	50.75	5.123	6.333
7	16:49:44	2.992	-6.969	-28.42	0.769	6.591
8	16:59:20	3.452	-6.972	-125.58	-4.732	6.882
9	17:09:51	3.682	-6.972	-180.11	-7.825	7.036
10	17:20:11	3.222	-6.972	-73.15	-1.788	6.733
11	17:30:14	2.306	-6.967	83.58	6.834	6.216
12	17:30:35	2.764	-6.968	14.26	3.119	6.457
13	17:40:29	0.459	-6.965	322.57	18.842	5.649
14	17:40:46	0.689	-6.966	292.77	17.287	5.680
15	17:41:02	0.918	-6.966	261.65	15.700	5.723
16	17:41:20	1.377	-6.968	200.71	12.656	5.844
17	17:41:37	1.847	-6.968	140.06	9.706	6.012
18	17:41:54	2.077	-6.968	112.12	8.299	6.110
19	18:01:26	2.216	-10.864	476.86	30.006	9.134
20	18:01:41	2.535	-10.905	416.05	27.113	9.274
21	18:10:57	3.483	-10.903	231.17	17.881	9.668
22	18:21:48	4.112	-10.905	95.86	10.711	9.988
23	18:31:08	4.751	-10.905	-80.45	0.808	10.354
24	18:41:21	4.431	-10.899	13.05	6.118	10.162
25	18:51:16	3.802	-10.901	167.56	14.539	9.823
26	19:01:09	2.843	-10.896	353.99	24.105	9.383
27	19:01:26	3.162	-10.897	293.60	21.130	9.517

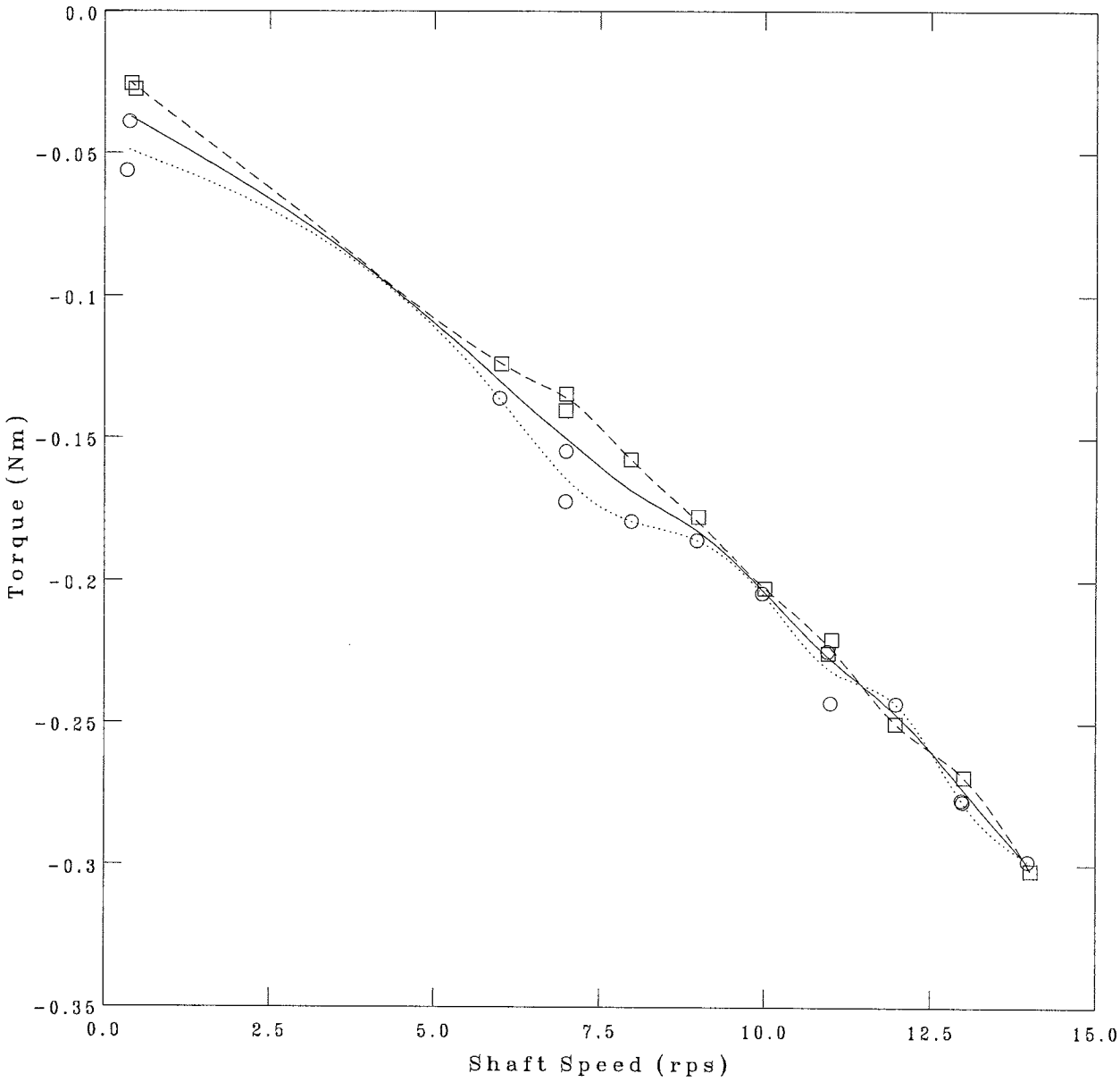
APPENDIX G

Offline Data Analysis Results

Shaft Friction Analysis

(Opens)

Propeller:	IOT319L	Test Date:	13-Jan-2006
Description:	WARSHIP PROPELLER	Analysis Date:	13-Jan-2006
Condition:	DESIGN PITCH	Project Number:	PJ2104
Rotation:	LEFT		
Tank:	Towing Tank		



○ Initial friction data

····· Initial friction curve

——— Average friction curve

□ Final friction data

- - - - Final friction curve

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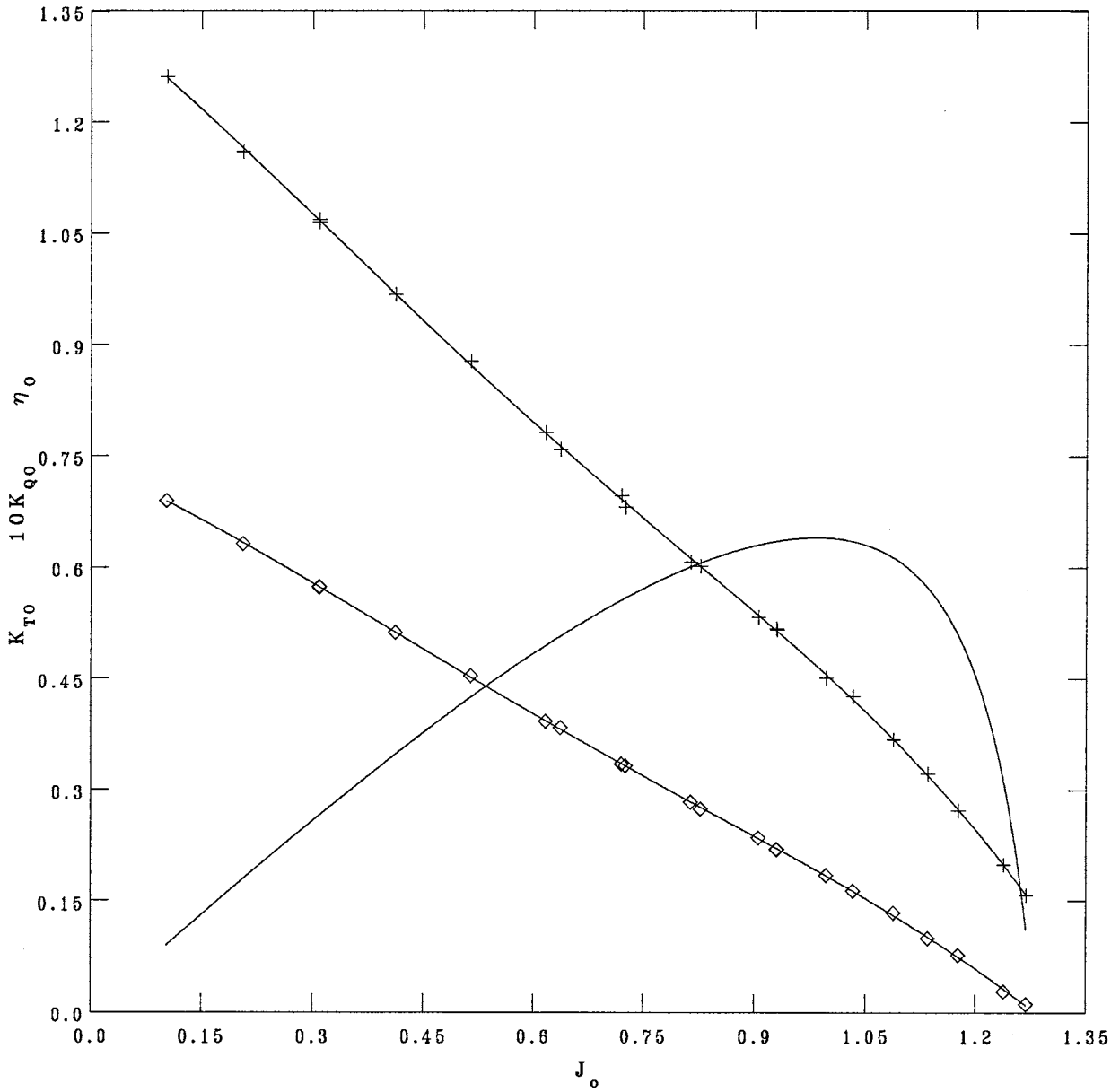
Propeller Open Water Coefficients

Propeller: IOT319L
Description: WARSHIP PROPELLER
Condition: DESIGN PITCH
Rotation: LEFT
Tank: Towing Tank
Avg. Test Temperature: 16.2 °C

Test Date: 13-Jan-2006
Analysis Date: 21-Apr-2006
Project Number: PJ2104



◇ K_{TO} data points

\+ $10K_{QO}$ data points

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Propeller Open Water Coefficients

Propeller: IOT319L
Description: WARSHIP PROPELLER
Condition: DESIGN PITCH
Rotation: LEFT

Test Date: 13-Jan-2006
Analysis Date: 21-Apr-2006
Project Number: PJ2104

Tank: Towing Tank
Avg. Test Temperature: 16.2 °C

$f(Jo) = \sum_{i=0}^{n} B(i) Jo^i$

Polynomial Coefficients to Fitted Lines

Term	Thrust Coefficient (K_{TO})	Torque Coefficient ($10K_{QO}$)
B(0)	0.73625	1.34344
B(1)	-0.41537	-0.74976
B(2)	-0.54627	-0.78240
B(3)	0.68625	1.15889
B(4)	-0.27894	-0.51746

Values from Fitted Lines

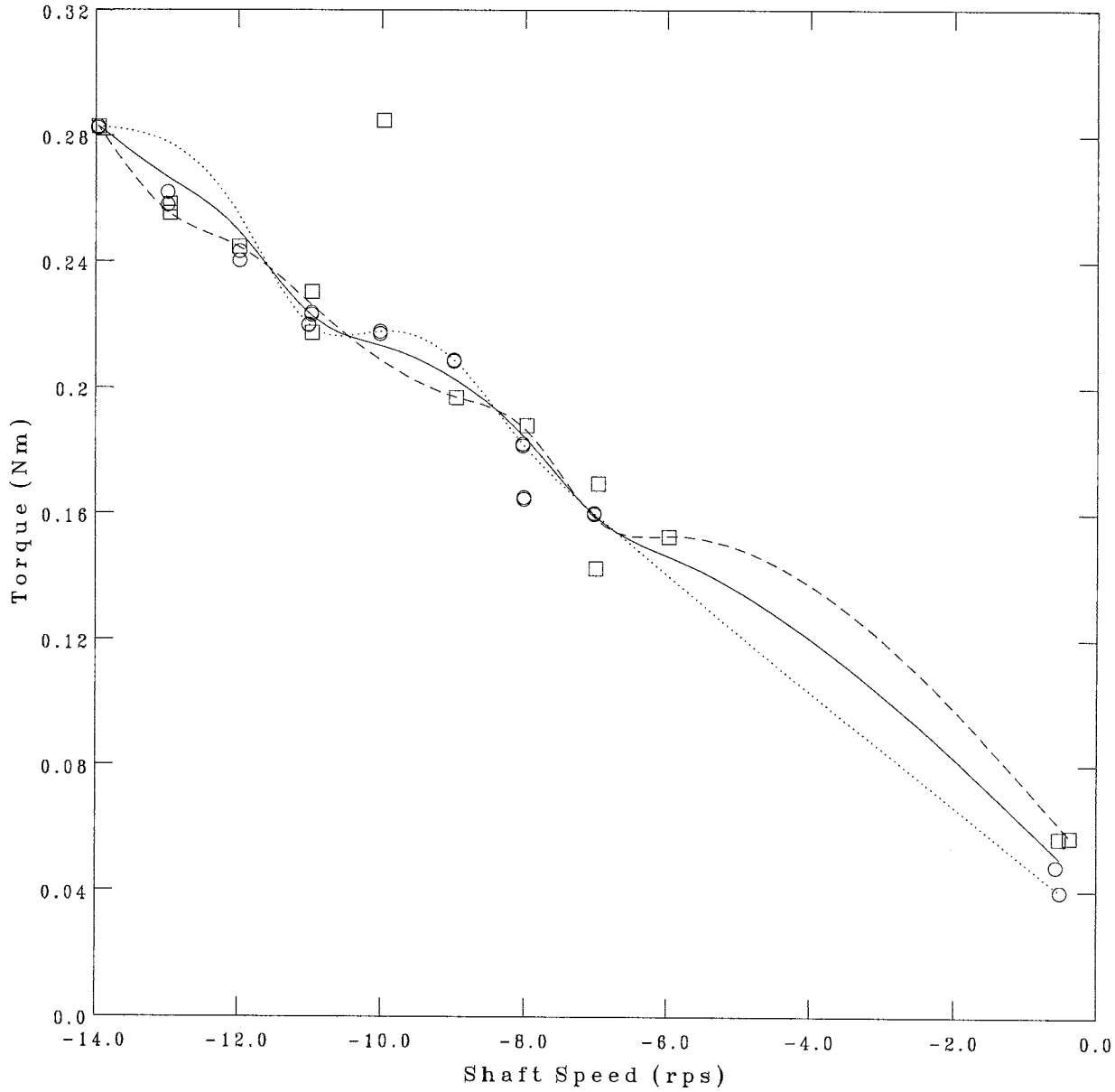
J_O	K_{TO}	$10K_{QO}$	η_O
0.15	0.6638	1.2170	0.1302
0.20	0.6364	1.1706	0.1730
0.25	0.6079	1.1232	0.2153
0.30	0.5787	1.0752	0.2570
0.35	0.5492	1.0271	0.2978
0.40	0.5195	0.9793	0.3377
0.45	0.4898	0.9320	0.3764
0.50	0.4603	0.8855	0.4137
0.55	0.4312	0.8399	0.4494
0.60	0.4024	0.7952	0.4833
0.65	0.3741	0.7514	0.5151
0.70	0.3462	0.7085	0.5444
0.75	0.3187	0.6662	0.5710
0.80	0.2914	0.6243	0.5944
0.85	0.2643	0.5825	0.6140
0.90	0.2372	0.5402	0.6289
0.95	0.2098	0.4972	0.6381
1.00	0.1819	0.4527	0.6395
1.05	0.1532	0.4062	0.6303
1.10	0.1234	0.3569	0.6051
1.15	0.0920	0.3040	0.5537
1.20	0.0586	0.2466	0.4538
1.25	0.0228	0.1839	0.2468

Shaft Friction Analysis

(Opens)

Propeller: IOT319R
Description: WARSHIP PROPELLER
Condition: DESIGN PITCH
Rotation: RIGHT
Tank: Towing Tank

Test Date: 13-Jan-2006
Analysis Date: 13-Jan-2006
Project Number: PJ2104



○ Initial friction data
Initial friction curve
Average friction curve
□ Final friction data
Final friction curve

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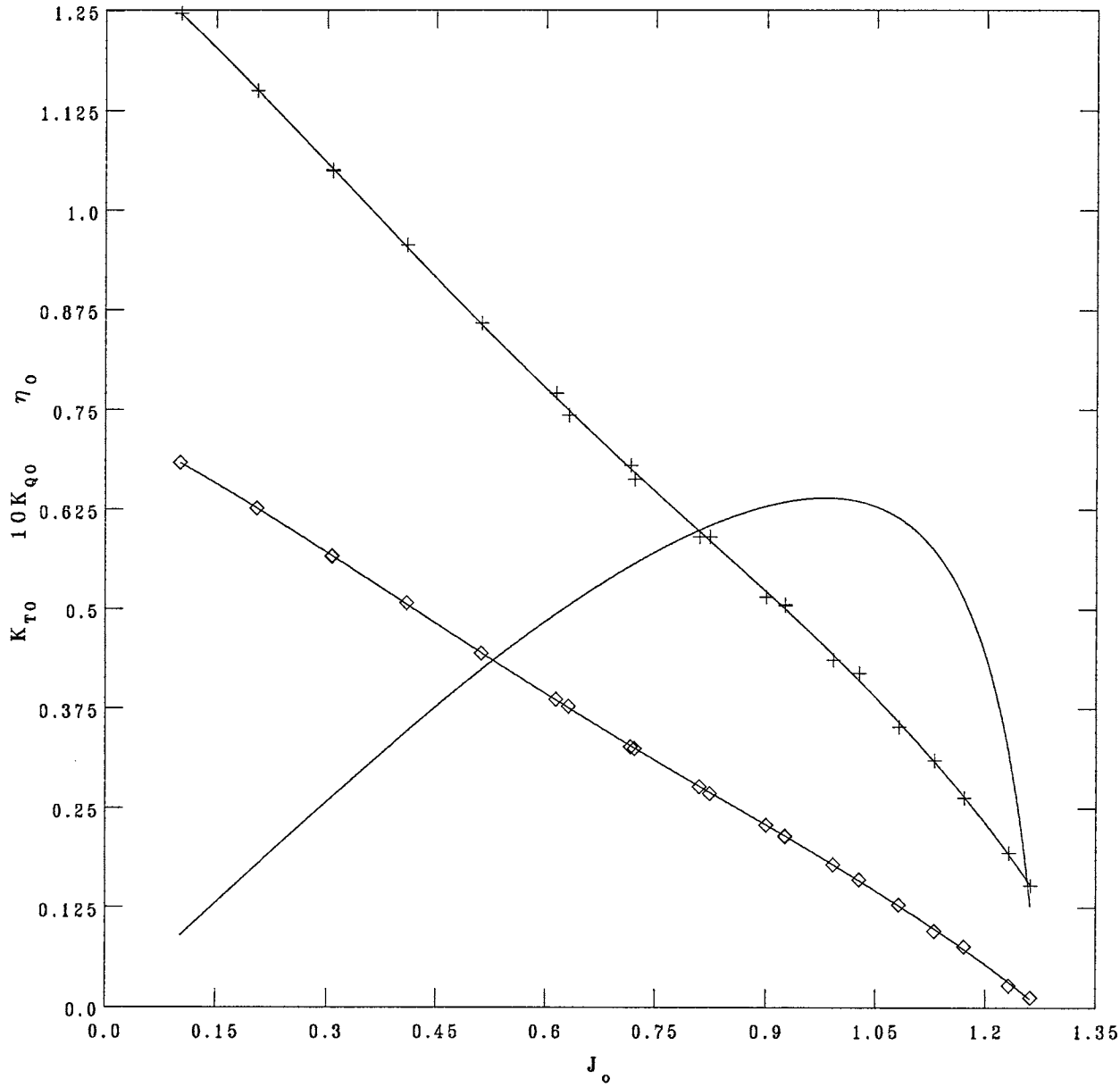
Propeller Open Water Coefficients

Propeller: IOT319R
Description: WARSHIP PROPELLER
Condition: DESIGN PITCH
Rotation: RIGHT
Tank: Towing Tank
Avg. Test Temperature: 16.2°C

Test Date: 13-Jan-2006
Analysis Date: 21-Apr-2006
Project Number: PJ2104



◇ K_{TO} data points

\+ $10K_{QO}$ data points

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Propeller Open Water Coefficients

Propeller: IOT319R
Description: WARSHIP PROPELLER
Condition: DESIGN PITCH
Rotation: RIGHT

Test Date: 13-Jan-2006
Analysis Date: 21-Apr-2006
Project Number: PJ2104

Tank: Towing Tank
Avg. Test Temperature: 16.2 °C

$f(Jo) = \sum_{i=0}^{n} B(i) Jo^i$

Polynomial Coefficients to Fitted Lines

Term	Thrust Coefficient (K_{TO})	Torque Coefficient ($10K_{QO}$)
B(0)	0.73155	1.32914
B(1)	-0.42611	-0.74542
B(2)	-0.54568	-0.82974
B(3)	0.69890	1.21871
B(4)	-0.28383	-0.53729

Values from Fitted Lines

J_O	K_{TO}	$10K_{QO}$	η_O
0.15	0.6576	1.2025	0.1305
0.20	0.6296	1.1558	0.1734
0.25	0.6007	1.1079	0.2157
0.30	0.5712	1.0594	0.2574
0.35	0.5413	1.0108	0.2983
0.40	0.5113	0.9625	0.3382
0.45	0.4814	0.9147	0.3769
0.50	0.4517	0.8678	0.4142
0.55	0.4224	0.8218	0.4500
0.60	0.3936	0.7768	0.4839
0.65	0.3653	0.7328	0.5157
0.70	0.3375	0.6898	0.5450
0.75	0.3101	0.6475	0.5716
0.80	0.2830	0.6057	0.5949
0.85	0.2562	0.5640	0.6144
0.90	0.2293	0.5221	0.6292
0.95	0.2023	0.4794	0.6381
1.00	0.1748	0.4354	0.6391
1.05	0.1466	0.3894	0.6291
1.10	0.1172	0.3407	0.6026
1.15	0.0864	0.2884	0.5483
1.20	0.0536	0.2316	0.4420
1.25	0.0184	0.1695	0.2160