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Report on Model Testing, Design Propeller

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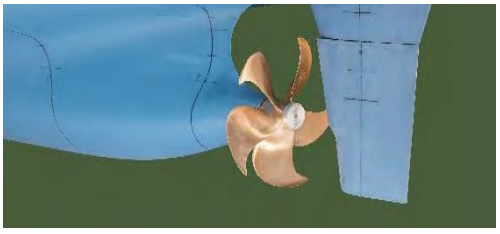
NATIONAL SECURITY MULTI-MISSION VESSEL – TOWING TANK TESTS WITH DESIGN PROPELLER





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REPORT

Date:
15 December 2016

SSPA Report No.:
RE30157634-04-00-A

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National Security Multi-Mission Vessel – towing tank tests with design propeller

On behalf of Herbert Engineering towing tank tests for a National Security Multi-Mission Vessel were performed at SSPA. This report documents test conditions, procedures and results covering

- propeller open water tests for the design propeller
  and
- self-propulsion tests at 4 draughts.

The tests were performed in calm water with ship model M5030-01-A with a scale factor of α = 24.375 and propeller model P5033-01-A.

SSPA Sweden AB

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Summary

On behalf of Herbert Engineering Corp. towing tank tests were performed for a National Security Multi-Mission Vessel.

Self-propulsion tests were carried out with ship model M5030-01-A with a scale factor of α = 24.375 . The hull lines were submitted by Herbert Engineering Corp. and further optimized using CFD by SSPA as is described in report RE30157634-01-00-A and also used for the stock propeller tests, wake measurement and streamline tests in RE30157634-01-00-A.

Design propeller P5033-01-A, designed by SSPA, was used for the propeller open water test, the self-propulsion tests as well as the streamline paint test.

The model tests were performed at four draughts and evaluated by means of the ITTC 1978 prediction method.

At a power delivered on trial, P_{DT}, of 7748kW (based on engine power 9 000kW with 15% sea margin and 1% in shaft line losses) the predicted ship speed is:

*Table 1 Predicted speed at trial condition (P_{DT} = 9000/1.15*0.99kW=7748kW)*

Loading Condition	Ship speed V_S [kn]
Full Load	18.23
Design	18.82
Trim Aft	19.12
Light	19.05

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1 Models

1.1 Designs used for manufacturing

The following files were used to manufacture the models for the towing tank tests.

Table 2 Geometry files used for manufacturing

Item	Designer	File name	SSPA no	Delivery date
Hull M5030-01-A	Herbert Engineering Corp.	F21A14.igs	EX106613-01-00	2016-09-21
Rudder R5068-01-A	Becker Marine Systems	20218 Blade and Skeg-.igs	EX106636-01-00	2016-10-03

1.2 Hull model

Hull model M5030-01-A was manufactured by SSPA according to customer's information reported in Table 2. It was built in the plastic foam material Divinycell with a geometric scale factor of α = 24.375 .

The model was marked with 21 equally spaced stations numbered 0 to 20 between the aft perpendicular (AP) and the forward perpendicular (FP). A continuous waterline was drawn along the entire length of the hull at the Design draught of 6.5 m and Full Load draught of 7.5m. Dashed waterlines were labelled at 1 m intervals from 4 to 10 m above baseline. In addition, bow and stern thruster tunnel positions were marked on the model at positions:

Bow Thruster: 138.90 m forward of AP, 1.92m above baseline, 2.1 m diameter
and
Stern Thruster: 25.65 m forward of AP, 1.98 m above baseline, 1.75m diameter.

A 1 mm trip wire was fitted at station 19 on the bow according to SSPA standard practice in order to develop the turbulent boundary layer during testing.

Main dimensions and hydrostatics of the hull are given in Figure 1. Body plan, fore and aft body profiles are shown in Figure 2 to Figure 4 while the section area curves can be seen in Figure 5 . Photos of the aft body arrangement can be seen in Figure 8.

1.3 Rudder model

The rudder model R5068-01-A was manufactured in plastic based on the drawings received from Becker Marine (see Table 2). It was made of two pieces: a rotatable rudder blade and a head box which was fixed to the hull. The rudder angle was set to 0° during the tests.

A sketch of the aft body arrangement showing the rudder planform is shown in Figure 6.

1.4 Propeller model

Propeller model P5033-01-A is a stock propeller with fixed pitch angle designed by SSPA and manufactured by SSPA. It was used for the open water test, the self-propulsion tests and the streamline paint test of the model testing programme described herein.

The propeller main data are specified in Table 3 while a drawing of the propeller geometry is provided in Figure 7.

The propeller open water characteristics can be found in Figure 9 to Figure 11 for both model scale and full scale propellers.

Table 3 Main data of the model propeller

Characteristics	**Value**
Model ID	P5033-01-A
Number of blades, Z	5
Diameter, full scale, D_s	5.850 m
Diameter, model scale, D_m	240mm
Hub ratio	0.179
Blade area ratio, A_D/A_0	0.648
Pitch ratio P/D at r/R = 0.75	0.9925
Turning direction	Right

2 Tests

2.1 Testing facility

All tests described in this report were performed in SSPA's towing tank which has the following main characteristics:

- Length 260 m
- Breadth 10 m
- Water depth 5 m
- Carriage speed 11 m/s

The basin is spanned by a carriage which supports a work platform, transports the measuring equipment, and provides the motive force to tow the model.

All tests were performed in calm water.

2.2 Test arrangements and procedures

For each loading condition the model was ballasted to the corresponding full-scale volume displacement. The draught was verified at forward perpendicular (FP), mid ships (MS) and aft perpendicular (AP), on both sides of the model.

During testing, the model was fixed axially to the carriage with a rod and an electrical transducer that measured the towing force exerted on the model. As the rod was adjusted to be parallel to the baseline, the force was measured in the horizontal direction at all tests.

The model was kept on course by two trim devices, one at each perpendicular. These devices also served to prevent the model from surging, swaying and yawing while leaving it free to heave, roll and pitch.

The methods of testing and analysis employed for each of the tests in the towing tank are described in the relevant sections below.

2.2.1 Propeller open water test

The propeller model was tested in open water in the towing tank. It was mounted on a horizontal shaft and moved through the water at an immersion of the shaft centre equal to the propeller diameter. Under normal conditions this is sufficient to prevent the propeller from ingesting air. If the propeller was observed ingesting air at the standard depth, the operators would adjust the propeller immersion accordingly to prevent air ingestion.

Thrust, T_m, torque, Q_m, and rate of revolutions, n_m, were measured on the shaft behind the propeller model. The normal test method keeps the rate of revolutions constant whilst the speed of advance V_A is varied so that the loading range of the propeller can be examined during the test. The propeller open water test evaluation based on the ITTC 1978 Recommended Procedures is described in Enclosure 1.

2.2.2 Resistance and self-propulsion tests

The hull model with mounted rudder was towed at speeds set according to Froude scaling. In the self-propulsion tests the model was equipped with propelling machinery and working propeller.

When the desired speed was reached and kept constant the following parameters were registered by a computer on the carriage:

- Model speed V_m
- Towing force R_{Tm}
- Vertical trim change at station 20 ΔT_F
- Vertical trim change at station 0 ΔT_A
- Shaft rate at shaft n_m
- Torque at shaft Q_m
- Thrust at shaft T_m

Photographs of the surface wave pattern were taken by above-water cameras at the bow, stern and amidships during the self-propulsion tests. Test methods and calculation principles for the resistance and self-propulsion tests according to the ITTC 1978 prediction method are described in the enclosures.

2.3 Test programme

The performed calm water towing tank tests as well as the applied hull configurations and loading conditions are summarised in the tables below.

Table 4 Test programme

Series	Date	Test	Loading condition	Hull	Propeller	Speeds
001	2016-10-24	Resistance	Full Load	M5030-01-A	-	8-20kn
003	2016-10-24	Resistance	Design	M5030-01-A	-	8-20kn
005	2016-10-25	Resistance	Trim Aft	M5030-01-A	-	8-20kn
007	2016-10-25	Resistance	Light	M5030-01-A	-	8-20kn
012	2016-12-12	Open water	-	-	P5033-01-A	
014	2016-12-13	Self-prop	Full Load	M5030-01-A	P5033-01-A	8-20kn
016	2016-12-13	Self-prop	Design	M5030-01-A	P5033-01-A	8-20kn
018	2016-12-13	Self-prop	Trim Aft	M5030-01-A	P5033-01-A	8-20kn
020	2016-12-13	Self-prop	Light	M5030-01-A	P5033-01-A	8-20kn

Table 5 Loading conditions

Loading condition	T_A [m]	T_F [m]
Full Load	7.5	7.5
Design	6.5	6.5
Trim Aft	6.5	5.7
Light	6.0	6.0

3 Results and comments

3.1 Resistance and self-propulsion tests

The results from the resistance and self-propulsion tests are summarised in Figure 12 to Figure 43. Photographs of the surface wave pattern during the self-propulsion tests are provided in Appendix 1 to Appendix 4.

The speed-power prediction in Table 6 is valid for calm water, no wind and includes a correction for the added resistance caused by the bow and stern thruster tunnel. The hull surface is assumed to be clean having a state of the art roughness. No bilge keels were fitted to the model, but their effect at full scale was taken into account in the extrapolation. In addition, the propeller is assumed to be unpainted and polished.

At a power delivered on trial, P_{DT}, of 7748kW (based on engine power 9 000kW with 15% sea margin and 1% in shaft line losses) the predicted ship speed is:

*Table 6 Predicted speed at trial condition (P_{DT} = 9000/1.15*0.99kW=7748kW)*

Loading Condition	Ship speed V_S [kn]
Full Load	18.23
Design	18.82
Trim Aft	19.12
Light	19.05

The quality of the hull shape is described in report RE 30157634-02-00-A.

Propulsive coefficients/efficiencies

Comparing the power requirement in self-propulsion the vessel is among the best in the whole speed range.

List of figures

General

Propeller open water tests – Series 012

Resistance and propulsion – Full Load draught, series 001 and 014

Resistance and propulsion – Design draught, series 003 and 016

Resistance and propulsion – Trim Aft draught, series 005 and 018

Resistance and propulsion – Light draught, series 007 and 020

Figure: 1

Ship model	M5030-01-A
Date	2016-10-18

Ship main characteristics			
Length between perpendiculars	L_{PP}	[m]	154.00
Beam	B	[m]	27.00

Water properties			
Density of water	ρ	[kg/m^3]	1025

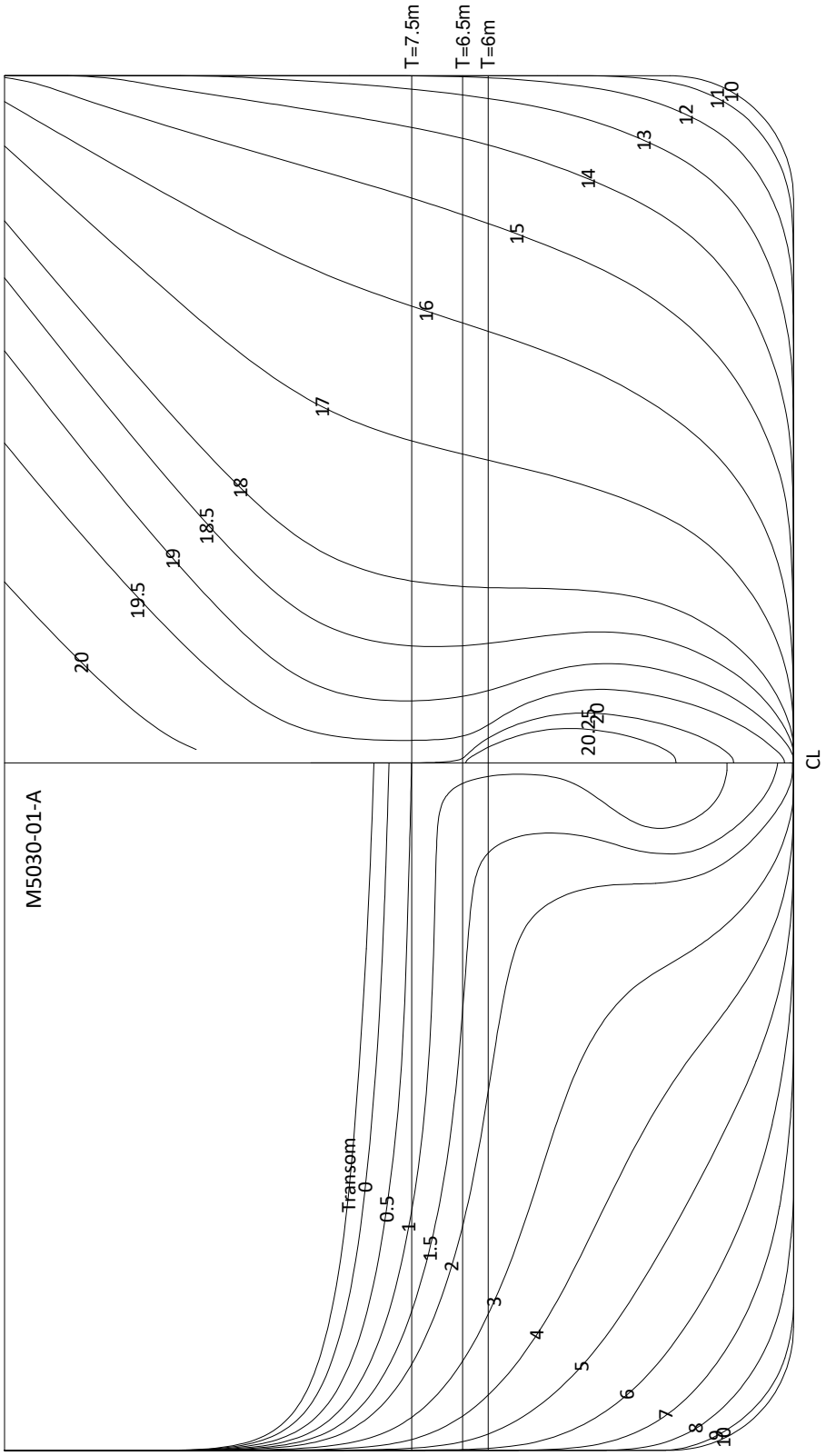
Hydrostatics						
Loading condition			Full Load	Design	Trim Aft	Light
Draft, fore	T_F	[m]	7.50	6.50	5.70	6.00
Draft, average	T_M	[m]	7.50	6.50	6.10	6.00
Draft, aft	T_A	[m]	7.50	6.50	6.50	6.00
Waterline length	L_{WL}	[m]	150.11	148.91	150.53	150.02
Beam in waterline	B_{WL}	[m]	27.00	27.00	27.00	27.00
Volume	∇	[m^3]	19606	16467	15325	14965
Wetted surface	S_{HULL}	[m^2]	4728	4286	4147	4083
Wetted surface coefficient		[-]	2.721	2.692	2.699	2.689
Maximum section area	A_{MAX}	[m^2]	200.0	173.0	162.6	159.5
Block coefficient	C_B	[-]	0.6287	0.6093	0.6042	0.5999
Prismatic coefficient	C_P	[-]	0.6365	0.6180	0.6118	0.6092
Waterplane area coefficient	C_{WP}	[-]	0.800	0.757	0.745	0.732
Centre of buoyancy, rel. to $L_{PP}/2$	L_{CB}	[%]	-0.788	-0.177	-0.757	0.067
Centre of flotation, rel. to $L_{PP}/2$	L_{CF}	[%]	-5.042	-3.033	-2.841	-2.179
Length to displacement ratio	$L_{WL}/\nabla^{1/3}$	[-]	5.567	5.853	6.060	6.088
Length to beam ratio	L_{WL}/B_{WL}	[-]	5.560	5.515	5.575	5.556
Beam to draft ratio	B_{WL}/T_M	[-]	3.600	4.154	4.426	4.500
Transverse metacentric radius	BM_t	[m]	8.65	9.44	9.97	9.95
Centre of buoyancy above BL	KB	[m]	4.07	3.51	3.31	3.24
Transverse metacentre above BL	KM_t	[m]	12.72	12.95	13.30	13.19
Weight to immerse		[t/cm]	33	31	31	30
Moment to change trim		[tm/cm]	290	246	243	231

NSMV

Body plan

M5030-01-A

Figure: 2



NSMV

Fore body

M5030-01-A

Figure: 3

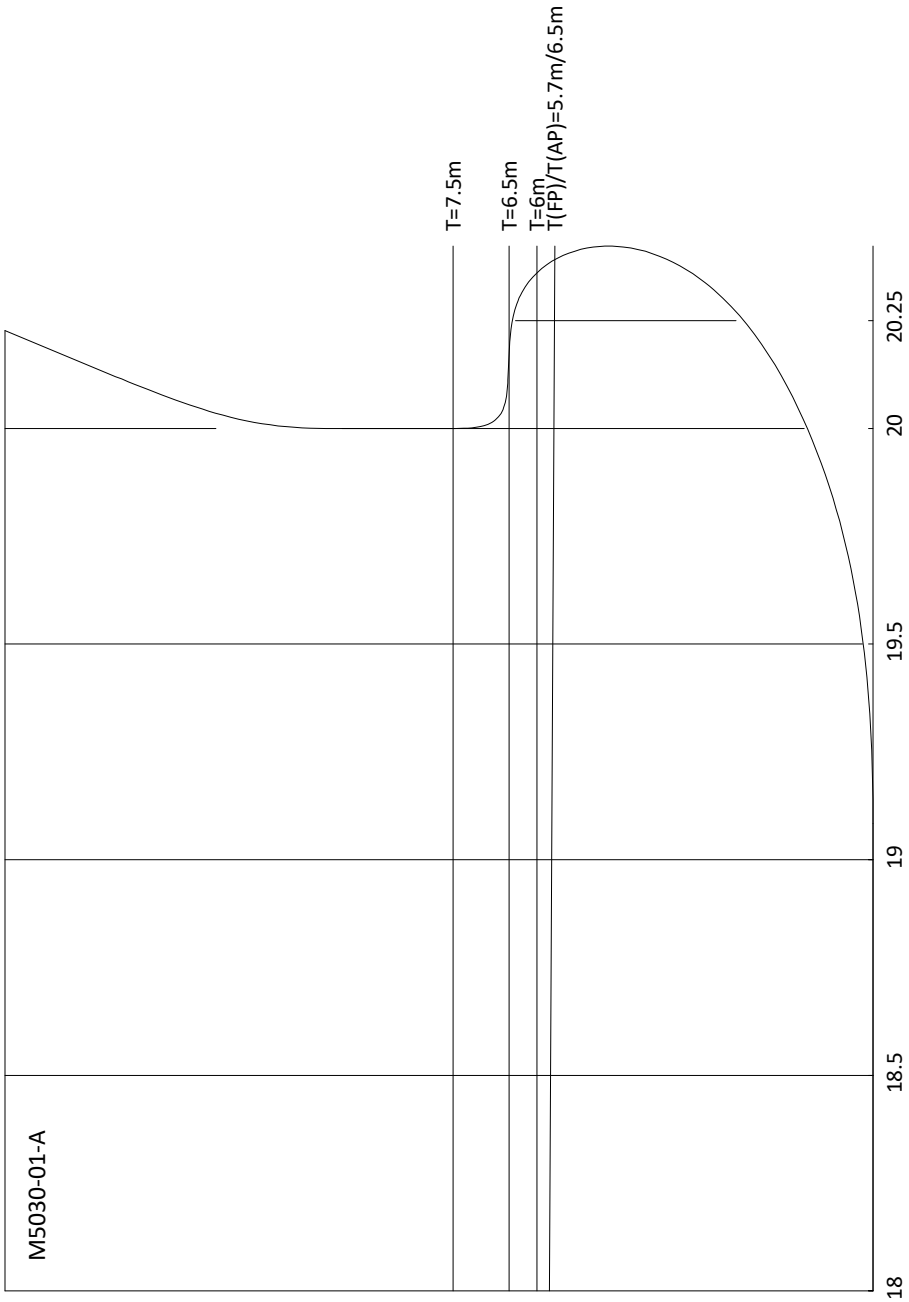
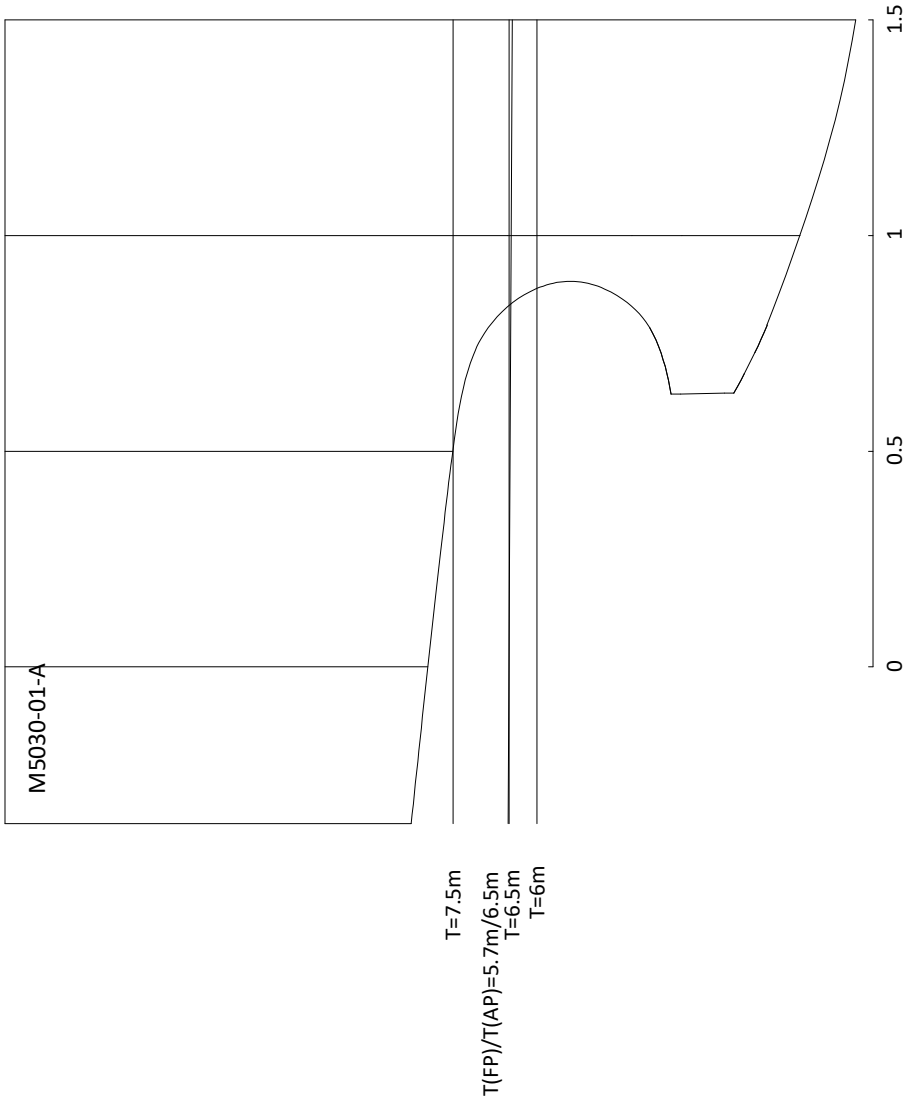


Figure: 4

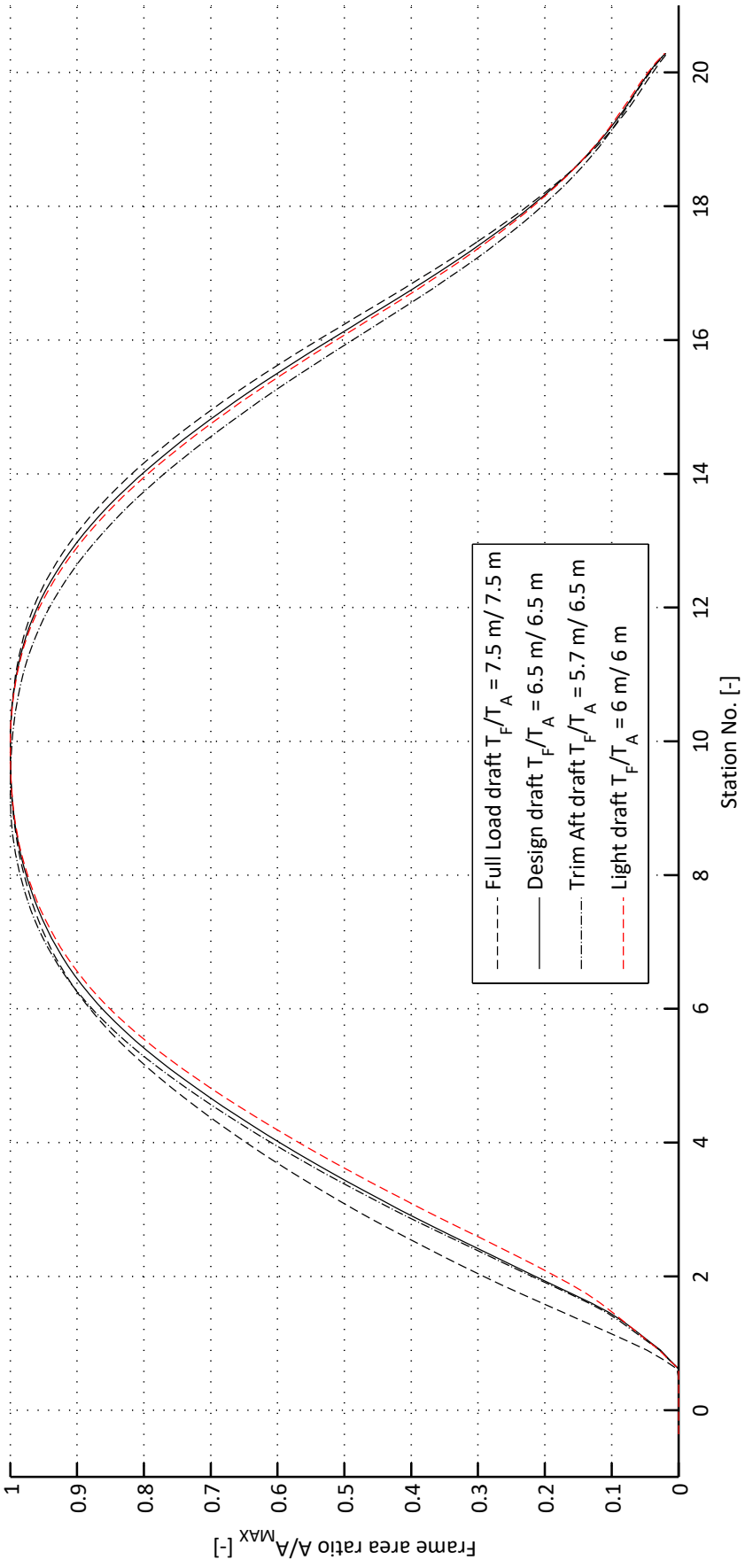


NSMV

Frame area curve

Ship model M5030-01-A

Figure: 5



NSMV

Model aft body arrangement (measures in full scale)

M5030-01-A

Figure: 6

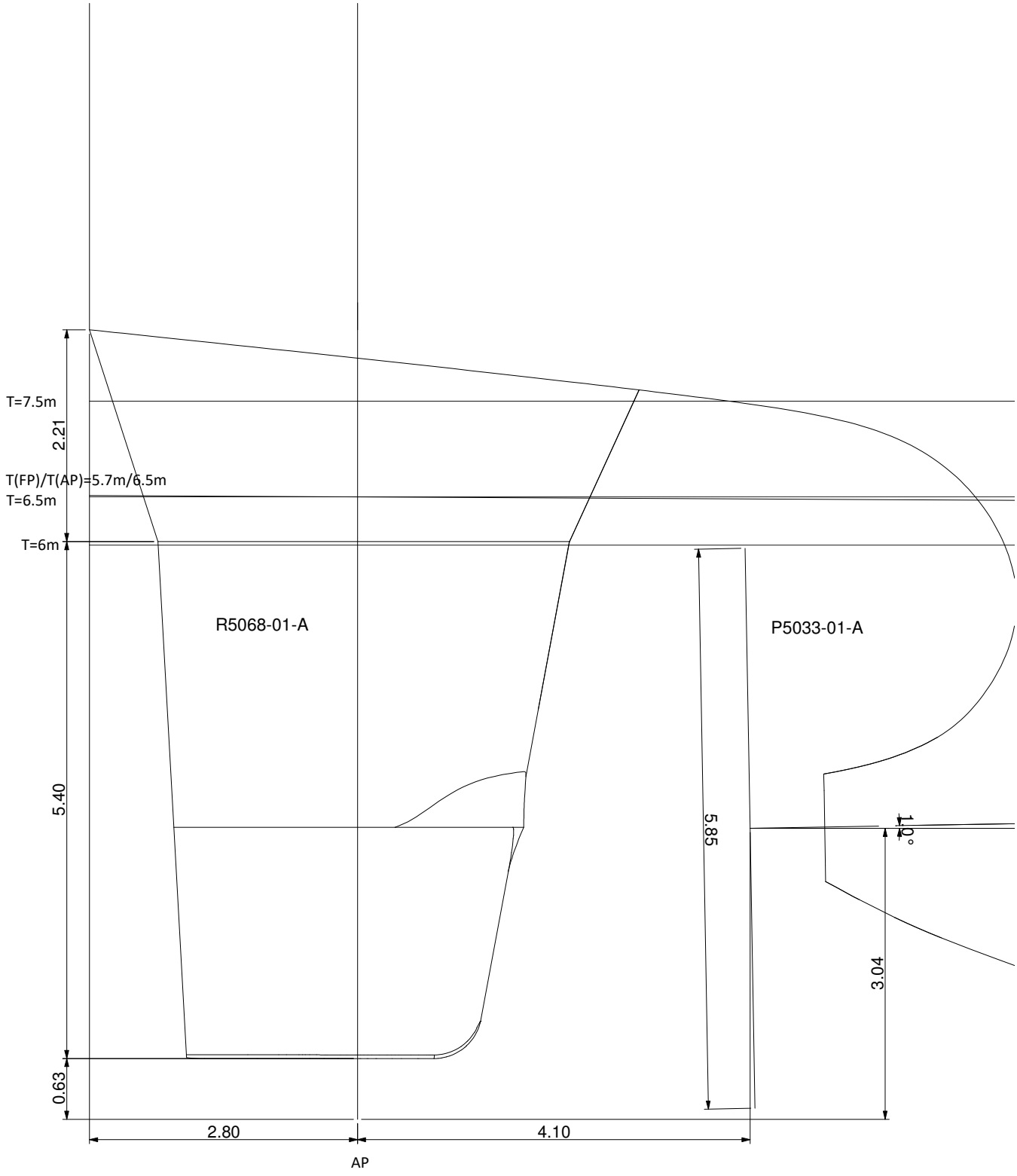


Figure: 7a

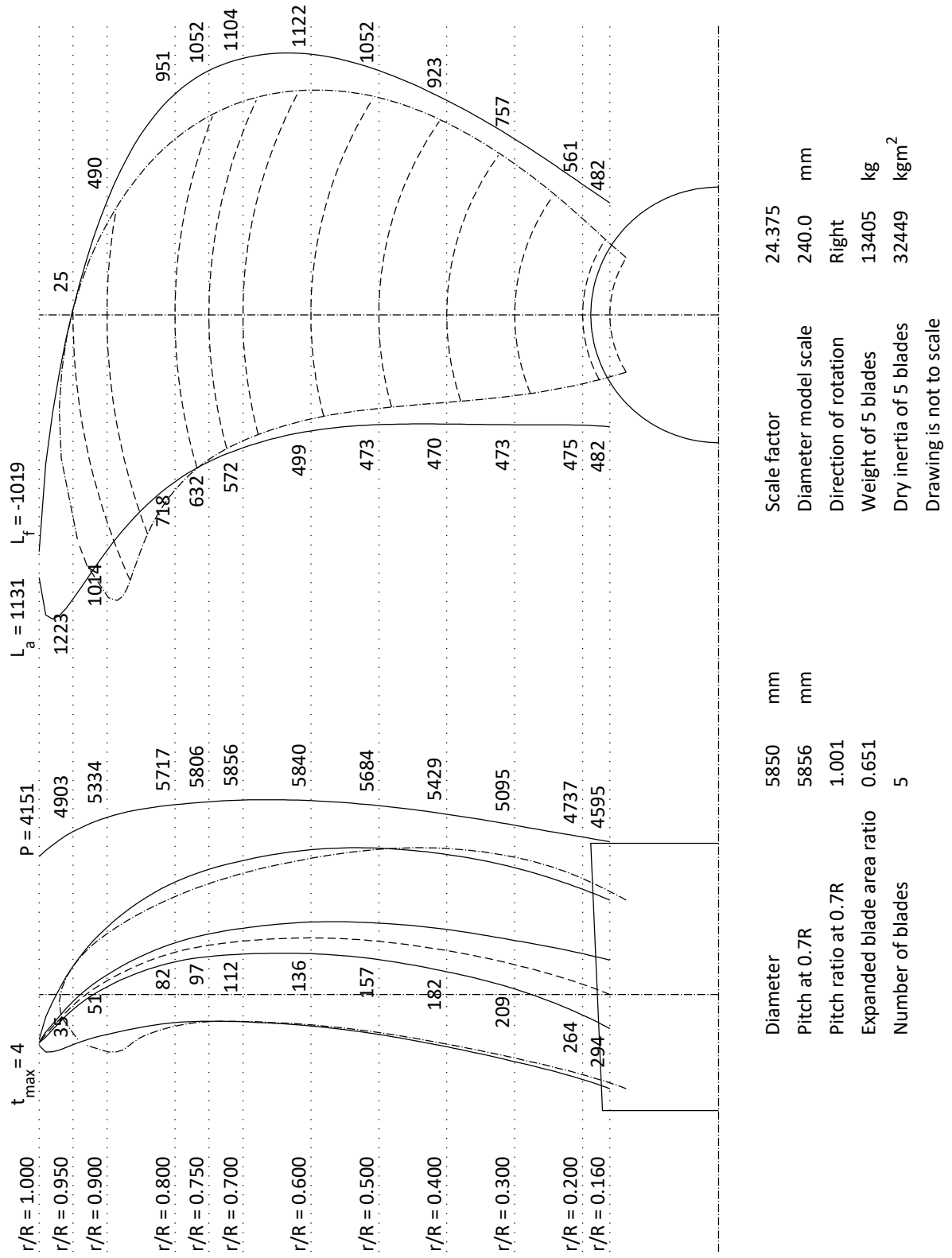
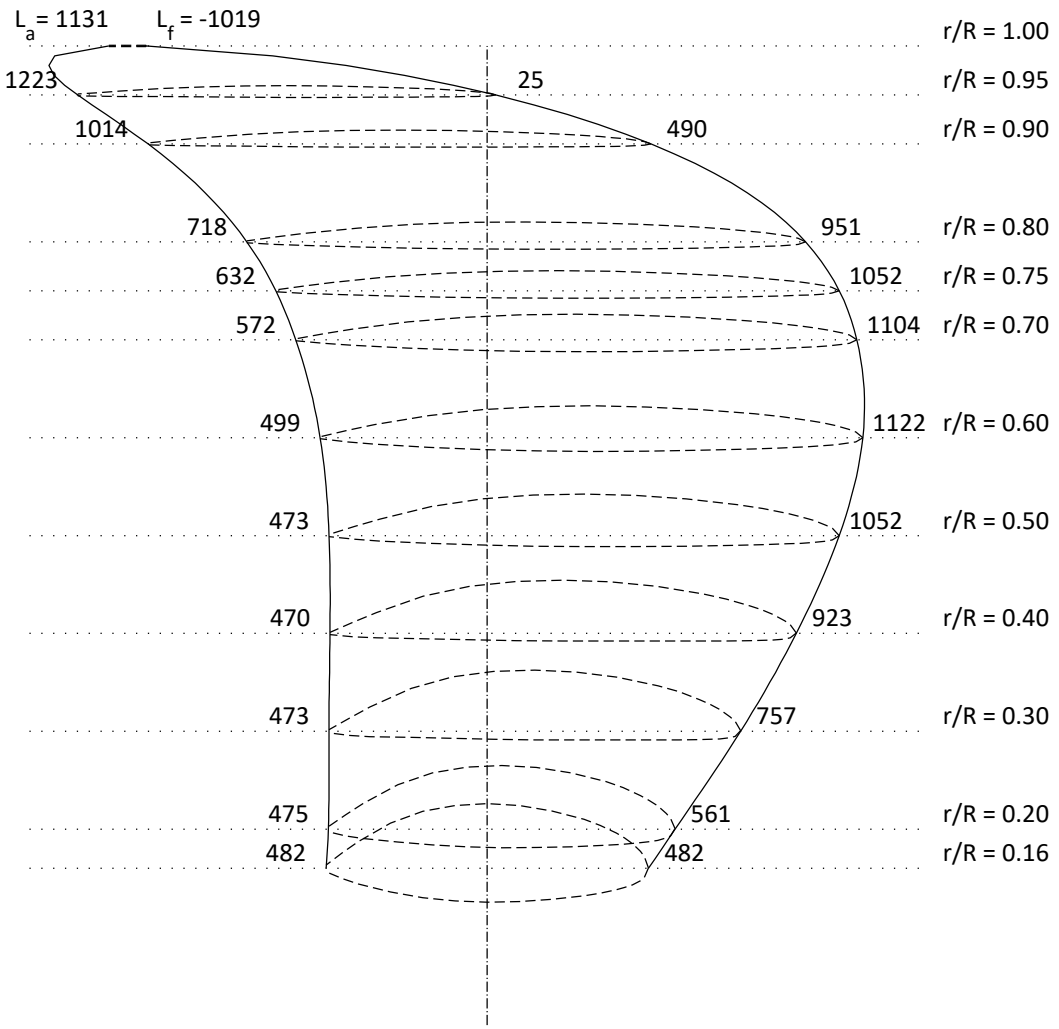

r/R = 1.000
r/R = 0.950
r/R = 0.900
r/R = 0.800
r/R = 0.750
r/R = 0.700
r/R = 0.600
r/R = 0.500
r/R = 0.400
r/R = 0.300
r/R = 0.200
r/R = 0.160
t_max = 4
P = 4151
L_a = 1131
L_f = -1019
Diameter 5850 mm
Pitch at 0.7R 5856 mm
Pitch ratio at 0.7R 1.001
Expanded blade area ratio 0.651
Number of blades 5
Scale factor 24.375
Diameter model scale 240.0 mm
Direction of rotation Right
Weight of 5 blades 13405 kg
Dry inertia of 5 blades 32449 kgm²
Drawing is not to scale

Figure: 7b

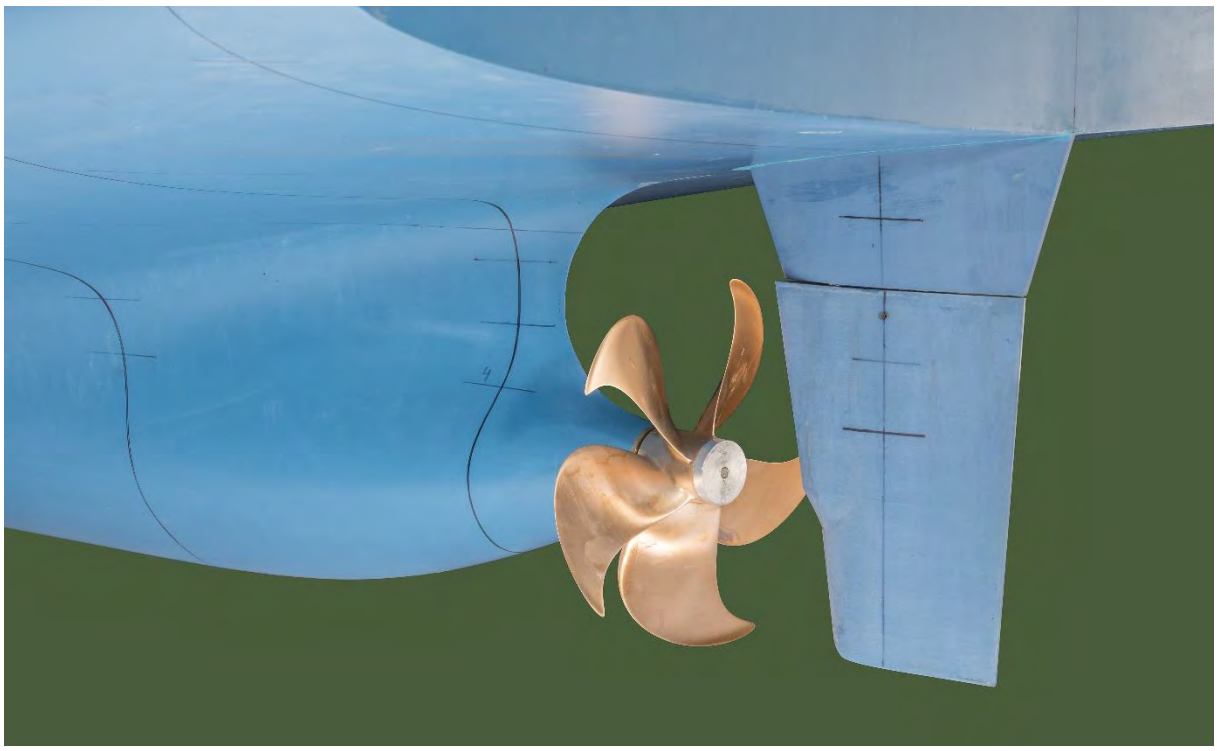

L_a = 1131
L_f = -1019
r/R = 1.00
1223
25
r/R = 0.95
1014
490
r/R = 0.90
718
951
r/R = 0.80
632
1052
r/R = 0.75
572
1104
r/R = 0.70
499
1122
r/R = 0.60
473
1052
r/R = 0.50
470
923
r/R = 0.40
473
757
r/R = 0.30
475
561
r/R = 0.20
482
482
r/R = 0.16

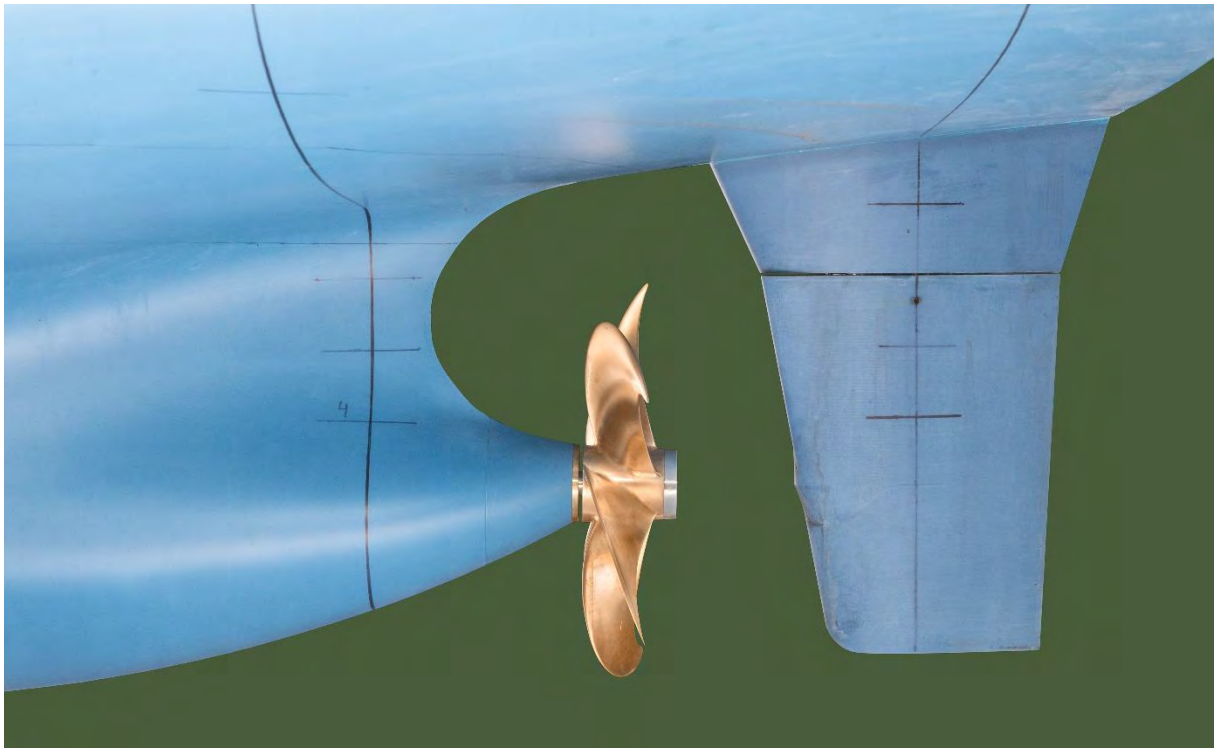
NSMV

Photos of the aft body

M5030-01-A

Figure: 8

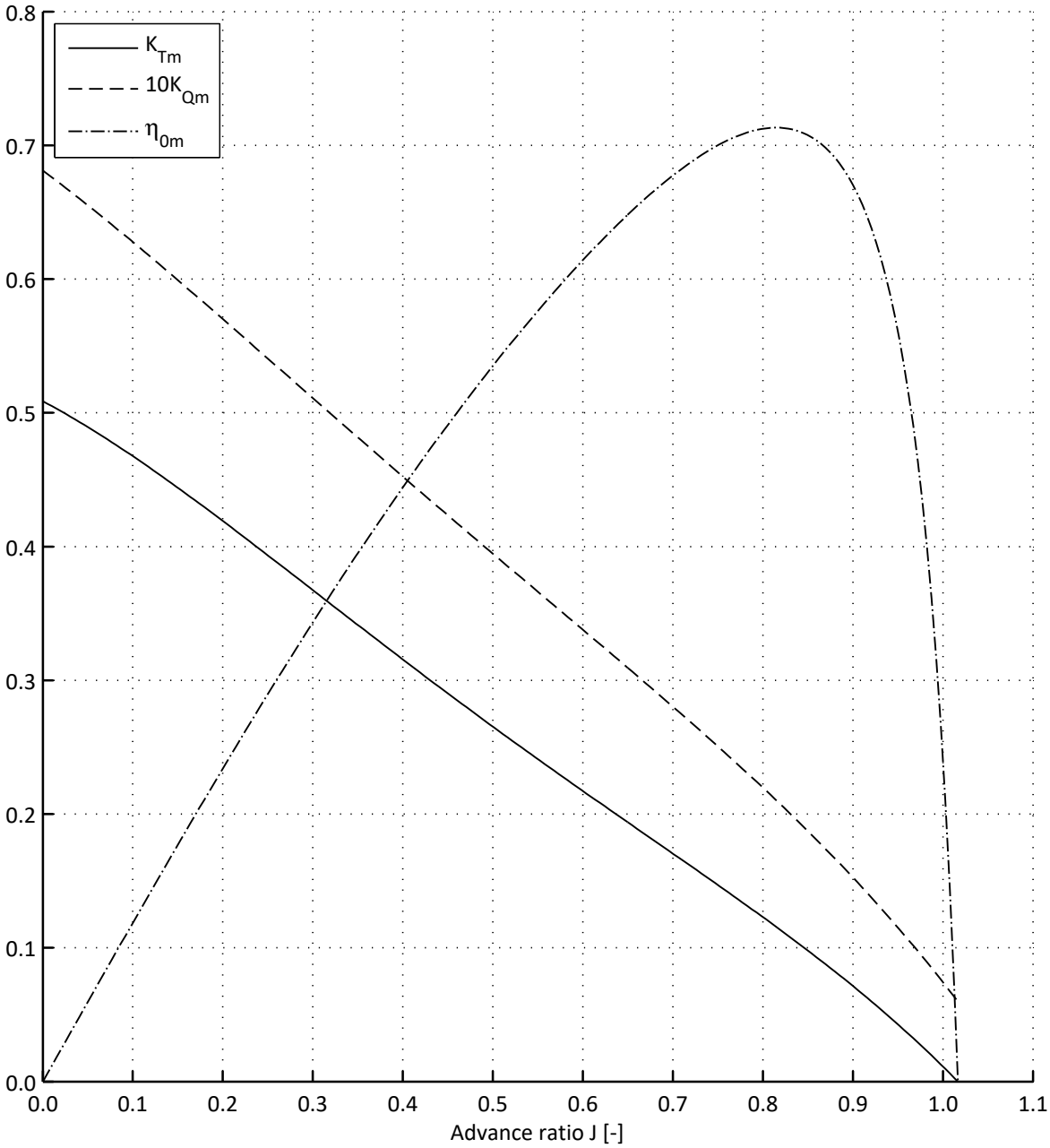




Propeller open water test

Open water characteristics model scale

Figure: 9

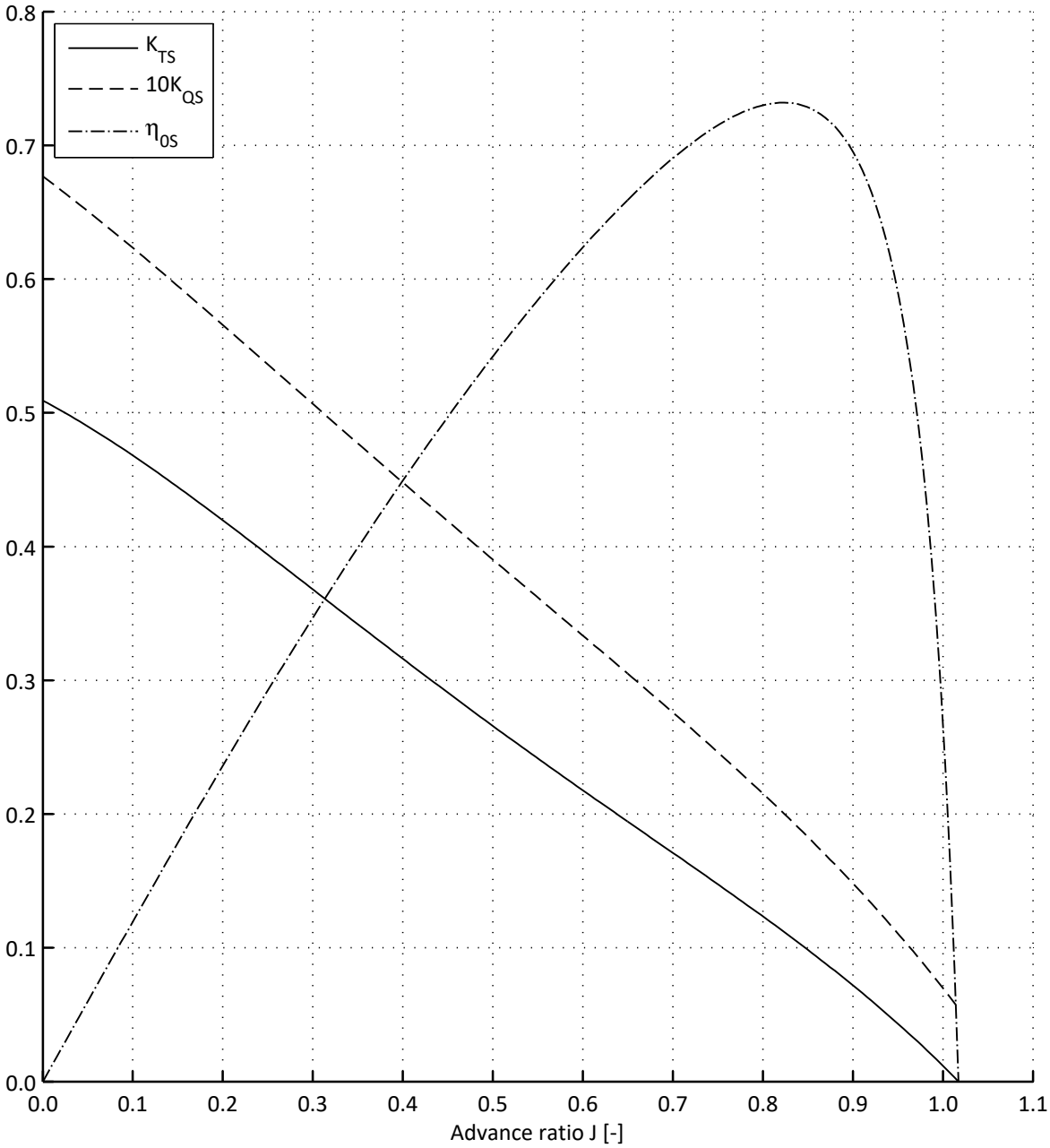


Test series	012	Propeller diameter D	0.240	m
Propeller model	P5033-01-A	Pitch ratio $(P/D)_{0.75R}$	0.992	
		Number of blades Z	5	
		Blade area ratio A_D/A_0	0.648	

Propeller open water test

Open water characteristics full scale

Figure: 10



Test series	012	Propeller diameter D	0.240	m
Propeller model	P5033-01-A	Pitch ratio $(P/D)_{0.75R}$	0.992	
Scale factor	24.375	Number of blades Z	5	
		Blade area ratio A_D/A_0	0.648	

Figure: 11a

Project number	30157634	**Date**	2016-12-12
Propeller model	P5033-01-A		
Test series	012		

Propeller - P5033-01-A			
Number of blades Z	5	Chord length $c_{0.75R}$ [m]	0.0691
Diameter D [m]	0.2400	Maximum thickness $t_{0.75R}$ [m]	0.0040
Pitch ratio $(P/D)_{0.75R}$ [-]	0.992		

Water properties			
Water density ρ_m [kg/m^3]	1000	Water temperature T [˚C]	16.7

Open water test results

Advance speed V_A [m/s]	Rate of revs. n_m [1/s]	Thrust T_m [N]	Torque Q_m [Nm]	Advance ratio J [-]	Thrust coeff. K_{Tm} [-]	Torque coeff. K_{Qm} [-]	Prop. eff. η_{0m} [-]
-0.001	18.01	546.97	17.58	0.000	0.508	0.06809	0.000
0.571	18.01	487.38	15.76	0.132	0.453	0.06105	0.156
1.142	18.04	416.83	13.79	0.264	0.386	0.05321	0.305
1.714	18.00	340.41	11.69	0.397	0.317	0.04531	0.441
2.285	18.02	271.31	9.79	0.528	0.252	0.03788	0.559
2.856	18.08	206.05	7.96	0.658	0.190	0.03055	0.651
3.427	17.96	134.74	5.72	0.795	0.126	0.02229	0.715
3.999	18.05	62.66	3.51	0.923	0.058	0.01351	0.630
4.569	18.02	-30.76	0.60	1.057	-0.029	0.00233	-2.064

Figure: 11b

Project number	30157634	**Date**	2016-12-12
Propeller model	P5033-01-A		
Test series	012		

Lerbs coefficients of polynomial		
	C_D	C_L
C_0	0.0103250	0.0349038
C_1	-0.0035389	0.0556164
C_2	0.0010822	0.0043195
C_3	-0.0000267	-0.0002556

R_{NC0}	Min: 645662
	Max: 708112

Analysis acc. to Lerbs			
Advance ratio J	Angle of attack α	Drag coeff. C_D	Lift coeff. C_L
-0.0002	22.8419	0.1757	0.5122
0.1321	5.6462	0.0204	0.4553
0.2638	4.9596	0.0154	0.3854
0.3968	4.2210	0.0123	0.3127
0.5284	3.3291	0.0100	0.2451
0.6580	2.3225	0.0086	0.1818
0.7951	1.1162	0.0073	0.1186
0.9229	0.0408	0.0089	0.0561
1.0565	-0.7427	0.0144	-0.0231

Prediction acc. to Lerbs			
Advance ratio J	Thrust coeff. K_T	Torque coeff. K_Q	Prop. eff. η_0
0.0000	0.533	0.06217	0.0000
0.0500	0.499	0.06195	0.0641
0.1000	0.469	0.06093	0.1225
0.1500	0.441	0.05926	0.1778
0.2000	0.416	0.05711	0.2317
0.2500	0.391	0.05459	0.2853
0.3000	0.368	0.05183	0.3390
0.3500	0.345	0.04891	0.3926
0.4000	0.321	0.04590	0.4456
0.4500	0.297	0.04287	0.4970
0.5000	0.273	0.03984	0.5454
0.5500	0.248	0.03683	0.5889
0.6000	0.222	0.03385	0.6258
0.6500	0.195	0.03087	0.6541
0.7000	0.168	0.02784	0.6721
0.7500	0.141	0.02473	0.6785
0.8000	0.113	0.02143	0.6728
0.8500	0.087	0.01787	0.6550
0.9000	0.061	0.01393	0.6268
0.9500	0.037	0.00947	0.5932
1.0000	0.016	0.00434	0.5817
1.0500	-0.002	-0.00163	0.2127
1.1000	-0.016	-0.00863	0.3192

Figure: 11c

Project number	30157634	**Date**	2016-12-12
Propeller model	P5033-01-A		
Test series	012		

Coefficients of polynomial			
K_T		K_Q	
A_0	0.5085789	B_0	0.0681123
A_1	-0.3546700	B_1	-0.0500673
A_2	-0.6492874	B_2	-0.0402647
A_3	1.0364716	B_3	0.0736592
A_4	-0.5298539	B_4	-0.0440138

R_{NC0}	Min: 645662
	Max: 708112

Values from polynomial			
Advance ratio J	Thrust coeff. K_T	Torque coeff. K_Q	Prop. eff. η_0
0.0000	0.509	0.06811	0.0000
0.0500	0.489	0.06552	0.0594
0.1000	0.468	0.06277	0.1186
0.1500	0.444	0.05992	0.1769
0.2000	0.419	0.05701	0.2340
0.2500	0.393	0.05406	0.2896
0.3000	0.367	0.05110	0.3433
0.3500	0.341	0.04815	0.3949
0.4000	0.316	0.04523	0.4442
0.4500	0.290	0.04234	0.4910
0.5000	0.265	0.03947	0.5350
0.5500	0.241	0.03662	0.5762
0.6000	0.217	0.03378	0.6141
0.6500	0.194	0.03093	0.6482
0.7000	0.170	0.02803	0.6774
0.7500	0.147	0.02506	0.7000
0.8000	0.123	0.02197	0.7124
0.8500	0.098	0.01872	0.7076
0.9000	0.071	0.01526	0.6704
0.9500	0.043	0.01151	0.5612
1.0000	0.011	0.00743	0.2409
1.0500	-0.024	0.00292	-1.3653
1.1000	-0.063	-0.00208	5.3313

Full scale propeller open water characteristics

Figure: 11d

Project number	30157634	**Date**	2016-12-12
Propeller model	P5033-01-A		
Test series	012		

Values from polynomial			
Advance ratio J	Thrust coeff. K_T	Torque coeff. K_Q	Prop. eff. η_0
0.0000	0.509	0.06767	0.0000
0.0500	0.490	0.06508	0.0599
0.1000	0.468	0.06233	0.1195
0.1500	0.445	0.05948	0.1784
0.2000	0.420	0.05657	0.2361
0.2500	0.394	0.05362	0.2924
0.3000	0.368	0.05066	0.3468
0.3500	0.342	0.04772	0.3992
0.4000	0.316	0.04479	0.4493
0.4500	0.291	0.04190	0.4970
0.5000	0.266	0.03903	0.5421
0.5500	0.242	0.03618	0.5844
0.6000	0.218	0.03334	0.6236
0.6500	0.194	0.03049	0.6593
0.7000	0.171	0.02759	0.6903
0.7500	0.147	0.02462	0.7150
0.8000	0.123	0.02154	0.7300
0.8500	0.098	0.01829	0.7284
0.9000	0.072	0.01482	0.6952
0.9500	0.043	0.01107	0.5906
1.0000	0.012	0.00699	0.2679
1.0500	-0.023	0.00248	-1.5714
1.1000	-0.063	-0.00252	4.3674

Figure: 12a

Project number	30157634	**Date**	2016-12-13
Ship model	M5030-01-A	**Loading condition**	Full Load
Test series	014	**Related resistance series**	001

Ship particulars - M5030-01-A - Full Load			
Scale factor α [-]	24.375	Wetted surface S_{Hull} [m^2]	4728
Length L_{PP} [m]	154.00	Bilge keel area S_{BK} [m^2]	68.4
Length L_{WL} [m]	150.11	Proj. area above water line A_T [m^2]	713.0
Draught forward T_F [m]	7.500	Displacement ∇ [m^3]	19606
Draught aft T_A [m]	7.500	Hull surface roughness k_s [μm]	150
Beam B [m]	27.00	LCB position rel. to $L_{PP}/2$ [% of L_{PP}]	-0.788
Assumed form factor k [-]	0.140		

Propeller - P5033-01-A			
Number of propellers	1	Pitch ratio $(P/D)_{0.75R}$ [-]	0.992
Number of blades Z	5	Chord length $c_{0.75R}$ [m]	1.684
Rotation direction	Right	Maximum thickness $t_{0.75R}$ [m]	0.097
Diameter D [m]	5.850	Blade roughness k_p [μm]	30

Rudder(s)		
Wetted surface S_R [m^2]	53.00	

Water properties			
Water density (resistance test) ρ_m [kg/m^3]	1000	Water temperature (resistance test) T [˚C]	17.6
Water density (self. prop. test) ρ_m [kg/m^3]	1000	Water temperature (self. prop. test) T [˚C]	16.6
Density of water (sea) ρ_s [kg/m^3]	1025	Water temperature (sea) T [˚C]	15.0

Figure: 12b

Project number	30157634	**Date**	2016-12-13
Ship model	M5030-01-A	**Loading condition**	Full Load
Test series	014	**Related resistance series**	001

Model test results					
Ship speed V_S [kn]	Resistance R_{Tm} [N]	Frict. corr. R_A [N]	Thrust T_m [N]	Torque Q_m [Ncm]	Rate of revs. n_m [1/s]
8.00	11.07	3.84	8.47	36.1	3.69
10.00	16.62	5.60	13.14	54.0	4.60
12.00	23.16	7.62	18.74	75.3	5.48
14.00	31.25	9.90	25.54	101.2	6.38
16.00	41.00	12.41	35.23	138.0	7.49
18.00	53.65	15.15	47.27	183.2	8.58
20.00	73.30	18.10	67.71	257.1	9.93

Model propulsor open water characteristics		
R_{NCm} = 645662		
Advance ratio J [-]	Thrust coeff. $10*K_{Tm}$ [-]	Torque coeff. $100*K_{Qm}$ [-]
0.203	4.174	5.681
0.282	3.766	5.214
0.361	3.354	4.748
0.441	2.950	4.288
0.520	2.558	3.835
0.599	2.179	3.386
0.678	1.808	2.933
0.757	1.437	2.465
0.836	1.051	1.966
0.915	0.631	1.417

Figure: 12c

Project number	30157634	**Date**	2016-12-13
Ship model	M5030-01-A	**Loading condition**	Full Load
Test series	014	**Related resistance series**	001

Ship model test results

Ship speed V_S [kn]	Model speed V_m [m/s]	Froude no. F_{nL} [-]	Res. coeff. total C_{Tm}*1000 [-]	Residual res. coeff. C_{Rm}*1000 [-]	Thrust ded. t_m [-]	Mean wake w_{Tm} [-]	Rel. rot. effic. η_{Rm} [-]	Prop. effic. η_{0m} [-]
8.00	0.834	0.107	3.959	0.042	0.147	0.294	0.906	0.657
10.00	1.042	0.134	3.805	0.045	0.161	0.297	0.938	0.657
12.00	1.250	0.161	3.681	0.044	0.171	0.302	0.960	0.656
14.00	1.459	0.188	3.650	0.111	0.164	0.306	0.972	0.655
16.00	1.667	0.215	3.666	0.209	0.189	0.290	0.983	0.654
18.00	1.876	0.241	3.790	0.403	0.185	0.286	0.988	0.648
20.00	2.084	0.268	4.195	0.869	0.185	0.288	0.994	0.630

Standard prediction

Correction factor for rate of revs. C_N = 1.000					Correction factor for delivered power C_P = 1.000					
Ship speed V_S [kn]	Eff. power P_E [MW]	Deliv. power P_D [MW]	Shaft rate n_S [1/s]	Thrust T_S [kN]	Torque Q_S [kNm]	Tot. eff. η_D [-]	Prop. eff. η_0 [-]	Hull eff. η_H [-]	Mean wake w_{TS} [-]	Advance ratio J_{TS} [-]
8.00	0.432	0.612	0.764	123	128	0.706	0.685	1.138	0.250	0.690
10.00	0.827	1.140	0.949	192	191	0.725	0.683	1.132	0.259	0.687
12.00	1.403	1.900	1.131	274	267	0.739	0.681	1.130	0.267	0.684
14.00	2.258	2.993	1.322	375	360	0.754	0.680	1.140	0.267	0.683
16.00	3.463	4.725	1.534	518	490	0.733	0.674	1.106	0.266	0.673
18.00	5.260	7.203	1.757	697	652	0.730	0.668	1.106	0.264	0.663
20.00	8.398	11.741	2.036	1001	918	0.715	0.649	1.109	0.265	0.635

Ship propulsor open water characteristics

Advance ratio J [-]	Thrust coeff. 10*K_{TS} [-]	Torque coeff. 100*K_{QS} [-]
0.203	4.180	5.637
0.282	3.771	5.170
0.361	3.360	4.704
0.441	2.955	4.244
0.520	2.563	3.791
0.599	2.184	3.342
0.678	1.814	2.889
0.757	1.442	2.421
0.836	1.056	1.922
0.915	0.636	1.373

Figure: 12d

Project number	30157634	**Date**	2016-12-13
Ship model	M5030-01-A	**Loading condition**	Full Load
Test series	014	**Related resistance series**	001

SSPA ship trial prediction				
Correction factor for rate of revs. C_N = 1.013				
Correction factor for delivered power C_P = 1.020				
Ship speed V_S	Delivered power P_{DT}		Rate of revs. n_T	
[kn]	[MW]	[ps]	[1/s]	[1/min]
8.00	0.625	849	0.774	46.5
10.00	1.163	1581	0.961	57.7
12.00	1.938	2635	1.146	68.8
14.00	3.053	4150	1.339	80.3
16.00	4.819	6552	1.554	93.2
18.00	7.347	9989	1.780	106.8
20.00	11.976	16283	2.062	123.7

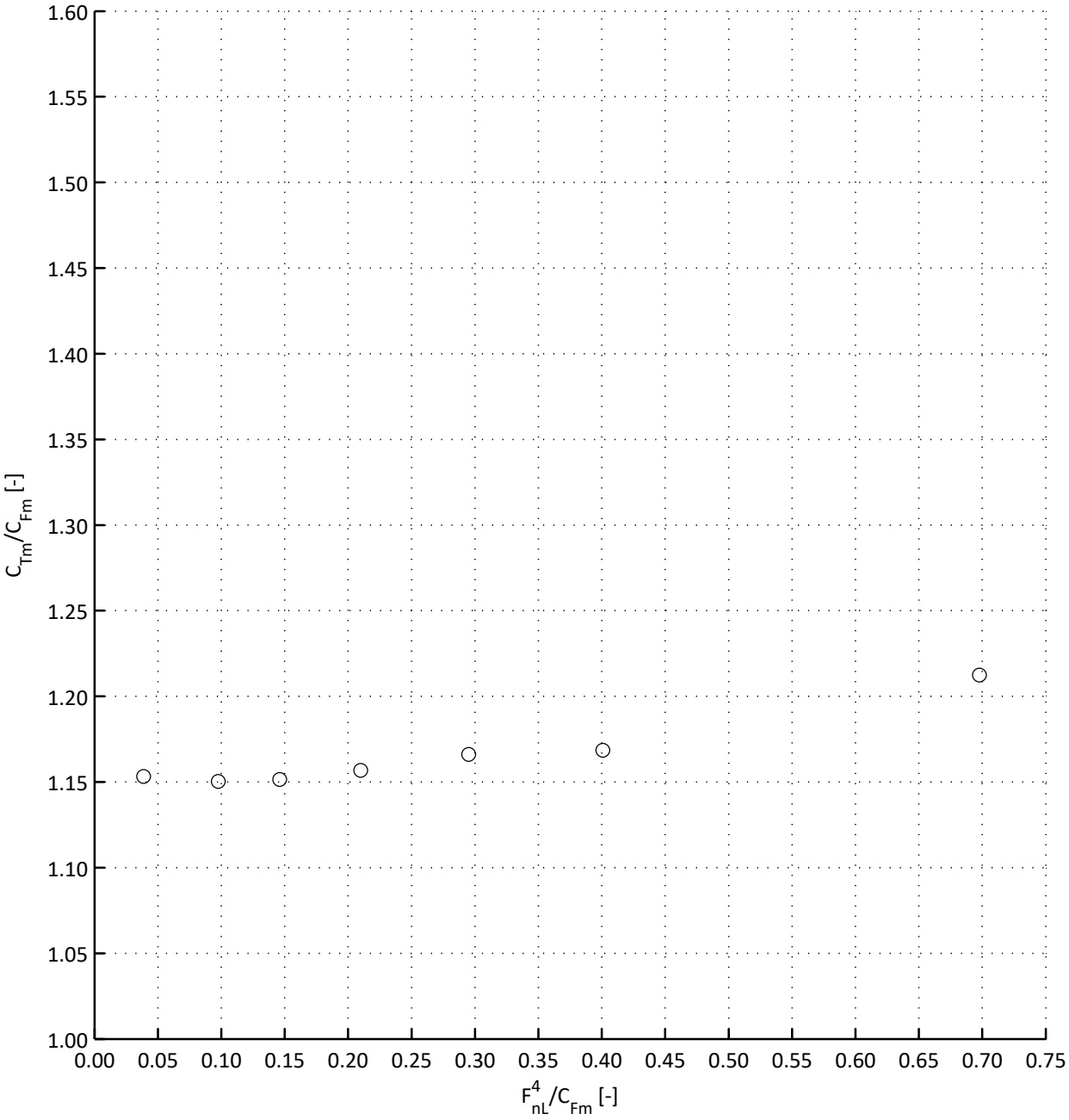
Draught changes				
Distance from origin to FP: 154.00 m				
Distance from origin to AP: 0.00 m				
Distance from origin to fwd draught: 154.00 m				
Distance from origin to aft draught: 7.70 m				
Ship speed V_s [kn]	Forward change T_F [m]	Aft change T_A [m]	Trim angle [deg]	CG elevation [m]
8.00	0.07	0.06	-0.01	-0.07
10.00	0.12	0.06	-0.03	-0.09
12.00	0.21	0.08	-0.05	-0.14
14.00	0.31	0.07	-0.09	-0.18
16.00	0.45	0.09	-0.13	-0.26
18.00	0.59	0.09	-0.18	-0.32
20.00	0.76	0.13	-0.23	-0.43

NSMV

Resistance prediction, ITTC 78 method

Prohaska plot

Figure: 13



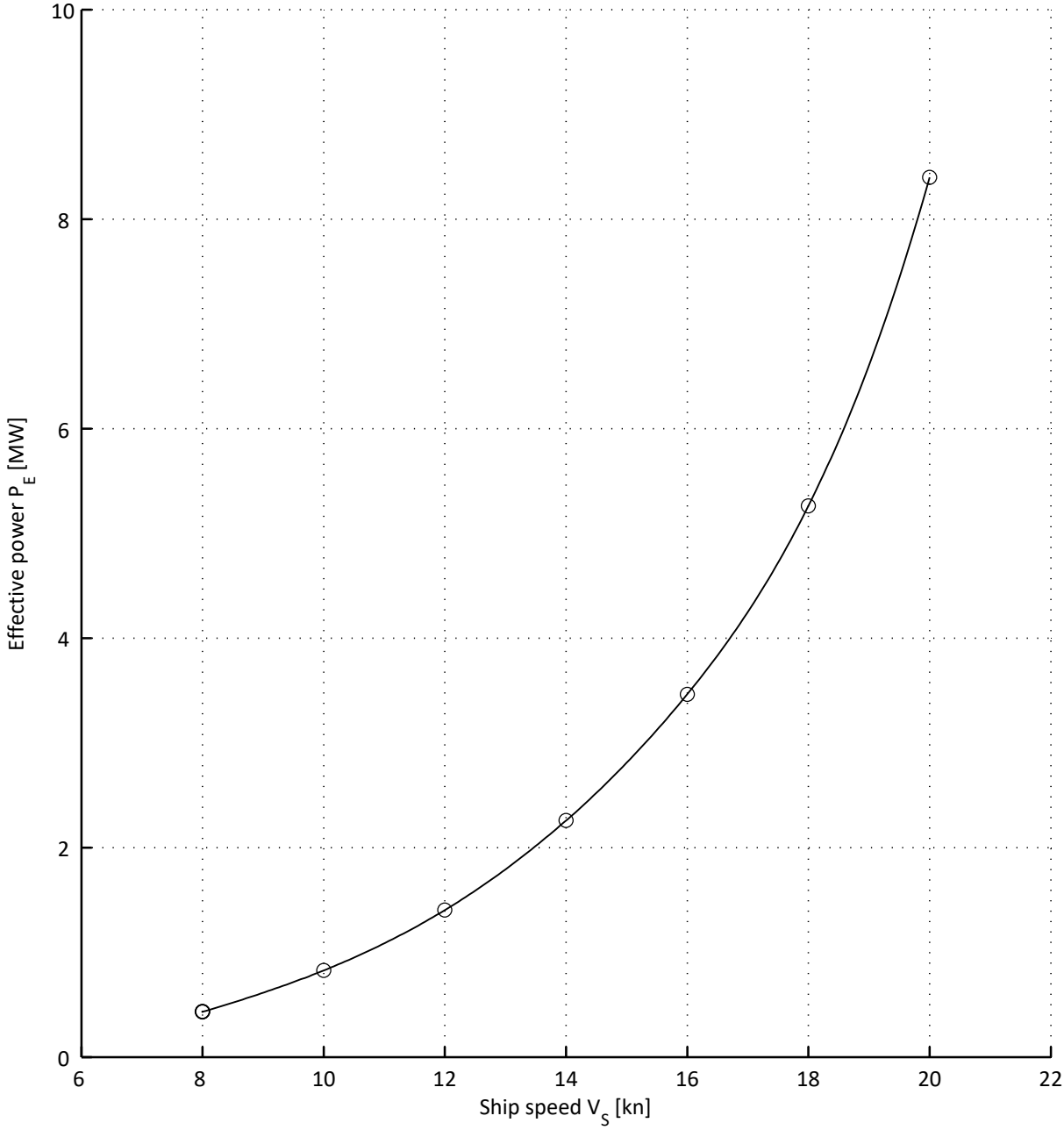
Test series	001	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	7.50	m
Loading condition	Full Load	Draught aft AP T_A	7.50	m
Scale factor α	24.375	Form factor k	0.140	
Displacement ∇	19606 m^3			

NSMV

Power prediction, ITTC 78 method

Effective power

Figure: 14

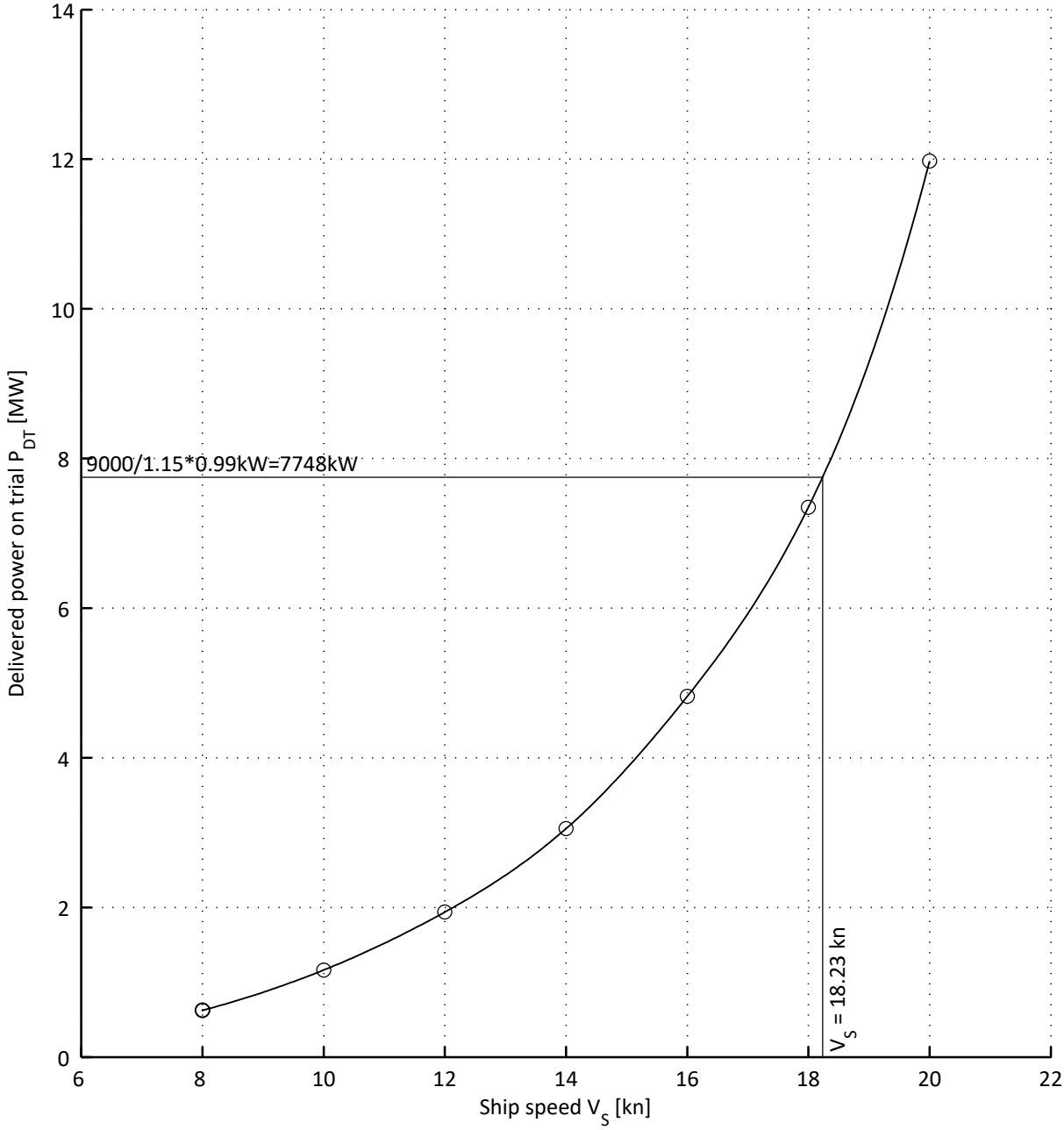


Test series	014	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	7.50	m
Loading condition	Full Load	Draught aft AP T_A	7.50	m
Propeller model	P5033-01-A	Form factor k	0.140	
Scale factor α	24.375			
Displacement ∇	19606 m^3			

Power prediction, ITTC 78 method

Delivered power on trial

Figure: 15



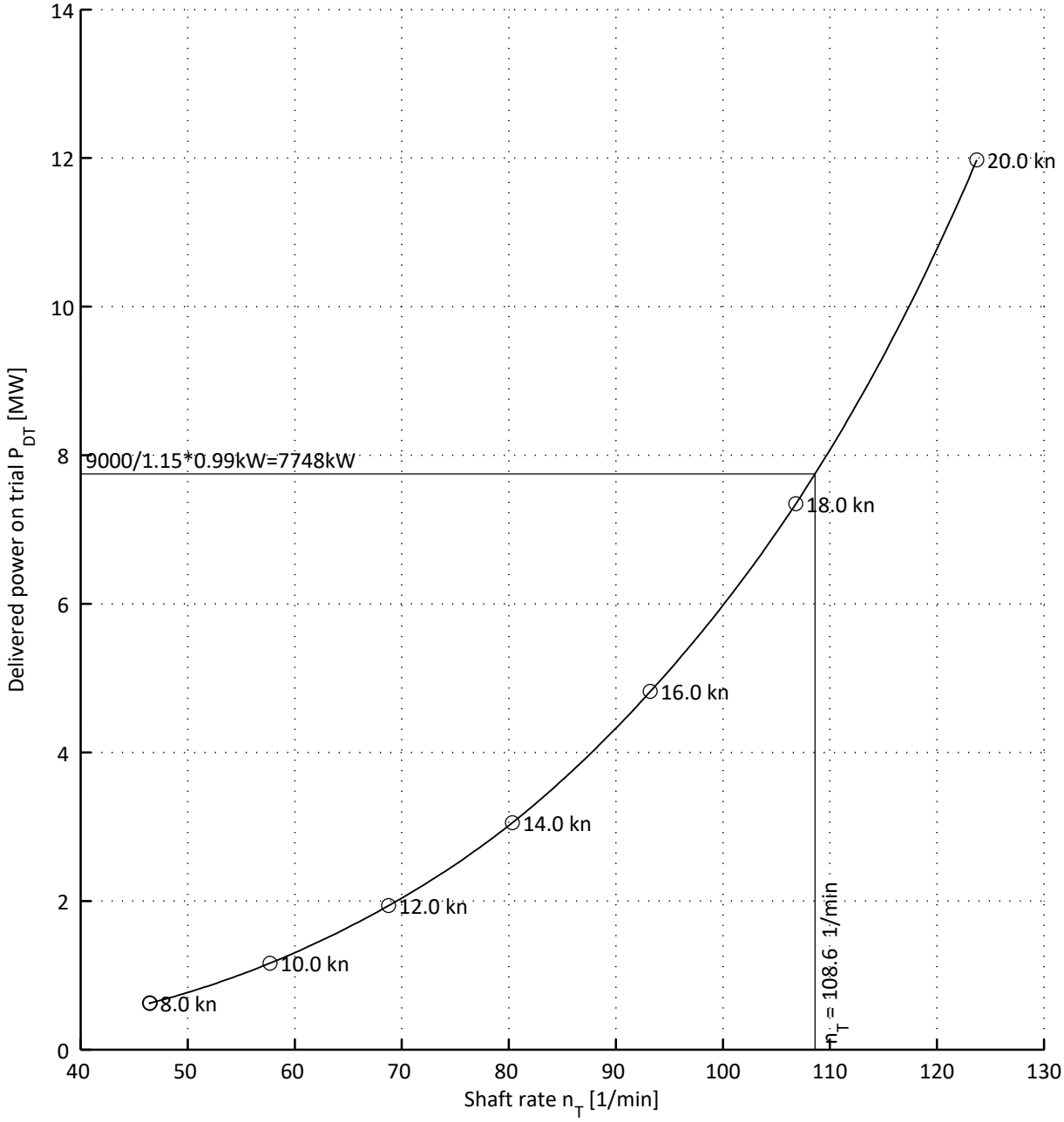
Test series	014	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	7.50	m
Loading condition	Full Load	Draught aft AP T_A	7.50	m
Propeller model	P5033-01-A	Form factor k	0.140	
Scale factor α	24.375			
Displacement ∇	19606 m^3			

NSMV

Power prediction, ITTC 78 method

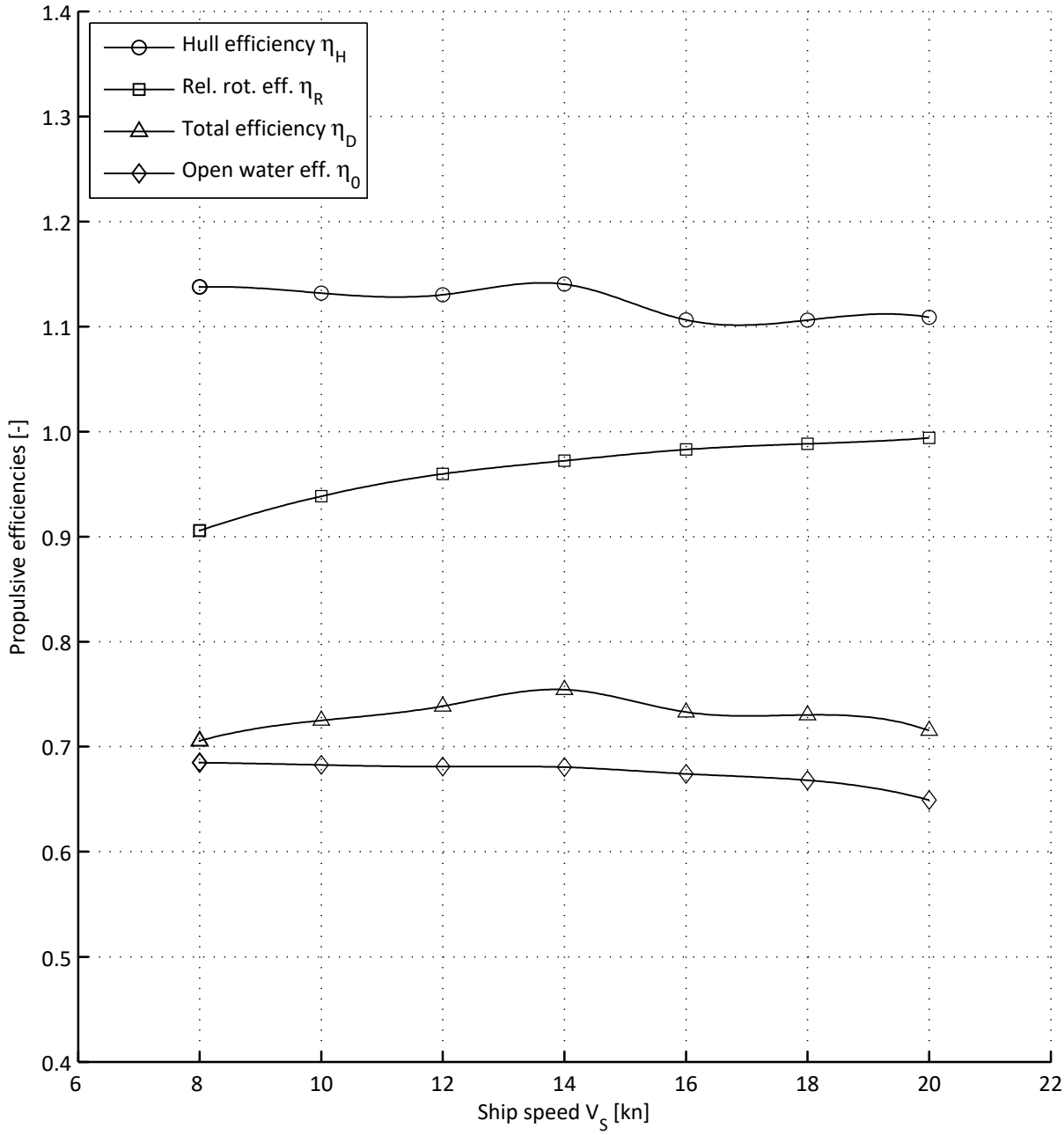
Delivered power on trial

Figure: 16



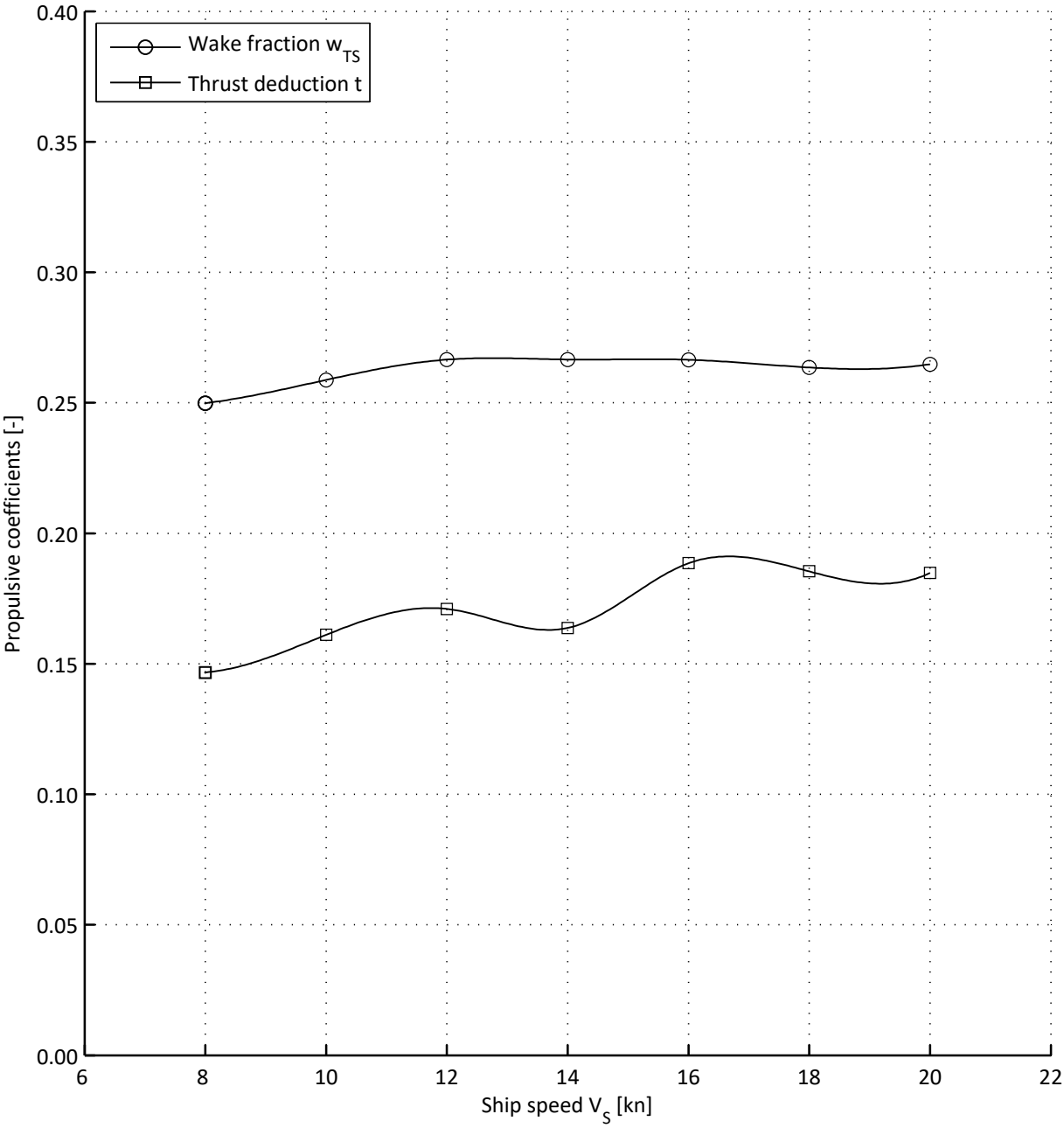
Test series	014	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	7.50	m
Loading condition	Full Load	Draught aft AP T_A	7.50	m
Propeller model	P5033-01-A	Form factor k	0.140	
Scale factor α	24.375			
Displacement ∇	19606 m^3			

Figure: 17



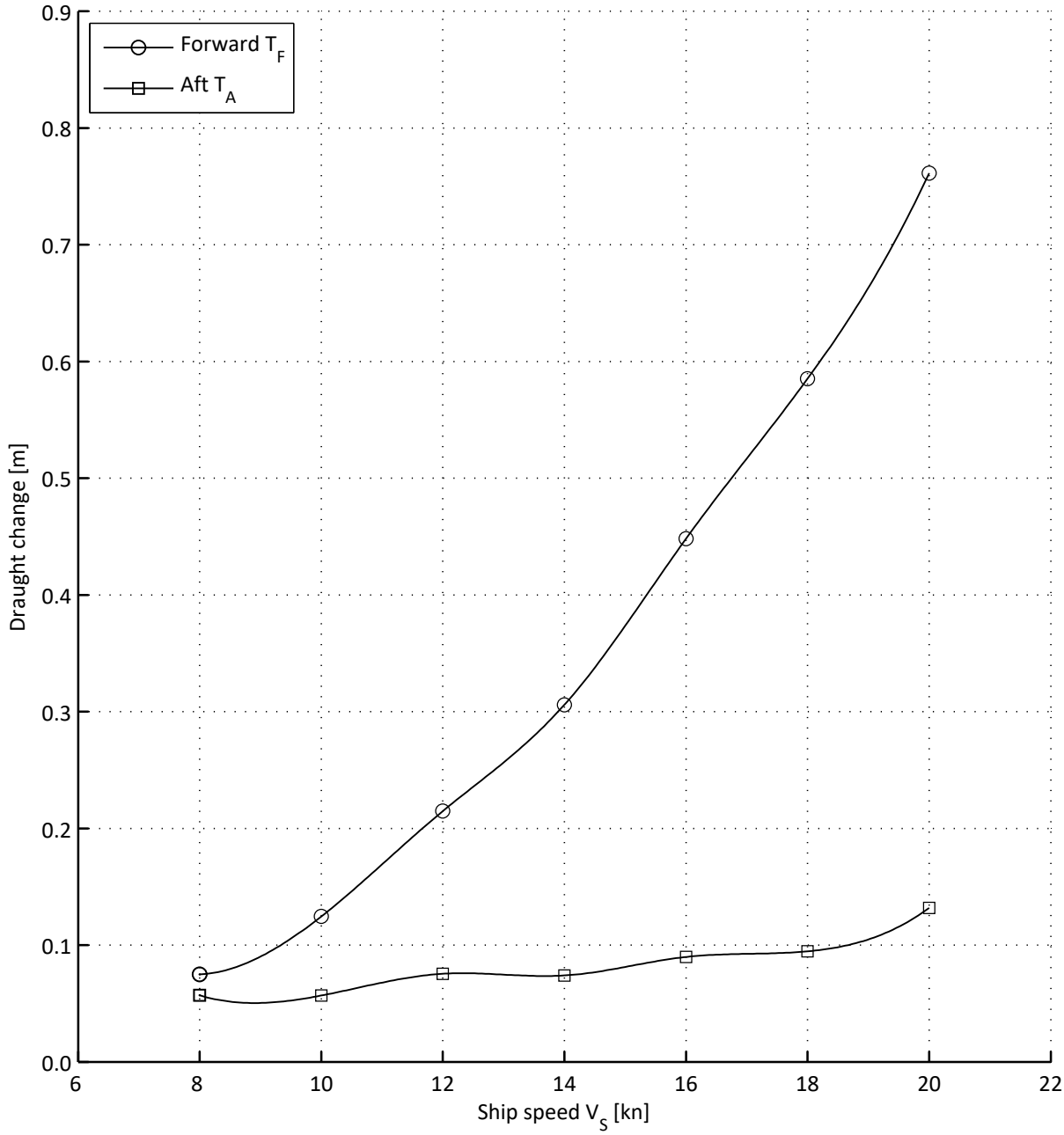
Test series	014	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	7.50	m
Loading condition	Full Load	Draught aft AP T_A	7.50	m
Propeller model	P5033-01-A	Form factor k	0.140	
Scale factor α	24.375			
Displacement ∇	19606 m^3			

Figure: 18



Test series	014	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	7.50	m
Loading condition	Full Load	Draught aft AP T_A	7.50	m
Propeller model	P5033-01-A	Form factor k	0.140	
Scale factor α	24.375			
Displacement ∇	19606 m^3			

Figure: 19



Test series	014	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	7.50	m
Loading condition	Full Load	Draught aft AP T_A	7.50	m
Propeller model	P5033-01-A	Form factor k	0.140	
Scale factor α	24.375			
Displacement ∇	19606 m^3			

Figure: 20a

Project number	30157634	**Date**	2016-12-13
Ship model	M5030-01-A	**Loading condition**	Design
Test series	016	**Related resistance series**	003

Ship particulars - M5030-01-A - Design			
Scale factor α [-]	24.375	Wetted surface S_{Hull} [m^2]	4286
Length L_{PP} [m]	154.00	Bilge keel area S_{BK} [m^2]	68.4
Length L_{WL} [m]	148.91	Proj. area above water line A_T [m^2]	740.0
Draught forward T_F [m]	6.500	Displacement ∇ [m^3]	16467
Draught aft T_A [m]	6.500	Hull surface roughness k_s [μm]	150
Beam B [m]	27.00	LCB position rel. to $L_{PP}/2$ [% of L_{PP}]	-0.177
Assumed form factor k [-]	0.170		

Propeller - P5033-01-A			
Number of propellers	1	Pitch ratio $(P/D)_{0.75R}$ [-]	0.992
Number of blades Z	5	Chord length $c_{0.75R}$ [m]	1.684
Rotation direction	Right	Maximum thickness $t_{0.75R}$ [m]	0.097
Diameter D [m]	5.850	Blade roughness k_P [μm]	30

Rudder(s)		
Wetted surface S_R [m^2]	43.40	

Water properties			
Water density (resistance test) ρ_m [kg/m^3]	1000	Water temperature (resistance test) T [˚C]	17.6
Water density (self. prop. test) ρ_m [kg/m^3]	1000	Water temperature (self. prop. test) T [˚C]	16.6
Density of water (sea) ρ_s [kg/m^3]	1025	Water temperature (sea) T [˚C]	15.0

Figure: 20b

Project number	30157634	**Date**	2016-12-13
Ship model	M5030-01-A	**Loading condition**	Design
Test series	016	**Related resistance series**	003

Model test results

Ship speed V_S [kn]	Resistance R_{Tm} [N]	Frict. corr. R_A [N]	Thrust T_m [N]	Torque Q_m [Ncm]	Rate of revs. n_m [1/s]
8.00	10.04	3.49	8.04	35.0	3.60
10.00	15.42	5.08	12.63	52.3	4.49
12.00	21.70	6.92	18.33	73.8	5.37
14.00	29.47	8.99	24.82	98.2	6.26
16.00	38.15	11.26	32.73	128.1	7.18
18.00	48.70	13.75	42.93	166.5	8.20
20.00	66.37	16.43	61.82	235.5	9.57

Model propulsor open water characteristics

R_{NCm} = 645662

Advance ratio J [-]	Thrust coeff. $10*K_{Tm}$ [-]	Torque coeff. $100*K_{Qm}$ [-]
0.203	4.174	5.681
0.282	3.766	5.214
0.361	3.354	4.748
0.441	2.950	4.288
0.520	2.558	3.835
0.599	2.179	3.386
0.678	1.808	2.933
0.757	1.437	2.465
0.836	1.051	1.966
0.915	0.631	1.417

Figure: 20c

Project number	30157634	**Date**	2016-12-13
Ship model	M5030-01-A	**Loading condition**	Design
Test series	016	**Related resistance series**	003

Ship model test results

Ship speed V_S [kn]	Model speed V_m [m/s]	Froude no. F_{nL} [-]	Res. coeff. total C_{Tm}*1000 [-]	Residual res. coeff. C_{Rm}*1000 [-]	Thrust ded. t_m [-]	Mean wake w_{Tm} [-]	Rel. rot. effic. η_{Rm} [-]	Prop. effic. η_{0m} [-]
8.00	0.834	0.108	3.968	-0.059	0.184	0.312	0.887	0.657
10.00	1.042	0.135	3.898	0.034	0.181	0.318	0.929	0.654
12.00	1.250	0.162	3.810	0.071	0.194	0.324	0.955	0.651
14.00	1.459	0.188	3.801	0.164	0.175	0.325	0.971	0.652
16.00	1.667	0.215	3.767	0.214	0.179	0.322	0.982	0.652
18.00	1.876	0.242	3.800	0.319	0.186	0.315	0.989	0.650
20.00	2.084	0.269	4.195	0.776	0.192	0.306	0.994	0.635

Standard prediction

Correction factor for rate of revs. C_N = 1.000					Correction factor for delivered power C_P = 1.000					
Ship speed V_S [kn]	Eff. power P_E [MW]	Deliv. power P_D [MW]	Shaft rate n_S [1/s]	Thrust T_S [kN]	Torque Q_S [kNm]	Tot. eff. η_D [-]	Prop. eff. η_0 [-]	Hull eff. η_H [-]	Mean wake w_{TS} [-]	Advance ratio J_{TS} [-]
8.00	0.388	0.568	0.740	116	122	0.683	0.684	1.126	0.275	0.689
10.00	0.769	1.069	0.925	183	184	0.719	0.682	1.136	0.279	0.685
12.00	1.326	1.808	1.107	266	260	0.733	0.678	1.133	0.288	0.678
14.00	2.152	2.835	1.296	362	348	0.759	0.680	1.150	0.282	0.682
16.00	3.237	4.246	1.486	479	455	0.762	0.678	1.145	0.282	0.679
18.00	4.747	6.280	1.690	630	591	0.756	0.674	1.133	0.282	0.673
20.00	7.562	10.346	1.965	910	838	0.731	0.656	1.120	0.279	0.646

Ship propulsor open water characteristics

Advance ratio J [-]	Thrust coeff. 10*K_{TS} [-]	Torque coeff. 100*K_{QS} [-]
0.203	4.180	5.637
0.282	3.771	5.170
0.361	3.360	4.704
0.441	2.955	4.244
0.520	2.563	3.791
0.599	2.184	3.342
0.678	1.814	2.889
0.757	1.442	2.421
0.836	1.056	1.922
0.915	0.636	1.373

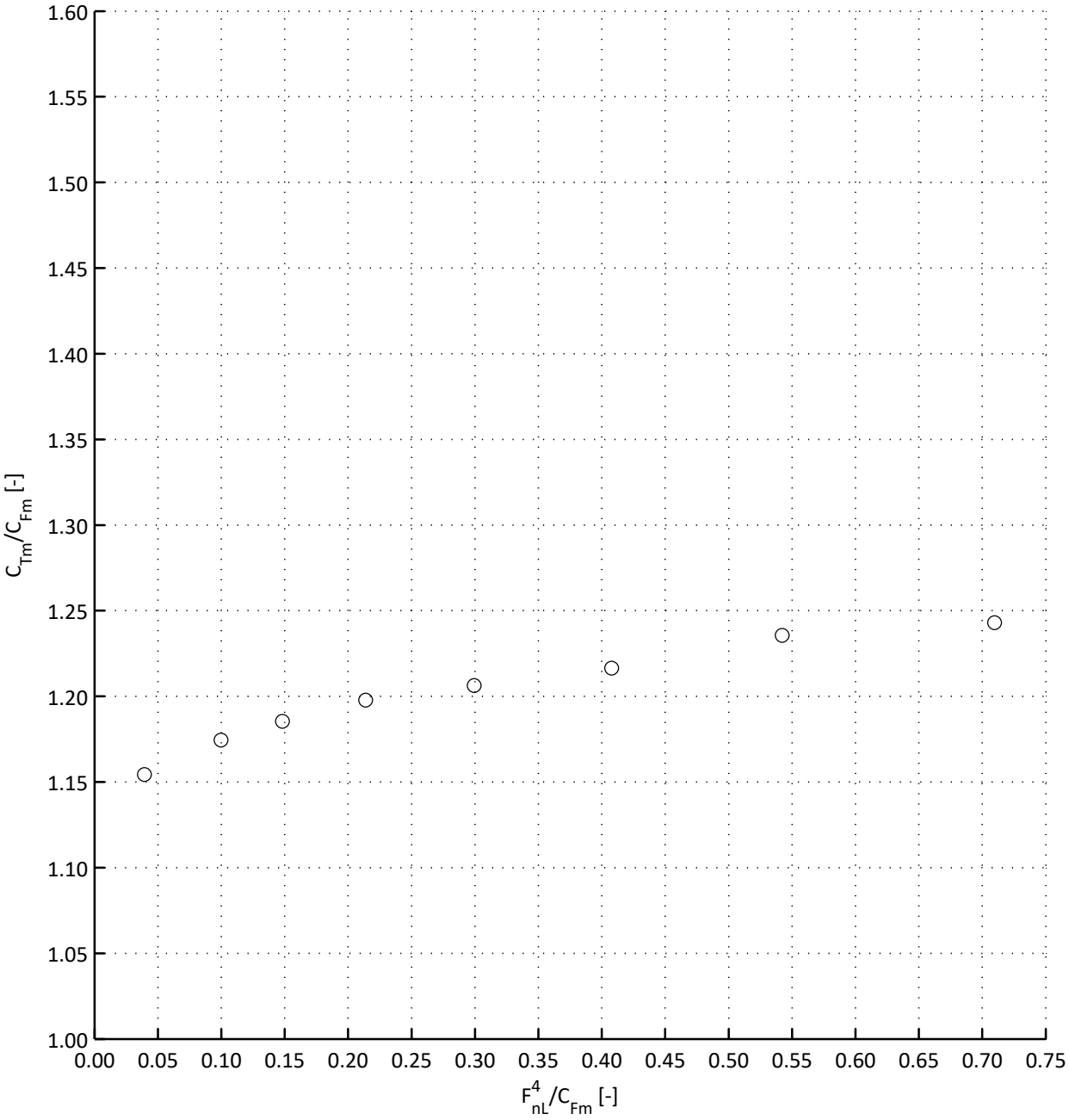
Figure: 20d

Project number	30157634	**Date**	2016-12-13
Ship model	M5030-01-A	**Loading condition**	Design
Test series	016	**Related resistance series**	003

SSPA ship trial prediction				
Correction factor for rate of revs. C_N = 1.013				
Correction factor for delivered power C_P = 1.020				
Ship speed V_S	Delivered power P_{DT}		Rate of revs. n_T	
[kn]	[MW]	[ps]	[1/s]	[1/min]
8.00	0.580	788	0.749	45.0
10.00	1.091	1483	0.937	56.2
12.00	1.844	2508	1.121	67.3
14.00	2.892	3932	1.313	78.8
16.00	4.331	5888	1.505	90.3
18.00	6.406	8710	1.712	102.7
20.00	10.553	14349	1.990	119.4

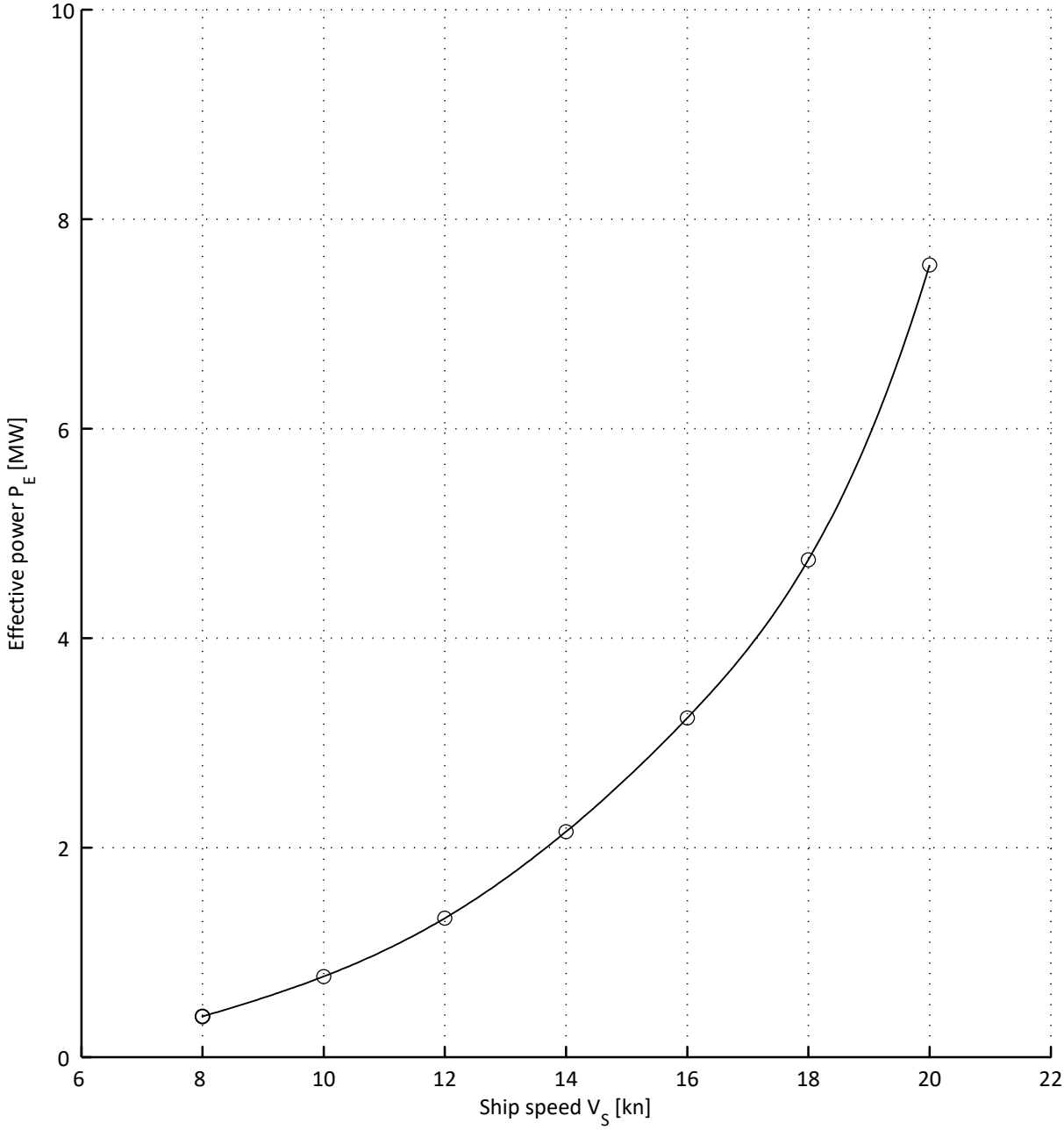
Draught changes				
Distance from origin to FP: 154.00 m				
Distance from origin to AP: 0.00 m				
Distance from origin to fwd draught: 154.00 m				
Distance from origin to aft draught: 7.70 m				
Ship speed V_s [kn]	Forward change T_F [m]	Aft change T_A [m]	Trim angle [deg]	CG elevation [m]
8.00	0.04	0.08	0.01	-0.06
10.00	0.08	0.10	0.01	-0.09
12.00	0.13	0.13	0.00	-0.13
14.00	0.21	0.16	-0.02	-0.18
16.00	0.31	0.20	-0.04	-0.25
18.00	0.44	0.23	-0.08	-0.33
20.00	0.60	0.28	-0.12	-0.43

Figure: 21



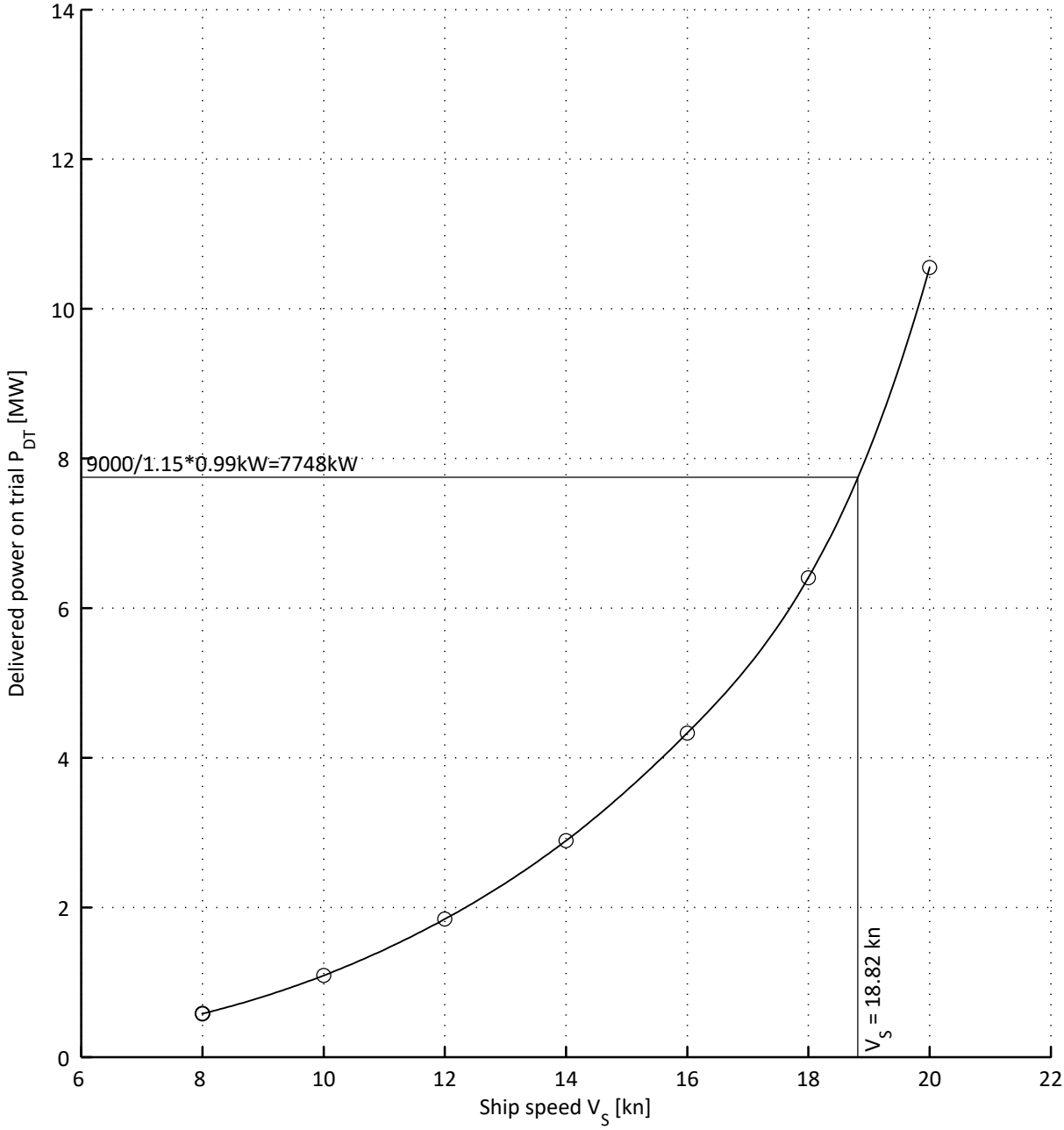
Test series	003	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	6.50	m
Loading condition	Design	Draught aft AP T_A	6.50	m
Scale factor α	24.375	Form factor k	0.170	
Displacement ∇	16467 m^3			

Figure: 22



Test series	016	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	6.50	m
Loading condition	Design	Draught aft AP T_A	6.50	m
Propeller model	P5033-01-A	Form factor k	0.170	
Scale factor α	24.375			
Displacement ∇	16467 m^3			

Figure: 23



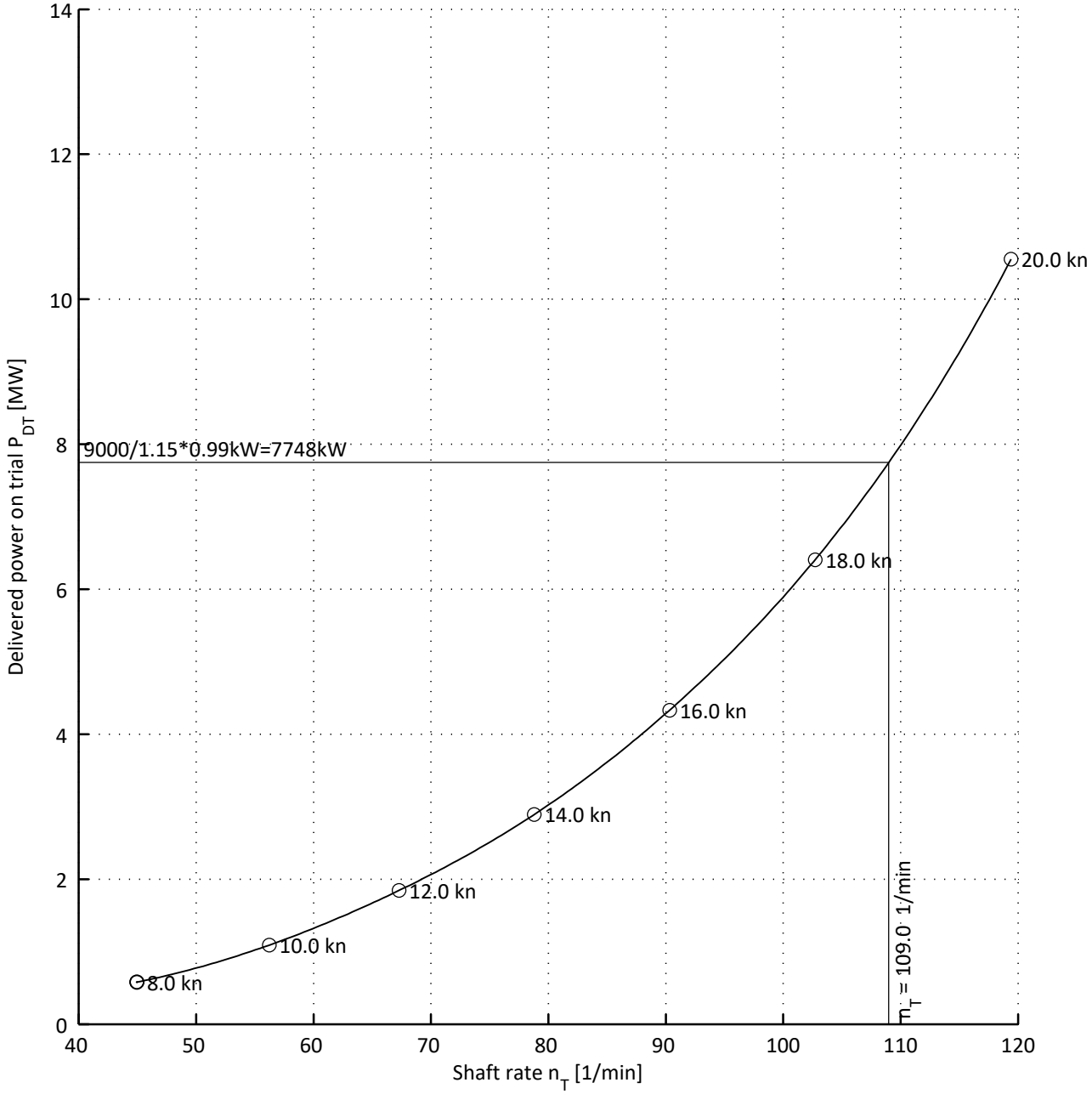
Test series	016	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	6.50	m
Loading condition	Design	Draught aft AP T_A	6.50	m
Propeller model	P5033-01-A	Form factor k	0.170	
Scale factor α	24.375			
Displacement ∇	16467 m^3			

NSMV

Power prediction, ITTC 78 method

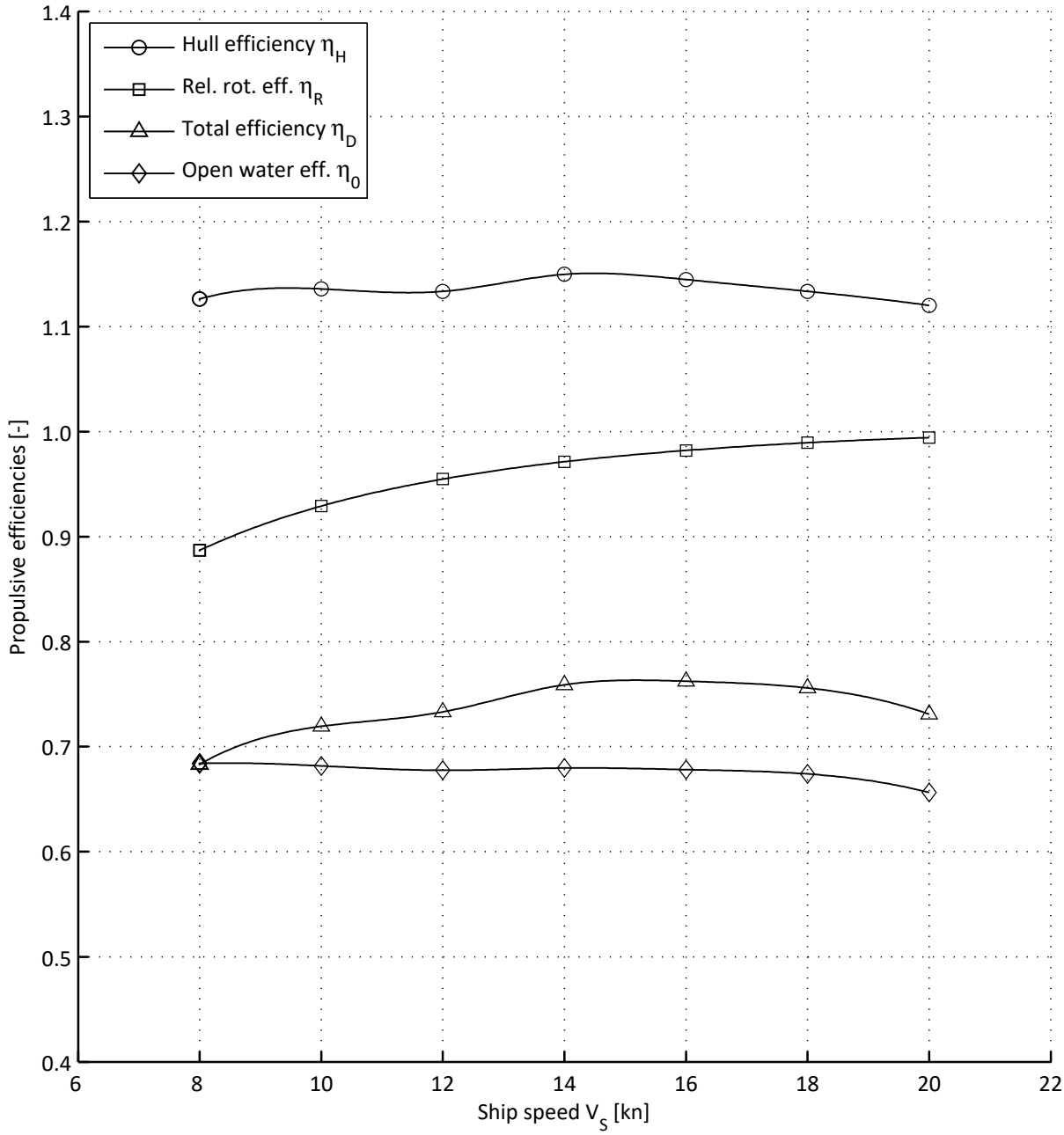
Delivered power on trial

Figure: 24



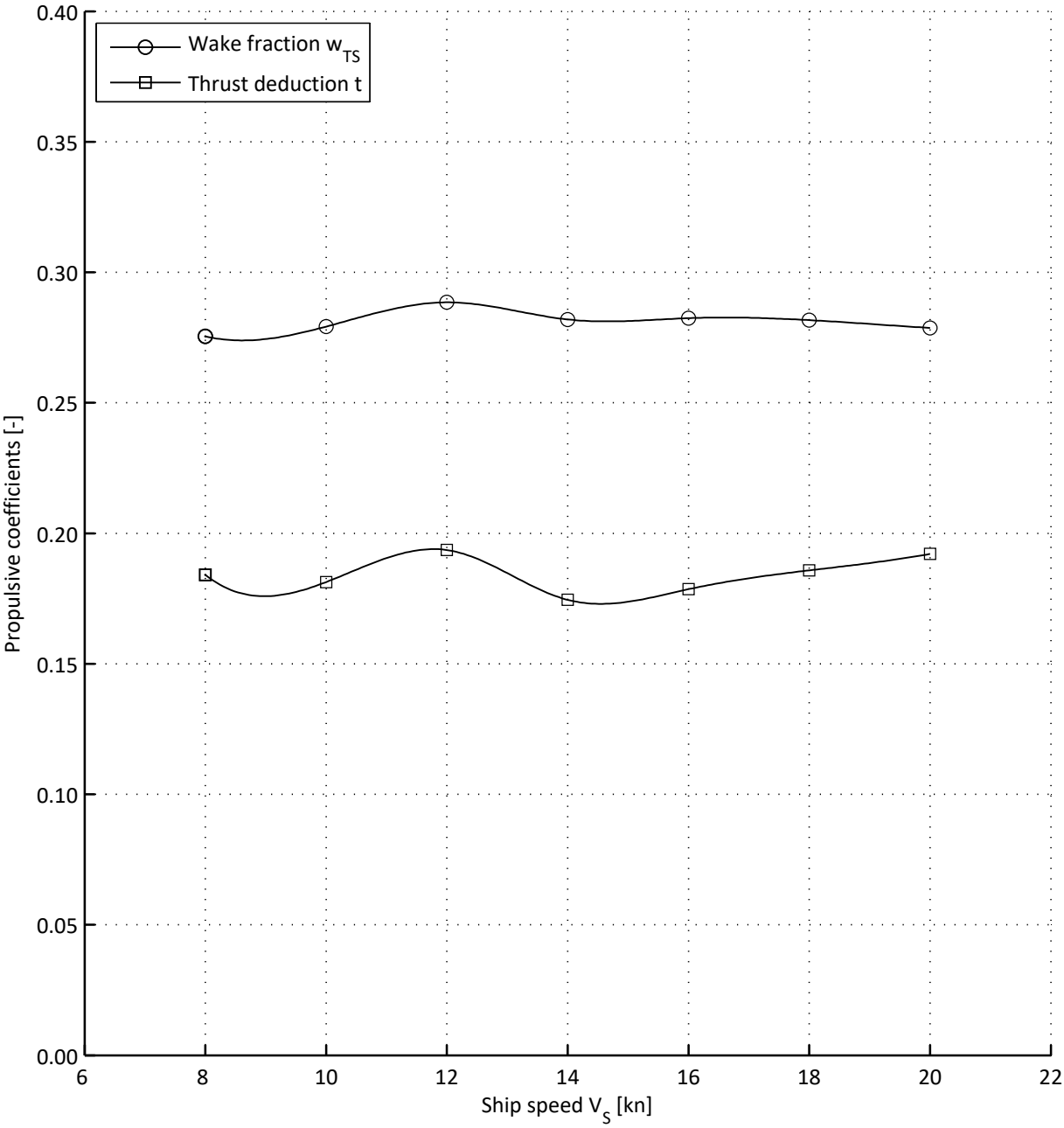
Test series	016	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	6.50	m
Loading condition	Design	Draught aft AP T_A	6.50	m
Propeller model	P5033-01-A	Form factor k	0.170	
Scale factor α	24.375			
Displacement ∇	16467 m^3			

Figure: 25



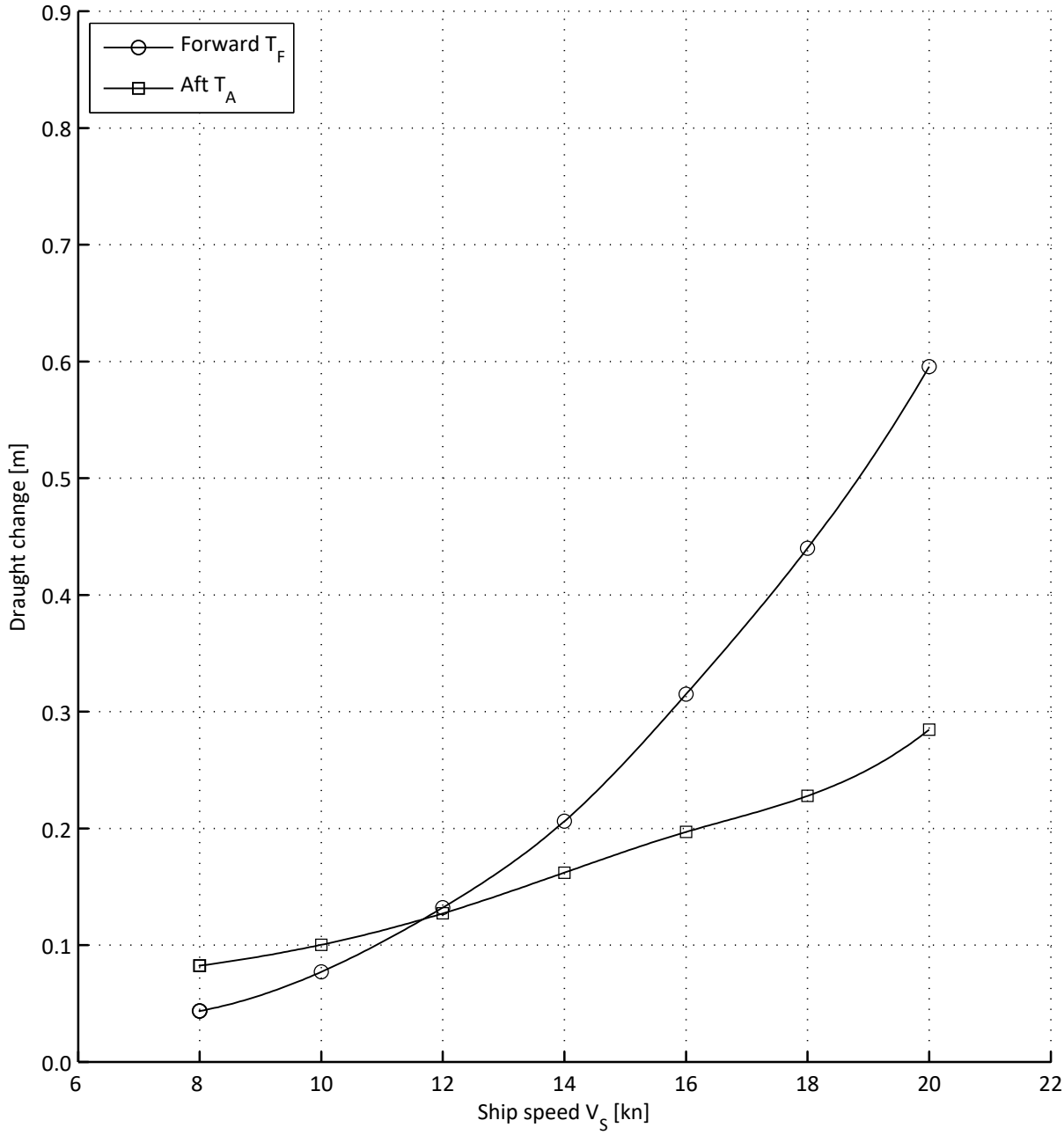
Test series	016	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	6.50	m
Loading condition	Design	Draught aft AP T_A	6.50	m
Propeller model	P5033-01-A	Form factor k	0.170	
Scale factor α	24.375			
Displacement ∇	16467 m^3			

Figure: 26



Test series	016	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	6.50	m
Loading condition	Design	Draught aft AP T_A	6.50	m
Propeller model	P5033-01-A	Form factor k	0.170	
Scale factor α	24.375			
Displacement ∇	16467 m^3			

Figure: 27



Test series	016	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	6.50	m
Loading condition	Design	Draught aft AP T_A	6.50	m
Propeller model	P5033-01-A	Form factor k	0.170	
Scale factor α	24.375			
Displacement ∇	16467 m^3			

Figure: 28a

Project number	30157634	**Date**	2016-12-13
Ship model	M5030-01-A	**Loading condition**	Trim Aft
Test series	018	**Related resistance series**	005

Ship particulars - M5030-01-A - Trim Aft			
Scale factor α [-]	24.375	Wetted surface S_{Hull} [m^2]	4147
Length L_{PP} [m]	154.00	Bilge keel area S_{BK} [m^2]	68.4
Length L_{WL} [m]	150.53	Proj. area above water line A_T [m^2]	750.0
Draught forward T_F [m]	5.700	Displacement ∇ [m^3]	15325
Draught aft T_A [m]	6.500	Hull surface roughness k_s [μm]	150
Beam B [m]	27.00	LCB position rel. to $L_{PP}/2$ [% of L_{PP}]	-0.757
Assumed form factor k [-]	0.225		

Propeller - P5033-01-A			
Number of propellers	1	Pitch ratio $(P/D)_{0.75R}$ [-]	0.992
Number of blades Z	5	Chord length $c_{0.75R}$ [m]	1.684
Rotation direction	Right	Maximum thickness $t_{0.75R}$ [m]	0.097
Diameter D [m]	5.850	Blade roughness k_P [μm]	30

Rudder(s)		
Wetted surface S_R [m^2]	43.40	

Water properties			
Water density (resistance test) ρ_m [kg/m^3]	1000	Water temperature (resistance test) T [˚C]	17.7
Water density (self. prop. test) ρ_m [kg/m^3]	1000	Water temperature (self. prop. test) T [˚C]	16.6
Density of water (sea) ρ_s [kg/m^3]	1025	Water temperature (sea) T [˚C]	15.0

Figure: 28b

Project number	30157634	**Date**	2016-12-13
Ship model	M5030-01-A	**Loading condition**	Trim Aft
Test series	018	**Related resistance series**	005

Model test results					
Ship speed V_S [kn]	Resistance R_{Tm} [N]	Frict. corr. R_A [N]	Thrust T_m [N]	Torque Q_m [Ncm]	Rate of revs. n_m [1/s]
8.00	9.98	3.36	7.70	33.8	3.55
10.00	15.60	4.90	12.62	52.4	4.48
12.00	21.74	6.68	18.27	73.5	5.35
14.00	29.05	8.67	24.62	97.6	6.23
16.00	37.17	10.87	31.97	125.7	7.15
18.00	46.97	13.26	41.89	163.2	8.17
20.00	62.73	15.85	58.18	223.4	9.43

Model propulsor open water characteristics		
R_{NCm} = 645662		
Advance ratio J [-]	Thrust coeff. $10*K_{Tm}$ [-]	Torque coeff. $100*K_{Qm}$ [-]
0.203	4.174	5.681
0.282	3.766	5.214
0.361	3.354	4.748
0.441	2.950	4.288
0.520	2.558	3.835
0.599	2.179	3.386
0.678	1.808	2.933
0.757	1.437	2.465
0.836	1.051	1.966
0.915	0.631	1.417

Figure: 28c

Project number	30157634	**Date**	2016-12-13
Ship model	M5030-01-A	**Loading condition**	Trim Aft
Test series	018	**Related resistance series**	005

Ship model test results

Ship speed V_S [kn]	Model speed V_m [m/s]	Froude no. F_{nL} [-]	Res. coeff. total C_{Tm}*1000 [-]	Residual res. coeff. C_{Rm}*1000 [-]	Thrust ded. t_m [-]	Mean wake w_{Tm} [-]	Rel. rot. effic. η_{Rm} [-]	Prop. effic. η_{0m} [-]
8.00	0.834	0.107	4.071	-0.135	0.141	0.317	0.883	0.660
10.00	1.042	0.134	4.073	0.036	0.153	0.320	0.927	0.654
12.00	1.250	0.161	3.943	0.036	0.176	0.329	0.953	0.650
14.00	1.459	0.187	3.871	0.070	0.172	0.327	0.970	0.652
16.00	1.667	0.214	3.793	0.080	0.177	0.318	0.981	0.656
18.00	1.876	0.241	3.786	0.149	0.195	0.310	0.989	0.654
20.00	2.084	0.268	4.096	0.523	0.194	0.303	0.994	0.643

Standard prediction

Correction factor for rate of revs. C_N = 1.000					Correction factor for delivered power C_P = 1.000					
Ship speed V_S [kn]	Eff. power P_E [MW]	Deliv. power P_D [MW]	Shaft rate n_S [1/s]	Thrust T_S [kN]	Torque Q_S [kNm]	Tot. eff. η_D [-]	Prop. eff. η_0 [-]	Hull eff. η_H [-]	Mean wake w_{TS} [-]	Advance ratio J_{TS} [-]
8.00	0.378	0.531	0.733	107	115	0.713	0.696	1.160	0.260	0.710
10.00	0.772	1.046	0.924	177	180	0.738	0.688	1.158	0.268	0.696
12.00	1.311	1.751	1.101	258	253	0.749	0.683	1.151	0.284	0.687
14.00	2.079	2.720	1.284	349	337	0.764	0.684	1.153	0.282	0.689
16.00	3.077	4.013	1.469	454	435	0.767	0.685	1.141	0.279	0.691
18.00	4.453	5.914	1.667	598	565	0.753	0.680	1.120	0.282	0.682
20.00	6.928	9.380	1.921	836	777	0.739	0.667	1.114	0.277	0.662

Ship propulsor open water characteristics

Advance ratio J [-]	Thrust coeff. 10*K_{TS} [-]	Torque coeff. 100*K_{QS} [-]
0.203	4.180	5.637
0.282	3.771	5.170
0.361	3.360	4.704
0.441	2.955	4.244
0.520	2.563	3.791
0.599	2.184	3.342
0.678	1.814	2.889
0.757	1.442	2.421
0.836	1.056	1.922
0.915	0.636	1.373

Figure: 28d

Project number	30157634	**Date**	2016-12-13
Ship model	M5030-01-A	**Loading condition**	Trim Aft
Test series	018	**Related resistance series**	005

SSPA ship trial prediction				
Correction factor for rate of revs. C_N = 1.013				
Correction factor for delivered power C_P = 1.020				
Ship speed V_S	Delivered power P_{DT}		Rate of revs. n_T	
[kn]	[MW]	[ps]	[1/s]	[1/min]
8.00	0.541	736	0.742	44.5
10.00	1.067	1450	0.936	56.2
12.00	1.786	2428	1.115	66.9
14.00	2.774	3772	1.300	78.0
16.00	4.093	5565	1.488	89.3
18.00	6.032	8201	1.688	101.3
20.00	9.567	13008	1.946	116.8

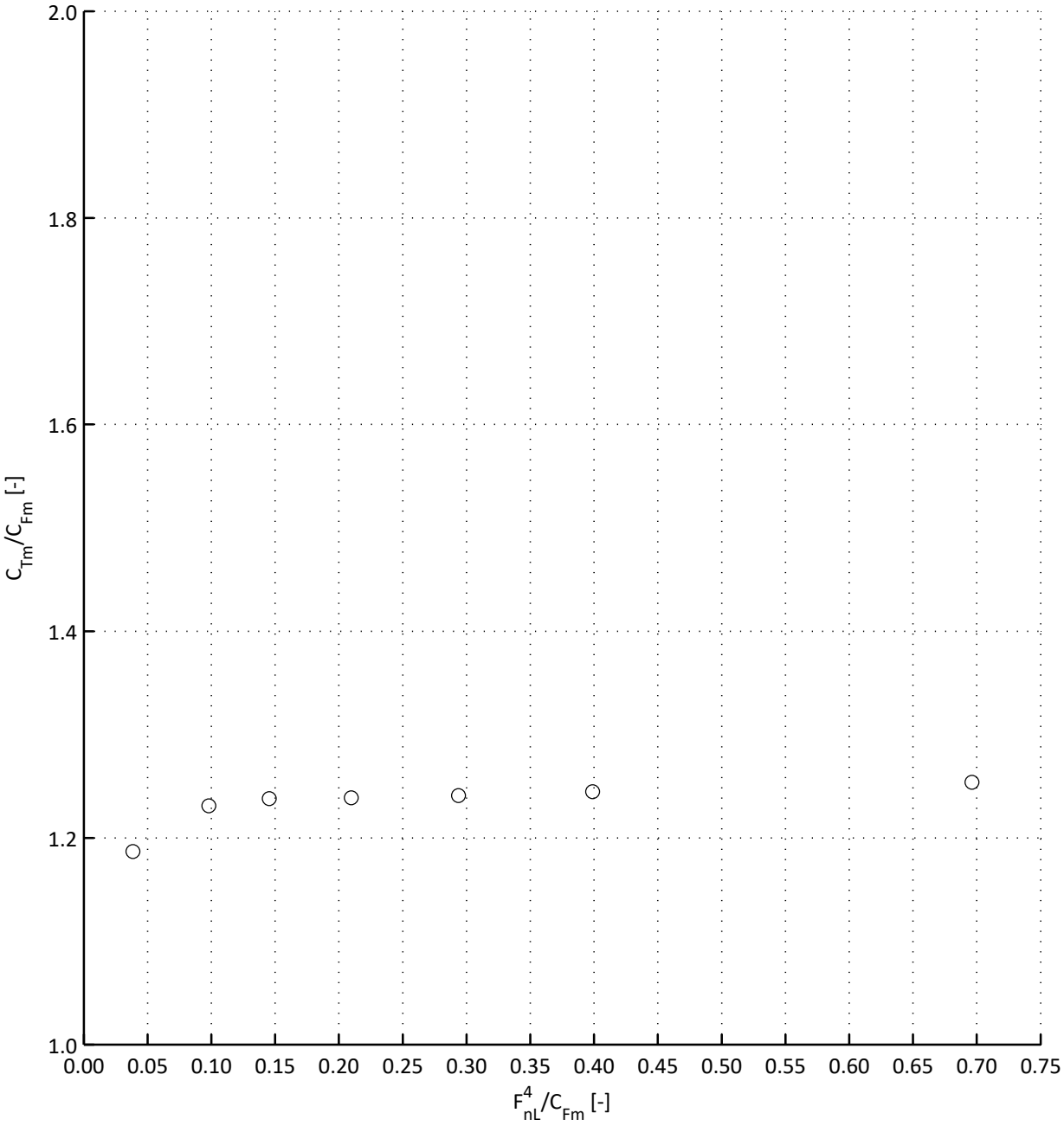
Draught changes				
Distance from origin to FP: 154.00 m				
Distance from origin to AP: 0.00 m				
Distance from origin to fwd draught: 154.00 m				
Distance from origin to aft draught: 7.70 m				
Ship speed V_s [kn]	Forward change T_F [m]	Aft change T_A [m]	Trim angle [deg]	CG elevation [m]
8.00	0.02	0.09	0.03	-0.05
10.00	0.04	0.11	0.03	-0.08
12.00	0.09	0.15	0.02	-0.12
14.00	0.15	0.20	0.02	-0.18
16.00	0.23	0.23	0.00	-0.23
18.00	0.34	0.27	-0.03	-0.30
20.00	0.48	0.34	-0.05	-0.40

NSMV

Resistance prediction, ITTC 78 method

Prohaska plot

Figure: 29



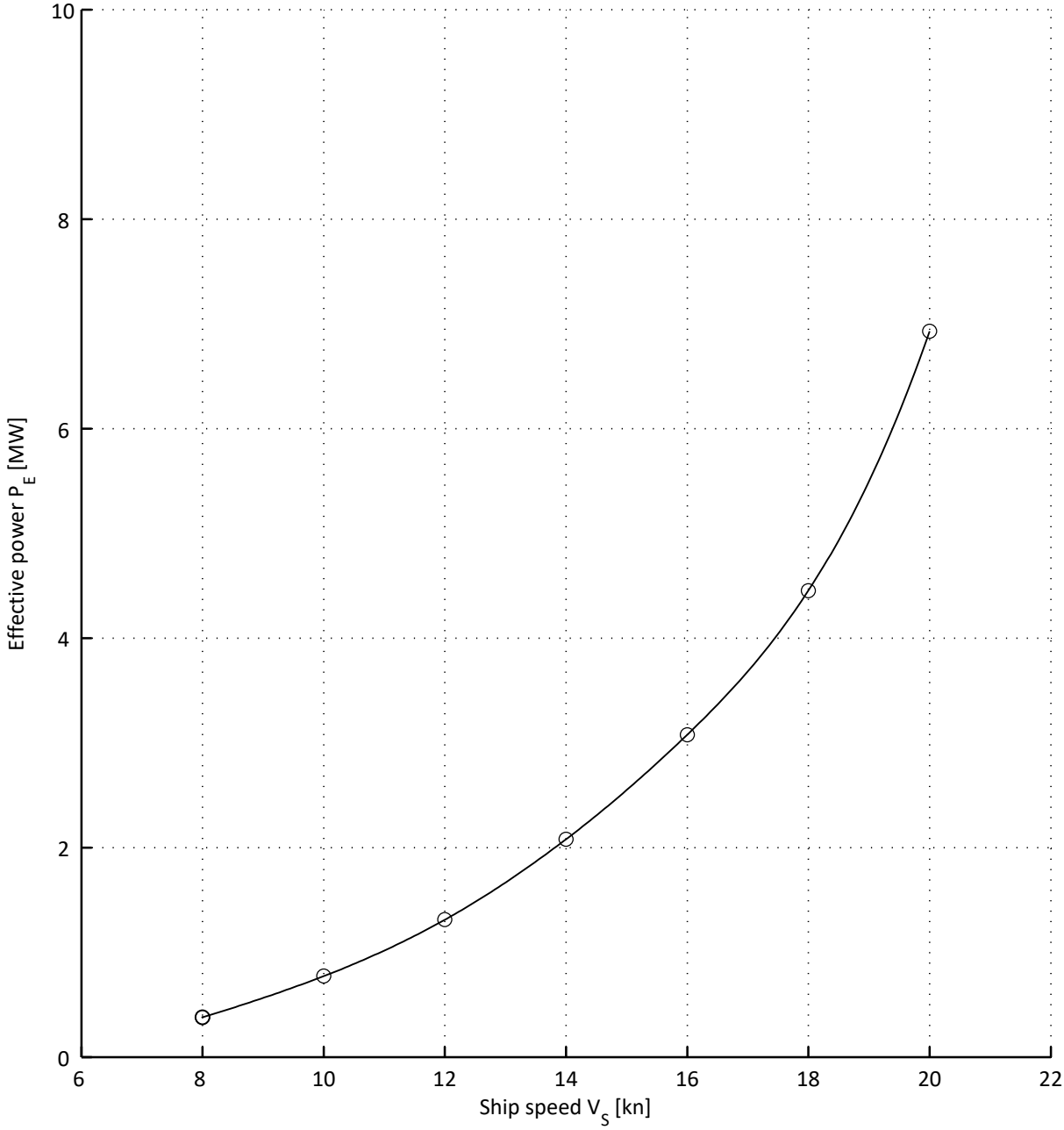
Test series	005	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	5.70	m
Loading condition	Trim Aft	Draught aft AP T_A	6.50	m
Scale factor α	24.375	Form factor k	0.225	
Displacement ∇	15325 m^3			

NSMV

Power prediction, ITTC 78 method

Effective power

Figure: 30

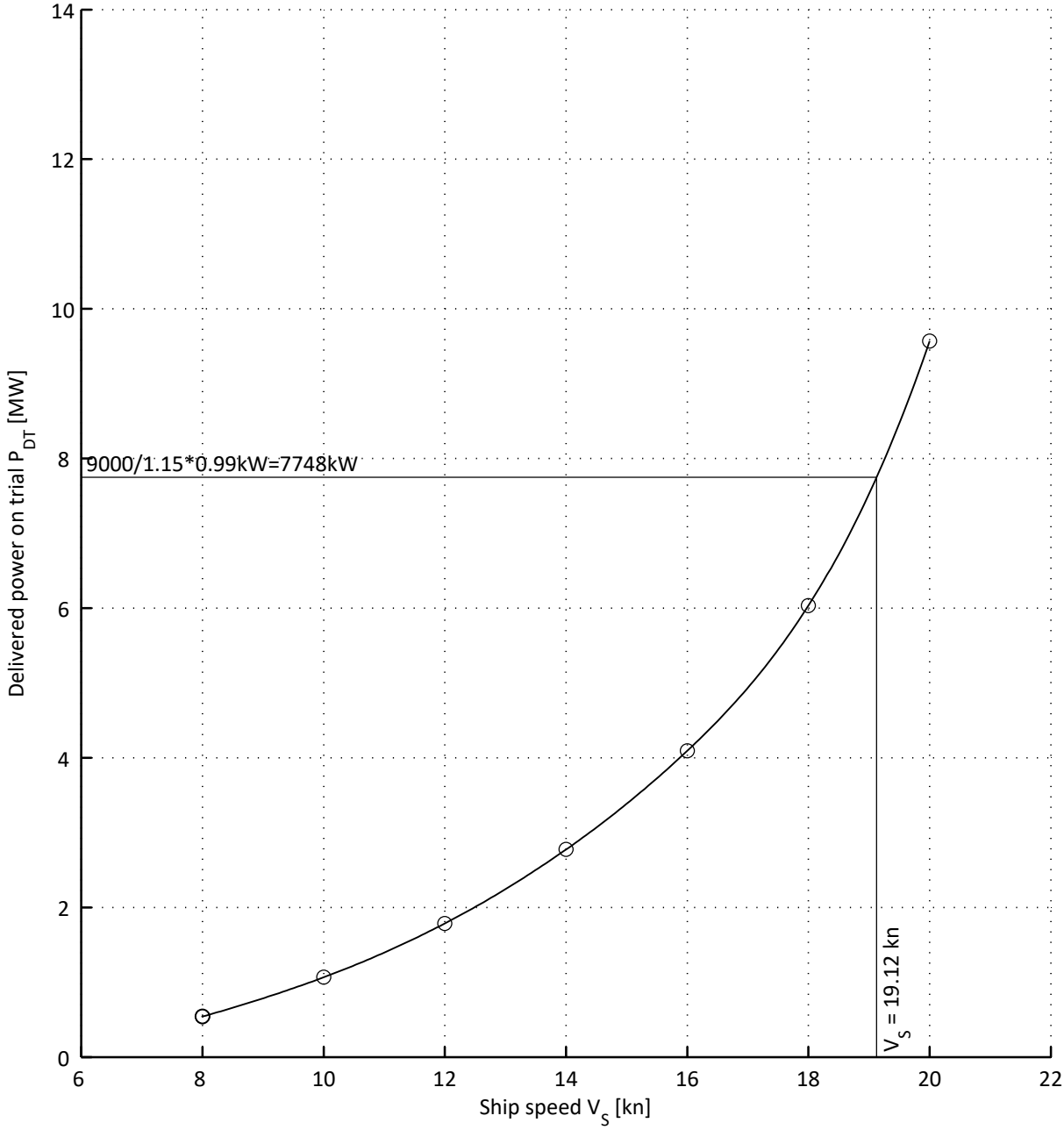


Test series	018	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	5.70	m
Loading condition	Trim Aft	Draught aft AP T_A	6.50	m
Propeller model	P5033-01-A	Form factor k	0.225	
Scale factor α	24.375			
Displacement ∇	15325 m^3			

Power prediction, ITTC 78 method

Delivered power on trial

Figure: 31

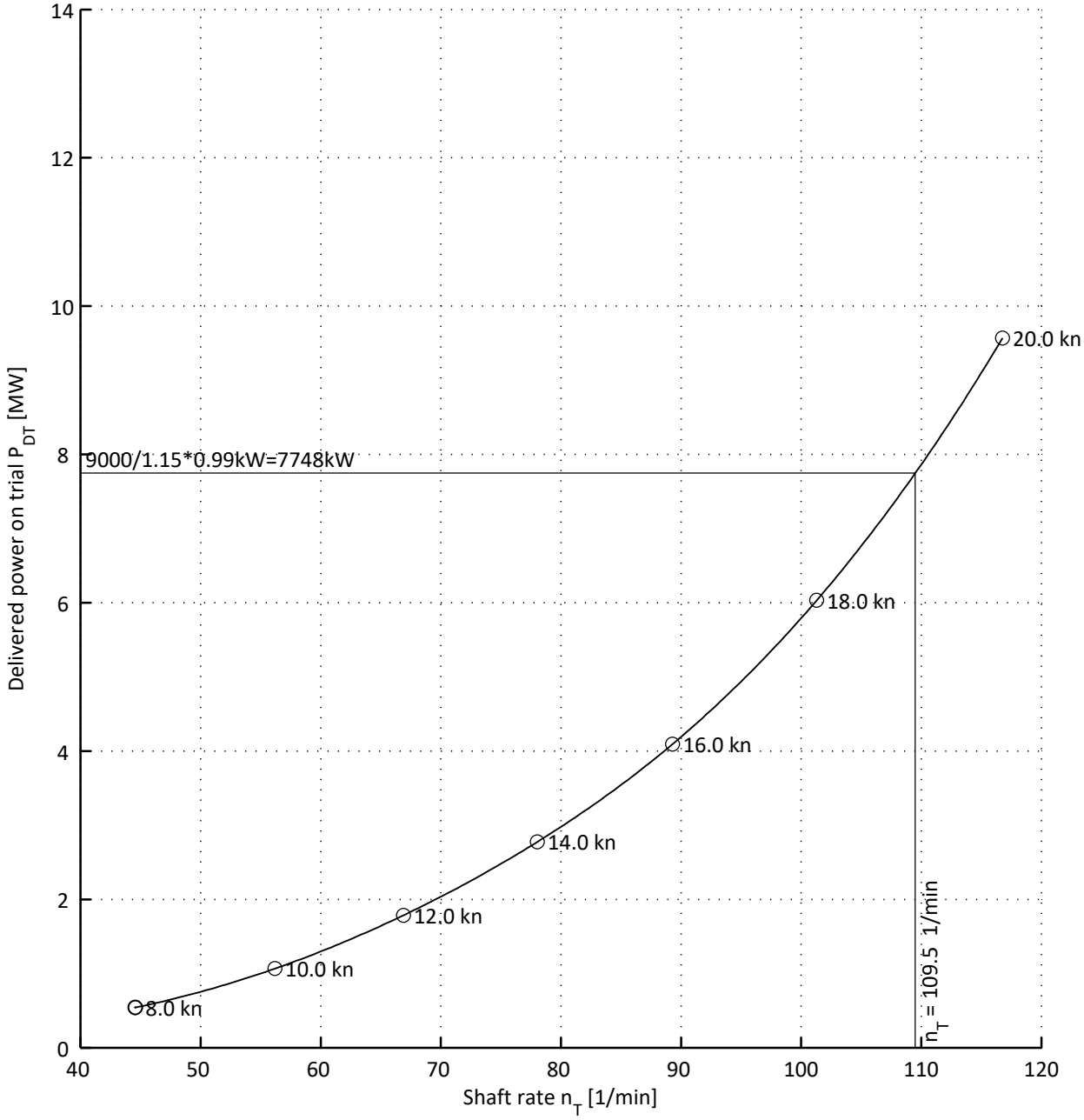


Test series	018	Length L_{PP}	154.00 m
Ship model	M5030-01-A	Draught fore FP T_F	5.70 m
Loading condition	Trim Aft	Draught aft AP T_A	6.50 m
Propeller model	P5033-01-A	Form factor k	0.225
Scale factor α	24.375		
Displacement ∇	15325 m^3		

Power prediction, ITTC 78 method

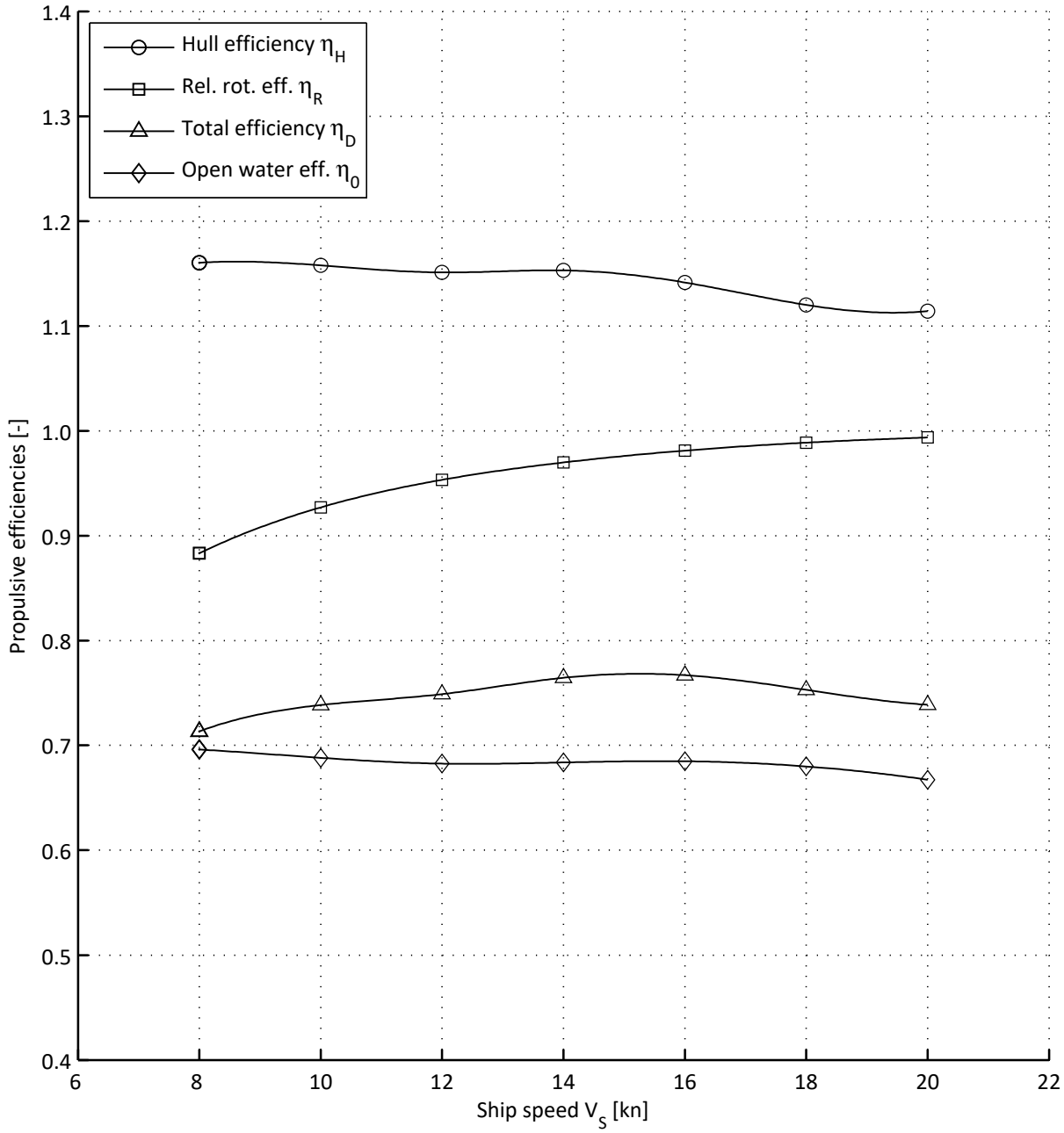
Delivered power on trial

Figure: 32



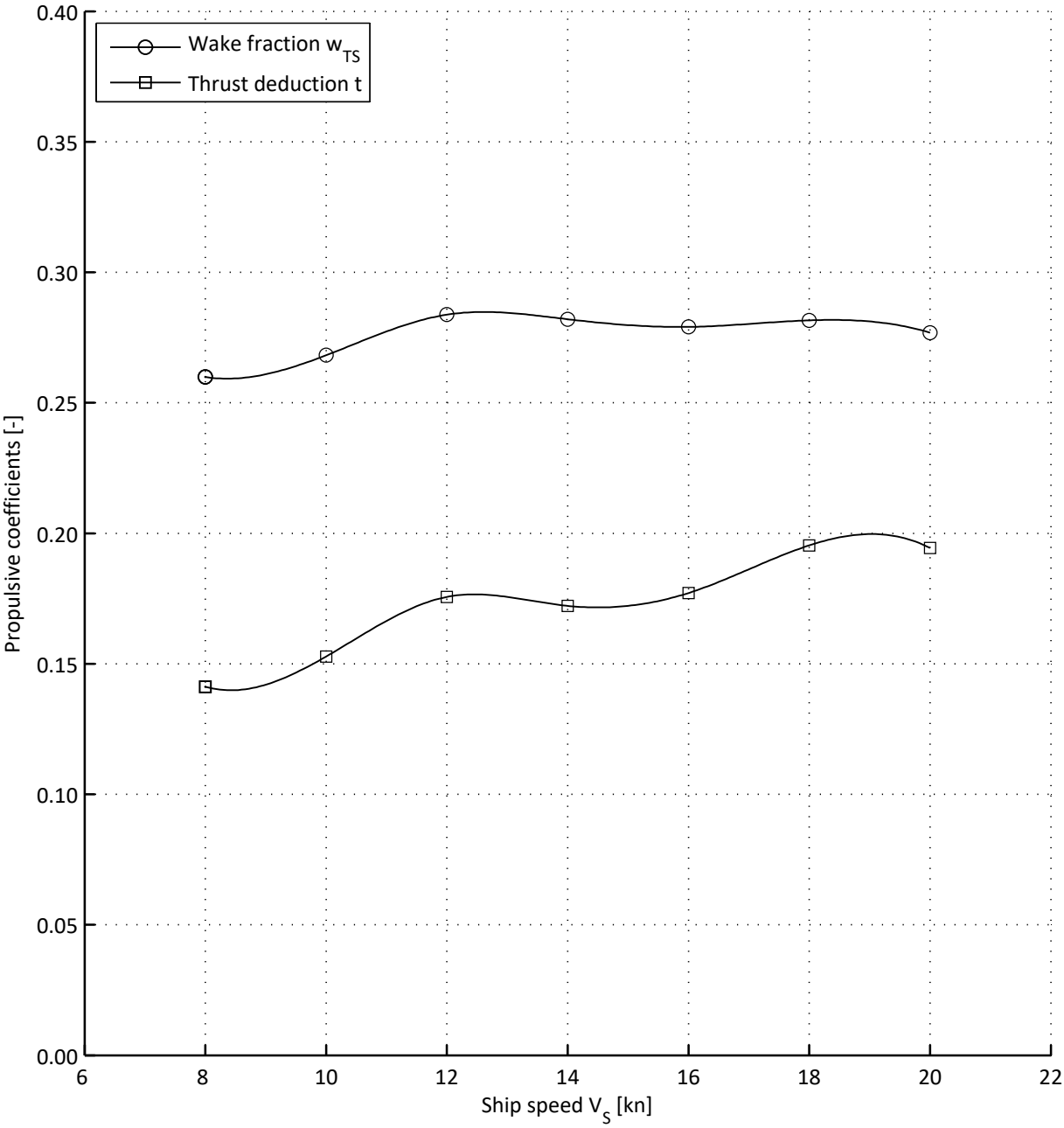
Test series	018	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	5.70	m
Loading condition	Trim Aft	Draught aft AP T_A	6.50	m
Propeller model	P5033-01-A	Form factor k	0.225	
Scale factor α	24.375			
Displacement ∇	15325 m^3			

Figure: 33



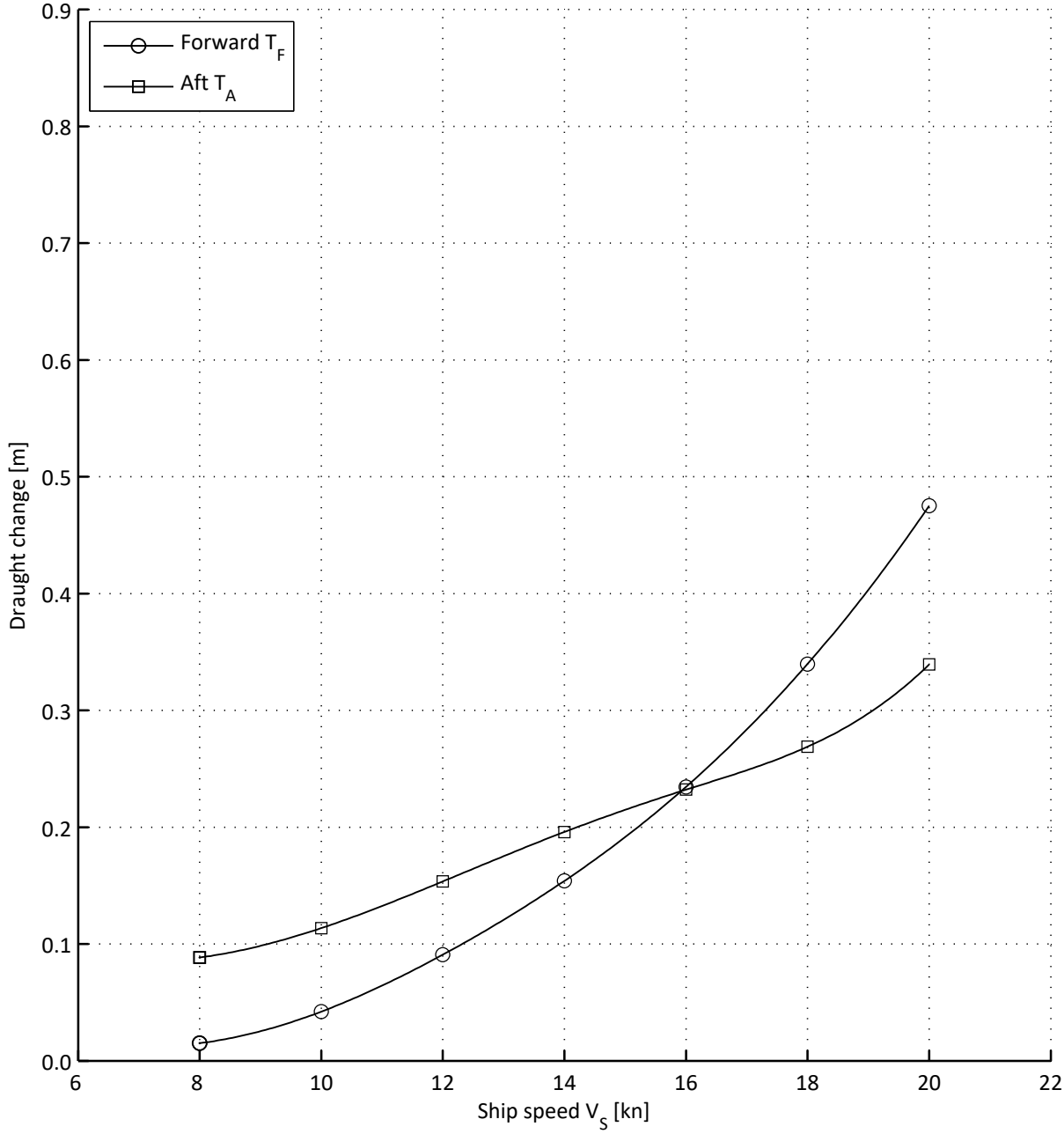
Test series	018	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	5.70	m
Loading condition	Trim Aft	Draught aft AP T_A	6.50	m
Propeller model	P5033-01-A	Form factor k	0.225	
Scale factor α	24.375			
Displacement ∇	15325 m^3			

Figure: 34



Test series	018	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	5.70	m
Loading condition	Trim Aft	Draught aft AP T_A	6.50	m
Propeller model	P5033-01-A	Form factor k	0.225	
Scale factor α	24.375			
Displacement ∇	15325 m^3			

Figure: 35



Test series	018	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	5.70	m
Loading condition	Trim Aft	Draught aft AP T_A	6.50	m
Propeller model	P5033-01-A	Form factor k	0.225	
Scale factor α	24.375			
Displacement ∇	15325 m^3			

Figure: 36a

Project number	30157634	**Date**	2016-12-13
Ship model	M5030-01-A	**Loading condition**	Light
Test series	020	**Related resistance series**	007

Ship particulars - M5030-01-A - Light			
Scale factor α [-]	24.375	Wetted surface S_{Hull} [m^2]	4083
Length L_{PP} [m]	154.00	Bilge keel area S_{BK} [m^2]	68.4
Length L_{WL} [m]	150.02	Proj. area above water line A_T [m^2]	753.0
Draught forward T_F [m]	6.000	Displacement ∇ [m^3]	14965
Draught aft T_A [m]	6.000	Hull surface roughness k_s [µm]	150
Beam B [m]	27.00	LCB position rel. to $L_{PP}/2$ [% of L_{PP}]	0.067
Assumed form factor k [-]	0.195		

Propeller - P5033-01-A			
Number of propellers	1	Pitch ratio $(P/D)_{0.75R}$ [-]	0.992
Number of blades Z	5	Chord length $c_{0.75R}$ [m]	1.684
Rotation direction	Right	Maximum thickness $t_{0.75R}$ [m]	0.097
Diameter D [m]	5.850	Blade roughness k_P [µm]	30

Rudder(s)		
Wetted surface S_R [m^2]	38.90	

Water properties			
Water density (resistance test) ρ_m [kg/m^3]	1000	Water temperature (resistance test) T [˚C]	17.7
Water density (self. prop. test) ρ_m [kg/m^3]	1000	Water temperature (self. prop. test) T [˚C]	16.6
Density of water (sea) ρ_s [kg/m^3]	1025	Water temperature (sea) T [˚C]	15.0

Figure: 36b

Project number	30157634	**Date**	2016-12-13
Ship model	M5030-01-A	**Loading condition**	Light
Test series	020	**Related resistance series**	007

Model test results

Ship speed V_S [kn]	Resistance R_{Tm} [N]	Frict. corr. R_A [N]	Thrust T_m [N]	Torque Q_m [Ncm]	Rate of revs. n_m [1/s]
8.00	9.70	3.31	7.70	33.7	3.54
10.00	14.97	4.83	12.30	50.8	4.41
12.00	20.93	6.58	17.30	70.2	5.28
14.00	28.09	8.54	23.68	94.3	6.15
16.00	36.47	10.70	31.51	123.3	7.05
18.00	46.98	13.06	41.92	161.9	8.05
20.00	62.82	15.61	59.00	224.5	9.36

Model propulsor open water characteristics

R_{NCm} = 645662

Advance ratio J [-]	Thrust coeff. $10*K_{Tm}$ [-]	Torque coeff. $100*K_{Qm}$ [-]
0.203	4.174	5.681
0.282	3.766	5.214
0.361	3.354	4.748
0.441	2.950	4.288
0.520	2.558	3.835
0.599	2.179	3.386
0.678	1.808	2.933
0.757	1.437	2.465
0.836	1.051	1.966
0.915	0.631	1.417

Figure: 36c

Project number	30157634	**Date**	2016-12-13
Ship model	M5030-01-A	**Loading condition**	Light
Test series	020	**Related resistance series**	007

Ship model test results

Ship speed V_S [kn]	Model speed V_m [m/s]	Froude no. F_{nL} [-]	Res. coeff. total C_{Tm}*1000 [-]	Residual res. coeff. C_{Rm}*1000 [-]	Thrust ded. t_m [-]	Mean wake w_{Tm} [-]	Rel. rot. effic. η_{Rm} [-]	Prop. effic. η_{0m} [-]
8.00	0.834	0.107	4.023	-0.083	0.171	0.320	0.885	0.659
10.00	1.042	0.134	3.975	0.034	0.175	0.333	0.930	0.653
12.00	1.250	0.161	3.860	0.046	0.170	0.327	0.951	0.657
14.00	1.459	0.188	3.805	0.095	0.174	0.331	0.968	0.655
16.00	1.667	0.215	3.782	0.158	0.182	0.335	0.982	0.652
18.00	1.876	0.241	3.850	0.299	0.191	0.333	0.991	0.647
20.00	2.084	0.268	4.170	0.683	0.200	0.320	0.996	0.635

Standard prediction

Correction factor for rate of revs. C_N = 1.000					Correction factor for delivered power C_P = 1.000					
Ship speed V_S [kn]	Eff. power P_E [MW]	Deliv. power P_D [MW]	Shaft rate n_S [1/s]	Thrust T_S [kN]	Torque Q_S [kNm]	Tot. eff. η_D [-]	Prop. eff. η_0 [-]	Hull eff. η_H [-]	Mean wake w_{TS} [-]	Advance ratio J_{TS} [-]
8.00	0.373	0.535	0.730	109	117	0.698	0.690	1.143	0.274	0.700
10.00	0.747	1.018	0.913	176	177	0.734	0.684	1.153	0.285	0.689
12.00	1.274	1.690	1.093	249	246	0.754	0.687	1.154	0.281	0.695
14.00	2.033	2.653	1.274	342	331	0.766	0.685	1.156	0.286	0.690
16.00	3.072	3.983	1.458	456	435	0.771	0.681	1.154	0.292	0.683
18.00	4.566	5.967	1.661	609	572	0.765	0.674	1.147	0.294	0.672
20.00	7.093	9.584	1.921	861	794	0.740	0.659	1.127	0.290	0.650

Ship propulsor open water characteristics

Advance ratio J [-]	Thrust coeff. 10*K_{TS} [-]	Torque coeff. 100*K_{QS} [-]
0.203	4.180	5.637
0.282	3.771	5.170
0.361	3.360	4.704
0.441	2.955	4.244
0.520	2.563	3.791
0.599	2.184	3.342
0.678	1.814	2.889
0.757	1.442	2.421
0.836	1.056	1.922
0.915	0.636	1.373

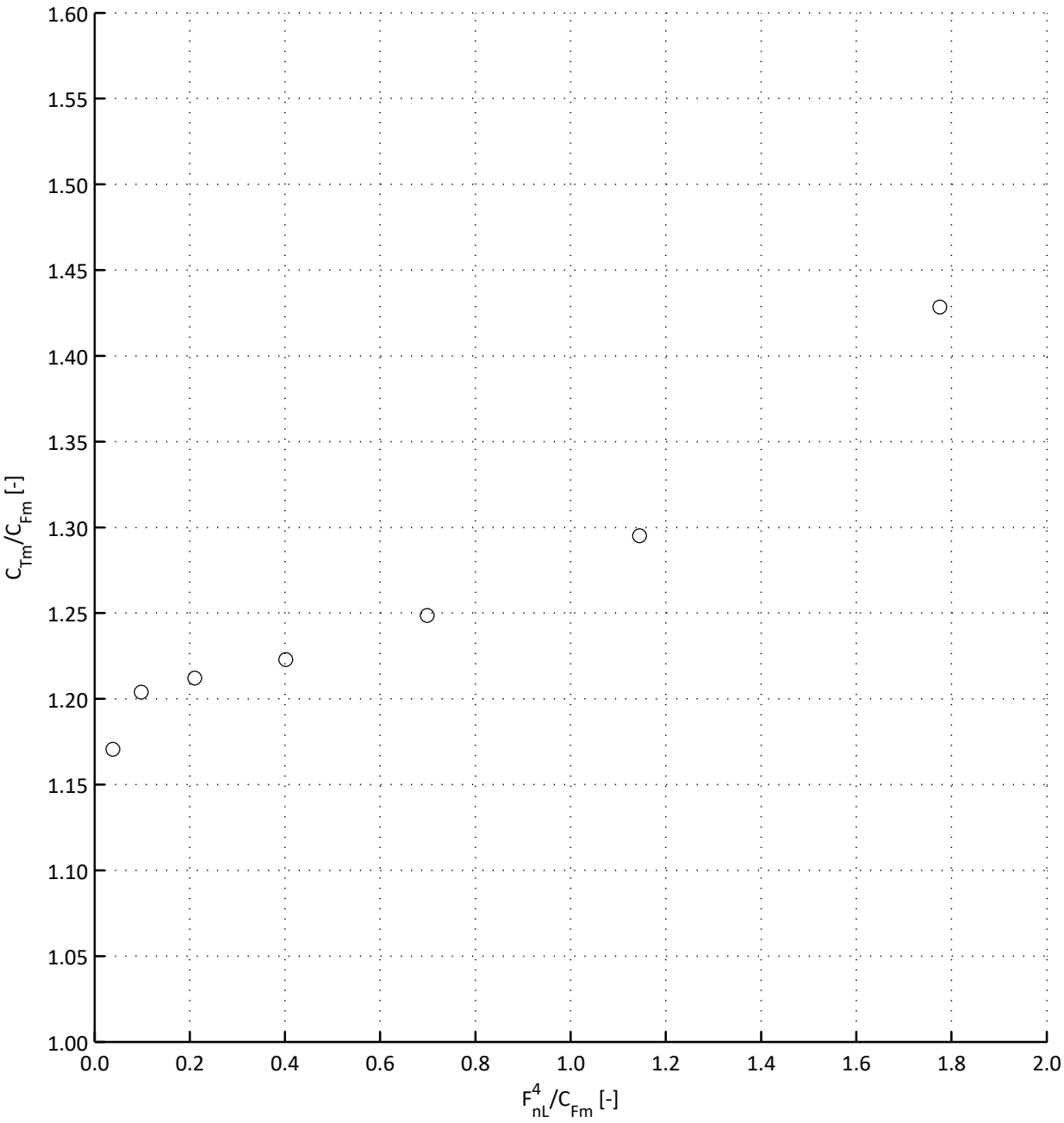
Figure: 36d

Project number	30157634	**Date**	2016-12-13
Ship model	M5030-01-A	**Loading condition**	Light
Test series	020	**Related resistance series**	007

SSPA ship trial prediction				
Correction factor for rate of revs. C_N = 1.013				
Correction factor for delivered power C_P = 1.020				
Ship speed V_S	Delivered power P_{DT}		Rate of revs. n_T	
[kn]	[MW]	[ps]	[1/s]	[1/min]
8.00	0.546	742	0.739	44.3
10.00	1.038	1411	0.924	55.5
12.00	1.723	2343	1.107	66.4
14.00	2.706	3679	1.291	77.4
16.00	4.063	5524	1.477	88.6
18.00	6.086	8274	1.683	101.0
20.00	9.776	13291	1.946	116.8

Draught changes				
Distance from origin to FP: 154.00 m				
Distance from origin to AP: 0.00 m				
Distance from origin to fwd draught: 154.00 m				
Distance from origin to aft draught: 7.70 m				
Ship speed V_s [kn]	Forward change T_F [m]	Aft change T_A [m]	Trim angle [deg]	CG elevation [m]
8.00	0.03	0.09	0.02	-0.06
10.00	0.06	0.11	0.02	-0.09
12.00	0.12	0.15	0.01	-0.13
14.00	0.17	0.19	0.01	-0.18
16.00	0.24	0.24	0.00	-0.24
18.00	0.35	0.30	-0.02	-0.33
20.00	0.47	0.38	-0.03	-0.42

Figure: 37



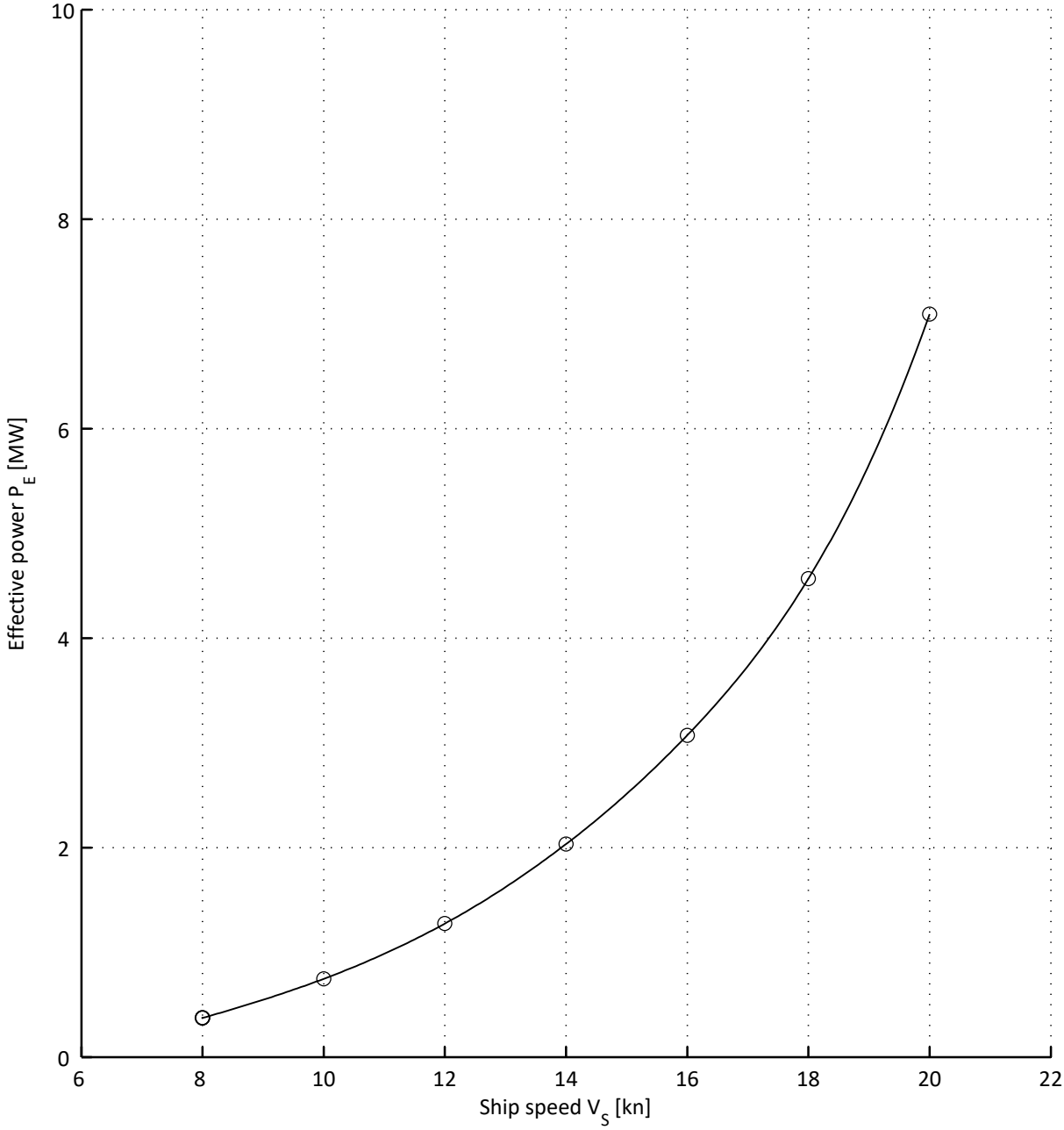
Test series	007	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	6.00	m
Loading condition	Light	Draught aft AP T_A	6.00	m
Scale factor α	24.375	Form factor k	0.195	
Displacement ∇	14965 m^3			

NSMV

Power prediction, ITTC 78 method

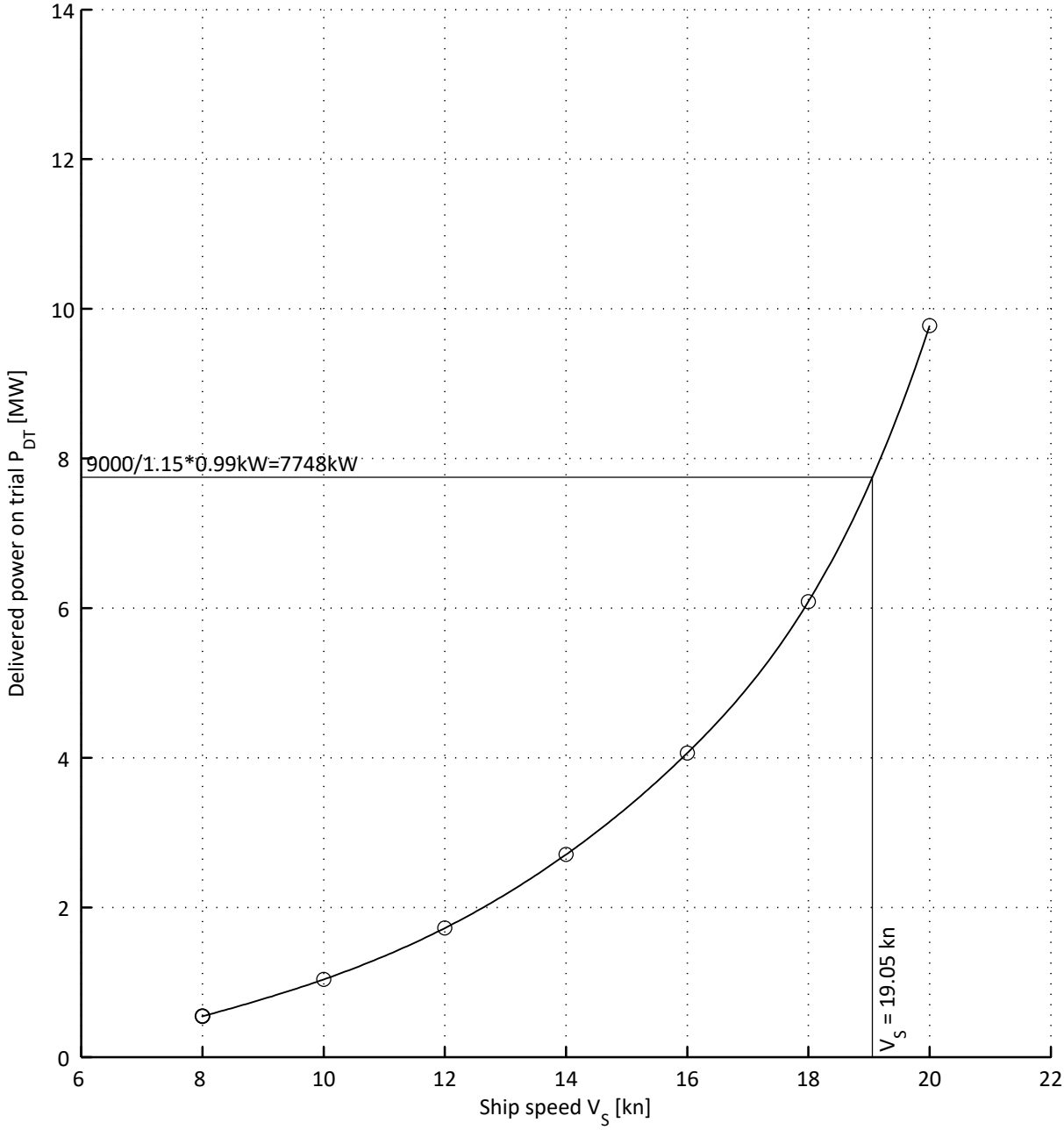
Effective power

Figure: 38



Test series	020	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	6.00	m
Loading condition	Light	Draught aft AP T_A	6.00	m
Propeller model	P5033-01-A	Form factor k	0.195	
Scale factor α	24.375			
Displacement ∇	14965 m^3			

Figure: 39



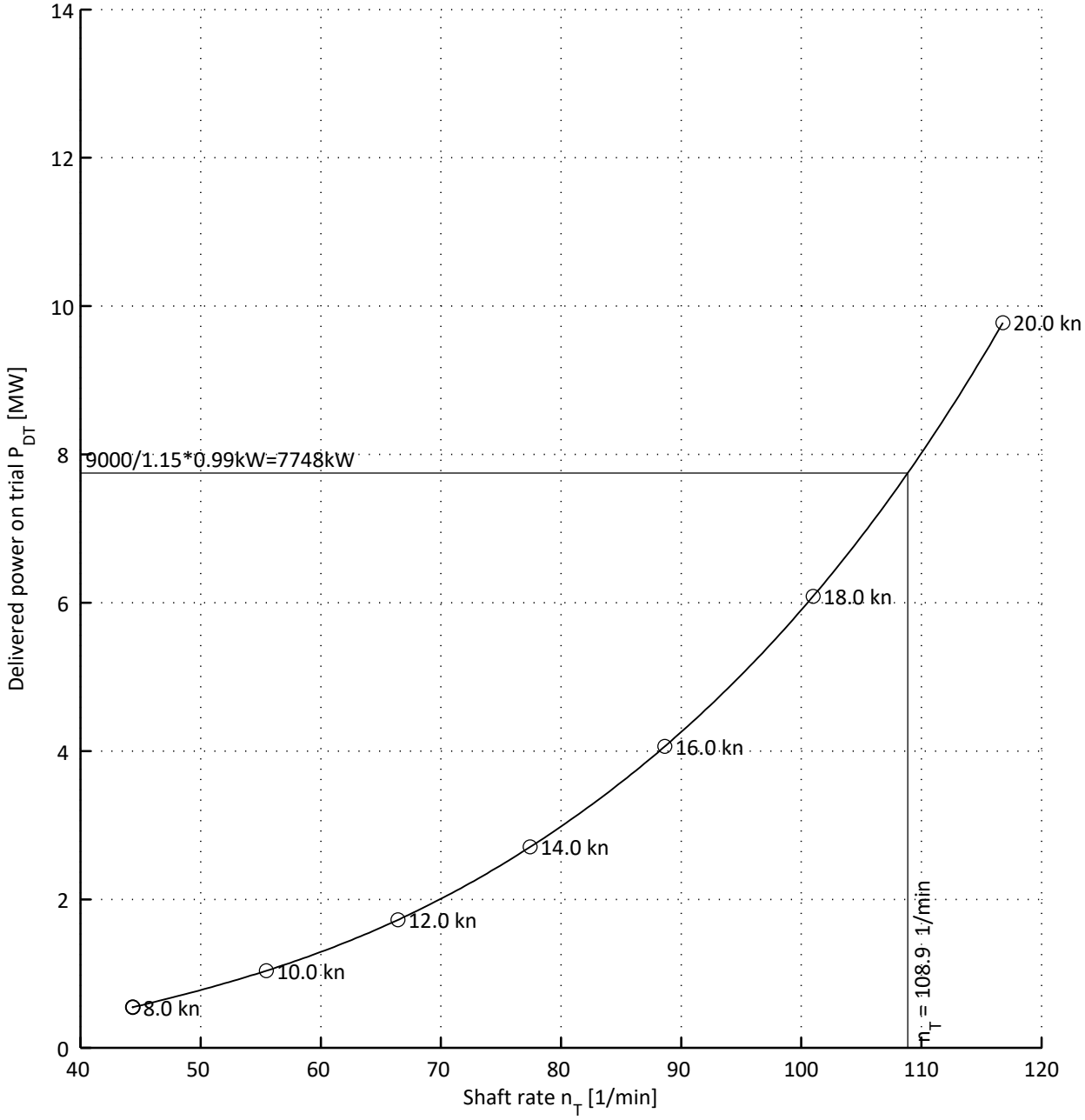
Test series	020	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	6.00	m
Loading condition	Light	Draught aft AP T_A	6.00	m
Propeller model	P5033-01-A	Form factor k	0.195	
Scale factor α	24.375			
Displacement ∇	14965 m^3			

NSMV

Power prediction, ITTC 78 method

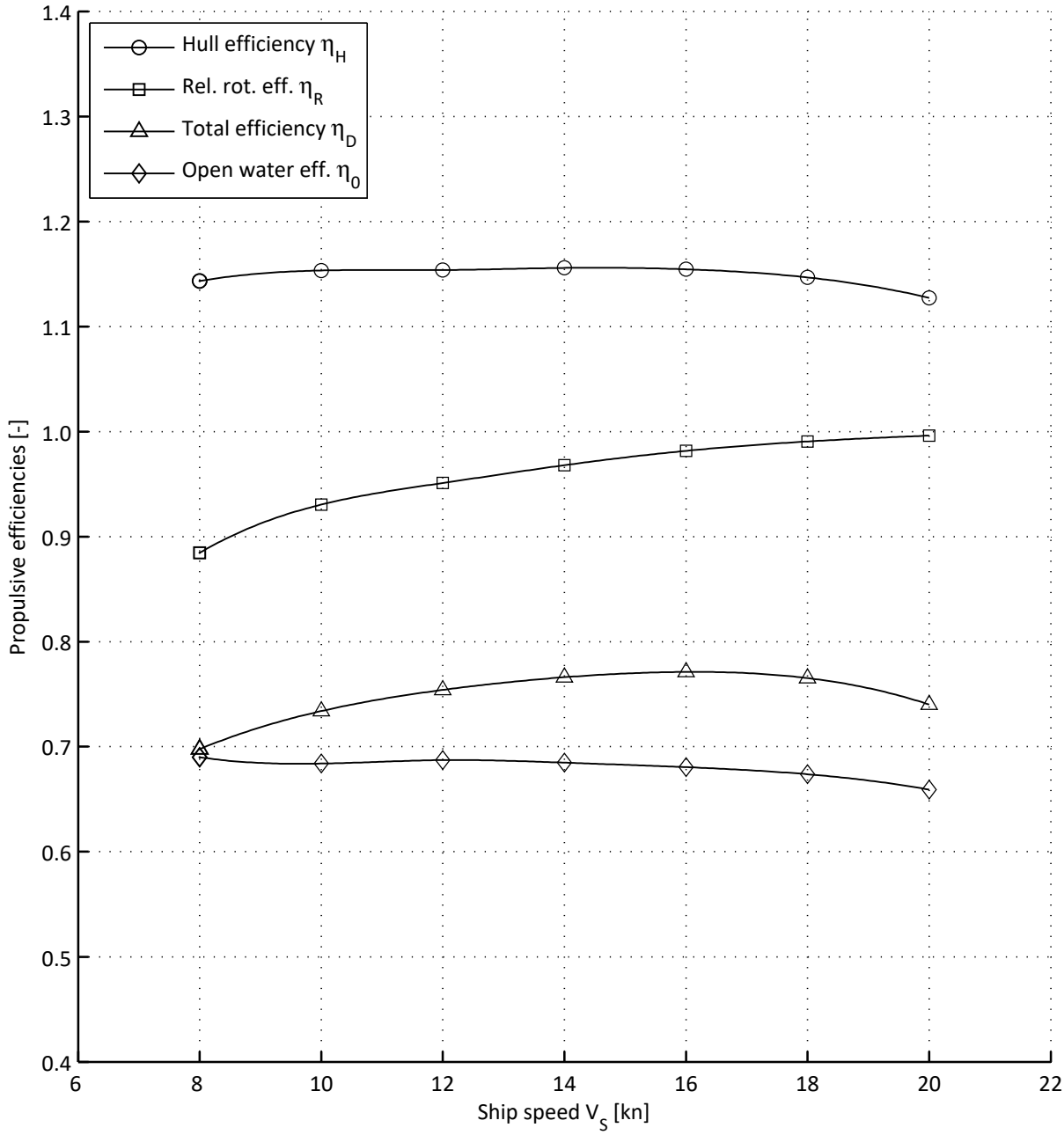
Delivered power on trial

Figure: 40



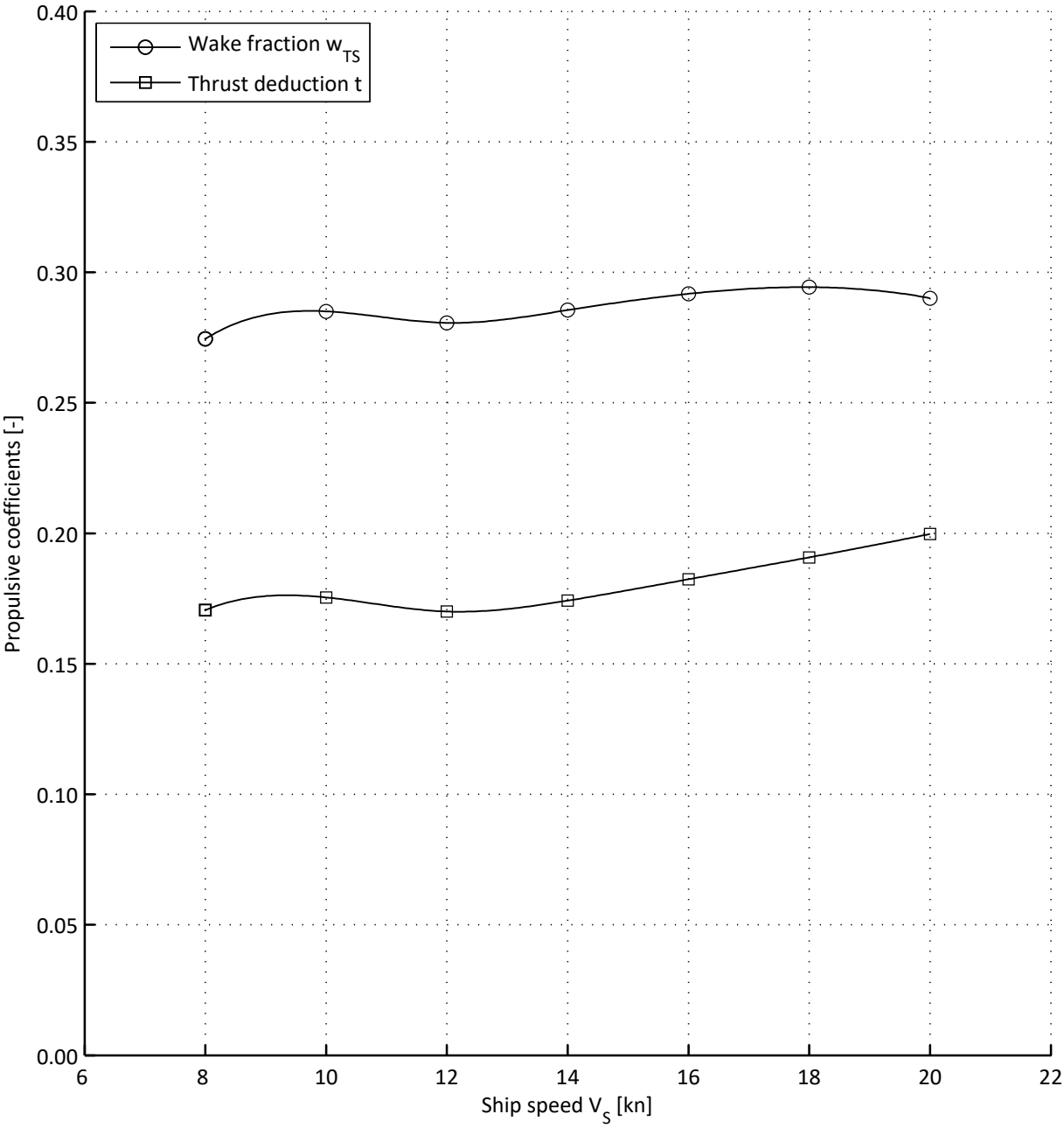
Test series	020	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	6.00	m
Loading condition	Light	Draught aft AP T_A	6.00	m
Propeller model	P5033-01-A	Form factor k	0.195	
Scale factor α	24.375			
Displacement ∇	14965 m^3			

Figure: 41



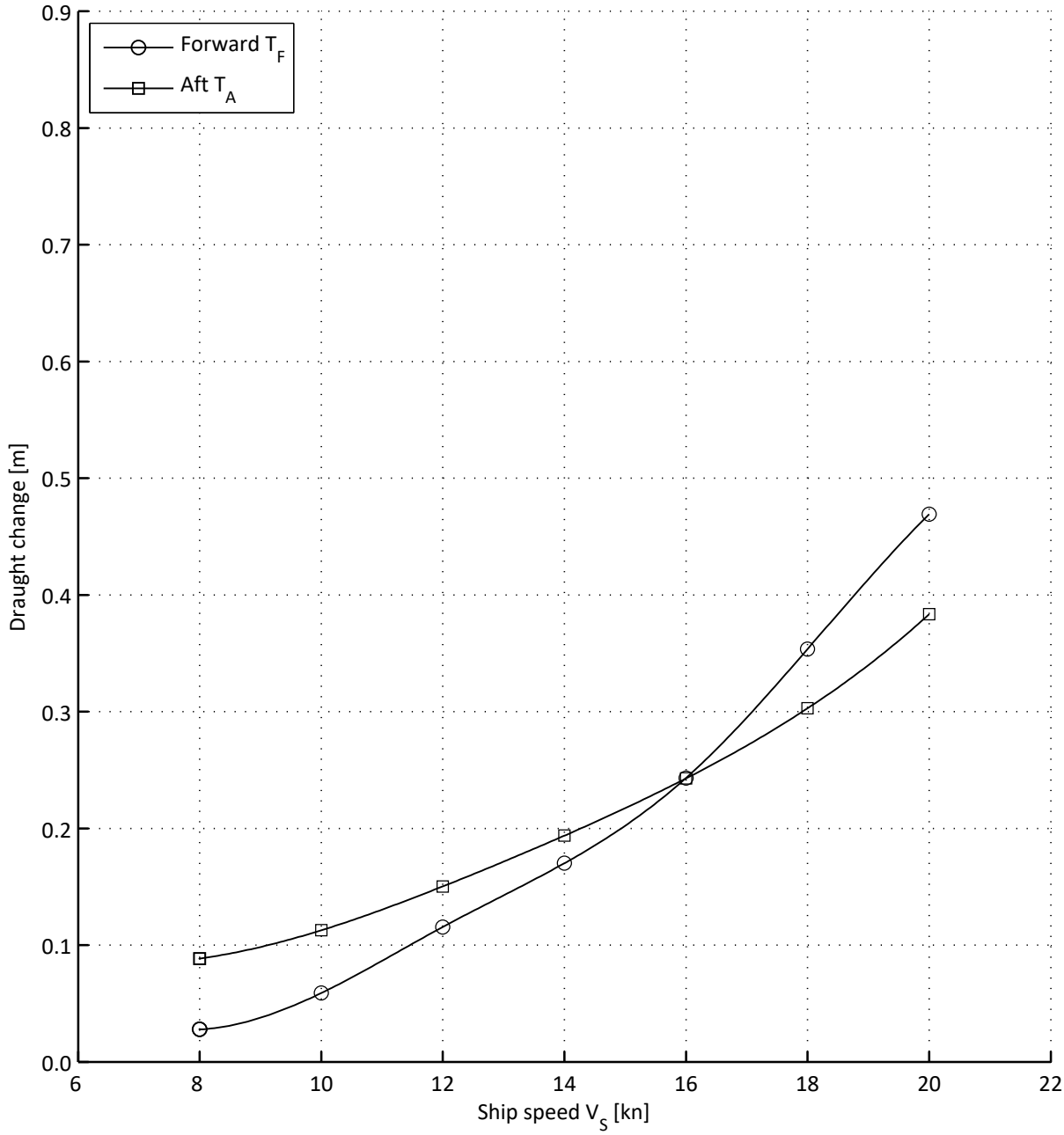
Test series	020	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	6.00	m
Loading condition	Light	Draught aft AP T_A	6.00	m
Propeller model	P5033-01-A	Form factor k	0.195	
Scale factor α	24.375			
Displacement ∇	14965 m^3			

Figure: 42

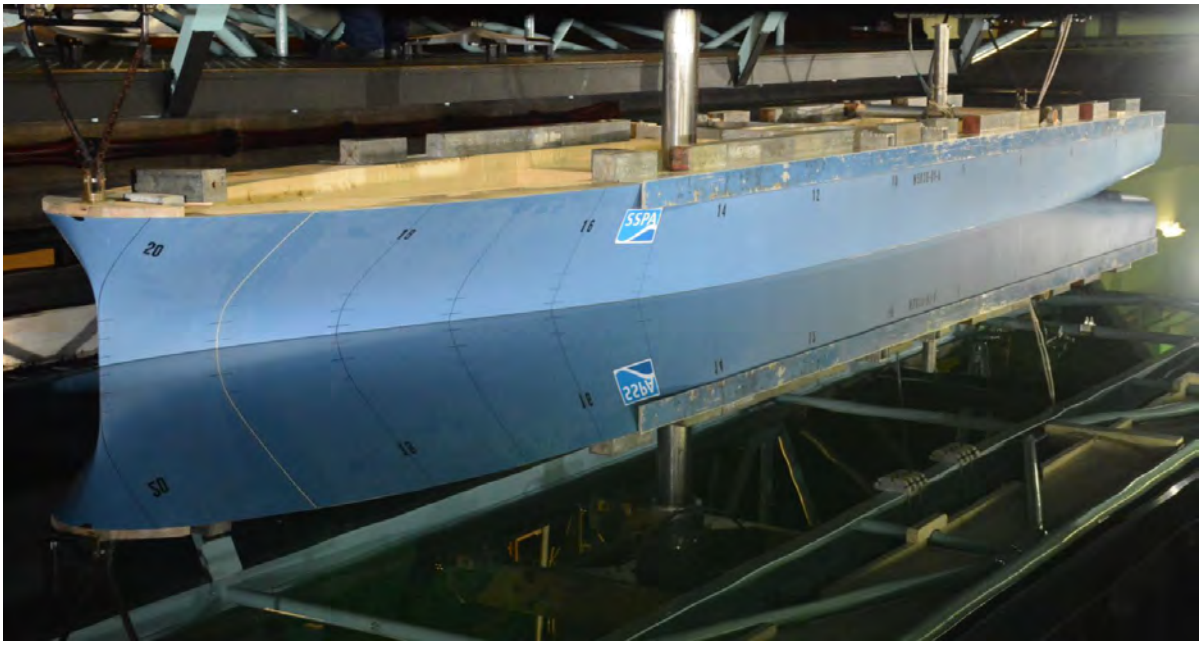


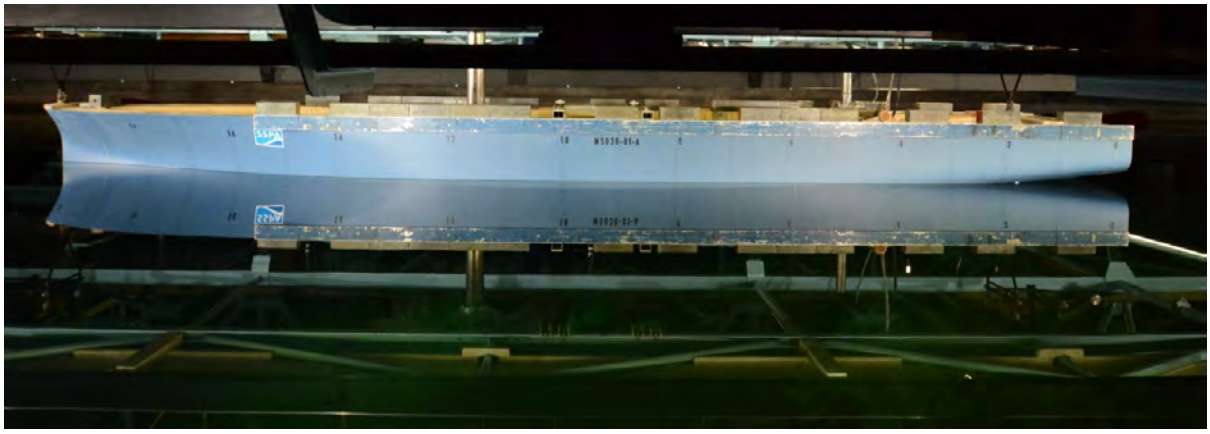
Test series	020	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	6.00	m
Loading condition	Light	Draught aft AP T_A	6.00	m
Propeller model	P5033-01-A	Form factor k	0.195	
Scale factor α	24.375			
Displacement ∇	14965 m^3			

Figure: 43

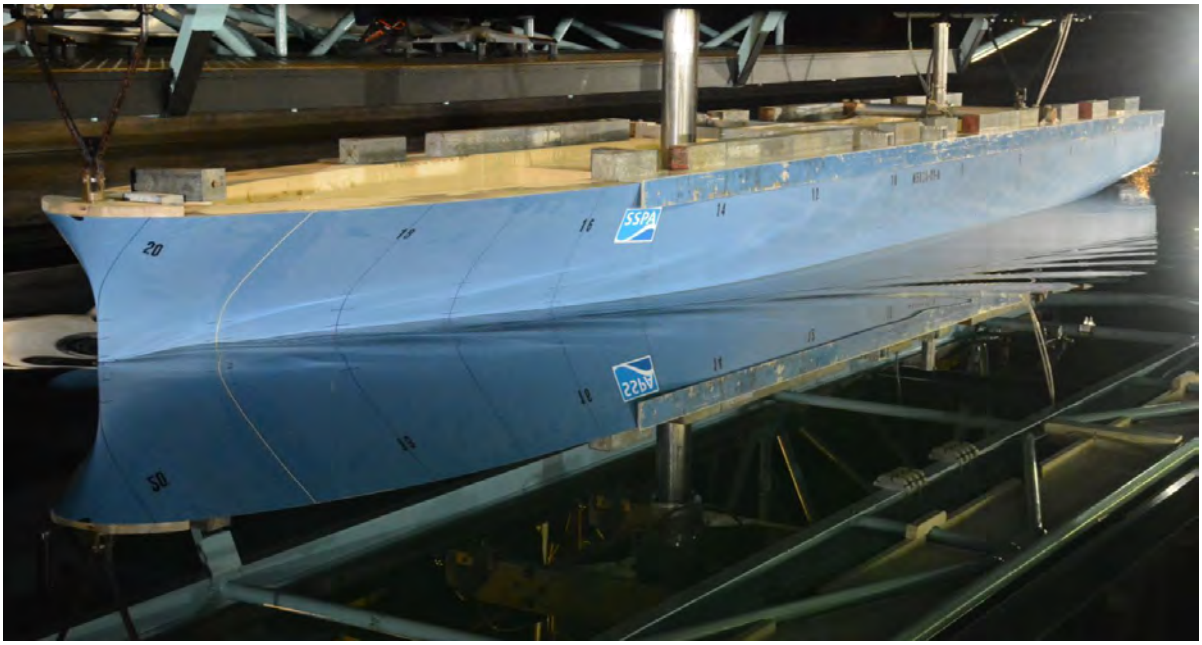


Test series	020	Length L_{PP}	154.00	m
Ship model	M5030-01-A	Draught fore FP T_F	6.00	m
Loading condition	Light	Draught aft AP T_A	6.00	m
Propeller model	P5033-01-A	Form factor k	0.195	
Scale factor α	24.375			
Displacement ∇	14965 m^3			






M5030-01-A
SSPA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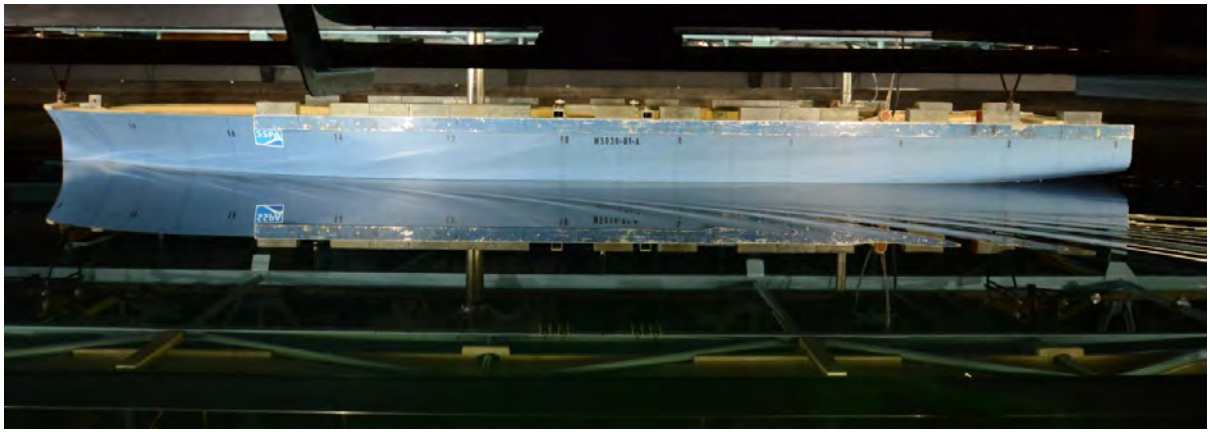


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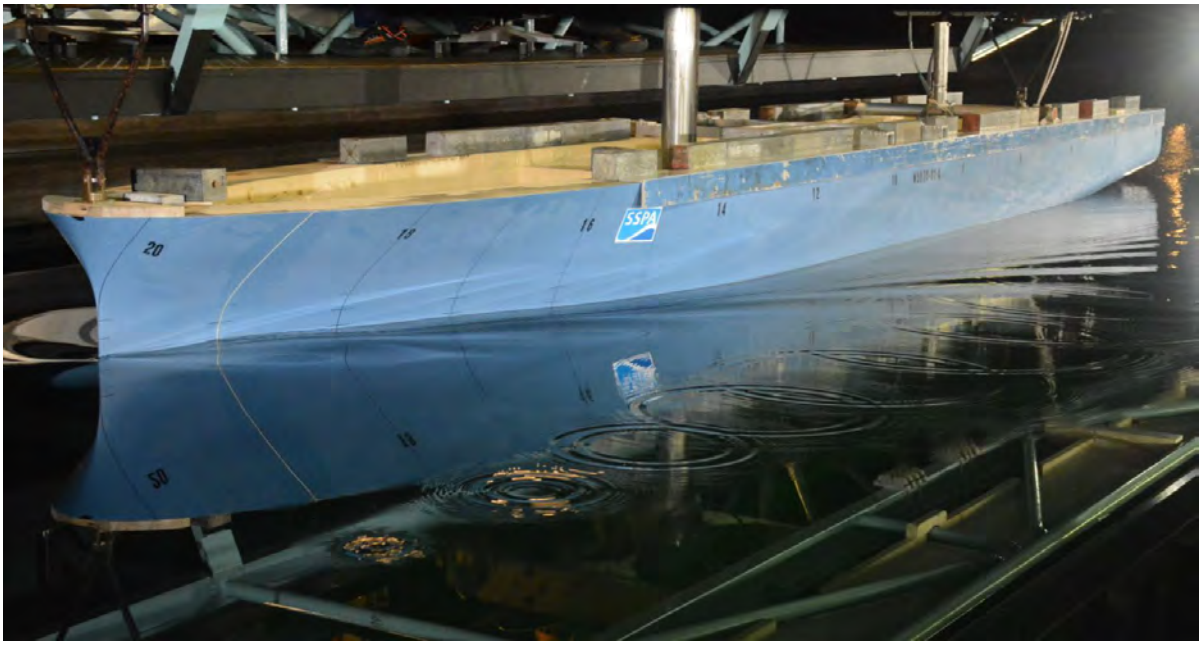
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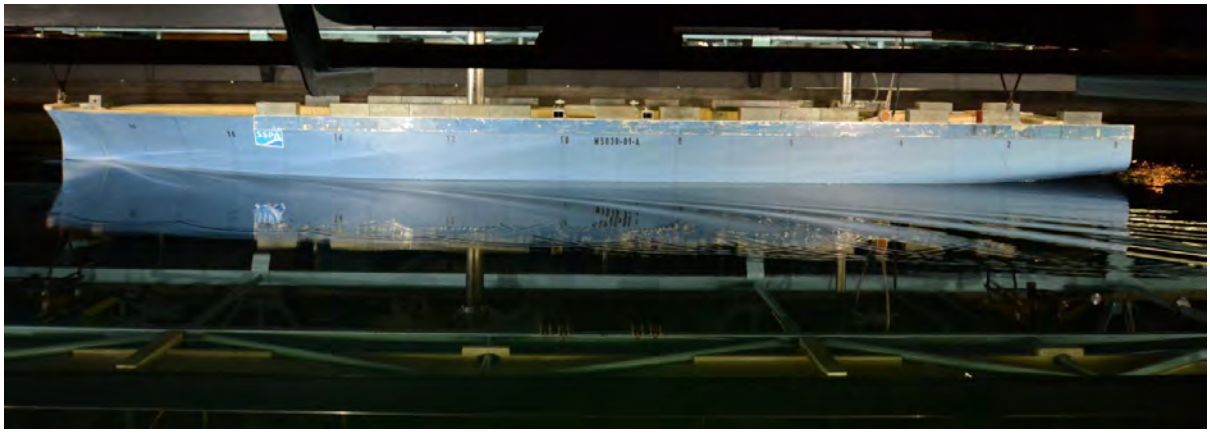


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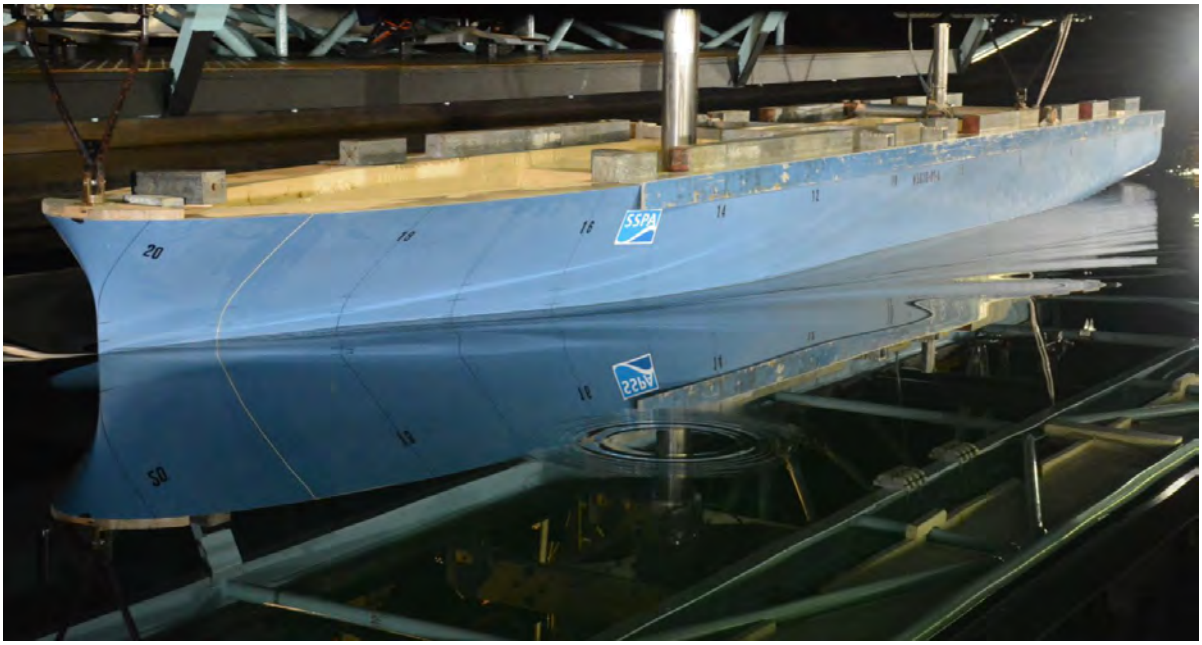

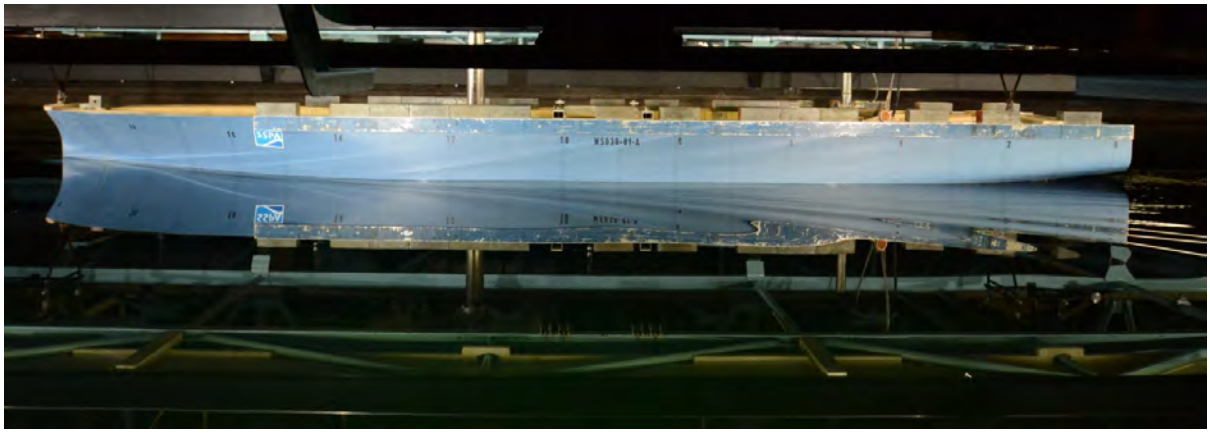


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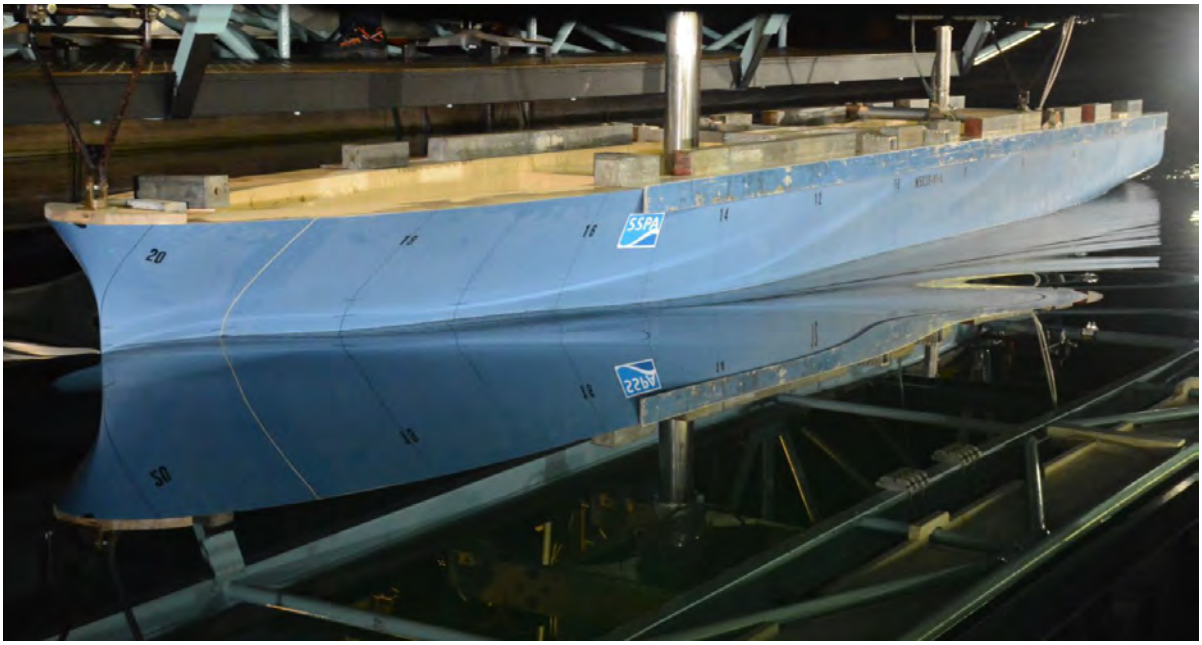
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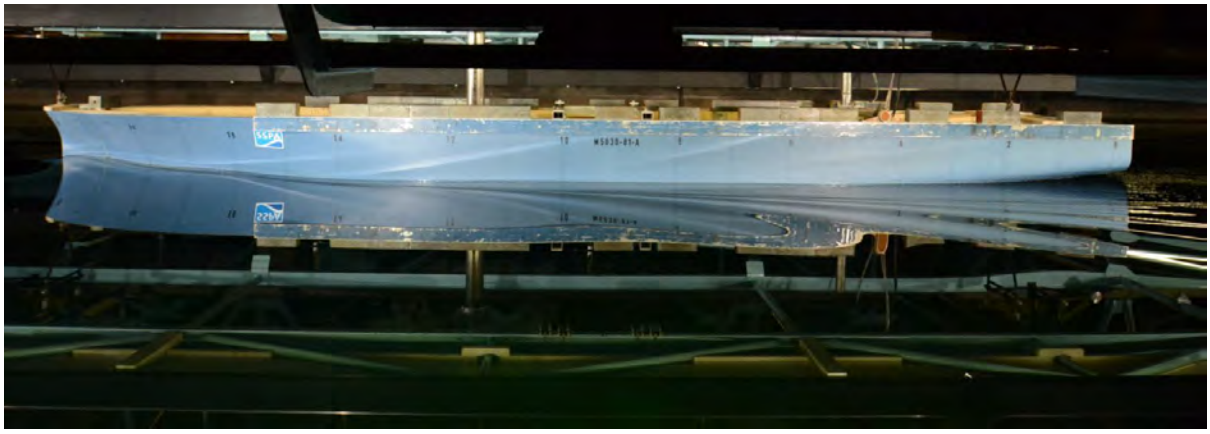


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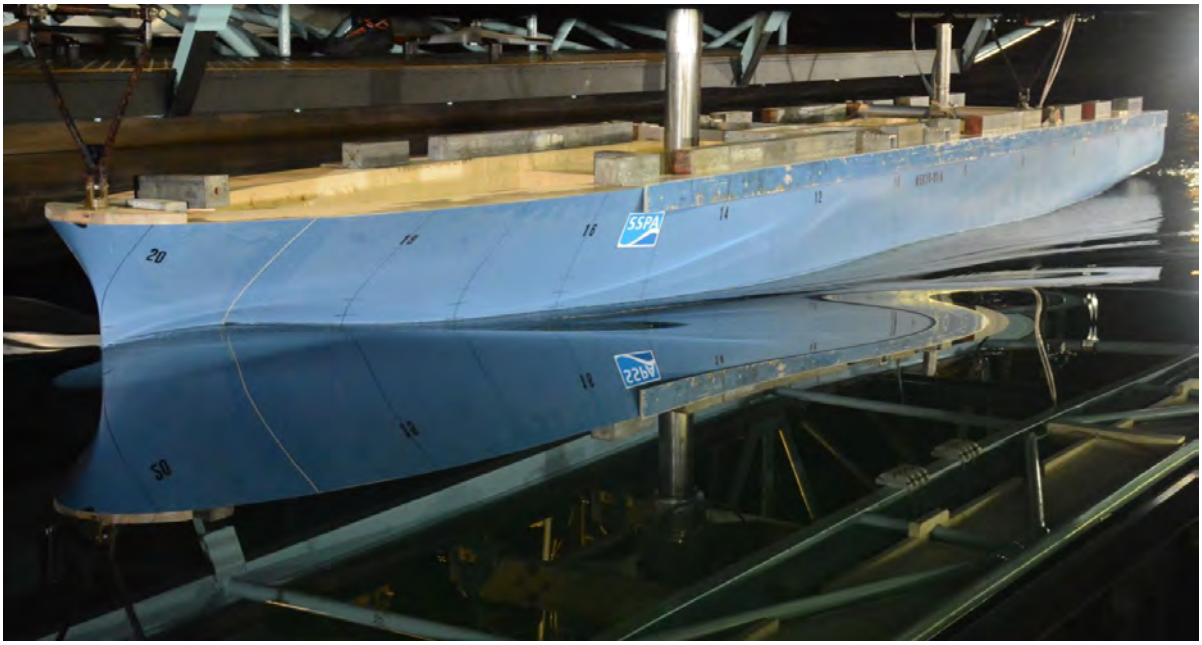
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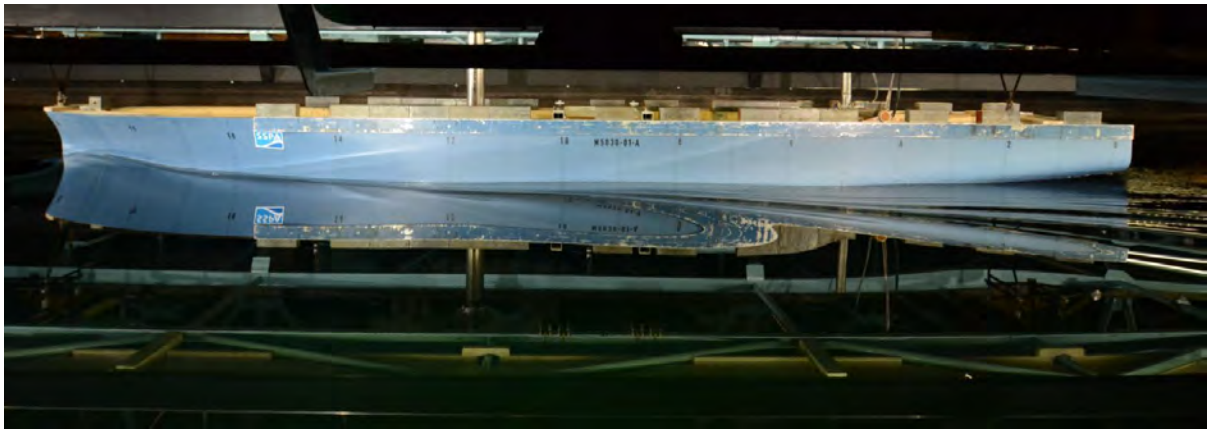


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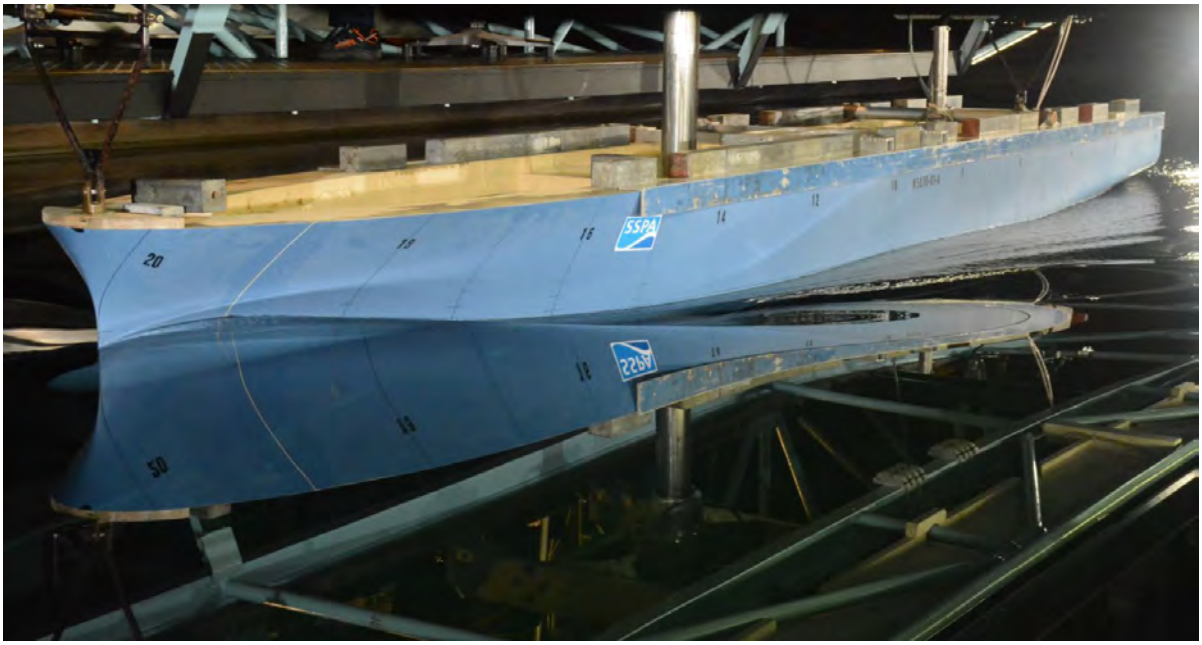
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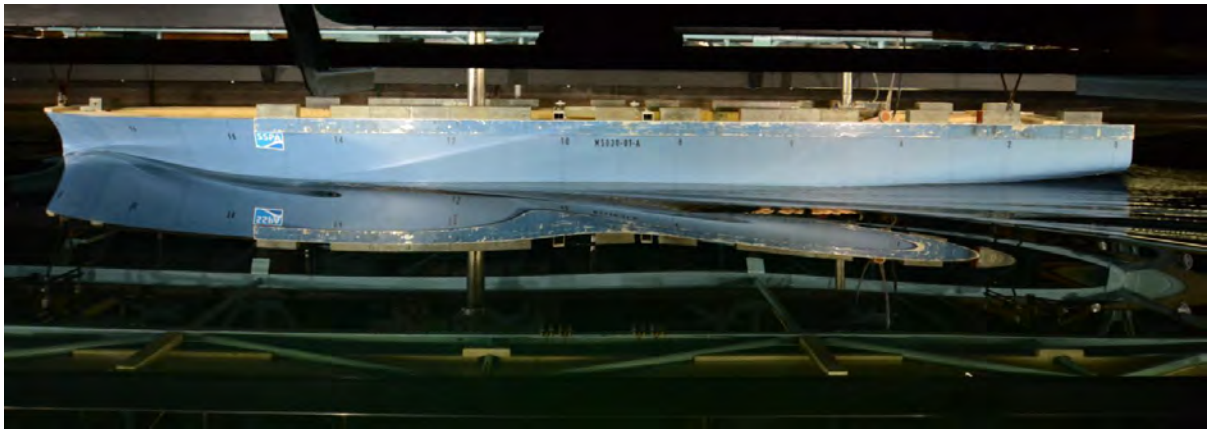
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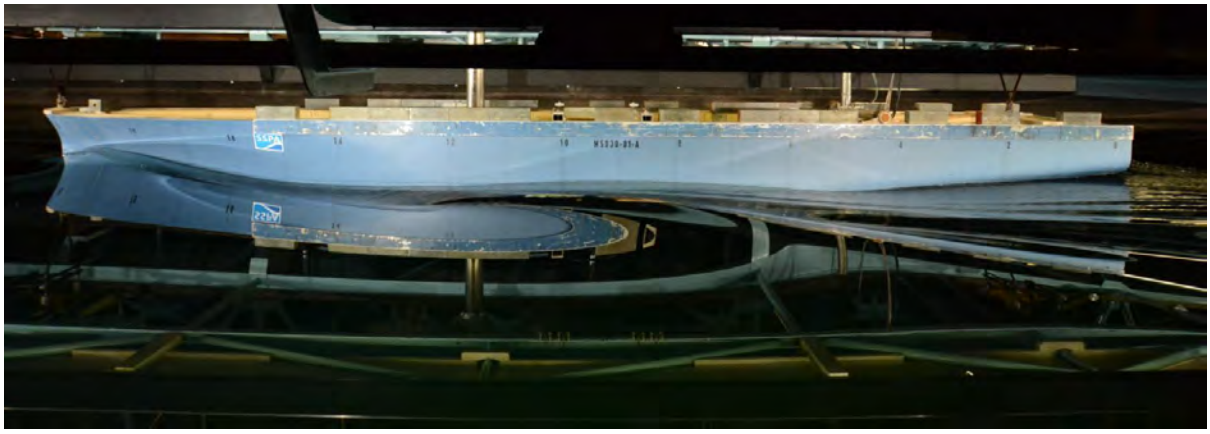
M5030-01-A
SSPA


SSPA
22LV

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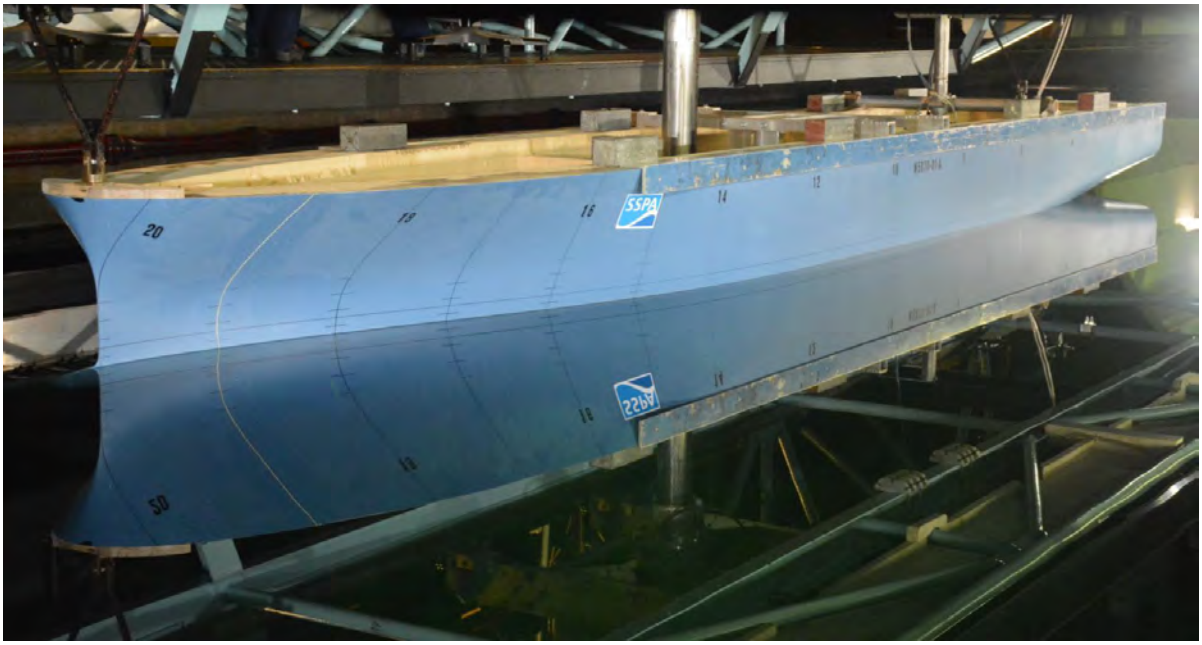

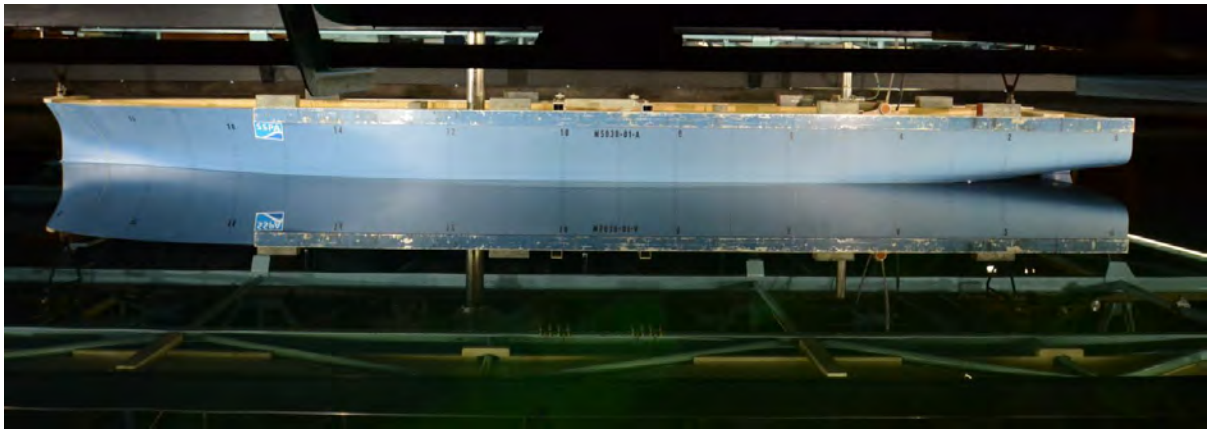


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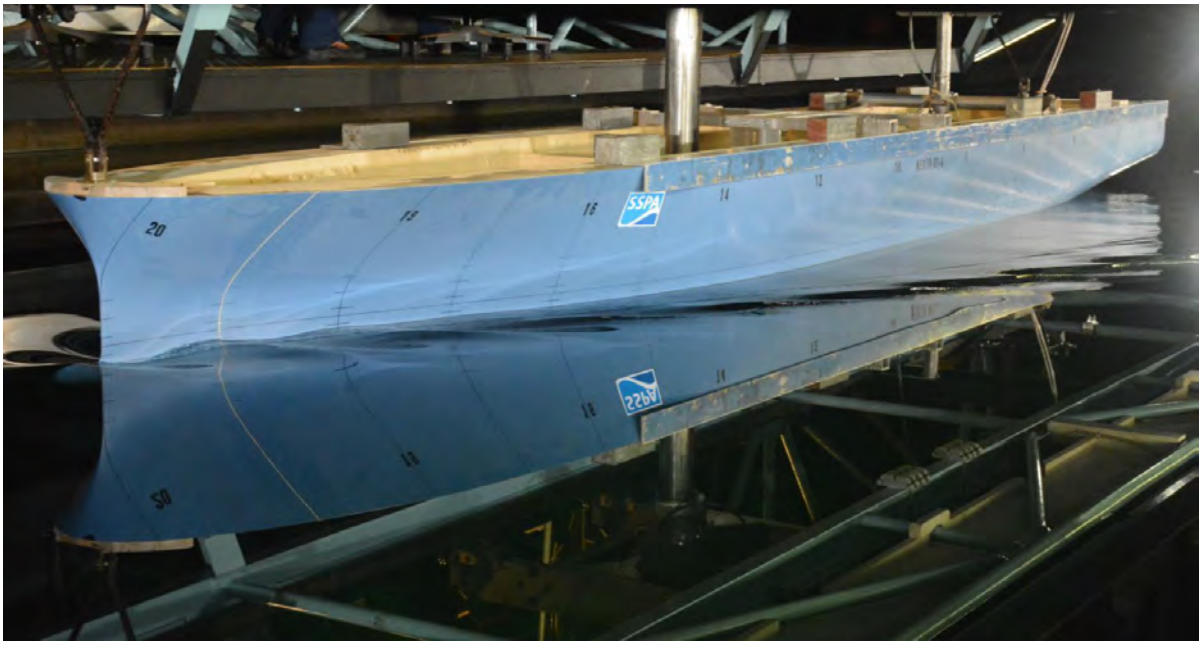

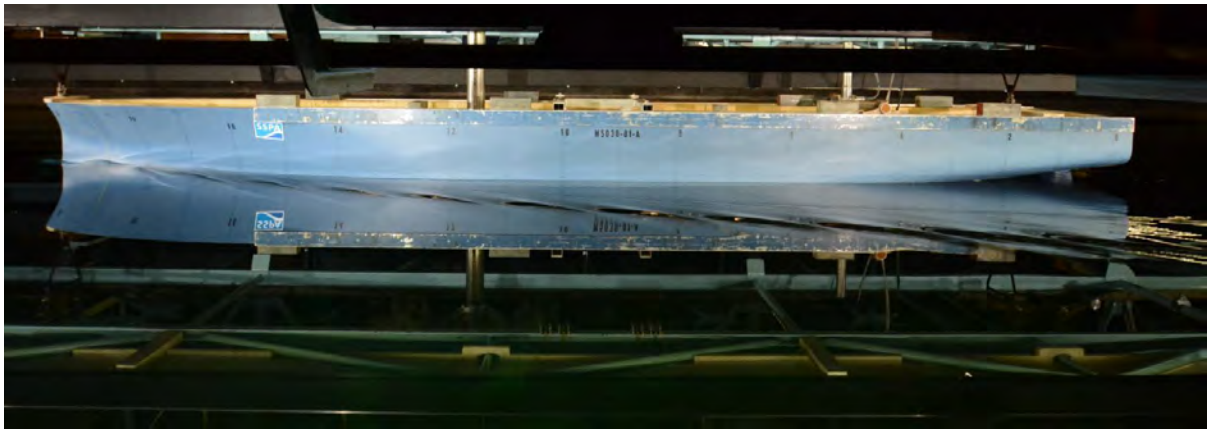


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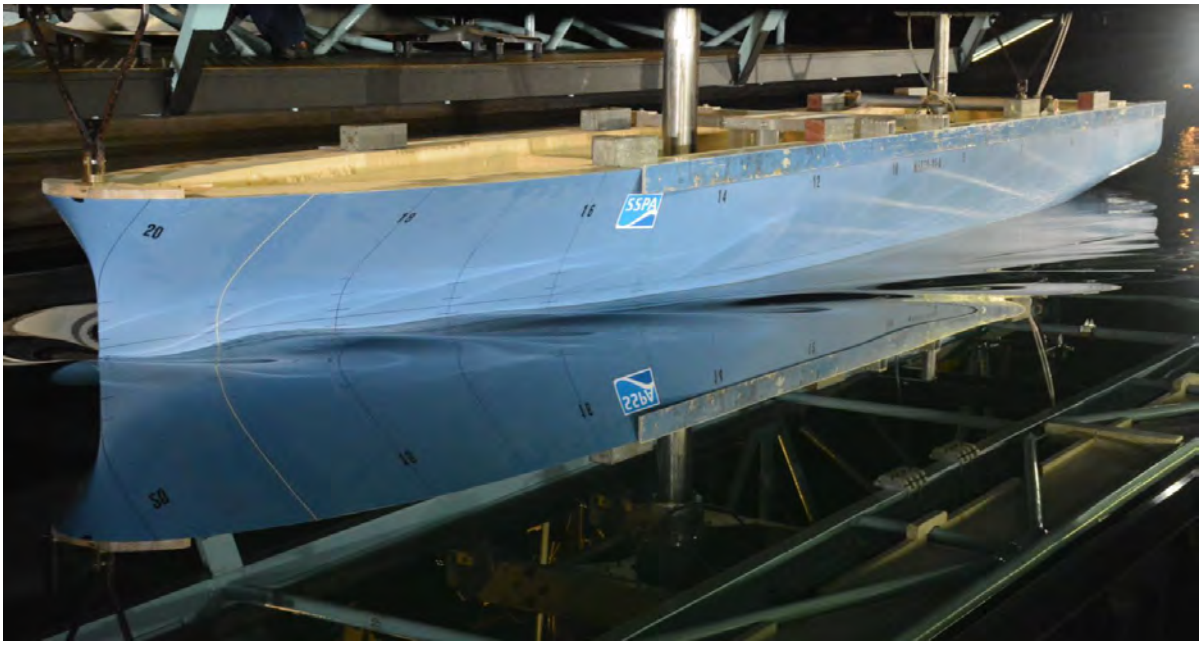
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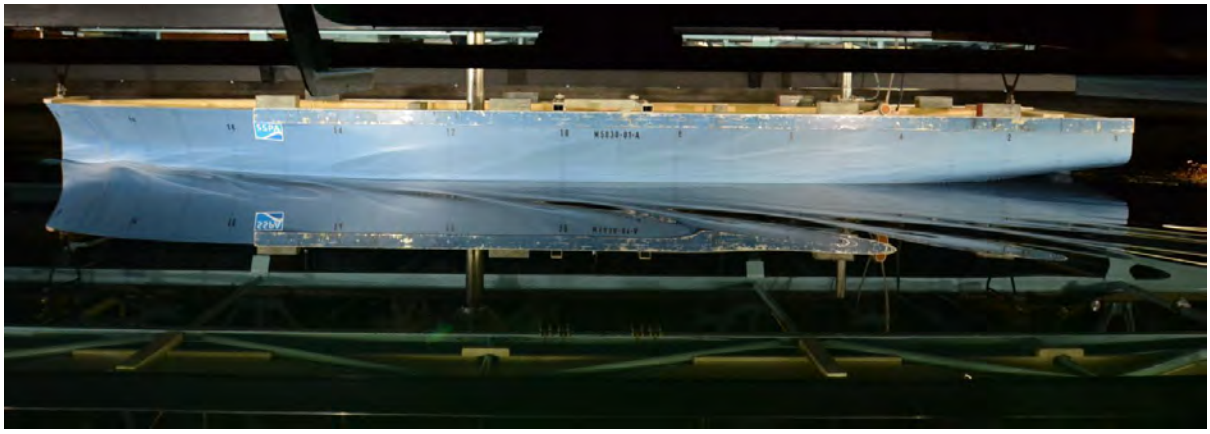


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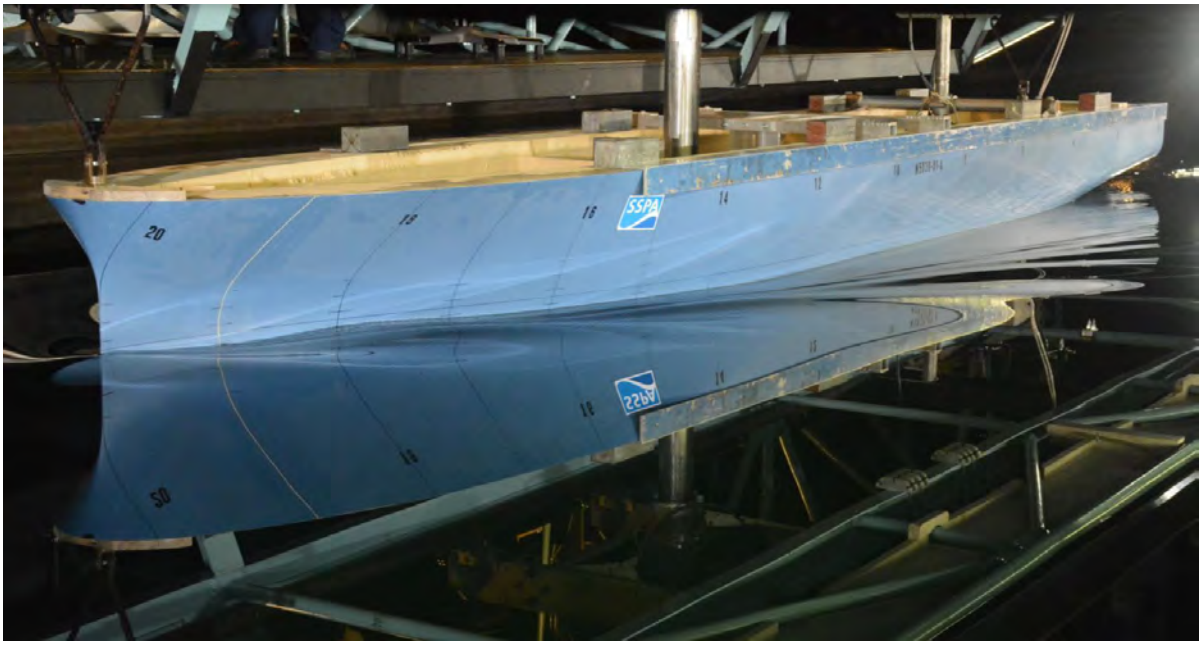
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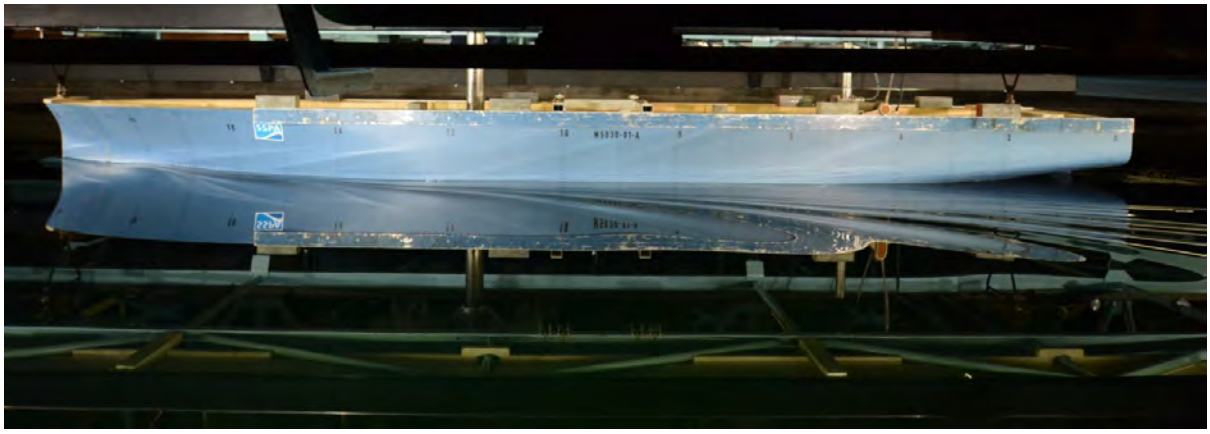


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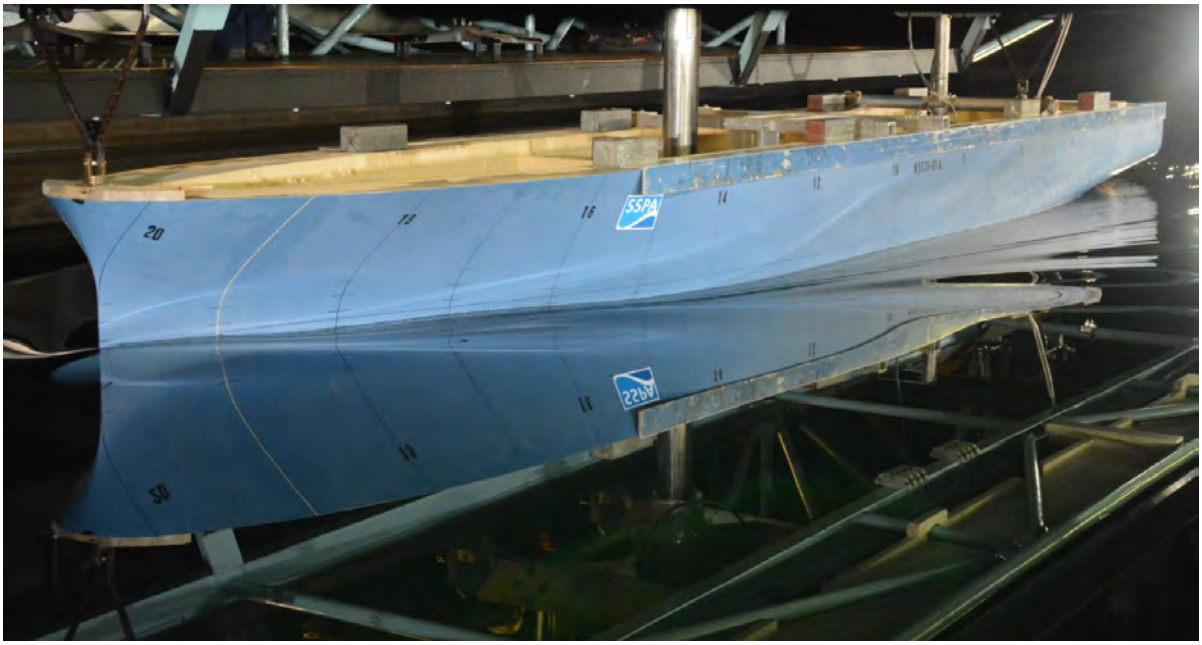
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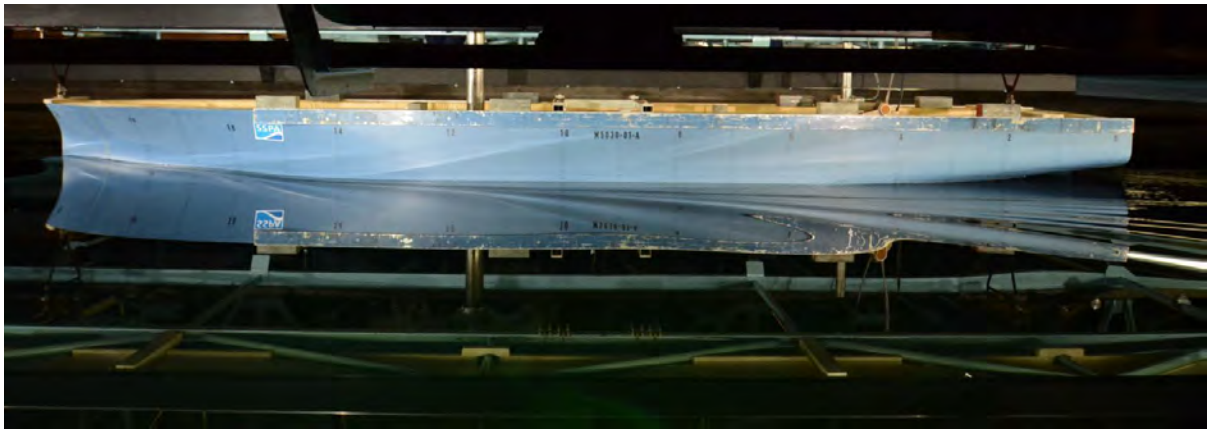


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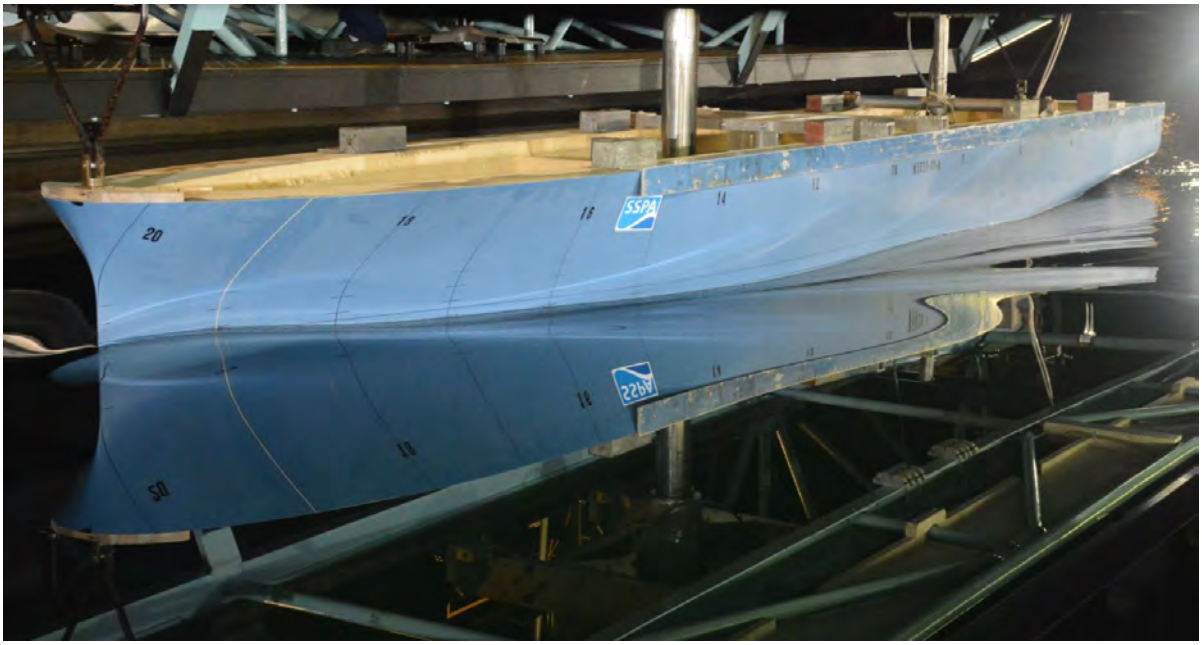
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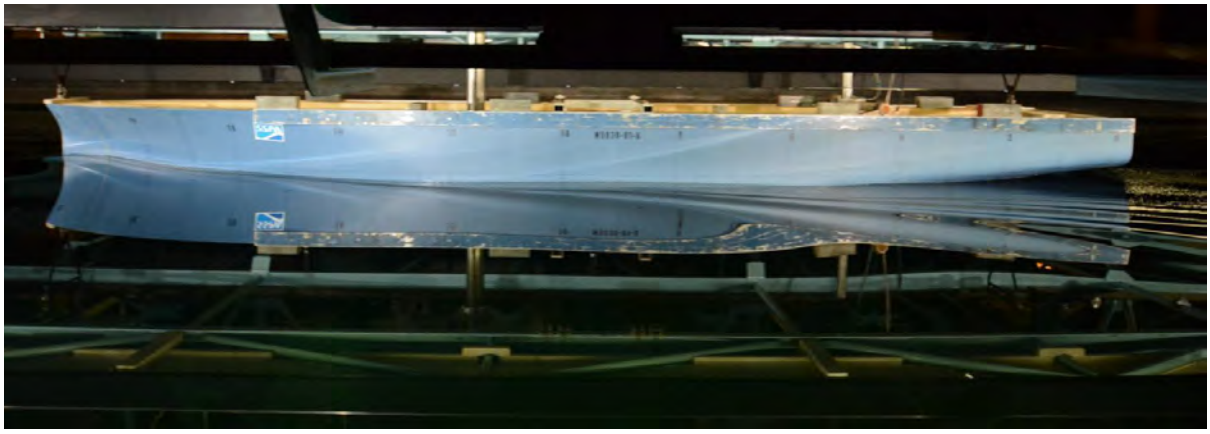
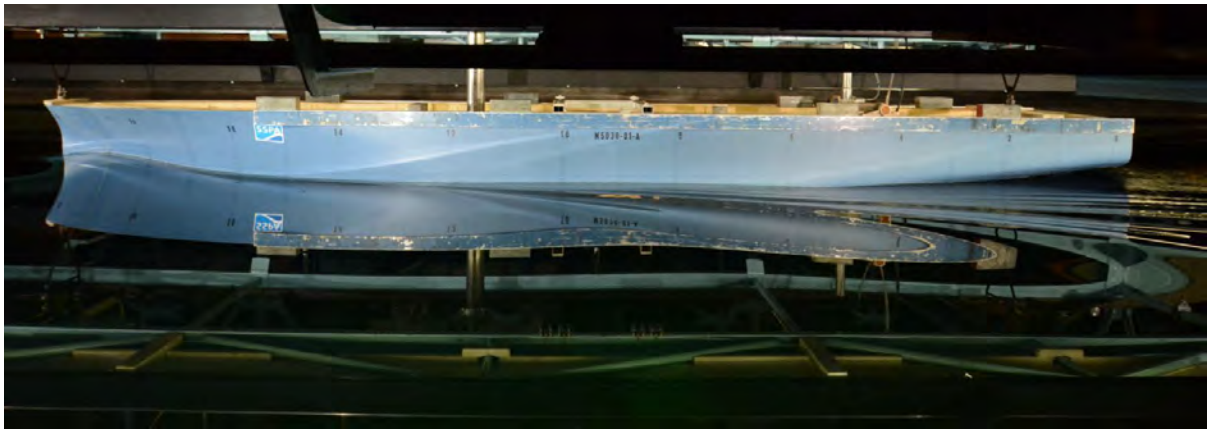



M5030-01-A
SSPA


SSPA

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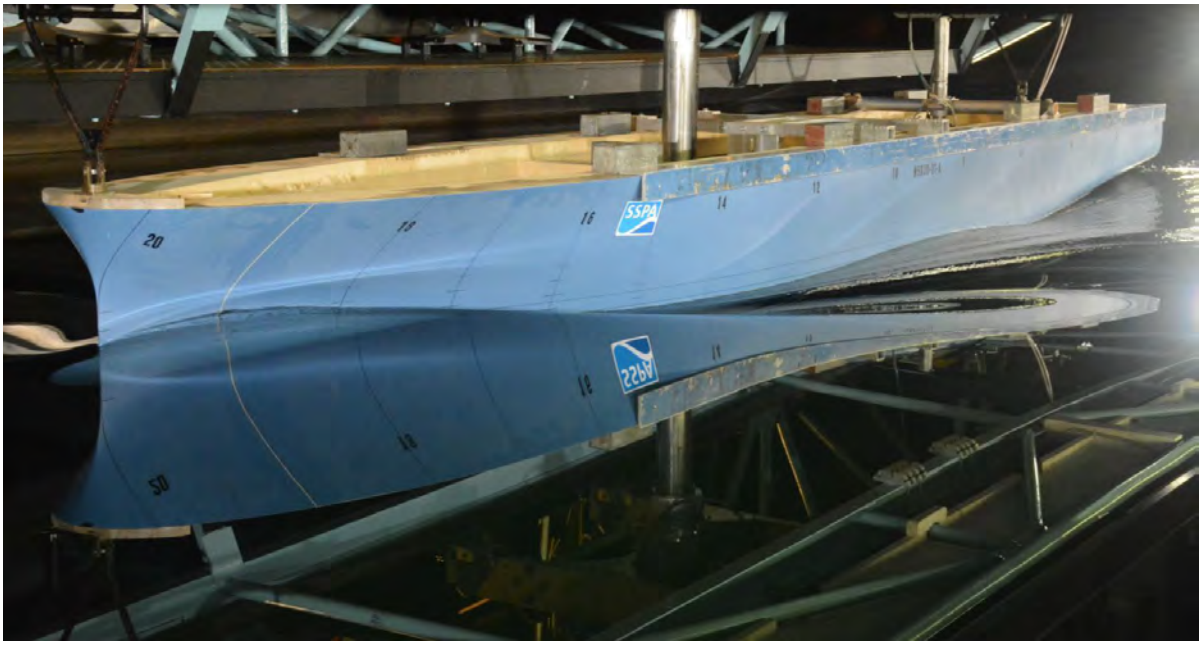
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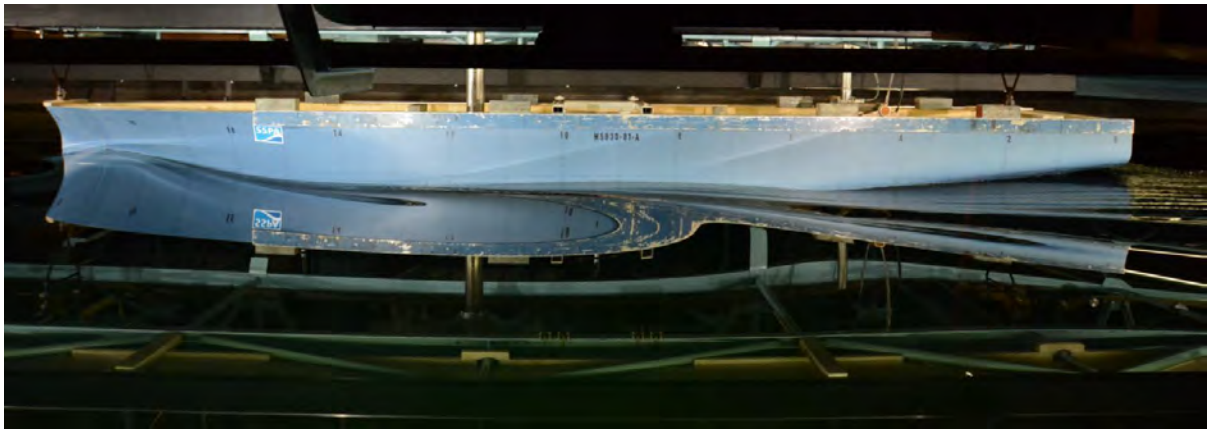


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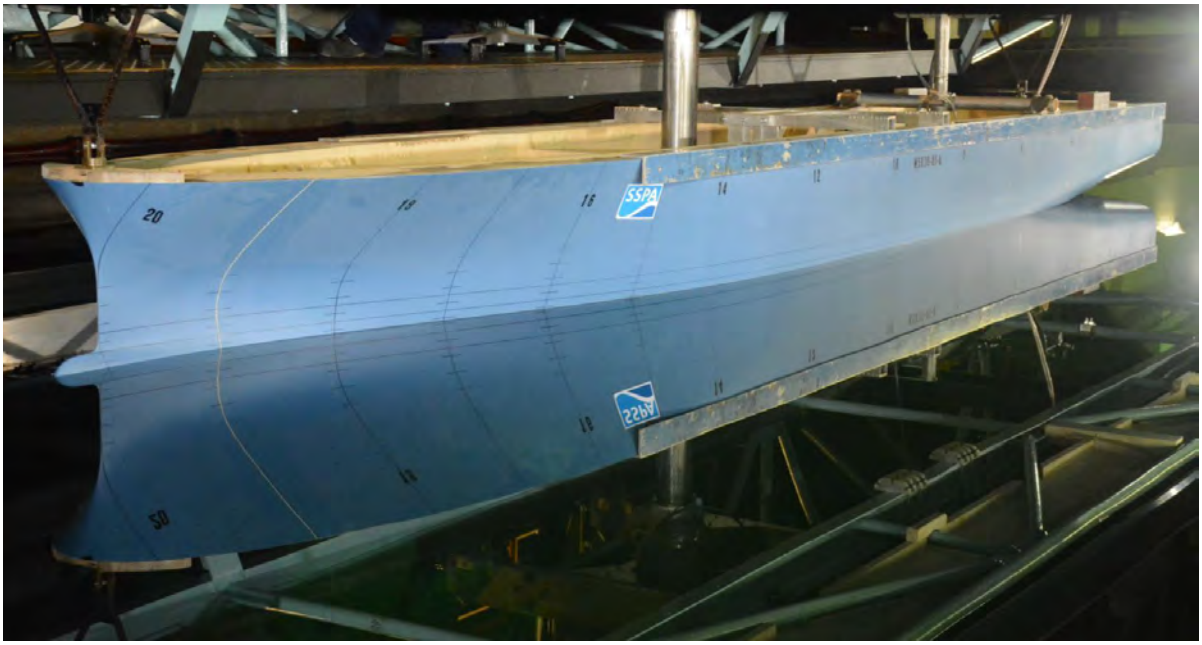
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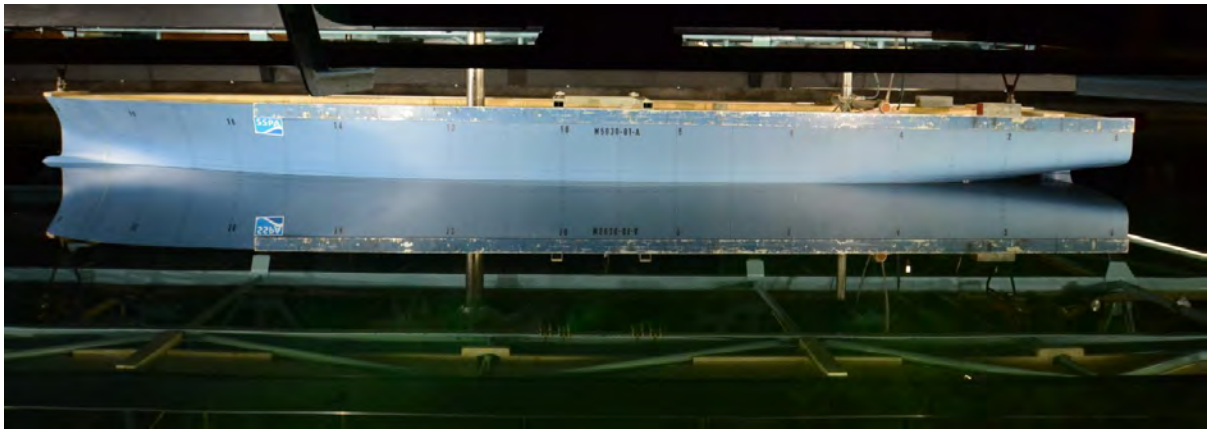


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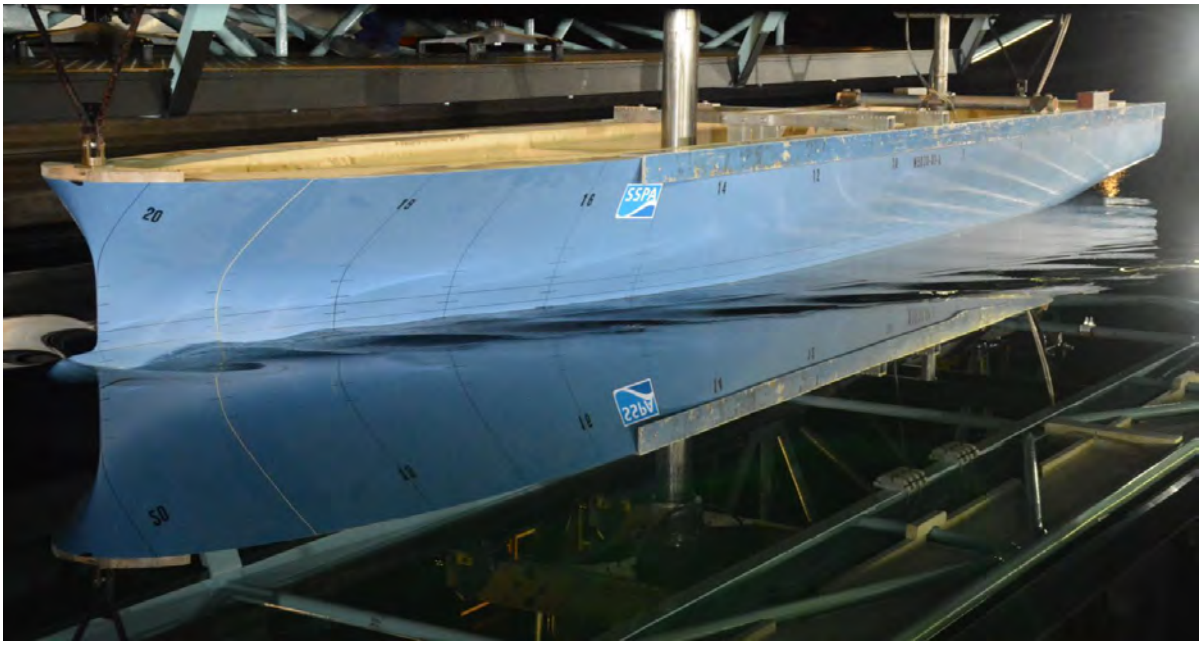
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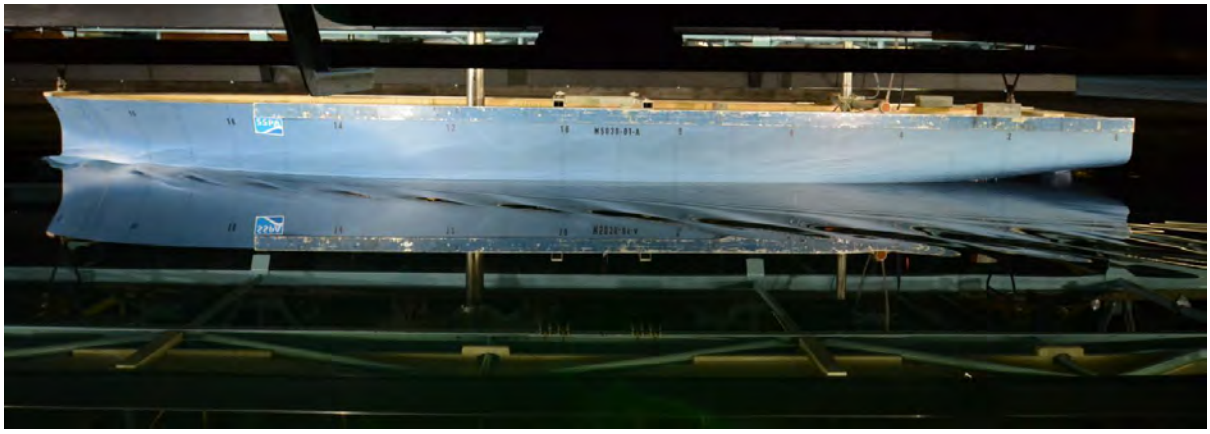


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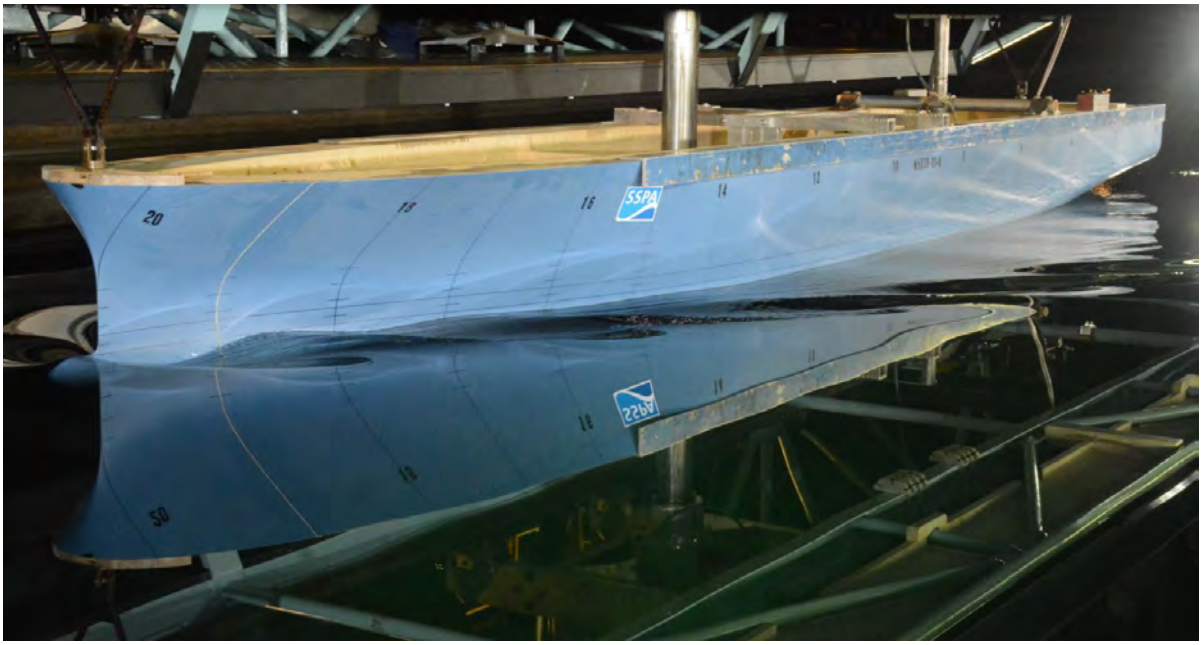
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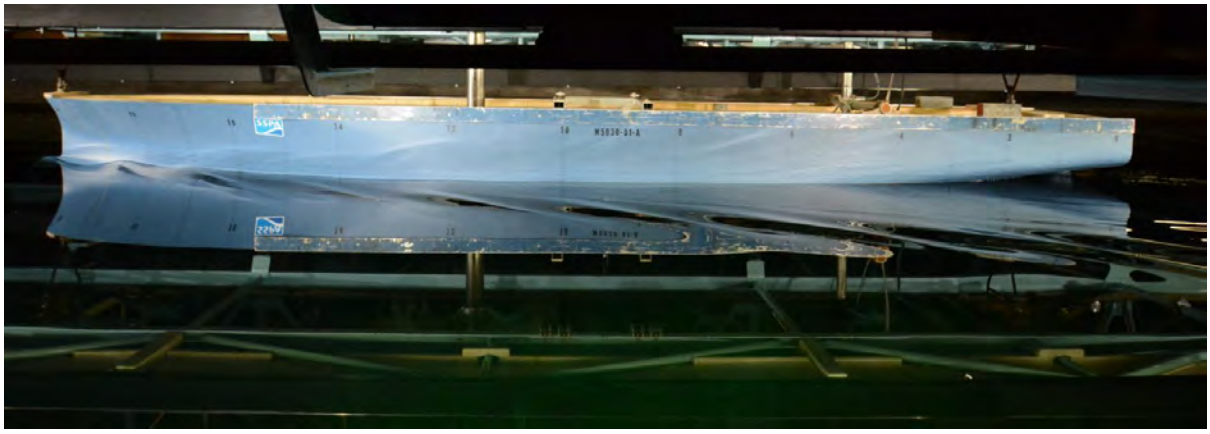


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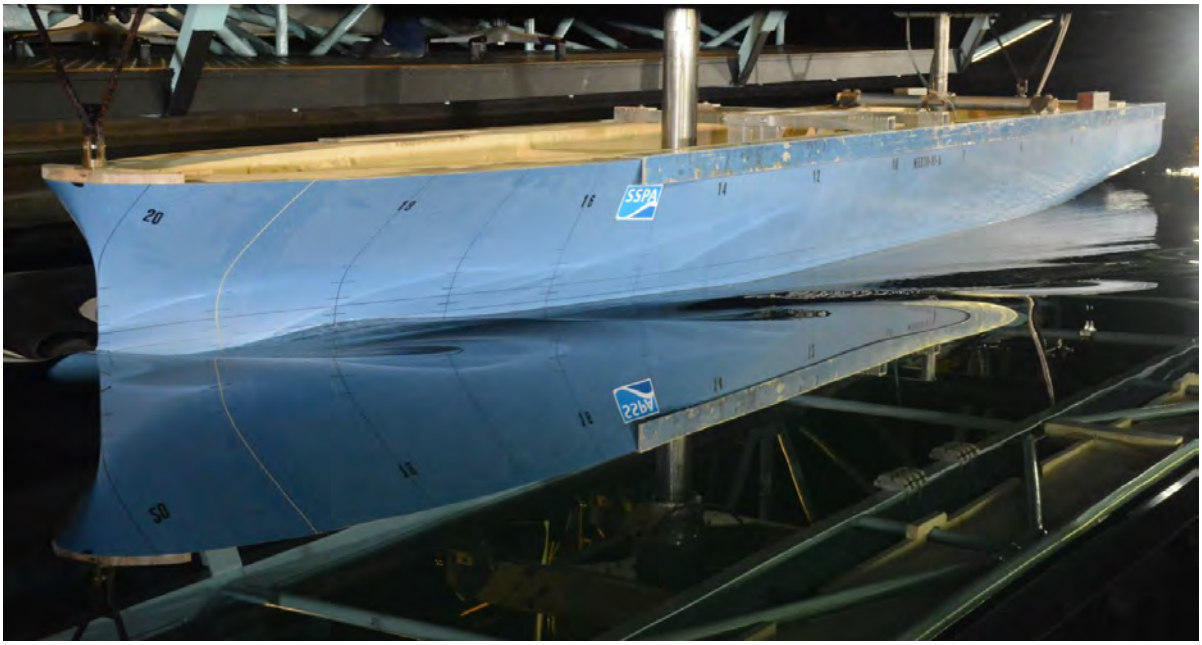
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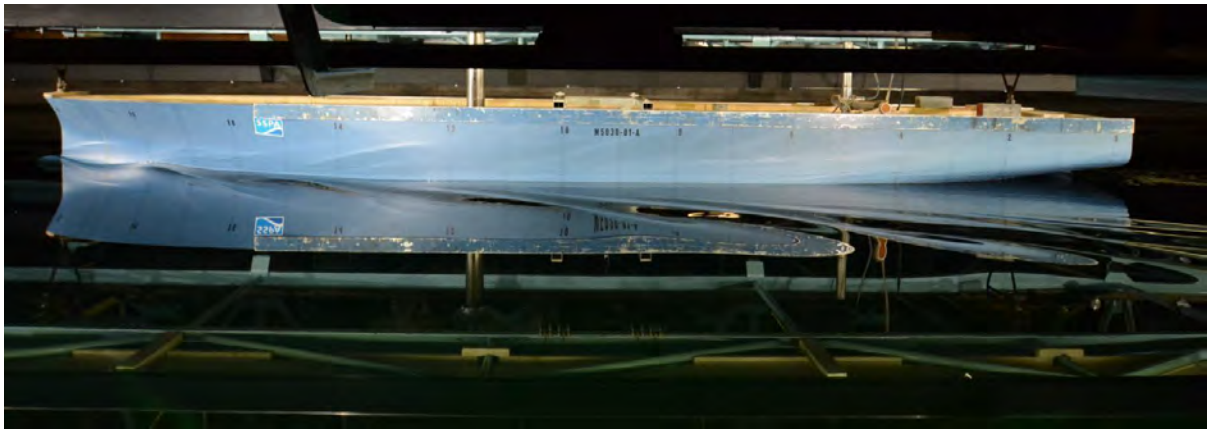


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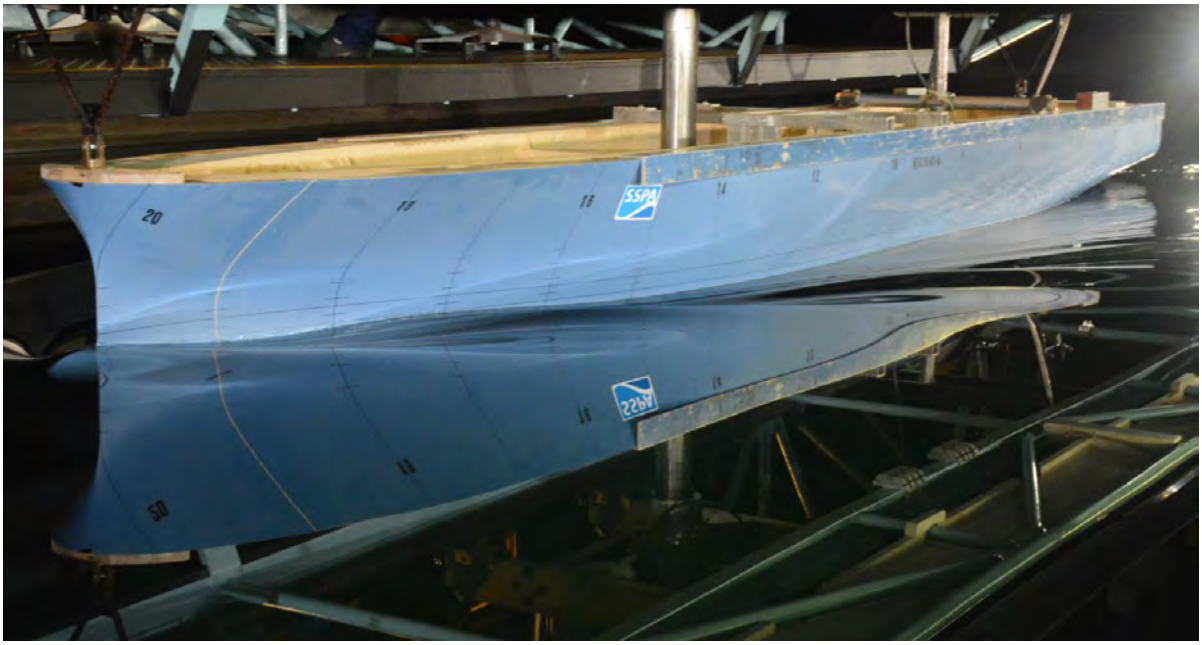
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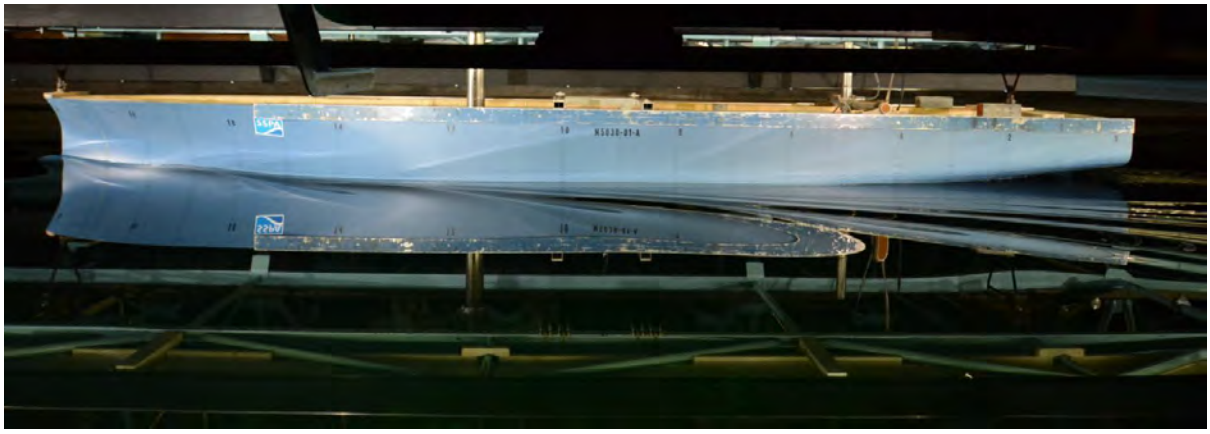
20
50

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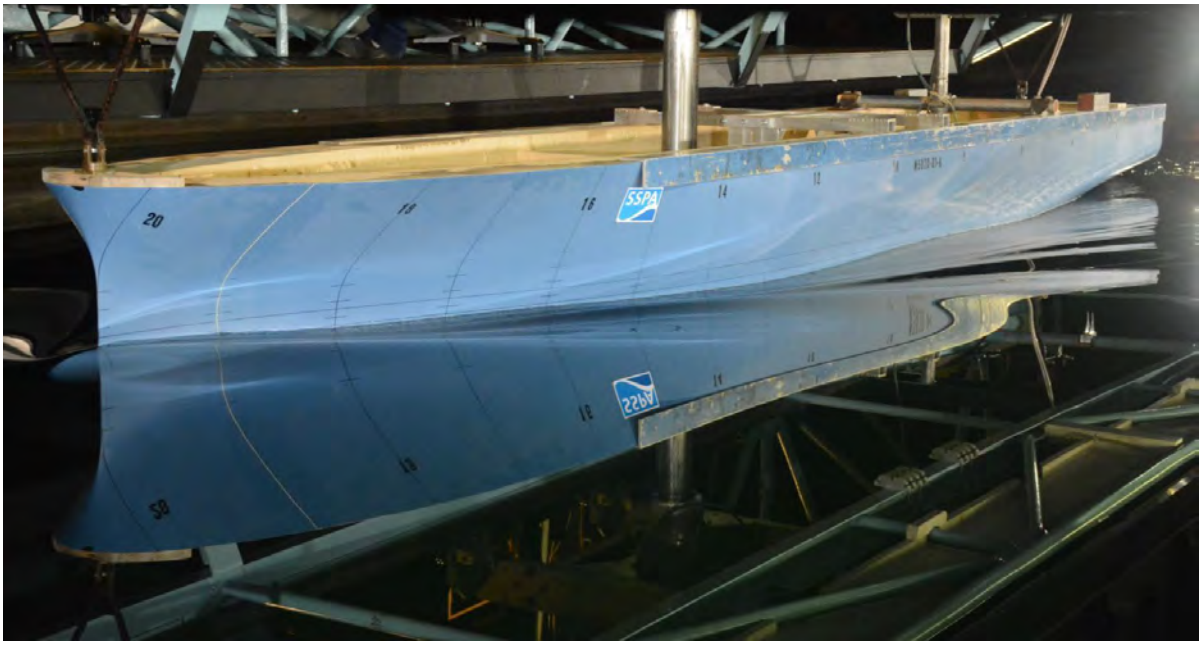
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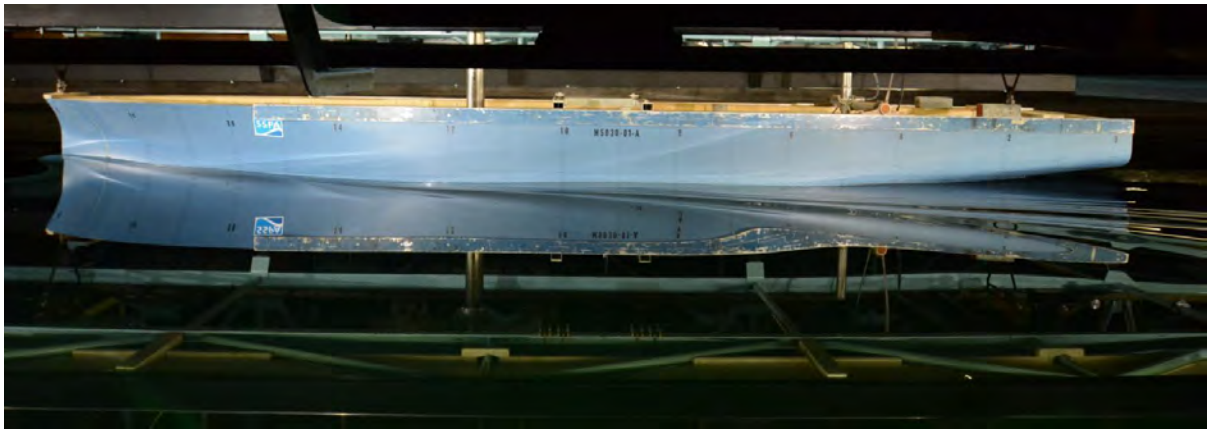


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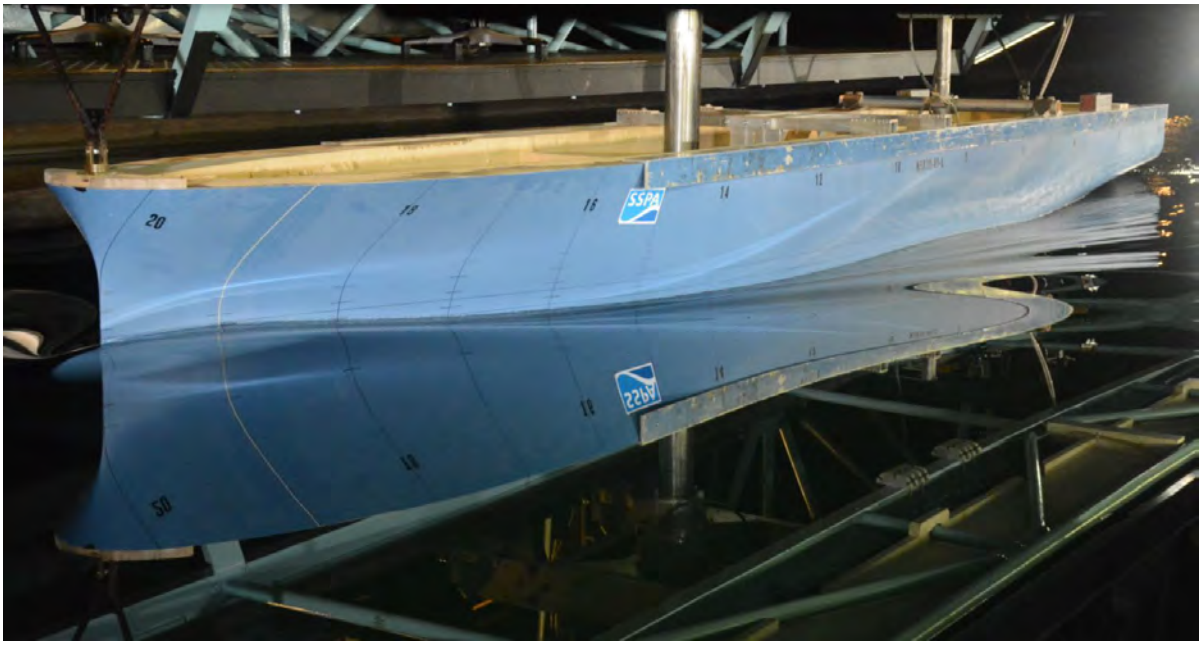

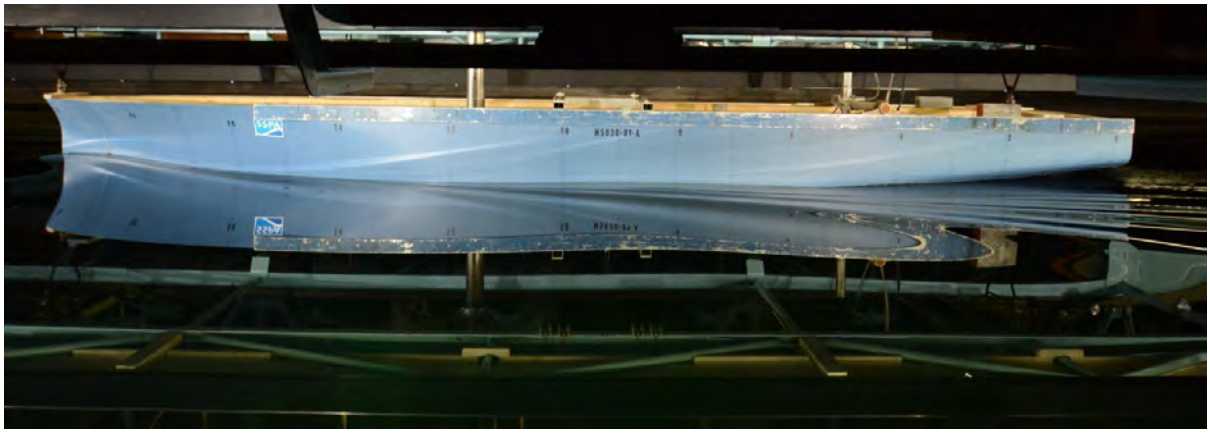


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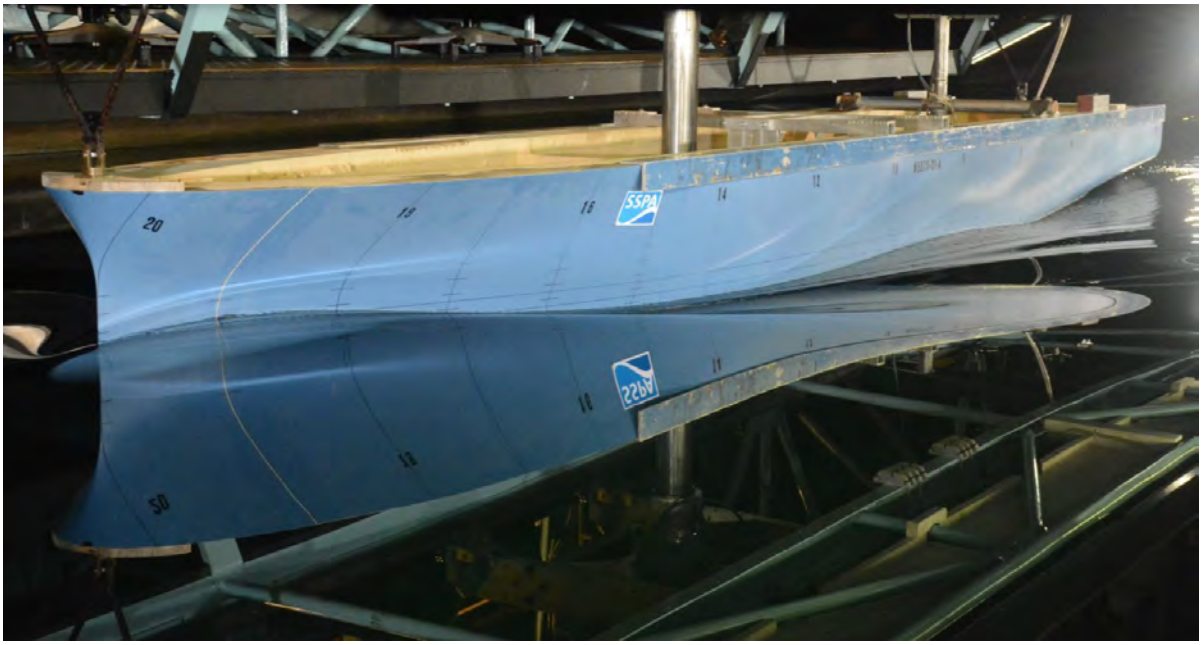
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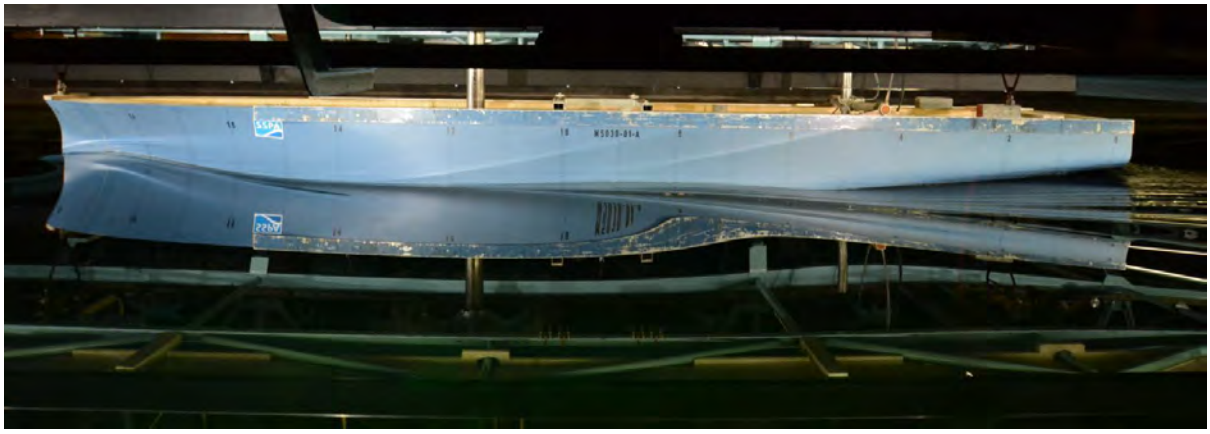


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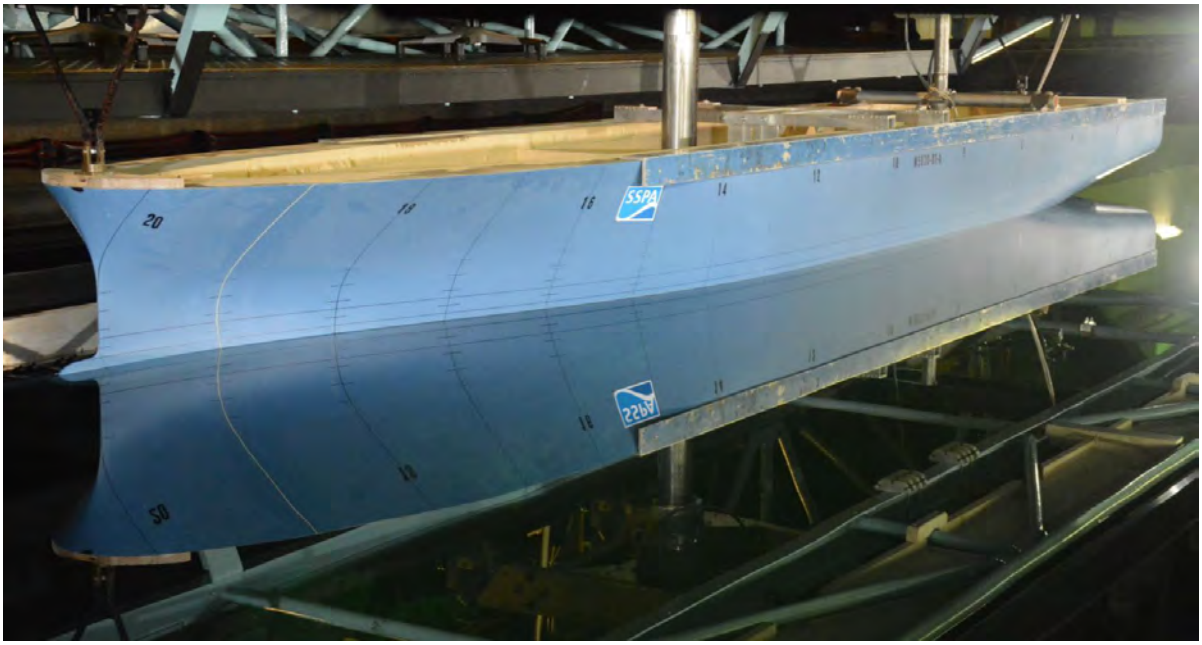
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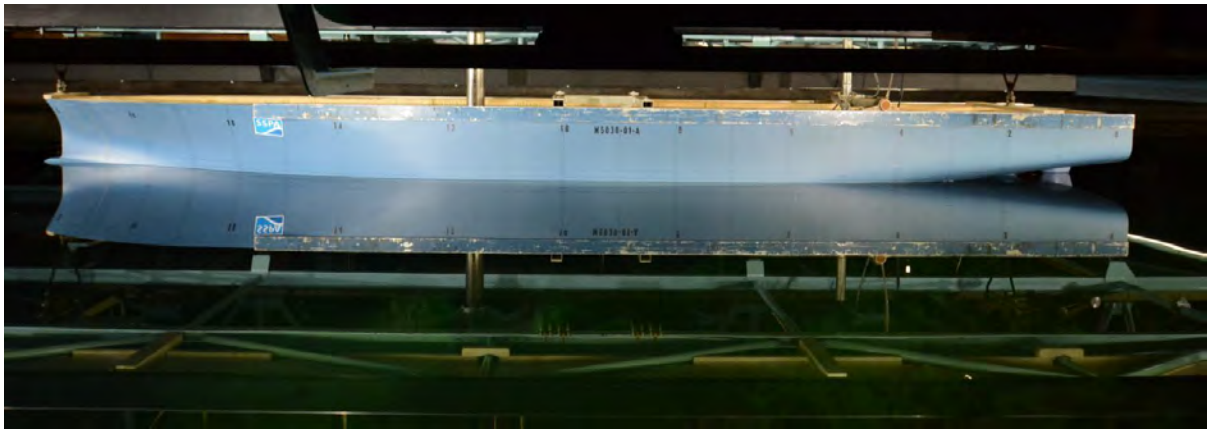


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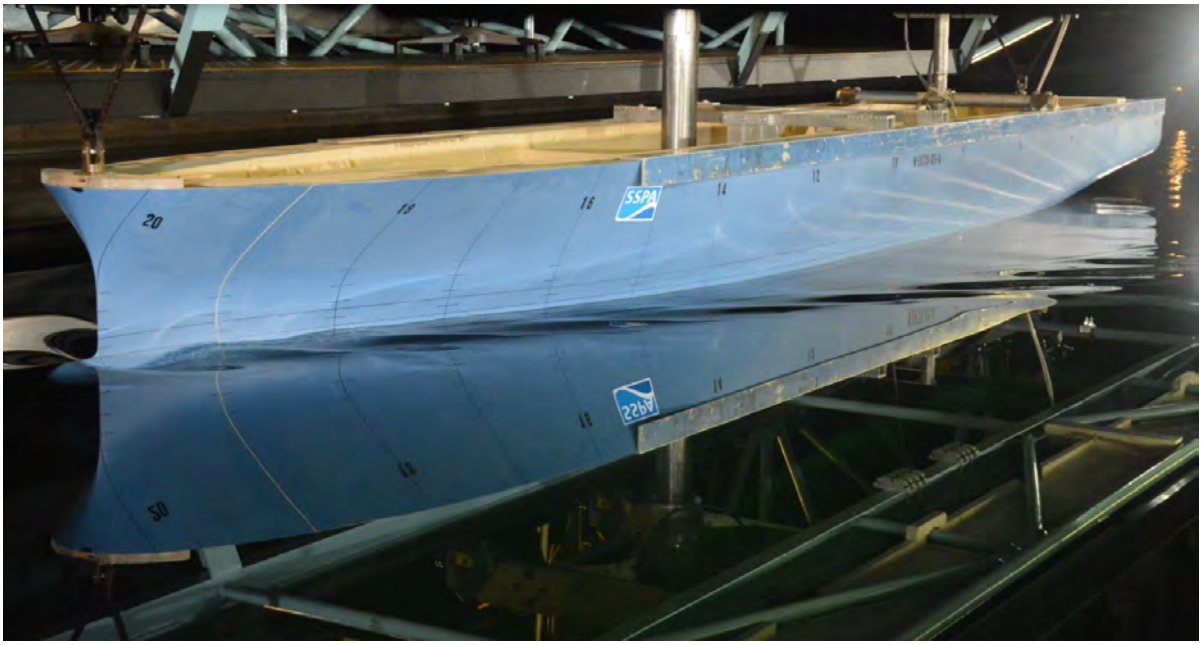
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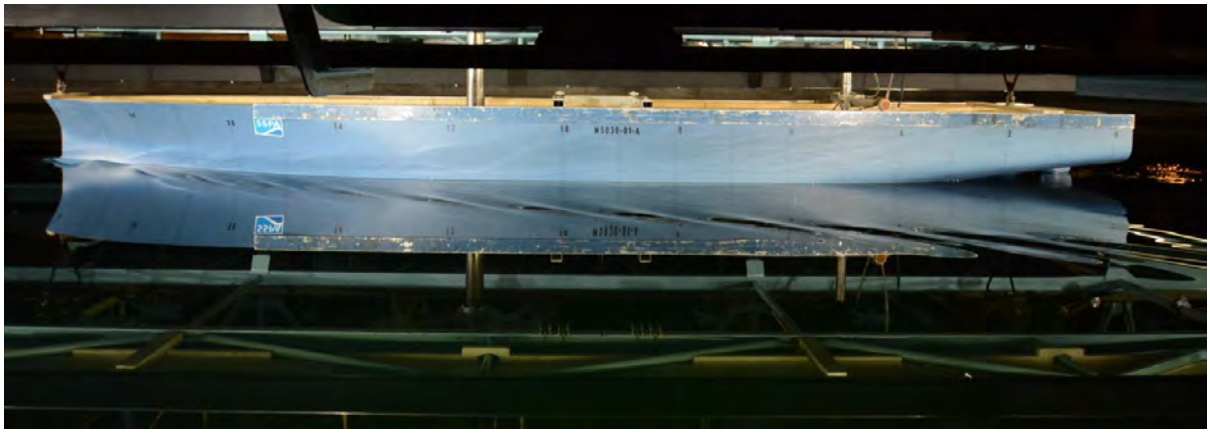


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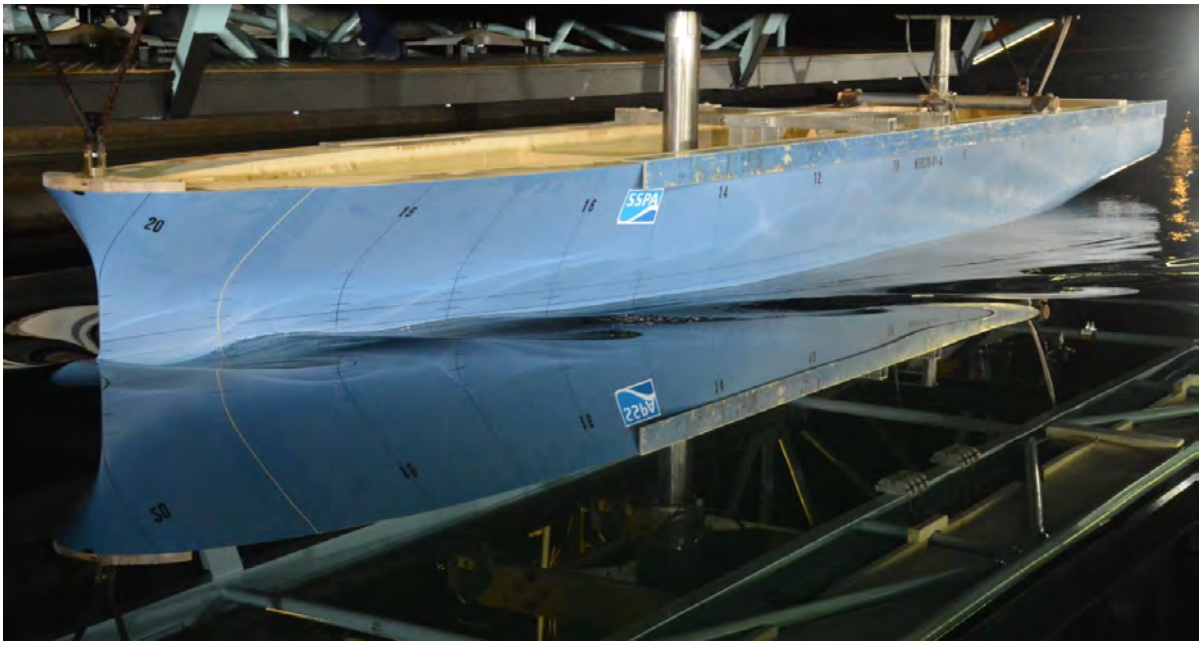
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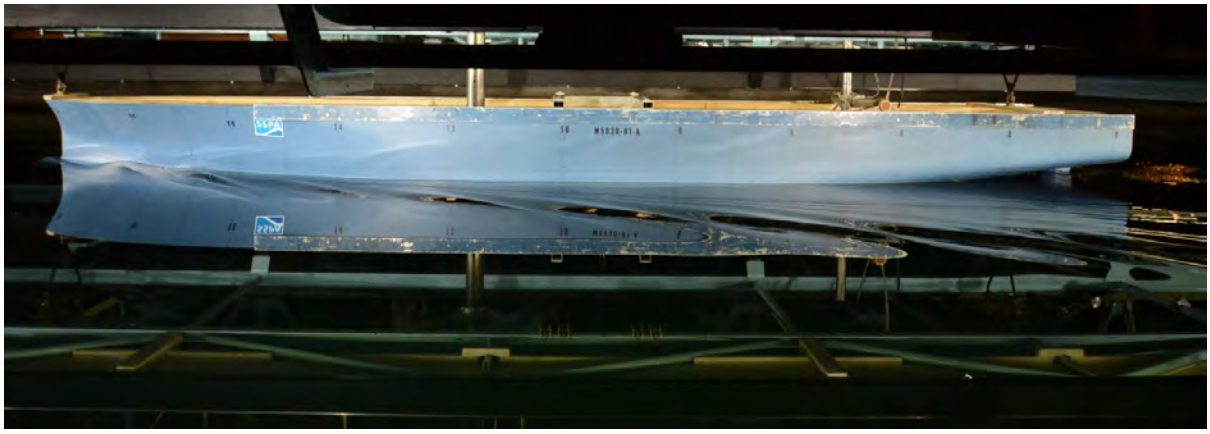


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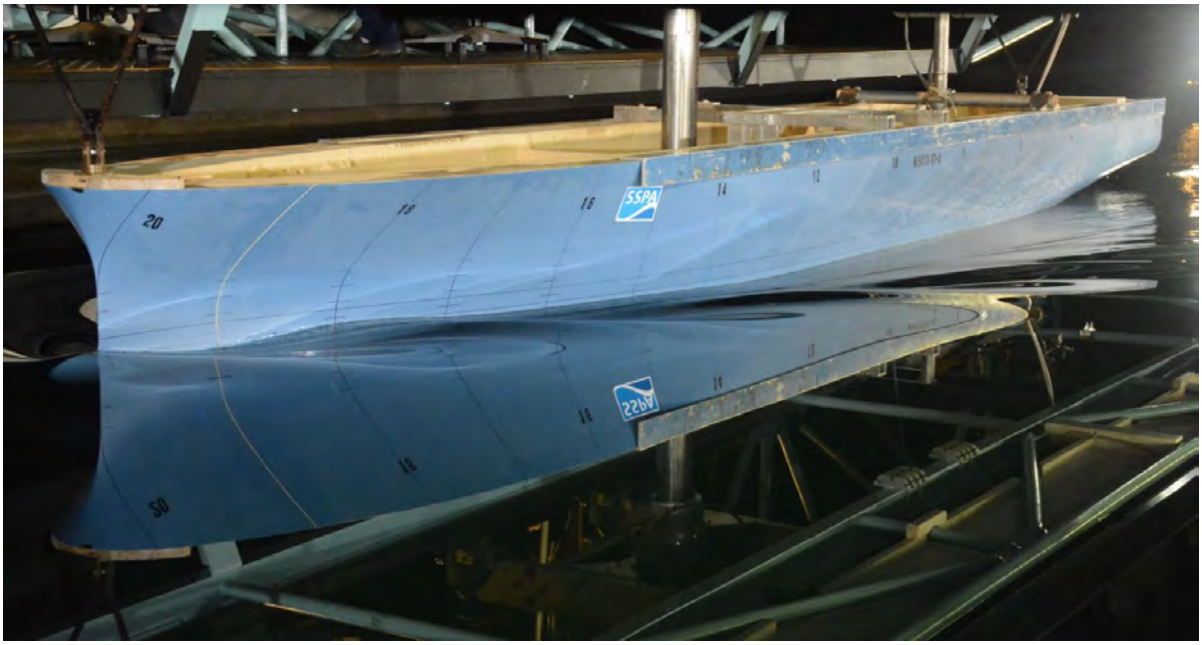

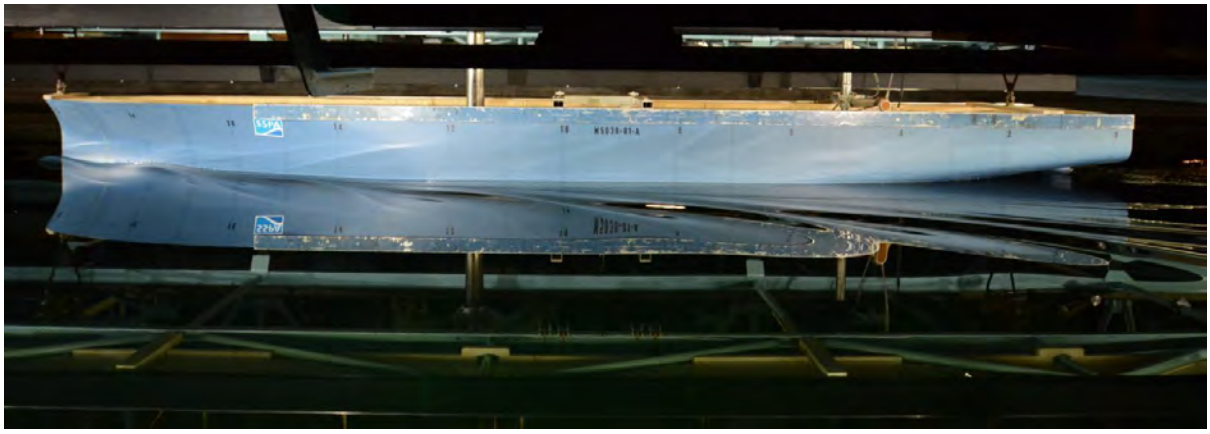


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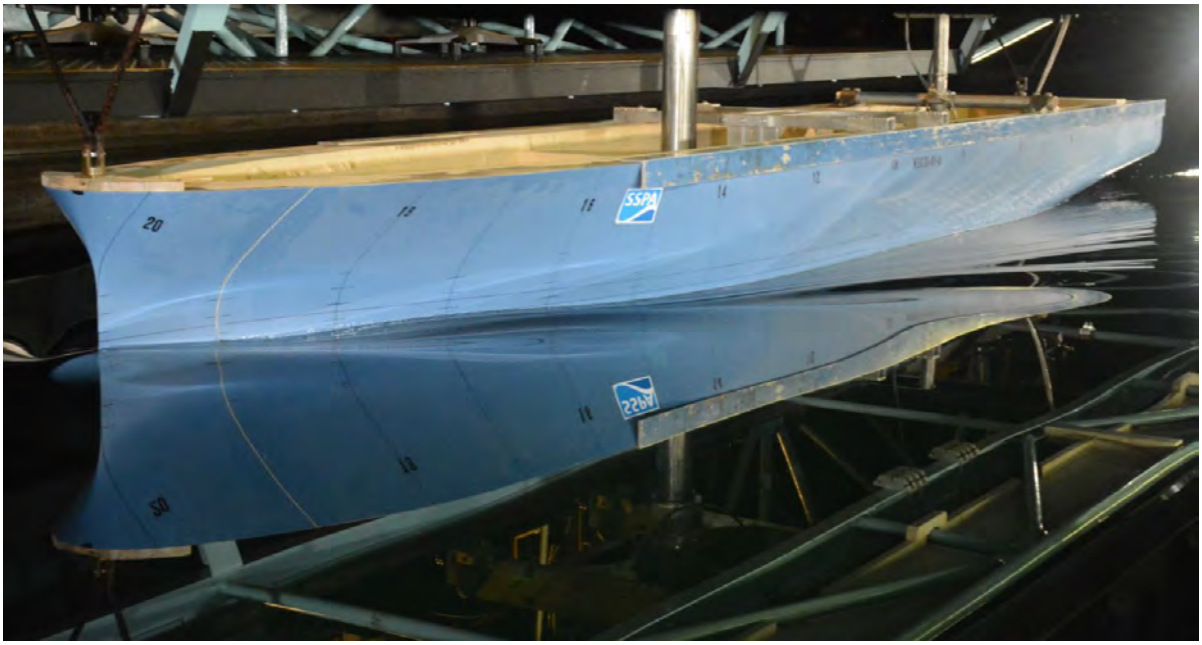

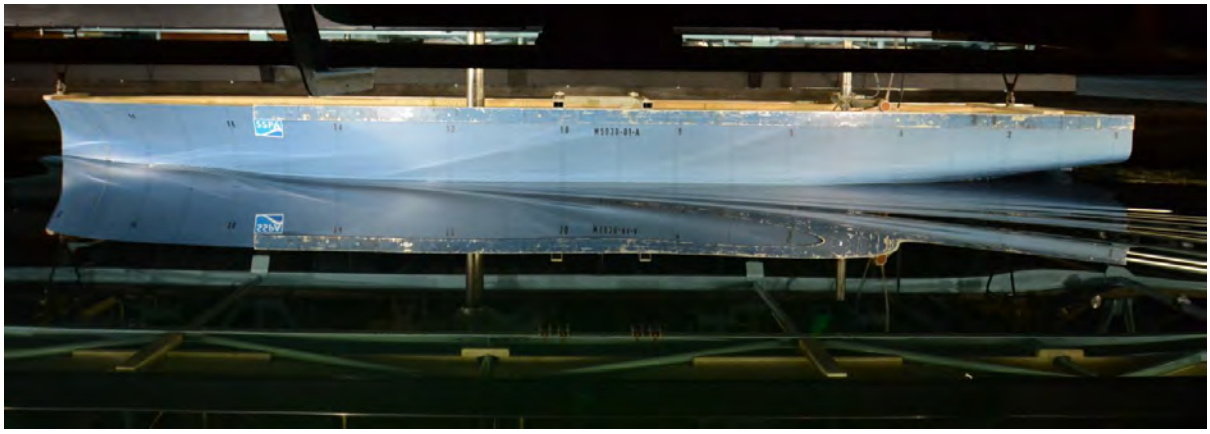


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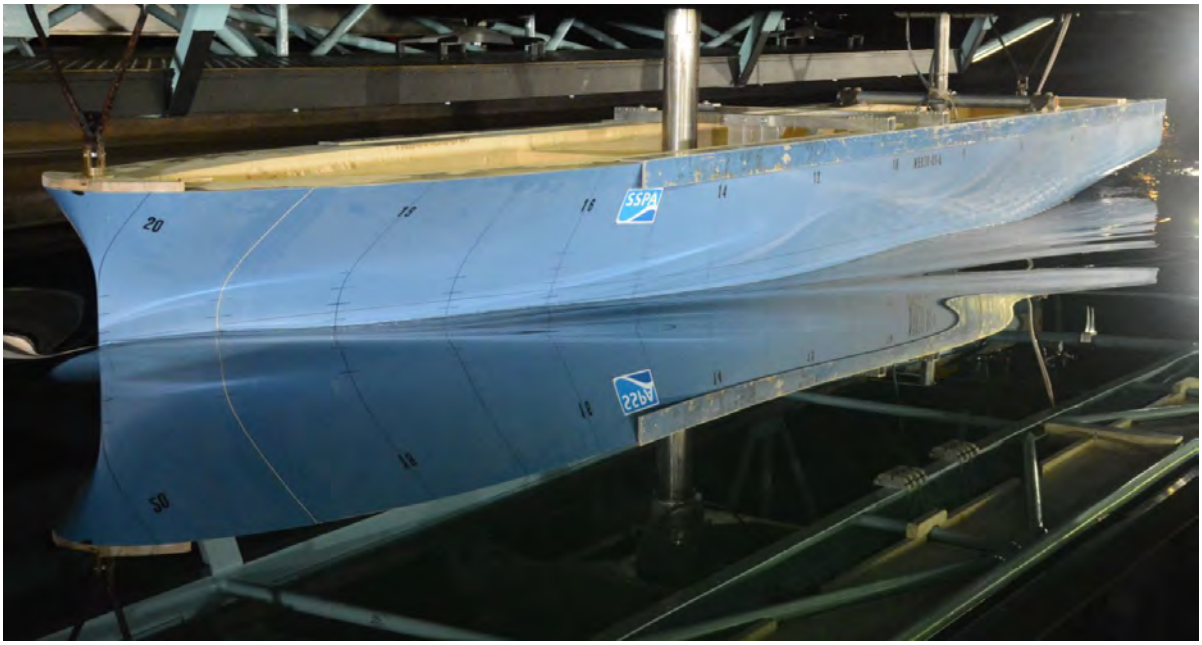
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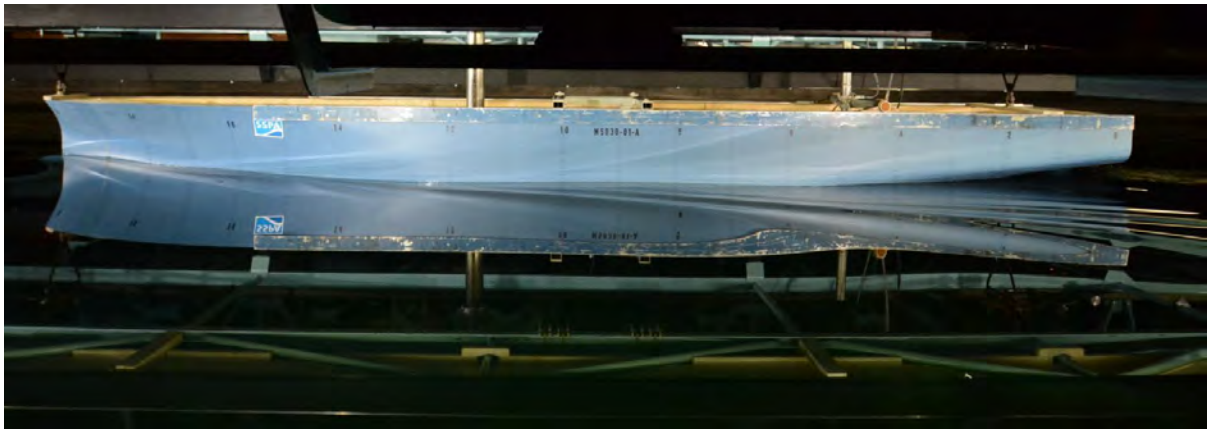


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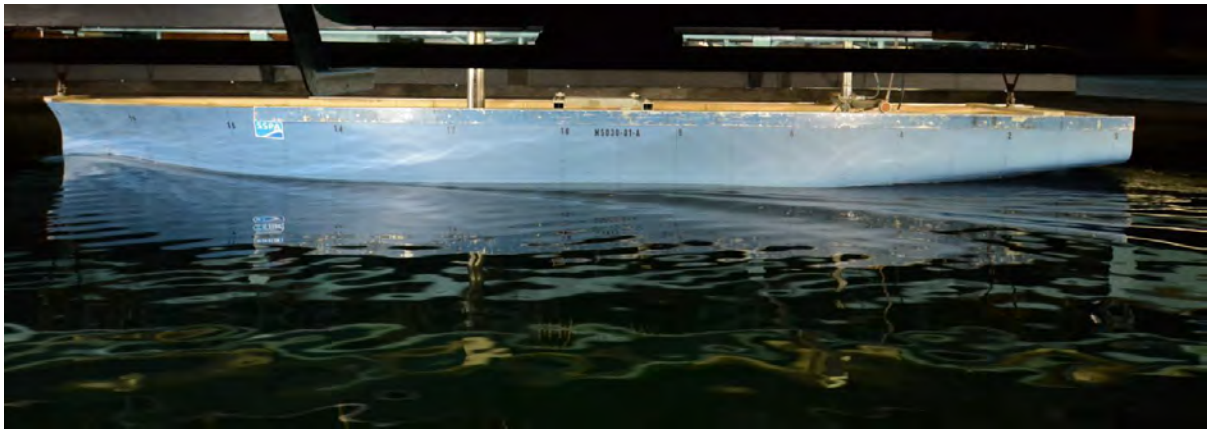


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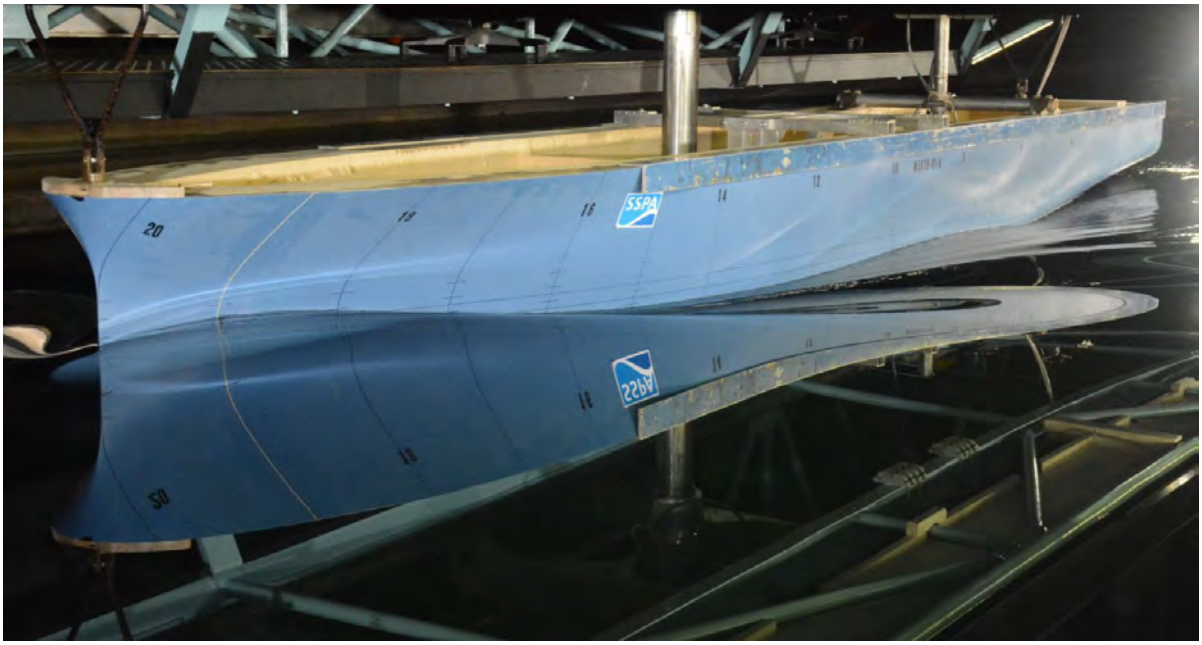
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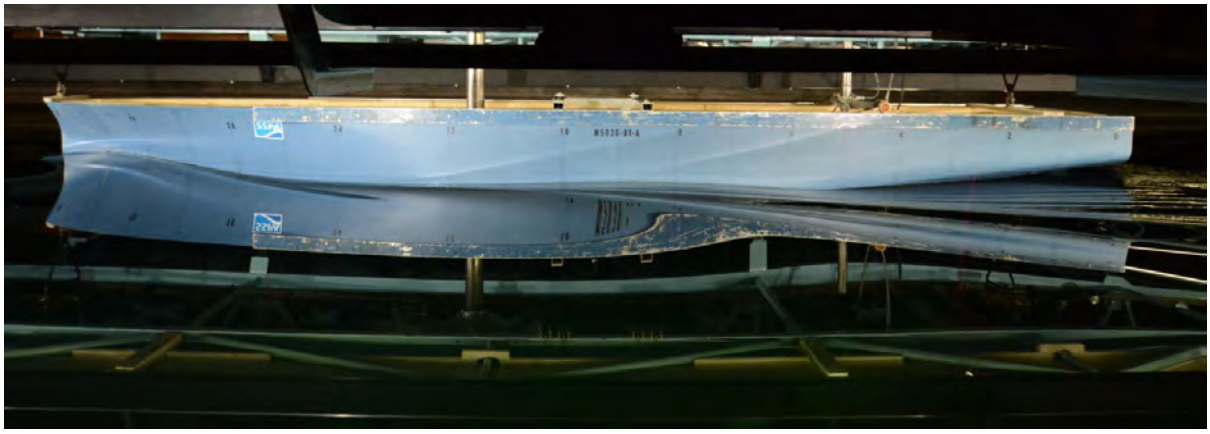


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The propeller model is mounted on a horizontal shaft and is moved through the water at an immersion of the shaft centre equal to the propeller diameter, if nothing else is mentioned.

Thrust (T), torque (Q) and rate of revolutions (n) are measured on the shaft behind the propeller model. The normal test method is to keep the rate of revolutions constant whilst the speed of advance (V_A) is varied so that a loading range of the propeller is examined.

The thrust (T) and torque (Q) measured during the tests are converted into non-dimensional coefficients (K_{Tm} and K_{Qm} respectively) which are defined as:

$$K_{Tm} = \frac{T}{\rho\, n^2\, D^4} \qquad K_{Qm} = \frac{Q}{\rho\, n^2\, D^5}$$ where

T and Q = thrust, in N and torque, in Nm respectively

ρ = mass density of tank water, in Ns^2/m^4

n = rate of revolutions, in r/s

D = propeller diameter, in m

The propeller efficiency η_0 and the advance ratio (J) are calculated according to:

$$\eta_0 = \frac{J\, K_T}{2\pi\, K_Q} \quad \text{where } J = \frac{V_A}{n\, D}$$ and V_A = speed of advance, in m/s

Notice that all the quantities and coefficients mentioned above refer to the propeller model. These propeller open water characteristics are used to calculate the mean wake fraction (w_{Tm}) and the relative rotative efficiency (η_{Rm}) from the self propulsion tests.

The 1978 ITTC Performance Prediction Method gives rate of revolutions and delivered power for the ship (s) obtained from the full scale propeller open water characteristics. These characteristics are determined by correcting the model (m) values for drag scale effects according to the following:

$$K_{Ts} = K_{Tm} + \Delta K_T \qquad K_{Qs} = K_{Qm} + \Delta K_Q$$ where

$$\Delta K_T = \Delta C_D\, 0.3\, \frac{P}{D}\, \frac{c\, Z}{D} \qquad \Delta K_Q = -\Delta C_D\, 0.25\, \frac{c\, Z}{D}$$

The difference in blade drag coefficient is $\Delta C_D = C_{Dm} - C_{Ds}$ where

$$C_{Dm} = 2\,(1 + 2\frac{t}{c})\left[\frac{0.044}{(R_{nco})^{\frac{1}{6}}} - \frac{5}{(R_{nco})^{\frac{2}{3}}}\right]$$ and

$$C_{Ds} = 2\,(1 + 2\frac{t}{c})\left[1.89 + 1.62\,\log\left(\frac{c}{k_p}\right)\right]^{-2.5}$$

In these formulas c is the cord length of the blades, t is the maximum blade thickness, P/D is the pitch ratio and R_{nco} is the local Reynolds number at radius $0.75\,\frac{D}{2}$.

$$R_{nco} = \frac{c\, V}{\nu} \quad \text{where} \quad V = V_A\sqrt{1 + \left(\frac{\pi\, 0.75}{J}\right)^2}$$ and

ν = kinematic viscosity, in m^2/s (ITTC 1960)

Z = number of propeller blades

k_p = full scale blade roughness, which is set to 30 μm

During the resistance test the model is towed at speeds giving the same Froude numbers (F_n) as for the full scale ship. The total model resistance (R_{Tm}) is measured.

The conversion from model (m) to ship (s) is made according to the 1978 ITTC Performance Prediction Method. This implies that the frictional resistance coefficient (C_F) is calculated from the ITTC 1957 model - ship correlation line, giving the relation between C_F and Reynolds number (R_n):

$$C_F = \frac{0.075}{(\log_{10} R_n - 2)^2} \qquad R_n = \frac{V\,L}{\nu} \qquad F_n = \frac{V}{\sqrt{g\,L}}$$ where

V = speed, in m/s

L = length of waterline for ship and model respectively, in m

ν = kinematic viscosity, in m^2/s (ITTC 1960)

g = acceleration of gravity, in m/s^2

It is further assumed that the form factor (k) based upon ITTC 1957 and the residuary resistance coefficient (C_R) are identical for model and ship at the same F_n. If ΔC_F is the roughness allowance coefficient and C_{AA} is the air resistance coefficient, the total ship resistance (R_{Ts}) can be calculated from:

$$R_{Ts} = C_{Ts}\,\frac{1}{2}\,\rho_s\,(0.5144\,V_s)^2\,S_s\,10^{-3}$$ where

$$C_{Ts} = \frac{S_s + S_{BK}}{S_s}[(1 + k)\,C_{Fs} + \Delta C_F] + C_R + C_{AA}$$

$$C_{Rm} = C_{Tm} - (1 + k)\,C_{Fm} = C_{Rs} \qquad C_{Tm} = \frac{R_{Tm}}{\frac{1}{2}\rho_m V_m^2 S_m}$$

C_{Tm} and C_{Ts} = the total resistance coefficient

R_{Tm} and R_{Ts} = total resistance, in N and kN respectively

ρ_m and ρ_s = mass density of tank water and sea water respectively, in Ns^2/m^4

V_m and V_s = speed, in m/s and knots (1852 m/h) respectively

S_m and S_s = wetted surface, in m^2

S_{BK} = wetted surface, in m^2 of ship bilge keels

The ship model is not in general fitted with bilge keels.

The form factor (k) showing how large the viscous resistance of model and ship is compared to the ITTC 1957 correlation line is determined from the resistance tests in the low speed range, where the wave resistance is small.

The roughness allowance coefficient (ΔC_F) is assumed to be:

$$\Delta C_F = \left[105\left(\frac{k_s}{L}\right)^{\frac{1}{3}} - 0.64\right] 10^{-3}$$ with hull roughness k_s = 150 µm

The air resistance coefficient (C_{AA}) is assumed to be:

$$C_{AA} = 0.001\frac{A_T}{S_s}$$ where

A_T = transverse projected area above the water of the ship including superstructures, in m^2

Finally, the ship's effective power (P_E) is calculated from:

$P_E = 0.5144\,V_s\,R_{Ts}\,10^{-3}$, in MW (megawatt)

The ship model is equipped with propelling machinery and working propeller(-s). In the self propulsion test the model is towed at speeds giving the same Froude numbers (F_n) as for the full scale ship. The propeller rate of revolutions is in general adjusted so that the towing force (R_a) will reach the value:

$$R_a = \frac{1}{2}\rho_m S_m V_m^2 [C_{Fm} - (C_{Fs} + \Delta C_F)] \quad \text{where}$$

R_a	=	towing force, in N
ρ_m	=	mass density of tank water, in Ns^2/m^4
S_m	=	wetted surface, in m^2
V_m	=	speed, in m/s
C_{Fm} and C_{Fs}	=	frictional resistance coefficients (ITTC 1957)
ΔC_F	=	friction correction dependent on surface condition of the ship hull (Normally $\Delta C_F = 0.0004$)

During the tests propeller thrust (T), torque (Q) and rate of revolutions (n) are measured. The thrust (T) and torque (Q) are expressed in non-dimensional form as:

$$K_{Tm} = \frac{\sum T}{\rho_m D_m^4 n^2 n_p} \qquad K_{Qm} = \frac{\sum Q}{\rho_m D_m^5 n^2 n_p} \quad \text{where}$$

D = propeller diameter in m
n_p = number of propellers

With K_{Tm} as input data the advance ratio (J_{Tm}) and the torque coefficient (K_{QTm}) are derived from the open water characteristics of the model propeller. The wake fraction (w_{Tm}) and the relative rotative efficiency (η_R) are calculated from:

$$w_{Tm} = 1 - \frac{J_{Tm} D n}{V} \qquad \text{and} \qquad \eta_R = \frac{K_{QTm}}{K_{Qm}}$$

The thrust deduction fraction (t) is obtained from:

$$t = \frac{\sum T + R_a - R}{\sum T}$$

where R is the measured model resistance R_{Tm} (see "Resistance tests") corrected for the difference in temperature between resistance and self propulsion tests.

The 1978 ITTC Performance Prediction Method gives the rate of revolutions (n_s) and delivered power (P_{Ds}) for the ship (s) obtained from the full scale propeller open water characteristics. These characteristics are determined by correcting the model (m) values for drag scale effects (see "Propeller open water tests").

The full scale wake (w_{Ts}) is calculated from the model wake (w_{Tm}) and the thrust deduction fraction (t) according to:

$$w_{Ts} = (t + 0.04) + (w_{Tm} - t - 0.04)\frac{(1+k)\,C_{Fs} + \Delta C_F}{(1+k)\,C_{Fm}} \quad \text{where}$$

k	=	form factor	(see "Resistance tests")
ΔC_F	=	roughness allowance coefficient	(see "Resistance tests")

If $w_{Ts} > w_{Tm}$, w_{Ts} will be set equal to w_{Tm}

The load of the full scale propeller is obtained from:

$$\frac{K_T}{J^2} = \frac{S_s}{2D^2}\frac{C_{Ts}}{(1-t)(1-w_{Ts})^2 n_p} \quad \text{where:}$$

S_s = wetted surface of hull, in m^2
D = propeller diameter, in m
C_{Ts} = total resistance coefficient

With K_T/J^2 as input value, the full scale advance ratio (J_{Ts}) and the torque coefficient (K_{QTs}) are determined from the full scale propeller open water characteristics and the following quantities are calculated. The rate of revolutions:

$$n_s = \frac{(1-w_{Ts})\ 0.5144\ V_s}{J_{Ts} D} \quad \text{r/s} \quad \text{where}$$

V_s = speed, in knots (1852 m/h)

The delivered power:

$$P_{Ds} = 2\pi\ \rho\ D^5\ n_s^3\ n_p\ \frac{K_{QTs}}{\eta_R}\ 10^{-6} \quad \text{MW (megawatt)} \quad \text{where}$$

ρ = mass density of sea water, in Ns^2/m^4

The thrust of the propeller:

$$T_s = \frac{K_T}{J^2}\ J_{Ts}^2\ \rho\ D^4\ n_s^2\ 10^{-3} \quad \text{kN}$$

The torque of the propeller:

$$Q_s = \frac{K_{QTs}}{\eta_R}\ \rho\ D^5\ n_s^2\ 10^{-3} \quad \text{kNm} \quad \text{where}$$

The total efficiency:

$$\eta_D = \frac{P_E}{P_{Ds}}$$

P_E is the ship's effective power, in MW (see "Resistance tests")

The propeller efficiency:,

$$\eta_0 = \frac{K_T}{K_Q}\frac{J_{Ts}}{2\pi} \quad \text{where}$$

K_T as well as K_Q are valid for $J = J_{Ts}$

The hull efficiency:

$$\eta_H = \frac{1-t}{1-w_{Ts}}$$

To make the prediction correspond to trial conditions ($_T$) the calculated rate of revolutions (n_s) and the delivered power (P_{Ds}) are corrected to our present trial statistics:

$n_T = C_n\ n_s$ $\quad$ $P_{DT} = C_P\ P_{Ds}$ where

n_T and P_{DT} = rate of revolutions and delivered power respectively on trials
C_n and C_P = correction factors for rate of revolutions and delivered power respectively

The given standard trial prediction is valid for the hull roughness (k_s = 150 μm) and the propeller blade roughness (k_p = 30 μm). The roughness for modern ships delivered over the last years is in general lower than the standard figures for k_s and k_p and therefore SSPA uses lower correction factors C_n and C_P.