POTSDAM MODEL BASIN

Potsdam Propeller Test Case (PPTC)

Open Water Tests with the Model Propeller VP1304

Report 3752

Potsdam, April 2011

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This report includes

5 pages text
13 pages tables
4 pages diagrams/drawings
3 pages photographs
5 pages annex

Potsdam, 15/04/2011

Management Author

Content

1 Summary

For the SMP'11 workshop the SVA provided the controllable pitch propeller VP1304 as a test case. Several investigations were conducted with this propeller: open water tests, cavitation tests [1] and LDV measurements [2].

The open water characteristics are presented on pages 3.2 and 3.3.

The influence of the hub and gab forces on the open water characteristic was analysed.

2 Introduction

In the intention to offer research groups the possibility to test and validate their numerical tools the SVA investigates the controllable pitch propeller VP1304. The measurements shall contribute to a better numerical prediction of open water characteristics.

Furthermore the propeller VP1304 shall become a standard test propeller within the SVA and is presented by the name PPTC, an acronym for "Potsdam Propeller Test Case". Therefore extensive tests shall expand the measurement data of this propeller.

In this report the open water characteristics measured in the towing tank of the SVA are presented.

It should be pointed out that the SVA reports 3753 [1] and 3754 [2] deal with the cavitation tests and the Laser Doppler Velocimetry (LDV) measurements respectively.

3 Tasks

The model propeller VP1304 was tested in the towing tank of the Potsdam Model Basin in homogeneous flow.

Open water characteristics were measured at two different numbers of revolutions (n = 10 and 15 s^{-1}).

Furthermore the resistance and idle torque of the propeller hub was investigated at the same velocities and numbers of revolutions with a dummy hub.

4 Description of the model propeller VP1304

The propeller was designed by the SVA in 1998. For the manufacture of the propeller cold-rolled brass was used as raw material. The blades were manufactured on a CNC-based milling machine with HSC (high speed cutting) technology.

The propeller main properties are shown in table 1 and in the drawing on page 3.1. Photos of the propeller are shown on page 4.1.

The propeller is a controllable pitch propeller. This affects the propeller blade design near the hub and results in a 0.3 mm gap between hub and propeller blade near the leading and trailing edge of the propeller.

Table 1: Main data of model propeller VP1304

			VP1304
Diameter	D	[m]	0.250
Pitch ratio $r/R = 0.7$	$P_{0.7}/D$	[–]	1.635
Area ratio	A_E/A_0	[–]	0.77896
Chord length $r/R = 0.7$	$c_{0.7}$	[m]	0.10417
Skew	θ_{EXT}	[°]	18.837
Hub ratio	d_h/D	[–]	0.300
Number of blades	Z	[–]	5
Sense of rotation		[–]	right
Type		[–]	controllable pitch propeller

5 Test arrangement

For the open water tests the dynamometer H39 from Kempf & Remmers has been arranged behind the propeller model. The assembly of caps, hub and propeller is shown on page 4.2. On page 4.3 the dynamometer H39 and the VP1304 are presented.

6 Test procedure

Apart from the calibration of the measuring device, runs have been made in order to measure the idle torque and the resistance of the hub cap with the dummy hub, having the same shape and mass as the real propeller hub.

Therefore the test 11F0391 provided data about the force and torque due to gap flows between hub and dynamometer shaft as well as the influence of the bearings for the condition $V = 0$ m/s.

The test runs 11F0392 and 11F0393 show the resistance and torque of the hub without blades for different advance coefficients. To eliminate the influence of the dynamometer bearings all following torque data were corrected by the dummy hub values.

In order to obtain the thrust create by the propeller blades the measured thrust was corrected by the resistance of the dummy hub.

The open water tests were carried out at two different numbers of revolutions to evaluate the dependency on the Reynolds number.

7 Open water test results

The measurements with different numbers of revolutions feature an influence of the Reynolds number on the open water characteristic (see page 3.1). The characteristics of K_T and $10K_Q$ at higher numbers of revolutions show a smaller gradient and cross the characteristics of lower numbers of revolutions at an advance coefficient of $J = 1.3$.

Therefore the open water efficiency maximum of $\eta_O = 0.7$ is reached at higher Reynolds numbers and the advance coefficient $J = 1.29$ for the propeller without a hub correction (see page 3.2).

The correction of the measured propeller thrust with the hub resistance leads to significant higher efficiencies and advance coefficients $J(\eta_{O,max})$. The maxima efficiencies of all configurations are summarised in table 2.

Table 2: Open water efficiency maxima (by polynomials)

rps [s^{-1}]	configuration	$J(\eta_{Omax})$ [-]	η_{Omax} [-]
10	blades and hub	1.27	0.690
10	only blades	1.33	0.738
15	blades and hub	1.29	0.700
15	only blades	1.36	0.751

8 References

[1] Heinke, H.–J.
Potsdam Propeller Test Case (PPTC) - Cavitation Tests with the Model Propeller VP1304
Report 3753, Schiffbau-Versuchsanstalt Potsdam, April 2011

[2] Mach, K.-P.
Potsdam Propeller Test Case (PPTC) - LDV velocity measurements with the Model Propeller VP1304
Report 3754, Schiffbau-Versuchsanstalt Potsdam, April 2011

Details of model tests

VP1304

Towing tank	
Dimensions of towing tank	280 x 9 x 4.5 m
Propeller:	VP1304
Propeller type	controllable pitch propeller
Material of model propeller	brass
Diameter of the propeller	0.25 m
Sense of rotation	right (looking on pressure side)
Arrangement:	
Shaft inclination	0°
Dynamometer shaft	behind the propeller
Measuring equipment:	dynamometer H39
	n_{max} = 60 s^{-1}
	T_{max} = 1 kN
	Q_{max} = 50 Nm

Overview of model tests in the towing tank

Test No.	Date	Test	Test parameters	Table	Diagram
11F0391	08/04/2011	Idle torque and gap forces with dummy hub	V = 0 m/s n = 10 - 20 s^{-1}	2.3	-
11F0392	08/04/2011	Idle torque and forces with dummy hub	V = 0 – 4 m/s n = 10 s^{-1}	2.4	-
11F0393	08/04/2011	Idle torque and forces with dummy hub	V = 0 – 6 m/s n = 15 s^{-1}	2.5	-
11F0394	08/04/2011	Open water test	V = 0 – 4.14 m/s n = 10 s^{-1}	2.6 - 2.9	3.1, 3.2
11F0395	08/04/2011	Open water test	V = 0 – 6.3 m/s n = 15 s^{-1}	2.10 - 2.13	3.1, 3.2

Pre-test with dummy hub, V = 0 m/s

Test **11F0391** Date 08.04.2011

Type of test **Idle torque and gap force measurement with dummy hub, V = 0 m/s**

Particulars of the dummy hub

d_h [m] **0.075**

Sense of rotation right-handed

Environmental data

t_W [°C] 15.6 ν [m²/s] 1.124e-6 ρ [kg/m³] 998.99

Propeller shaft downstream

Measured values

No.	V [m/s]	n [rps]	R [N]	Q [Nm]
1	0.000	9.988	-0.44	0.205
2	0.000	10.035	-0.38	0.189
3	0.000	14.985	-0.72	0.200
4	0.000	15.043	-0.73	0.228
5	0.000	20.029	-1.28	0.229

Pre-test with dummy hub, n = 10 s^{-1}

Test **11F0392** Date 08.04.2011

Type of test **Idle torque and force measurement with dummy hub, n = 10 s^{-1}**

Particulars of the dummy hub

d_h [m] **0.075**

Sense of rotation right-handed

Environmental data

t_W [°C] 15.6 ν [m²/s] 1.124e-6 ρ [kg/m³] 998.99

Propeller shaft downstream

Measured values

No.	V [m/s]	n [rps]	R [N]	Q [Nm]
1	0.000	10.035	-0.46	0.215
2	1.000	10.033	-1.75	0.198
3	2.000	10.033	-3.08	0.201
4	2.999	10.034	-5.30	0.206
5	4.000	10.032	-8.40	0.207

Pre-test with dummy hub, n = 15 s^{-1}

Test **11F0393** Date 08.04.2011

Type of test **Idle torque and force measurement with dummy hub, n = 15 s^{-1}**

Particulars of the dummy hub

d_h [m] **0.075**

Sense of rotation right-handed

Environmental data

t_W [°C] 15.6 ν [m²/s] 1.124e-6 ρ [kg/m³] 998.99

Propeller shaft downstream

Measured values

No.	V [m/s]	n [rps]	R [N]	Q [Nm]
1	0.000	14.985	-0.77	0.214
2	0.999	15.036	-2.88	0.210
3	1.998	15.035	-4.34	0.215
4	3.000	15.034	-6.51	0.215
5	4.001	15.030	-9.55	0.215
6	5.002	15.029	-13.62	0.219
7	6.000	15.029	-18.45	0.223

Open water test, n = 10 s^{-1}

Test	**11F0394**				Date		08.04.2011
Type of test	**Open water test, corrected with idle torque and gap force**						

Particulars of the propulsor

Propeller	**VP1304**	D	[m]	**0.25000**	$P_{0.7}/D$	[-]	**1.63500**
Sense of rotation	right-handed	$c_{0.7}$	[m]	0.10417	d_h/D	[-]	0.30000

Environmental data

t_W	[°C] 15.6	v	[m²/s]	1.124e-6	ρ	[kg/m³]	998.99
Propeller shaft	downstream						

Measured and corrected values

No.	V [m/s]	n [rps]	T [N]	Q [Nm]
1	0.000	9.981	371.07	20.217
2	0.399	9.981	347.16	18.867
3	0.803	9.982	310.51	16.885
4	1.202	9.982	272.74	15.032
5	1.602	9.983	234.67	13.291
6	2.002	9.985	198.42	11.665
7	2.399	9.986	163.50	10.116
8	2.799	9.987	126.06	8.374
9	3.203	9.986	90.19	6.646
10	3.600	9.984	54.60	4.890
11	3.999	9.985	11.14	2.605
12	4.136	9.988	-4.91	1.738

Open water test, n = 10 s^{-1}

Test	**11F0394**				Date		08.04.2011
Type of test	**Open water test, corrected with idle torque and gap force**						

Particulars of the propulsor

Propeller	**VP1304**	D	[m]	**0.25000**	$P_{0.7}/D$	[-]	**1.63500**
Sense of rotation	right-handed	$c_{0.7}$	[m]	0.10417	d_h/D	[-]	0.30000

Environmental data

t_W	[°C] 15.6	v	[m²/s]	1.124e-6	ρ	[kg/m³]	998.99
Propeller shaft	downstream						

Characteristic of propeller (model scale)

No.	J	K_T	$10K_Q$	η_O	C_{Th}	Re [10^{-6}]
1	0.0000	0.9545	2.0801	0.000	999.99	0.509
2	0.1600	0.8929	1.9412	0.117	88.78	0.510
3	0.3217	0.7986	1.7370	0.235	19.65	0.514
4	0.4816	0.7014	1.5463	0.348	7.70	0.521
5	0.6418	0.6034	1.3669	0.451	3.73	0.530
6	0.8021	0.5100	1.1994	0.543	2.02	0.542
7	0.9610	0.4202	1.0399	0.618	1.16	0.555
8	1.1212	0.3239	0.8606	0.672	0.66	0.571
9	1.2830	0.2318	0.6832	0.693	0.36	0.589
10	1.4422	0.1404	0.5029	0.641	0.17	0.608
11	1.6021	0.0286	0.2678	0.273	0.03	0.630
12	1.6563	-0.0126	0.1786	-0.186	-0.01	0.637

Coefficients of polynoms

p	a_0	a_1	a_2	a_3	a_4
K_T	0.956454	-0.347156	-0.584163	0.525066	-0.156480
$10K_Q$	2.086429	-0.908317	-0.748857	0.857837	-0.298699

Valid in area 0.000 <= J <= 1.656, $p(x) = a_0 + a_1x + a_2x^2 + a_3x^3 + a_4x^4$

Open water test, n = 10 s^{-1}

Test	**11F0394**				Date		08.04.2011
Type of test	**Open water test, corrected with idle torque and hub resistance**						

Particulars of the propulsor

Propeller	**VP1304**	D	[m]	**0.25000**	$P_{0.7}/D$	[-]	**1.63500**
Sense of rotation	right-handed	$c_{0.7}$	[m]	0.10417	d_h/D	[-]	0.30000

Environmental data

t_W	[°C]	15.6	ν	[m²/s]	1.124e-6	ρ	[kg/m³] 998.99
Propeller shaft		downstream					

Measured and corrected values

No.	V [m/s]	n [rps]	T [N]	Q [Nm]
1	0.000	9.981	371.10	20.217
2	0.399	9.981	347.51	18.867
3	0.803	9.982	311.29	16.885
4	1.202	9.982	274.06	15.032
5	1.602	9.983	236.63	13.291
6	2.002	9.985	201.12	11.665
7	2.399	9.986	167.04	10.116
8	2.799	9.987	130.55	8.374
9	3.203	9.986	95.74	6.646
10	3.600	9.984	61.30	4.890
11	3.999	9.985	19.10	2.605
12	4.136	9.988	3.50	1.738

Open water test, n = 10 s^{-1}

Test	**11F0394**				Date		08.04.2011
Type of test	**Open water test, corrected with idle torque and hub resistance**						

Particulars of the propulsor

Propeller	**VP1304**	D	[m]	**0.25000**	$P_{0.7}/D$	[-]	**1.63500**
Sense of rotation	right-handed	$c_{0.7}$	[m]	0.10417	d_h/D	[-]	0.30000

Environmental data

t_W	[°C] 15.6	v	[m²/s]	1.124e-6	ρ	[kg/m³]	998.99
Propeller shaft	downstream						

Characteristic of propeller (model scale)

No.	J	K_T	$10K_Q$	η_O	C_{Th}	Re [10^{-6}]
1	0.0000	0.9546	2.0801	0.000	999.99	0.509
2	0.1600	0.8939	1.9412	0.117	88.87	0.510
3	0.3217	0.8006	1.7370	0.236	19.70	0.514
4	0.4816	0.7048	1.5463	0.349	7.74	0.521
5	0.6418	0.6084	1.3669	0.455	3.76	0.530
6	0.8021	0.5170	1.1994	0.550	2.05	0.542
7	0.9610	0.4293	1.0399	0.631	1.18	0.555
8	1.1212	0.3354	0.8606	0.695	0.68	0.571
9	1.2830	0.2460	0.6832	0.735	0.38	0.589
10	1.4422	0.1576	0.5029	0.719	0.19	0.608
11	1.6021	0.0491	0.2678	0.467	0.05	0.630
12	1.6563	0.0090	0.1786	0.133	0.01	0.637

Coefficients of polynoms

p	a_0	a_1	a_2	a_3	a_4
K_T	0.956529	-0.342733	-0.579025	0.525112	-0.156494
$10K_Q$	2.086429	-0.908317	-0.748857	0.857837	-0.298699

Valid in area 0.000 <= J <= 1.656, $p(x) = a_0 + a_1x + a_2x^2 + a_3x^3 + a_4x^4$

Open water test, n = 15 s^{-1}

Test	**11F0395**				Date		08.04.2011
Type of test	**Open water test, corrected with idle torque and gap force**						

Particulars of the propulsor

Propeller	**VP1304**	D	[m]	**0.25000**	$P_{0.7}/D$	[-]	**1.63500**
Sense of rotation	right-handed	$c_{0.7}$	[m]	0.10417	d_h/D	[-]	0.30000

Environmental data

t_W	[°C] 15.6	v	[m²/s]	1.124e-6	ρ	[kg/m³]	998.99
Propeller shaft	downstream						

Measured and corrected values

No.	V [m/s]	n [rps]	T [N]	Q [Nm]
1	0.000	14.984	835.00	45.315
2	0.500	14.984	792.09	42.773
3	1.000	14.983	726.41	39.186
4	1.501	14.983	651.87	35.385
5	2.000	14.982	580.78	32.073
6	2.500	14.981	512.66	29.013
7	3.000	15.026	445.10	26.071
8	3.498	15.023	378.40	23.102
9	4.000	14.978	309.71	19.907
10	4.500	14.974	244.70	16.791
11	5.000	15.028	183.45	13.880
12	5.502	15.080	123.69	10.968
13	6.002	15.026	37.93	6.419
14	6.301	15.029	-15.03	3.545

Open water test, n = 15 s^{-1}

Test	**11F0395**				Date		08.04.2011
Type of test	**Open water test, corrected with idle torque and gap force**						

Particulars of the propulsor

Propeller	**VP1304**	D	[m]	**0.25000**	$P_{0.7}/D$	[-]	**1.63500**
Sense of rotation	right-handed	$c_{0.7}$	[m]	0.10417	d_h/D	[-]	0.30000

Environmental data

t_W	[°C] 15.6	v	[m²/s]	1.124e-6	ρ	[kg/m³]	998.99
Propeller shaft	downstream						

Characteristic of propeller (model scale)

No.	J	K_T	$10K_Q$	η_O	C_{Th}	Re [10^{-6}]
1	0.0000	0.9531	2.0689	0.000	999.99	0.764
2	0.1334	0.9041	1.9529	0.098	129.44	0.765
3	0.2670	0.8292	1.7892	0.197	29.63	0.769
4	0.4006	0.7442	1.6158	0.294	11.81	0.776
5	0.5341	0.6631	1.4648	0.385	5.92	0.786
6	0.6676	0.5854	1.3251	0.469	3.34	0.798
7	0.7985	0.5052	1.1836	0.542	2.02	0.815
8	0.9314	0.4297	1.0493	0.607	1.26	0.831
9	1.0683	0.3538	0.9096	0.661	0.79	0.849
10	1.2021	0.2797	0.7676	0.697	0.49	0.870
11	1.3308	0.2082	0.6300	0.700	0.30	0.895
12	1.4594	0.1394	0.4944	0.655	0.17	0.922
13	1.5978	0.0430	0.2914	0.376	0.04	0.947
14	1.6769	-0.0171	0.1609	-0.283	-0.02	0.963

Coefficients of polynoms

p	a_0	a_1	a_2	a_3	a_4
K_T	0.955438	-0.346932	-0.629537	0.586304	-0.175174
$10K_Q$	2.076022	-0.949651	-0.719299	0.873861	-0.306054

Valid in area 0.000 <= J <= 1.677, $p(x) = a_0 + a_1x + a_2x^2 + a_3x^3 + a_4x^4$

Open water test, n = 15 s^{-1}

Test	**11F0395**				Date		08.04.2011
Type of test	**Open water test, corrected with idle torque and hub resistance**						

Particulars of the propulsor

Propeller	**VP1304**	D	[m]	**0.25000**	$P_{0.7}/D$	[-]	**1.63500**
Sense of rotation	right-handed	$c_{0.7}$	[m]	0.10417	d_h/D	[-]	0.30000

Environmental data

t_W	[°C] 15.6	ν	[m²/s]	1.124e-6	ρ	[kg/m³]	998.99
Propeller shaft	downstream						

Measured values

No.	V [m/s]	n [rps]	T [N]	Q [Nm]
1	0.000	14.984	835.00	45.315
2	0.500	14.984	792.62	42.773
3	1.000	14.983	727.63	39.186
4	1.501	14.983	653.97	35.385
5	2.000	14.982	583.92	32.073
6	2.500	14.981	517.02	29.013
7	3.000	15.026	450.84	26.071
8	3.498	15.023	385.70	23.102
9	4.000	14.978	318.74	19.907
10	4.500	14.974	255.63	16.791
11	5.000	15.028	196.45	13.880
12	5.502	15.080	138.95	10.968
13	6.002	15.026	55.60	6.419
14	6.301	15.029	4.17	3.545

Open water test, n = 15 s^{-1}

Test	**11F0395**				Date		08.04.2011
Type of test	**Open water test, corrected with idle torque and hub resistance**						

Particulars of the propulsor

Propeller	**VP1304**	D	[m]	**0.25000**	$P_{0.7}/D$	[-]	**1.63500**
Sense of rotation	right-handed	$c_{0.7}$	[m]	0.10417	d_h/D	[-]	0.30000

Environmental data

t_W	[°C] 15.6	v	[m²/s]	1.124e-6	ρ	[kg/m³]	998.99
Propeller shaft	downstream						

Characteristic of propeller (model scale)

No.	J	K_T	$10K_Q$	η_O	C_{Th}	Re [10^{-6}]
1	0.0000	0.9531	2.0689	0.000	999.99	0.764
2	0.1334	0.9047	1.9529	0.098	129.52	0.765
3	0.2670	0.8306	1.7892	0.197	29.68	0.769
4	0.4006	0.7466	1.6158	0.295	11.84	0.776
5	0.5341	0.6667	1.4648	0.387	5.95	0.786
6	0.6676	0.5903	1.3251	0.473	3.37	0.798
7	0.7985	0.5117	1.1836	0.549	2.04	0.815
8	0.9314	0.4380	1.0493	0.619	1.29	0.831
9	1.0683	0.3641	0.9096	0.681	0.81	0.849
10	1.2021	0.2922	0.7676	0.728	0.51	0.870
11	1.3308	0.2229	0.6300	0.749	0.32	0.895
12	1.4594	0.1566	0.4944	0.736	0.19	0.922
13	1.5978	0.0631	0.2914	0.551	0.06	0.947
14	1.6769	0.0047	0.1609	0.078	0.00	0.963

Coefficients of polynoms

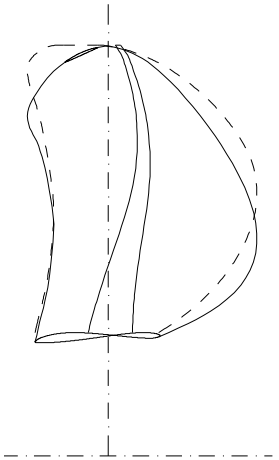
p	a_0	a_1	a_2	a_3	a_4
K_T	0.955439	-0.343185	-0.623945	0.586207	-0.175145
$10K_Q$	2.076022	-0.949651	-0.719299	0.873861	-0.306054

Valid in area 0.000 <= J <= 1.677, $p(x) = a_0 + a_1x + a_2x^2 + a_3x^3 + a_4x^4$

Model propeller VP1304

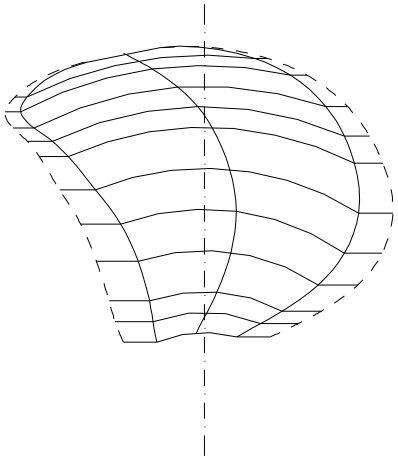
SIDE VIEW

CLEARANCE CURVE



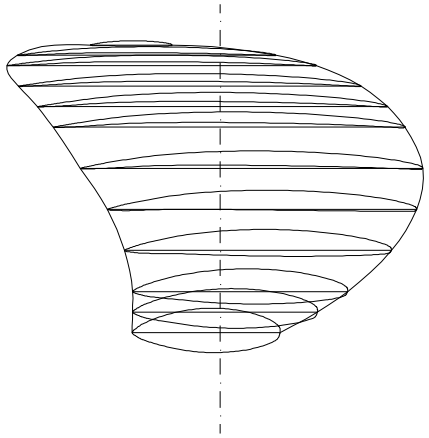
PROJECTED OUTLINE

DEVELOPED OUTLINE

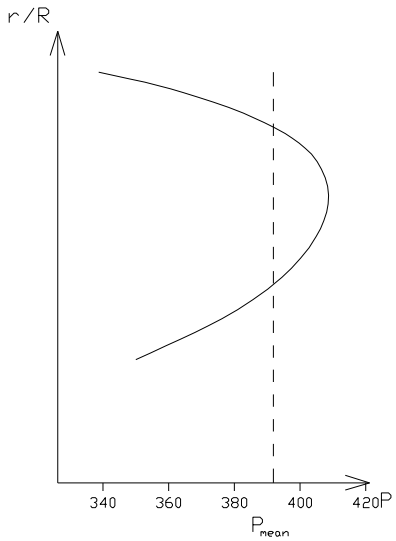


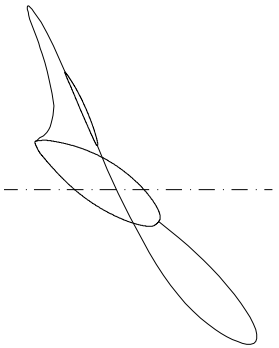
BLADE SECTIONS

EXPANDED OUTLINE



PITCH DISTRIBUTION





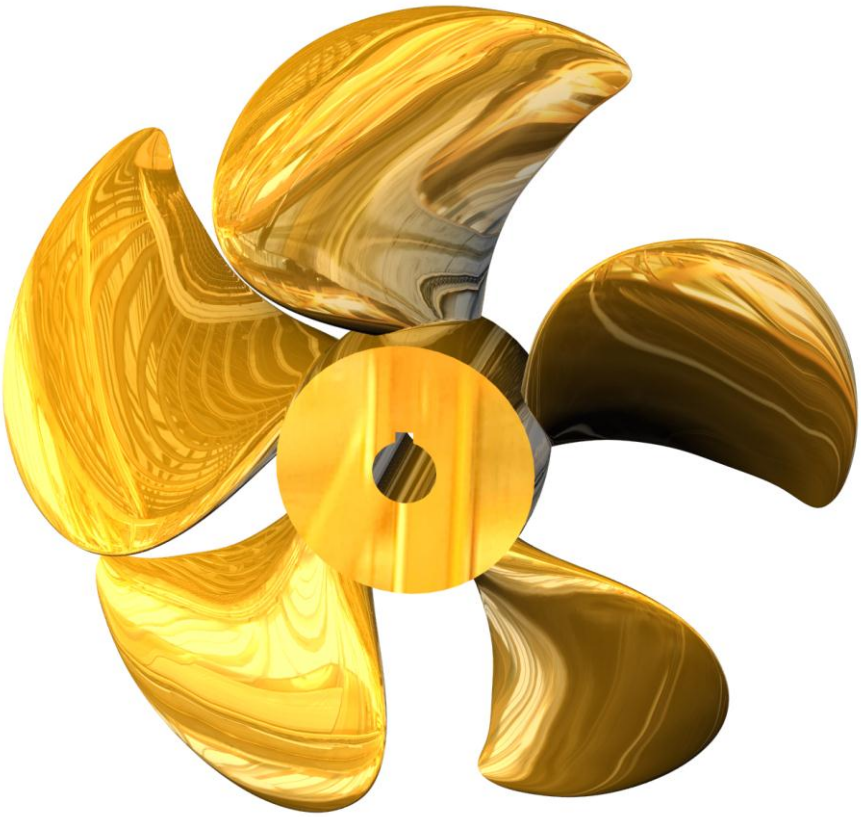
r/R	r	t	c	c_LE	f	rake	P
0.30000	37.50	13.525	45.00	18.25	0.675	0.000	350.00
0.35000	43.75	12.050	56.25	29.63	1.125	-0.500	363.75
0.40000	50.00	10.688	65.42	38.79	1.570	-1.250	376.25
0.50000	62.50	8.137	81.25	52.13	2.356	-3.350	394.50
0.60000	75.00	6.050	94.17	59.83	2.837	-5.875	405.00
0.70000	87.50	4.425	104.17	61.67	3.093	-7.500	408.75
0.80000	100.00	3.250	107.08	56.29	3.052	-7.375	403.50
0.85000	106.25	2.775	106.54	50.93	2.967	-6.625	395.50
0.90000	112.50	2.375	104.17	42.83	2.672	-5.450	382.75
0.95000	118.75	2.013	94.17	29.33	2.194	-4.033	364.50
0.97500	121.88	1.825	78.67	17.00	1.715	-3.300	352.75
1.00000	125.00	1.638	25.00	-14.58	0.500	-2.500	338.75

PROPELLER DIAMETER	D	250.0000mm
PITCH AT r/R=0.7	$P_{0.7}$	408.7500mm
PITCH AT r/R=0.75	$P_{0.75}$	407.3804mm
MEAN PITCH	P_{mean}	391.8812mm
CORDL. AT r/R=0.75	$c_{0.75}$	106.3476mm
THICKN. AT r/R=0.75	$t_{0.75}$	3.7916mm
PITCH RATIO	$P_{0.7}/D$	1.63500
MEAN PITCH RATIO	P_{mean}/D	1.56752
AREA RATIO	A_E/A_0	0.77896
SKEW		18.837°
HUB DIAMETER RATIO	d_h/D	0.30000
NUMBER OF BLADES	z	5
DIRECTION OF ROTATION		RIGHT-HANDED

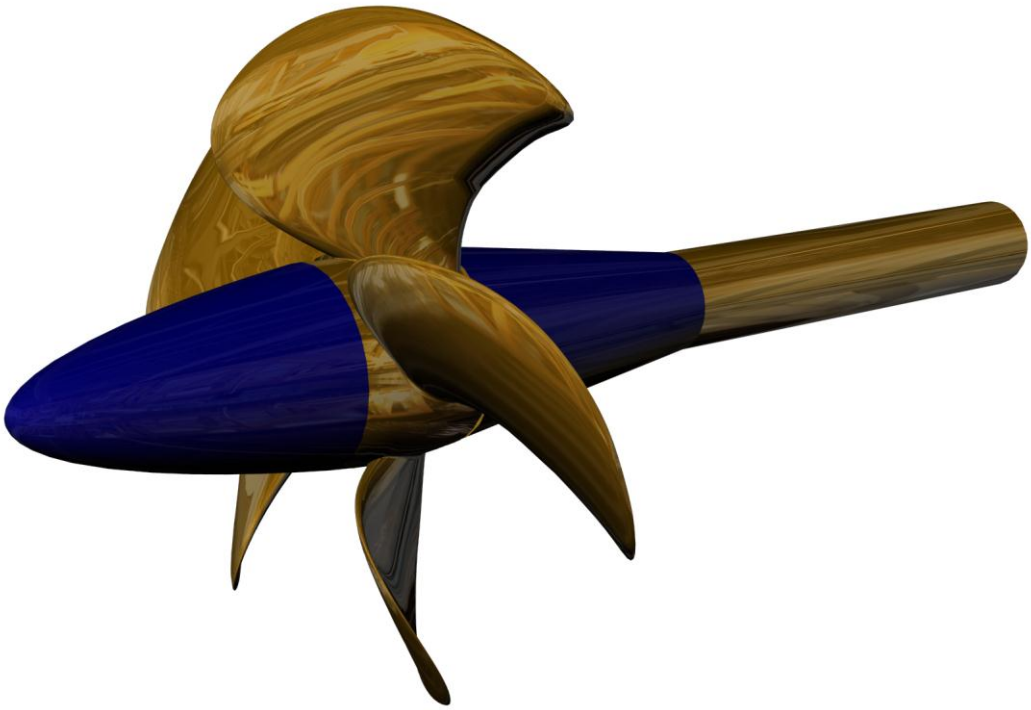
MODEL SCALE 1 : 1.000000

DIAGRAMS/DRAWINGS

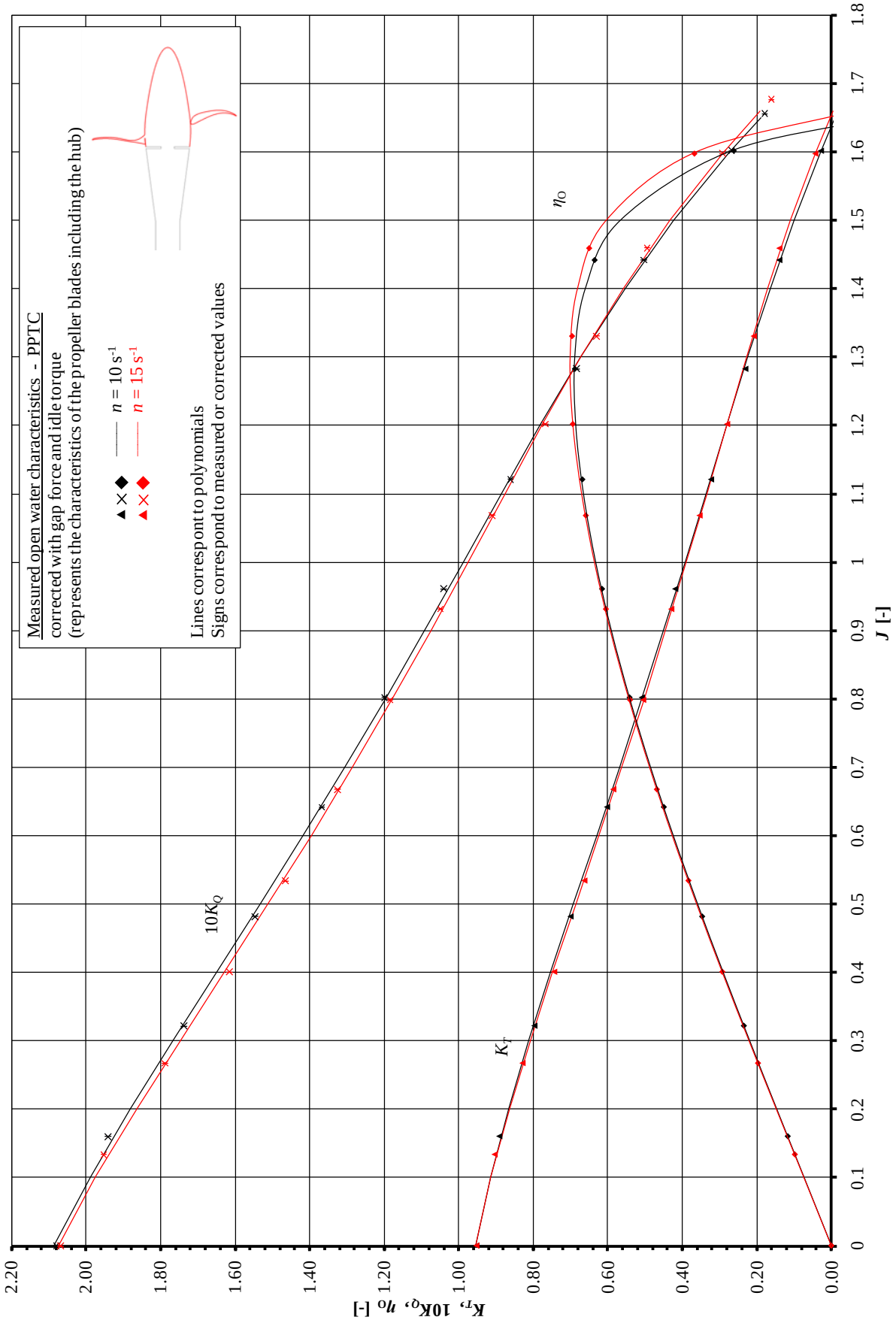
Propeller VP1304



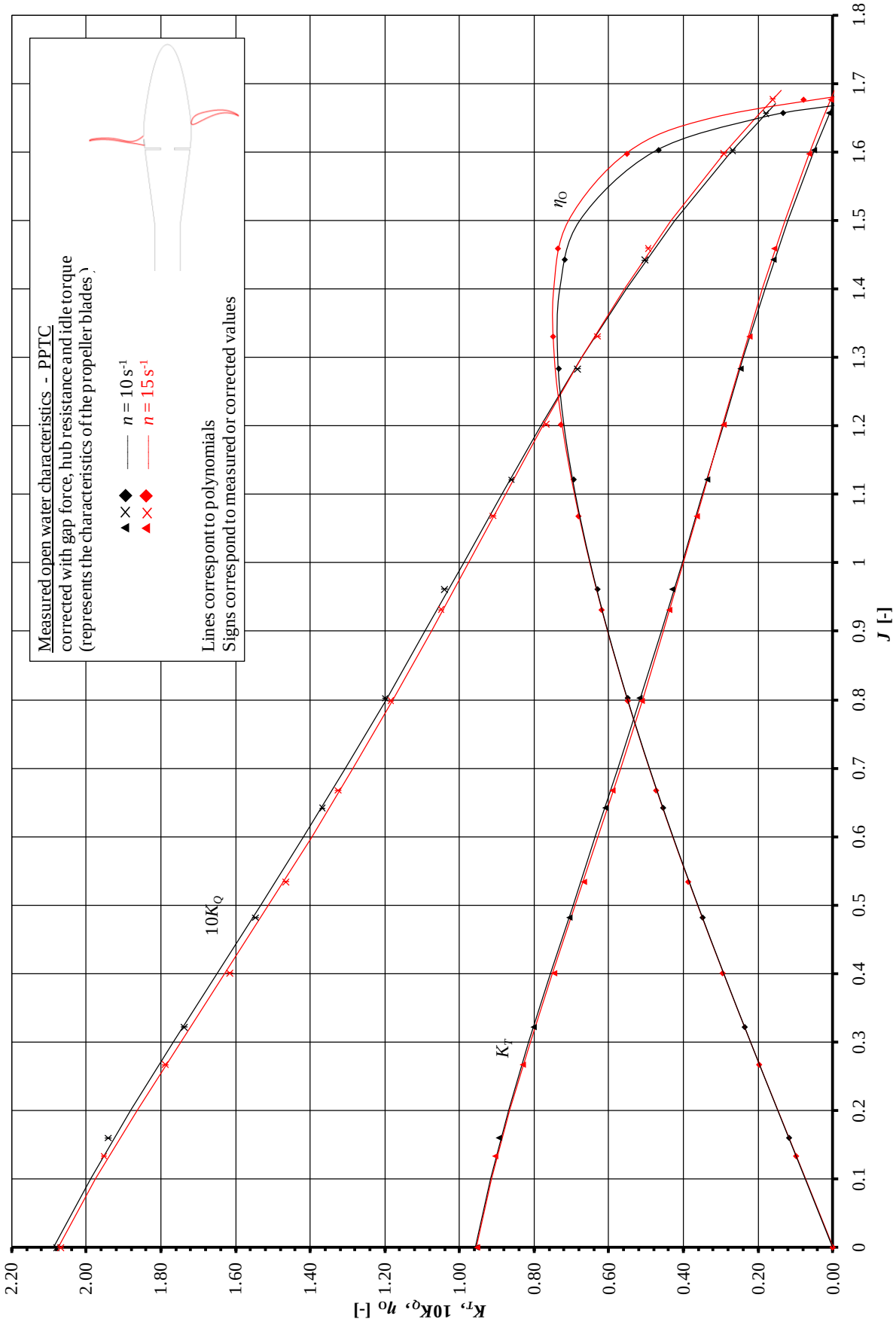
VP1304 in open water configuration



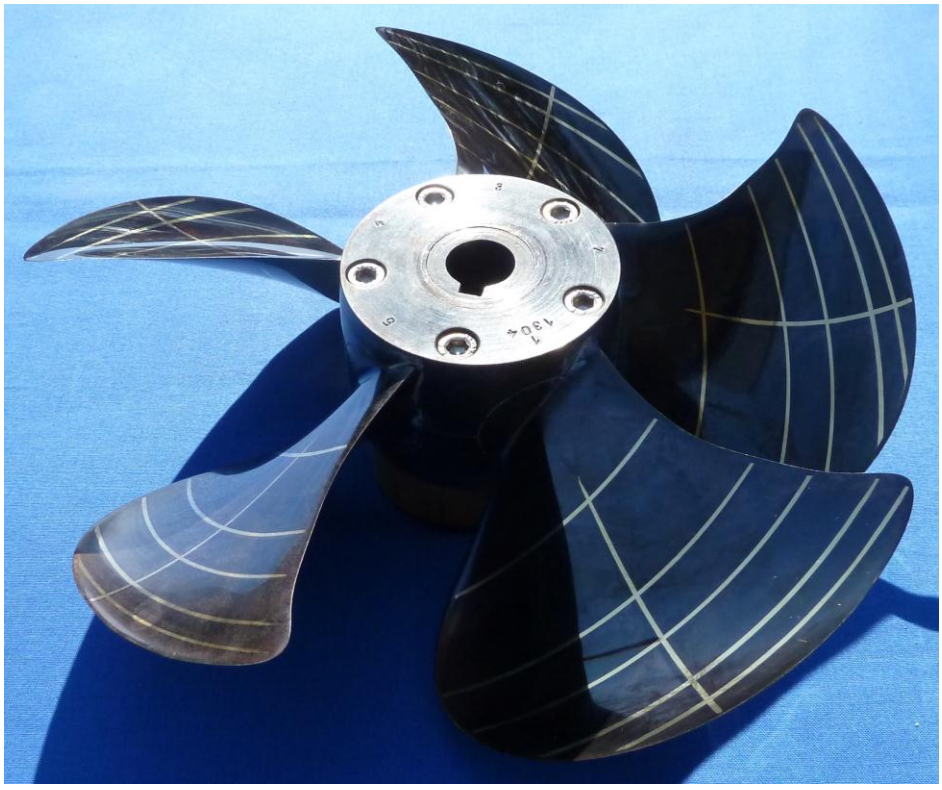
Open water characteristics of VP1304



Open water characteristic of VP1304



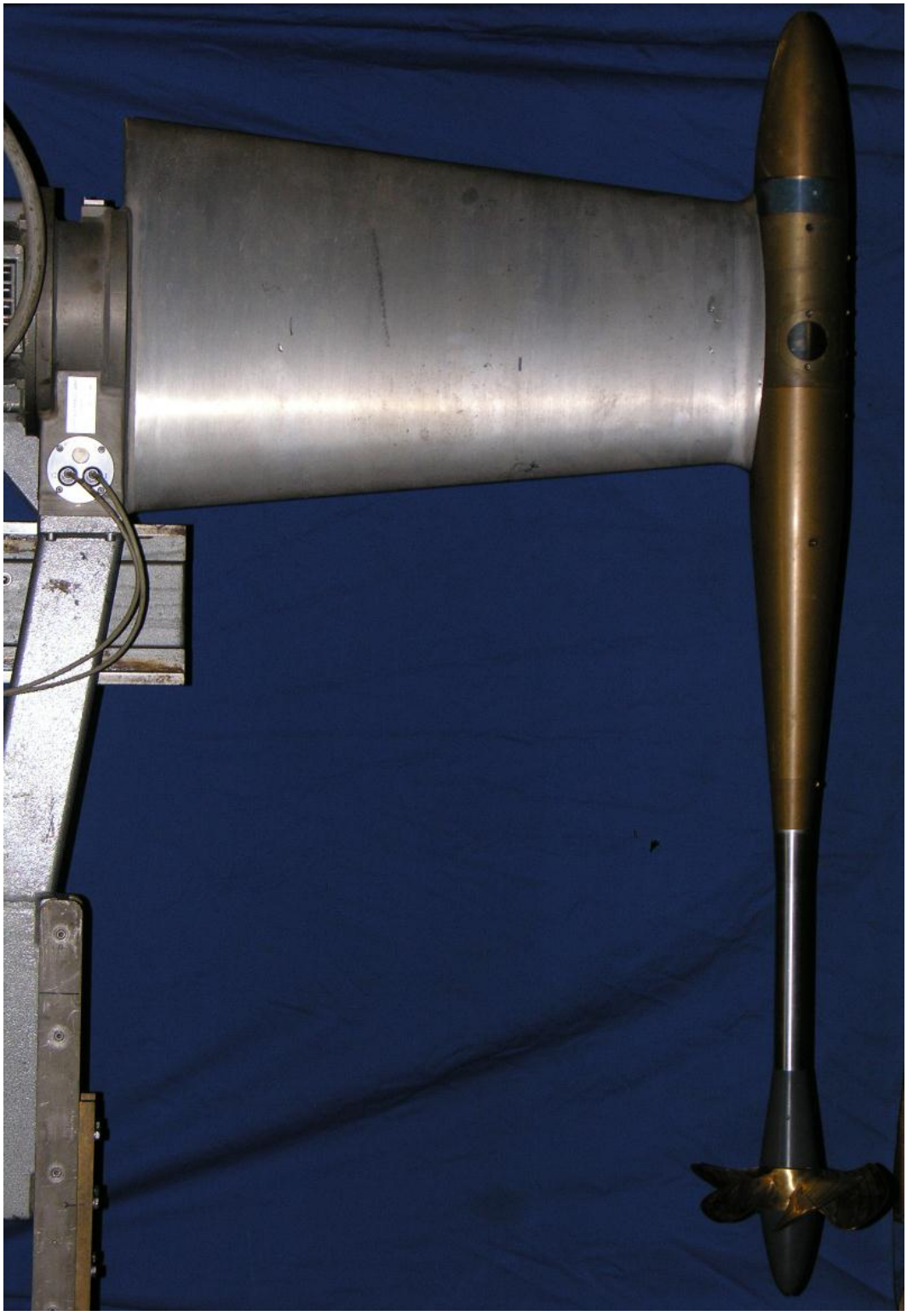
Model propeller VP1304



Dummy hub configuration

VP1304 with caps

Dynamometer H39 with VP1304



Symbols

symbol	name	definition or explanation	SI - unit
A_E	Expanded blade area	Expanded blade area of a screw propeller outside the boss or hub	m^2
A_0	Propeller disc area	$\pi D^2 / 4$	m^2
A_P	Projected blade area	Projected blade area of a screw propeller outside the boss or hub	m^2
C_{Th}	Thrust loading coefficient	$T / (A_P q_A) = (T_P / A_P) / q_A$	1
D	Rotor diameter		m
c	Chord length		m
d_h	Boss or hub diameter		m
F	Force		N
g	Acceleration of gravity	Weight force / mass, strength of the earth gravity field	m/s^2
n	Frequency or rate of revolution	Alias RPS (RPM in some propulsor applications)	Hz
h_0	Immersion	The depth of submergence of the propeller measured vertically from the propeller centre to the free surface	m
J	Propeller advance ratio	$V_A / (D n)$	1
K_Q	Torque coefficient	$Q / (\rho n^2 D^5)$	1
K_T	Thrust coefficient	$T / ((\rho n^2 D^4)$	1
P	Power		W
P	Pitch in general		m
p_a	Atmospheric pressure		Pa
P_D, P_P	Delivered power, rotor power	$Q \omega$	W
P_T	Thrust power	$T V_A$	W
P/D	Pitch ratio		1
Q	Torque	P_D / ω	Nm
q_A	Dynamic pressure based on advance speed	$\rho V_A^2 / 2$	Pa
R	Resistance (force)	Force opposing translatory velocity	N
R	Radius		m
Re	Reynolds number	$(c_{0.7} \cdot \sqrt{V_A^2 + (0.7\pi \cdot n \cdot D)^2}) / \nu$	1
r	Radius		m

ANNEX

Symbols

symbol	name	definition or explanation	SI - unit
T	Thrust		N
t	Time	$-\infty$ ... $+\infty$	s
t_W	Temperature of water		°C
t	Blade section thickness		m
V	Velocity of a body, speed in general of the model or the ship		m/s
V_A	Advance speed	Equivalent propeller open water speed based on thrust or torque identity	m/s
Z, z	Number of blades		1
ε	Angle of rake		deg
θ	Angle of blade position		deg
λ	Scale ratio, linear scale of model	Propeller (index $_S$) dimension divided by corresponding model (index $_M$) dimension $\lambda = D_S / D_M$	1
μ	Viscosity		kg/ms
ν	Kinematic viscosity	μ / ρ	m^2/s
π	Circular constant	3.1415926535	1
ρ	Mass density of fluid	dm / dV	kg/m^3
ω	Propellerr rotational velocity	$2 \pi n$	s^{-1}

ANNEX

Indices

index	name	definition or explanation
A	Air	
c	Construction, design	
M	Model	
S	Ship	
W	Water	
max	Maximum	
min	Minimum	
0.7	According radius $r/R = 0.7$	

Methods and procedures

Open water test

The dynamometer H39 from Kempf & Remmers will be used for the open water tests (Figure A1). The configuration is with the shaft in upstream direction. The drag, the torque and the number of revolutions as well as the inflow speed will be measured during the tests.

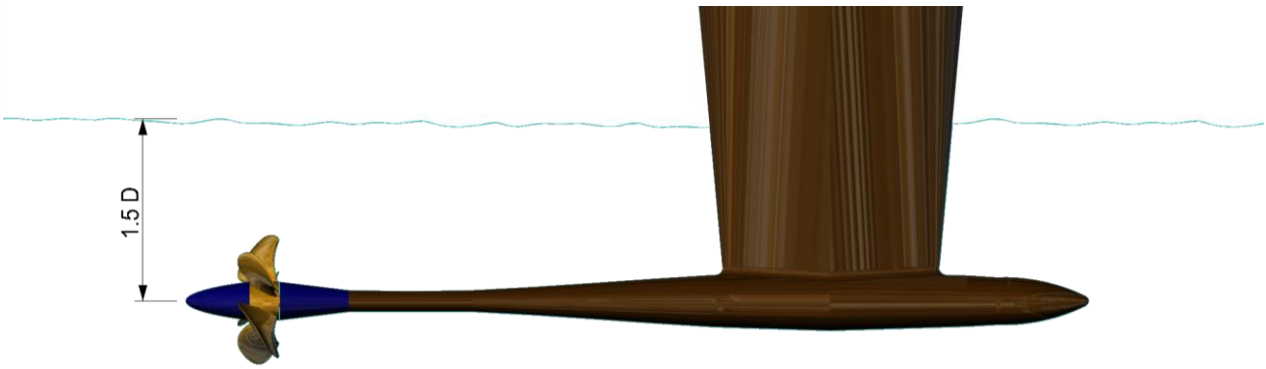


Figure A1: Test arrangement in the towing tank

Measuring values

Inflow velocity	V	[m/s]
Number of revolutions	n	[s^{-1}]
Thrust	T	[N]
Torque	Q	[Nm]

Before the open water tests the zero reference values of thrust and torque will be determined.

The open water tests will be carried out in a range of $J = 0$ to $K_T < 0$. Variation in J will be achieved by varying the inflow speed for a given rotational speed.

During each run the measured values of drag, torque, rotational speed and inflow speed will be recorded, together with time series, maximum and minimum values and standard deviations of the signals.

The measured drag will be corrected for the effect of the streamlined hub cap.

The measured torque will be corrected for the effect frictional values of torque, taken with the shaft rotating at the same speed with an axis symmetric mass mounted at the position of the rotor.

Open water characteristics

Measuring values: *T, Q, n, V*

Advance coefficient $$J = \frac{V}{n \cdot D}$$

Thrust coefficient $$K_T = \frac{T}{\rho \cdot n^2 \cdot D^4}$$

Torque coefficient $$K_Q = \frac{Q}{\rho \cdot n^2 \cdot D^5}$$

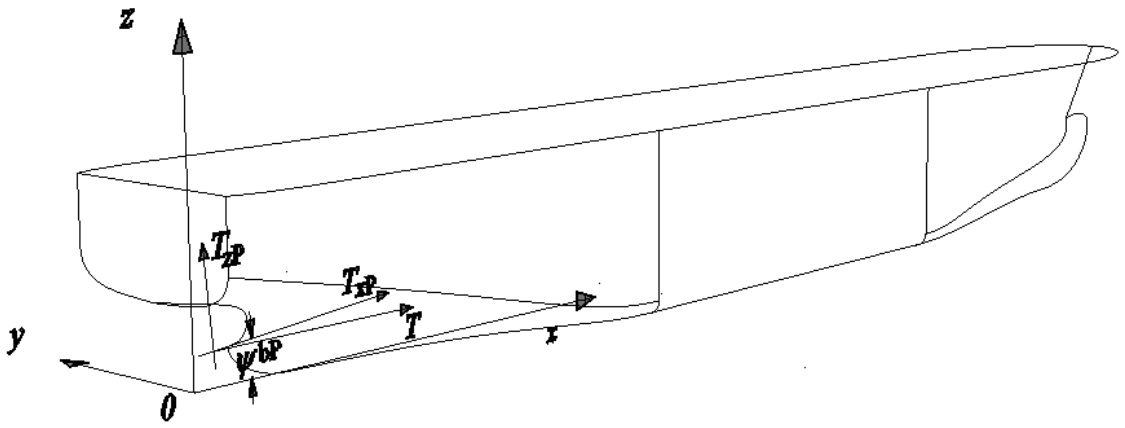
Propeller efficiency $$\eta_O = \frac{J}{2\pi} \cdot \frac{K_T}{K_Q}$$

Reynolds number $$Re = \frac{c_{0.7}}{\nu} \cdot \sqrt{V^2 + (0.7 \cdot D \cdot \pi \cdot n)^2}$$

Thrust loading coefficient $$C_{Th} = \frac{8}{\pi} \cdot \frac{K_T}{J^2}$$

Coordinate system

Cartesian coordinate system



Cylindrical propeller coordinate system looking on pressure side