BETTER SHIPS, BLUE OCEANS

Open water tests for the Vor-Prop propulsor

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Open water tests for the Vor-Prop propulsor

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MARIN Project Manager : Jesse Slot
Propulsor models No. : 7939R

Classification : Company confidential
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MANAGEMENT SUMMARY

Vor-Prop LLC has developed a prototype of the vortex Propulsor, or Vor-Prop. The Vor-Prop is a new hydraulic propulsion concept, which utilises a hydrofoil array in a cylindrical helix form to produce a vortex. The Vor-Prop is claimed as a more efficient alternative to the standard screw propeller. After earlier CFD studies, the next step in the development of the Vor-Prop is an experimental test.

The aim of the present investigations is to determine the open water characteristic of the Vor-Prop by experiments in MARINs Deep Water Towing Tank. This data can be used to compare the performance of the Vor-Prop to other available propulsor options.

The open water measurements showed that the maximum efficiency of the Vor-Prop is 0.074, which is very low compared to similar B-series propellers. It is our hypothesis that the thrust comes from the impeller-like connection between the hub and the forward ring and that the helices do not produce any thrust. Moreover, significant lateral forces are expected when using the Vor-Prop since the centre of gravity is located relatively far behind the connection to the shaft.

1 INTRODUCTION

1.1 Background

Vor-Prop LLC has developed a prototype of the vortex Propulsor, or Vor-Prop. The Vor-Prop is a new hydraulic propulsion concept, which utilises a hydrofoil array in a cylindrical helix form to produce a vortex. The Vor-Prop is claimed as a more efficient alternative to the standard screw propeller. After earlier CFD studies, the next step in the development of the Vor-Prop is an experimental test.

1.2 Objectives

The aim of the present investigations is to determine the open water characteristic of the Vor-Prop by experiments in MARINs Deep Water Towing Tank. This data can be used to compare the performance of the Vor-Prop to other available propulsor options.

1.3 Report outline

Chapter 2 discusses the scope of work and chapter 3 the model test arrangement. The data processing procedure is given in Chapter 4. Chapter 5 presents the results of the tests and chapter 6 lists the conclusions. Throughout this report SI units are used unless indicated otherwise; a list of symbols is given in Appendix I. The descriptions of the procedures for conducting the model tests are presented in Appendices II.



Figure 1-1: Photo of the Vor-Prop attached to MARIN open water measurement setup.

2 SCOPE OF WORK

An open water test was carried out to verify the propulsive performance of the Vor-Prop, as listed in the table below. The quasi-steady method to measure the open water characteristics was applied. In this procedure, the forward velocity of the towing carriage is varied while the thrust and torque are measured continuously. The Vor-prop will rotate with a fixed rotation rate during a test run.

Type of test	Test No.	Test date	Draught T_F/T_A [m]	Speed range [m/s]	Results on pages:		
					Tables	Figures	Photos
Open water	33494002	16-Mar-2022	N/A	0 - 3	T2	F1	PH1-PH5

Notes:

- A maximum rotation rate was applied of 800 rpm to limit the vibrations caused by the Vor-Prop, the standard testing procedure uses .a rotation rate of 900 rpm.
- The test setup was used in pulling mode due to the geometry features of the Vor-Prop.
- All tests were carried out in the Deep Water Towing Tank (see enclosed documentation sheet).
- The procedures for conducting the model tests are presented in Appendix II.

During the open water tests, the Vor-Prop was recorded by means of an underwater video camera. Copies of this recording have been delivered to the client by a download link. A selection of photographs of the setup is presented in this report.

3 DESCRIPTION OF MODEL TEST ARRANGEMENT

3.1 Test facilities

The open water tests have been conducted in the Deep Water Towing Tank (DT), which measures 250 m by 10.5 m by 5.5 m in length, width and depth respectively. More information about the Deep Water Towing Tank can be found in the documentation sheet.



Figure 3-1: Deep Water Towing Tank

3.2 Information for model manufacture.

The model of the Vor-Prop was made by Vor-Prop LLC. It is casted in bronze and had a diameter of about 200mm and a length of about 400mm. The hole which connected the Vor-Prop to the shaft of the open water setup had to be enlarged in order to fit the 20mm shaft with measurement sensor. Some imbalances were observed in the Vor-Prop during spinning tests in air. Among others the shaft connection was not placed fully concentric. The model of the Vor-Prop was given MARIN propulsor No. 7939 R.

3.3 Test arrangement

A captive test setup was used for the open water tests, in which the propulsor is rigidly attached to the carriage. During the tests, the carriage speed, the propeller thrust, torque and rpm were measured. The measurement setup was used in pulling mode. This means that the propulsor was following behind the driving shaft and strut.

4 DATA PROCESSING

The towing speed of the carriage, the propeller shaft rotation rates, the propeller thrust and torque have been recorded, sampled, reduced and averaged. The mean values have been used for further analysis of the test results. These values are expressed in non-dimensional coefficients KTo and KQo. Together with the open water efficiency η_o they are presented as a function of the advance coefficient J. The non-dimensional thrust and torque coefficients, the open water efficiency and advance coefficient are defined as:

$$\mathrm{KTo} = \frac{\mathrm{T}}{\rho \mathrm{n}^2 \mathrm{D}^4}, \qquad \mathrm{KQo} = \frac{\mathrm{Q}}{\rho \mathrm{n}^2 \mathrm{D}^5}, \qquad \eta\mathrm{o} = \frac{J}{2\pi}\frac{\mathrm{KTo}}{\mathrm{KQo}}, \qquad \mathrm{J} = \frac{\mathrm{V}}{\mathrm{nD}}.$$

The open water characteristics are not corrected for scale effects.

5 PRESENTATION AND DISCUSSION RESULTS

The results of the open water test on the propulsor model No. 7939R are presented on table page T2 and figure page F3. The latter is also given below in Figure 5-1. The maximum value of KT is found at J = 0.08, not at bollard pull. It decreases to KTo = 0 at J = 0.68. The KQo only slightly decreases with increasing J. The torque that is absorbed by the rings and helices thus depends mainly on the rotation rate and not much on the forward speed. The measured level of the KQo are high compared to typical values for similar propellers. The propeller efficiency reaches a maximum of η_o = 0.074 at J = 0.38.

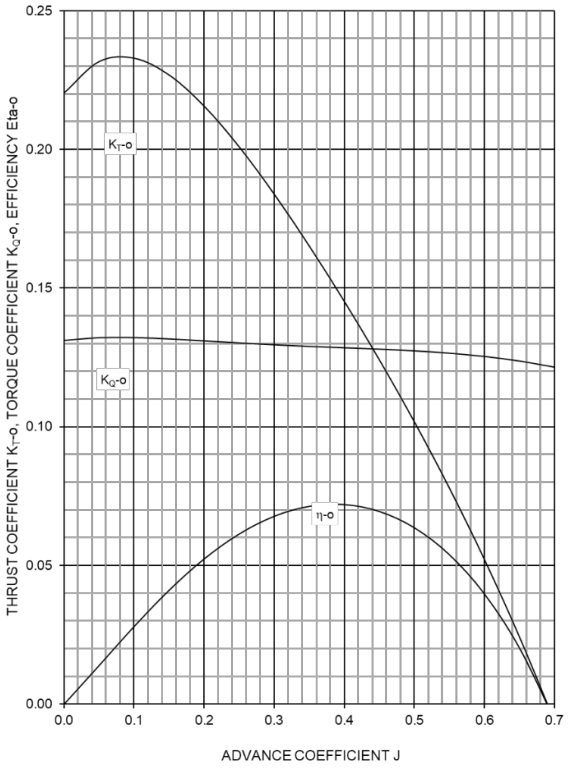


Figure 5-1: Open water characteristics of Vor-Prop propulsor.

For comparison these results are compared to those of a four-bladed B-series propeller with a pitch ration P/D = 0.6 and a blade area ratio Ae/Ao = 0.60. Such a propeller has a comparable KT at bollard pull and has zero thrust just before J = 0.7 as well. This B-series propeller has a maximum at propeller efficiency of about of η_o = 0.55 near J = 0.5. Therefore it can be stated that the propeller efficiency of the Vor-Prop is very low. It is our hypothesis that the thrust mainly comes from the impeller-like connection between the hub and the forward ring and that the helices do not produce any thrust.

The Vor-Prop produces significant lateral forces and vibrations at higher rotation rates. This is mainly due to the fact that the centre of gravity is located well aft of the shaft connection. In addition, the imbalance in the geometry of the Vor-Prop contributes to its swaying motion. Therefore the test were carried out up to a rotation rate of only 800 rpm. Usually, a rotation rate of 900 rpm is applied in open water tests. However, this is still reasonably close to our standard practice.

The reason for testing at a relatively high rotation rates is to limit the scale effects that appear in model scale testing as much as possible. At low rotation rates, the flow around the propulsor does not represent well the flow that is experienced by the propulsor in an actual application, in which the flow over the surfaces will be turbulent. Thus results obtained at low rotation rates, with low Reynolds numbers, can give inaccurate results.

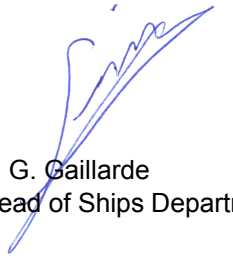
6 CONCLUSIONS

The following conclusions summarise the findings of the present project:

- The open water measurements showed that the maximum efficiency of the Vor-Prop is 0.074, which is very low compared to similar B-series propellers.
- It is our hypothesis that the thrust mainly comes from the impeller-like connection between the hub and the forward ring and that the helices do not produce any thrust.
- Significant lateral forces are expected when using the Vor-Prop since the centre of gravity is located relatively far behind the connection to the shaft.

The above conclusions do not supersede the statements made in the previous chapters and in the tables and figures with results.

Wageningen, March 2022
MARITIME RESEARCH INSTITUTE NETHERLANDS



Ir. G. Gaillarde
Head of Ships Department

PARTICULARS OF PROPULSOR

Propeller particulars represented by propeller model No. 7939R:

Particular	Symbol	Value	Unit
Diameter	D	0.200	m
Pitch adjusted at 0.7R	$P_{0.7}$	N/A	m
Pitch ratio at 0.7R	$P_{0.7}/D$	N/A	-
Boss-diameter ratio	d/D	0.2	-
Expanded blade area ratio	A_E/A_0	N/A	-
Number of blades	Z	4	-

Propeller model material : bronze

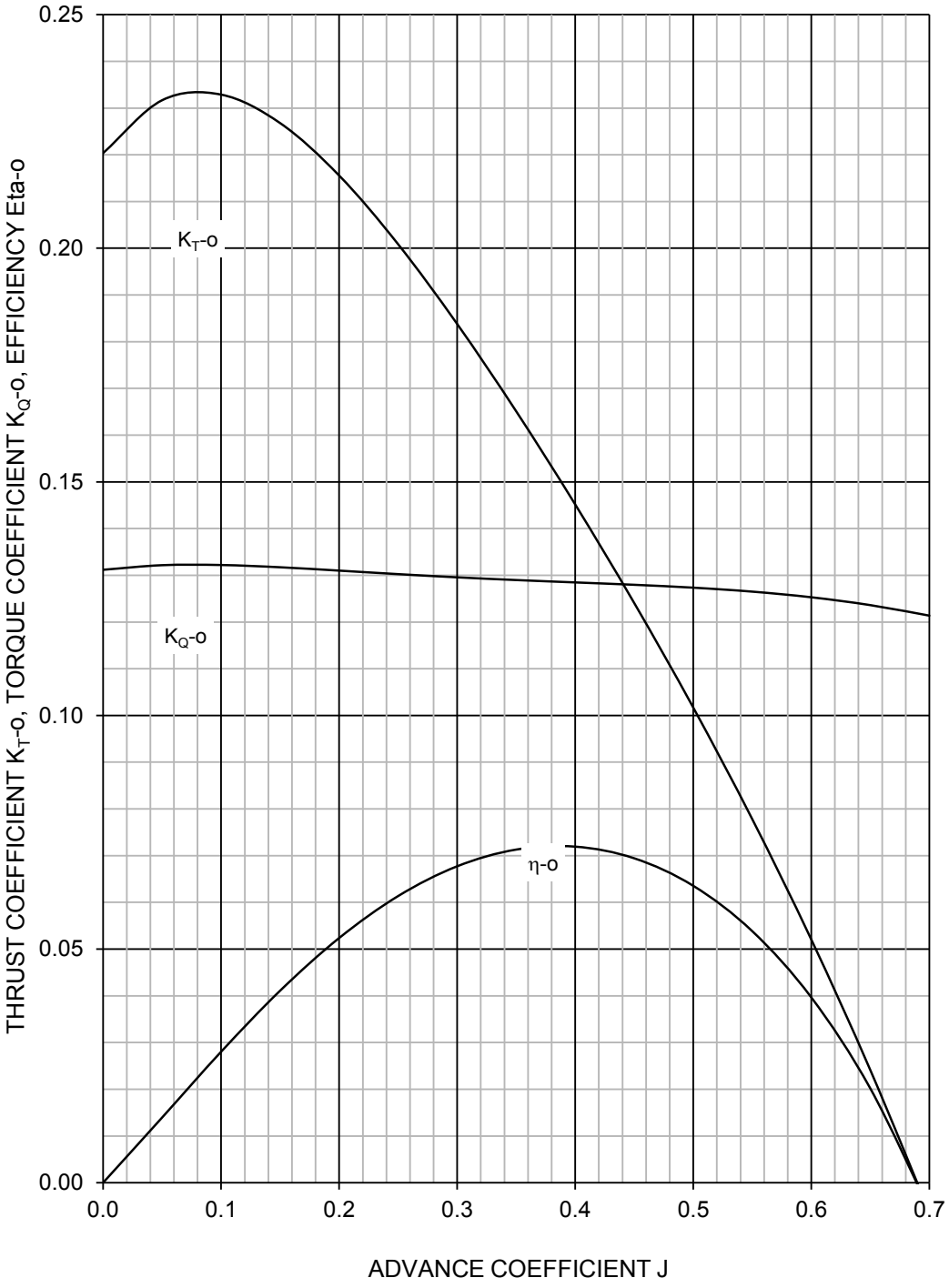
PROPELLER OPEN WATER TEST RESULTS

OPEN WATER TEST NO. 33494002
PROPELLER MODEL NO. 7939 R Vor-prop

J	KT-O	KQ-O	ETA-O
.00	.2204	.13118	.000
.05	.2317	.13216	.014
.10	.2329	.13220	.028
.15	.2268	.13172	.041
.20	.2156	.13100	.052
.25	.2008	.13025	.061
.30	.1838	.12956	.068
.35	.1651	.12898	.071
.40	.1451	.12847	.072
.45	.1241	.12797	.069
.50	.1017	.12735	.064
.55	.0778	.12650	.054
.60	.0520	.12530	.040
.65	.0241	.12362	.020
.690	.0000	.12186	.000

NOTES:-FOR EXPLANATION OF ABBREVIATIONS SEE LIST OF SYMBOLS
-TEMPERATURE TANK WATER 15.2 DEGREES C.
-ROTATION RATE 13.3 HZ (= 800.0 RPM) ON MODEL SCALE

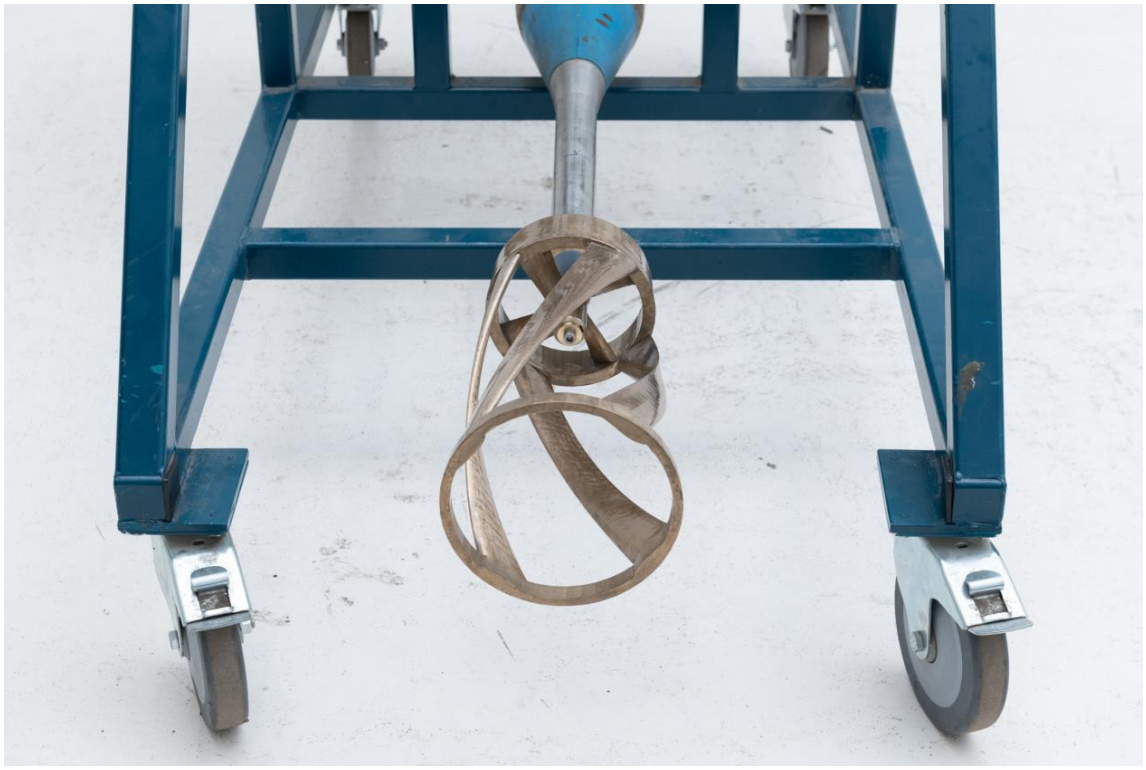
OPEN WATER TEST No. : 33494002
PROPELLER MODELS No. : 7939R



PROPELLER OPEN WATER TEST RESULTS

OPEN WATER TEST SETUP





OPEN WATER TEST SETUP



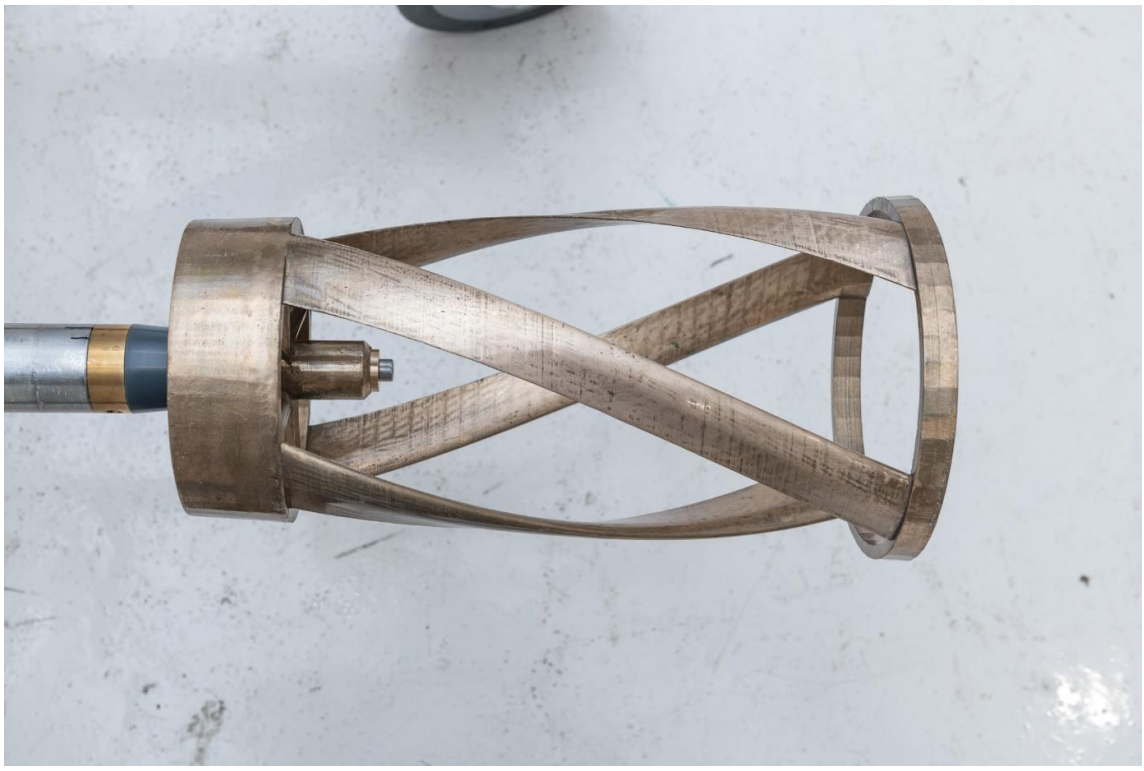


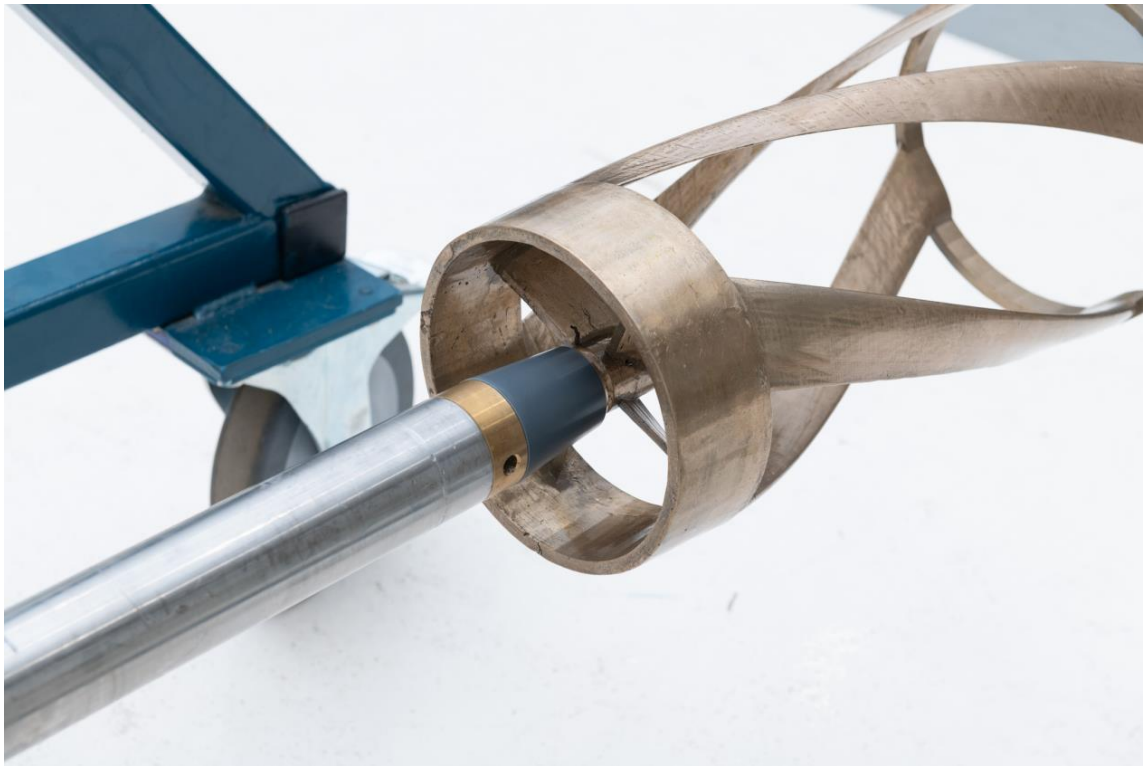
OPEN WATER TEST SETUP



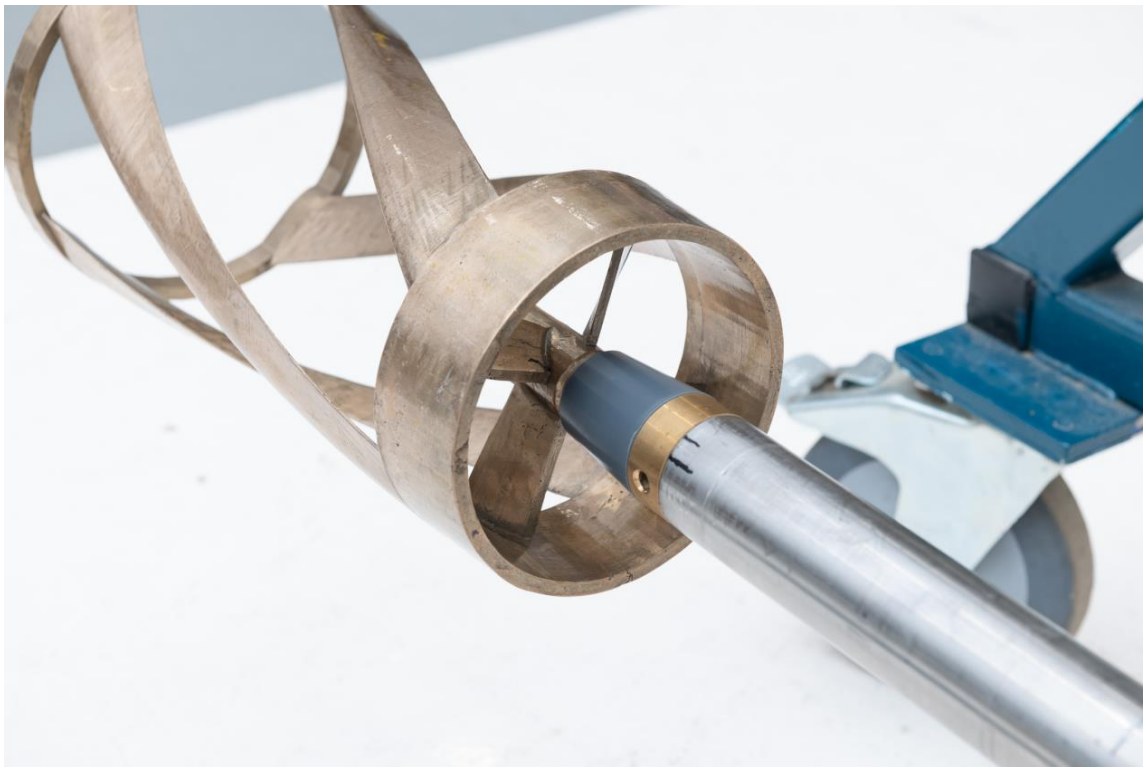


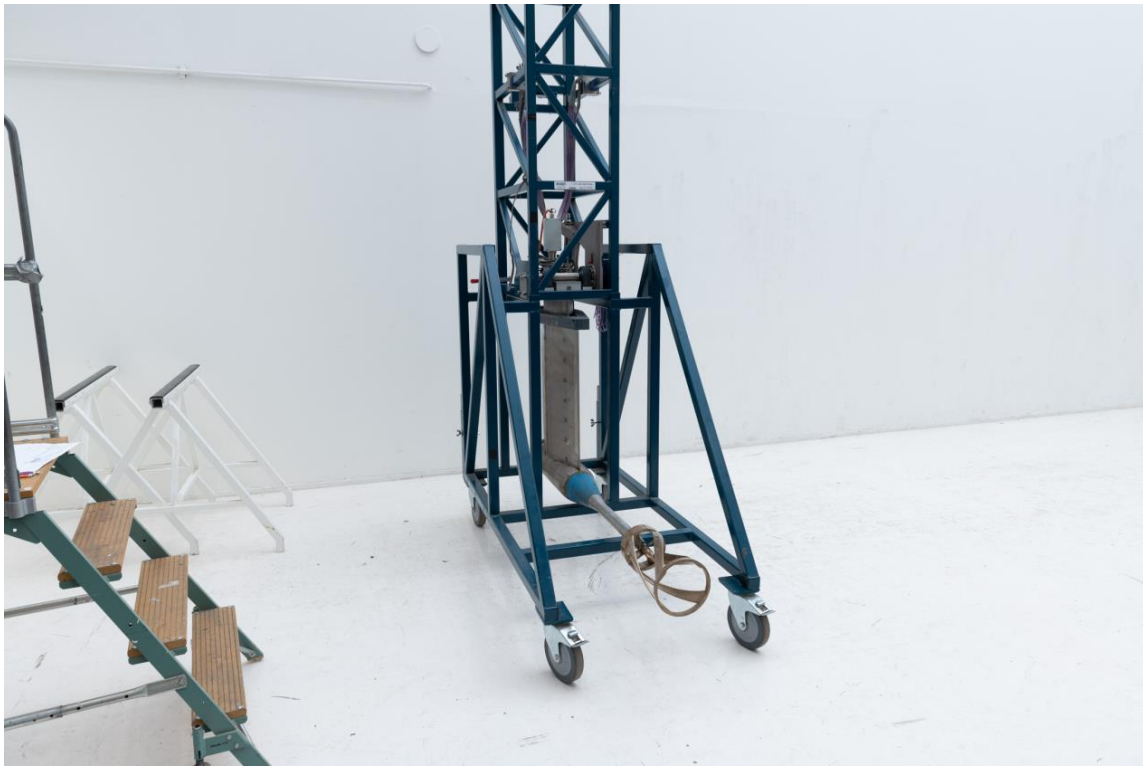
OPEN WATER TEST SETUP





OPEN WATER TEST SETUP





APPENDIX I

LIST OF SYMBOLS

Symbol	Symbol in computer print	Title
GEOMETRY OF SHIP AND PROPELLER		
A_{BT}		Transverse cross-section area of bulbous bow
A_E		Expanded propeller blade area
A_E/A_O		Expanded propeller blade area ratio
A_M		Midship sectional area below still waterline
A_O		Propeller disc area
A_T		Transom area below still waterline
A_T/A_M		Transom area ratio
A_W		Waterplane area
A_X		Maximum transverse sectional area below still waterline
A_V	AV	Area of portion of ship above waterline projected normally to the direction of relative wind
B		Maximum breadth moulded at or below still waterline
B_M		Maximum breadth moulded at midship
B_{WL}		Maximum breadth moulded at still waterline
c		Chord length of propeller blade section
c/D		Chord length-diameter ratio
c_{REF}		Chord length between reference line and leading edge
c_t		Chord length between maximum thickness point and leading edge
C_B		Block coefficient
C_M		Midship section coefficient
C_P		Longitudinal prismatic coefficient
C_{WP}		Waterplane area coefficient
d		Hub diameter
d/D		Hub-diameter ratio
D		Propeller diameter
FB		Position of centre of buoyancy aft of FP
f		Camber of propeller blade section
h_o		Submergence of propeller shaft axis measured from still water-plane
h_B		Height of centroid of A_{BT} above keel
i_E		Half angle of entrance
L_{OA}		Length overall
L_{OS}		Length overall submerged
L_{PP}		Length between perpendiculars
L_{WL}		Length on still waterline
LCB		Longitudinal position of centre of buoyancy

Symbol	Symbol in computer print	Title
P		Propeller pitch
P/D		Pitch-diameter ratio
r		Radius of propeller blade section
R		Radius of propeller
S, S_{HULL}		Projected wetted surface bare hull
S_{APP}		Wetted surface area appendages
S_1, S_{TOT}		Total wetted surface area
t		Maximum thickness of propeller blade section
t/c		Maximum thickness-chord length ratio
T		Mean draught moulded
T_A		Moulded draught at aft perpendicular
T_F		Moulded draught at forward perpendicular
dTA	dTA	Dynamic draught change at aft perpendicular
dTF	dTF	Dynamic draught change at forward perpendicular
Z		Number of blades
λ		Scale ratio
Φ		Pitch angle of propeller section
∇	DISV	Displacement volume moulded

$-_m$	$-_M$	Subscript for model
$-_s$	$-_S$	Subscript for ship

Symbol	Symbol in computer print	Title
RESISTANCE, OPEN WATER AND PROPULSION		
AC_{Res}		Ship resistance admiralty coefficient
AC_{Prop}		Ship propulsive power admiralty coefficient
C_A	CA	Total Incremental resistance coefficient for model-ship correlation
C_{A0}	CA_0	C_A basic
C_{Arough}	Crough	C_A roughness
C_{Aas}	Caas	C_A air resistance
C_{Abk}	Cbk	C_A bilge keels
$C_{Aballast}$	Cballast	C_A small draught
C_{AD}	CAD	Admiralty coefficient for propulsion
C_D		Drag coefficient
$C_{D\nabla}$		Power-displacement coefficient
C_E	CE	Admiralty coefficient for resistance
C_F	CF	Specific frictional resistance coefficient
ΔC_F		Roughness allowance coefficient
C_L	CL	Lift coefficient
C_P		Power loading coefficient
C_Q	C_Q	Propeller torque coefficient
C_{QBL}	C_{QBL}	Propeller blade spindle torque coefficient
C_R	CRES	Specific residual resistance coefficient
C_T	CT	Specific total resistance coefficient
C_{Th}		Thrust loading coefficient
C_{TP}	C_{TP}	Propeller thrust coefficient
C_{TD}	C_{TD}	Duct thrust coefficient
C_V	CV	Specific total viscous resistance coefficient
C_W	CW	Specific wavemaking resistance coefficient
C_X	CX	Specific air resistance coefficient
Ⓒ	CIRCC	R.E. Froude's resistance coefficient
F	F	Towing force in propulsion test
F_D	FD	Viscous scale effect on resistance
F_n	FN	Froude number
F_P	PULL	Pull of ship
F_{PO}	PULL	Pull of ship in bollard condition
Ⓕ	CIRCF	R.E. Froude's frictional resistance coefficient
g		Acceleration due to gravity
J	J	Advance coefficient
J_V	JV	Apparent advance coefficient
1+k	1+K	Three-dimensional form factor on flat plate friction

Symbol	Symbol in computer print	Title
k_p		Equivalent sandroughness of propeller blade surface
k_s		Roughness height of hull surface
k_{siP}	k_{siP}	Dependency of propulsive efficiency with resistance increase
k_{siN}	k_{siN}	Dependency of propeller shaft speed with power increase
k_{siV}	k_{siV}	Dependency of propeller shaft speed with speed change
K_Q	KQ	Torque coefficient
K_T	KT	Thrust coefficient
K_{TD}	KT-D	Duct thrust coefficient
K_{TP}	KT-P	Propeller thrust coefficient
K_{TS}	KT-S	Stator thrust coefficient
Ⓚ	CIRCK	R.E. Froude's speed-displacement coefficient
MCR		Maximum continuous rating
SMCR		Specified maximum continuous rating
NCR		Normal continuous rating
n	N	Rate of revolutions
P_B		Brake power
P_D	PD	Power delivered to the propeller(s)
P_E	PE	Effective power
P_I		Indicated power
P_S	PS	Shaft power
Q	Q	Torque
R	R	Resistance in general
R_n	RN	Reynolds number
R_A		Model-ship correlation resistance
R_F	RF	Frictional resistance
R_V	RV	Total viscous resistance
R_W	RW	Wavemaking resistance
s_A		Apparent slip ratio
s_R		Real slip ratio
t	THDF	Thrust deduction fraction
t*		Thrust deduction fraction from load variation test
T	TH	Thrust
T_D	TH-D	Duct thrust
T_P	TH-P	Propeller thrust
T_S	TH-S	Stator thrust
T_U	TH-U	Azimuthing thruster unit thrust
t_V	TV	Running trim

Symbol	Symbol in computer print	Title
V	V	Speed of ship or ship model
V_r	Vr	Radial flow velocity component in the direction of the z-axis of the Pitot tube, and is positive if directed down for strut orientation tests or outward in a wake survey
V_t	Vt	Tangential flow velocity component in the direction of the y-axis of the Pitot tube, and is positive if directed to port for strut orientation tests or in clockwise direction in a wake survey
V_x	Vx	Longitudinal flow velocity component in the direction of the x-axis of the Pitot tube, and is positive if directed aft
V_A	VA	Advance speed of propeller relative to water flow
w_T	WT	Effective wake fraction on thrust identity
w_Q	WQ	Effective wake fraction on torque identity
β		Advance angle of propeller blade section
β_h		Angle of the flow in the x-y plane of the Pitot tube co-ordinate system, and is positive if the flow is directed to port for strut orientation tests
β_v		Angle of the flow in the x-z plane of the Pitot tube co-ordinate system, and is positive if the flow is directed to the hub for strut orientation tests
η_B		Propeller efficiency behind ship
η_D	ETA-D	Propulsive efficiency
η_ε	ETA-ε	Merit coefficient
η_G		Gearing efficiency
η_H	ETA-H	Hull efficiency
η_M		Mechanical efficiency
η_o	ETA-O	Propeller efficiency in open water
η_R	ETA-R	Relative-rotative efficiency on thrust or torque identity
η_S		Shafting efficiency

Symbol	Symbol in computer print	Title
ν		Coefficient of kinematic viscosity
ρ		Mass density
τ		Ratio propeller thrust and total thrust of ducted propeller system
τ_w		Wall shear stress

$_m$	$_M$	Subscript for model
$_o$	$_O$	Subscript for open water
$_s$	$_S$	Subscript for ship

APPENDIX II

PROCEDURES OF MODEL TESTS

Procedure of open water tests

Single propeller

The propeller model is fitted on a horizontal driving shaft, and is moved through the water at an immersion of the shaft axis of at least the diameter of the propeller. The thrust and torque are measured in the hub of the propeller model.

In the test the loading of the propeller is normally varied by varying the speed of advance and keeping the rate of revolutions constant. When limitations in the measuring range (for J-values close to zero) and/or carriage speed (for high J-values) are reached, the rate of revolutions is varied too.

The measured thrust values are corrected for the resistance of the hub and streamlined cap experienced in the test. This correction is determined experimentally in a test with the hub only.

The torque and (corrected) thrust are expressed in non-dimensional coefficients K_{To} and K_{Qo}. Together with the open water efficiency η_o they are presented as a function of the advance coefficient J.

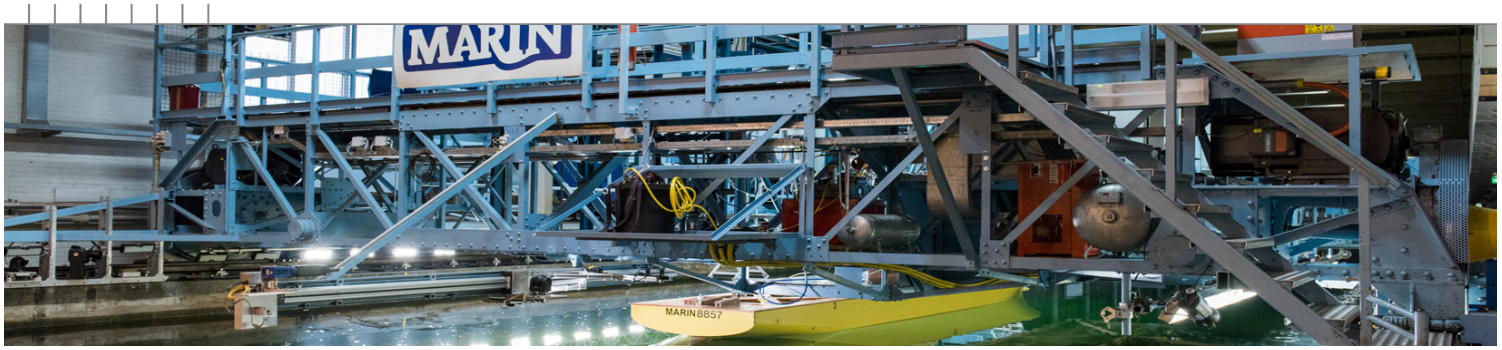
The non-dimensional thrust and torque coefficients are defined as:

$K_{To} = T/(\rho n^2 D^4)$ and $K_{Qo} = Q/(\rho n^2 D^5)$

The open water efficiency and advance coefficient are defined as:

$\eta_o = J K_{To}/(2\pi K_{Qo})$ and $J = V/(nD)$

The open water characteristics are not corrected for scale effects, unless stated otherwise.



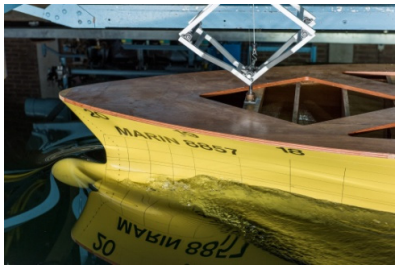
Deep Water Towing Tank

Test capabilities

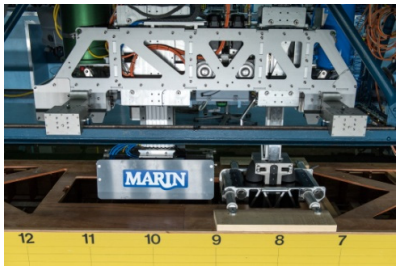
- Resistance and (quasi-steady) self-propulsion tests in calm water
- Open water tests of various types of propulsor (open or ducted propeller, thruster, pod, etc.)
- 3-D wake surveys
- Measurement of hydrodynamic forces and moments on submerged bodies, foils etc.
- Steady or unsteady propeller blade force measurements
- Flow observation tests by 3D Particle Image Velocimetry (3D-PIV), paint or tufts
- Vertical/horizontal planar motion measurements
- Longitudinal wave cut experiments

Dimensions	250 m × 10.5 m, 5.5 m deep (length x width x depth)
Model length range	1.5 - 14 m
Carriage speed range	0 - 9 m/s for models ≤ 4000 kg
	0 - 4 m/s for models ≤ 12000 kg

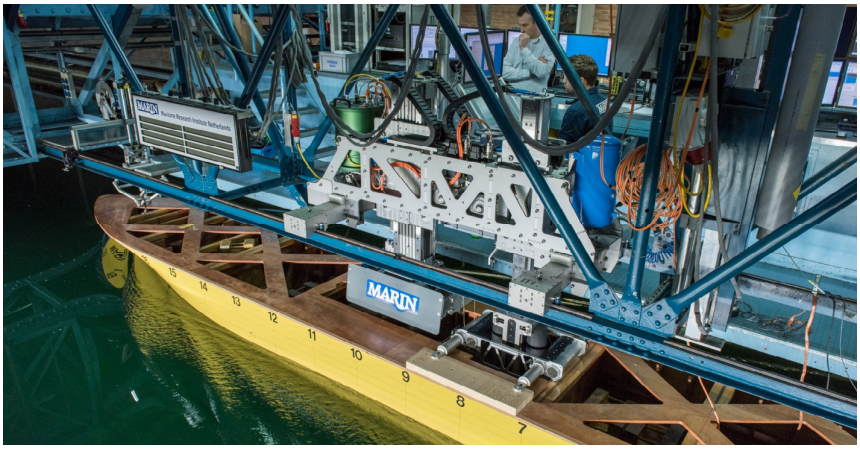


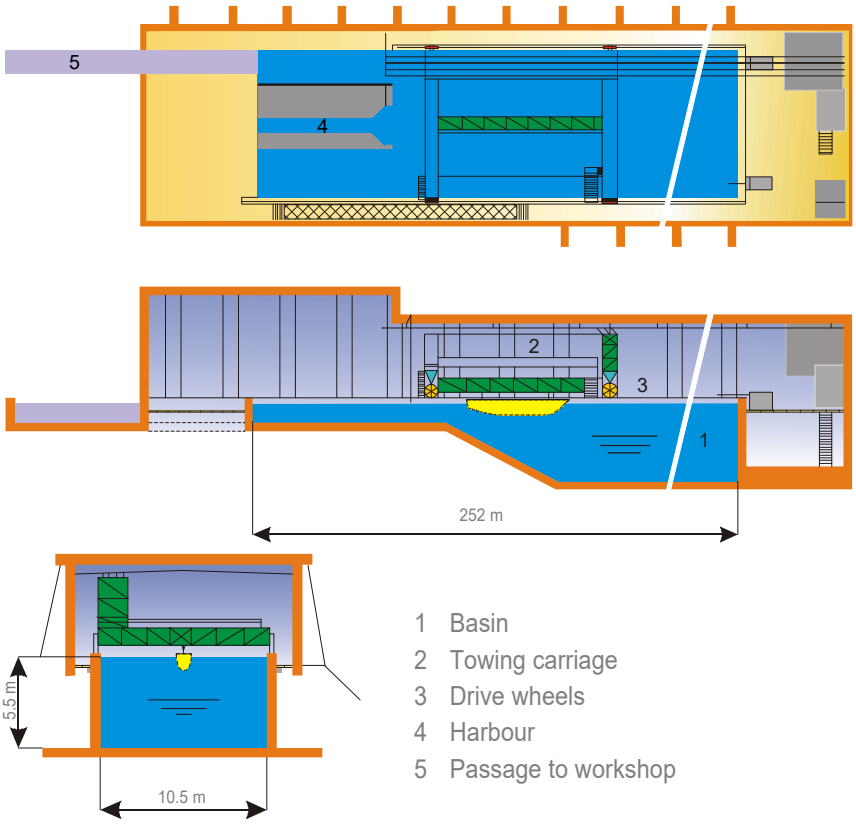












1 Basin
2 Towing carriage
3 Drive wheels
4 Harbour
5 Passage to workshop

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