



ITTC Propeller Benchmark

Tip Rake Propeller - P1727

Report 4487

Potsdam, April 2016

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Management

Rundfahrt
in die
Rücke

Author

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1 Introduction

1.1 Propeller benchmark

The current ITTC scaling method for propellers is well proven and in use by the majority of the institutions. Nevertheless, problems with applying this method for unconventional propellers like Kappel or CLT propellers occurred and a need to update the procedure has arisen. Therefore the propulsion committee of the 27th ITTC conference has been asked to initiate a benchmark test for CFD calculations, with the intention to investigate the capabilities of CFD to predict scale effects on the propeller performance. Two different types of propellers had to be investigated, a conventional and an unconventional propeller.

For this purpose the controllable pitch propeller VP1304 was used to study the scale effects for a conventional propeller. The VP1304 was already published by the SVA Potsdam in the course of the propeller workshop under the acronym PPTC (Potsdam Propeller Test Case) held at the smp'11 conference in Hamburg. During the period of the 27th ITTC no free geometry of an unconventional propeller was available. Therefore the propulsion committee of the 28th ITTC conference has continued this work.

SVA Potsdam has provided P1727 as an example for an unconventional propeller. It has been designed by SVA Potsdam for the ongoing research project "TIP RAKE - Further development of the prognosis methods for tip rake propellers", funded by the German Federal Ministry for Economic Affairs and Energy.

In the course of the ITTC benchmark, both propellers were investigated in full scale and model scale. Excel sheets were provided for the submission of the computational results. The evaluation of the results is anonymous. Despite the comparison of the CFD results with EFD results is not the main topic of this investigation, EFD results are presented, too. Open water tests have been carried out in SVA Potsdam for both propellers. Furthermore the ITTC scaling method was applied to the open water test results and plotted together with the full scale CFD results. These curves shall show the current state.

Within this report the results of the conventional propeller are presented. The results of the unconventional propeller can be found in report 4487.

Table 1 shows all participants in alphabetic order and which propeller has been calculated by each of them. Within the report each result is numbered in chronologic order of incoming. Table 2 lists the main data of both propellers.

1.2 Participants

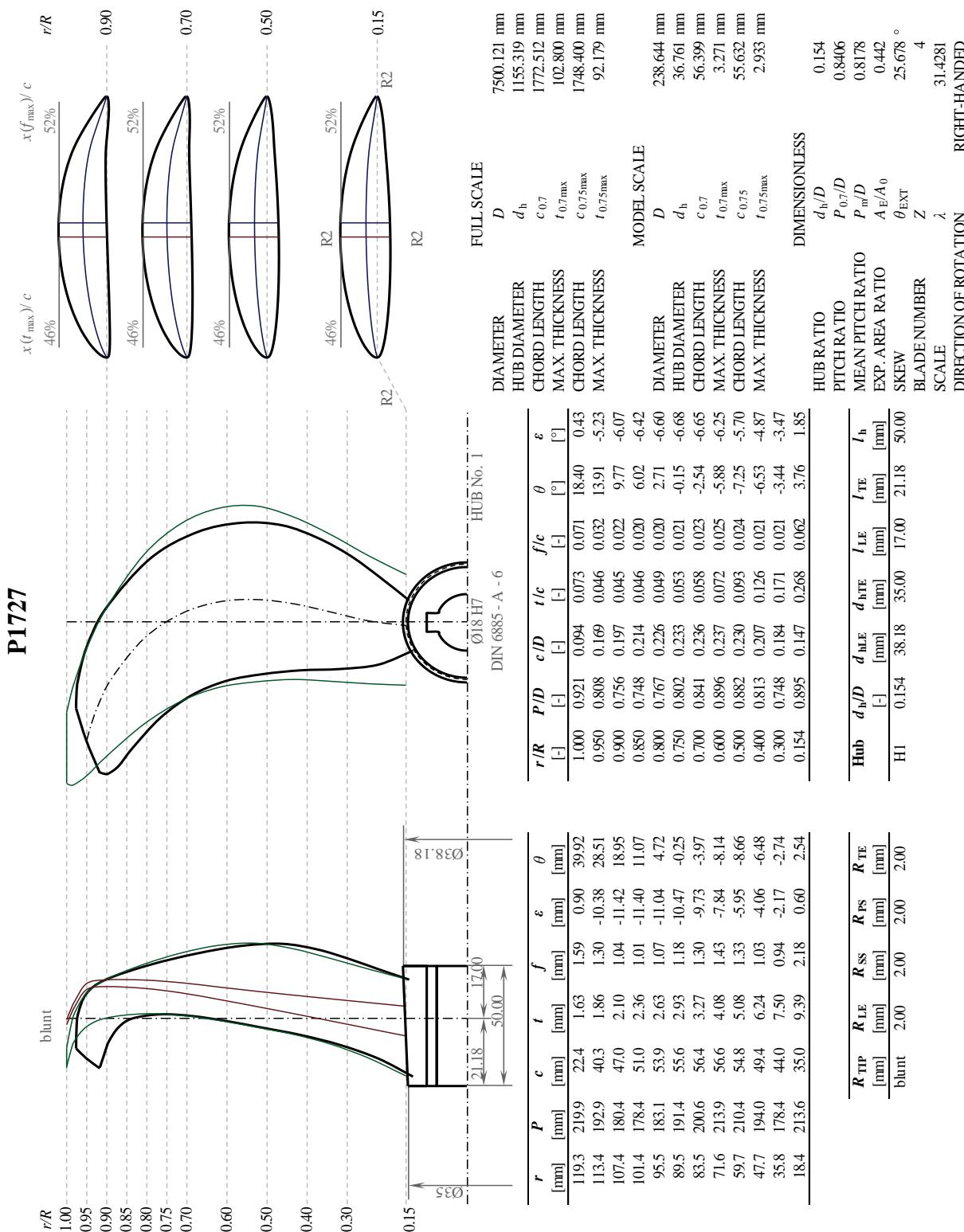
Institute	PPTC VP1304	TRP P1727
China Ship Scientific Research Center	X	X
Dalian University of Technology	X	X
Hamburgische Schiffbau-Versuchsanstalt	X	X
Hyundai Maritime Research Institute	X	X
Indian Institute of Technology Madras		X
Istanbul Technical University	X	X
Japan Marine United Corporation	X	X
Krylov State Research Centre	X	X
Marine Design & Research Institute of China	X	
Pusan National University		X
Samsung Ship Model Basin	X	X
Schiffbau-Versuchsanstalt Potsdam	X	X
Shanghai Jiao Tong University	X	X
Shanghai Ship and Shipping Research Institute	X	
Ship Design and Research Centre Gdansk	X	X
SSPA Sweden AB	X	
Total results	14	13

1.3 Propeller

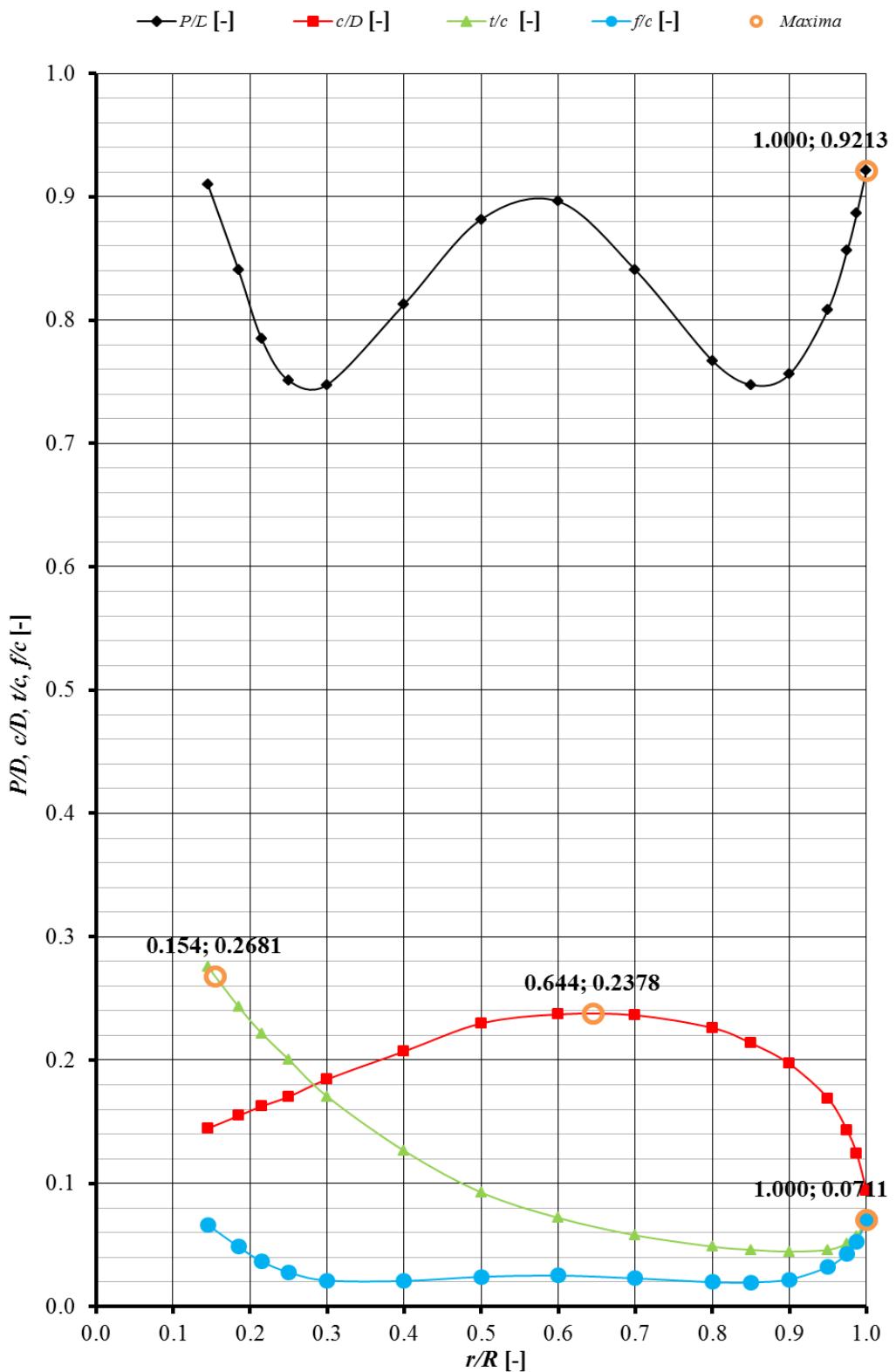
Propeller	PPTC			TRP	
	VP1304		P1727		
Scale ratio	l	[$-$]	12	1	31.428
Propeller diameter	D	[mm]	250	3000	238.6
Pitch at $r/R = 0.70$	$P_{0.7}$	[mm]	408.8	4905	200.6
Pitch at $r/R = 0.75$	$P_{0.75}$	[mm]	407.4	4889	191
Mean pitch	P_{mean}	[mm]	391.9	4703	195.5
Chord length at $r/R = 0.70$	$C_{0.7}$	[mm]	104.2	1250	56.4
Chord length at $r/R = 0.75$	$C_{0.75}$	[mm]	106.3	1276	55.6
Thickness at $r/R = 0.75$	$t_{0.75}$	[mm]	3.8	46	2.9
Pitch ratio	$P_{0.7}/D$	[$-$]		1.635	0.841
Mean pitch ratio	P_{mean}/D	[$-$]		1.568	0.819
Area ratio	A_E/A_0	[$-$]		0.779	0.444
Skew	Θ_{eff}	[$^{\circ}$]		18.8	25.7
Rake at $r/R = 0.70$	$\varepsilon_{0.7}$	[$^{\circ}$]			-9
Rake at $r/R = 0.75$	$\varepsilon_{0.75}$	[$^{\circ}$]			-8.8
Hub diameter ratio	d_h/D	[$-$]		0.3	0.154
Number of blades	Z	[$-$]		5	4
Direction of rotation			right-handed		right-handed

Operation point		model	full
Tip Rake Propeller	P1727	scale	scale
ratio	λ	31.43	1.00
Water density	ρ	[kg/m ³]	999.00
Kinematic viscosity of	ν	[m ² /s]	1.139E-06
Rate of revolutions	n	[1/s]	18.00

1.4 Tip rake propeller - P1727



1.5 Tip rake propeller - P1727, main data



1.6 Tip rake propeller - P1727, 3D

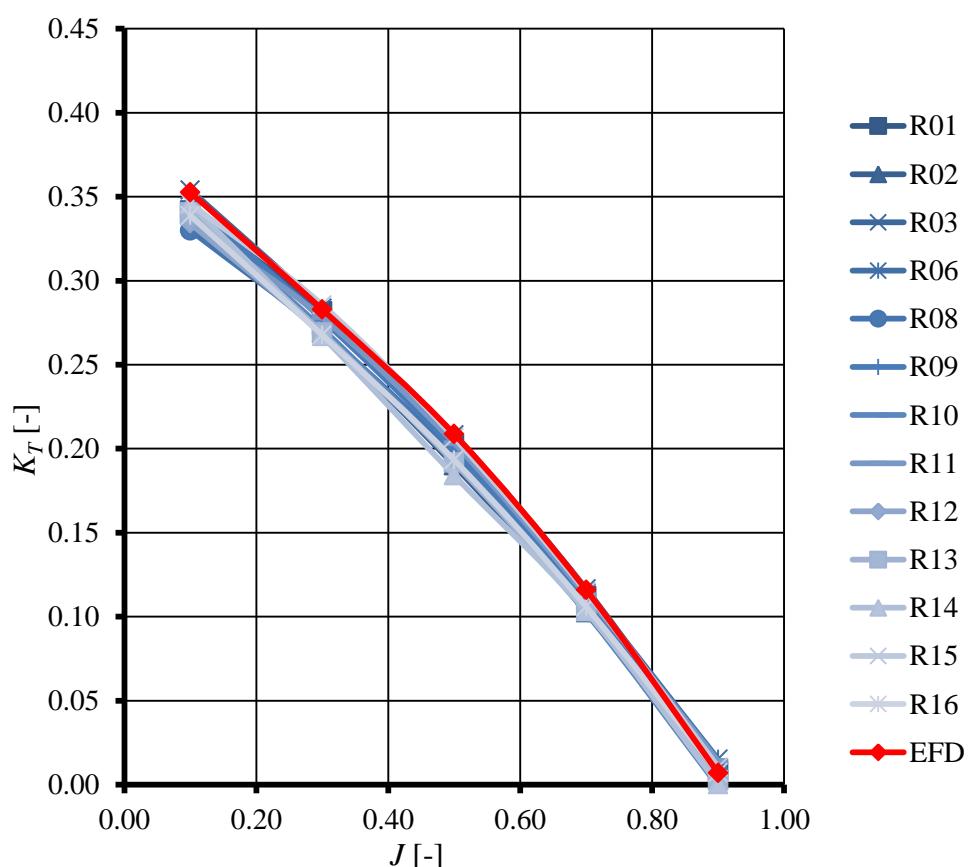


2 Overview

2.1 Open water characteristic - thrust model scale

K_T [-] model scale

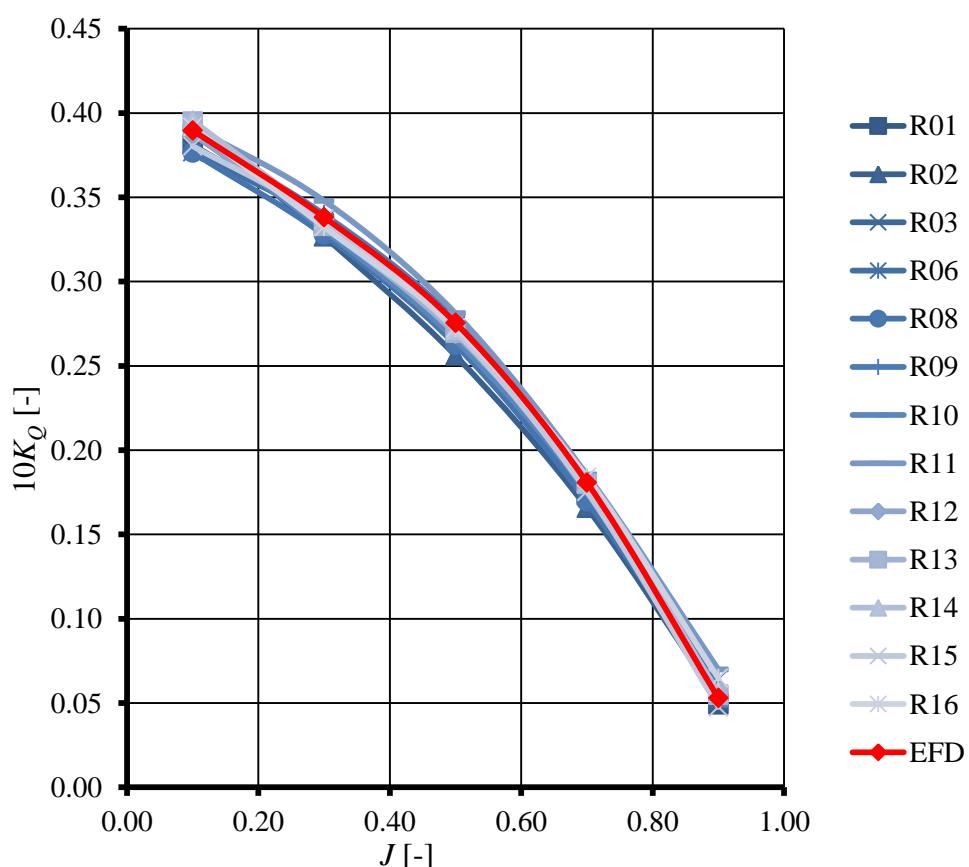
J [-]	0.10	0.30	0.50	0.70	0.90	Average over J	CFD - EFD	[-] **
						[-]*	[-]**	
EFD	0.353	0.283	0.209	0.116	0.007	0.000	0.0%	
R01	0.342	0.282	0.203	0.112	0.008	-0.004	-2.1%	
R02	0.341	0.269	0.190	0.103	0.003	-0.012	-6.3%	
R03	0.354	0.284	0.208	0.116	0.009	0.001	0.4%	
R06	0.339	0.279	0.203	0.114	0.015	-0.003	-1.8%	
R08	0.330	0.269	0.196	0.107	0.007	-0.011	-5.9%	
R09	0.346	0.277	0.200	0.108	0.006	-0.006	-3.2%	
R10	0.340	0.271	0.192	0.102	-0.001	-0.012	-6.4%	
R11	0.335	0.278	0.203	0.113	0.014	-0.005	-2.5%	
R12	0.334	0.268	0.192	0.104	0.000	-0.014	-7.0%	
R13	0.341	0.269	0.192	0.104	0.003	-0.012	-6.1%	
R14	0.345	0.267	0.184	0.103	0.000	-0.013	-6.9%	
R15	0.346	0.286	0.206	0.115	0.010	-0.001	-0.4%	
R16	0.339	0.268	0.193	0.106	0.007	-0.011	-5.6%	



2.2 Open water characteristic - torque model scale

10K_Q [-] model scale

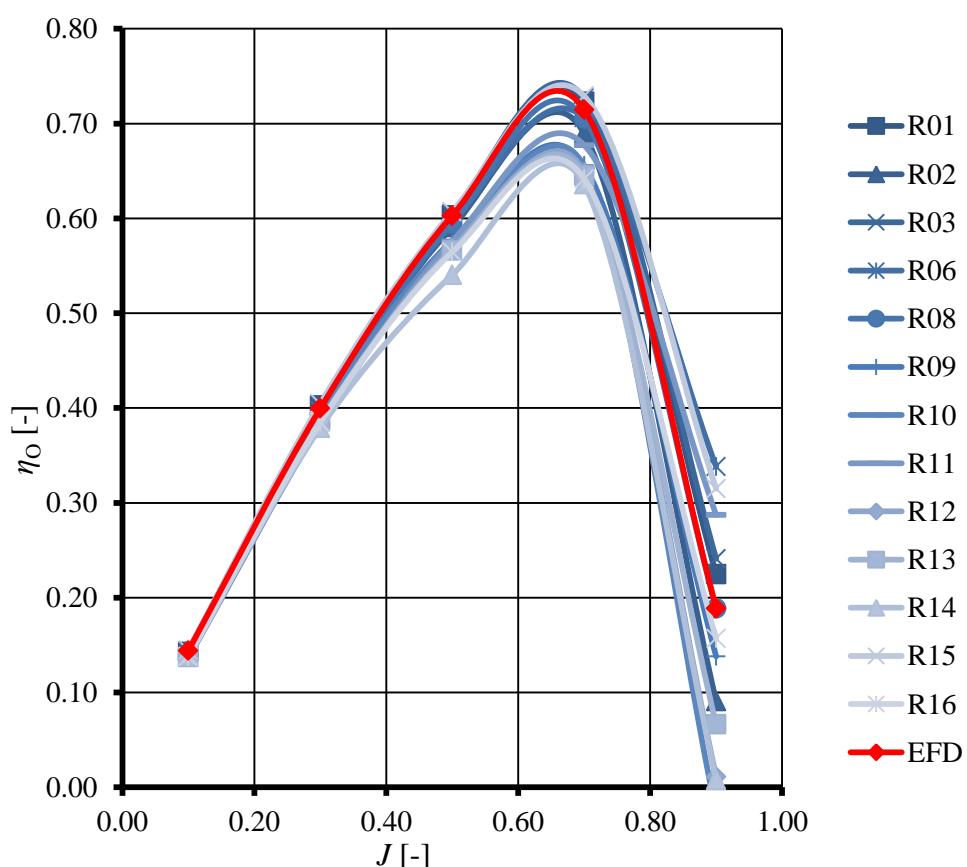
J [-]	0.10	0.30	0.50	0.70	0.90	Average over J	CFD - EFD
						[-]*	[-]**
EFD	0.390	0.338	0.275	0.181	0.053	0.000	0.0%
R01	0.381	0.334	0.268	0.173	0.049	-0.006	-2.5%
R02	0.395	0.327	0.256	0.166	0.051	-0.008	-3.4%
R03	0.393	0.336	0.274	0.178	0.052	-0.001	-0.2%
R06	0.377	0.335	0.271	0.180	0.064	-0.002	-0.7%
R08	0.376	0.328	0.262	0.170	0.055	-0.009	-3.7%
R09	0.387	0.340	0.277	0.183	0.060	0.002	0.8%
R10	0.388	0.331	0.265	0.174	0.049	-0.006	-2.4%
R11	0.392	0.348	0.281	0.185	0.070	0.008	3.2%
R12	0.388	0.333	0.269	0.179	0.056	-0.002	-1.0%
R13	0.395	0.333	0.270	0.180	0.055	-0.001	-0.4%
R14	0.396	0.336	0.271	0.181	0.056	0.001	0.2%
R15	0.380	0.337	0.271	0.175	0.048	-0.005	-2.1%
R16	0.392	0.332	0.272	0.184	0.065	0.002	0.7%



2.3 Open water characteristic - efficiency model scale

 $\eta_o [-]$ model scale

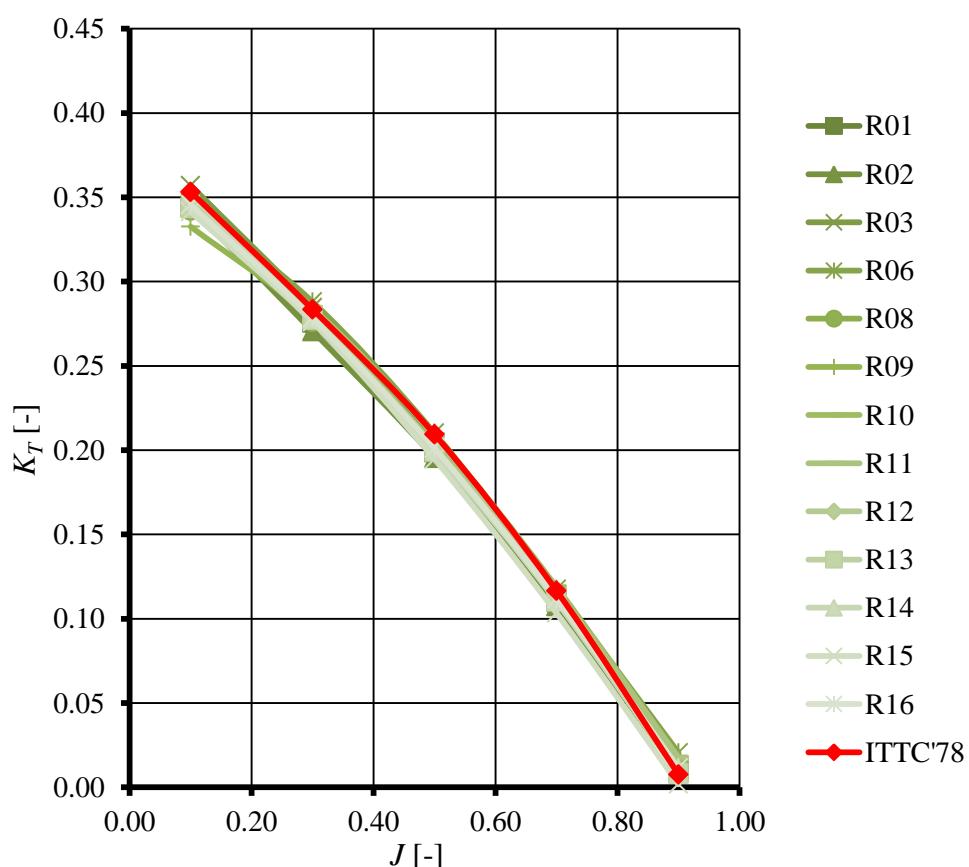
J [-]	0.10	0.30	0.50	0.70	0.90	Avarage obver J	
						CFD-EFD	
EFD	0.144	0.399	0.603	0.715	0.189	0.000	0.0%
R01	0.143	0.403	0.603	0.723	0.225	0.009	2.3%
R02	0.137	0.393	0.591	0.689	0.091	-0.030	-7.2%
R03	0.143	0.403	0.605	0.727	0.241	0.014	3.4%
R06	0.143	0.397	0.595	0.706	0.338	0.026	6.3%
R08	0.140	0.392	0.595	0.705	0.189	-0.006	-1.4%
R09	0.143	0.389	0.573	0.656	0.138	-0.030	-7.4%
R10	0.140	0.392	0.577	0.654	-0.027	-0.063	-15.4%
R11	0.136	0.382	0.576	0.677	0.287	0.002	0.4%
R12	0.137	0.384	0.568	0.648	0.011	-0.060	-14.7%
R13	0.137	0.386	0.566	0.645	0.066	-0.050	-12.2%
R14	0.139	0.379	0.540	0.636	0.008	-0.070	-17.0%
R15	0.145	0.405	0.607	0.729	0.315	0.030	7.3%
R16	0.138	0.385	0.565	0.642	0.157	-0.033	-8.0%



2.4 Open water characteristic - thrust full scale

 $K_T [-]$ full scale

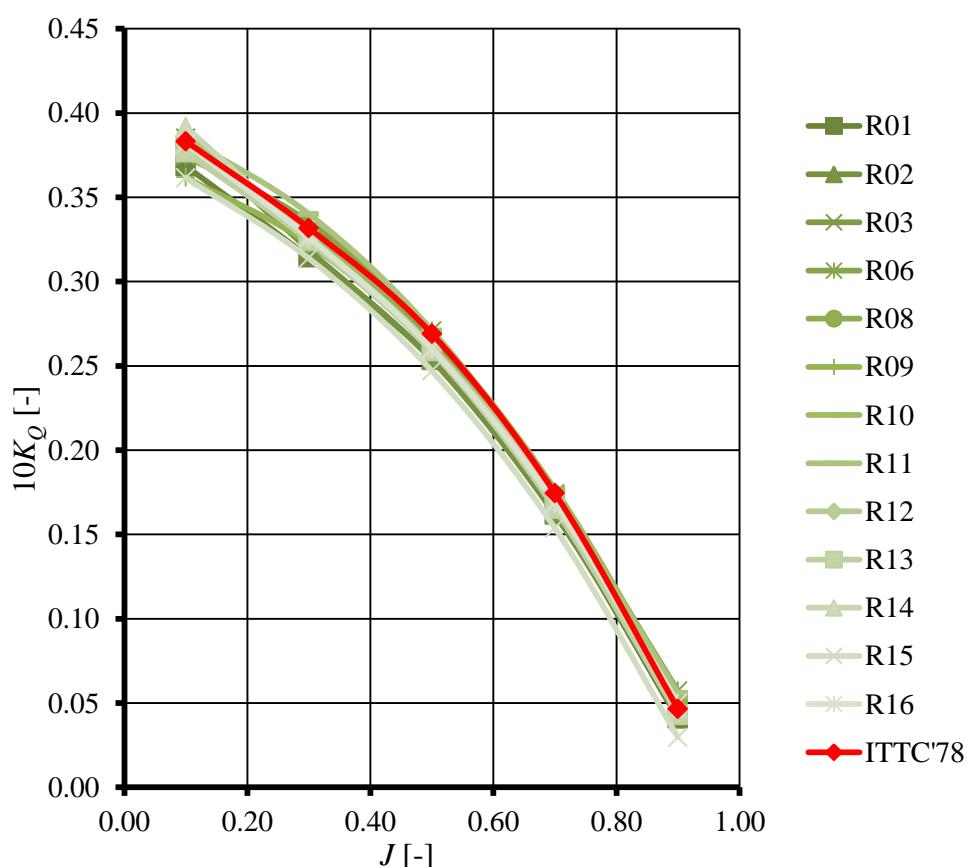
J [-]	0.10	0.30	0.50	0.70	0.90	Average over J	CFD - EFD	[-] [*]	[-] ^{**}
						CFD - EFD			
ITTC'78	0.353	0.284	0.209	0.117	0.008		0.000	0.0%	
R01	0.345	0.276	0.199	0.110	0.010		-0.006	-3.2%	
R02	0.344	0.271	0.195	0.107	0.009		-0.009	-4.5%	
R03	0.357	0.284	0.203	0.114	0.008		-0.001	-0.3%	
R06	0.346	0.288	0.210	0.117	0.020		0.002	1.2%	
R08	0.342	0.276	0.200	0.112	0.011		-0.006	-3.0%	
R09	0.333	0.278	0.203	0.114	0.015		-0.005	-2.8%	
R10	0.347	0.283	0.209	0.119	0.017		0.001	0.6%	
R11	0.342	0.284	0.209	0.117	0.018		0.000	-0.1%	
R12	0.347	0.280	0.202	0.113	0.010		-0.004	-1.9%	
R13	0.344	0.278	0.201	0.110	0.008		-0.006	-3.0%	
R14	0.352	0.277	0.199	0.110	0.008		-0.005	-2.4%	
R15	0.341	0.276	0.195	0.103	0.002		-0.011	-5.5%	
R16	0.346	0.278	0.201	0.112	0.011		-0.004	-2.3%	



2.5 Open water characteristic - torque full scale

10K_Q [-] full scale

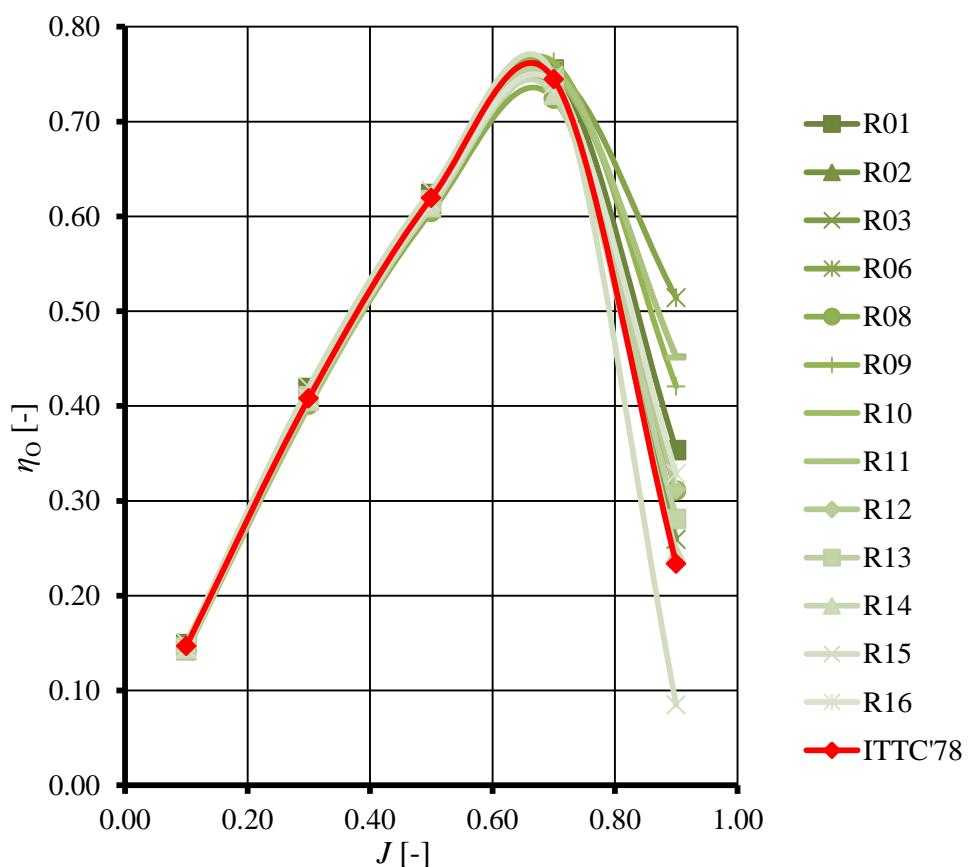
J [-]	0.10	0.30	0.50	0.70	0.90	Average over J	CFD - EFD
						[-]*	[-]**
ITTC'78	0.383	0.332	0.269	0.174	0.046	0.000	0.0%
R01	0.368	0.314	0.254	0.163	0.041	-0.013	-5.4%
R02	0.385	0.319	0.254	0.162	0.045	-0.008	-3.4%
R03	0.385	0.330	0.264	0.173	0.045	-0.001	-0.6%
R06	0.374	0.335	0.271	0.174	0.057	0.001	0.6%
R08	0.382	0.328	0.263	0.172	0.051	-0.002	-0.7%
R09	0.362	0.322	0.259	0.167	0.052	-0.009	-3.5%
R10	0.380	0.329	0.269	0.177	0.054	0.001	0.3%
R11	0.385	0.340	0.271	0.173	0.056	0.004	1.7%
R12	0.379	0.326	0.262	0.170	0.046	-0.004	-1.8%
R13	0.377	0.324	0.259	0.165	0.043	-0.007	-3.1%
R14	0.391	0.327	0.260	0.169	0.046	-0.002	-0.9%
R15	0.362	0.314	0.247	0.154	0.030	-0.020	-8.2%
R16	0.382	0.326	0.260	0.168	0.050	-0.004	-1.5%



2.6 Open water characteristic - efficiency full scale

 η_o [-] full scale

J [-]	Avarage over J					CFD - EFD	[-] [*]	[-] ^{**}
	0.10	0.30	0.50	0.70	0.90			
ITTC'78	0.147	0.408	0.619	0.745	0.234		0.000	0.0%
R01	0.149	0.419	0.623	0.755	0.353		0.029	6.8%
R02	0.142	0.405	0.613	0.740	0.281		0.006	1.4%
R03	0.148	0.412	0.612	0.733	0.259		0.002	0.6%
R06	0.147	0.410	0.617	0.751	0.514		0.057	13.3%
R08	0.143	0.401	0.605	0.724	0.311		0.006	1.5%
R09	0.146	0.412	0.623	0.763	0.421		0.043	9.9%
R10	0.145	0.411	0.618	0.748	0.452		0.045	10.4%
R11	0.141	0.399	0.613	0.753	0.451		0.041	9.5%
R12	0.146	0.410	0.616	0.742	0.312		0.015	3.4%
R13	0.145	0.410	0.617	0.743	0.281		0.009	2.1%
R14	0.143	0.405	0.609	0.728	0.245		-0.004	-1.0%
R15	0.150	0.420	0.627	0.748	0.085		-0.024	-5.7%
R16	0.144	0.408	0.615	0.739	0.329		0.016	3.8%



* / ** see at formula page

3 Statistics

3.1 Tables - model scale

 K_T [-] model scale

J [-]	0.10	0.30	0.50	0.70	0.90	Avarage over J	
						CFD - EFD [-] [*]	CFD - EFD [-] ^{**}
Minimum	0.330	0.267	0.184	0.102	-0.001	-0.014	-7.0%
1 th Quartile	0.339	0.269	0.192	0.104	0.003	-0.012	-6.3%
Median	0.341	0.271	0.196	0.107	0.007	-0.011	-5.6%
3 th Quartile	0.345	0.279	0.203	0.113	0.009	-0.004	-2.1%
Maximum	0.354	0.286	0.208	0.116	0.015	0.001	0.4%

 $10K_Q$ [-] model scale

J [-]	0.10	0.30	0.50	0.70	0.90	Avarage over J	
						CFD - EFD [-] [*]	CFD - EFD [-] ^{**}
Minimum	0.376	0.327	0.256	0.166	0.048	-0.009	-3.7%
1 th Quartile	0.381	0.332	0.268	0.174	0.051	-0.006	-2.4%
Median	0.388	0.334	0.271	0.179	0.055	-0.002	-0.7%
3 th Quartile	0.393	0.336	0.272	0.181	0.060	0.001	0.2%
Maximum	0.396	0.348	0.281	0.185	0.070	0.008	3.2%

 η_o [-] model scale

J [-]	0.10	0.30	0.50	0.70	0.90	Avarage over J	
						CFD - EFD [-] [*]	CFD - EFD [-] ^{**}
Minimum	0.136	0.379	0.540	0.636	-0.027	-0.070	-17.0%
1 th Quartile	0.137	0.385	0.568	0.648	0.066	-0.050	-12.2%
Median	0.140	0.392	0.577	0.677	0.157	-0.030	-7.2%
3 th Quartile	0.143	0.397	0.595	0.706	0.241	0.009	2.3%
Maximum	0.145	0.405	0.607	0.729	0.338	0.030	7.3%

3.2 Tables - full scale

 K_T [-] full scale

J [-]	0.10	0.30	0.50	0.70	0.90	Avarage over J	
						CFD - EFD [-] [*]	EFD [-] ^{**}
Minimum	0.333	0.271	0.195	0.103	0.002	-0.011	-5.5%
1 th Quartile	0.342	0.276	0.199	0.110	0.008	-0.006	-3.0%
Median	0.345	0.278	0.201	0.112	0.010	-0.005	-2.4%
3 th Quartile	0.347	0.283	0.203	0.114	0.015	-0.001	-0.3%
Maximum	0.357	0.288	0.210	0.119	0.020	0.002	1.2%

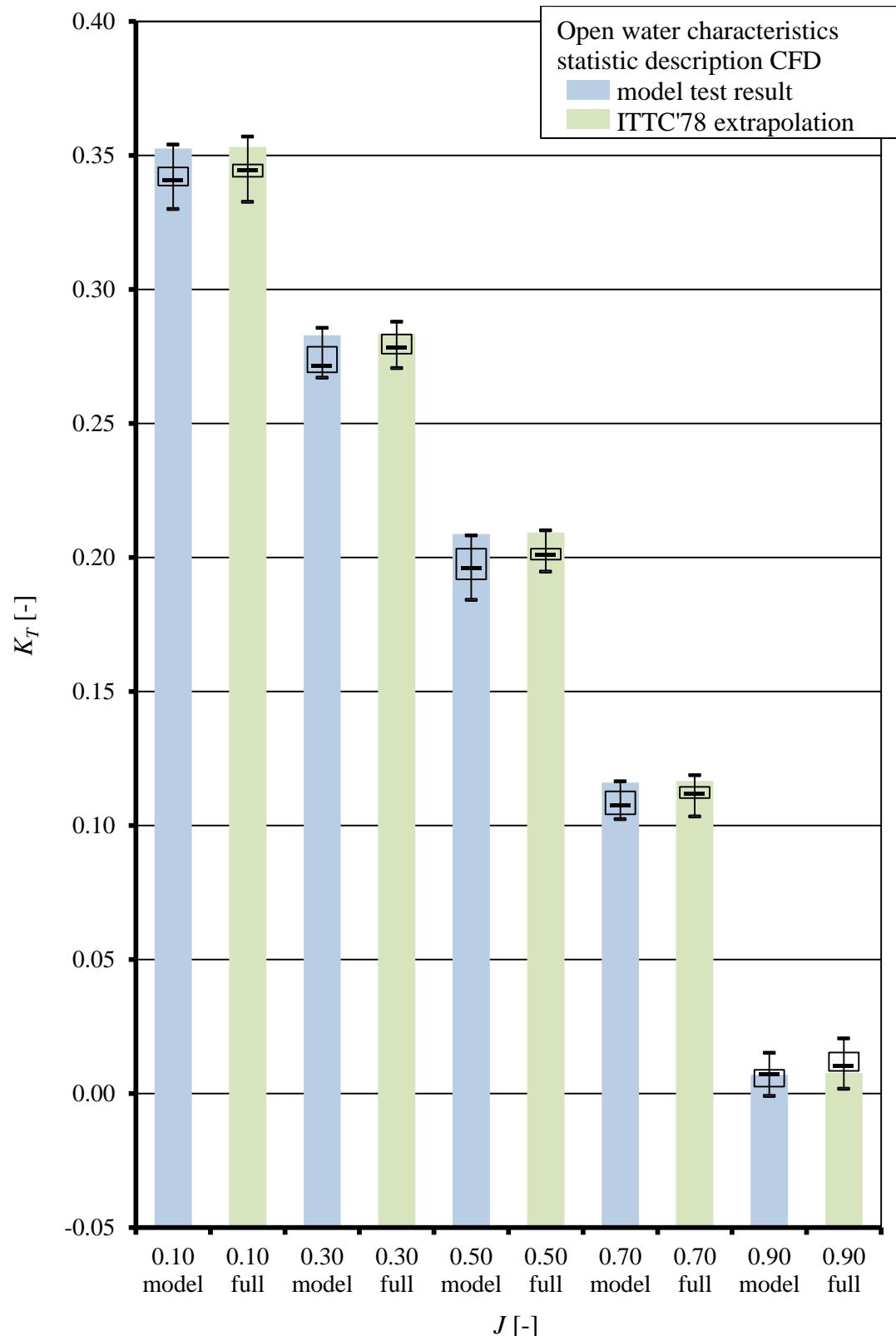
 $10K_Q$ [-] full scale

J [-]	0.10	0.30	0.50	0.70	0.90	Avarage over J	
						CFD - EFD [-] [*]	EFD [-] ^{**}
Minimum	0.362	0.314	0.247	0.154	0.030	-0.020	-8.2%
1 th Quartile	0.374	0.322	0.259	0.165	0.045	-0.008	-3.4%
Median	0.380	0.326	0.260	0.169	0.046	-0.004	-1.5%
3 th Quartile	0.385	0.329	0.264	0.173	0.052	-0.001	-0.6%
Maximum	0.391	0.340	0.271	0.177	0.057	0.004	1.7%

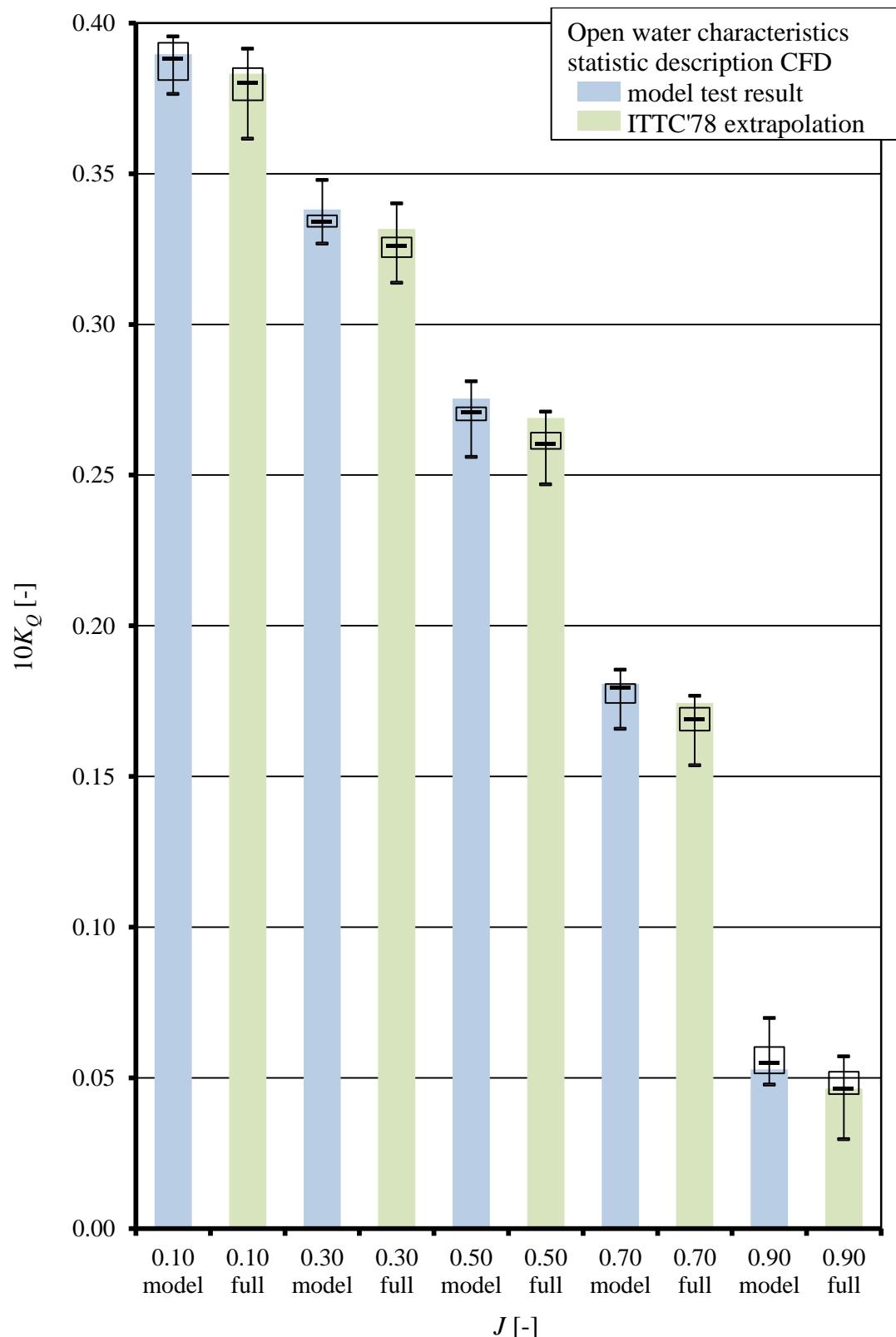
 η_o [-] full scale

J [-]	0.10	0.30	0.50	0.70	0.90	Avarage over J	
						CFD - EFD [-] [*]	EFD [-] ^{**}
Minimum	0.141	0.399	0.605	0.724	0.085	-0.024	-5.7%
1 th Quartile	0.143	0.405	0.613	0.739	0.281	0.006	1.4%
Median	0.145	0.410	0.616	0.743	0.312	0.015	3.4%
3 th Quartile	0.147	0.412	0.618	0.751	0.421	0.041	9.5%
Maximum	0.150	0.420	0.627	0.763	0.514	0.057	13.3%

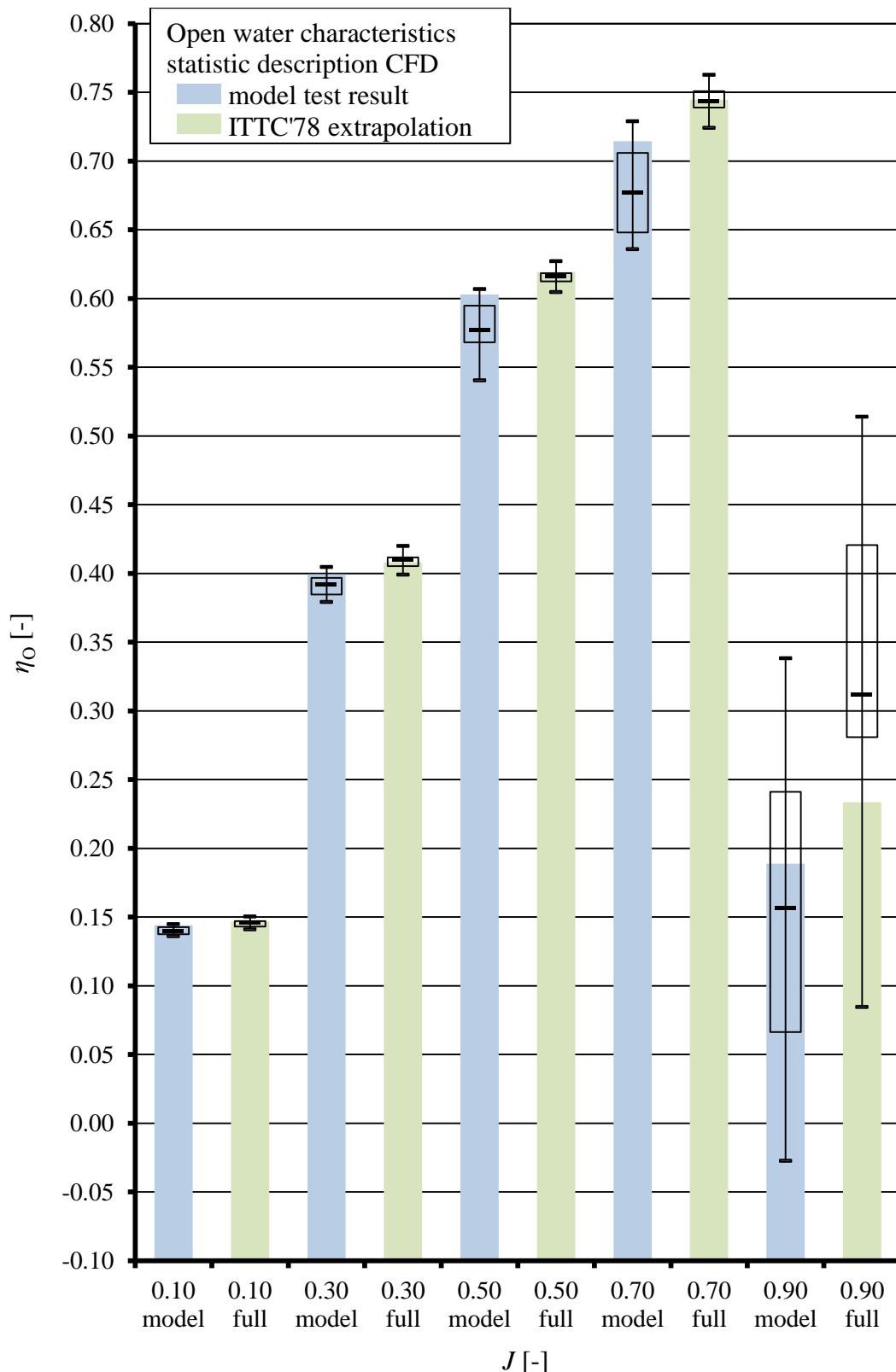
3.3 Diagrams - Thrust



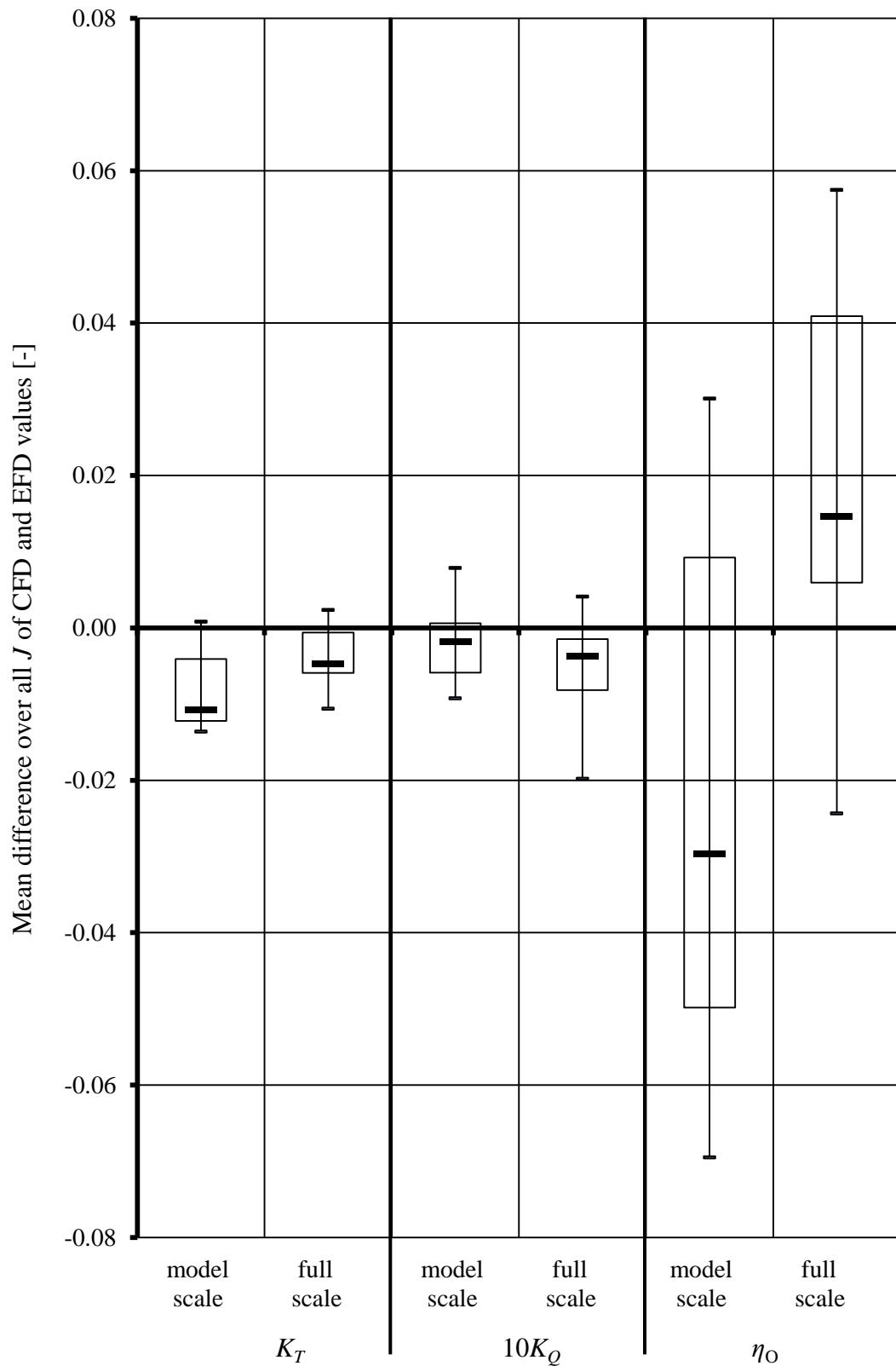
3.4 Diagrams - Torque



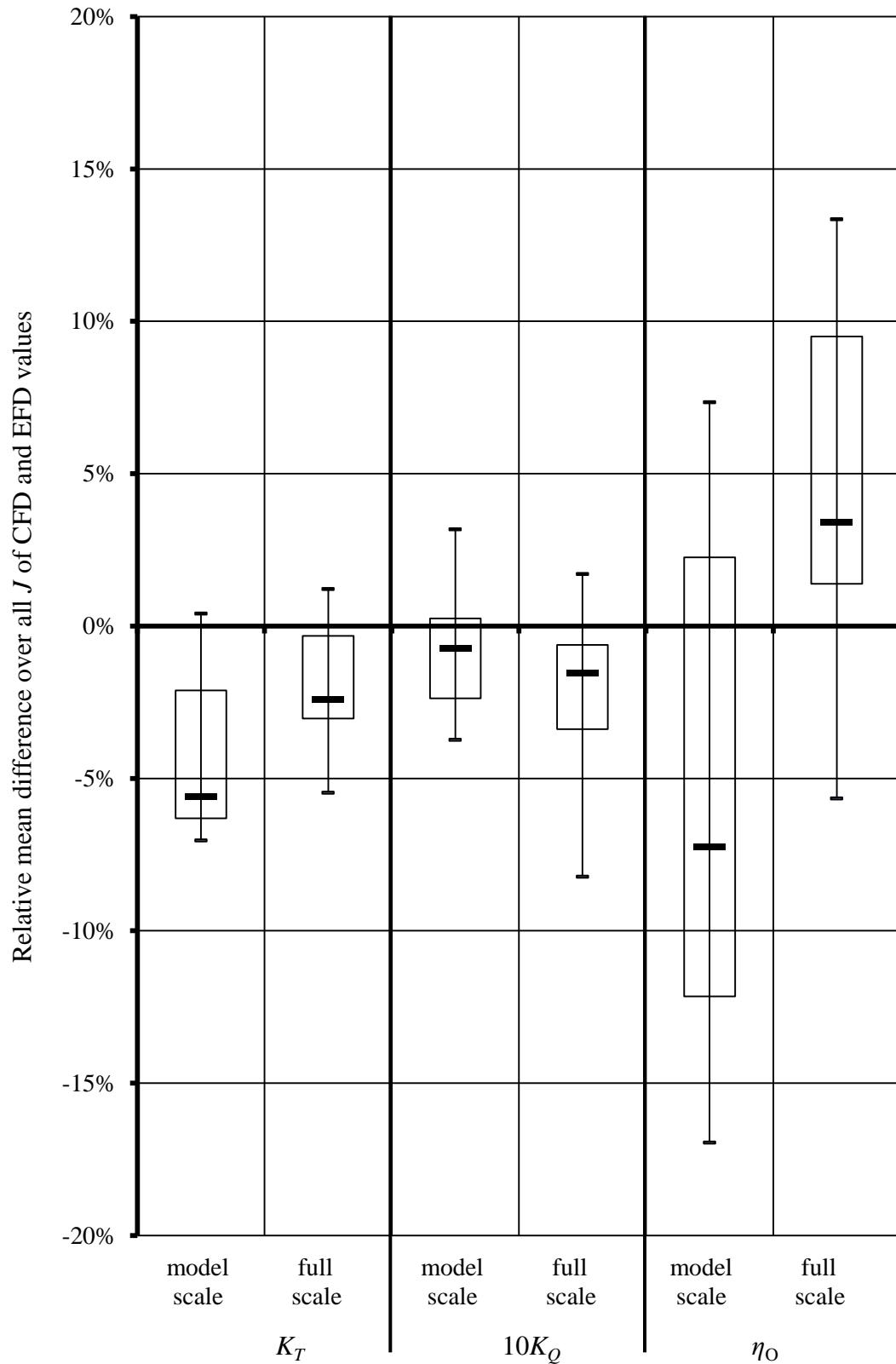
3.5 Diagrams - Efficiency



3.6 Diagrams - Difference CFD and EFD



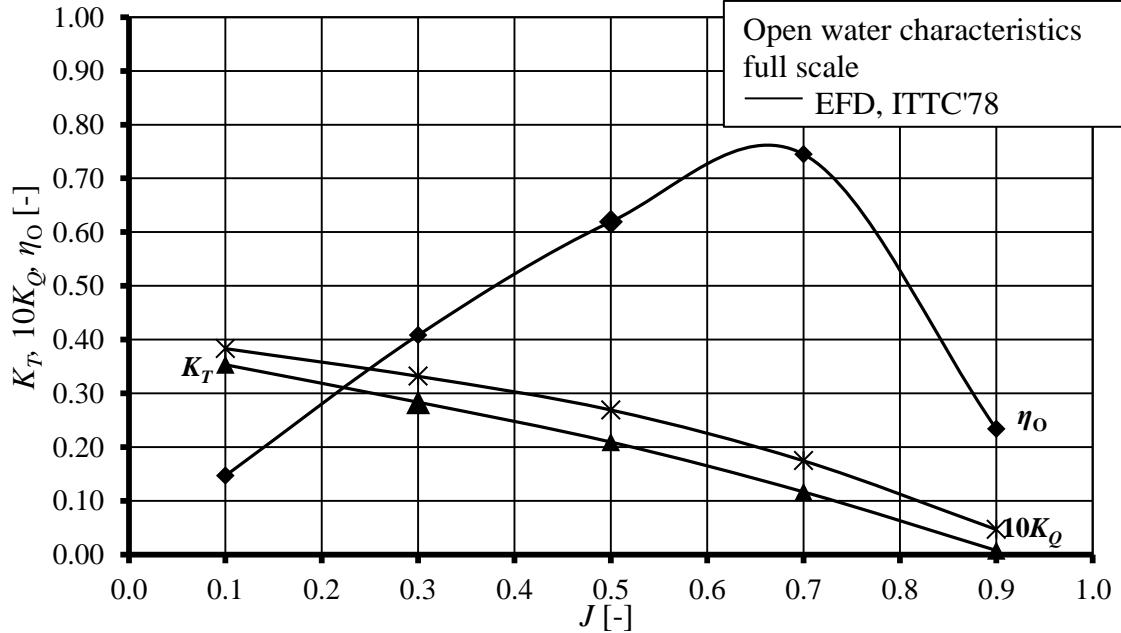
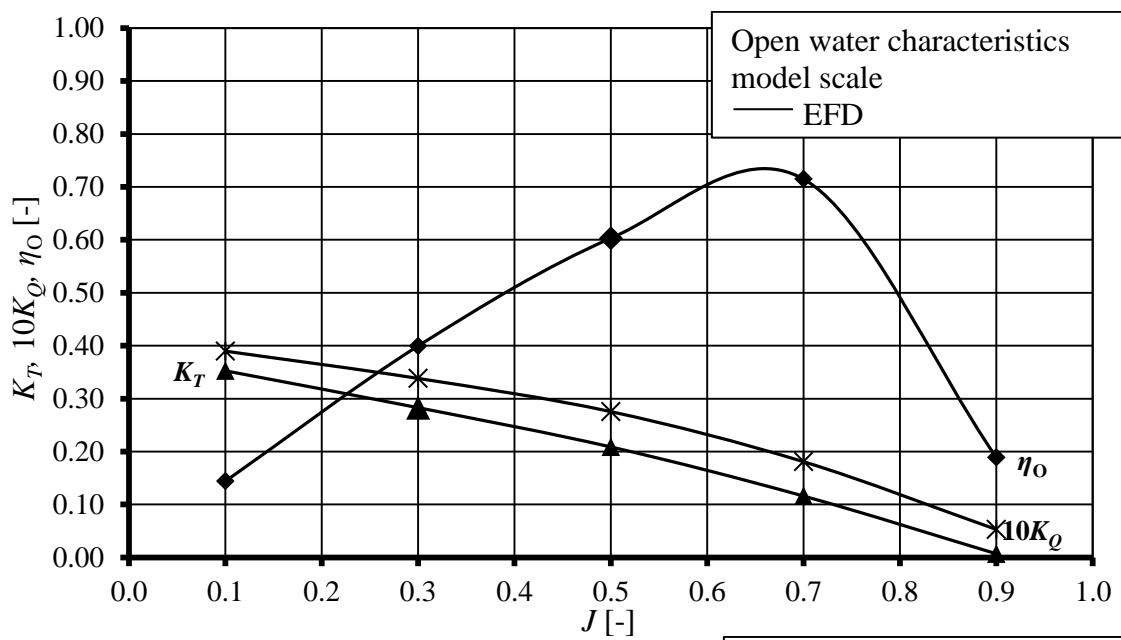
3.7 Diagrams - Relative difference CFD and EFD



4 Result EFD

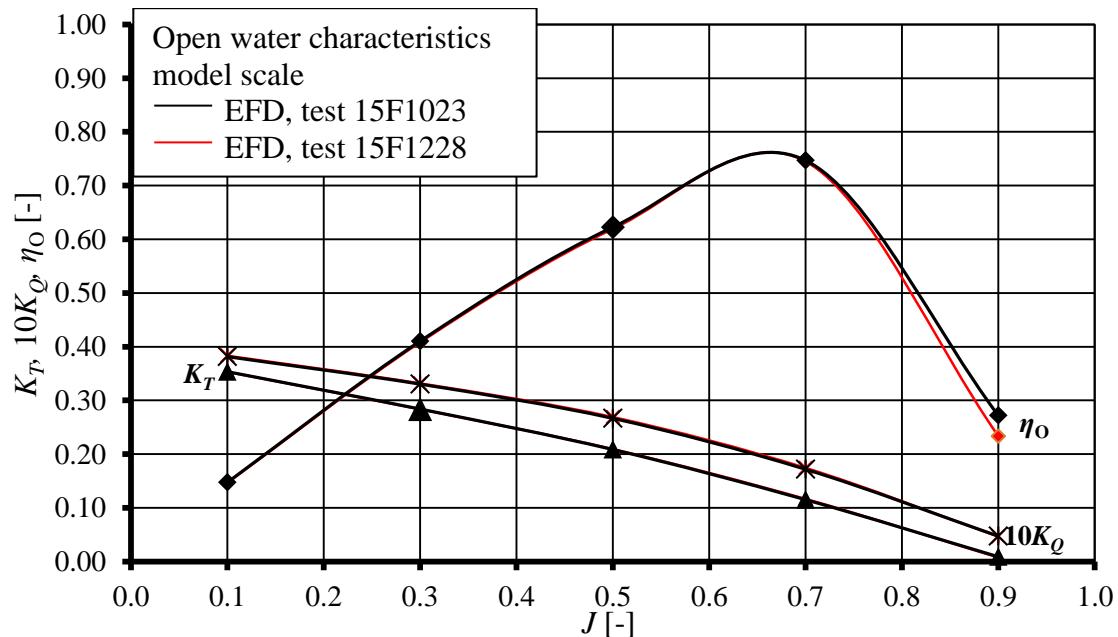
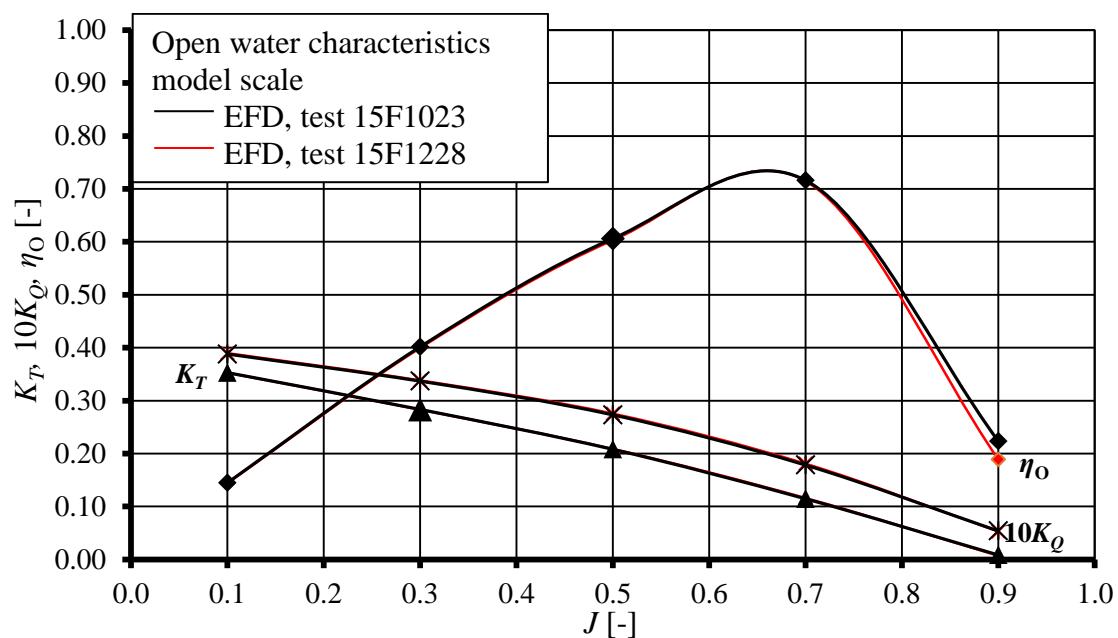
4.1 Open Water Characteristic - test 15F1023

J [-]	EFD, model scale			EFD, full scale, ITTC'78		
	K_T [-]	$10K_Q$ [-]	η_O [-]	K_T [-]	$10K_Q$ [-]	η_O [-]
	0.100	0.353	0.390	0.144	0.353	0.383
0.300	0.283	0.338	0.399	0.284	0.332	0.408
0.500	0.209	0.275	0.603	0.209	0.269	0.619
0.700	0.116	0.181	0.715	0.117	0.174	0.745
0.900	0.007	0.053	0.189	0.008	0.046	0.234



4.2 Open Water Characteristic - test 15F1228

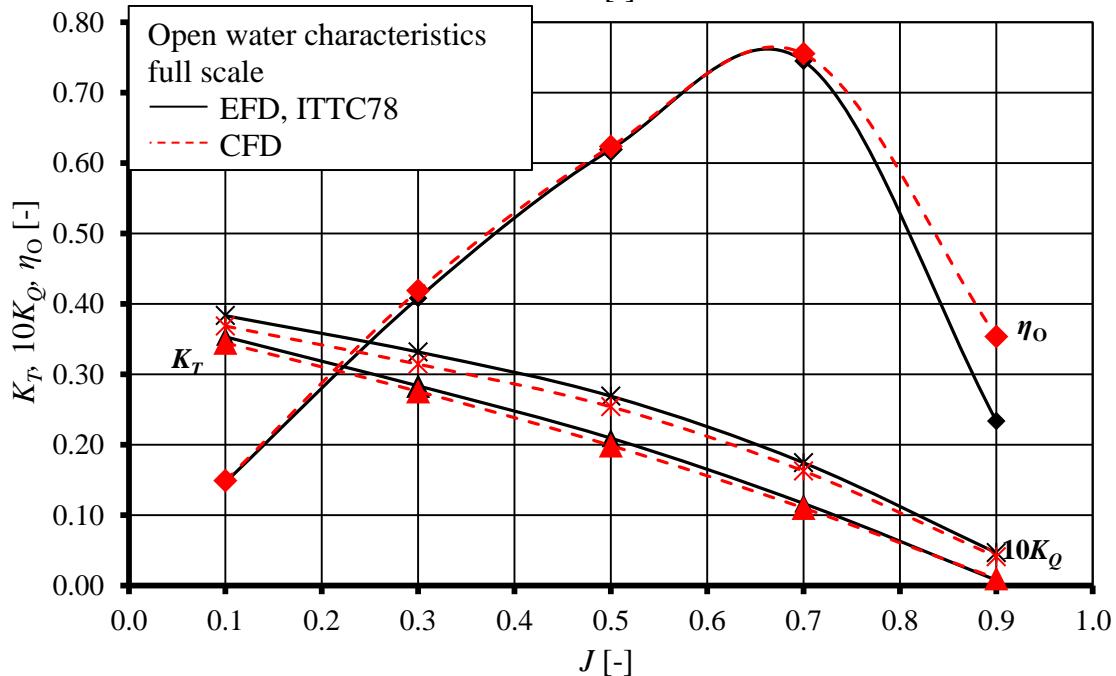
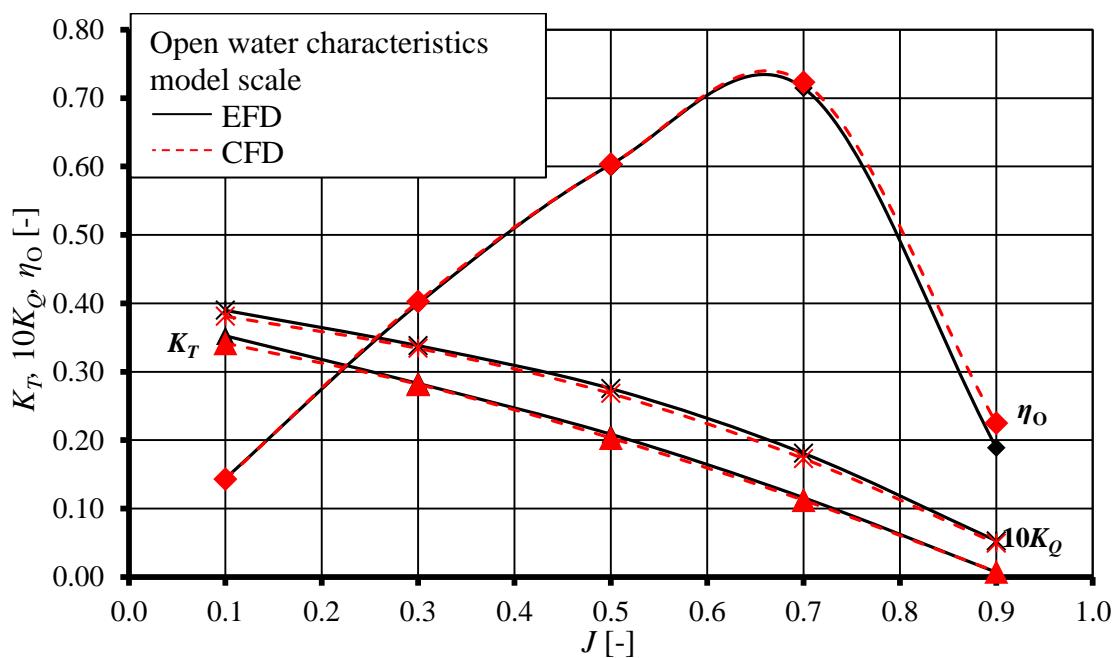
J [-]	EFD, model scale			EFD, full scale, ITTC'78		
	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
	[-]	[-]	[-]	[-]	[-]	[-]
0.100	0.353	0.388	0.145	0.354	0.382	0.147
0.300	0.283	0.337	0.402	0.284	0.330	0.410
0.500	0.208	0.273	0.606	0.209	0.267	0.623
0.700	0.115	0.178	0.716	0.115	0.172	0.747
0.900	0.008	0.054	0.223	0.009	0.047	0.272



5 Result R01

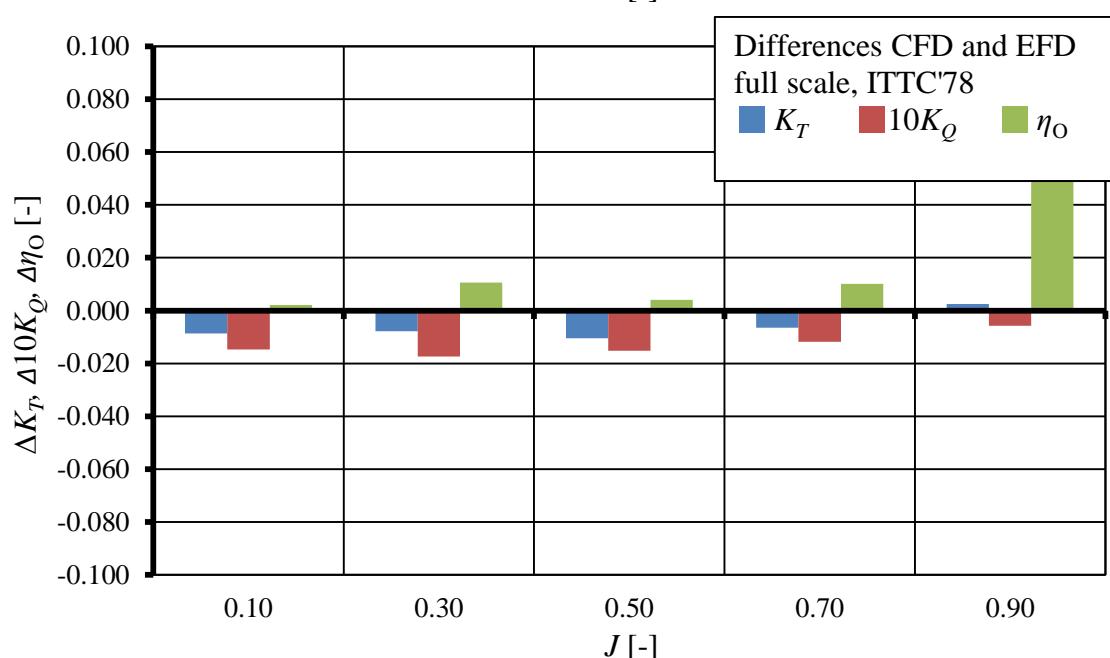
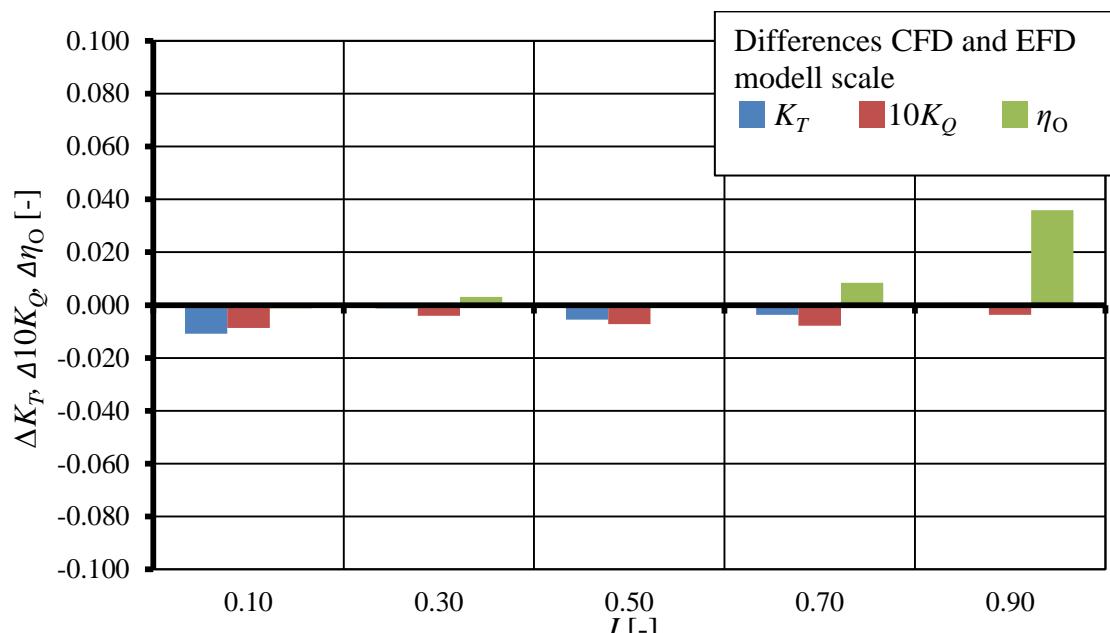
5.1 R01 - Open water characteristic

J [-]	CFD, model scale			CFD, full scale		
	K_T [-]	$10K_Q$ [-]	η_O [-]	K_T [-]	$10K_Q$ [-]	η_O [-]
	0.100	0.342	0.381	0.143	0.345	0.368
0.300	0.282	0.334	0.403	0.276	0.314	0.419
0.500	0.203	0.268	0.603	0.199	0.254	0.623
0.700	0.112	0.173	0.723	0.110	0.163	0.755
0.900	0.008	0.049	0.225	0.010	0.041	0.353



5.2 R01 - Differences CFD and EFD

CFD - EFD, model scale			CFD - EFD, full scale		
K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]
0.10	-0.011	-0.009	-0.001	-0.009	-0.015
0.30	-0.001	-0.004	0.003	-0.008	-0.017
0.50	-0.005	-0.007	0.000	-0.010	-0.015
0.70	-0.004	-0.008	0.008	-0.006	-0.012
0.90	0.001	-0.004	0.036	0.002	-0.006



5.3 R01 - Radial distribution tables

model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.010	0.009	0.007	0.003	-0.002	0.009	0.009	0.007	0.004	-0.003
0.370	0.025	0.022	0.016	0.008	-0.002	0.027	0.025	0.021	0.012	-0.001
0.505	0.043	0.037	0.028	0.016	0.002	0.053	0.048	0.040	0.026	0.007
0.630	0.060	0.051	0.038	0.022	0.004	0.074	0.066	0.053	0.035	0.011
0.745	0.070	0.057	0.040	0.022	0.002	0.078	0.067	0.052	0.034	0.010
0.850	0.072	0.057	0.039	0.021	0.000	0.073	0.061	0.047	0.030	0.008
0.938	0.052	0.040	0.029	0.016	0.004	0.054	0.044	0.037	0.025	0.011
0.988	0.009	0.008	0.006	0.003	0.001	0.014	0.012	0.010	0.008	0.006

full scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.011	0.010	0.008	0.004	0.000	0.010	0.009	0.008	0.004	-0.002
0.370	0.025	0.022	0.017	0.009	-0.001	0.026	0.025	0.021	0.013	0.000
0.505	0.043	0.037	0.028	0.016	0.002	0.050	0.046	0.038	0.025	0.007
0.630	0.060	0.049	0.036	0.021	0.003	0.070	0.061	0.050	0.033	0.010
0.745	0.070	0.055	0.039	0.021	0.001	0.075	0.063	0.049	0.031	0.007
0.850	0.073	0.054	0.037	0.019	0.000	0.071	0.056	0.044	0.027	0.005
0.938	0.054	0.040	0.028	0.015	0.004	0.053	0.042	0.034	0.022	0.009
0.988	0.010	0.008	0.006	0.004	0.002	0.013	0.012	0.011	0.008	0.005

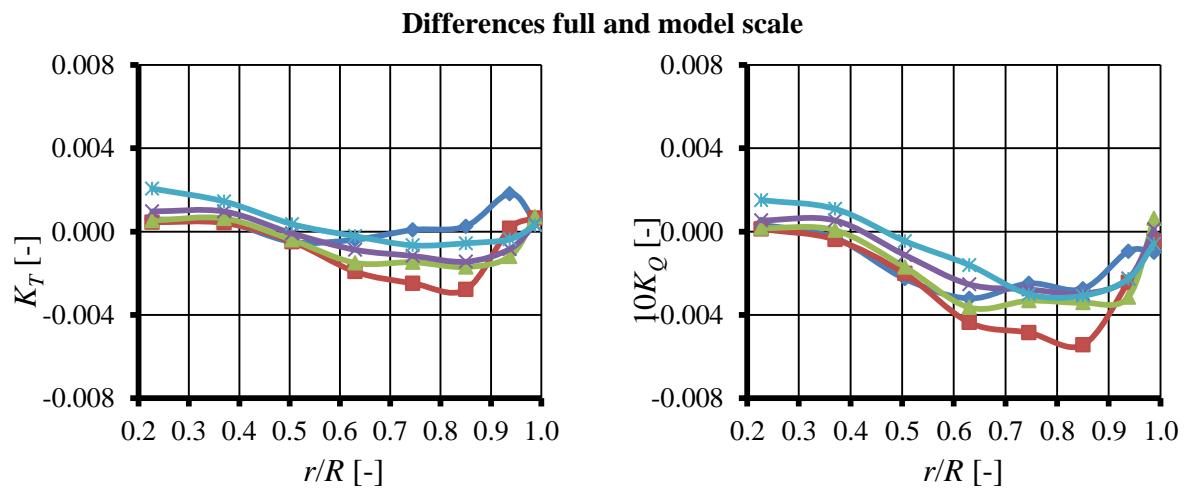
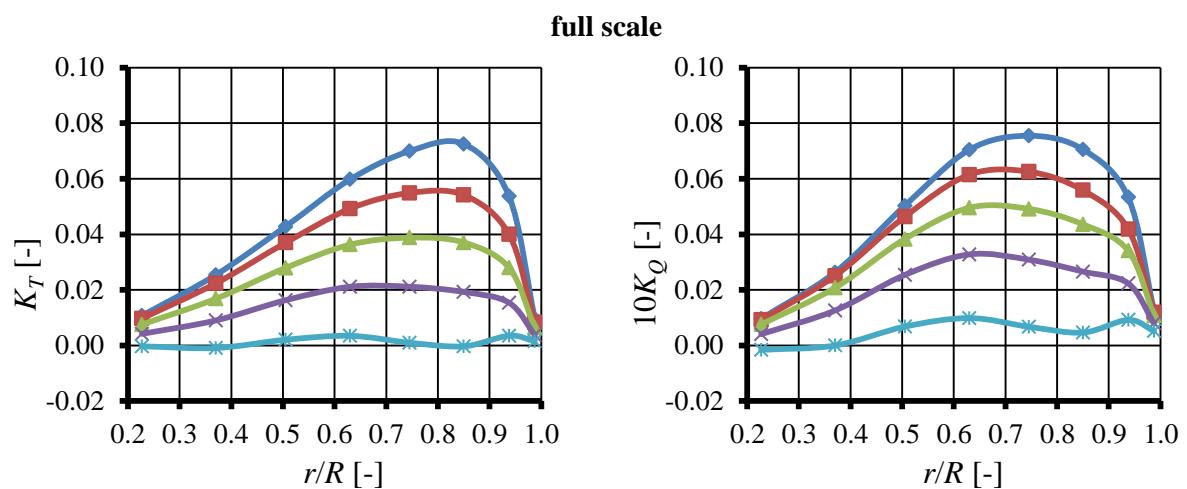
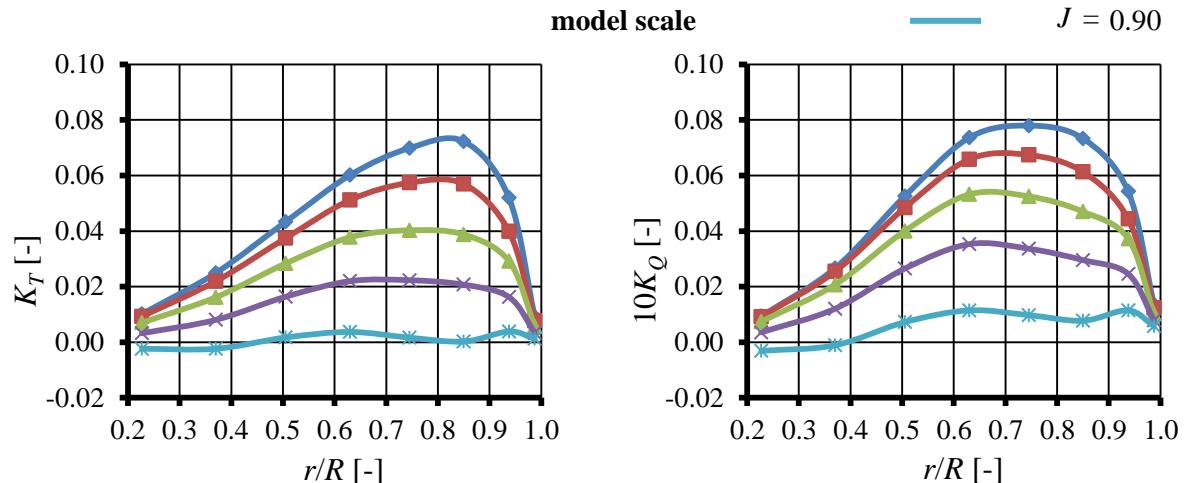
Differences full and model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.0006	0.0004	0.0005	0.0010	0.0021	0.0003	0.0001	0.0002	0.0005	0.0015
0.370	0.0005	0.0004	0.0006	0.0010	0.0014	-0.0003	-0.0004	0.0001	0.0005	0.0011
0.505	-0.0005	-0.0005	-0.0004	-0.0001	0.0004	-0.0023	-0.0020	-0.0017	-0.0011	-0.0005
0.630	-0.0004	-0.0019	-0.0015	-0.0009	-0.0002	-0.0032	-0.0044	-0.0036	-0.0025	-0.0016
0.745	0.0001	-0.0025	-0.0015	-0.0012	-0.0007	-0.0025	-0.0048	-0.0033	-0.0028	-0.0030
0.850	0.0003	-0.0028	-0.0017	-0.0014	-0.0006	-0.0028	-0.0054	-0.0034	-0.0030	-0.0031
0.938	0.0018	0.0002	-0.0012	-0.0008	-0.0004	-0.0009	-0.0024	-0.0031	-0.0023	-0.0023
0.988	0.0005	0.0006	0.0007	0.0003	0.0003	-0.0010	-0.0004	0.0006	0.0001	-0.0006

5.4 R01 - Radial distribution diagrams



 $J = 0.10$
 $J = 0.30$
 $J = 0.50$
 $J = 0.70$
 $J = 0.90$



5.5 R01 - Questionnaire part I

	model scale	full scale
Solver	STAR-CCM+	STAR-CCM+
Computational Domain		
A1 Domain topology	Multiple domains	Multiple domains
A2 Grid-coupling technique	Sliding	Sliding
Propeller Representation		
B1 Number of considered blades	Complete propeller	Complete propeller
Computational Grid		
C1 Type	Unstructured	Unstructured
C2 Local-grid refinement	Possible - used here	Possible - used here
C3 Primary volume elements	Polyhedral	Polyhedral
C4 Primary surface elements	Other	Other
C5 Wall-boundary layer type	Prism Layer	Prism Layer
C7 Number of cells at boundary layer	18	24
C8 Y ⁺ -value at r/R=0.4, 0.7, 0.9	1.008,0.96,0.968	3.04,1.918,2.223
C9 Averaged Y ⁺ -value	0.988	2.433
C10 Number of cells on blade surface	303087	621590
Norm. Dim. the Physical Domain		
D1 X_upstream/D, X_downstream/D	21,42	21,42
D2 Cross area of domain in prop. plain	559	559
Numerical Approximation		
E1 Finite Approximation Scheme (Fluid)	FV-NS	FV-NS
E2 Coordinates	Cartesian	Cartesian
E3 Convection scheme (momentum eq.)	2nd-order centered	2nd-order centered
E4 Transient approximation	implicit	implicit
E5 Spatial order of acc. (neglecting BC)	2nd-order	2nd-order
E6 Temporal order of accuracy	1st-order	1st-order
E7 Time step	0.000154 sec	0.000865 sec
E8 Equivalent rot. Angle for a time step	1 deg	1deg
Turbulence treatment		
F1 Model name	k-omega	k-omega
F2 Convection scheme (Turb. Eqn.)	2nd-order centered	2nd-order centered
Boundary conditions		
G1 Blade	resolved	resolved
G2 Hub	resolved	resolved
G3 Inlet	Fixed Velocity	Fixed Velocity
G4 Outlet	Fixed Pressure	Fixed Pressure
G5 Outer domain	Slip flow	Slip flow

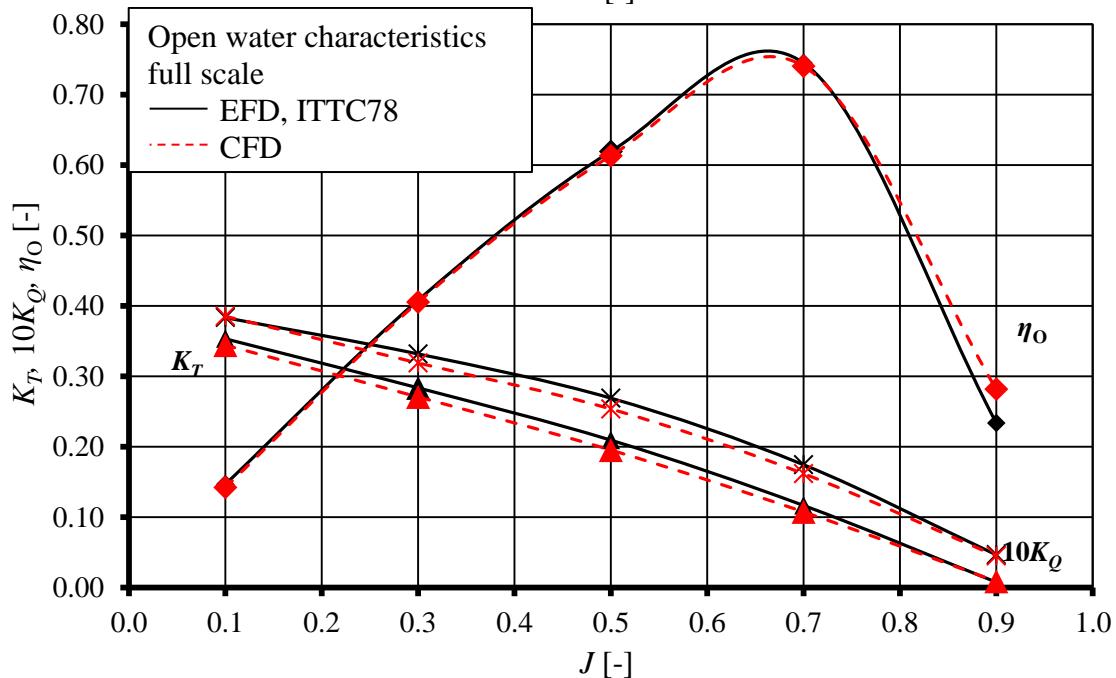
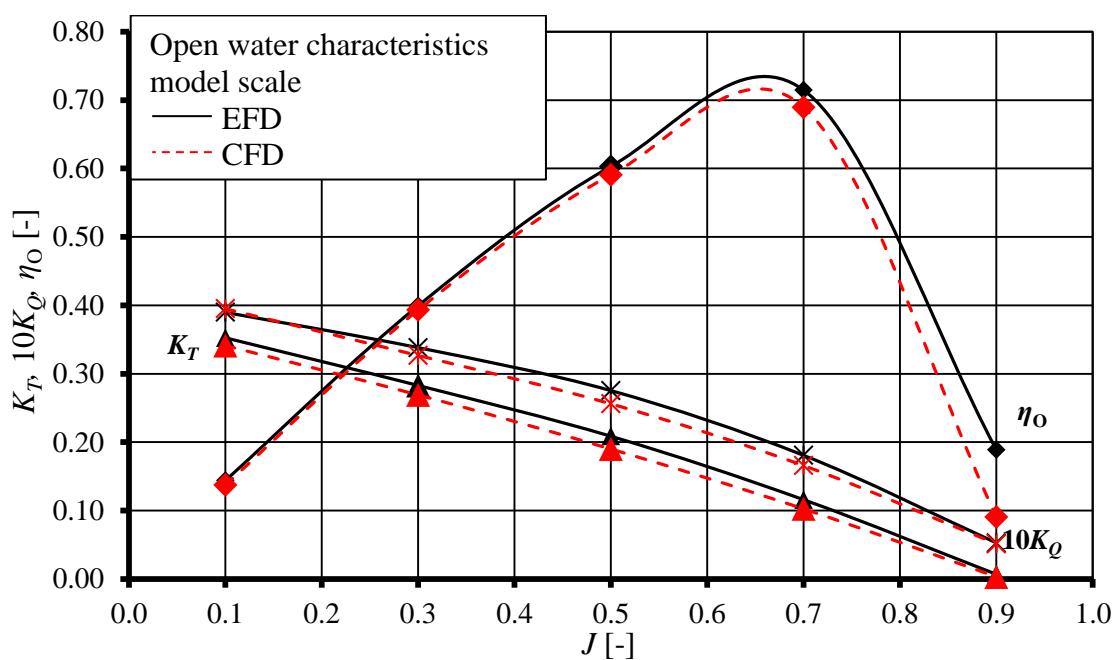
5.5 R01 - Questionnaire part II

	model scale	full scale
Computational Model		
H1 Fluid	incompressible	incompressible
H2 Pressure	pressure correction	pressure correction
Transition		
I Please comment	yes / Gamma ReTheta method	0 / 0
Computational Demands		
J1 Number of processors used	256	256
J2 Number of timesteps (steady)	0	0
J3 Number of timesteps (transient)	2448	3276
J4 Wall-clock time per revolution	5384sec	8744 sec
Code		
K References	STAR-CCM+ V10.04 / Primary surface elements: Polyhedral	STAR-CCM+ V10.04 / Primary surface elements: Polyhedral
Comments		
L Add. info.	0 / 0	0 / 0

6 Result R02

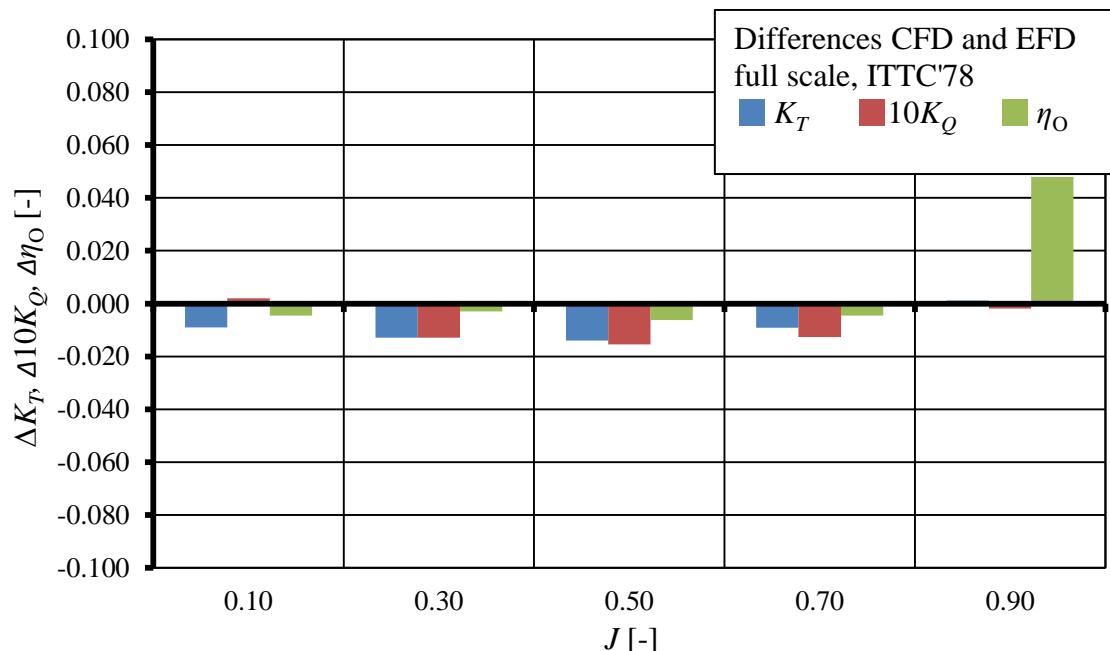
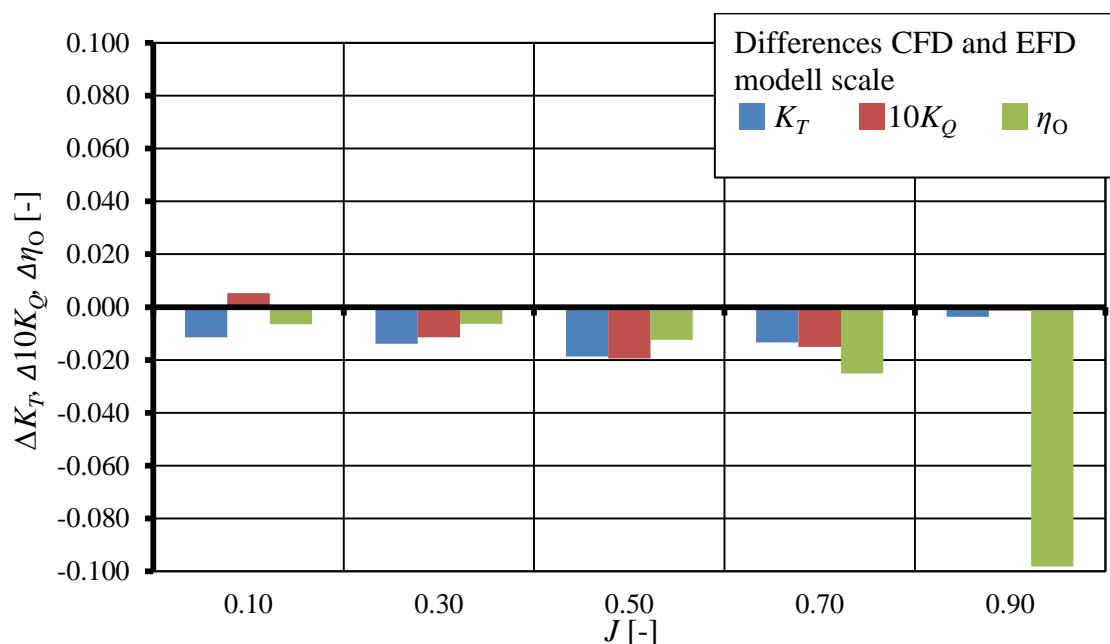
6.1 R02 - Open water characteristic

J	CFD, model scale			CFD, full scale		
	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.100	0.341	0.395	0.137	0.344	0.385	0.142
0.300	0.269	0.327	0.393	0.271	0.319	0.405
0.500	0.190	0.256	0.591	0.195	0.254	0.613
0.700	0.103	0.166	0.689	0.107	0.162	0.740
0.900	0.003	0.051	0.091	0.009	0.045	0.281



6.2 R02 - Differences CFD and EFD

CFD - EFD, model scale			CFD - EFD, full scale		
K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]
0.10	-0.011	0.005	-0.006	-0.009	0.002
0.30	-0.014	-0.011	-0.006	-0.013	-0.013
0.50	-0.019	-0.019	-0.012	-0.014	-0.015
0.70	-0.013	-0.015	-0.025	-0.009	-0.013
0.90	-0.004	-0.001	-0.098	0.001	-0.002
					0.048



6.3 R02 - Radial distribution tables

model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.010	0.009	0.007	0.003	-0.002	0.009	0.009	0.007	0.003	-0.003
0.370	0.025	0.022	0.016	0.008	-0.002	0.027	0.025	0.020	0.011	-0.001
0.505	0.042	0.036	0.027	0.015	0.001	0.052	0.046	0.037	0.024	0.007
0.630	0.059	0.048	0.035	0.020	0.003	0.073	0.063	0.049	0.033	0.011
0.745	0.069	0.054	0.037	0.020	0.001	0.079	0.065	0.050	0.032	0.010
0.850	0.071	0.053	0.036	0.018	-0.001	0.075	0.059	0.046	0.029	0.009
0.938	0.057	0.039	0.027	0.015	0.002	0.066	0.046	0.035	0.025	0.011
0.988	0.008	0.007	0.006	0.004	0.001	0.014	0.013	0.012	0.010	0.006

full scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.010	0.009	0.007	0.003	-0.001	0.009	0.009	0.007	0.003	-0.002
0.370	0.025	0.021	0.016	0.008	-0.001	0.026	0.024	0.020	0.011	0.000
0.505	0.042	0.036	0.027	0.015	0.002	0.051	0.046	0.037	0.024	0.006
0.630	0.059	0.048	0.035	0.020	0.003	0.072	0.062	0.049	0.032	0.011
0.745	0.068	0.054	0.038	0.021	0.001	0.077	0.064	0.050	0.031	0.009
0.850	0.072	0.054	0.037	0.020	0.000	0.072	0.058	0.045	0.028	0.006
0.938	0.059	0.040	0.028	0.016	0.003	0.065	0.044	0.035	0.023	0.010
0.988	0.009	0.008	0.006	0.004	0.001	0.013	0.012	0.011	0.008	0.005

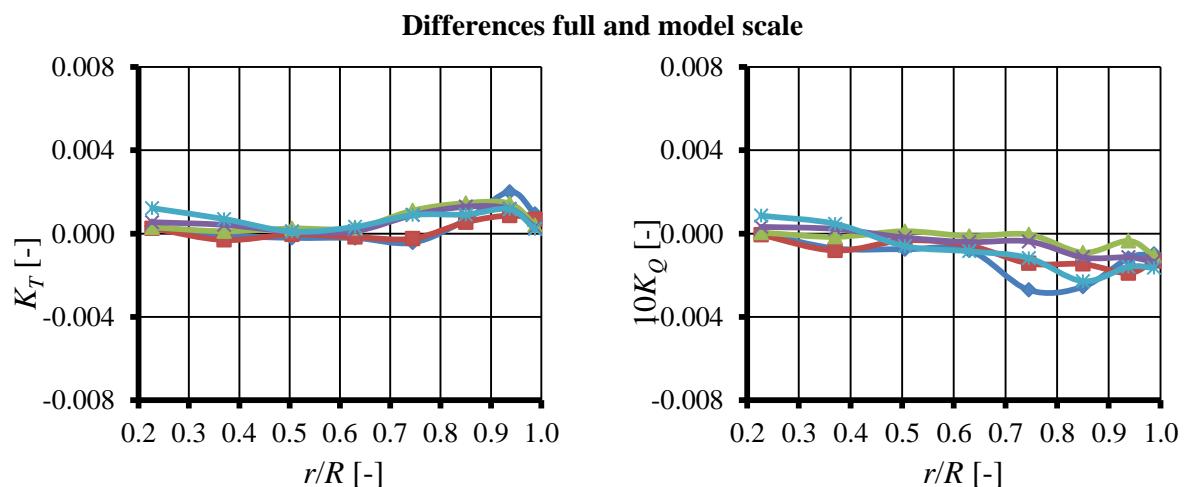
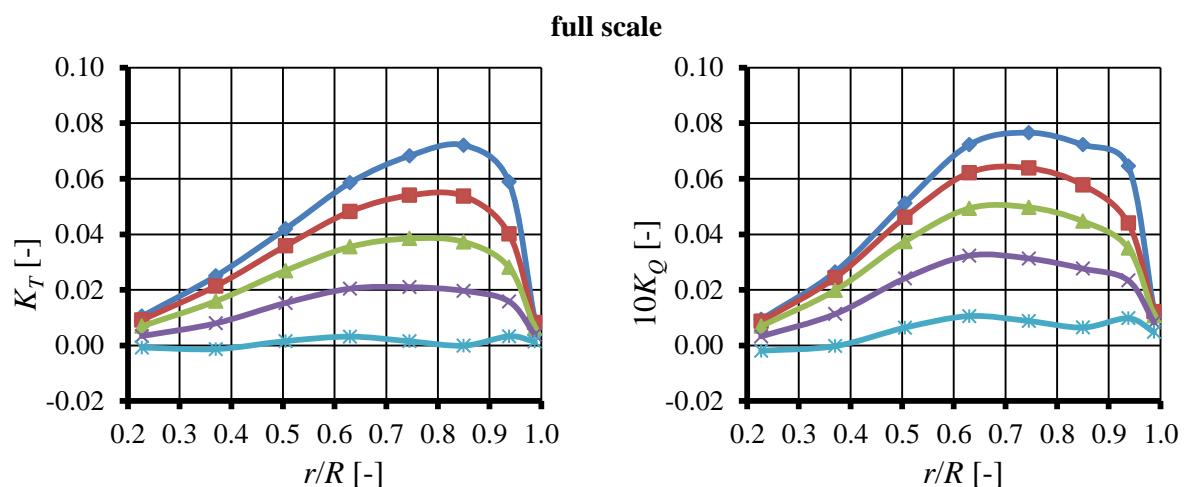
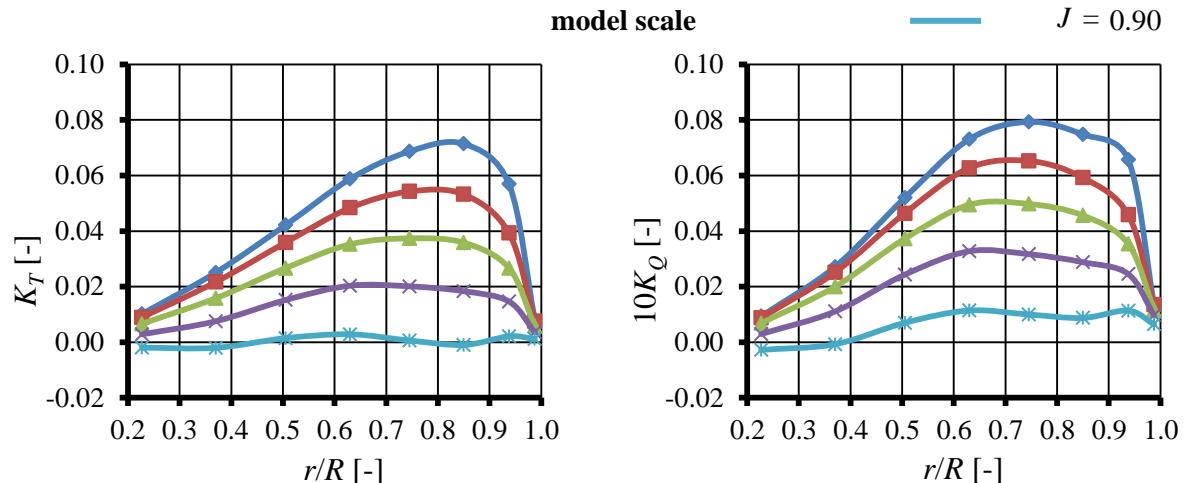
Differences full and model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.0003	0.0002	0.0003	0.0005	0.0012	0.0000	-0.0001	0.0000	0.0003	0.0009
0.370	-0.0001	-0.0003	0.0001	0.0004	0.0007	-0.0007	-0.0008	-0.0002	0.0002	0.0005
0.505	-0.0002	0.0000	0.0002	0.0001	0.0001	-0.0008	-0.0003	0.0001	-0.0002	-0.0006
0.630	-0.0002	-0.0002	0.0003	0.0001	0.0003	-0.0008	-0.0006	-0.0001	-0.0004	-0.0009
0.745	-0.0004	-0.0002	0.0011	0.0009	0.0009	-0.0027	-0.0014	0.0000	-0.0004	-0.0012
0.850	0.0007	0.0005	0.0015	0.0013	0.0009	-0.0026	-0.0015	-0.0009	-0.0011	-0.0023
0.938	0.0020	0.0009	0.0014	0.0012	0.0012	-0.0012	-0.0019	-0.0004	-0.0011	-0.0016
0.988	0.0009	0.0007	0.0004	0.0003	0.0002	-0.0010	-0.0013	-0.0011	-0.0014	-0.0016

6.4 R02 - Radial distribution diagrams



 $J = 0.10$
 $J = 0.30$
 $J = 0.50$
 $J = 0.70$
 $J = 0.90$



6.5 R02 - Questionnaire part I

	model scale	full scale
Solver	ANSYS-FLUENT	ANSYS-FLUENT
Computational Domain		
A1 Domain topology	1 rotating domain	1 rotating domain
A2 Grid-coupling technique	None	None
Propeller Representation		
B1 Number of considered blades	1 blade, non-matching	1 blade, non-matching
Computational Grid		
C1 Type	Unstructured	Unstructured
C2 Local-grid refinement	Possible - not used here	Possible - not used here
C3 Primary volume elements	Tetraheder	Tetraheder
C4 Primary surface elements	Quads	Quads
C5 Wall-boundary layer type	Prism Layer	Prism Layer
C7 Number of cells at boundary layer	abt 432000cells in balde sur	abt 624000cells in balde sur
C8 Y ⁺ -value at r/R=0.4, 0.7, 0.9	abt 1y ₊ at 0.7R	abt 5y ₊ at 0.7R
C9 Averaged Y ⁺ -value	0.35 y ₊	2.4 y ₊
C10 Number of cells on blade surface	abt 24000cells	abt 24000cells
Norm. Dim. the Physical Domain		
D1 X_upstream/D, X_downstream/D	4D,10D	4D,10D
D2 Cross area of domain in prop. plain	12D	12D
Numerical Approximation		
E1 Finite Approximation Scheme (Fluid)	FV-NS	FV-NS
E2 Coordinates	Cartesian	Cartesian
E3 Convection scheme (momentum eq.)	blended UDS / CDS	blended UDS / CDS
E4 Transient approximation	implicit	implicit
E5 Spatial order of acc. (neglecting BC)	2nd order	2nd order
E6 Temporal order of accuracy	steady	steady
E7 Time step	steady	steady
E8 Equivalent rot. Angle for a time step	steady	steady
Turbulence treatment		
F1 Model name	k-omega	k-omega
F2 Convection scheme (Turb. Eqn.)	blended UDS / CDS	blended UDS / CDS
Boundary conditions		
G1 Blade	resolved	resolved
G2 Hub	resolved	resolved
G3 Inlet	Fixed Velocity	Fixed Velocity
G4 Outlet	Fixed Pressure	Fixed Pressure
G5 Outer domain	Slip flow	Slip flow

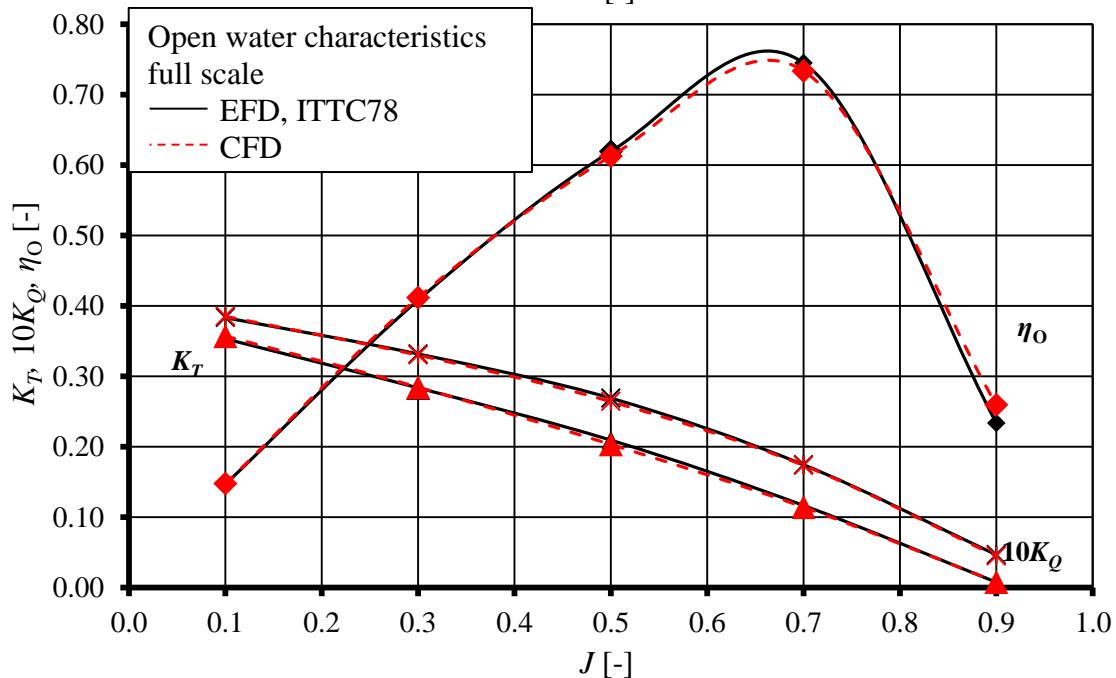
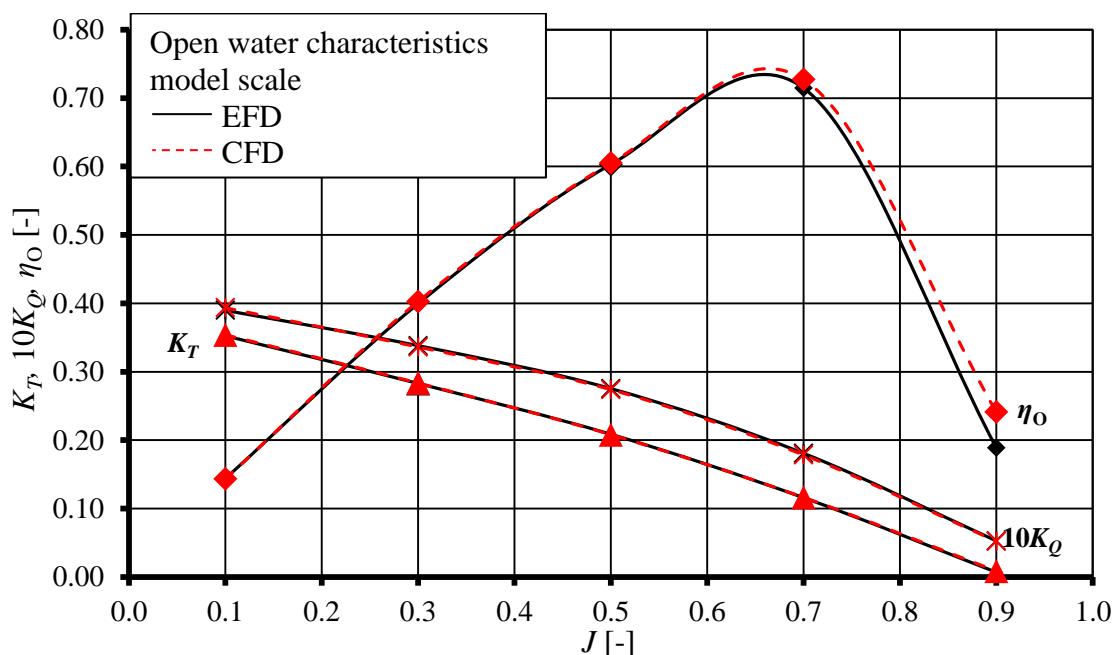
6.5 R02 - Questionnaire part II

	model scale	full scale
Computational Model		
H1 Fluid	incompressible	incompressible
H2 Pressure	Coupled	Coupled
Transition		
I Please comment	considered	considered, but whole flowfield is fully turbulent
Computational Demands		
J1 Number of processors used	16proc	16proc
J2 Number of timesteps (steady)	1500iterations	1500iterations
J3 Number of timesteps (transient)	-	-
J4 Wall-clock time per revolution	35min/1500iteration	40min/1500iteration
Code		
K References	FLUENT15.0	FLUENT15.0
Comments		
L Add. info.	0 / 0	0 / 0

7 Result R03

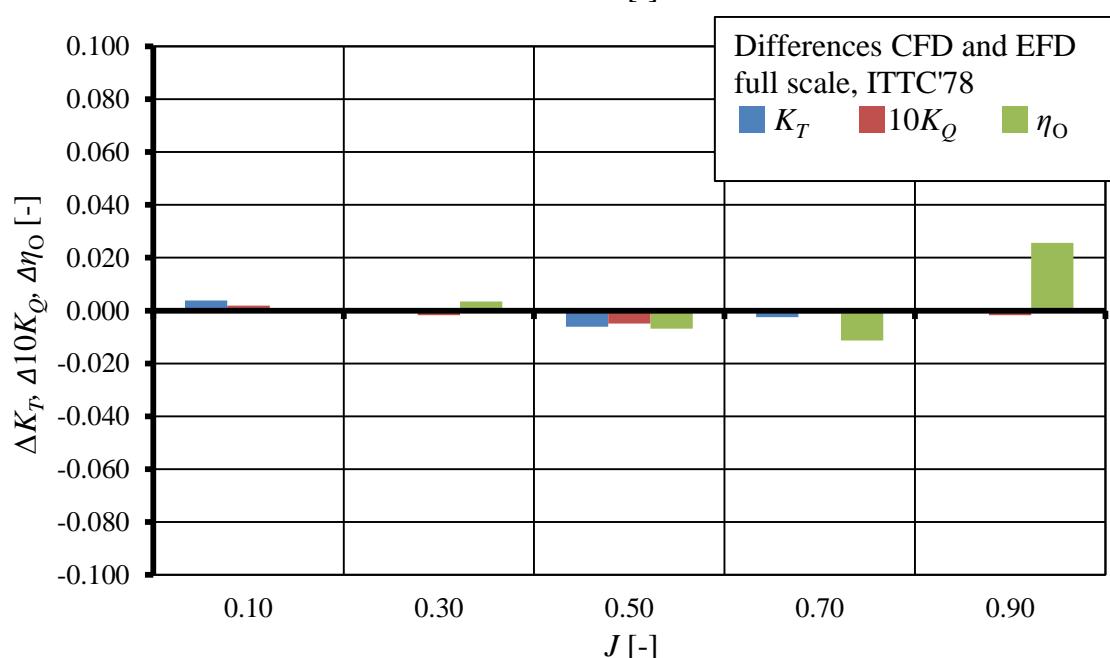
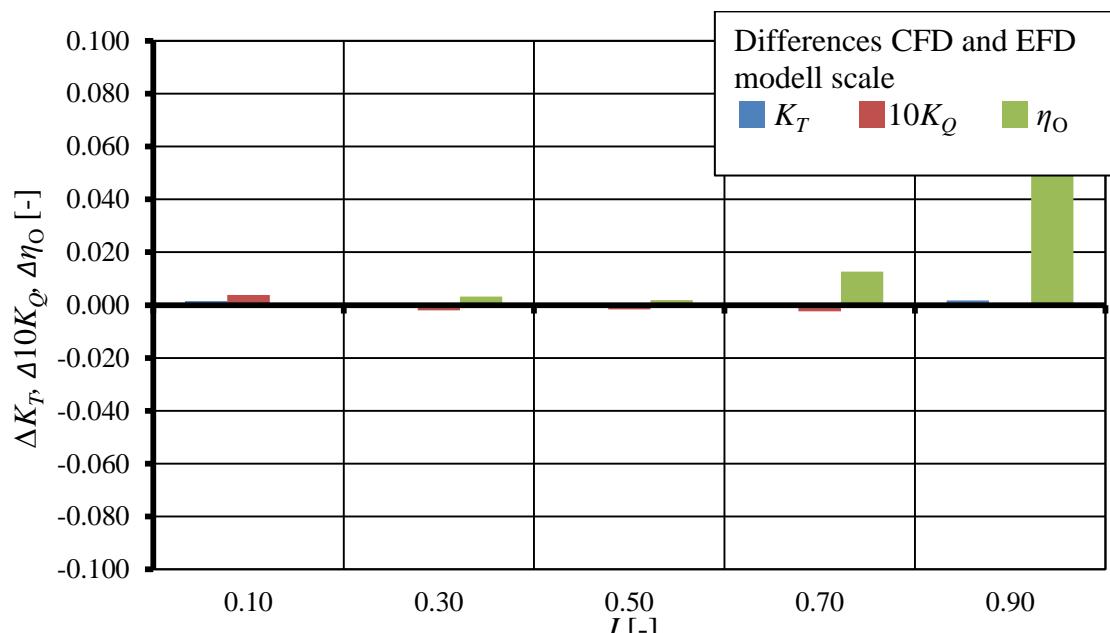
7.1 R03 - Open water characteristic

J [-]	CFD, model scale			CFD, full scale		
	K_T [-]	$10K_Q$ [-]	η_O [-]	K_T [-]	$10K_Q$ [-]	η_O [-]
	0.100	0.354	0.393	0.143	0.357	0.385
0.300	0.284	0.336	0.403	0.284	0.330	0.412
0.500	0.208	0.274	0.605	0.203	0.264	0.612
0.700	0.116	0.178	0.727	0.114	0.173	0.733
0.900	0.009	0.052	0.241	0.008	0.045	0.259



7.2 R03 - Differences CFD and EFD

CFD - EFD, model scale			CFD - EFD, full scale		
K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]
0.10	0.001	0.004	-0.001	0.004	0.002
0.30	0.001	-0.002	0.003	0.001	-0.002
0.50	-0.001	-0.002	0.002	-0.006	-0.005
0.70	0.001	-0.002	0.013	-0.002	-0.001
0.90	0.002	-0.001	0.052	0.001	-0.002



7.3 R03 - Radial distribution tables

model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.010	0.009	0.007	0.003	-0.002	0.010	0.009	0.008	0.004	-0.003
0.370	0.026	0.023	0.017	0.009	-0.002	0.027	0.026	0.022	0.013	-0.001
0.505	0.074	0.055	0.039	0.021	0.000	0.074	0.059	0.048	0.030	0.008
0.630	0.060	0.041	0.030	0.017	0.003	0.064	0.045	0.038	0.026	0.011
0.745	0.044	0.038	0.029	0.017	0.002	0.052	0.049	0.041	0.028	0.008
0.850	0.060	0.052	0.038	0.022	0.004	0.072	0.066	0.053	0.035	0.012
0.938	0.071	0.058	0.042	0.023	0.002	0.078	0.068	0.054	0.035	0.011
0.988	0.010	0.008	0.006	0.004	0.001	0.016	0.013	0.011	0.008	0.006

full scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.011	0.010	0.008	0.004	0.000	0.010	0.009	0.008	0.004	-0.002
0.370	0.026	0.023	0.017	0.010	-0.001	0.027	0.026	0.021	0.014	0.000
0.505	0.073	0.056	0.038	0.020	-0.001	0.070	0.059	0.046	0.028	0.006
0.630	0.062	0.042	0.028	0.016	0.003	0.064	0.045	0.036	0.023	0.010
0.745	0.044	0.038	0.028	0.017	0.002	0.051	0.048	0.039	0.028	0.008
0.850	0.061	0.051	0.037	0.022	0.003	0.071	0.064	0.051	0.034	0.011
0.938	0.071	0.057	0.040	0.022	0.001	0.077	0.066	0.052	0.033	0.009
0.988	0.011	0.009	0.006	0.004	0.001	0.015	0.013	0.011	0.009	0.005

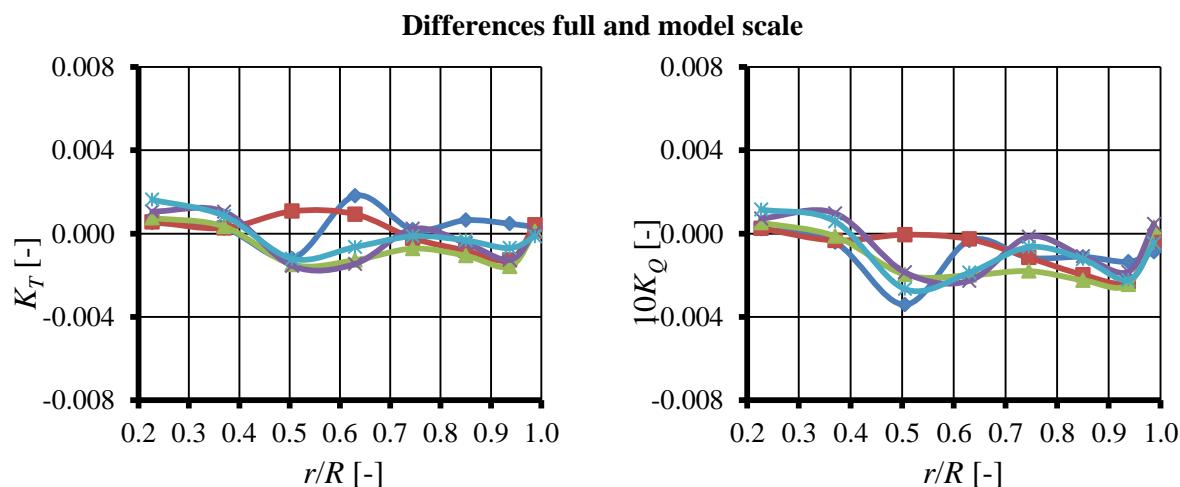
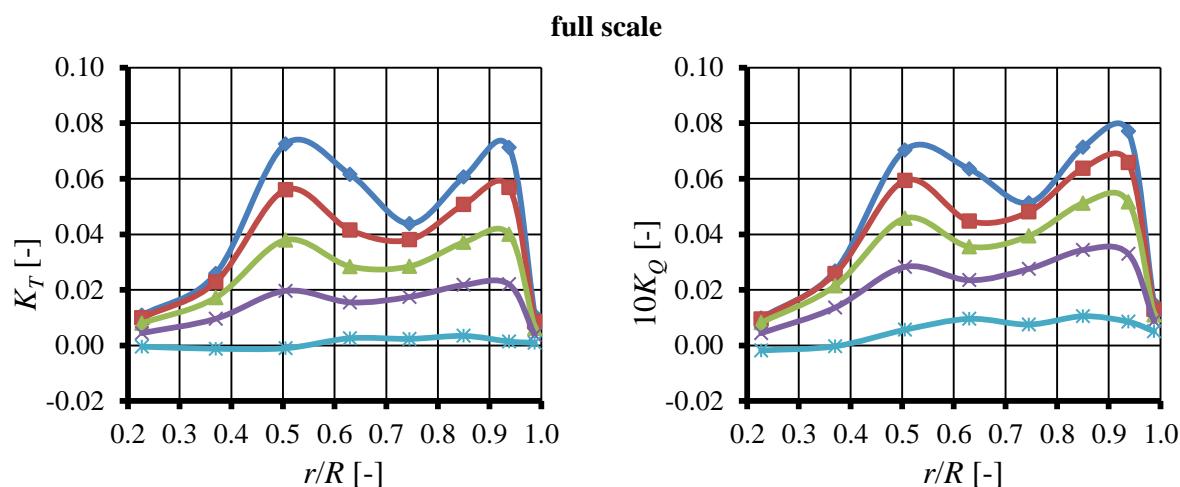
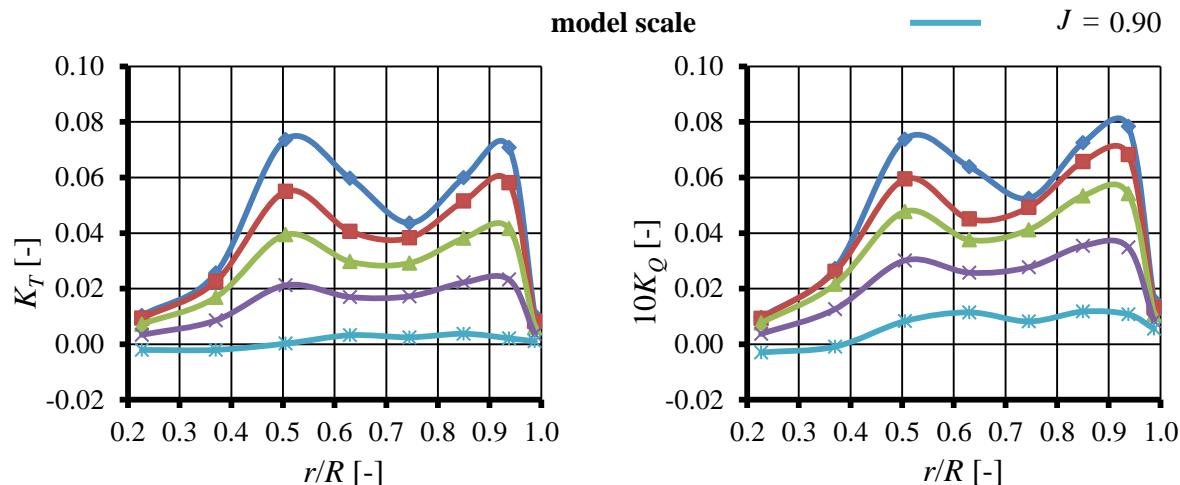
Differences full and model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.0005	0.0006	0.0007	0.0011	0.0016	0.0002	0.0002	0.0005	0.0007	0.0012
0.370	0.0003	0.0003	0.0003	0.0010	0.0008	-0.0004	-0.0003	-0.0001	0.0010	0.0006
0.505	-0.0012	0.0011	-0.0015	-0.0015	-0.0012	-0.0034	-0.0001	-0.0020	-0.0019	-0.0027
0.630	0.0018	0.0009	-0.0013	-0.0015	-0.0006	-0.0003	-0.0003	-0.0020	-0.0023	-0.0019
0.745	0.0002	-0.0002	-0.0007	0.0002	-0.0001	-0.0012	-0.0012	-0.0018	-0.0002	-0.0007
0.850	0.0006	-0.0008	-0.0011	-0.0005	-0.0003	-0.0011	-0.0020	-0.0022	-0.0011	-0.0012
0.938	0.0005	-0.0013	-0.0016	-0.0013	-0.0007	-0.0014	-0.0023	-0.0024	-0.0018	-0.0022
0.988	0.0003	0.0004	0.0001	0.0001	-0.0001	-0.0009	-0.0003	0.0003	0.0005	-0.0005

7.4 R03 - Radial distribution diagrams



 $J = 0.10$
 $J = 0.30$
 $J = 0.50$
 $J = 0.70$
 $J = 0.90$



7.5 R03 - Questionnaire part I

	model scale	full scale
Solver	STAR_CCM+	STAR_CCM+
Computational Domain		
A1 Domain topology	Multiple domains	Multiple domains
A2 Grid-coupling technique	Sliding	Sliding
Propeller Representation		
B1 Number of considered blades	Complete propeller	Complete propeller
Computational Grid		
C1 Type	Unstructured	Unstructured
C2 Local-grid refinement	Possible - used here	Possible - used here
C3 Primary volume elements	Hexahedral	Hexahedral
C4 Primary surface elements	Triangles	Triangles
C5 Wall-boundary layer type	Prism Layer	Prism Layer
C7 Number of cells at boundary layer	0	0
C8 Y ⁺ -value at r/R=0.4, 0.7, 0.9	Approx. 0.4, 0.5, 0.6	Approx. 100.0, 123.0, 150.0
C9 Averaged Y ⁺ -value	0.4	145
C10 Number of cells on blade surface	102000	108000
Norm. Dim. the Physical Domain		
D1 X_upstream/D, X_downstream/D	4.2, 8.4	4.2, 8.4
D2 Cross area of domain in prop. plain	101	101
Numerical Approximation		
E1 Finite Approximation Scheme (Fluid)	FV-NS	FV-NS
E2 Coordinates	Cartesian	Cartesian
E3 Convection scheme (momentum eq.)	2nd-order centered	2nd-order centered
E4 Transient approximation	implicit	implicit
E5 Spatial order of acc. (neglecting BC)	0	0
E6 Temporal order of accuracy	1st-order	1st-order
E7 Time step	0.0003	0.0017
E8 Equivalent rot. Angle for a time step	2	2
Turbulence treatment		
F1 Model name	k-omega	k-omega
F2 Convection scheme (Turb. Eqn.)	2nd-order centered	2nd-order centered
Boundary conditions		
G1 Blade	resolved	wall function
G2 Hub	resolved	wall function
G3 Inlet	Fixed Velocity	Fixed Velocity
G4 Outlet	Fixed Pressure	Fixed Pressure
G5 Outer domain	resolved	resolved

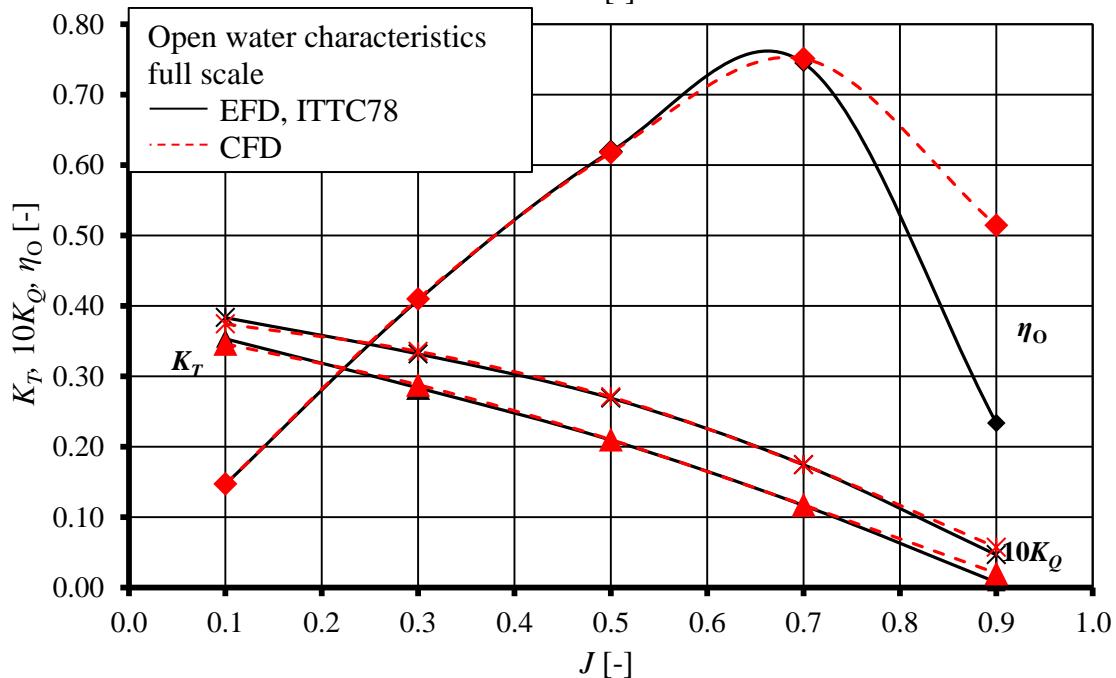
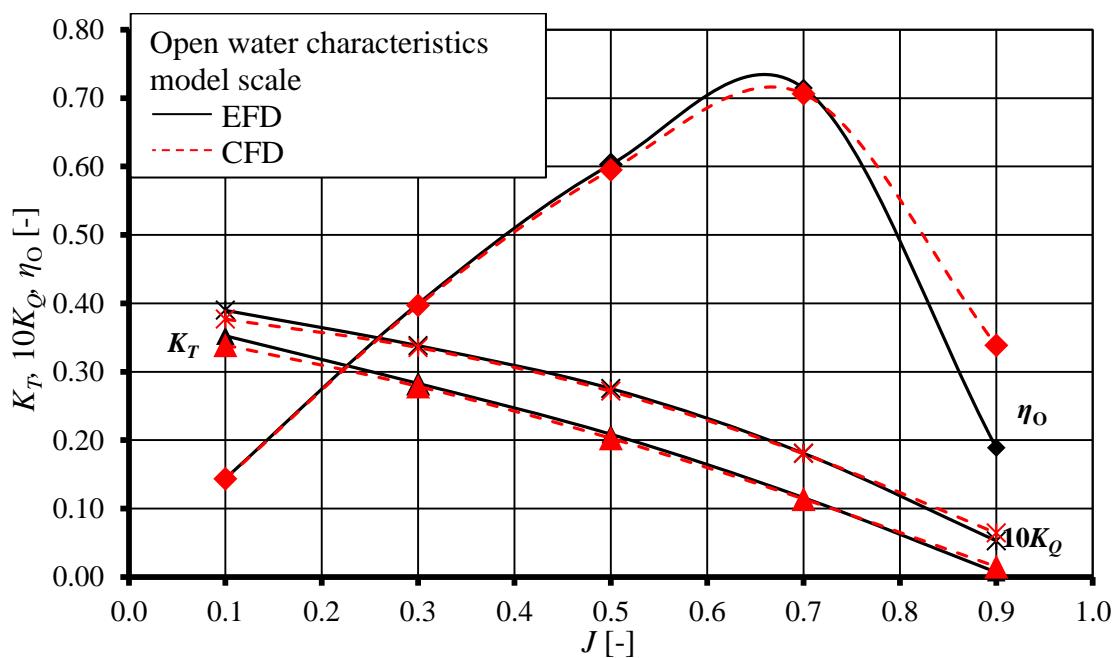
7.5 R03 - Questionnaire part II

	model scale	full scale
Computational Model		
H1 Fluid	incompressible	incompressible
H2 Pressure	pressure correction	pressure correction
Transition		
I Please comment	yes / Gamma Re-Theta transition model	0 / 0
Computational Demands		
J1 Number of processors used	0	0
J2 Number of timesteps (steady)	0	0
J3 Number of timesteps (transient)	0	0
J4 Wall-clock time per revolution	0	0
Code		
K References	Star-CCM+	Star-CCM+
Comments		
L Add. info.	0 / 0	0 / 0

8 Result R06

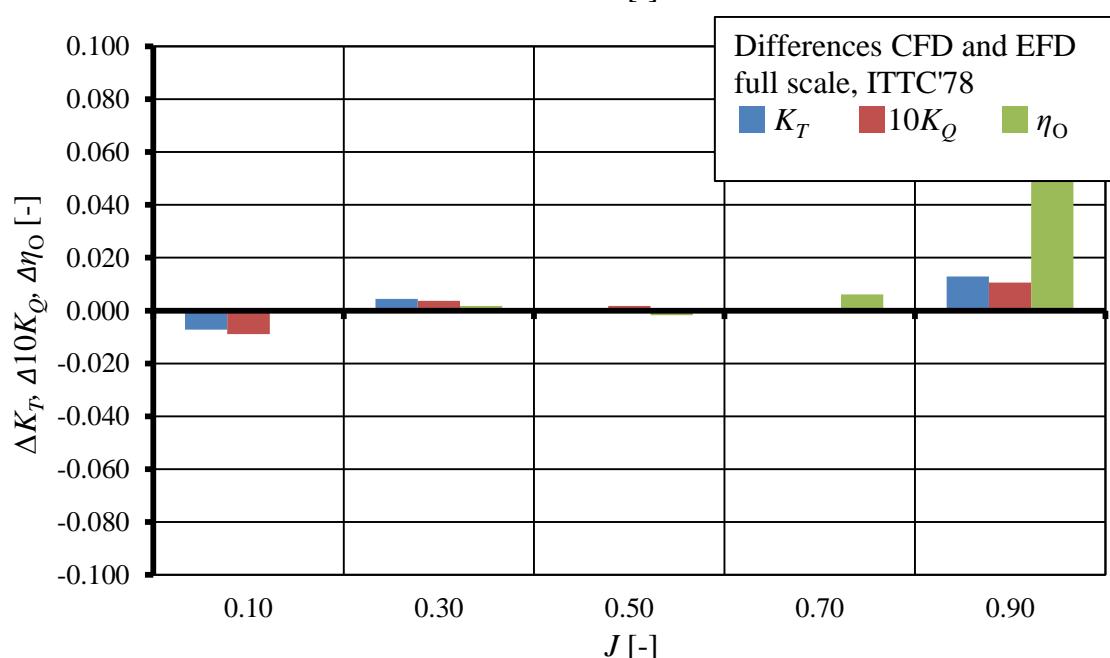
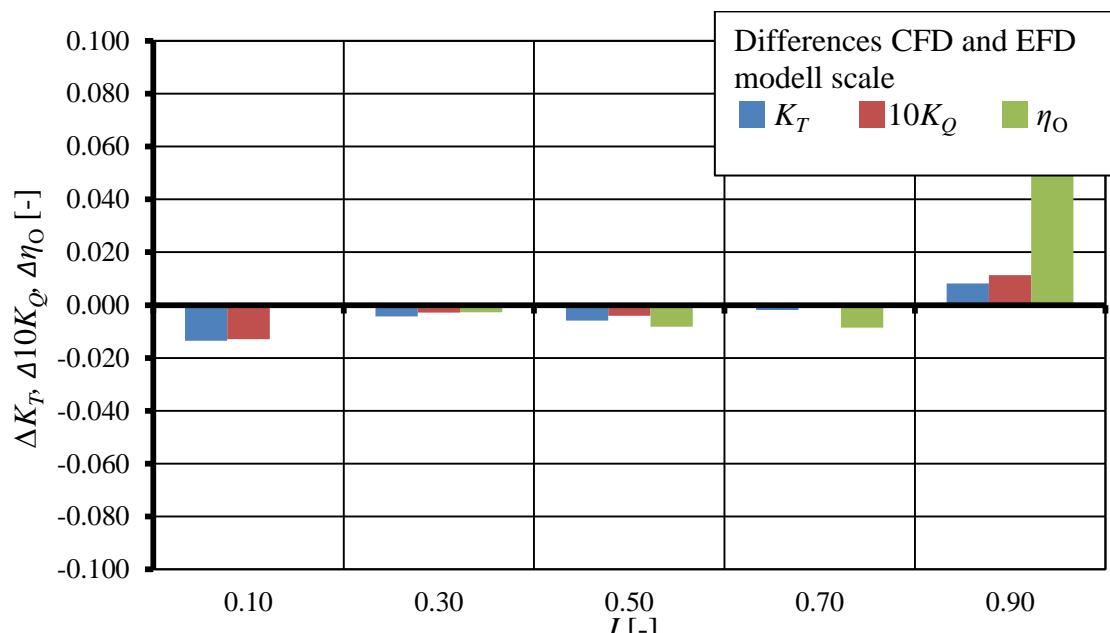
8.1 R06 - Open water characteristic

J [-]	CFD, model scale			CFD, full scale		
	K_T [-]	$10K_Q$ [-]	η_O [-]	K_T [-]	$10K_Q$ [-]	η_O [-]
	0.100	0.339	0.377	0.143	0.346	0.374
0.300	0.279	0.335	0.397	0.288	0.335	0.410
0.500	0.203	0.271	0.595	0.210	0.271	0.617
0.700	0.114	0.180	0.706	0.117	0.174	0.751
0.900	0.015	0.064	0.338	0.020	0.057	0.514



8.2 R06 - Differences CFD and EFD

CFD - EFD, model scale			CFD - EFD, full scale		
K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]
0.10	-0.014	-0.013	-0.001	-0.007	-0.009
0.30	-0.004	-0.003	-0.003	0.004	0.004
0.50	-0.006	-0.004	-0.008	0.001	0.002
0.70	-0.002	-0.001	-0.009	0.001	0.000
0.90	0.008	0.011	0.149	0.013	0.011



8.3 R06 - Radial distribution tables

model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.010	0.009	0.007	0.004	0.000	0.009	0.009	0.008	0.004	0.000
0.370	0.025	0.022	0.017	0.009	-0.001	0.027	0.026	0.022	0.013	0.001
0.505	0.042	0.037	0.028	0.017	0.002	0.051	0.048	0.040	0.027	0.009
0.630	0.059	0.050	0.037	0.022	0.004	0.072	0.065	0.053	0.036	0.014
0.745	0.069	0.056	0.040	0.022	0.002	0.077	0.067	0.053	0.034	0.011
0.850	0.073	0.055	0.038	0.020	0.001	0.074	0.061	0.048	0.030	0.009
0.938	0.051	0.040	0.029	0.016	0.004	0.052	0.046	0.037	0.025	0.012
0.988	0.010	0.008	0.006	0.004	0.002	0.015	0.014	0.011	0.010	0.008

full scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.011	0.010	0.008	0.005	0.001	0.010	0.010	0.008	0.005	0.001
0.370	0.025	0.023	0.017	0.009	0.000	0.026	0.026	0.022	0.013	0.002
0.505	0.042	0.038	0.029	0.017	0.003	0.050	0.048	0.040	0.027	0.009
0.630	0.060	0.051	0.038	0.023	0.005	0.071	0.065	0.053	0.035	0.012
0.745	0.071	0.058	0.041	0.023	0.003	0.077	0.067	0.053	0.033	0.009
0.850	0.074	0.057	0.040	0.021	0.002	0.073	0.060	0.047	0.029	0.007
0.938	0.052	0.042	0.030	0.016	0.005	0.052	0.046	0.037	0.024	0.011
0.988	0.010	0.009	0.006	0.004	0.002	0.014	0.013	0.011	0.008	0.006

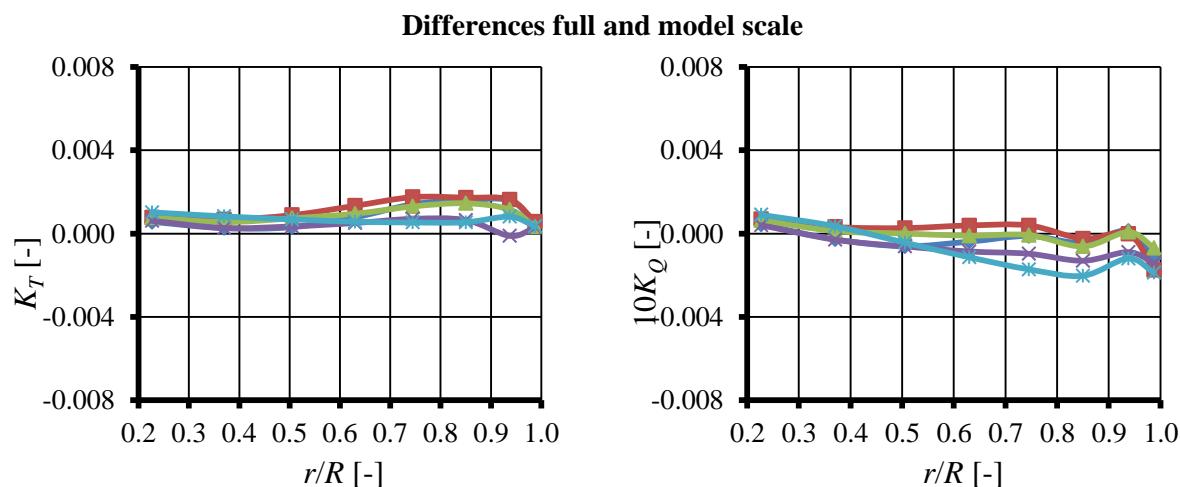
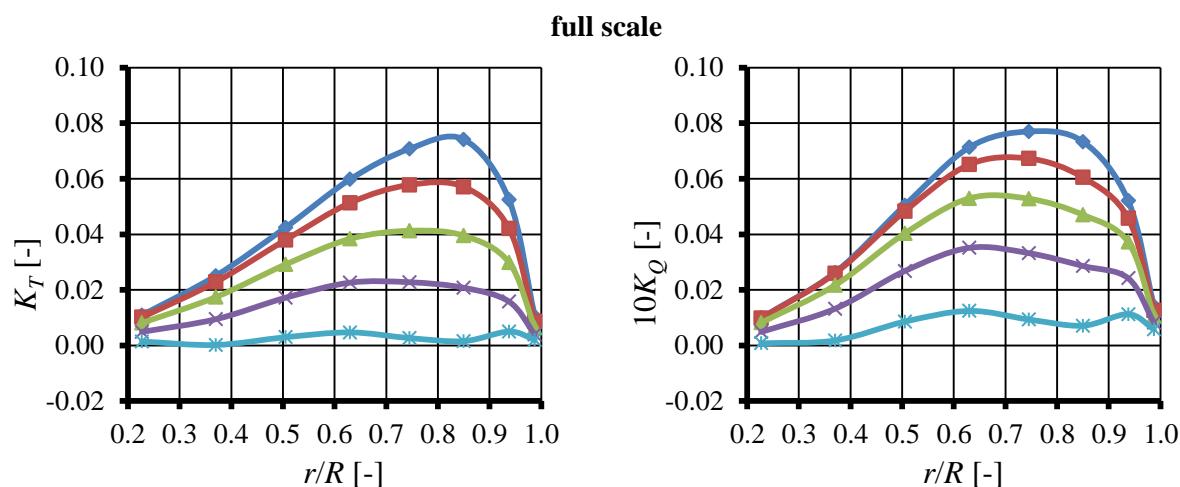
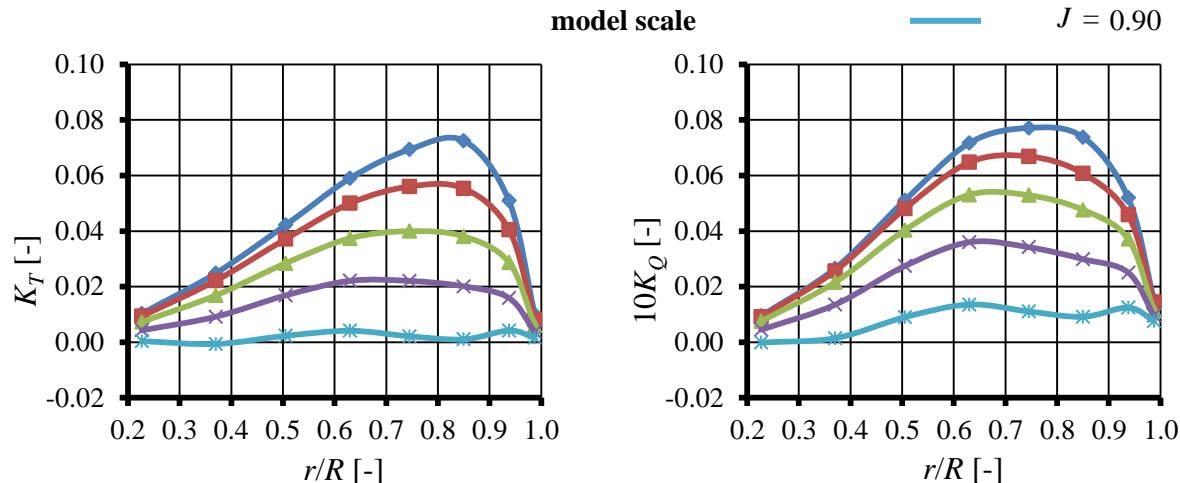
Differences full and model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.0006	0.0008	0.0008	0.0006	0.0010	0.0004	0.0007	0.0006	0.0004	0.0009
0.370	0.0003	0.0007	0.0006	0.0003	0.0008	-0.0003	0.0003	0.0001	-0.0003	0.0004
0.505	0.0003	0.0009	0.0007	0.0003	0.0007	-0.0006	0.0003	0.0000	-0.0006	-0.0004
0.630	0.0008	0.0013	0.0010	0.0005	0.0006	-0.0004	0.0004	-0.0001	-0.0009	-0.0011
0.745	0.0014	0.0017	0.0013	0.0007	0.0005	-0.0001	0.0004	-0.0001	-0.0010	-0.0017
0.850	0.0016	0.0017	0.0015	0.0006	0.0005	-0.0005	-0.0002	-0.0006	-0.0013	-0.0020
0.938	0.0016	0.0016	0.0012	-0.0001	0.0008	0.0001	0.0000	0.0001	-0.0009	-0.0012
0.988	0.0005	0.0006	0.0003	0.0003	0.0003	-0.0012	-0.0017	-0.0007	-0.0014	-0.0019

8.4 R06 - Radial distribution diagrams



 $J = 0.10$
 $J = 0.30$
 $J = 0.50$
 $J = 0.70$
 $J = 0.90$



8.5 R06 - Questionnaire part I

	model scale	full scale
Solver	ANSYS_FLUENT	ANSYS FLUENT
Computational Domain		
A1 Domain topology	1 rotating domain	1 rotating domain
A2 Grid-coupling technique	Multiple ref. frames	Multiple ref. frames
Propeller Representation		
B1 Number of considered blades	1 blade, matching	1 blade, matching
Computational Grid		
C1 Type	Unstructured	Unstructured
C2 Local-grid refinement	Possible - used here	Possible - used here
C3 Primary volume elements	Tetraheder	Tetraheder
C4 Primary surface elements	Triangles	Triangles
C5 Wall-boundary layer type	Prism Layer	Prism Layer
C7 Number of cells at boundary layer	10	10
C8 Y ⁺ -value at r/R=0.4, 0.7, 0.9	0.64, 0.91, 1.12 (J=0.7)	32.0, 47.6, 61.8 (J=0.7)
C9 Averaged Y ⁺ -value	0.89 (J=0.7)	46.1 (J=0.7)
C10 Number of cells on blade surface	37411	37411
Norm. Dim. the Physical Domain		
D1 X_upstream/D, X_downstream/D	5, 10	5, 10
D2 Cross area of domain in prop. plain	100	100
Numerical Approximation		
E1 Finite Approximation Scheme (Fluid)	FV-NS	FV-NS
E2 Coordinates	Cartesian	Cartesian
E3 Convection scheme (momentum eq.)	high-order upwind	high-order upwind
E4 Transient approximation	-	-
E5 Spatial order of acc. (neglecting BC)	2nd-order	2nd-order
E6 Temporal order of accuracy	N/A	N/A
E7 Time step	N/A	N/A
E8 Equivalent rot. Angle for a time step	N/A	N/A
Turbulence treatment		
F1 Model name	k-omega	k-omega
F2 Convection scheme (Turb. Eqn.)	high-order upwind	high-order upwind
Boundary conditions		
G1 Blade	resolved	wall function
G2 Hub	wall function	wall function
G3 Inlet	Fixed Velocity	Fixed Velocity
G4 Outlet	Fixed Pressure	Fixed Pressure
G5 Outer domain	-	-

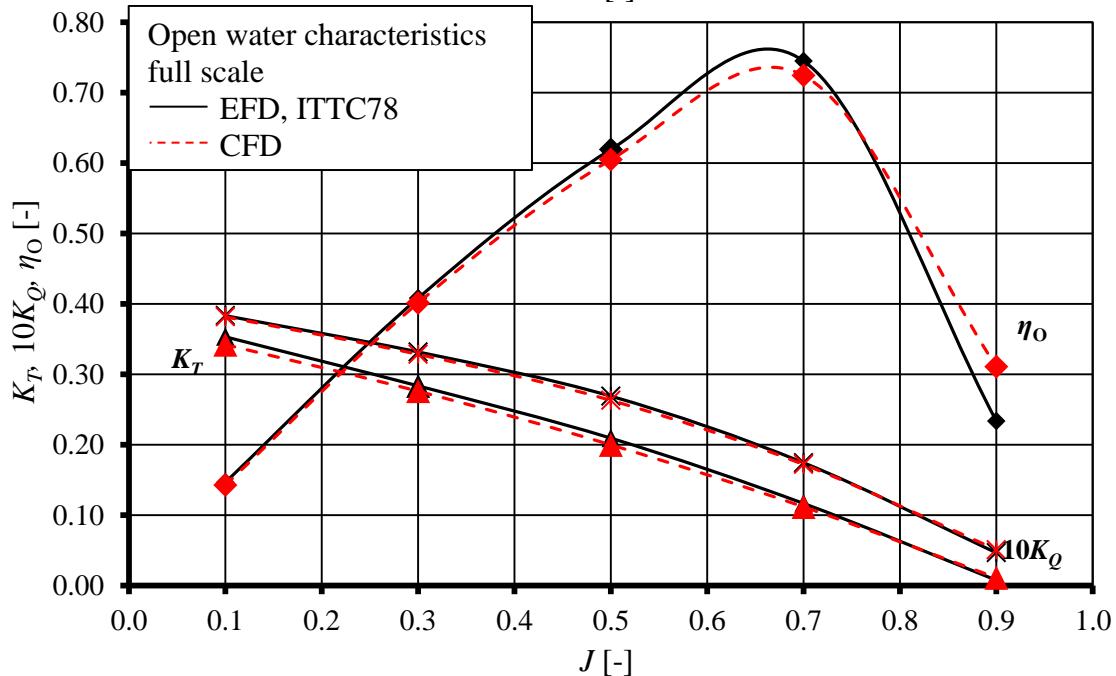
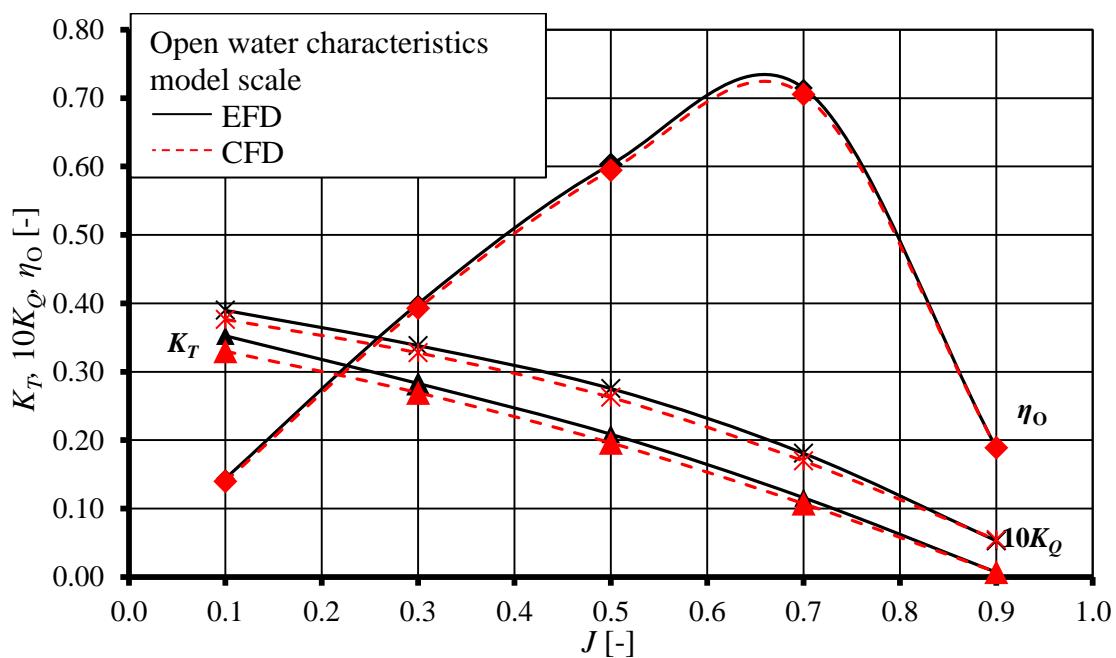
8.5 R06 - Questionnaire part II

	model scale	full scale
Computational Model		
H1 Fluid	incompressible	incompressible
H2 Pressure	pressure correction	pressure correction
Transition		
I Please comment	yes	0 / 0
Computational Demands		
J1 Number of processors used	24	24
J2 Number of timesteps (steady)	6000~12000	8000~14000
J3 Number of timesteps (transient)	N/A	N/A
J4 Wall-clock time per revolution	1 hr per 1500 iters	1 hr per 1500 iters
Code		
K References	FLUENT 6.3	FLUENT 6.3
Comments		
L Add. info.	0 / 0	0 / 0

9 Result R08

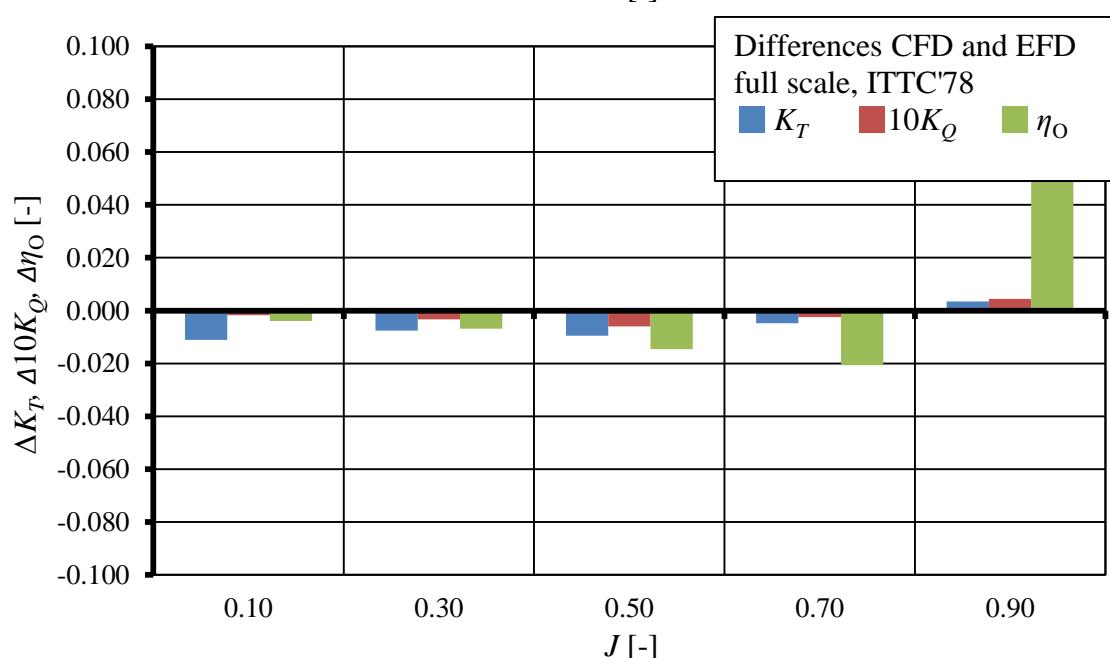
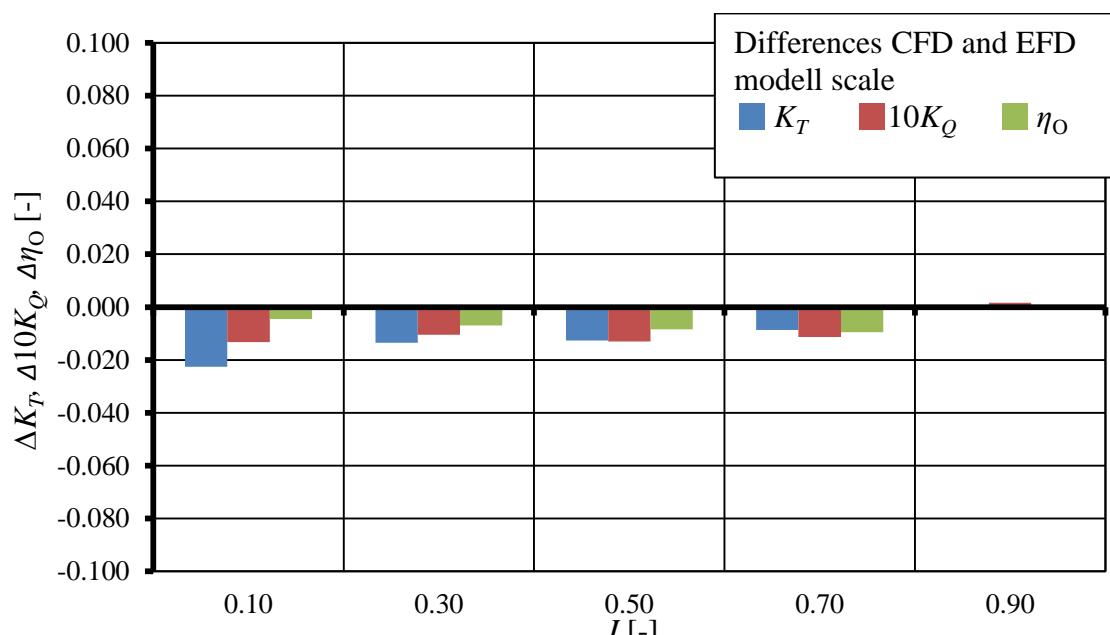
9.1 R08 - Open water characteristic

J [-]	CFD, model scale			CFD, full scale		
	K_T [-]	$10K_Q$ [-]	η_O [-]	K_T [-]	$10K_Q$ [-]	η_O [-]
	0.100	0.330	0.376	0.342	0.382	0.143
0.300	0.269	0.328	0.392	0.276	0.328	0.401
0.500	0.196	0.262	0.595	0.200	0.263	0.605
0.700	0.107	0.170	0.705	0.112	0.172	0.724
0.900	0.007	0.055	0.189	0.011	0.051	0.311



9.2 R08 - Differences CFD and EFD

CFD - EFD, model scale			CFD - EFD, full scale		
K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]
0.10	-0.023	-0.013	-0.004	-0.011	-0.002
0.30	-0.014	-0.010	-0.007	-0.008	-0.003
0.50	-0.013	-0.013	-0.008	-0.009	-0.006
0.70	-0.009	-0.011	-0.010	-0.005	-0.002
0.90	0.000	0.002	0.000	0.003	0.004
					0.077



9.3 R08 - Radial distribution tables

model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.008	0.007	0.006	0.003	-0.001	0.008	0.007	0.006	0.003	-0.002
0.370	0.022	0.019	0.014	0.007	-0.002	0.023	0.022	0.018	0.010	-0.001
0.505	0.038	0.033	0.025	0.014	0.001	0.046	0.043	0.035	0.023	0.005
0.630	0.056	0.049	0.036	0.021	0.003	0.069	0.063	0.051	0.034	0.010
0.745	0.069	0.058	0.041	0.022	0.001	0.079	0.070	0.054	0.035	0.010
0.850	0.072	0.055	0.039	0.020	0.000	0.076	0.062	0.048	0.030	0.010
0.938	0.054	0.041	0.029	0.016	0.005	0.059	0.048	0.039	0.026	0.015
0.988	0.010	0.008	0.006	0.004	0.002	0.016	0.014	0.011	0.009	0.007

full scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.009	0.008	0.006	0.004	0.000	0.008	0.008	0.006	0.004	-0.001
0.370	0.022	0.020	0.015	0.008	-0.001	0.024	0.022	0.018	0.011	0.000
0.505	0.039	0.034	0.026	0.015	0.002	0.046	0.043	0.036	0.024	0.007
0.630	0.058	0.049	0.037	0.022	0.004	0.070	0.062	0.051	0.035	0.011
0.745	0.072	0.057	0.041	0.022	0.001	0.080	0.068	0.053	0.034	0.009
0.850	0.075	0.058	0.039	0.020	-0.001	0.078	0.064	0.048	0.030	0.007
0.938	0.057	0.043	0.030	0.016	0.003	0.061	0.049	0.038	0.025	0.011
0.988	0.010	0.009	0.006	0.004	0.002	0.015	0.013	0.011	0.009	0.006

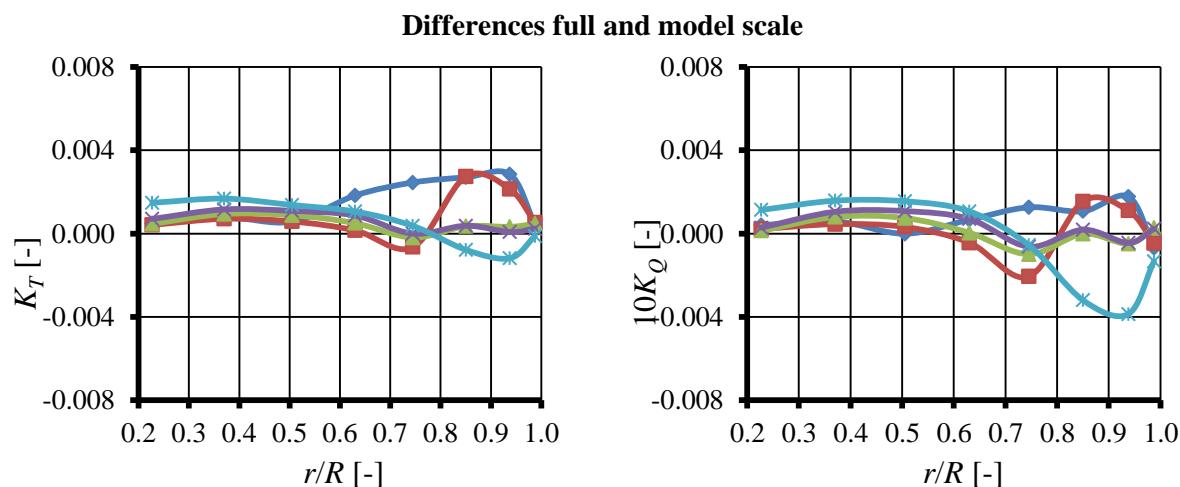
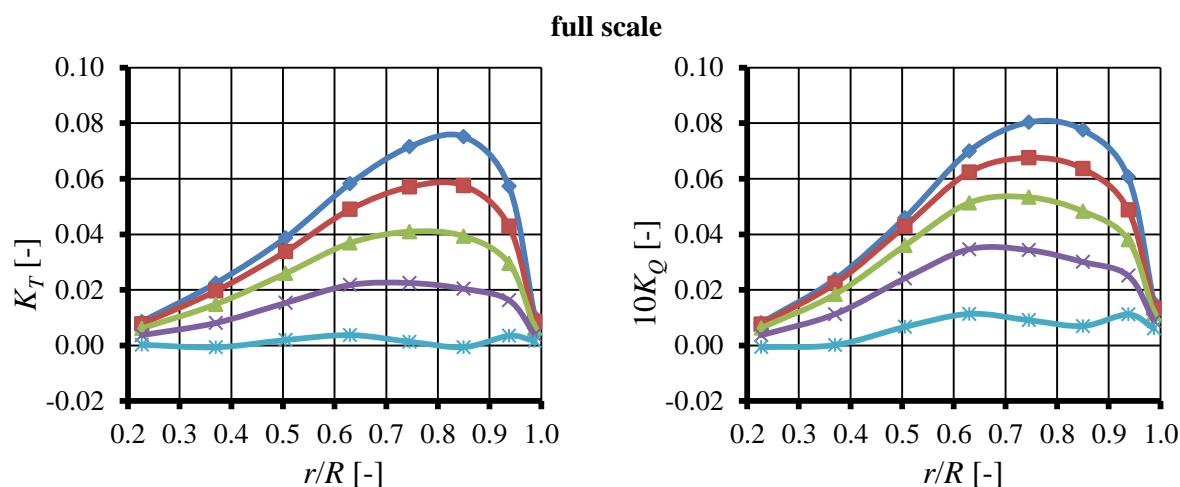
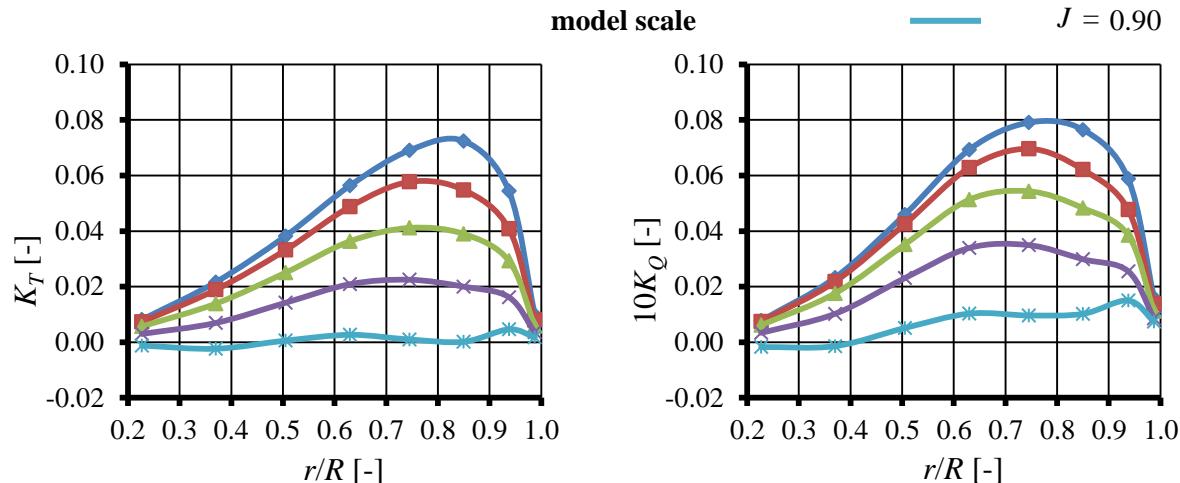
Differences full and model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.0005	0.0004	0.0005	0.0007	0.0015	0.0004	0.0002	0.0001	0.0003	0.0011
0.370	0.0008	0.0007	0.0009	0.0012	0.0017	0.0006	0.0005	0.0008	0.0010	0.0016
0.505	0.0006	0.0006	0.0009	0.0011	0.0014	0.0000	0.0003	0.0007	0.0011	0.0015
0.630	0.0018	0.0002	0.0005	0.0009	0.0011	0.0007	-0.0004	0.0000	0.0007	0.0011
0.745	0.0025	-0.0006	-0.0002	0.0000	0.0004	0.0013	-0.0021	-0.0010	-0.0006	-0.0006
0.850	0.0027	0.0027	0.0003	0.0004	-0.0008	0.0011	0.0015	0.0000	0.0002	-0.0032
0.938	0.0028	0.0021	0.0003	0.0001	-0.0012	0.0018	0.0011	-0.0005	-0.0004	-0.0039
0.988	0.0004	0.0005	0.0005	0.0002	-0.0001	-0.0007	-0.0005	0.0003	0.0002	-0.0013

9.4 R08 - Radial distribution diagrams



 $J = 0.10$
 $J = 0.30$
 $J = 0.50$
 $J = 0.70$
 $J = 0.90$



9.5 R08 - Questionnaire part I

	model scale	full scale
Solver	ANSYS CFX	ANSYS CFX
Computational Domain		
A1 Domain topology	Multiple domains	Multiple domains
A2 Grid-coupling technique	Multiple ref. frames	Multiple ref. frames
Propeller Representation		
B1 Number of considered blades	1 blade, matching	1 blade, matching
Computational Grid		
C1 Type	Unstructured	Unstructured
C2 Local-grid refinement	Possible - used here	Possible - used here
C3 Primary volume elements	Tetraheder	Tetraheder
C4 Primary surface elements	Quads	Quads
C5 Wall-boundary layer type	Prism Layer	Prism Layer
C7 Number of cells at boundary layer	0	0
C8 Y ⁺ -value at r/R=0.4, 0.7, 0.9	0.42, 0.55, 0.66	58.9, 90.6, 118.2
C9 Averaged Y ⁺ -value	0.52	82.6
C10 Number of cells on blade surface	35123	35123
Norm. Dim. the Physical Domain		
D1 X_upstream/D, X_downstream/D	4.6;12.5	4.6;12.5
D2 Cross area of domain in prop. plain	215	215
Numerical Approximation		
E1 Finite Approximation Scheme (Fluid)	FV-NS	FV-NS
E2 Coordinates	Cartesian	Cartesian
E3 Convection scheme (momentum eq.)	blended UDS / CDS	blended UDS / CDS
E4 Transient approximation	implicit	implicit
E5 Spatial order of acc. (neglecting BC)	2nd order	2nd order
E6 Temporal order of accuracy	0	0
E7 Time step	automatic	automatic
E8 Equivalent rot. Angle for a time step	stationary	stationary
Turbulence treatment		
F1 Model name	k-omega	k-omega
F2 Convection scheme (Turb. Eqn.)	blended UDS / CDS	blended UDS / CDS
Boundary conditions		
G1 Blade	wall function	wall function
G2 Hub	wall function	wall function
G3 Inlet	Fixed Velocity	Fixed Velocity
G4 Outlet	Fixed Pressure	Fixed Pressure
G5 Outer domain	Slip flow	Slip flow

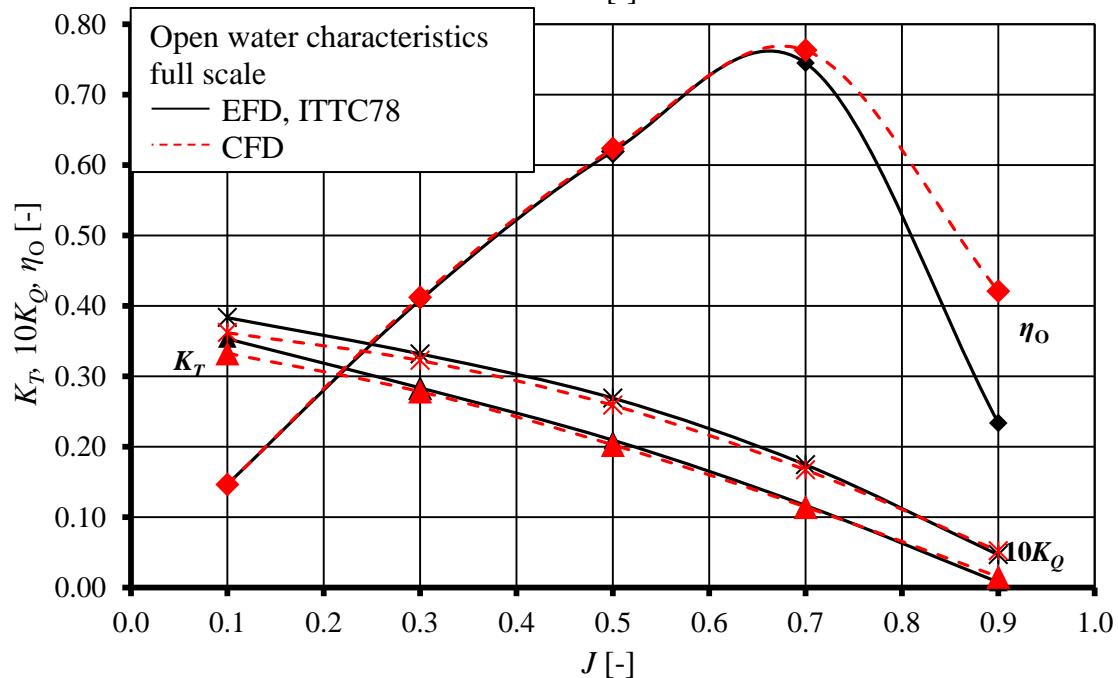
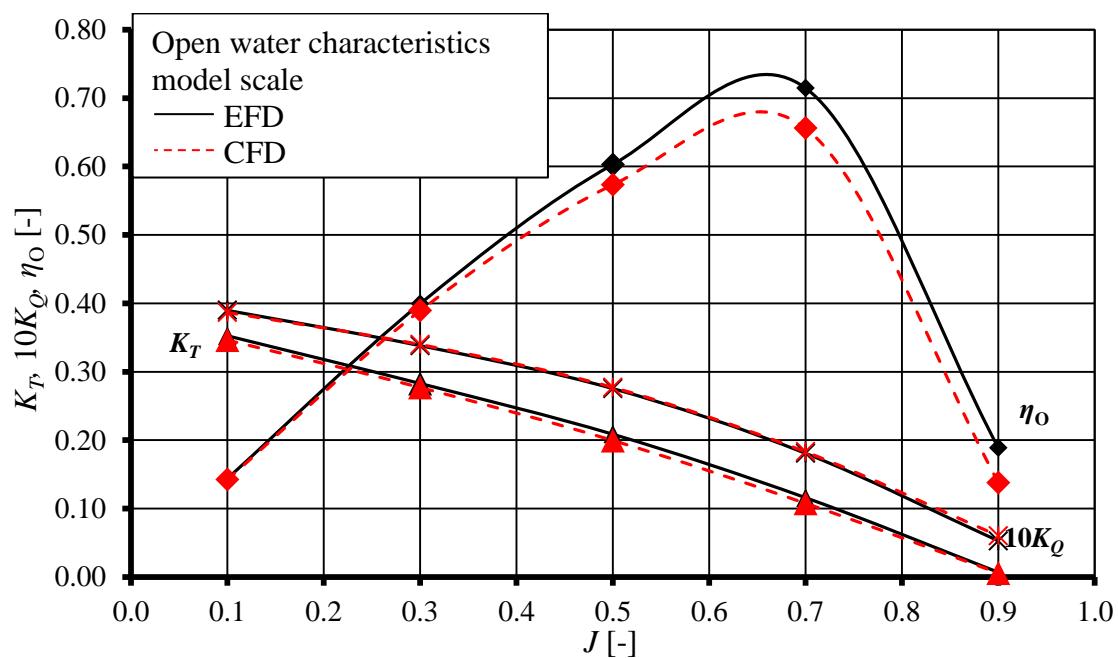
9.5 R08 - Questionnaire part II

	model scale	full scale
Computational Model		
H1 Fluid	incompressible	incompressible
H2 Pressure	Coupled	Coupled
Transition		
I Please comment	yes / Gamma-Theta-model	0 / 0
Computational Demands		
J1 Number of processors used	8	8
J2 Number of timesteps (steady)	2000	2000
J3 Number of timesteps (transient)	-	-
J4 Wall-clock time per revolution	0	0
Code		
K References	ANSYS CFX 16.0	ANSYS CFX 16.0
Comments		
L Add. info.	0 / 0	0 / 0

10 Result R09

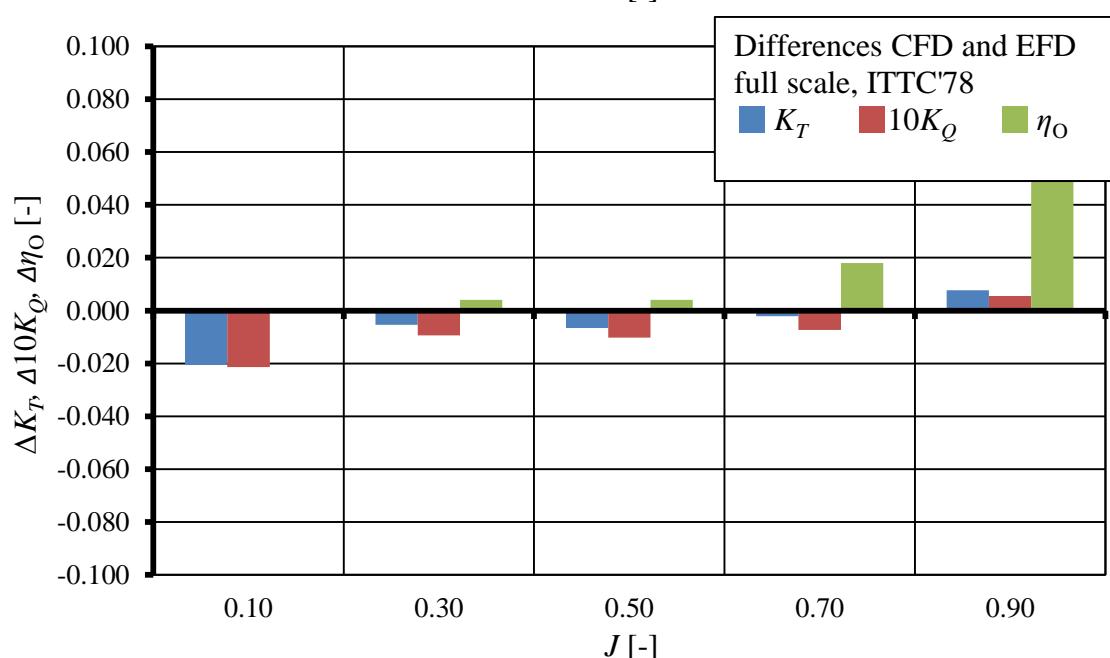
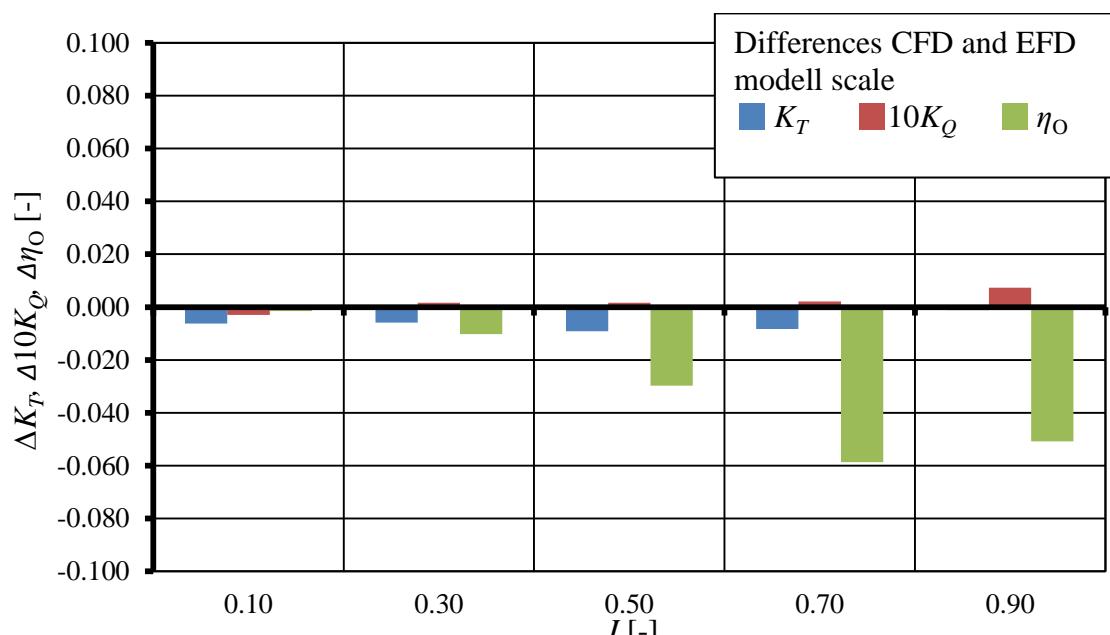
10.1 R09 - Open water characteristic

J	CFD, model scale			CFD, full scale		
	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.100	0.346	0.387	0.143	0.333	0.362	0.146
0.300	0.277	0.340	0.389	0.278	0.322	0.412
0.500	0.200	0.277	0.573	0.203	0.259	0.623
0.700	0.108	0.183	0.656	0.114	0.167	0.763
0.900	0.006	0.060	0.138	0.015	0.052	0.421



10.2 R09 - Differences CFD and EFD

	CFD - EFD, model scale			CFD - EFD, full scale		
	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
	[-]	[-]	[-]	[-]	[-]	[-]
0.10	-0.006	-0.003	-0.001	-0.021	-0.021	0.000
0.30	-0.006	0.002	-0.010	-0.005	-0.009	0.004
0.50	-0.009	0.002	-0.030	-0.007	-0.010	0.004
0.70	-0.008	0.002	-0.059	-0.002	-0.007	0.018
0.90	-0.001	0.007	-0.051	0.008	0.006	0.187



10.3 R09 - Radial distribution tables

model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.010	0.009	0.007	0.004	0.000	0.010	0.009	0.008	0.004	-0.001
0.370	0.025	0.022	0.017	0.009	-0.002	0.027	0.026	0.022	0.013	0.001
0.505	0.042	0.037	0.028	0.016	0.001	0.052	0.048	0.040	0.026	0.008
0.630	0.060	0.049	0.037	0.021	0.002	0.073	0.065	0.053	0.035	0.012
0.745	0.071	0.056	0.040	0.021	0.001	0.079	0.068	0.054	0.035	0.010
0.850	0.073	0.055	0.038	0.019	-0.001	0.074	0.063	0.049	0.031	0.009
0.938	0.054	0.040	0.028	0.015	0.003	0.056	0.046	0.038	0.027	0.013
0.988	0.011	0.008	0.006	0.004	0.001	0.016	0.014	0.013	0.011	0.008

full scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.010	0.009	0.007	0.004	0.001	0.009	0.009	0.008	0.004	0.001
0.370	0.024	0.022	0.017	0.009	0.000	0.025	0.025	0.020	0.012	0.002
0.505	0.041	0.037	0.028	0.016	0.002	0.049	0.046	0.038	0.025	0.008
0.630	0.057	0.050	0.037	0.022	0.004	0.068	0.063	0.051	0.034	0.011
0.745	0.068	0.056	0.040	0.022	0.002	0.074	0.065	0.051	0.033	0.009
0.850	0.070	0.055	0.038	0.021	0.000	0.070	0.058	0.045	0.028	0.006
0.938	0.052	0.041	0.029	0.016	0.004	0.053	0.044	0.035	0.023	0.011
0.988	0.010	0.008	0.006	0.004	0.001	0.014	0.012	0.010	0.007	0.005

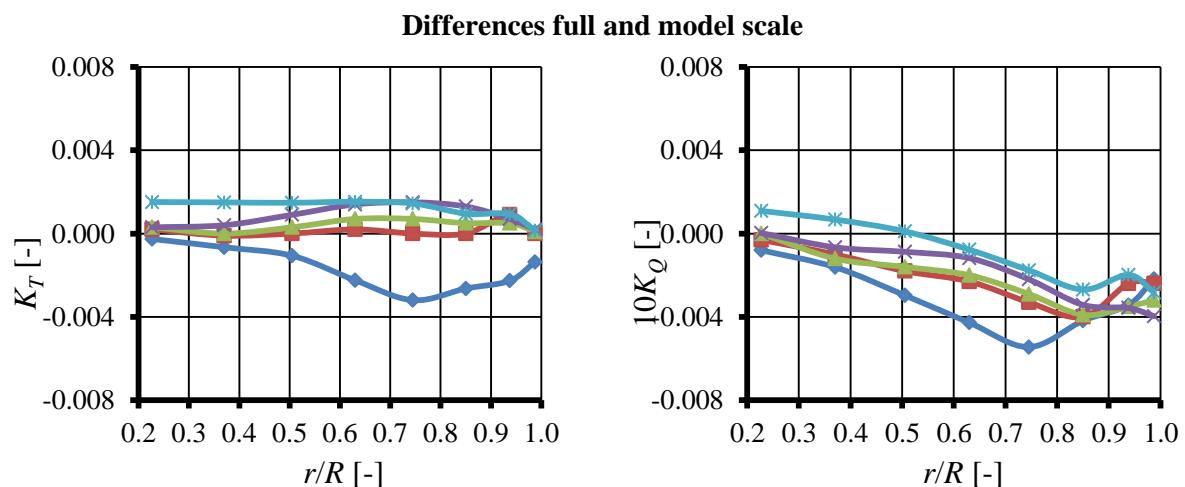
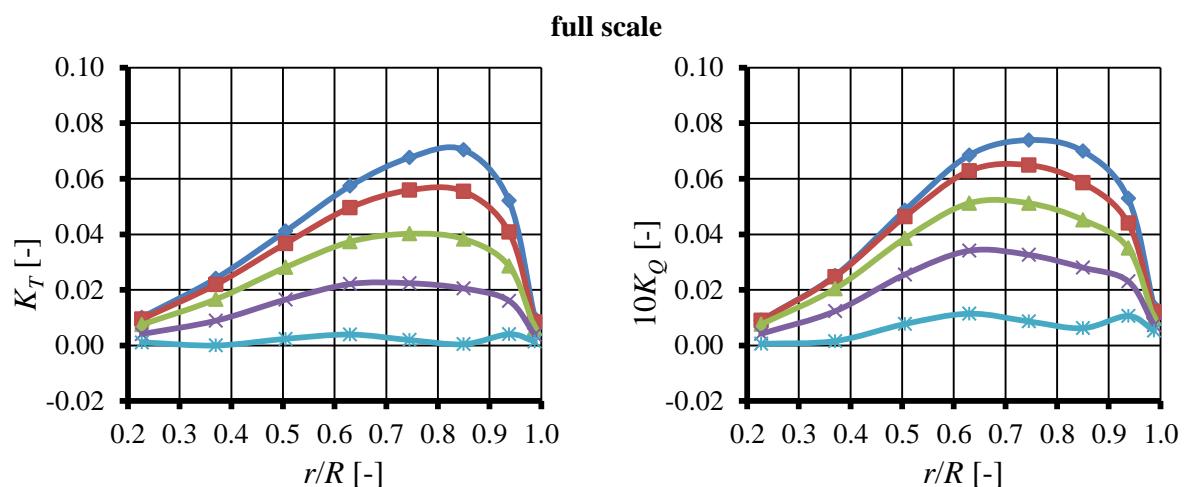
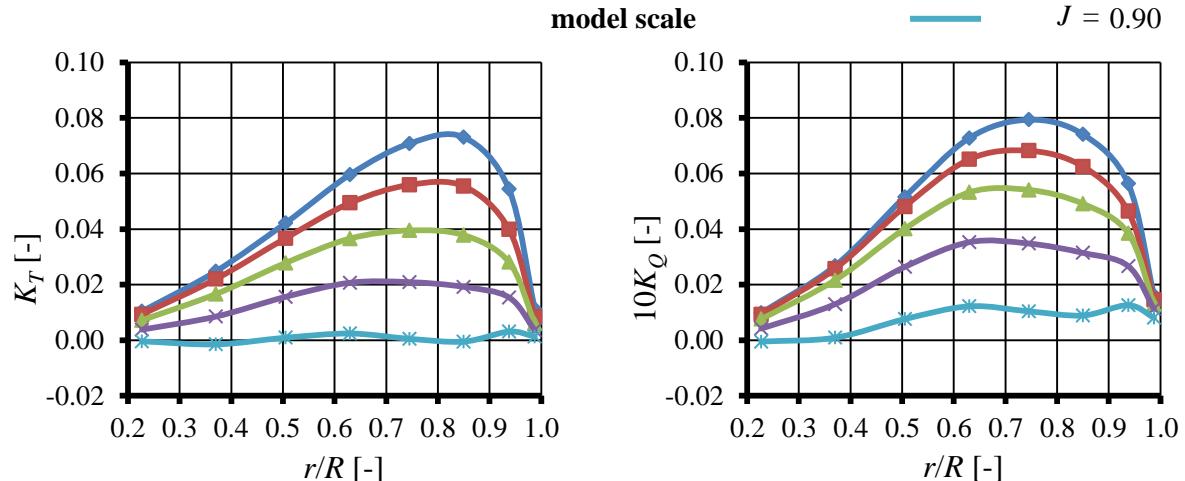
Differences full and model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	-0.0003	0.0002	0.0003	0.0003	0.0015	-0.0008	-0.0003	0.0000	0.0000	0.0011
0.370	-0.0007	-0.0001	0.0000	0.0004	0.0015	-0.0016	-0.0010	-0.0012	-0.0007	0.0007
0.505	-0.0011	0.0000	0.0003	0.0009	0.0015	-0.0030	-0.0018	-0.0016	-0.0009	0.0001
0.630	-0.0022	0.0002	0.0007	0.0014	0.0015	-0.0043	-0.0023	-0.0020	-0.0012	-0.0008
0.745	-0.0032	0.0000	0.0007	0.0015	0.0014	-0.0054	-0.0033	-0.0029	-0.0022	-0.0018
0.850	-0.0026	0.0000	0.0005	0.0013	0.0010	-0.0042	-0.0040	-0.0039	-0.0034	-0.0027
0.938	-0.0023	0.0009	0.0005	0.0007	0.0009	-0.0034	-0.0024	-0.0035	-0.0036	-0.0020
0.988	-0.0014	0.0000	0.0001	0.0002	0.0001	-0.0022	-0.0024	-0.0032	-0.0040	-0.0028

10.4 R09 - Radial distribution diagrams



 $J = 0.10$
 $J = 0.30$
 $J = 0.50$
 $J = 0.70$
 $J = 0.90$



10.5 R09 - Questionnaire part I

	model scale	full scale
Solver		
Computational Domain		
A1 Domain topology	Multiple domains	Multiple domains
A2 Grid-coupling technique	Sliding	Sliding
Propeller Representation		
B1 Number of considered blades	Complete propeller	Complete propeller
Computational Grid		
C1 Type	Unstructured	Unstructured
C2 Local-grid refinement	Possible - used here	Possible - used here
C3 Primary volume elements	Hexahedral	Hexahedral
C4 Primary surface elements	Mixed	Mixed
C5 Wall-boundary layer type	Prism Layer	Prism Layer
C7 Number of cells at boundary layer	3	3
C8 Y^+ -value at $r/R=0.4, 0.7, 0.9$	30	30
C9 Averaged Y^+ -value	30	30
C10 Number of cells on blade surface	2E+06	2E+06
Norm. Dim. the Physical Domain		
D1 X_upstream/D, X_downstream/D	4,12	4,12
D2 Cross area of domain in prop. plain	1.96	1.96
Numerical Approximation		
E1 Finite Approximation Scheme (Fluid)	FV-NS	FV-NS
E2 Coordinates	Cartesian	Cartesian
E3 Convection scheme (momentum eq.)	2nd-order centered	2nd-order centered
E4 Transient approximation	implicit	implicit
E5 Spatial order of acc. (neglecting BC)	2	2
E6 Temporal order of accuracy	1	1
E7 Time step	0.001	0.001
E8 Equivalent rot. Angle for a time step	0	0
Turbulence treatment		
F1 Model name	k-omega	k-omega
F2 Convection scheme (Turb. Eqn.)	2nd-order centered	2nd-order centered
Boundary conditions		
G1 Blade	wall function	wall function
G2 Hub	wall function	wall function
G3 Inlet	Fixed Velocity	Fixed Velocity
G4 Outlet	Fixed Pressure	Fixed Pressure
G5 Outer domain	Slip flow	Slip flow

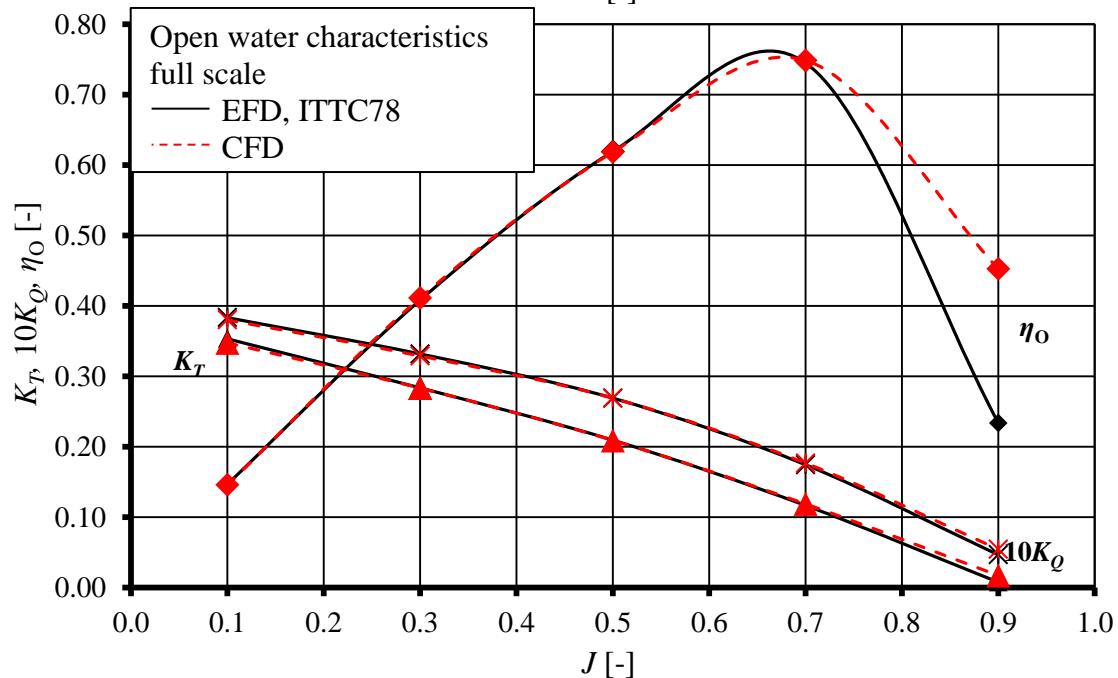
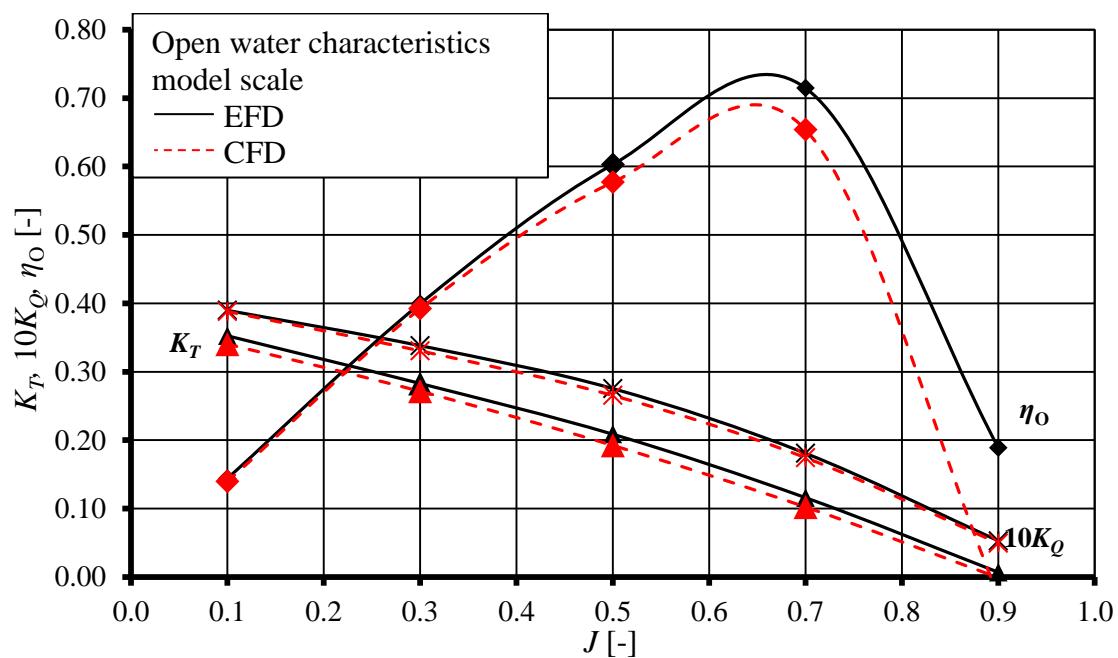
10.5 R09 - Questionnaire part II

	model scale	full scale
Computational Model		
H1 Fluid	incompressible	incompressible
H2 Pressure	Coupled	Coupled
Transition		
I Please comment	yes	0 / 0
Computational Demands		
J1 Number of processors used	8	8
J2 Number of timesteps (steady)	0	0
J3 Number of timesteps (transient)	30000	30000
J4 Wall-clock time per revolution	0	0
Code		
K References	0 / 0	0 / 0
Comments		
L Add. info.	0 / 0	0 / 0

11 Result R10

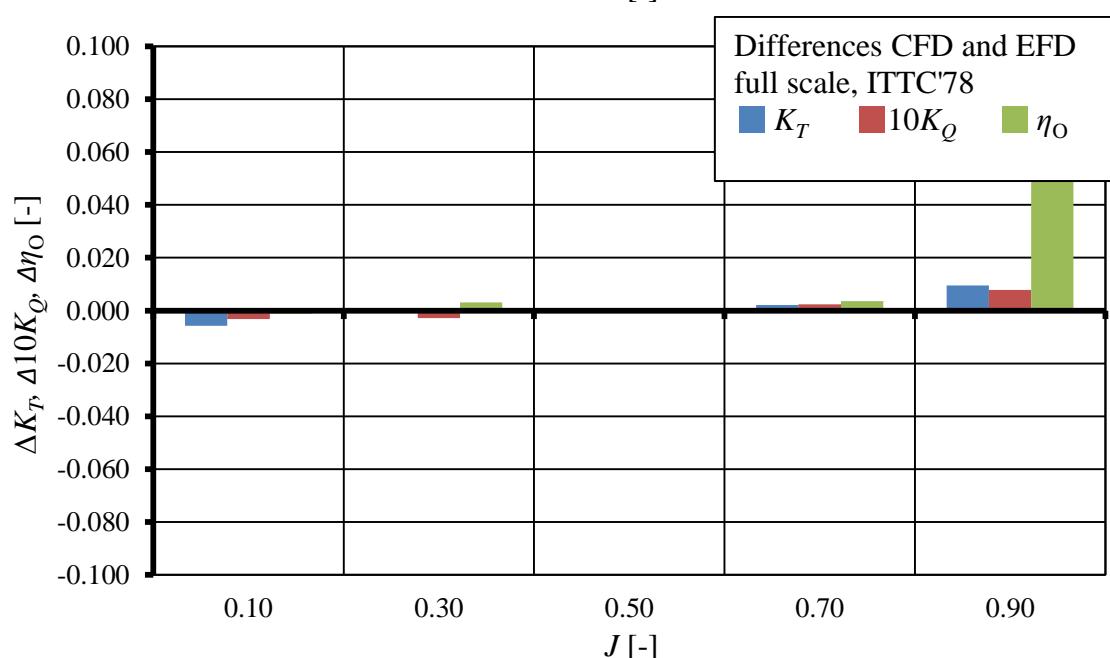
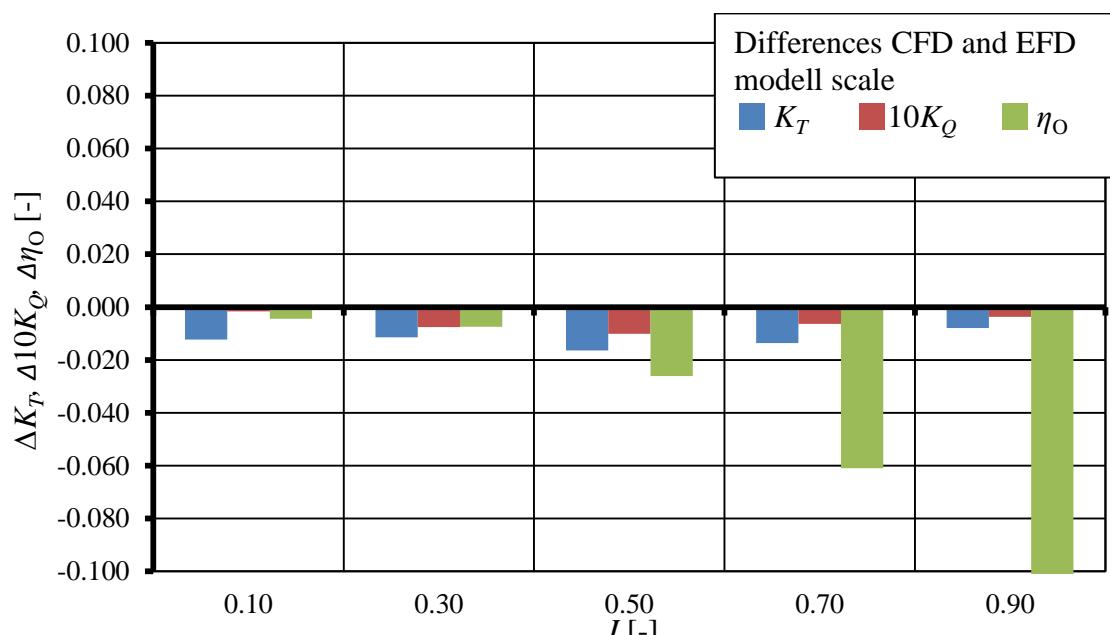
11.1 R10 - Open water characteristic

J [-]	CFD, model scale			CFD, full scale		
	K_T [-]	$10K_Q$ [-]	η_O [-]	K_T [-]	$10K_Q$ [-]	η_O [-]
	0.100	0.340	0.388	0.347	0.380	0.145
0.300	0.271	0.331	0.392	0.283	0.329	0.411
0.500	0.192	0.265	0.577	0.209	0.269	0.618
0.700	0.102	0.174	0.654	0.119	0.177	0.748
0.900	-0.001	0.049	-0.027	0.017	0.054	0.452



11.2 R10 - Differences CFD and EFD

CFD - EFD, model scale			CFD - EFD, full scale		
K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]
0.10	-0.012	-0.002	-0.004	-0.006	-0.003
0.30	-0.011	-0.008	-0.007	0.000	-0.003
0.50	-0.016	-0.010	-0.026	0.000	0.000
0.70	-0.014	-0.006	-0.061	0.002	0.002
0.90	-0.008	-0.004	-0.216	0.010	0.008



11.3 R10 - Radial distribution tables

model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.010	0.009	0.006	0.003	-0.002	0.009	0.008	0.007	0.003	-0.003
0.370	0.025	0.022	0.016	0.008	-0.003	0.027	0.025	0.021	0.012	-0.001
0.505	0.042	0.036	0.027	0.015	0.000	0.051	0.046	0.038	0.025	0.006
0.630	0.060	0.049	0.036	0.020	0.002	0.074	0.064	0.051	0.034	0.011
0.745	0.069	0.054	0.037	0.019	-0.001	0.078	0.065	0.051	0.032	0.008
0.850	0.073	0.055	0.037	0.019	-0.001	0.076	0.061	0.047	0.030	0.008
0.938	0.054	0.039	0.028	0.015	0.003	0.059	0.045	0.037	0.026	0.012
0.988	0.009	0.008	0.006	0.004	0.001	0.015	0.015	0.013	0.011	0.008

full scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.011	0.010	0.008	0.005	0.001	0.010	0.009	0.008	0.005	0.000
0.370	0.026	0.023	0.018	0.010	0.001	0.027	0.026	0.022	0.014	0.002
0.505	0.043	0.037	0.029	0.017	0.002	0.051	0.047	0.039	0.026	0.008
0.630	0.061	0.051	0.038	0.023	0.004	0.073	0.065	0.053	0.035	0.012
0.745	0.070	0.056	0.040	0.022	0.002	0.076	0.065	0.051	0.033	0.008
0.850	0.073	0.057	0.040	0.021	0.001	0.073	0.060	0.047	0.030	0.007
0.938	0.055	0.041	0.030	0.017	0.005	0.058	0.045	0.037	0.025	0.011
0.988	0.009	0.008	0.007	0.004	0.002	0.012	0.012	0.011	0.009	0.006

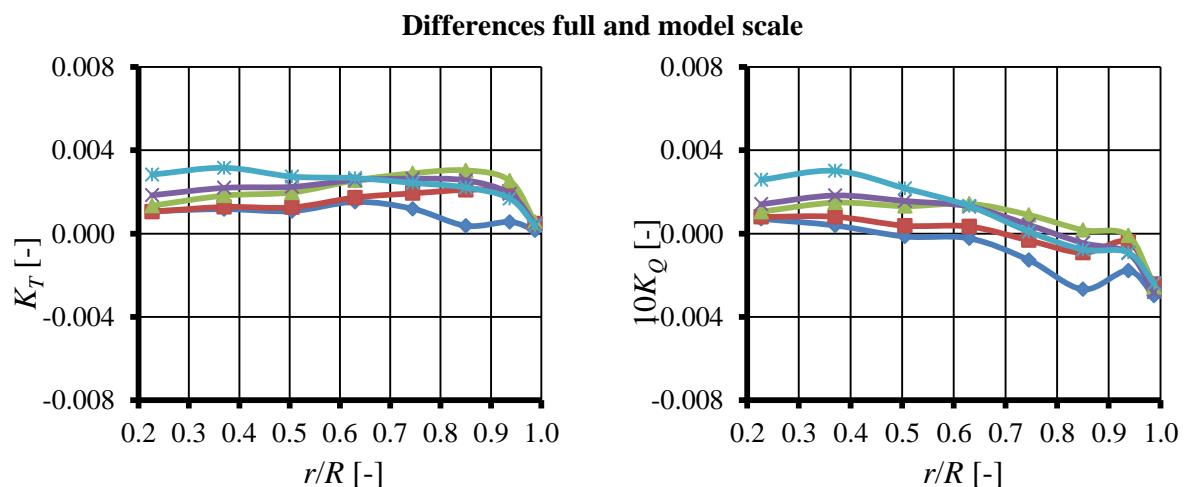
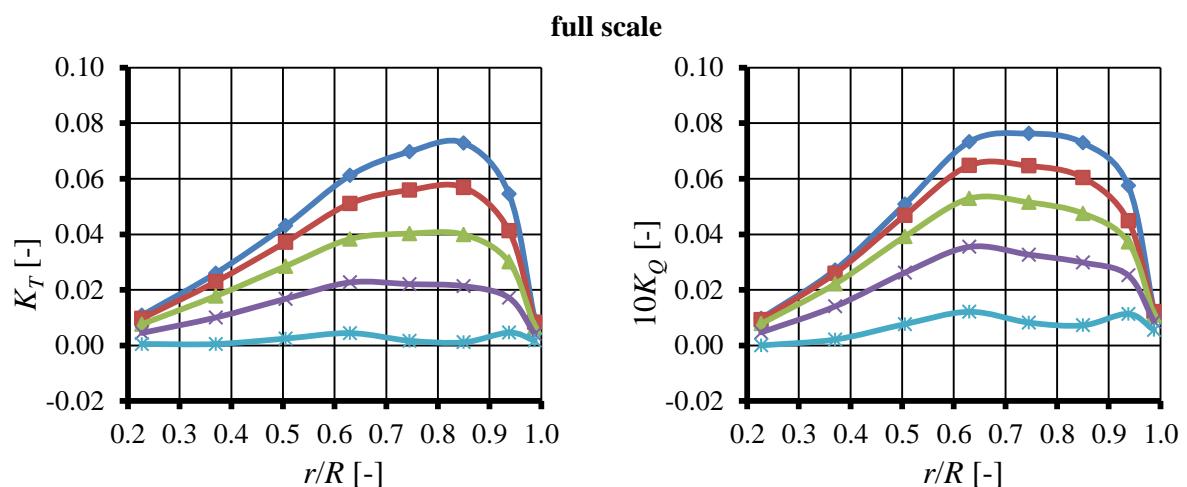
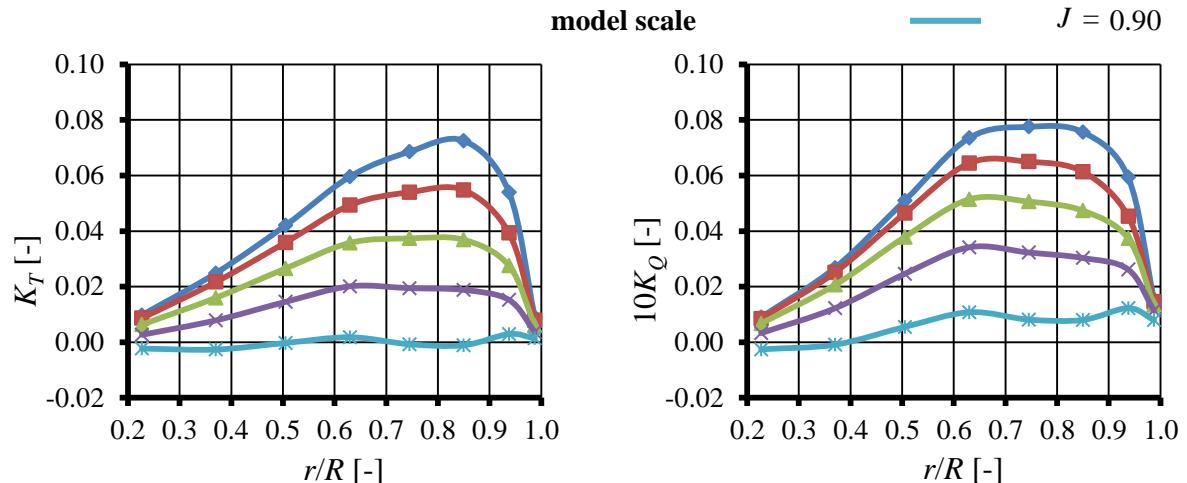
Differences full and model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.0011	0.0010	0.0013	0.0018	0.0028	0.0007	0.0008	0.0011	0.0014	0.0026
0.370	0.0012	0.0013	0.0018	0.0022	0.0032	0.0004	0.0008	0.0015	0.0018	0.0030
0.505	0.0011	0.0013	0.0020	0.0022	0.0027	-0.0001	0.0004	0.0013	0.0016	0.0022
0.630	0.0015	0.0017	0.0025	0.0026	0.0027	-0.0002	0.0003	0.0014	0.0013	0.0013
0.745	0.0012	0.0019	0.0029	0.0026	0.0024	-0.0013	-0.0003	0.0009	0.0004	0.0001
0.850	0.0004	0.0021	0.0030	0.0026	0.0022	-0.0027	-0.0009	0.0002	-0.0005	-0.0008
0.938	0.0006	0.0020	0.0025	0.0019	0.0017	-0.0018	-0.0004	-0.0001	-0.0009	-0.0009
0.988	0.0002	0.0005	0.0006	0.0005	0.0004	-0.0030	-0.0024	-0.0026	-0.0028	-0.0024

11.4 R10 - Radial distribution diagrams



 $J = 0.10$
 $J = 0.30$
 $J = 0.50$
 $J = 0.70$
 $J = 0.90$



11.5 R10 - Questionnaire part I

	model scale	full scale
Solver		
Computational Domain		
A1 Domain topology	Multiple domains	Multiple domains
A2 Grid-coupling technique	Sliding	Sliding
Propeller Representation		
B1 Number of considered blades	Complete propeller	Complete propeller
Computational Grid		
C1 Type	Unstructured	Unstructured
C2 Local-grid refinement	Possible - used here	Possible - used here
C3 Primary volume elements	Tetraheder	Tetraheder
C4 Primary surface elements	Triangles	Triangles
C5 Wall-boundary layer type	Prism Layer	Prism Layer
C7 Number of cells at boundary layer	717015	717015
C8 Y ⁺ -value at r/R=0.4, 0.7, 0.9	50,50,50	1571.4,1571.4,1571.4
C9 Averaged Y ⁺ -value	50	1571.4
C10 Number of cells on blade surface	135264	135264
Norm. Dim. the Physical Domain		
D1 X_upstream/D, X_downstream/D	2.0952,8.3808	2.0952,8.3808
D2 Cross area of domain in prop. plain	137.67	137.67
Numerical Approximation		
E1 Finite Approximation Scheme (Fluid)	FV-NS	FV-NS
E2 Coordinates	Cartesian	Cartesian
E3 Convection scheme (momentum eq.)	high-order upwind	high-order upwind
E4 Transient approximation	implicit	implicit
E5 Spatial order of acc. (neglecting BC)	0	0
E6 Temporal order of accuracy	0	0
E7 Time step	0.00046296s	0.00086535s
E8 Equivalent rot. Angle for a time step	3	1
Turbulence treatment		
F1 Model name	k-epsilon	k-epsilon
F2 Convection scheme (Turb. Eqn.)	high-order upwind	high-order upwind
Boundary conditions		
G1 Blade	wall function	wall function
G2 Hub	wall function	wall function
G3 Inlet	Fixed Velocity	Fixed Velocity
G4 Outlet	Fixed Pressure	Fixed Pressure
G5 Outer domain	Slip flow	Slip flow

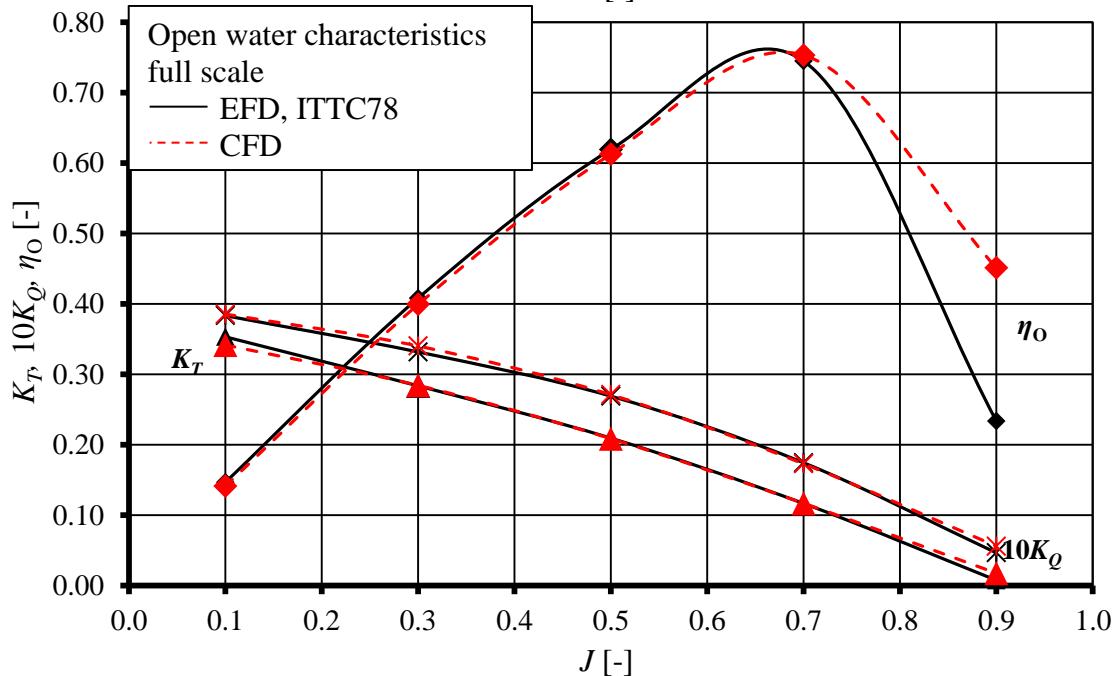
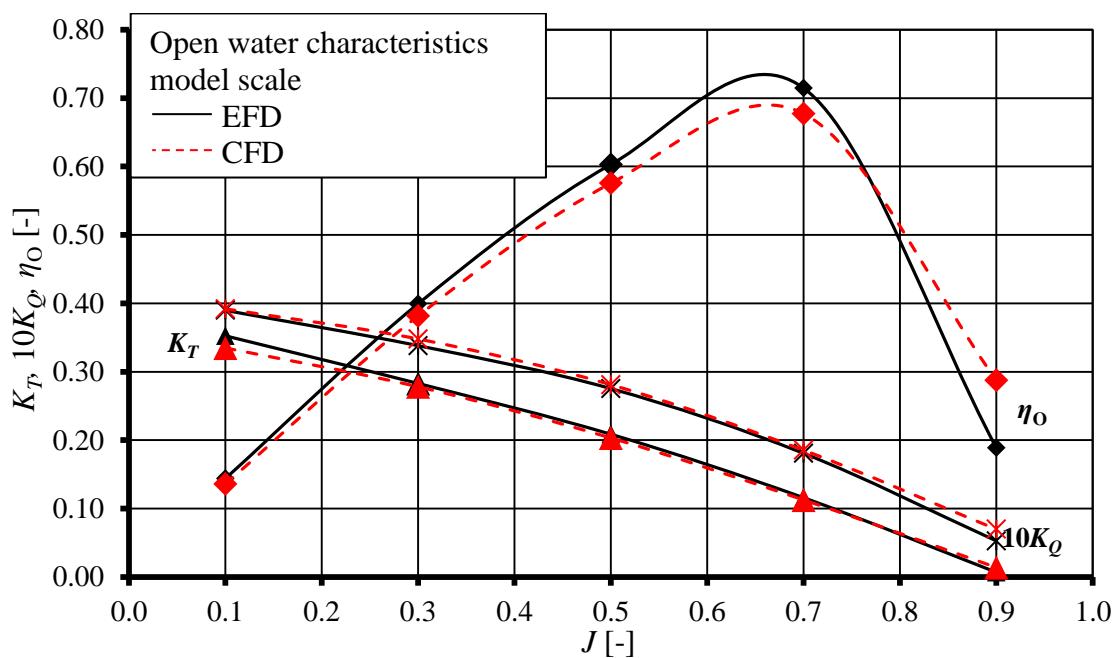
11.5 R10 - Questionnaire part II

	model scale	full scale
Computational Model		
H1 Fluid	incompressible	incompressible
H2 Pressure	pressure correction	pressure correction
Transition		
I Please comment	no	no
Computational Demands		
J1 Number of processors used	20	20
J2 Number of timesteps (steady)	0	0
J3 Number of timesteps (transient)	1297	1734
J4 Wall-clock time per revolution	7.35h	20h
Code		
K References	0 / 0	0 / 0
Comments		
L Add. info.	0 / 0	0 / 0

12 Result R11

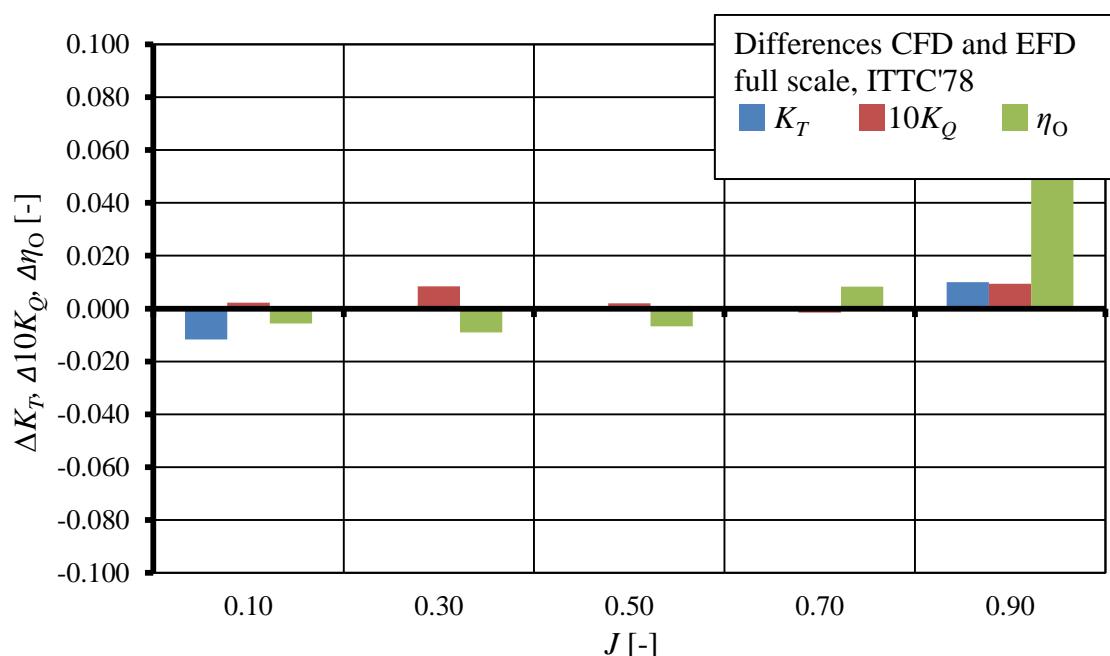
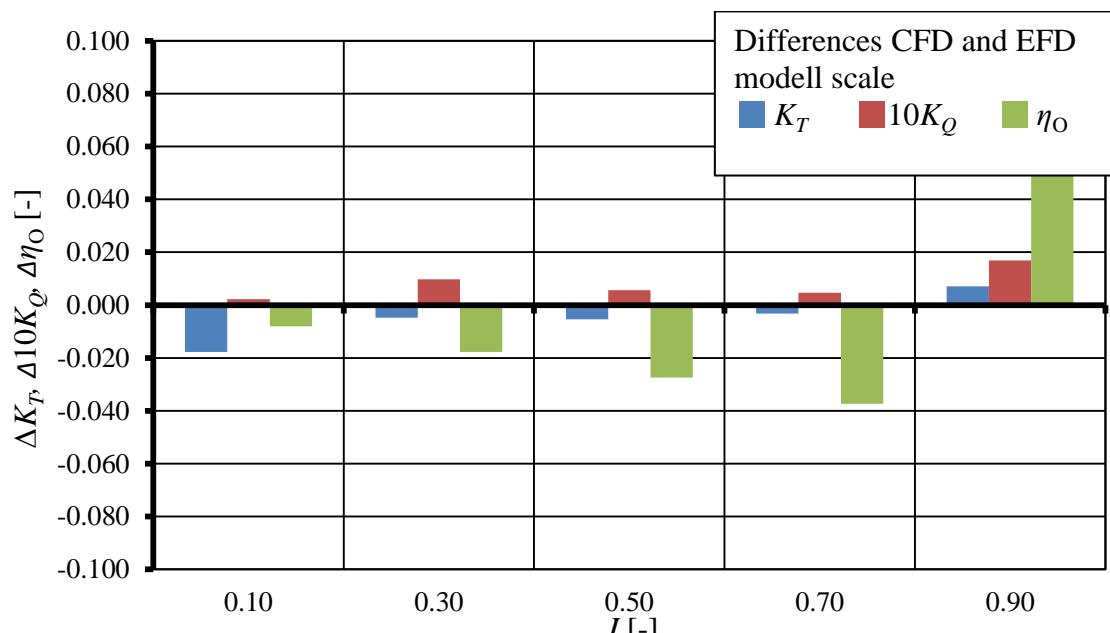
12.1 R11 - Open water characteristic

J	CFD, model scale			CFD, full scale		
	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.100	0.335	0.392	0.136	0.342	0.385	0.141
0.300	0.278	0.348	0.382	0.284	0.340	0.399
0.500	0.203	0.281	0.576	0.209	0.271	0.613
0.700	0.113	0.185	0.677	0.117	0.173	0.753
0.900	0.014	0.070	0.287	0.018	0.056	0.451



12.2 R11 - Differences CFD and EFD

CFD - EFD, model scale			CFD - EFD, full scale		
K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]
0.10	-0.018	0.002	-0.008	-0.012	0.002
0.30	-0.005	0.010	-0.018	0.001	0.008
0.50	-0.005	0.006	-0.027	-0.001	0.002
0.70	-0.003	0.005	-0.037	0.000	-0.002
0.90	0.007	0.017	0.099	0.010	0.009



12.3 R11 - Radial distribution tables

model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.010	0.010	0.008	0.005	0.000	0.011	0.010	0.009	0.005	0.001
0.370	0.025	0.023	0.017	0.009	-0.001	0.028	0.027	0.023	0.014	0.002
0.505	0.042	0.038	0.029	0.017	0.003	0.053	0.050	0.042	0.028	0.010
0.630	0.058	0.050	0.038	0.022	0.004	0.075	0.068	0.055	0.037	0.014
0.745	0.067	0.056	0.040	0.022	0.002	0.078	0.069	0.055	0.035	0.012
0.850	0.071	0.055	0.038	0.019	0.000	0.075	0.063	0.048	0.031	0.010
0.938	0.051	0.039	0.027	0.015	0.004	0.056	0.048	0.038	0.025	0.014
0.988	0.010	0.008	0.005	0.003	0.002	0.016	0.013	0.011	0.009	0.008

full scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.011	0.010	0.008	0.005	0.001	0.011	0.011	0.010	0.006	0.001
0.370	0.026	0.023	0.018	0.010	0.000	0.029	0.027	0.023	0.014	0.002
0.505	0.043	0.038	0.030	0.018	0.003	0.053	0.051	0.042	0.028	0.009
0.630	0.059	0.051	0.040	0.023	0.005	0.074	0.067	0.055	0.036	0.013
0.745	0.068	0.057	0.042	0.022	0.002	0.076	0.068	0.053	0.033	0.009
0.850	0.072	0.056	0.038	0.020	0.001	0.073	0.060	0.045	0.028	0.007
0.938	0.052	0.040	0.028	0.016	0.004	0.055	0.046	0.035	0.022	0.011
0.988	0.011	0.008	0.005	0.003	0.002	0.014	0.011	0.008	0.006	0.005

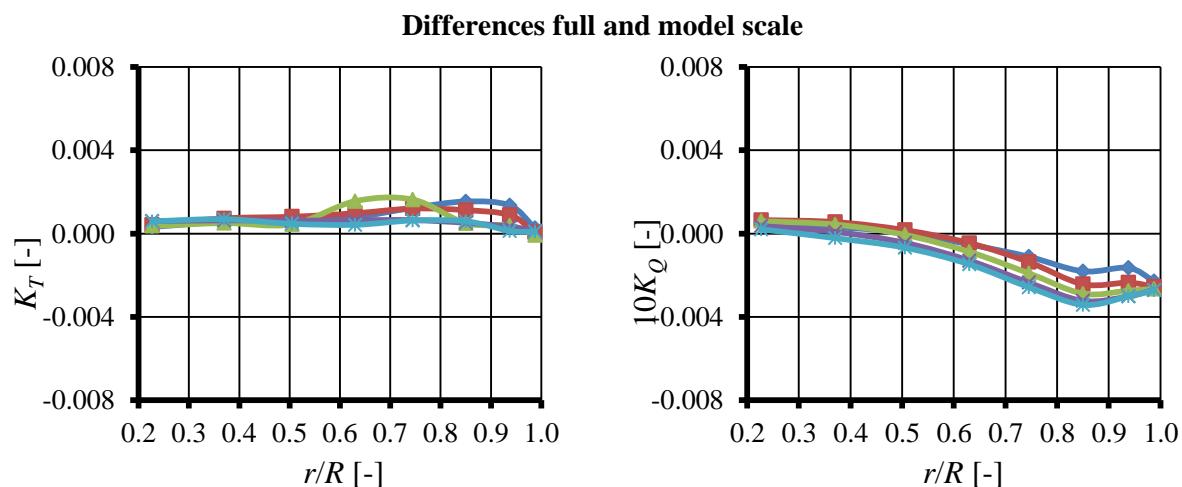
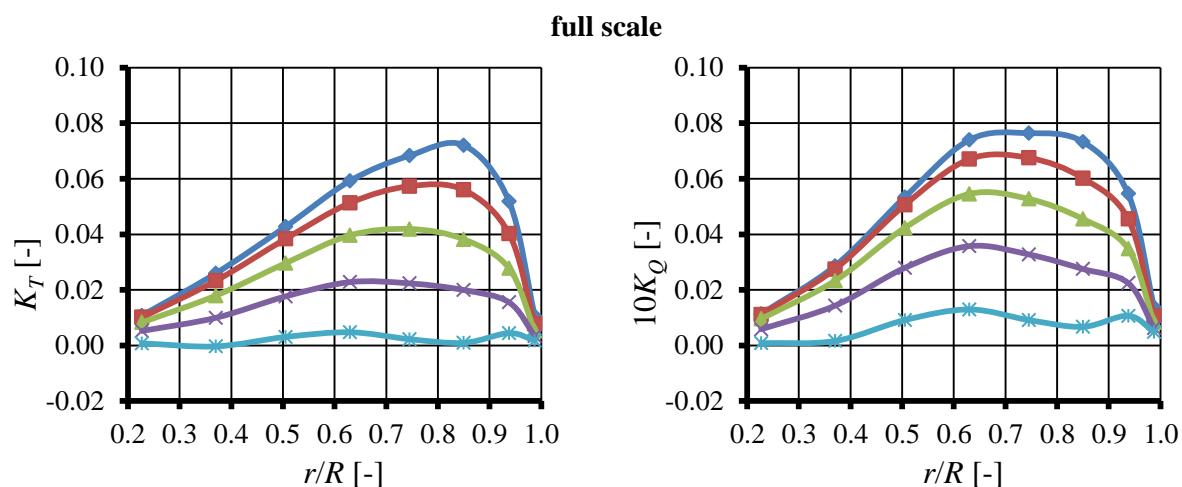
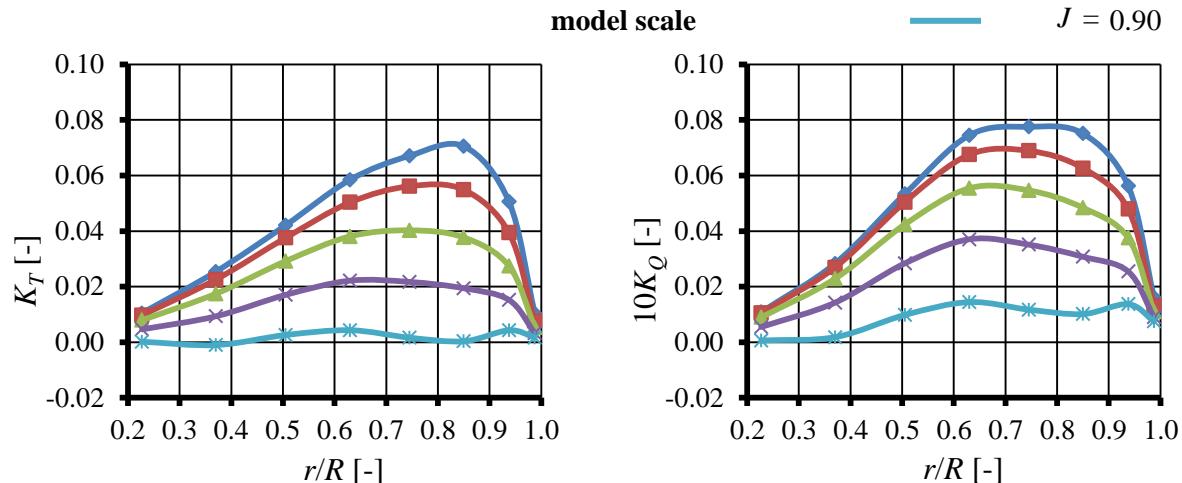
Differences full and model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.0003	0.0004	0.0004	0.0006	0.0006	0.0005	0.0006	0.0006	0.0004	0.0002
0.370	0.0006	0.0007	0.0005	0.0006	0.0007	0.0003	0.0006	0.0004	0.0001	-0.0002
0.505	0.0007	0.0008	0.0004	0.0006	0.0005	0.0001	0.0002	-0.0001	-0.0004	-0.0007
0.630	0.0008	0.0010	0.0016	0.0006	0.0004	-0.0005	-0.0005	-0.0009	-0.0013	-0.0015
0.745	0.0012	0.0012	0.0016	0.0006	0.0006	-0.0011	-0.0014	-0.0019	-0.0024	-0.0026
0.850	0.0015	0.0011	0.0005	0.0005	0.0006	-0.0018	-0.0024	-0.0029	-0.0032	-0.0034
0.938	0.0013	0.0009	0.0004	0.0003	0.0001	-0.0016	-0.0024	-0.0027	-0.0030	-0.0030
0.988	0.0003	0.0001	-0.0001	0.0001	0.0001	-0.0023	-0.0025	-0.0027	-0.0027	-0.0027

12.4 R11 - Radial distribution diagrams



 $J = 0.10$
 $J = 0.30$
 $J = 0.50$
 $J = 0.70$
 $J = 0.90$



12.5 R11 - Questionnaire part I

	model scale	full scale
Solver	ANSYS FLUENT	ANSYS FLUENT
Computational Domain		
A1 Domain topology	1 rotating domain	1 rotating domain
A2 Grid-coupling technique	None	None
Propeller Representation		
B1 Number of considered blades	1 blade, matching	1 blade, matching
Computational Grid		
C1 Type	Unstructured	Unstructured
C2 Local-grid refinement	Possible - used here	Possible - used here
C3 Primary volume elements	Tetraheder	Tetraheder
C4 Primary surface elements	Triangles	Triangles
C5 Wall-boundary layer type	-	-
C7 Number of cells at boundary layer	0	0
C8 Y ⁺ -value at r/R=0.4, 0.7, 0.9	75, 130, 150	250, 300, 350
C9 Averaged Y ⁺ -value	120	300
C10 Number of cells on blade surface	11256	14062
Norm. Dim. the Physical Domain		
D1 X_upstream/D, X_downstream/D	6, 10	6, 10
D2 Cross area of domain in prop. plain	0	0
Numerical Approximation		
E1 Finite Approximation Scheme (Fluid)	FV-NS	FV-NS
E2 Coordinates	Cartesian	Cartesian
E3 Convection scheme (momentum eq.)	high-order upwind	high-order upwind
E4 Transient approximation	-	-
E5 Spatial order of acc. (neglecting BC)	2	2
E6 Temporal order of accuracy	0	0
E7 Time step	0	0
E8 Equivalent rot. Angle for a time step	0	0
Turbulence treatment		
F1 Model name	k-omega	k-omega
F2 Convection scheme (Turb. Eqn.)	high-order upwind	high-order upwind
Boundary conditions		
G1 Blade	wall function	wall function
G2 Hub	wall function	wall function
G3 Inlet	Fixed Velocity	Fixed Velocity
G4 Outlet	Fixed Pressure	Fixed Pressure
G5 Outer domain	-	-

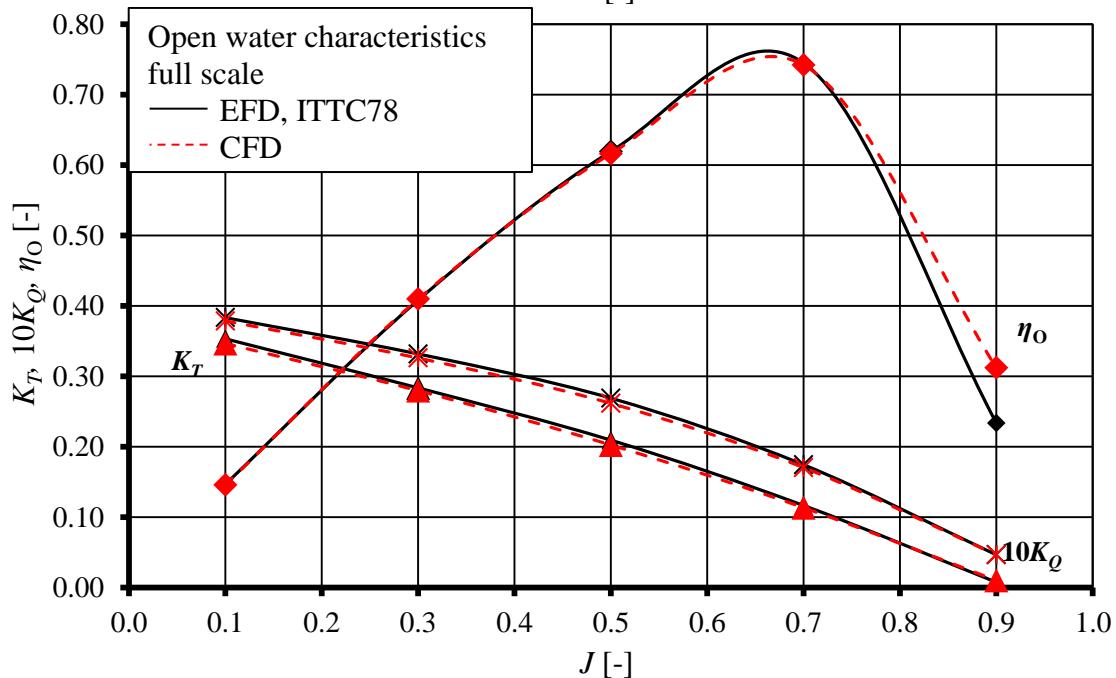
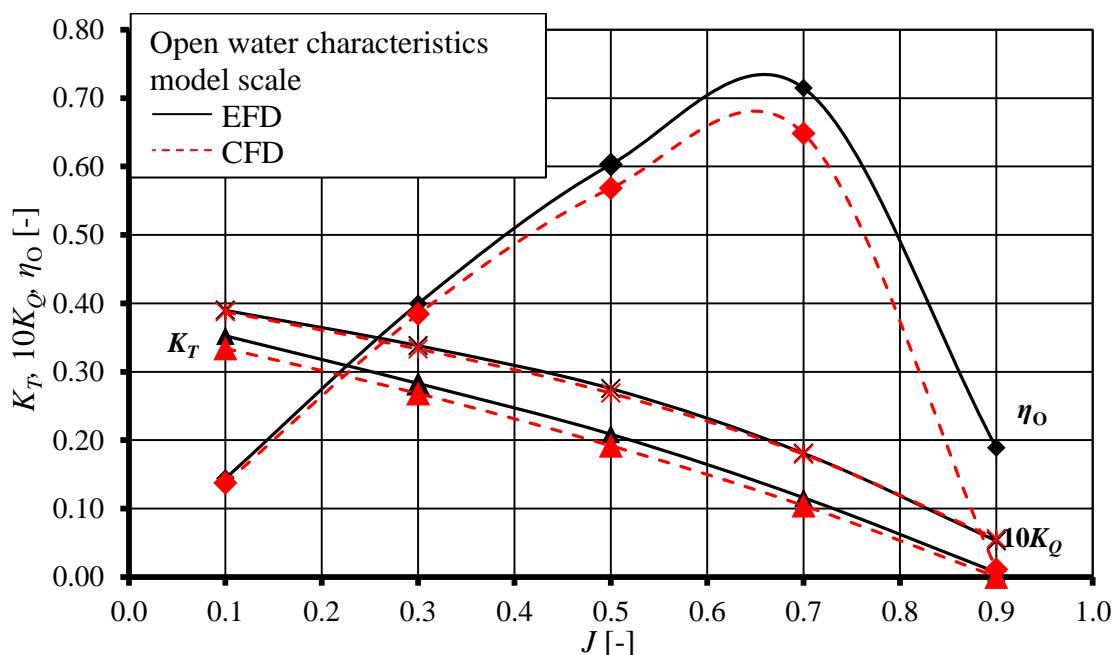
12.5 R11 - Questionnaire part II

	model scale	full scale
Computational Model		
H1 Fluid	incompressible	incompressible
H2 Pressure	pressure correction	pressure correction
Transition		
I Please comment	no	no
Computational Demands		
J1 Number of processors used	32	32
J2 Number of timesteps (steady)	2000	2000
J3 Number of timesteps (transient)	0	0
J4 Wall-clock time per revolution	0	0
Code		
K References	FLUENT	FLUENT
Comments		
L Add. info.	0 / 0	0 / 0

13 Result R12

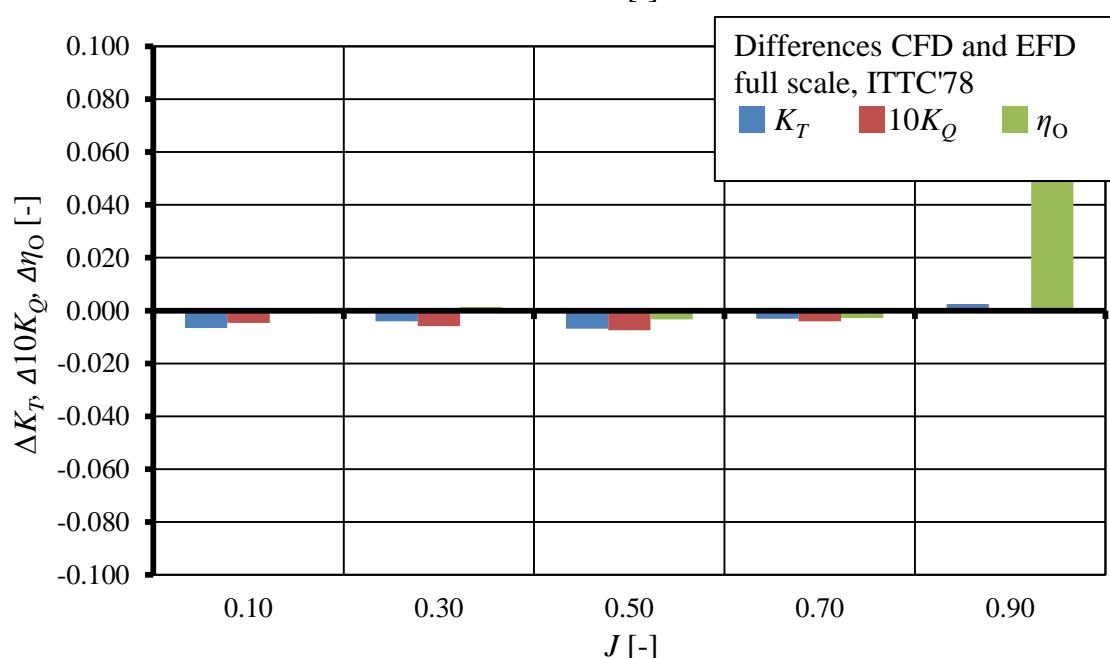
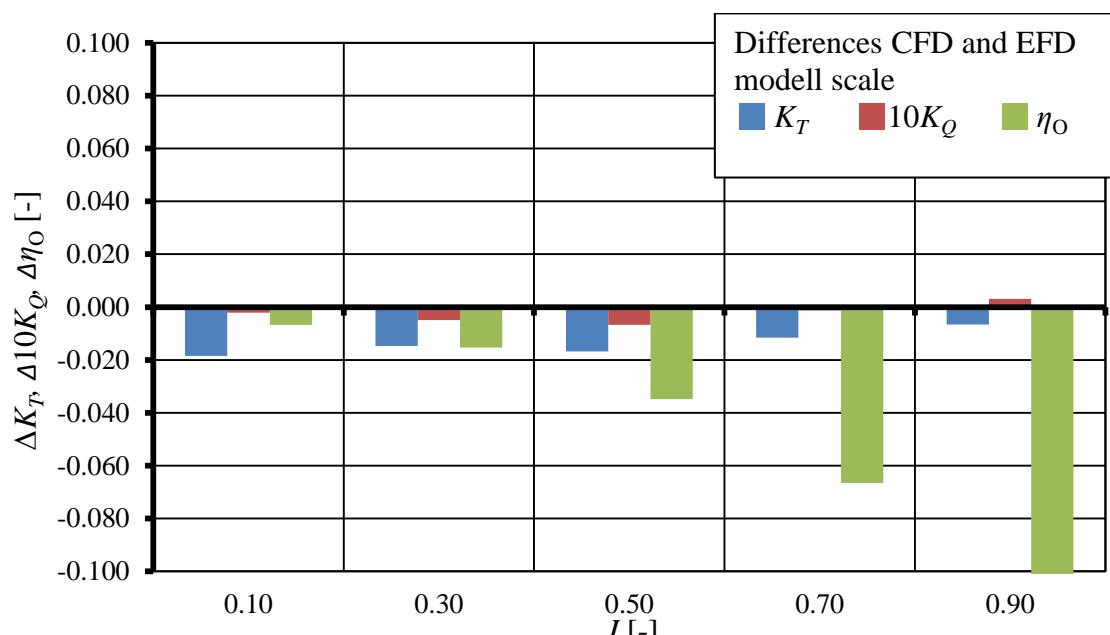
13.1 R12 - Open water characteristic

J [-]	CFD, model scale			CFD, full scale		
	K_T [-]	$10K_Q$ [-]	η_O [-]	K_T [-]	$10K_Q$ [-]	η_O [-]
	0.100	0.334	0.388	0.137	0.347	0.379
0.300	0.268	0.333	0.384	0.280	0.326	0.410
0.500	0.192	0.269	0.568	0.202	0.262	0.616
0.700	0.104	0.179	0.648	0.113	0.170	0.742
0.900	0.000	0.056	0.011	0.010	0.046	0.312



13.2 R12 - Differences CFD and EFD

	CFD - EFD, model scale			CFD - EFD, full scale		
	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
	[-]	[-]	[-]	[-]	[-]	[-]
0.10	-0.018	-0.002	-0.007	-0.007	-0.005	-0.001
0.30	-0.015	-0.005	-0.015	-0.004	-0.006	0.001
0.50	-0.017	-0.007	-0.035	-0.007	-0.007	-0.003
0.70	-0.012	-0.001	-0.066	-0.003	-0.004	-0.003
0.90	-0.007	0.003	-0.178	0.003	0.000	0.078



13.3 R12 - Radial distribution tables

model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.009	0.008	0.006	0.003	-0.002	0.008	0.008	0.006	0.003	-0.003
0.370	0.024	0.021	0.015	0.008	-0.003	0.026	0.024	0.020	0.012	-0.001
0.505	0.041	0.035	0.027	0.015	0.001	0.050	0.047	0.039	0.026	0.007
0.630	0.057	0.048	0.036	0.021	0.002	0.071	0.064	0.052	0.035	0.012
0.745	0.067	0.054	0.038	0.021	0.000	0.077	0.066	0.052	0.034	0.010
0.850	0.069	0.053	0.036	0.019	-0.001	0.073	0.061	0.047	0.031	0.009
0.938	0.056	0.039	0.027	0.015	0.002	0.063	0.046	0.037	0.026	0.012
0.988	0.010	0.008	0.006	0.004	0.001	0.015	0.014	0.013	0.011	0.007

full scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.010	0.009	0.007	0.004	0.000	0.009	0.009	0.007	0.004	-0.001
0.370	0.025	0.022	0.017	0.009	-0.001	0.026	0.025	0.021	0.013	0.000
0.505	0.043	0.037	0.028	0.017	0.002	0.051	0.047	0.039	0.026	0.007
0.630	0.059	0.050	0.037	0.022	0.004	0.071	0.063	0.051	0.034	0.011
0.745	0.070	0.056	0.040	0.022	0.001	0.076	0.065	0.051	0.032	0.008
0.850	0.072	0.055	0.038	0.020	0.000	0.071	0.059	0.045	0.028	0.006
0.938	0.057	0.041	0.029	0.016	0.004	0.060	0.045	0.035	0.024	0.010
0.988	0.010	0.008	0.006	0.004	0.001	0.013	0.012	0.011	0.008	0.005

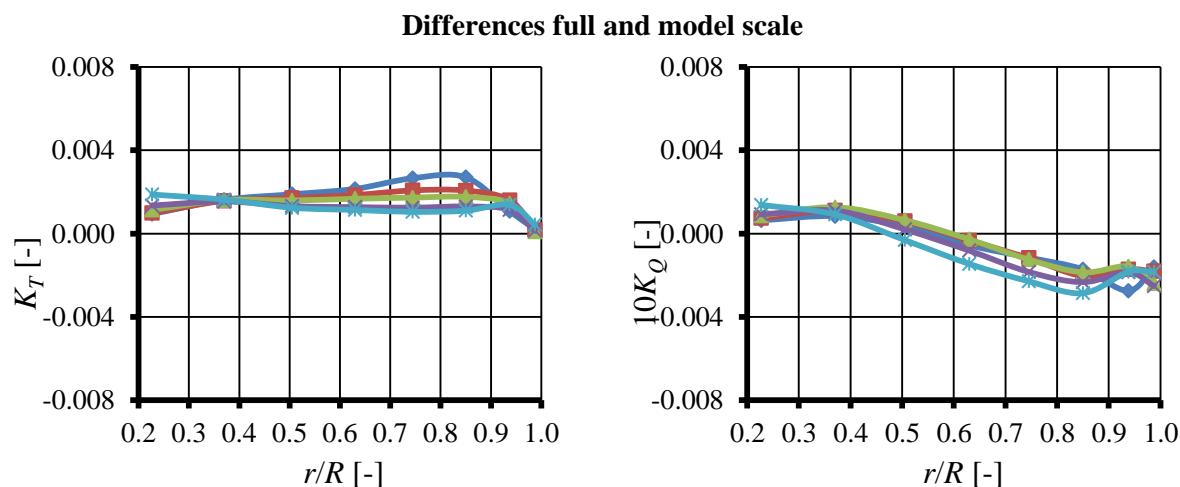
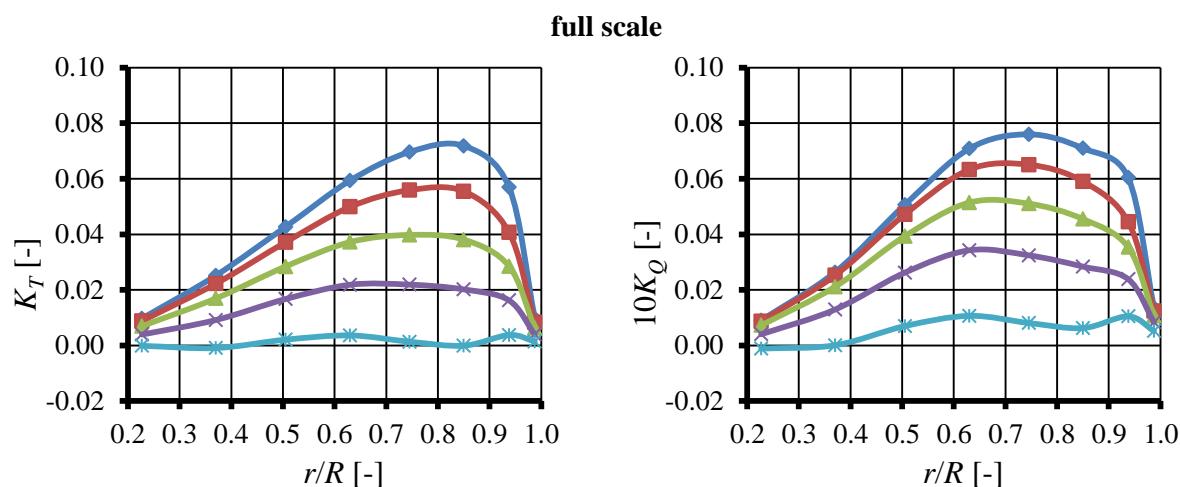
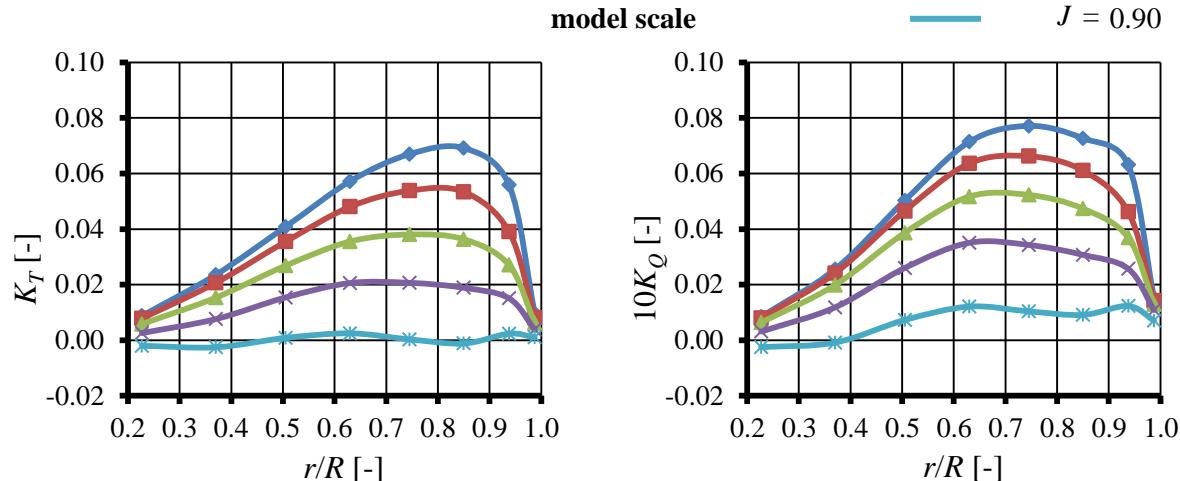
Differences full and model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.0009	0.0010	0.0011	0.0013	0.0019	0.0006	0.0007	0.0009	0.0009	0.0014
0.370	0.0016	0.0016	0.0016	0.0015	0.0016	0.0008	0.0011	0.0013	0.0011	0.0009
0.505	0.0019	0.0017	0.0016	0.0013	0.0012	0.0003	0.0006	0.0006	0.0002	-0.0003
0.630	0.0021	0.0018	0.0017	0.0013	0.0011	-0.0006	-0.0003	-0.0003	-0.0008	-0.0015
0.745	0.0027	0.0021	0.0017	0.0012	0.0010	-0.0011	-0.0012	-0.0012	-0.0018	-0.0023
0.850	0.0027	0.0021	0.0018	0.0013	0.0011	-0.0017	-0.0020	-0.0019	-0.0023	-0.0029
0.938	0.0011	0.0016	0.0014	0.0011	0.0014	-0.0027	-0.0017	-0.0016	-0.0019	-0.0018
0.988	0.0002	0.0002	0.0001	0.0001	0.0004	-0.0016	-0.0018	-0.0024	-0.0025	-0.0018

13.4 R12 - Radial distribution diagrams



 $J = 0.10$
 $J = 0.30$
 $J = 0.50$
 $J = 0.70$
 $J = 0.90$



13.5 R12 - Questionnaire part I

	model scale	full scale
Solver		
Computational Domain		
A1 Domain topology	1 rotating domain	1 rotating domain
A2 Grid-coupling technique	None	None
Propeller Representation		
B1 Number of considered blades	Complete propeller	Complete propeller
Computational Grid		
C1 Type	Unstructured	Unstructured
C2 Local-grid refinement	Possible - used here	Possible - used here
C3 Primary volume elements	Hexahedral	Hexahedral
C4 Primary surface elements	Quads	Quads
C5 Wall-boundary layer type	Hex Layer	Hex Layer
C7 Number of cells at boundary layer	0	0
C8 Y ⁺ -value at r/R=0.4, 0.7, 0.9	3, 5, 6.5	40, 70, 90
C9 Averaged Y ⁺ -value	4	70
C10 Number of cells on blade surface	71000	77000
Norm. Dim. the Physical Domain		
D1 X_upstream/D, X_downstream/D	4,10	4, 10
D2 Cross area of domain in prop. plain	100	100
Numerical Approximation		
E1 Finite Approximation Scheme (Fluid)	FV-NS	FV-NS
E2 Coordinates	Cartesian	Cartesian
E3 Convection scheme (momentum eq.)	high-order upwind	high-order upwind
E4 Transient approximation	explicit	explicit
E5 Spatial order of acc. (neglecting BC)	0	0
E6 Temporal order of accuracy	0	0
E7 Time step	0.00016 sec	0
E8 Equivalent rot. Angle for a time step	1°	0
Turbulence treatment		
F1 Model name	k-omega	k-omega
F2 Convection scheme (Turb. Eqn.)	-	-
Boundary conditions		
G1 Blade	resolved	wall function
G2 Hub	wall function	wall function
G3 Inlet	Fixed Velocity	Fixed Velocity
G4 Outlet	Fixed Pressure	please select
G5 Outer domain	Slip flow	Slip flow

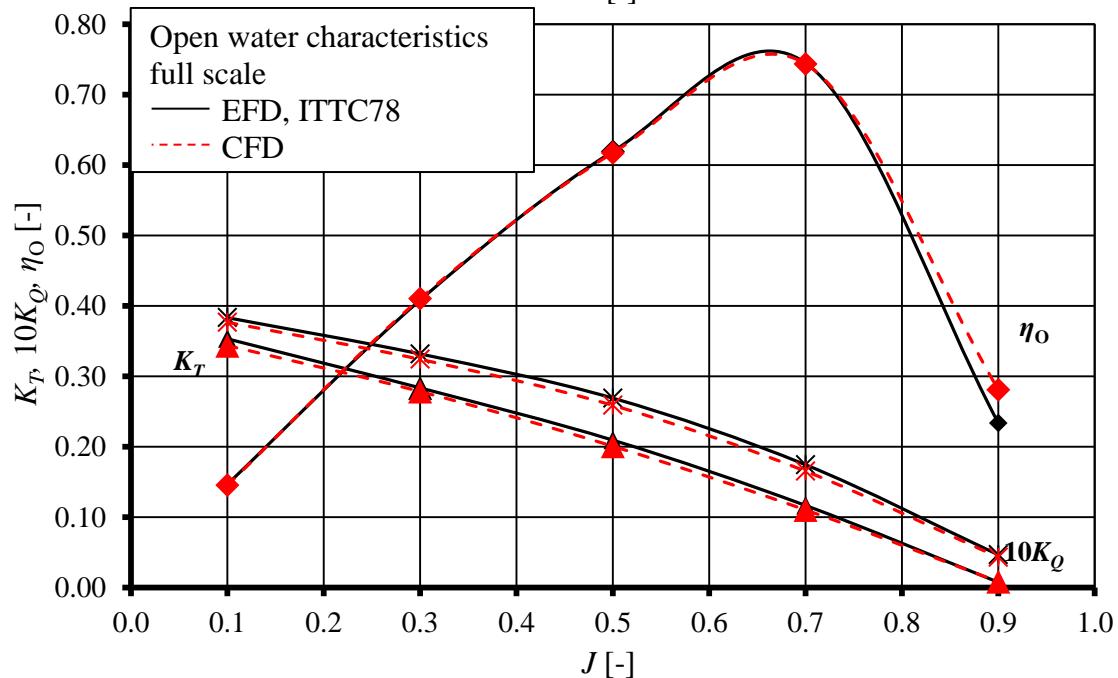
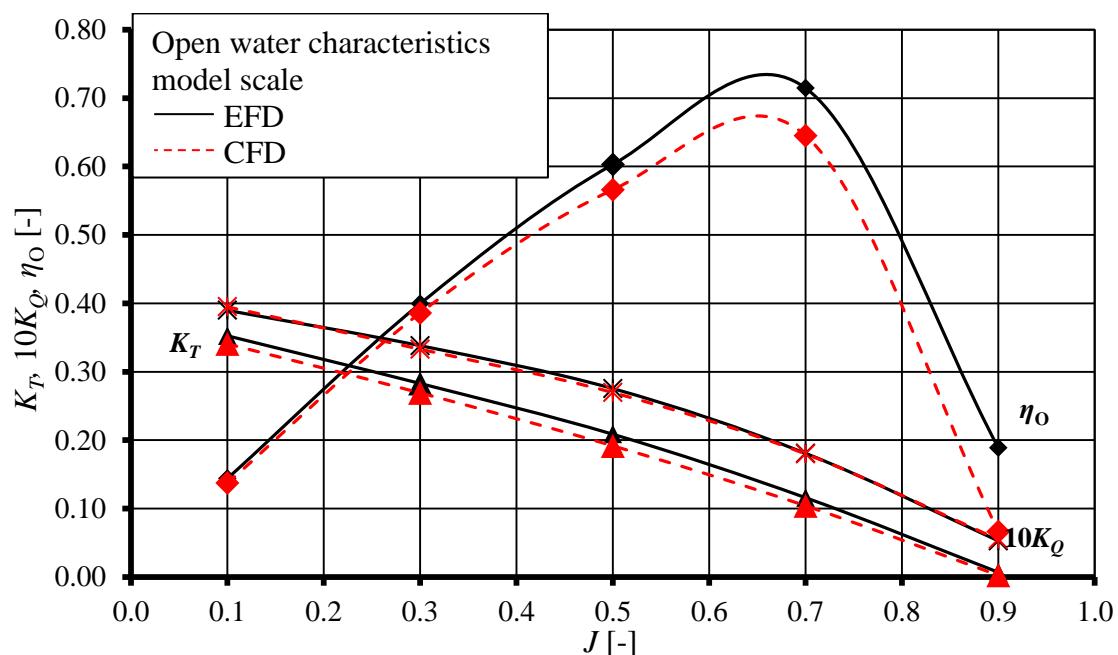
13.5 R12 - Questionnaire part II

	model scale	full scale
Computational Model		
H1 Fluid	incompressible	incompressible
H2 Pressure	pressure correction	pressure correction
Transition		
I Please comment	no	no
Computational Demands		
J1 Number of processors used	32	32
J2 Number of timesteps (steady)	0	0
J3 Number of timesteps (transient)	1750	1750
J4 Wall-clock time per revolution	4-6 hours	4-6 hours
Code		
K References	www.hsva.de/our-services/software/fresco.html Hafermann, D.: The New RANSE Code FreSCo for Ship Applications	0 / 0
Comments		
L Add. info.	A Sheet 'J=0.5dK' was introduced to isolate the tang. Force Influence. The propeller was also scaled with the Strip Method of HSVA, representing HSVA's standards procedure for propeller performance scaling. No roughness accounted for in RANS analysis. A Sheet 'HSVA_Strip' includes efficiency scaled with HSVA Strip Method (HSVA-NewsWave 2_2012) .	0 / 0

14 Result R13

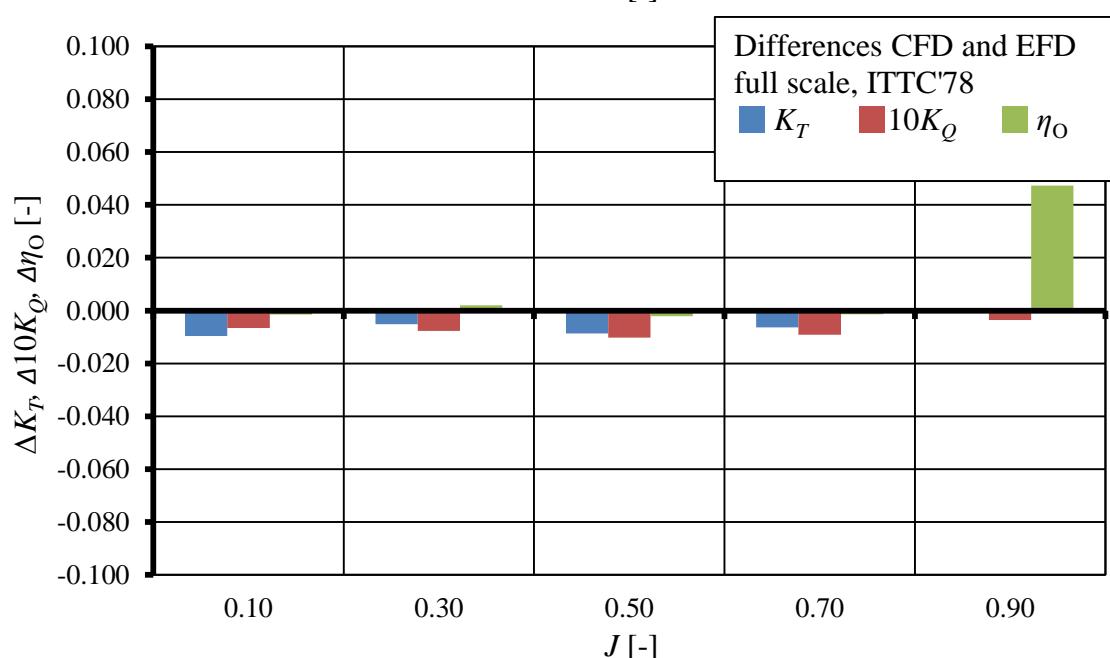
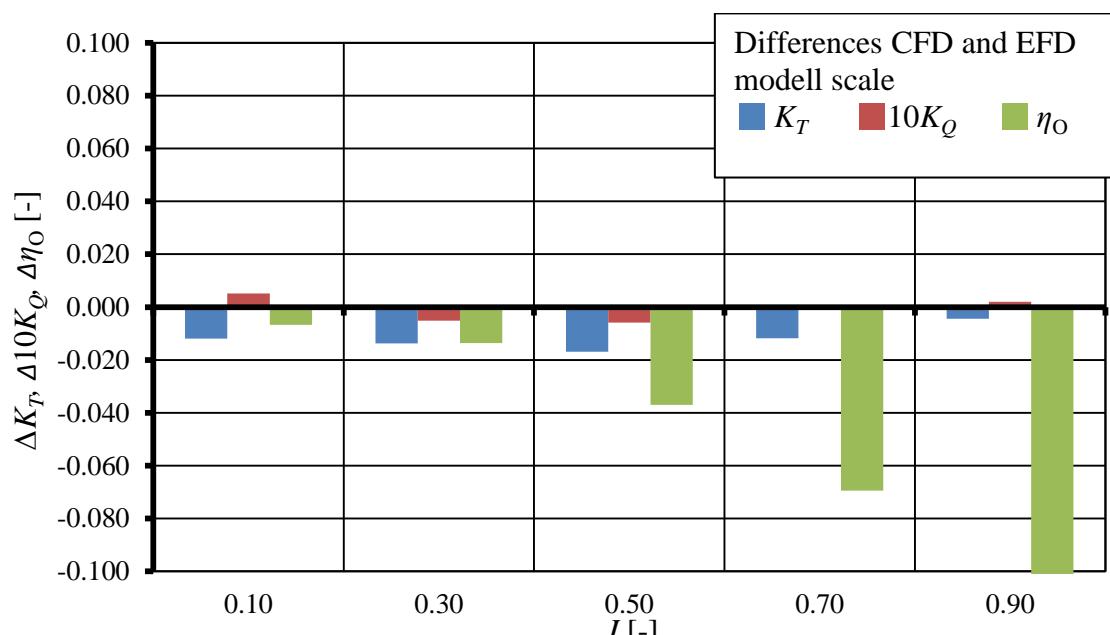
14.1 R13 - Open water characteristic

J [-]	CFD, model scale			CFD, full scale		
	K_T [-]	$10K_Q$ [-]	η_O [-]	K_T [-]	$10K_Q$ [-]	η_O [-]
	0.100	0.341	0.395	0.137	0.344	0.377
0.300	0.269	0.333	0.386	0.278	0.324	0.410
0.500	0.192	0.270	0.566	0.201	0.259	0.617
0.700	0.104	0.180	0.645	0.110	0.165	0.743
0.900	0.003	0.055	0.066	0.008	0.043	0.281



14.2 R13 - Differences CFD and EFD

CFD - EFD, model scale			CFD - EFD, full scale		
K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]
0.10	-0.012	0.005	-0.007	-0.010	-0.007
0.30	-0.014	-0.005	-0.014	-0.005	-0.008
0.50	-0.017	-0.006	-0.037	-0.009	-0.010
0.70	-0.012	-0.001	-0.069	-0.006	-0.009
0.90	-0.004	0.002	-0.122	0.001	-0.004



14.3 R13 - Radial distribution tables

model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.009	0.008	0.006	0.003	-0.001	0.009	0.008	0.007	0.004	-0.001
0.370	0.024	0.021	0.016	0.008	-0.002	0.026	0.025	0.021	0.013	0.000
0.505	0.042	0.036	0.027	0.015	0.001	0.051	0.047	0.039	0.026	0.008
0.630	0.059	0.048	0.036	0.020	0.002	0.073	0.064	0.052	0.035	0.012
0.745	0.069	0.054	0.038	0.020	0.000	0.079	0.066	0.052	0.034	0.009
0.850	0.074	0.054	0.037	0.019	-0.001	0.079	0.062	0.048	0.031	0.008
0.938	0.056	0.039	0.027	0.015	0.002	0.064	0.047	0.037	0.026	0.012
0.988	0.008	0.007	0.006	0.003	0.001	0.014	0.014	0.013	0.011	0.007

full scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.010	0.009	0.007	0.004	0.000	0.009	0.009	0.007	0.004	-0.001
0.370	0.025	0.022	0.017	0.009	-0.001	0.026	0.025	0.021	0.012	-0.001
0.505	0.043	0.037	0.028	0.016	0.001	0.051	0.047	0.039	0.025	0.006
0.630	0.059	0.050	0.037	0.021	0.003	0.071	0.063	0.051	0.033	0.010
0.745	0.070	0.056	0.040	0.021	0.001	0.077	0.065	0.051	0.032	0.008
0.850	0.073	0.056	0.038	0.019	0.000	0.074	0.059	0.045	0.027	0.006
0.938	0.054	0.041	0.028	0.016	0.004	0.056	0.045	0.035	0.023	0.010
0.988	0.009	0.008	0.006	0.004	0.002	0.012	0.012	0.010	0.008	0.005

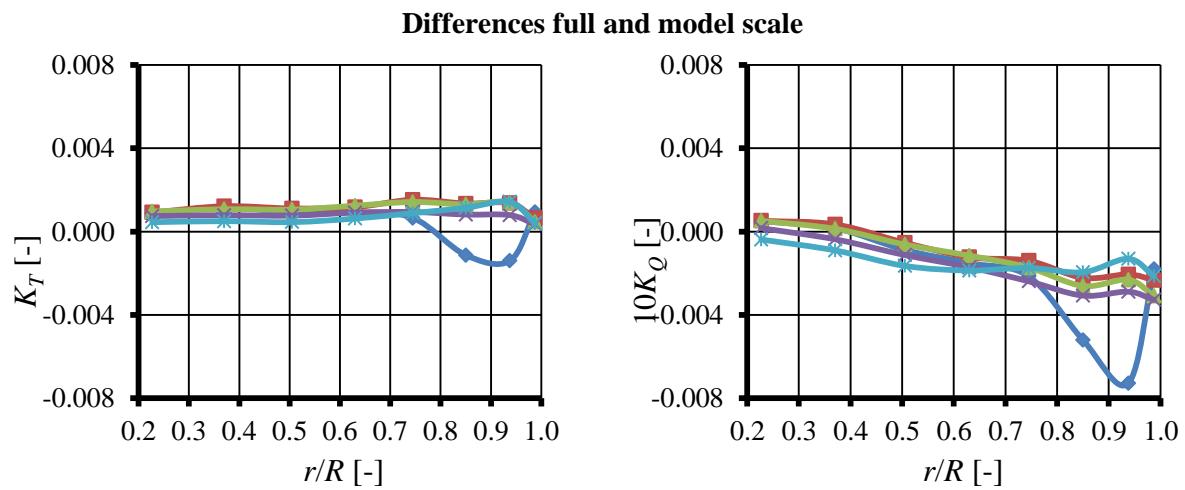
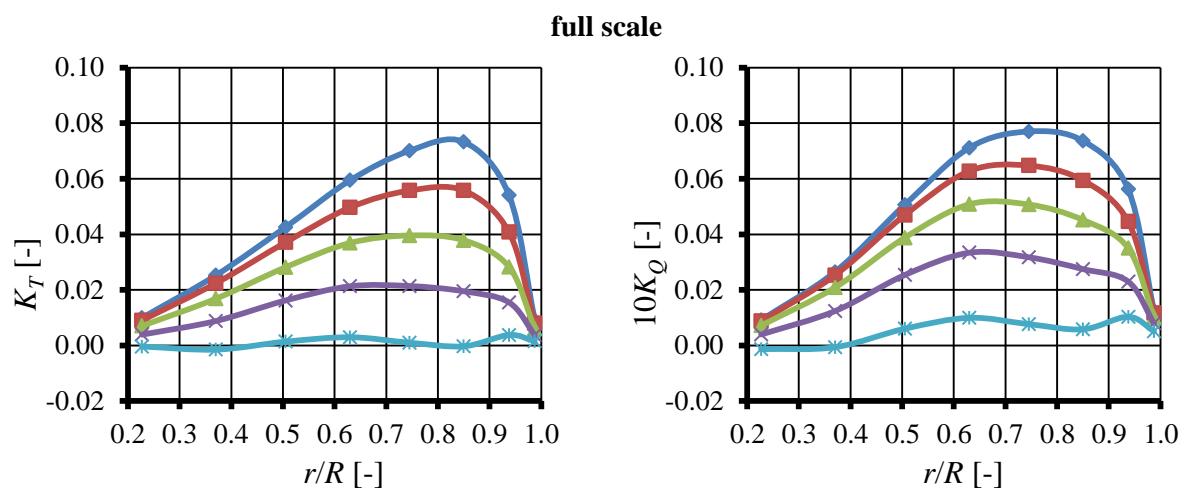
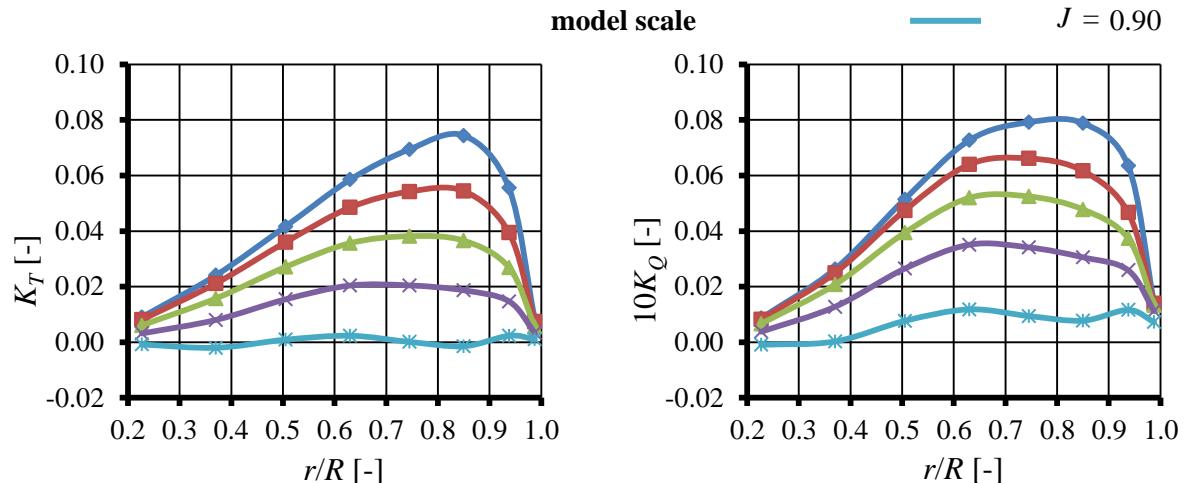
Differences full and model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.0009	0.0009	0.0010	0.0007	0.0004	0.0005	0.0005	0.0005	0.0002	-0.0004
0.370	0.0012	0.0012	0.0011	0.0008	0.0005	0.0002	0.0003	0.0001	-0.0004	-0.0009
0.505	0.0009	0.0011	0.0011	0.0008	0.0005	-0.0009	-0.0005	-0.0006	-0.0011	-0.0016
0.630	0.0009	0.0012	0.0012	0.0009	0.0006	-0.0015	-0.0012	-0.0012	-0.0017	-0.0019
0.745	0.0007	0.0015	0.0014	0.0009	0.0009	-0.0021	-0.0014	-0.0017	-0.0024	-0.0017
0.850	-0.0011	0.0013	0.0013	0.0008	0.0011	-0.0052	-0.0022	-0.0026	-0.0031	-0.0020
0.938	-0.0014	0.0014	0.0014	0.0008	0.0014	-0.0073	-0.0021	-0.0023	-0.0029	-0.0013
0.988	0.0009	0.0006	0.0005	0.0004	0.0004	-0.0018	-0.0023	-0.0031	-0.0033	-0.0021

14.4 R13 - Radial distribution diagrams



 $J = 0.10$
 $J = 0.30$
 $J = 0.50$
 $J = 0.70$
 $J = 0.90$



14.5 R13 - Questionnaire part I

	model scale	full scale
Solver		
Computational Domain		
A1 Domain topology	Multiple domains	Multiple domains
A2 Grid-coupling technique	Multiple ref. frames	Multiple ref. frames
Propeller Representation		
B1 Number of considered blades	Complete propeller	Complete propeller
Computational Grid		
C1 Type	Unstructured	Unstructured
C2 Local-grid refinement	Possible - used here	Possible - used here
C3 Primary volume elements	Hexahedral	Hexahedral
C4 Primary surface elements	Mixed	Mixed
C5 Wall-boundary layer type	Prism Layer	Prism Layer
C7 Number of cells at boundary layer	6	6
C8 Y ⁺ -value at r/R=0.4, 0.7, 0.9	0.7352377, 1.077397, 1.325	62.69834, 100.2231, 123.88
C9 Averaged Y ⁺ -value	0.9618	87.108
C10 Number of cells on blade surface	134264	115549
Norm. Dim. the Physical Domain		
D1 X_upstream/D, X_downstream/D	5.12 , 13.7	5.12 , 13.7
D2 Cross area of domain in prop. plain	101.12	101.12
Numerical Approximation		
E1 Finite Approximation Scheme (Fluid)	FV-NS	FV-NS
E2 Coordinates	Cartesian	Cartesian
E3 Convection scheme (momentum eq.)	2nd-order centered	2nd-order centered
E4 Transient approximation	-	-
E5 Spatial order of acc. (neglecting BC)	0	0
E6 Temporal order of accuracy	0	0
E7 Time step	0	0
E8 Equivalent rot. Angle for a time step	0	0
Turbulence treatment		
F1 Model name	k-epsilon	k-epsilon
F2 Convection scheme (Turb. Eqn.)	2nd-order centered	2nd-order centered
Boundary conditions		
G1 Blade	resolved	wall function
G2 Hub	resolved	wall function
G3 Inlet	Fixed Velocity	Fixed Velocity
G4 Outlet	Fixed Pressure	Fixed Pressure
G5 Outer domain	wall function	wall function

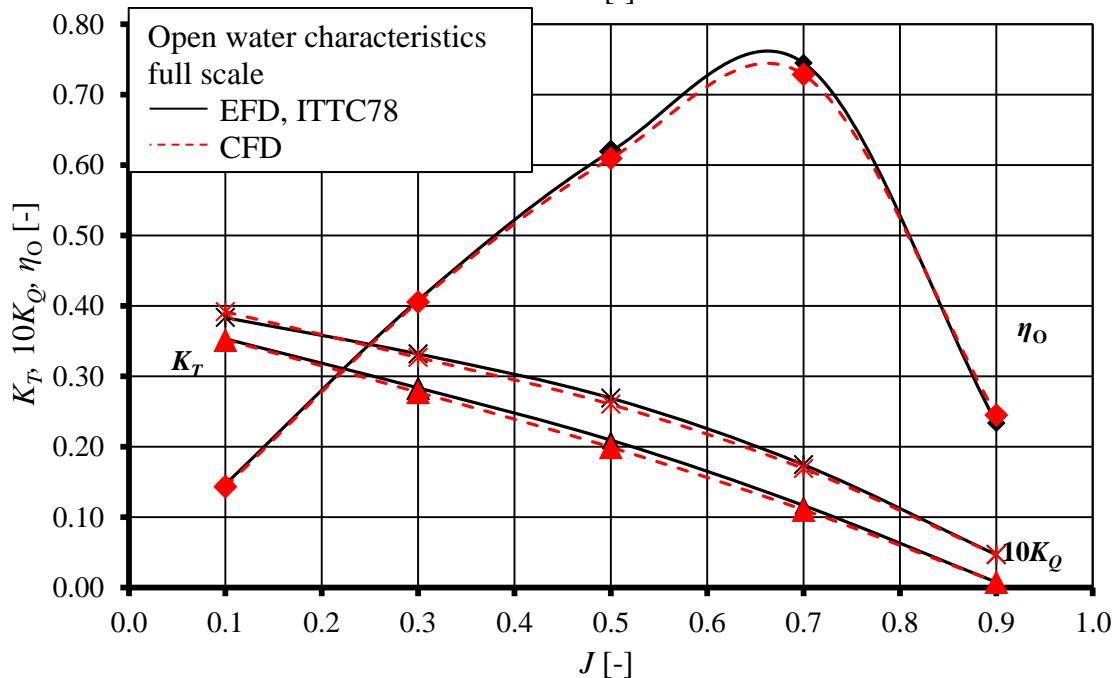
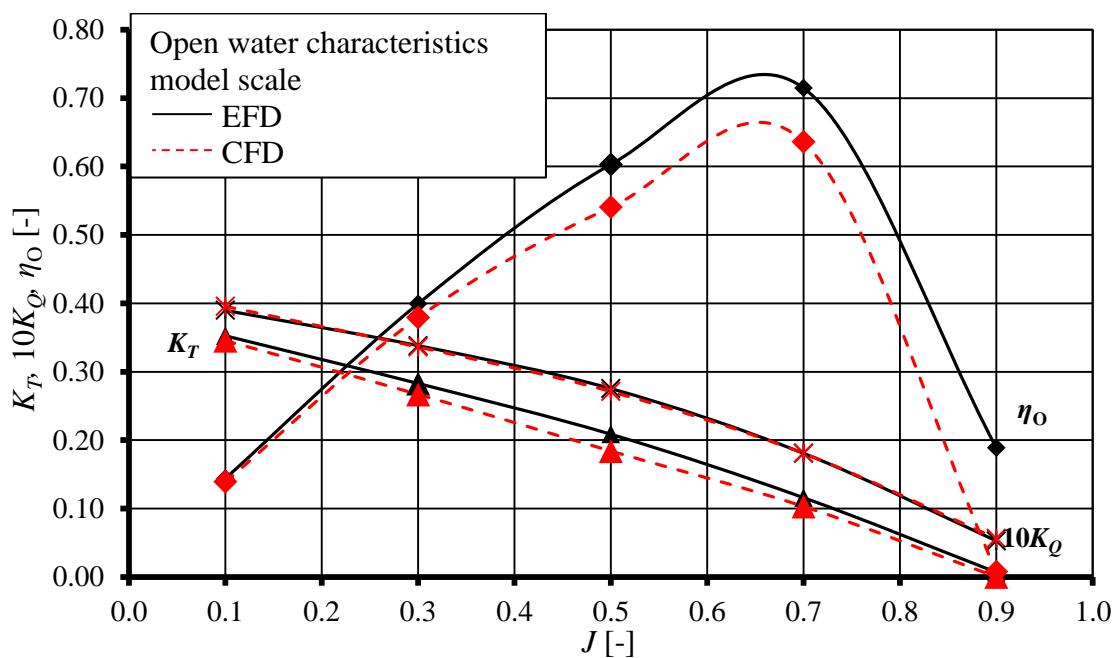
14.5 R13 - Questionnaire part II

	model scale	full scale
Computational Model		
H1 Fluid	incompressible	incompressible
H2 Pressure	pressure correction	pressure correction
Transition		
I Please comment	yes / Turbulence Suppression Model is used along with Transition boundary distance estimation to model	0 / 0
Computational Demands		
J1 Number of processors used	4	4
J2 Number of timesteps (steady)	2400	2400
J3 Number of timesteps (transient)	0	0
J4 Wall-clock time per revolution	0	0
Code		
K References	0 / 0	0 / 0
Comments		
L Add. info.	0 / 0	0 / 0

15 Result R14

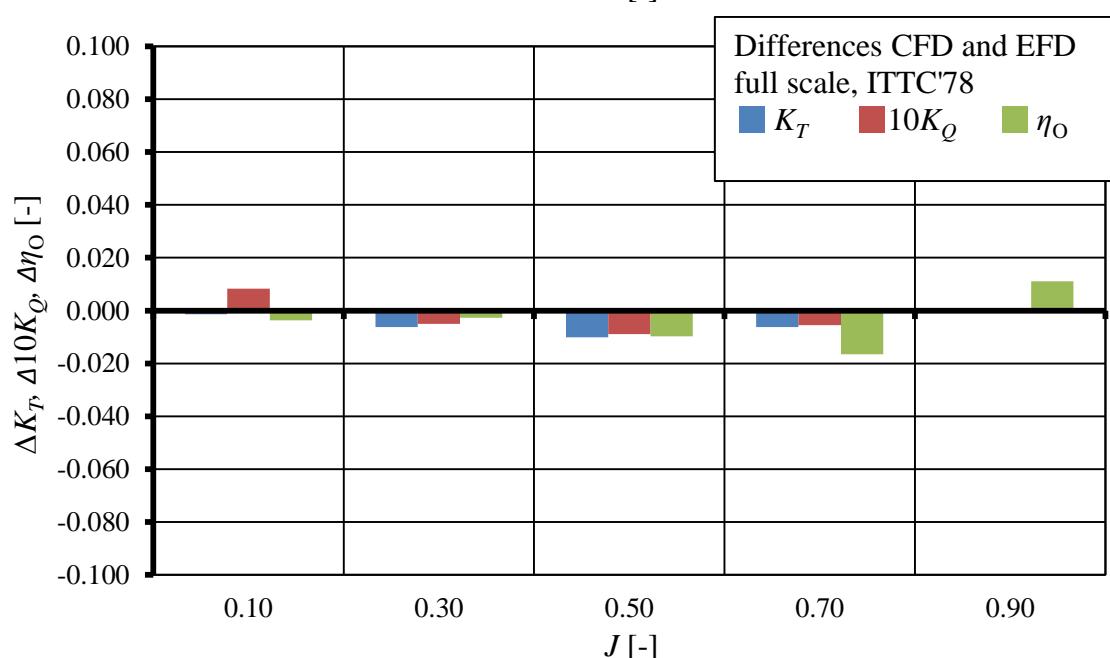
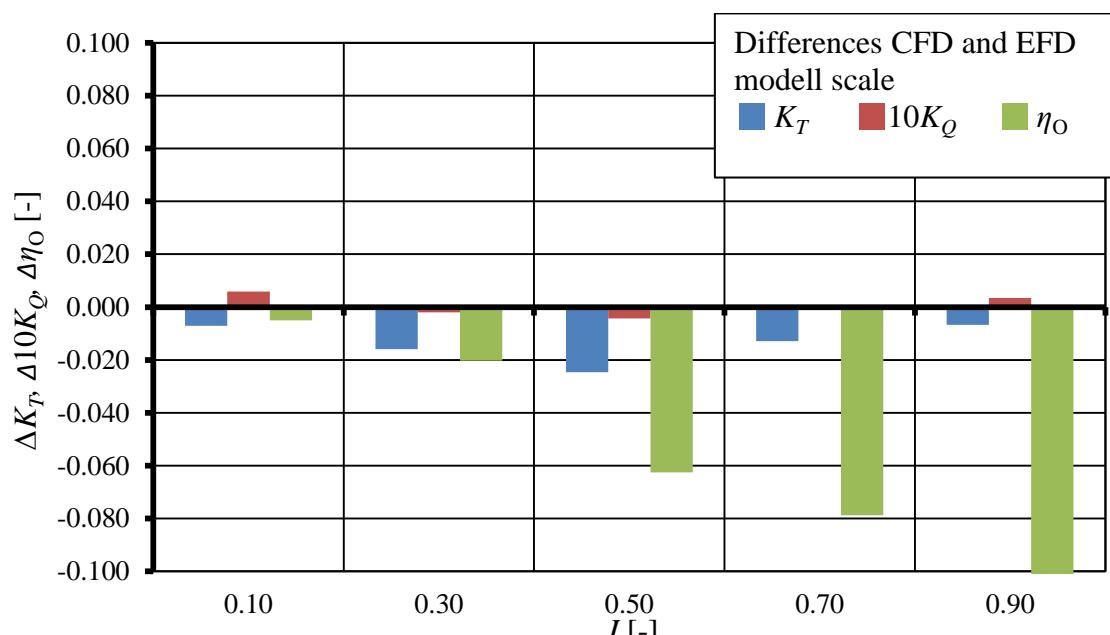
15.1 R14 - Open water characteristic

J [-]	CFD, model scale			CFD, full scale		
	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
	[-]	[-]	[-]	[-]	[-]	[-]
0.100	0.345	0.396	0.139	0.352	0.391	0.143
0.300	0.267	0.336	0.379	0.277	0.327	0.405
0.500	0.184	0.271	0.540	0.199	0.260	0.609
0.700	0.103	0.181	0.636	0.110	0.169	0.728
0.900	0.000	0.056	0.008	0.008	0.046	0.245



15.2 R14 - Differences CFD and EFD

	CFD - EFD, model scale			CFD - EFD, full scale		
	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
	[-]	[-]	[-]	[-]	[-]	[-]
0.10	-0.007	0.006	-0.005	-0.001	0.008	-0.004
0.30	-0.016	-0.002	-0.020	-0.006	-0.005	-0.003
0.50	-0.025	-0.004	-0.063	-0.010	-0.009	-0.010
0.70	-0.013	0.000	-0.079	-0.006	-0.005	-0.017
0.90	-0.007	0.004	-0.181	0.000	0.000	0.011



15.3 R14 - Radial distribution tables

model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.008	0.007	0.005	0.003	-0.002	0.008	0.007	0.006	0.003	-0.002
0.370	0.021	0.019	0.014	0.007	-0.002	0.023	0.022	0.018	0.011	0.000
0.505	0.039	0.033	0.025	0.014	0.001	0.047	0.044	0.037	0.025	0.007
0.630	0.060	0.049	0.028	0.020	0.002	0.073	0.065	0.052	0.035	0.012
0.745	0.072	0.057	0.040	0.021	0.000	0.082	0.070	0.055	0.036	0.011
0.850	0.076	0.056	0.038	0.019	-0.002	0.079	0.064	0.050	0.032	0.009
0.938	0.060	0.038	0.028	0.015	0.002	0.067	0.049	0.039	0.027	0.012
0.988	0.009	0.008	0.006	0.003	0.001	0.016	0.015	0.014	0.012	0.008

full scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.009	0.008	0.006	0.004	0.000	0.008	0.008	0.006	0.004	-0.001
0.370	0.022	0.020	0.015	0.008	-0.001	0.024	0.022	0.019	0.011	0.000
0.505	0.040	0.034	0.026	0.015	0.002	0.047	0.044	0.036	0.024	0.006
0.630	0.059	0.049	0.037	0.021	0.003	0.072	0.063	0.051	0.034	0.011
0.745	0.073	0.058	0.041	0.022	0.001	0.081	0.068	0.053	0.034	0.009
0.850	0.078	0.057	0.039	0.020	-0.001	0.079	0.062	0.047	0.029	0.006
0.938	0.062	0.042	0.029	0.016	0.003	0.067	0.047	0.036	0.024	0.010
0.988	0.009	0.008	0.006	0.004	0.002	0.013	0.012	0.011	0.009	0.006

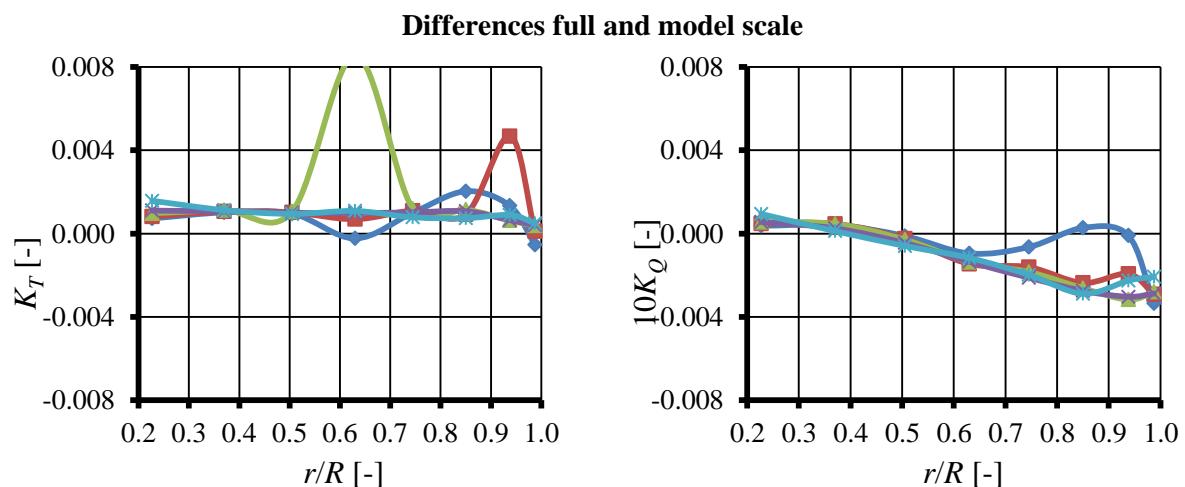
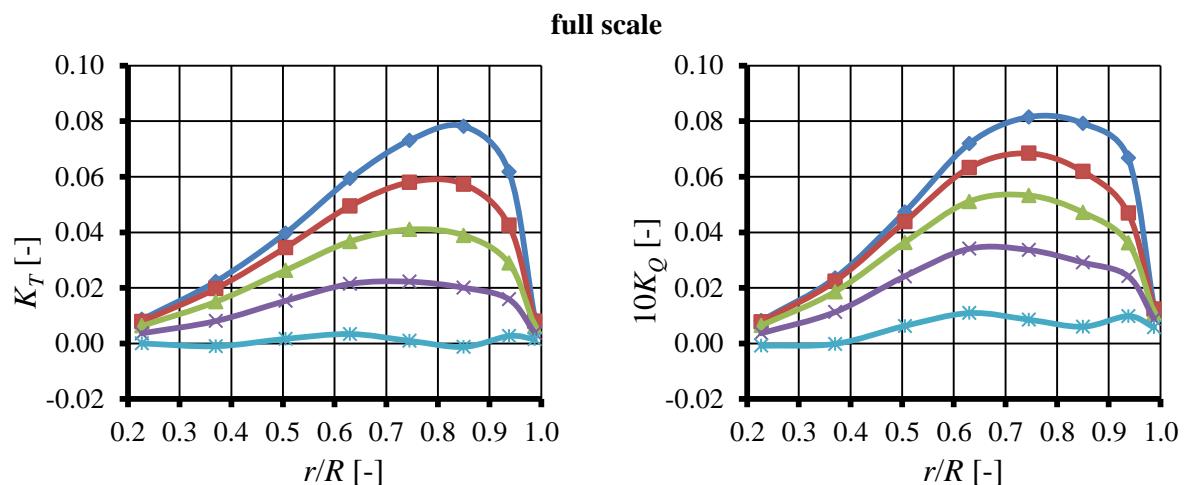
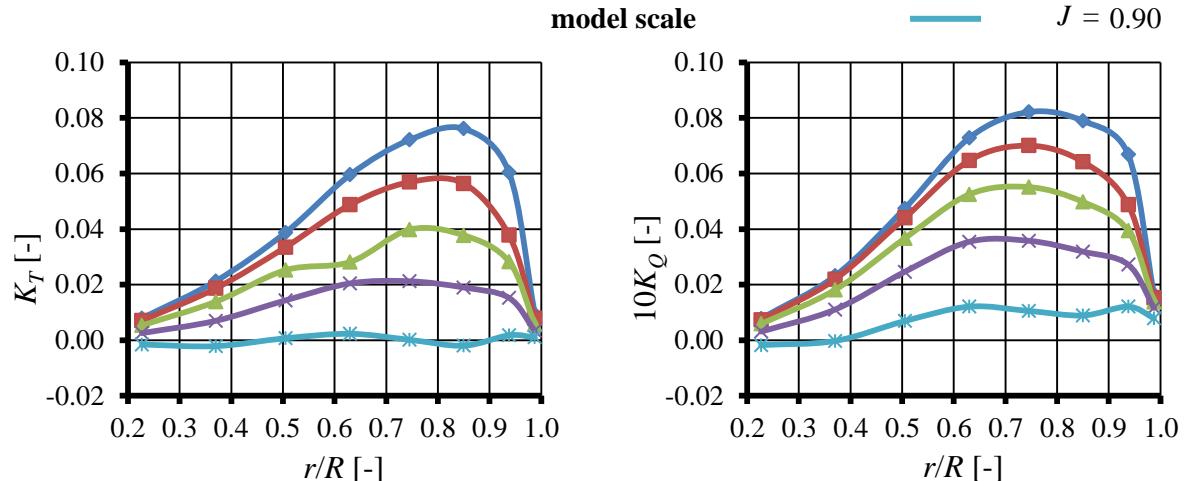
Differences full and model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.0007	0.0008	0.0010	0.0011	0.0016	0.0004	0.0005	0.0006	0.0006	0.0009
0.370	0.0010	0.0011	0.0011	0.0011	0.0011	0.0004	0.0005	0.0005	0.0002	0.0001
0.505	0.0010	0.0010	0.0011	0.0010	0.0009	-0.0001	-0.0003	-0.0003	-0.0005	-0.0006
0.630	-0.0002	0.0007	0.0086	0.0010	0.0011	-0.0010	-0.0015	-0.0014	-0.0014	-0.0012
0.745	0.0010	0.0011	0.0012	0.0010	0.0008	-0.0006	-0.0016	-0.0018	-0.0021	-0.0020
0.850	0.0020	0.0009	0.0012	0.0011	0.0007	0.0003	-0.0024	-0.0026	-0.0027	-0.0029
0.938	0.0013	0.0047	0.0006	0.0006	0.0009	-0.0001	-0.0019	-0.0032	-0.0030	-0.0023
0.988	-0.0005	0.0001	0.0004	0.0004	0.0005	-0.0033	-0.0029	-0.0028	-0.0029	-0.0021

15.4 R14 - Radial distribution diagrams



 $J = 0.10$
 $J = 0.30$
 $J = 0.50$
 $J = 0.70$
 $J = 0.90$



15.5 R14 - Questionnaire part I

	model scale	full scale
Solver	STAR-CCM+	STAR-CCM+
Computational Domain		
A1 Domain topology	-	-
A2 Grid-coupling technique	-	-
Propeller Representation		
B1 Number of considered blades	4	1
Computational Grid		
C1 Type	Polyhedral	Polyhedral
C2 Local-grid refinement	yes	yes
C3 Primary volume elements	-	-
C4 Primary surface elements	-	-
C5 Wall-boundary layer type	Prism layer	Prism layer
C7 Number of cells at boundary layer	12	12
C8 Y ⁺ -value at r/R=0.4, 0.7, 0.9	12,18,20	35,60,84
C9 Averaged Y ⁺ -value	15	55
C10 Number of cells on blade surface	~88000	~25000
Norm. Dim. the Physical Domain		
D1 X_upstream/D, X_downstream/D	5.5, 4.4	5.5, 4.4
D2 Cross area of domain in prop. plain	~5m ²	~5000m ²
Numerical Approximation		
E1 Finite Approximation Scheme (Fluid)	FV-NS	FV-NS
E2 Coordinates	cartesian	cartesian
E3 Convection scheme (momentum eq.)	second order	second order
E4 Transient approximation	implicit	implicit
E5 Spatial order of acc. (neglecting BC)	0	0
E6 Temporal order of accuracy	1-st order	1-st order
E7 Time step	4.62962E-4 s	0.002596 s
E8 Equivalent rot. Angle for a time step	3	3
Turbulence treatment		
F1 Model name	k-omega	k-omega
F2 Convection scheme (Turb. Eqn.)	second order	second order
Boundary conditions		
G1 Blade	resolved + wall func.	resolved + wall func.
G2 Hub	resolved + wall func.	resolved + wall func.
G3 Inlet	Velocity	Velocity
G4 Outlet	Pressure	Pressure
G5 Outer domain	Velocity	Velocity

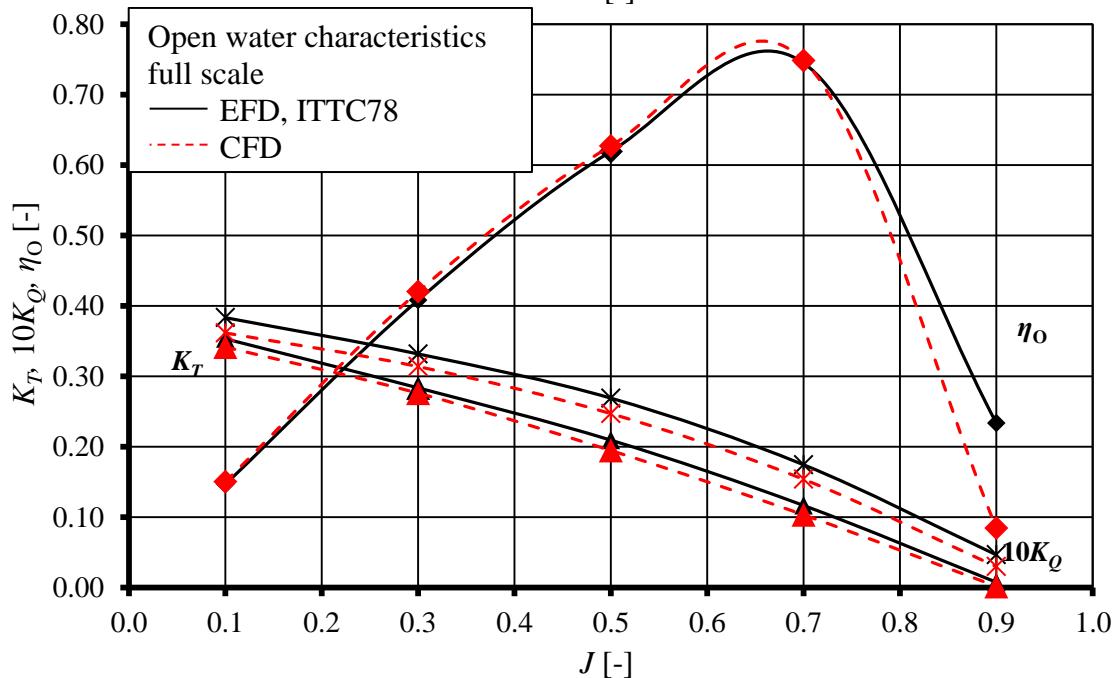
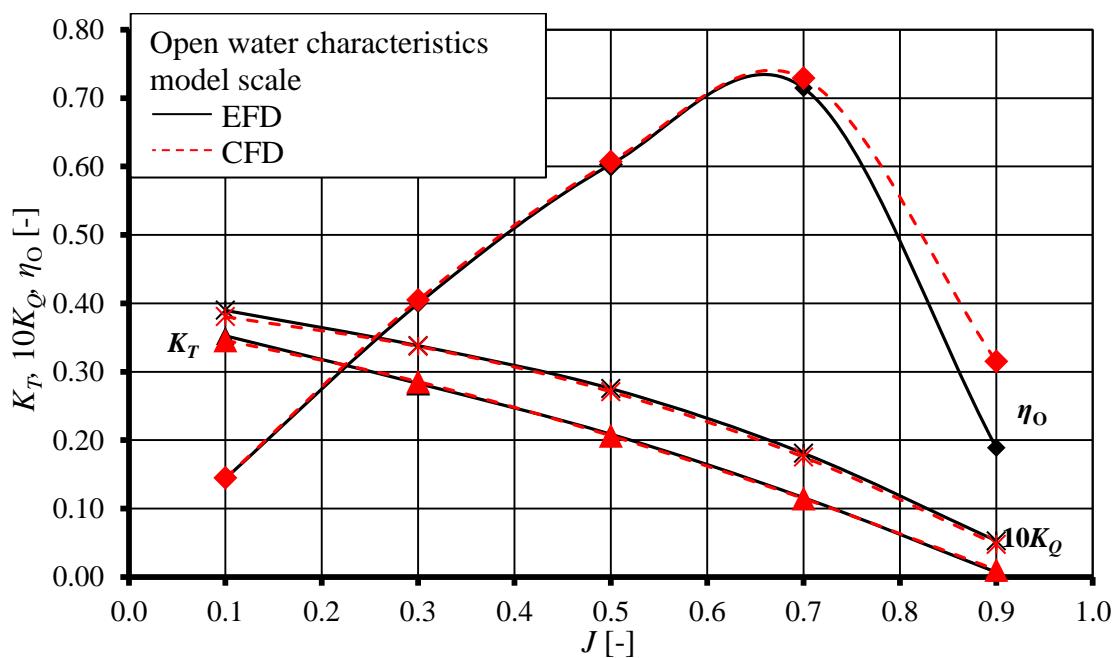
15.5 R14 - Questionnaire part II

	model scale	full scale
Computational Model		
H1 Fluid	incompressible	incompressible
H2 Pressure	segregated flow	segregated flow
Transition		
I Please comment	no	no
Computational Demands		
J1 Number of processors used	18	18
J2 Number of timesteps (steady)	0	0
J3 Number of timesteps (transient)	~34000	~25000
J4 Wall-clock time per revolution	~2500s	~1600s
Code		
K References	Star-CCM+	Star-CCM+
Comments		
L Add. info.	0 / 0	0 / 0

16 Result R15

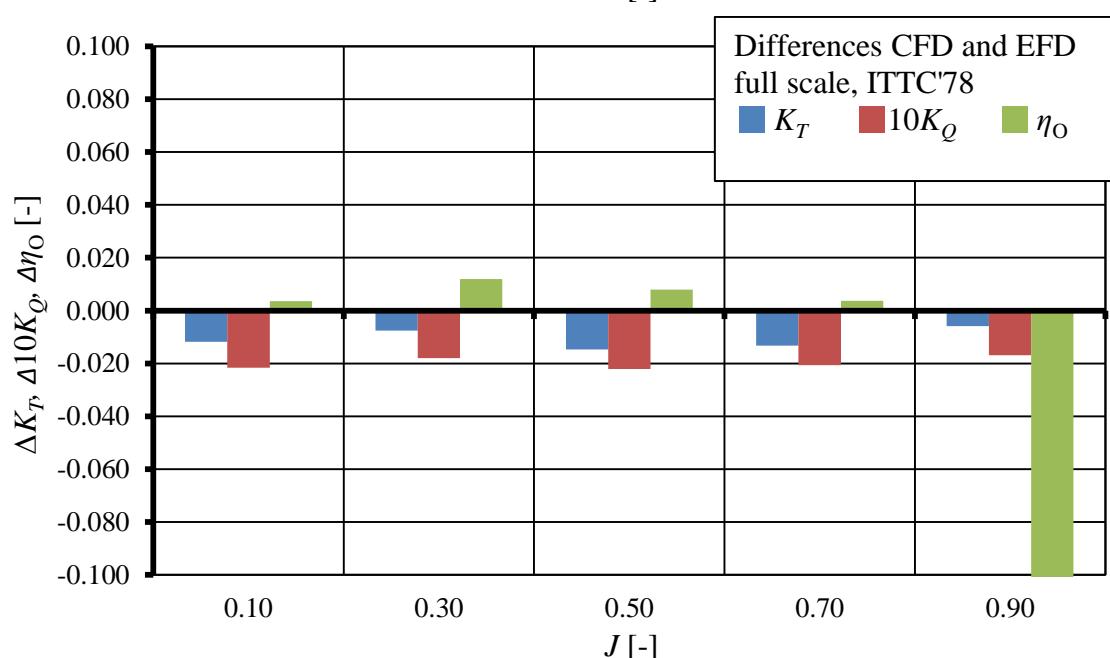
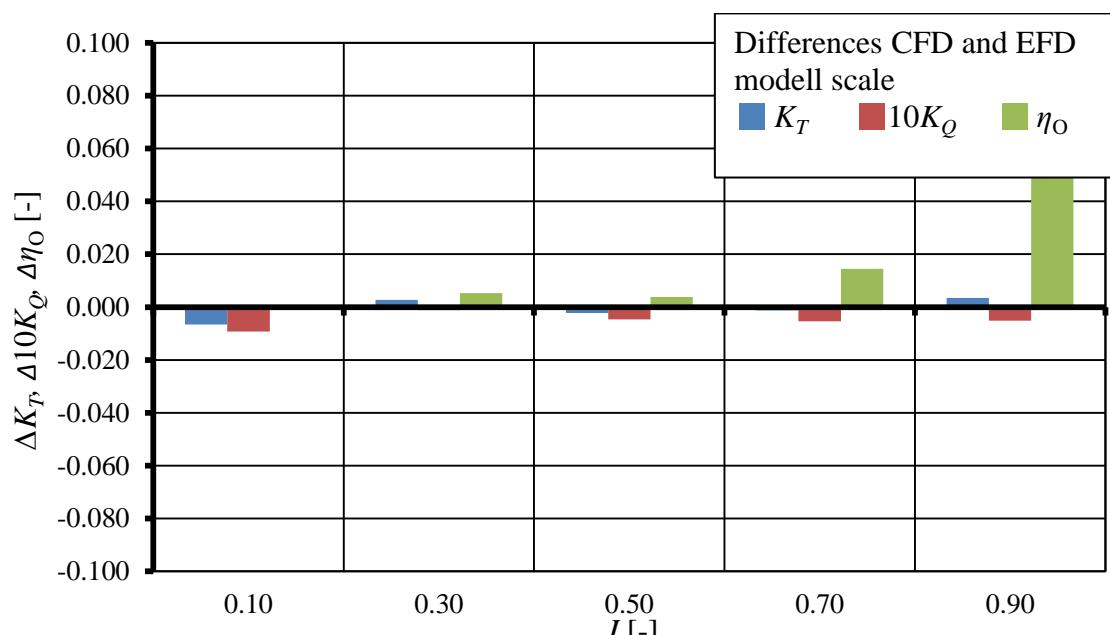
16.1 R15 - Open water characteristic

J [-]	CFD, model scale			CFD, full scale		
	K_T [-]	$10K_Q$ [-]	η_O [-]	K_T [-]	$10K_Q$ [-]	η_O [-]
0.100	0.346	0.380	0.145	0.341	0.362	0.150
0.300	0.286	0.337	0.405	0.276	0.314	0.420
0.500	0.206	0.271	0.607	0.195	0.247	0.627
0.700	0.115	0.175	0.729	0.103	0.154	0.748
0.900	0.010	0.048	0.315	0.002	0.030	0.085



16.2 R15 - Differences CFD and EFD

	CFD - EFD, model scale			CFD - EFD, full scale		
	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
	[-]	[-]	[-]	[-]	[-]	[-]
0.10	-0.007	-0.009	0.001	-0.012	-0.022	0.004
0.30	0.003	-0.001	0.005	-0.008	-0.018	0.012
0.50	-0.002	-0.005	0.004	-0.015	-0.022	0.008
0.70	-0.001	-0.005	0.014	-0.013	-0.021	0.004
0.90	0.004	-0.005	0.126	-0.006	-0.017	-0.149



16.3 R15 - Radial distribution tables

model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.010	0.009	0.007	0.004	-0.001	0.009	0.009	0.007	0.004	-0.002
0.370	0.025	0.022	0.017	0.009	-0.001	0.027	0.026	0.021	0.013	0.000
0.505	0.043	0.038	0.029	0.017	0.002	0.052	0.049	0.041	0.027	0.008
0.630	0.061	0.051	0.038	0.022	0.004	0.073	0.066	0.054	0.036	0.012
0.745	0.071	0.058	0.041	0.022	0.002	0.079	0.068	0.053	0.034	0.009
0.850	0.074	0.057	0.039	0.020	0.000	0.074	0.061	0.047	0.029	0.006
0.938	0.052	0.041	0.029	0.016	0.003	0.052	0.045	0.036	0.024	0.010
0.988	0.010	0.009	0.006	0.004	0.002	0.014	0.013	0.011	0.009	0.006

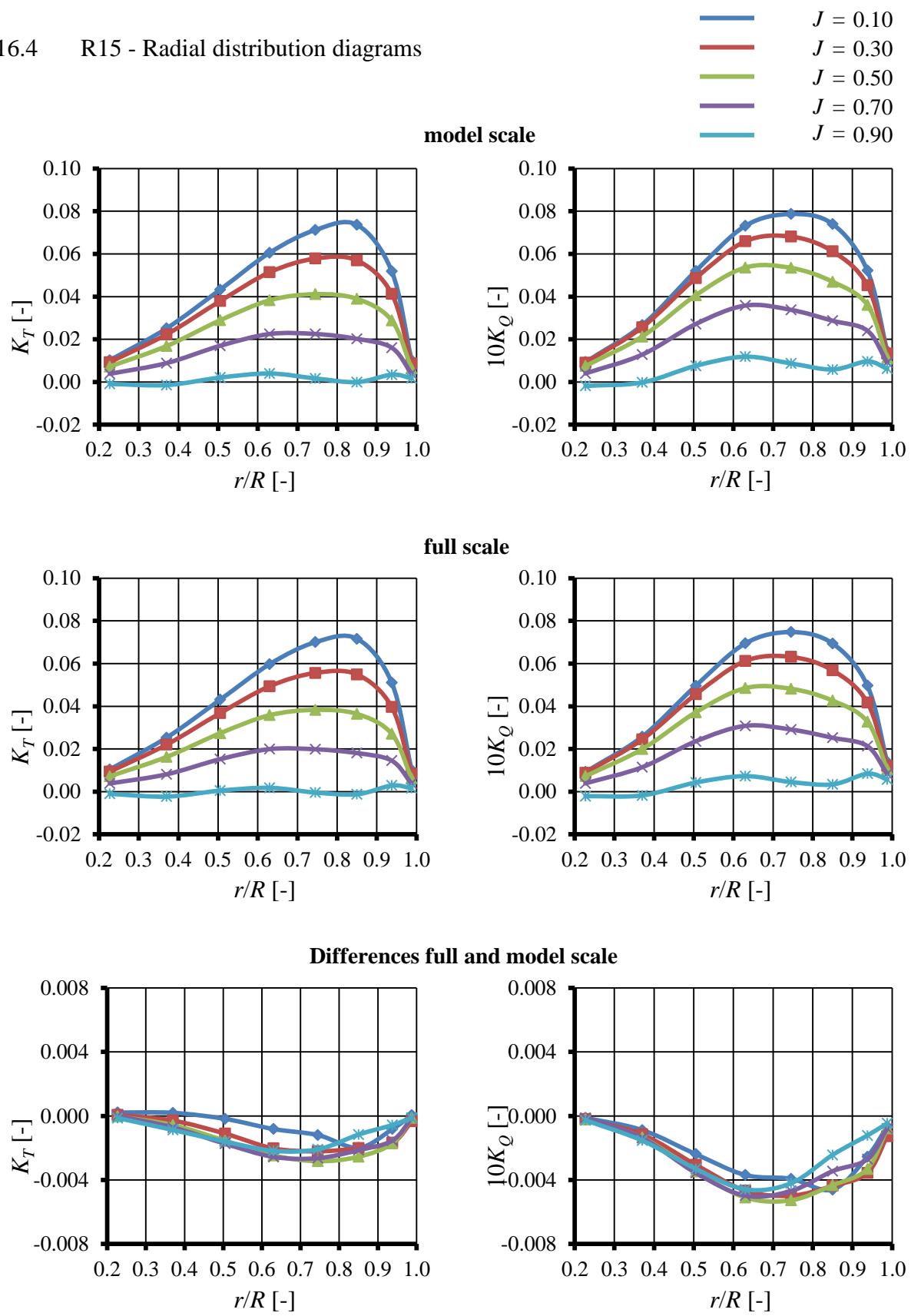
full scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.010	0.009	0.007	0.004	-0.001	0.009	0.009	0.007	0.004	-0.002
0.370	0.025	0.022	0.016	0.008	-0.002	0.026	0.024	0.020	0.011	-0.002
0.505	0.043	0.037	0.027	0.015	0.000	0.050	0.046	0.037	0.024	0.004
0.630	0.060	0.049	0.036	0.020	0.002	0.069	0.061	0.049	0.031	0.007
0.745	0.070	0.056	0.038	0.020	0.000	0.075	0.063	0.048	0.029	0.004
0.850	0.072	0.055	0.036	0.018	-0.001	0.069	0.057	0.043	0.025	0.003
0.938	0.051	0.040	0.027	0.015	0.003	0.050	0.042	0.033	0.021	0.008
0.988	0.010	0.008	0.006	0.004	0.002	0.014	0.012	0.010	0.008	0.006

Differences full and model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.0002	0.0001	0.0000	0.0000	-0.0001	-0.0001	-0.0002	-0.0002	-0.0001	-0.0003
0.370	0.0002	-0.0003	-0.0006	-0.0007	-0.0009	-0.0009	-0.0012	-0.0014	-0.0014	-0.0015
0.505	-0.0002	-0.0011	-0.0016	-0.0017	-0.0016	-0.0024	-0.0031	-0.0035	-0.0036	-0.0033
0.630	-0.0008	-0.0020	-0.0025	-0.0026	-0.0022	-0.0037	-0.0047	-0.0051	-0.0050	-0.0046
0.745	-0.0012	-0.0022	-0.0028	-0.0026	-0.0021	-0.0039	-0.0050	-0.0053	-0.0047	-0.0042
0.850	-0.0020	-0.0020	-0.0025	-0.0021	-0.0012	-0.0046	-0.0044	-0.0043	-0.0035	-0.0024
0.938	-0.0008	-0.0017	-0.0017	-0.0015	-0.0006	-0.0025	-0.0036	-0.0033	-0.0027	-0.0012
0.988	0.0000	-0.0003	-0.0001	-0.0001	-0.0001	-0.0007	-0.0013	-0.0008	-0.0008	-0.0005

16.4 R15 - Radial distribution diagrams



16.5 R15 - Questionnaire part I

	model scale	full scale
Solver	STAR-CCM+	STAR-CCM+
Computational Domain		
A1 Domain topology	Multiple domains	Multiple domains
A2 Grid-coupling technique	Multiple ref. frames	Multiple ref. frames
Propeller Representation		
B1 Number of considered blades	Complete propeller	Complete propeller
Computational Grid		
C1 Type	Unstructured	Unstructured
C2 Local-grid refinement	Possible - used here	Possible - used here
C3 Primary volume elements	Polyhedral	Polyhedral
C4 Primary surface elements	Triangles	Triangles
C5 Wall-boundary layer type	Prism Layer	Prism Layer
C7 Number of cells at boundary layer	5	5
C8 Y ⁺ -value at r/R=0.4, 0.7, 0.9	1.2, 1.7, 1.85	337, 586, 670
C9 Averaged Y ⁺ -value	1.53	497
C10 Number of cells on blade surface	3E+06	0
Norm. Dim. the Physical Domain		
D1 X_upstream/D, X_downstream/D	4.2, 27	4.2, 27
D2 Cross area of domain in prop. plain	10	10
Numerical Approximation		
E1 Finite Approximation Scheme (Fluid)	FV-NS	FV-NS
E2 Coordinates	Cartesian	Cartesian
E3 Convection scheme (momentum eq.)	high-order upwind	high-order upwind
E4 Transient approximation	-	-
E5 Spatial order of acc. (neglecting BC)	0	0
E6 Temporal order of accuracy	0	0
E7 Time step	0	0
E8 Equivalent rot. Angle for a time step	0	0
Turbulence treatment		
F1 Model name	k-omega	RS-transport
F2 Convection scheme (Turb. Eqn.)	high-order upwind	high-order upwind
Boundary conditions		
G1 Blade	resolved	resolved
G2 Hub	resolved	resolved
G3 Inlet	Fixed Velocity	Fixed Velocity
G4 Outlet	Fixed Pressure	Fixed Pressure
G5 Outer domain	Slip flow	Slip flow

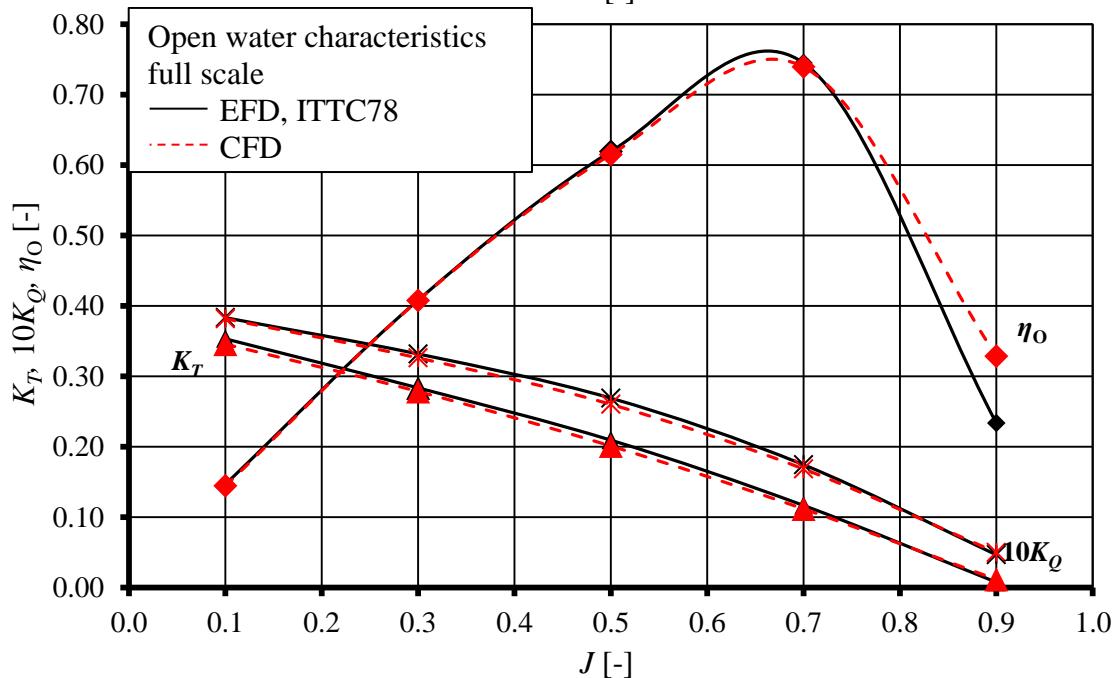
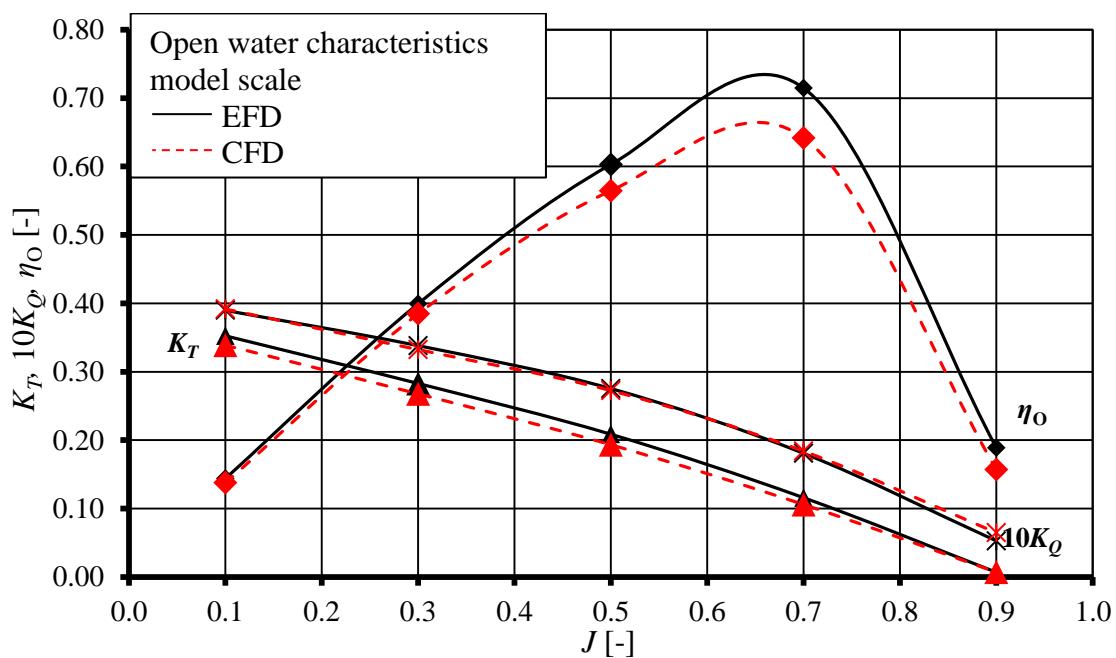
16.5 R15 - Questionnaire part II

	model scale	full scale
Computational Model		
H1 Fluid	incompressible	incompressible
H2 Pressure	pressure correction	pressure correction
Transition		
I Please comment	yes / Gamma_Re Threlat Model in K-W SST model	0 / 0
Computational Demands		
J1 Number of processors used	64	64
J2 Number of timesteps (steady)	2000	2000
J3 Number of timesteps (transient)	0	0
J4 Wall-clock time per revolution	0	0
Code		
K References	STAR CCM+ V.9.06	STAR CCM+ V.9.06
Comments		
L Add. info.	0 / 0	0 / 0

17 Result R16

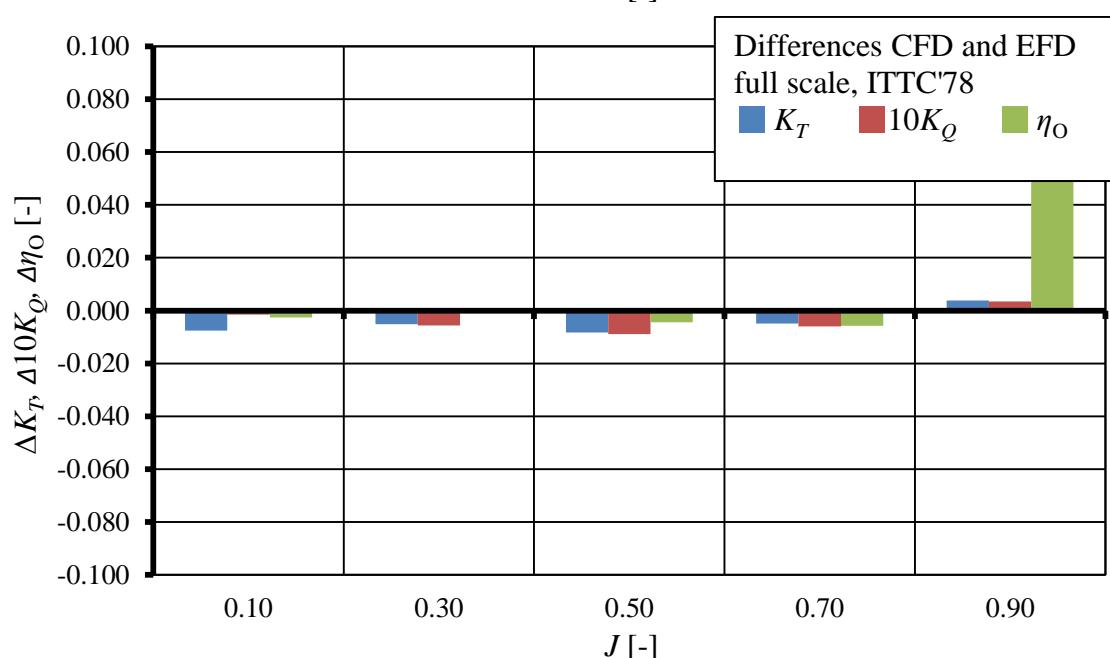
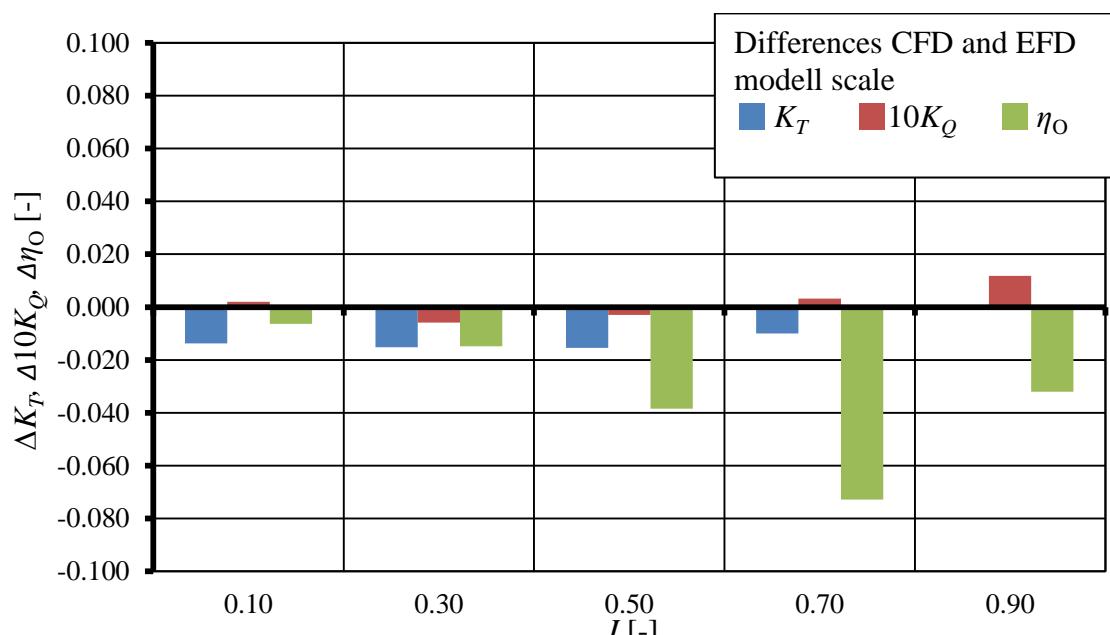
17.1 R16 - Open water characteristic

J [-]	CFD, model scale			CFD, full scale		
	K_T [-]	$10K_Q$ [-]	η_O [-]	K_T [-]	$10K_Q$ [-]	η_O [-]
	0.100	0.339	0.392	0.138	0.346	0.382
0.300	0.268	0.332	0.385	0.278	0.326	0.408
0.500	0.193	0.272	0.565	0.201	0.260	0.615
0.700	0.106	0.184	0.642	0.112	0.168	0.739
0.900	0.007	0.065	0.157	0.011	0.050	0.329



17.2 R16 - Differences CFD and EFD

CFD - EFD, model scale			CFD - EFD, full scale		
K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]
0.10	-0.014	0.002	-0.006	-0.008	-0.002
0.30	-0.015	-0.006	-0.015	-0.005	-0.006
0.50	-0.015	-0.003	-0.038	-0.008	-0.009
0.70	-0.010	0.003	-0.073	-0.005	-0.006
0.90	0.000	0.012	-0.032	0.004	0.003



17.3 R16 - Radial distribution tables

model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.009	0.008	0.006	0.003	0.000	0.009	0.008	0.007	0.004	0.000
0.370	0.024	0.021	0.016	0.008	-0.001	0.026	0.025	0.021	0.013	0.001
0.505	0.041	0.036	0.027	0.015	0.001	0.051	0.047	0.039	0.026	0.008
0.630	0.058	0.048	0.035	0.020	0.003	0.072	0.064	0.052	0.035	0.013
0.745	0.069	0.054	0.038	0.021	0.001	0.078	0.066	0.053	0.035	0.011
0.850	0.071	0.054	0.037	0.019	0.000	0.074	0.062	0.049	0.032	0.010
0.938	0.058	0.039	0.028	0.015	0.003	0.066	0.045	0.039	0.027	0.013
0.988	0.009	0.008	0.006	0.004	0.001	0.015	0.015	0.014	0.012	0.008

full scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.010	0.009	0.007	0.004	0.000	0.009	0.009	0.007	0.004	-0.001
0.370	0.025	0.022	0.017	0.009	-0.001	0.026	0.025	0.021	0.013	0.000
0.505	0.042	0.037	0.028	0.016	0.002	0.050	0.047	0.039	0.026	0.007
0.630	0.059	0.050	0.037	0.021	0.003	0.072	0.063	0.051	0.033	0.011
0.745	0.070	0.056	0.040	0.022	0.001	0.078	0.065	0.051	0.032	0.009
0.850	0.073	0.055	0.038	0.020	0.000	0.074	0.059	0.046	0.028	0.007
0.938	0.056	0.042	0.029	0.016	0.004	0.060	0.046	0.036	0.024	0.011
0.988	0.009	0.008	0.006	0.004	0.002	0.013	0.012	0.011	0.008	0.006

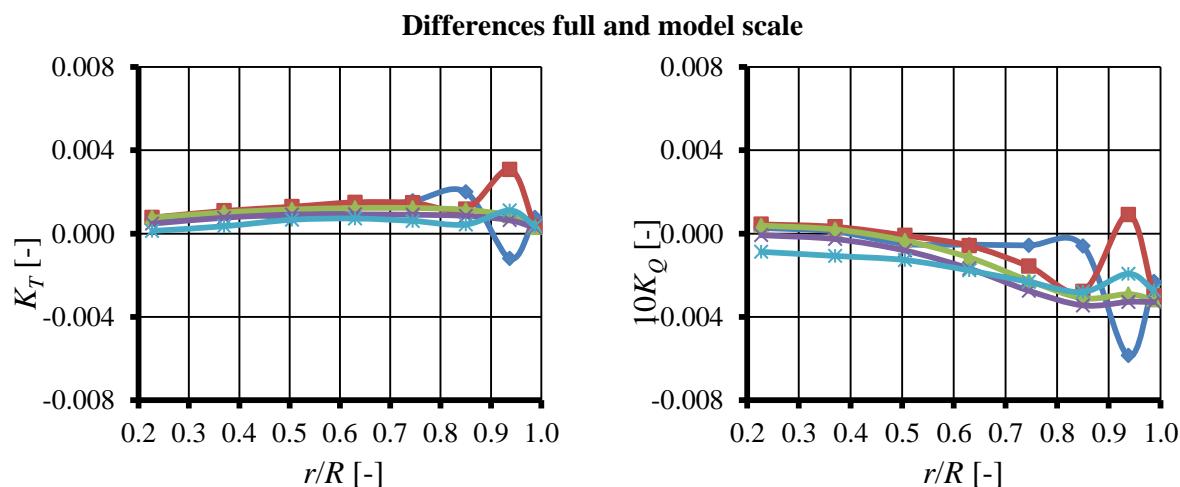
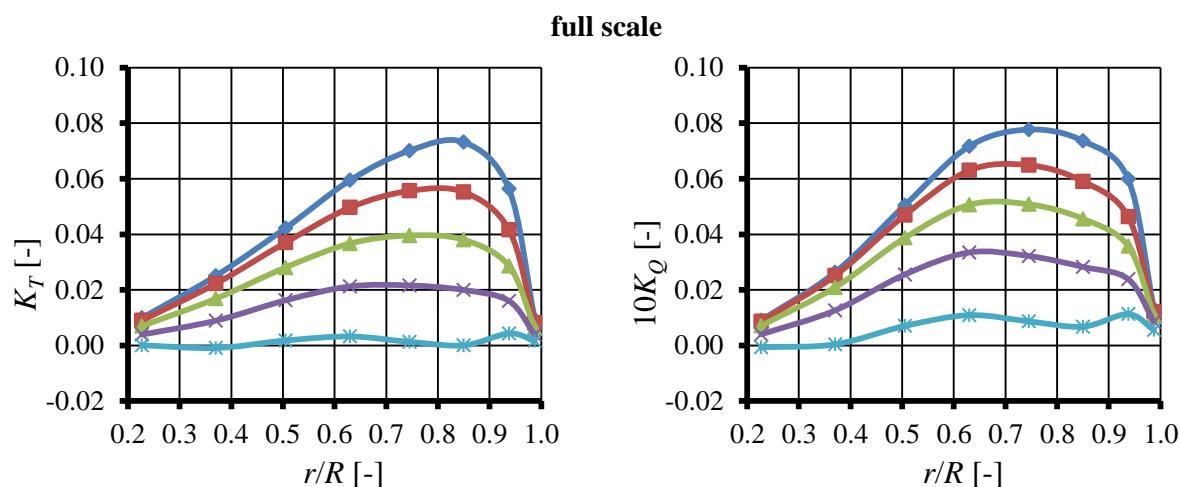
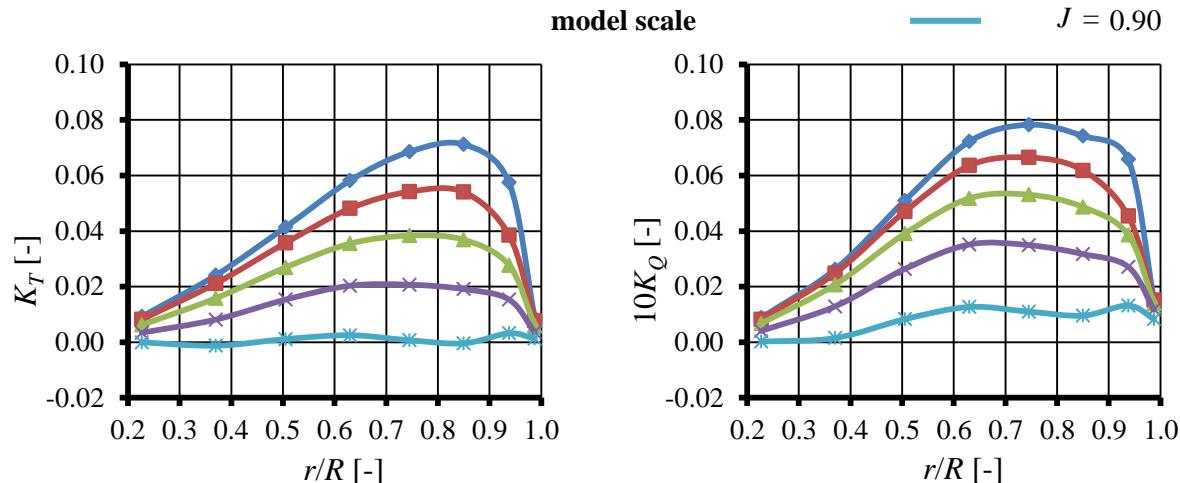
Differences full and model scale

J [-]	K_T [-]					$10K_Q$ [-]				
	0.10	0.30	0.50	0.70	0.90	0.10	0.30	0.50	0.70	0.90
r/R [-]										
0.227	0.0007	0.0008	0.0008	0.0005	0.0001	0.0003	0.0004	0.0004	-0.0001	-0.0009
0.370	0.0010	0.0011	0.0010	0.0008	0.0004	0.0001	0.0003	0.0002	-0.0003	-0.0011
0.505	0.0008	0.0013	0.0012	0.0009	0.0007	-0.0005	-0.0001	-0.0003	-0.0008	-0.0013
0.630	0.0013	0.0015	0.0012	0.0009	0.0007	-0.0005	-0.0006	-0.0011	-0.0017	-0.0018
0.745	0.0016	0.0015	0.0012	0.0009	0.0006	-0.0006	-0.0016	-0.0023	-0.0027	-0.0023
0.850	0.0020	0.0012	0.0011	0.0008	0.0004	-0.0006	-0.0028	-0.0031	-0.0034	-0.0028
0.938	-0.0012	0.0031	0.0009	0.0006	0.0011	-0.0059	0.0009	-0.0029	-0.0033	-0.0019
0.988	0.0008	0.0003	0.0003	0.0003	0.0004	-0.0023	-0.0030	-0.0032	-0.0033	-0.0027

17.4 R16 - Radial distribution diagrams



 $J = 0.10$
 $J = 0.30$
 $J = 0.50$
 $J = 0.70$
 $J = 0.90$



17.5 R16 - Questionnaire part I

	model scale	full scale
Solver	STAR-CCM+	STAR-CCM+
Computational Domain		
A1 Domain topology	1 rotating domain	1 rotating domain
A2 Grid-coupling technique	Multiple ref. frames	Multiple ref. frames
Propeller Representation		
B1 Number of considered blades	Complete propeller	Complete propeller
Computational Grid		
C1 Type	Unstructured	Unstructured
C2 Local-grid refinement	Possible - used here	Possible - used here
C3 Primary volume elements	Hexahedral	Hexahedral
C4 Primary surface elements	Mixed	Mixed
C5 Wall-boundary layer type	Prism Layer	Prism Layer
C7 Number of cells at boundary layer	4	18
C8 Y ⁺ -value at r/R=0.4, 0.7, 0.9	41, 60, 81	53, 83, 118
C9 Averaged Y ⁺ -value	60	84
C10 Number of cells on blade surface	80248 (total)	82344 (total)
Norm. Dim. the Physical Domain		
D1 X_upstream/D, X_downstream/D	5D, 13D	5D, 13D
D2 Cross area of domain in prop. plain	100	100
Numerical Approximation		
E1 Finite Approximation Scheme (Fluid)	FV-NS	FV-NS
E2 Coordinates	Cartesian	Cartesian
E3 Convection scheme (momentum eq.)	2nd-order centered	2nd-order centered
E4 Transient approximation	implicit	implicit
E5 Spatial order of acc. (neglecting BC)	2nd order	2nd order
E6 Temporal order of accuracy	nothing (steady)	nothing (steady)
E7 Time step	nothing (steady)	nothing (steady)
E8 Equivalent rot. Angle for a time step	nothing (steady)	nothing (steady)
Turbulence treatment		
F1 Model name	k-omega	k-omega
F2 Convection scheme (Turb. Eqn.)	2nd-order centered	2nd-order centered
Boundary conditions		
G1 Blade	wall function	wall function
G2 Hub	wall function	wall function
G3 Inlet	Fixed Velocity	Fixed Velocity
G4 Outlet	Fixed Pressure	Fixed Pressure
G5 Outer domain	Slip flow	Slip flow

17.5 R16 - Questionnaire part II

	model scale	full scale
Computational Model		
H1 Fluid	incompressible	incompressible
H2 Pressure	Equation of state	Equation of state
Transition		
I Please comment	NO	NO
Computational Demands		
J1 Number of processors used	48	48
J2 Number of timesteps (steady)	3750	3750
J3 Number of timesteps (transient)	0	0
J4 Wall-clock time per revolution	0	0
Code		
K References	STAR-CCM+ 10.06.009	STAR-CCM+ 10.06.009
Comments		
L Add. info.	0 / 0	0 / 0

18 Remarks

Altogether thirteen different groups participated at the ITTC benchmark for the unconventional propeller. Also thirteen questionnaires could be evaluated.

Computational approach:

- Five participants used STAR-CCM+, three ANSYS FLUENT and one ANSYS CFX as solver. Four participants did not mention which solver was used for the benchmark calculations.
- All participants used unstructured numerical meshes. Meshes based on tetrahedral and hexahedral elements were used five times each, while polyhedral cells were employed in three cases.
- Eight participants simulated the whole propeller; while four participants calculated one blade passage. In one case the entire propeller was calculated in full-scale, while in model scale a single blade passage was calculated.
- Large differences can be found regarding the ratio between the cross sectional area of the computational domain in the propeller plane to the propeller disc area, ranging from approximately two to fivehundredfiftynine.
- For model scale all participants used a 2-equation turbulence model. In full-scale also a Reynolds-Stress model was employed. Most participants used the k- ω turbulence model, while the k- ϵ model was used only by two participants.
- In model scale eight of the participants calculated with and the other five without transition model. The calculations taking laminar-turbulent transition into account appear to have a better agreement with the corresponding measurements.
- In eight model scale calculations the boundary flow was resolved down to the wall, with the mean dimensionless wall distances on the propeller blades being smaller than $y^+ < 4$. In the other calculations wall-functions were employed.
- In full-scale the boundary layer flow was resolved down to the wall in case of two simulations, while the other computations were conducted with wall-functions.

Open water characteristics:

- In model scale the thrust and torque coefficients were computed in general lower than the corresponding measurements. Also the open water efficiency is predicted to low.
- The agreement between the computed full-scale thrust coefficients with the extrapolated values according to the ITTC78 method is quite good. However the discrepancies between the computations and measurements are larger for the torque coefficient. The best agreement is obtained for both thrust and torque coefficients in full-scale for higher advance coefficients.
- The computed open water efficiency in full-scale agrees well to the extrapolated values. Behind the efficiency maximum the differences get larger, with the calculated efficiency being higher than the corresponding extrapolated values.
- In general the computed full-scale results agree better with the extrapolated data, than the model scale values with the measurements.
- In general the calculated highest thrust is generated on the radial section between $0.8 < r/R < 0.9$. Except for one result were the thrust distribution resembles more the pitch distribution of the propeller.
- In many CFD computations a distinct Reynolds-number effect can also be found for the propeller thrust, while according to the ITTC78 extrapolation method the influence on the thrust coefficient is rather small.
- In the computations the Reynolds-number effect seems to be also a function of the advance coefficient.

On basis of the collected data the Reynolds-number effects can be evaluated and analyzed in more detail, also with respect to the radial thrust and torque distribution on the propeller blade.

20 References

- [1] Barkmann, U.
Potsdam Propeller Test Case (PPTC) –
Open Water Tests with the Model Propeller VP1304
Report 3752, Schiffbau-Versuchsanstalt Potsdam, April 2011
- [2] Klose, R.
Kavitationsbeobachtungen und Druckschwankungsmessungen mit konventionellen
Propellern und Tip Rake Propellern im Vergleich
Report 4482, Schiffbau-Versuchsanstalt Potsdam, 2016 (unpublished)
- [3] ITTC – Recommended Procedures and Guidelines 7.5-02-03-02.1
Open Water Test, 2008
- [4] ITTC – Recommended Procedures and Guidelines 7.5-02-03-01.5
1978 ITTC Performance Prediction Method, 2014
- [5] Grabert, R., et al.
ITTC Propeller Benchmark - PPTC Propeller - VP1304
Report 4488, Schiffbau-Versuchsanstalt Potsdam, 2017

21 Formulas

Generell:

Thrust coefficient:

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

Torque coefficient:

$$10K_Q = \frac{Q}{\rho \cdot n^2 D^5}$$

Open water efficiency:

$$\eta_O = \frac{J}{2 \cdot \pi} \cdot \frac{10 \cdot K_T}{10K_Q}$$

Overview:

Average over J CFD - EFD:

$$* \Delta K_T = \frac{1}{5} \cdot \sum_{i=1}^5 K_{T_{CFD}}(J_i) - \frac{1}{5} \cdot \sum_{i=1}^5 K_{T_{EFD}}(J_i)$$

$$** \frac{\Delta K_T}{K_{T_{EFD}}} = \left(\frac{1}{5} \cdot \sum_{i=1}^5 K_{T_{CFD}}(J_i) - \frac{1}{5} \cdot \sum_{i=1}^5 K_{T_{EFD}}(J_i) \right) \Bigg/ \frac{1}{5} \cdot \sum_{i=1}^5 K_{T_{EFD}}(J_i)$$

$$* \Delta 10K_Q = \frac{1}{5} \cdot \sum_{i=1}^5 10K_{Q_{CFD}}(J_i) - \frac{1}{5} \cdot \sum_{i=1}^5 10K_{Q_{EFD}}(J_i)$$

$$** \frac{\Delta 10K_Q}{10K_{Q_{EFD}}} = \left(\frac{1}{5} \cdot \sum_{i=1}^5 10K_{Q_{CFD}}(J_i) - \frac{1}{5} \cdot \sum_{i=1}^5 10K_{Q_{EFD}}(J_i) \right) \Bigg/ \frac{1}{5} \cdot \sum_{i=1}^5 10K_{Q_{EFD}}(J_i)$$

$$* \Delta \eta_O = \frac{1}{5} \cdot \sum_{i=1}^5 \eta_{O_{CFD}}(J_i) - \frac{1}{5} \cdot \sum_{i=1}^5 \eta_{O_{EFD}}(J_i)$$

$$** \frac{\Delta \eta_O}{\eta_{O_{EFD}}} = \left(\frac{1}{5} \cdot \sum_{i=1}^5 \eta_{O_{CFD}}(J_i) - \frac{1}{5} \cdot \sum_{i=1}^5 \eta_{O_{EFD}}(J_i) \right) \Bigg/ \frac{1}{5} \cdot \sum_{i=1}^5 \eta_{O_{EFD}}(J_i)$$

Result pages:

Differences result pages RXX.2:

$$\Delta K_T = K_{T_{CFD}} - K_{T_{EFD}}$$

$$\Delta 10K_Q = 10K_{Q_{CFD}} - 10K_{Q_{EFD}}$$

$$\Delta \eta_O = \eta_{O_{CFD}} - \eta_{O_{EFD}}$$

Differences result pages RXX.3:

$$\Delta K_T = K_{T_{full scale}} - K_{T_{model scale}}$$

$$\Delta 10K_Q = 10K_{Q_{full scale}} - 10K_{Q_{model scale}}$$

Statistic box plot:

