ITTC Propeller Benchmark

PPTC Propeller - VP1304

Report 4488

Potsdam, April 2016

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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 Paticipants

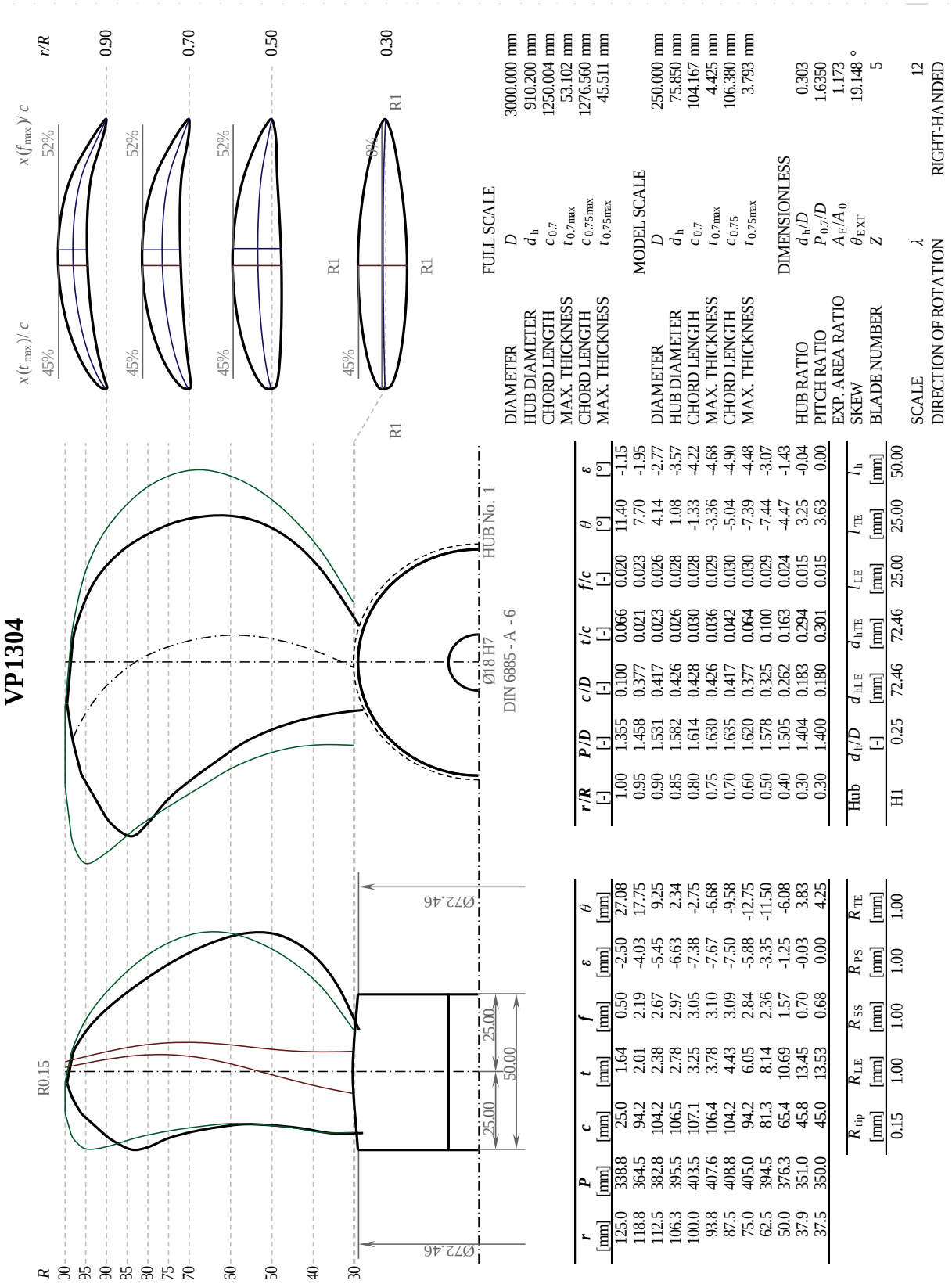
Institute	**PPTC VP1304**	**TRP P1727**
China Ship Scientific Research Center	X	X
Dalian University of Technology	X	X
Hamburgische Schiffbau-Versuchsanstalt	X	X
Hyundai Maritime Research Institute	X	X
Indian Institute of Technology Madras		X
Istanbul Technical University	X	X
Japan Marine United Corporation	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 VP1304		TRP P1727	
Scale ratio	l	[-]	12	1	31.428	1
Propeller diameter	D	[mm]	250	3000	238.6	7500
Pitch at r/R = 0.70	$P_{0.7}$	[mm]	408.8	4905	200.6	6305
Pitch at r/R = 0.75	$P_{0.75}$	[mm]	407.4	4889	191	6003
Mean pitch	P_{mean}	[mm]	391.9	4703	195.5	6143
Chord length at r/R = 0.70	$C_{0.7}$	[mm]	104.2	1250	56.4	1772
Chord length at r/R = 0.75	$C_{0.75}$	[mm]	106.3	1276	55.6	1748
Thickness at r/R = 0.75	$t_{0.75}$	[mm]	3.8	46	2.9	92
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}	[°]		18.8		25.7
Rake at r/R = 0.70	$\varepsilon_{0.7}$	[°]				-9
Rake at r/R = 0.75	$\varepsilon_{0.75}$	[°]				-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 PPTC Propeller VP1304			model scale	full scale
ratio	λ		12.00	1.00
Water density	ρ	[kg/m^3]	999.00	1025.87
Kinematic viscosity of	ν	[m²/s]	1.139E-06	1.188E-06
Rate of revolutions	n	[1/s]	15.00	4.33

1.4 PPTC - VP1304



	FULL SCALE	
DIAMETER	D	3000.000 mm
HUB DIAMETER	d_h	910.200 mm
CHORD LENGTH	$c_{0.7}$	1250.004 mm
MAX. THICKNESS	$t_{0.7max}$	53.102 mm
CHORD LENGTH	$c_{0.75max}$	1276.560 mm
MAX. THICKNESS	$t_{0.75max}$	45.511 mm
	MODEL SCALE	
DIAMETER	D	250.000 mm
HUB DIAMETER	d_h	75.850 mm
CHORD LENGTH	$c_{0.7}$	104.167 mm
MAX. THICKNESS	$t_{0.7max}$	4.425 mm
CHORD LENGTH	$c_{0.75}$	106.380 mm
MAX. THICKNESS	$t_{0.75max}$	3.793 mm
	DIMENSIONLESS	
HUB RATIO	d_h/D	0.303
PITCH RATIO	$P_{0.7}/D$	1.6350
EXP. AREA RATIO	A_E/A_0	1.173
SKEW	θ_{EXT}	19.148 °
BLADE NUMBER	Z	5
SCALE	λ	12
DIRECTION OF ROTATION		RIGHT-HANDED

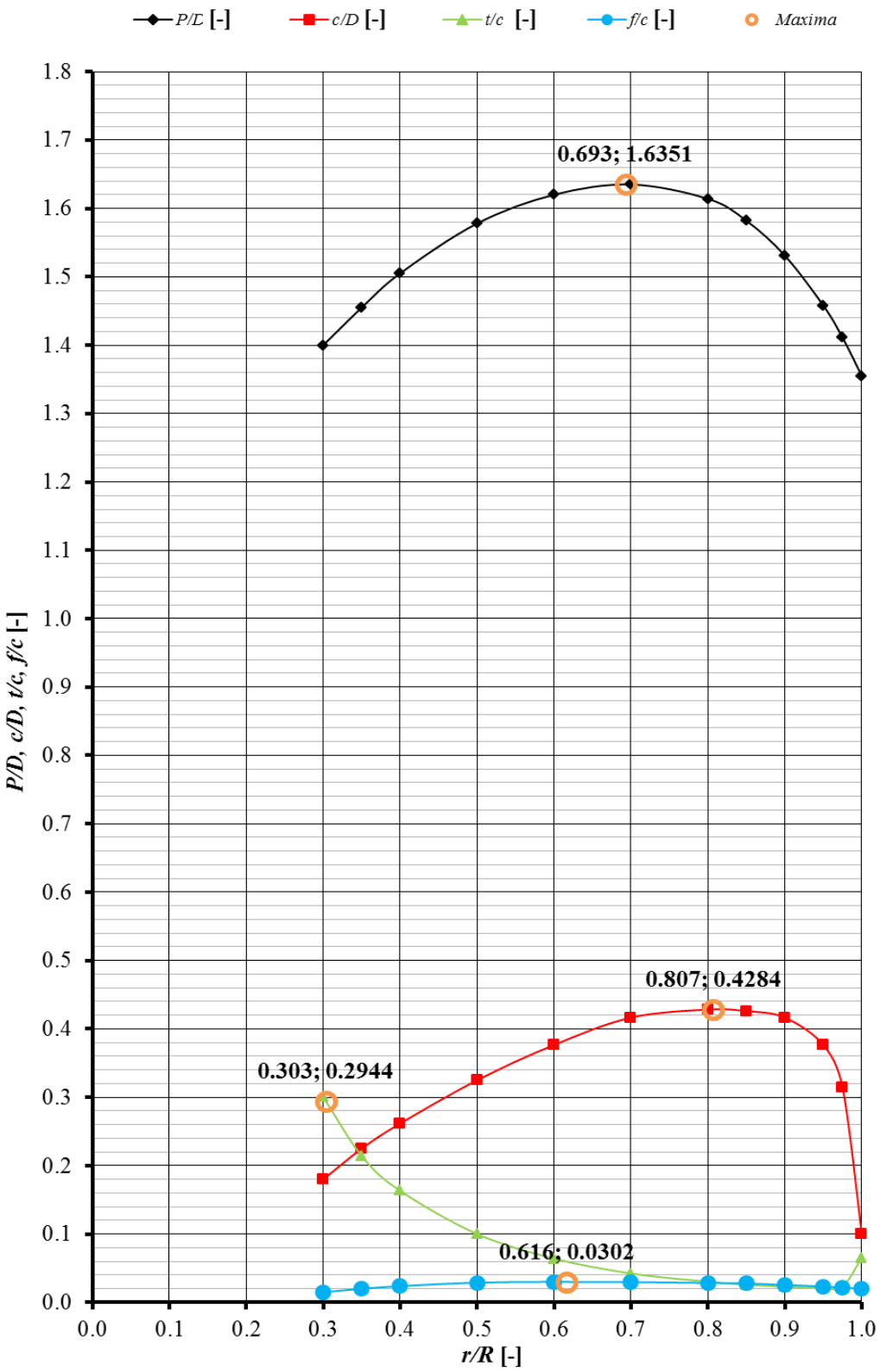
r [mm]	P [mm]	c [mm]	t [mm]	f [mm]	ε [mm]	θ [mm]
125.0	338.8	25.0	1.64	0.50	-2.50	27.08
118.8	364.5	94.2	2.01	2.19	-4.03	17.75
112.5	382.8	104.2	2.38	2.67	-5.45	9.25
106.3	395.5	106.5	2.78	2.97	-6.63	2.34
100.0	403.5	107.1	3.25	3.05	-7.38	-2.75
93.8	407.6	106.4	3.78	3.10	-7.67	-6.68
87.5	408.8	104.2	4.43	3.09	-7.50	-9.58
75.0	405.0	94.2	6.05	2.84	-5.88	-12.75
62.5	394.5	81.3	8.14	2.36	-3.35	-11.50
50.0	376.3	65.4	10.69	1.57	-1.25	-6.08
37.9	351.0	45.8	13.45	0.70	-0.03	3.83
37.5	350.0	45.0	13.53	0.68	0.00	4.25

R_{tip} [mm]	R_{LE} [mm]	R_{SS} [mm]	R_{PS} [mm]	R_{TE} [mm]
0.15	1.00	1.00	1.00	1.00

r/R [-]	P/D [-]	c/D [-]	t/c [-]	f/c [-]	θ [°]	ε [°]
1.00	1.355	0.100	0.066	0.020	11.40	-1.15
0.95	1.458	0.377	0.021	0.023	7.70	-1.95
0.90	1.531	0.417	0.023	0.026	4.14	-2.77
0.85	1.582	0.426	0.026	0.028	1.08	-3.57
0.80	1.614	0.428	0.030	0.028	-1.33	-4.22
0.75	1.630	0.426	0.036	0.029	-3.36	-4.68
0.70	1.635	0.417	0.042	0.030	-5.04	-4.90
0.60	1.620	0.377	0.064	0.030	-7.39	-4.48
0.50	1.578	0.325	0.100	0.029	-7.44	-3.07
0.40	1.505	0.262	0.163	0.024	-4.47	-1.43
0.30	1.404	0.183	0.294	0.015	3.25	-0.04
0.30	1.400	0.180	0.301	0.015	3.63	0.00

Hub	d_h/D [-]	d_{hLE} [mm]	d_{hTE} [mm]	l_{LE} [mm]	l_{TE} [mm]	l_h [mm]
H1	0.25	72.46	72.46	25.00	25.00	50.00

1.5 PPTC - VP1304, main data



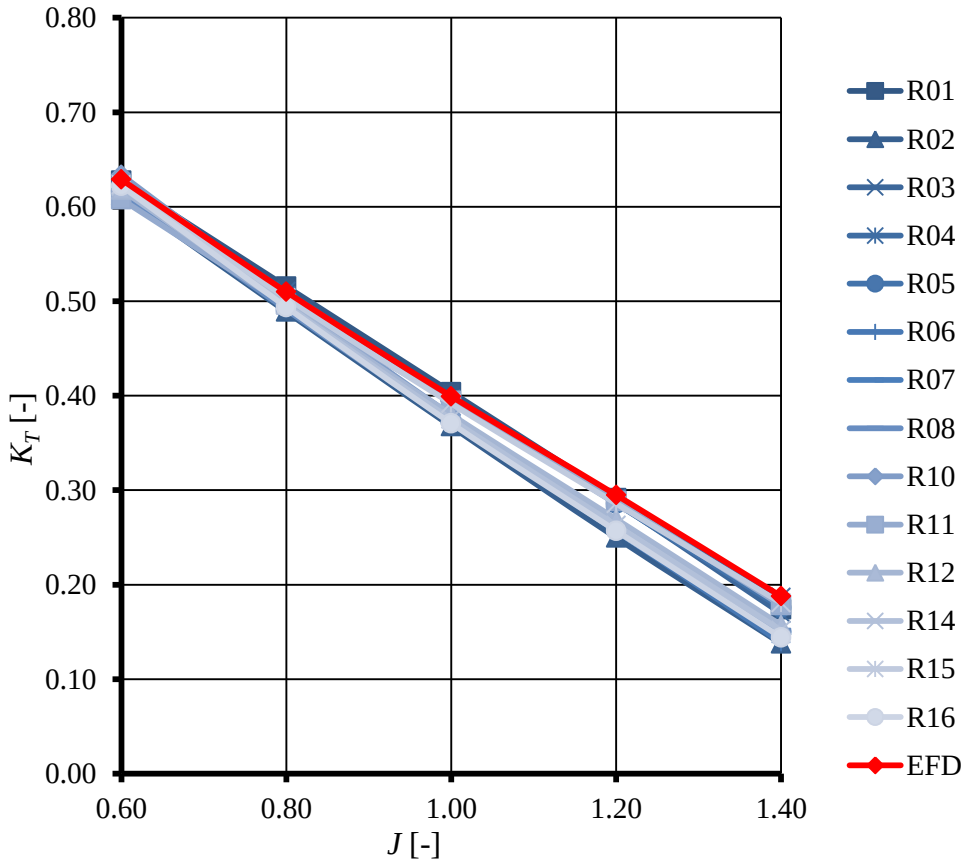
1.6 PPTC - VP1304, 3D

2 Overview

2.1 Open water characteristic - thrust model scale

K_T [-] model scale

J [-]	0.60	0.80	1.00	1.20	1.40	Avarage over J [-]*	CFD - EFD [-]**
EFD	0.629	0.510	0.399	0.295	0.188	0.000	0.0%
R01	0.628	0.516	0.404	0.292	0.174	-0.002	-0.4%
R02	0.612	0.489	0.368	0.250	0.138	-0.033	-8.2%
R03	0.625	0.510	0.396	0.287	0.170	-0.007	-1.6%
R04	0.624	0.506	0.394	0.291	0.186	-0.004	-0.9%
R05	0.617	0.505	0.396	0.286	0.176	-0.008	-2.1%
R06	0.618	0.492	0.372	0.257	0.139	-0.028	-7.0%
R07	0.624	0.498	0.375	0.262	0.149	-0.023	-5.6%
R08	0.615	0.491	0.372	0.261	0.151	-0.026	-6.4%
R10	0.634	0.504	0.379	0.262	0.150	-0.018	-4.5%
R11	0.608	0.496	0.394	0.288	0.178	-0.011	-2.7%
R12	0.618	0.497	0.380	0.269	0.157	-0.020	-4.9%
R14	0.622	0.496	0.375	0.263	0.152	-0.023	-5.6%
R15	0.623	0.504	0.392	0.286	0.181	-0.007	-1.8%
R16	0.622	0.494	0.371	0.257	0.144	-0.027	-6.6%

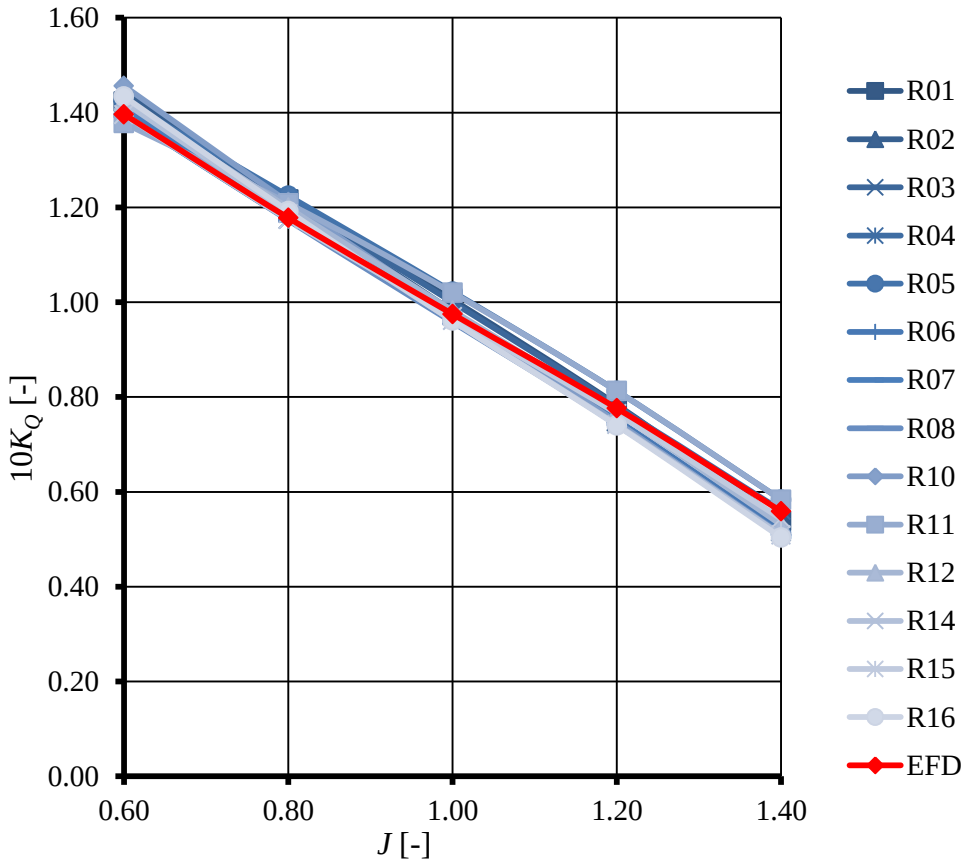


* / ** see at formula page

2.2 Open water characteristic - torque model scale

$10K_Q$ [-] model scale

J [-]	0.60	0.80	1.00	1.20	1.40	Avarage over J CFD - EFD [-]*	[-]**
EFD	1.396	1.178	0.975	0.776	0.559	0.000	0.0%
R01	1.423	1.216	1.005	0.784	0.539	0.017	1.7%
R02	1.442	1.212	0.981	0.749	0.517	0.003	0.3%
R03	1.422	1.215	1.000	0.781	0.539	0.015	1.5%
R04	1.394	1.175	0.972	0.778	0.561	-0.001	-0.1%
R05	1.425	1.224	1.022	0.813	0.583	0.037	3.8%
R06	1.431	1.196	0.973	0.752	0.518	-0.003	-0.3%
R07	1.410	1.184	0.961	0.742	0.506	-0.016	-1.7%
R08	1.394	1.173	0.958	0.744	0.511	-0.021	-2.1%
R10	1.456	1.211	0.978	0.747	0.509	0.003	0.3%
R11	1.378	1.208	1.020	0.813	0.583	0.024	2.4%
R12	1.424	1.199	0.983	0.767	0.531	0.004	0.4%
R14	1.422	1.187	0.961	0.742	0.509	-0.013	-1.3%
R15	1.396	1.175	0.969	0.765	0.543	-0.007	-0.8%
R16	1.434	1.192	0.961	0.740	0.504	-0.011	-1.1%

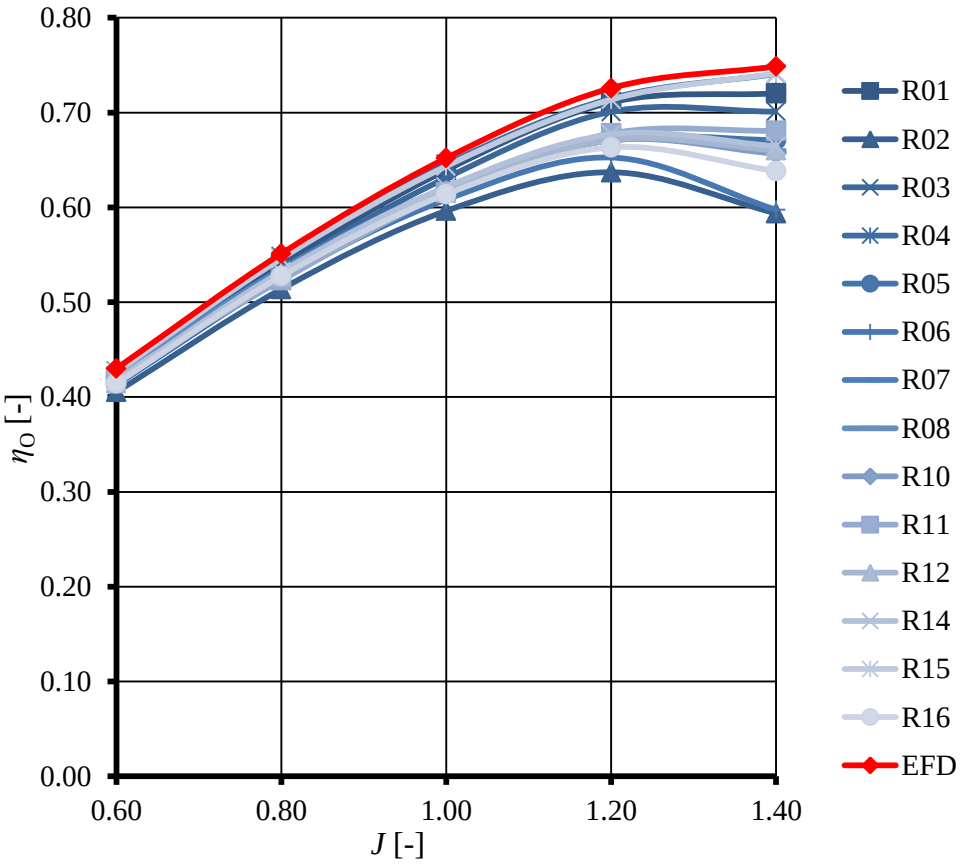


* / ** see at formula page

2.3 Open water characteristic - efficiency model scale

η_O [-] model scale

J [-]	0.60	0.80	1.00	1.20	1.40	Avarage obver J	CFD-EFD
EFD	0.430	0.551	0.652	0.726	0.749	0.000	0.0%
R01	0.421	0.540	0.639	0.711	0.720	-0.015	-2.5%
R02	0.405	0.514	0.596	0.637	0.594	-0.072	-11.6%
R03	0.420	0.535	0.631	0.701	0.701	-0.024	-3.9%
R04	0.427	0.548	0.646	0.715	0.741	-0.006	-1.0%
R05	0.413	0.525	0.616	0.672	0.671	-0.042	-6.8%
R06	0.413	0.524	0.608	0.653	0.597	-0.062	-10.1%
R07	0.423	0.535	0.621	0.673	0.658	-0.039	-6.4%
R08	0.421	0.533	0.618	0.671	0.659	-0.041	-6.6%
R10	0.416	0.529	0.618	0.671	0.657	-0.044	-7.0%
R11	0.421	0.523	0.616	0.678	0.681	-0.038	-6.1%
R12	0.414	0.528	0.616	0.671	0.660	-0.044	-7.0%
R14	0.417	0.532	0.621	0.677	0.665	-0.039	-6.3%
R15	0.426	0.546	0.643	0.714	0.741	-0.007	-1.2%
R16	0.414	0.528	0.614	0.663	0.638	-0.050	-8.1%

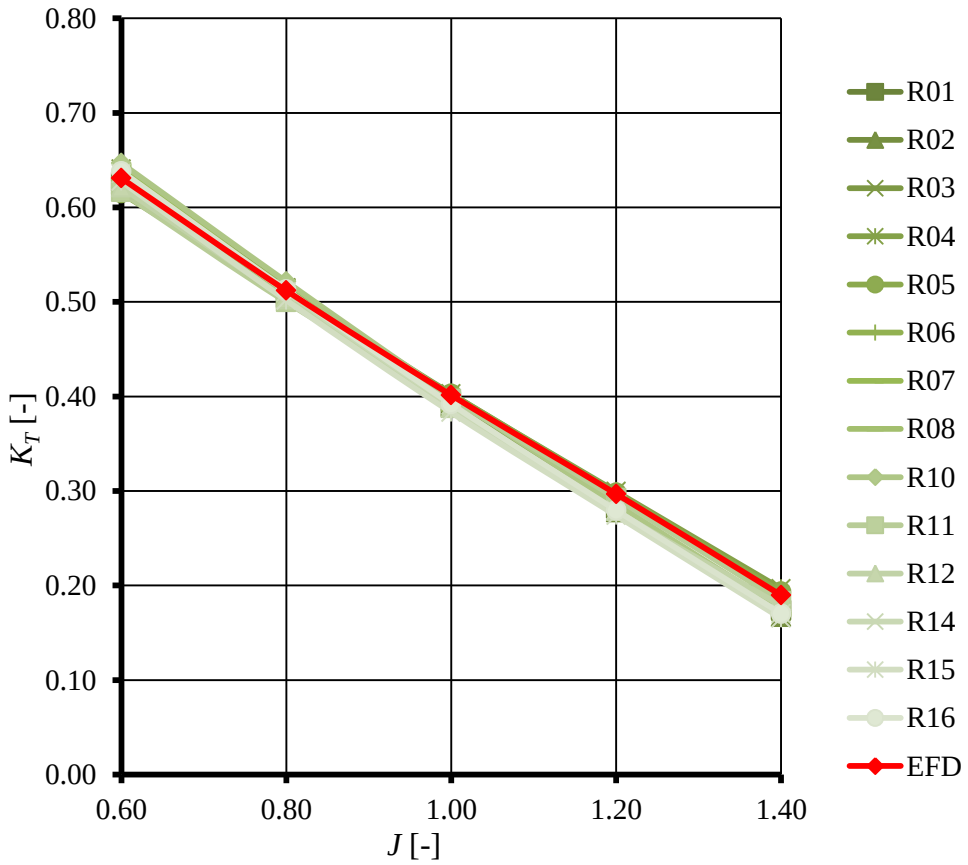


* / ** see at formula page

2.4 Open water characteristic - thrust full scale

K_T [-] **full scale**

J [-]	0.60	0.80	1.00	1.20	1.40	Avarage over J CFD - EFD [-]*	[-]**
ITTC'78	0.631	0.512	0.401	0.297	0.190	0.000	0.0%
R01	0.627	0.504	0.388	0.281	0.174	-0.011	-2.8%
R02	0.631	0.509	0.390	0.278	0.167	-0.011	-2.8%
R03	0.640	0.515	0.395	0.283	0.172	-0.005	-1.3%
R04	0.629	0.514	0.403	0.299	0.197	0.002	0.5%
R05	0.615	0.508	0.403	0.298	0.193	-0.003	-0.7%
R06	0.635	0.515	0.401	0.293	0.189	0.000	0.1%
R07	0.644	0.512	0.390	0.279	0.170	-0.007	-1.8%
R08	0.630	0.505	0.387	0.279	0.171	-0.012	-2.9%
R10	0.647	0.521	0.400	0.286	0.176	0.000	0.0%
R11	0.616	0.500	0.398	0.292	0.183	-0.008	-2.0%
R12	0.621	0.503	0.388	0.279	0.179	-0.012	-3.0%
R14	0.636	0.511	0.390	0.280	0.170	-0.009	-2.2%
R15	0.628	0.502	0.383	0.274	0.165	-0.016	-3.9%
R16	0.638	0.513	0.392	0.280	0.170	-0.008	-1.9%

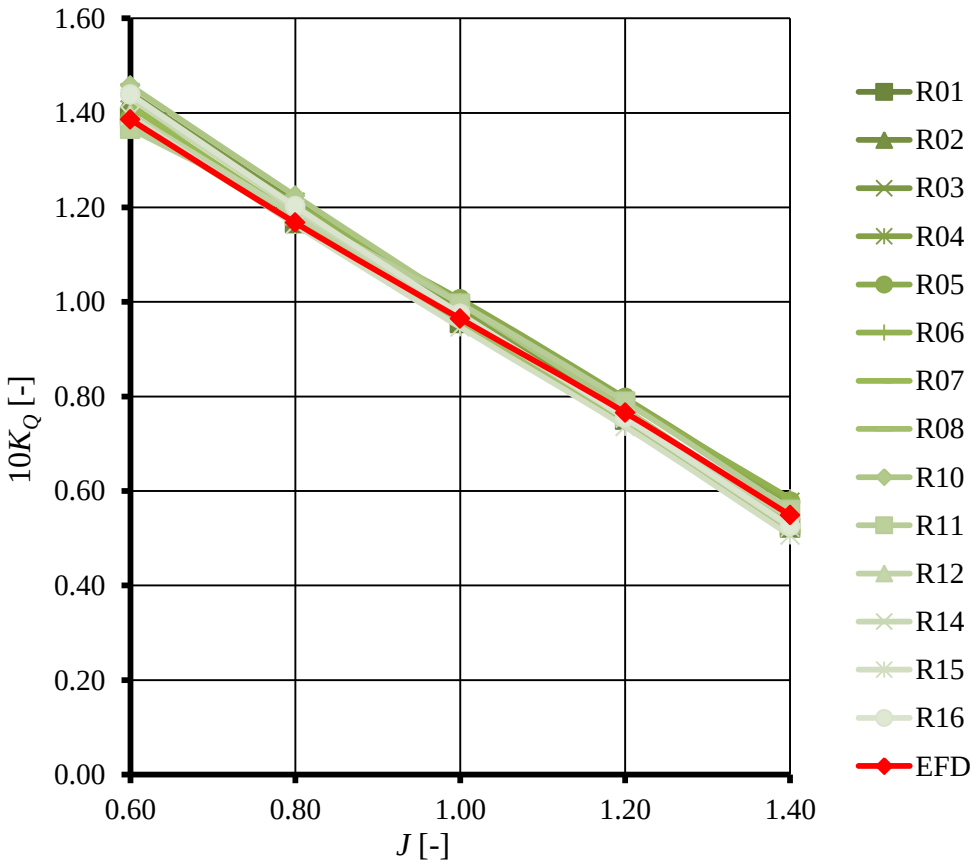


* / ** see at formula page

2.5 Open water characteristic - torque full scale

$10K_Q$ [-] **full scale**

J [-]	0.60	0.80	1.00	1.20	1.40	Avarage over J [-]*	CFD - EFD [-]**
ITTC'78	1.386	1.168	0.965	0.766	0.549	0.000	0.0%
R01	1.391	1.167	0.955	0.751	0.522	-0.009	-1.0%
R02	1.429	1.204	0.983	0.762	0.527	0.015	1.5%
R03	1.442	1.211	0.989	0.771	0.536	0.023	2.4%
R04	1.393	1.184	0.982	0.787	0.576	0.018	1.9%
R05	1.388	1.191	1.005	0.797	0.577	0.025	2.6%
R06	1.425	1.207	0.998	0.790	0.584	0.034	3.5%
R07	1.414	1.183	0.966	0.751	0.515	-0.001	-0.1%
R08	1.383	1.167	0.957	0.749	0.515	-0.012	-1.3%
R10	1.458	1.224	0.997	0.773	0.538	0.031	3.3%
R11	1.367	1.188	0.996	0.788	0.560	0.013	1.4%
R12	1.397	1.183	0.973	0.758	0.544	0.005	0.5%
R14	1.430	1.196	0.970	0.753	0.522	0.008	0.8%
R15	1.394	1.163	0.946	0.736	0.506	-0.017	-1.8%
R16	1.439	1.202	0.975	0.756	0.526	0.013	1.3%

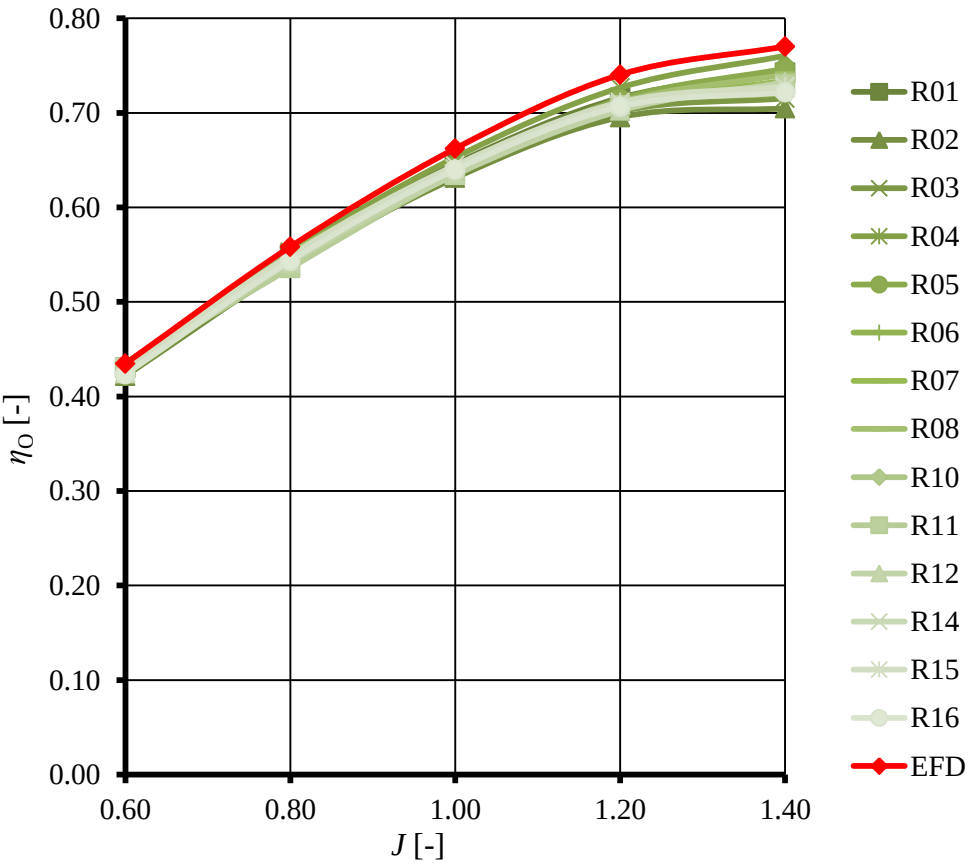


* / ** see at formula page

2.6 Open water characteristic - efficiency full scale

η_O [-] full scale

J [-]	0.60	0.80	1.00	1.20	1.40	Avarage over J CFD - EFD [-]*	[-]**
ITTC'78	0.435	0.558	0.662	0.740	0.770	0.000	0.0%
R01	0.430	0.550	0.646	0.716	0.742	-0.016	-2.6%
R02	0.422	0.538	0.631	0.696	0.705	-0.035	-5.5%
R03	0.424	0.542	0.636	0.701	0.715	-0.030	-4.7%
R04	0.431	0.553	0.653	0.727	0.761	-0.008	-1.3%
R05	0.423	0.543	0.638	0.714	0.747	-0.020	-3.2%
R06	0.425	0.543	0.640	0.708	0.721	-0.026	-4.1%
R07	0.435	0.551	0.643	0.708	0.734	-0.019	-3.0%
R08	0.435	0.551	0.643	0.712	0.741	-0.017	-2.7%
R10	0.424	0.542	0.639	0.707	0.728	-0.025	-4.0%
R11	0.431	0.536	0.635	0.708	0.730	-0.025	-4.0%
R12	0.425	0.541	0.634	0.702	0.732	-0.026	-4.1%
R14	0.424	0.544	0.640	0.709	0.726	-0.025	-3.9%
R15	0.430	0.549	0.644	0.711	0.728	-0.021	-3.3%
R16	0.424	0.543	0.640	0.707	0.722	-0.026	-4.1%



* / ** see at formula page

3 Statistics

3.1 Tables - model scale

K_T [-] model scale

	J [-]	0.60	0.80	1.00	1.20	1.40	Avarage over J CFD - EFD [-]*	[-]**
Minimum		0.608	0.489	0.368	0.250	0.138	-0.033	-8.2%
1th Quartile		0.617	0.494	0.373	0.261	0.150	-0.025	-6.2%
Median		0.622	0.497	0.380	0.266	0.154	-0.019	-4.7%
3th Quartile		0.624	0.505	0.394	0.286	0.175	-0.007	-1.8%
Maximum		0.634	0.516	0.404	0.292	0.186	-0.002	-0.4%

$10K_Q$ [-] model scale

	J [-]	0.60	0.80	1.00	1.20	1.40	Avarage over J CFD - EFD [-]*	[-]**
Minimum		1.378	1.173	0.958	0.740	0.504	-0.021	-2.1%
1th Quartile		1.399	1.185	0.963	0.745	0.510	-0.010	-1.0%
Median		1.423	1.198	0.976	0.759	0.524	0.001	0.1%
3th Quartile		1.429	1.211	0.996	0.780	0.542	0.012	1.2%
Maximum		1.456	1.224	1.022	0.813	0.583	0.037	3.8%

η_O [-] model scale

	J [-]	0.60	0.80	1.00	1.20	1.40	Avarage over J CFD - EFD [-]*	[-]**
Minimum		0.405	0.514	0.596	0.637	0.594	-0.072	-11.6%
1th Quartile		0.414	0.526	0.616	0.671	0.657	-0.044	-7.0%
Median		0.419	0.531	0.618	0.673	0.662	-0.040	-6.5%
3th Quartile		0.421	0.535	0.629	0.695	0.696	-0.027	-4.4%
Maximum		0.427	0.548	0.646	0.715	0.741	-0.006	-1.0%

* / ** see at formula page

3.2 Tables - full scale

K_T [-] full scale

	J [-]	0.60	0.80	1.00	1.20	1.40	Avarage over J [-]*	CFD - EFD [-]**
Minimum		0.615	0.500	0.383	0.274	0.165	-0.016	-3.9%
1th Quartile		0.627	0.504	0.388	0.279	0.170	-0.011	-2.8%
Median		0.630	0.510	0.391	0.280	0.173	-0.008	-1.9%
3th Quartile		0.638	0.514	0.400	0.291	0.182	-0.003	-0.8%
Maximum		0.647	0.521	0.403	0.299	0.197	0.002	0.5%

$10K_Q$ [-] full scale

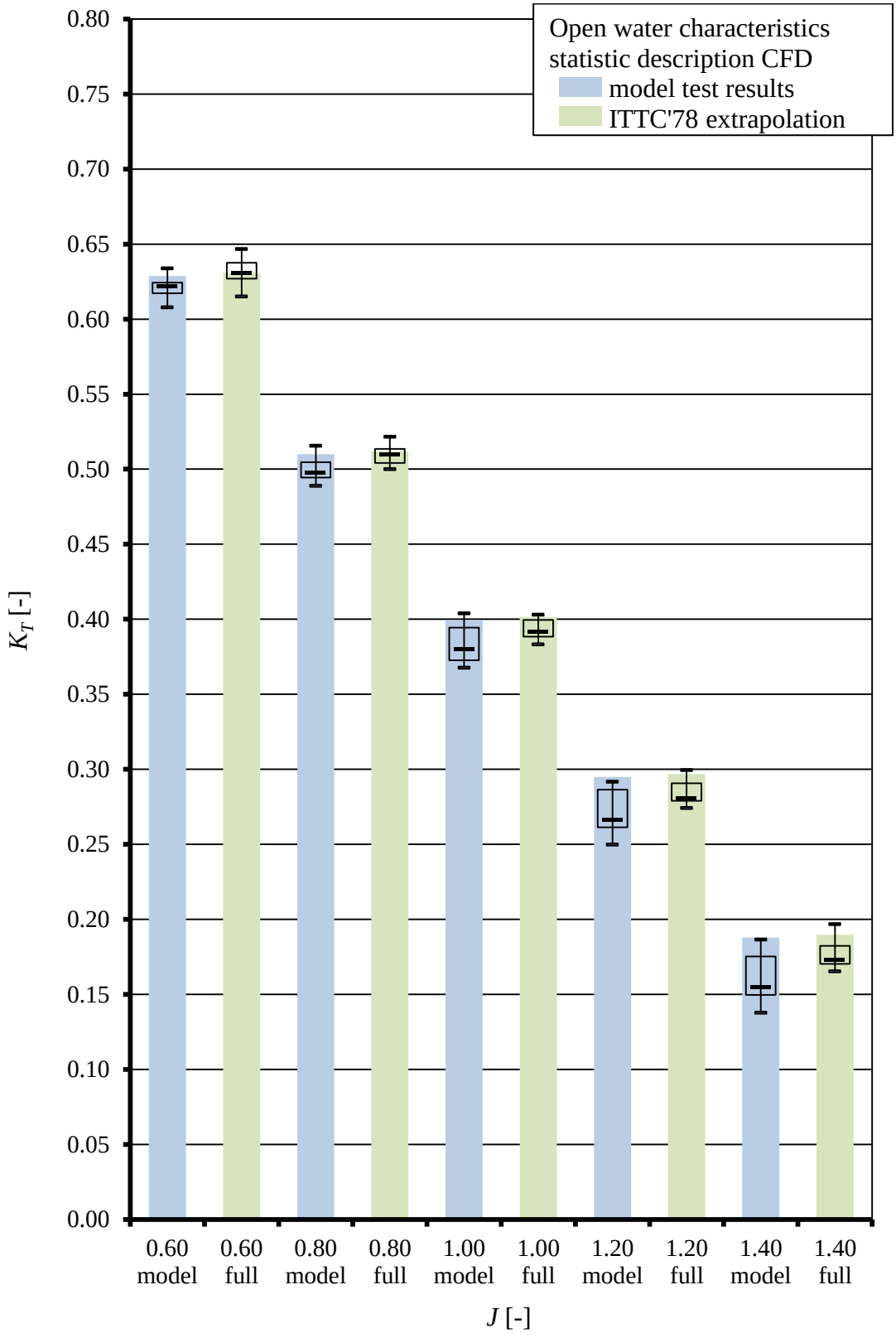
	J [-]	0.60	0.80	1.00	1.20	1.40	Avarage over J [-]*	CFD - EFD [-]**
Minimum		1.367	1.163	0.946	0.736	0.506	-0.017	-1.8%
1th Quartile		1.392	1.183	0.967	0.752	0.522	0.000	0.1%
Median		1.405	1.189	0.978	0.760	0.532	0.013	1.4%
3th Quartile		1.430	1.203	0.994	0.783	0.556	0.022	2.3%
Maximum		1.458	1.224	1.005	0.797	0.584	0.034	3.5%

η_O [-] full scale

	J [-]	0.60	0.80	1.00	1.20	1.40	Avarage over J [-]*	CFD - EFD [-]**
Minimum		0.422	0.536	0.631	0.696	0.705	-0.035	-5.5%
1th Quartile		0.424	0.542	0.636	0.707	0.723	-0.026	-4.1%
Median		0.425	0.543	0.640	0.708	0.729	-0.025	-3.9%
3th Quartile		0.431	0.550	0.643	0.711	0.739	-0.019	-3.0%
Maximum		0.435	0.553	0.653	0.727	0.761	-0.008	-1.3%

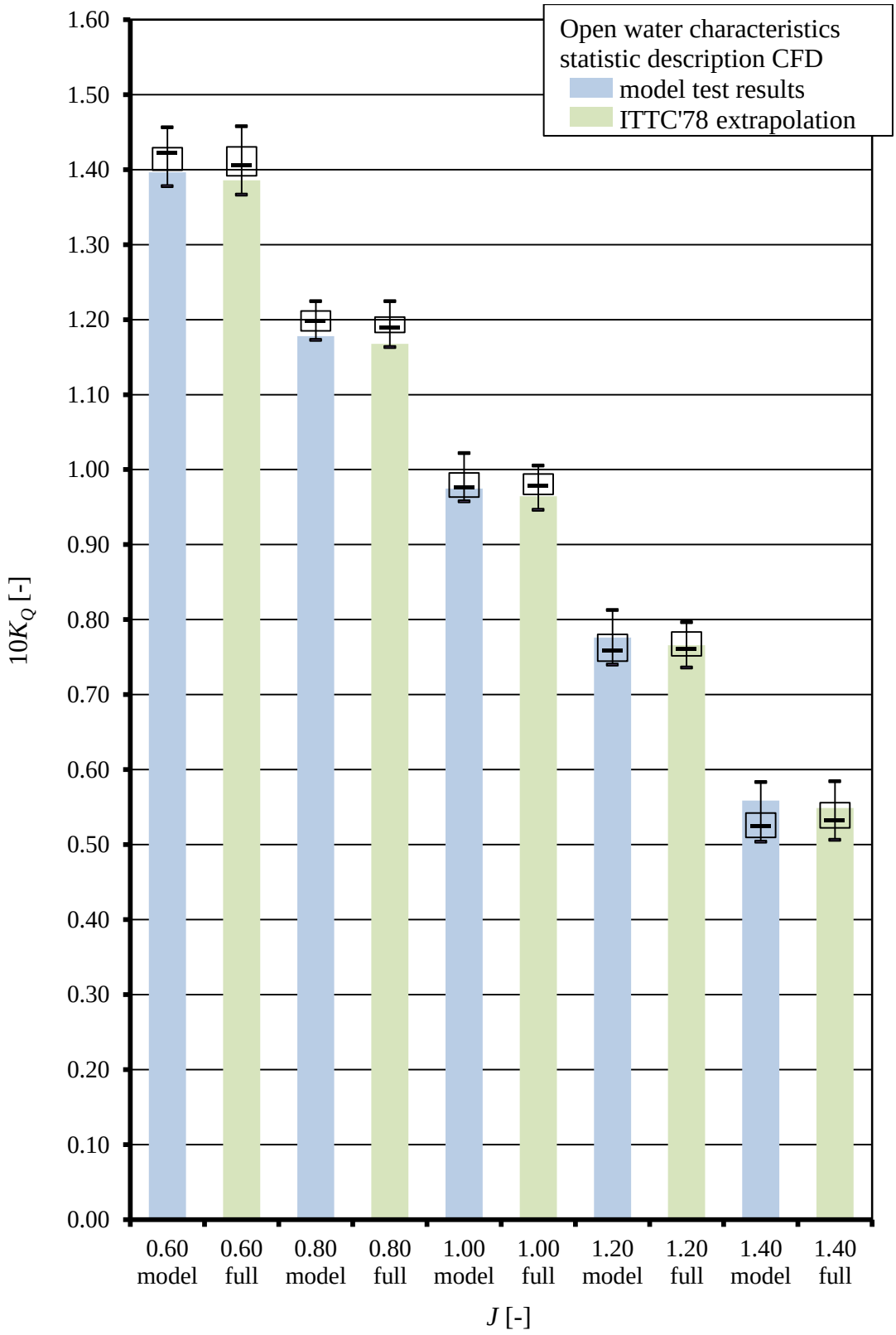
* / ** see at formula page

3.3 Diagrams - Thrust



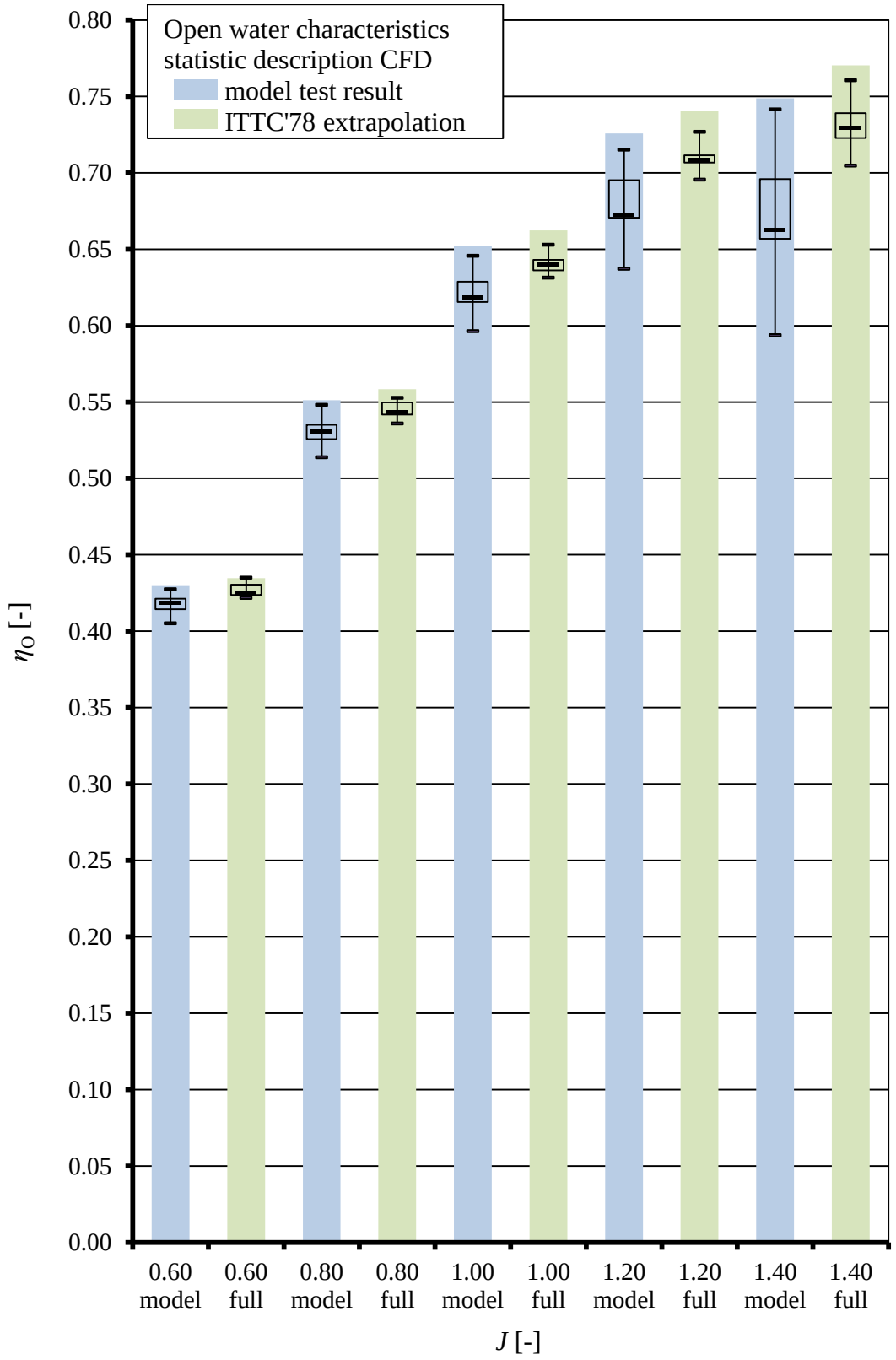
* / ** see at formula page

3.4 Diagrams - Torque



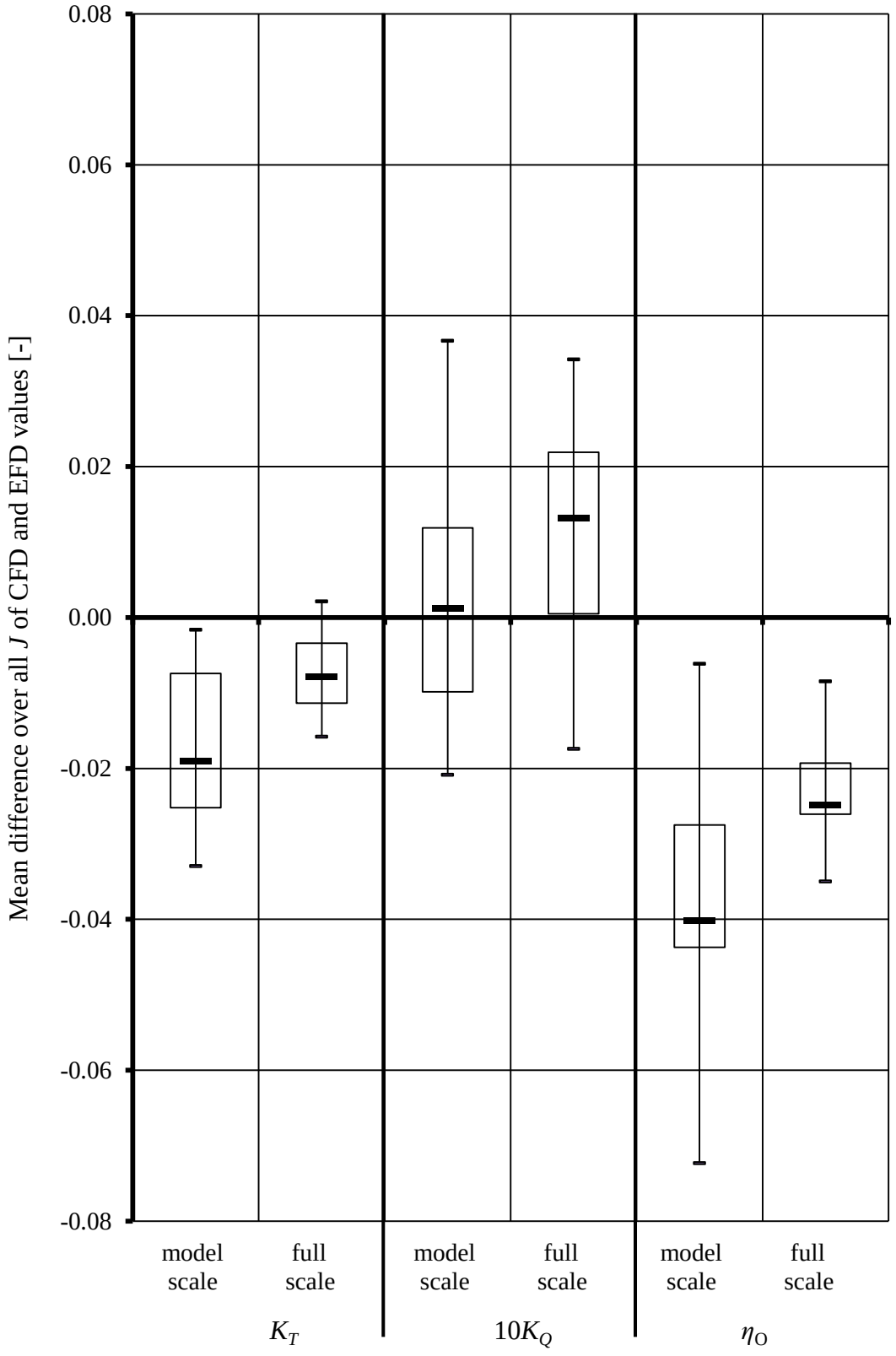
* / ** see at formula page

3.5 Diagrams - Efficiency



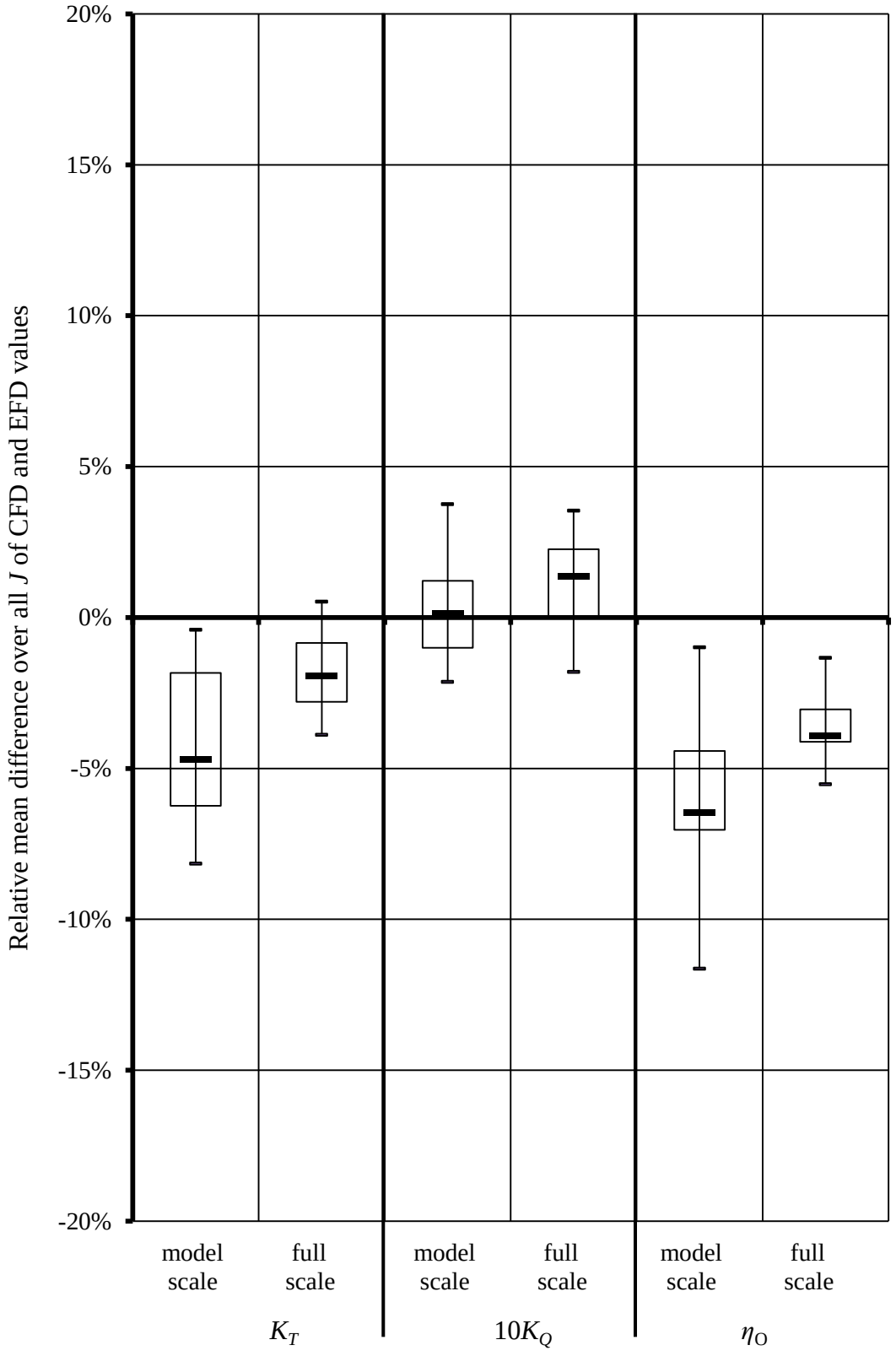
* / ** see at formula page

3.6 Diagrams - Difference CFD and EFD



* / ** see at formula page

3.7 Diagrams - Relative difference CFD and EFD

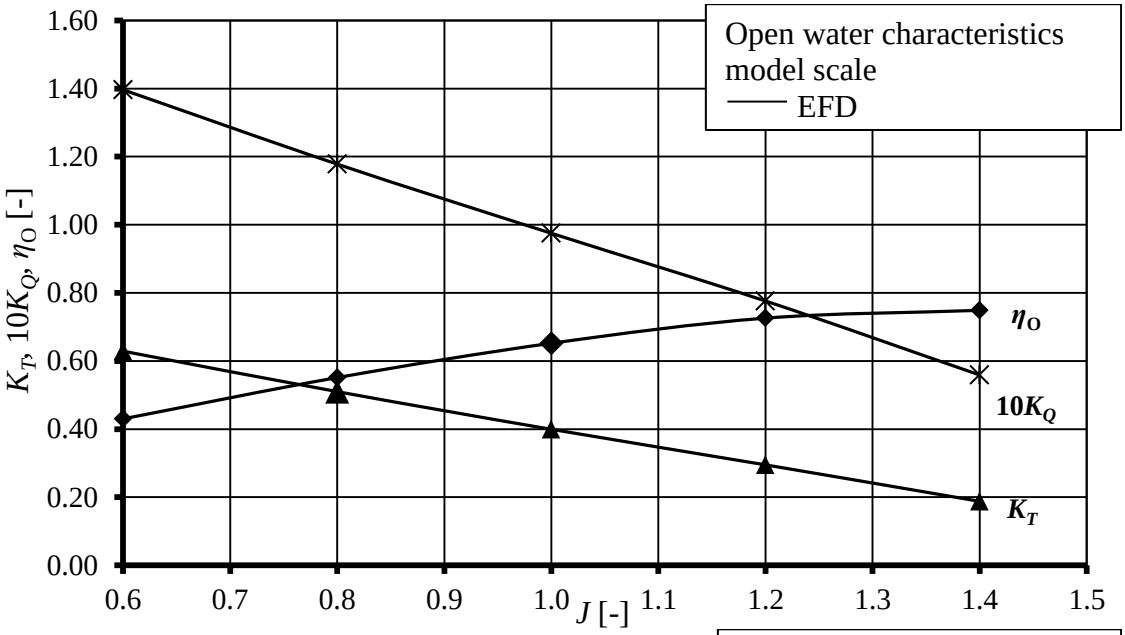


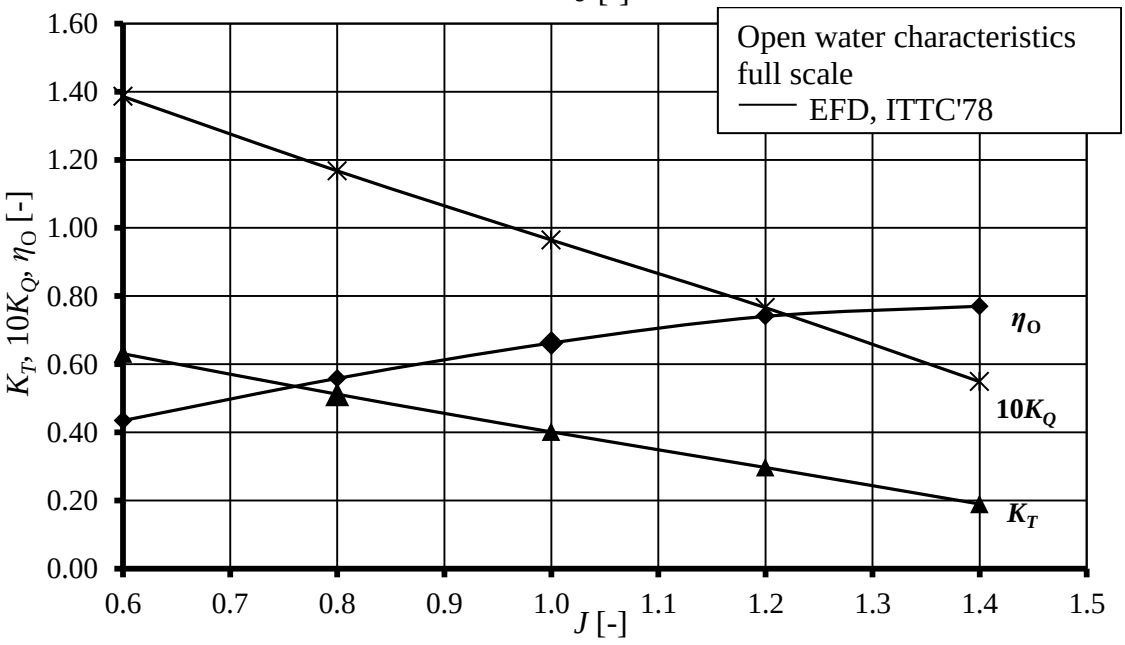
* / ** see at formula page

4 Result EFD

4.1 Open Water Characteristic

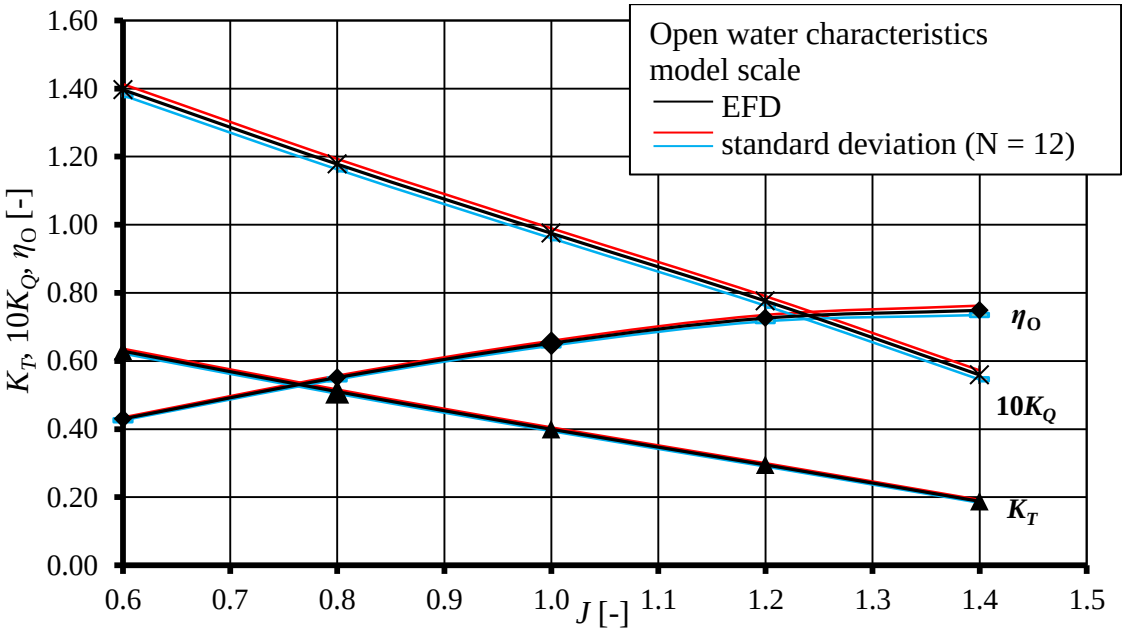
	EFD, model scale			EFD, full scale, ITTC'78		
J	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.600	0.629	1.396	0.430	0.631	1.386	0.435
0.800	0.510	1.178	0.551	0.512	1.168	0.558
1.000	0.399	0.975	0.652	0.401	0.965	0.662
1.200	0.295	0.776	0.726	0.297	0.766	0.740
1.400	0.188	0.559	0.749	0.190	0.549	0.770

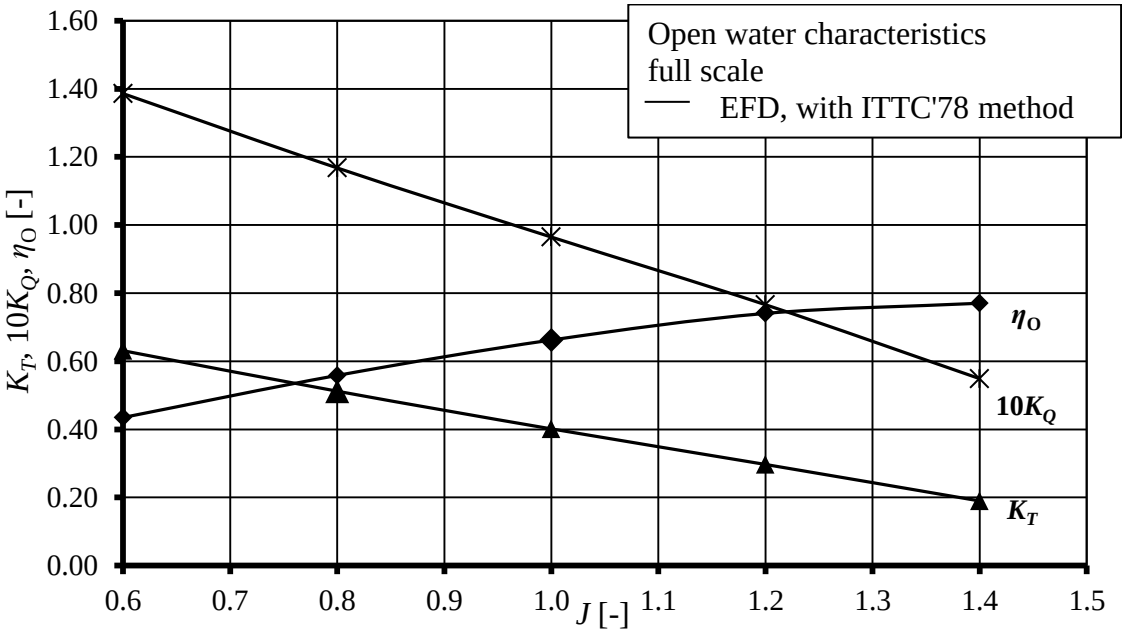




4.2 EFD - Statistics

	EFD, model scale			EFD, full scale, ITTC'78		
J	$\sigma(K_T)$	$\sigma(10K_Q)$	$\sigma(\eta_O)$	$\sigma(K_T)$	$\sigma(10K_Q)$	$\sigma(\eta_O)$
[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.600	0.007	0.016	0.004	0.007	0.016	0.004
0.800	0.006	0.015	0.006	0.006	0.015	0.006
1.000	0.005	0.015	0.007	0.005	0.015	0.007
1.200	0.005	0.014	0.009	0.005	0.014	0.009
1.400	0.004	0.013	0.014	0.004	0.013	0.014

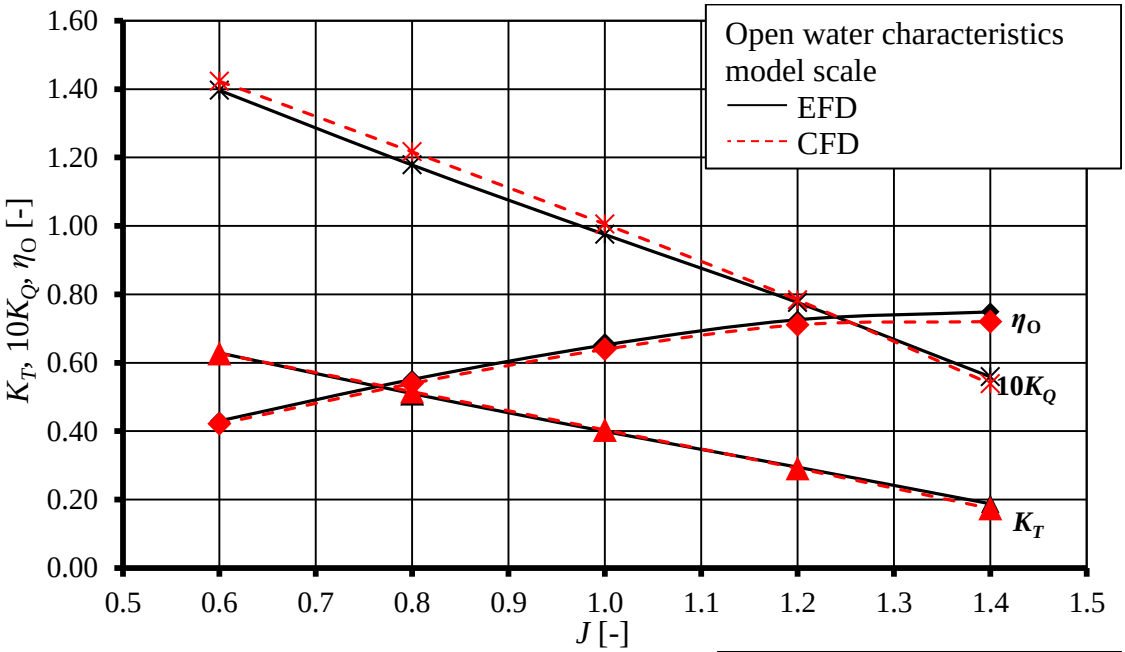


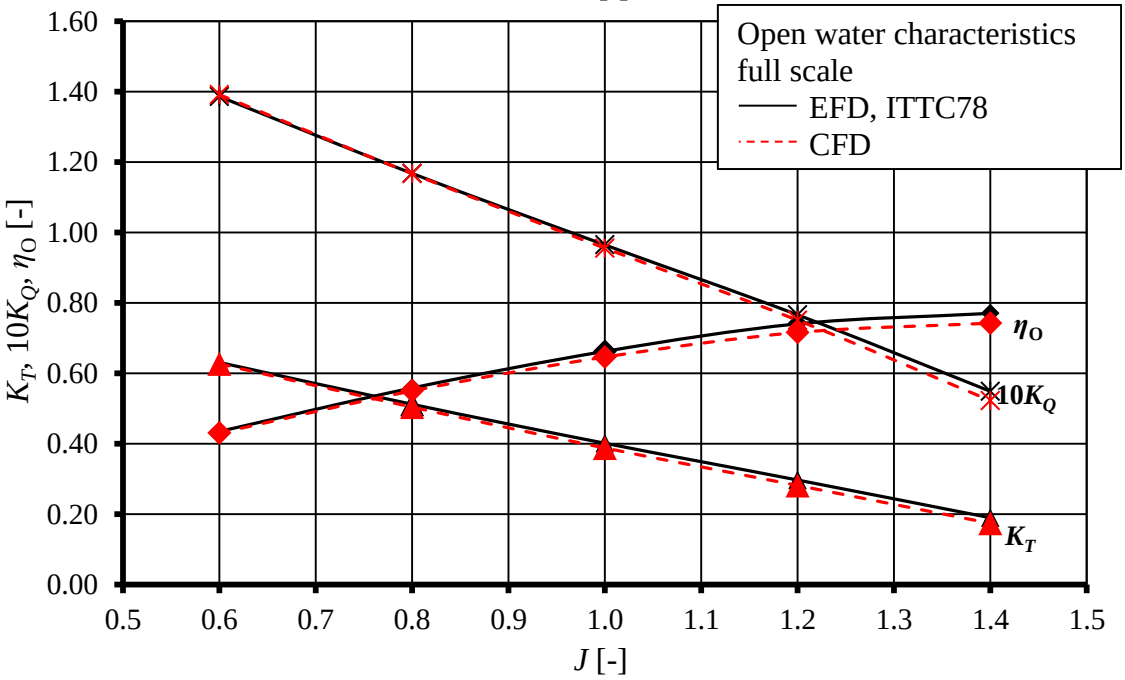


5 Result R01

5.1 R01 - Open water characteristic

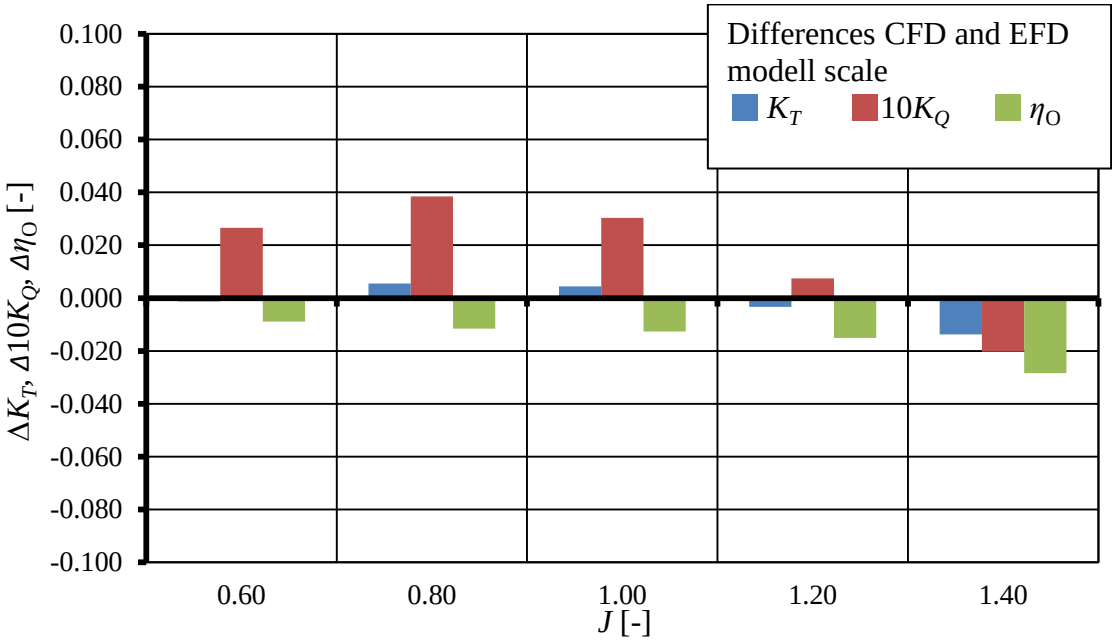
	CFD, model scale			CFD, full scale		
J	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.600	0.628	1.423	0.421	0.627	1.391	0.430
0.800	0.516	1.216	0.540	0.504	1.167	0.550
1.000	0.404	1.005	0.639	0.388	0.955	0.646
1.200	0.292	0.784	0.711	0.281	0.751	0.716
1.400	0.174	0.539	0.720	0.174	0.522	0.742

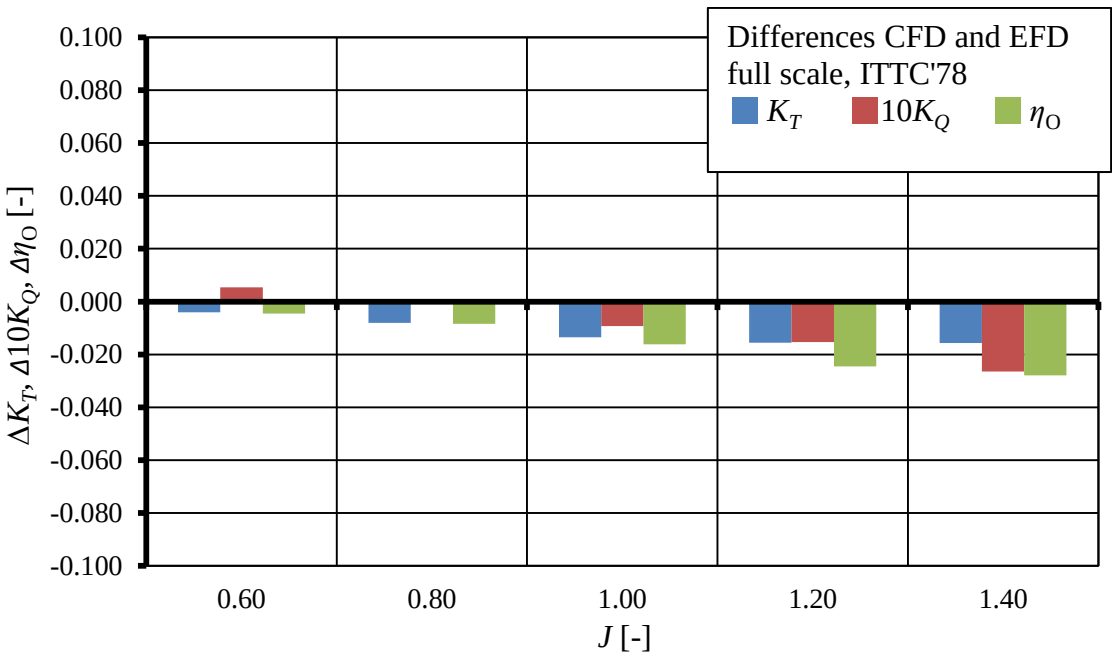




5.2 R01 - Differences CFD and EFD

	CFD - EFD, model scale			CFD - EFD, full scale		
	K_T [-]	$10K_Q$ [-]	η_O [-]	K_T [-]	$10K_Q$ [-]	η_O [-]
0.60	-0.001	0.027	-0.009	-0.004	0.005	-0.005
0.80	0.006	0.038	-0.012	-0.008	-0.001	-0.008
1.00	0.004	0.030	-0.013	-0.014	-0.009	-0.016
1.20	-0.003	0.008	-0.015	-0.016	-0.015	-0.024
1.40	-0.014	-0.020	-0.028	-0.016	-0.026	-0.028





5.3 R01 - Radial distribution tables

model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.011	0.010	0.008	0.006	0.004	0.017	0.017	0.014	0.010	0.004
0.400	0.031	0.027	0.022	0.015	0.007	0.063	0.062	0.054	0.041	0.024
0.500	0.049	0.043	0.036	0.027	0.015	0.108	0.103	0.092	0.076	0.052
0.600	0.073	0.063	0.053	0.041	0.025	0.169	0.152	0.138	0.114	0.081
0.700	0.100	0.086	0.071	0.055	0.035	0.235	0.210	0.182	0.150	0.109
0.800	0.130	0.109	0.087	0.065	0.042	0.303	0.263	0.218	0.175	0.127
0.900	0.157	0.121	0.091	0.063	0.037	0.360	0.285	0.220	0.164	0.111
0.975	0.076	0.055	0.036	0.021	0.010	0.168	0.126	0.086	0.054	0.031

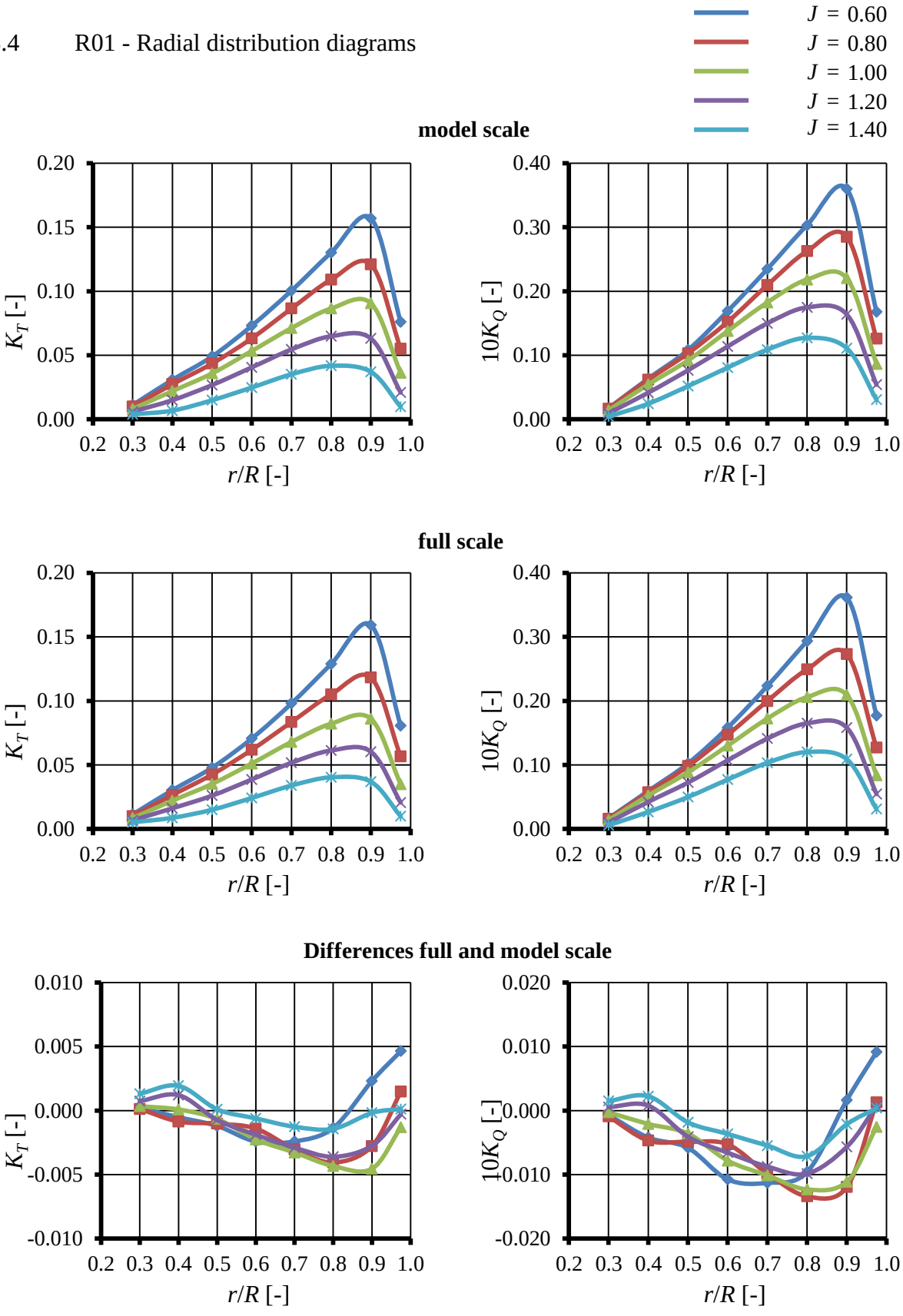
full scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.011	0.010	0.008	0.007	0.005	0.017	0.016	0.014	0.010	0.006
0.400	0.030	0.027	0.022	0.016	0.009	0.059	0.057	0.052	0.042	0.027
0.500	0.048	0.042	0.035	0.026	0.015	0.102	0.098	0.088	0.072	0.050
0.600	0.071	0.062	0.051	0.039	0.024	0.158	0.147	0.130	0.107	0.077
0.700	0.098	0.083	0.068	0.052	0.034	0.223	0.200	0.172	0.141	0.103
0.800	0.129	0.105	0.082	0.061	0.040	0.293	0.249	0.206	0.165	0.120
0.900	0.159	0.118	0.086	0.060	0.037	0.361	0.273	0.209	0.158	0.109
0.975	0.081	0.057	0.035	0.021	0.010	0.177	0.127	0.084	0.055	0.031

Differences full and model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.000	0.000	0.000	0.001	0.001	-0.001	-0.001	0.000	0.001	0.001
0.400	-0.001	-0.001	0.000	0.001	0.002	-0.004	-0.005	-0.002	0.001	0.002
0.500	-0.001	-0.001	-0.001	-0.001	0.000	-0.006	-0.005	-0.004	-0.004	-0.002
0.600	-0.002	-0.001	-0.002	-0.002	-0.001	-0.011	-0.005	-0.008	-0.007	-0.004
0.700	-0.002	-0.003	-0.003	-0.003	-0.001	-0.011	-0.010	-0.010	-0.009	-0.005
0.800	-0.001	-0.004	-0.004	-0.004	-0.001	-0.010	-0.013	-0.012	-0.010	-0.007
0.900	0.002	-0.003	-0.005	-0.003	0.000	0.002	-0.012	-0.011	-0.006	-0.002
0.975	0.005	0.001	-0.001	0.000	0.000	0.009	0.001	-0.003	0.001	0.000

5.4 R01 - Radial distribution diagrams



5.5 R01 - Questionaire 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	17	24
C8	Y^+-value at r/R=0.4, 0.7, 0.9	0.73,0.88,1.045	0.974,1.24,1.53
C9	Averaged Y^+-value	0.893	1.249
C10	Number of cells on blade surface	278945	520385
	Norm. Dim. the Physical Domain		
D1	X_upstream/D, X_downstream/D	20,40	20,40
D2	Cross area of domain in prop. plain	510	510
	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	0.000185 sec	0.000642 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

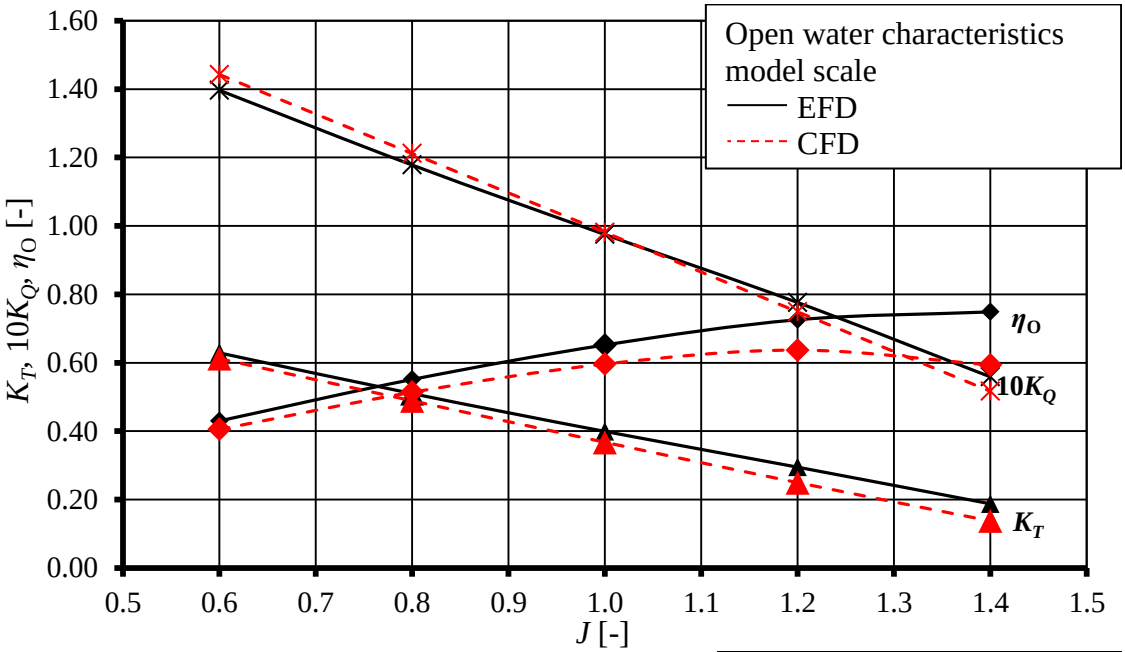
5.5 R01 - Questionaire part II

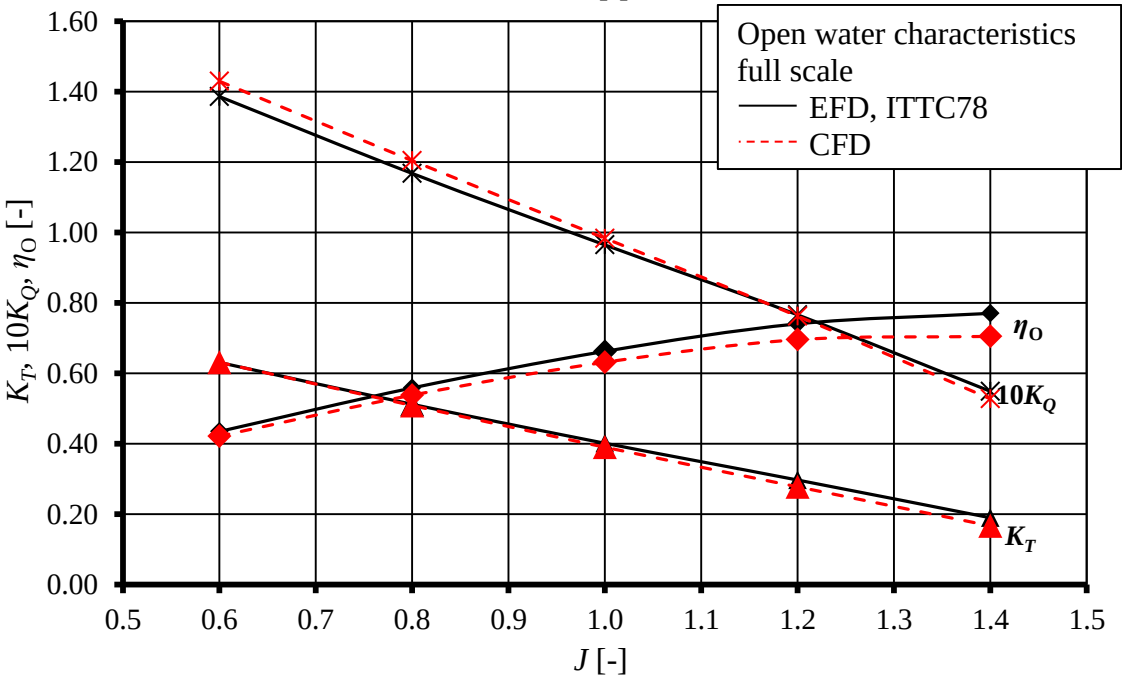
		model scale	full scale
	Computational Model		
H1	Fluid	incompressible	incompressible
H2	Pressure	pressure correction	pressure correction
	Transition		
I	Please comment	Gamma ReTheta method	no
	Computational Demands		
J1	Number of processors used	256	320
J2	Number of timesteps (steady)	0	0
J3	Number of timesteps (transient)	2070	2088
J4	Wall-clock time per revolution	5460 sec	5813 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

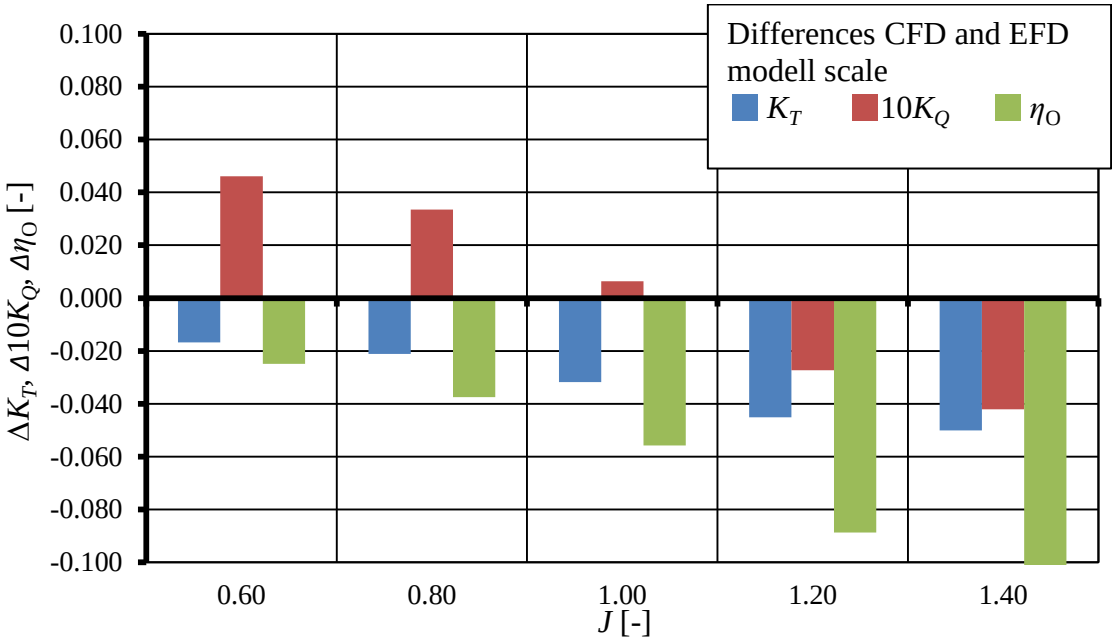
	CFD, model scale			CFD, full scale		
J	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.600	0.612	1.442	0.405	0.631	1.429	0.422
0.800	0.489	1.212	0.514	0.509	1.204	0.538
1.000	0.368	0.981	0.596	0.390	0.983	0.631
1.200	0.250	0.749	0.637	0.278	0.762	0.696
1.400	0.138	0.517	0.594	0.167	0.527	0.705

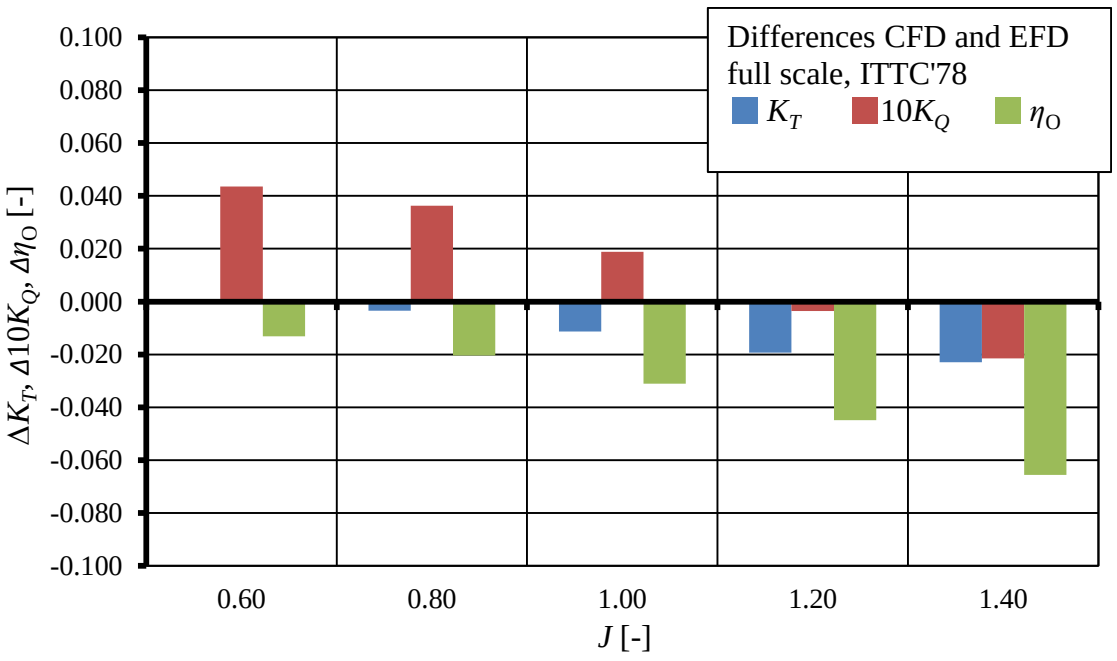




6.2 R02 - Differences CFD and EFD

	CFD - EFD, model scale			CFD - EFD, full scale		
	K_T [-]	$10K_Q$ [-]	η_O [-]	K_T [-]	$10K_Q$ [-]	η_O [-]
0.60	-0.017	0.046	-0.025	0.000	0.044	-0.013
0.80	-0.021	0.034	-0.037	-0.003	0.036	-0.020
1.00	-0.032	0.006	-0.056	-0.011	0.019	-0.031
1.20	-0.045	-0.027	-0.089	-0.019	-0.004	-0.045
1.40	-0.050	-0.042	-0.155	-0.023	-0.021	-0.066





6.3 R02 - Radial distribution tables

model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.009	0.009	0.007	0.004	0.001	0.016	0.015	0.013	0.007	0.001
0.400	0.029	0.025	0.019	0.010	0.002	0.062	0.058	0.049	0.034	0.017
0.500	0.047	0.041	0.033	0.022	0.010	0.105	0.100	0.087	0.068	0.043
0.600	0.070	0.060	0.049	0.035	0.020	0.163	0.151	0.132	0.106	0.075
0.700	0.097	0.082	0.066	0.048	0.030	0.233	0.208	0.178	0.144	0.104
0.800	0.126	0.103	0.080	0.057	0.036	0.304	0.260	0.214	0.169	0.124
0.900	0.152	0.111	0.081	0.055	0.032	0.363	0.277	0.214	0.161	0.116
0.975	0.083	0.057	0.034	0.018	0.008	0.195	0.143	0.094	0.060	0.037

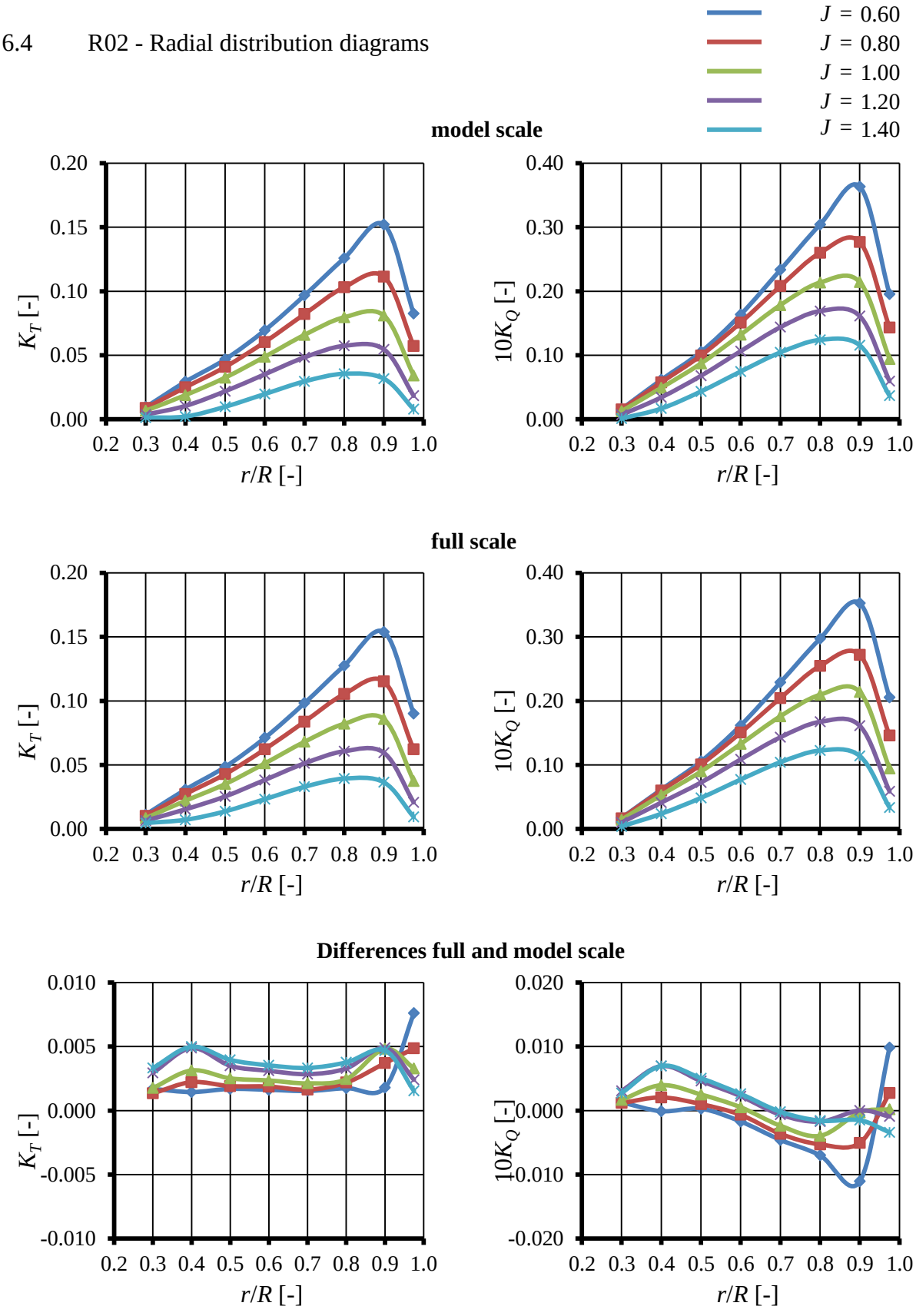
full scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.011	0.010	0.008	0.007	0.005	0.017	0.017	0.014	0.010	0.004
0.400	0.031	0.027	0.022	0.015	0.007	0.062	0.060	0.053	0.041	0.024
0.500	0.048	0.043	0.035	0.025	0.014	0.105	0.101	0.090	0.072	0.049
0.600	0.071	0.062	0.051	0.038	0.023	0.162	0.150	0.133	0.109	0.077
0.700	0.098	0.084	0.068	0.051	0.033	0.229	0.204	0.176	0.143	0.104
0.800	0.128	0.105	0.082	0.061	0.039	0.297	0.255	0.210	0.167	0.122
0.900	0.154	0.115	0.086	0.059	0.036	0.352	0.272	0.214	0.161	0.114
0.975	0.090	0.062	0.038	0.021	0.009	0.205	0.146	0.094	0.059	0.033

Differences full and model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.002	0.001	0.002	0.003	0.003	0.001	0.001	0.002	0.003	0.003
0.400	0.001	0.002	0.003	0.005	0.005	0.000	0.002	0.004	0.007	0.007
0.500	0.002	0.002	0.003	0.003	0.004	0.000	0.001	0.003	0.005	0.005
0.600	0.002	0.002	0.002	0.003	0.004	-0.002	-0.001	0.001	0.002	0.003
0.700	0.002	0.002	0.002	0.003	0.003	-0.005	-0.004	-0.002	-0.001	0.000
0.800	0.002	0.002	0.002	0.003	0.004	-0.007	-0.005	-0.004	-0.002	-0.002
0.900	0.002	0.004	0.005	0.005	0.005	-0.011	-0.005	0.000	0.000	-0.002
0.975	0.008	0.005	0.003	0.002	0.002	0.010	0.003	0.000	-0.001	-0.003

6.4 R02 - Radial distribution diagrams



6.5 R02 - Questionaire 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	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	Mixed	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	0	0
C9	Averaged Y^+-value	0	0
C10	Number of cells on blade surface	0	0
	Norm. Dim. the Physical Domain		
D1	X_upstream/D, X_downstream/D	0	0
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	implicit	implicit
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	k-omega
F2	Convection scheme (Turb. Eqn.)	high-order upwind	high-order upwind
	Boundary conditions		
G1	Blade	resolved	resolved
G2	Hub	-	-
G3	Inlet	Fixed Velocity	Fixed Velocity
G4	Outlet	Fixed Pressure	Fixed Pressure
G5	Outer domain	Slip flow	Slip flow

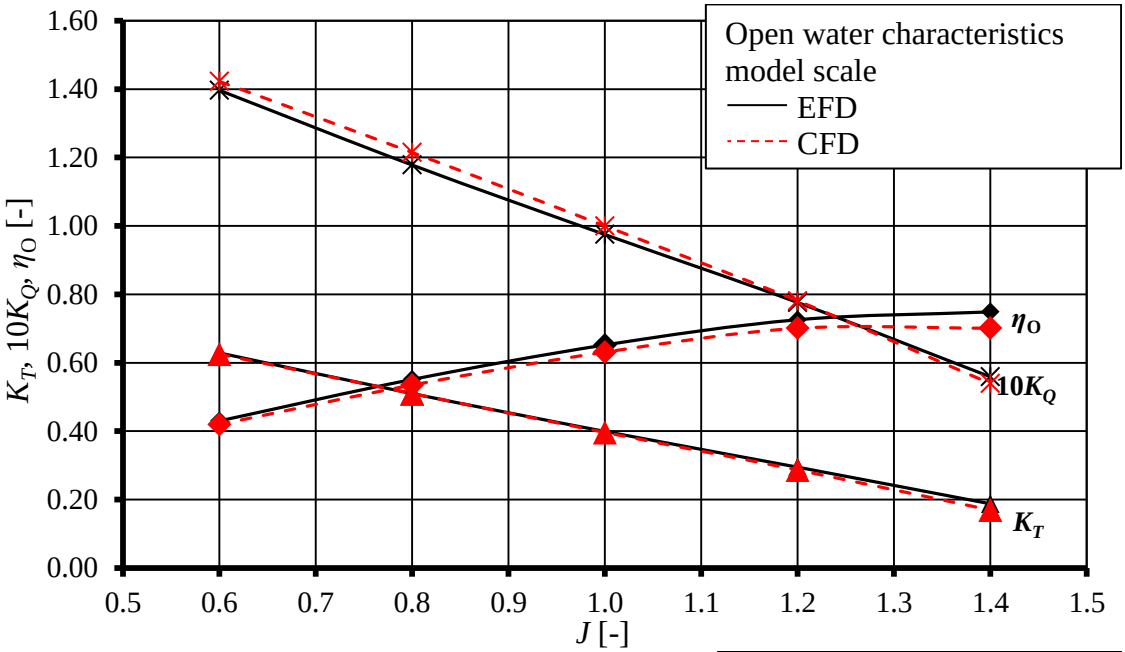
6.5 R02 - Questionaire part II

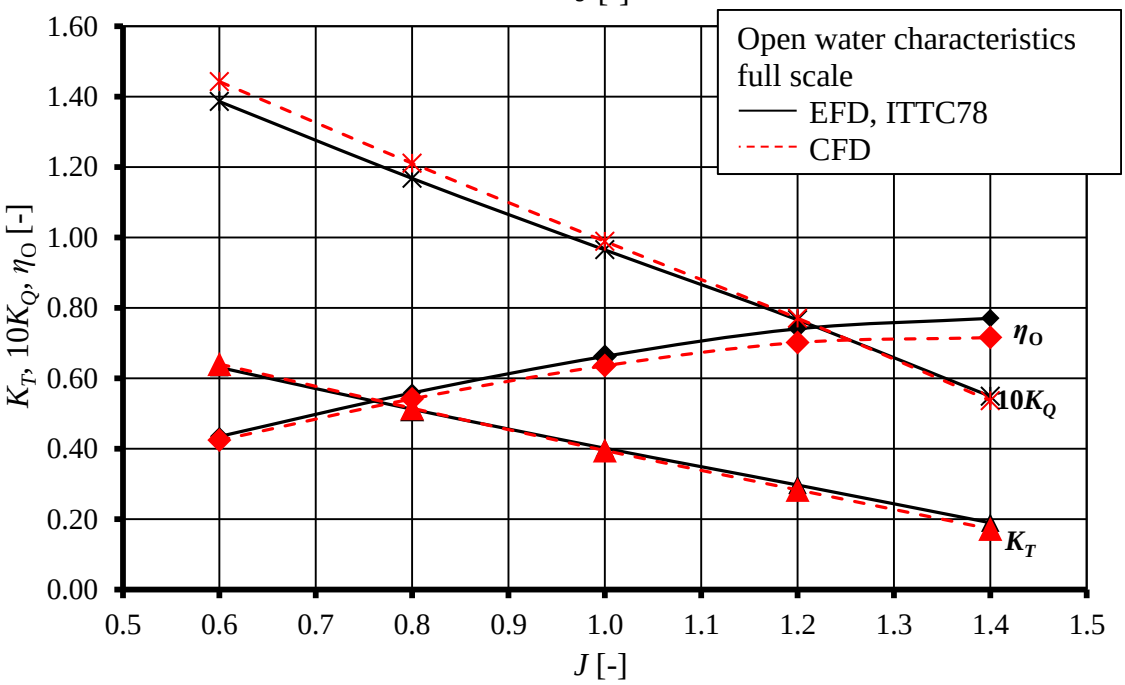
		model scale	**full scale**
	Computational Model		
H1	Fluid	incompressible	incompressible
H2	Pressure	Coupled	Coupled
	Transition		
I		0 / 0	0 / 0
	Please comment		
	Computational Demands		
J1	Number of processors used	0	0
J2	Number of timesteps (steady)	0	0
J3	Number of timesteps (transient)	0	0
J4	Wall-clock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

7 Result R03

7.1 R03 - Open water characteristic

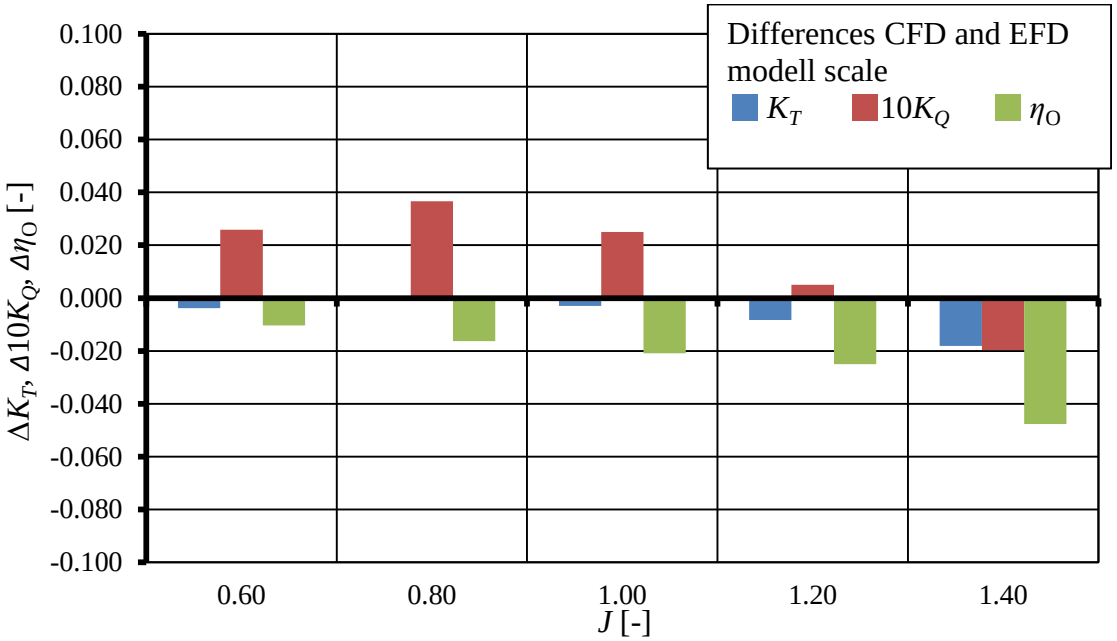
	CFD, model scale			CFD, full scale		
J	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.600	0.625	1.422	0.420	0.640	1.442	0.424
0.800	0.510	1.215	0.535	0.515	1.211	0.542
1.000	0.396	1.000	0.631	0.395	0.989	0.636
1.200	0.287	0.781	0.701	0.283	0.771	0.701
1.400	0.170	0.539	0.701	0.172	0.536	0.715

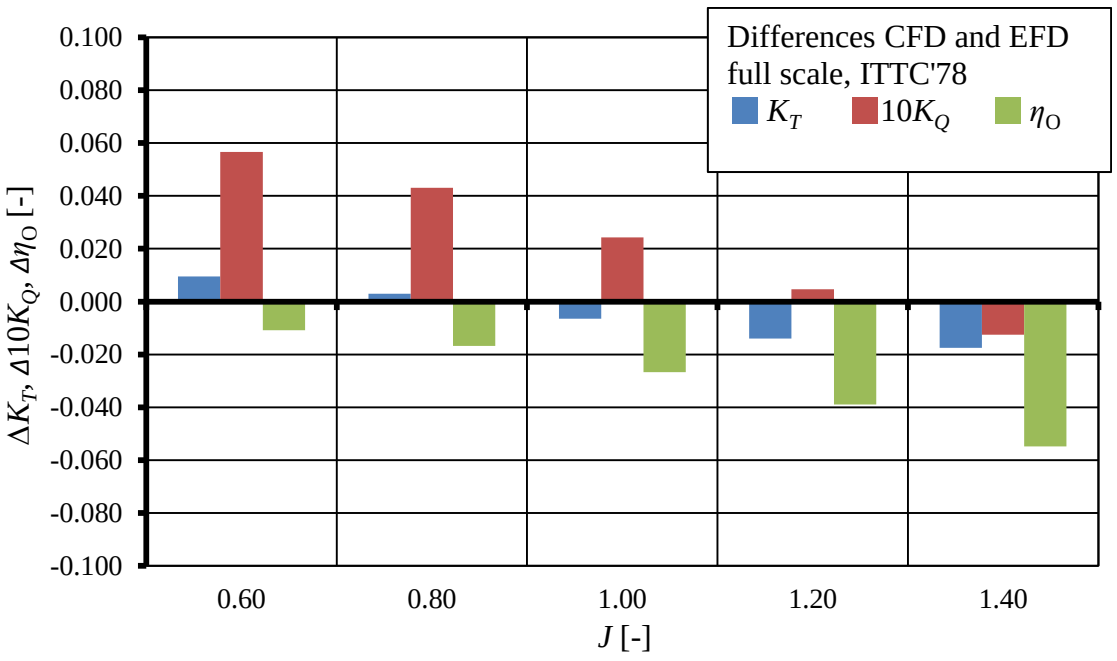




7.2 R03 - Differences CFD and EFD

	CFD - EFD, model scale			CFD - EFD, full scale		
	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
	[-]	[-]	[-]	[-]	[-]	[-]
0.60	-0.004	0.026	-0.010	0.009	0.057	-0.011
0.80	0.000	0.037	-0.016	0.003	0.043	-0.017
1.00	-0.003	0.025	-0.021	-0.006	0.024	-0.027
1.20	-0.008	0.005	-0.025	-0.014	0.005	-0.039
1.40	-0.018	-0.020	-0.048	-0.018	-0.013	-0.055





7.3 R03 - Radial distribution tables

model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.011	0.010	0.008	0.006	0.004	0.017	0.016	0.014	0.009	0.003
0.400	0.031	0.027	0.023	0.016	0.008	0.061	0.060	0.054	0.043	0.024
0.500	0.049	0.045	0.037	0.028	0.015	0.107	0.105	0.097	0.078	0.051
0.600	0.072	0.065	0.054	0.042	0.025	0.164	0.157	0.140	0.118	0.081
0.700	0.094	0.082	0.067	0.050	0.030	0.225	0.206	0.178	0.146	0.103
0.800	0.128	0.107	0.086	0.064	0.042	0.300	0.260	0.217	0.174	0.129
0.900	0.150	0.114	0.087	0.060	0.037	0.343	0.269	0.212	0.158	0.115
0.975	0.090	0.060	0.035	0.020	0.010	0.205	0.141	0.087	0.055	0.033

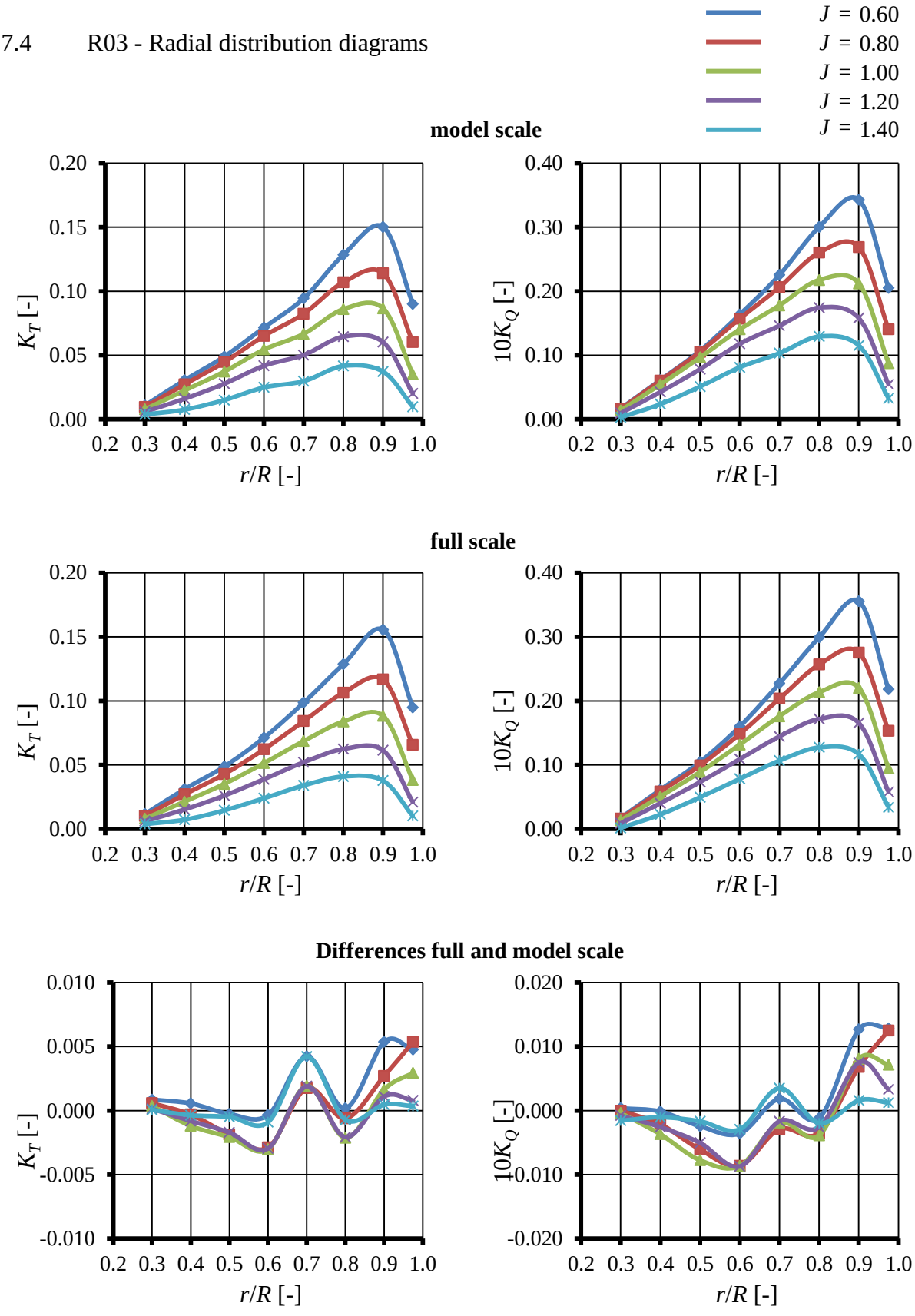
full scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.012	0.010	0.008	0.006	0.004	0.017	0.016	0.013	0.009	0.002
0.400	0.031	0.027	0.021	0.015	0.007	0.061	0.058	0.051	0.040	0.023
0.500	0.049	0.043	0.035	0.026	0.015	0.105	0.099	0.089	0.073	0.049
0.600	0.071	0.062	0.051	0.039	0.024	0.160	0.148	0.132	0.109	0.078
0.700	0.099	0.084	0.069	0.052	0.034	0.227	0.203	0.176	0.144	0.107
0.800	0.129	0.106	0.084	0.062	0.041	0.299	0.257	0.214	0.172	0.127
0.900	0.156	0.117	0.088	0.061	0.038	0.356	0.275	0.220	0.166	0.117
0.975	0.095	0.066	0.038	0.021	0.010	0.218	0.153	0.095	0.058	0.034

Differences full and model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	-0.001	-0.002
0.400	0.001	0.000	-0.001	-0.001	0.000	0.000	-0.002	-0.004	-0.003	-0.001
0.500	0.000	-0.002	-0.002	-0.002	0.000	-0.002	-0.006	-0.008	-0.005	-0.002
0.600	0.000	-0.003	-0.003	-0.003	-0.001	-0.004	-0.009	-0.009	-0.009	-0.003
0.700	0.004	0.002	0.002	0.002	0.004	0.002	-0.003	-0.002	-0.002	0.004
0.800	0.000	-0.001	-0.002	-0.002	-0.001	-0.001	-0.004	-0.004	-0.003	-0.002
0.900	0.005	0.003	0.002	0.001	0.000	0.013	0.007	0.008	0.008	0.002
0.975	0.005	0.005	0.003	0.001	0.000	0.013	0.012	0.007	0.003	0.001

7.4 R03 - Radial distribution diagrams



7.5 R03 - Questionaire 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	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	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	0,35 0,45 0,65	40 55 65
C9	Averaged Y^+-value	0.45	45
C10	Number of cells on blade surface	0	0
	Norm. Dim. the Physical Domain		
D1	X_upstream/D, X_downstream/D	3, 8	3, 8
D2	Cross area of domain in prop. plain	64	64
	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	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.)	2nd-order centered	2nd-order centered
	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	resolved	resolved

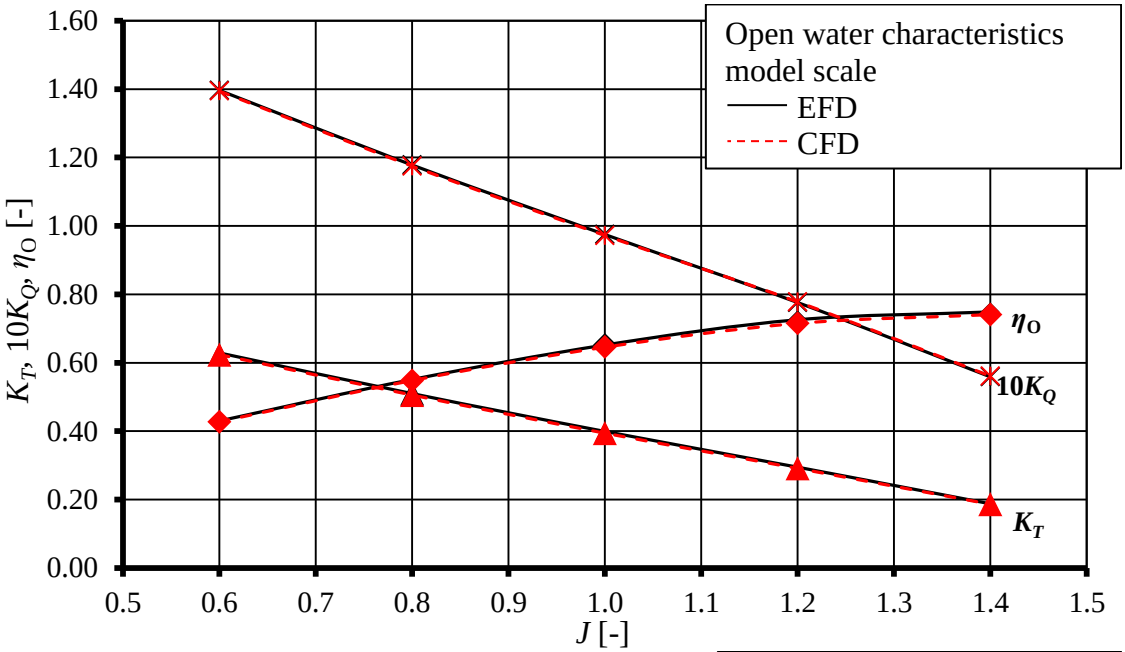
7.5 R03 - Questionaire part II

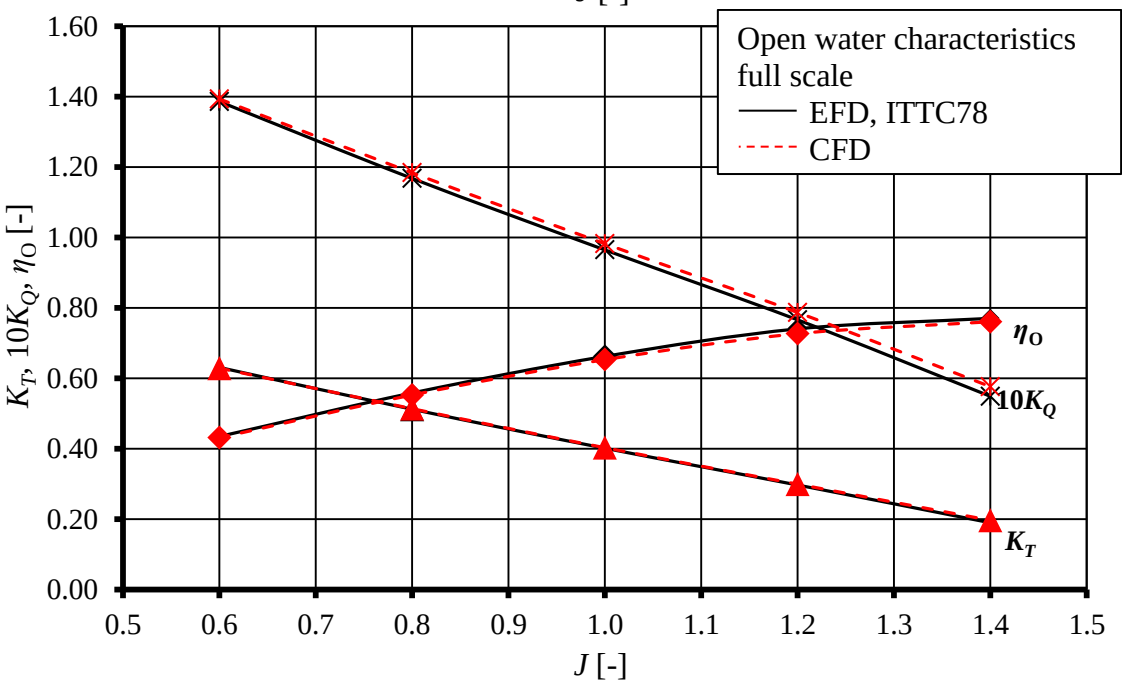
		model scale	full scale
	Computational Model		
H1	Fluid	incompressible	incompressible
H2	Pressure	pressure correction	pressure correction
	Transition		
I	Please comment	gamma re theta model	no
	Computational Demands		
J1	Number of processors used	0	0
J2	Number of timesteps (steady)	0	0
J3	Number of timesteps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

8 Result R04

8.1 R04 - Open water characteristic

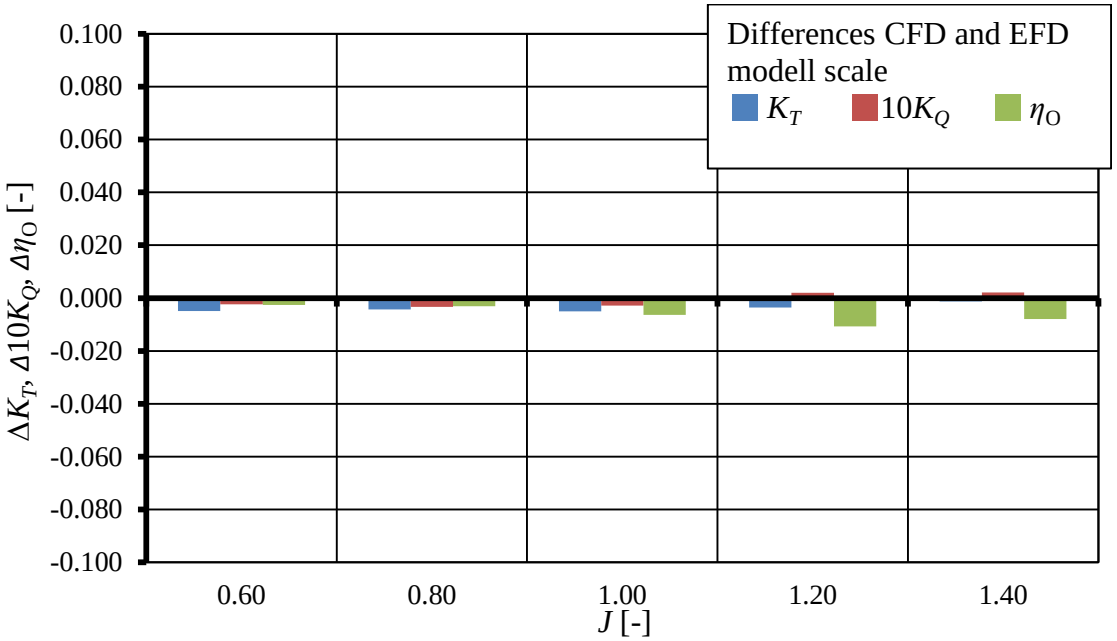
	CFD, model scale			CFD, full scale		
J	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.600	0.624	1.394	0.427	0.629	1.393	0.431
0.800	0.506	1.175	0.548	0.514	1.184	0.553
1.000	0.394	0.972	0.646	0.403	0.982	0.653
1.200	0.291	0.778	0.715	0.299	0.787	0.727
1.400	0.186	0.561	0.741	0.197	0.576	0.761

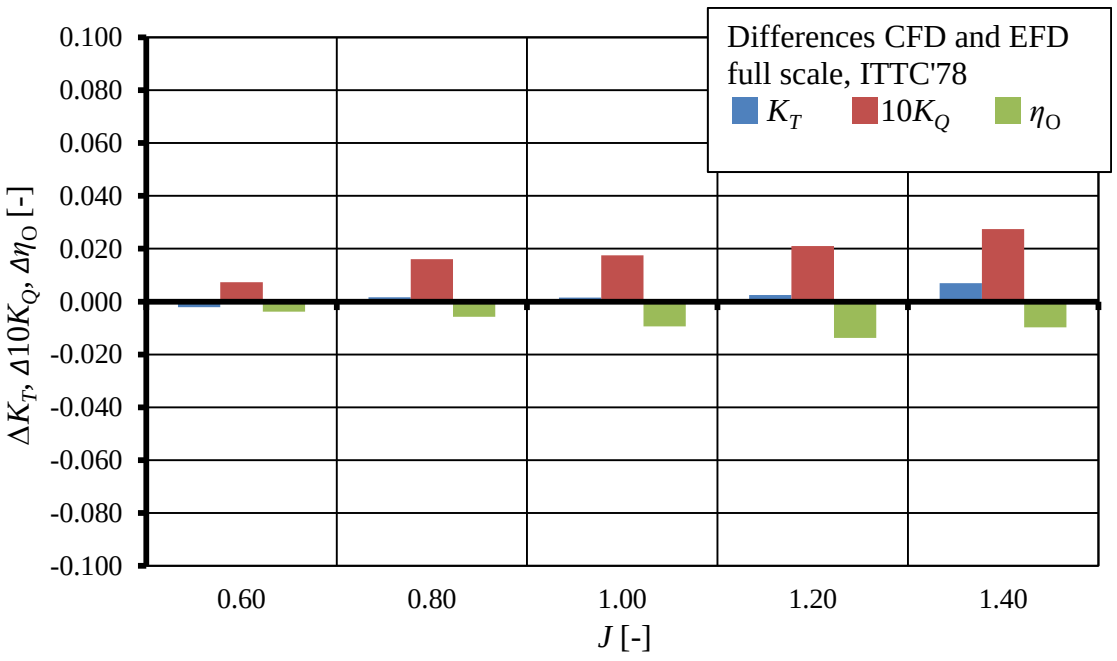




8.2 R04 - Differences CFD and EFD

	CFD - EFD, model scale			CFD - EFD, full scale		
	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
	[-]	[-]	[-]	[-]	[-]	[-]
0.60	-0.005	-0.002	-0.003	-0.002	0.007	-0.004
0.80	-0.004	-0.003	-0.003	0.002	0.016	-0.006
1.00	-0.005	-0.003	-0.006	0.002	0.018	-0.009
1.20	-0.004	0.002	-0.011	0.002	0.021	-0.014
1.40	-0.001	0.002	-0.008	0.007	0.027	-0.010

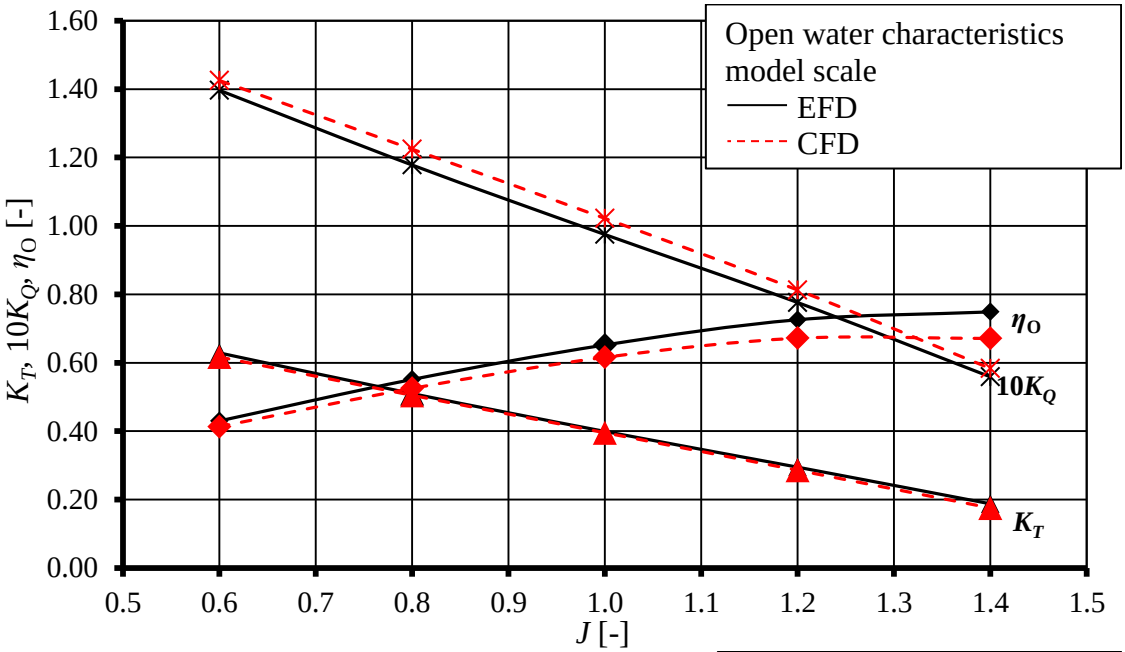


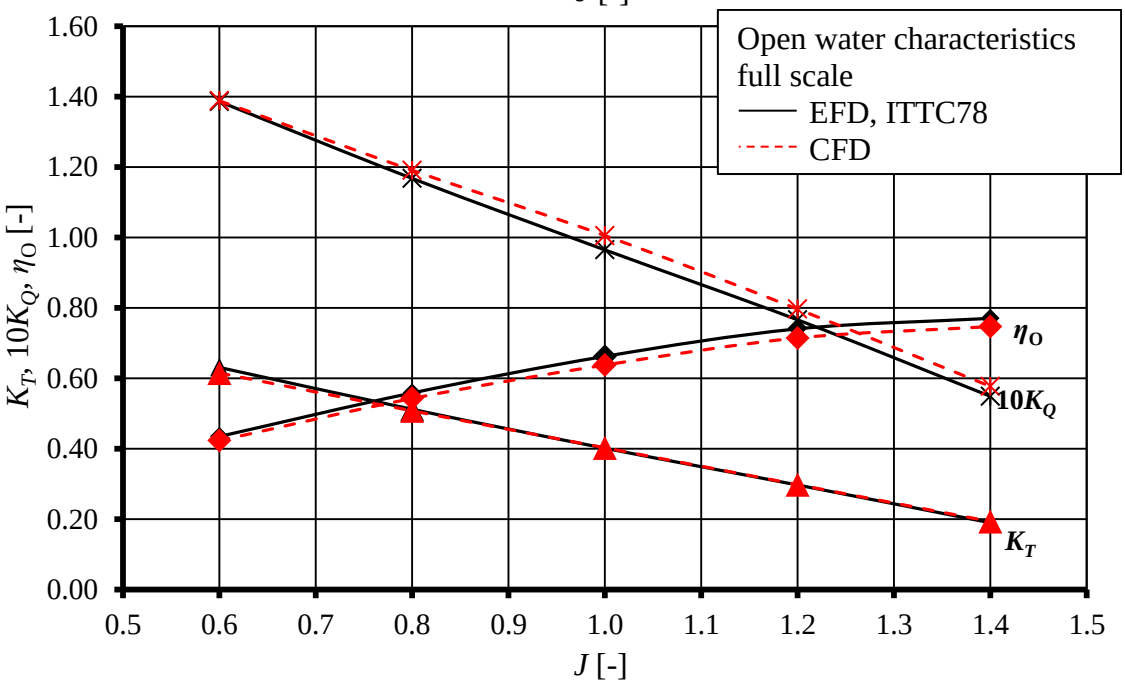


9 Result R05

9.1 R05 - Open water characteristic

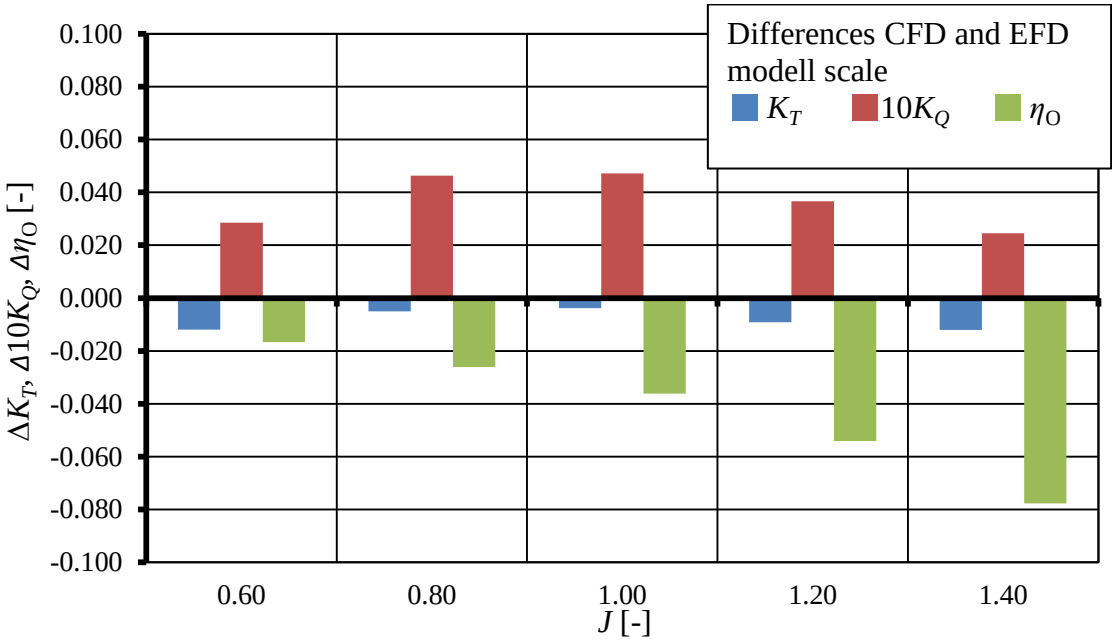
	CFD, model scale			CFD, full scale		
J	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.600	0.617	1.425	0.413	0.615	1.388	0.423
0.800	0.505	1.224	0.525	0.508	1.191	0.543
1.000	0.396	1.022	0.616	0.403	1.005	0.638
1.200	0.286	0.813	0.672	0.298	0.797	0.714
1.400	0.176	0.583	0.671	0.193	0.577	0.747

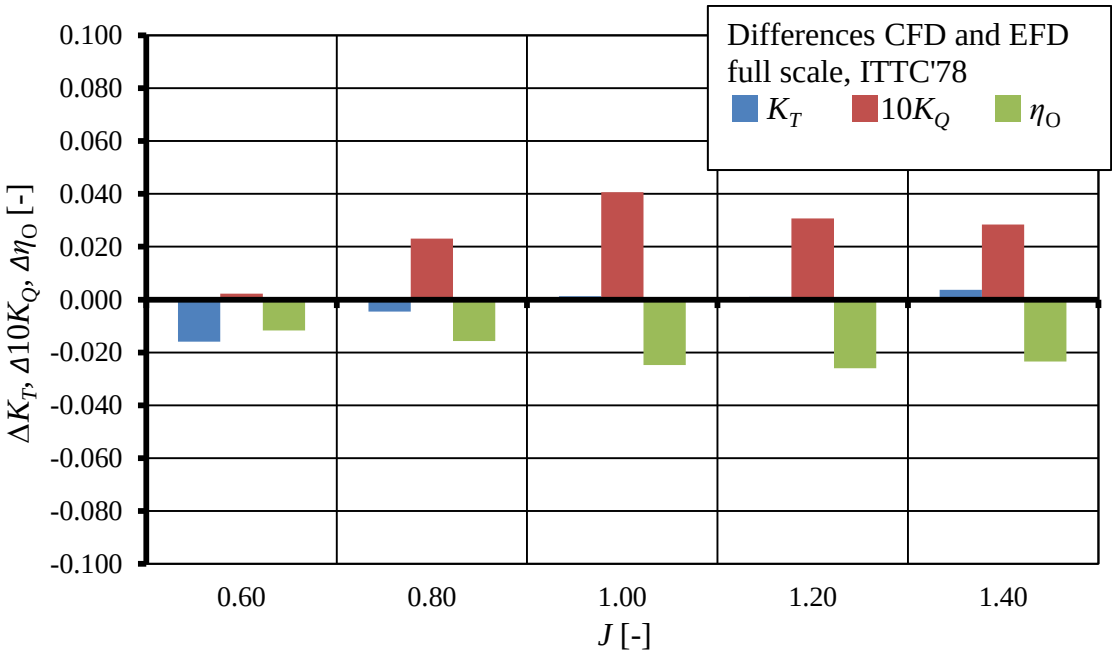




9.2 R05 - Differences CFD and EFD

	CFD - EFD, model scale			CFD - EFD, full scale		
	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
	[-]	[-]	[-]	[-]	[-]	[-]
0.60	-0.012	0.029	-0.017	-0.016	0.002	-0.012
0.80	-0.005	0.046	-0.026	-0.004	0.023	-0.016
1.00	-0.004	0.047	-0.036	0.001	0.041	-0.025
1.20	-0.009	0.037	-0.054	0.001	0.031	-0.026
1.40	-0.012	0.025	-0.078	0.004	0.028	-0.023





9.3 R05 - Radial distribution tables

model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.012	0.011	0.010	0.008	0.007	0.019	0.020	0.018	0.015	0.010
0.400	0.030	0.027	0.022	0.016	0.009	0.061	0.060	0.055	0.045	0.031
0.500	0.047	0.042	0.035	0.026	0.015	0.106	0.102	0.092	0.076	0.054
0.600	0.071	0.062	0.051	0.038	0.024	0.165	0.154	0.136	0.113	0.083
0.700	0.098	0.084	0.069	0.052	0.034	0.233	0.211	0.183	0.151	0.113
0.800	0.128	0.106	0.084	0.062	0.040	0.304	0.263	0.221	0.179	0.132
0.900	0.154	0.118	0.089	0.062	0.037	0.360	0.287	0.228	0.174	0.122
0.975	0.078	0.054	0.035	0.021	0.010	0.177	0.129	0.090	0.060	0.037

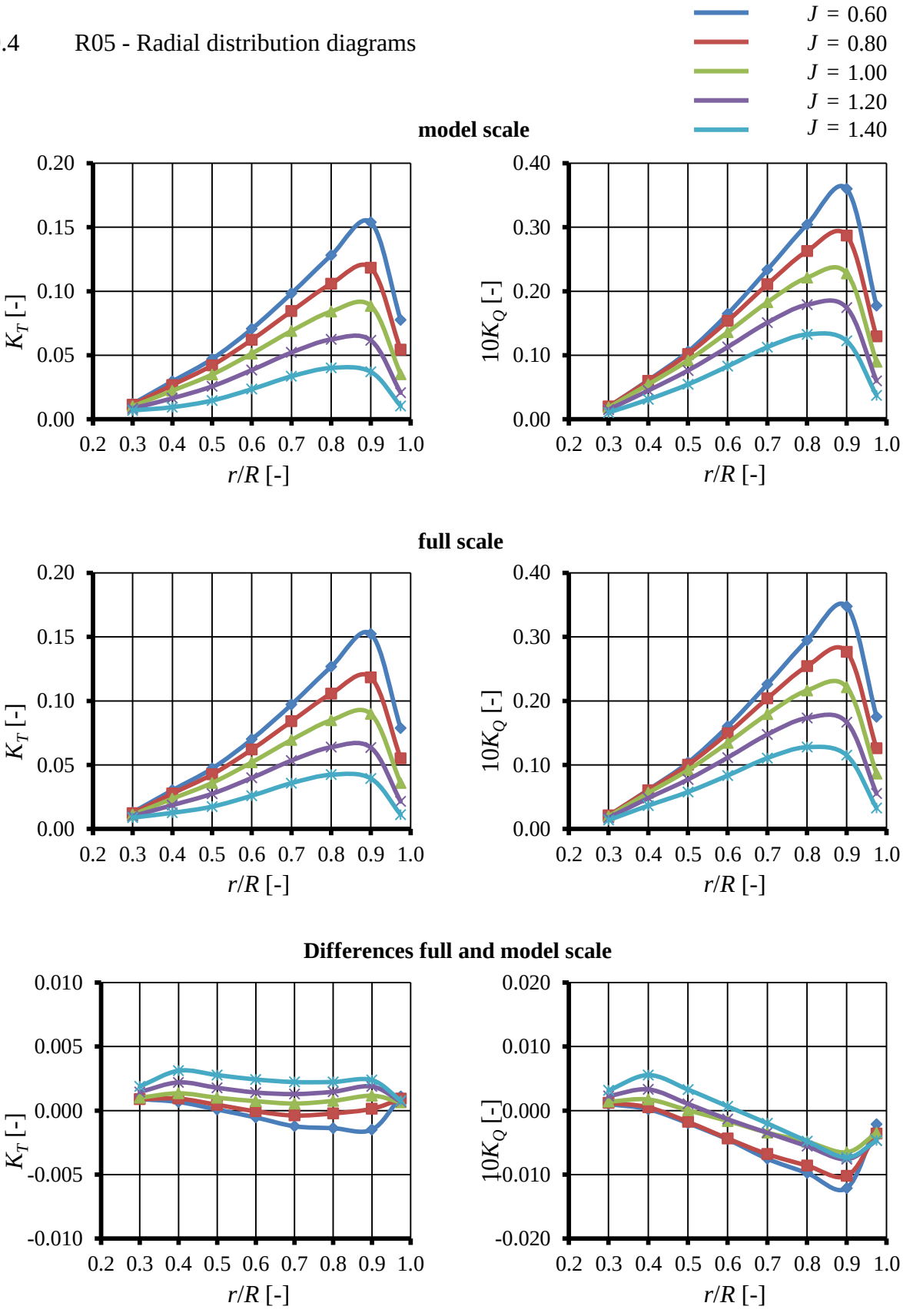
full scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.013	0.012	0.011	0.010	0.009	0.020	0.021	0.020	0.017	0.014
0.400	0.030	0.028	0.024	0.019	0.013	0.061	0.060	0.056	0.048	0.036
0.500	0.047	0.043	0.036	0.027	0.017	0.104	0.100	0.092	0.077	0.058
0.600	0.070	0.062	0.052	0.040	0.026	0.160	0.149	0.134	0.111	0.083
0.700	0.097	0.084	0.070	0.053	0.036	0.226	0.204	0.179	0.147	0.111
0.800	0.127	0.106	0.085	0.064	0.042	0.294	0.254	0.216	0.173	0.128
0.900	0.152	0.118	0.090	0.063	0.039	0.348	0.277	0.221	0.167	0.115
0.975	0.079	0.055	0.036	0.021	0.011	0.175	0.126	0.086	0.055	0.033

Differences full and model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.002	0.003
0.400	0.001	0.001	0.001	0.002	0.003	0.000	0.001	0.002	0.003	0.006
0.500	0.000	0.000	0.001	0.002	0.003	-0.002	-0.002	0.000	0.001	0.003
0.600	-0.001	0.000	0.001	0.001	0.002	-0.005	-0.004	-0.002	-0.001	0.001
0.700	-0.001	0.000	0.001	0.001	0.002	-0.008	-0.007	-0.003	-0.003	-0.002
0.800	-0.001	0.000	0.001	0.001	0.002	-0.010	-0.009	-0.005	-0.006	-0.005
0.900	-0.001	0.000	0.001	0.002	0.002	-0.012	-0.010	-0.007	-0.008	-0.007
0.975	0.001	0.001	0.001	0.001	0.001	-0.002	-0.004	-0.004	-0.005	-0.005

9.4 R05 - Radial distribution diagrams



9.5 R05 - Questionaire 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	Tetraheder	Tetraheder
C4	Primary surface elements	Triangles	Triangles
C5	Wall-boundary layer type	-	-
C7	Number of cells at boundary layer	none	none
C8	Y^+-value at r/R=0.4, 0.7, 0.9	35 , 45 ,50	1200, 1500, 1800
C9	Averaged Y^+-value	48	1400
C10	Number of cells on blade surface	80000	80000
	Norm. Dim. the Physical Domain		
D1	X_upstream/D, X_downstream/D	30D, 60D	30D, 60D
D2	Cross area of domain in prop. plain	3600	3600
	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)	double	double
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.)	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

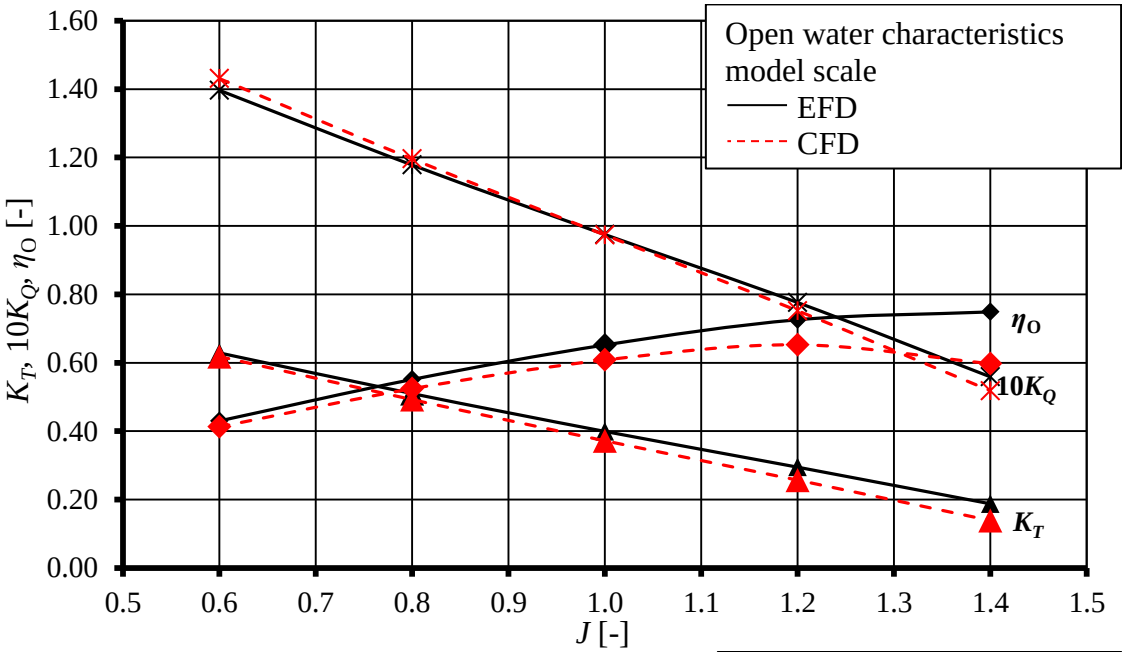
9.5 R05 - Questionaire part II

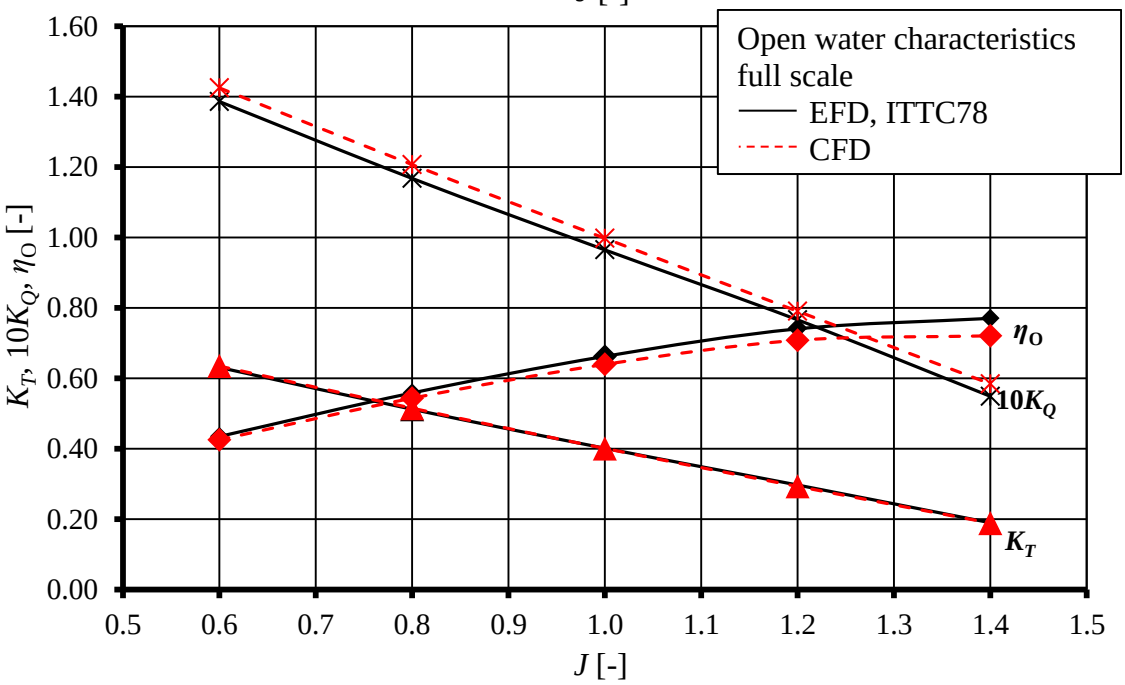
		model scale	full scale
	Computational Model		
H1	Fluid	incompressible	incompressible
H2	Pressure	Coupled	Coupled
	Transition		
I	Please comment	0 / 0	0 / 0
	Computational Demands		
J1	Number of processors used	11	11
J2	Number of timesteps (steady)	3500	3500
J3	Number of timesteps (transient)	0	0
J4	Wall-clock time per revolution	6.86	6.86
	Code		
K	References	0 / 0	0 / 0
	Comments		
L	Add. info.	0 / 0	0 / 0

10 Result R06

10.1 R06 - Open water characteristic

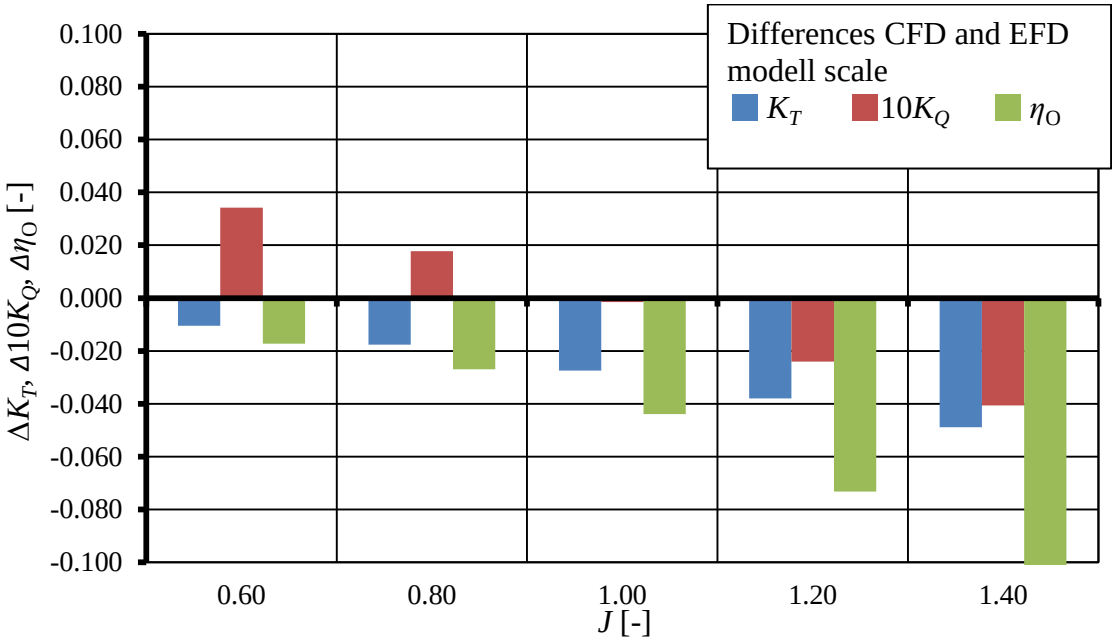
	CFD, model scale			CFD, full scale		
J	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.600	0.618	1.431	0.413	0.635	1.425	0.425
0.800	0.492	1.196	0.524	0.515	1.207	0.543
1.000	0.372	0.973	0.608	0.401	0.998	0.640
1.200	0.257	0.752	0.653	0.293	0.790	0.708
1.400	0.139	0.518	0.597	0.189	0.584	0.721

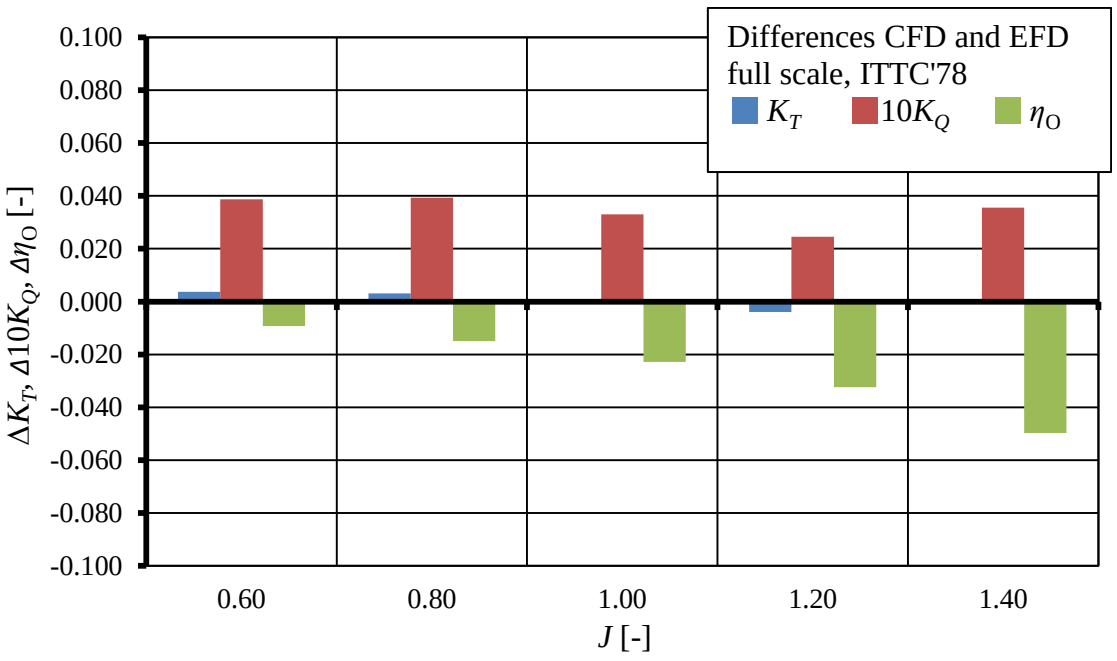




10.2 R06 - Differences CFD and EFD

	CFD - EFD, model scale			CFD - EFD, full scale		
	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
	[-]	[-]	[-]	[-]	[-]	[-]
0.60	-0.010	0.034	-0.017	0.004	0.039	-0.009
0.80	-0.018	0.018	-0.027	0.003	0.039	-0.015
1.00	-0.027	-0.001	-0.044	-0.001	0.033	-0.023
1.20	-0.038	-0.024	-0.073	-0.004	0.024	-0.032
1.40	-0.049	-0.041	-0.151	-0.001	0.036	-0.050





10.3 R06 - Radial distribution tables

model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.010	0.009	0.007	0.005	0.003	0.016	0.015	0.012	0.008	0.002
0.400	0.029	0.025	0.020	0.013	0.005	0.059	0.056	0.049	0.037	0.019
0.500	0.047	0.041	0.033	0.023	0.010	0.104	0.098	0.087	0.069	0.044
0.600	0.069	0.060	0.049	0.035	0.019	0.162	0.150	0.132	0.108	0.076
0.700	0.096	0.081	0.065	0.047	0.027	0.228	0.205	0.176	0.142	0.104
0.800	0.127	0.102	0.079	0.057	0.035	0.301	0.253	0.209	0.168	0.125
0.900	0.152	0.114	0.083	0.056	0.031	0.353	0.275	0.213	0.159	0.112
0.975	0.089	0.061	0.037	0.021	0.009	0.207	0.145	0.095	0.061	0.036

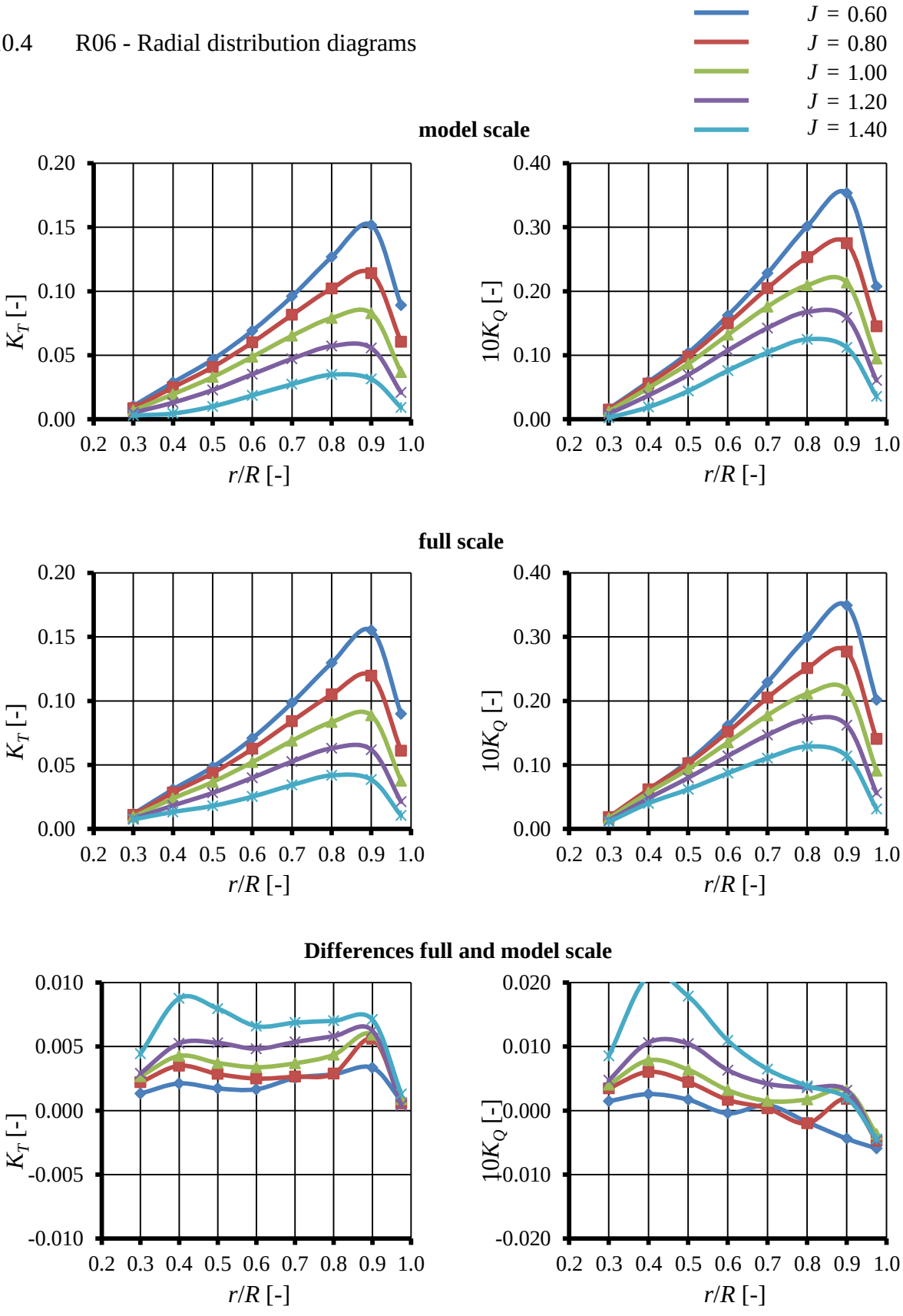
full scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.012	0.011	0.010	0.008	0.007	0.018	0.018	0.016	0.013	0.011
0.400	0.031	0.028	0.024	0.018	0.013	0.061	0.062	0.057	0.048	0.040
0.500	0.048	0.044	0.037	0.028	0.018	0.105	0.102	0.093	0.080	0.062
0.600	0.071	0.063	0.052	0.040	0.025	0.162	0.151	0.135	0.114	0.087
0.700	0.099	0.084	0.069	0.053	0.034	0.229	0.205	0.177	0.147	0.111
0.800	0.130	0.105	0.083	0.063	0.042	0.299	0.251	0.211	0.171	0.129
0.900	0.155	0.120	0.089	0.062	0.038	0.349	0.277	0.216	0.162	0.114
0.975	0.090	0.061	0.038	0.021	0.010	0.201	0.140	0.091	0.056	0.031

Differences full and model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.001	0.002	0.003	0.003	0.004	0.001	0.003	0.004	0.005	0.009
0.400	0.002	0.003	0.004	0.005	0.009	0.003	0.006	0.008	0.011	0.021
0.500	0.002	0.003	0.004	0.005	0.008	0.002	0.004	0.006	0.010	0.018
0.600	0.002	0.002	0.003	0.005	0.007	0.000	0.002	0.003	0.006	0.011
0.700	0.003	0.003	0.004	0.005	0.007	0.001	0.000	0.001	0.004	0.006
0.800	0.003	0.003	0.004	0.006	0.007	-0.002	-0.002	0.002	0.004	0.004
0.900	0.003	0.006	0.006	0.006	0.007	-0.004	0.002	0.003	0.003	0.002
0.975	0.001	0.001	0.001	0.000	0.001	-0.006	-0.005	-0.004	-0.005	-0.004

10.4 R06 - Radial distribution diagrams



10.5 R06 - Questionaire 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	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	17, 21, 27 (J=1.0)	15, 18, 23 (J=1.0)
C9	Averaged Y^+-value	22 (J=1.0)	18 (J=1.0)
C10	Number of cells on blade surface	18488 (back) 17994 (face+tip) = 36482	18488 (back) + 17994 (face+tip) = 36482
	Norm. Dim. the Physical Domain		
D1	X_upstream/D, X_downstream/D	4, 8	4, 8
D2	Cross area of domain in prop. plain	16	16
	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	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	-	-

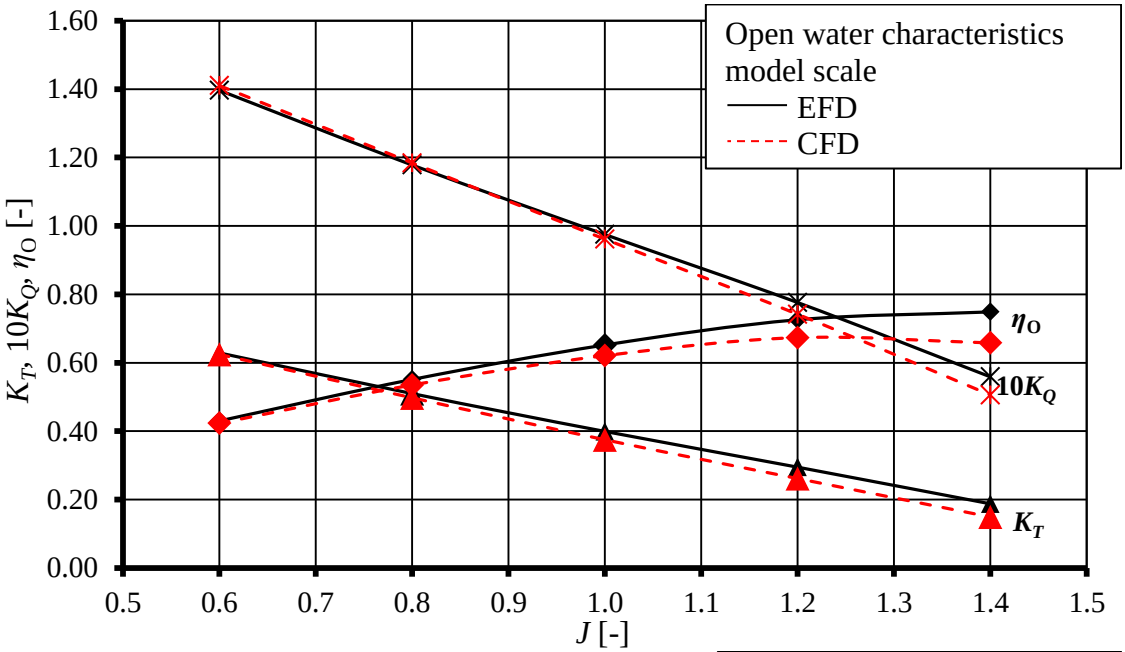
10.5 R06 - Questionaire part II

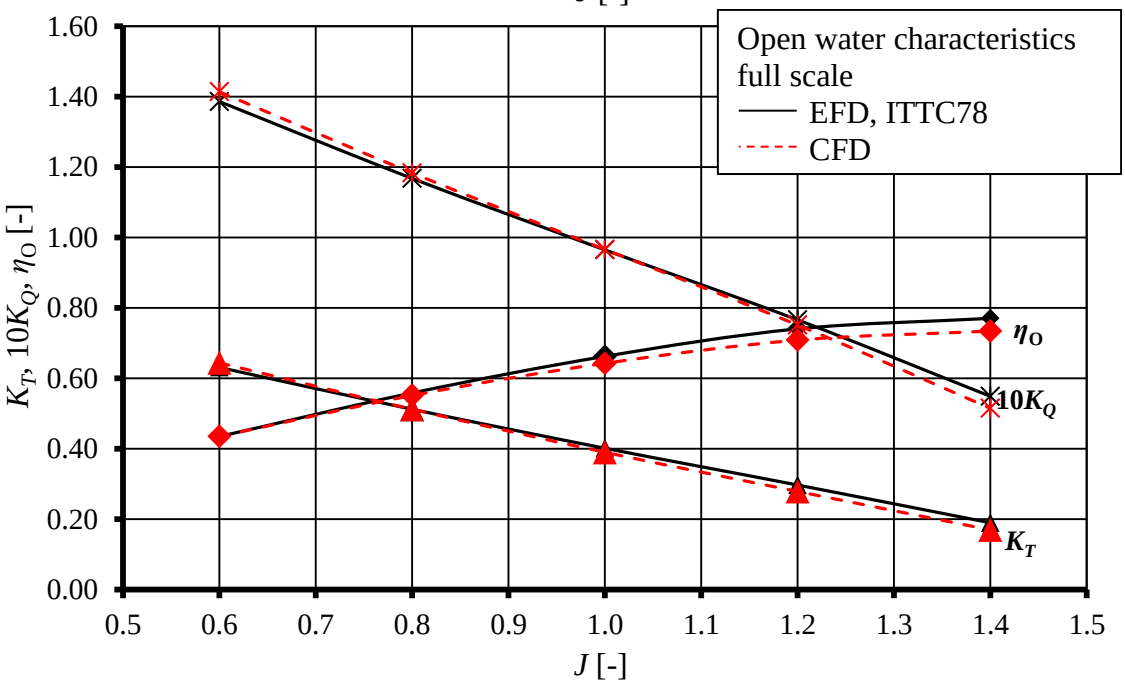
		model scale	**full scale**
	Computational Model		
H1	Fluid	incompressible	incompressible
H2	Pressure	pressure correction	pressure correction
	Transition		
I	Please comment	no / 0	0 / 0
	Computational Demands		
J1	Number of processors used	32	32
J2	Number of timesteps (steady)	5000	5000 ~ 8000, more iteration
J3	Number of timesteps (transient)	N/A	N/A
J4	Wall-clock time per revolution	approx. 1 hr / 4000 iters.	approx. 1 hr / 4000 iters.
	Code		
K	References	FLUENT 6.3	FLUENT 6.3
	Comments		
L	Add. info.	FLUENT 6.3 / 0	FLUENT 6.3 / 0

11 Result R07

11.1 R07 - Open water characteristic

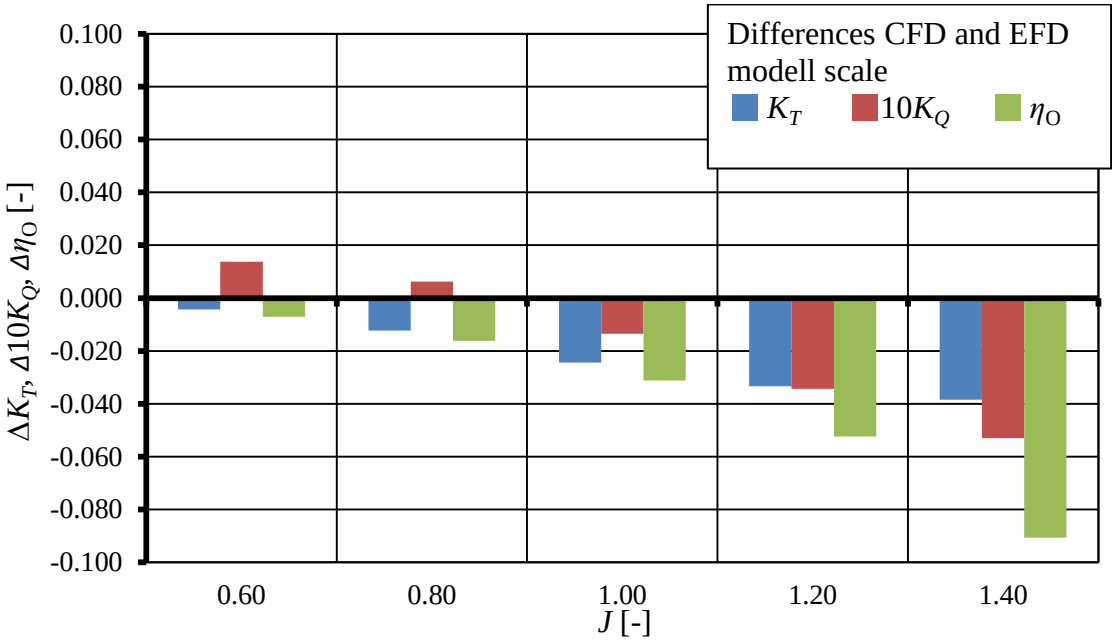
	CFD, model scale			CFD, full scale		
J	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.600	0.624	1.410	0.423	0.644	1.414	0.435
0.800	0.498	1.184	0.535	0.512	1.183	0.551
1.000	0.375	0.961	0.621	0.390	0.966	0.643
1.200	0.262	0.742	0.673	0.279	0.751	0.708
1.400	0.149	0.506	0.658	0.170	0.515	0.734

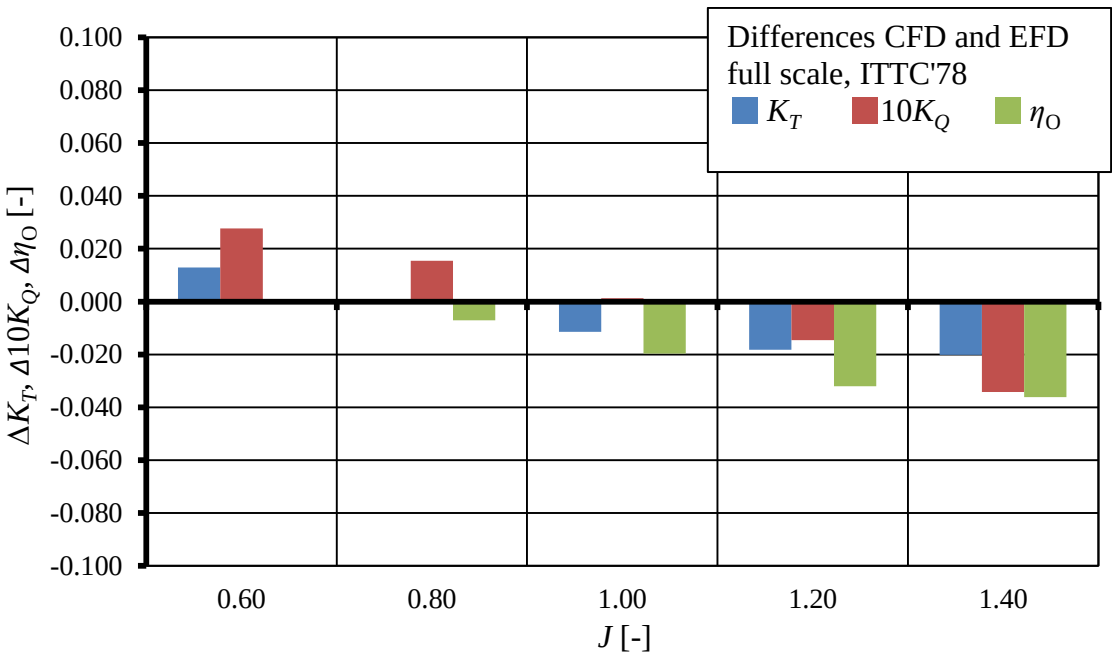




11.2 R07 - Differences CFD and EFD

	CFD - EFD, model scale			CFD - EFD, full scale		
	K_T [-]	$10K_Q$ [-]	η_O [-]	K_T [-]	$10K_Q$ [-]	η_O [-]
0.60	-0.004	0.014	-0.007	0.013	0.028	0.000
0.80	-0.012	0.006	-0.016	0.000	0.015	-0.007
1.00	-0.024	-0.013	-0.031	-0.011	0.001	-0.020
1.20	-0.033	-0.034	-0.052	-0.018	-0.015	-0.032
1.40	-0.038	-0.053	-0.091	-0.020	-0.034	-0.036





11.3 R07 - Radial distribution tables

model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.010	0.009	0.007	0.004	0.002	0.015	0.014	0.012	0.007	0.000
0.400	0.030	0.026	0.020	0.013	0.004	0.059	0.056	0.049	0.036	0.018
0.500	0.047	0.041	0.033	0.022	0.010	0.101	0.096	0.084	0.065	0.039
0.600	0.069	0.060	0.050	0.037	0.023	0.156	0.146	0.130	0.107	0.078
0.700	0.100	0.084	0.067	0.049	0.030	0.231	0.207	0.177	0.142	0.101
0.800	0.128	0.104	0.081	0.059	0.038	0.296	0.254	0.211	0.168	0.122
0.900	0.146	0.112	0.083	0.057	0.034	0.335	0.266	0.211	0.159	0.112
0.975	0.095	0.061	0.034	0.019	0.009	0.217	0.145	0.088	0.057	0.035

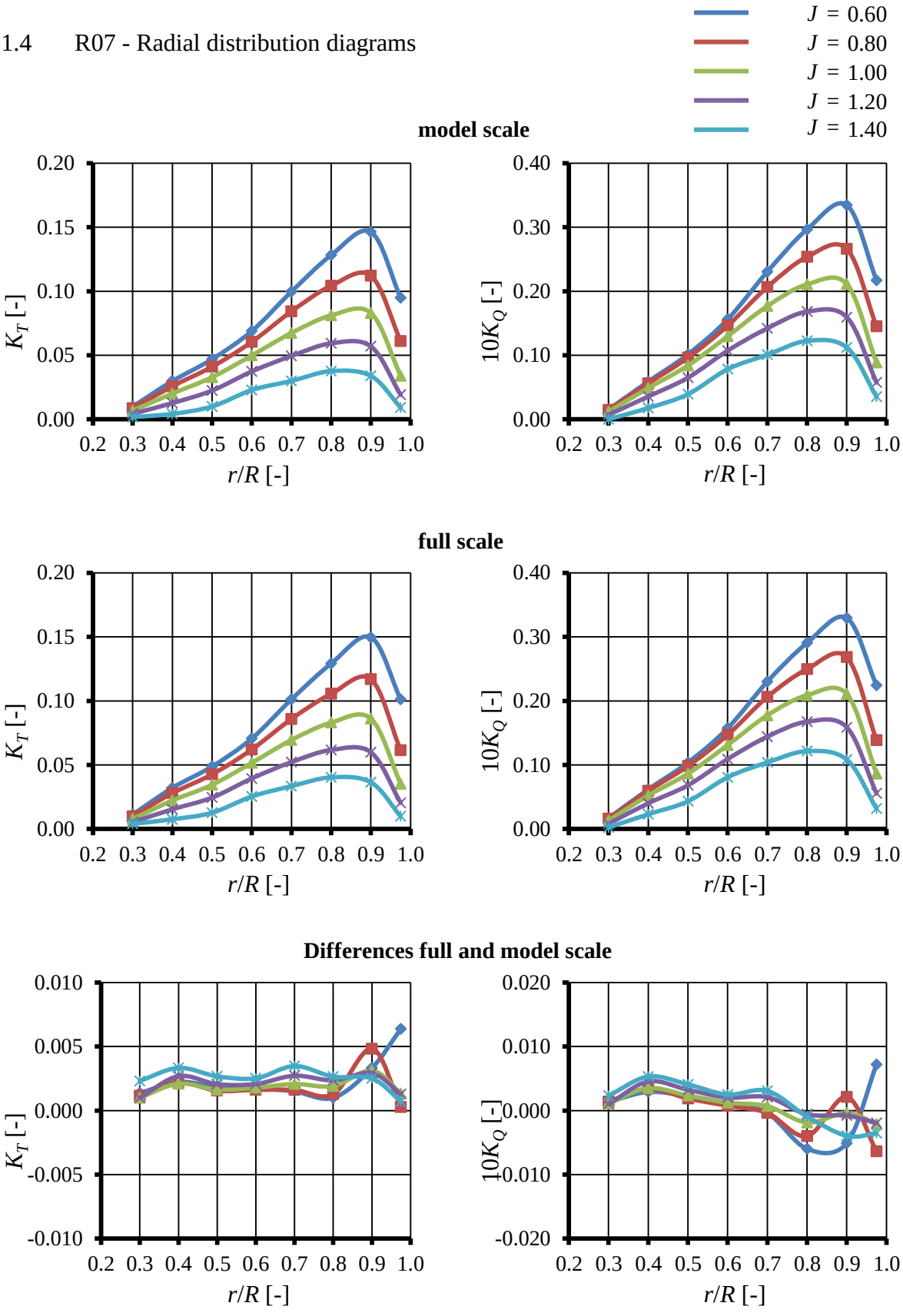
full scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.011	0.010	0.008	0.005	0.004	0.017	0.016	0.013	0.008	0.002
0.400	0.032	0.028	0.022	0.015	0.008	0.062	0.060	0.052	0.040	0.023
0.500	0.049	0.043	0.034	0.024	0.013	0.104	0.098	0.086	0.068	0.043
0.600	0.071	0.062	0.052	0.039	0.025	0.157	0.147	0.131	0.109	0.081
0.700	0.101	0.086	0.069	0.052	0.033	0.230	0.206	0.177	0.144	0.104
0.800	0.129	0.106	0.083	0.062	0.040	0.290	0.250	0.209	0.167	0.122
0.900	0.150	0.117	0.086	0.060	0.036	0.329	0.268	0.211	0.159	0.108
0.975	0.101	0.061	0.035	0.020	0.010	0.224	0.139	0.086	0.056	0.032

Differences full and model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.002
0.400	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.005	0.005
0.500	0.002	0.002	0.002	0.002	0.003	0.002	0.002	0.002	0.003	0.004
0.600	0.002	0.002	0.002	0.002	0.003	0.001	0.001	0.001	0.002	0.002
0.700	0.001	0.002	0.002	0.003	0.003	0.000	0.000	0.001	0.002	0.003
0.800	0.001	0.001	0.002	0.002	0.003	-0.006	-0.004	-0.002	-0.001	-0.001
0.900	0.003	0.005	0.003	0.003	0.003	-0.005	0.002	0.000	-0.001	-0.004
0.975	0.006	0.000	0.001	0.001	0.001	0.007	-0.006	-0.002	-0.002	-0.004

11.4 R07 - Radial distribution diagrams



11.5 R07 - Questionaire part I

		model scale	full scale
Solver			
	Computational Domain		
A1	Domain topology	-	-
A2	Grid-coupling technique	-	-
	Propeller Representation		
B1	Number of considered blades	-	-
	Computational Grid		
C1	Type	-	-
C2	Local-grid refinement	-	-
C3	Primary volume elements	-	-
C4	Primary surface elements	-	-
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	0	0
C9	Averaged Y^+-value	1	1
C10	Number of cells on blade surface	9800	11300
	Norm. Dim. the Physical Domain		
D1	X_upstream/D, X_downstream/D	2	2
D2	Cross area of domain in prop. plain	4	4
	Numerical Approximation		
E1	Finite Approximation Scheme (Fluid)	-	-
E2	Coordinates	-	-
E3	Convection scheme (momentum eq.)	-	-
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	-	-
F2	Convection scheme (Turb. Eqn.)	-	-
	Boundary conditions		
G1	Blade	-	-
G2	Hub	-	-
G3	Inlet	please select	please select
G4	Outlet	please select	please select
G5	Outer domain	-	-

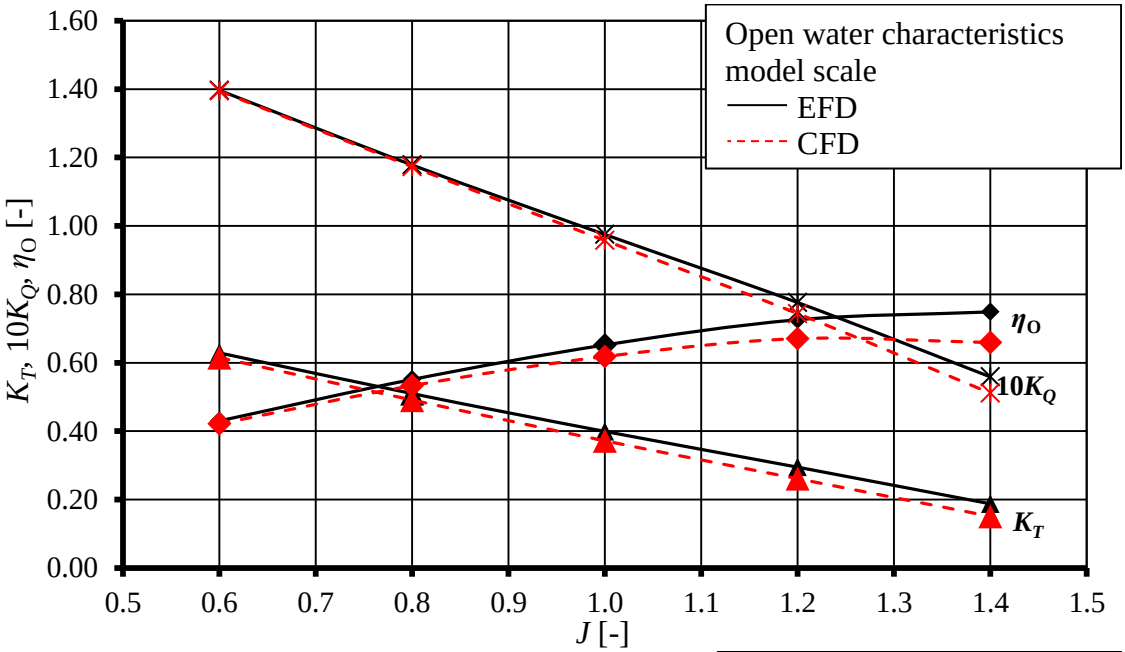
11.5 R07 - Questionaire part II

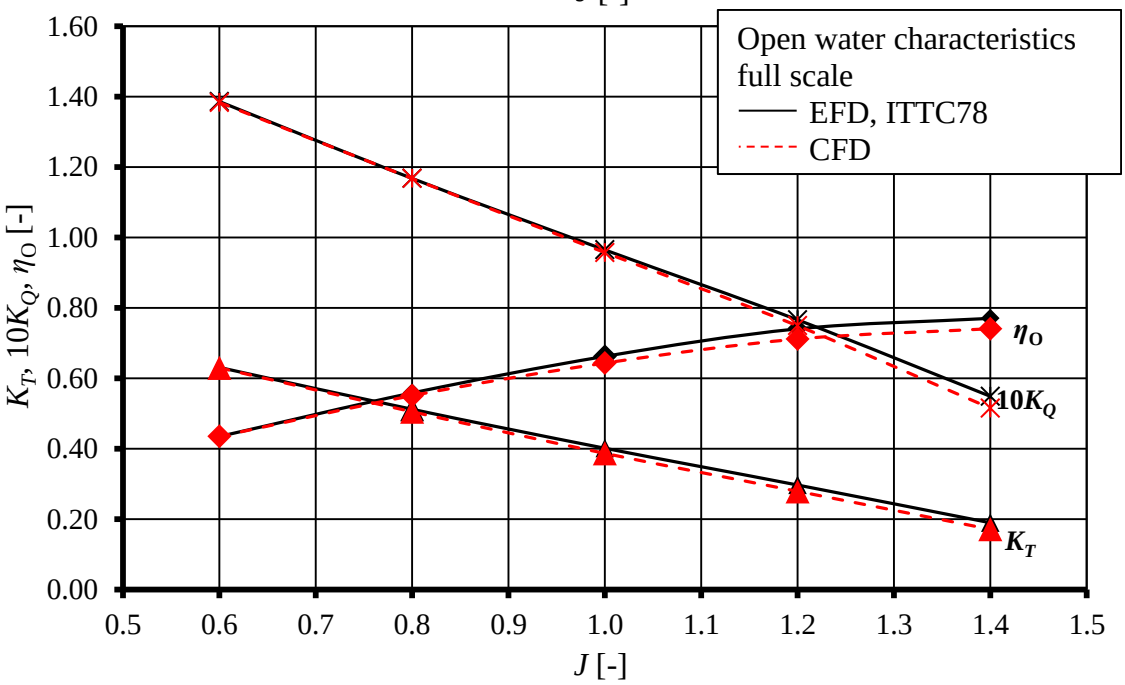
		model scale	full scale
	Computational Model		
H1	Fluid	-	-
H2	Pressure	-	-
	Transition		
I	Please comment	0 / 0	0 / 0
	Computational Demands		
J1	Number of processors used	32	32
J2	Number of timesteps (steady)	0	0
J3	Number of timesteps (transient)	0	0
J4	Wall-clock time per revolution	0	0
	Code		
K	References	0 / 0	0 / 0
	Comments		
L	Add. info.	0 / 0	0 / 0

12 Result R08

12.1 R08 - Open water characteristic

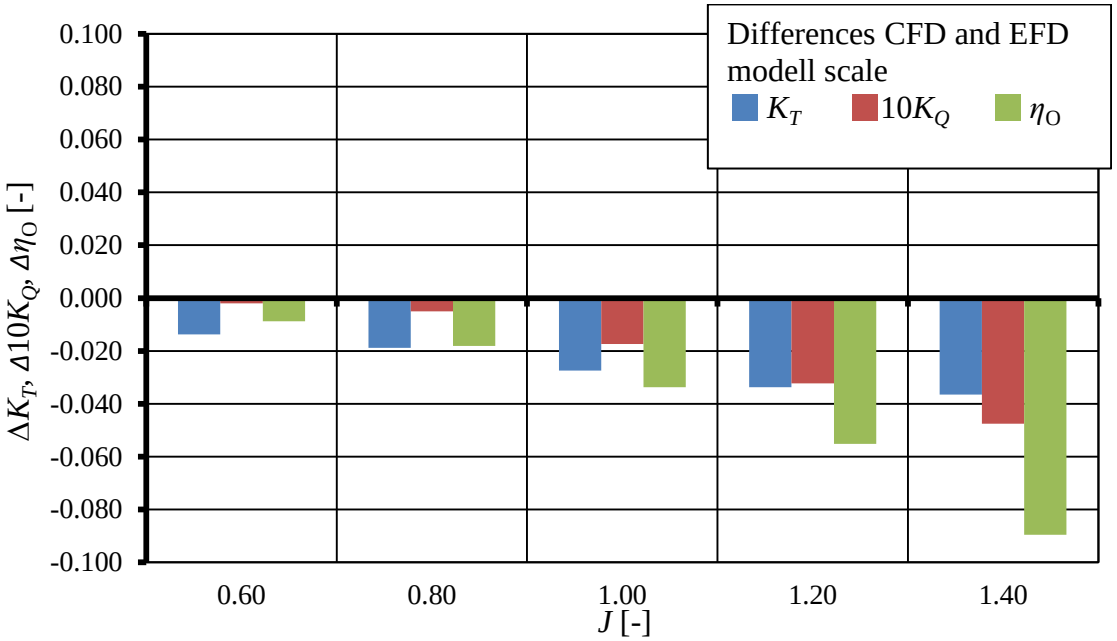
	CFD, model scale			CFD, full scale		
J	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.600	0.615	1.394	0.421	0.630	1.383	0.435
0.800	0.491	1.173	0.533	0.505	1.167	0.551
1.000	0.372	0.958	0.618	0.387	0.957	0.643
1.200	0.261	0.744	0.671	0.279	0.749	0.712
1.400	0.151	0.511	0.659	0.171	0.515	0.741

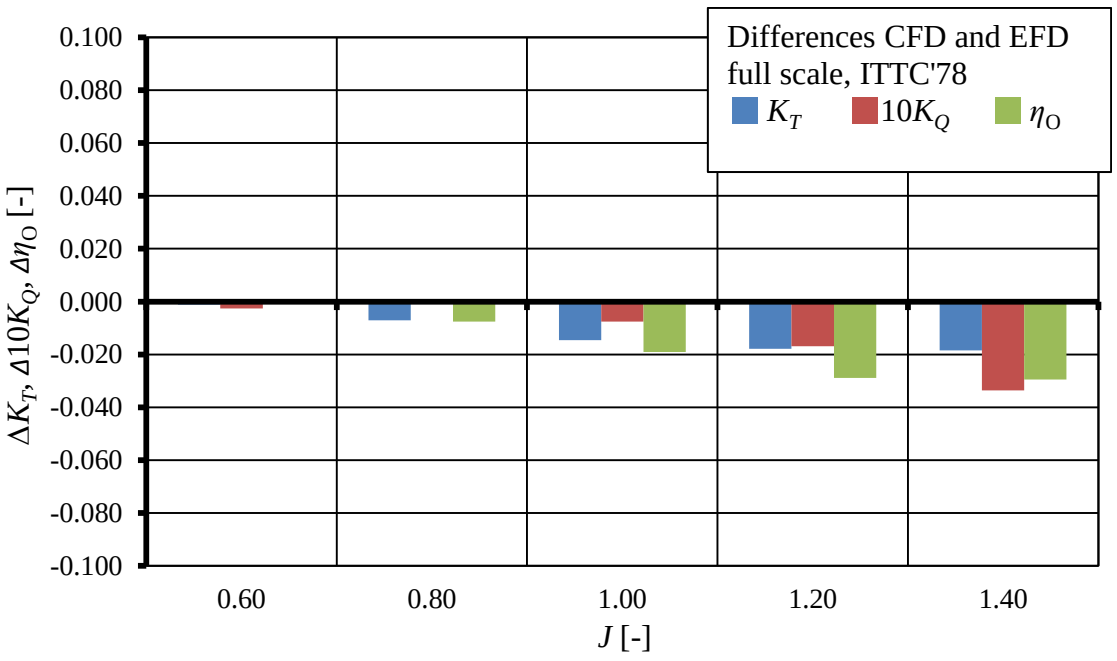




12.2 R08 - Differences CFD and EFD

	CFD - EFD, model scale			CFD - EFD, full scale		
	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
	[-]	[-]	[-]	[-]	[-]	[-]
0.60	-0.014	-0.002	-0.009	-0.001	-0.003	0.000
0.80	-0.019	-0.005	-0.018	-0.007	0.000	-0.008
1.00	-0.027	-0.017	-0.034	-0.015	-0.008	-0.019
1.20	-0.034	-0.032	-0.055	-0.018	-0.017	-0.029
1.40	-0.037	-0.048	-0.090	-0.018	-0.034	-0.030





12.3 R08 - Radial distribution tables

model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.010	0.008	0.007	0.004	0.002	0.015	0.014	0.012	0.007	0.000
0.400	0.029	0.025	0.019	0.012	0.004	0.059	0.055	0.048	0.035	0.017
0.500	0.047	0.041	0.033	0.023	0.012	0.102	0.097	0.086	0.069	0.044
0.600	0.070	0.061	0.050	0.036	0.021	0.159	0.147	0.130	0.106	0.075
0.700	0.097	0.082	0.066	0.050	0.031	0.225	0.202	0.174	0.142	0.104
0.800	0.127	0.103	0.080	0.059	0.038	0.295	0.251	0.209	0.168	0.123
0.900	0.144	0.112	0.083	0.057	0.034	0.330	0.266	0.211	0.160	0.113
0.975	0.091	0.059	0.034	0.019	0.009	0.209	0.141	0.088	0.058	0.036

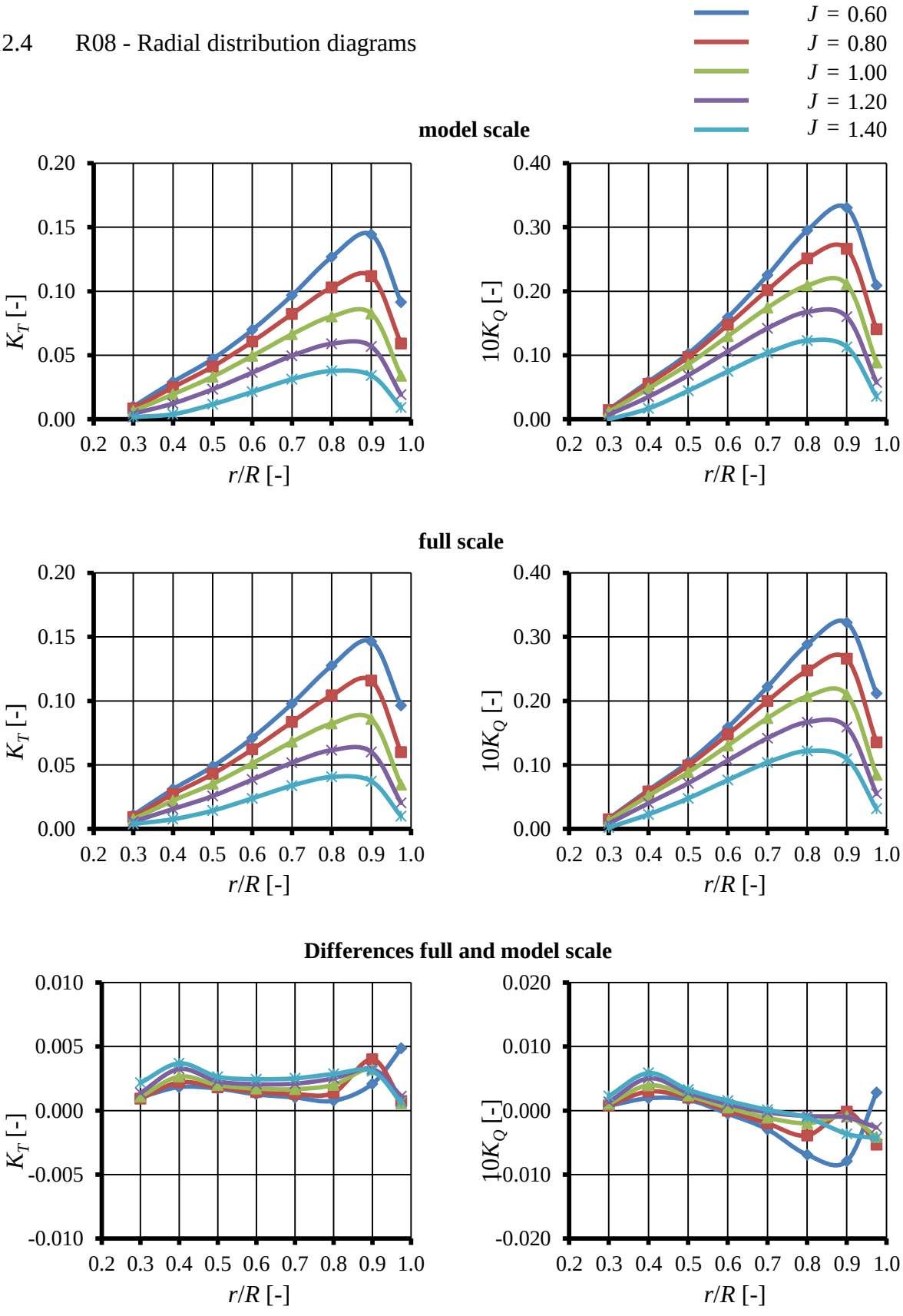
full scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.011	0.009	0.008	0.006	0.004	0.016	0.015	0.013	0.008	0.002
0.400	0.031	0.027	0.022	0.016	0.008	0.061	0.058	0.052	0.040	0.023
0.500	0.049	0.043	0.035	0.026	0.014	0.104	0.099	0.088	0.071	0.048
0.600	0.071	0.062	0.051	0.039	0.024	0.159	0.147	0.130	0.107	0.076
0.700	0.098	0.083	0.068	0.052	0.034	0.222	0.200	0.173	0.142	0.104
0.800	0.127	0.104	0.082	0.062	0.041	0.288	0.247	0.207	0.167	0.122
0.900	0.146	0.116	0.086	0.060	0.037	0.322	0.266	0.210	0.159	0.109
0.975	0.096	0.060	0.034	0.020	0.010	0.212	0.135	0.084	0.055	0.031

Differences full and model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.002
0.400	0.002	0.002	0.003	0.003	0.004	0.002	0.003	0.004	0.005	0.006
0.500	0.002	0.002	0.002	0.002	0.003	0.002	0.002	0.002	0.003	0.003
0.600	0.001	0.001	0.002	0.002	0.002	0.000	0.000	0.000	0.001	0.002
0.700	0.001	0.001	0.002	0.002	0.003	-0.003	-0.002	-0.001	0.000	0.000
0.800	0.001	0.001	0.002	0.003	0.003	-0.007	-0.004	-0.002	-0.001	-0.001
0.900	0.002	0.004	0.003	0.003	0.003	-0.008	0.000	-0.001	-0.001	-0.004
0.975	0.005	0.001	0.001	0.001	0.001	0.003	-0.005	-0.004	-0.003	-0.004

12.4 R08 - Radial distribution diagrams



12.5 R08 - Questionaire part I

		model scale	**full scale**
Solver		ANSYS CFX	ANSYS CFX
	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, non-matching	1 blade, non-matching
	Computational Grid		
C1	Type	Structured	Structured
C2	Local-grid refinement	Possible - not used here	Possible - not 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	20	20
C8	Y^+-value at r/R=0.4, 0.7, 0.9	0	0
C9	Averaged Y^+-value	0.53	2.5
C10	Number of cells on blade surface	5369	5369
	Norm. Dim. the Physical Domain		
D1	X_upstream/D, X_downstream/D	20, 50	20,50
D2	Cross area of domain in prop. plain	900	900
	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)	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.)	2nd-order centered	2nd-order centered
	Boundary conditions		
G1	Blade	resolved	resolved
G2	Hub	resolved	resolved
G3	Inlet	Fixed Velocity	Fixed Pressure
G4	Outlet	Fixed Pressure	Fixed Pressure
G5	Outer domain	Slip flow	Slip flow

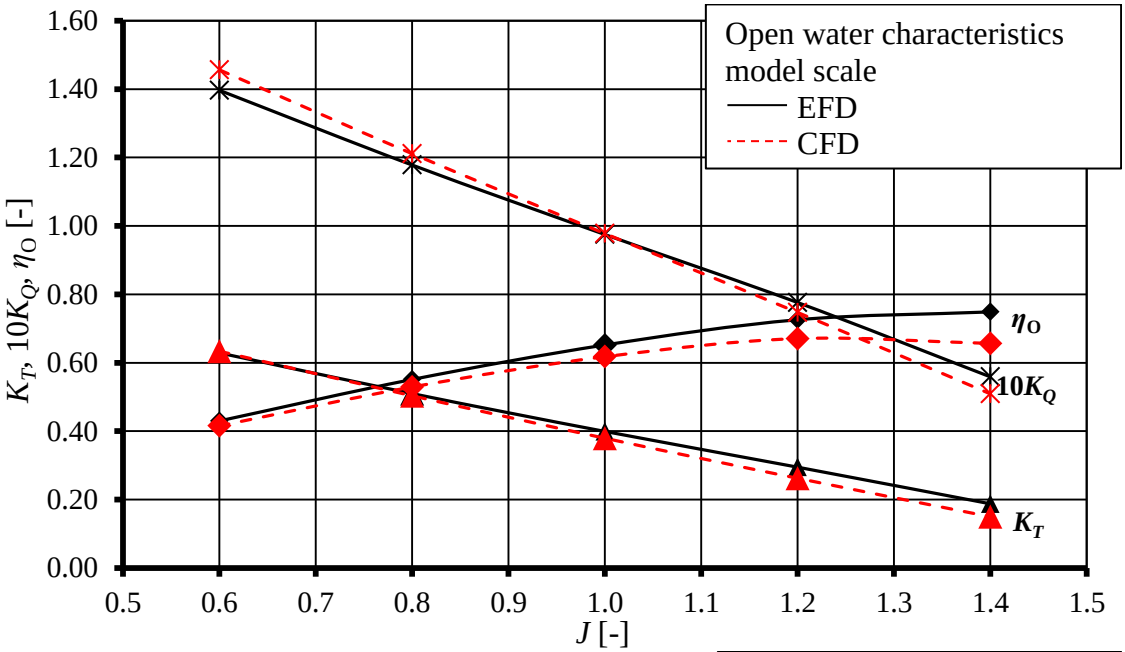
12.5 R08 - Questionaire part II

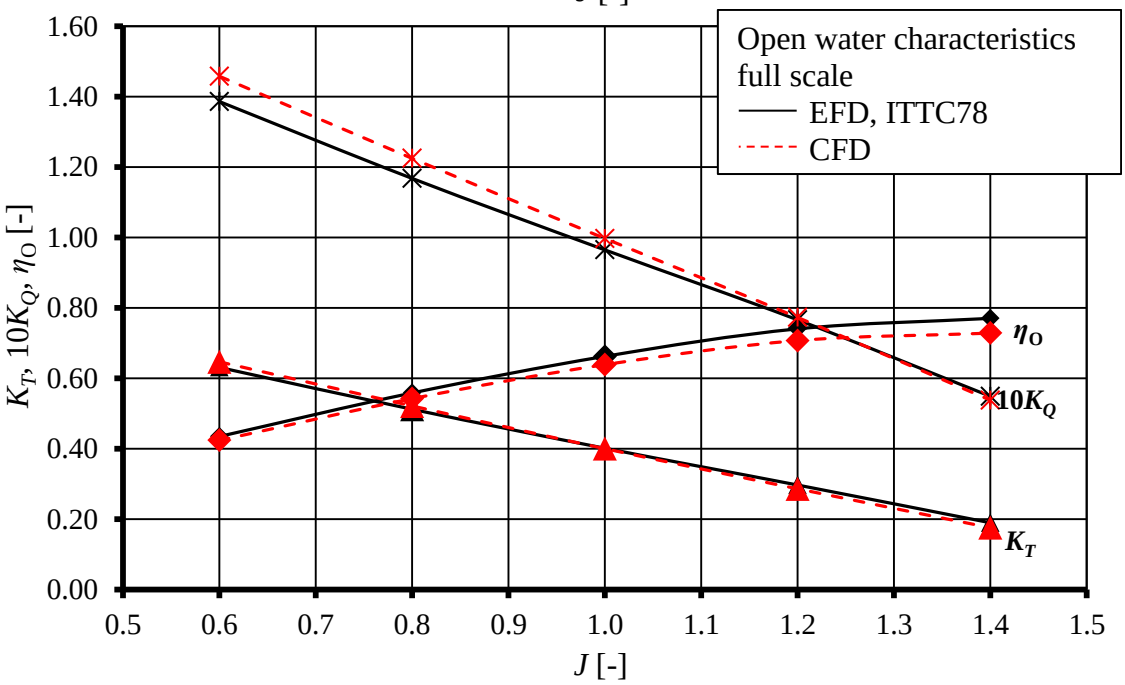
		model scale	full scale
	Computational Model		
H1	Fluid	incompressible	incompressible
H2	Pressure	Coupled	Coupled
	Transition		
I	Please comment	no / 0	0 / 0
	Computational Demands		
J1	Number of processors used	0	0
J2	Number of timesteps (steady)	0	0
J3	Number of timesteps (transient)	0	0
J4	Wall-clock time per revolution	0	0
	Code		
K	References	ANSYS CFX 13.0	ANSYS CFX 13.0
	Comments		
L	Add. info.	0 / 0	0 / 0

13 Result R10

13.1 R10 - Open water characteristic

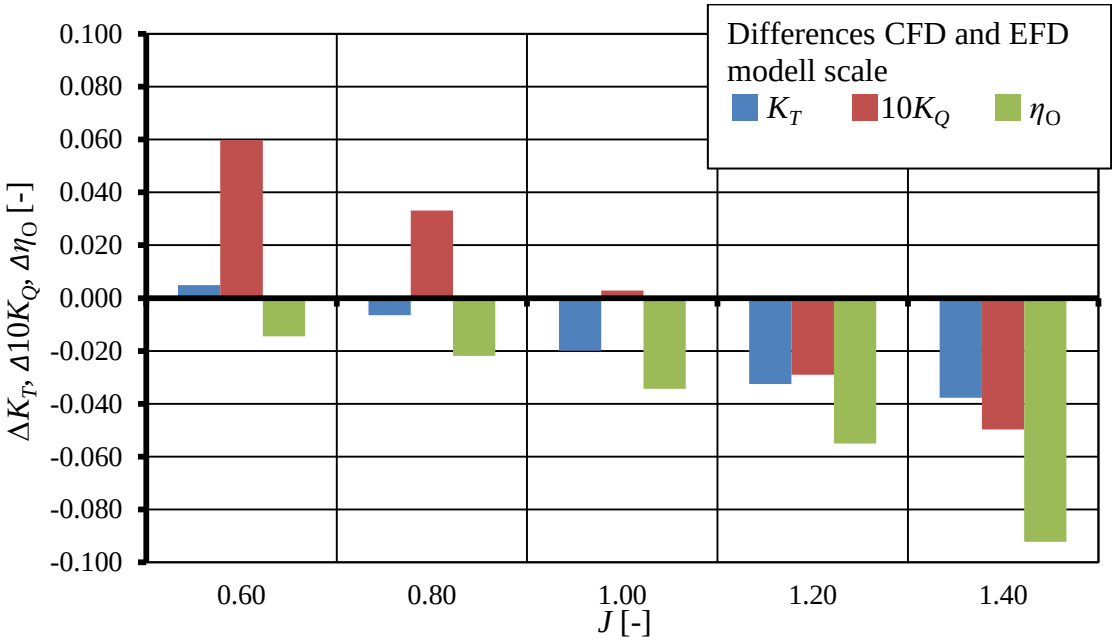
	CFD, model scale			CFD, full scale		
J	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.600	0.634	1.456	0.416	0.647	1.458	0.424
0.800	0.504	1.211	0.529	0.521	1.224	0.542
1.000	0.379	0.978	0.618	0.400	0.997	0.639
1.200	0.262	0.747	0.671	0.286	0.773	0.707
1.400	0.150	0.509	0.657	0.176	0.538	0.728

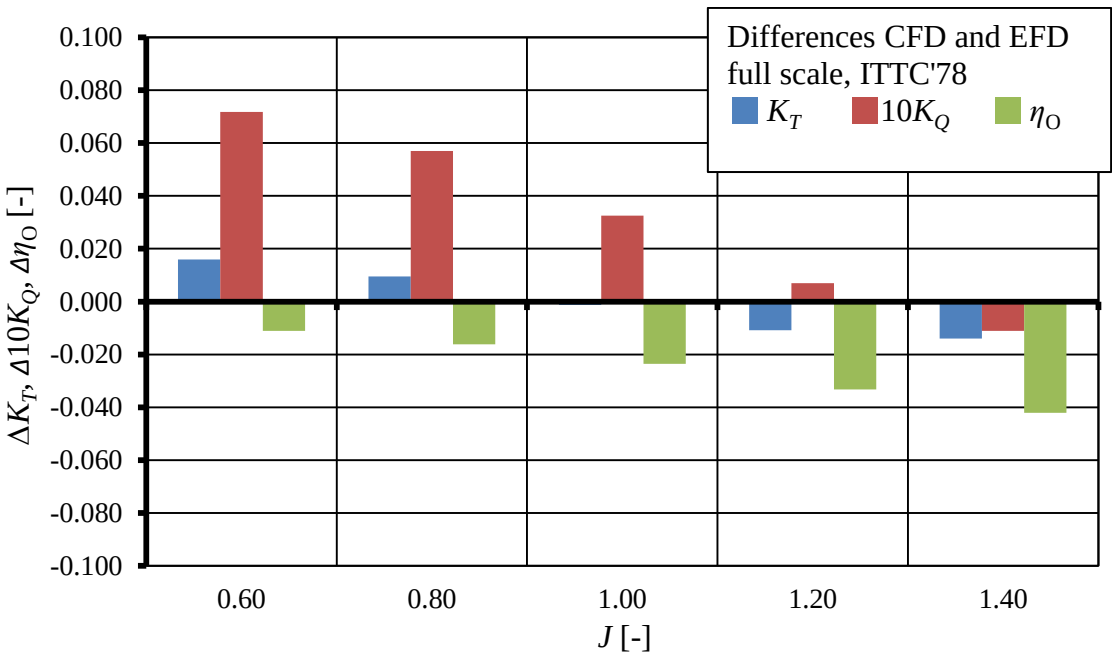




13.2 R10 - Differences CFD and EFD

	CFD - EFD, model scale			CFD - EFD, full scale		
	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
	[-]	[-]	[-]	[-]	[-]	[-]
0.60	0.005	0.060	-0.014	0.016	0.072	-0.011
0.80	-0.006	0.033	-0.022	0.009	0.057	-0.016
1.00	-0.020	0.003	-0.034	-0.001	0.032	-0.024
1.20	-0.033	-0.029	-0.055	-0.011	0.007	-0.033
1.40	-0.038	-0.050	-0.092	-0.014	-0.011	-0.042





13.3 R10 - Radial distribution tables

model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.010	0.009	0.007	0.005	0.003	0.016	0.015	0.013	0.008	0.002
0.400	0.029	0.025	0.019	0.012	0.004	0.058	0.055	0.047	0.035	0.018
0.500	0.047	0.041	0.033	0.023	0.011	0.102	0.096	0.085	0.068	0.043
0.600	0.069	0.060	0.049	0.036	0.020	0.159	0.147	0.129	0.104	0.073
0.700	0.099	0.084	0.068	0.050	0.031	0.232	0.207	0.178	0.144	0.104
0.800	0.130	0.106	0.082	0.059	0.037	0.308	0.260	0.213	0.168	0.122
0.900	0.161	0.119	0.085	0.058	0.034	0.376	0.286	0.218	0.162	0.112
0.975	0.089	0.061	0.036	0.020	0.009	0.206	0.145	0.094	0.058	0.035

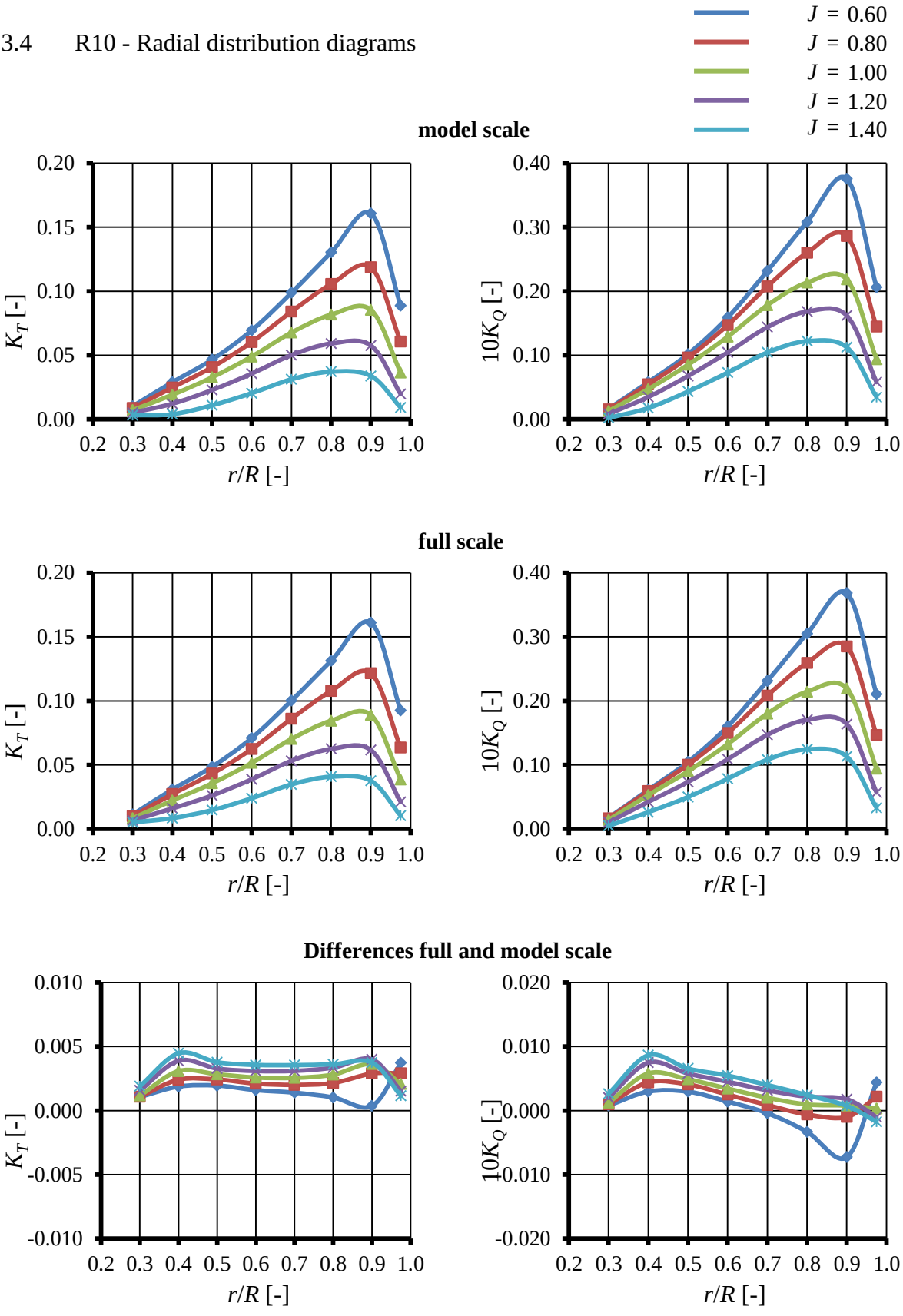
full scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.011	0.010	0.008	0.007	0.005	0.017	0.016	0.014	0.010	0.005
0.400	0.031	0.027	0.022	0.016	0.008	0.061	0.059	0.053	0.042	0.026
0.500	0.049	0.043	0.036	0.026	0.015	0.105	0.100	0.090	0.073	0.050
0.600	0.071	0.062	0.052	0.039	0.024	0.160	0.150	0.132	0.109	0.078
0.700	0.100	0.086	0.070	0.053	0.035	0.231	0.208	0.180	0.147	0.108
0.800	0.131	0.108	0.085	0.062	0.041	0.305	0.259	0.214	0.170	0.124
0.900	0.161	0.122	0.089	0.062	0.038	0.368	0.285	0.219	0.164	0.113
0.975	0.092	0.064	0.039	0.021	0.010	0.210	0.147	0.094	0.057	0.033

Differences full and model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.002	0.003
0.400	0.002	0.002	0.003	0.004	0.004	0.003	0.004	0.006	0.007	0.009
0.500	0.002	0.002	0.003	0.003	0.004	0.003	0.004	0.005	0.006	0.007
0.600	0.002	0.002	0.003	0.003	0.004	0.001	0.002	0.003	0.004	0.005
0.700	0.001	0.002	0.003	0.003	0.004	0.000	0.001	0.002	0.003	0.004
0.800	0.001	0.002	0.003	0.003	0.004	-0.003	-0.001	0.001	0.002	0.002
0.900	0.000	0.003	0.004	0.004	0.004	-0.007	-0.001	0.001	0.002	0.001
0.975	0.004	0.003	0.002	0.002	0.001	0.004	0.002	0.000	-0.001	-0.002

13.4 R10 - Radial distribution diagrams



13.5 R10 - Questionaire 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	511110	511110
C8	Y^+-value at r/R=0.4, 0.7, 0.9	50,50,50	6E+08
C9	Averaged Y^+-value	50	600
C10	Number of cells on blade surface	86930	86930
	Norm. Dim. the Physical Domain		
D1	X_upstream/D, X_downstream/D	2,8	2,8
D2	Cross area of domain in prop. plain	125.44	125.44
	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	0.0005556s	0.00069444s
E8	Equivalent rot. Angle for a time step	3	1.0825
	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

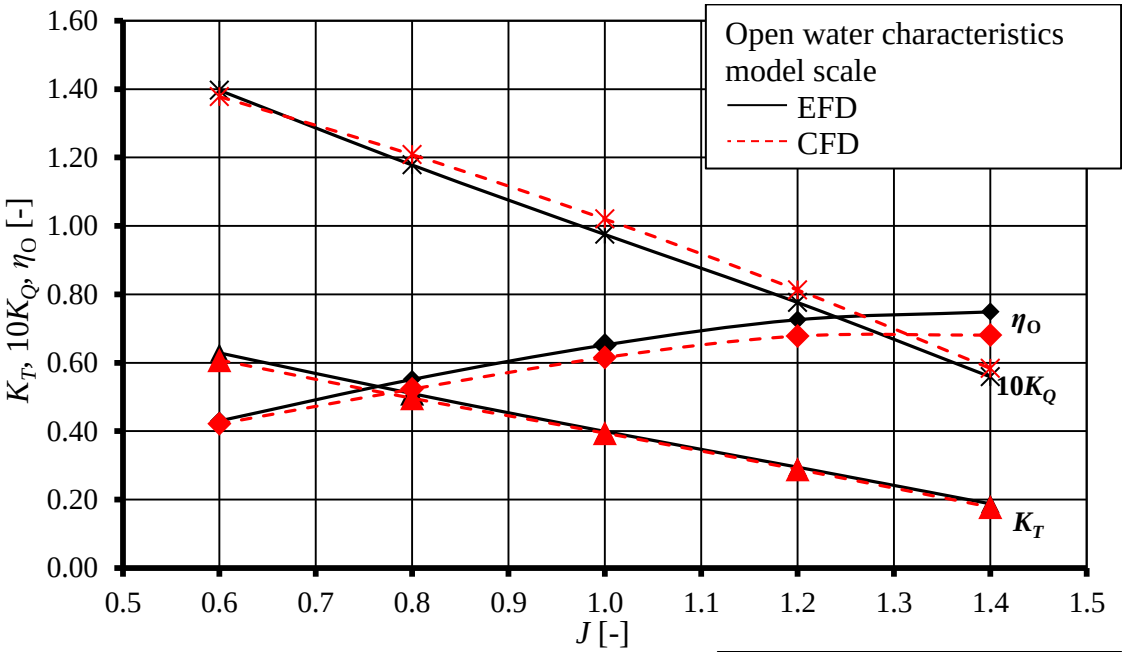
13.5 R10 - Questionaire part II

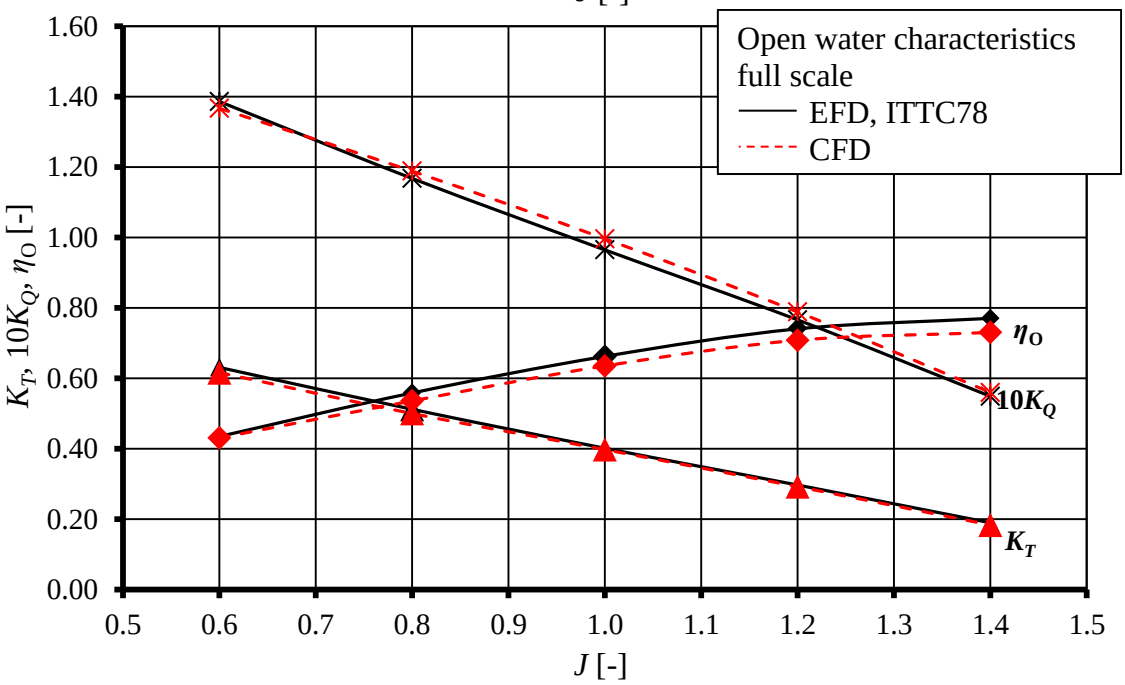
		model scale	**full scale**
	Computational Model		
H1	Fluid	incompressible	incompressible
H2	Pressure	pressure correction	pressure correction
	Transition		
I	Please comment	no / 0	0 / 0
	Computational Demands		
J1	Number of processors used	20	20
J2	Number of timesteps (steady)	0	0
J3	Number of timesteps (transient)	1080	865
J4	Wall-clock time per revolution	3.65h	2.9h
	Code		
K	References	0 / 0	0 / 0
	Comments		
L	Add. info.	0 / 0	0 / 0

14 Result R11

14.1 R11 - Open water characteristic

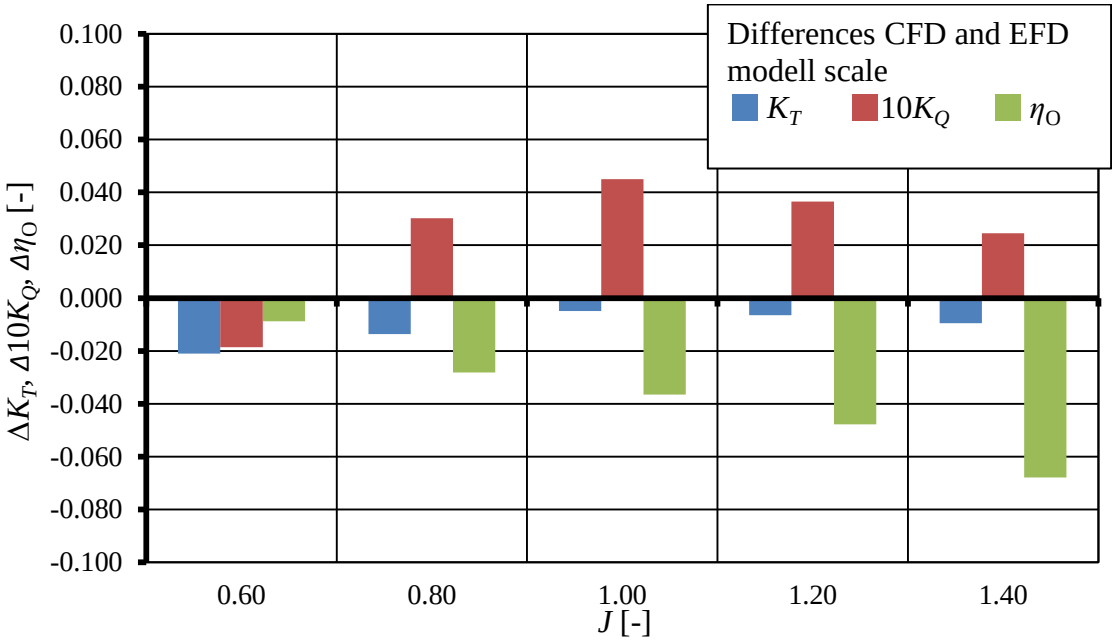
	CFD, model scale			CFD, full scale		
J	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.600	0.608	1.378	0.421	0.616	1.367	0.431
0.800	0.496	1.208	0.523	0.500	1.188	0.536
1.000	0.394	1.020	0.616	0.398	0.996	0.635
1.200	0.288	0.813	0.678	0.292	0.788	0.708
1.400	0.178	0.583	0.681	0.183	0.560	0.730

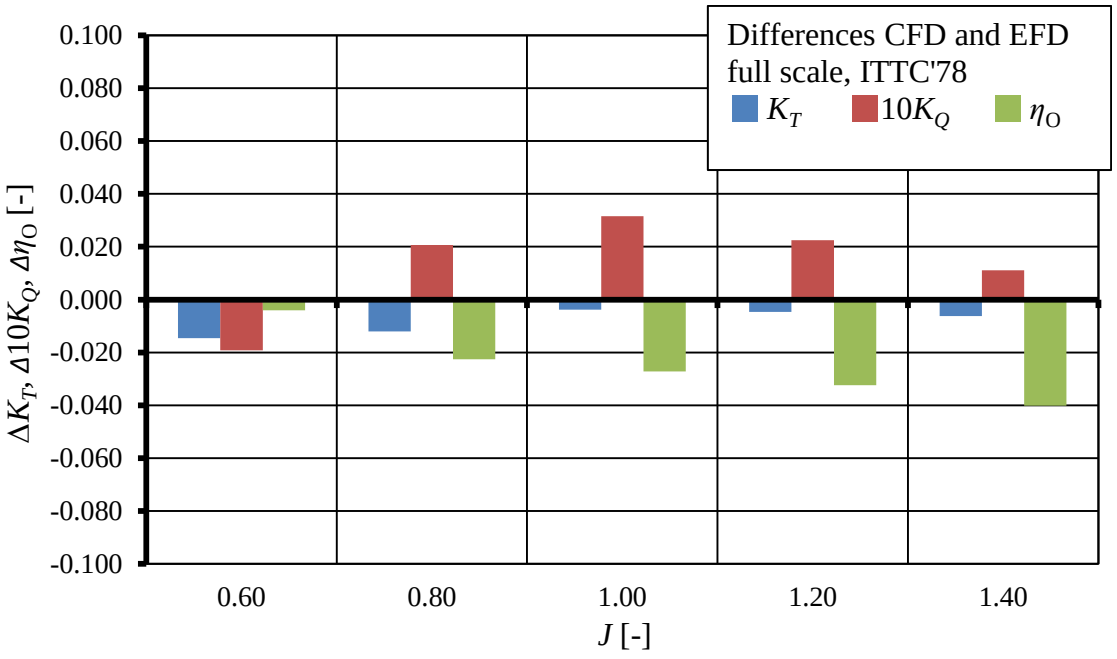




14.2 R11 - Differences CFD and EFD

	CFD - EFD, model scale			CFD - EFD, full scale		
	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
	[-]	[-]	[-]	[-]	[-]	[-]
0.60	-0.021	-0.019	-0.009	-0.015	-0.019	-0.004
0.80	-0.014	0.030	-0.028	-0.012	0.021	-0.023
1.00	-0.005	0.045	-0.036	-0.004	0.032	-0.027
1.20	-0.006	0.036	-0.048	-0.005	0.022	-0.032
1.40	-0.010	0.025	-0.068	-0.006	0.011	-0.040





14.3 R11 - Radial distribution tables

model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.011	0.010	0.009	0.007	0.005	0.018	0.017	0.016	0.013	0.008
0.400	0.031	0.027	0.022	0.016	0.008	0.065	0.062	0.057	0.047	0.032
0.500	0.048	0.042	0.035	0.026	0.015	0.109	0.104	0.094	0.078	0.055
0.600	0.072	0.062	0.051	0.039	0.025	0.166	0.155	0.138	0.116	0.086
0.700	0.099	0.084	0.069	0.053	0.035	0.231	0.210	0.184	0.153	0.115
0.800	0.129	0.105	0.084	0.063	0.041	0.300	0.262	0.221	0.178	0.132
0.900	0.152	0.117	0.088	0.062	0.038	0.343	0.281	0.224	0.169	0.119
0.975	0.066	0.049	0.035	0.022	0.011	0.145	0.116	0.087	0.059	0.037

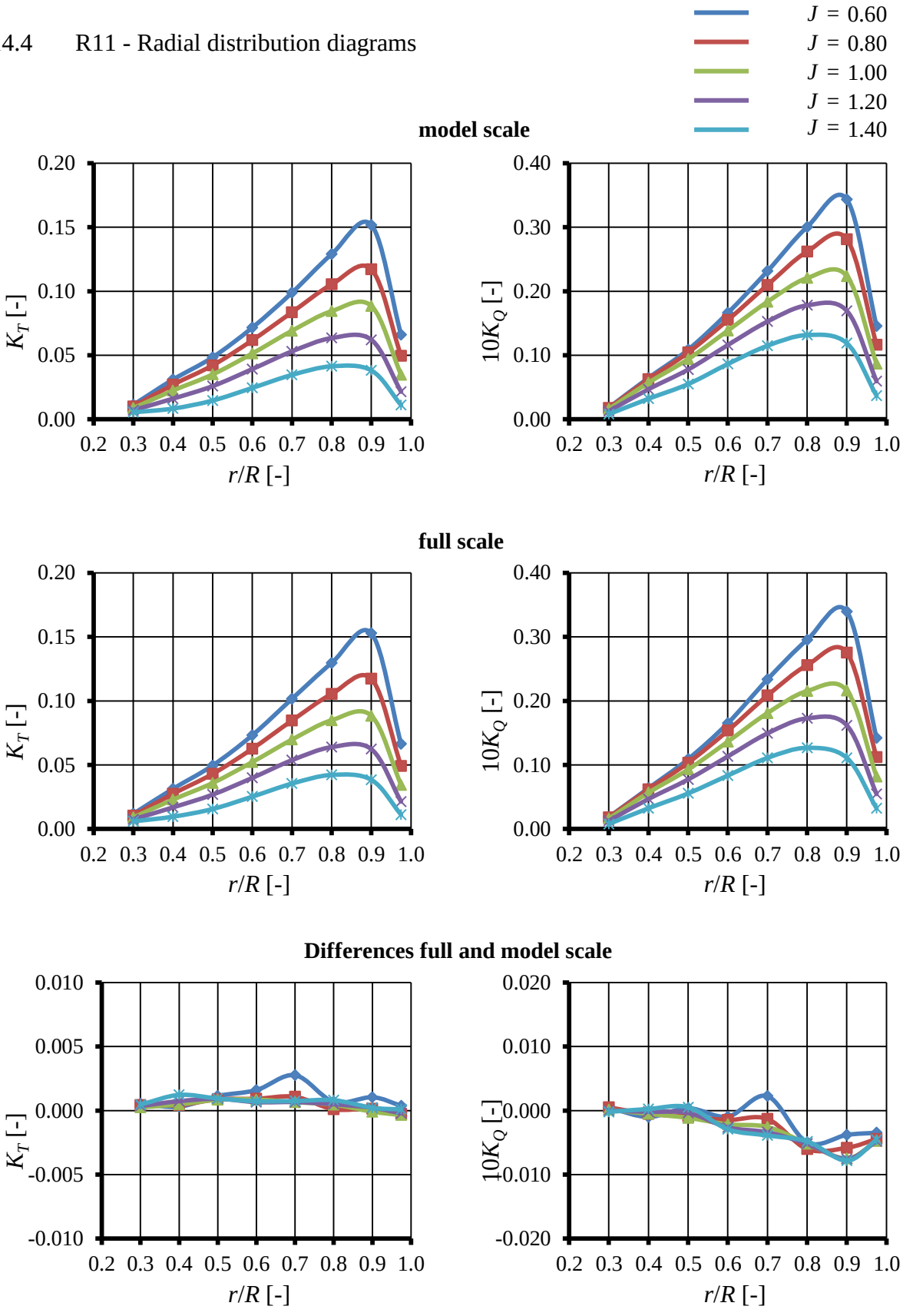
full scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.012	0.010	0.009	0.007	0.006	0.019	0.018	0.016	0.013	0.008
0.400	0.031	0.027	0.023	0.017	0.010	0.064	0.062	0.057	0.047	0.032
0.500	0.050	0.043	0.036	0.027	0.016	0.109	0.103	0.093	0.077	0.055
0.600	0.073	0.063	0.052	0.040	0.025	0.165	0.153	0.136	0.113	0.083
0.700	0.102	0.085	0.070	0.054	0.035	0.234	0.208	0.181	0.149	0.111
0.800	0.130	0.105	0.085	0.064	0.042	0.295	0.256	0.215	0.173	0.127
0.900	0.153	0.117	0.088	0.062	0.038	0.340	0.275	0.216	0.162	0.111
0.975	0.066	0.049	0.034	0.021	0.011	0.142	0.112	0.082	0.055	0.032

Differences full and model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.400	0.000	0.000	0.000	0.001	0.001	-0.001	-0.001	-0.001	0.000	0.000
0.500	0.001	0.001	0.001	0.001	0.001	0.000	-0.001	-0.001	0.000	0.001
0.600	0.002	0.001	0.001	0.001	0.001	-0.001	-0.001	-0.002	-0.003	-0.003
0.700	0.003	0.001	0.001	0.001	0.001	0.002	-0.001	-0.003	-0.003	-0.004
0.800	0.001	0.000	0.000	0.000	0.001	-0.005	-0.006	-0.005	-0.005	-0.005
0.900	0.001	0.000	0.000	0.000	0.000	-0.004	-0.006	-0.007	-0.008	-0.008
0.975	0.000	0.000	0.000	0.000	0.000	-0.003	-0.004	-0.005	-0.005	-0.005

14.4 R11 - Radial distribution diagrams



14.5 R11 - Questionaire 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	1 blade, non-matching	1 blade, matching
	Computational Grid		
C1	Type	Unstructured	Unstructured
C2	Local-grid refinement	Possible - used here	Possible - used here
C3	Primary volume elements	Hexahedral	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	80, 120, 150	150, 250, 300
C9	Averaged Y^+-value	115	240
C10	Number of cells on blade surface	7126	9052
	Norm. Dim. the Physical Domain		
D1	X_upstream/D, X_downstream/D	6,10	6,10
D2	Cross area of domain in prop. plain	0.9997	0.9997
	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	-	-

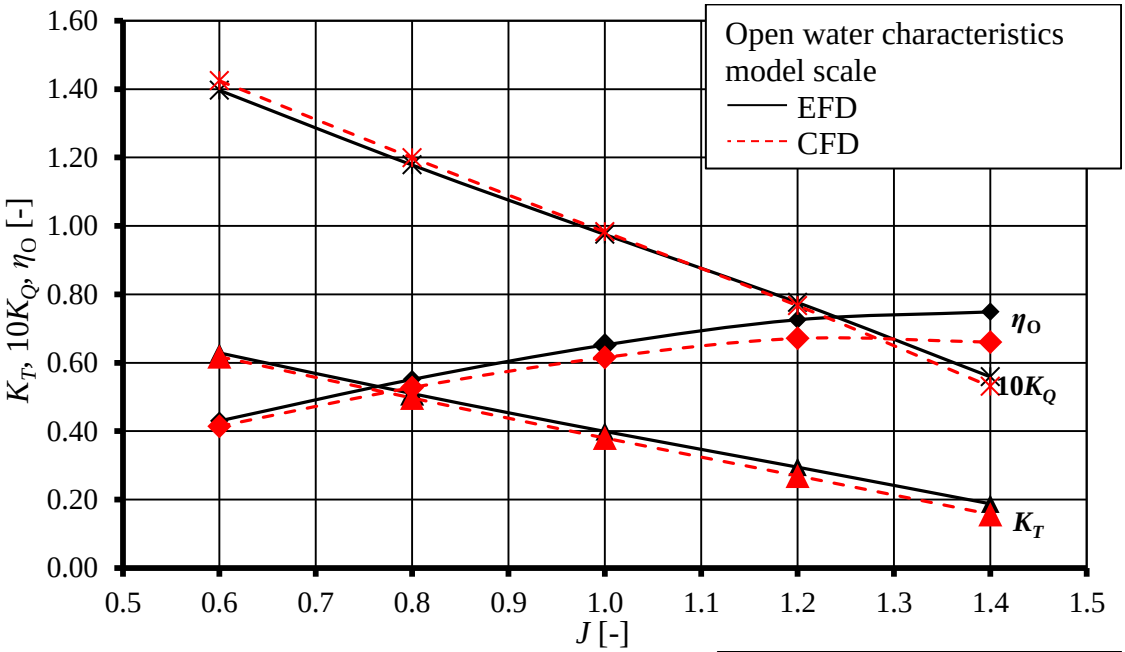
14.5 R11 - Questionaire part II

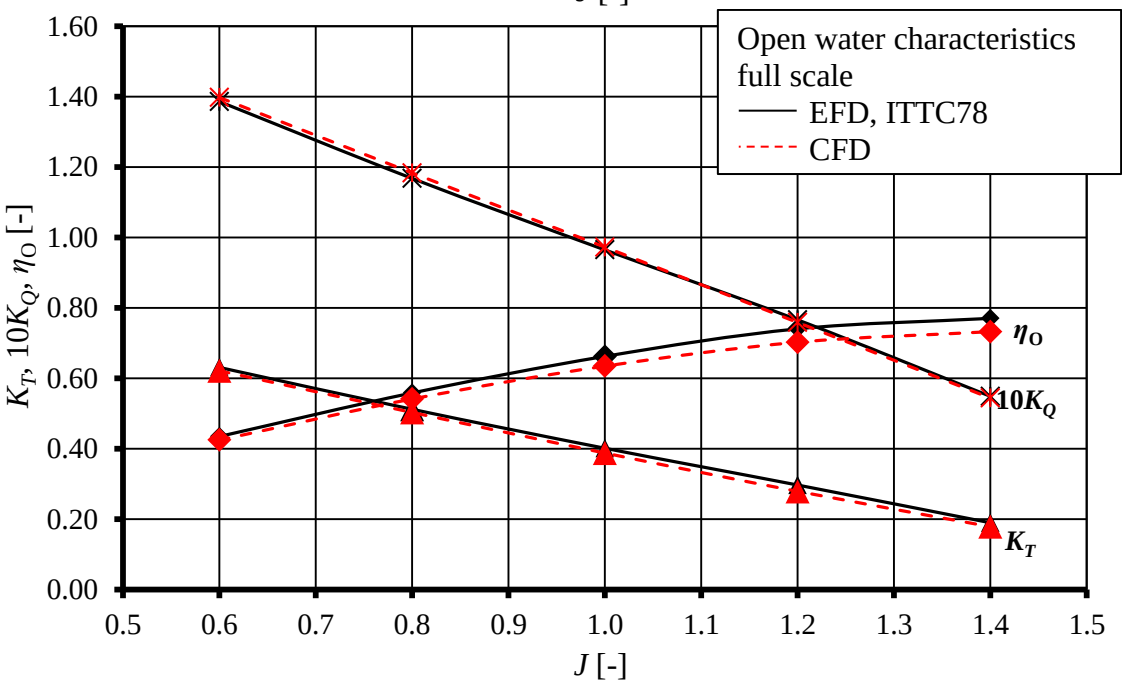
		model scale	full scale
	Computational Model		
H1	Fluid	incompressible	incompressible
H2	Pressure	pressure correction	pressure correction
	Transition		
I	Please comment	no	no
	Computational Demands		
J1	Number of processors used	32	32
J2	Number of timesteps (steady)	2000	2000
J3	Number of timesteps (transient)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

15 Result R12

15.1 R12 - Open water characteristic

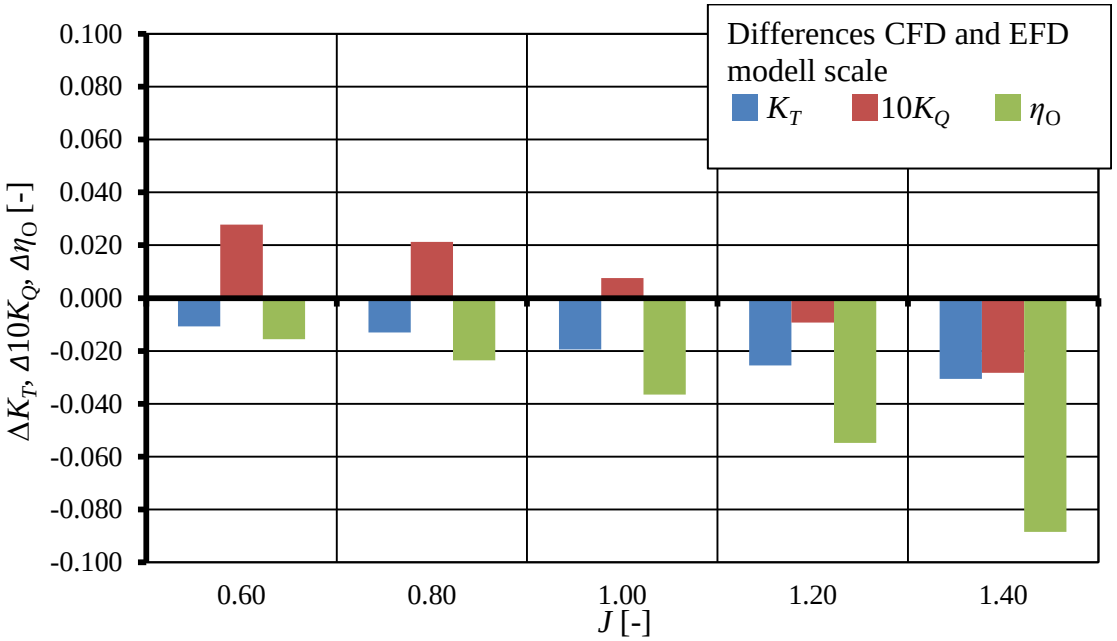
	CFD, model scale			CFD, full scale		
J	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.600	0.618	1.424	0.414	0.621	1.397	0.425
0.800	0.497	1.199	0.528	0.503	1.183	0.541
1.000	0.380	0.983	0.616	0.388	0.973	0.634
1.200	0.269	0.767	0.671	0.279	0.758	0.702
1.400	0.157	0.531	0.660	0.179	0.544	0.732

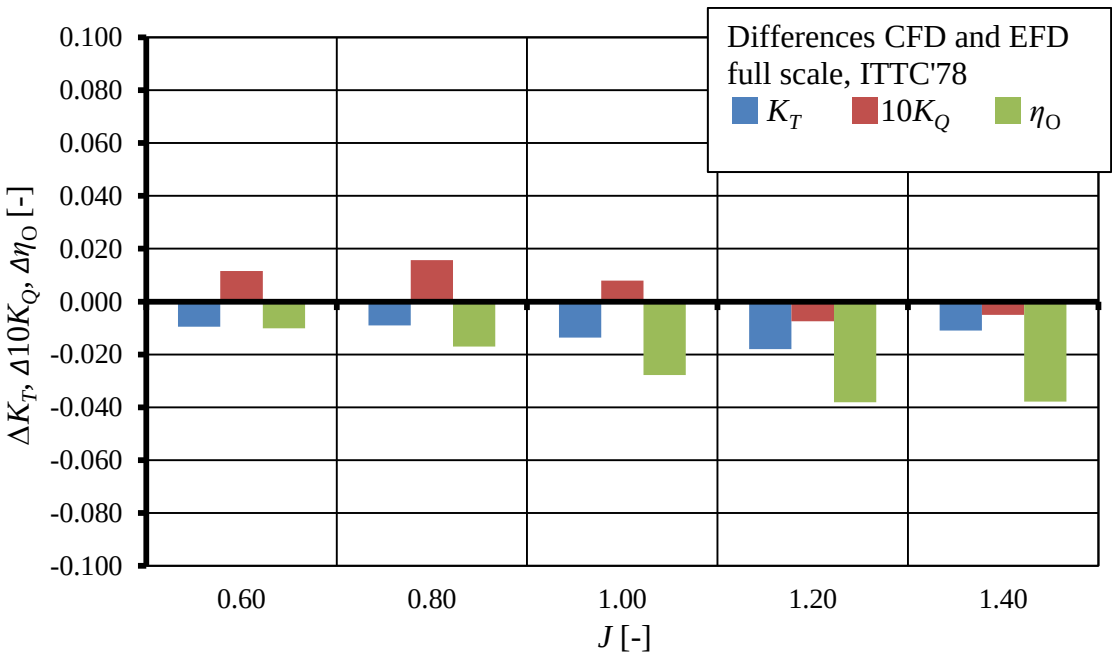




15.2 R12 - Differences CFD and EFD

	CFD - EFD, model scale			CFD - EFD, full scale		
	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
	[-]	[-]	[-]	[-]	[-]	[-]
0.60	-0.011	0.028	-0.016	-0.010	0.012	-0.010
0.80	-0.013	0.021	-0.024	-0.009	0.016	-0.017
1.00	-0.019	0.008	-0.036	-0.014	0.008	-0.028
1.20	-0.026	-0.009	-0.055	-0.018	-0.007	-0.038
1.40	-0.031	-0.028	-0.088	-0.011	-0.005	-0.038





15.3 R12 - Radial distribution tables

model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.009	0.008	0.006	0.004	0.001	0.014	0.013	0.011	0.006	0.000
0.400	0.029	0.025	0.020	0.013	0.004	0.059	0.057	0.050	0.038	0.019
0.500	0.046	0.041	0.033	0.024	0.012	0.102	0.098	0.088	0.071	0.048
0.600	0.069	0.061	0.050	0.037	0.022	0.160	0.149	0.131	0.109	0.078
0.700	0.097	0.083	0.067	0.051	0.033	0.228	0.205	0.176	0.146	0.108
0.800	0.126	0.104	0.081	0.061	0.039	0.297	0.256	0.212	0.173	0.128
0.900	0.152	0.116	0.085	0.060	0.037	0.356	0.279	0.216	0.167	0.119
0.975	0.087	0.059	0.035	0.021	0.011	0.201	0.140	0.090	0.060	0.037

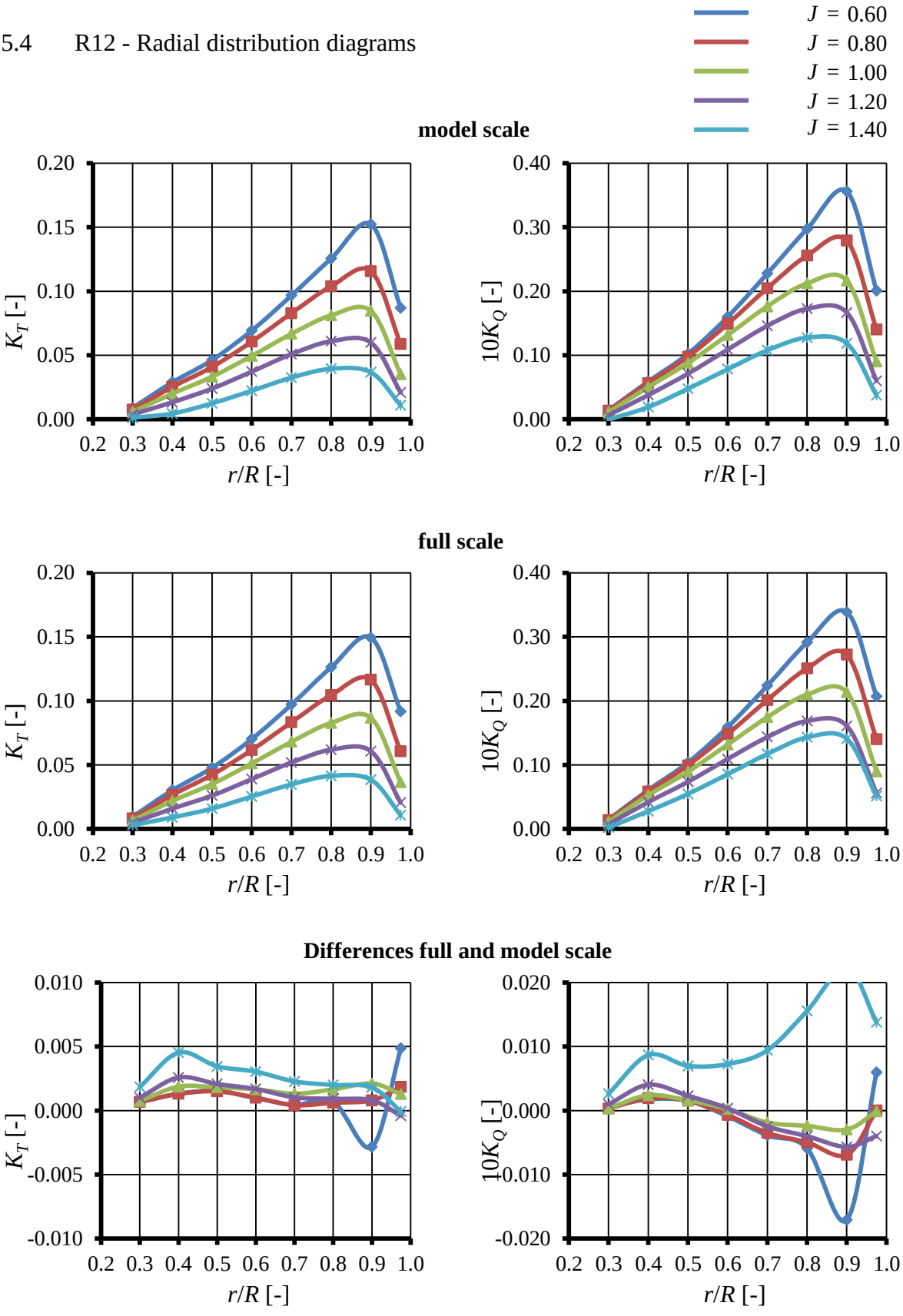
full scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.010	0.008	0.007	0.005	0.003	0.015	0.014	0.011	0.007	0.002
0.400	0.030	0.027	0.022	0.016	0.009	0.061	0.058	0.053	0.042	0.028
0.500	0.048	0.042	0.035	0.026	0.016	0.104	0.099	0.089	0.074	0.055
0.600	0.070	0.062	0.051	0.039	0.025	0.159	0.148	0.132	0.109	0.085
0.700	0.097	0.083	0.068	0.052	0.035	0.224	0.201	0.175	0.143	0.117
0.800	0.126	0.105	0.083	0.062	0.041	0.291	0.251	0.210	0.169	0.143
0.900	0.149	0.116	0.087	0.061	0.038	0.339	0.272	0.213	0.161	0.141
0.975	0.092	0.061	0.036	0.021	0.011	0.207	0.140	0.090	0.056	0.051

Differences full and model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.001	0.001	0.001	0.001	0.002	0.000	0.000	0.000	0.001	0.003
0.400	0.001	0.001	0.002	0.003	0.005	0.002	0.002	0.002	0.004	0.009
0.500	0.002	0.002	0.002	0.002	0.003	0.002	0.002	0.002	0.002	0.007
0.600	0.001	0.001	0.002	0.002	0.003	-0.001	-0.001	0.000	0.000	0.007
0.700	0.000	0.000	0.001	0.001	0.002	-0.004	-0.003	-0.002	-0.002	0.009
0.800	0.001	0.001	0.002	0.001	0.002	-0.006	-0.005	-0.002	-0.004	0.016
0.900	-0.003	0.001	0.002	0.001	0.002	-0.017	-0.007	-0.003	-0.006	0.022
0.975	0.005	0.002	0.001	0.000	0.000	0.006	0.000	0.000	-0.004	0.014

15.4 R12 - Radial distribution diagrams



15.5 R12 - Questionaire 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	Structured	Structured
C2	Local-grid refinement	Possible - used here	Possible - used here
C3	Primary volume elements	Hexahedral	Hexahedral
C4	Primary surface elements	Quads	Triangles
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	0.8, 1.0, 1.3	15,20,27
C9	Averaged Y^+-value	1	40
C10	Number of cells on blade surface	42000	115000
	Norm. Dim. the Physical Domain		
D1	X_upstream/D, X_downstream/D	5,10	5,10
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	explicit	explicit
E5	Spatial order of acc. (neglecting BC)	0	0
E6	Temporal order of accuracy	0	0
E7	Time step	0.0002 sec	0.00064 sec
E8	Equivalent rot. Angle for a time step	1°	1°
	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	Fixed Pressure
G5	Outer domain	Slip flow	Slip flow

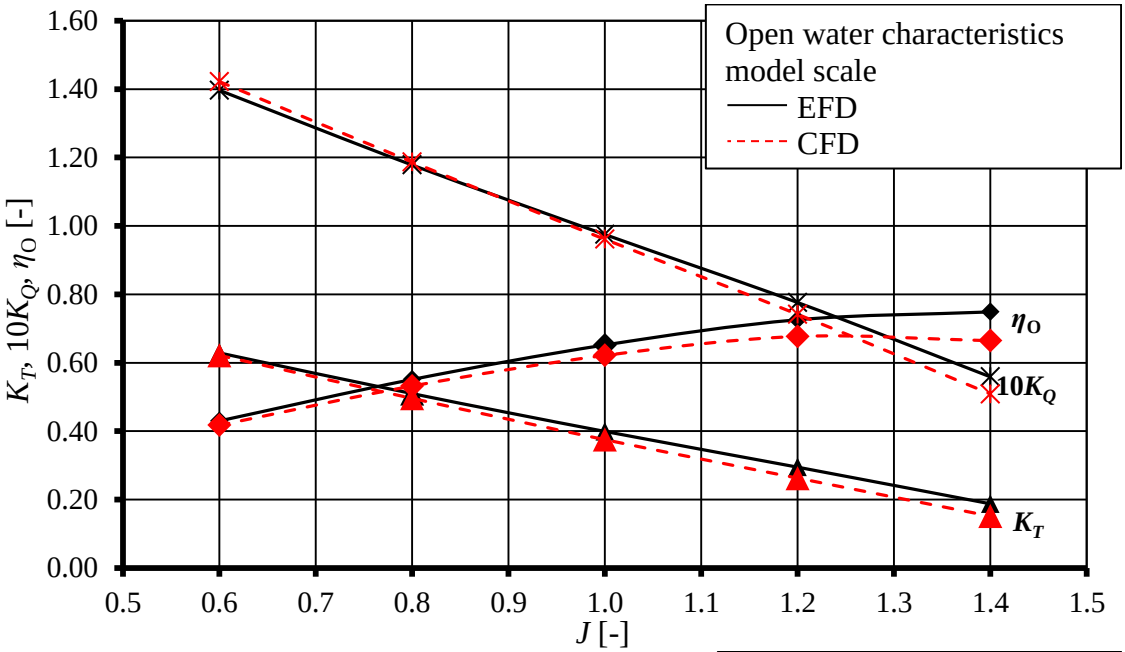
15.5 R12 - Questionaire part II

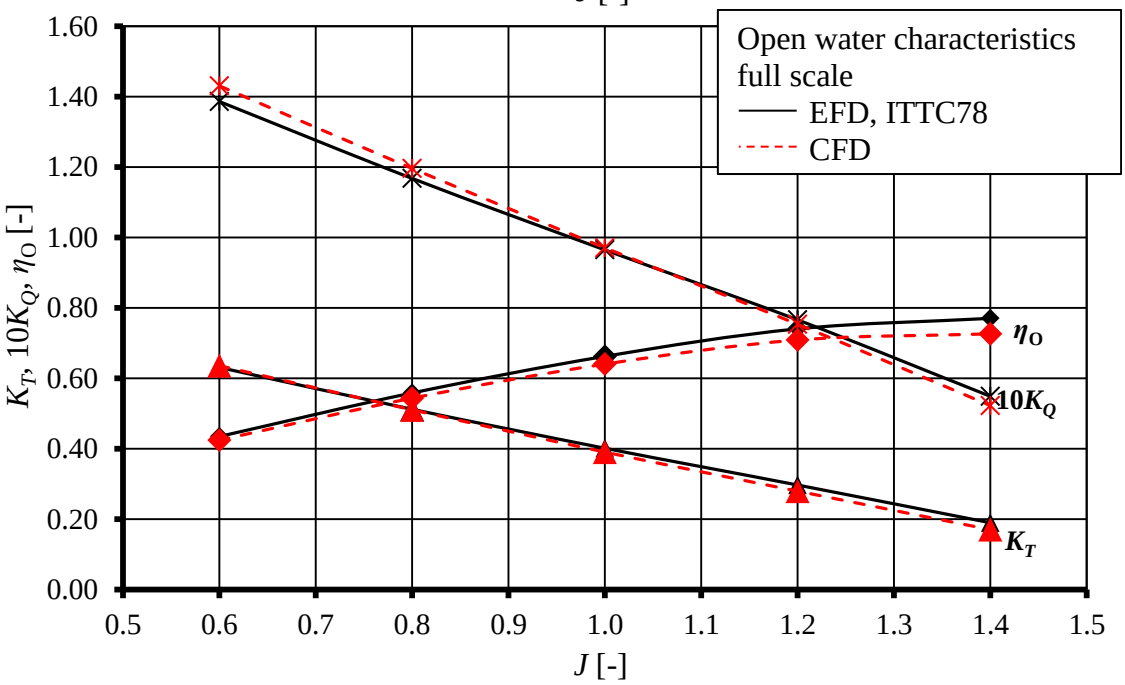
		model scale	full scale
	Computational Model		
H1	Fluid	incompressible	incompressible
H2	Pressure	pressure correction	pressure correction
	Transition		
I	Please comment	no / 0	0 / 0
	Computational Demands		
J1	Number of processors used	32	32
J2	Number of timesteps (steady)	0	0
J3	Number of timesteps (transient)	1750	1750
J4	Wall-clock time per revolution	3 hours	3 hours
	Code		
K	References	0 / 0	0 / 0
	Comments		
L	Add. info.	0 / 0	0 / 0

16 Result R14

16.1 R14 - Open water characteristic

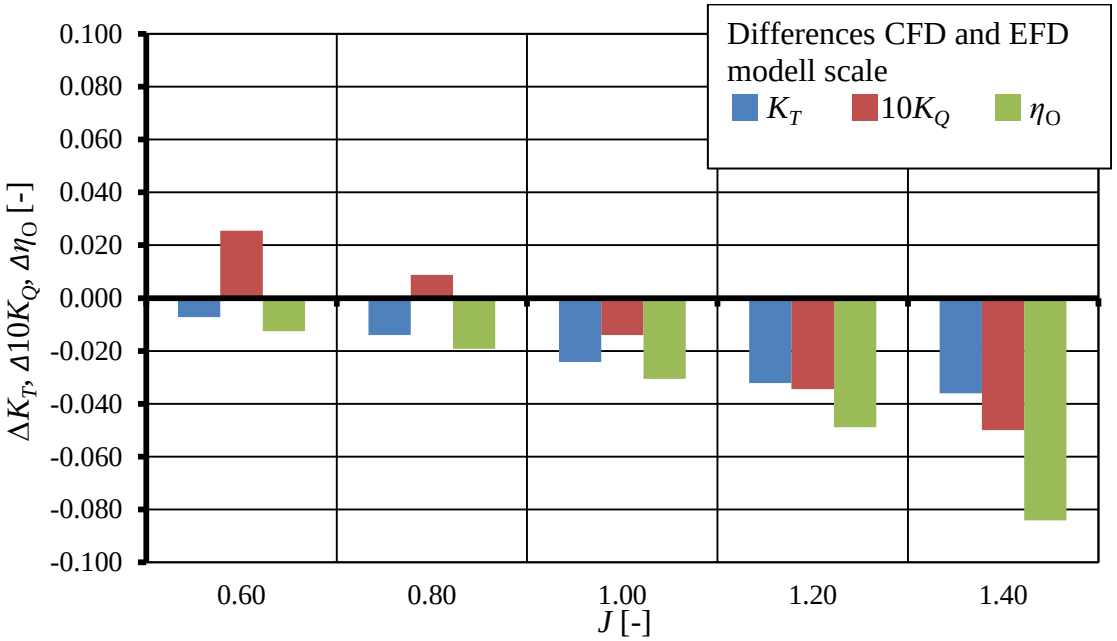
	CFD, model scale			CFD, full scale		
J	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.600	0.622	1.422	0.417	0.636	1.430	0.424
0.800	0.496	1.187	0.532	0.511	1.196	0.544
1.000	0.375	0.961	0.621	0.390	0.970	0.640
1.200	0.263	0.742	0.677	0.280	0.753	0.709
1.400	0.152	0.509	0.665	0.170	0.522	0.726

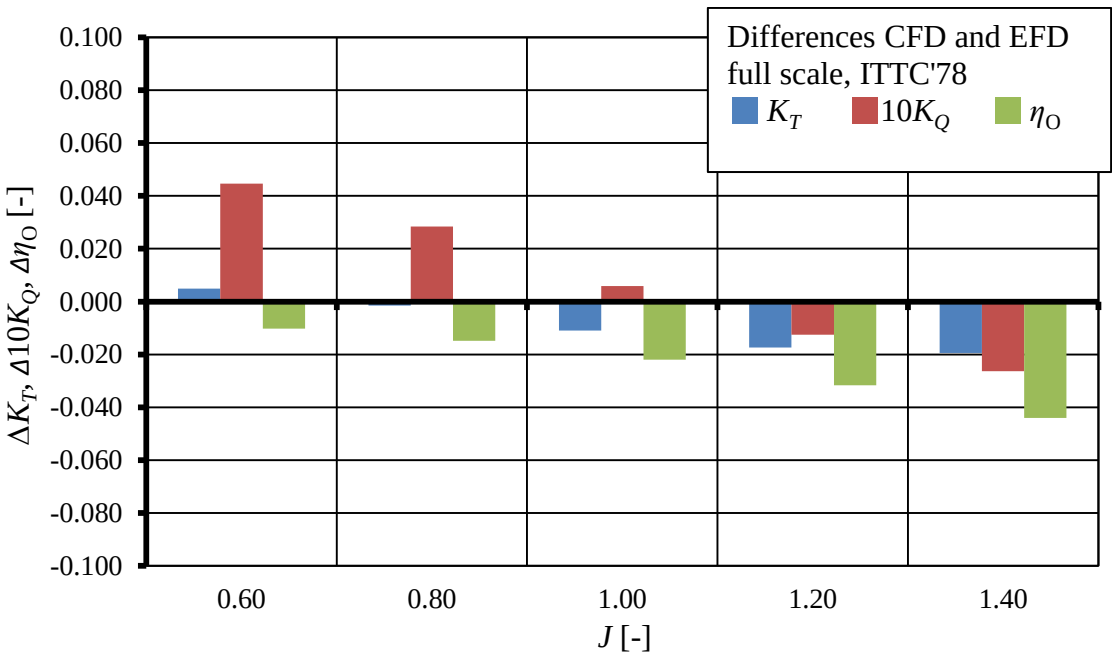




16.2 R14 - Differences CFD and EFD

	CFD - EFD, model scale			CFD - EFD, full scale		
	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
	[-]	[-]	[-]	[-]	[-]	[-]
0.60	-0.007	0.026	-0.013	0.005	0.045	-0.010
0.80	-0.014	0.009	-0.019	-0.001	0.028	-0.015
1.00	-0.024	-0.014	-0.031	-0.011	0.006	-0.022
1.20	-0.032	-0.034	-0.049	-0.017	-0.013	-0.032
1.40	-0.036	-0.050	-0.084	-0.019	-0.026	-0.044





16.3 R14 - Radial distribution tables

model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.006	0.005	0.005	0.004	0.003	0.010	0.009	0.008	0.006	0.003
0.400	0.021	0.018	0.015	0.010	0.005	0.044	0.042	0.038	0.030	0.020
0.500	0.035	0.031	0.026	0.020	0.012	0.077	0.075	0.069	0.058	0.043
0.600	0.057	0.051	0.043	0.033	0.021	0.131	0.125	0.113	0.095	0.071
0.700	0.091	0.079	0.064	0.048	0.030	0.215	0.195	0.169	0.138	0.101
0.800	0.139	0.115	0.089	0.064	0.038	0.325	0.281	0.231	0.179	0.123
0.900	0.181	0.132	0.096	0.063	0.033	0.408	0.308	0.238	0.173	0.112
0.975	0.092	0.064	0.037	0.021	0.009	0.209	0.148	0.093	0.059	0.035

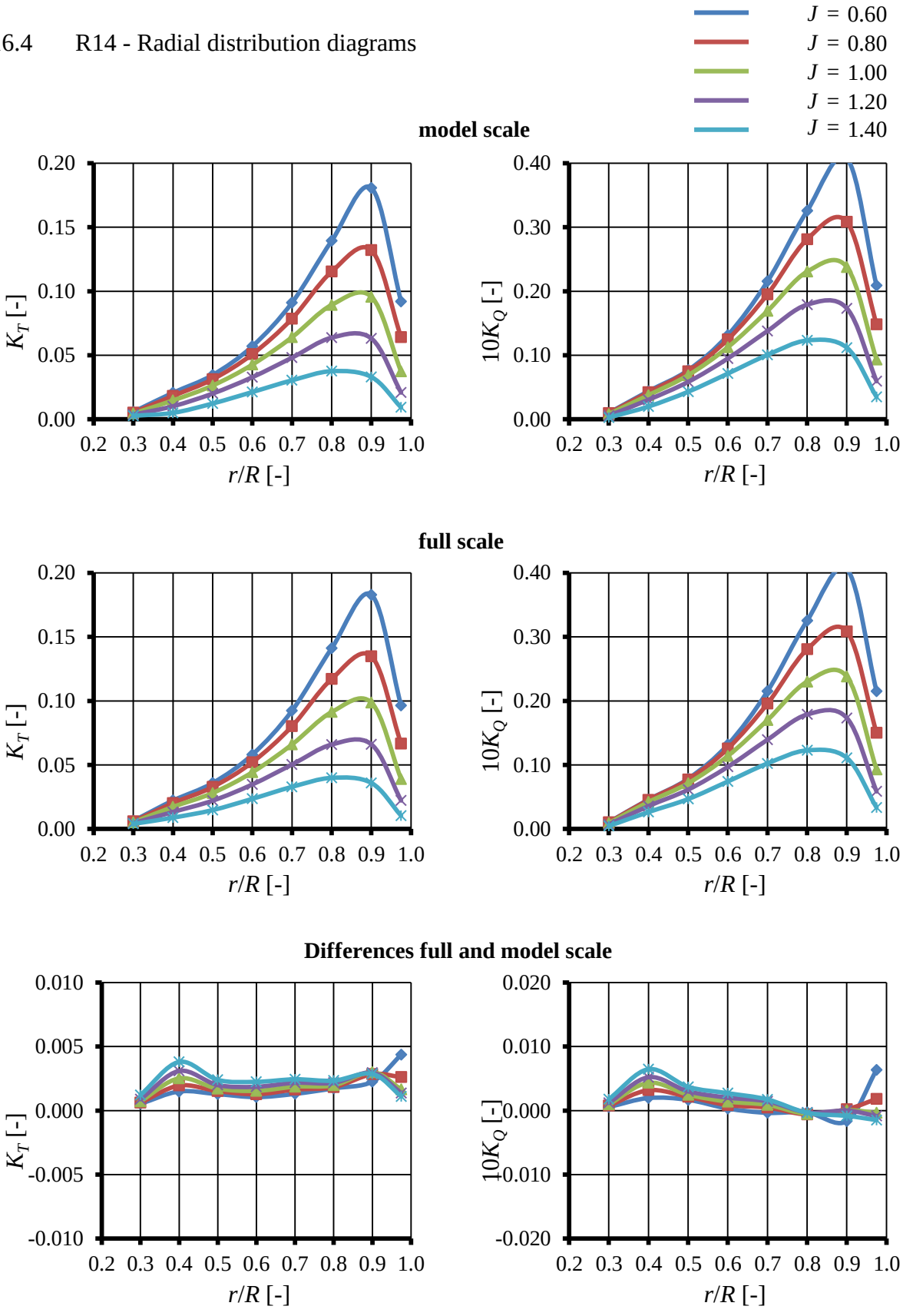
full scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.006	0.006	0.005	0.005	0.004	0.011	0.010	0.009	0.007	0.004
0.400	0.022	0.020	0.017	0.013	0.009	0.046	0.045	0.042	0.036	0.026
0.500	0.036	0.033	0.028	0.022	0.015	0.078	0.077	0.071	0.061	0.047
0.600	0.058	0.052	0.044	0.035	0.024	0.132	0.126	0.114	0.097	0.074
0.700	0.092	0.080	0.066	0.050	0.033	0.215	0.196	0.170	0.139	0.102
0.800	0.141	0.117	0.091	0.066	0.040	0.325	0.281	0.230	0.179	0.123
0.900	0.183	0.135	0.099	0.066	0.036	0.406	0.308	0.238	0.173	0.111
0.975	0.096	0.067	0.039	0.022	0.010	0.215	0.150	0.093	0.059	0.033

Differences full and model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002
0.400	0.001	0.002	0.003	0.003	0.004	0.002	0.003	0.004	0.005	0.006
0.500	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.003	0.004
0.600	0.001	0.001	0.002	0.002	0.002	0.000	0.001	0.001	0.002	0.003
0.700	0.001	0.002	0.002	0.002	0.002	0.000	0.000	0.001	0.001	0.002
0.800	0.002	0.002	0.002	0.002	0.002	0.000	-0.001	-0.001	0.000	0.000
0.900	0.002	0.003	0.003	0.003	0.003	-0.002	0.000	0.000	0.000	-0.001
0.975	0.004	0.003	0.002	0.001	0.001	0.006	0.002	0.000	-0.001	-0.001

16.4 R14 - Radial distribution diagrams



16.5 R14 - Questionaire 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	Polyhedral	Polyhedral
C4	Primary surface elements	Triangles	Triangles
C5	Wall-boundary layer type	Prism Layer	Prism Layer
C7	Number of cells at boundary layer	21	20
C8	Y^+-value at r/R=0.4, 0.7, 0.9	1.212 ; 1.533 ; 1.825	30.9, 39.9, 49.1
C9	Averaged Y^+-value	1.5	41.6
C10	Number of cells on blade surface	~20663	~20236
	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.)	2nd-order centered	2nd-order centered
E4	Transient approximation	implicit	implicit
E5	Spatial order of acc. (neglecting BC)	2nd-irdered	2nd-irdered
E6	Temporal order of accuracy	1st -ordered	1st -ordered
E7	Time step	0.0006	0.0019
E8	Equivalent rot. Angle for a time step	3°	3°
	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	wall function	wall function
G3	Inlet	Fixed Velocity	Fixed Velocity
G4	Outlet	Fixed Pressure	Fixed Pressure
G5	Outer domain	-	-

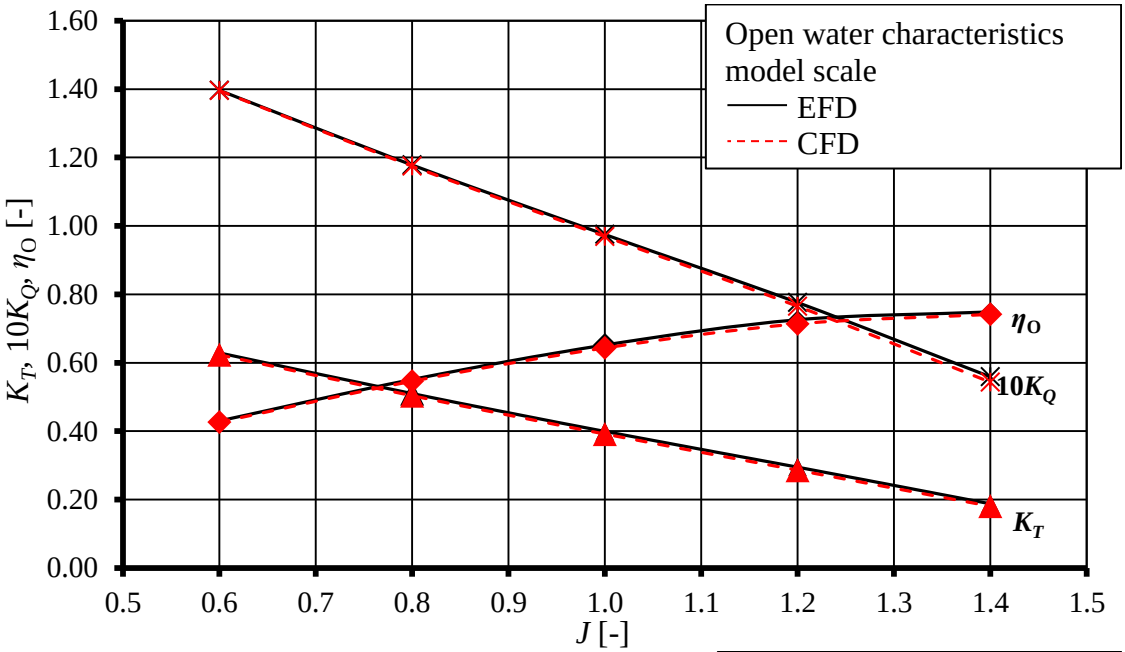
16.5 R14 - Questionaire part II

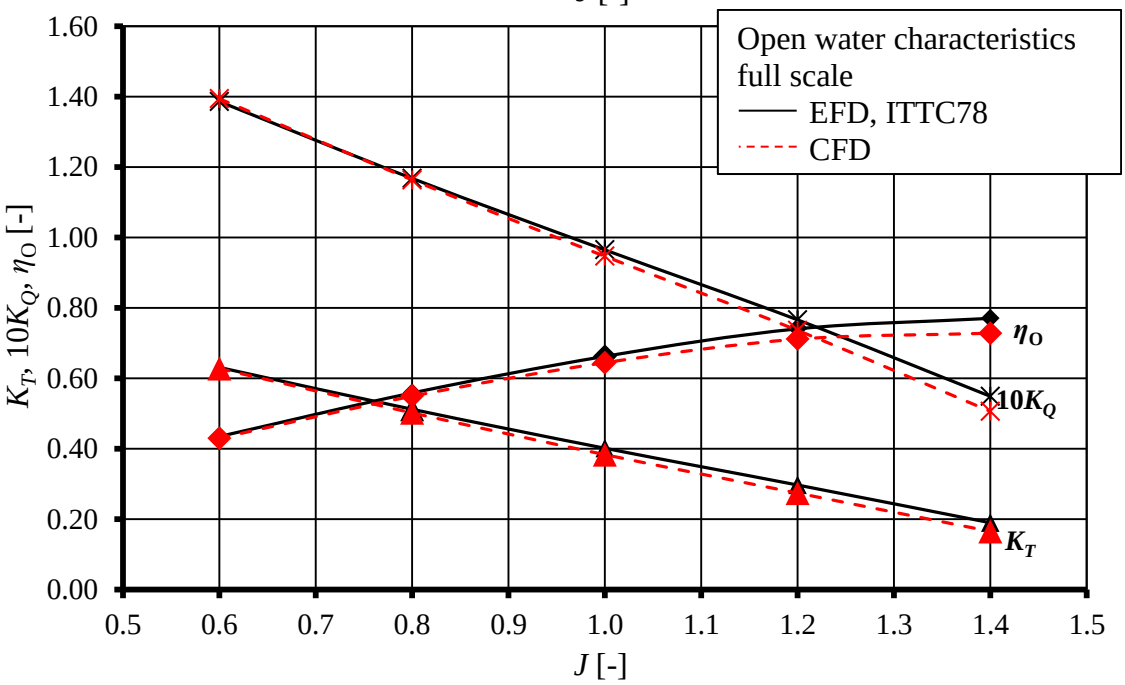
		model scale	**full scale**
	Computational Model		
H1	Fluid	incompressible	incompressible
H2	Pressure	pressure correction	pressure correction
	Transition		
I	Please comment	no	no
	Computational Demands		
J1	Number of processors used	6	6
J2	Number of timesteps (steady)	0	0
J3	Number of timesteps (transient)	5	5
J4	Wall-clock time per revolution	0	0
	Code		
K	References	0 / 0	0 / 0
	Comments		
L	Add. info.	0 / 0	0 / 0

17 Result R15

17.1 R15 - Open water characteristic

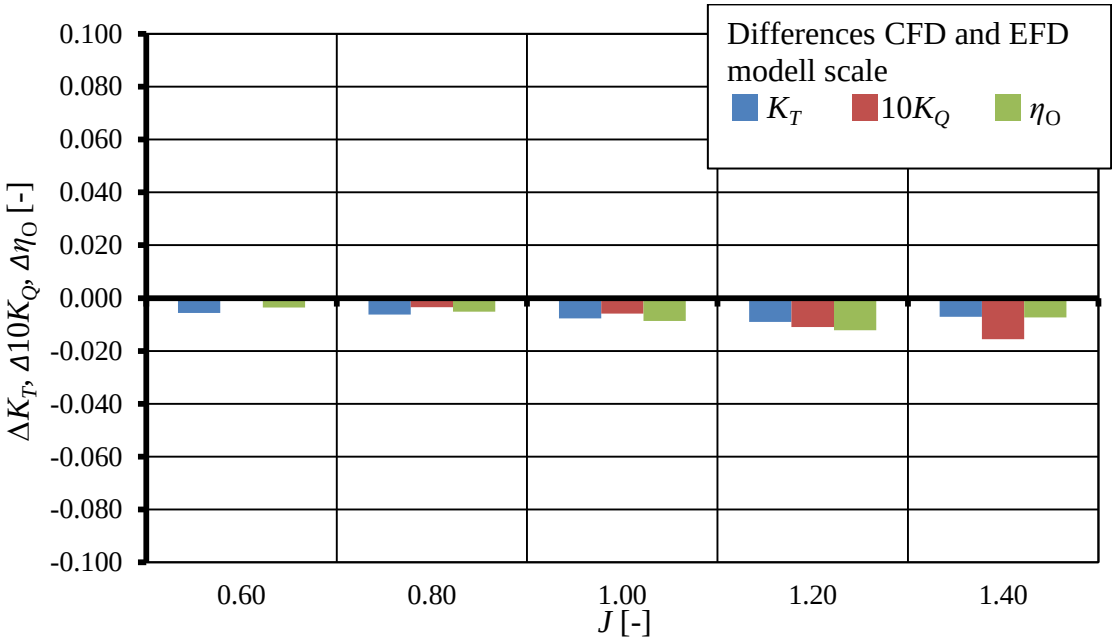
	CFD, model scale			CFD, full scale		
J	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.600	0.623	1.396	0.426	0.628	1.394	0.430
0.800	0.504	1.175	0.546	0.502	1.163	0.549
1.000	0.392	0.969	0.643	0.383	0.946	0.644
1.200	0.286	0.765	0.714	0.274	0.736	0.711
1.400	0.181	0.543	0.741	0.165	0.506	0.728

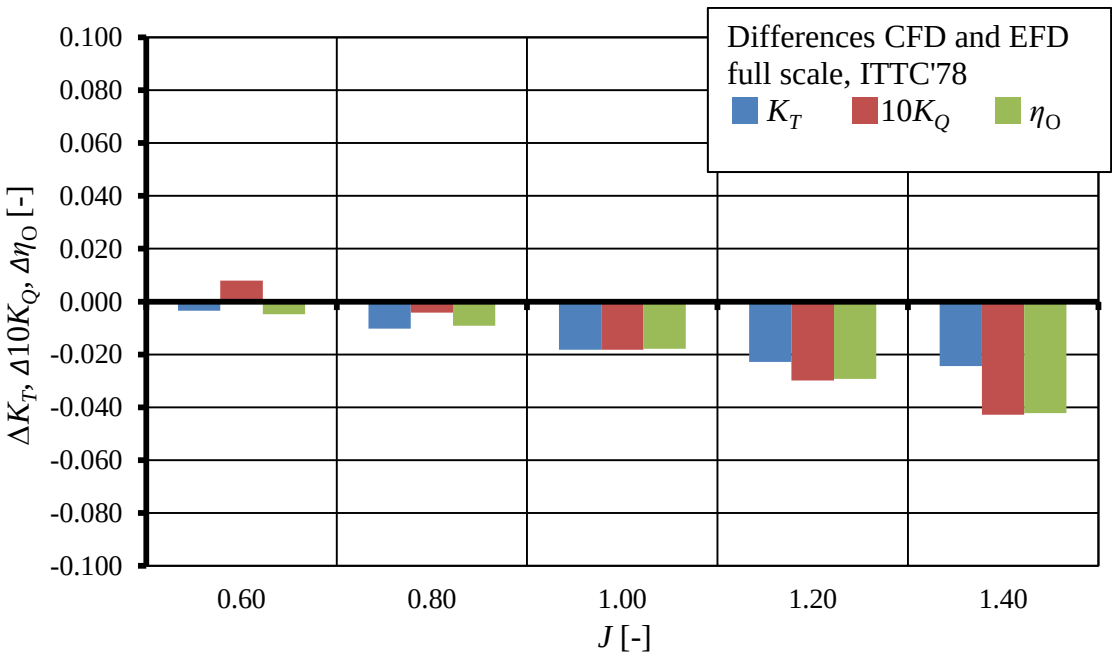




17.2 R15 - Differences CFD and EFD

	CFD - EFD, model scale			CFD - EFD, full scale		
	K_T [-]	$10K_Q$ [-]	η_O [-]	K_T [-]	$10K_Q$ [-]	η_O [-]
0.60	-0.006	-0.001	-0.004	-0.003	0.008	-0.005
0.80	-0.006	-0.003	-0.005	-0.010	-0.004	-0.009
1.00	-0.008	-0.006	-0.009	-0.018	-0.018	-0.018
1.20	-0.009	-0.011	-0.012	-0.023	-0.030	-0.029
1.40	-0.007	-0.016	-0.007	-0.024	-0.043	-0.042





17.3 R15 - Radial distribution tables

model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.011	0.010	0.008	0.007	0.005	0.017	0.016	0.014	0.011	0.006
0.400	0.031	0.028	0.023	0.016	0.009	0.062	0.060	0.054	0.043	0.028
0.500	0.049	0.044	0.036	0.027	0.016	0.107	0.102	0.091	0.075	0.053
0.600	0.073	0.064	0.053	0.040	0.026	0.167	0.154	0.136	0.112	0.082
0.700	0.101	0.086	0.070	0.053	0.036	0.234	0.208	0.178	0.146	0.109
0.800	0.130	0.105	0.083	0.062	0.041	0.299	0.252	0.209	0.168	0.124
0.900	0.155	0.116	0.086	0.061	0.038	0.350	0.268	0.208	0.158	0.110
0.975	0.073	0.052	0.034	0.020	0.010	0.160	0.115	0.080	0.053	0.031

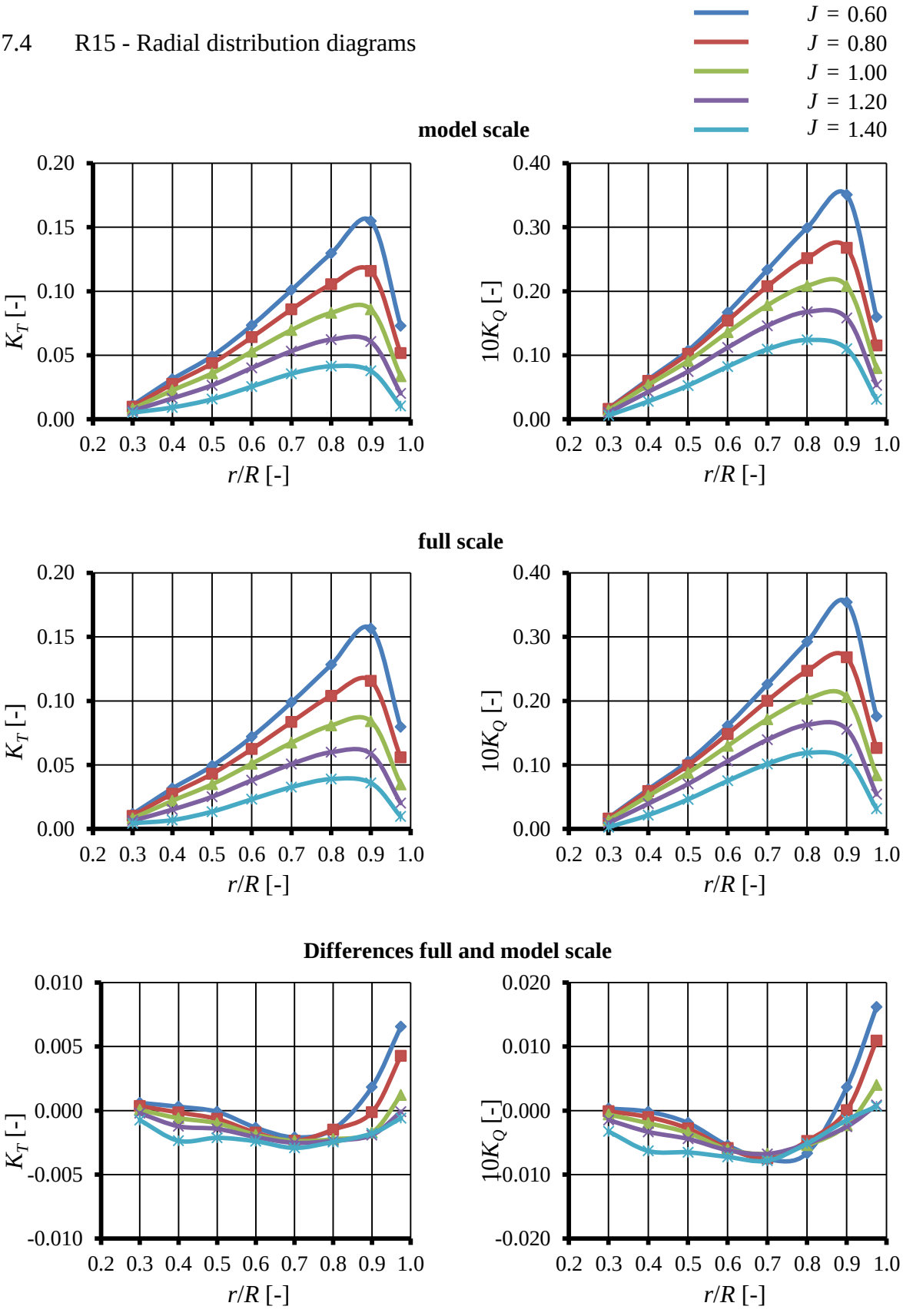
full scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.012	0.010	0.008	0.006	0.004	0.017	0.016	0.014	0.009	0.003
0.400	0.032	0.028	0.022	0.015	0.007	0.062	0.059	0.052	0.039	0.022
0.500	0.049	0.043	0.035	0.025	0.014	0.105	0.099	0.088	0.070	0.046
0.600	0.072	0.062	0.051	0.038	0.023	0.161	0.148	0.130	0.106	0.075
0.700	0.099	0.083	0.067	0.051	0.033	0.226	0.200	0.171	0.139	0.102
0.800	0.128	0.104	0.081	0.060	0.039	0.292	0.247	0.203	0.162	0.119
0.900	0.157	0.116	0.084	0.059	0.036	0.354	0.268	0.206	0.156	0.109
0.975	0.080	0.056	0.035	0.020	0.010	0.176	0.126	0.084	0.054	0.032

Differences full and model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.001	0.000	0.000	0.000	-0.001	0.000	0.000	-0.001	-0.001	-0.003
0.400	0.000	0.000	-0.001	-0.001	-0.002	0.000	-0.001	-0.002	-0.003	-0.006
0.500	0.000	-0.001	-0.001	-0.001	-0.002	-0.002	-0.003	-0.003	-0.004	-0.007
0.600	-0.001	-0.002	-0.002	-0.002	-0.002	-0.005	-0.006	-0.006	-0.006	-0.007
0.700	-0.002	-0.002	-0.002	-0.003	-0.003	-0.008	-0.007	-0.007	-0.007	-0.008
0.800	-0.001	-0.001	-0.002	-0.002	-0.002	-0.007	-0.005	-0.005	-0.005	-0.005
0.900	0.002	0.000	-0.002	-0.002	-0.002	0.004	0.000	-0.002	-0.003	-0.001
0.975	0.007	0.004	0.001	0.000	-0.001	0.016	0.011	0.004	0.001	0.001

17.4 R15 - Radial distribution diagrams



17.5 R15 - Questionaire 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	1.38, 1.65, 1.97	450, 543, 707
C9	Averaged Y^+-value	1.7	570.8
C10	Number of cells on blade surface	4E+06	3E+06
	Norm. Dim. the Physical Domain		
D1	X_upstream/D, X_downstream/D	4,26	4,26
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	wall function
G2	Hub	resolved	wall function
G3	Inlet	Fixed Velocity	Fixed Velocity
G4	Outlet	Fixed Pressure	Fixed Pressure
G5	Outer domain	Slip flow	Slip flow

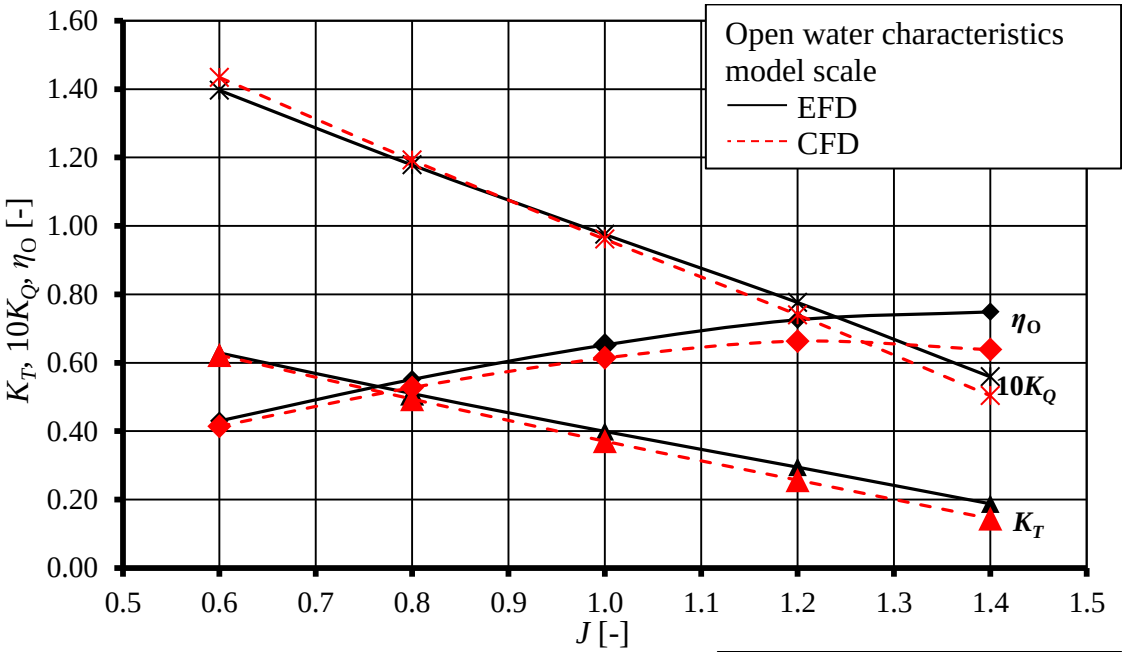
17.5 R15 - Questionaire part II

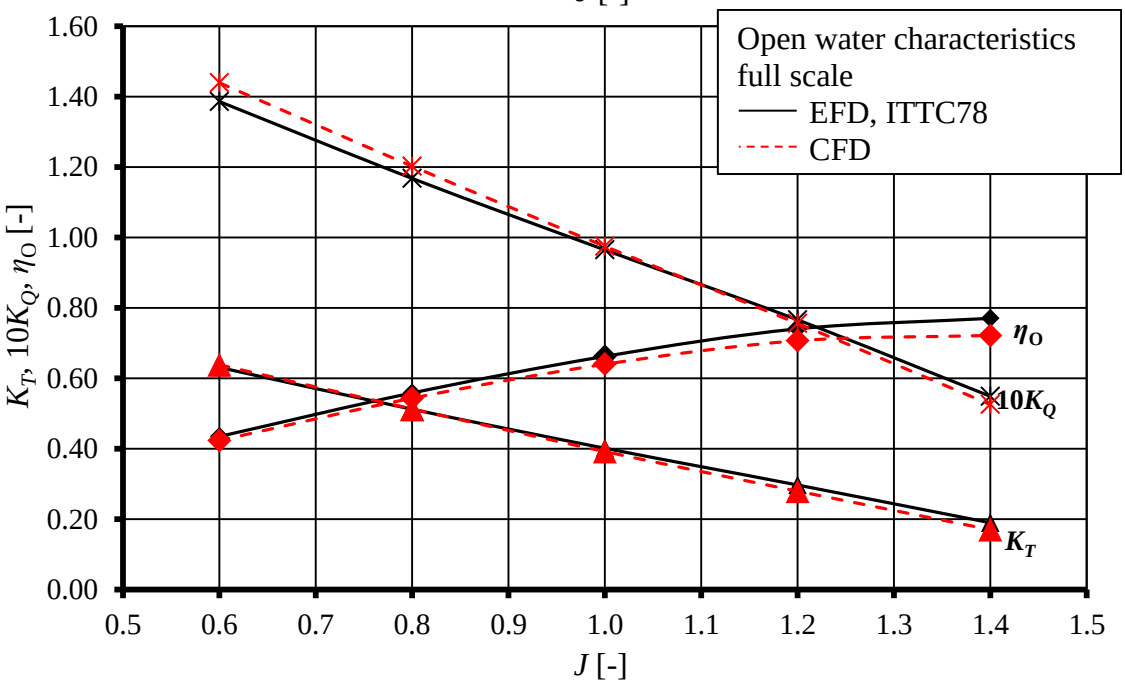
		model scale	full scale
	Computational Model		
H1	Fluid	incompressible	incompressible
H2	Pressure	pressure correction	pressure correction
	Transition		
I	Please comment	yes / Re_theta - gamma_Model in K-W SST model	0 / 0
	Computational Demands		
J1	Number of processors used	64	64
J2	Number of timesteps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

18 Result R16

18.1 R16 - Open water characteristic

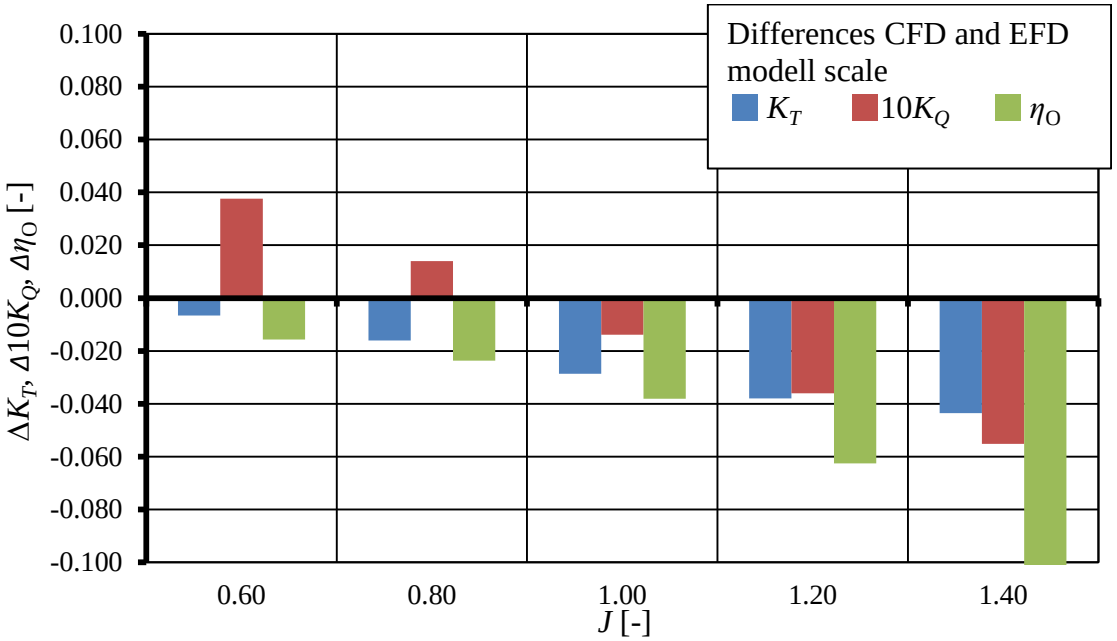
	CFD, model scale			CFD, full scale		
J	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
[-]	[-]	[-]	[-]	[-]	[-]	[-]
0.600	0.622	1.434	0.414	0.638	1.439	0.424
0.800	0.494	1.192	0.528	0.513	1.202	0.543
1.000	0.371	0.961	0.614	0.392	0.975	0.640
1.200	0.257	0.740	0.663	0.280	0.756	0.707
1.400	0.144	0.504	0.638	0.170	0.526	0.722

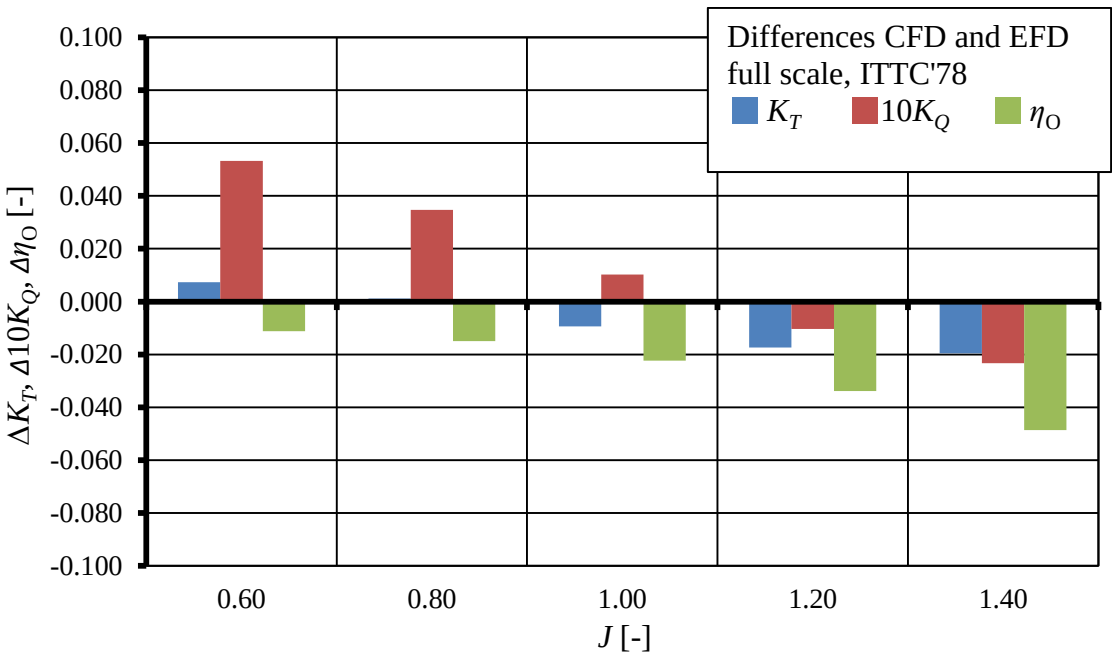




18.2 R16 - Differences CFD and EFD

	CFD - EFD, model scale			CFD - EFD, full scale		
	K_T	$10K_Q$	η_O	K_T	$10K_Q$	η_O
	[-]	[-]	[-]	[-]	[-]	[-]
0.60	-0.007	0.038	-0.016	0.007	0.053	-0.011
0.80	-0.016	0.014	-0.024	0.001	0.035	-0.015
1.00	-0.029	-0.014	-0.038	-0.009	0.010	-0.022
1.20	-0.038	-0.036	-0.063	-0.017	-0.010	-0.034
1.40	-0.043	-0.055	-0.110	-0.019	-0.023	-0.049





18.3 R16 - Radial distribution tables

model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.010	0.009	0.007	0.005	0.002	0.016	0.014	0.012	0.007	0.000
0.400	0.028	0.024	0.018	0.012	0.003	0.057	0.053	0.046	0.034	0.016
0.500	0.046	0.040	0.032	0.022	0.010	0.101	0.095	0.084	0.067	0.042
0.600	0.070	0.061	0.049	0.036	0.020	0.161	0.148	0.130	0.105	0.073
0.700	0.097	0.083	0.066	0.049	0.030	0.230	0.205	0.175	0.141	0.102
0.800	0.128	0.104	0.080	0.058	0.036	0.303	0.258	0.211	0.167	0.121
0.900	0.157	0.113	0.083	0.056	0.033	0.368	0.273	0.213	0.160	0.113
0.975	0.085	0.060	0.035	0.019	0.009	0.200	0.145	0.091	0.058	0.036

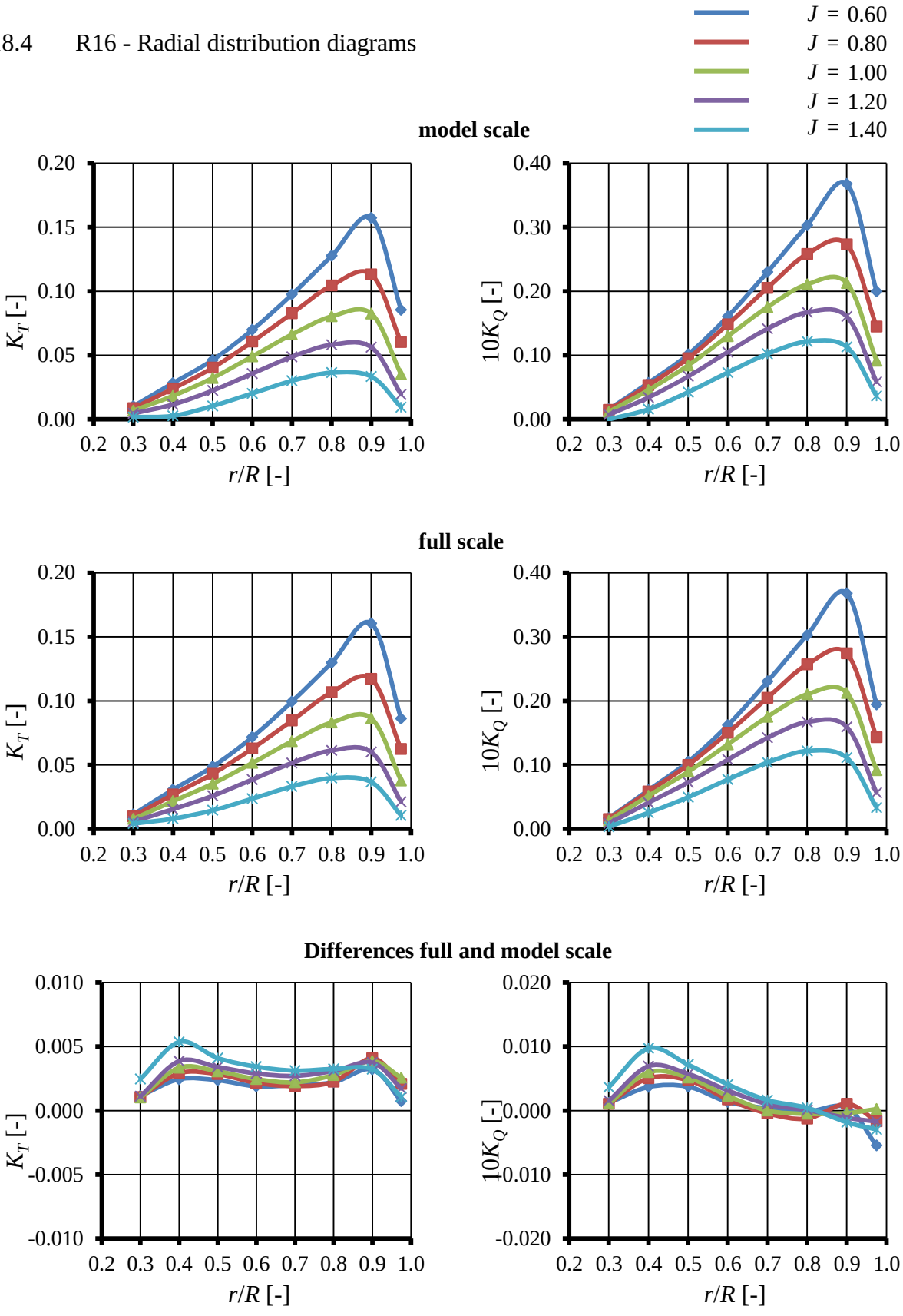
full scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.011	0.010	0.008	0.006	0.004	0.017	0.015	0.013	0.009	0.004
0.400	0.031	0.027	0.022	0.015	0.008	0.061	0.058	0.052	0.041	0.025
0.500	0.049	0.043	0.035	0.026	0.014	0.105	0.100	0.089	0.073	0.050
0.600	0.072	0.063	0.052	0.039	0.024	0.162	0.150	0.132	0.108	0.077
0.700	0.099	0.085	0.068	0.052	0.033	0.230	0.205	0.175	0.142	0.104
0.800	0.130	0.107	0.083	0.061	0.040	0.303	0.257	0.210	0.167	0.122
0.900	0.160	0.117	0.086	0.060	0.037	0.368	0.274	0.212	0.159	0.111
0.975	0.086	0.062	0.038	0.021	0.010	0.194	0.143	0.092	0.057	0.033

Differences full and model scale

	K_T [-]					$10K_Q$ [-]				
J [-]	0.60	0.80	1.00	1.20	1.40	0.60	0.80	1.00	1.20	1.40
r/R [-]										
0.300	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.002	0.004
0.400	0.002	0.003	0.003	0.004	0.005	0.004	0.005	0.006	0.007	0.010
0.500	0.002	0.003	0.003	0.003	0.004	0.004	0.005	0.005	0.006	0.007
0.600	0.002	0.002	0.002	0.003	0.003	0.001	0.002	0.002	0.003	0.004
0.700	0.002	0.002	0.002	0.003	0.003	0.000	0.000	0.000	0.001	0.002
0.800	0.002	0.002	0.003	0.003	0.003	0.000	-0.001	-0.001	0.000	0.000
0.900	0.003	0.004	0.004	0.004	0.003	0.000	0.001	0.000	-0.001	-0.002
0.975	0.001	0.002	0.003	0.002	0.001	-0.005	-0.002	0.000	-0.002	-0.003

18.4 R16 - Radial distribution diagrams



18.5 R16 - Questionaire 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	Polyhedral	Polyhedral
C4	Primary surface elements	Mixed	Mixed
C5	Wall-boundary layer type	Prism Layer	Prism Layer
C7	Number of cells at boundary layer	10	25
C8	Y^+-value at r/R=0.4, 0.7, 0.9	22.5, 30, 40	22, 30, 41
C9	Averaged Y^+-value	30	31
C10	Number of cells on blade surface	75677 (total)	75695 (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	2nd
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

18.5 R16 - Questionaire part II

		model scale	**full scale**
	Computational Model		
H1	Fluid	incompressible	incompressible
H2	Pressure	Equation of state	Equation of state
	Transition		
I		NO	NO
	Please comment		
	Computational Demands		
J1	Number of processors used	48	48
J2	Number of timesteps (steady)	2500	2500
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+ 10.06.010
	Comments		
L	Add. info.	0 / 0	0 / 0

19 Remarks

Altogether 14 different groups participated in the ITTC benchmark for the conventional propeller. From the 14 results 13 questionnaires could be evaluated.

Computational approach:

- Four participants used STAR-CCM+, two ANSYS FLUENT and one ANSYS CFX as solver. The majority of the participants did not mention which solver was used for the benchmark calculations.
- Ten participants used an unstructured numerical mesh, while two participants employed a block-structured mesh on basis of hexahedral elements. For one participant the mesh type was not mentioned. In case of five participants the unstructured meshes were generated on basis of tetrahedral elements, while four employed polyhedral cells. One participant generated a hex-dominant mesh with mostly triangular cells on the blade surface.
- Eight participants simulated the whole propeller; while four participants calculated one blade passage. For one participant the data was not provided.
- 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 4 to 3600.
- 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 three of the participants calculated with, while the other nine without transition model. One participant didn't provide the information. The number of calculations with transition model is too small to make any comments about the benefits of employing a transition model.
- In seven 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 $y^+ < 1.7$. In the other calculations wall-functions were employed.
- In full-scale the boundary layer flow was resolved down to the wall in case of 4 simulations, while the other computations were conducted with wall-functions.

Open water characteristics:

- In general the thrust and torque coefficients in model scale were computed to a lower level than the corresponding measurements. The differences in thrust coefficient between computation and measurements are relatively higher compared to the torque coefficient. This has a big impact on the open water efficiency.
- In full-scale the computed thrust coefficients match quiet good with the extrapolated full scale values according to the ITTC78 method. Only for higher advance coefficients a difference between computed and measured thrust data can be found.
- The calculated torque coefficients in full-scale are in general larger than the corresponding extrapolated full-scale data, except for higher advance coefficients where the differences are small.
- In general the computed full-scale results show a better coincidence with extrapolated data from model tests than the comparison between the model scale data itself.
- The highest thrust is generated on the radial section between $0.85 < r/R < 0.95$.
- 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 - Tip Rake Propeller - P1727
Report 4487, 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:

Avarage over J CFD - EFD:

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

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

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

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

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

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

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: