Report of the Results for KCS Resistance & Self-Propulsion (Case 2-1, 2-5,and 2-7)

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Tokyo 2015 Workshop on CFD in Ship Hydrodynamics

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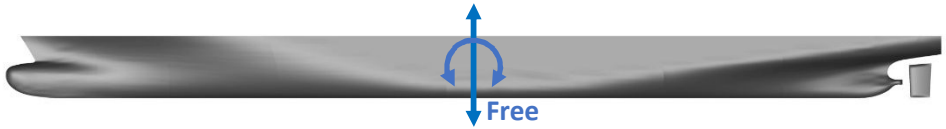
CASE 2.1



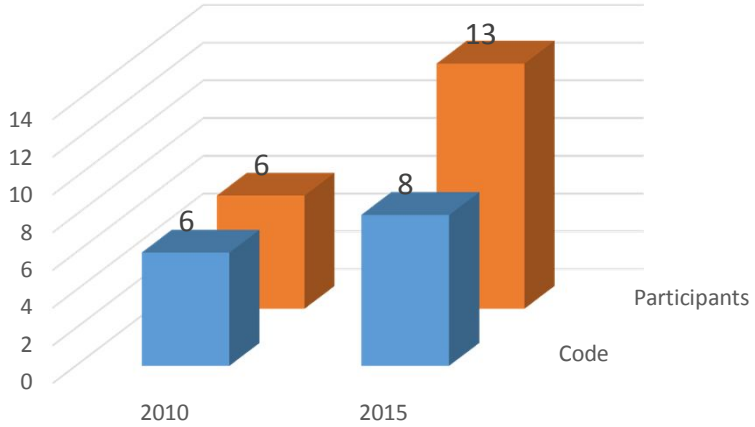
- With rudder
- Calm water condition
- $FR_{Z\theta}$
- L_{PP} = 7.2786 [m]
- Six speeds:

No.	1	2	3	4	5	6
Speeds [m/s]	0.915	1.281	1.647	1.922	2.196	2.379
Froude number (Fr)	0.108	0.152	0.195	0.227	0.260	0.282
Reynolds number (Re)	$5.23x10^6$	$7.33x10^6$	$9.42x10^6$	$1.10x10^7$	$1.26x10^7$	$1.36x10^7$

Participants

Gothenburg2010

Organization	Code
CD-adapco	Star-CCM
CSSRC	Fluent
Univ. Duisburg	Comet OpenFOAM
KRISO (MOERI)	WAVIS
Southampton univ. QinetiQ	CFX



Tokyo2015

Organization	Code
CTO	Star-CCM
MARIC	FINE/Marine
FSB	NavalFOAM
HHI	Star-CCM
UDE	Comet, FINE/Marine, OpenFOAM
SJTU	NaoeFOAM
KRISO	WAVIS
DAMEN	FINE/Marine
NUMECA	FINE/Marine
UM	OpenFOAM
PNU	Fluent

Submissions

Participants	CTO	MARIC	UNIZAG-FSB	HHI	UDE-Comet	UDE-FINEMarine	UDE-OpenFOAM	SJTU	KRISO	DAMEN	NUMECA	UM	PNU
Grid Type	unstructured		unstructured	unstructured		unstructured	unstructured	unstructured	structured	unstructured	unstructured	unstructured	unstructured
Free Surface	VOF	VOF	VOF	VOF		VOF	VOF	VOF	Level-set	VOF	VOF	VOF	VOF
Turbulence	two-eqn.	two-eqn.	two-eqn.	RSM		two-eqn.	two-eqn.	two-eqn.	two-eqn.	two-eqn.	two-eqn.	two-eqn.	two-eqn.
Grid Motion	all moving	deforming grid	all moving	all moving		deforming grid	deforming grid	overset	all moving	deforming grid	deforming grid	all moving	all moving
Discretization	FV	FV	FV	FV		FV	FV	FV	FV	FV	FV	FV	FV
Grid Size			4.7M	1.1M		1.1M	1.1M	3.4M	4.3M	2.6M	6.2M	2.6M	6.6M
V&V			●	◇		◇		●	●		●		●

V&V Analysis (computed CT, Sinkage and Trim @Fr=0.26)

Organization	rG		CT					Sinkage $\sigma \times 10^2$ [m]					Trim τ [deg]				
			Grid#5	Grid#4	Grid#3	Grid#2	Grid#1	Grid#5	Grid#4	Grid#3	Grid#2	Grid#1	Grid#5	Grid#4	Grid#3	Grid#2	Grid#1
EFD(KRISO)		D	3.711					-1.394					-0.169				
HHI		S		3.679	3.642	3.714			-1.4400	-1.4390	-1.4340			-0.1740	-0.1740	-0.1700	
		E%D		0.86%	1.86%	-0.08%			-3.30%	-3.23%	-2.87%			-2.96%	-2.96%	-0.59%	
KRISO	1.414	S			3.780	3.738	3.707			-1.3080	-1.3771	-1.4281			-0.1661	-0.1767	-0.1768
		E%D			-1.85%	-0.73%	0.12%			6.17%	1.21%	-2.44%			1.73%	-4.53%	-4.64%
NUMECA	1.250	S	3.972	3.816	3.761	3.743	3.726	-1.3804	-1.3782	-1.3708	-1.3635	-1.3591	-0.1624	-0.1650	-0.1678	0.1675	-0.1684
		E%D	-7.03%	-2.83%	-1.34%	-0.85%	-0.41%	0.97%	1.13%	1.66%	2.19%	2.50%	3.88%	2.38%	0.73%	0.88%	0.34%
PNU	1.414	S			3.929	3.695	3.620			-1.6460	-1.6220	-1.6330			-0.1520	-0.1350	-0.1220
		E%D			-5.87%	0.43%	2.45%			-18.08%	-16.36%	-17.14%			10.06%	20.12%	27.81%
SJTU	1.400	S			3.987	3.725	3.733			-1.5080	-1.4617	-1.4403			-0.2010	-0.1922	-0.1885
		E%D			-7.44%	-0.38%	-0.59%			-8.18%	-4.86%	-3.32%			-18.93%	-13.73%	-11.54%
UDE_FINEMarine	1.500	S			4.004	3.806	3.728			-1.3516	-1.3658	-1.3779			-0.1590	-0.1619	-0.1576
		E%D			-7.89%	-2.57%	-0.46%			3.04%	2.03%	1.16%			5.91%	4.18%	6.77%
UNIZAG-FSB	1.280	S		3.981	3.910	3.808	3.726		-1.3765	-1.3520	-1.3487	-1.3455		-0.1743	-0.1705	-0.1695	-0.1707
		E%D		-7.27%	-5.37%	-2.62%	-0.39%		1.26%	3.01%	3.25%	3.48%		-3.15%	-0.86%	-0.28%	-1.03%

V&V Analysis (CT @Fr=0.26)

Organization	CT						CF				CPV			
	$\epsilon_{12}\%S_1$	U_I/ε_{12}	$P_G/P_{G,th}$	$U_G\%S_1$	$U_D\%D$	$U_v\%$	$\epsilon_{12}\%S_1$	U_I/ε_{12}	$P_G/P_{G,th}$	$U_G\%S_1$	$\epsilon_{12}\%S_1$	U_I/ε_{12}	$P_G/P_{G,th}$	$U_G\%S_1$
KRISO	0.85	-	0.394	2.7		2.88	0.61	0.0	1.349	0.82	6.2	0.0	0.811	8.22
NUMECA	0.44	-	1.32	3.07		-	0.14	-	2.432	0.06	2.75	-	1.068	11.82
PNU	2.07	0.967	1.642	-2.57	1.0	12.36	1.04	0.0	0.45	2.36	14.32	0.281	1.389	-3.41
SJTU	0.21	0.045	-	3.51		3.62	0.22	0.04	-	3.14	0.19	0.01	-	4.48
UNIZAG-FSB	2.22	-0.315	0.429	9.39		0.35	1.35	0	-	1.99	5.24	-0.601	1.324	5.68

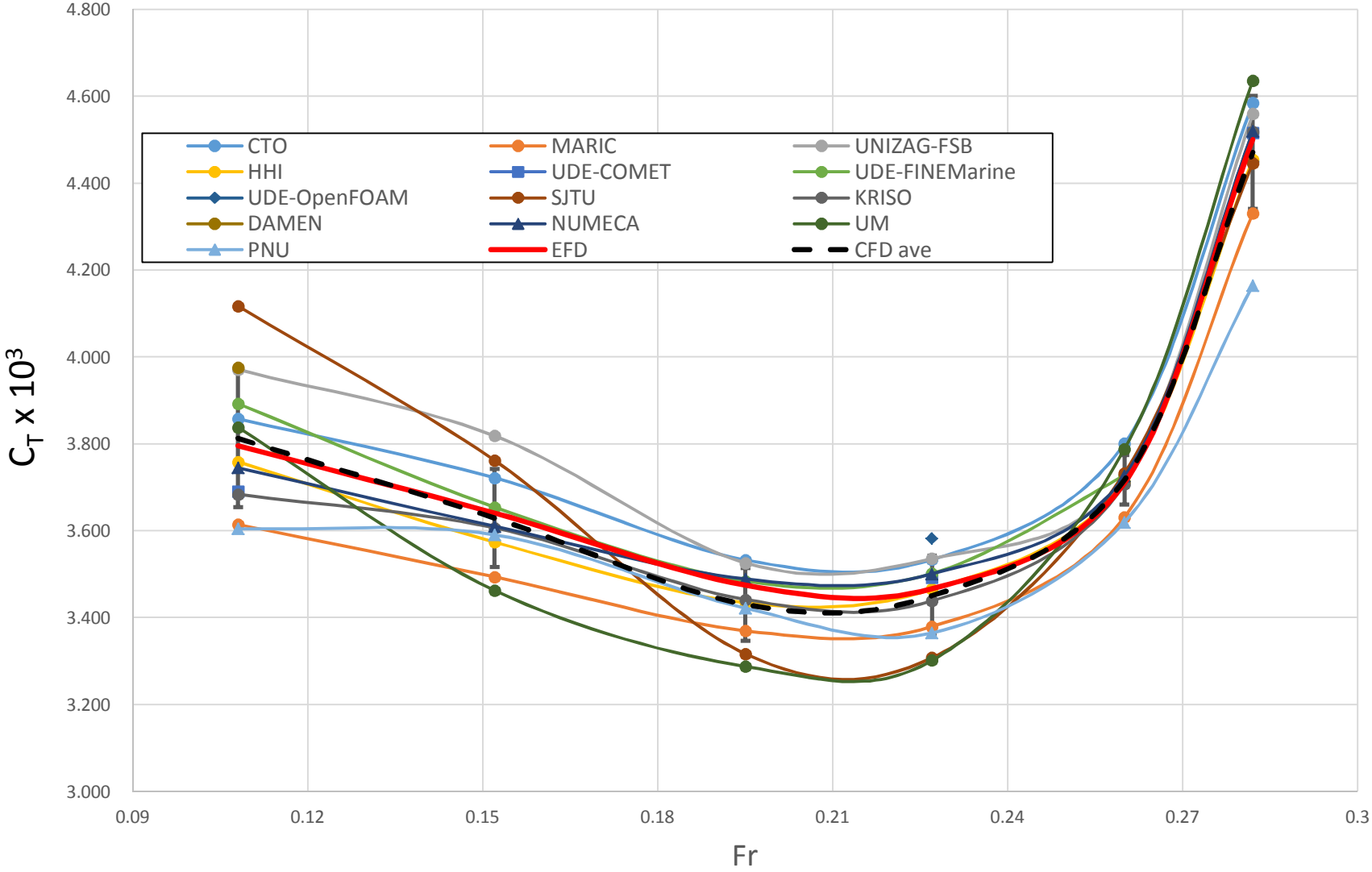
Table: V&V results for C_T, C_F, C_{PV} of different grid densities at Fr=0.260

V&V Analysis (Sinkage&Trim)

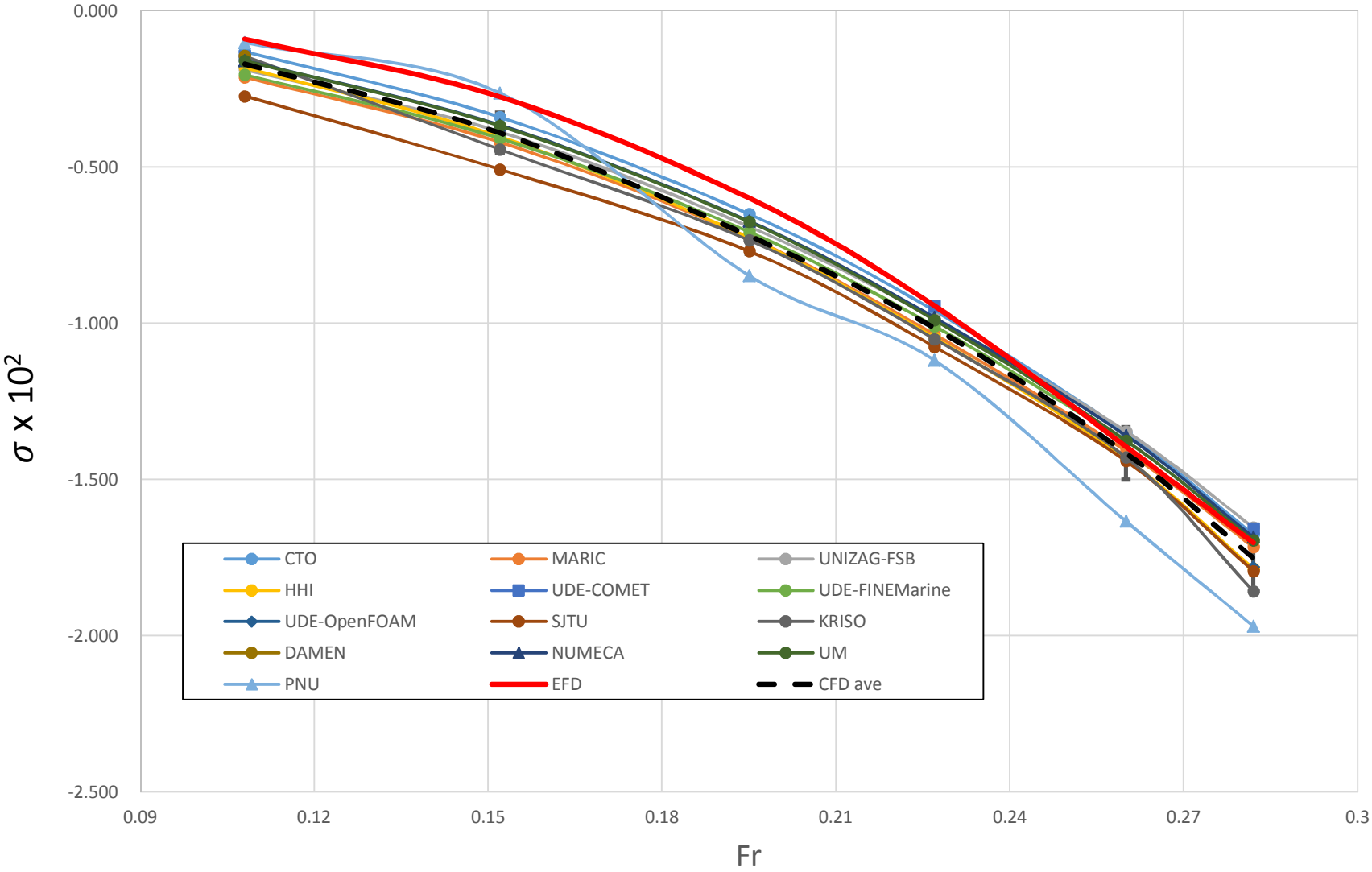
Organization	Sinakage						Trim					
	$\epsilon_{12}\%S_1$	U_I/ε_{12}	$P_G/P_{G,th}$	$U_G\%S_1$	$U_D\%D$	$U_V\%$	$\epsilon_{12}\%S_1$	U_I/ε_{12}	$P_G/P_{G,th}$	$U_G\%S_1$	$U_D\%D$	$U_V\%$
KRISO	3.57	0.0	0.441	9.99		10.16	0.1	0.0	5.871	0.2		2.28
NUMECA	0.32	-	0.062	-1.54		-	0.54	-	0.712	-2.04		-
PNU	0.78	0.818	1.126	-0.43	1.85	2.82	10.66	-1.07	0.387	-25.41	2.27	3.42
SJTU	-1.49	0.002	1.147	2.71		3.28	-1.96	0.024	1.288	3.79		4.42
UNIZAG-FSB	0.24	0.004	0.062	7.61		0.11	0.74	-0.008	-	0.37		0.0

Table: V&V results for Sinkage (σ) and Trim (τ) at Fr=0.260

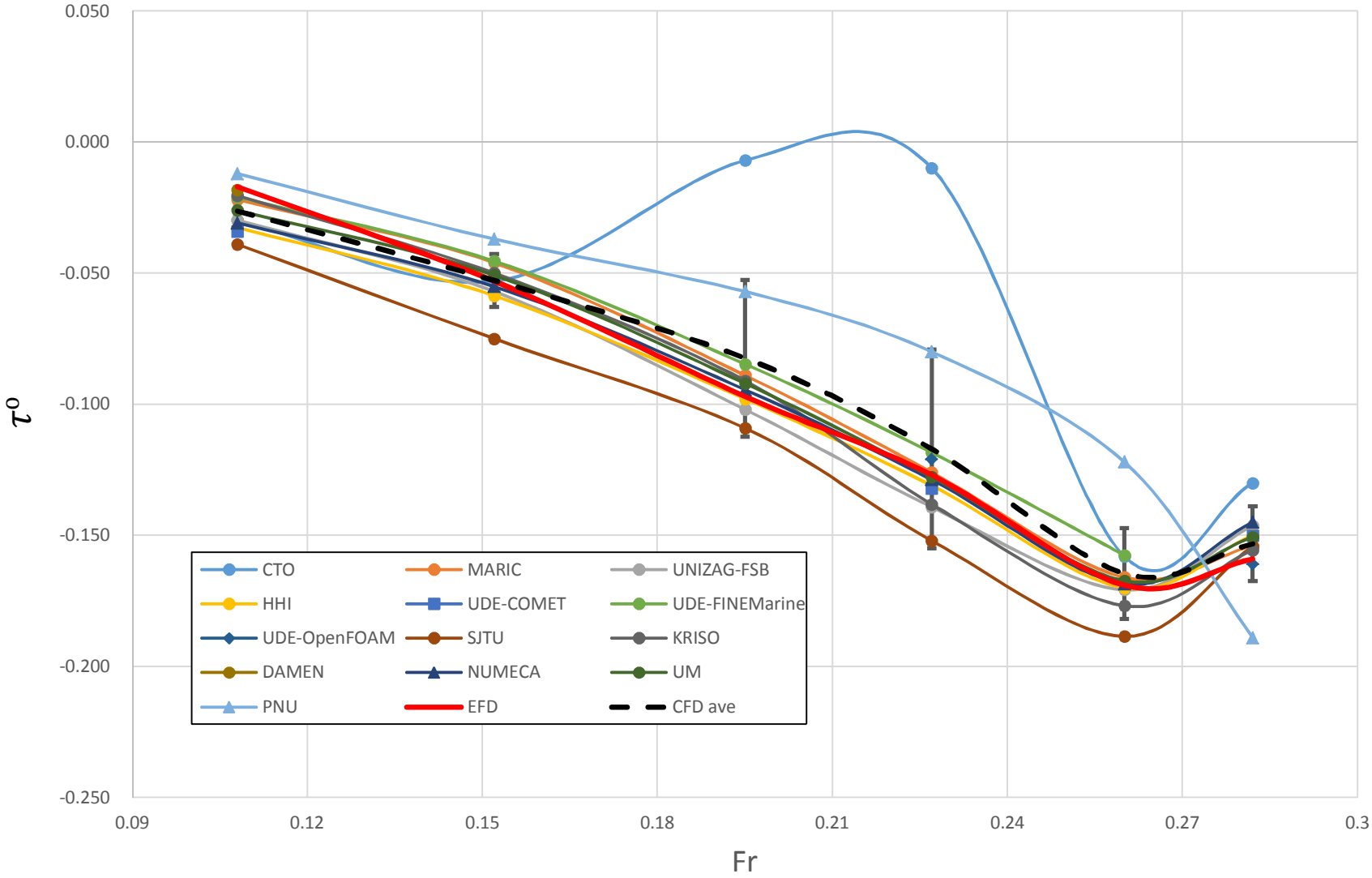
EFD and submissions for C_T



EFD and submissions for Sinkage



EFD and submissions for Trim



Outliers

$|E|_{outlier} > 2\sigma$

X : outlier

C_T

Fr	0.108	0.152	0.195	0.227	0.260	0.282
1	O	O	O	O	O	O
2	O	O	O	O	O	O
3	O	O	O	O	O	O
4	O	O	O	O	O	O
5	O	NA	NA	O	NA	O
6	O	O	O	O	O	NA
7	NA	NA	NA	O	NA	O
8	O	O	O	O	O	O
9	O	O	O	O	O	O
10	O	NA	NA	NA	NA	NA
11	O	O	O	O	O	O
12	O	O	O	O	O	O
13	O	O	O	O	O	X

Sinkage

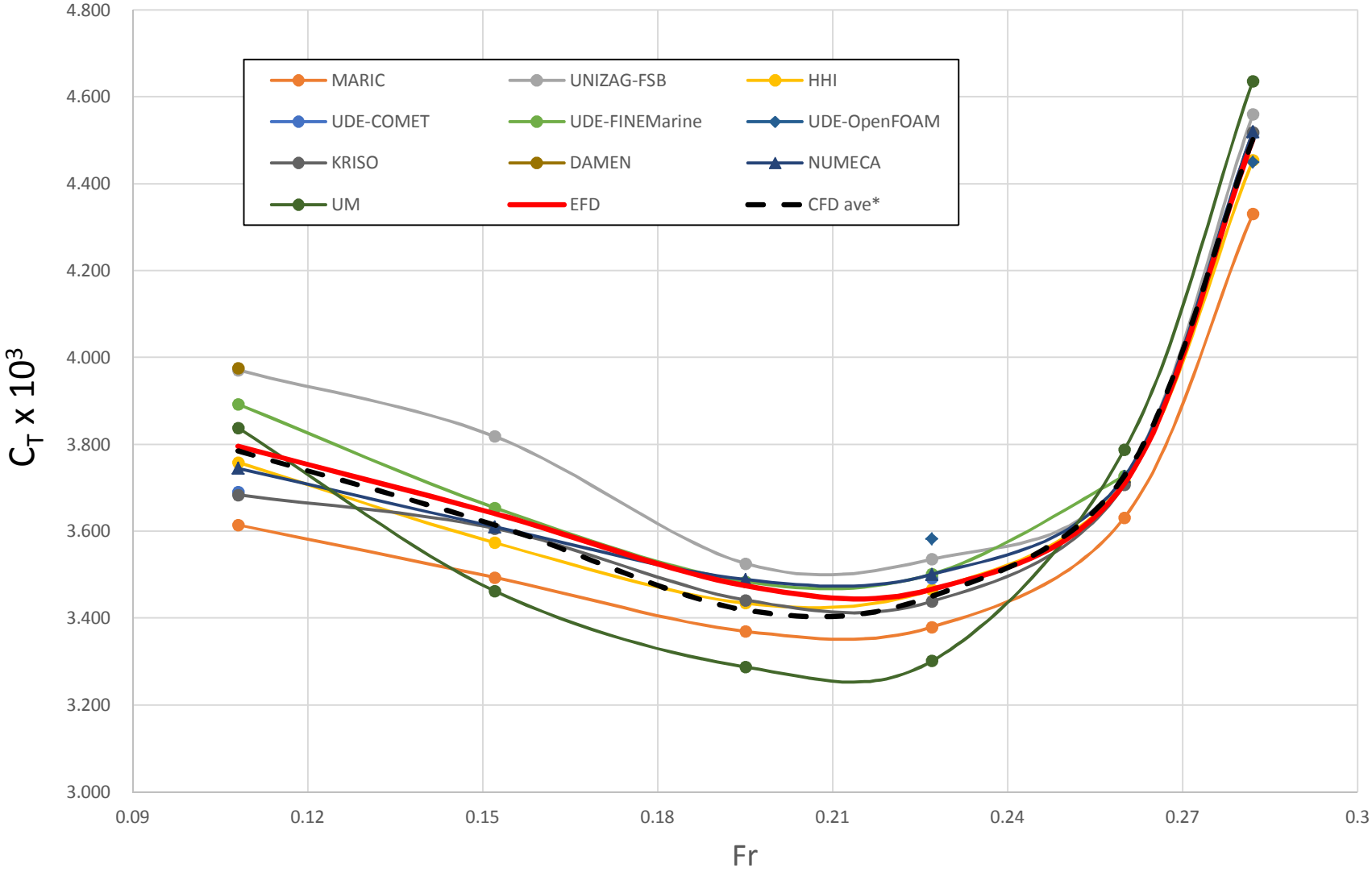
Fr	0.108	0.152	0.195	0.227	0.260	0.282
1	O	O	O	O	O	O
2	O	O	O	O	O	O
3	O	O	O	O	O	O
4	O	O	O	O	O	O
5	O	NA	NA	O	NA	O
6	O	O	O	O	O	NA
7	NA	NA	NA	O	NA	O
8	X	O	O	O	O	O
9	O	O	O	O	O	O
10	O	NA	NA	NA	NA	NA
11	O	O	O	O	O	O
12	O	O	O	O	O	O
13	O	O	X	X	X	X

Trim

Fr	0.108	0.152	0.195	0.227	0.260	0.282
1	O	O	X	X	O	O
2	O	O	O	O	O	O
3	O	O	O	O	O	O
4	O	O	O	O	O	O
5	O	NA	NA	O	NA	O
6	O	O	O	O	O	NA
7	NA	NA	NA	O	NA	O
8	O	X	O	O	O	O
9	O	O	O	O	O	O
10	O	NA	NA	NA	NA	NA
11	O	O	O	O	O	O
12	O	O	O	O	O	O
13	O	O	O	O	X	X

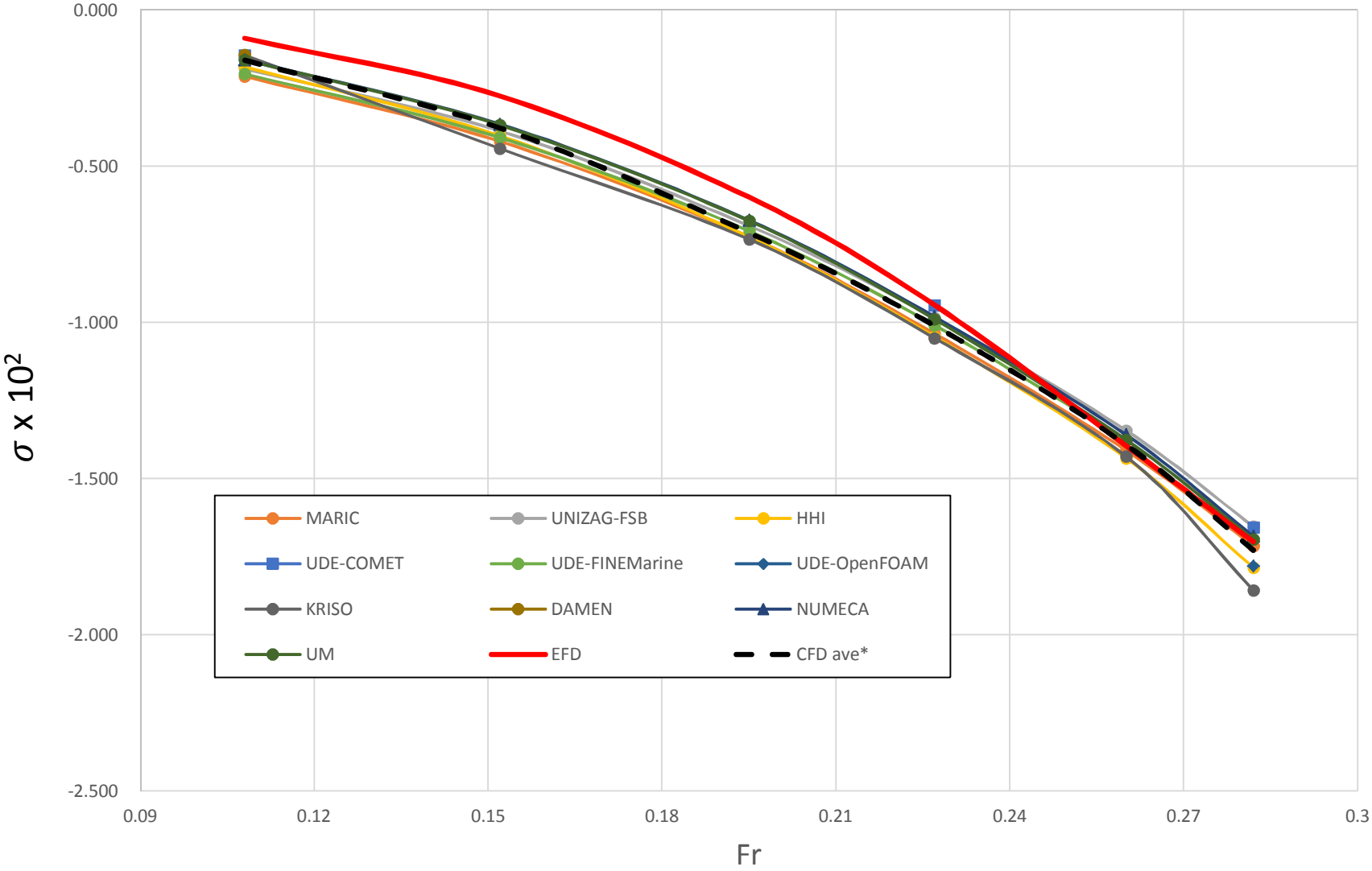
EFD and submissions for C_T

without outliers



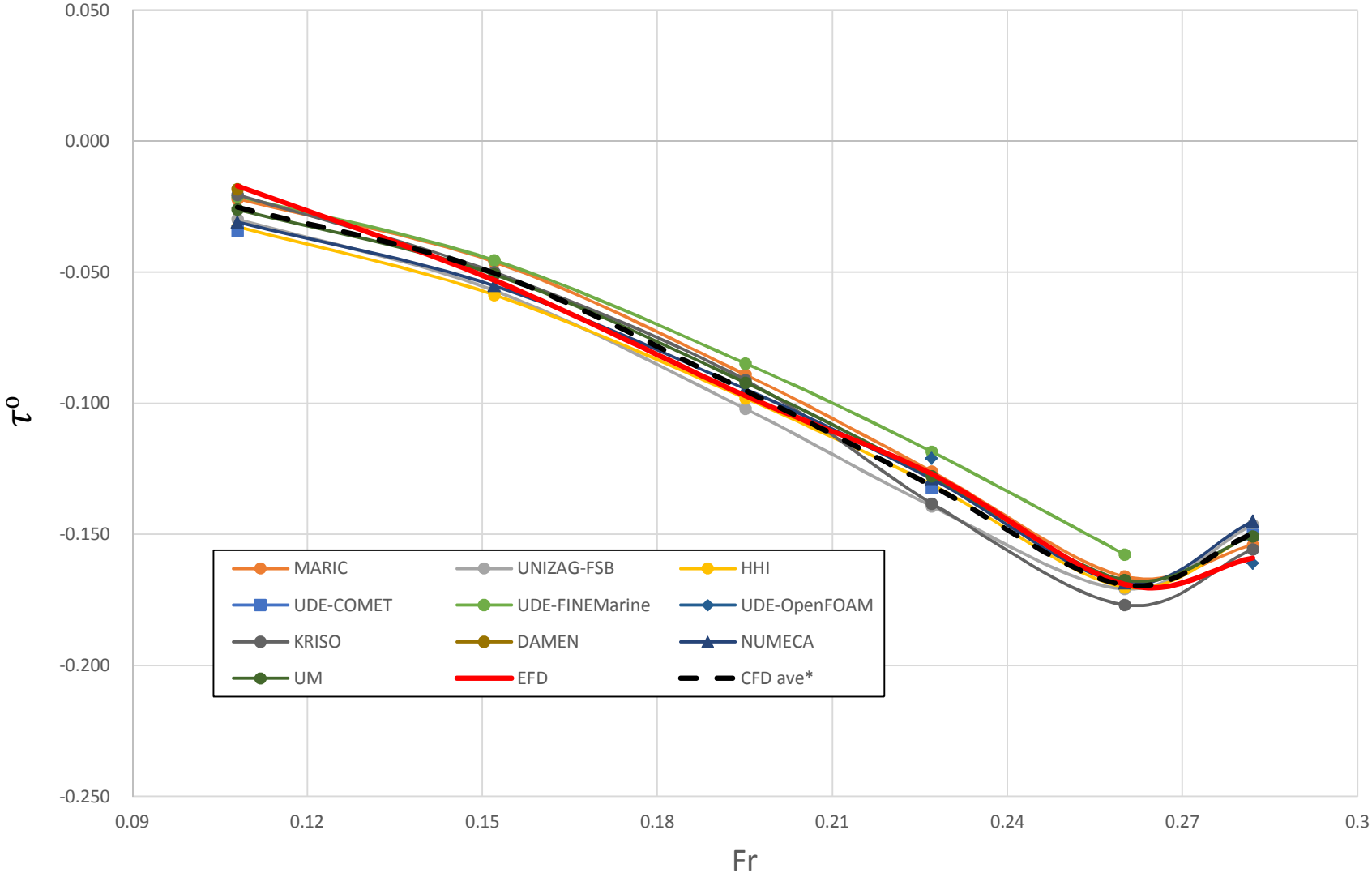
EFD and submissions for Sinkage

without outliers

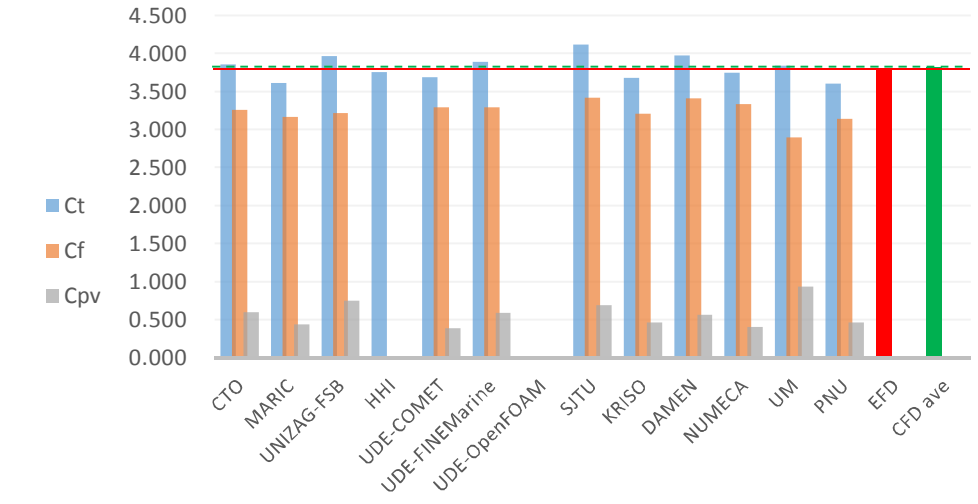


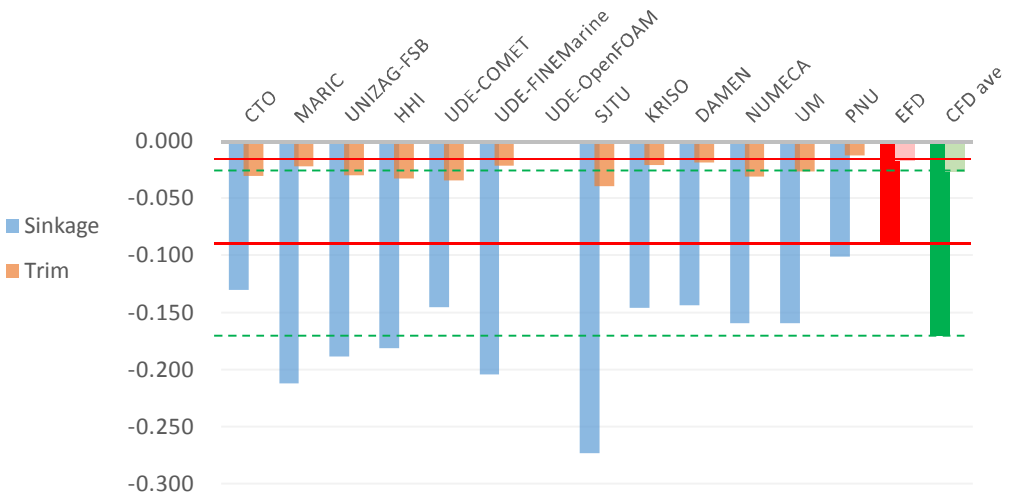
EFD and submissions for Trim

without outliers



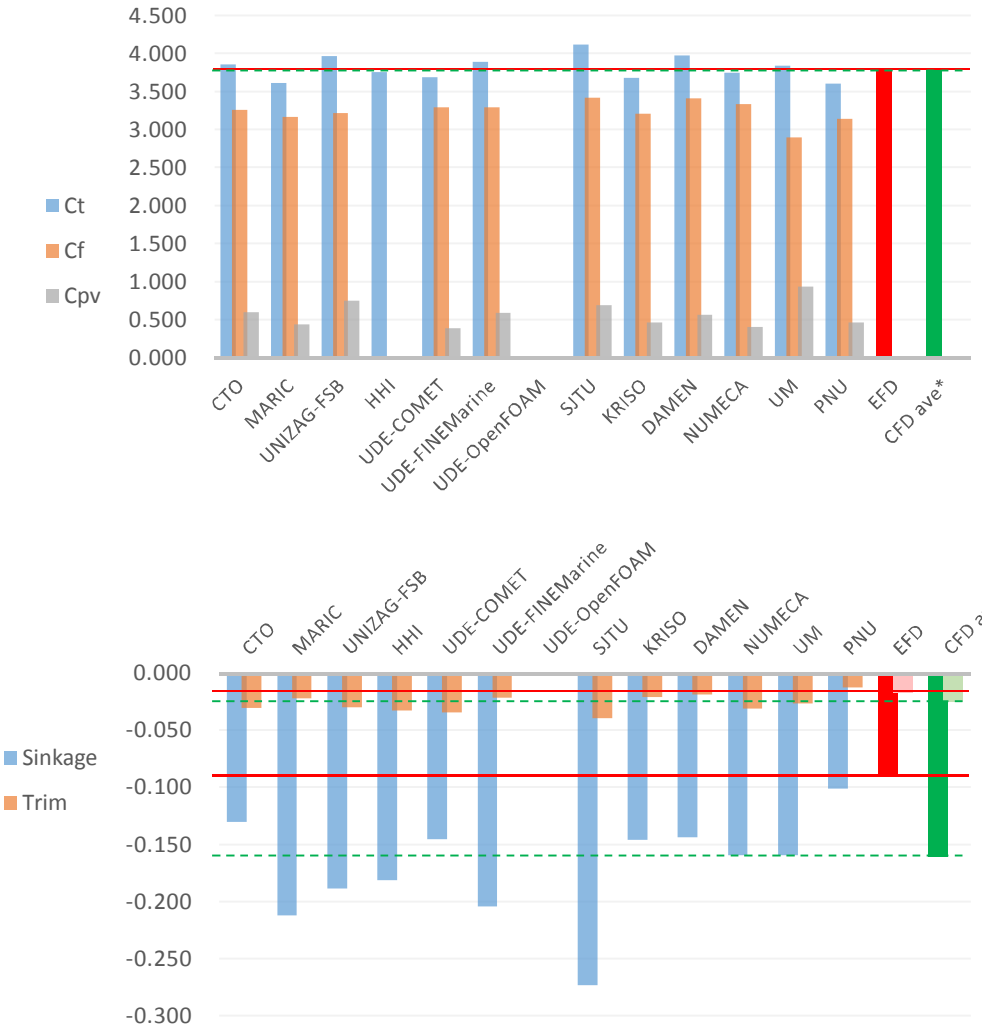
F r=0.108





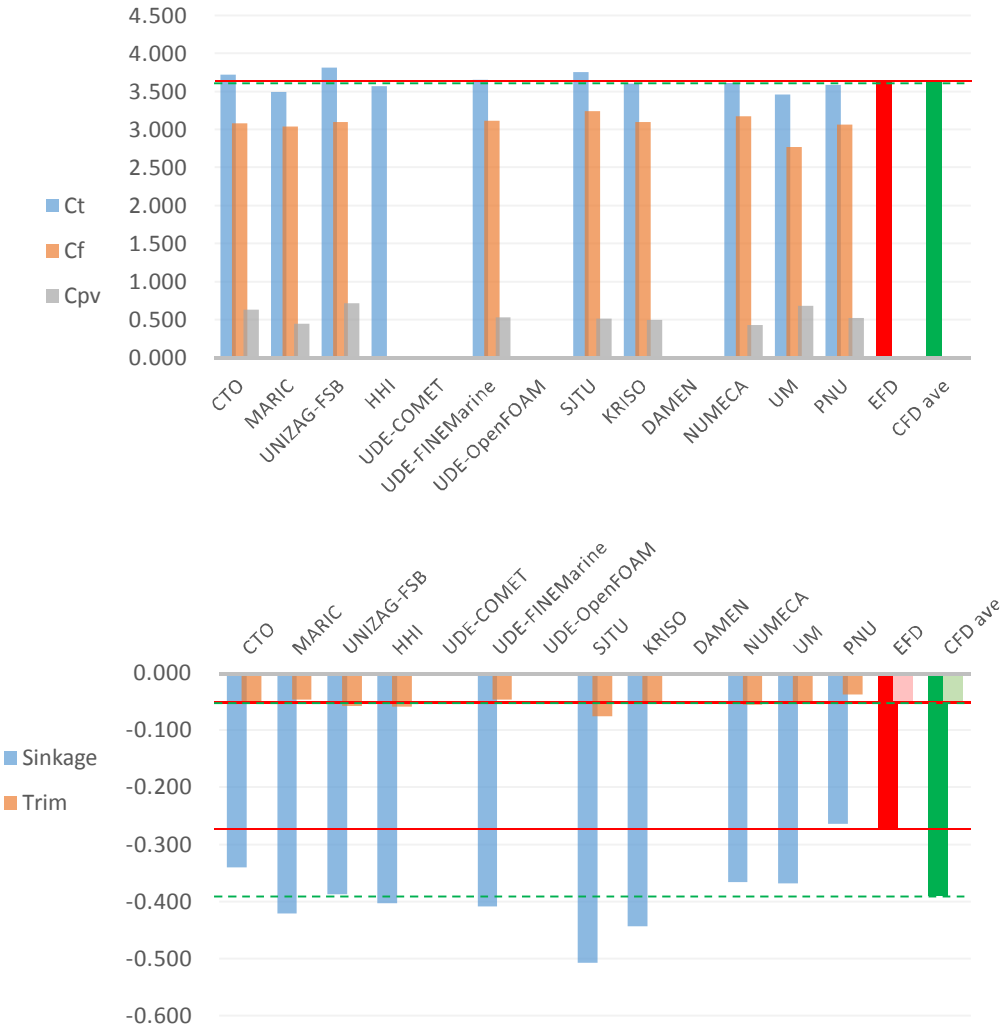
	2010	2015
Participants	4	12
Ct E_{mean}%D	+1.6	-0.4
Ct σ_{SD}%D	1.4	4.2
Sinkage E_{mean}%D	-67.1	-89.0
Sinkage σ_{SD}%D	8.2	50.3
Trim E_{mean}%D	-60.3	-54.8
Trim σ_{SD}%D	38.6	45.5
Ct $\lvert E\rvert_{mean}$%D	NA	3.4
Ct $\sigma_{SD}\lvert E\rvert$%D	NA	2.2
Sinkage $\lvert E\rvert_{mean}$%D	NA	89.0
Sinkage $\sigma_{SD}\lvert E\rvert$%D	NA	50.3
Trim $\lvert E\rvert_{mean}$%D	NA	59.7
Trim $\sigma_{SD}\lvert E\rvert$%D	NA	38.1

F r=0.108 (without outliers)



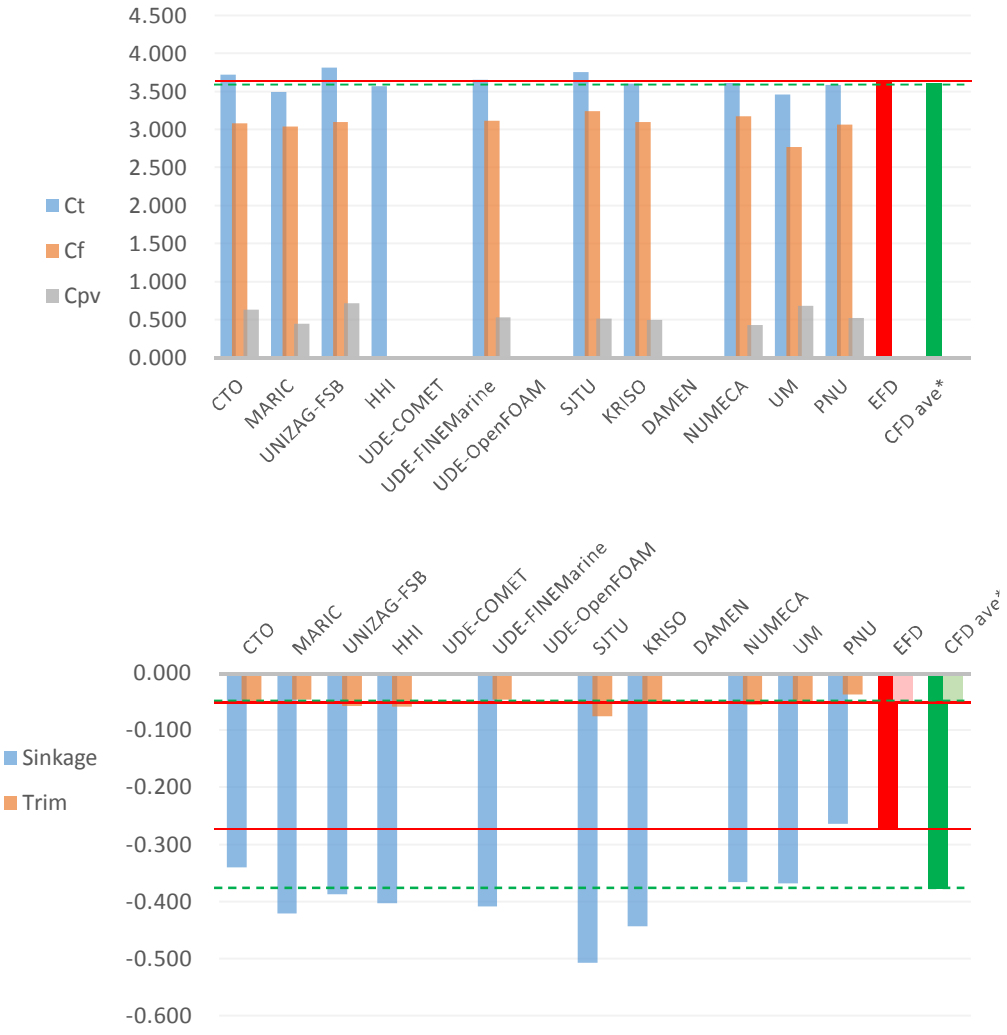
	2010	2015	2015*
Participants	4	12	
Ct E_{mean}%D	+1.6	-0.4	0.3
Ct σ_{SD}%D	1.4	4.2	3.5
Sinkage E_{mean}%D	-67.1	-89.0	-78.7
Sinkage σ_{SD}%D	8.2	50.3	36.8
Trim E_{mean}%D	-60.3	-54.8	-48.0
Trim σ_{SD}%D	38.6	45.5	40.8
Ct $\lvert E\rvert_{mean}$%D	NA	3.4	3.0
Ct $\sigma_{SD}\lvert E\rvert$%D	NA	2.2	1.6
Sinkage $\lvert E\rvert_{mean}$%D	NA	89.0	78.7
Sinkage $\sigma_{SD}\lvert E\rvert$%D	NA	50.3	36.8
Trim $\lvert E\rvert_{mean}$%D	NA	59.7	53.4
Trim $\sigma_{SD}\lvert E\rvert$%D	NA	38.1	32.7

Fr=0.152



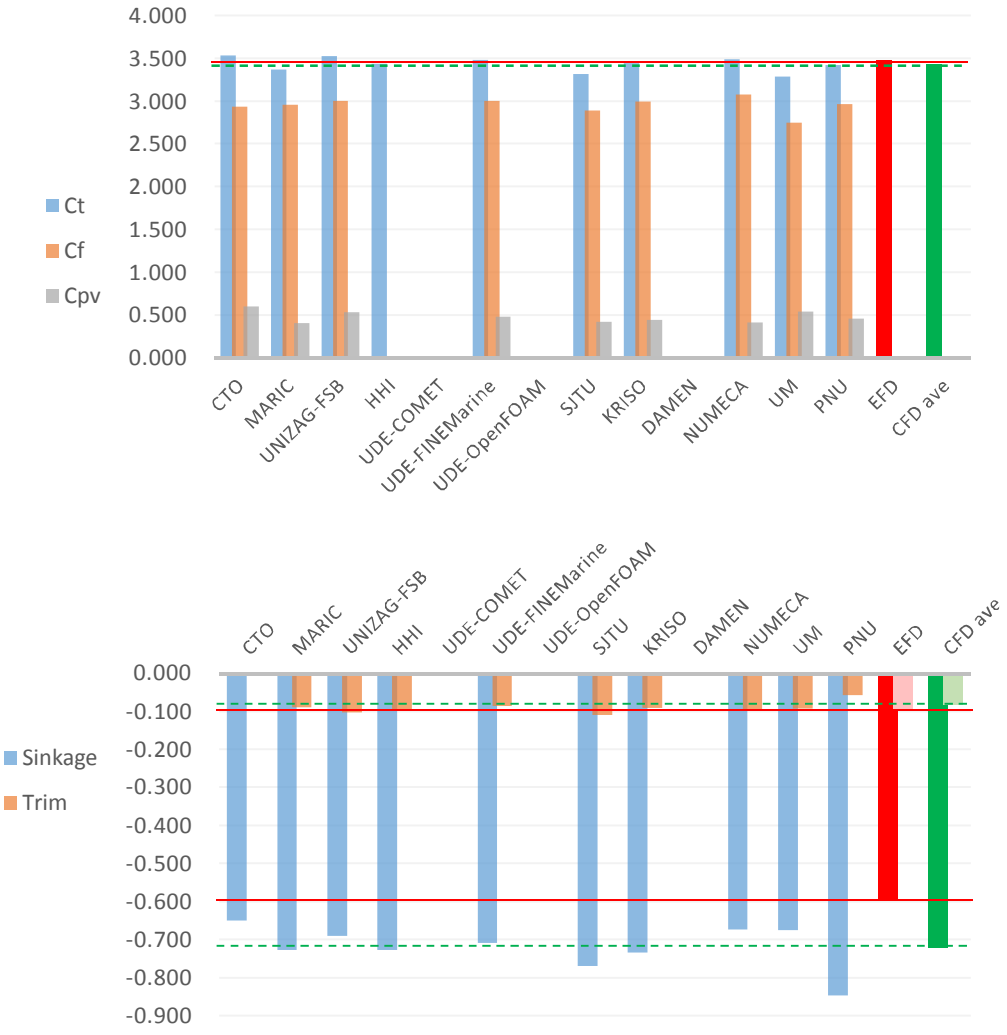
	2010	2015
Participants	3	10
Ct E_{mean}%D	-0.1	0.3
Ct σ_{SD}%D	1.1	3.1
Sinkage E_{mean}%D	-44.1	-41.9
Sinkage σ_{SD}%D	15.1	23.5
Trim E_{mean}%D	0.7	0.4
Trim σ_{SD}%D	4.9	19.0
Ct $\lvert E\rvert_{mean}$%D	NA	2.3
Ct $\sigma_{SD}\lvert E\rvert$%D	NA	1.7
Sinkage $\lvert E\rvert_{mean}$%D	NA	43.9
Sinkage $\sigma_{SD}\lvert E\rvert$%D	NA	21.7
Trim $\lvert E\rvert_{mean}$%D	NA	14.7
Trim $\sigma_{SD}\lvert E\rvert$%D	NA	13.0

F r=0.152 (without outliers)



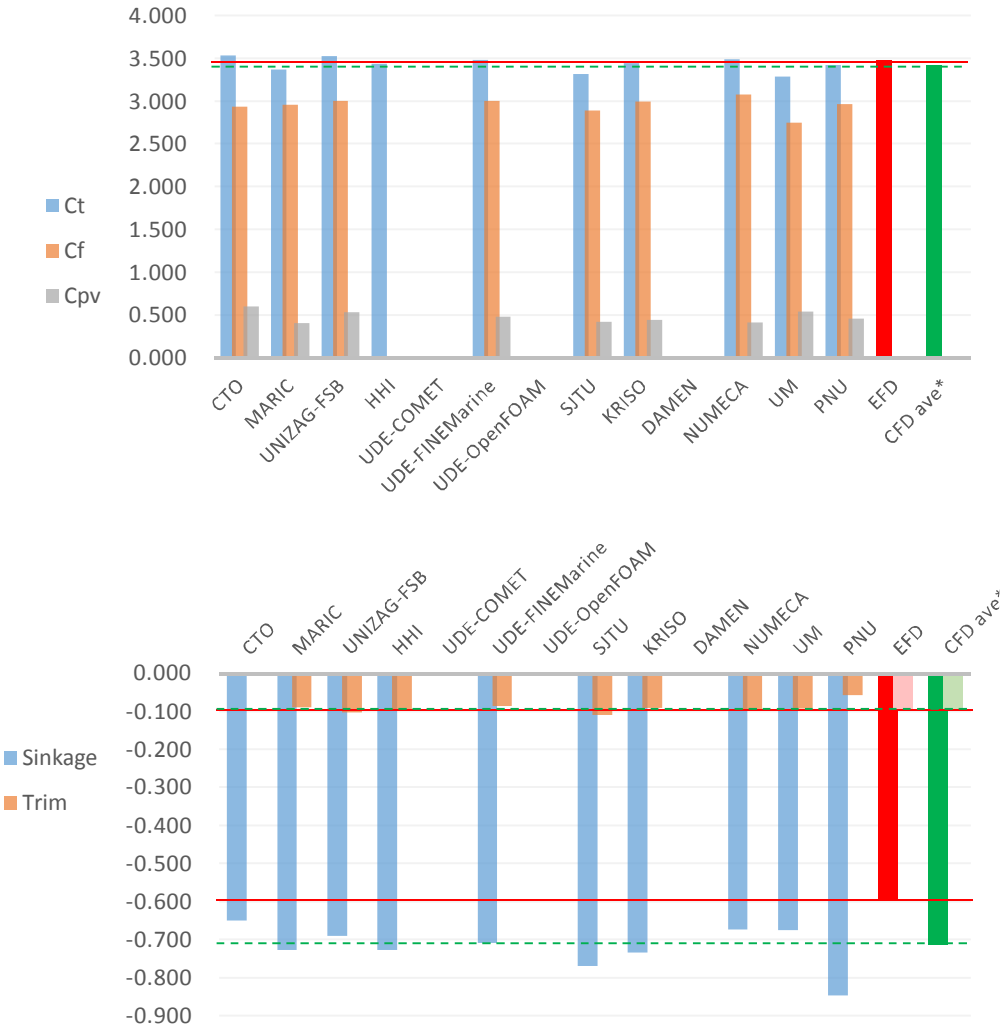
	2010	2015	2015*
Participants	3	10	
Ct E_{mean}%D	-0.1	0.3	0.7
Ct σ_{SD}%D	1.1	3.1	3.0
Sinkage E_{mean}%D	-44.1	-41.9	-37.2
Sinkage σ_{SD}%D	15.1	23.5	19.3
Trim E_{mean}%D	0.7	0.4	5.1
Trim σ_{SD}%D	4.9	19.0	12.7
Ct $\lvert E\rvert_{mean}$%D	NA	2.3	2.4
Ct $\sigma_{SD}\lvert E\rvert$%D	NA	1.7	1.8
Sinkage $\lvert E\rvert_{mean}$%D	NA	43.9	38.2
Sinkage $\sigma_{SD}\lvert E\rvert$%D	NA	21.7	17.0
Trim $\lvert E\rvert_{mean}$%D	NA	14.7	10.0
Trim $\sigma_{SD}\lvert E\rvert$%D	NA	13.0	8.9

Fr=0.195



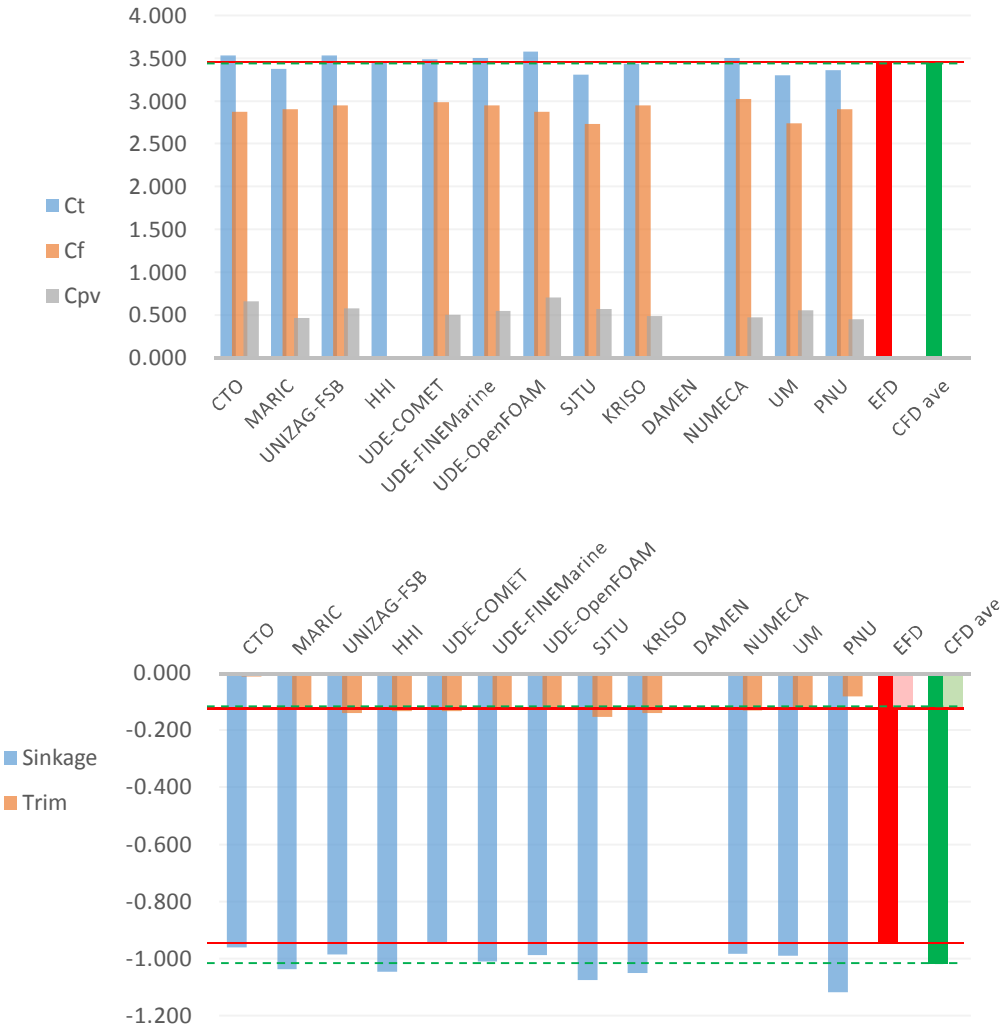
	2010	2015
Participants	4	10
Ct E_{mean}%D	-0.9	1.3
Ct σ_{SD}%D	1.7	2.4
Sinkage E_{mean}%D	-12.9	-20.2
Sinkage σ_{SD}%D	6.6	9.5
Trim E_{mean}%D	1.6	15.0
Trim σ_{SD}%D	3.8	30.8
Ct $\lvert E\rvert_{mean}$%D	NA	2.0
Ct $\sigma_{SD}\lvert E\rvert$%D	NA	1.7
Sinkage $\lvert E\rvert_{mean}$%D	NA	20.2
Sinkage $\sigma_{SD}\lvert E\rvert$%D	NA	9.5
Trim $\lvert E\rvert_{mean}$%D	NA	18.8
Trim $\sigma_{SD}\lvert E\rvert$%D	NA	28.4

F r=0.195 (without outliers)



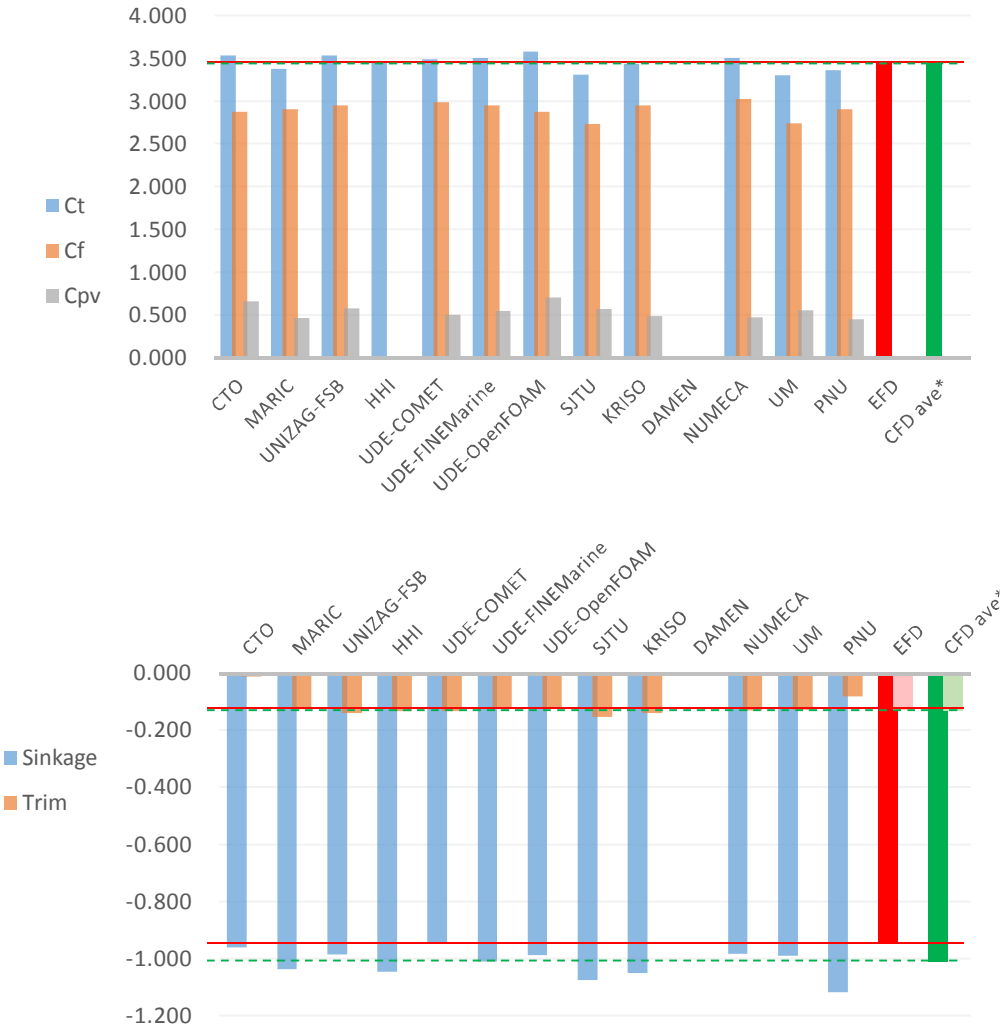
	2010	2015	2015*
Participants	4	10	
Ct E_{mean}%D	-0.9	1.3	1.6
Ct σ_{SD}%D	1.7	2.4	2.5
Sinkage E_{mean}%D	-12.9	-20.2	-19.0
Sinkage σ_{SD}%D	6.6	9.5	5.5
Trim E_{mean}%D	1.6	15.0	2.0
Trim σ_{SD}%D	3.8	30.8	8.0
Ct $\lvert E\rvert_{mean}$%D	NA	2.0	2.2
Ct $\sigma_{SD}\lvert E\rvert$%D	NA	1.7	1.9
Sinkage $\lvert E\rvert_{mean}$%D	NA	20.2	19.0
Sinkage $\sigma_{SD}\lvert E\rvert$%D	NA	9.5	5.5
Trim $\lvert E\rvert_{mean}$%D	NA	18.8	6.7
Trim $\sigma_{SD}\lvert E\rvert$%D	NA	28.4	4.2

Fr=0.227



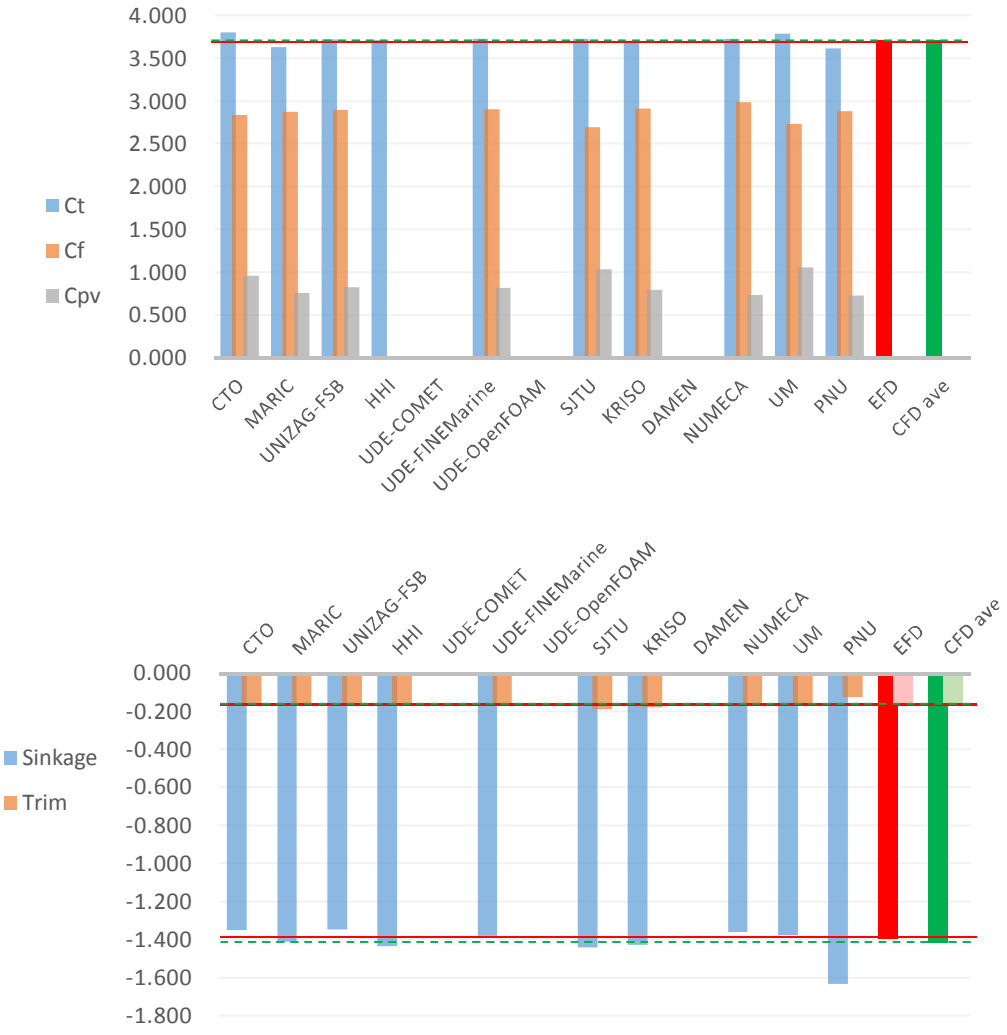
	2010	2015
Participants	6	12
Ct E_{mean}%D	-1.0	0.5
Ct σ_{SD}%D	1.4	2.7
Sinkage E_{mean}%D	-4.2	-7.5
Sinkage σ_{SD}%D	4.1	5.4
Trim E_{mean}%D	-3.2	7.9
Trim σ_{SD}%D	4.6	29.8
Ct $\lvert E\rvert_{mean}$%D	NA	2.1
Ct $\sigma_{SD}\lvert E\rvert$%D	NA	1.5
Sinkage $\lvert E\rvert_{mean}$%D	NA	7.5
Sinkage $\sigma_{SD}\lvert E\rvert$%D	NA	5.4
Trim $\lvert E\rvert_{mean}$%D	NA	15.7
Trim $\sigma_{SD}\lvert E\rvert$%D	NA	26.2

F r=0. 227 (without outliers)



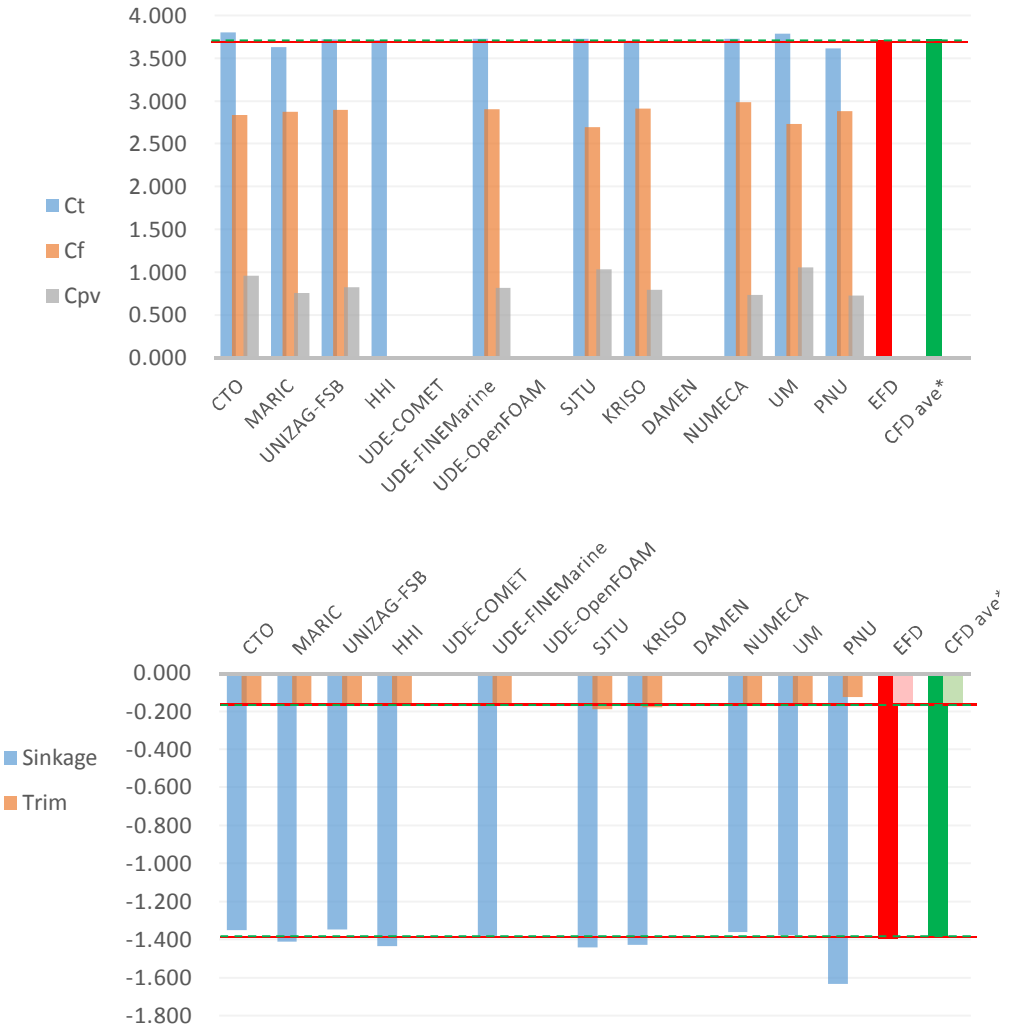
	2010	2015	2015*
Participants	6	12	
Ct E_{mean}%D	-1.0	0.5	0.5
Ct σ_{SD}%D	1.4	2.7	2.7
Sinkage E_{mean}%D	-4.2	-7.5	-7.0
Sinkage σ_{SD}%D	4.1	5.4	4.2
Trim E_{mean}%D	-3.2	7.9	-3.5
Trim σ_{SD}%D	4.6	29.8	7.7
Ct $\lvert E\rvert_{mean}$%D	NA	2.1	2.1
Ct $\sigma_{SD}\lvert E\rvert$%D	NA	1.5	1.7
Sinkage $\lvert E\rvert_{mean}$%D	NA	7.5	7.0
Sinkage $\sigma_{SD}\lvert E\rvert$%D	NA	5.4	4.2
Trim $\lvert E\rvert_{mean}$%D	NA	15.7	5.9
Trim $\sigma_{SD}\lvert E\rvert$%D	NA	26.2	5.8

F r=0. 260



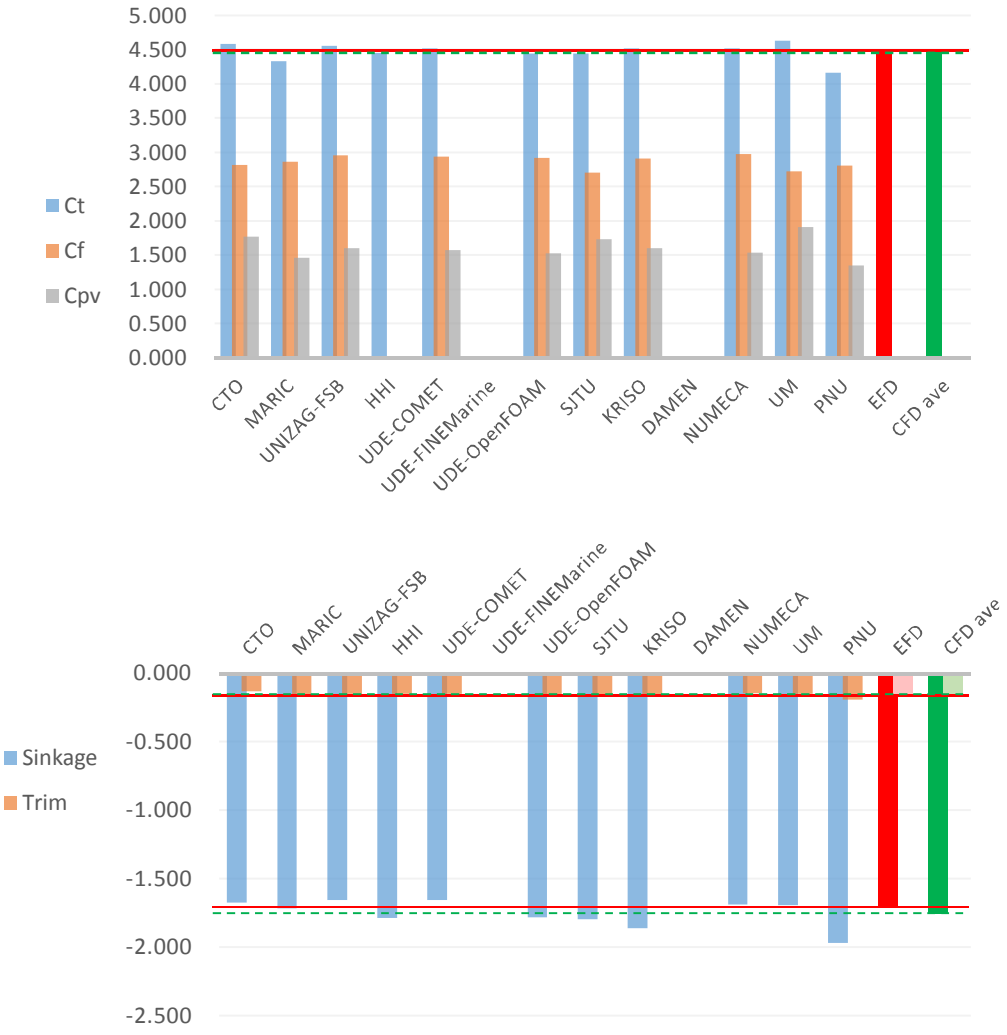
	2010	2015
Participants	4	10
Ct E_{mean}%D	-0.3	-0.2
Ct σ_{SD}%D	1.2	1.5
Sinkage E_{mean}%D	1.5	-1.5
Sinkage σ_{SD}%D	4.8	6.0
Trim E_{mean}%D	-3.1	2.6
Trim σ_{SD}%D	3.0	10.3
Ct $\lvert E\rvert_{mean}$%D	NA	1.1
Ct $\sigma_{SD}\lvert E\rvert$%D	NA	1.0
Sinkage $\lvert E\rvert_{mean}$%D	NA	3.9
Sinkage $\sigma_{SD}\lvert E\rvert$%D	NA	4.8
Trim $\lvert E\rvert_{mean}$%D	NA	6.2
Trim $\sigma_{SD}\lvert E\rvert$%D	NA	8.4

F r=0. 260 (without outliers)



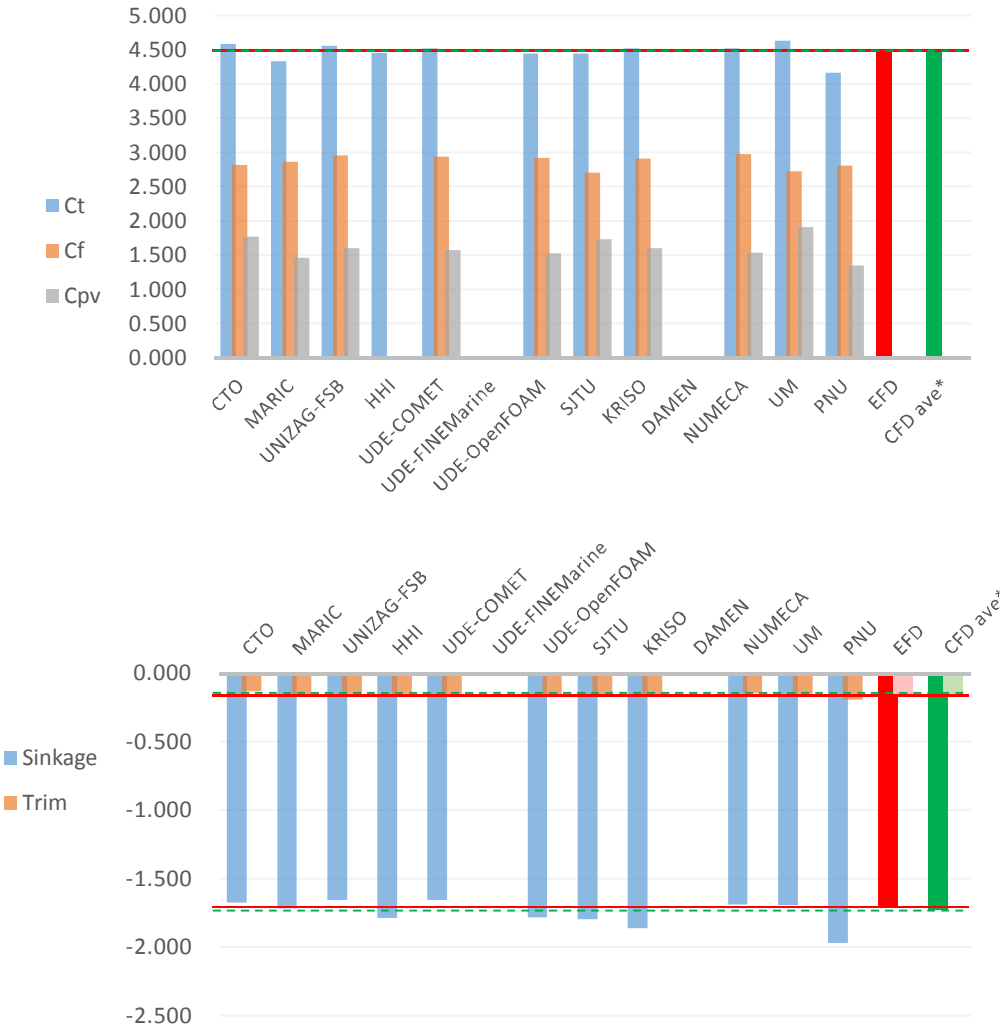
	2010	2015	2015*
Participants	4	10	
Ct E_{mean}%D	-0.3	-0.2	-0.5
Ct σ_{SD}%D	1.2	1.5	1.3
Sinkage E_{mean}%D	1.5	-1.5	0.2
Sinkage σ_{SD}%D	4.8	6.0	2.7
Trim E_{mean}%D	-3.1	2.6	-0.2
Trim σ_{SD}%D	3.0	10.3	5.6
Ct $\lvert E\rvert_{mean}$%D	NA	1.1	1.0
Ct $\sigma_{SD}\lvert E\rvert$%D	NA	1.0	1.0
Sinkage $\lvert E\rvert_{mean}$%D	NA	3.9	2.4
Sinkage $\sigma_{SD}\lvert E\rvert$%D	NA	4.8	0.9
Trim $\lvert E\rvert_{mean}$%D	NA	6.2	3.8
Trim $\sigma_{SD}\lvert E\rvert$%D	NA	8.4	3.8

Fr=0.282



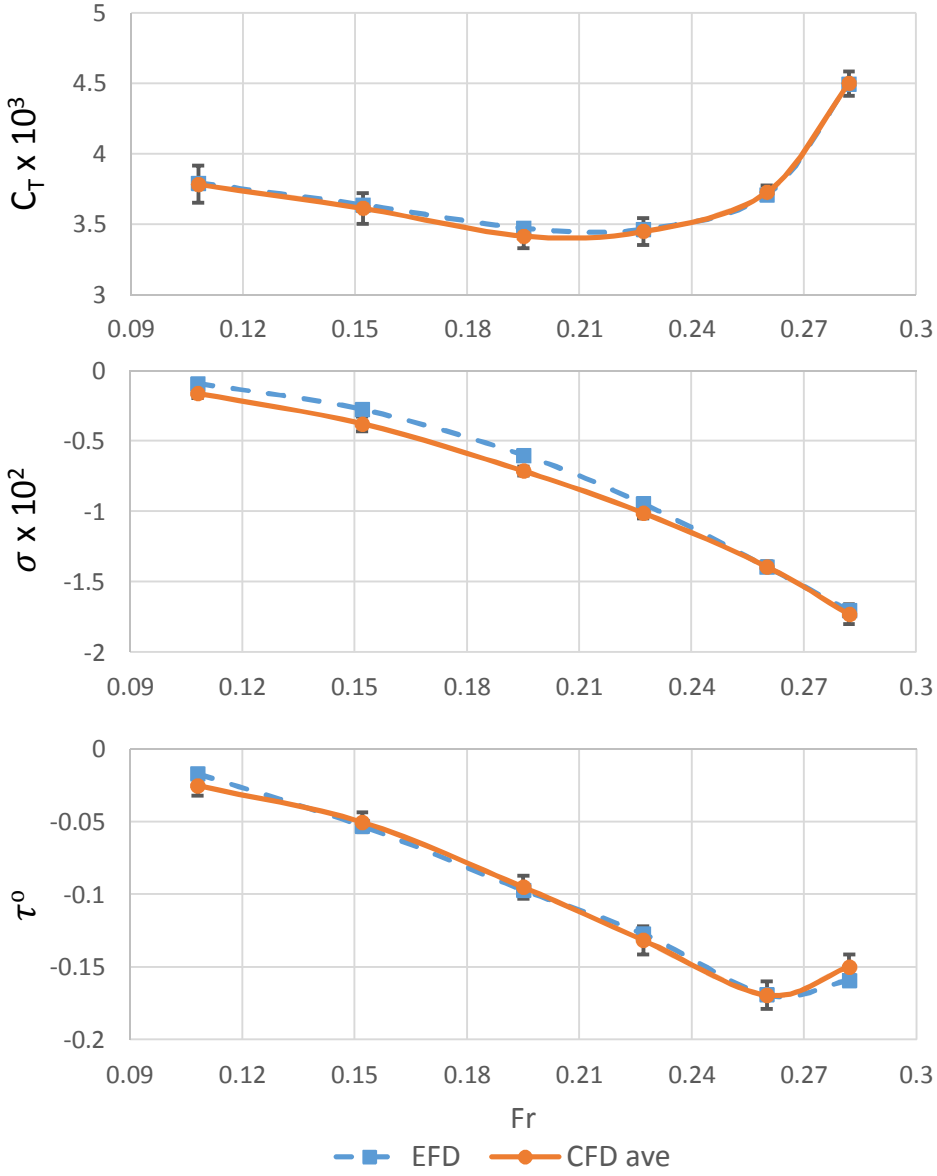
	2010	2015
Participants	6	11
Ct E_{mean}%D	-0.4	0.7
Ct σ_{SD}%D	0.8	2.9
Sinkage E_{mean}%D	-2.1	-2.9
Sinkage σ_{SD}%D	5.6	5.8
Trim E_{mean}%D	3.6	3.6
Trim σ_{SD}%D	4.2	9.0
Ct $\lvert E\rvert_{mean}$%D	NA	2.0
Ct $\sigma_{SD}\lvert E\rvert$%D	NA	2.1
Sinkage $\lvert E\rvert_{mean}$%D	NA	4.5
Sinkage $\sigma_{SD}\lvert E\rvert$%D	NA	4.5
Trim $\lvert E\rvert_{mean}$%D	NA	7.3
Trim $\sigma_{SD}\lvert E\rvert$%D	NA	6.0

F r=0. 282 (without outliers)



	2010	2015	2015*
Participants	6	11	
Ct E_{mean}%D	-0.4	0.7	-0.0
Ct σ_{SD}%D	0.8	2.9	1.9
Sinkage E_{mean}%D	-2.1	-2.9	-1.6
Sinkage σ_{SD}%D	5.6	5.8	4.1
Trim E_{mean}%D	3.6	3.6	5.9
Trim σ_{SD}%D	4.2	9.0	5.2
Ct $\lvert E\rvert_{mean}$%D	NA	2.0	1.5
Ct $\sigma_{SD}\lvert E\rvert$%D	NA	2.1	1.1
Sinkage $\lvert E\rvert_{mean}$%D	NA	4.5	3.3
Sinkage $\sigma_{SD}\lvert E\rvert$%D	NA	4.5	2.7
Trim $\lvert E\rvert_{mean}$%D	NA	7.3	6.1
Trim $\sigma_{SD}\lvert E\rvert$%D	NA	6.0	4.9

Mean of KCS (without outliers)

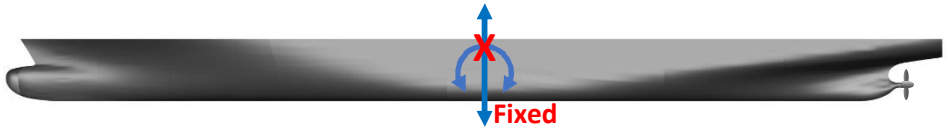


	2010	2015
Participants	4	13
Ct E_{mean}%D	-0.3	0.43
Ct σ_{SD}%D	1.3	2.48
Sinkage E_{mean}%D	-21.9	-23.87
Sinkage σ_{SD}%D	9.9	12.09
Trim E_{mean}%D	-9.6	-6.45
Trim σ_{SD}%D	11.2	13.34
Ct $\lvert E\rvert_{mean}$%D	1.64	2.00
Sinkage $\lvert E\rvert_{mean}$%D (Fr<0.2)	55.6	45.26
Sinkage $\lvert E\rvert_{mean}$%D (Fr≥0.2)	7.5	4.25
Trim $\lvert E\rvert_{mean}$%D (Fr<0.2)	30.5	23.34
Trim $\lvert E\rvert_{mean}$%D (Fr≥0.2)	3.62	5.29

Summary

- No. of grid point is not much dependent (more than 1M is enough?)
- Two-eqn. turbulence model is good enough
- CT: signed E is 0.43%D, absolute E is 2.00%D
- Sinkage: signed E is -23.9%D, absolute E is 24.8%D
- Trim: signed E is -6.5%D, absolute E is 14.3%D
- Sinkage and trim errors for Fn$\geq$0.2 are less than for Fn<0.2
- σ_{SD} of CT at design Fn is very small while σ_{SD} at low Fn is relatively big
- Sinkage is over-predicted in low Fn range

CASE 2.5 and 2.7



- Self propelled at ship point in calm water
- Free (even keel)
- With propeller, without rudder
- FR_0
- L_{PP} = 7.2786 [m]
- Fr = 0.260

Participants

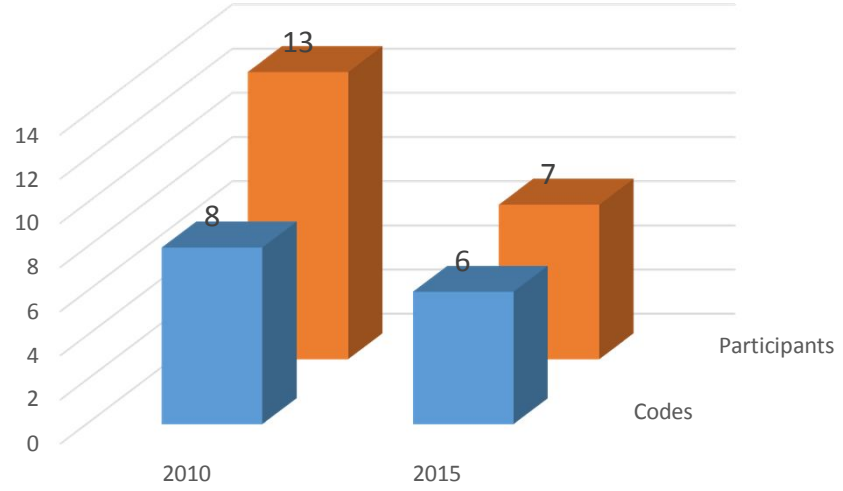
Gothenburg2010

Organization	Code
CSSRC	Fluent
CTO	Stat-CCM
IIHR	CFDShip-Iowa
IIHR-SJTU	Fluent
MARIC	Fluent
MARIN	PARNASSOS
KRISO (MOERI)	WAVIS
NMRI	SURF
SNUTT	Fluent
Southampton Univ. QinetiQ	CFX
SSPA	SHIPFLOW
SSRC Univ. Strathclyde	Fluent
TUHH ANSYS	CFX

Tokyo2015

Organization	Code
MARIC	FINE/Marine
PNU	Fluent
MARIN	PARNASSOS
KRISO	WAVIS
UM	OpenFOAM
HHI*	Star-CCM
CTO*	Star-CCM

*case 2.5 only



Submissions

Participants	CTO	HHI	MARIN	MARIC	KRISO	UM	PNU
Grid Type	unstructured	unstructured	structured	unstructured	structured	unstructured	unstructured
Turbulence	two-eqn.	RSM	one-eqn.	two-eqn.	two-eqn.	two-eqn.	two-eqn.
Grid Size		4.5M	12M		8.6M	2.6M	15M
Propeller model		Actual	Lifting-surf.		Lifting-surf.	Actual	Actual
Ship point	FD fixed	rps fixed	FD fixed	rps fixed	FD fixed	rps fixed	?
V&V			◇		●		●

V&V Analysis (computed results of different grid densities)

Organization	rG		CT					CF					CPV				
			Grid#5	Grid#4	Grid#3	Grid#2	Grid#1	Grid#5	Grid#4	Grid#3	Grid#2	Grid#1	Grid#5	Grid#4	Grid#3	Grid#2	Grid#1
EFD(KRISO)		D	3.966					-					-				
KRISO	1.414	S			4.184	4.007	3.965			2.831	2.834	2.83			1.353	1.173	1.135
		E%D			-5.50%	-1.03%	0.03%										
MARIN		S	3.921	3.771	3.953	3.954	3.955	2.962	2.956	2.953	2.953	0.956	0.959	0.815	1.000	1.001	0.999
		E%D	1.13%	4.92%	0.33%	0.30%	0.28%										
PNU	1.414	S			4.435	4.369	4.308			2.829	2.811	2.808			1.606	1.558	1.530
		E%D			-11.83%	-10.16%	-8.62%										

Organization	rG		KT					KQ				
			Grid#5	Grid#4	Grid#3	Grid#2	Grid#1	Grid#5	Grid#4	Grid#3	Grid#2	Grid#1
EFD(KRISO)		D	0.170					0.0288				
KRISO	1.414	S			0.174	0.166	0.167			0.0300	0.0280	0.0290
		E%D			-2.12%	2.37%	1.76%			-2.74%	4.03%	0.66%
MARIN		S	0.178	0.172	0.1766	0.1762	0.1759	0.0309	0.0299	0.0306	0.0305	0.0305
		E%D	-4.71%	-1.18%	-3.88%	-3.65%	-3.47%	-7.43%	-3.96%	-6.15%	-5.90%	-5.76%
PNU	1.414	S			0.190	0.185	0.183			0.032	0.032	0.031
		E%D			-11.75%	-8.94%	-7.91%			-11.81%	-9.38%	-9.03%

Organization	rG		n (for given SFC)					[RT-T] (for given n)				
			Grid#5	Grid#4	Grid#3	Grid#2	Grid#1	Grid#5	Grid#4	Grid#3	Grid#2	Grid#1
EFD(KRISO)		D	9.500					30.25				
KRISO	1.414	S			9.7806	9.686	9.6059					
		E%D			-2.95%	-1.96%	1.11%					
MARIN		S	9.208	9.096	9.3210	9.3170	9.3280					
		E%D	3.07%	4.25%	1.88%	1.93%	1.81%					
PNU	1.414	S			9.9400	9.7240	9.7220			41.6508	35.4398	35.3128
		E%D			-4.63%	-2.36%	-2.34%			-37.69%	-17.16%	-16.74%

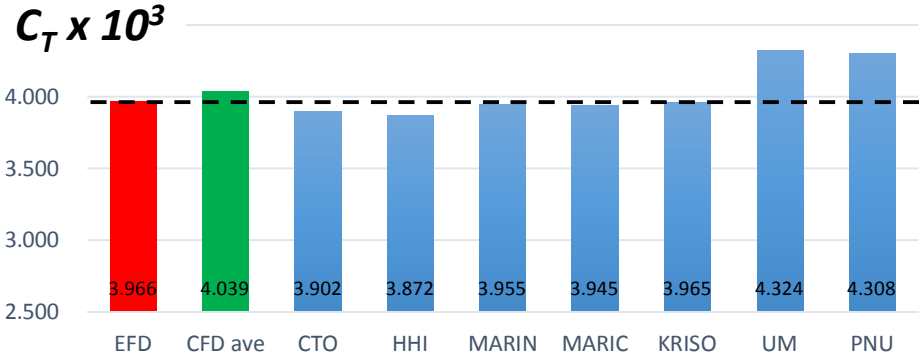
V&V Analysis

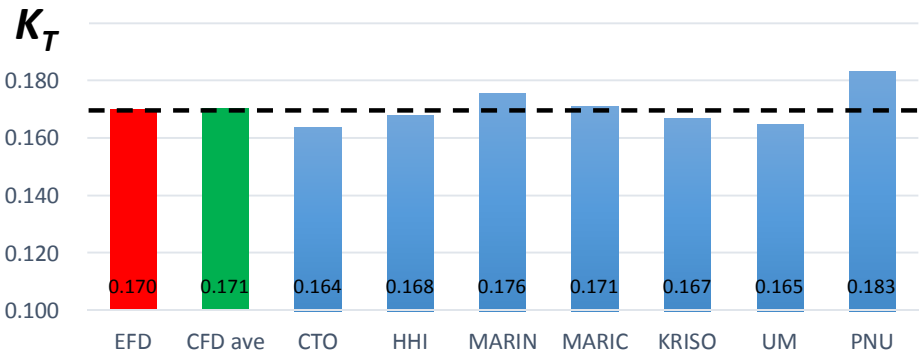
Organization	CT				CF				CP			
	$\epsilon_{12}\%S_1$	U_I/ε_{12}	$P_G/P_{G,th}$	$U_G\%S_1$	$\epsilon_{12}\%S_1$	U_I/ε_{12}	$P_G/P_{G,th}$	$U_G\%S_1$	$\epsilon_{12}\%S_1$	U_I/ε_{12}	$P_G/P_{G,th}$	$U_G\%S_1$
KRISO	1.05	0.00	2.09	1.78	0.16	0.00	0.40	0.51	3.35	0.00	2.25	5.80
PNU	1.42	2.34	0.11	4.02	2.17	1.67	2.58	-0.75	3.99	36.49	4.77	-5.70

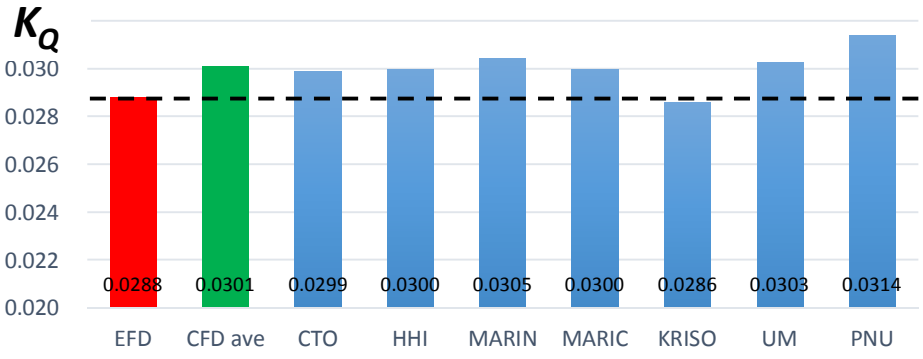
Organization	KT				KQ			
	$\epsilon_{12}\%S_1$	U_I/ε_{12}	$P_G/P_{G,th}$	$U_G\%S_1$	$\epsilon_{12}\%S_1$	U_I/ε_{12}	$P_G/P_{G,th}$	$U_G\%S_1$
KRISO	0.61	0.00	2.90	1.13	3.40	0.00	1.01	3.43
PNU	0.96	0.09	1.44	-0.42	0.32	0.25	2.81	-2.87

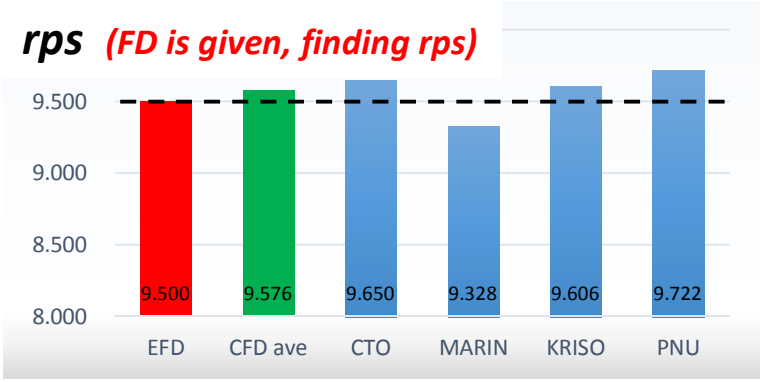
Organization	n (for given SFC)				[RT-T] (for given n)			
	$\epsilon_{12}\%S_1$	U_I/ε_{12}	$P_G/P_{G,th}$	$U_G\%S_1$	$\epsilon_{12}\%S_1$	U_I/ε_{12}	$P_G/P_{G,th}$	$U_G\%S_1$
KRISO	0.83	0.00	0.24	4.63				
PNU	0.02	0.00	6.75	-4.34	0.36	17.01	5.61	-33.38

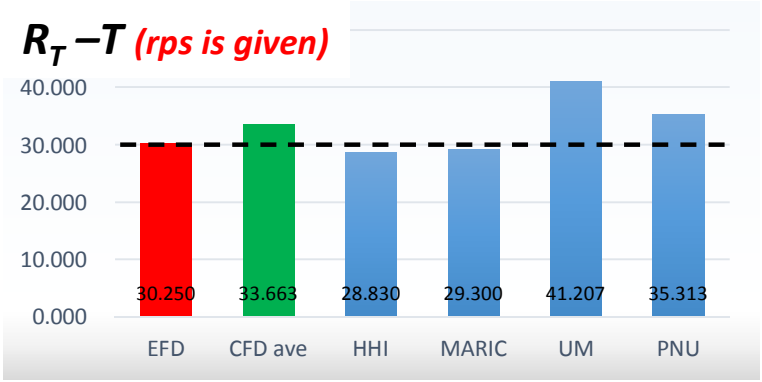
EFD and submissions



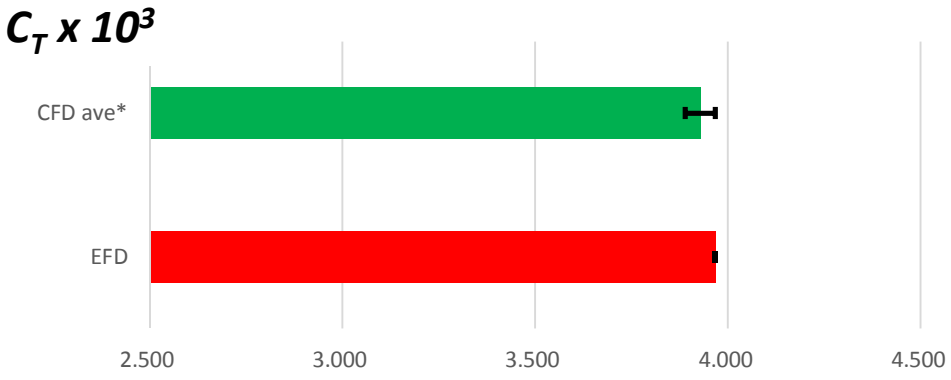




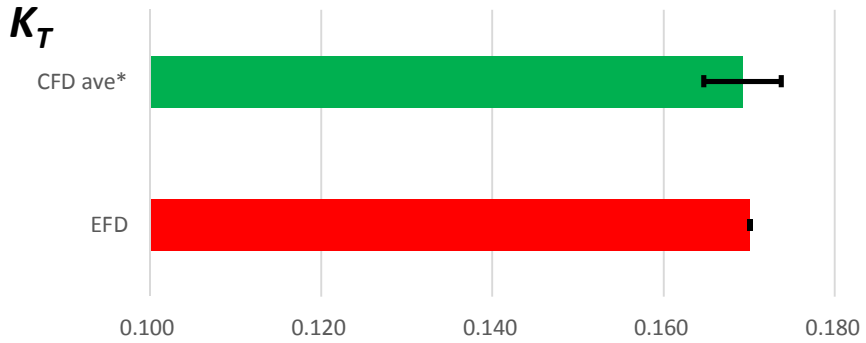


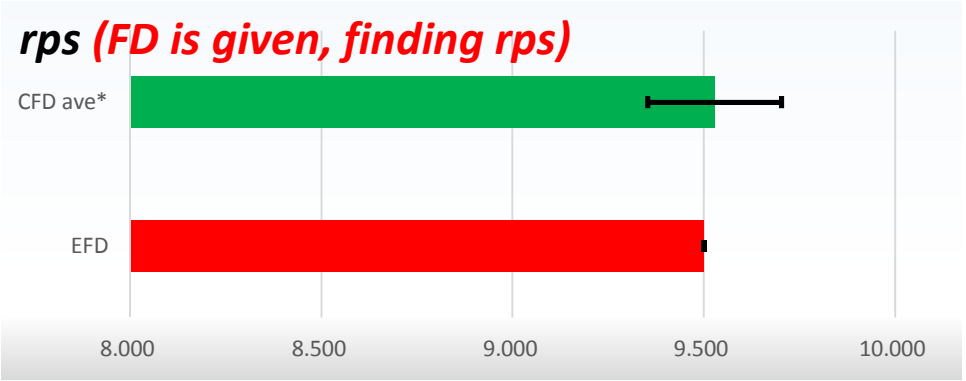


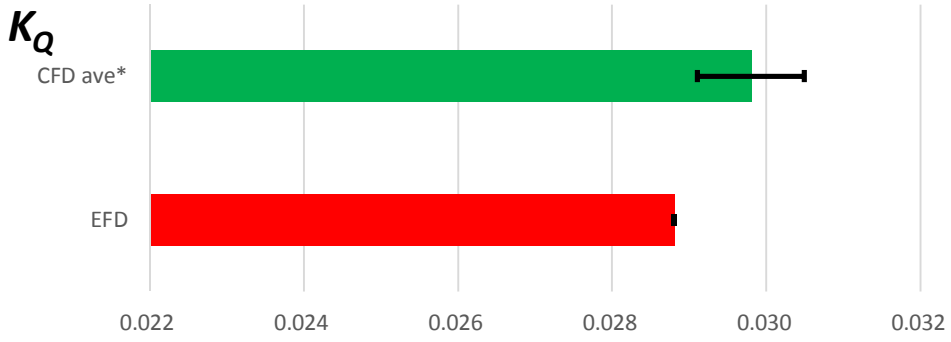
Mean of KCS without outliers

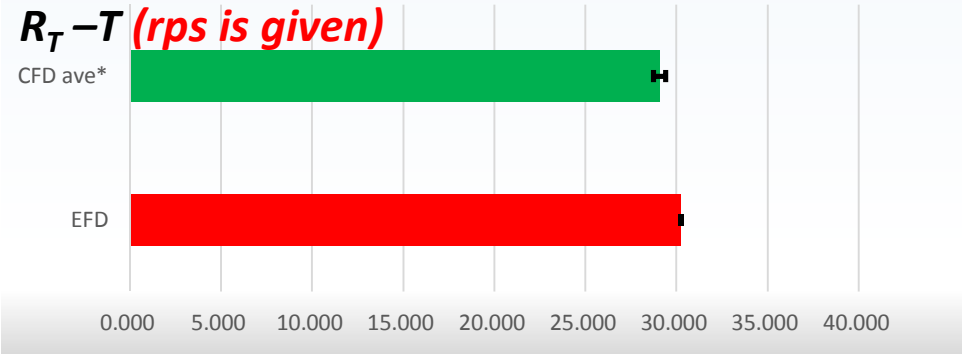


$|E|_{outlier} > 2\sigma$









Mean of KCS without outliers

		2005	2010	2015
Participants		4	13	**7**
C_T	E_{mean}%D	-0.9	-0.3	**1.0**
	σ_{SD}%D	1.0	3.1	**1.0**
K_T	E_{mean}%D		-0.6	**0.5**
	σ_{SD}%D		7.2	**2.7**
K_Q	E_{mean}%D		-4.6	**-3.5**
	σ_{SD}%D		6.1	**2.4**
rps	E_{mean}%D		0.6	**-0.3**
	σ_{SD}%D		2.8	**1.8**
R_T-T	E_{mean}%D		-7.8	**3.9**
	σ_{SD}%D		4.4	**1.1**

		2015
C_T	$\lvert E\rvert_{mean}$%D	1.0
	$\sigma_{SD}\lvert E\rvert$%D	1.0
K_T	$\lvert E\rvert_{mean}$%D	2.1
	$\sigma_{SD}\lvert E\rvert$%D	1.3
K_Q	$\lvert E\rvert_{mean}$%D	3.7
	$\sigma_{SD}\lvert E\rvert$%D	1.9
rps	$\lvert E\rvert_{mean}$%D	1.5
	$\sigma_{SD}\lvert E\rvert$%D	0.4
R_T-T	$\lvert E\rvert_{mean}$%D	3.9
	$\sigma_{SD}\lvert E\rvert$%D	1.1

Mean of KCS (FD fixed vs. rps fixed)

FD is given, finding rps

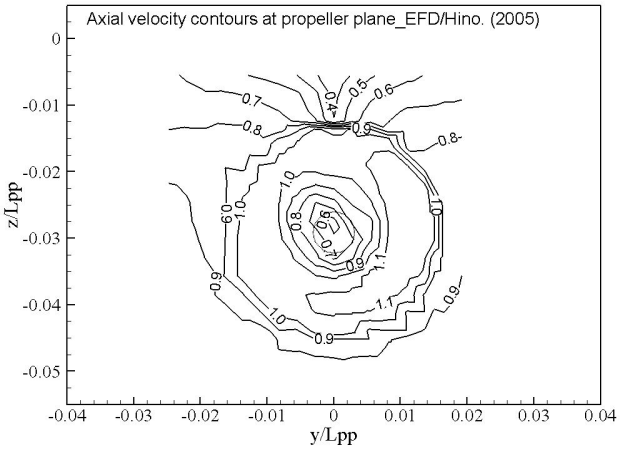
		2015		2015
Participants		**3**		
C_T	E_{mean}%D	**0.6**	$\|E\|_{mean}$%D	0.6
K_T	E_{mean}%D	**0.6**	$\|E\|_{mean}$%D	2.9
K_Q	E_{mean}%D	**-3.0**	$\|E\|_{mean}$%D	3.4
rps	E_{mean}%D	**-0.3**	$\|E\|_{mean}$%D	1.5
R_T-T	E_{mean}%D	**-**	$\|E\|_{mean}$%D	-

rps is given

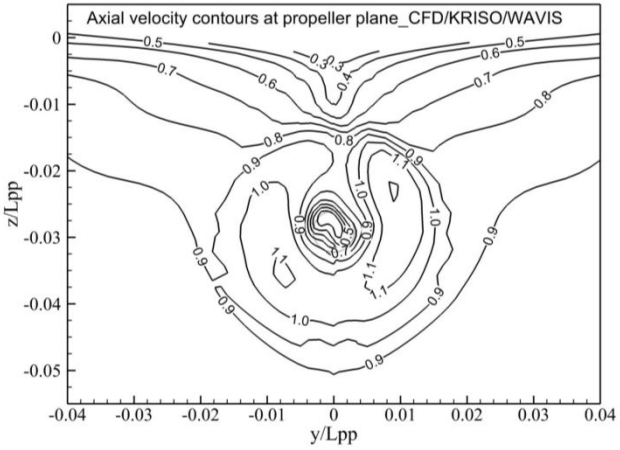
		2015		2015
Participants		**2**		
C_T	E_{mean}%D	**1.5**	$\|E\|_{mean}$%D	1.5
K_T	E_{mean}%D	**0.3**	$\|E\|_{mean}$%D	0.9
K_Q	E_{mean}%D	**-4.2**	$\|E\|_{mean}$%D	4.2
rps	E_{mean}%D	**-**	$\|E\|_{mean}$%D	-
R_T-T	E_{mean}%D	**3.9**	$\|E\|_{mean}$%D	3.9

Axial velocity contours

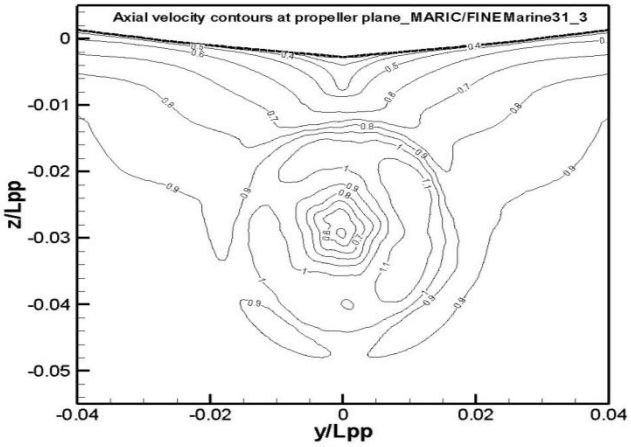
Propeller model : Actual
Lifting-surface



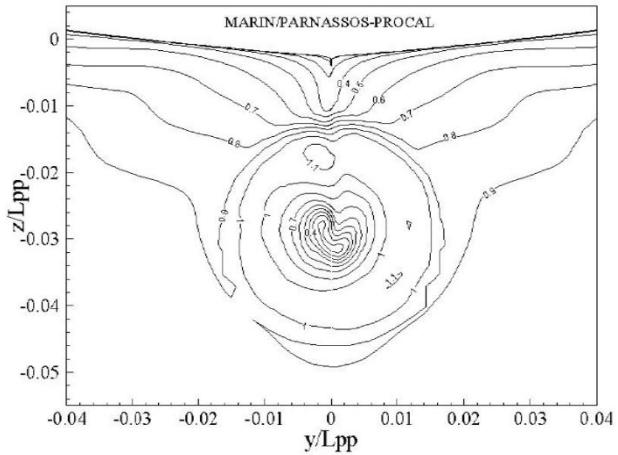
EFD



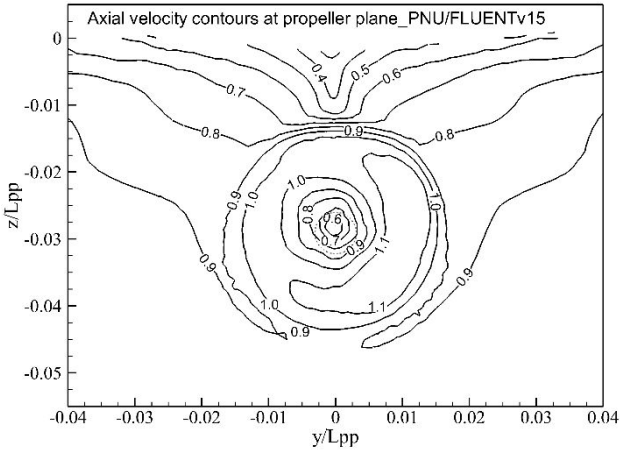
KRISO/WAVIS



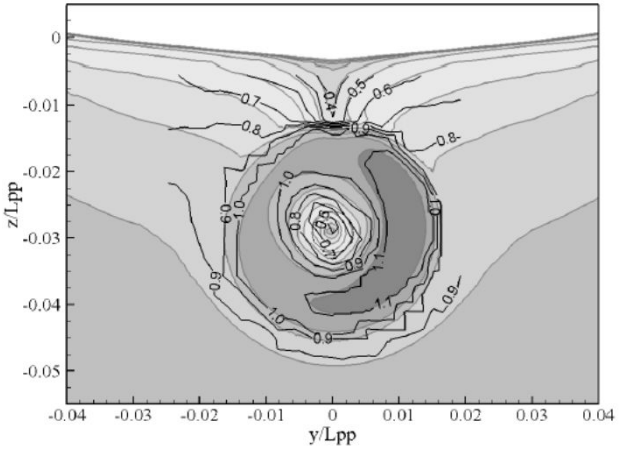
MARIC/FINEMarine



MARIN/PARNASSOS



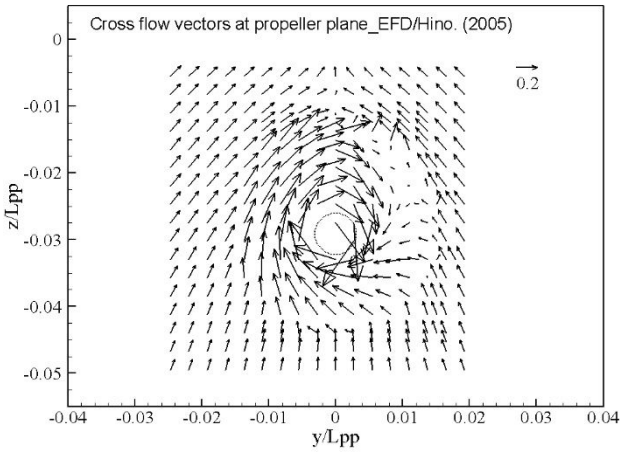
PNU/Fluent



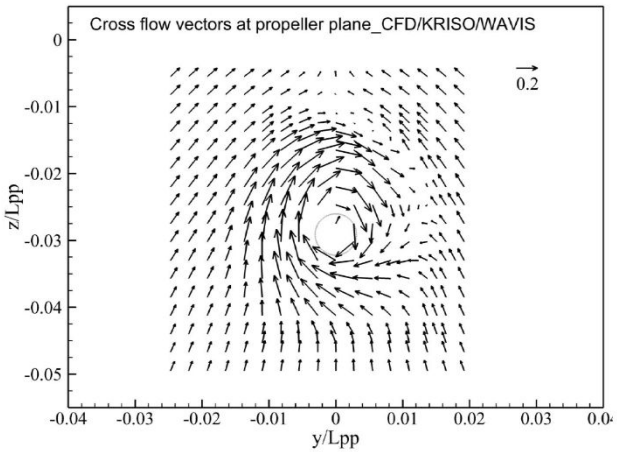
UM/OpenFOAM

Cross flow vectors

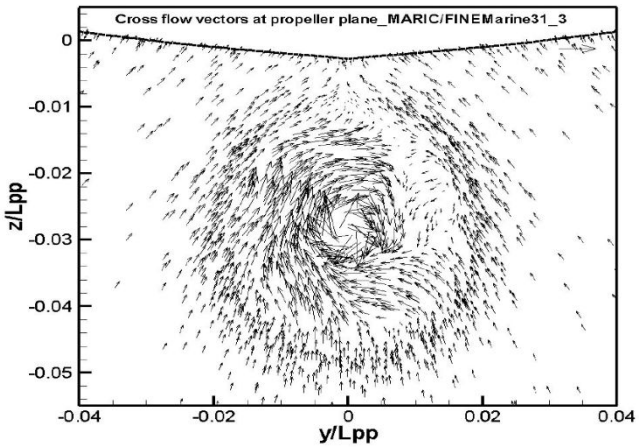
Propeller model : Actual
Lifting-surface



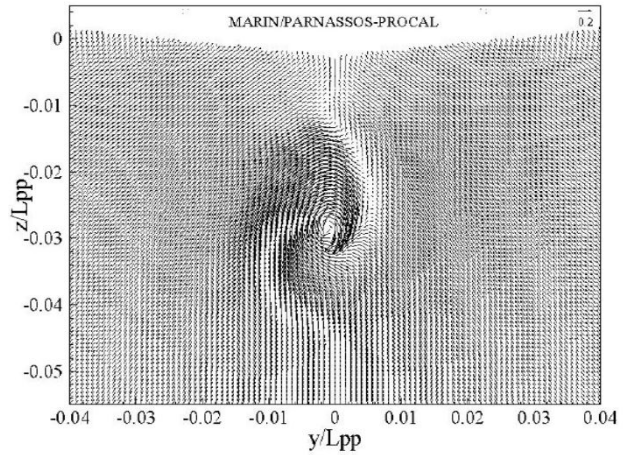
EFD



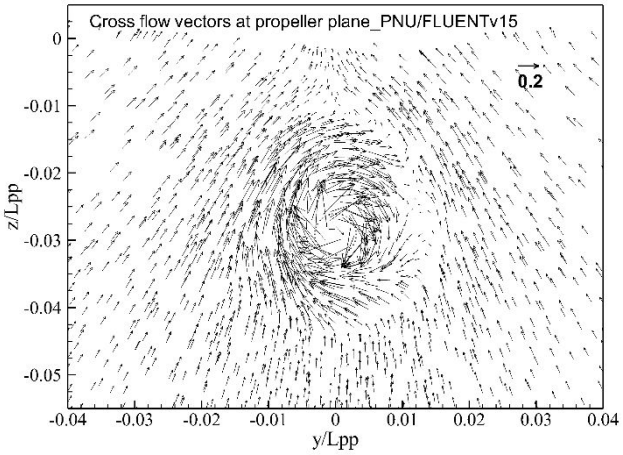
KRISO/WAVIS



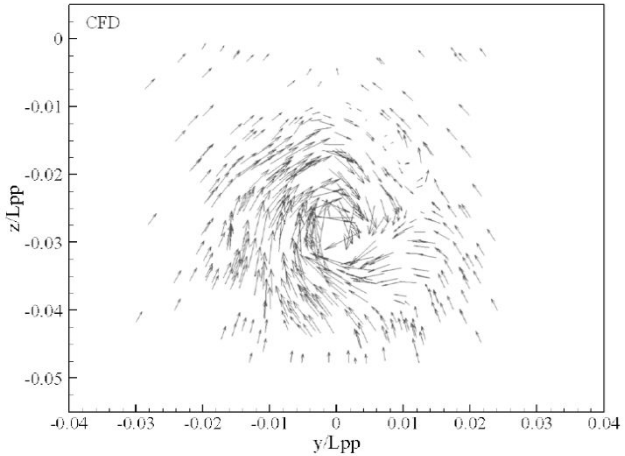
MARIC/FINEMarine



MARIN/PARNASSOS



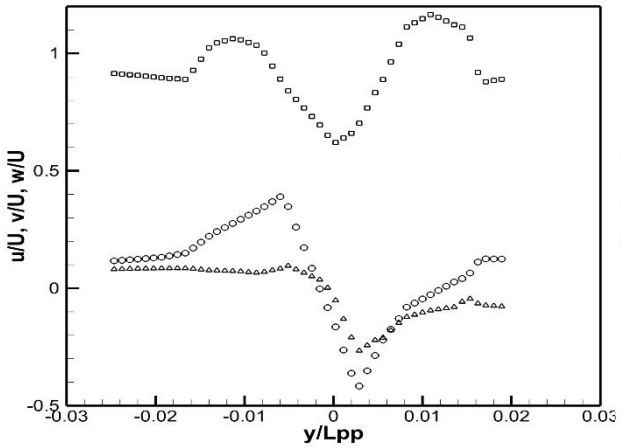
PNU/Fluent



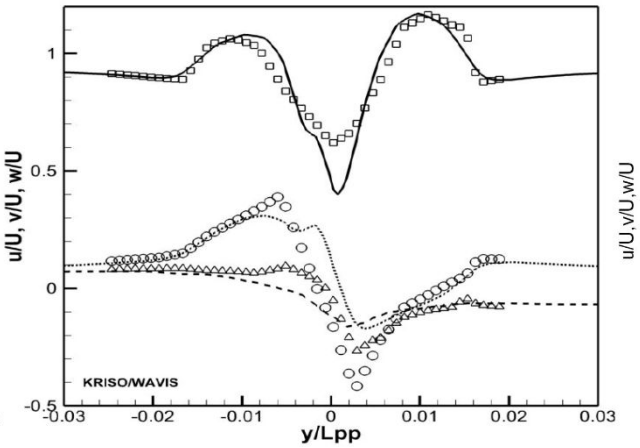
UM/OpenFOAM

Velocity downstream of propeller plane at z/Lpp=-0.03

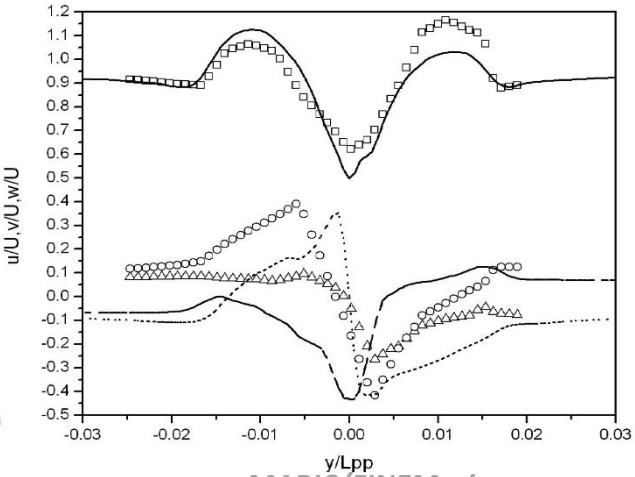
Propeller model : Actual
Lifting-surface



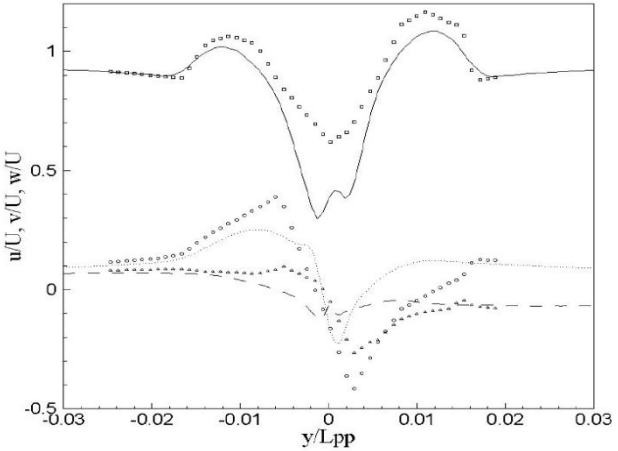
EFD



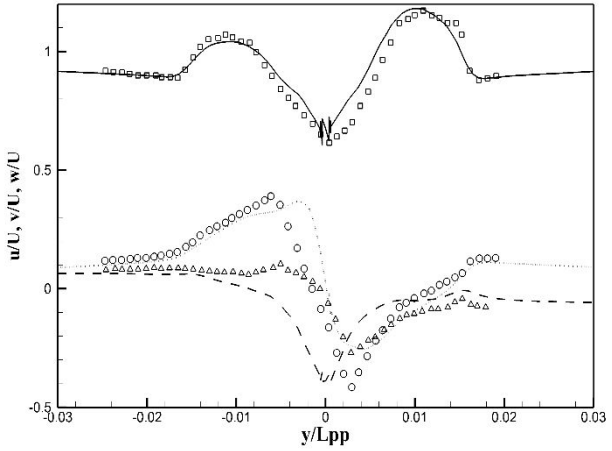
KRISO/WAVIS



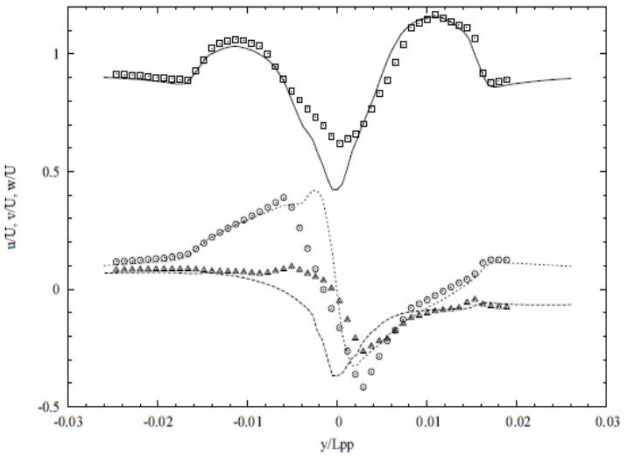
MARIC/FINEMarine



MARIN/PARNASSOS

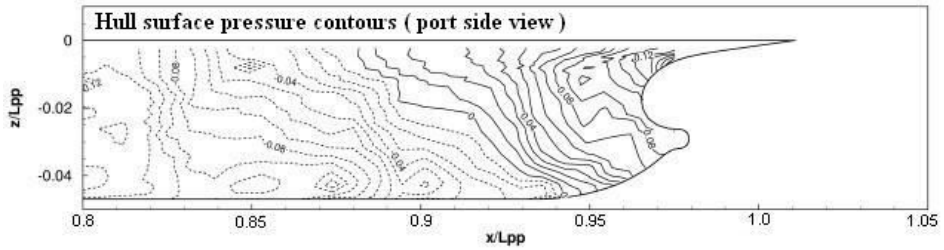


PNU/Fluent



UM/OpenFOAM

Hull surface pressure contours



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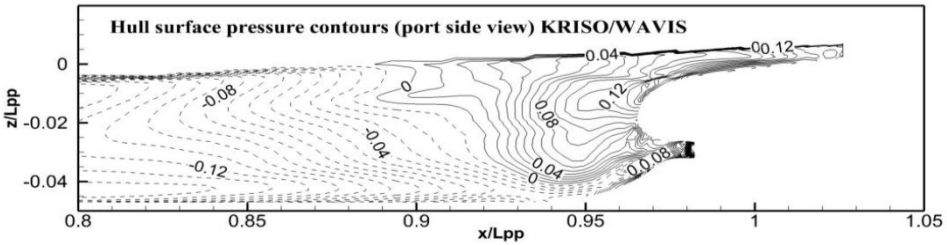

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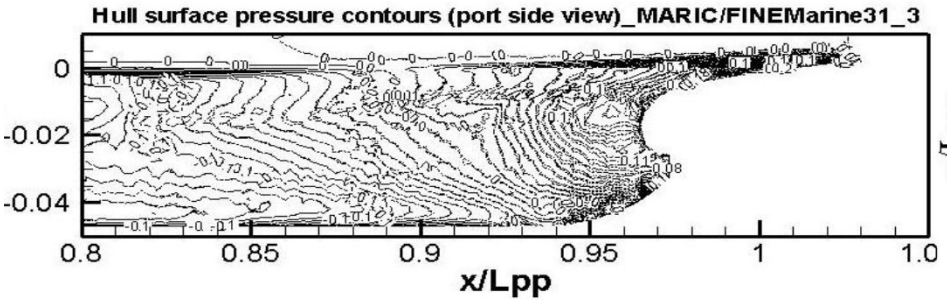
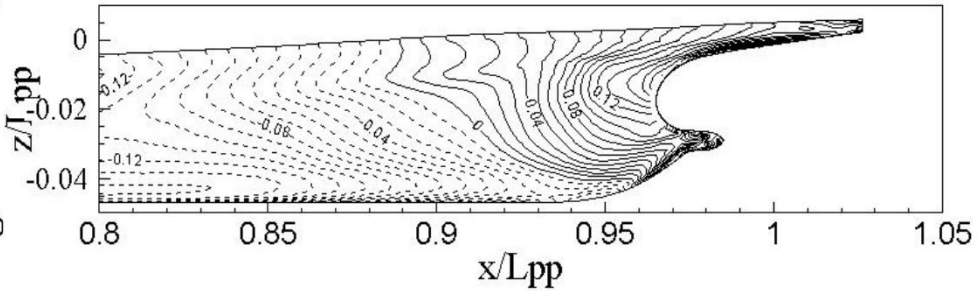
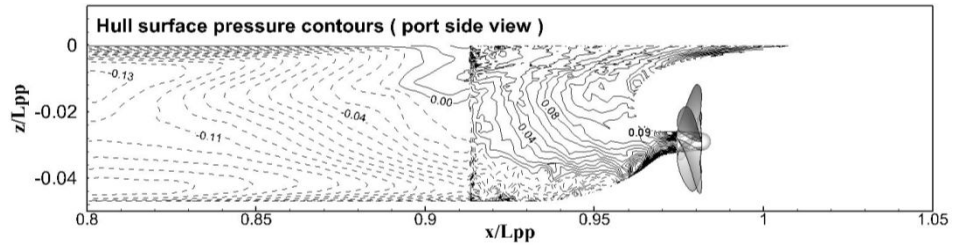


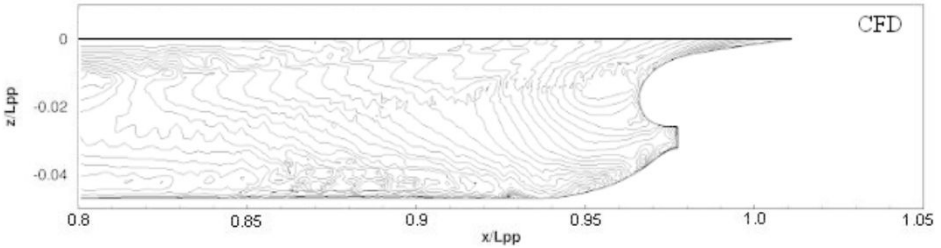
MARIC/FINEMarine



MARIN/PARNASSOS



PNU/Fluent



UM/OpenFOAM

Propeller model : Actual
Lifting-surface

Summary

- Improved results comparing with 2010 Gothenburg
- K_Q is still over predicted (E%D=-3.5)
- Self-propulsion parameters are slightly better predicted by body force methods (given FD)
- Local flow characteristics are comparatively well predicted by actual propeller model (given rps)