JBC
Resistance, sinkage, trim and wave pattern - review

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How accurately can resistance be predicted for bluff hulls?

- 88 fine grid resistance predictions submitted
- Use statistics to answer the question
- Related question 1: **How close are we to experimental accuracy?**
- Related question 2: **Is there any improvement since 2005 and 2010?**

Resistance statistics

Hull	Year/Case	E_{mean} %D	$/E/_{mean}$ %D	σ %D	U_D %D	No. of Entries
KVLCC2m	2005/1.4	0.0		6.2	0.7	13
KVLCC2	2010/1.2a	-1.7		1.3	1.0	5
JBC	2015/1.1a	1.0	2.1	2.4	1.0	22
	2015/1.2a	1.0	1.5	2.0	1.0	20
	2015/1.5a	-0.1	3.2	4.0	1.0	23
	2015/1.6a	0.7	3.1	4.0	1.0	23

Blue: Towing

Yellow: Self-propulsion

E: Comparison error, *D*: Measured data, *S*: Simulated value, *E=D-S*

Resistance change due to ESD

	Computed (mean)	Measured
Towing (1.2a-1.1a)%	-0.7	-0.6
Self-propulsion (1.6a-1.5a)%	-0.2	-1.0

Conclusions on resistance accuracy

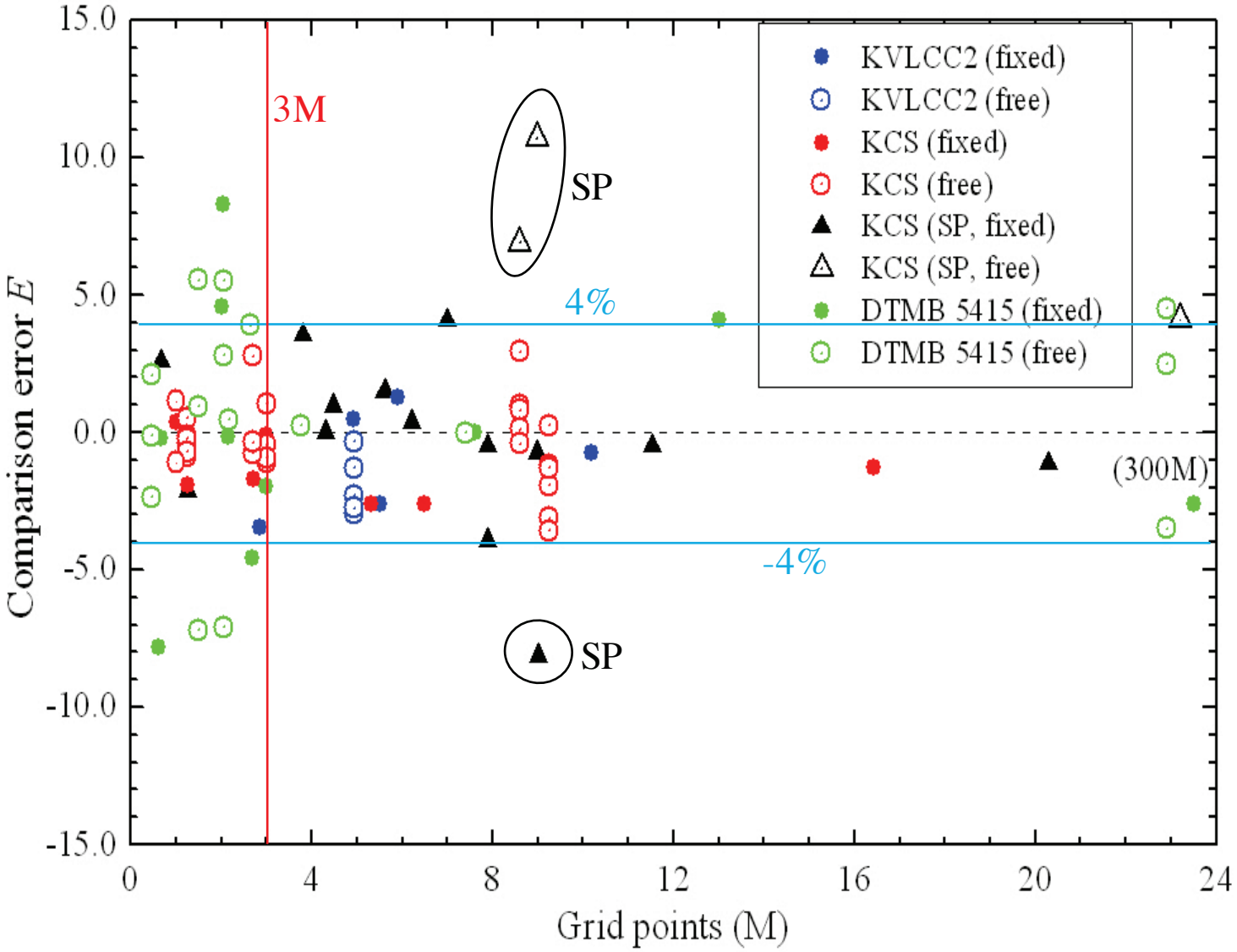
- The systematic error is within the experimental accuracy for all T2015 computations. Slightly better than at G2010
- The random error causes a standard deviation around 2% for the towed hull. Slightly worse than G2010
- The random error for the self-proplelled hull is around 4%

How dependent is resistance on grid *size* ?

- Plot all resistance errors versus grid size!

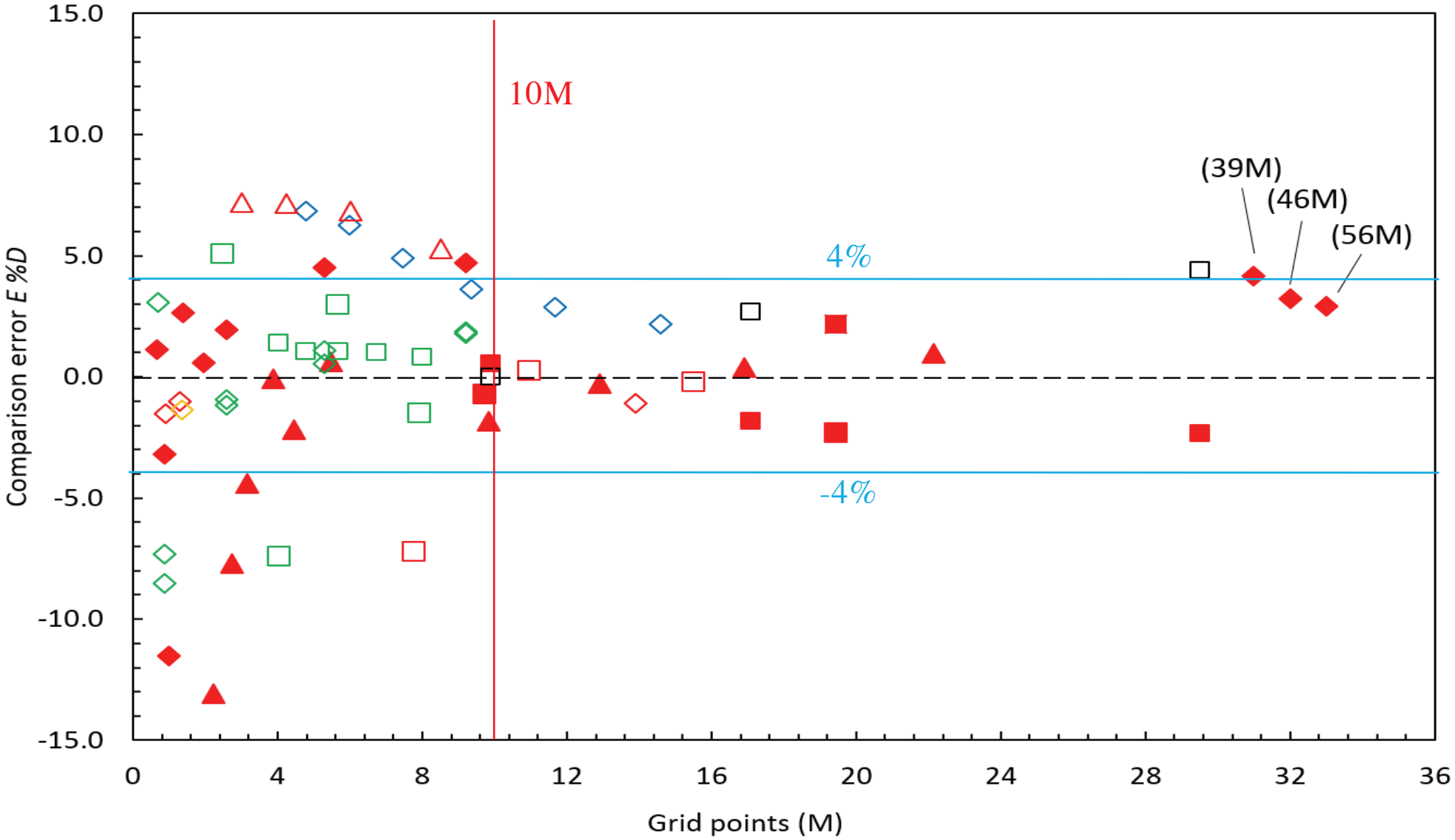
Comparison error vs. grid size

Gothenburg 2010, *All cases*



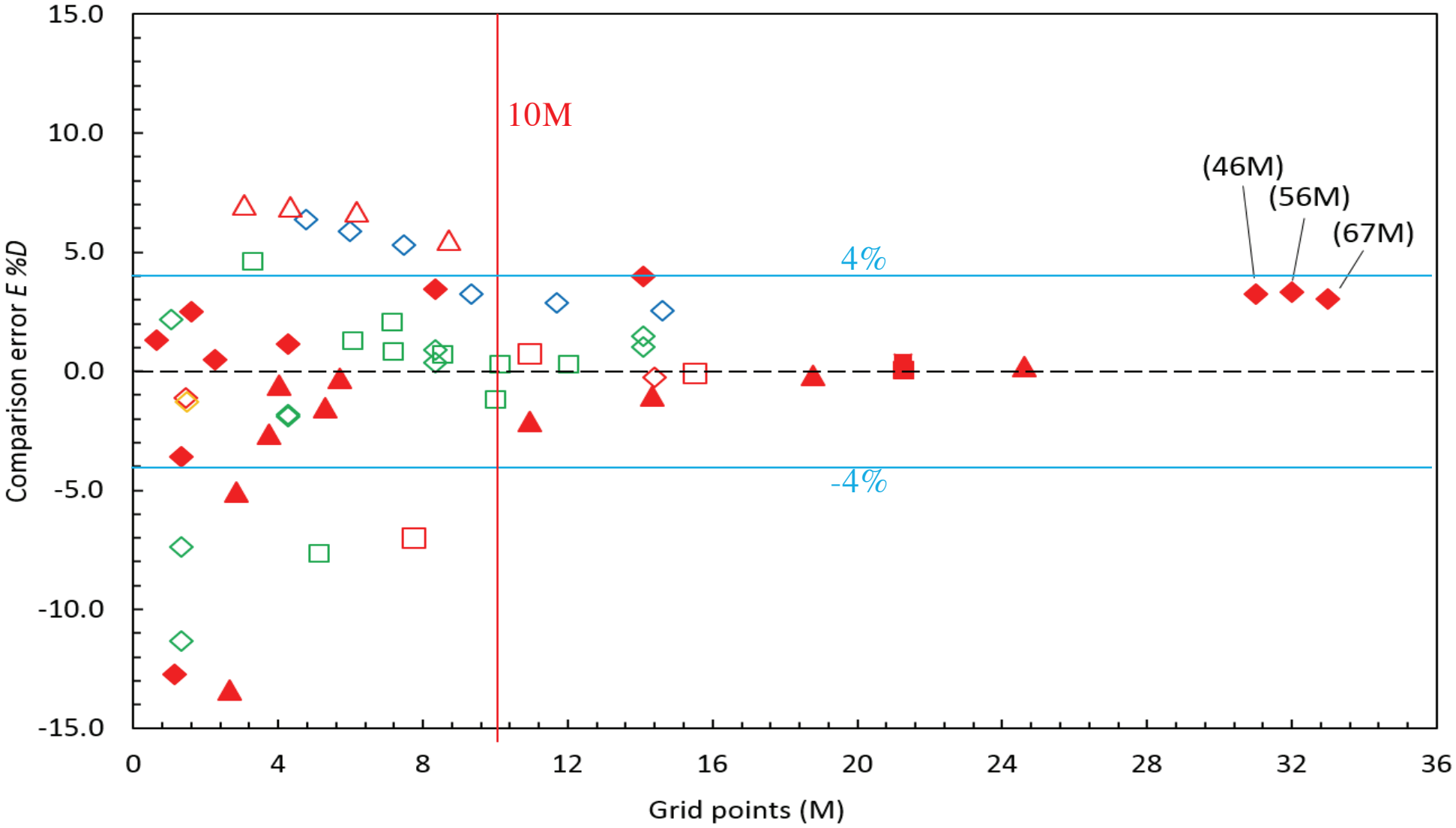
Comparison error vs.grid size

Bare hull, Case 1.1



Comparison error vs.grid size

Hull with ESD, Case 1.2



Conclusions on grid size

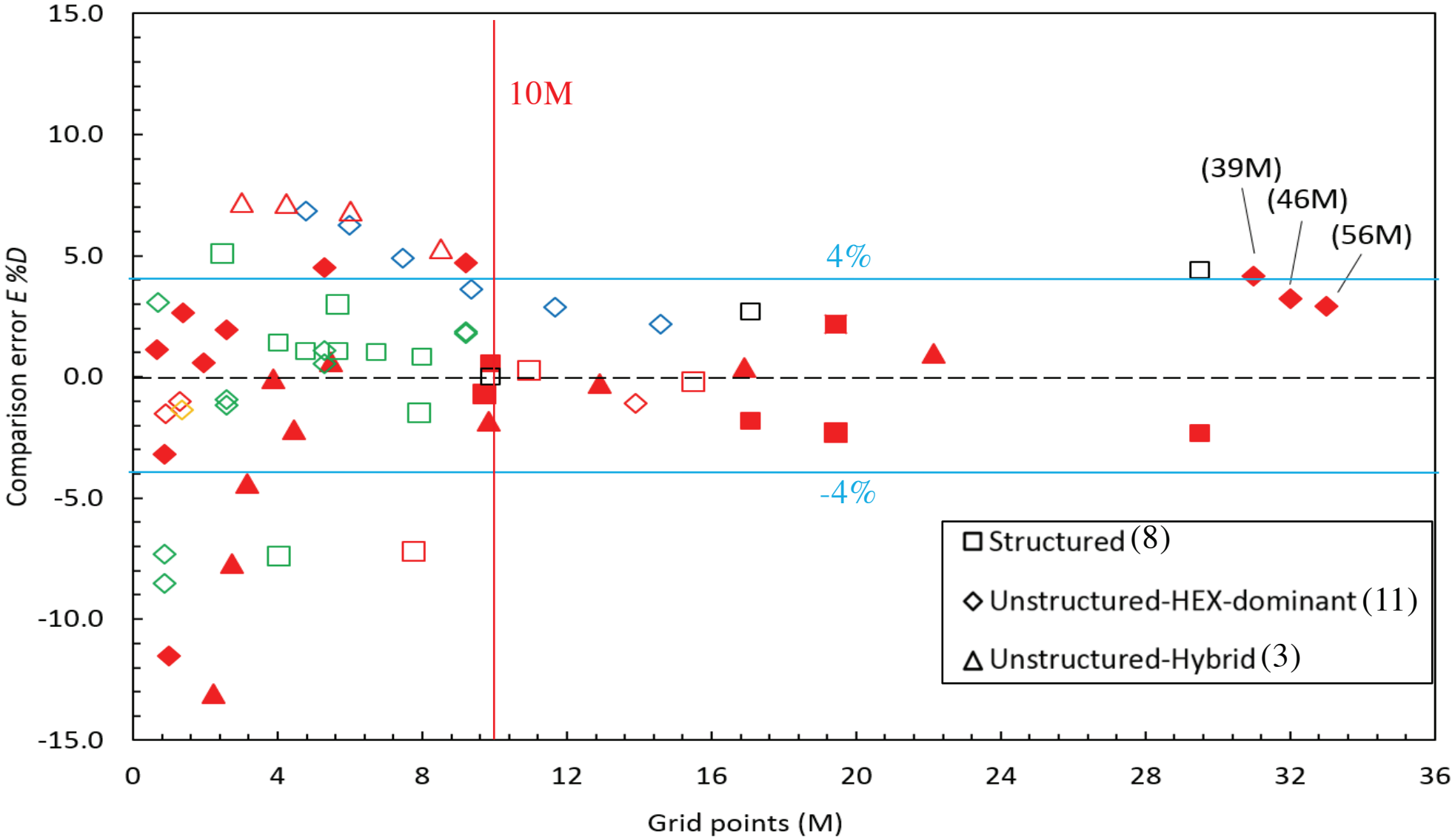
- The scatter is larger than at G 2010
- The limit for 4% accuracy is around 10Mcells, as compared to 3M cells (for all hulls) at G 2010

How dependent is resistance on grid *type* ?

- Look at grid type in previous plots!

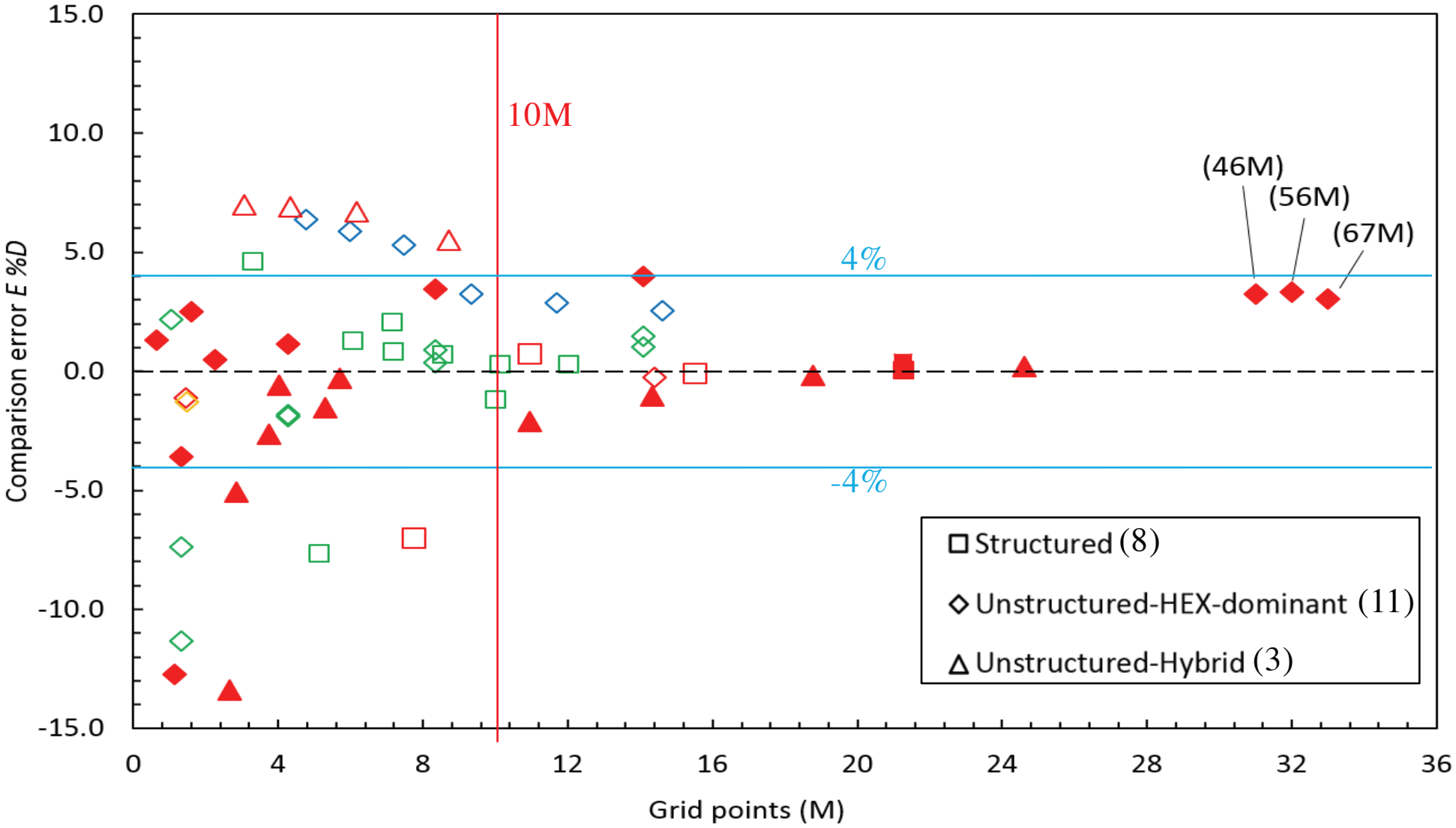
Grid type

Bare hull, Case 1.1



Grid type

Hull with ESD, Case 1.2



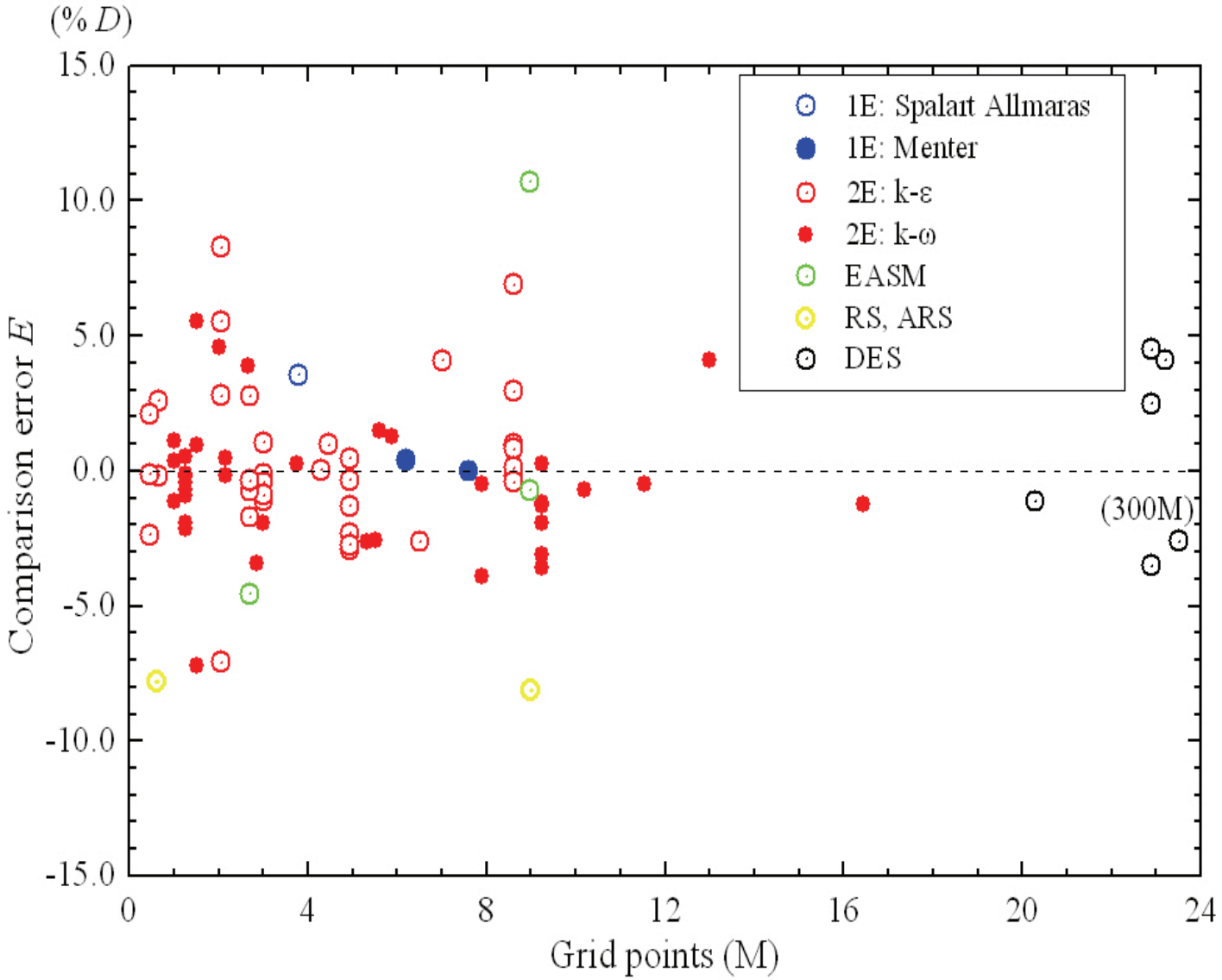
Conclusions on grid type

- Hard to draw conclusions

How dependent is resistance on turbulence model

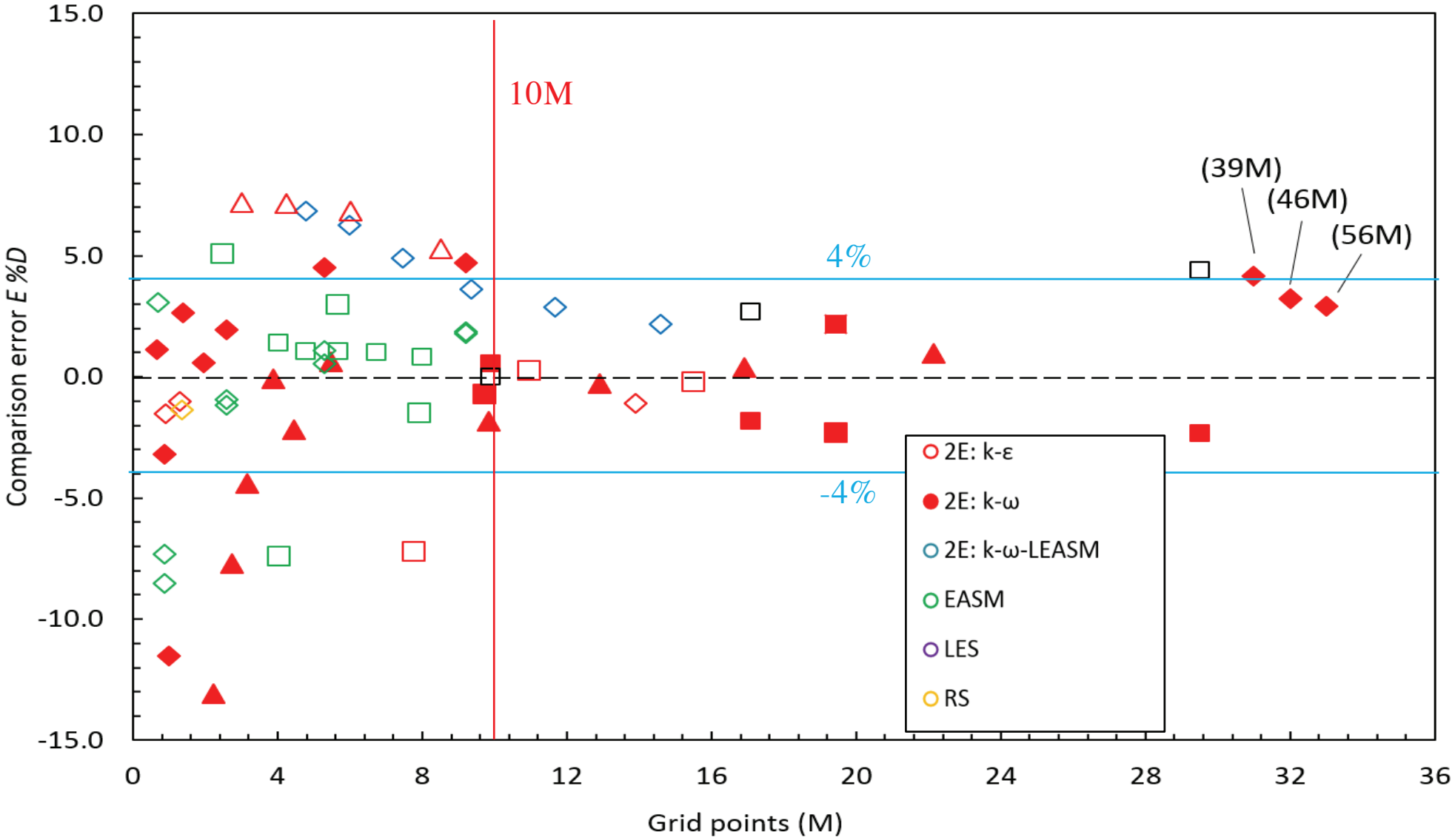
- Compute statistics
- Look at previous plots

Comparison error, turbulence models, G 2010



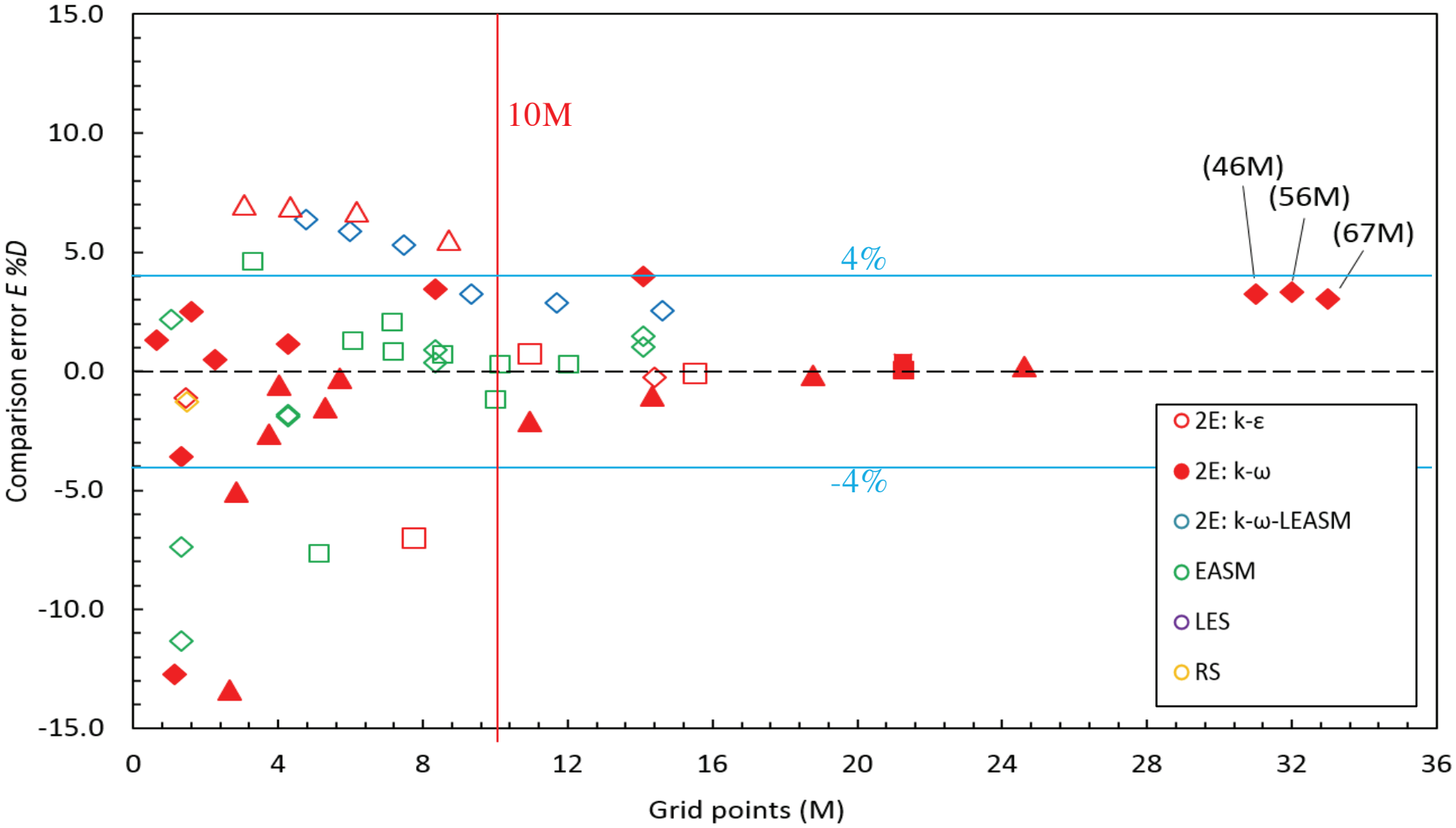
Turbulence model

Bare hull, Case 1.1



Turbulence model

Hull with ESD, Case 1.2



Mean comparison error for turbulence models

Turbulence model	E_{mean}%D		$\|E\|_{mean}$%D		No. of entries	
	2015 1.1,1.2	2010 All	2015 1.1,1.2	2010 All	2015 1.1,1.2	2010 All
1-E Spalart Allmaras	-	3.6		3.6	-	1
1-E Menter	-	0.1		0.1	-	3
2-E k-ε	0.8	0.3	1.8	2.1	8	37
2-E k-ω	0.7	-0.5	1.6	1.8	19	37
EASM	1.6	1.8	2.0	5.9	12	3
RS, ARS	-1.3	-8.0	1.3	-8.0	2	2
DES	4.4	0.6	4.4	3.1	1	6

Conclusion, turbulence model

- Conclusion from 2010 :

”The present material does not indicate any advantage of turbulence models more complex than two-equation models. The statistical basis for the more advanced models is small, however.”

- The same conclusion still holds!

- Note that this is for Resistance; Local flow is a completely different matter!

Are wall-functions as accurate as wall-resolved?

- Check statistics!

Comparison wall functions (WF)/wall resolved (LRN)

Cases 1.1a and 1.2a

Comparison error C_T%D

	Emean	/E/mean	Std	# Entries
1.1a, WF	0.3	1.2	1.4	8
1.1a, LRN	1.4	2.6	2.7	14
1.2a, WF	0.3	1.1	1.3	8
1.2a, LRN	1.4	1.8	2.2	12

Conclusion, wall functions

- There is no indication in the results of 1.1a and 1.2a that wall functions give less accurate resistance predictions than wall resolved, rather the opposite!

Verification and Validation (V&V)

- Validation uncertainty $U_V^2 = U_{SN}^2 + U_D^2$
  - U_{SN} : Simulation uncertainty. $U_{SN}^2 = U_G^2 + U_I^2$
    - U_G: Grid uncertainty
    - U_I : Iterative uncertainty
  - U_D : Data uncertainty
- Validation achieved at U_V level for $|E| \leq U_V$ (error within “noise” level)

Iterative uncertainty, U_I

- Requested from participants.
- Normally estimated from amplitude of fluctuations in quantity of interest (resistance) towards the end of the iterations
- Assumption: U_I negligiblle for $|U_I/\varepsilon_{12}|<<1$.
  - $-\varepsilon_{12}$: difference in solution between the two finest grids
- Adopted criterion: $U_I < 10\% \, |\varepsilon_{12}|$.
- Criterion not satisfied by 25% of V&V estimates

Grid uncertainty, U_G

- Obtained through grid sequencing (systematically refined grids)
- Assumption: $\phi_0 = \phi_1 - \alpha h^p$
  - *h:* step size (known)
  - *p: achieved order of accuracy*
  - α*: constant*
  - ϕ_0 *: solution extrapolated to zero step size*
  - ϕ_1*: known solution*
- Three unknowns: p, α, ϕ_0. Can be determined from three solutions ϕ_1, ϕ_2, ϕ_3
- Alternatively from more than 3 solutions + least squares fit
- Basic theory: For *h* in "**asymptotic range**" $p = p_{th}$
  - p_{th} :theoretical order of accuracy (No effect of higher order error terms)

Grid uncertainty (cont.)

- For h in the asymptotic range $\delta_{RE} = \phi_1 - \phi_0$ is the true error
- For h outside the asymptotic range δ_{RE} is not the true error, but it can be used as a measure of uncertainty
- Basic approach by **Roache**: $U_G = FS\,|\delta_{RE}|$
  - *FS:* Factor of safety: 1.25 or 3.0
- Approach by **Stern et al (ITTC** similar): compute FS based on $p/p_{th.}$ Different formulas above and below1.
- Approach by **Eca & Hoekstra**: U_G determined mainly from δ_{RE} based on p/p_{th}

=> p/p_{th} used as a measure of the "distance" to the asymptotic range; the larger the distance the larger the uncertainty.

Empirical relations used to related U_G to δ_{RE}

Number of grids

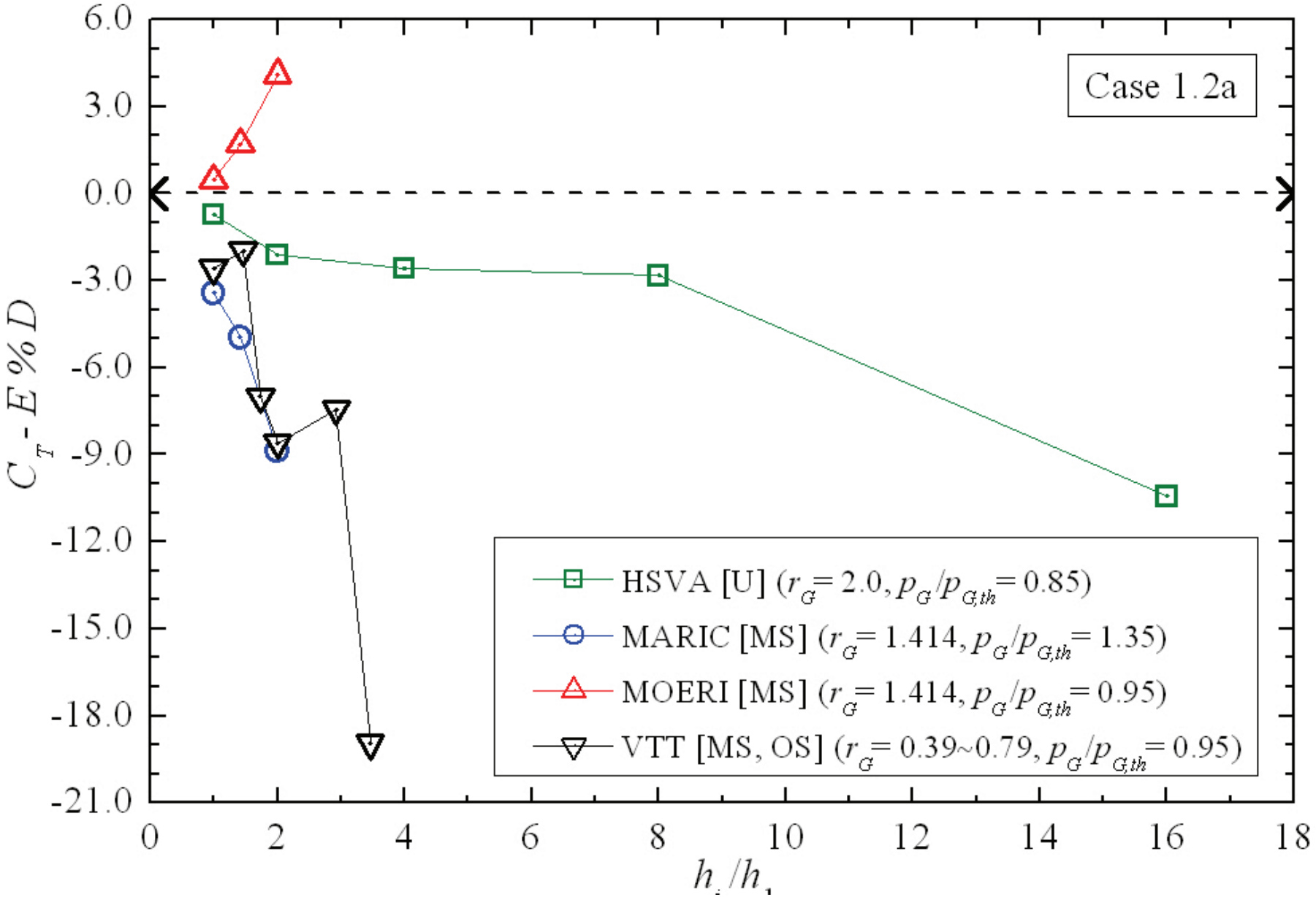
# grids	1.1a	1.2a	1.5a	1.6a	Sum
6	1	1	0	0	2
5	2	2	1	1	6
4	4	4	4	4	16
3	8	6	11	11	36
2	2	0	0	0	2
1	5	7	7	7	26
Sum	22	20	23	23	88
Sum >2	15	13	16	16	

60 out of 88 (68%) provided at least 3 grids!

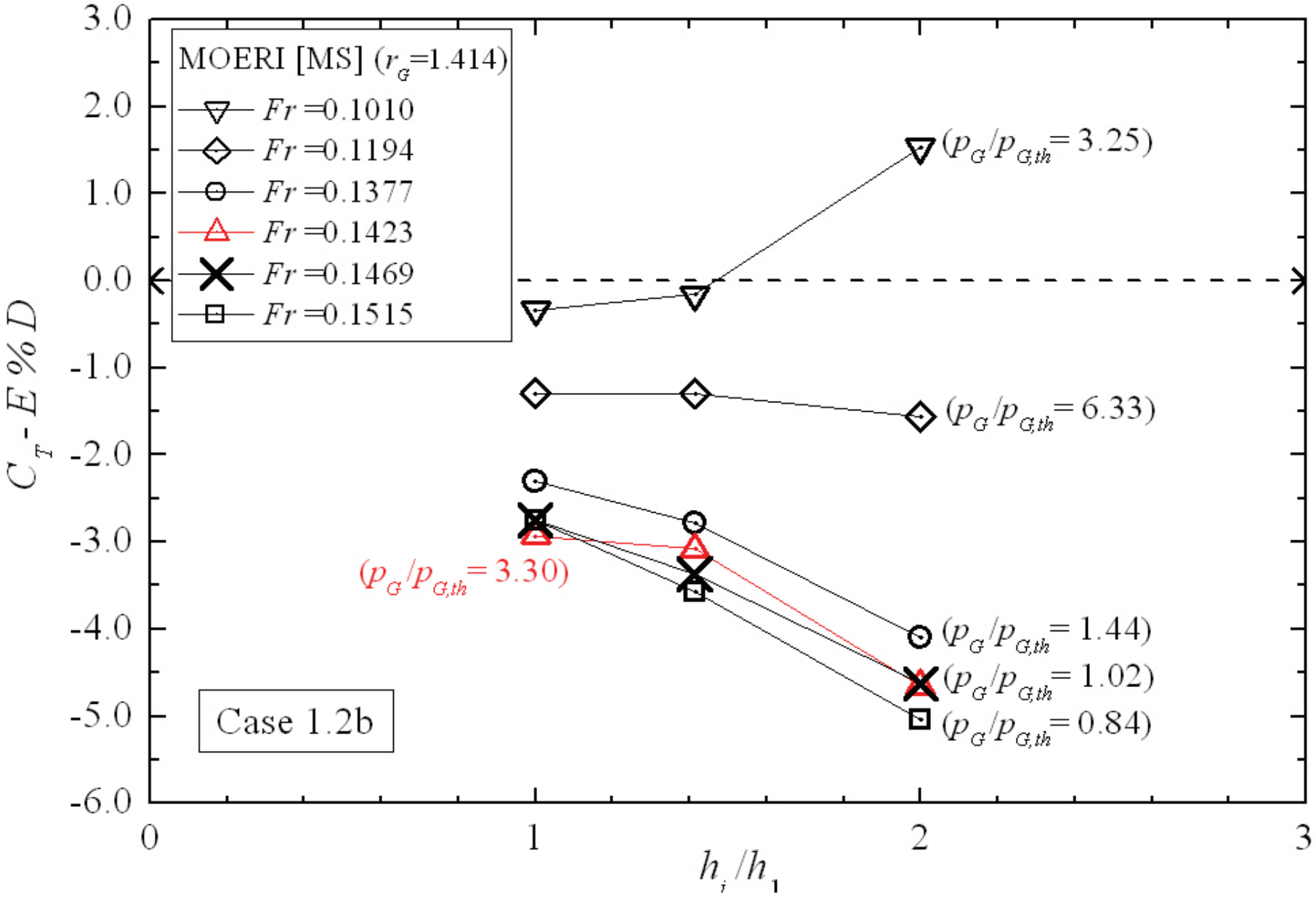
How well does grid sequencing work for industrial applications?

- We have 60 triplets with three or more grids. Best material ever?
- Are the solutions convergent? ($/R/=/\phi_2-\phi_1/(\phi_3-\phi_2/<1$)
- How large is the scatter (due to non-systematic grids, limiters…)
- Empirical relations based on simple test cases. Do they work here?
- p/p_{th} relatively close to 1? (< 2 for Stern et al)

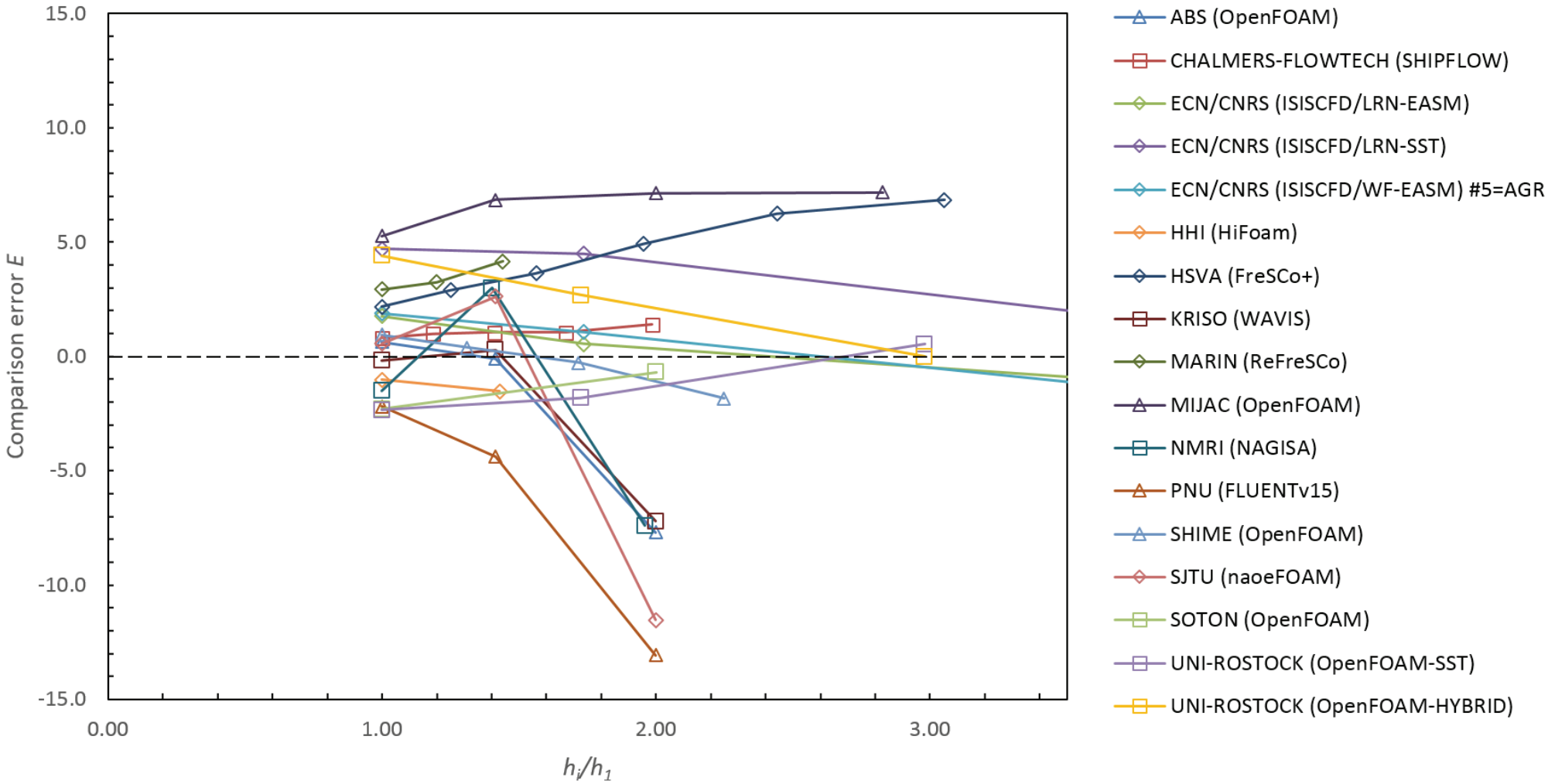
Grid refinement, KVLCC2, Case1.2a



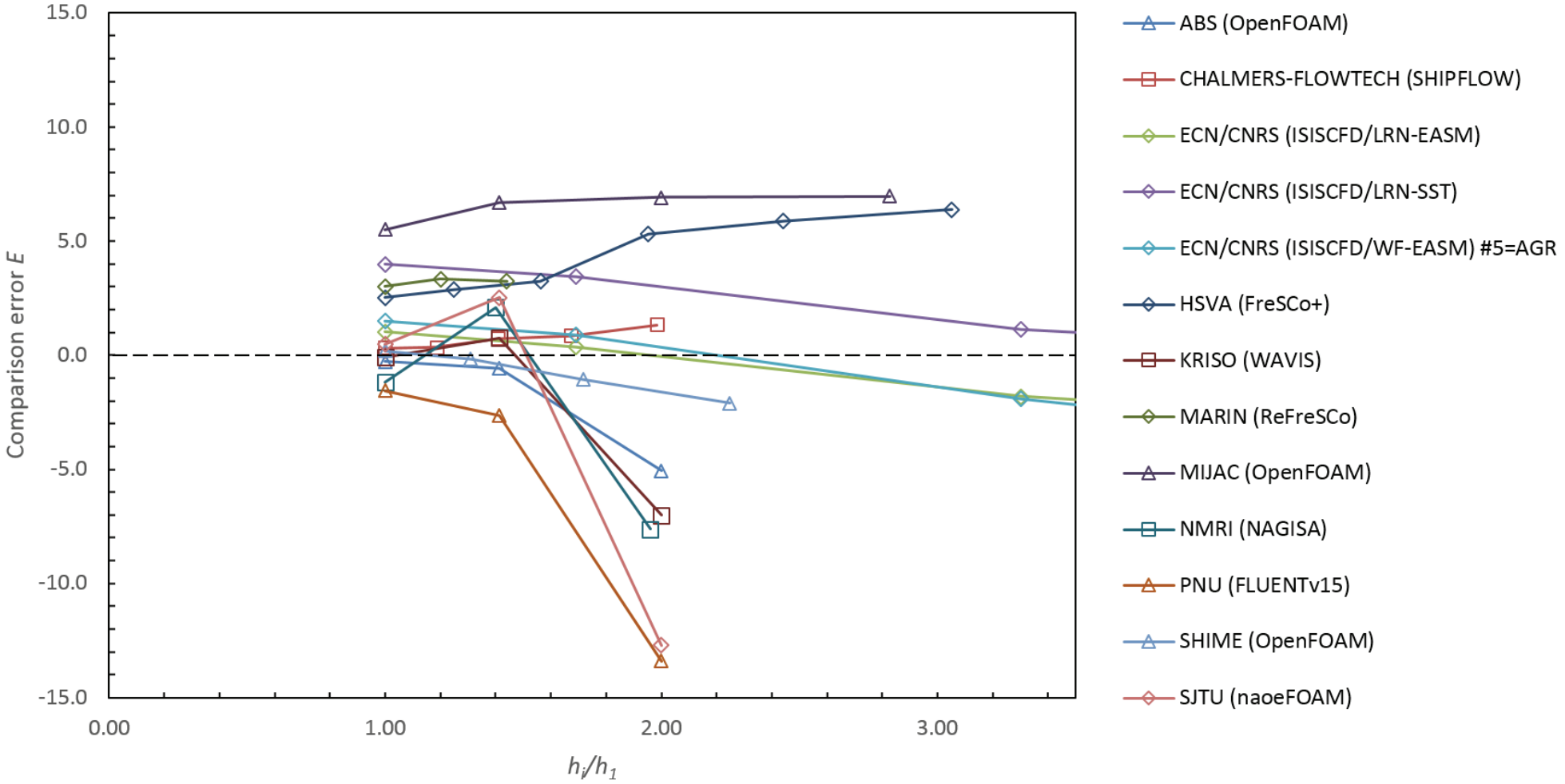
Grid refinement, KVLCC2,Case1.2b



Grid refinement, JBC, Bare hull (1.1a)



Grid refinement, JBC, with ESD(1.2a)



Conclusions grid refinement

	G2010 All	T2015 1.1,1.2
Submissions > 2 grids	42	28
Total # triplets	?	38
Structured grids	33	13
-convergent	32	10
-divergent	1	3
Unstructured grids	7	25
-convergent	5	16
-divergent	2	9

- Tendency towards unstructured grids
- Difference in convergence struct/unstruct smaller now

Conclusions grid refinement (cont.)

	G2010 All	T2015 1.1,1.2
# submissions with p/pth	29	27
# $p/p_{th}>1$	18	21
- mean value	2.7	2.3
# $p/p_{th}<1$	11	6
- mean value	0.7	0.5

- Most p larger than p_{th}
- Very large value of p for these. Uncertainty assessment questionable. Empirical data base too small!
- Mean value of smaller p reduced
- Values of p smaller than p_{th} can be explained

Conclusions validation (1.1a, 1.2a)

- 28 validations made
  - 23 cases with E<Uval (82%)

  5 cases with E>Uval
- G2010
  - FS method 60% E<Uval
  - LRS method 91% E<Uval

- Total validation:
  - Uvalmean = 6.5%D
  - /E/mean = 2.0 (for those where Uval was computed)
  - The codes validated in a mean sense!

Sinkage statistics

Hull	Case No.	E_{mean} %D	$/E/_{mean}$ %D	s%D	U_D %D	No. of Entries
All hulls	**2010**/1.2b, 2.2b, 2.3b 3.2	-21.0		11.2	5	51
KVLCC2 All Fr	**2010**/1.2b	-33.3	33.3	-	7	1
KVLCC2 Fr= 0.142	**2010**/1.2b	-18.2	18.2	-	6	1
JBC	**2015**/1.1a, 1.2a	-1.9	4.7	5.6	?	26

Sinkage, comments

- Only one submission for KVLCC2 at G2010, but comparing with this and the results for all hulls and Froude numbers there is a significant improvement at T2015!

Trim statistics

Hull	Case No.	E_{mean} %D	$/E/_{mean}$ %D	s%D	U_D %D	No. of Entries
All hulls	**2010**/1.2b, 2.2b, 2.3b 3.2	8.9		36.9	6	51
KVLCC2 All Fr	**2010**/1.2b	7.4	7.4	-	7	1
KVLCC2 Fr= 0.142	**2010**/1.2b	3.2	3.2	-	7	1
JBC	**2015**/1.1a, 1.2a	0.6	3.1	3.5	?	26

Trim, comments

- Only one submission for KVLCC2 at G2010, but comparing with this and the results for all hulls and Froude numbers there is a significant improvement at T2015!

Wave pattern evaluation

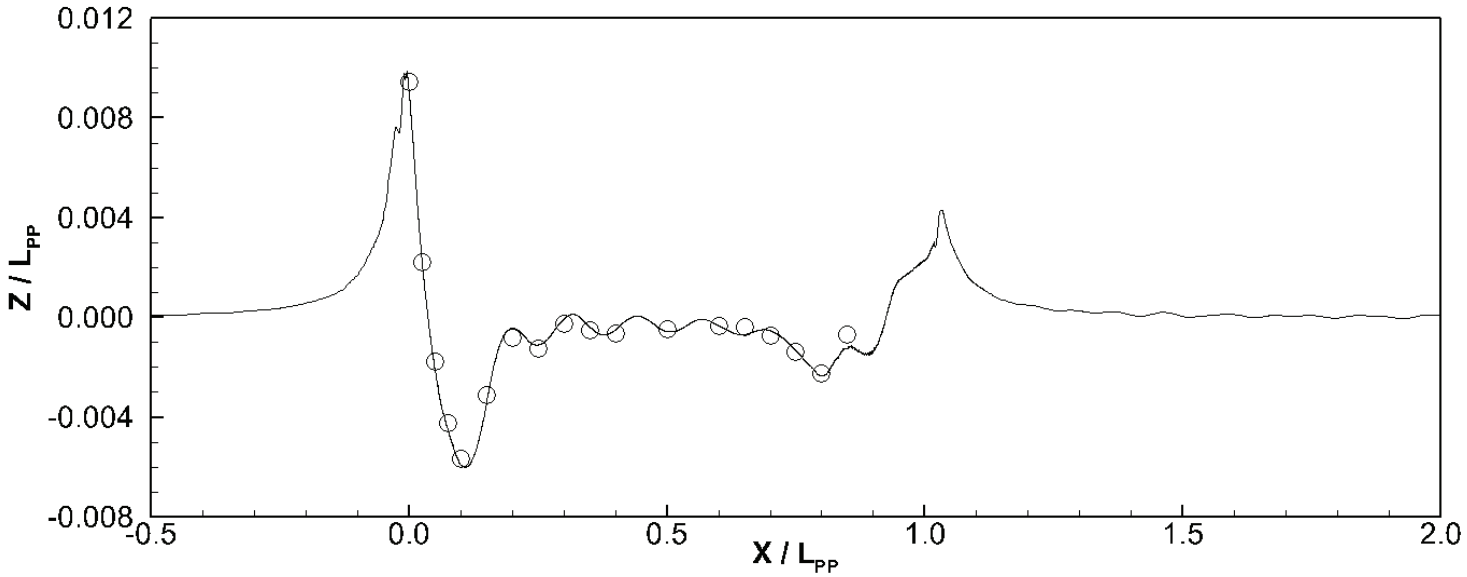
- Wave contours not shown since exp wave grid too coarse
- Wave profile along the hull
- Two wave cuts
- Grid density plots

Wave pattern submissions, 1.3a

Code identifier	Free surface method	Grid type	No. of grid points [M]
ECN CNRS-ISISCFD-LRN EASM	V	U,hex	9.2
ECN CNRS-ISISCFD-LRN SST	V	U,hex	5.5
ECN CNRS-ISISCFD-WF EASM	V	U,hex	2.2
HSVA-FreSCo+	V	U,hex	14.6?
KRISO-WAVIS	LS	S	15.5
MARIC-FINEMarine	V	U, hex	0.7
MARIN-ReFRESCO	V	U,hex	55
MHI-FLUENTv14	V	U,hex	13.9
NMRI-NAGISA	LS	S	7.8
PNU-FLUENTv15	V	U,hex	4.5
SJTU-naoeFOAM	V	U,hex	?

Wave profile along the hull

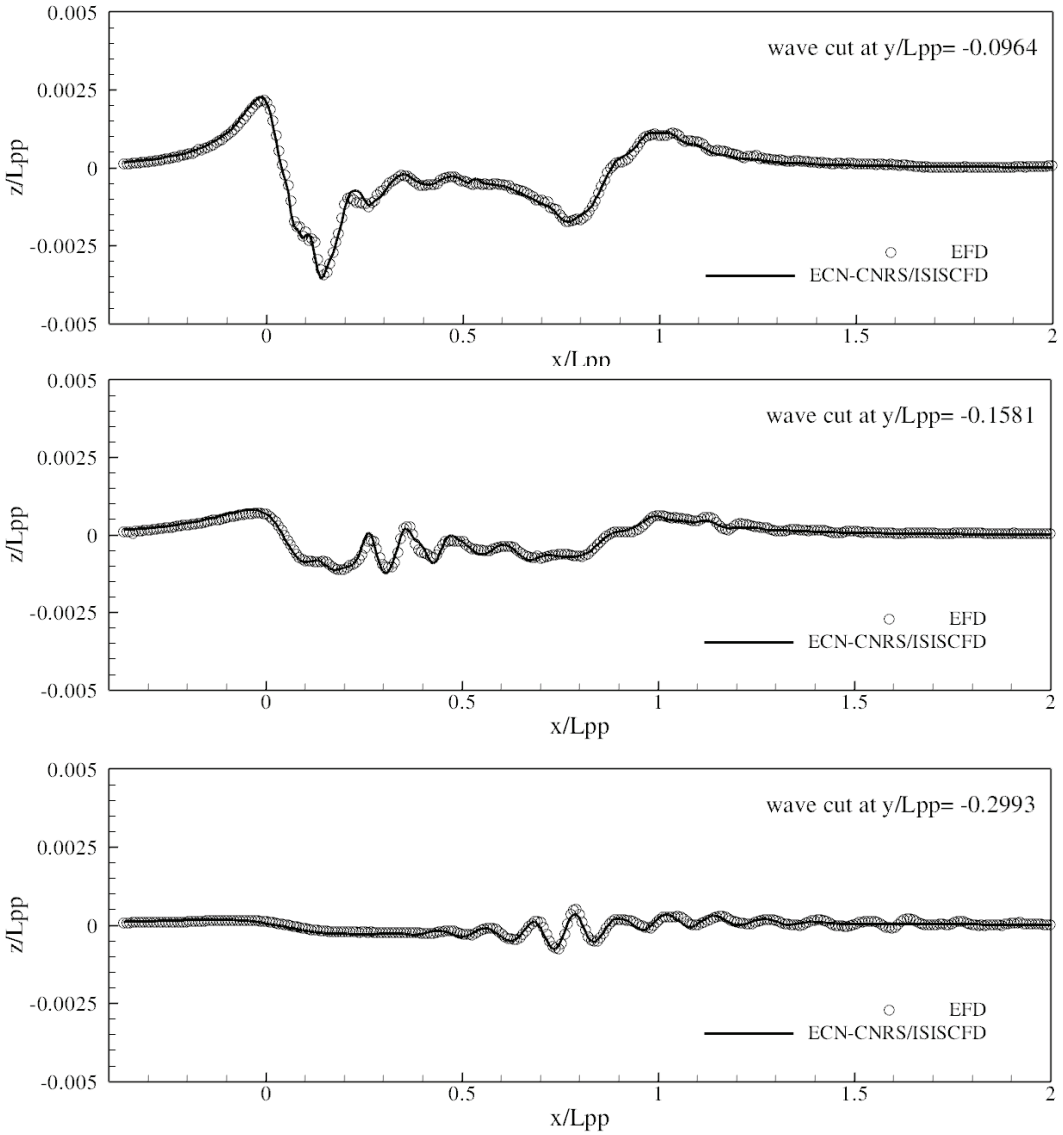
Typical example



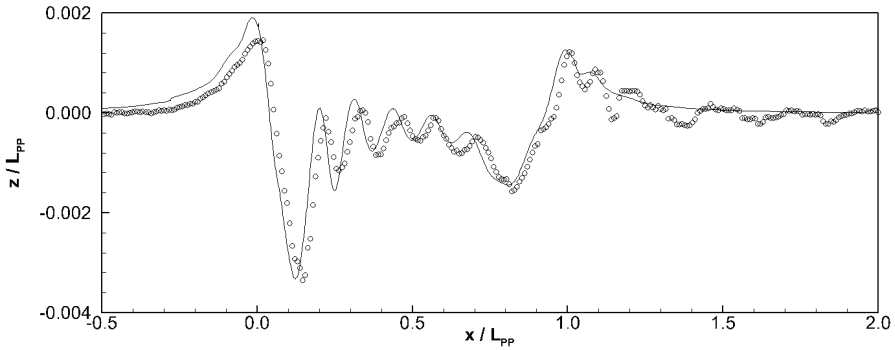
All methods predict the wave profile very well!

G 2010, KVLCC2

Best result



JBC,Y=0.1043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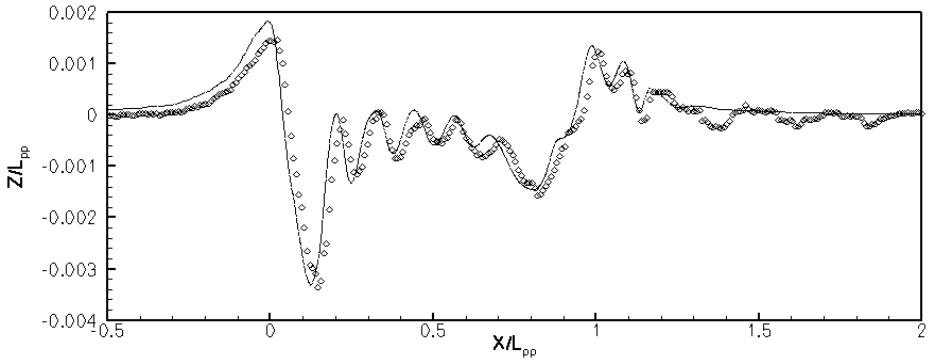
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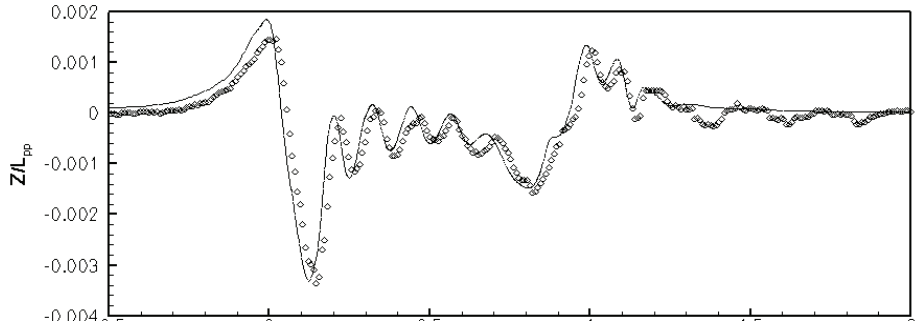
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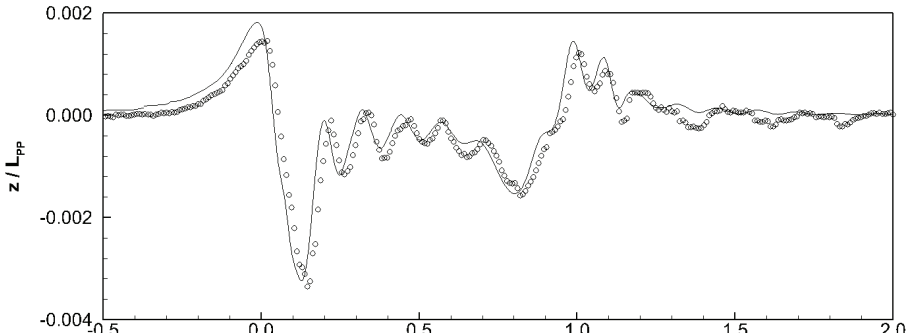
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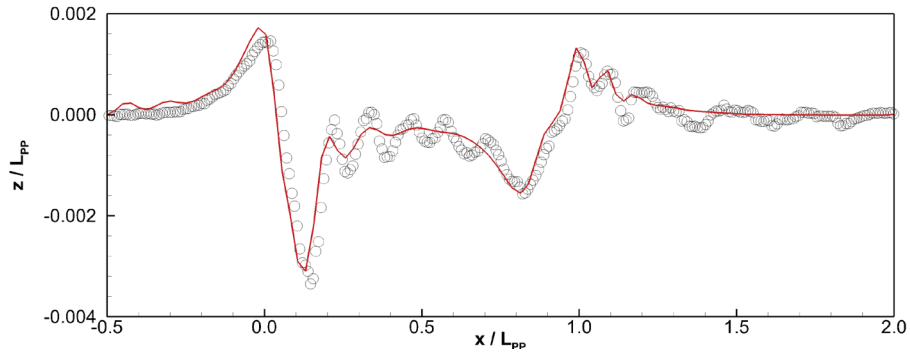
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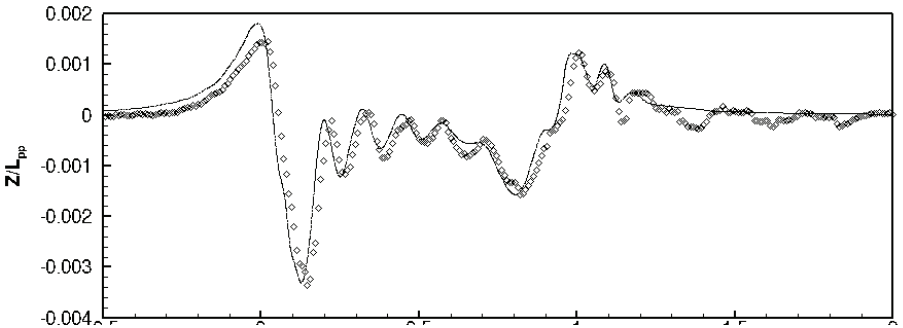
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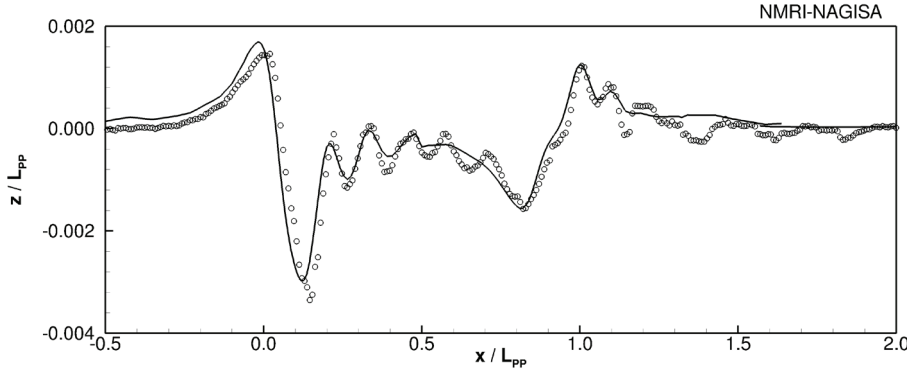
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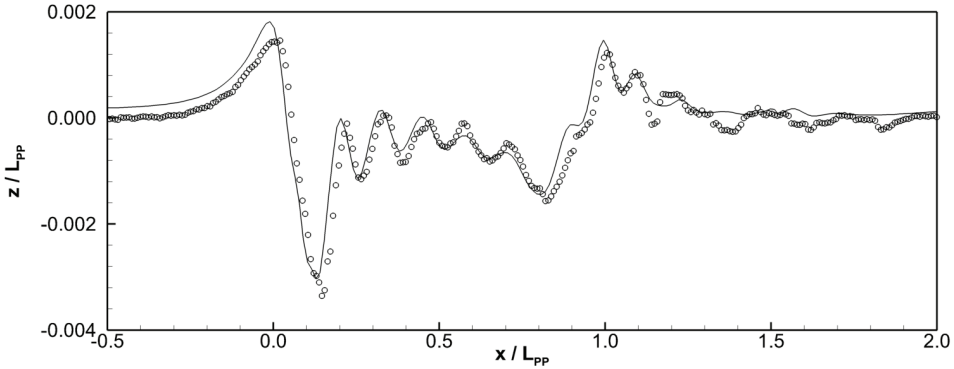
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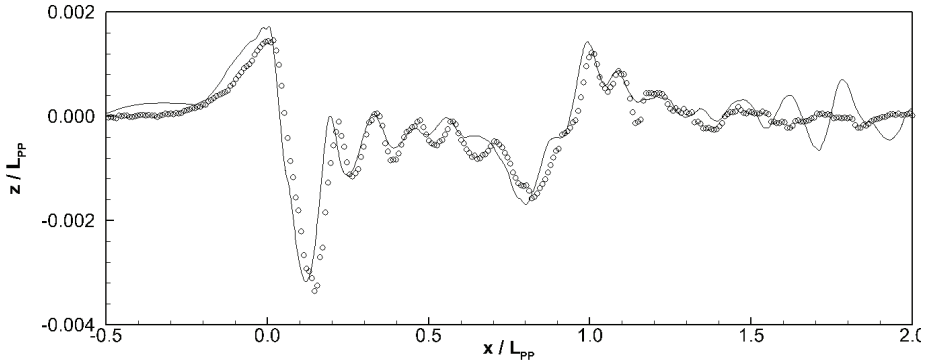
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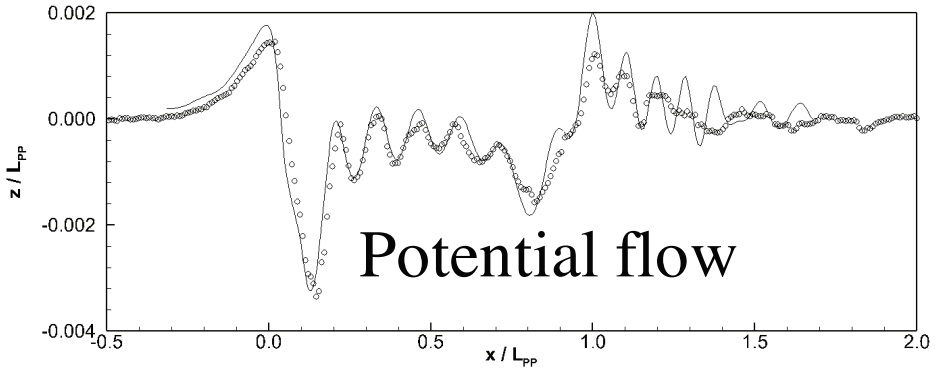
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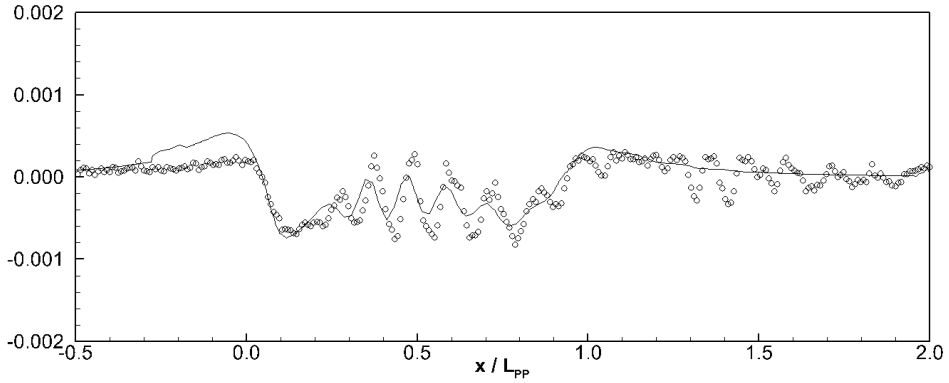
Potential flow

JBC, Y=0.19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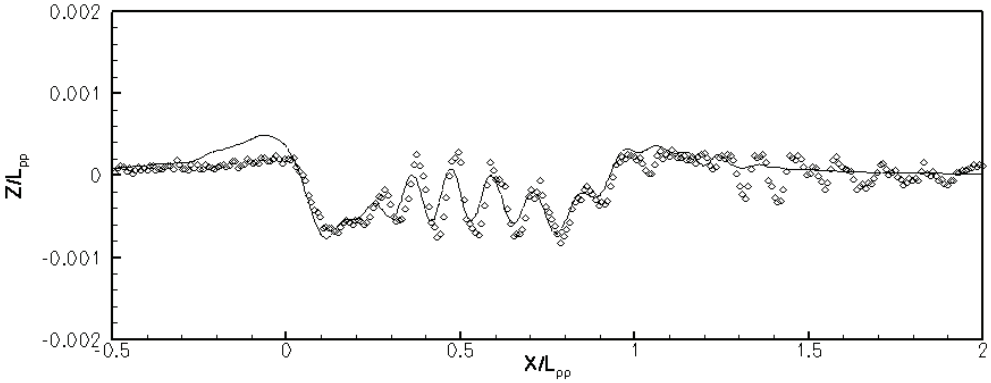
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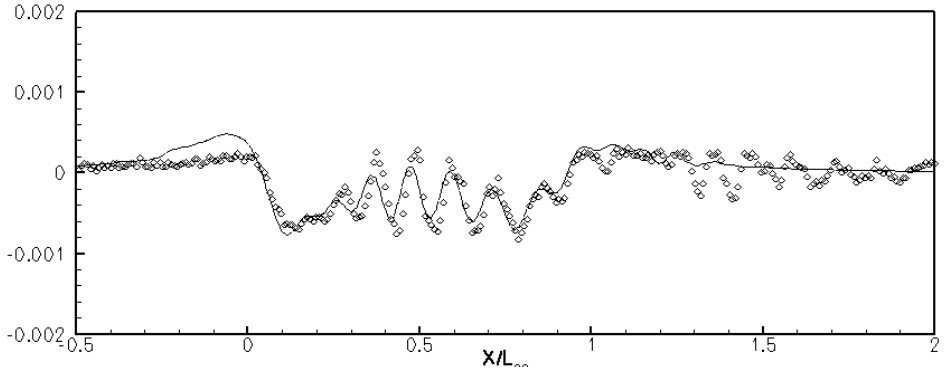
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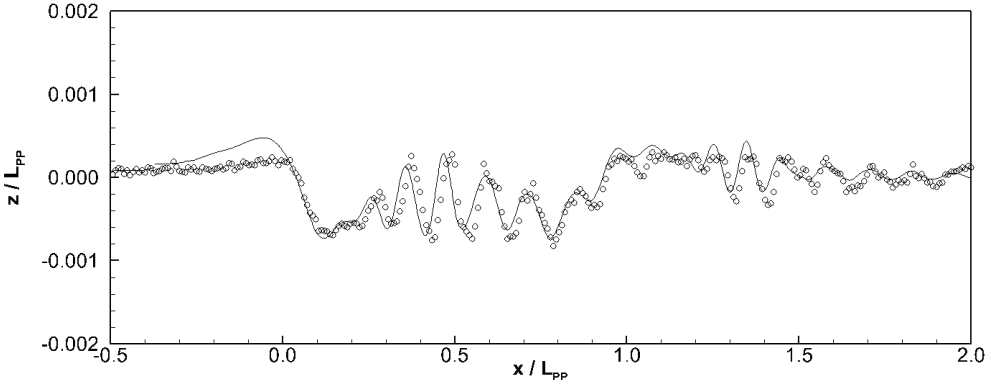
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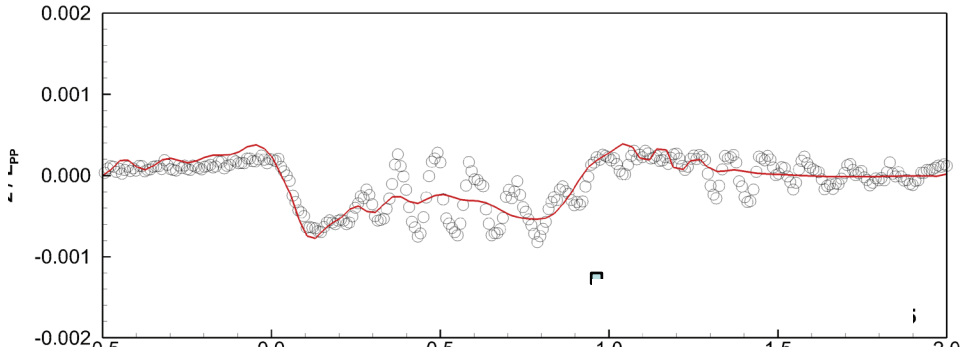
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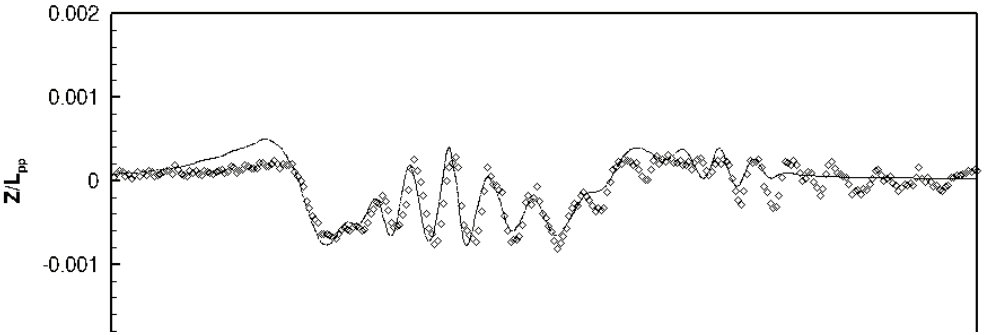
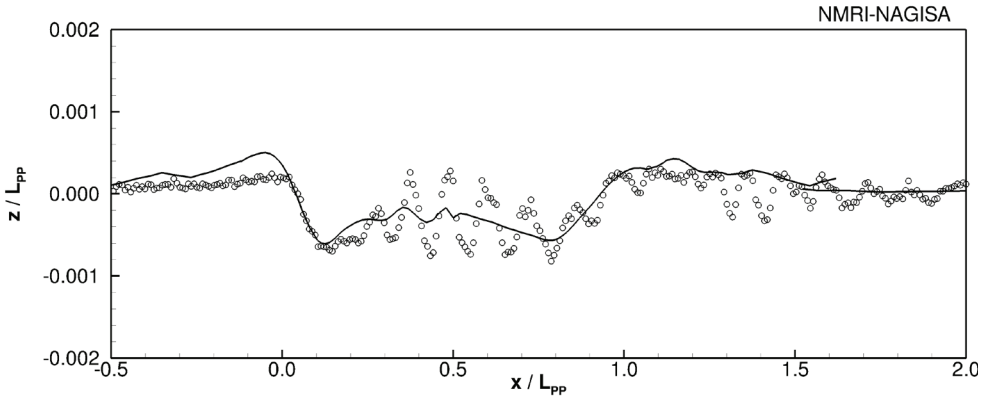
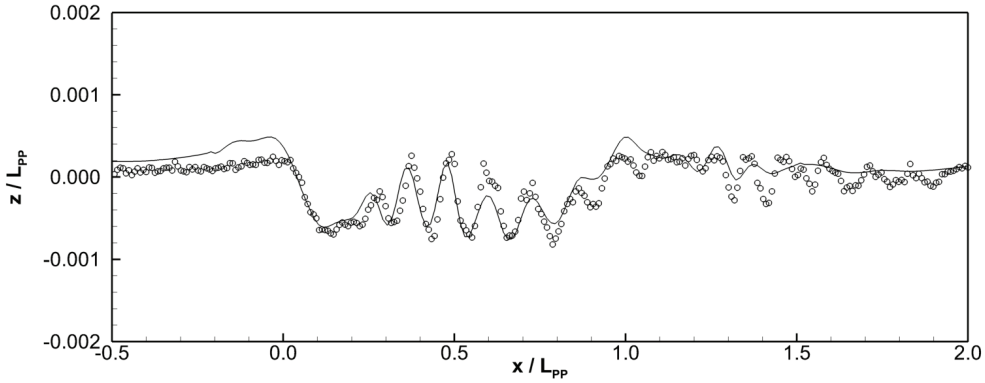
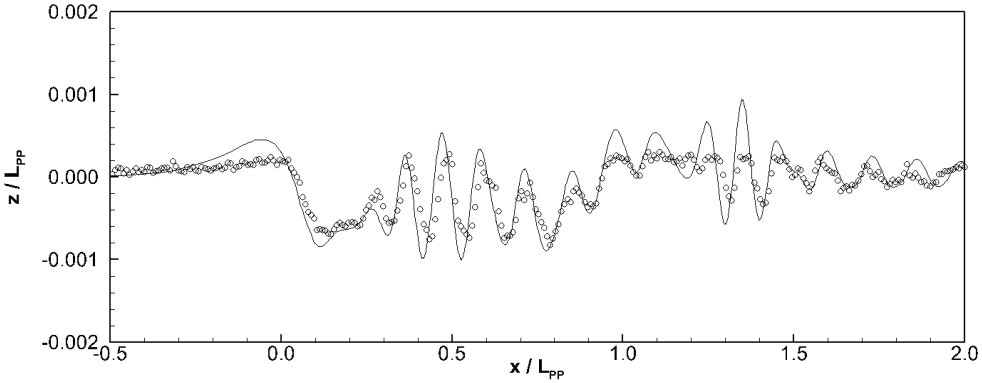
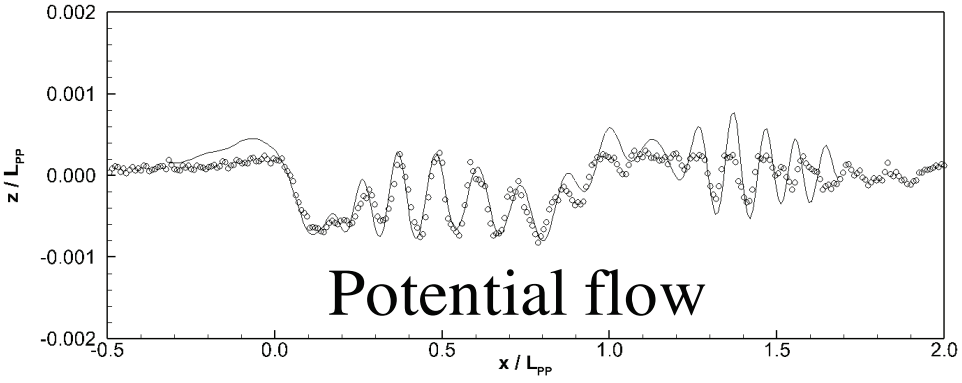

0.002
0.001
0
-0.001
Z/L_PP

JBC, Y=0.19

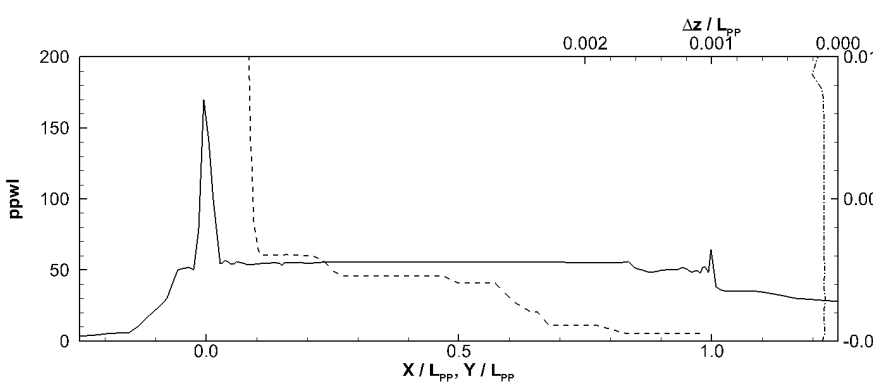

NMRI-NAGISA
0.002
0.001
0.000
-0.001
-0.002
z / L_PP
-0.5
0.0
0.5
1.0
1.5
2.0
x / L_PP

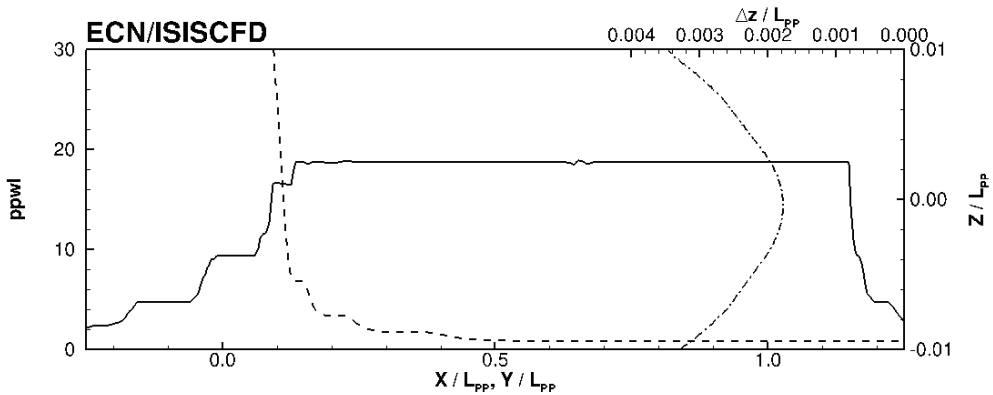

0.002
0.001
0.000
-0.001
-0.002
z / L_PP
-0.5
0.0
0.5
1.0
1.5
2.0
x / L_PP

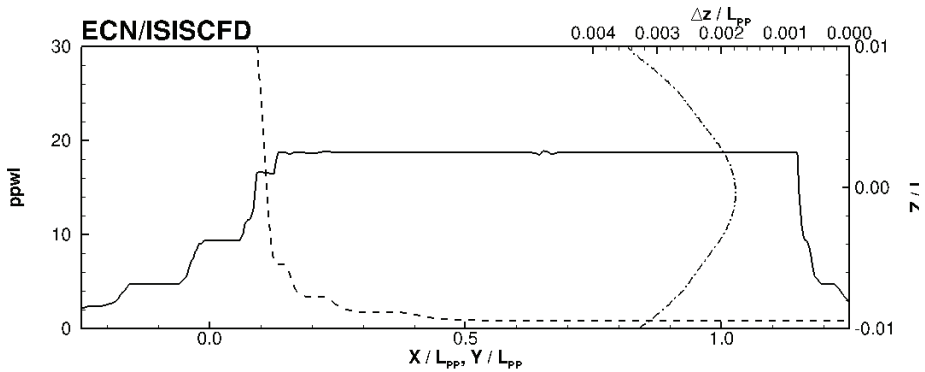

0.002
0.001
0.000
-0.001
-0.002
z / L_PP
-0.5
0.0
0.5
1.0
1.5
2.0
x / L_PP

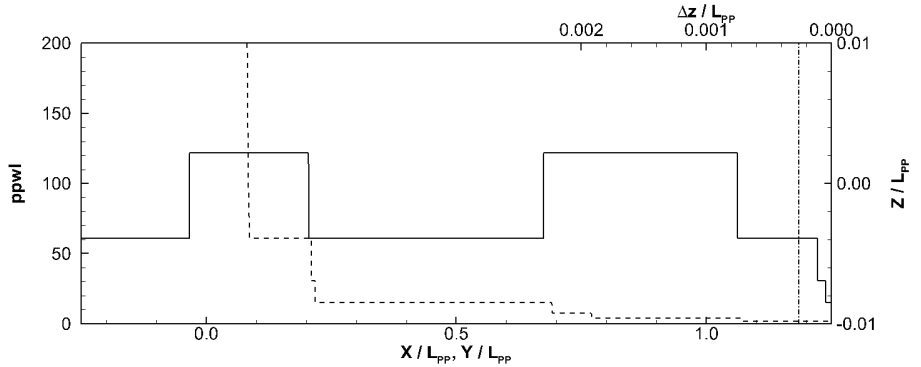

0.002
0.001
0.000
-0.001
-0.002
z / L_PP
-0.5
0.0
0.5
1.0
1.5
2.0
x / L_PP
Potential flow

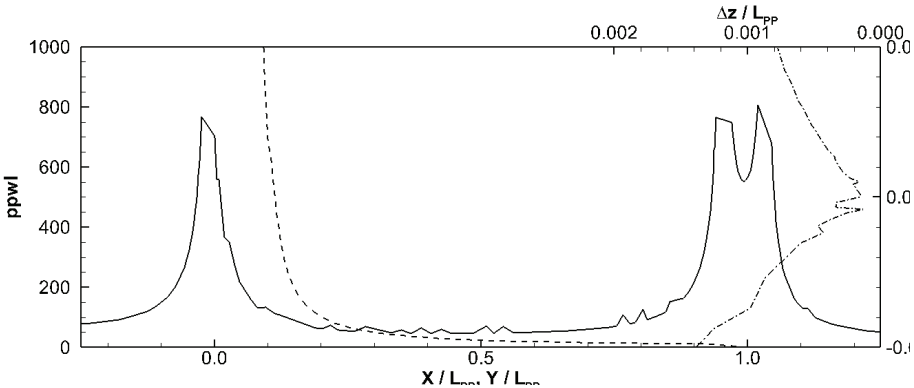
JBC,Grid density

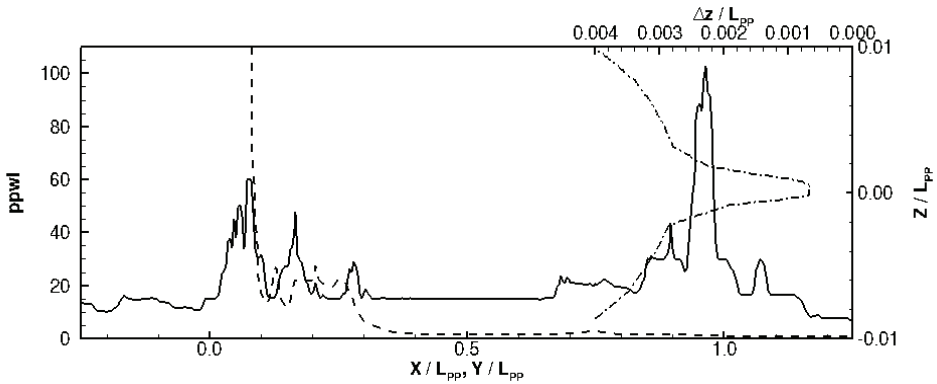




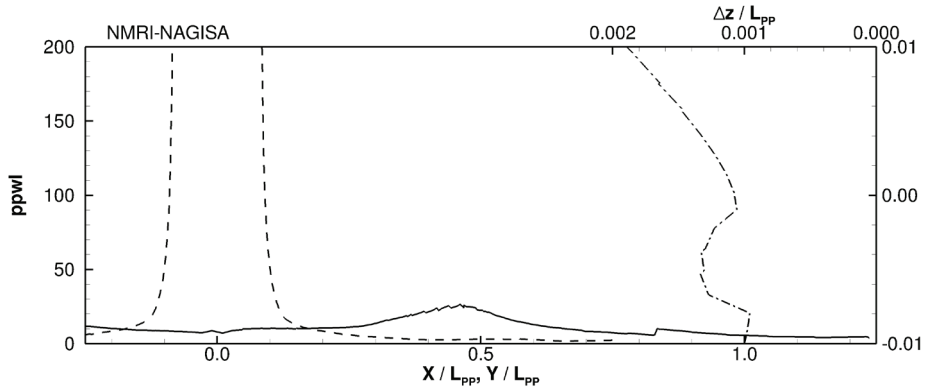


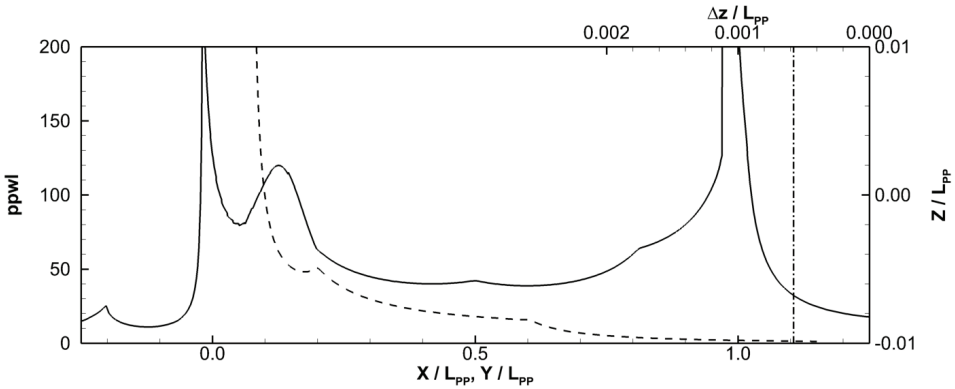


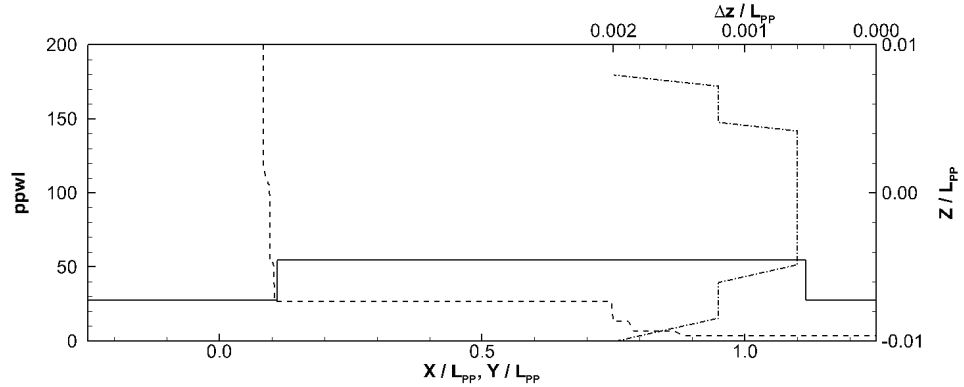




JBC, Grid density







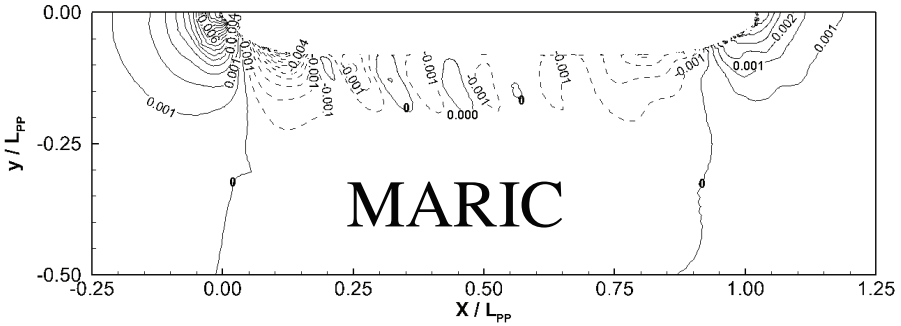
Conclusions, wave pattern

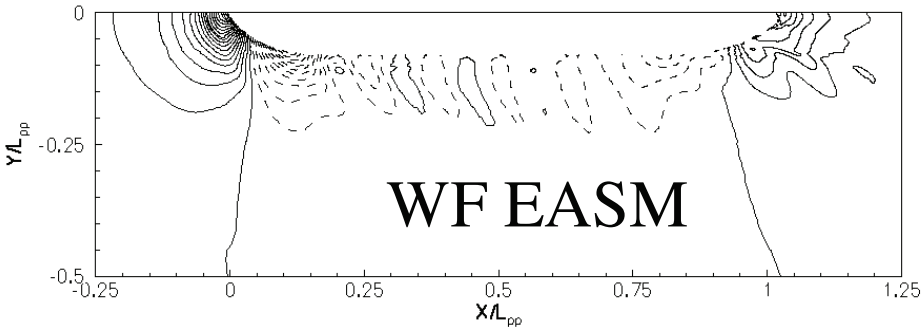
- Some systematic differences are noted in all results
- These differences were not noted in 2010
- Differences between methods smaller than in 2010
- Most methods predict waves well
- Large differences in grid density

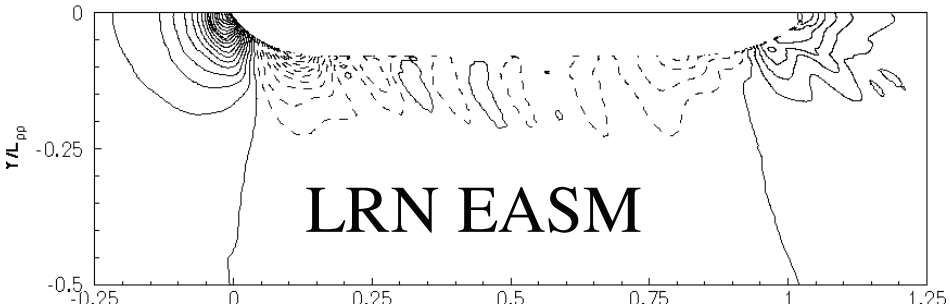
That's All!

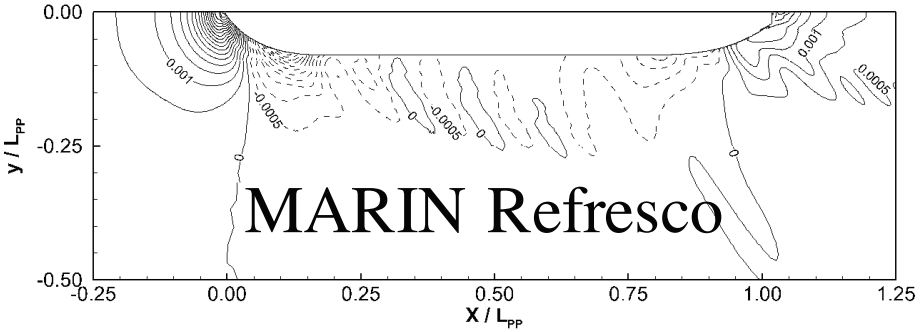
Look forward to an interesting discussion!

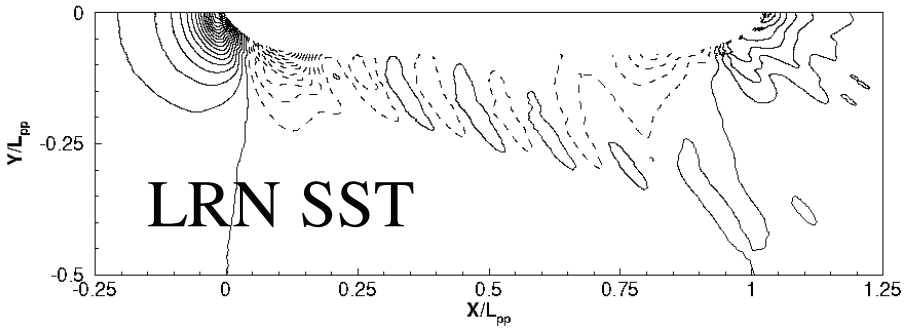
Wave pattern











Wave pattern