

Computational/Meshing Challenge C1 - DLR F11

4th International Workshop on High-Order CFD Methods

June 4th-5th 2016, Crete Island, Greece

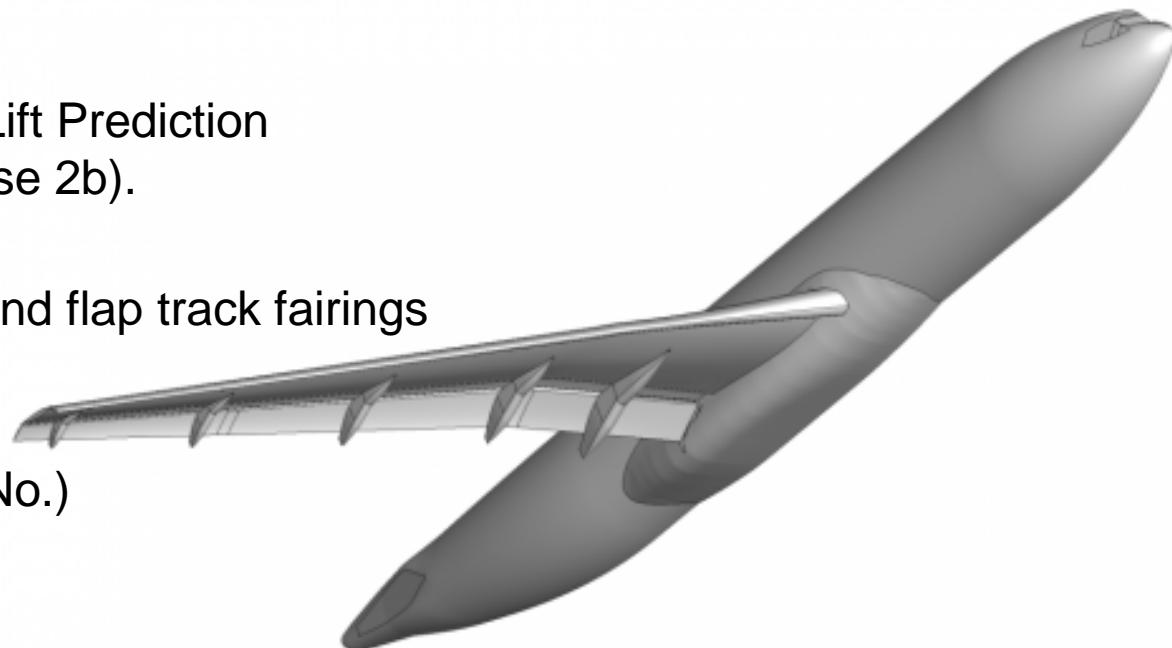
Ralf Hartmann



Knowledge for Tomorrow

The DLR F11 high lift configuration

- Part of the 2nd AIAA High Lift Prediction workshop (HiLiftPW-2, Case 2b).
- Config 4: with slat tracks and flap track fairings
- Flow conditions
 - $Ma = 0.175$
 - $Re = 15.1 \times 10^6$ (high Re-No.)
 - $\alpha = 7^\circ, 16^\circ, 18.5^\circ$
 - run fully turbulent
- Available data:
 - Experiments and a collection of 2nd-order FV results
 - <http://hiliftpw.larc.nasa.gov/index-workshop2.html>
 - Rudnik, R., Huber, K., and Melber-Wilkending, S., EUROLIFT Test Case Description for the 2nd High Lift Prediction Workshop, AIAA Paper 2012-2924, June 2012.
 - Rumsey, C. L., Slotnick, J. P., Overview and summary of the Second AIAA High Lift Prediction Workshop. AIAA Paper 2014-0747, Jan. 2014.



The Computational/meshing challenge

Quoted from the HioCFD-4 webpage:

- **Meshes:** participants are expected to demonstrate a methodology to generate hybrid curved meshes, including high aspect ratio extrusion boundary layers, with at least a quadratic representation of the boundary.
- **Computations:** participants are expected to provide a single simulation for each of the three conditions.



Contributions to the Computational/meshing challenge

Contribution 1 (DLR, Config 4, DG-O3):

- R. Hartmann (DLR), H. McMorris (CentaurSoft), T. Leicht (DLR)
- Quadratic (3rd-order) curved hybrid mesh (CENTAUR) for Config 4
- RANS Wilcox k- ω
- 3rd-order Discontinuous Galerkin (DG) flow solution for Config 4 ($\alpha=7^\circ$)
- 35.2e6 DoFs/eqn.

Contribution 2 (NUDT, Config 2, FD-O5):

- S. Wang¹, L. Xiao¹, G. Wang², W. Liu¹, X. Deng¹
 - ¹ National University of Defense Technology (NUDT), China
 - ² Sun Yat-sen University, China
- Linear block-structured meshes (ICEM): family (Config 2), single mesh (Config 4)
- RANS Menter-SST
- 5th-order Finite Difference (FD) flow solution for Config 2 ($\alpha=7^\circ, 16^\circ, 18.5^\circ$)
- 9.8e6, 32.0e6, 100.6e6 DoFs/eqn



Individual Presentation(s)



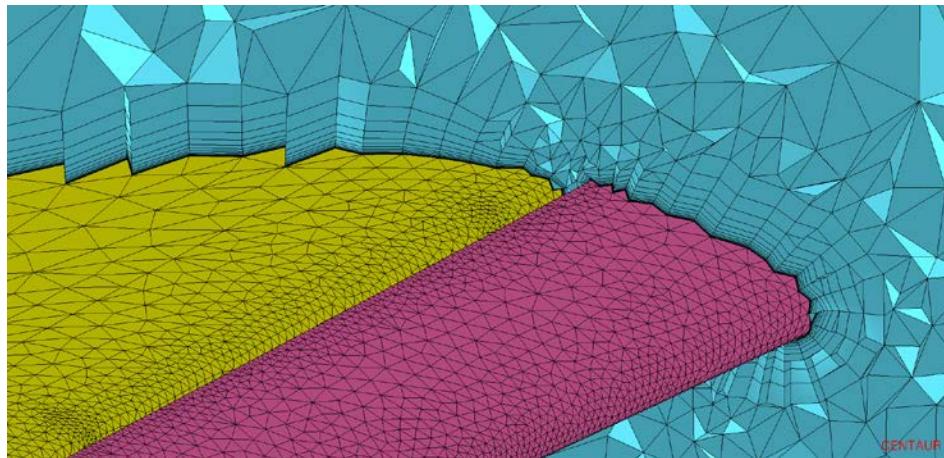
Summary



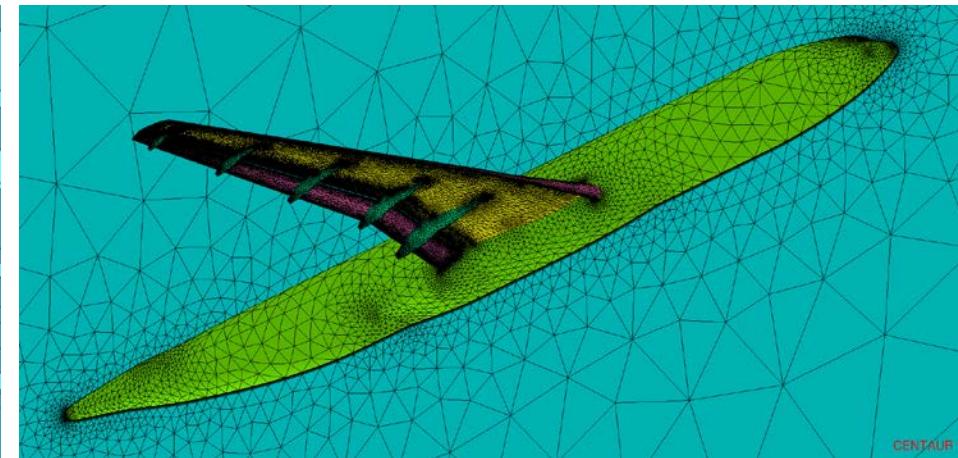
Meshing Challenge: Contribution 1 (CentaurSoft, DLR)

by Harlan McMorris (CentaurSoft) in collaboration with Ralf Hartmann (DLR)

- Quadratic curved hybrid mesh
- 3.5e6 elements (prisms, pyramids and tetrahedra), 1.4e6 vertices, 11.2e6 nodes
- Is available in Gmsh and CGNS format
- Can be provided upon request (Ralf.Hartmann@dlr.de)



Prism layers around the slat and leading edge of the main



Quadratic mesh around the DLR-F11 high lift configuration (Config 4)

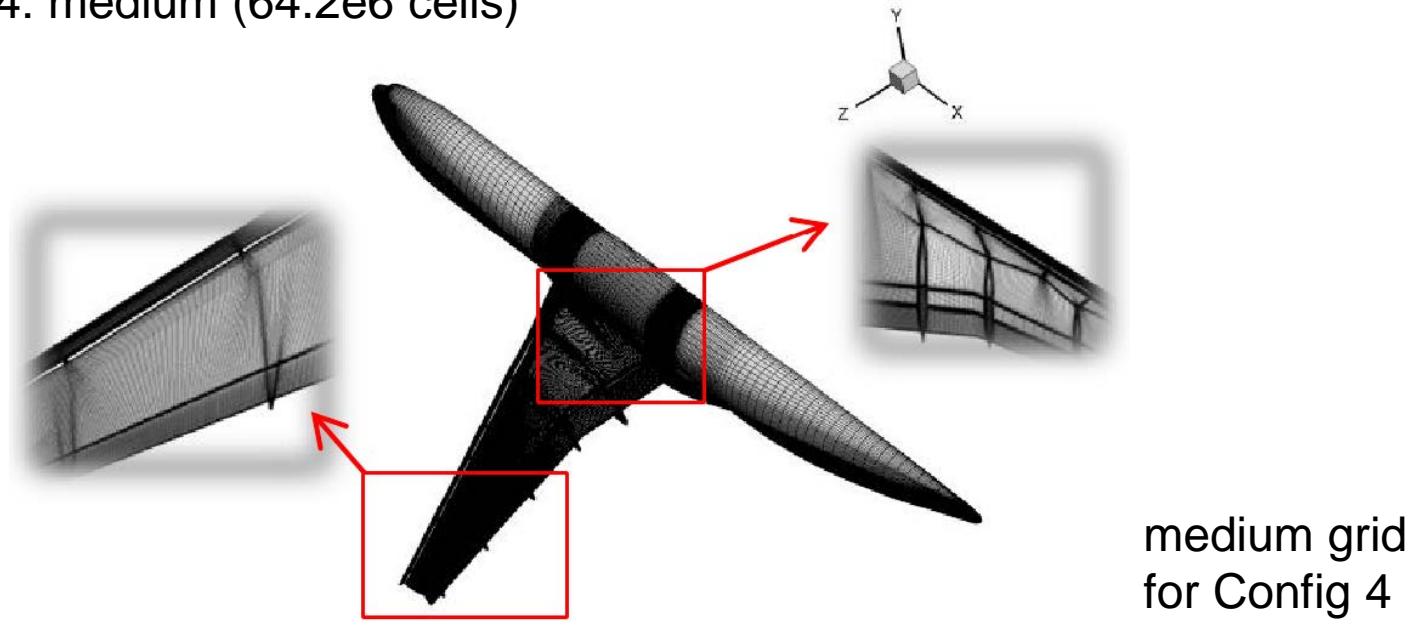
Meshing Challenge: Contribution 2 (NUDT)

by S. Wang¹, L. Xiao¹, G. Wang², W. Liu¹, X. Deng¹

- ¹ National University of Defense Technology (NUDT), China
- ² Sun Yat-sen University, China

- Linear block-structured meshes (ICEM):

- Config 2: coarse (9.8e6), medium (32.0e6), fine (100.6e6 cells)
- Config 4: medium (64.2e6 cells)



Meshing Challenge: Summary

HioCFD-4 webpage: Participants are expected to demonstrate a methodology to generate *hybrid curved* meshes, including high aspect ratio extrusion boundary layers, with at least a *quadratic* representation of the boundary. A series of meshes [...] should be provided [...].

Contribution 1 (CentaurSoft, DLR):

- DLR F11 Config 4 (w slat track and flap track fairings) ✓
- Hybrid mesh (prisms, pyramids and tetrahedra) ✓
- Curved with quadratic representation of boundary ✓
- A single mesh for Config 4 is provided (✓) ✓

Contribution 2 (NUDT):

- DLR F11 Config 4 (w slat track and flap track fairings) ✓
- Block-structured meshes ✗
- Linear meshes ✗
- A single mesh for Config 4 not (yet) provided (✓) ✗



Meshing Challenge: Conclusions (1)

Only one contribution of a hybrid curved mesh for the DLR-F11 Config 4.

CentaurSoft, DLR:

- The grid provided is not completely regular:
 - Validity: It is valid in the sense that all cell volumes are positive.
 - „Discrete regularity“:
 - It is „discretely regular“ for DG-O2, i.e. Jacobian determinants are positive in all quadrature points involved in DG-O2.
 - It is „slightly irregular“ for DG-O3. 14 cells have negative Jacobian determinants in at most 2 out of 64 quadrature points.



Meshing Challenge: Conclusions (2)

Possible improvements in the hybrid curved grid generation process:

Improved cell quality measures:

- Positivity check of cell volumes and sub-cell volumes not sufficient
- „Discrete regularity“ in quadrature points (costly, and discretization specific)
- Validity check based on Bézier functions (possibly even more costly)
- Possible next step: „Discrete regularity“ in vertices and higher order nodes.

Curved grid generation should **not** stop at quadratic boundaries/elements:

- What about cubic (and quartic) elements?

Final conclusion:

- Feasibility of curved mesh generation for DLR-F11 configuration demonstrated.
- Curved grid generation still remains a challenging task for this complexity.



Contributions to the Computational/meshing challenge

Contribution 1 (DLR, Config 4, DG-O3):

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- RANS Wilcox k- ω
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Contribution 2 (NUDT, Config 2, FD-O5):

- S. Wang¹, L. Xiao¹, G. Wang², W. Liu¹, X. Deng¹
 - ¹ National University of Defense Technology (NUDT), China
 - ² Sun Yat-sen University, China
- Family of linear block-structured meshes (ICEM) for Config 2 & 4
- RANS Menter-SST
- 5th-order Finite Difference (FD) flow solution for Config 2 ($\alpha=7^\circ, 16^\circ, 18.5^\circ$)
- 9.8e6, 32.0e6, 100.6e6 DoFs/eqn



Reference solution (HiLiftPW-2, DLR)

Reference solutions (DLR, Config 2 & 4, FV)

- R. Rudnik, S. Melber-Wilkending (DLR), DLR-TAU solver, HiLiftPW-2, 2013
- Linear hybrid meshes (SOLAR)
- RANS-SAO (Spalart Allmaras, original 1992 formulation)
- 32.4e6 DoFs/eqn

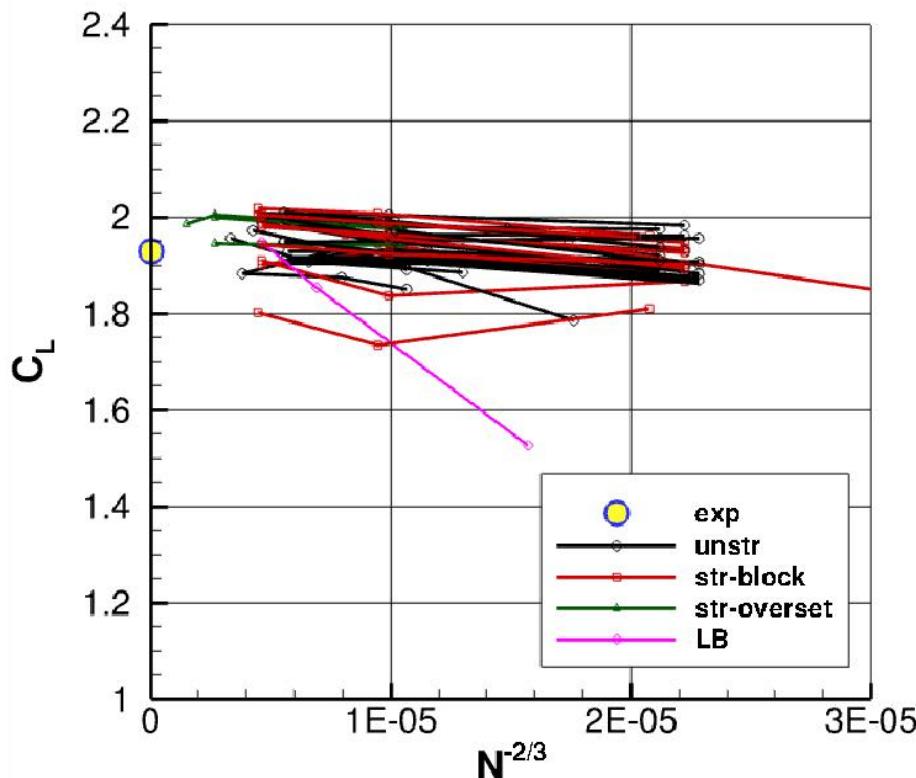
In the following: Comparison of computational results

- Force coefficients: C_L , C_D , C_M
- cp-distributions at specific wing sections
against reference solutions and experimental data.

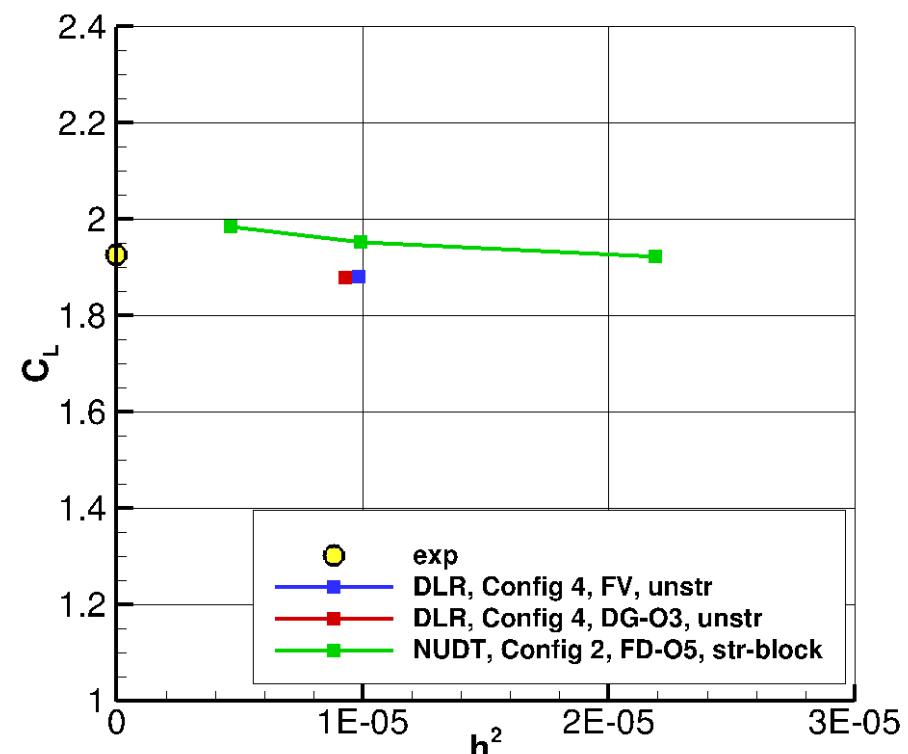


Computational challenge: Results

Ma= 0.175, Re=15.1e6 (high Re-No.), $\alpha = 7^\circ$



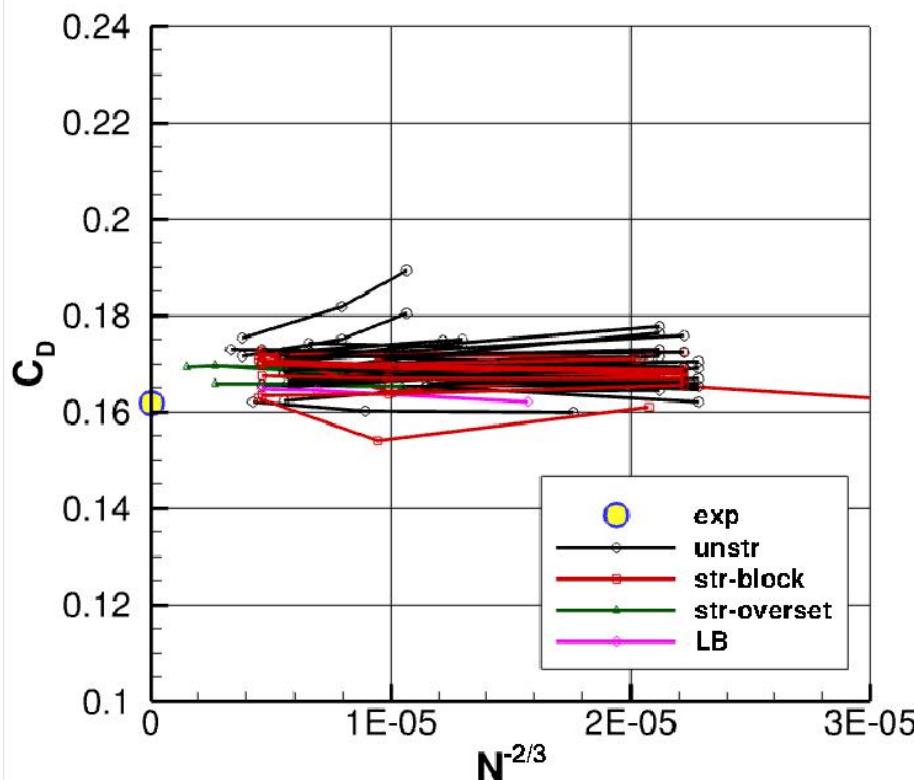
HiLiftPW-2, Config 2



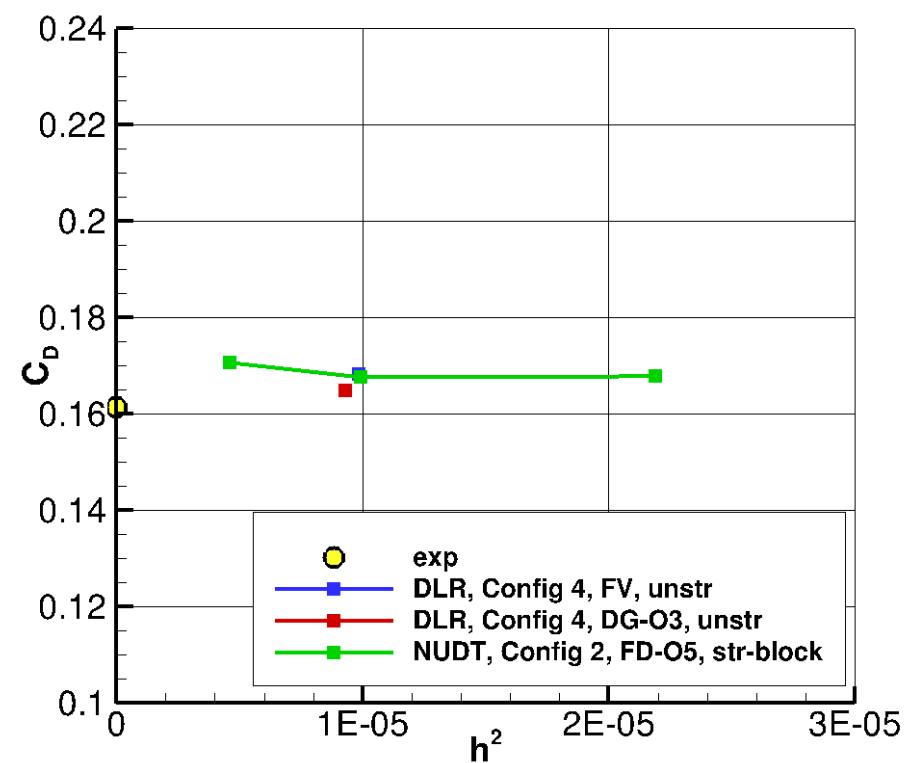
present results

Computational challenge: Results

Ma= 0.175, Re=15.1e6 (high Re-No.), $\alpha = 7^\circ$



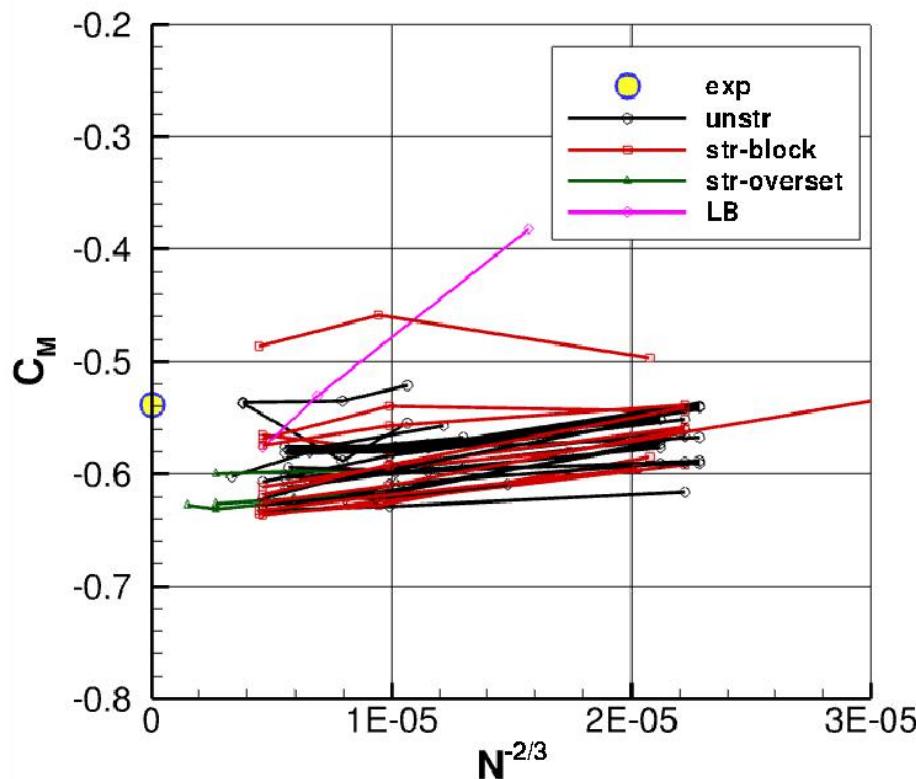
HiLiftPW-2, Config 2



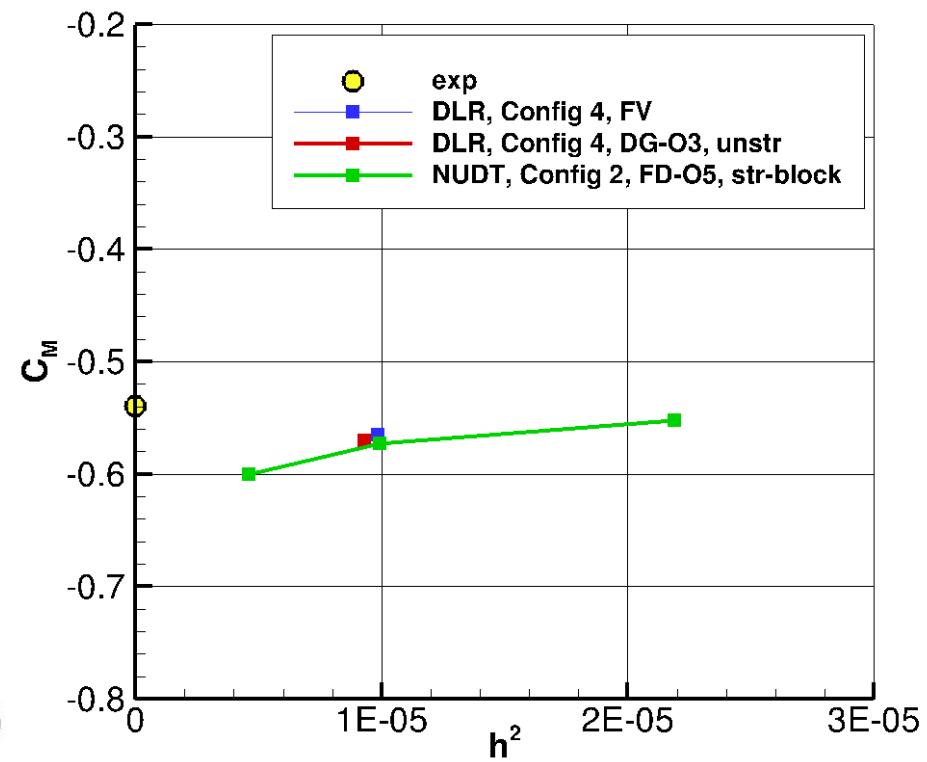
present results

Computational challenge: Results

Ma= 0.175, Re=15.1e6 (high Re-No.), $\alpha = 7^\circ$



HiLiftPW-2, Config 2



present results

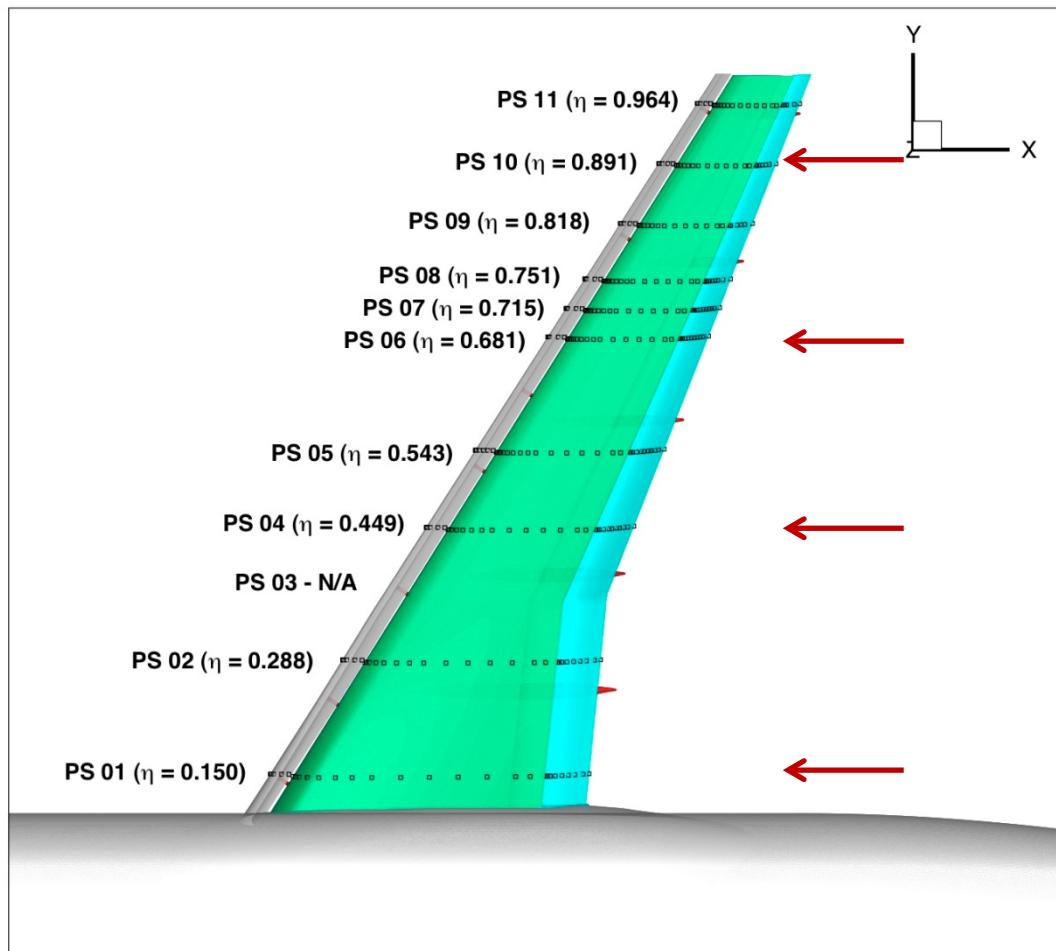
Computational challenge: Finest results

			C_L		C_D		C_M	
	Exp.		1.9270		0.1615		-0.5390	
DLR	Config 4	FV*	1.8794	-2.5%	0.1681	+4.1%	-0.5647	-4.8%
DLR	Config 4	DG-O3	1.8781	-2.5%	0.1649	+2.1%	-0.5704	-5.8%
DLR	Config 2	FV*	1.9110	-0.8%	0.1660	+2.8%	-0.5791	-7.4%
NUDT	Config 2	FD-O5	1.9851	+3.0%	0.1706	+5.6%	-0.5999	-11.3%

* Rudnik, Melber, DLR-TAU solver with SAO, HiLiftPW-2, 2013.



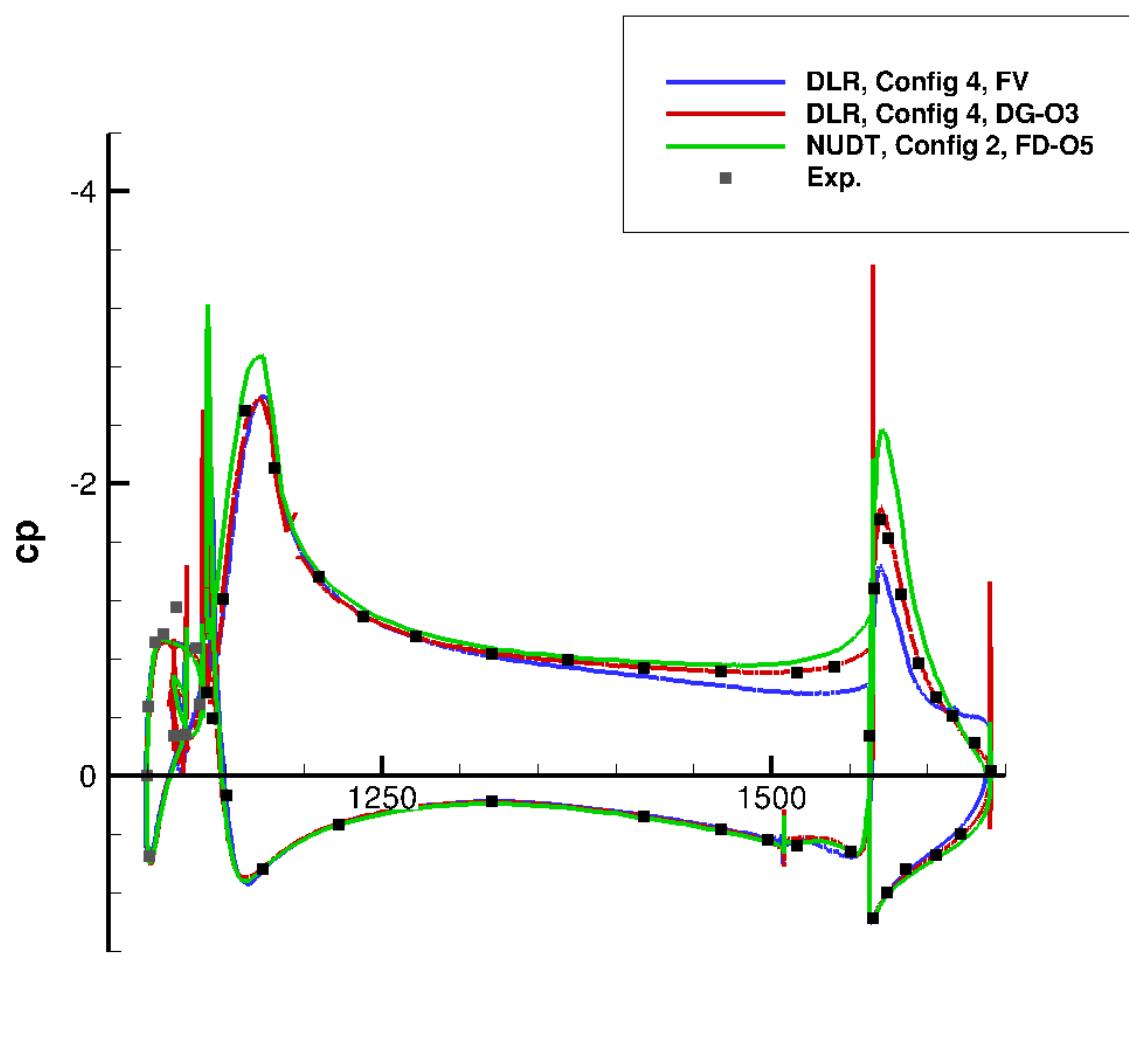
Computational challenge: Results



Consider following pressure tap locations:

- PS 01, $\eta=0.150$
- PS 04, $\eta=0.449$
- PS 06, $\eta=0.681$
- PS 10, $\eta=0.891$

Computational challenge: Results



$Ma = 0.175$
 $Re = 15.1e6$ (high Re-No.)
 $\alpha = 7^\circ$

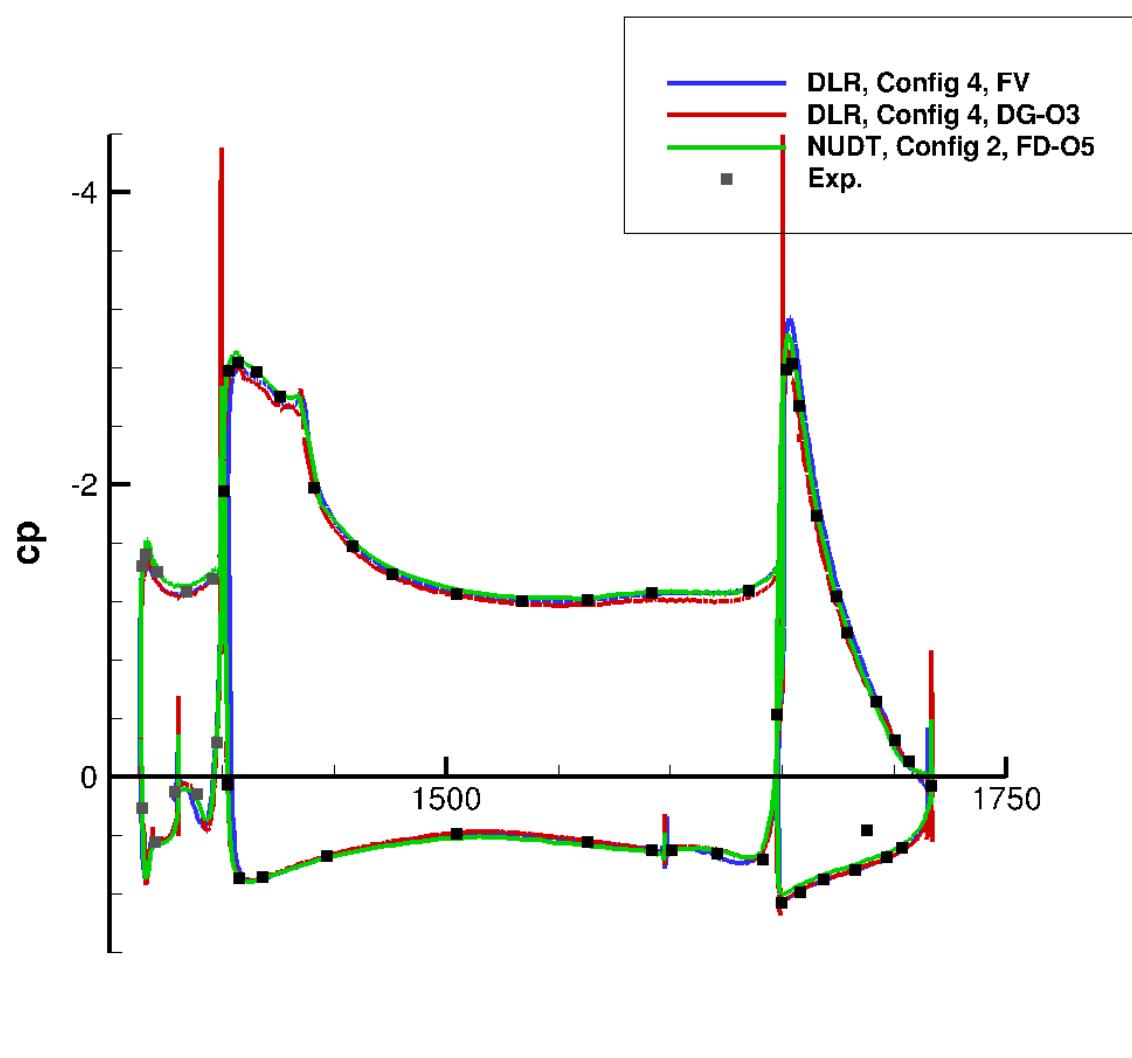
PS 01, $\eta=0.150$

DLR, FV: Pressure too high on main and flap, strong separation on flap.

DLR, DG-O3: Right on top of the experiments.

NUDT, FD-O5: Pressure too low on main and flap.

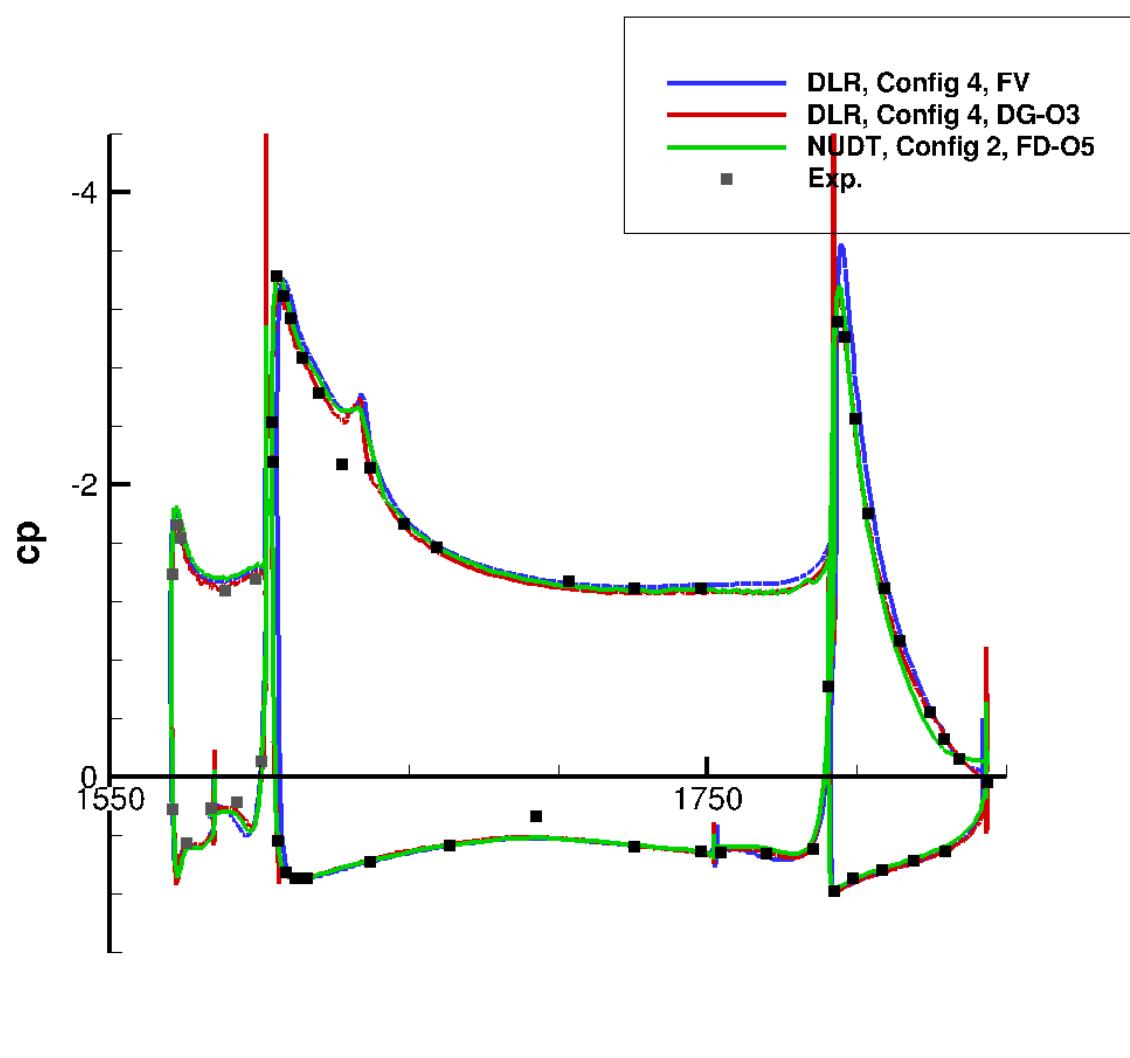
Computational challenge: Results



Ma = 0.175
Re = 15.1e6 (high Re-No.)
 $\alpha = 7^\circ$

PS 04, $\eta=0.449$

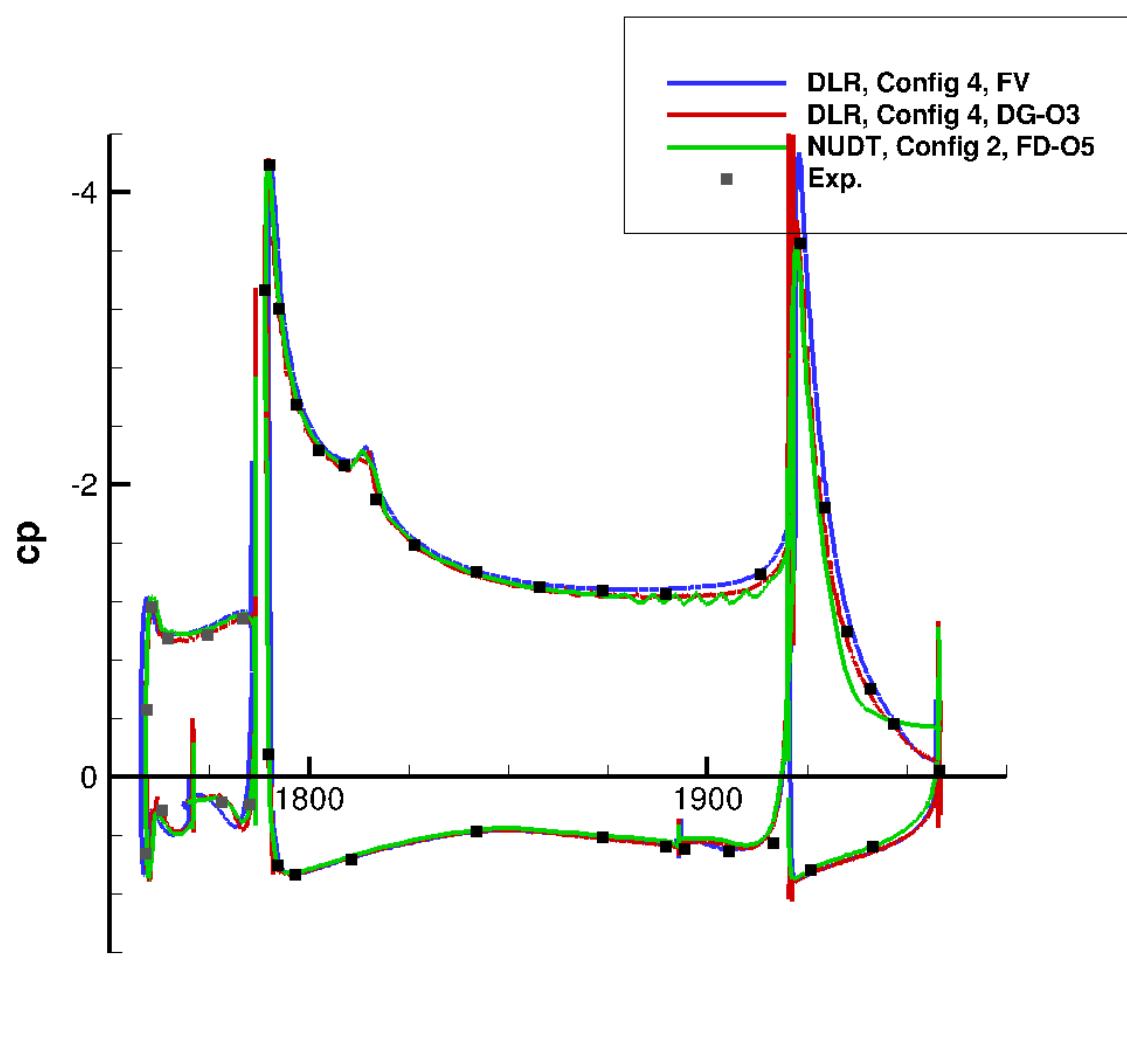
Computational challenge: Results



Ma= 0.175
Re=15.1e6 (high Re-No.)
 $\alpha = 7^\circ$

PS 06, $\eta=0.681$

Computational challenge: Results



$Ma = 0.175$

$Re = 15.1e6$ (high Re-No.)
 $\alpha = 7^\circ$

PS 10, $\eta=0.891$

DLR, FV: Slightly too low pressures on suction side.

DLR, DG-O3: Right on top of the experiments.

NUDT, FD-O5: Strong separation on flap.

Computational challenge: Summary (1)

HioCFD-4 webpage: Participants are expected to provide a single simulation for each of the three conditions.

Contribution 1 (DLR, CentaurSoft):

- 3rd-order flow solution for Config 4 ✓
- alpha = 7° (✓)

Contribution 2 (NUDT):

- 5th-order flow solution for Config 2 (✓)
- alpha = 7°, 14°, 18.5° ✓



Computational challenge: Summary (2) & Conclusions

Force coefficients:

- High-order solutions are in the range of HiLiftPW-2 results.
- **DLR, DG-O3** is close to **DLR, FV** with half the error in C_D .
- Larger difference of **NUDT, FD-O5** to the experiments and the reference solutions of **DLR, FV** for Configs 2 & 4.

cp-distributions:

- Larger differences (separation) to experiments in
 - **DLR, FV** on PS 01, $\eta=0.150$,
 - **NUDT, FD-O5** on PS 10, $\eta=0.891$.
- **DLR, DG-O3**: Right on top of the experiments in each of the sections.

Final conclusion:

- Feasibility of high-order CFD for DLR-F11 configuration demonstrated.
- High-order CFD still remains a challenging task for this complexity.

