DLR Contribution to the first High Lift Prediction Workshop

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Overview

- Motivation
- DLR Grid Generation Contributions
    - SOLAR hybrid unstructured grid family
    - CENTAUR hybrid unstructured grid family (incomplete)
- CFD solutions for the Trap Wing configuration, case 1
    - Grid convergence study - SOLAR/TAU and CENTAUR/TAU
    - Turbulence model variation - CENTAUR/TAU
- CFD solutions for the Trap Wing configuration, case 2 - SOLAR/TAU
- CFD solutions for the Trap Wing configuration, case 3 - SOLAR/TAU
- Conclusion and outlook

DLR Motivation for Workshop Participation

- Extend validation and verification of the DLR TAU-code's predictive capabilities for a 'new' 3D high lift test case
- Benchmark hybrid unstructured grid generation approaches, namely CENTAUR/TAU vs. SOLAR/TAU for a 3D high lift configuration
    - consideration of gridding guidelines for high lift cases
    - check prism-dominant vs. hex-dominant near wall grid topologies
    - grid refinement study for 3D configuration
- Check/improve best practice approaches for complex high lift configurations
    - turbulence model performance
    - convergence and start-up procedures
    - efficiency aspects, simplifications (e.g. b.t.e. resolution)

SOLAR Grid Family

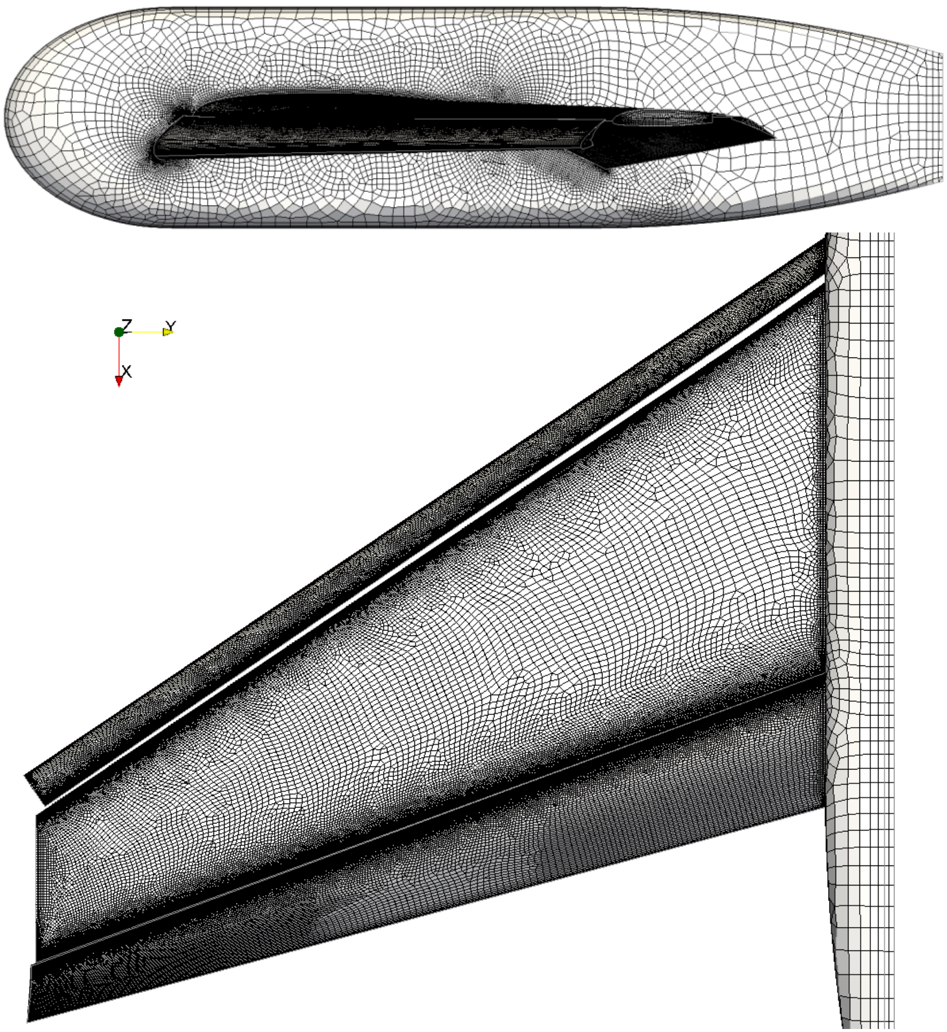
Grid Generation - SOLAR

- Grid family approach with 3 levels for configuration 1
- Medium grids for configuration 8 (case 2) and configuration 1 with brackets (case 3)
- Grid level characteristics (volume grid scaling factor = 3)

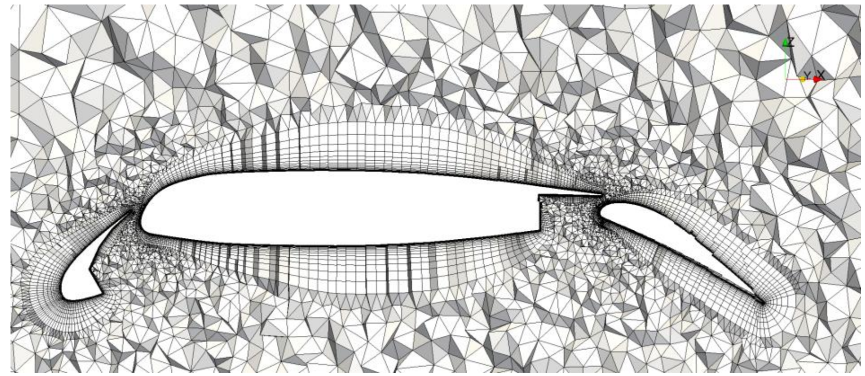
Grid Level	Pts.	Tet Elem.	Surf. Pts.	Tot. Elem.	Wall-normal Layers
C	12,307,000	5,294,000	328,000	16,785,000	35
M	36,968,000	13,666,000	682,000	48,500,000	51
F	110,746,000	36,286,000	1,419,000	141,308,000	74

- Grid generation and adaptation approach
  - ➢ surface resolution quad-based (about 0,3 % of total surface elements triangle based)
  - ➢ constant first cell height according to overall y^+ -adaptation
  - ➢ hex-layer thickness driven by variable expansion ratio
  - ➢ semi-automated source distribution

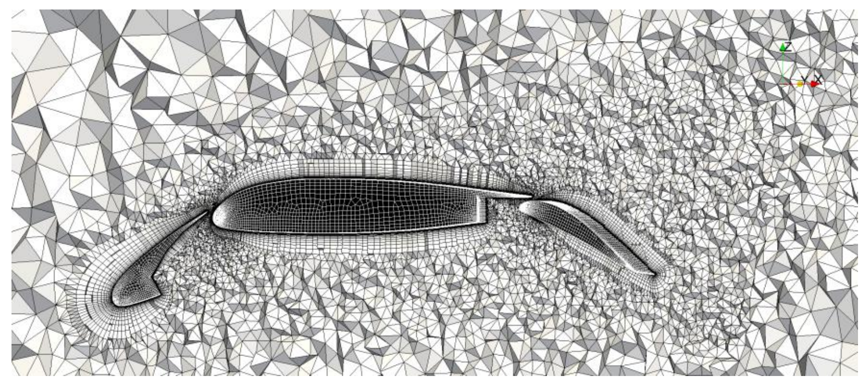
- **Solar coarse grid - configuration 1**



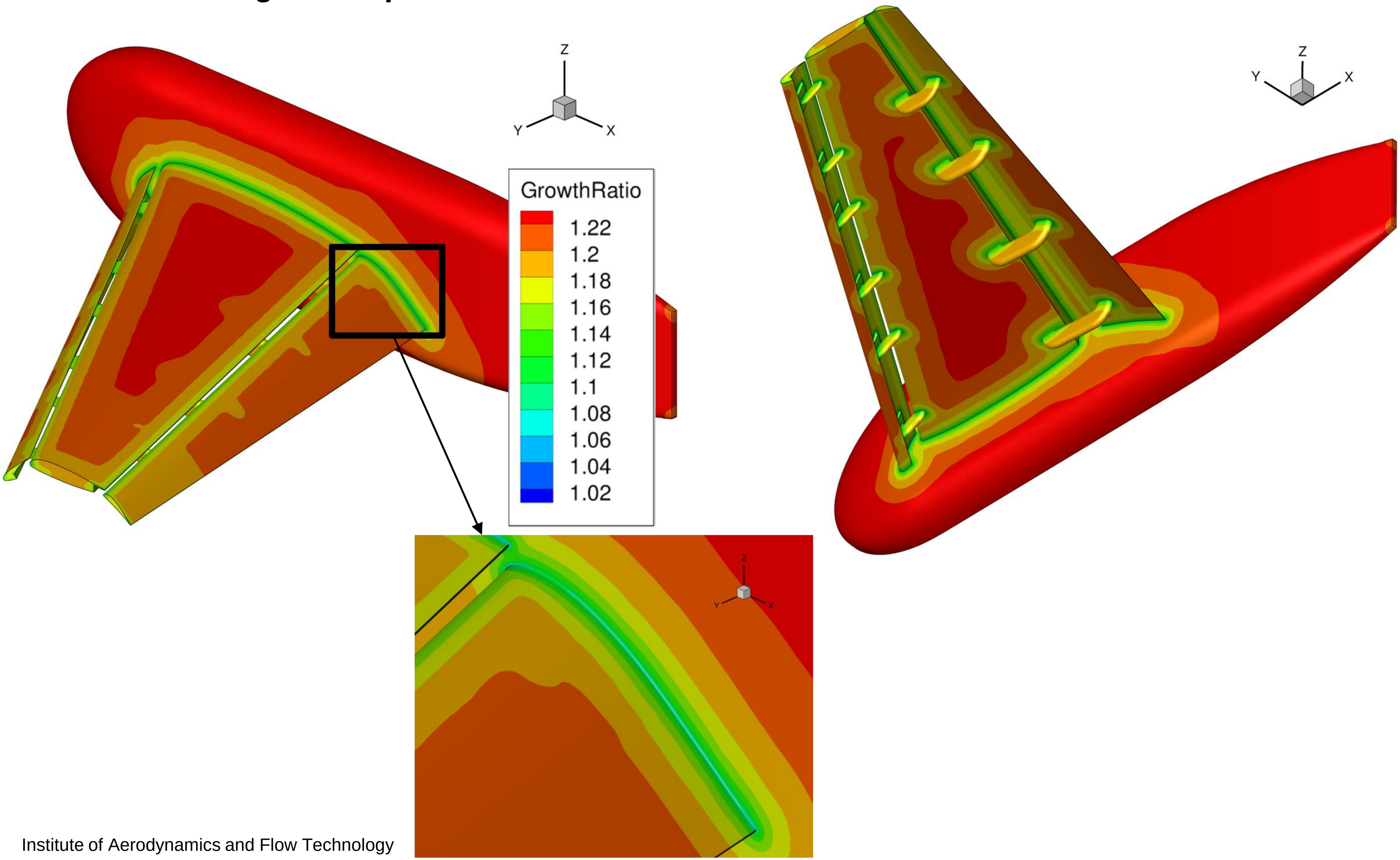
cut at η = 0.50



cut at wing tip



- **Surface grid – expansion ratio distribution**



CENTAUR Grid Family

Grid Generation - CENTAUR

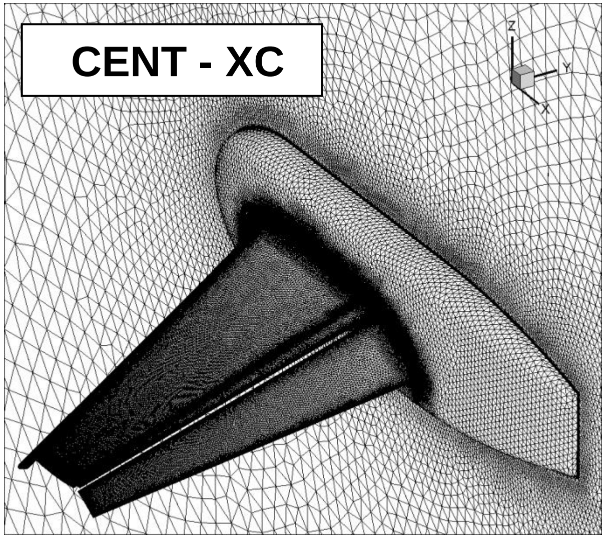
- Grid family approach with 3 levels (initially 4) for configuration 1
- Grid level characteristics (no grid family, but grid resolution variation)

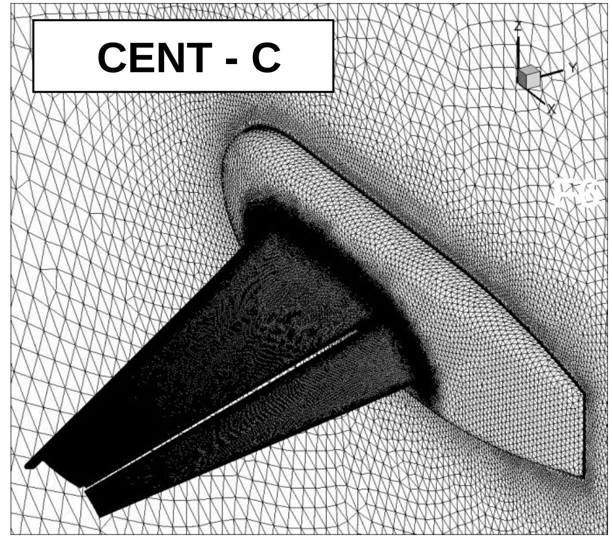
Grid Level	Pts.	Tet Elem.	Surf. Pts..	Tot. Elem.	Wall-normal Layers
XC	12,923,391	18,104,000	307,000	37,419,000	34
C	16,374,761	17,032,000	392,000	43,549,000	36
M	31,498,984	25,052,000	756,000	78,726,000	38

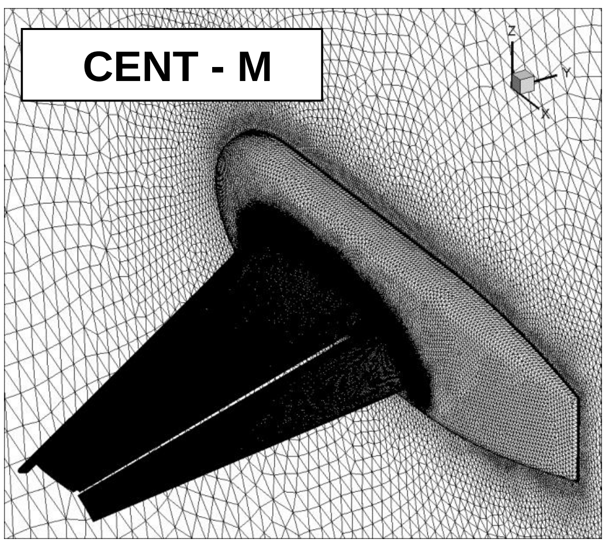
- Grid generation and adaptation approach
  - surface resolution triangle-based
  - y^+ -adaptation sectionwise and spanwise
  - spanwise adaptation of streamwise surface resolution at l.e. and t.e.
  - additional refinement by local cylinder sources along trim curves at root and tip
  - semi-automated source distribution

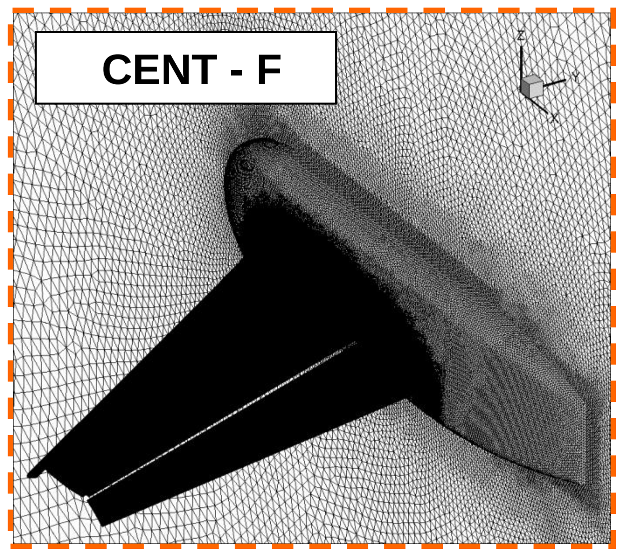
Grid Generation – CENTAUR, Grid Family

- **Surface grid - configuration - rear view**



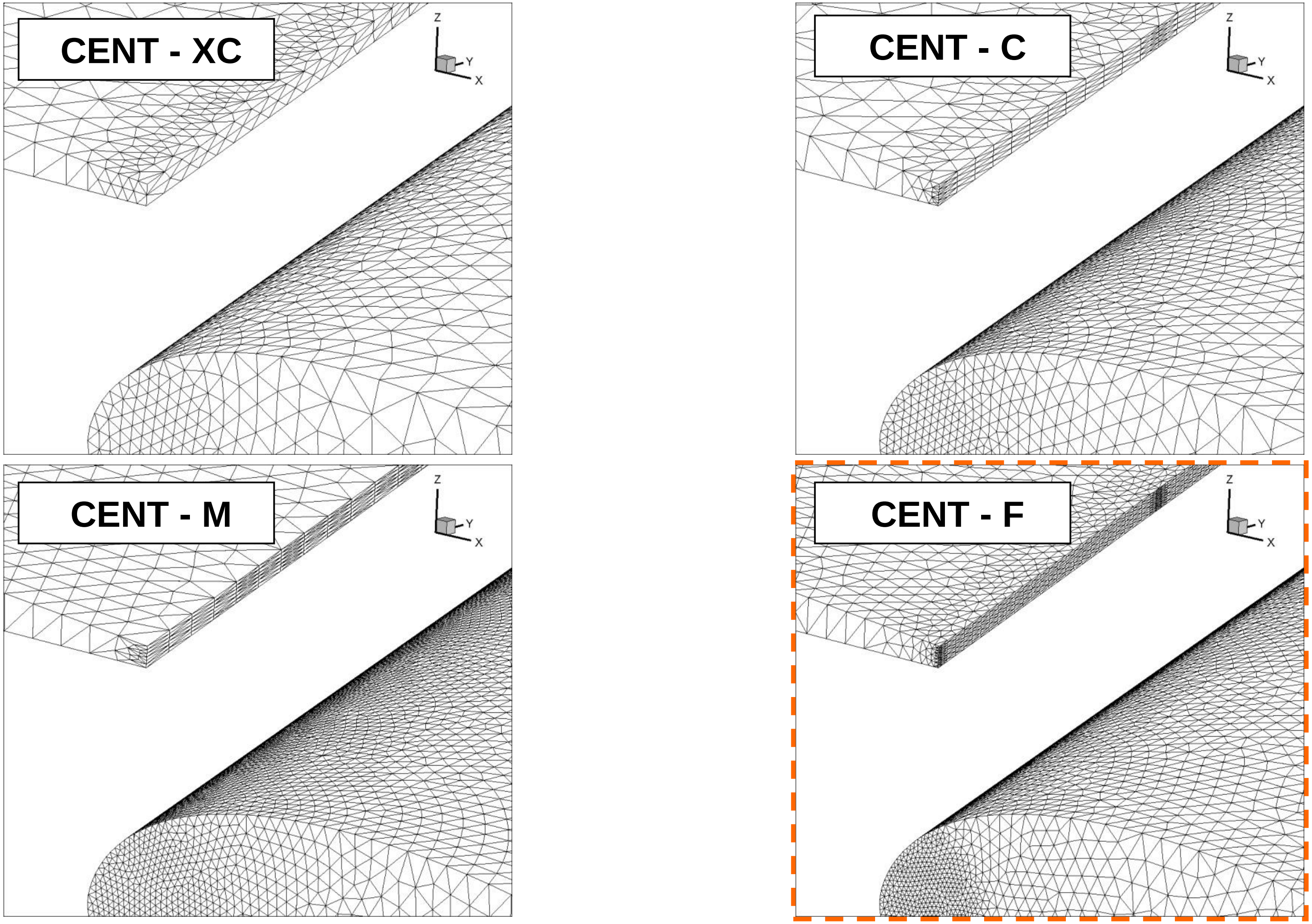






Grid Generation - CENTAUR Grid Family

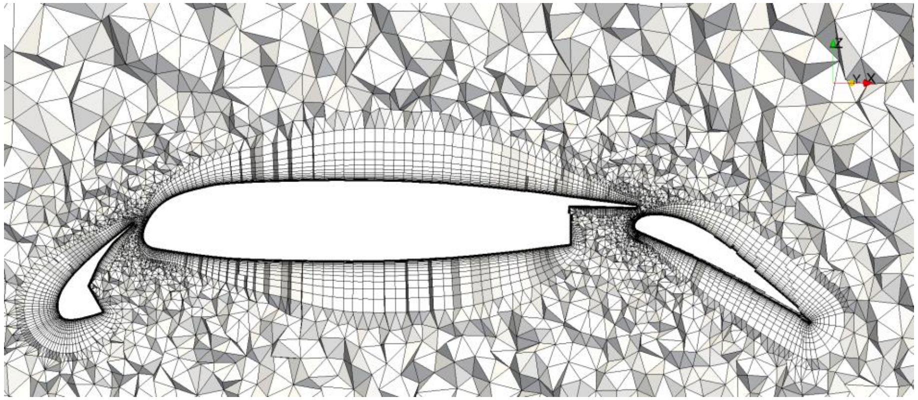
- **Surface grid – wing t.e., flap gap - upper side view**

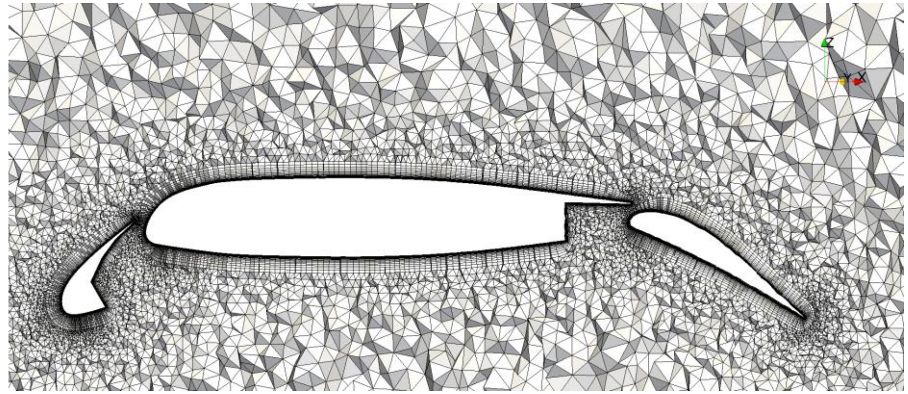


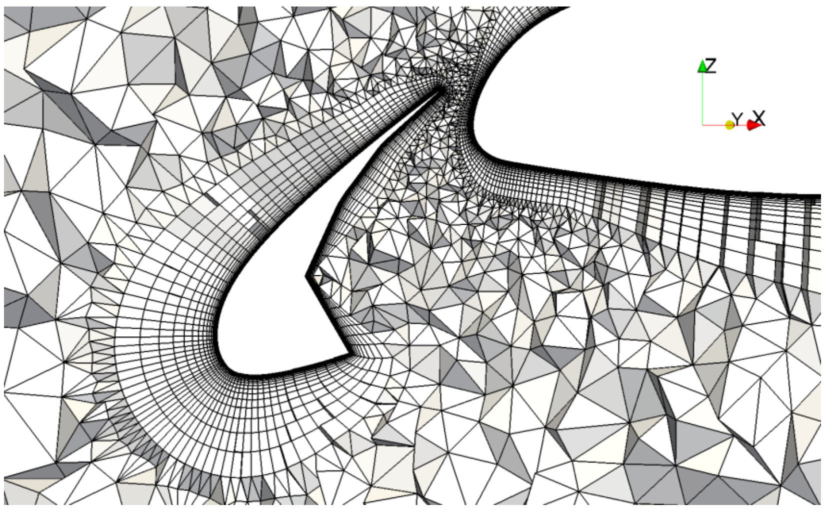
- grid cut for coarse grids at $\eta = 50$

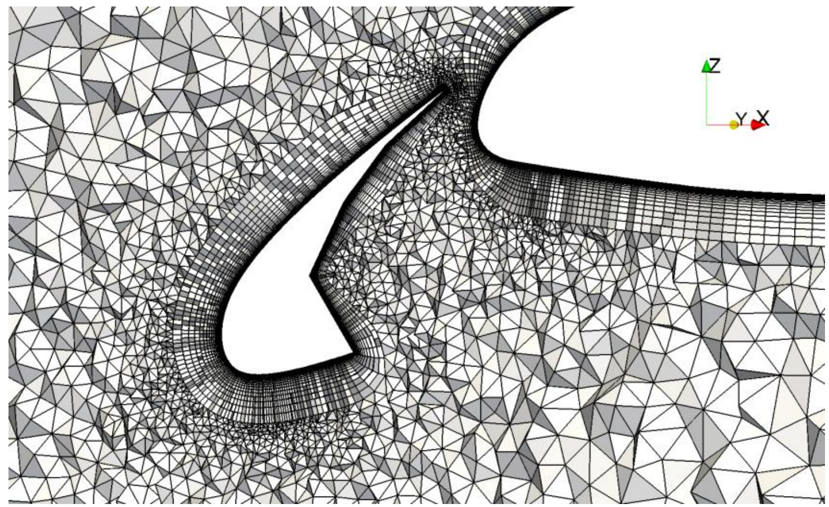
SOLAR - C

CENT - C









Grid Generation - Comparison SOLAR vs. CENTAUR

- Gridding guidelines compliance/deviations:
  - Solar:
    - 1st cell height lower than recommended value ($y^+ > 1$)
    - initial no. of layers with constant height scaled to grid levels to improve similarity
    - target no. of pts at grid levels achieved with accuracy of about 1.5 percent
    - nearfield value of growth rate of 1.25 only partially met

- CENTAUR:
  - initial no. of layers with constant height could not be met (inherent to approach)
  - No of wall-normal layers not consistenly varied
  - target no. of pts at grid levels not consistently achieved – no grid family, more sequence of grid

CASE 1

SOLAR/TAU, CENTAUR/TAU

Baseline CFD Results - Medium grid

Grid Refinement

TAU Computations – Parameter-Settings

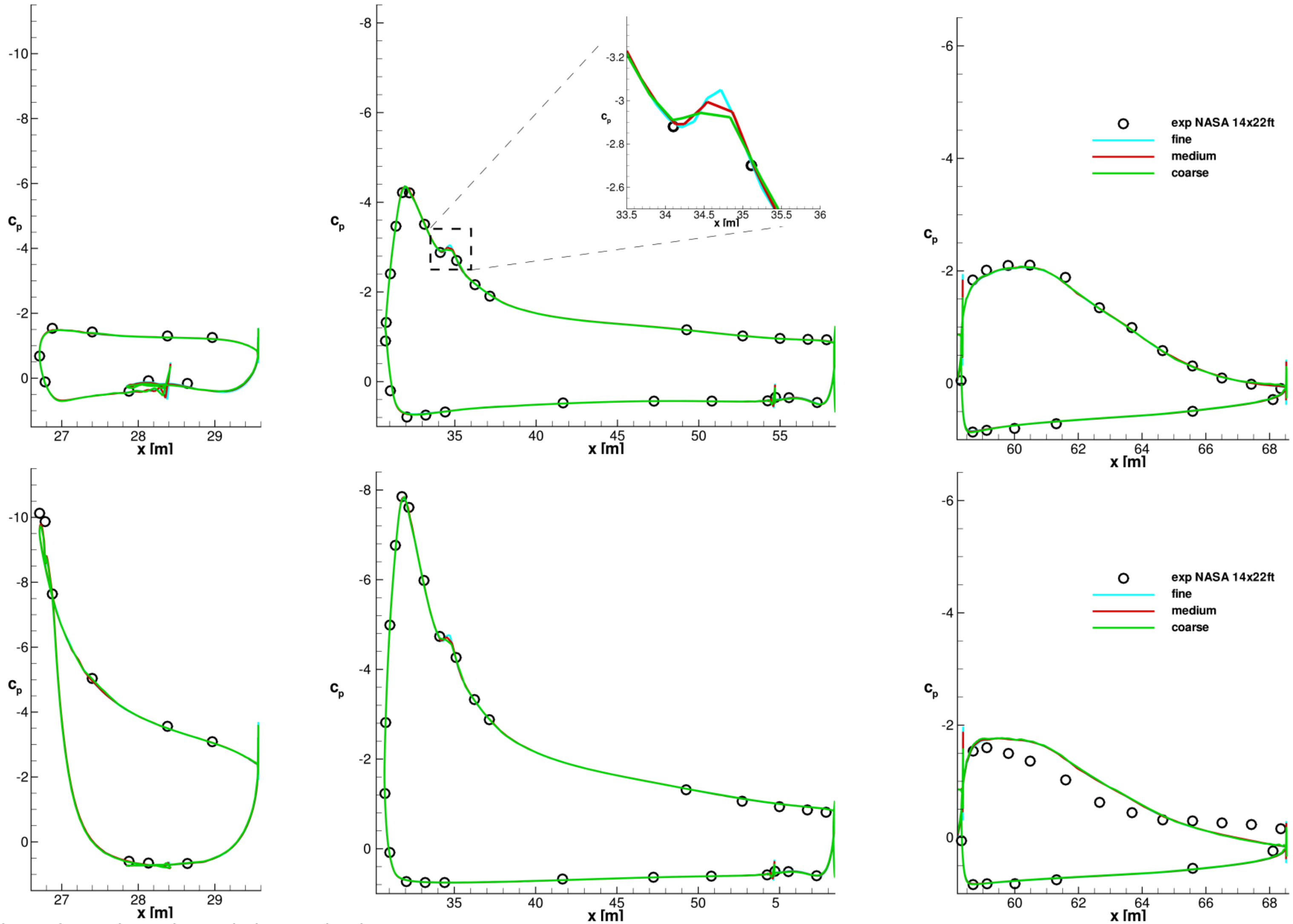
- **Code Version:** **DLR TAU code 2010.1.0**

- **Spatial Discretization:**
  - **Main equations:** **Jameson central, 2nd order;**
    Blend scalar (80%) – matrix (20%) dissipation
  - **Turb. Equations:** **Roe upwind, 2nd order**

- **Turbulence Models:**
  - Spalart-Allmaras, original formul. (SAO)
  - Menter k-ω SST (SST)
  - SSG/LRR-ω diff. Re-stress model (RSM)

- **Temp. Integration:**
  - LU-SGS Backward Euler
  - Multigrid, 3V cycle

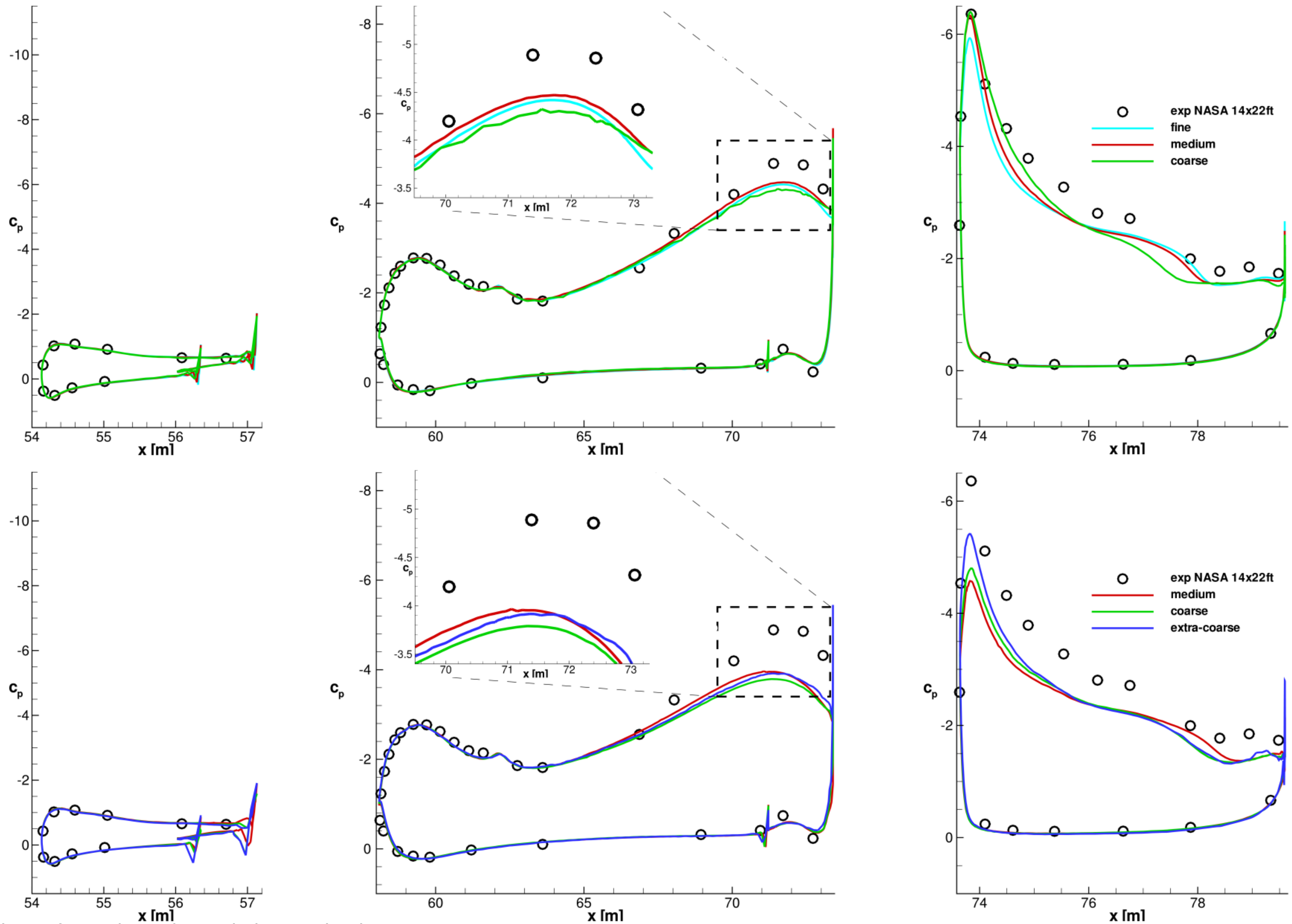
- **TAU-SAO, SOLAR grid-family; η = 0.50** **pressure distribution at**



α = 13°

α = 28°

- **TAU-SAO, SOLAR vs. CENTAUR grid-families; η = 0.98 pressure distribution at α = 13°**



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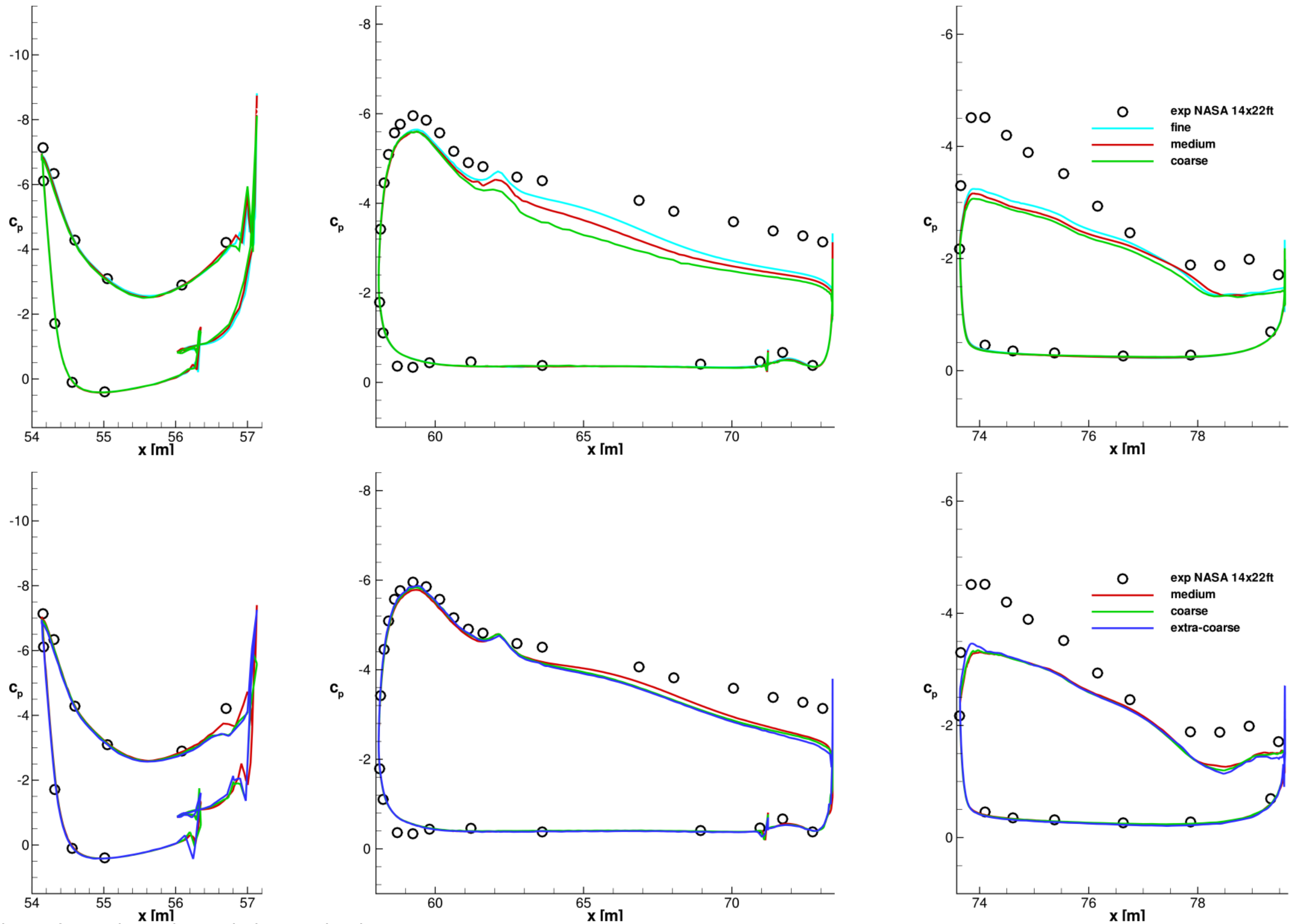
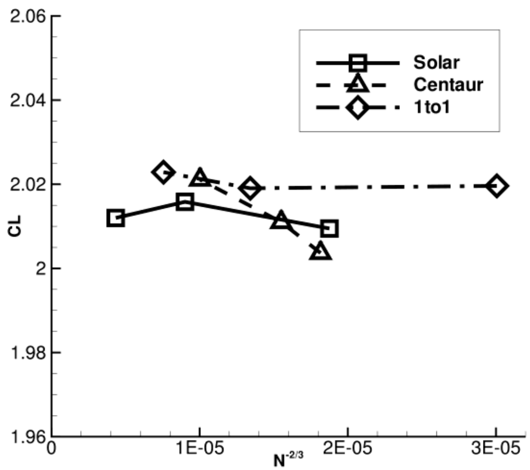
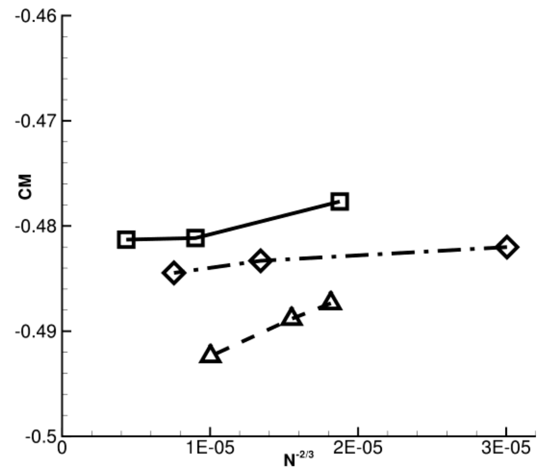


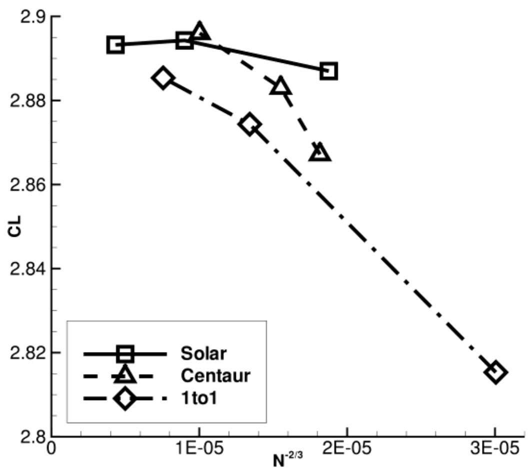
TAU-Computations - Case 1

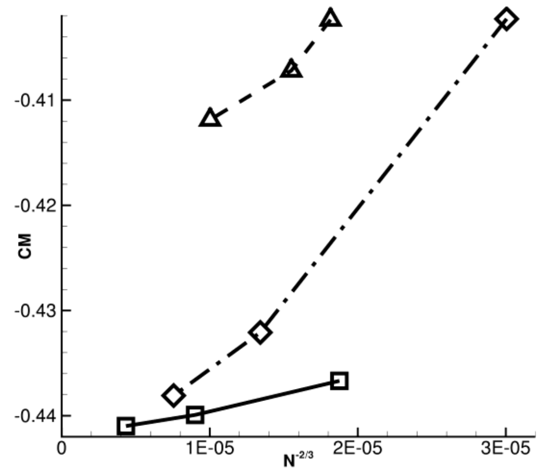
- **TAU-SAO, SOLAR vs. CENTAUR grid-families lift (left) and pitching moment at**





α = 13º



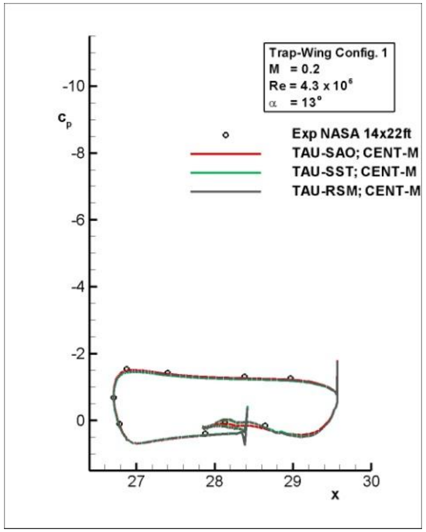


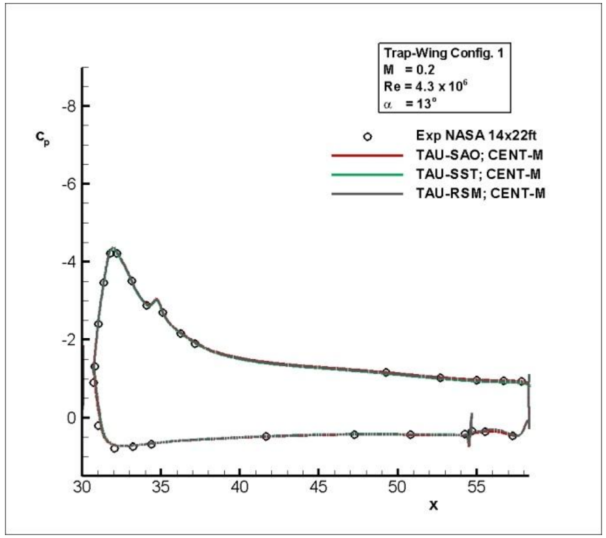
α = 28º

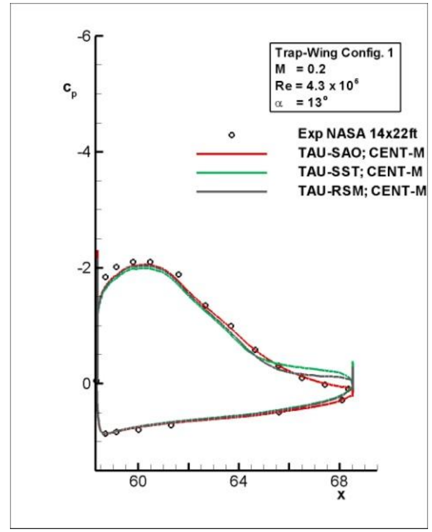
TAU-Computations - Case 1

- **TAU-SAO, grid-n; α = 13°: turb.-model-var. pressure distribution at**

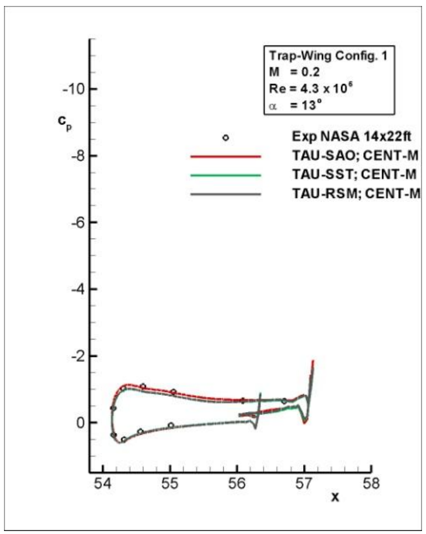
η = 0.50

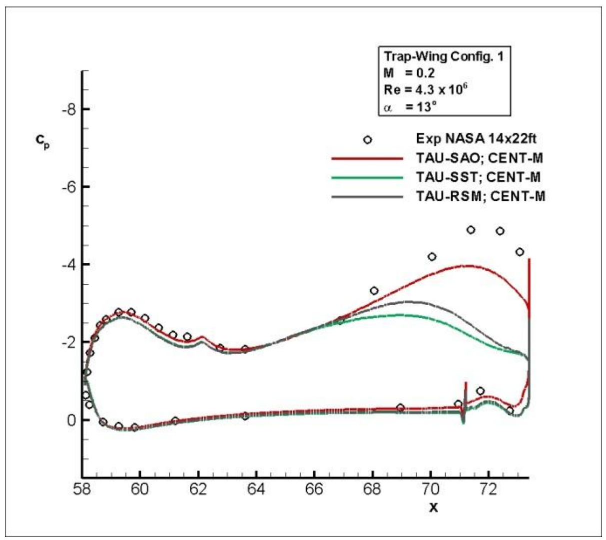


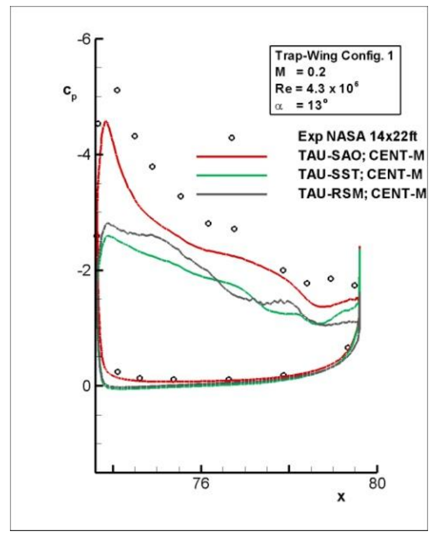




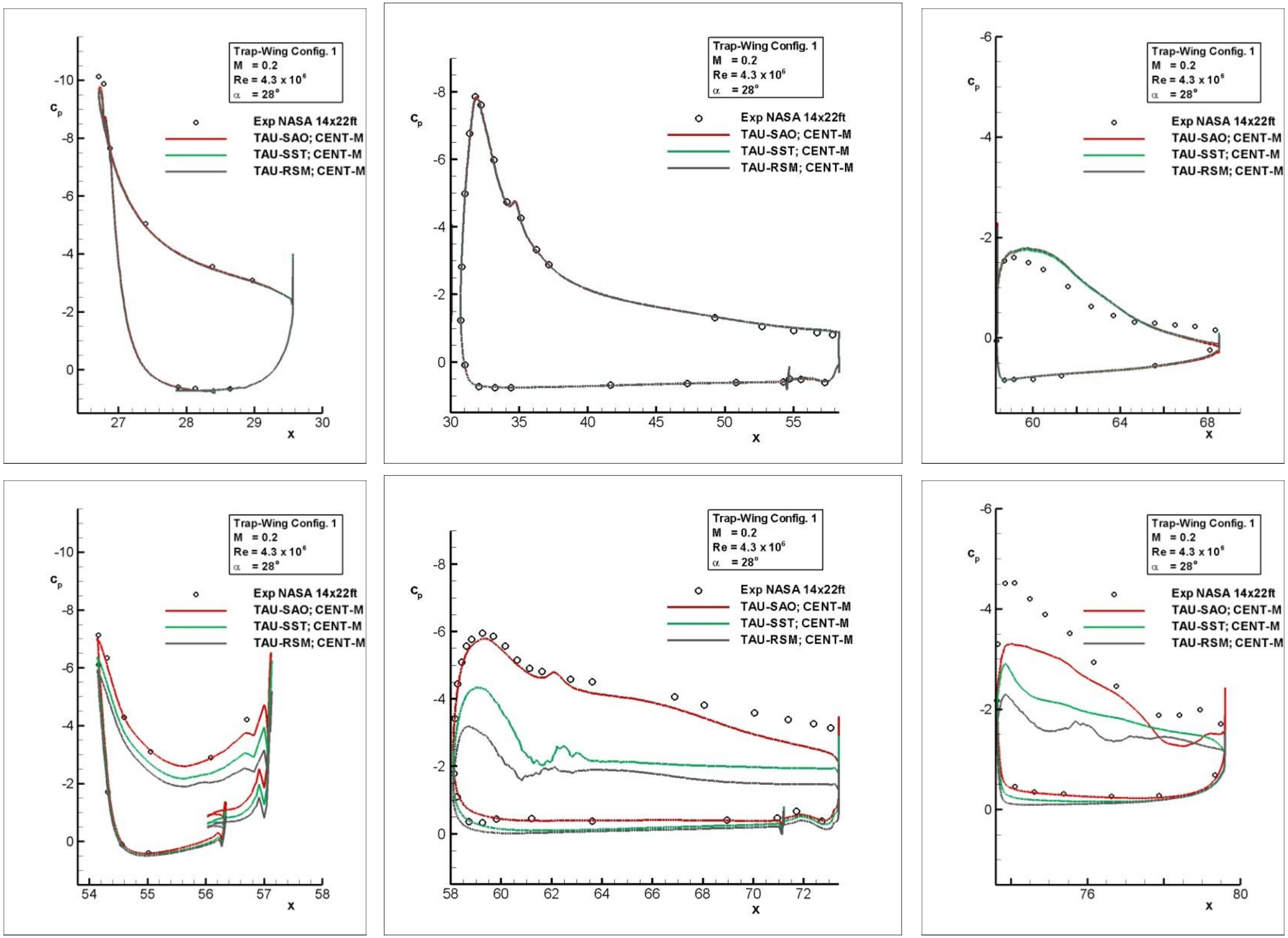
and 0.98







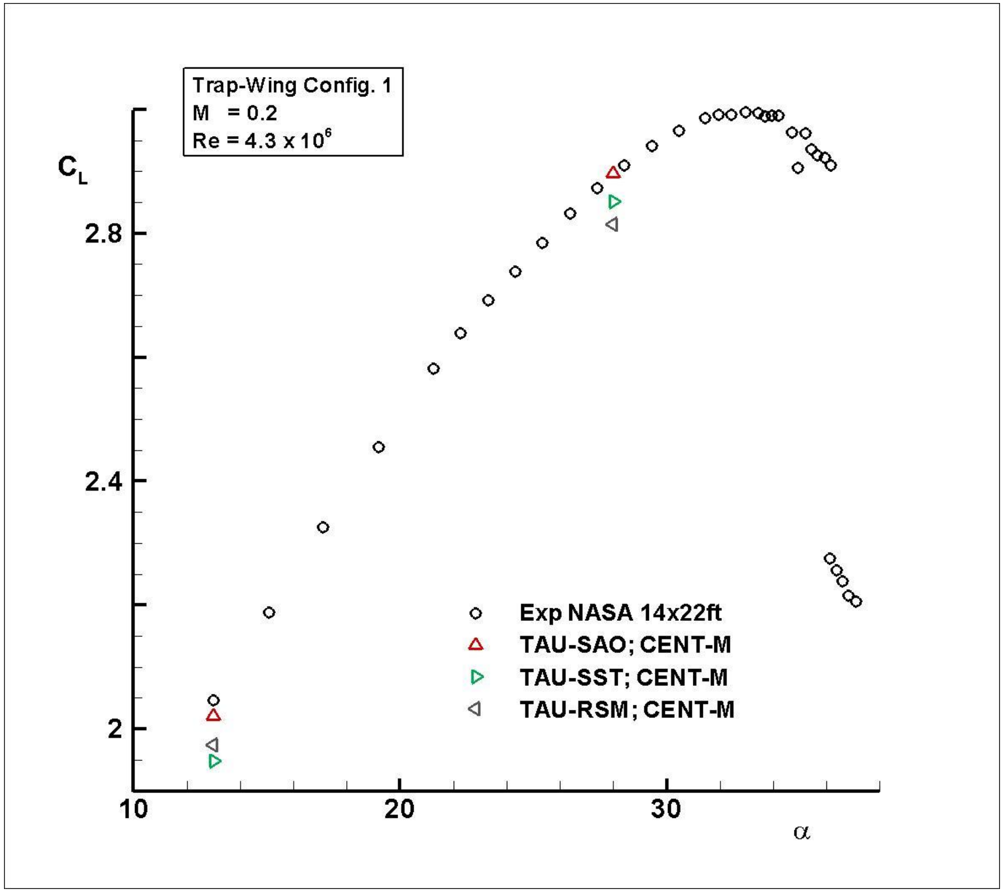
- **TAU-SAO, grid-n; α = 28°: turb.-model-var.** **pressure distribution at**



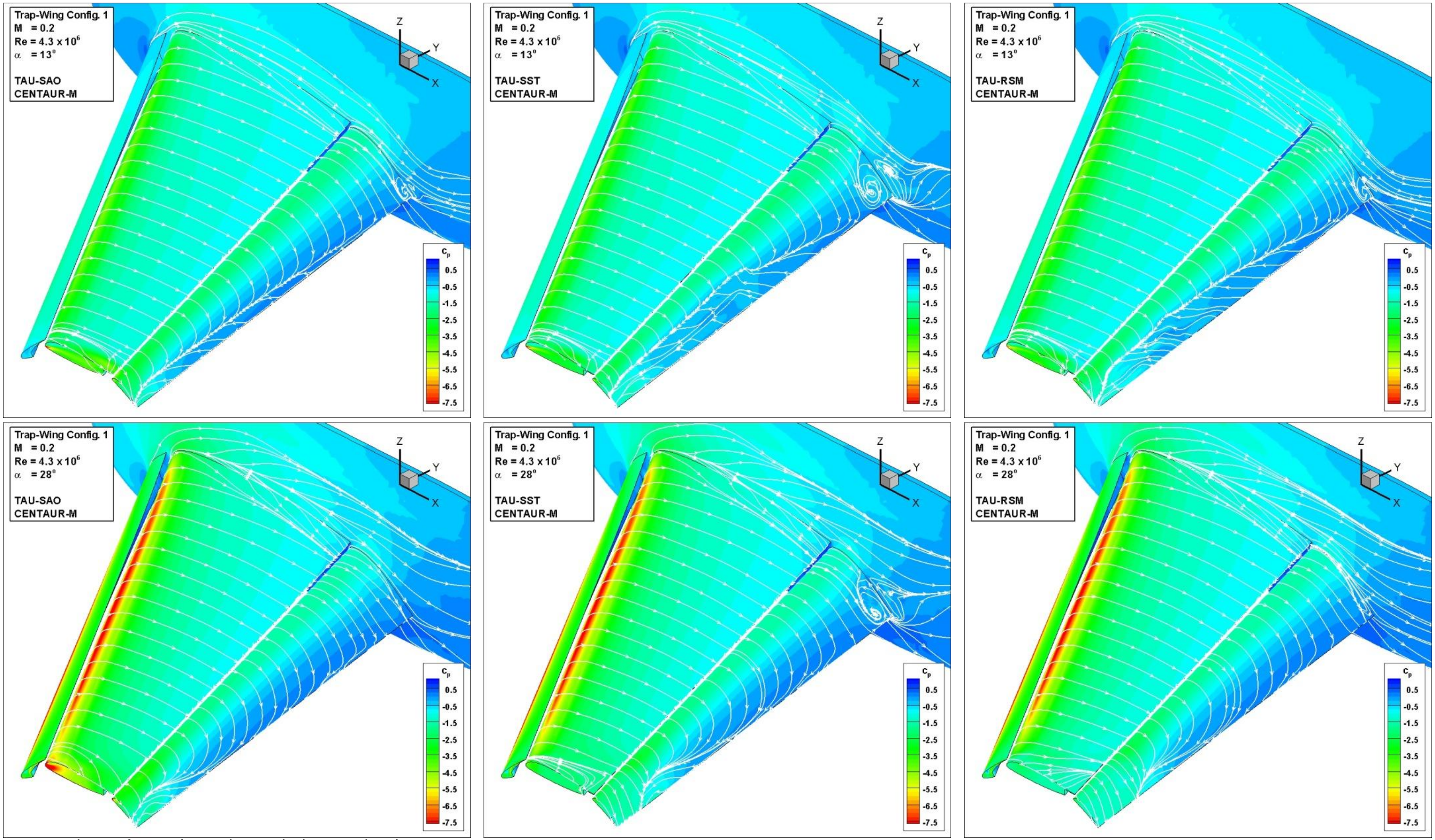
η = 0.50

and 0.98

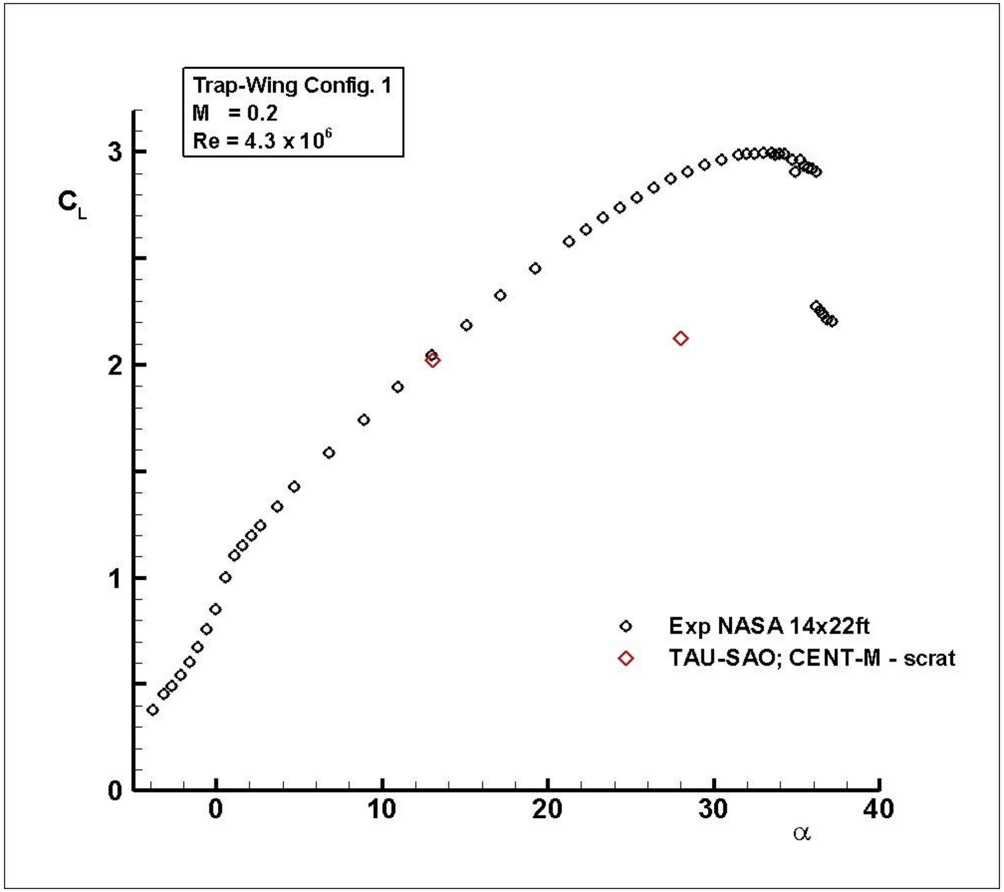
- **TAU-SAO, grid-family; α = 13, 28º : turb.-model var.**

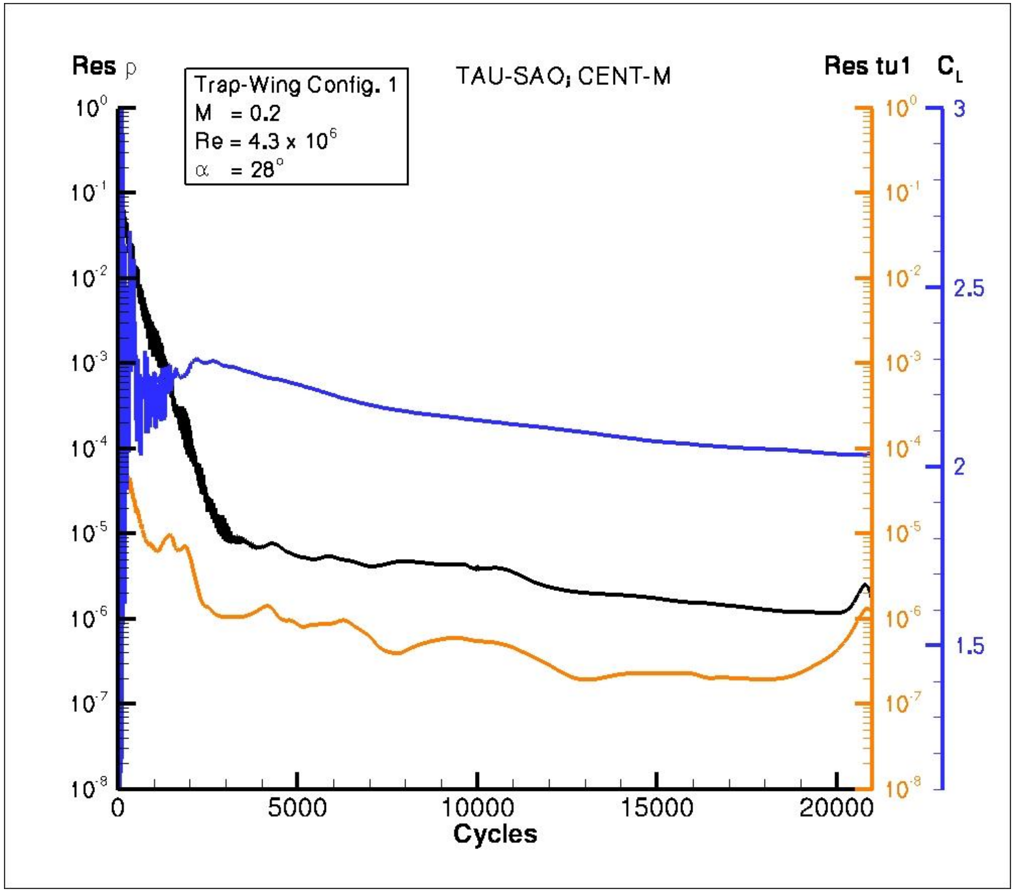


- **TAU-SAO/SST/RSM, grid-m; α = 13, 28°: isobars and surface streamlines**

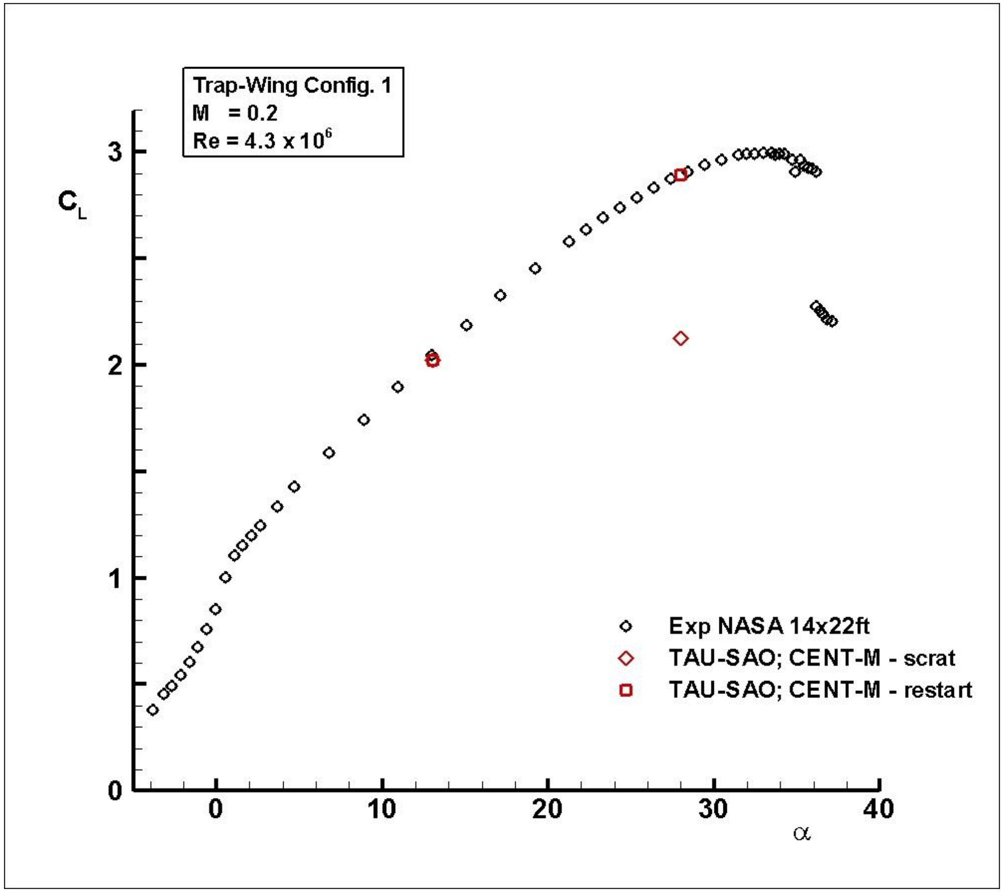


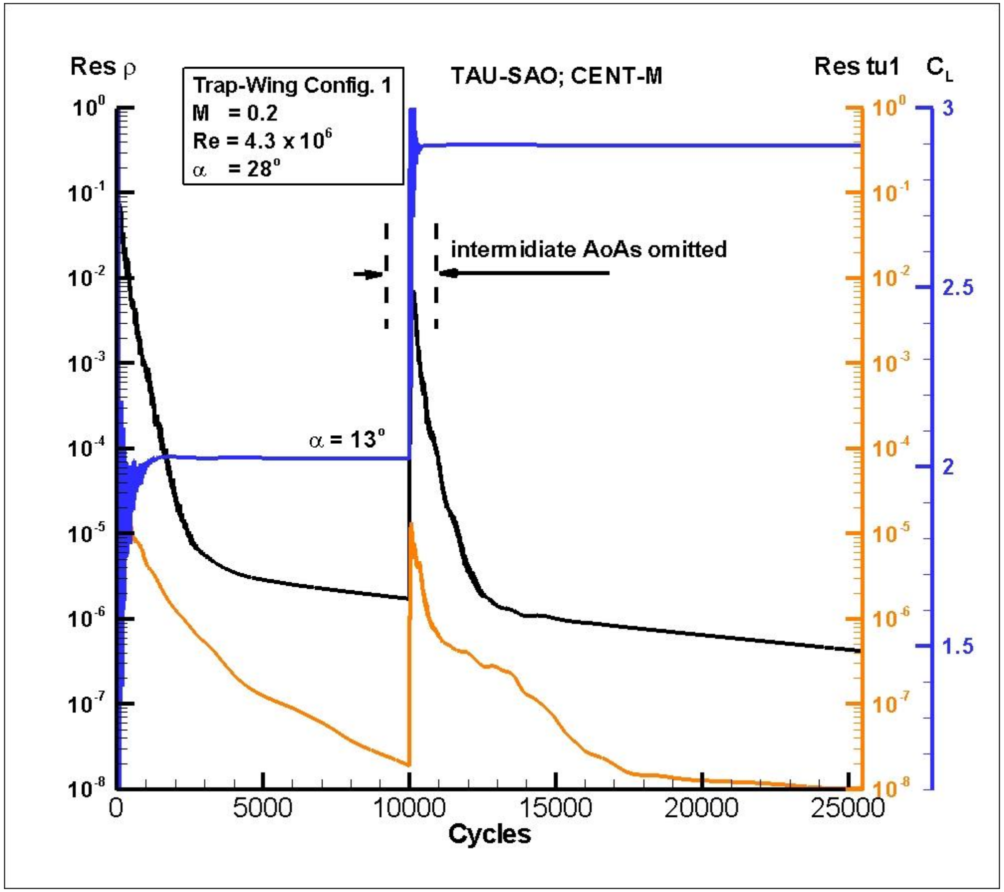
- **TAU-SAO, grid-m; α = 13, 28°:   start-up procedure: scratch**





- **TAU-SAO, grid-m; α = 13, 28°: start-up procedure stepwise restart ($\Delta\alpha$ = 2°)**





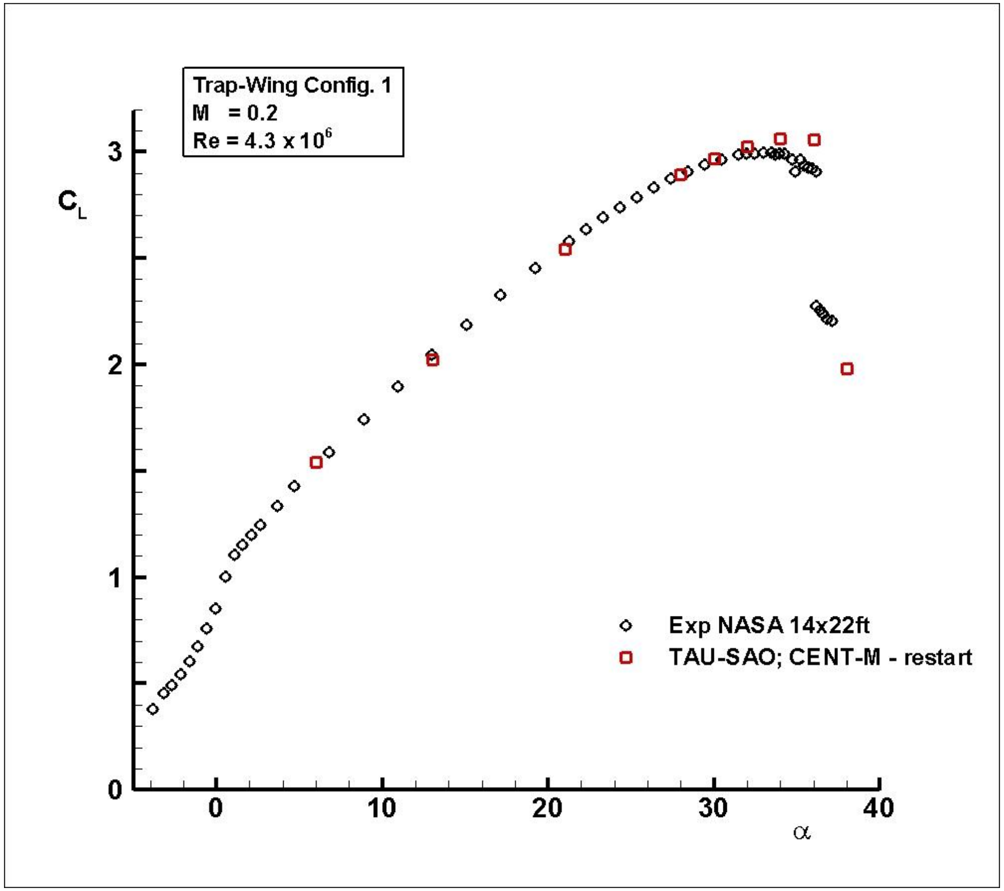
CASE 2

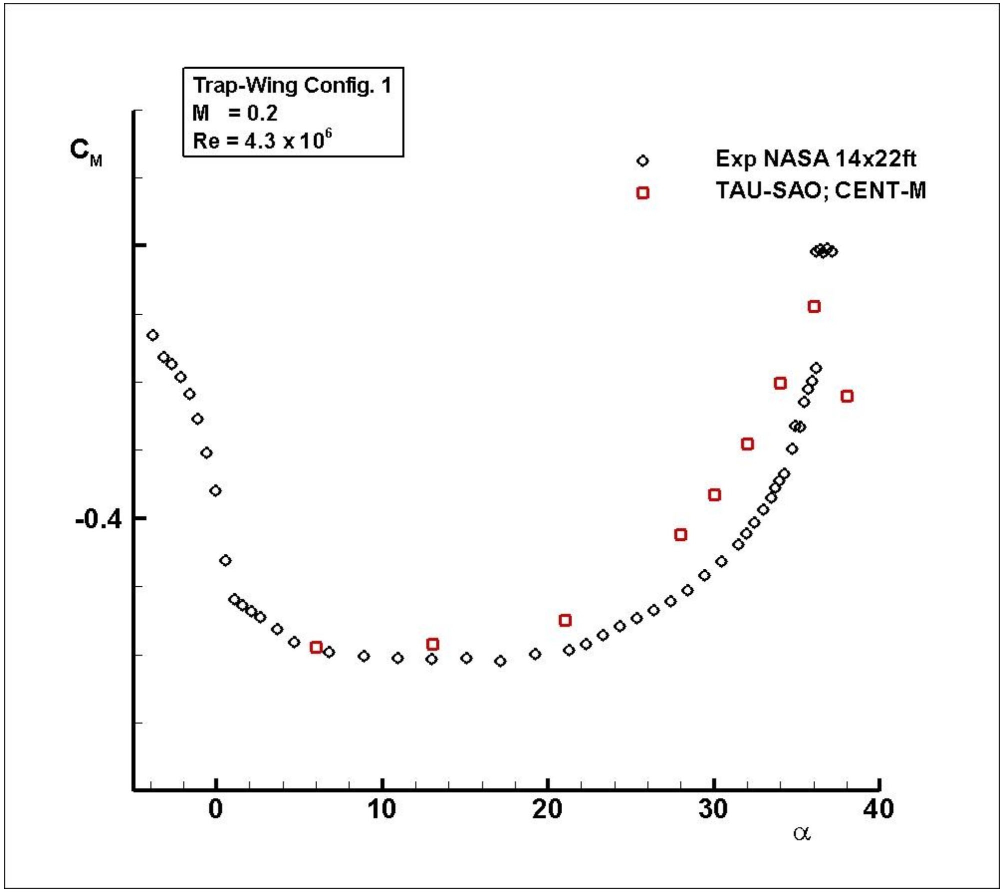
SOLAR/TAU, CENTAUR/TAU

Configuration 1 and 8 - Medium Grid

TAU-Computations - Case 2

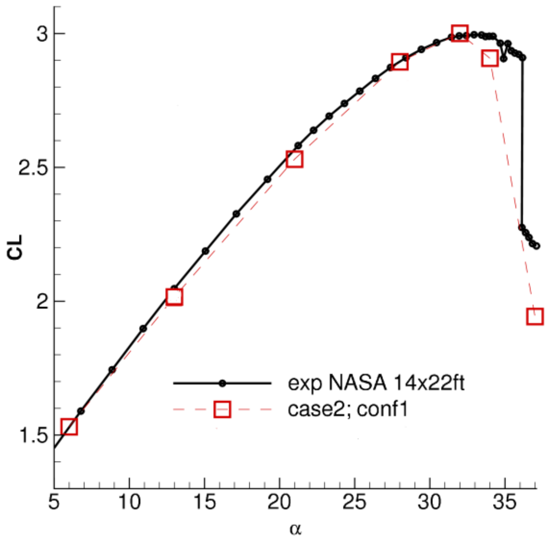
- **TAU-SAO, grid-m; polar computations for config. 1**

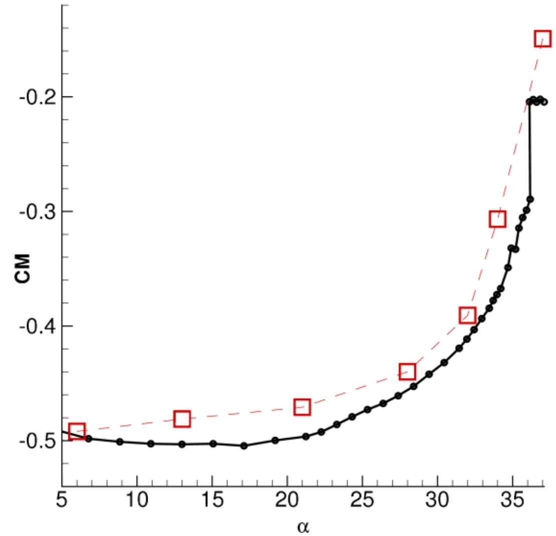


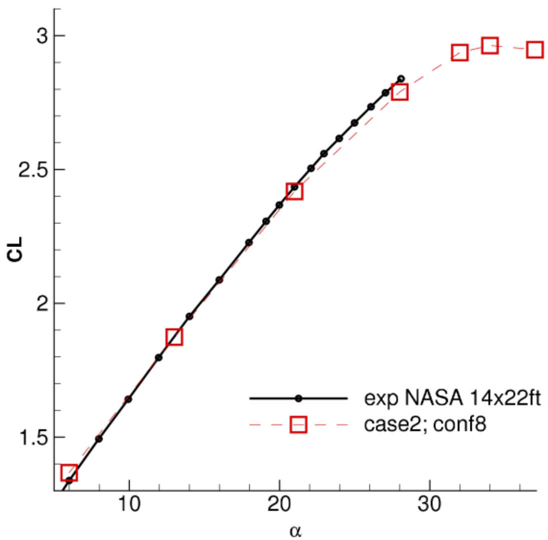


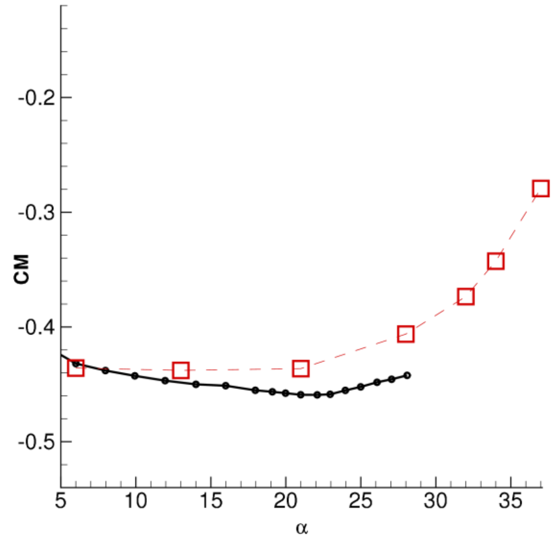
TAU-Computations - Case 2

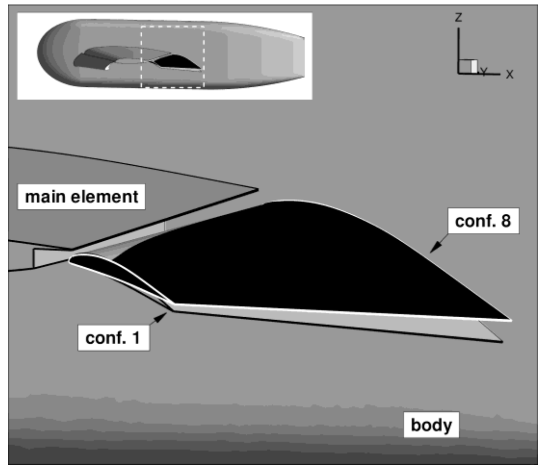
- **TAU-SAO, SOLAR grid; polar computations for config. 1 and 8**











CASE 3

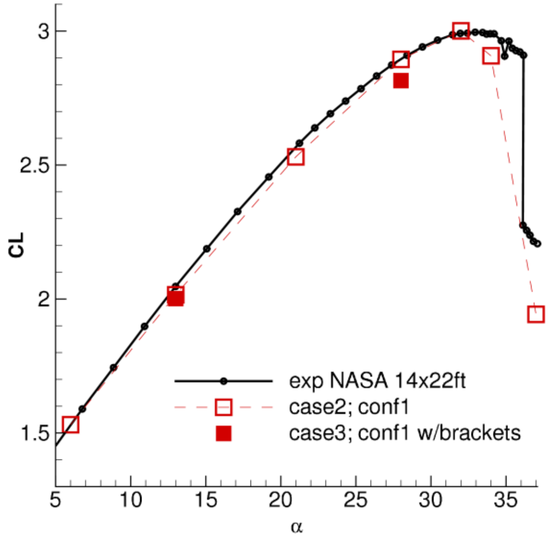
SOLAR/TAU

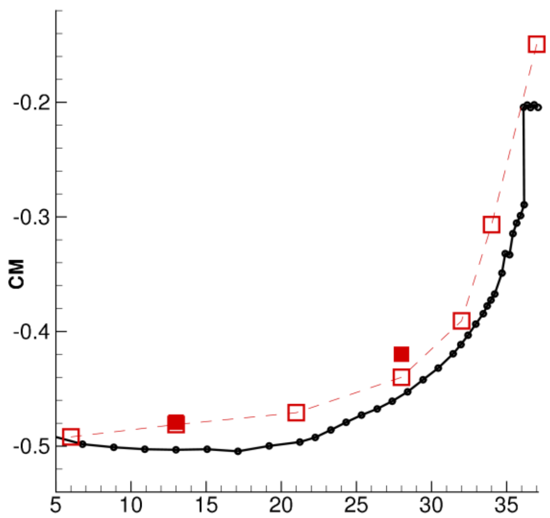
Configuration 1 with brackets - Medium Grid

TAU-Computations - Case 3

- **TAU-SAO, SOLAR grid; bracket influence**

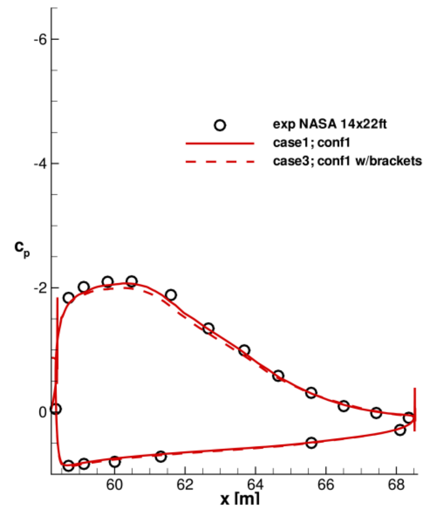
flap pressure distribution at

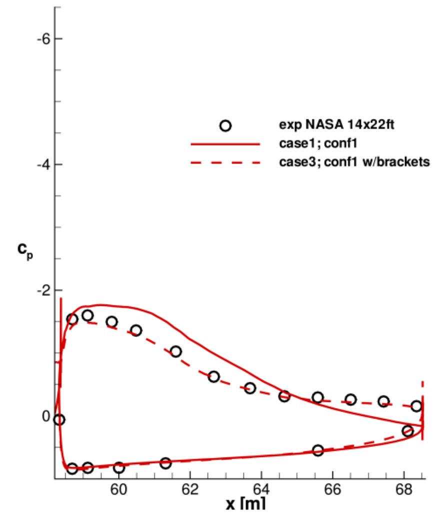




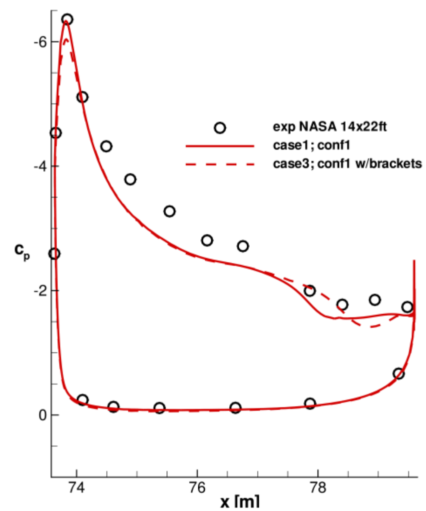
α = 13°

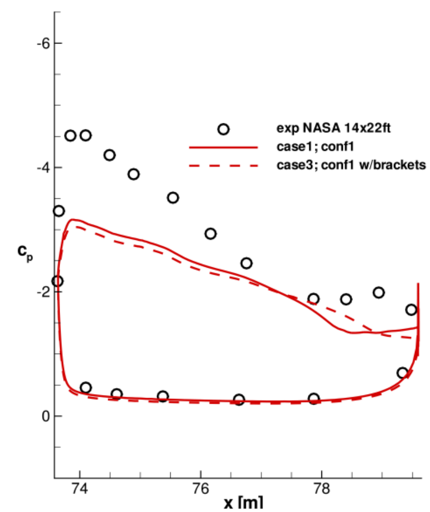
α = 28°





η = 0.50





and 0.98

Conclusion & Outlook

- Validation and verification of the DLR TAU-code extended for NASA Trap Wing test case for two flap settings and configuration with support brackets
  - in general good agreement obtained w.r.t. forces, moments, cp-distributions
  - effect of flap setting variation and brackets consistently captured
  - wingtip area most critical part of the configuration with significant deviations between CFD and w/t test results
- Benchmark of hybrid unstructured grid generation package SOLAR
  - generation of grid family (widely) considering gridding guidelines achieved
  - grid convergence not reached at higher AoA's
- Benchmark of hybrid unstructured grid generation packages CENTAUR/TAU
  - consistent grid family could not be successfully completed on fine grid level
  - high input effort to resolve bte.'s due to patchwise grid generation approach
  - grid resolution variation carried out on three grid levels with mderate impact
- Moderate influence of grid resolution on forces, moments and cp-distributions; most pronounced at wing tip area and in extend of side-of-body separation

Conclusion & Outlook

- Turbulence model variation carried out based on 1-, 2-equation eddy viscosity models and a differential RSM model on CENTAUR medium level grid
  - in general moderate influence on pressure distribution except at wingtip area
  - SST model predicts strongest side-of-body separation
  - RSM model shows strongest trend for tip separation at high AoA'S
  - based on current evidence higher fidelity approaches don't offer superior agreement to experimental evidence, but
  - slat vortex interaction with rear part of the wing and flap currently not properly resolved – seen as a requirement for reliable assessment of model performance (in outer wing area)
- Sensitivity of convergence start-up procedure requires best practice guidelines and investigation of possible means to alleviate it
- Outlook for DLR activities:
  - detailed study of slat edge vortex and interaction with downstream elements
  - extend validation on Trap wing for field data and transition effects

Thank You