DLR Contribution to the 2nd High Lift Prediction Workshop

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CFD High Lift Prediction Workshop

Outline

- DLR Contribution and Objectives for HiLiftPW-2 Computations
- SOLAR grids and TAU-solver settings
- Baseline validation based on (Case 3a)
- Reynolds Number Effects (Case 3a - Case 3b)
- Impact of Wind tunnel Model Details (Case 3b - Case 2b - Case1)
- Impact of Pressure Tube Bundles, Validation (Case2a - Case3a)
- Turbulence Model Variation SA-RC (Case3a)
- Grid Refinement Study
- Conclusion and Outlook

DLR Contribution and Objectives for HiLiftPW-2 Computations

- **Grid Generation: Supply of hybrid unstructured grids for all Configurations based on SOLAR grid generation system**
  - **Assessment of present SOLAR features taking into account grid family requirement and gridding guidelines (a.f.a.p.)**
  - **Grid refinement study for moderately complex 3D configuration variations**
  - **Reynolds number adapted gridding approach**

- **Numerical analysis based on TAU computations**
  - **Improved understanding of geometry simplifications at low and high Re-No. conditions and scaling effects**
  - **Assessment of TAU capability to simulate OoM Reynolds-number effects**
  - **Improved understanding of simulation quality and shortcomings**
  - **Turbulence model performance assessment**
  - **Identification of grid resolution and topology impact**

Grid Generation - SOLAR

- Hybrid unstructured grids, hex-based near surfaces, individual grids for all configurations and Reynolds number conditions

- Grid generation and adaptation approach
  - y^+ -manual adaptation, const. first cell height
  - grid family approach according to DPW IV, HiLiftPW-1 (SOLAR)
  - special treatment of sources

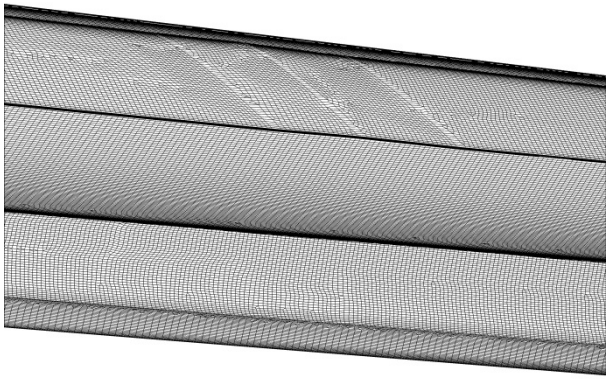
- Grids provided for low Re conditions for complexity stages II, IV and V
  - total grid point numbers: 29.7 mil. / 37.3 mil / 37.7 mil.

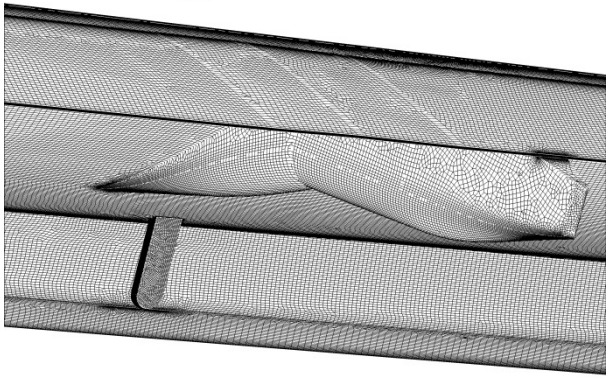
- Grids provided for high Re conditions for complexity stages II, IV and V
  - total grid point numbers: 25.6 mil. / 32.4 mil / 34.2 mil.

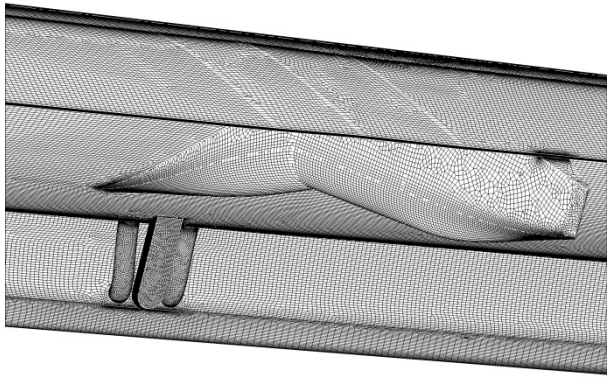
- Grid family for Stage II, (high Re) with 3 levels
  - total grid point numbers: 9.2 mil. / 25.6 mil / 73.4 mil.

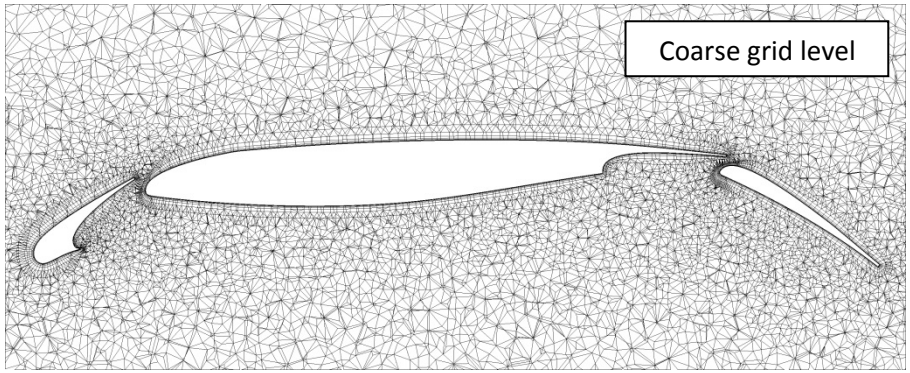
Grid Generation - SOLAR

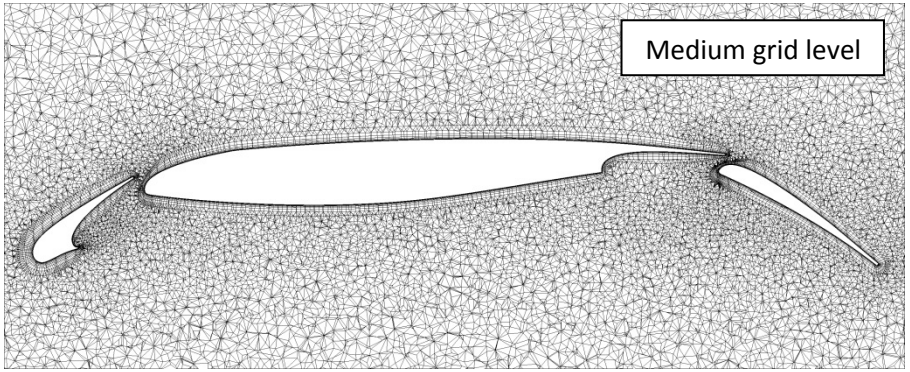
- **Characteristics of the DLR-SOLAR grids**

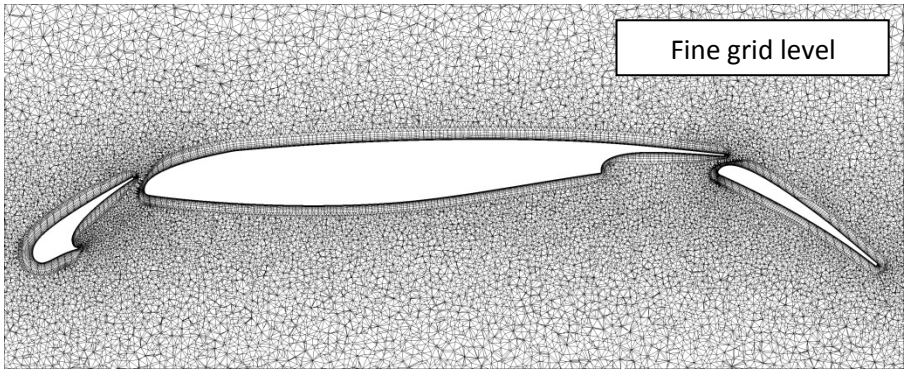












TAU Computations - Parameter-Settings

- **Code Version:** DLR TAU code 2012.1.0

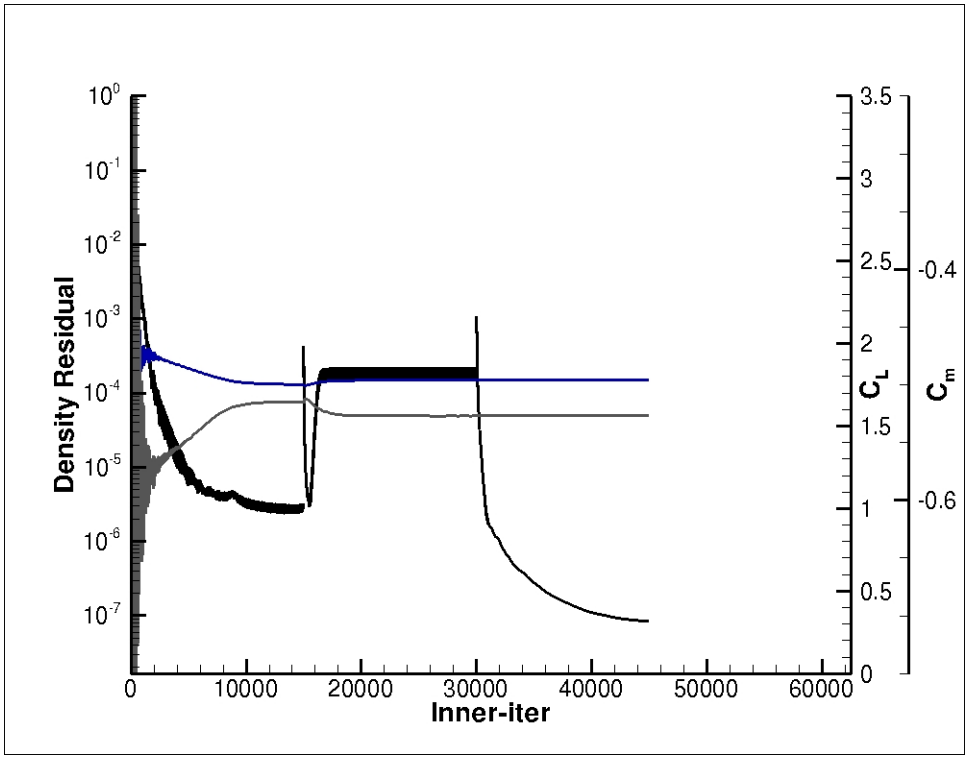
- **Spatial Discretization:**
  - **Main equations:** Jameson central, 2nd order;
    Blend scalar (20%) – matrix (80%) dissipation
  - **Turbulent equations:** AUSMDV upwind, 2nd order
  - **Full NS Discretization**

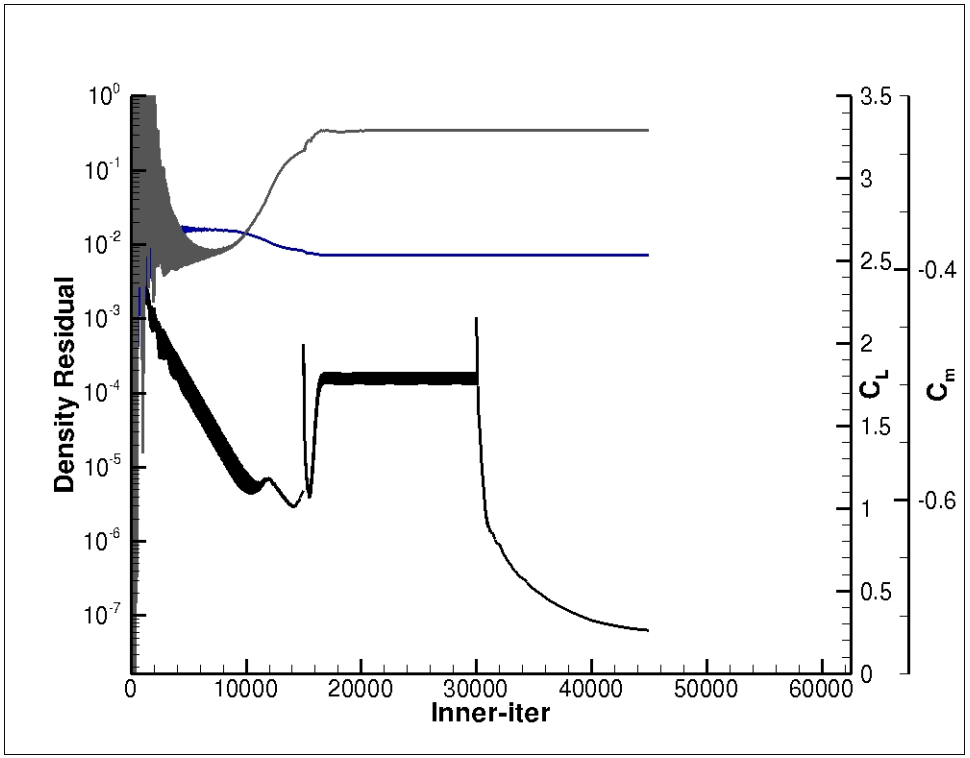
- **Turbulence Models:**
  - Spalart-Allmaras, original 1992 formul. (SAO)
  - Spalart-Allmaras with rotational correction (SARC)

- **Temp. Integration:**
  - LU-SGS Backward Euler
  - Multigrid, 3V cycle, main and turb. equations
  - final set of iterations approaching global time step

TAU Computations - Convergence behavior

- **Convergence of main flow residual, density, lift, and moment for α = 7° and α = 18.5°**





Case 3a

TAU-SAO / SOLAR

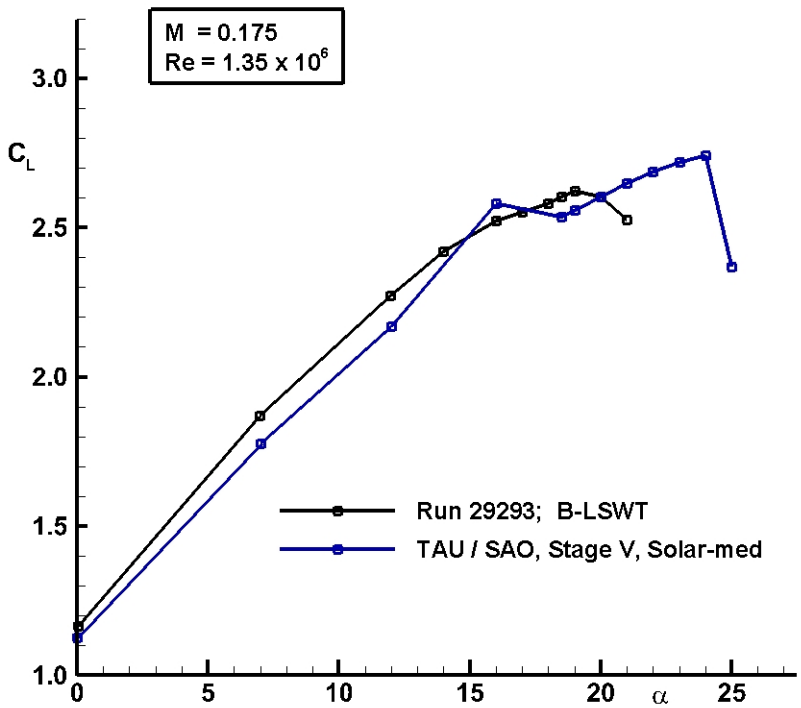
Baseline Validation

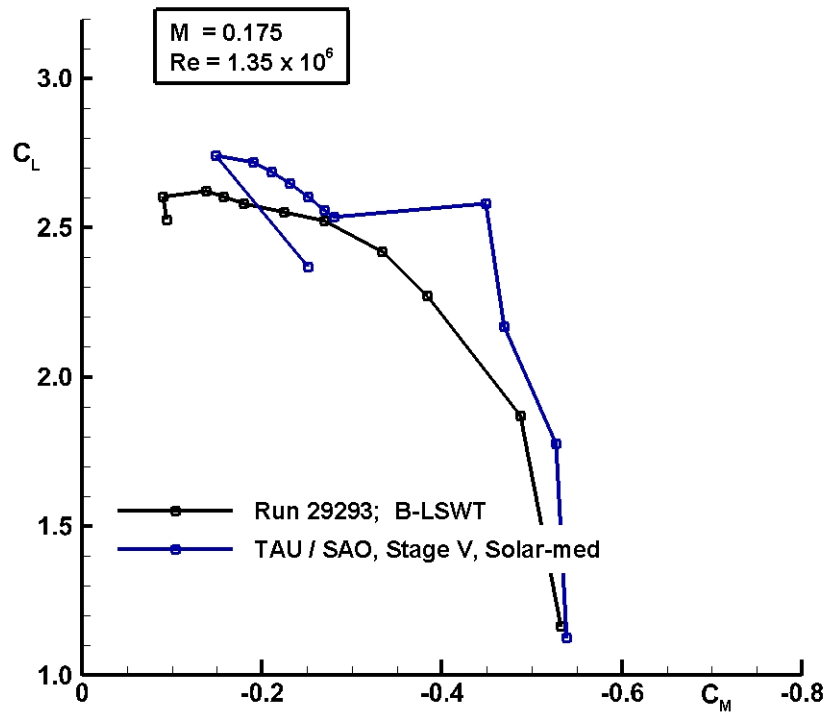
Full Complexity (WB+HLS+PFS+FTF+ST+PTB)

Low Re No.

TAU/SAO, Solar Grid - Case 3a (low Re-No.)

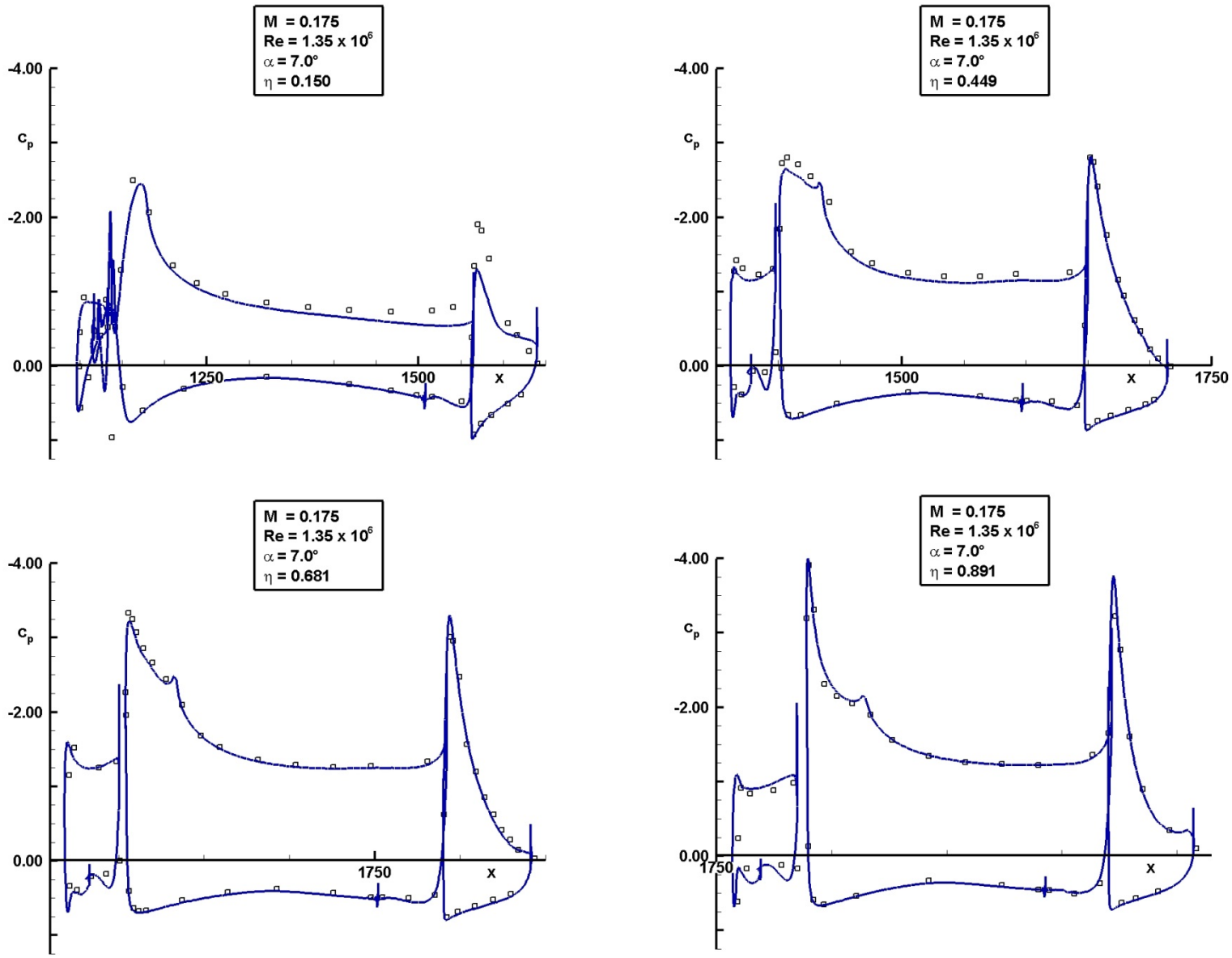
- **Lift curve and pitching moment**





TAU/SAO, Solar Grid - Case 3a (low Re-No.)

CFD High Lift Prediction Workshop

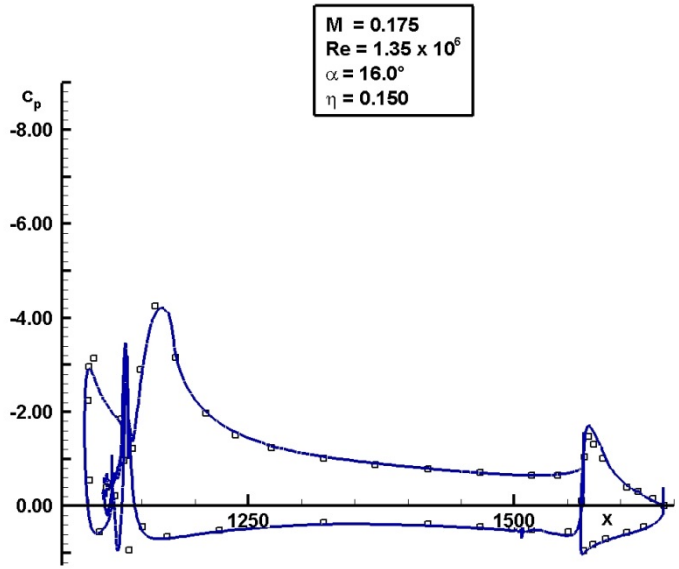


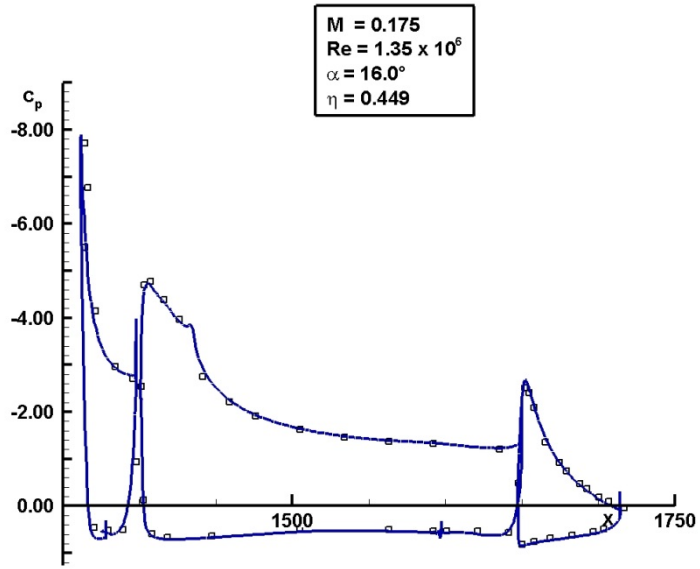
$\alpha = 7°$

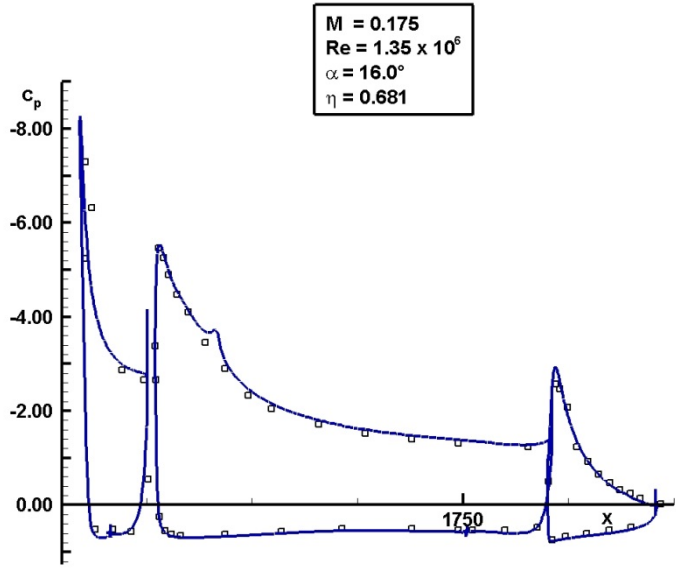
PS1, PS4, PS6, PS10

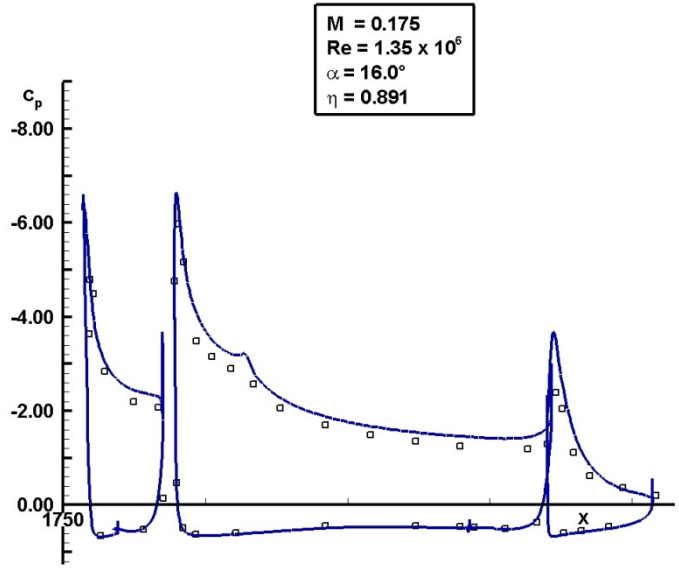
TAU/SAO, Solar Grid - Case 3a (low Re-No.)

CFD High Lift Prediction Workshop







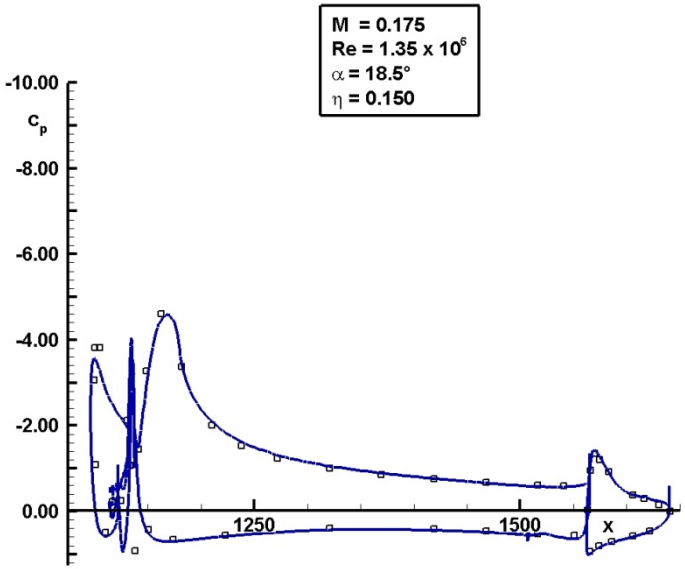


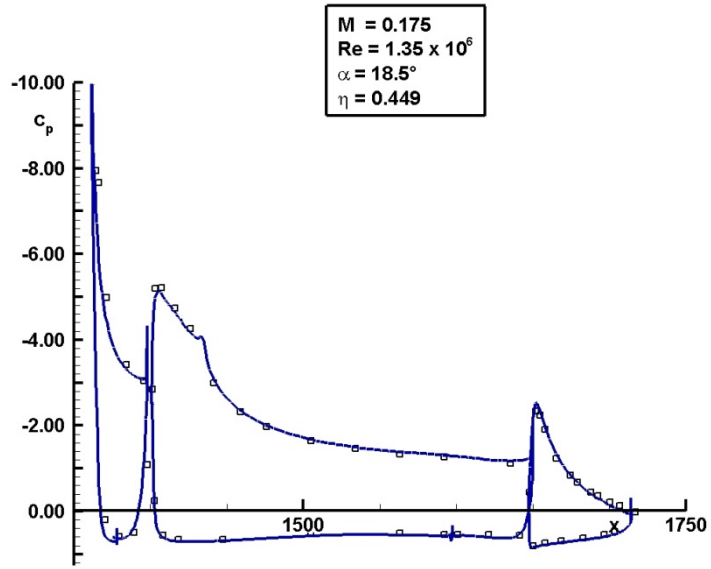
α = 16°

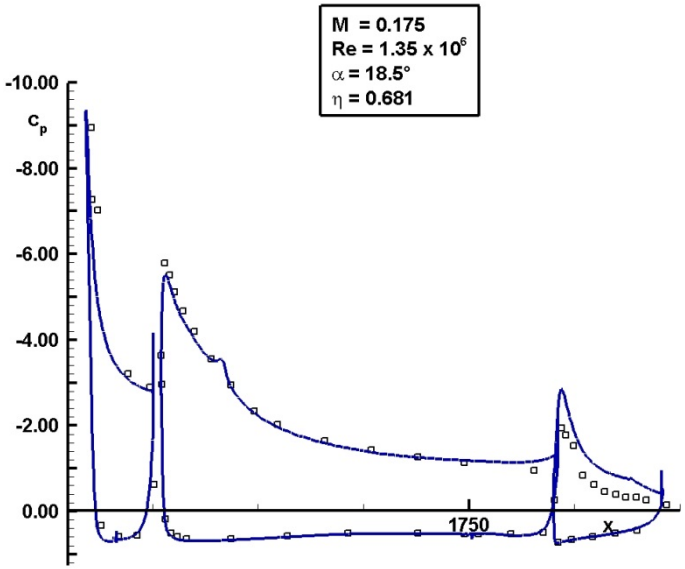
PS1, PS4, PS6, PS10

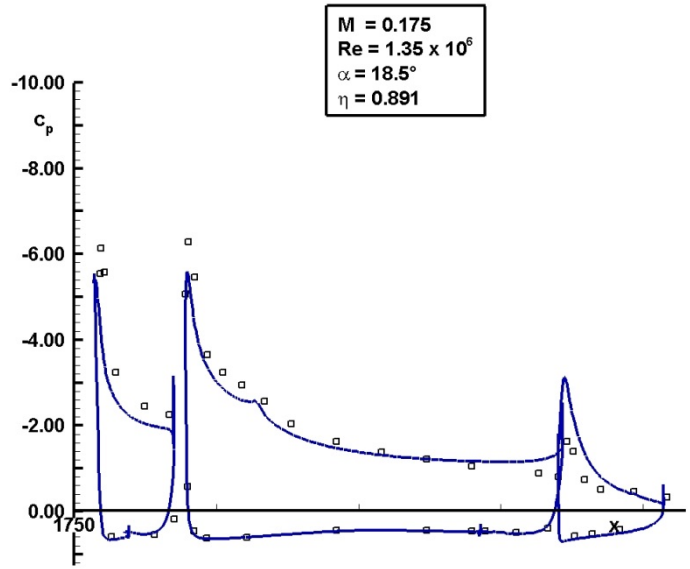
TAU/SAO, Solar Grid - Case 3a (low Re-No.)

CFD High Lift Prediction Workshop







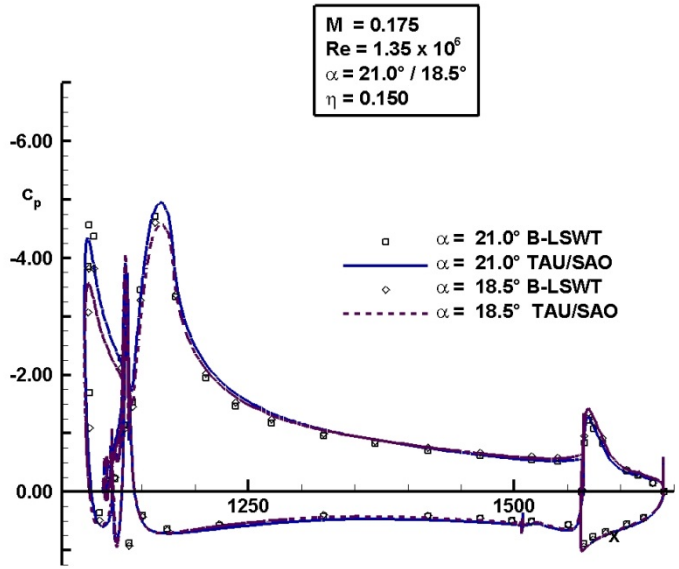


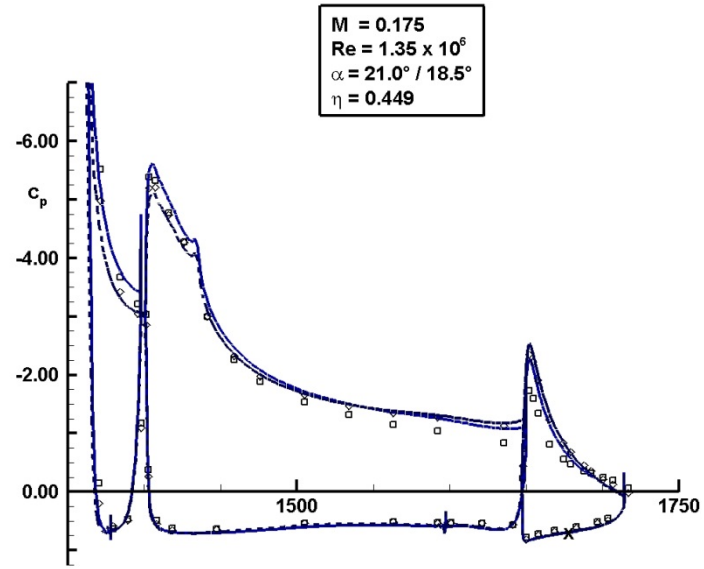
α = 18.5°

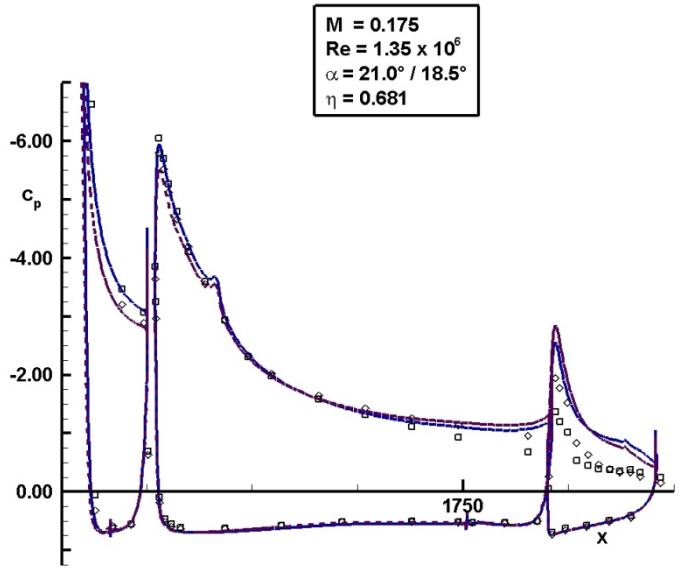
PS1, PS4, PS6, PS10

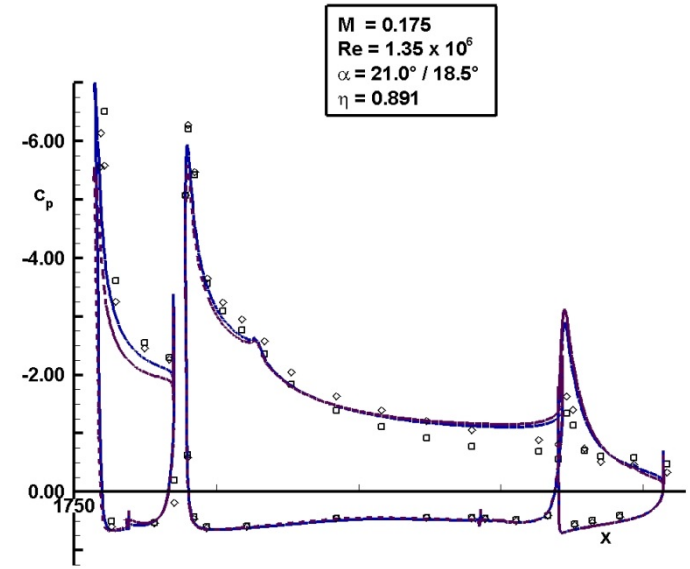
TAU/SAO, Solar Grid - Case 3a (low Re-No.)

CFD High Lift Prediction Workshop







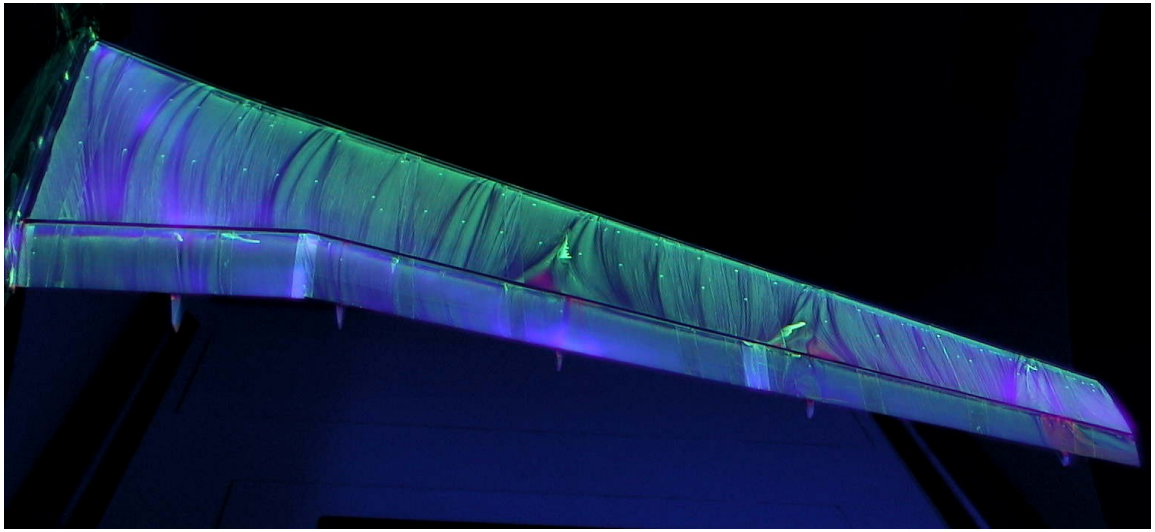


α = 21°

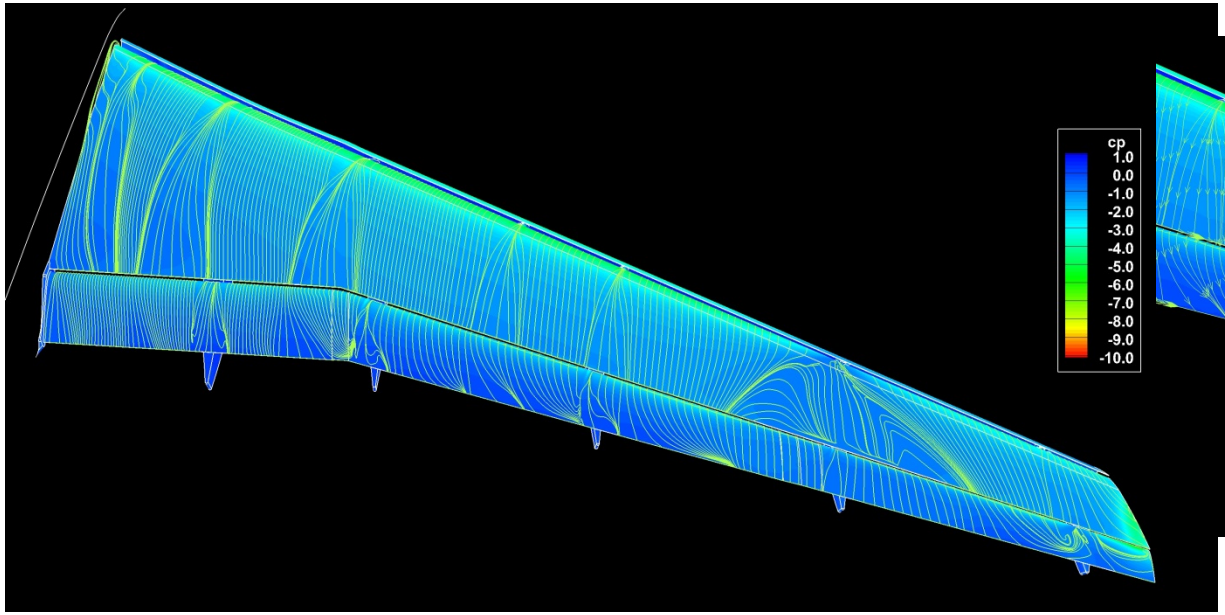
PS1, PS4, PS6, PS10

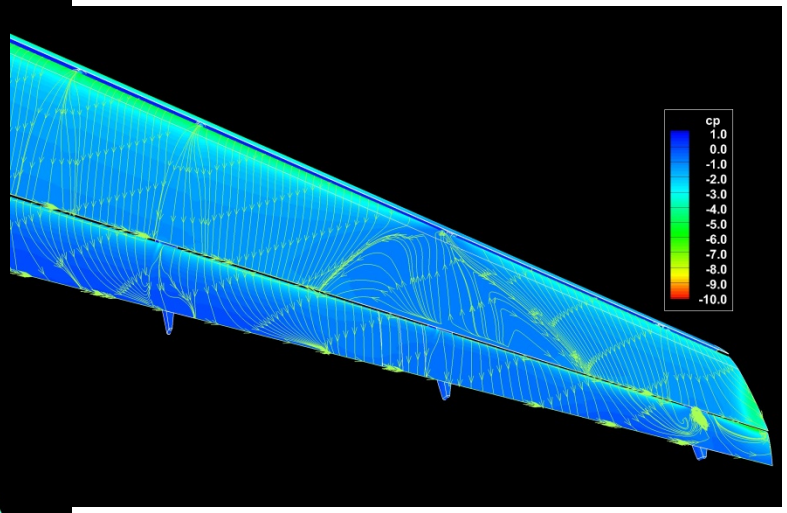
TAU/SAO, Solar Grid - Case 3a (low Re-No.)

CFD High Lift Prediction Workshop



$\alpha = 18.5°$





Case 3b (vs. Case3 a)

TAU-SAO / SOLAR

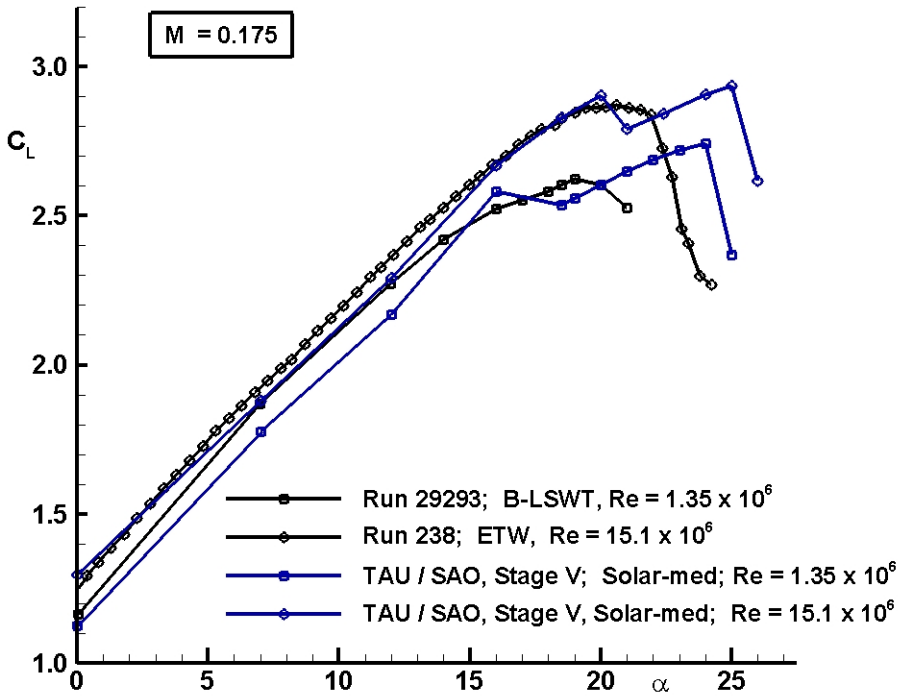
Reynolds Number Effects

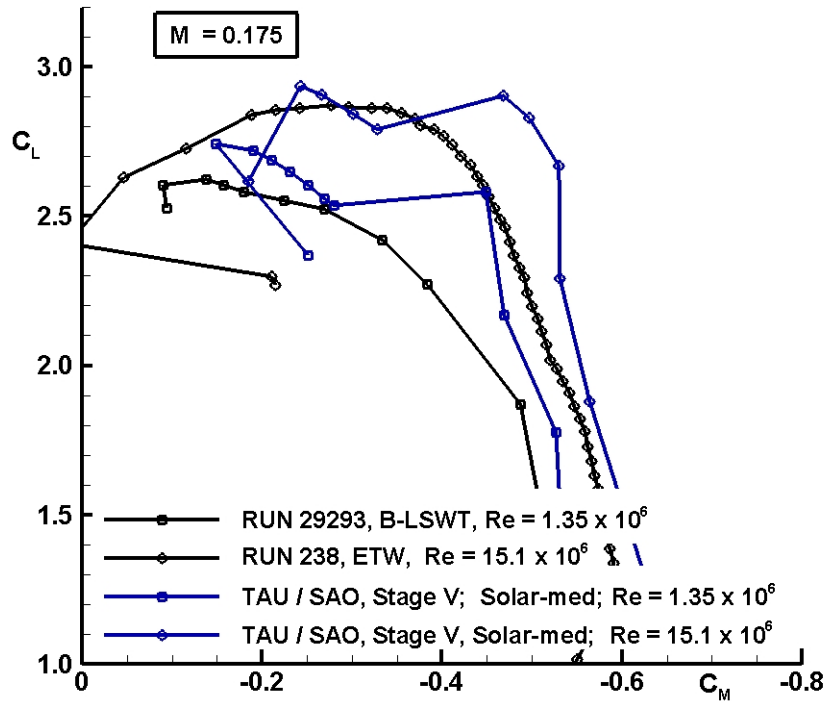
Full Complexity (i.e. WB+HLS+PFS+FTF+ST+PTB)

High Re No.

TAU/SAO-Computations, Solar Grid - Case 3b (high Re-No.)

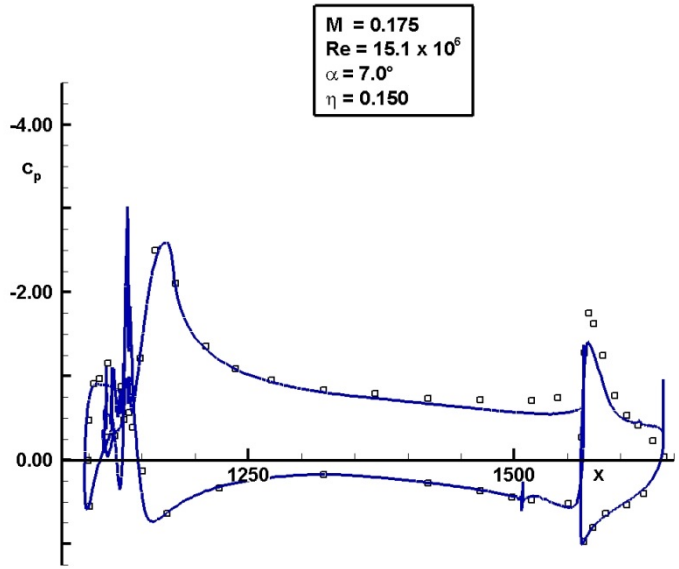
- **Lift curve and pitching moments 3a vs. Case 3b**

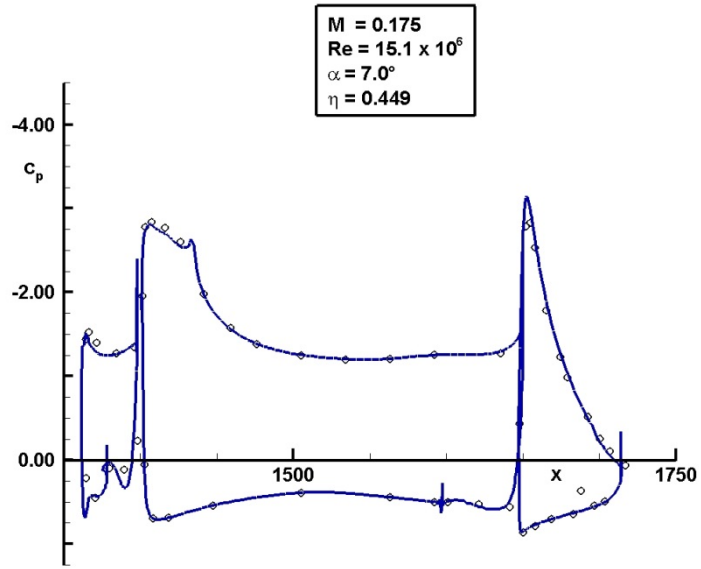


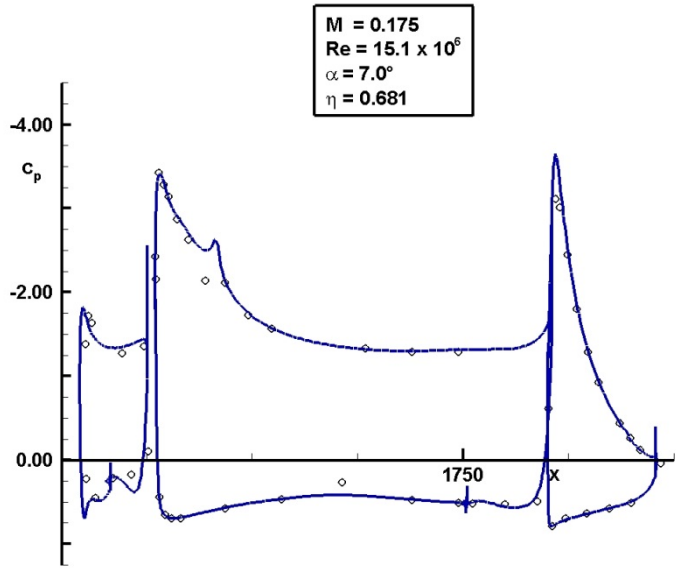


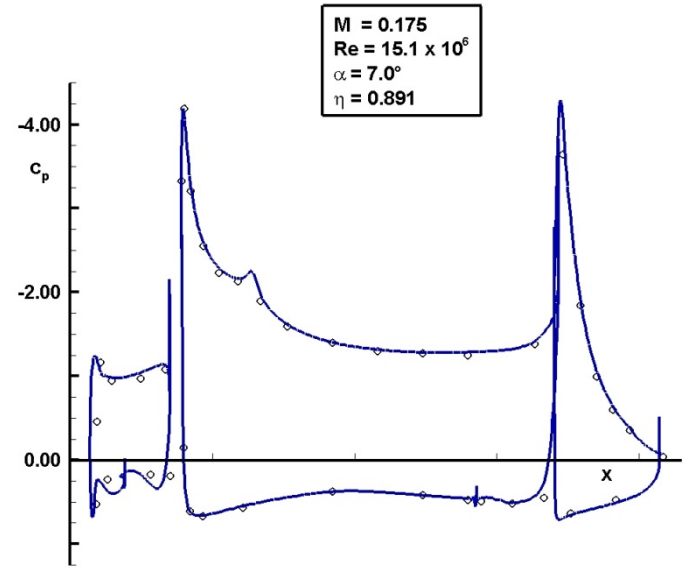
TAU/SAO, Solar Grid - Case 3b (high Re-No.)

CFD High Lift Prediction Workshop







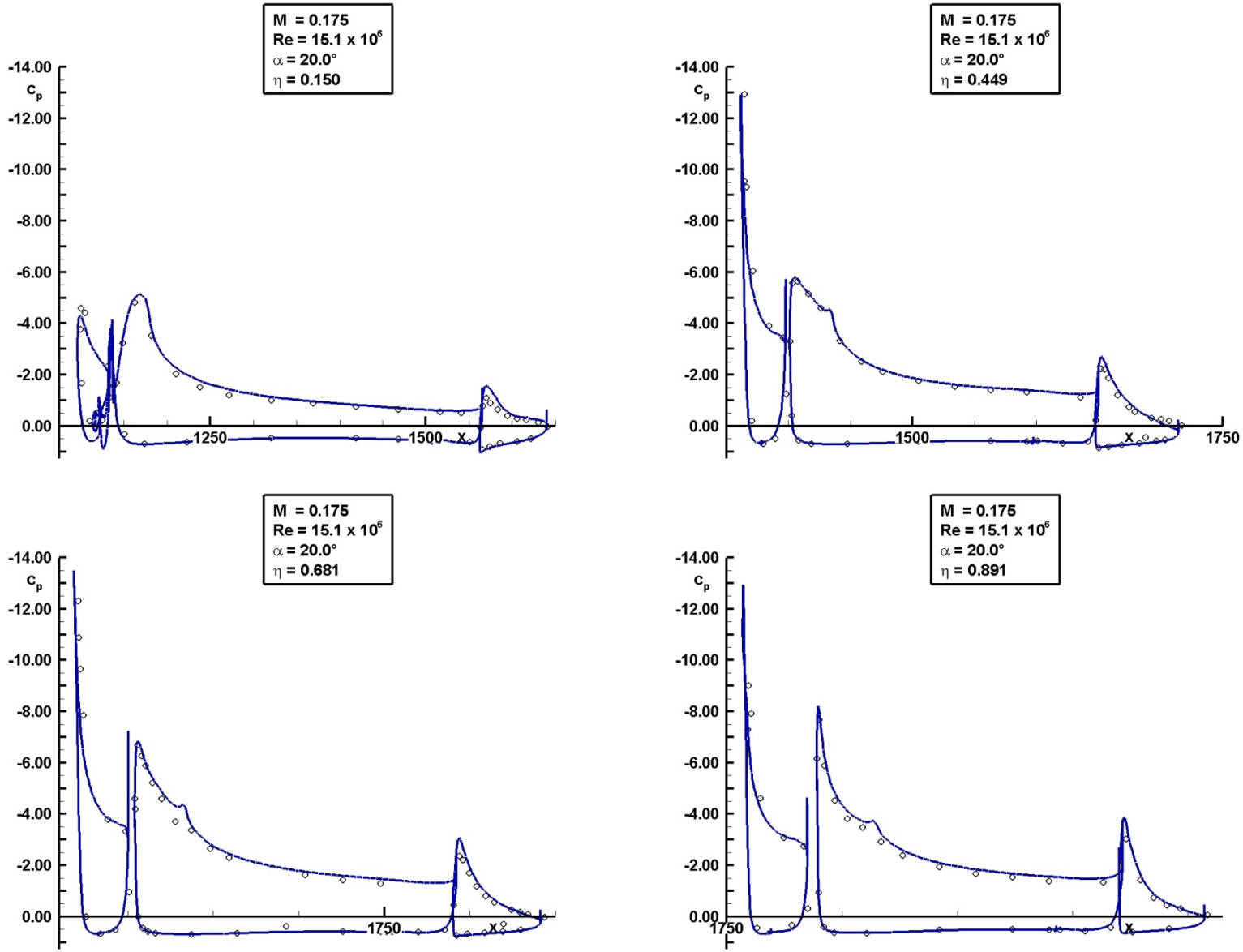


α = 7°

PS1, PS4, PS6, PS10

TAU/SAO, Solar Grid - Case 3b (high Re-No.)

CFD High Lift Prediction Workshop

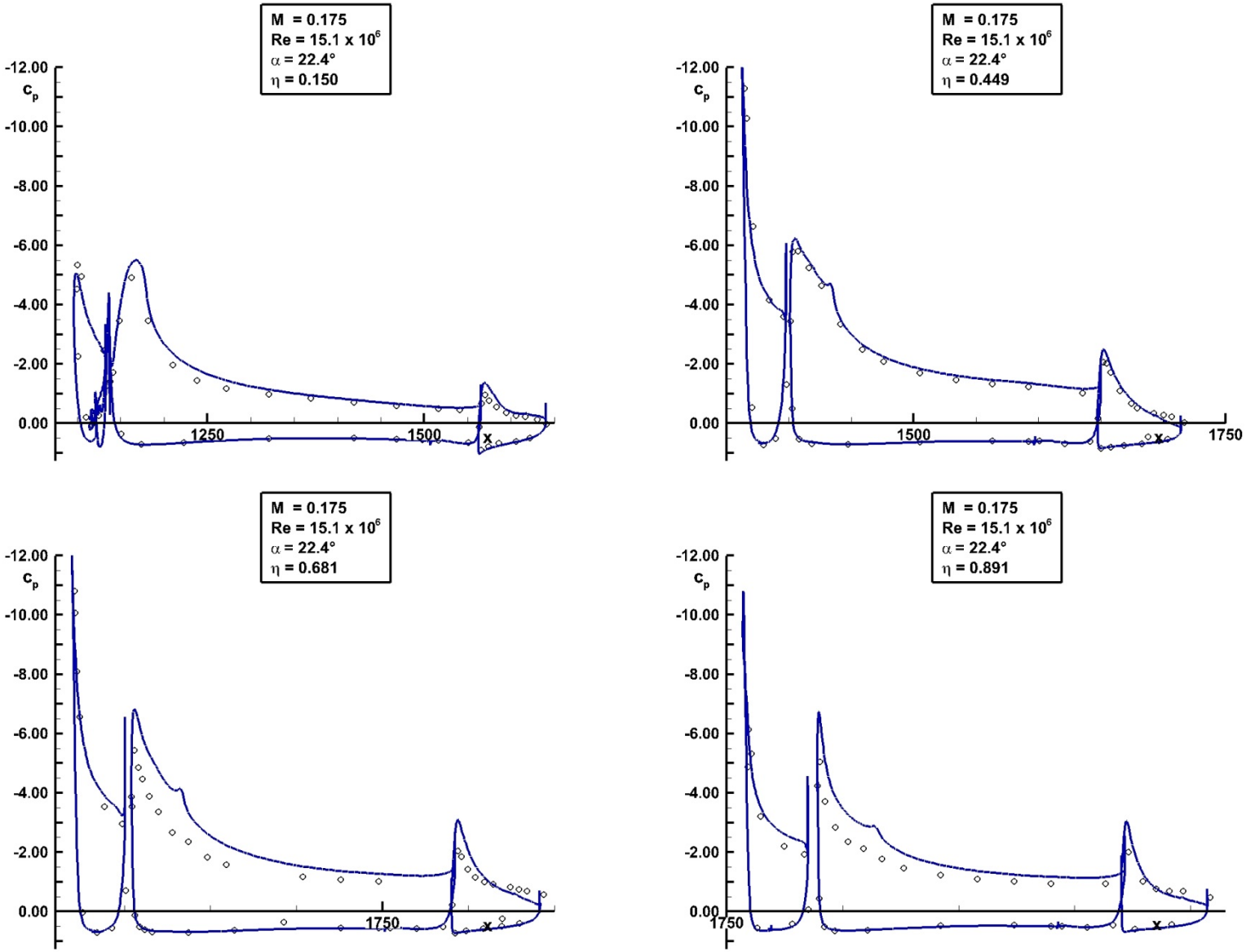


α = 20°

PS1, PS4, PS6, PS10

TAU/SAO, Solar Grid - Case 3b (high Re-No.)

CFD High Lift Prediction Workshop



α = 22.4°

PS1, PS4, PS6, PS10

Case 3b vs. Case 2b vs. Case 1

TAU-SAO / SOLAR

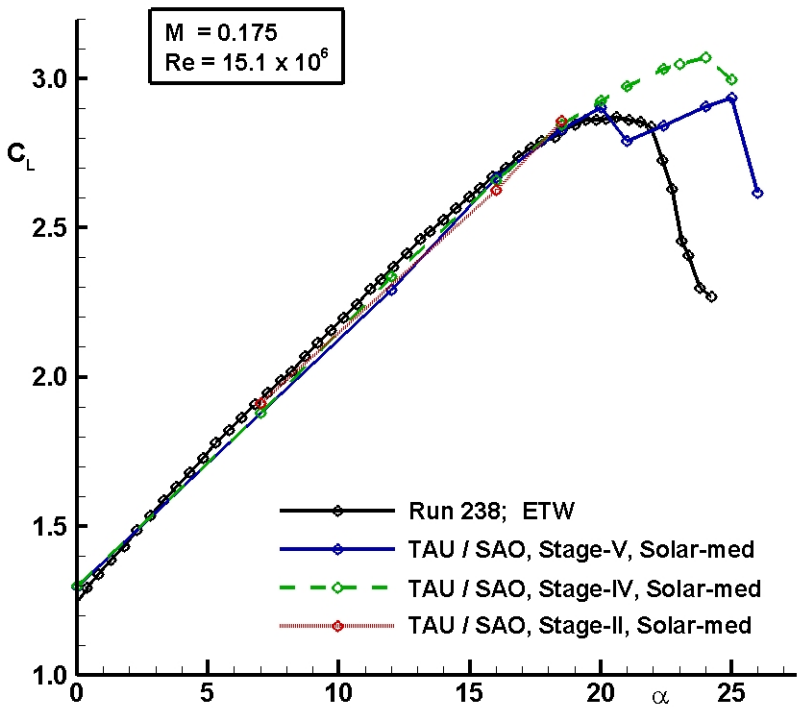
Impact of Wind Tunnel Model Details

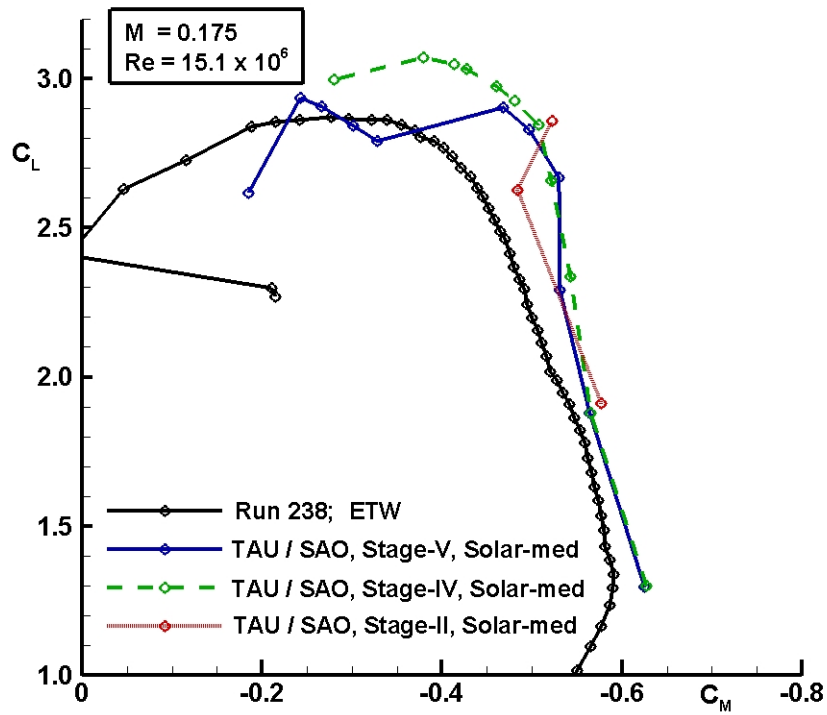
Varying Complexity

High Re No.

TAU/SAO, Solar Grid - Case 1 vs. Case 2b vs. Case 3b (high Re-No.)

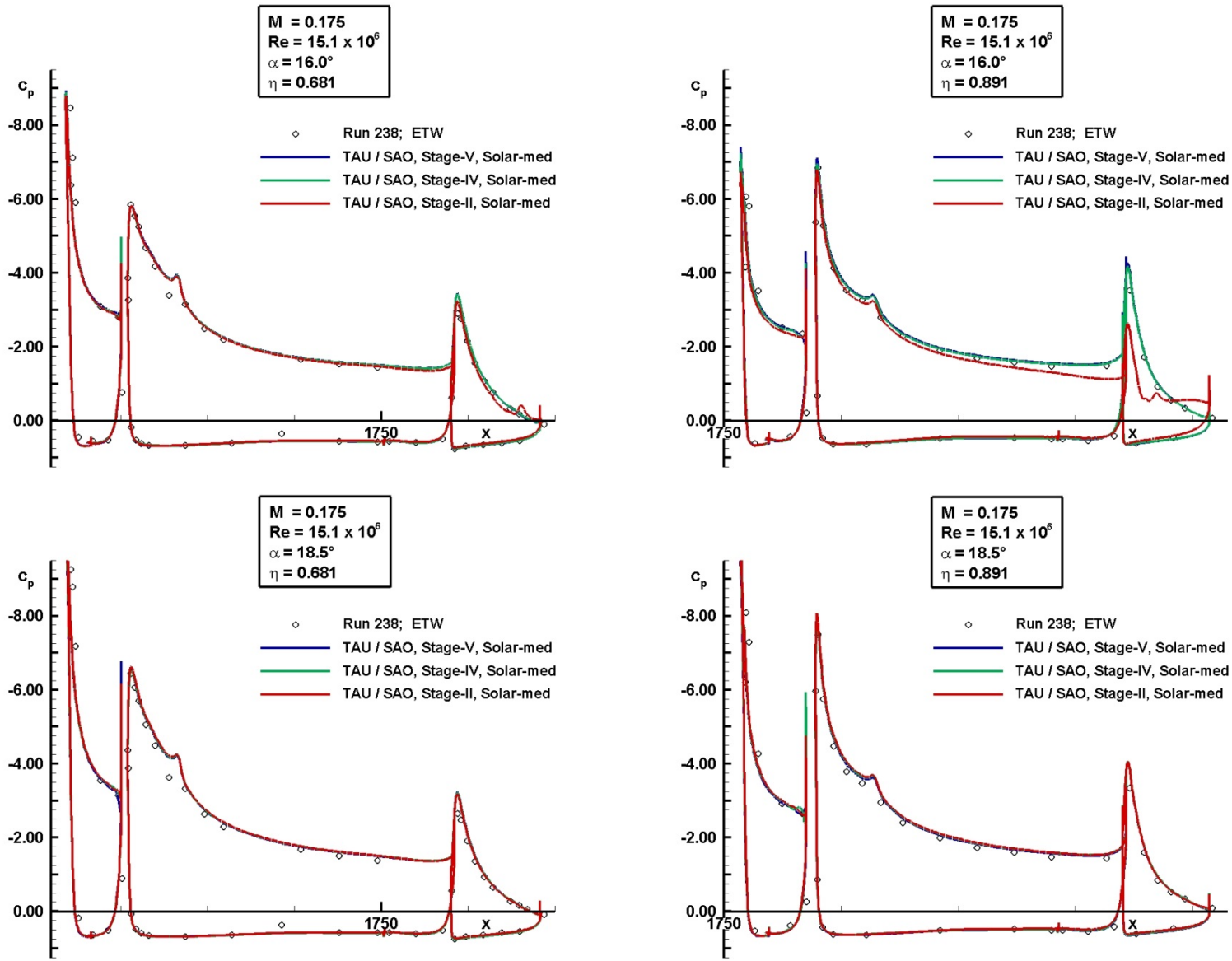
- **Lift curve and pitching moment**





TAU/SAO, Solar Grid - Case 1 vs. Case 2b vs. Case 3b (high Re-No.)

CFD High Lift Prediction Workshop



α = 16.0°

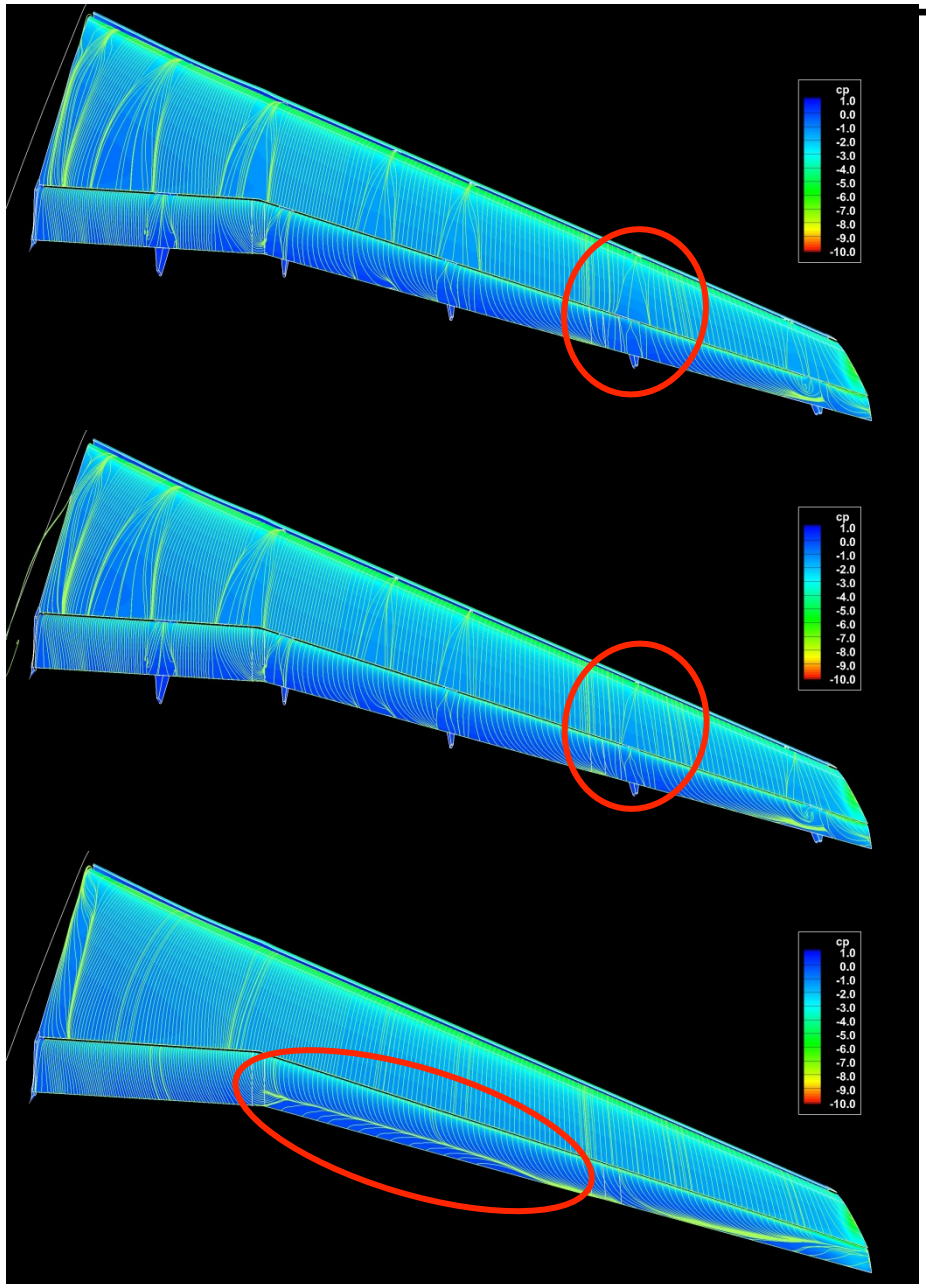
PS6, PS10

α = 18.5°

PS6, PS10

TAU/SAO, Solar Grid - Case 1 vs. Case 2b vs. Case 3b (high Re-No.)

CFD High Lift Prediction Workshop



Case 3b, Configuration Stage V

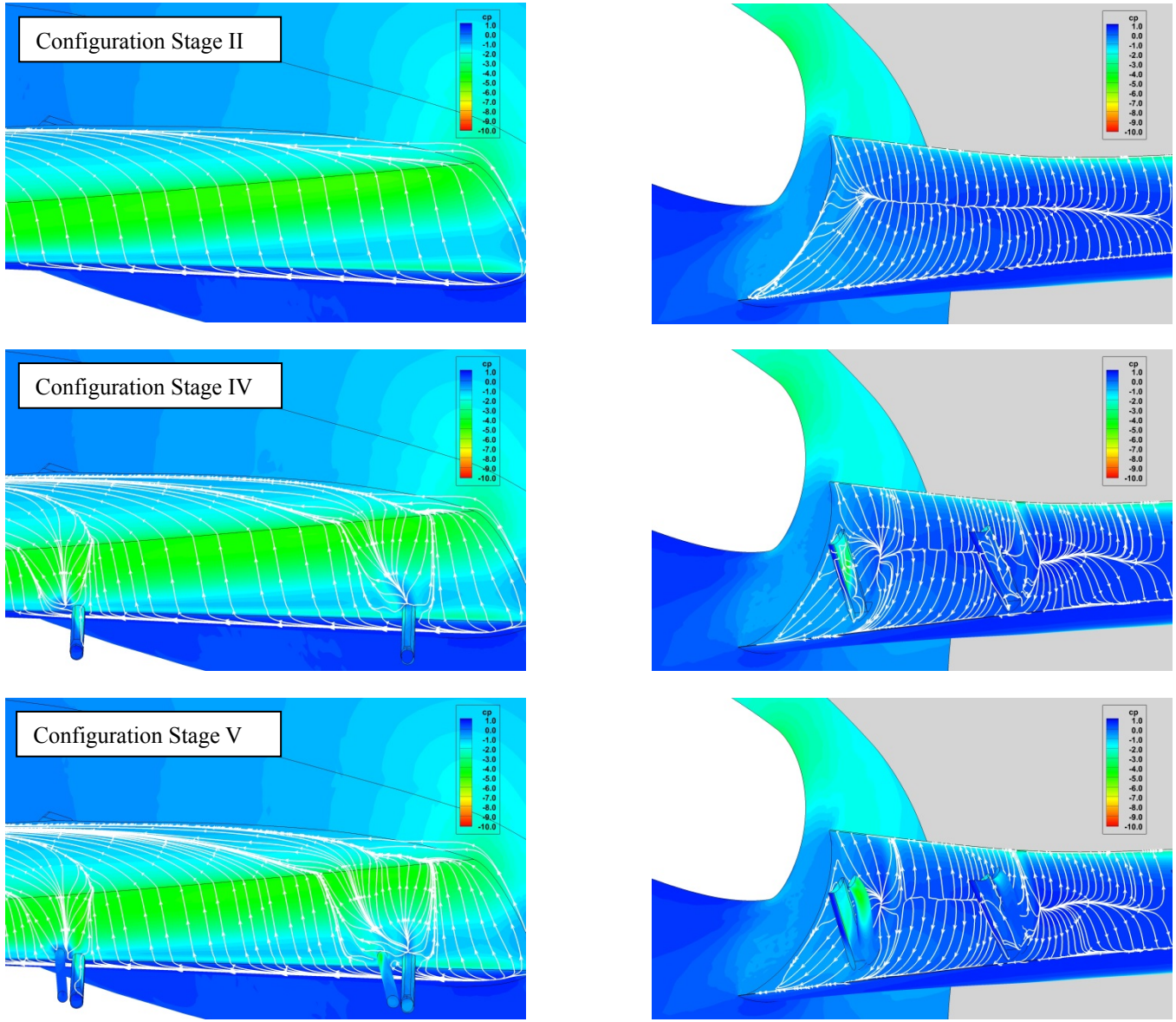
$\alpha = 18.5°$

Case 2b, Configuration Stage IV

Case 1, Configuration Stage II

TAU/SAO, Solar Grid - Case 1 vs. Case 2b vs. Case 3b (high Re-No.)

CFD High Lift Prediction Workshop



α = 18.5°

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Case 3a vs. Case 2a

TAU-SAO / SOLAR

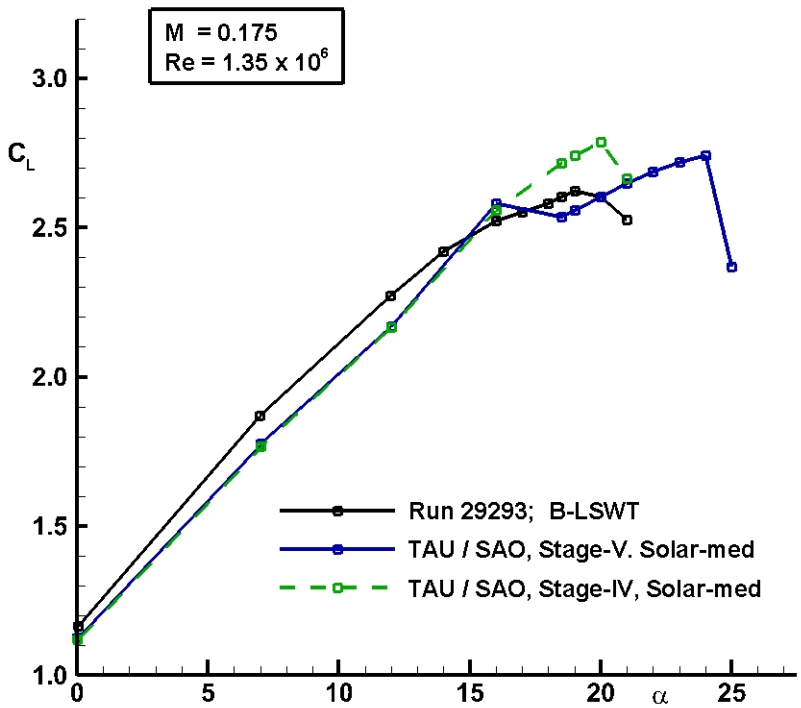
Impact of Pressure Tube Bundles, Validation

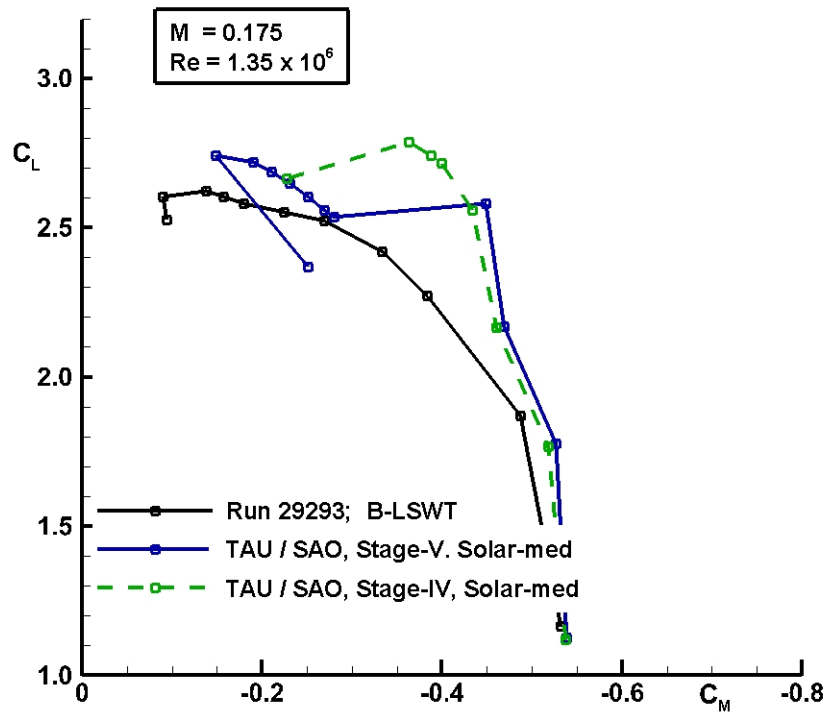
Varying Complexity (+/- PTB)

Low Re No.

TAU/SAO, Solar Grid - Case 3a vs. Case 2a (low Re-No.)

- **Lift curve and pitching moment**

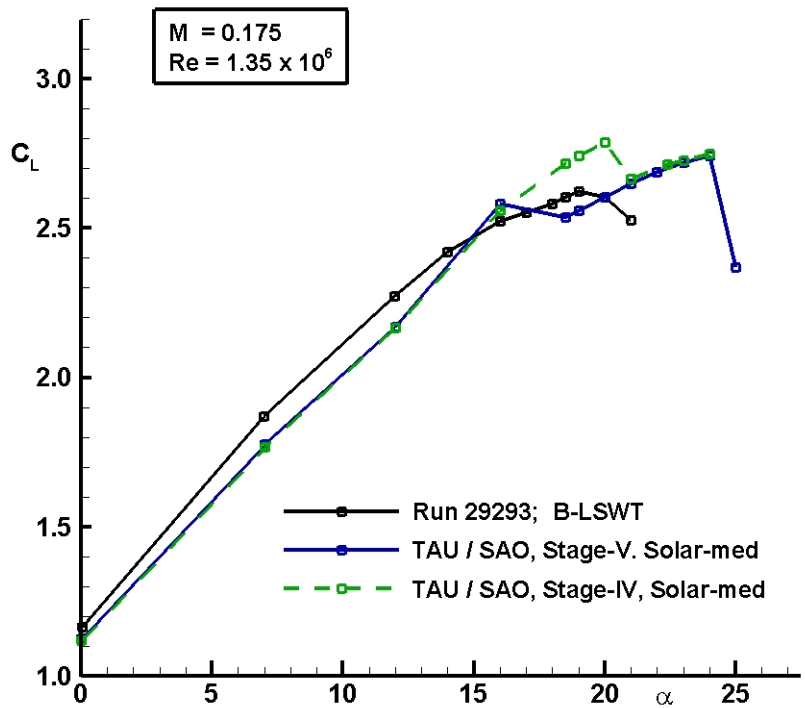




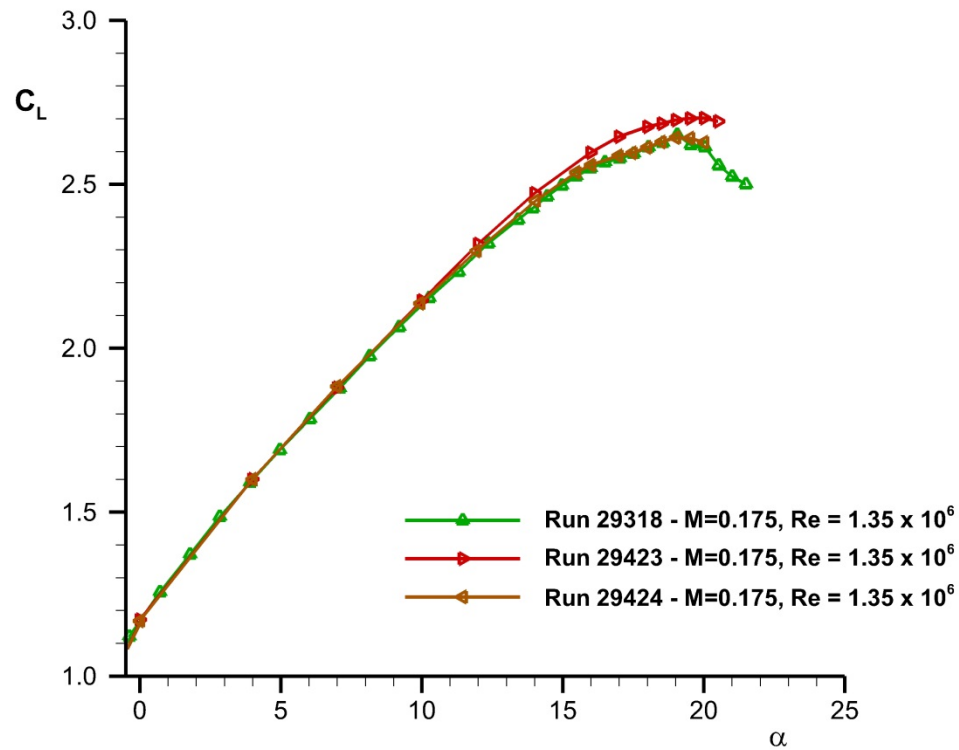
TAU/SAO, Solar Grid - Case 3a vs. Case 2a (low Re-No.)

- **Lift curves**

Computations TAU-SAO



B-LSTW W/T Experiment



Case 3a

TAU-SAO / SOLAR

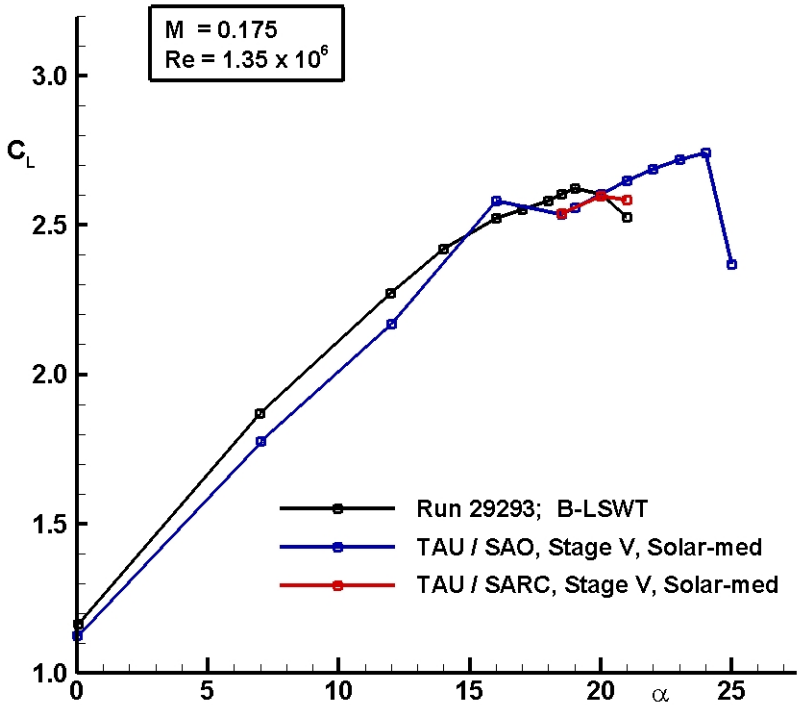
Turbulence Model Variation SA-RC (in progress)

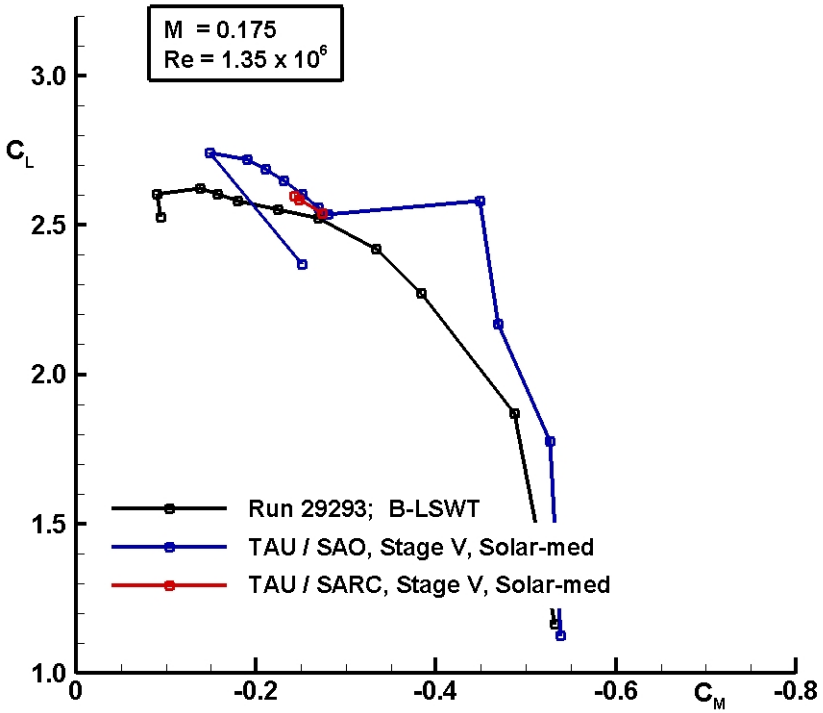
Full Complexity (WB+HLS+PFS+TF+ST+PTB)

Low Re No.

TAU/SAO-SARC, Solar Grid - Case 3a (low Re-No.)

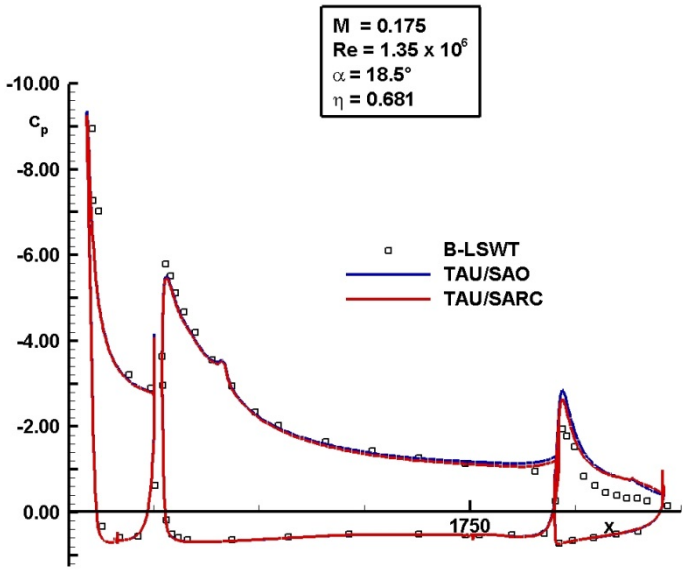
- **Lift curve and pitching moment**

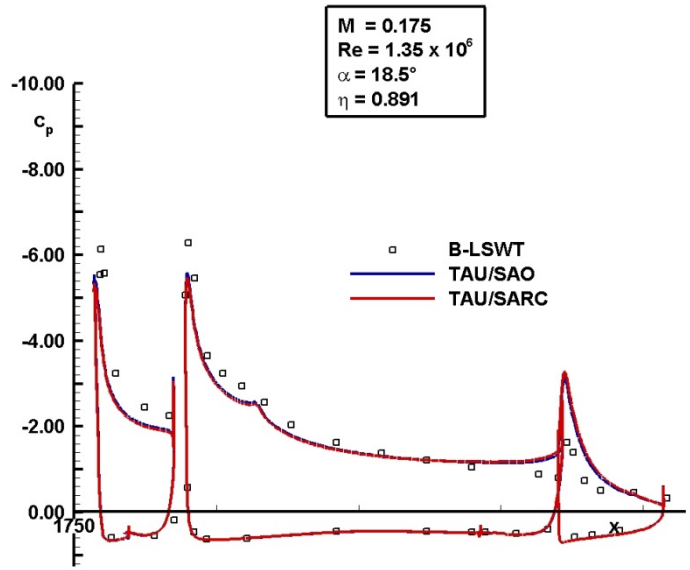




TAU/SAO-SARC, Solar Grid - Case 3a (low Re-No.)

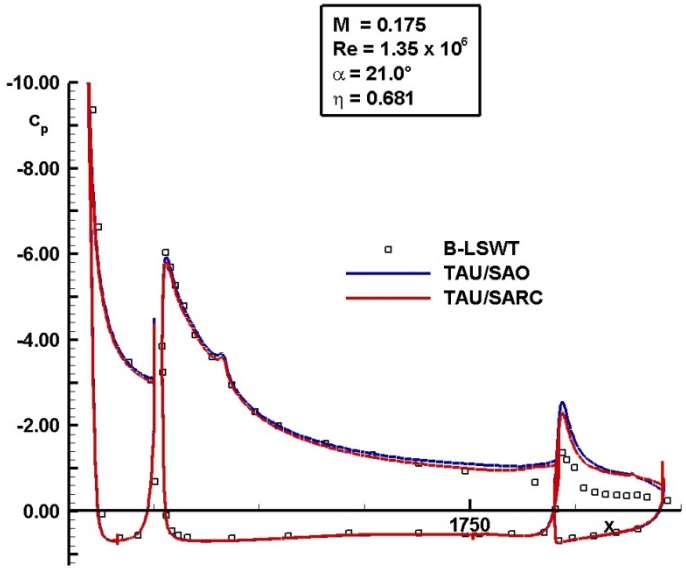
CFD High Lift Prediction Workshop

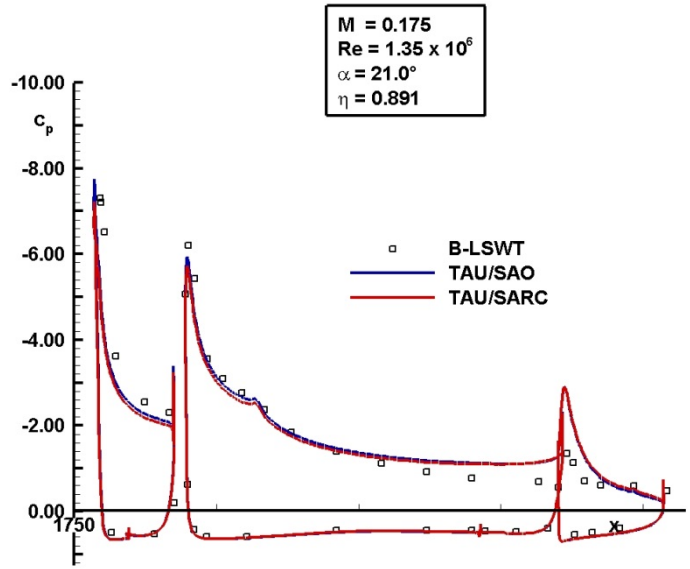




α = 18.5°

PS6, PS10





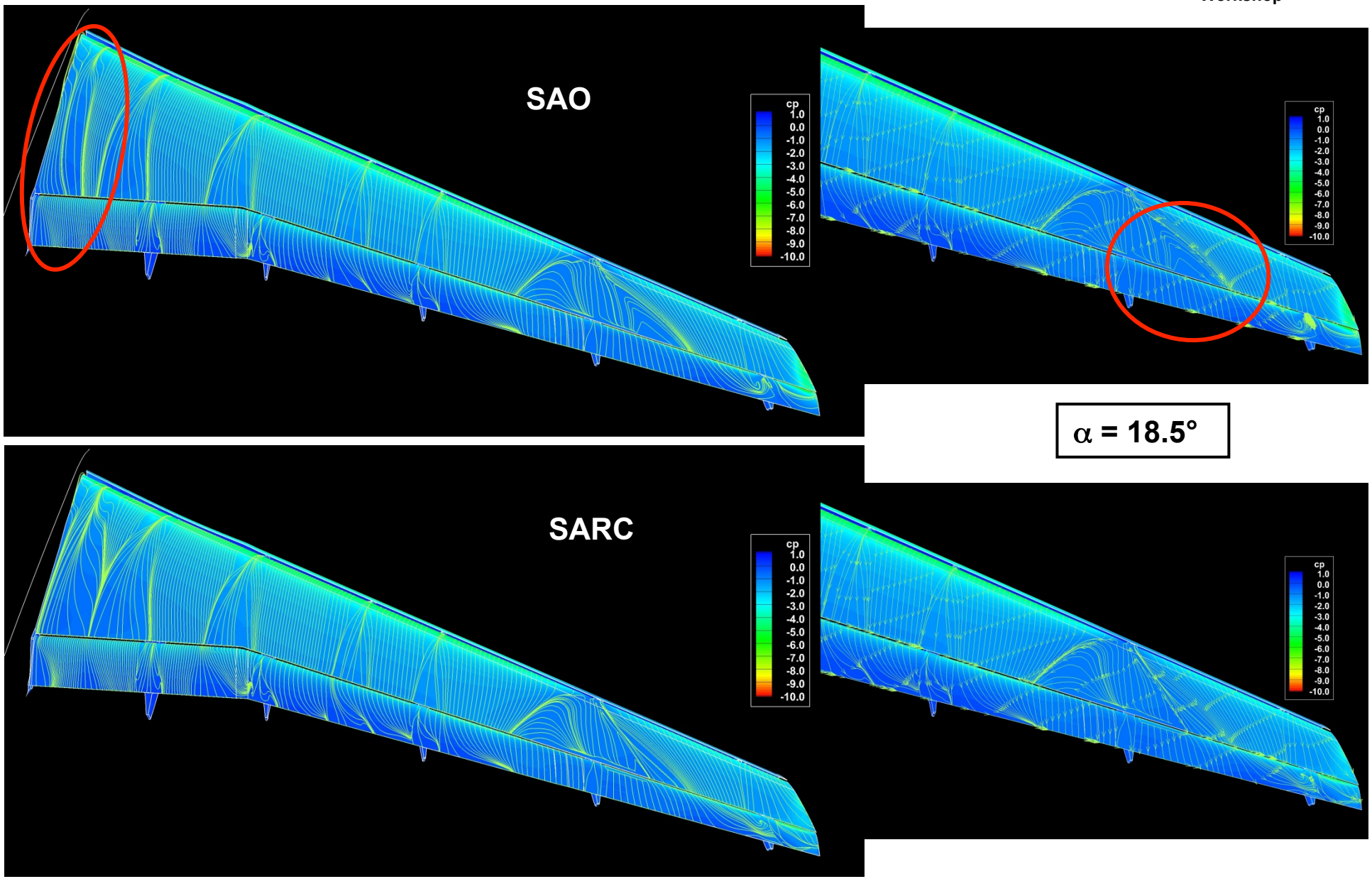
α = 21.0°

PS6, PS10

TAU/SAO-SARC Solar Grid - Case 3a (low Re-No.)

DLR

CFD High Lift Prediction Workshop



Case 1

TAU-SAO / SOLAR

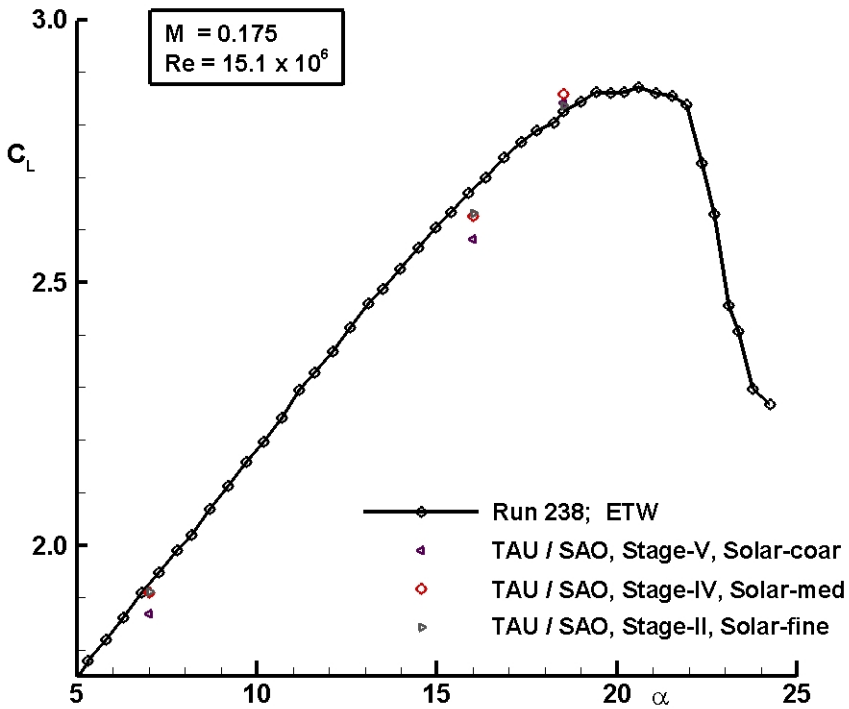
Grid Refinement Study

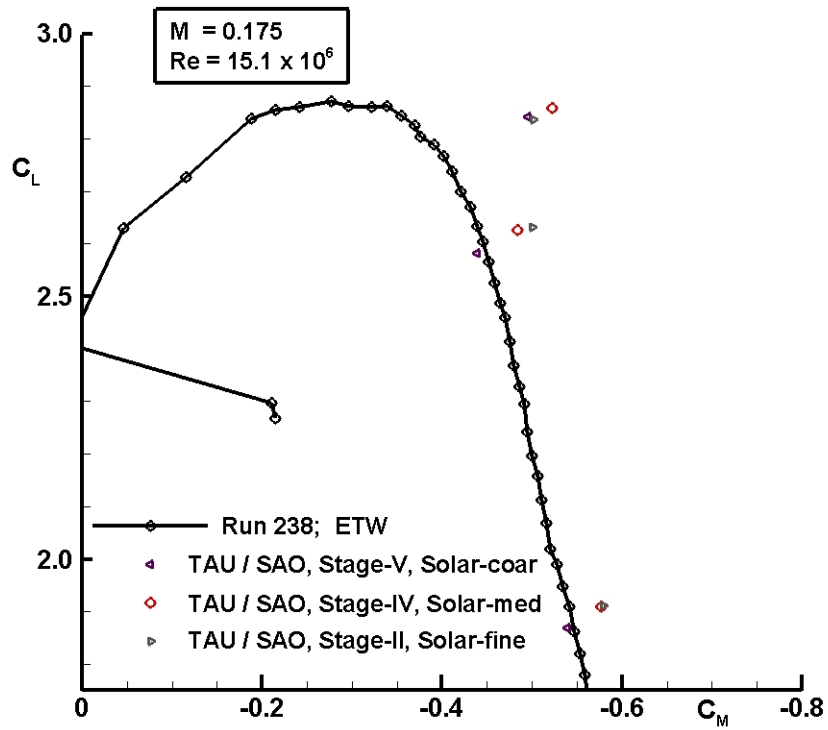
Simplified Configuration (WB+HLS+PFS)

High Re No.

TAU/SAO, Solar Grid - Case 1 (high Re-No.)

- **Lift curve and pitching moment**



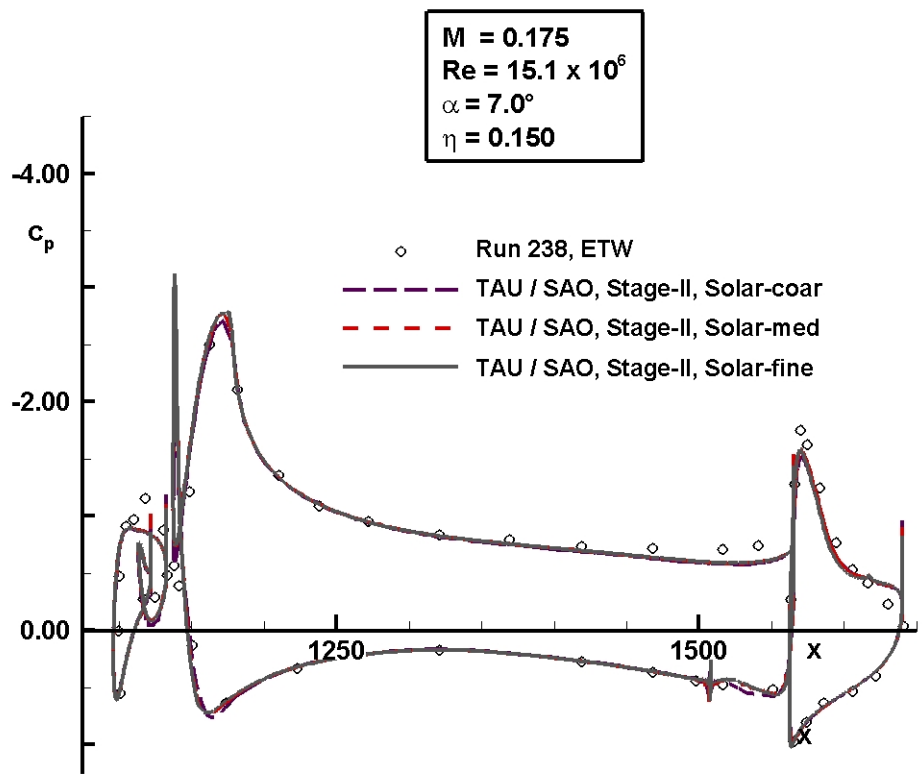


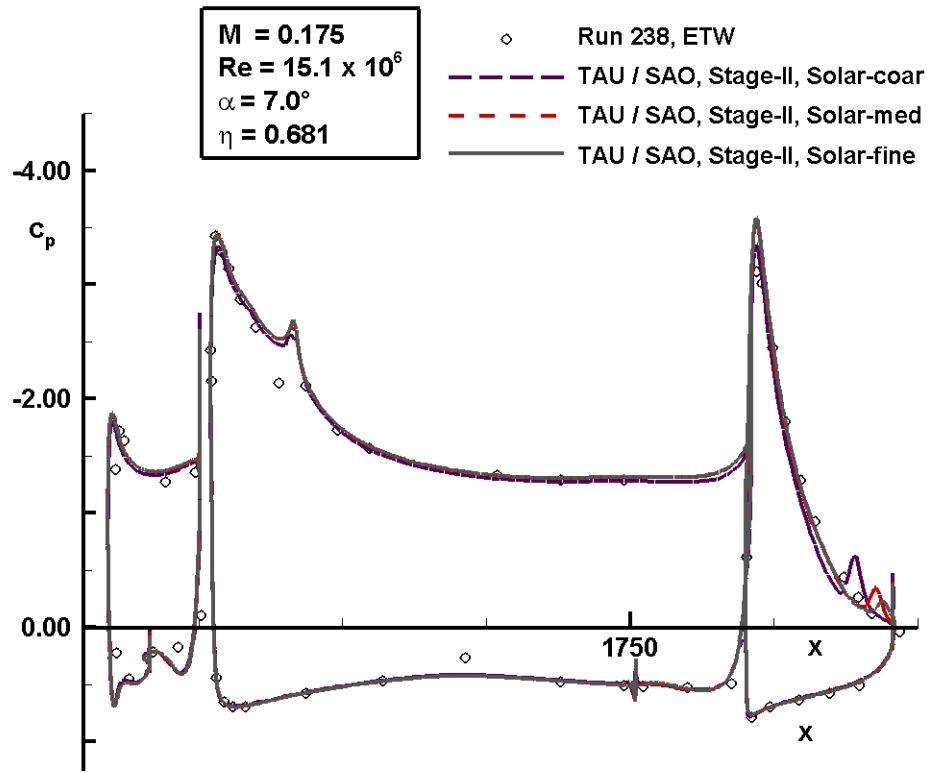
TAU/SAO, Solar Grid - Case 1 (high Re-No.)

CFD High Lift Prediction Workshop

α = 7°

PS1, PS6



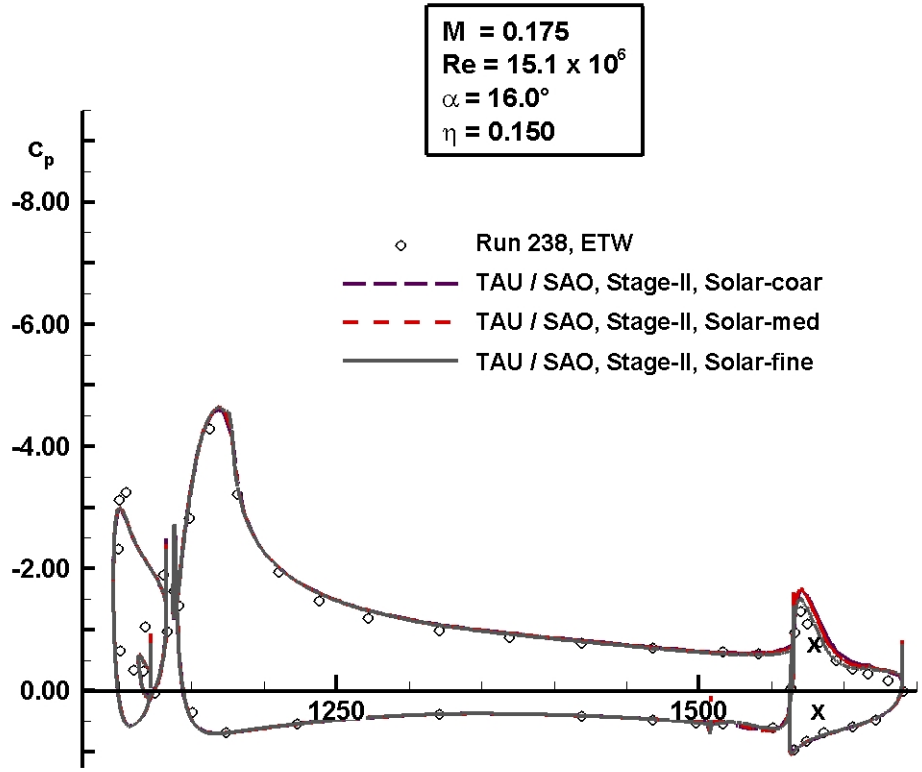


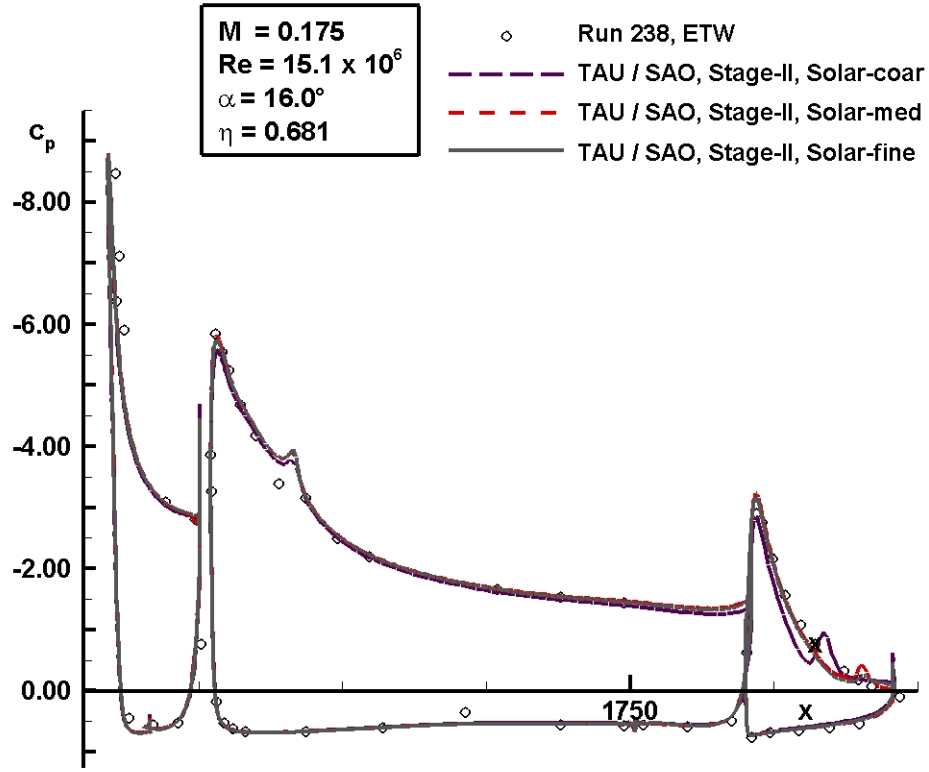
TAU/SAO, Solar Grid - Case 1 (high Re-No.)

CFD High Lift Prediction Workshop

α = 16°

PS1, PS6



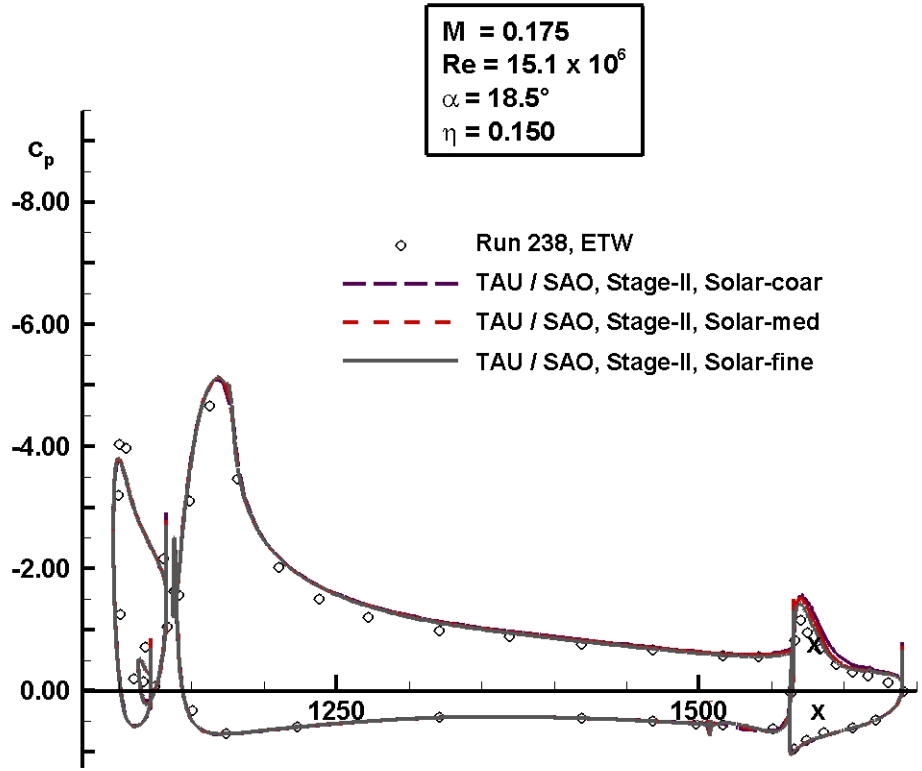


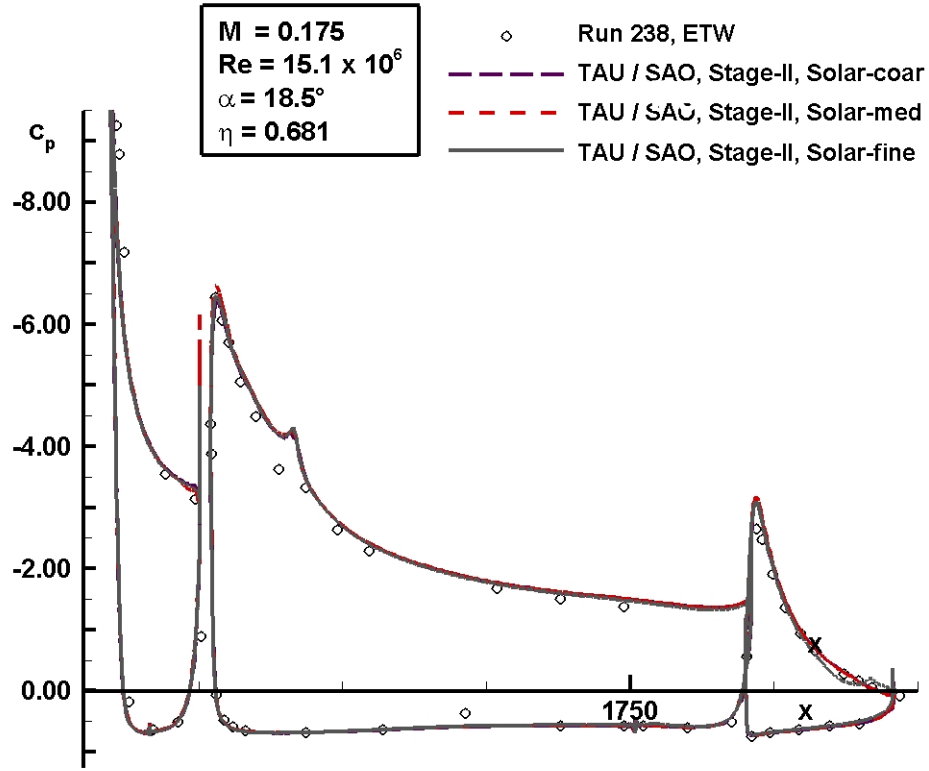
TAU/SAO, Solar Grid - Case 1 (high Re-No.)

CFD High Lift Prediction Workshop

α = 18.5°

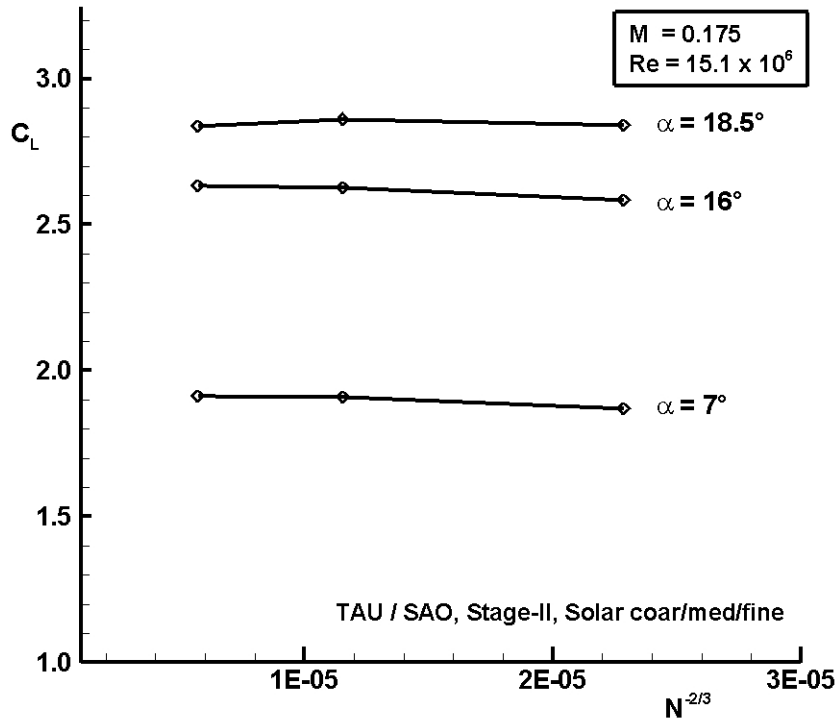
PS1, PS6

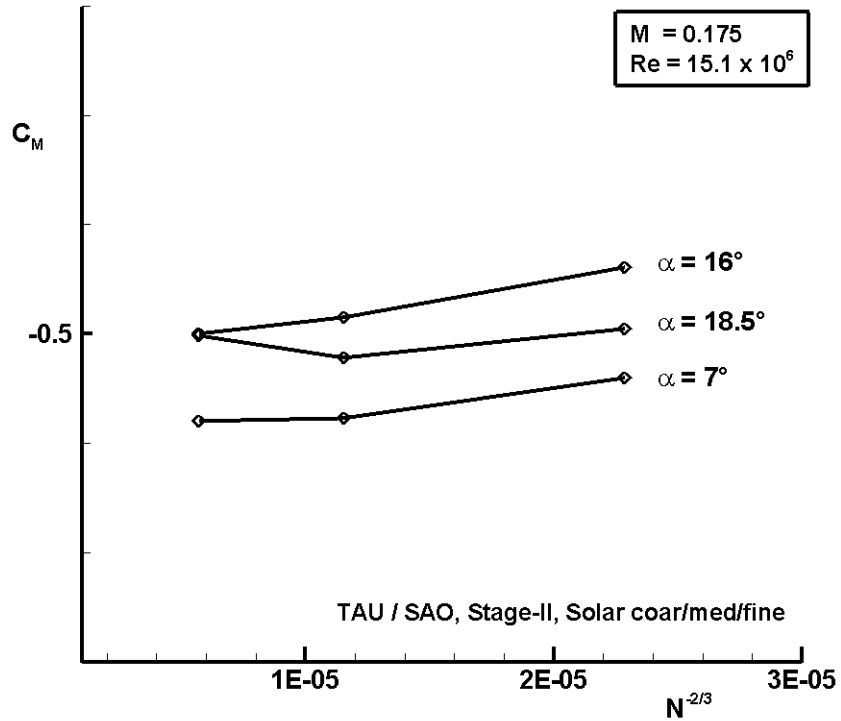




TAU/SAO, Solar Grid - Case 1 (high Re-No.)

- **Lift and pitching moment vs. grid point no.**





Conclusion

- RANS computations of the DLR-F11 configuration have been carried out using the DLR TAU code and the SAO turbulence model on hybrid- unstructured grids.
- Hex-dominant grids have been generated with the SOLAR grid generation system for all three complexity stages adapted to low and high Re-No. conditions as well as for a 3-level grid refinement study on the most simplified configuration
- Baseline validation using the SAO model on the most representative configuration reveals:
  - good agreement of c_p-distributions and forces in the linear lift range
  - singular deviation for α = 16°
  - significant deviations in lift breakdown mechanism and in C_{Lmax} and α_{max}
- Reynolds Number Effects are consistently captures, taking into account that the lift breakdown mechanisms (and its simulated deviations) are not affected
- Computed impact of wind tunnel model details on the surface flowfield results in minor effects of the pressure tube bundles and a stronger impact of tracks and FTFs

Conclusion

- Impact of Pressure Tube Bundles is widely limited to the maximum lift regime

  - first order effects are simulated

  - an impact of the singularity at α = 16° is observed, yet the experimental effects on the lift curve are not consistently reflected

- The rotational correction of the SA model results in a trend to provide an improved agreement to the experimental evidence for low Reynolds number conditions with a large part of the deviations remaining (comp's need to be progressed)

- The grid refinement study shows comparatively small effects on the overall aerodynamic properties, most pronounced at the flap t.e.

Outlook - Open Issues

- **Grid generation**
  - Assessment of normal to wall resolution improvements
  - Assessment of track wake resolution
  - Assessment and cross comparison of a different grid system

- **TAU computations**
  - Completion of post C_{Lmax} SAO-computations
  - Turbulence model performance assessment for low Re conditions Case 5a (SA-QCR, SSG/LLR-ω) with a focus on $C_{L,max}$ range and “16°-singularity”
  - Validation of to simulate and predict transitional effects