TAU-SOLAR Contributions to the 3rd High Lift Prediction Workshop

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CFD High Lift Prediction Workshop

Outline

- Contribution and objectives for HiLiftPW-3 computations
- TAU flow solver and settings
- SOLAR grid generation package
- JAXA JSM High Lift Configuration (Case 2a - Case 2c)
  - Grid generation efforts by DLR and ARA
  - Computational results on the DLR-Solar grid (Benchmark)
  - Computational results on the respective partner grids (WB and then WBNP)
- NASA CRM High Lift Configuration (Case 1a)
  - Grid generation efforts by DLR
  - Computational results of DLR
- Conclusion and Outlook

Objectives for HiLiftPW-3 Computations

Objectives of DLR

- Assessment of present SOLAR features and DLR modifications
- Supply of hybrid unstructured SOLAR grids complying with gridding guidelines
- Grid refinement study to identification grid resolution and topology impact
- Improved understanding of geometry features as slat tracks and spanwise gaps
- Improved understanding of simulation quality and shortcomings

Objectives of ARA

- Benchmark in-house best practice grid generation approach for high lift configurations
- Use HiLiftPW-3 activities to further ensure all of ARA's CFD processes are the
  - best they can be
  - fit for purpose
  - industrially robust

TAU Computations - Parameter-Settings

Commonly used TAU solver features for present studies

- DLR TAU code is an edge-based, finite volume, unstructured flow solver
- Turbulence Models: Spalart-Allmaras, negative formul. (SAN)
- Full NS Discretization turbulence eq.: AUSMDV upwind, 2nd order
- Progressive pitch-up procedure to limit hysteresis effects

DLR settings

- Code Version: DLR TAU code 2015.2.0
- Spatial Discretization: - main eq.: Jameson central, 2nd order;
  blend scalar (20%) – matrix (80%) dissipation
- Temp. Integration: - LU-SGS Backward Euler, 2V MG cycle

ARA settings

- Code Version: DLR TAU code 2016.1.0
- Spatial Discretization: - main eq.: Jameson central, 2nd order scalar dissipation
- Temp. Integration: - LU-SGS Backward Euler, 3V MG cycle

Case 2a and 2c

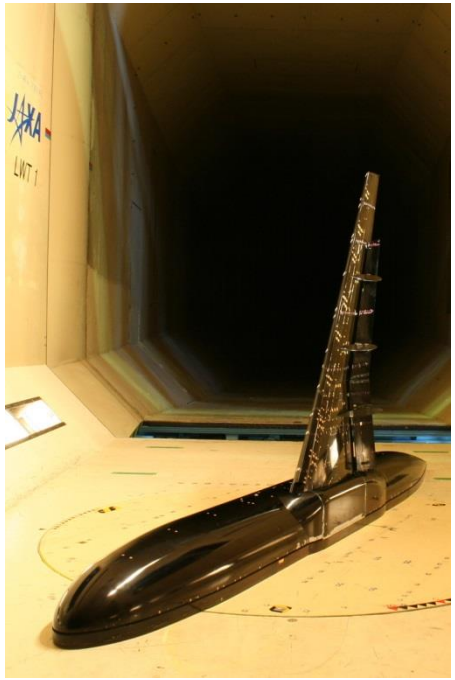
JAXA JSM High Lift Configuration

Validation of Engine Installation Effects

- **JSM-Configuration: WB and WBNP**
- **Dimensions:**
  - half span = 2.3 m
  - c_{ref} = 0.5292 m
  - Λ = 9.42
  - φ_{LE} = 33°
  - δ_s = 30°
  - δ_f = 30°
- **Flow conditions (JAXA LWT-1):**

  M = 0.172

  Re = 1.93×10^6



JSM Grid Generation - SOLAR

Commonly used SOLAR features

- Hybrid unstructured grids
- Surface discretization: mixed element, but quad-dominant mesh
- Volume discretization: hex-dominant mesh near aerodynamic surfaces
- y^+ -manual adaptation, const. first cell height

Grid generation approach for ARA's participant grid (coarse resolution)

- According to ARA's best practices, anisotropic stretching used on wing, nacelle and fuselage surfaces
- Placement of sources is largely semi-automatic process using templates

Grid generation approach for DLR's committee grid (medium resolution)

- Special CAD-based treatment of grid refinement sources for improved surface discretization
- Attempt made to match grid generation guidelines as close as possible

  Deviations: - 1st wall distance reduced from 3.6e-3 mm to 1.0e-3 mm

  - no. of points on blunt t.e. increased from 8 to 12

JSM Surface Grid Generation - SOLAR

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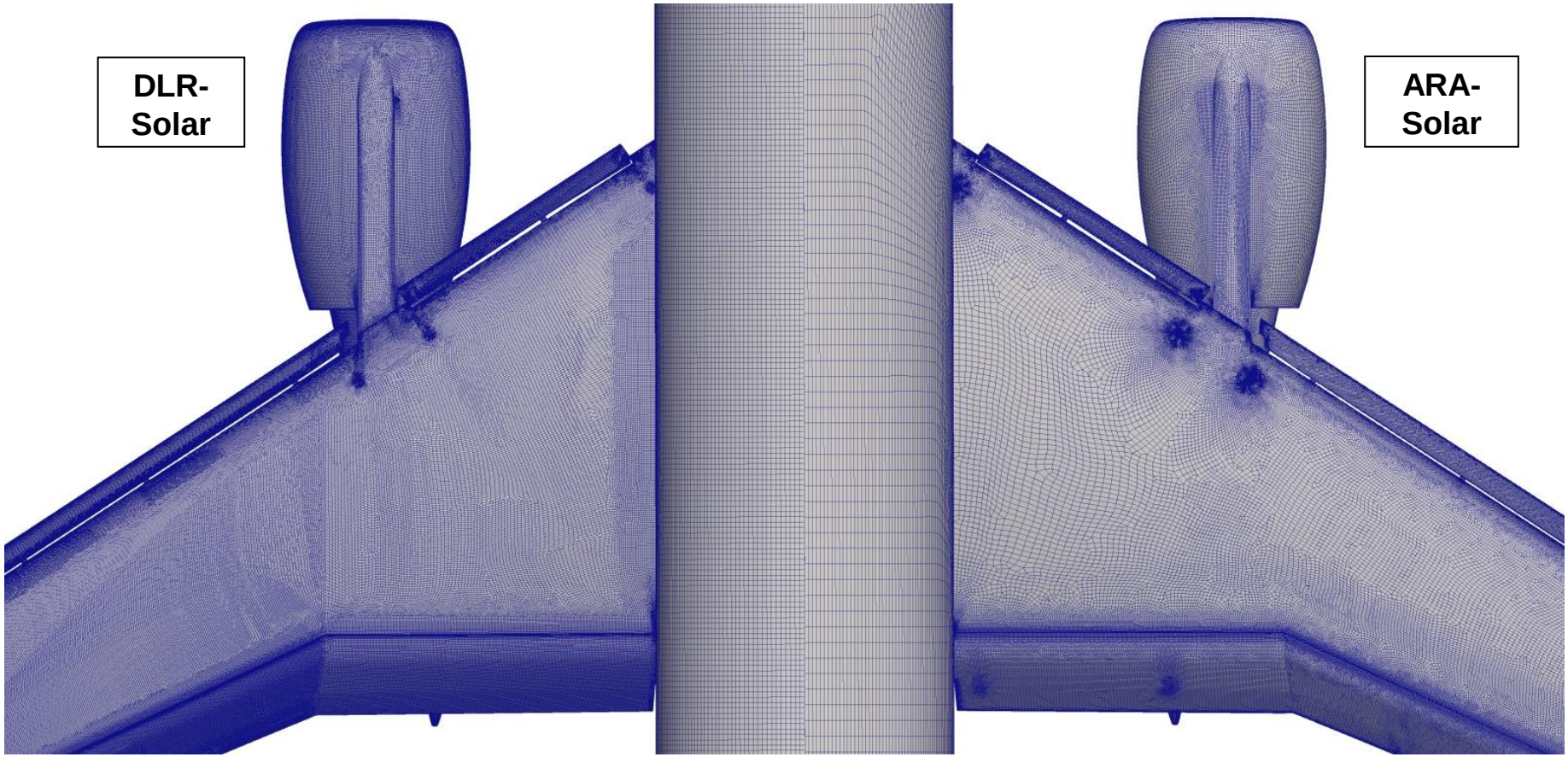
Case / Provider	y1 in mm	Stretching factor	No. of layers normal to wing t.e.
Case 2a,c – ARA	6.7e-3	1.3	22
Case 2a,c – DLR	1.0e-3	1.16	48



JSM Volume Grid Generation - SOLAR

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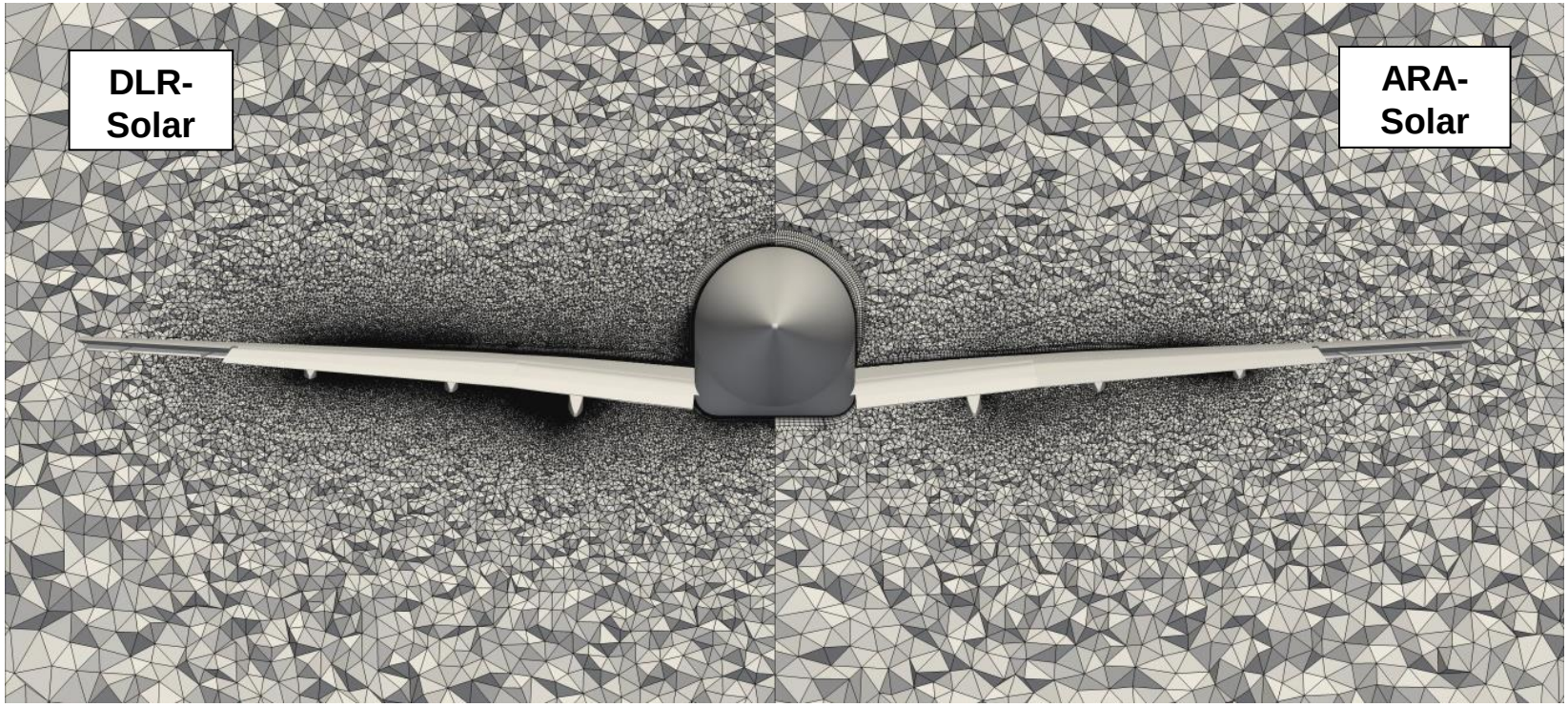
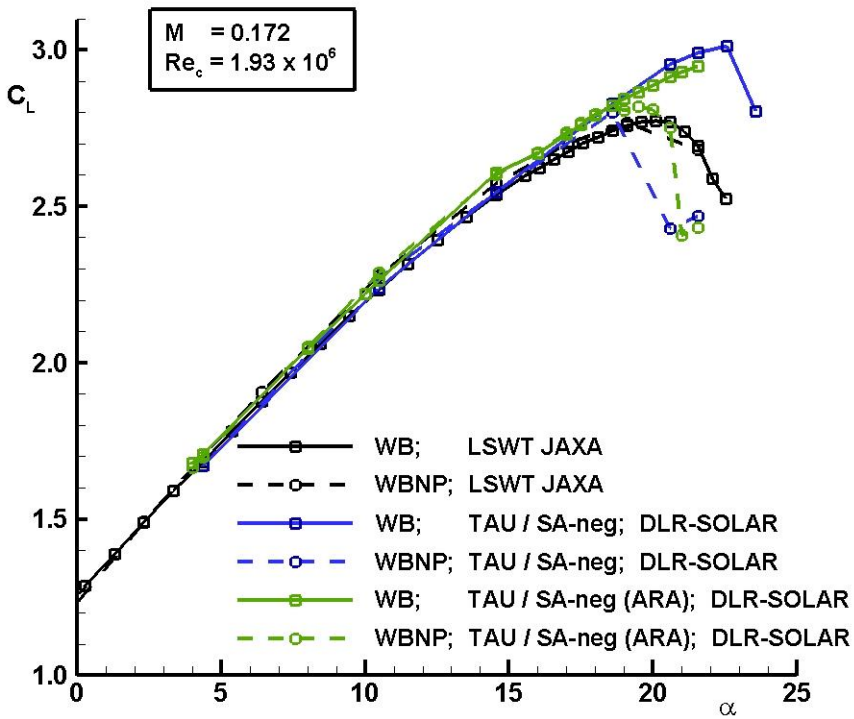
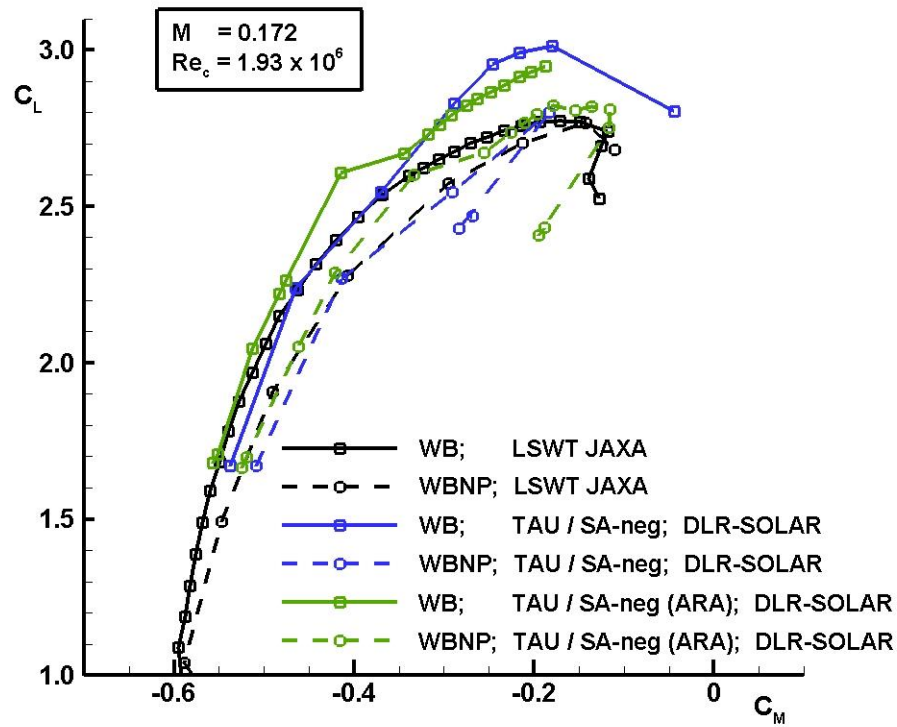
Case / Provider	Grid Points	Hexahedra	Surface Elem.	Total Elem.
Case 2a - ARA	27.348.000	19.723.000	1.013.000	61.488.000
Case 2a - DLR	102.027.000	88.294.000	2.290.000	161.744.000
Case 2c - ARA	30.974.000	22.343.000	1.145.000	69.560.000
Case 2c - DLR	125.622.000	107.249.000	2.712.000	206.921.000



JSM-WB/WBNP: Benchmark Computation on DLR Solar Grids

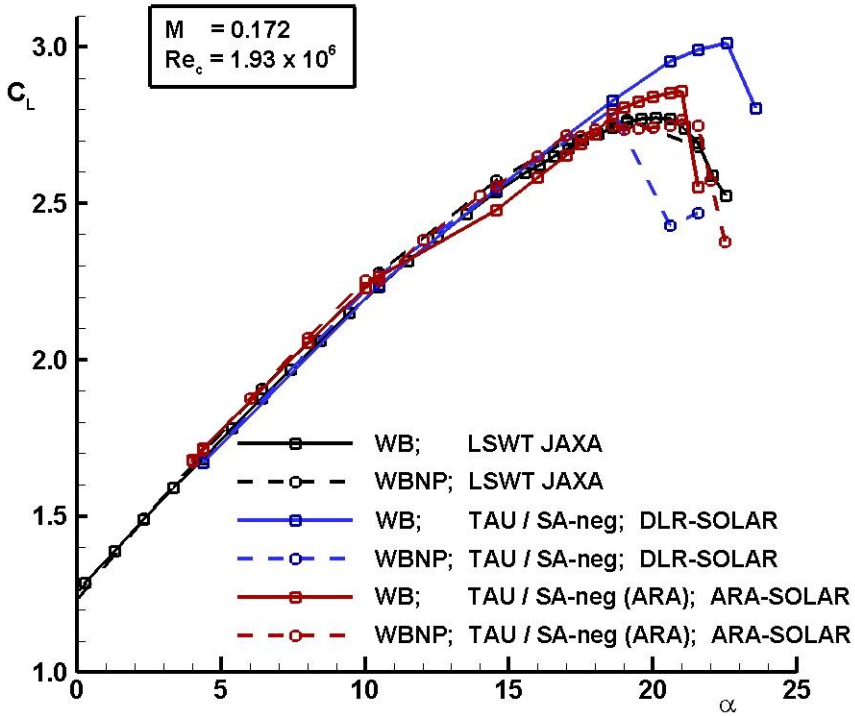
- **Lift curve and pitching moment JSM WB vs. WBNP**

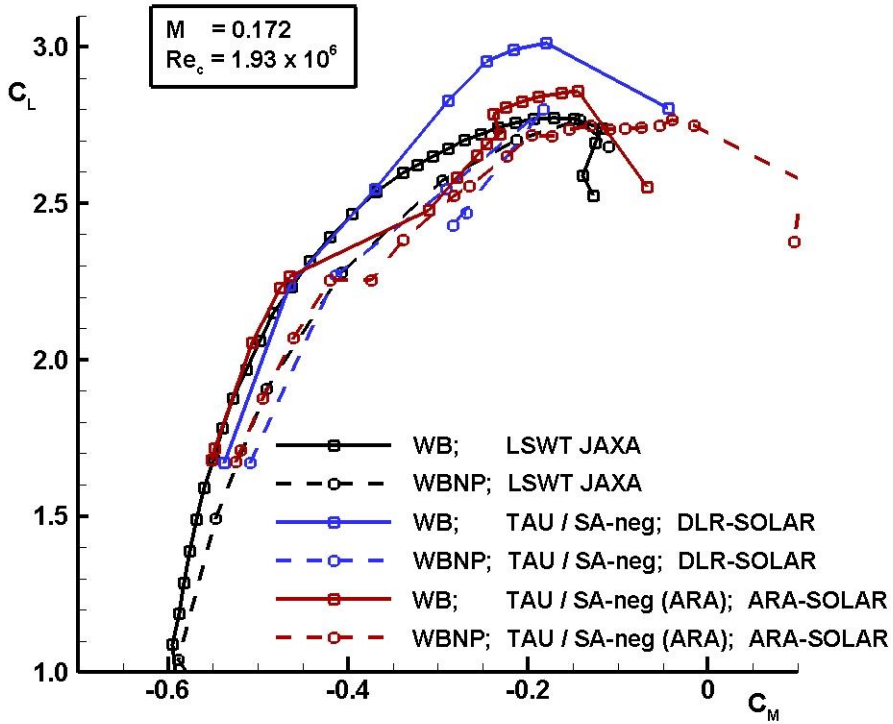




JSM-WB/WBNP: Computations on DLR/ARA Respective Solar Grids

- **Lift curve and pitching moment JSM WB vs. WBNP**





JSM-WB: Computations on DLR/ARA Respective Solar Grids

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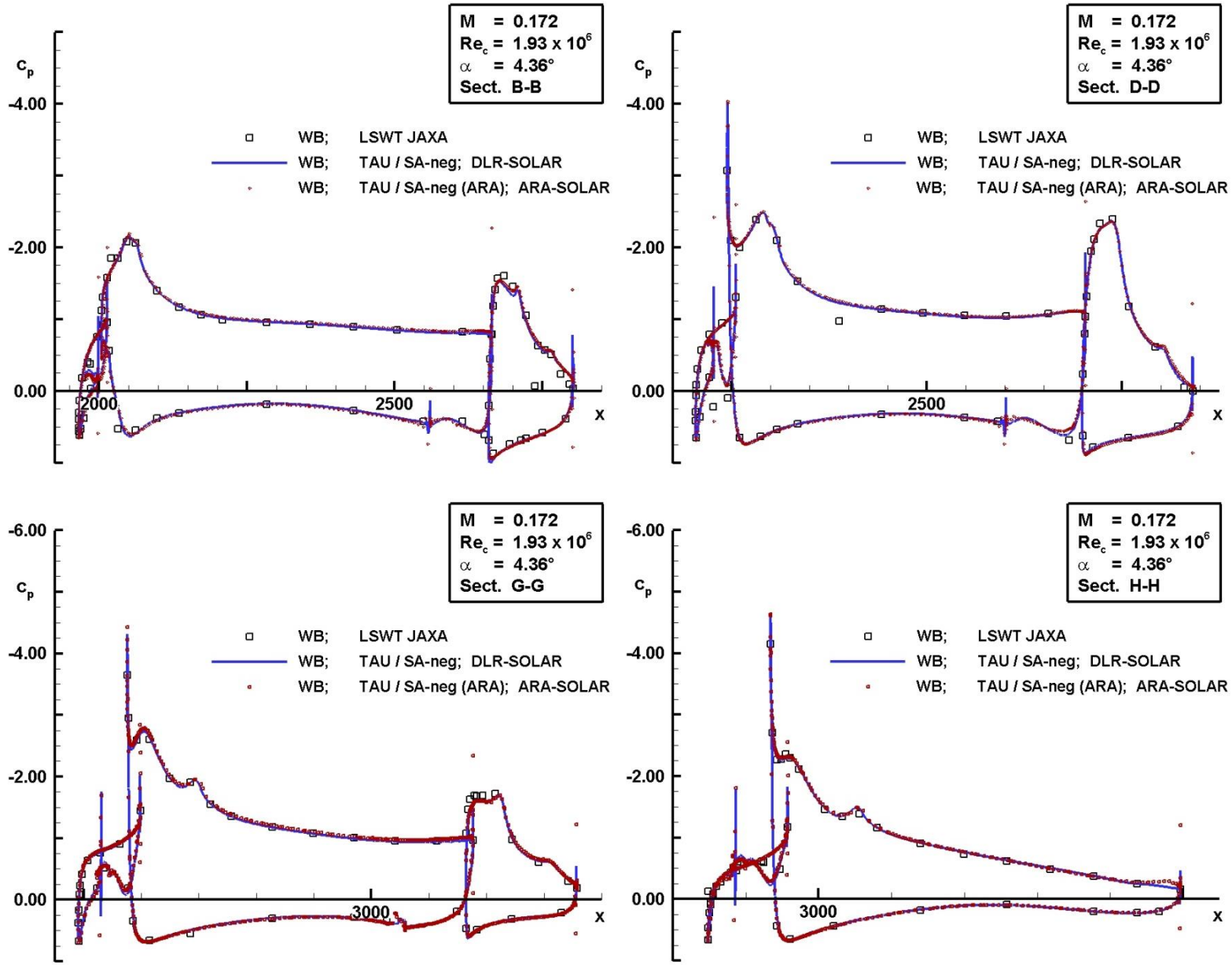

α = 4.36°

B-B, D-D, G-G, H-H

JSM-WB: Computations on DLR/ARA Respective Solar Grids

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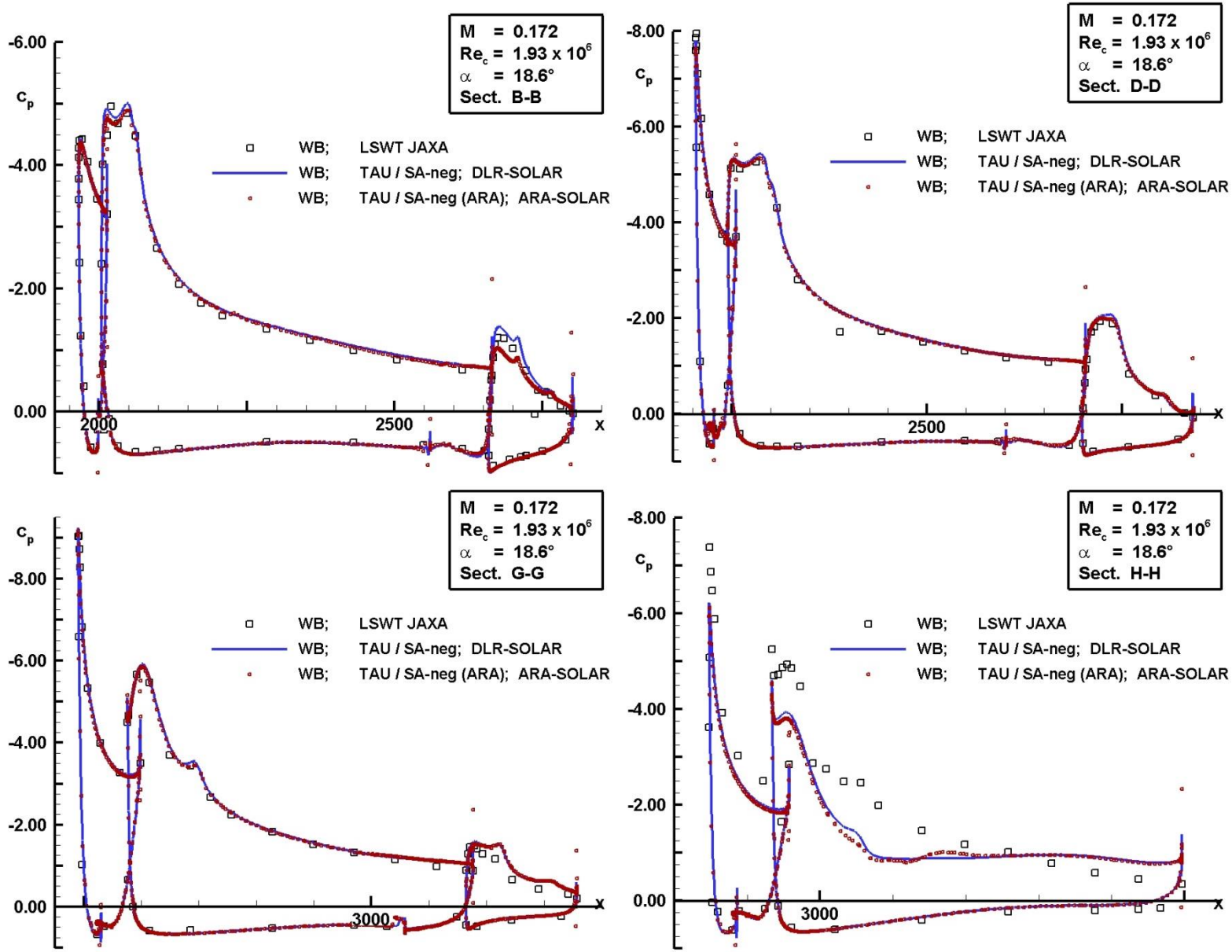
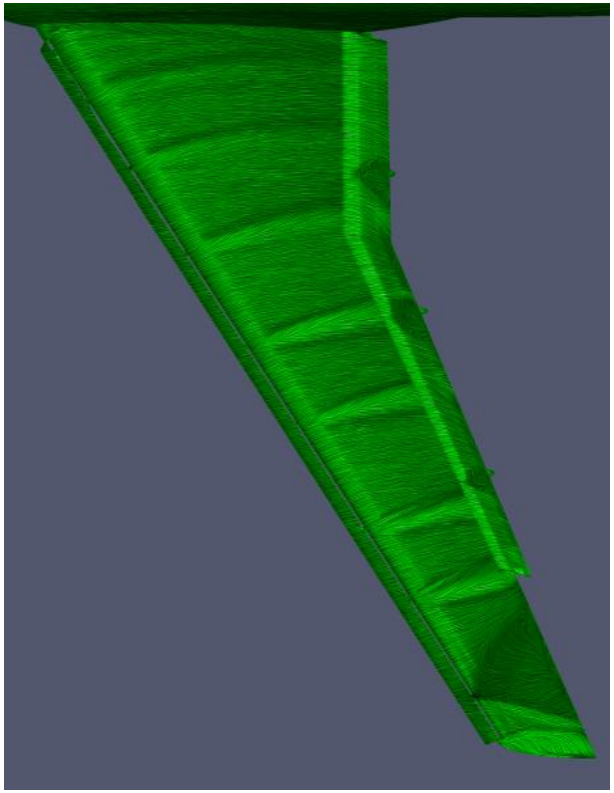


α = 18.6°

B-B, D-D, G-G, H-H

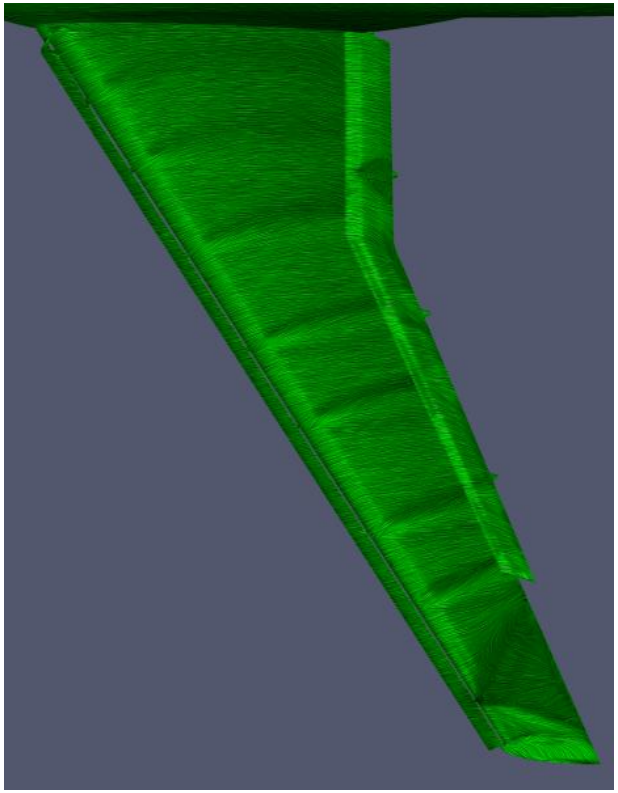
JSM-WB: Computations on DLR/ARA Respective Solar Grids

- **Surface streamlines for JSM-WB, α = 18.6°**



DLR-SOLAR

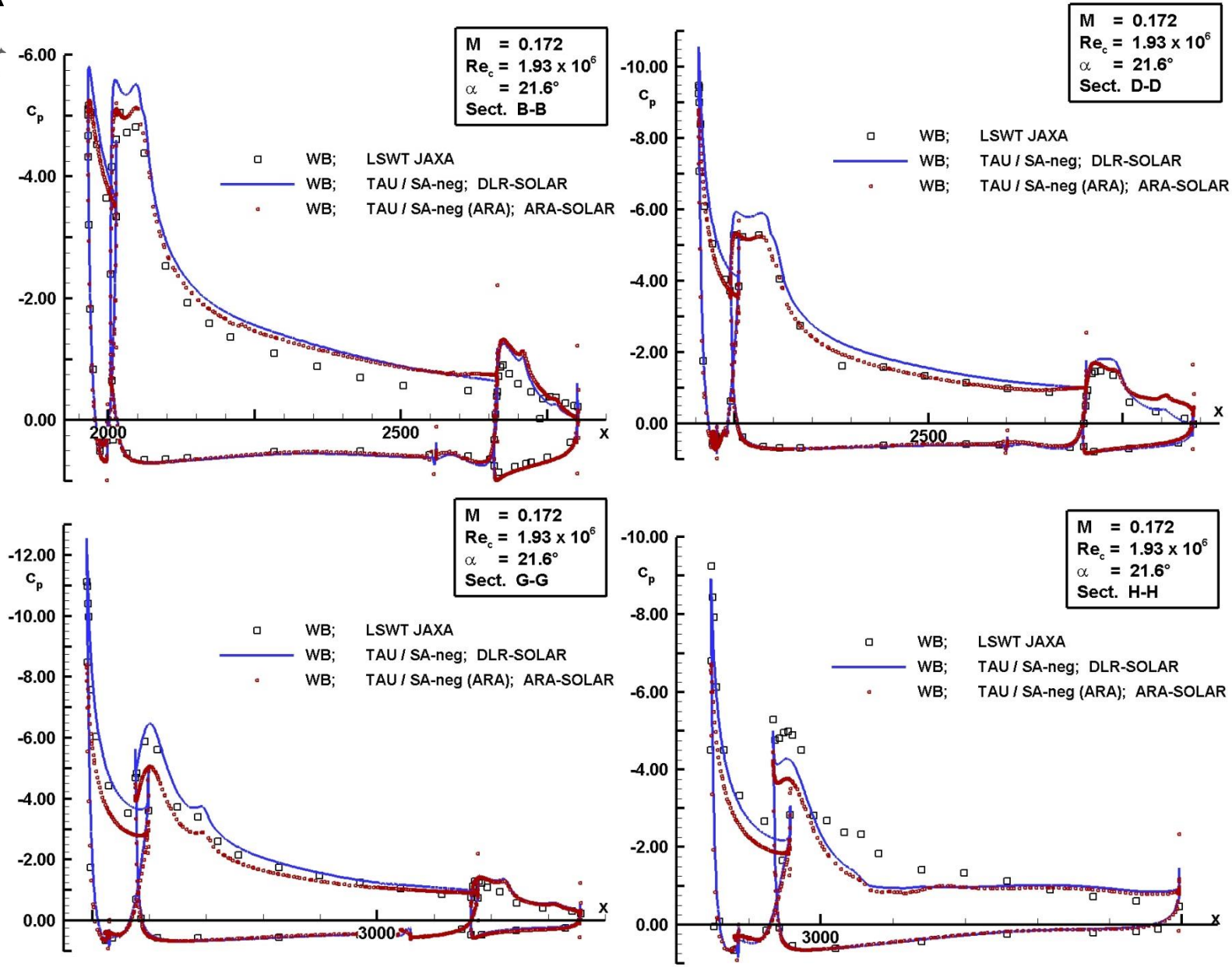
JAXA LWT-1



ARA-SOLAR

JSM-WB: Computations on DLR/ARA Respective Solar Grids

CFD High Lift Prediction Workshop

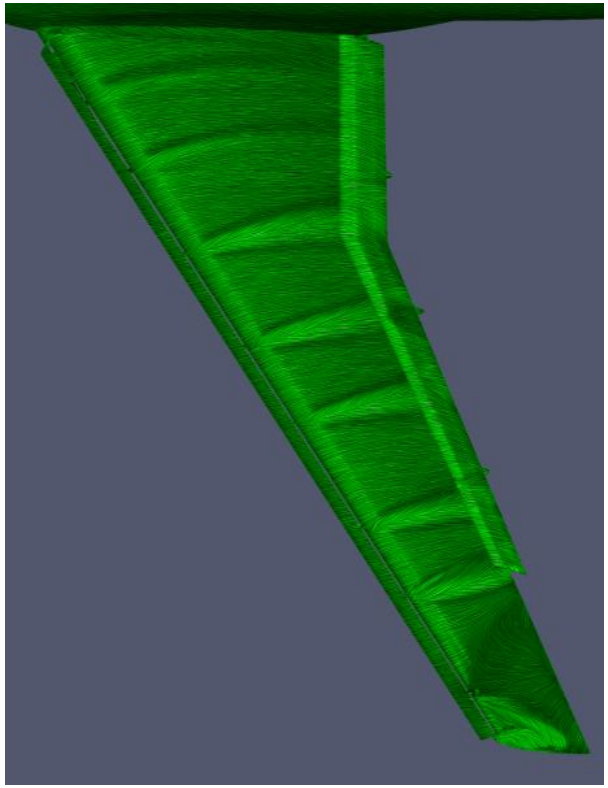


α = 21.6°

B-B, D-D, G-G, H-H

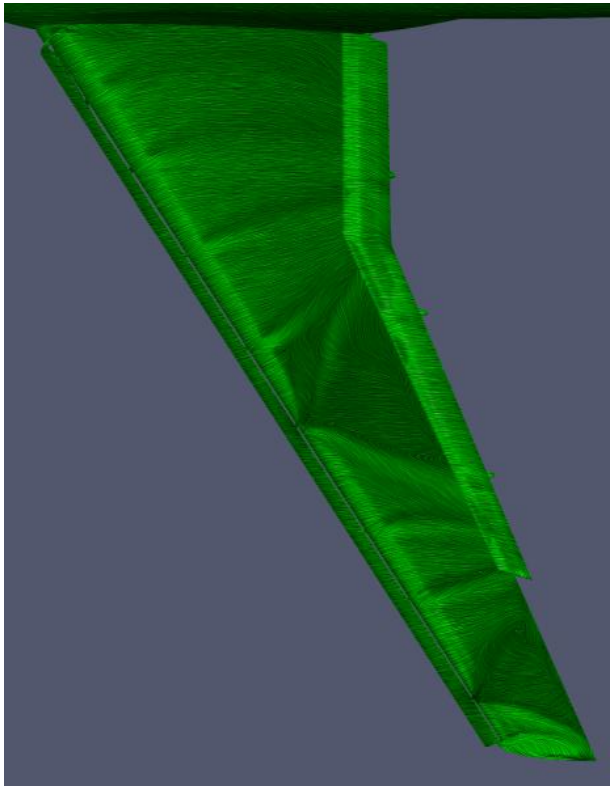
JSM-WB: Computations on DLR/ARA Respective Solar Grids

- **Surface streamlines for JSM-WB, α = 21.6°**



DLR-SOLAR

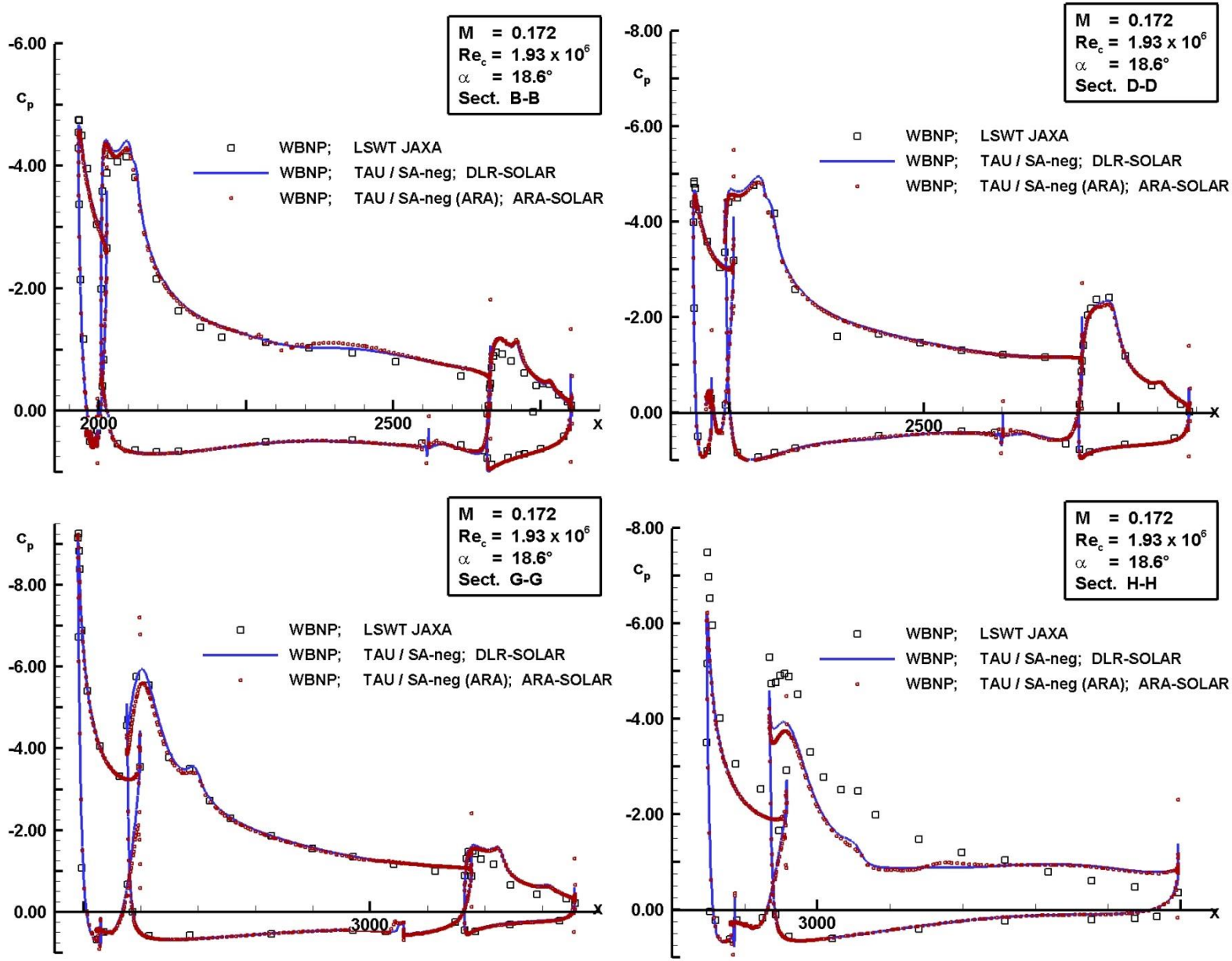
JAXA LWT-1



ARA-SOLAR

JSM-WBNP: Computations on DLR/ARA Respective Solar Grids

CFD High Lift Prediction Workshop

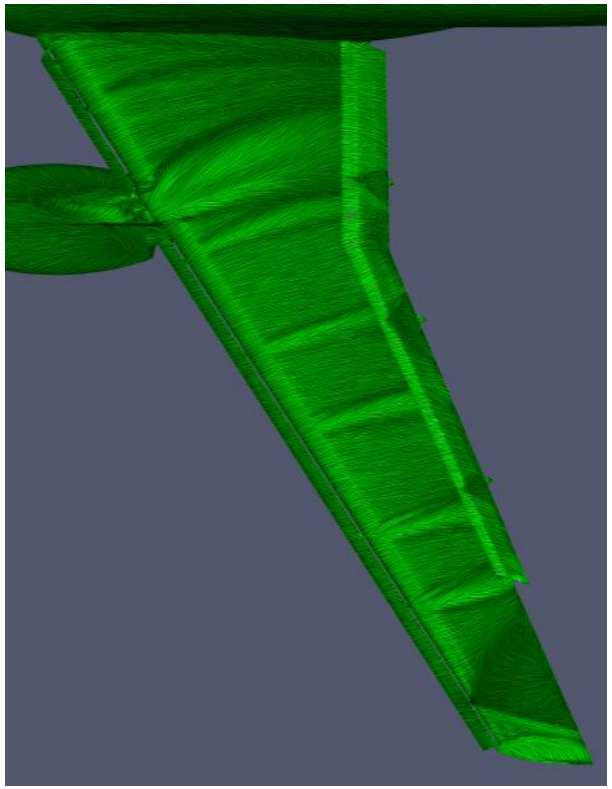


α = 18.6°

B-B, D-D, G-G, H-H

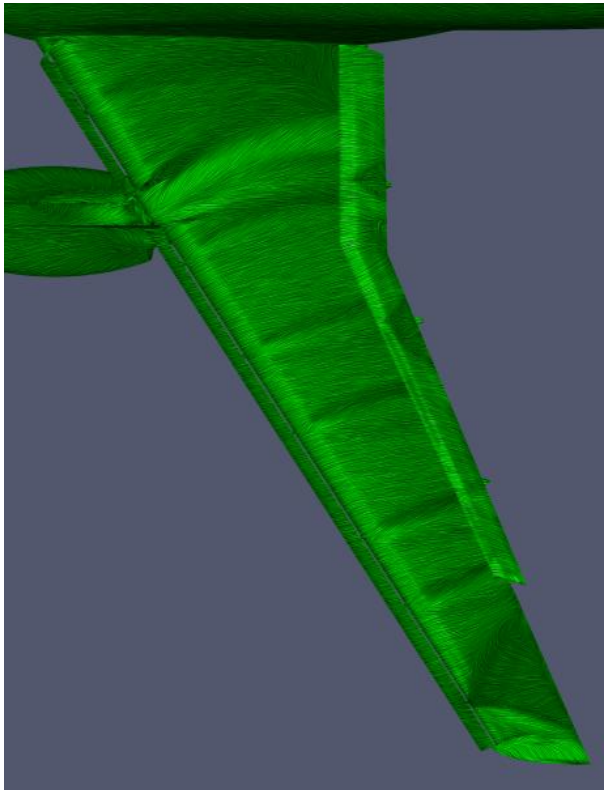
JSM-WBNP: Computations on DLR/ARA Respective Solar Grids

- **Surface streamlines for JSM-WBNP, α = 18.6°**



DLR-SOLAR

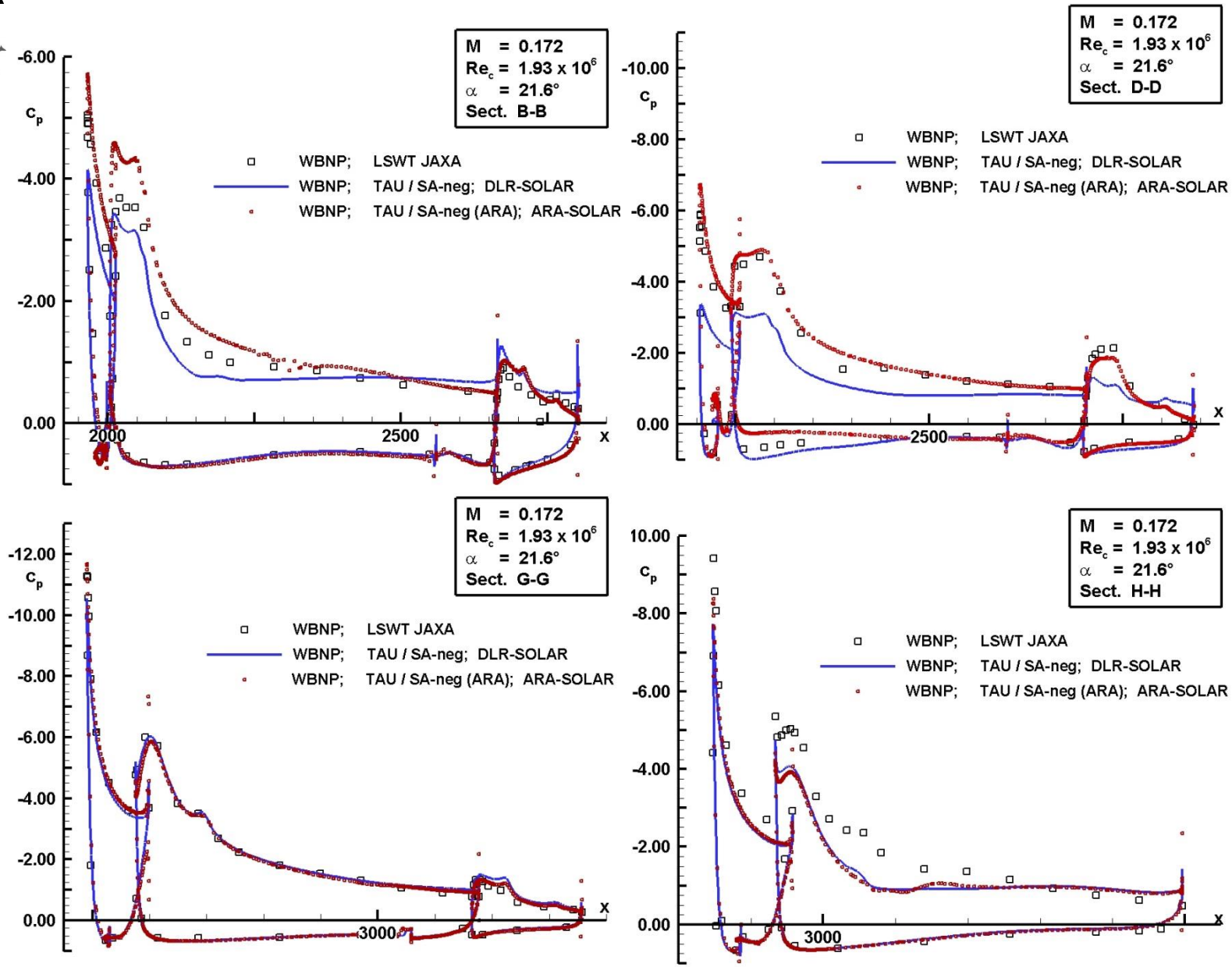
JAXA LWT-1



ARA-SOLAR

JSM-WBNP: Computations on DLR/ARA Respective Solar Grids

CFD High Lift Prediction Workshop

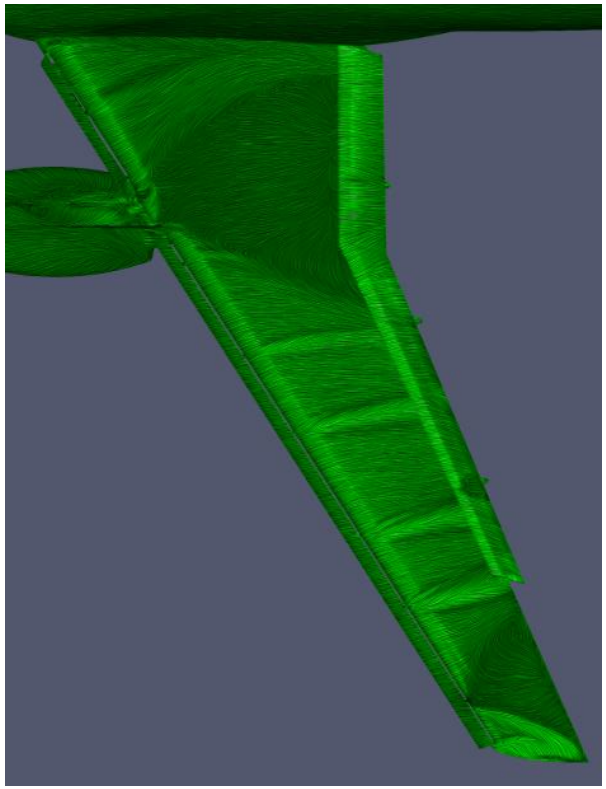


α = 21.6°

B-B, D-D, G-G, H-H

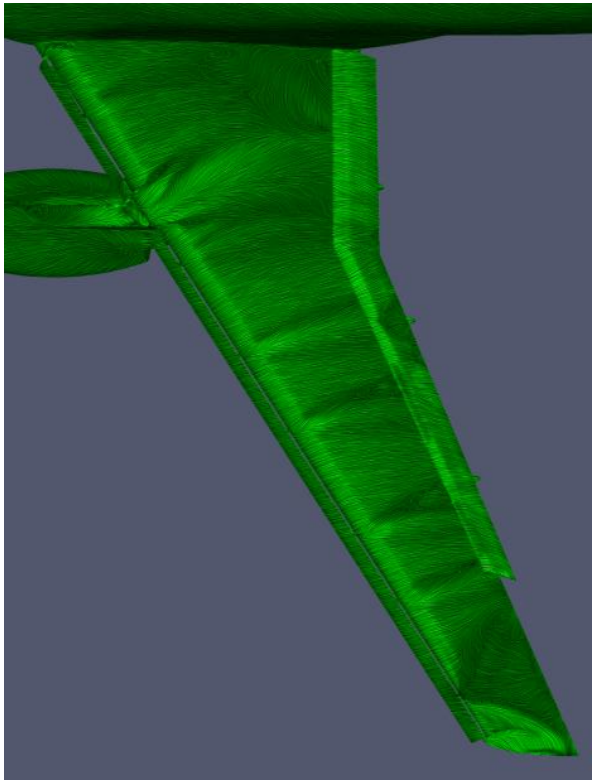
JSM-WBNP: Computations on DLR/ARA Respective Solar Grids

- **Surface streamlines for JSM-WBNP, α = 21.6°**



DLR-SOLAR

JAXA LWT-1

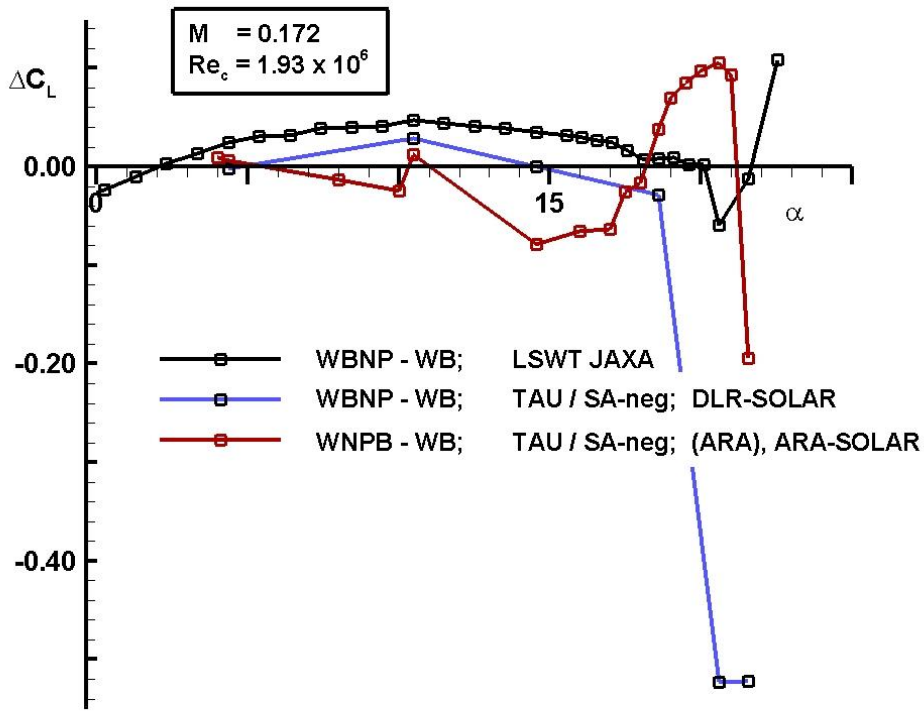


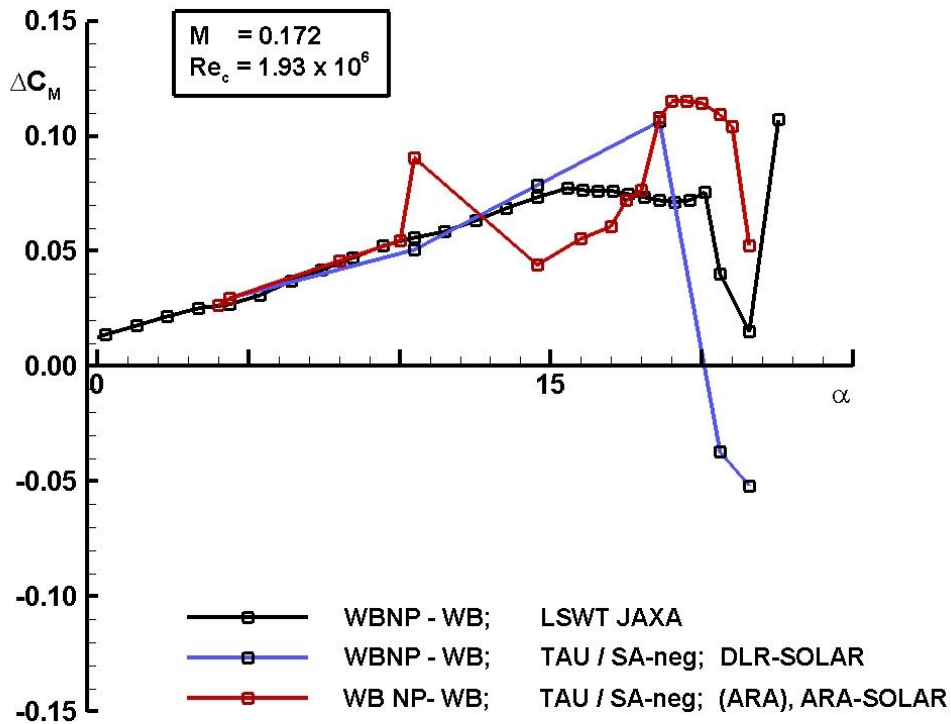
ARA-SOLAR

JSM-WB/WBNP: Computations on DLR/ARA Respective Solar Grids

CFD High Lift Prediction Workshop

- **Increment in lift and pitching moment coefficient due to nacelle installation**





Case 1a

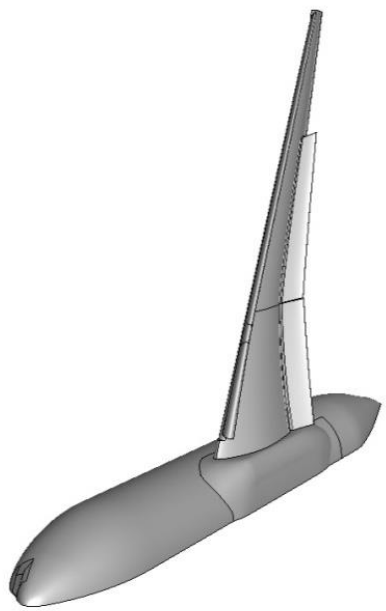
NASA CRM High Lift Configuration

Grid Resolution Study

- **CRM-Configuration: WB**
- **Dimensions:**
  - half span = 1156.75 in.
  - c_{ref} = 275.8 in.
  - Λ = 9.0
  - $\varphi_{0.25c}$ = 35°
  - δ_s = 30°
  - δ_f = 37°
- **Flow conditions (represent. for wtt):**

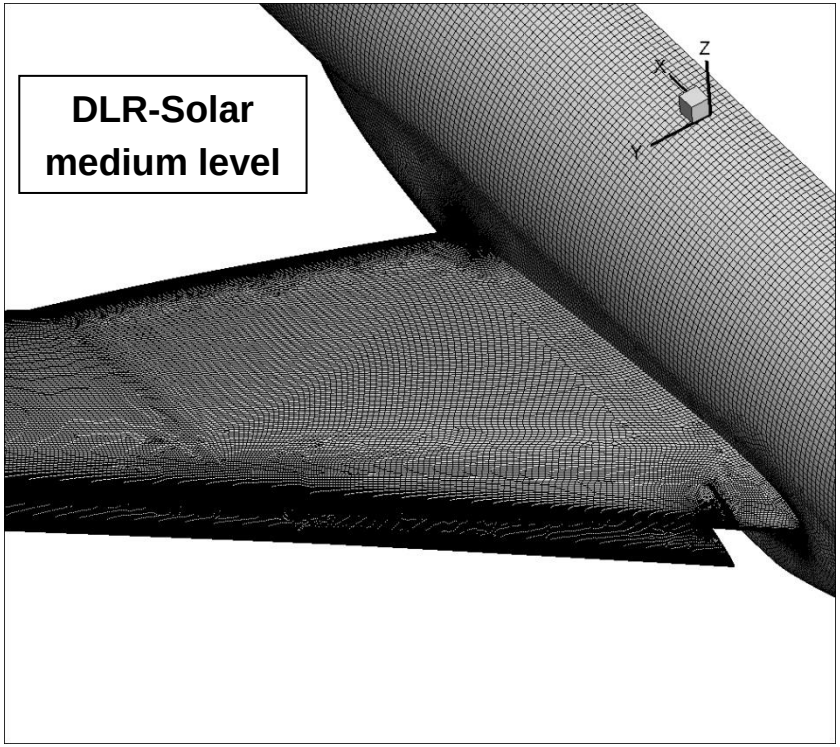
  M = 0.200

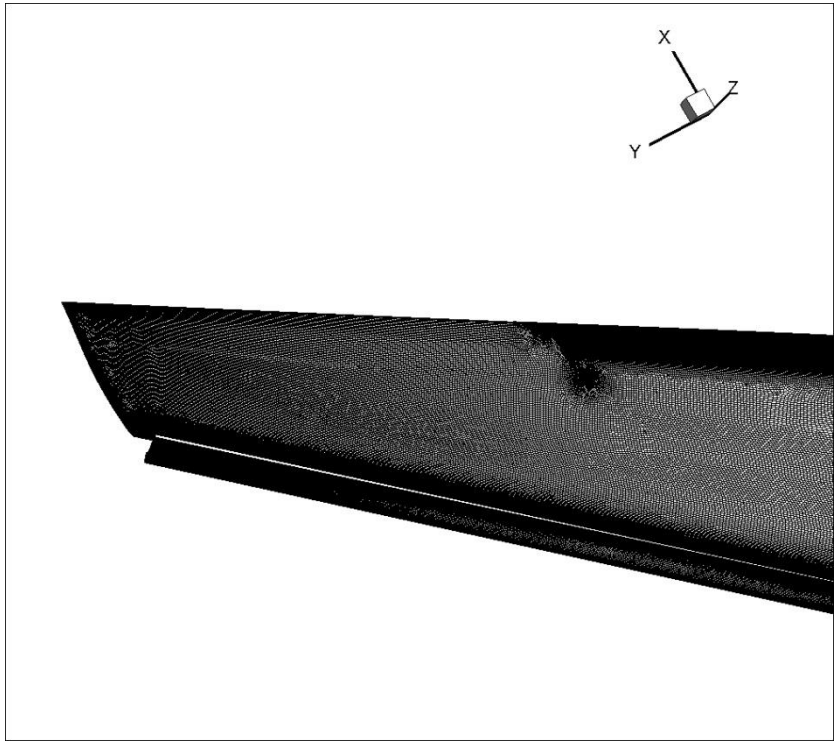
  Re = 3.26×10^6



CRM Grid Generation - DLR SOLAR Grid Family

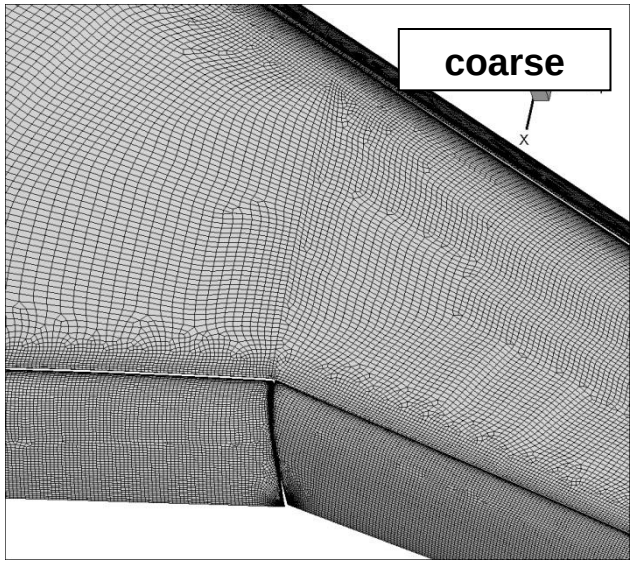
Case	y1 in mm	Stretching factor	Number of cells on fixed wing trailing edge
Coarse Grid	0.04445	1.25	5
Medium Grid	0.02972	1.16	8
Fine Grid	0.01981	1.10	12

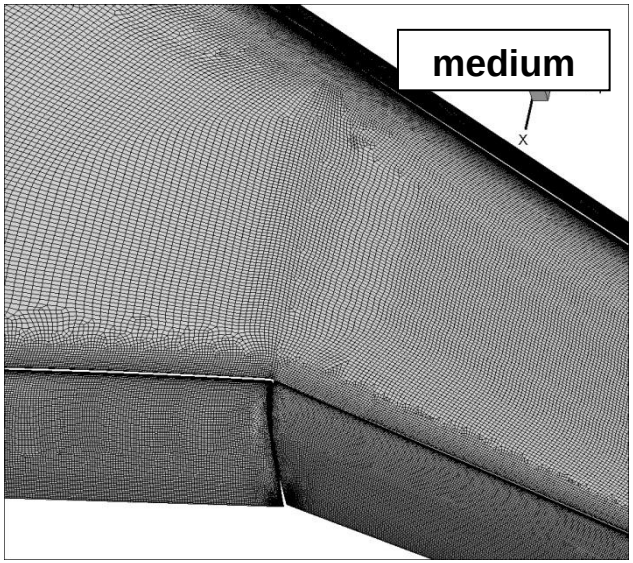


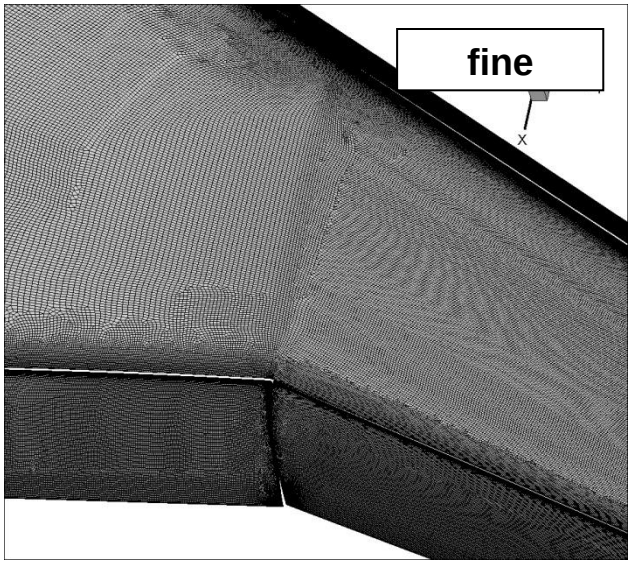


JSM Grid Generation - DLR SOLAR Grid Family

Grid Level	Grid Points	Hexahedra	Surface Elements	No. of layers above fixed wing trailing edge	Total Elem.
Coarse	11.827.581	9.915.235	489.690	31	20.248.983
Medium	38.324.069	33.161.989	1.028.851	45	62.026.198
Fine	138.801.871	124.686.859	2.357.883	70	204.695.516

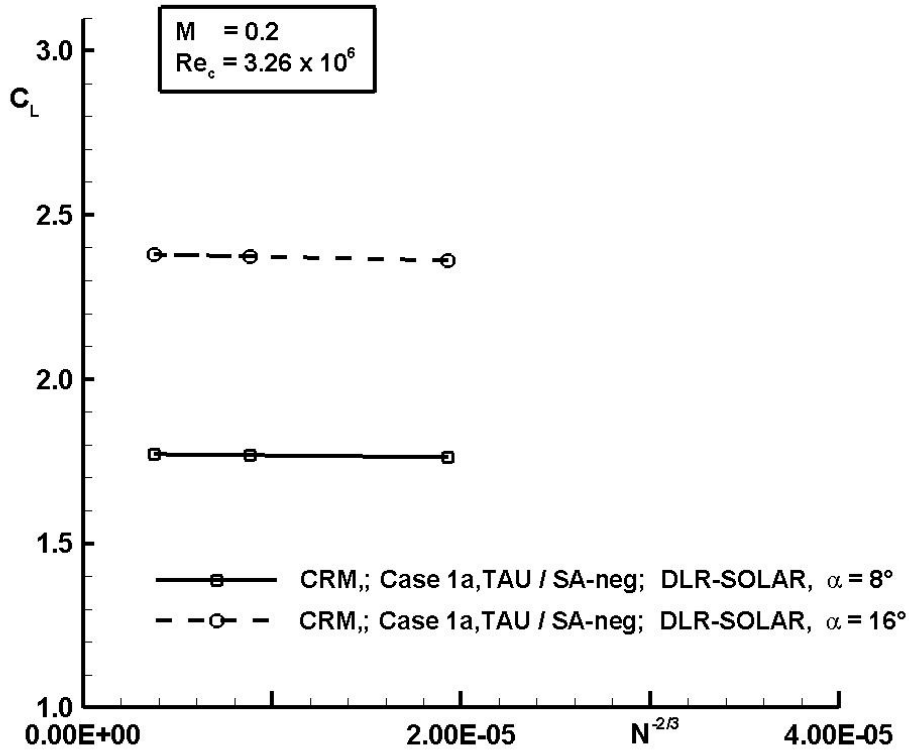


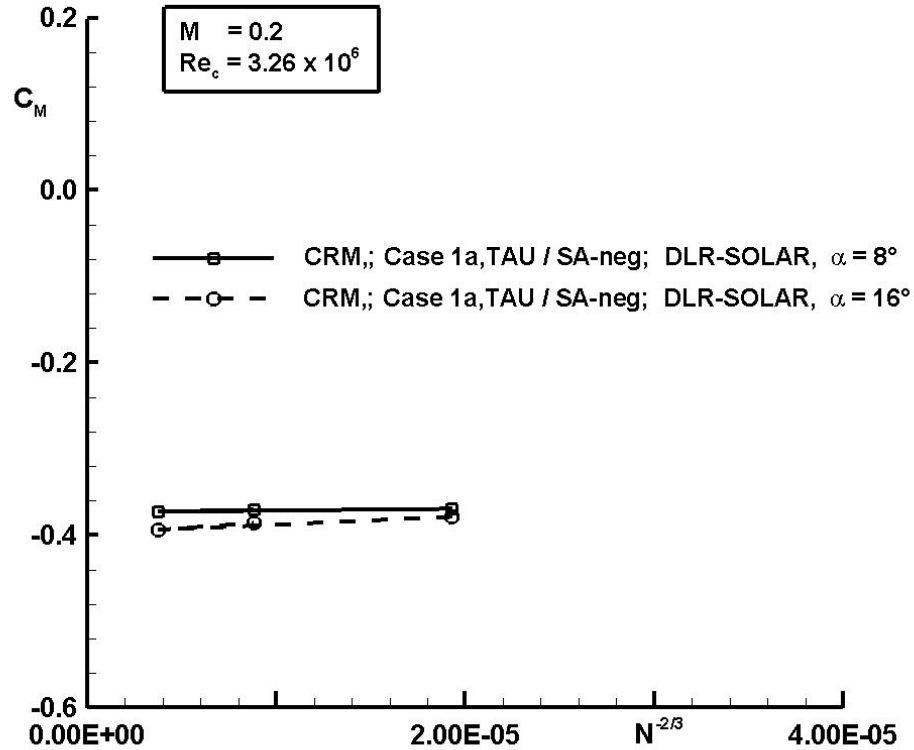




CRM-WB: DLR Computations on DLR Solar Grid Family

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

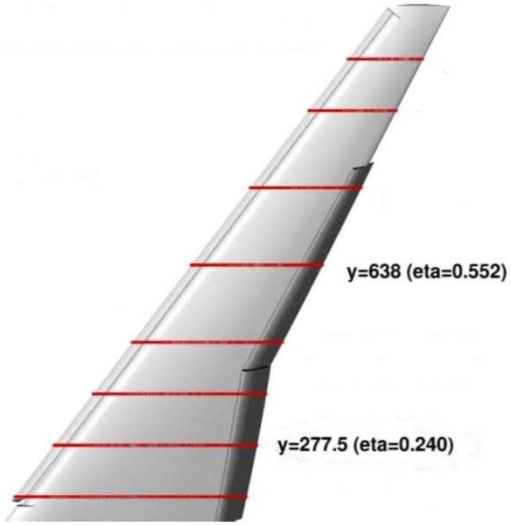


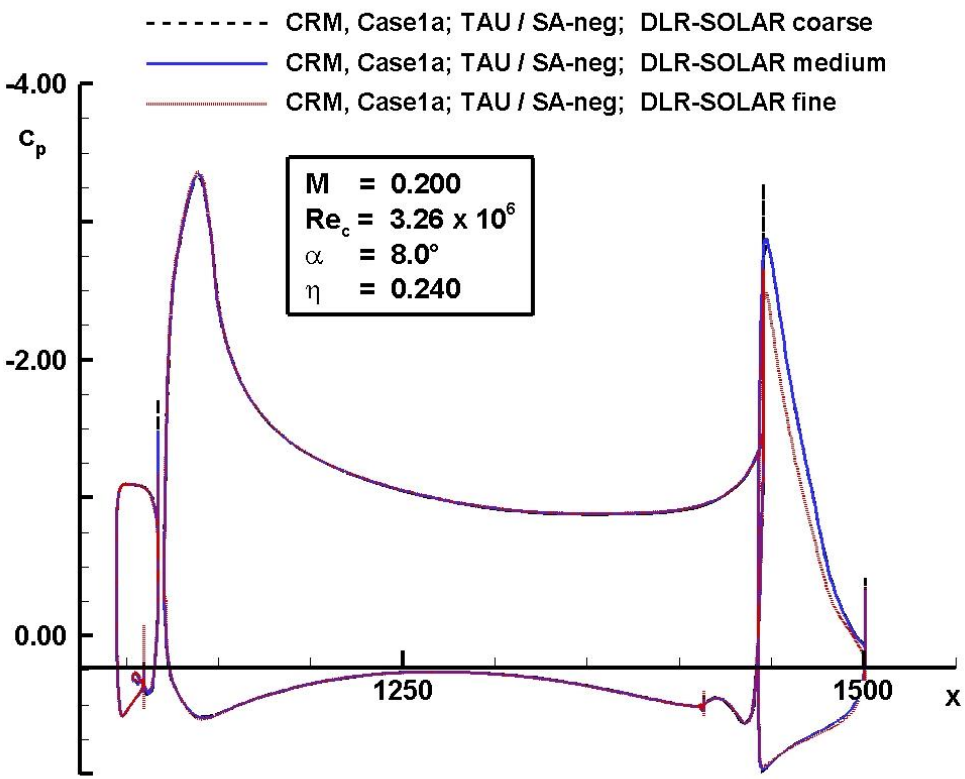


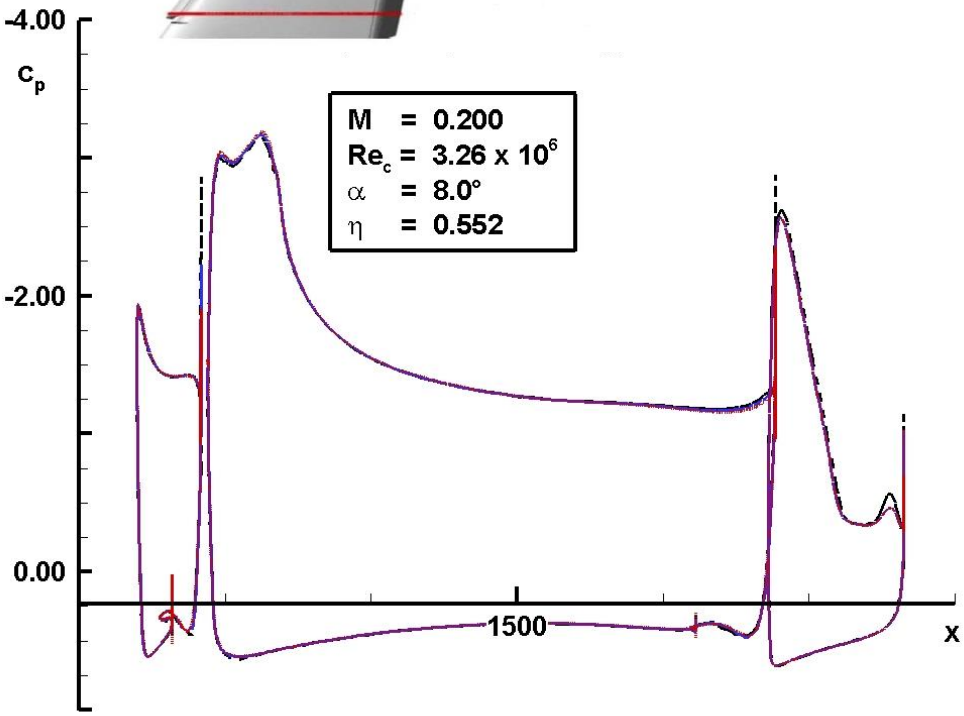
CRM-WB: DLR Computations on DLR Solar Grid Family

- **Grid resolution influence on c_p-distributions;**

  i/b and o/b 3-element section
  at η = 0.240 and 0.552 for α = 8°



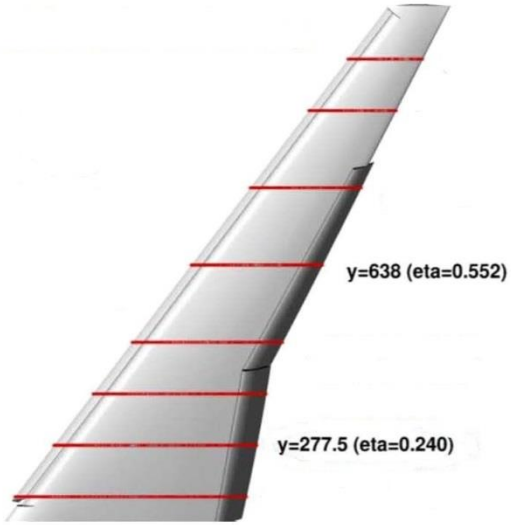


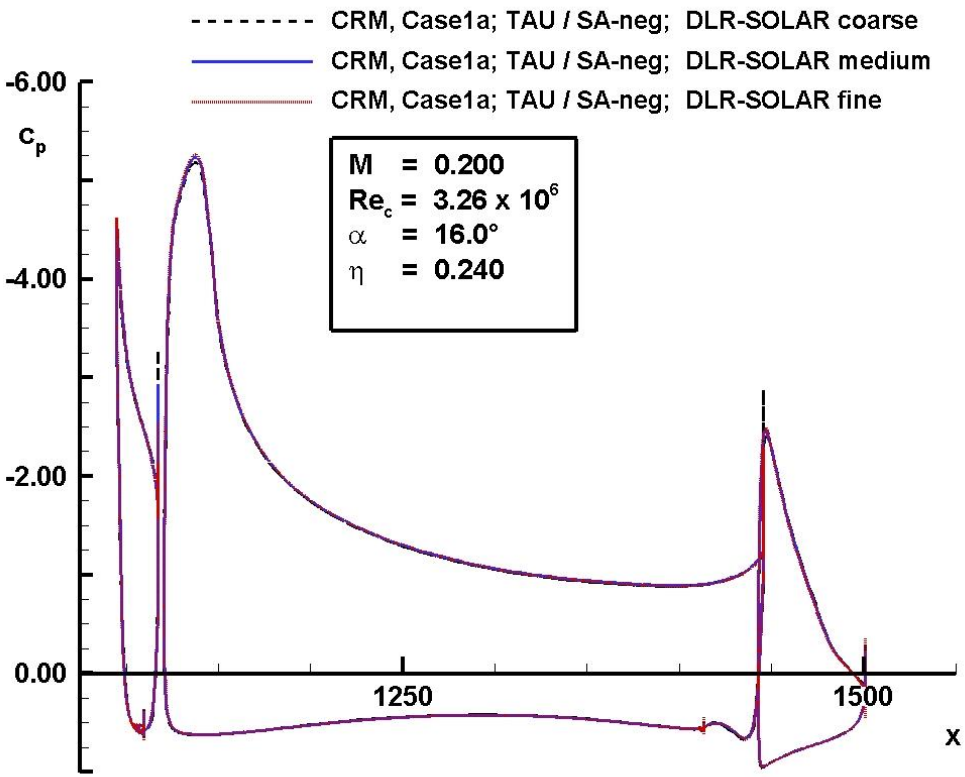


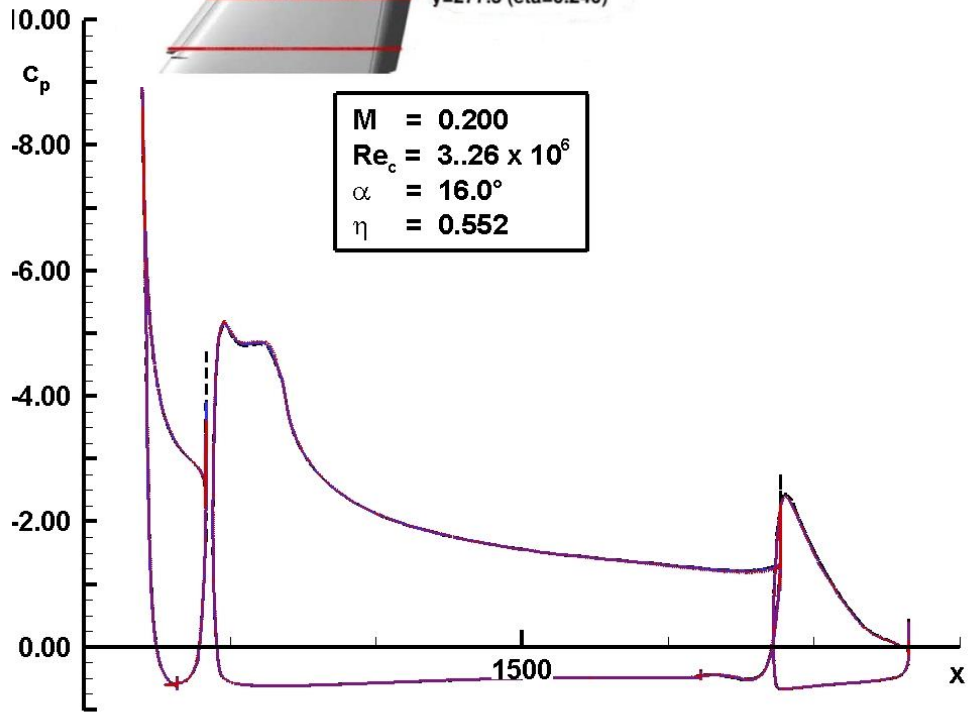
CRM-WB: DLR computations on DLR Solar Grid Family

- **Grid resolution influence on c_p-distributions;**

  i/b and o/b 3-element section
  at η = 0.240 and 0.552 for α = 16°

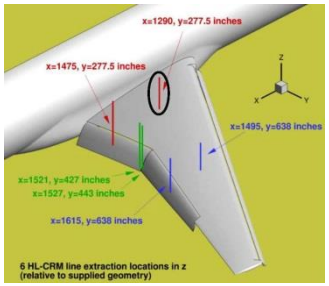


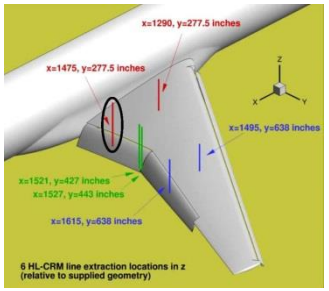


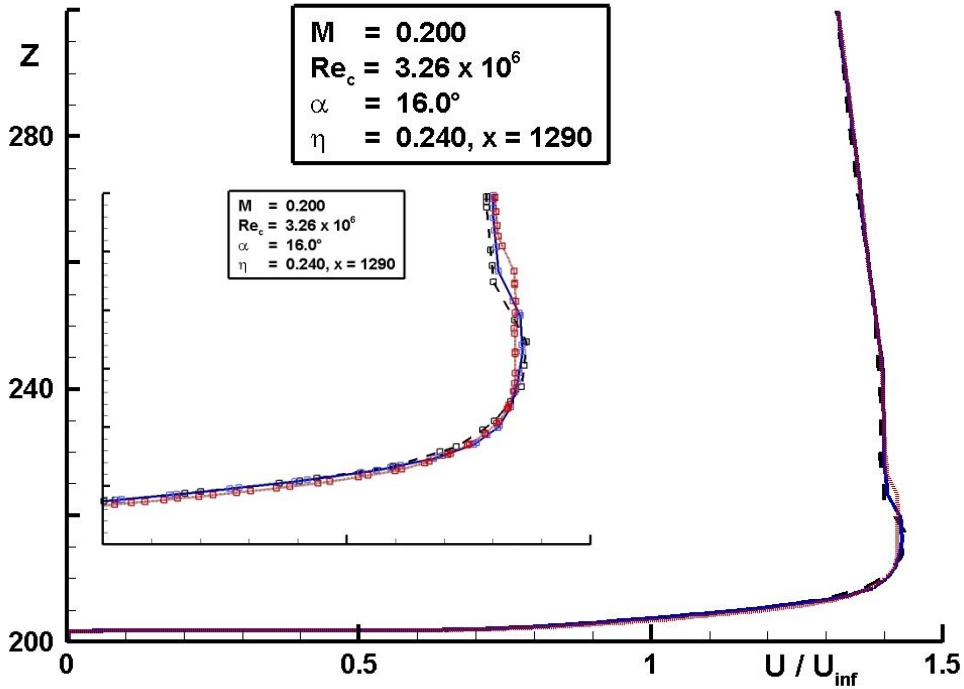


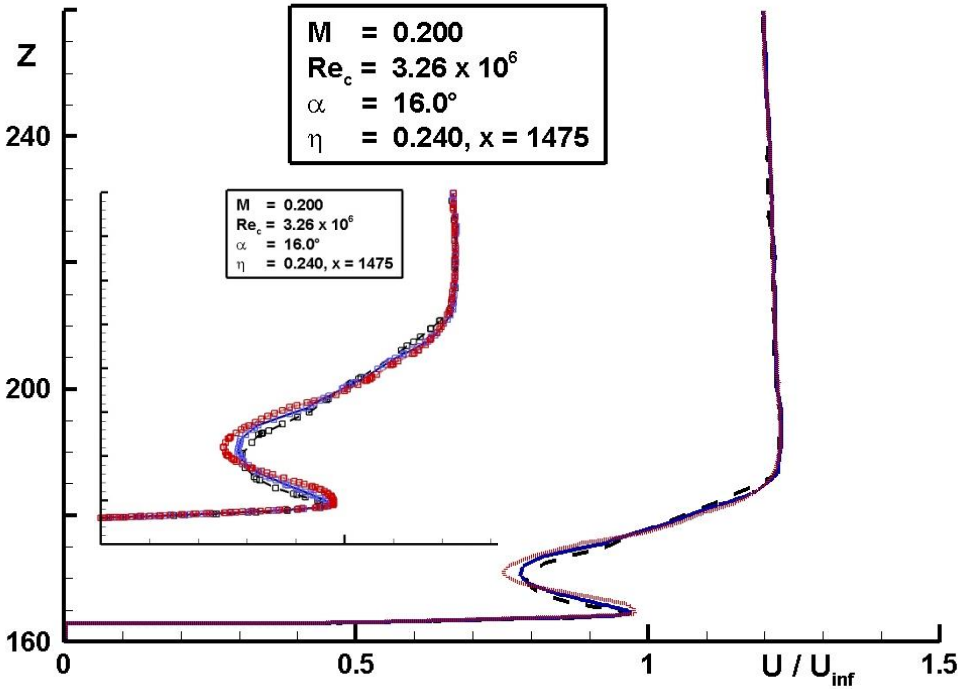
CRM-WB: DLR Computations on DLR Solar Grid Family

- **Grid resolution influence on velocity profiles; η = 0.240 for α = 16°**



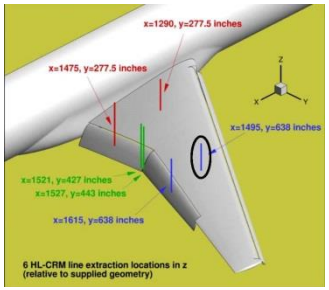


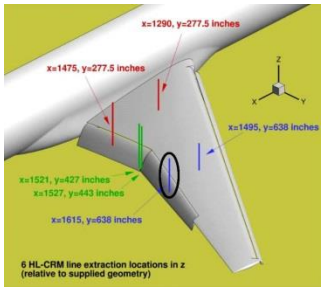


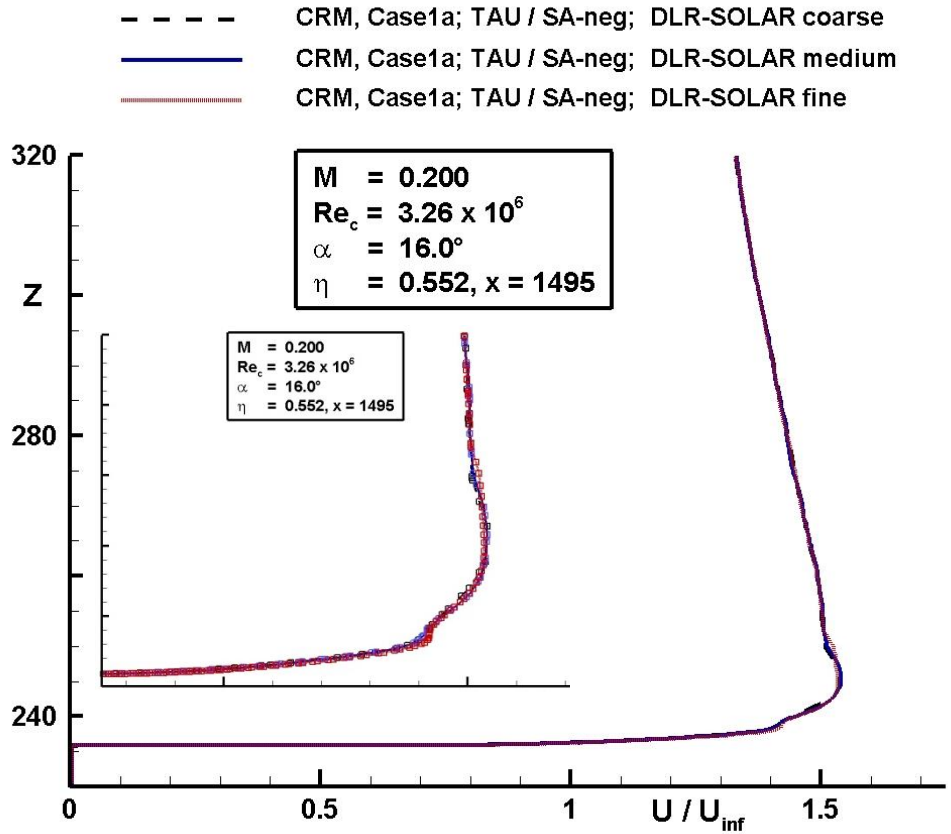


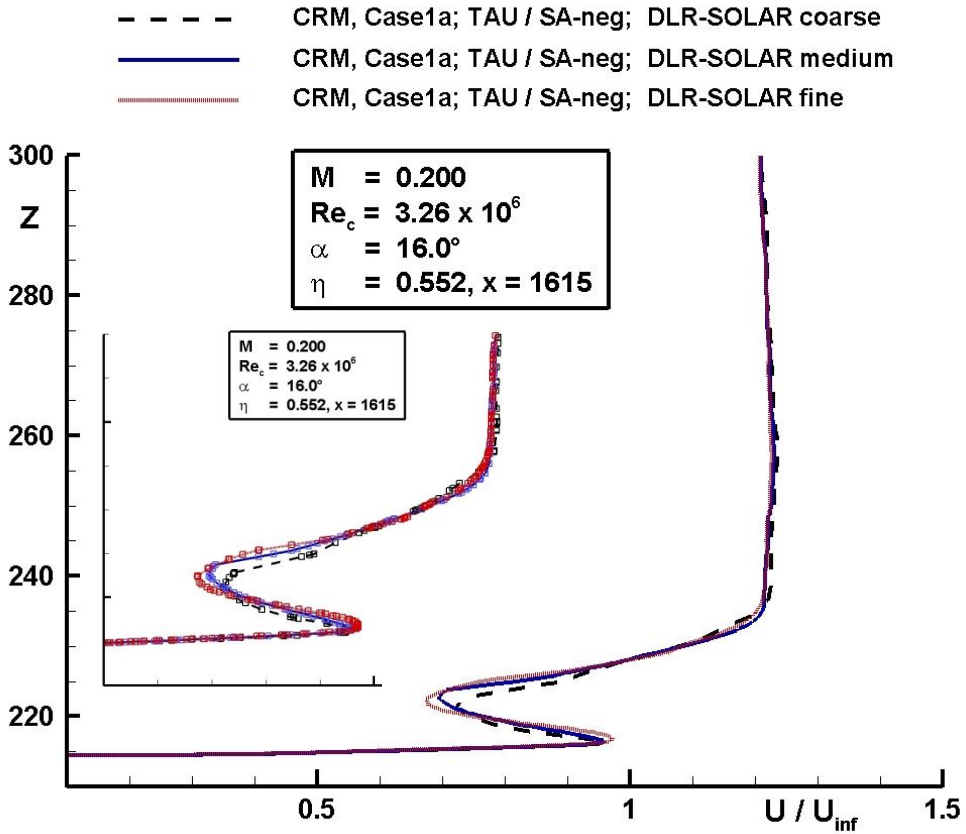
CRM-WB: DLR Computations on DLR Solar Grid Family

- **Grid resolution influence on velocity profiles; η = 0.552 for α = 16°**









Conclusion

- HL-CRM and JSM computed on SOLAR hybrid unstructured hex-dominant grids using a standard robust best practice numerical set-up of the TAU code
- JAXA-JSM Validation exercise carried out by DLR and ARA:
  - benchmark computation on DLR grid revealed considerable differences for widely identical solver settings
  - computations on respective partner grids reflect basically coarse grid resolution vs. medium grid resolution
  - good agreement w.r.t F & M and cp-distributions in the linear lift range
  - WB: significant over-prediction of $C_{L,max}$ (24 lcts.) and α_{max} (2.5°) for finer grid, overprediction reduced on coarse grid
  - WBNP: good prediction of $C_{L,max}$ (4 lcts.) and for α_{max} (0.5°), only weakly affected by grid resolution
  - suction peaks better resolved on medium grid, agreement to experimental evidence depending on location better or worse (less dissip. should be target)
  - increments due to propulsion integration in F & M well captured up to α ~ 18° by medium grid, trends not captured by coarse grid

Conclusion

- JAXA-JSM Validation exercise carried out by DLR and ARA (cont.):
  - deviations between computed and measured lift breakdown observed at
    - o wing root
    - o downstream of nacelle (DLR)
    - o downstream of track # 8 (DLR & ARA), and track # 5 (ARA)

    specifically for a = 21.6°
  - reliable prediction of lift breakdown requires improved simulation of track impact and probably end and cut-out effects of the slat ()
  - in-depth study has been initiated

Conclusion

- **HL-CRM verification and grid refinement exercise carried out by DLR:**
  - **widely 2nd order behavior of F & M w.r.t. grid refinement for linear range (ΔC_L ~ 1 lcts. for $\alpha = 8°$ / ΔC_L ~ 2 lcts. for $\alpha = 16°$) for grid pt. no. variation of a factor of nearly 11**
  - **Refinement in cp-distributions and velocity profiles moderate form coarse to medium comparatively weak from medium to fine, most pronounced in suction peak**
  - **high quality surface grid resolution achieved**
  - **slat wakes probably underestimated due to missing resolution, improved grid quality for wake resolutions required (hex-blocks, topology) ⇨ under investigation**