Third Aerodynamics Prediction Challenge (APC-III)

Task 1

NASA-CRM aerodynamic prediction at cruise state and high angle of attack

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Content

Third Aerodynamic Prediction Challenge (APC-III)

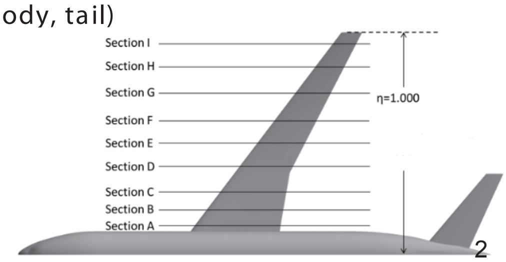
Task 1

NASA-Common Research Model (CRM[1]) aerodynamic prediction at cruise state and high angle of attack (presence of tail plane, wing deformation from measurement data).

→ Mach = 0.847
→ Re_{MAC} = 2.26E+06
→ AoA range = [-1.79, 5.72] deg.
1 mesh for each AoA (aeroelastic effect)
→ Tail incidence angle is 0 deg.

Deliverables

- Aerodynamic coefficient (C_D , C_L , C_m)
  → contribution of pressure and friction
  → contribution by components (main wing, body, tail)
- Surface Cp distribution
  → main wing
- Experimental data[3] for comparison
  → JAXA wind tunnel test data
  → Aerodynamic coefficient (C_D , C_L , C_m)
  → Surface C_p distribution
  → Deformation amount



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Introduction

Scope of study

The present report includes results for task 1 obtained on the NASA-CRM using **NUMECA FINE^{TM}/Open** CFD solver:

- Finite volume discretization
- Cell centred, 2nd order central scheme
- Scalar or Matrix numerical dissipation
- Initial conditions: freestream values
- CPUBooster^{TM} convergence acceleration technique on fine grid

Grids, provided by JAXA, take into account wing deformation data due to lift. Two meshing approaches are considered:

- **Structured hexahedral** (referred to as '**upacs**' within APC-III website)
  - 3 grid levels with Full-Multigrid
- **Unstructured hybrid** tet-dominant (referred as '**megg3d**' within APC-III website)
  - 4 grid levels with Full-Multigrid

Several turbulence models are tested:

- Linear Eddy Viscosity Turbulence Models
  - Spalart-Allmaras One-Equation Model with f_{v3} Term[4-5] (SA-fv3)
  - Menter SST Two-Equation Model from 2003[4-6] (SST-2003)
  - K-Epsilon Two-Equation Model by Yang-Shih[7] (KE-YS-1993)
- Non Linear Eddy Viscosity Turbulence Models
  - Explicit Algebraic Reynolds Stress Model proposed by Menter et al. (2009), which is based on the BSL k-ω model of Menter (1994) and allows the inclusion of anisotropic effects into the turbulence model[8]. (SBSL-EARSM)
  - Separation Sensitive Corrected Explicit Algebraic Reynolds Stress Model, developed and introduced by Numeca in 2016 from SBSL-EARSM with the aim of better predicting separated flows[9]. (SSC-EARSM)

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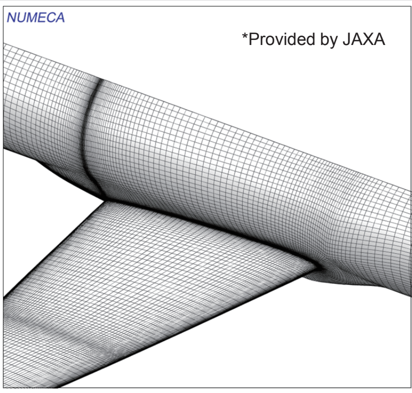
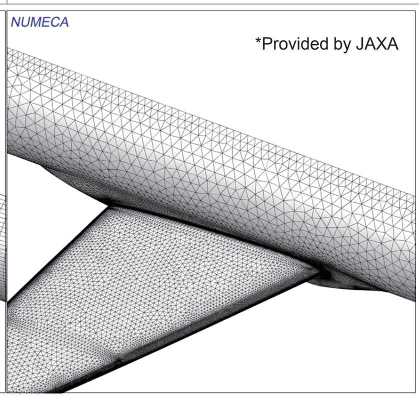
Grids description

	Structured (upacs)	Unstructured (megg3d)
Cell count	9,145,023	29,976,421
Min. orthogonality [deg.]	9.64	3.02
Max. skewness	0.933	0.999
Max. adjacent volume ratio	7.20	293.21
Max. expansion ratio	6.89	223.27





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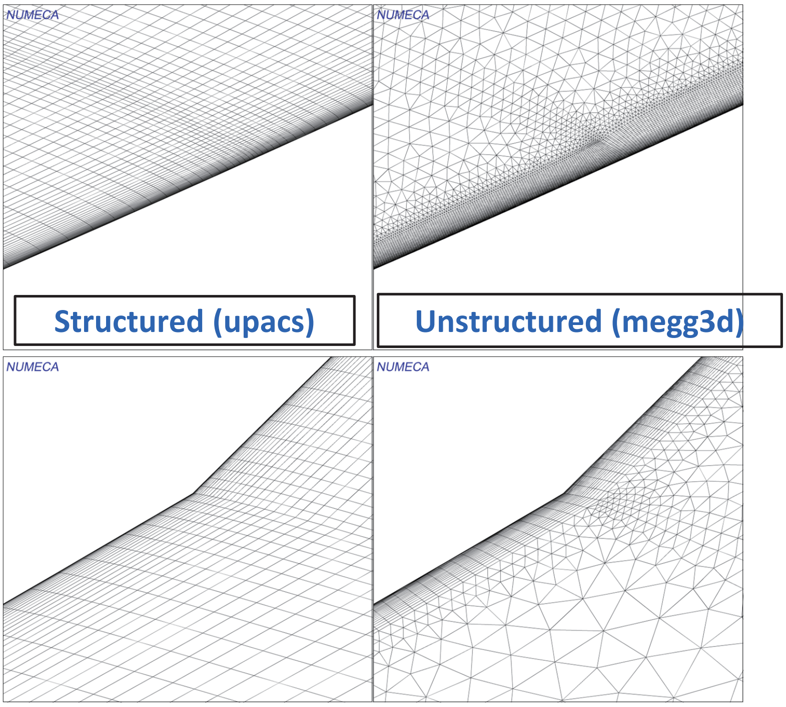
Grids description

Wing leading egde

Wing trailing egde



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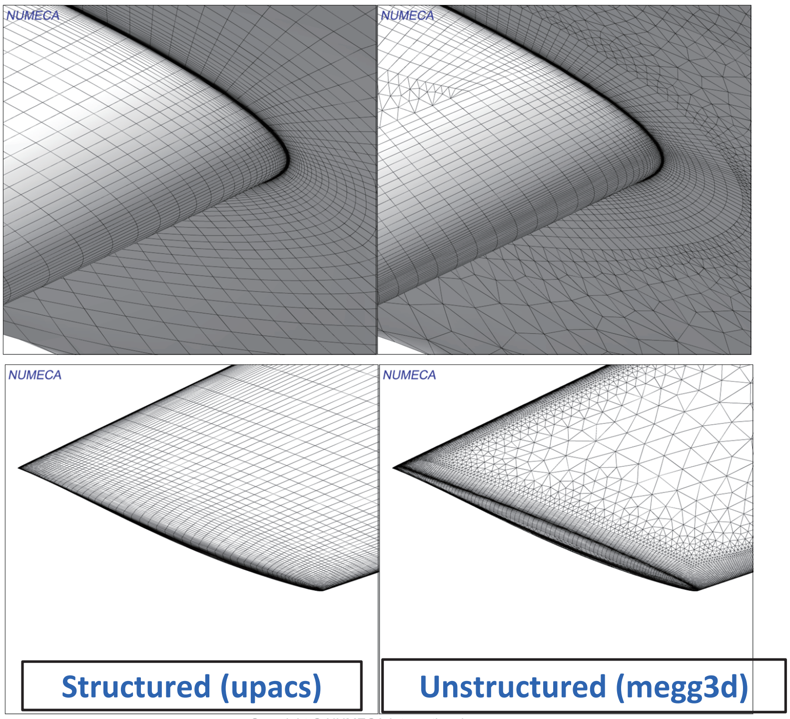
Grids description

Wing root leading edge

Wing tip



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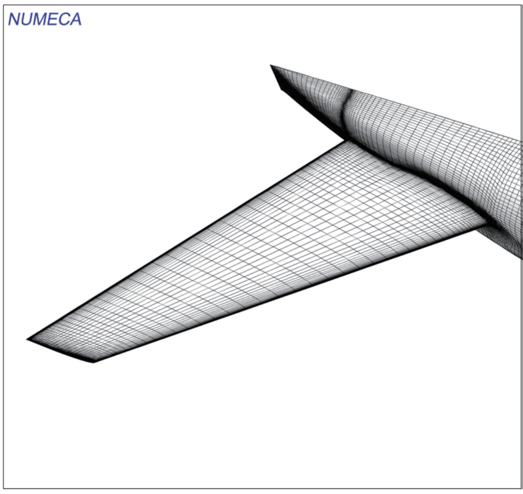
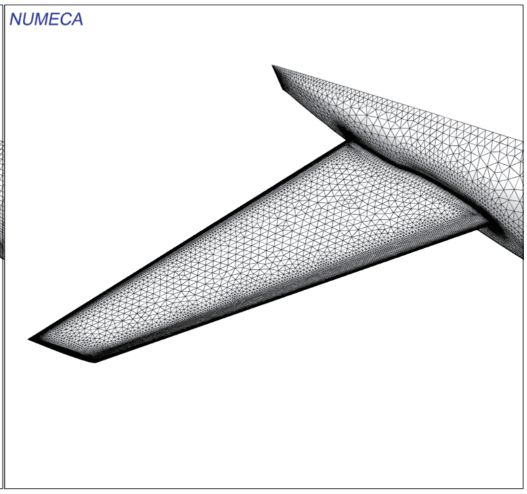
Grids description

Structured (upacs) | **Unstructured (megg3d)**

Tail plane





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Results

RESULTS
UNSTRUCTURED(megg3d) MESHES

Turbulence models:

- SA-fv3
- SST-2003
- KE-YS-1993
- SBSL-EARSM
- SSC-EARSM

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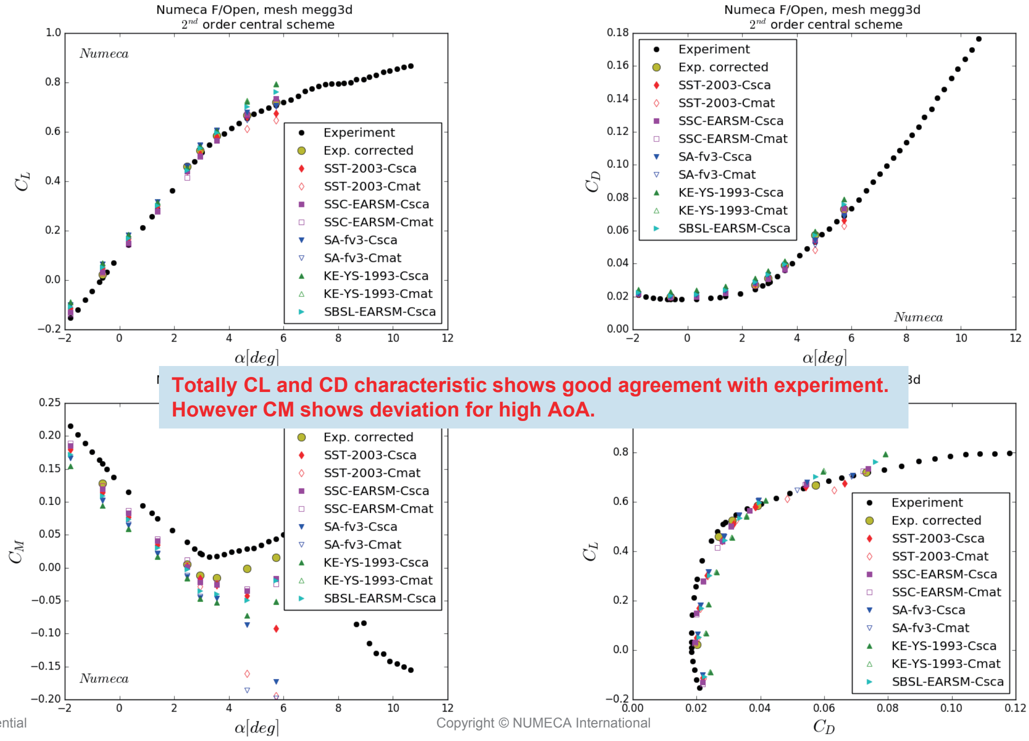
RESULTS – UNSTRUCTURED(megg3d)

Aerodynamic Forces



Totally CL and CD characteristic shows good agreement with experiment.
However CM shows deviation for high AoA.

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Results

Wing Pressure Coefficient Cuts
AoA = 0.32, 2.47, 3.55, 4.65 deg.
Unstructured(megg3d) meshes

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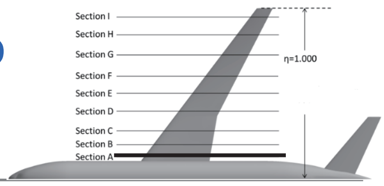
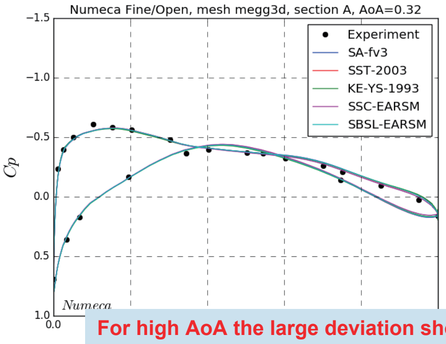
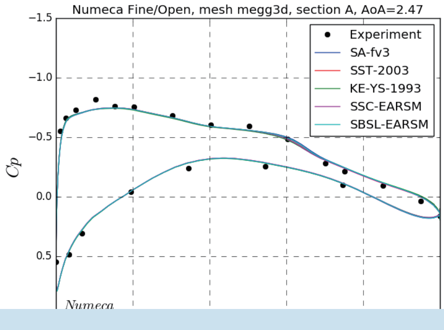
RESULTS – UNSTRUCTURED (megg3d)

Cp wing cuts section A

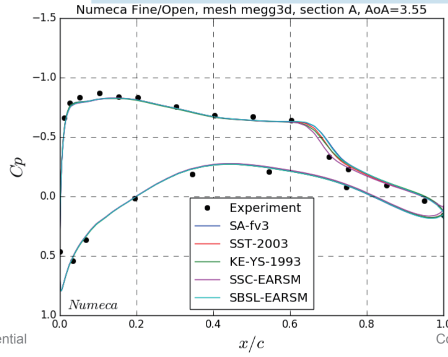


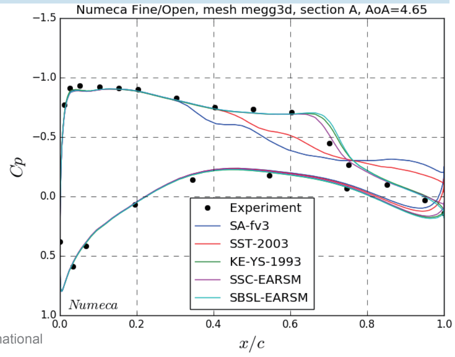
2nd order central scheme, scalar dissipation





For high AoA the large deviation shows.
SSC-EARSM turbulence model shows good agreement with experiment for wide range of AoA.





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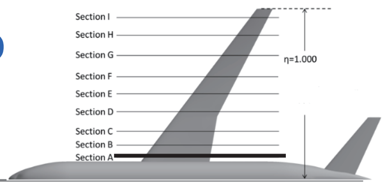
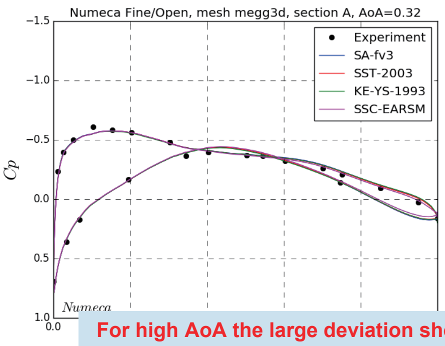
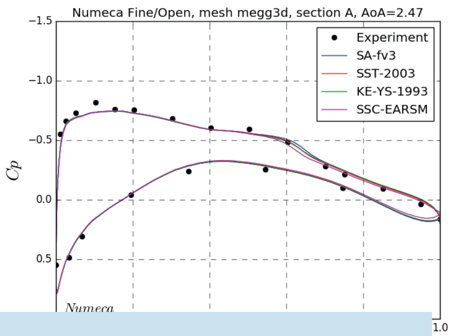
RESULTS – UNSTRUCTURED (megg3d)

Cp wing cuts section A



2nd order central scheme, matrix dissipation





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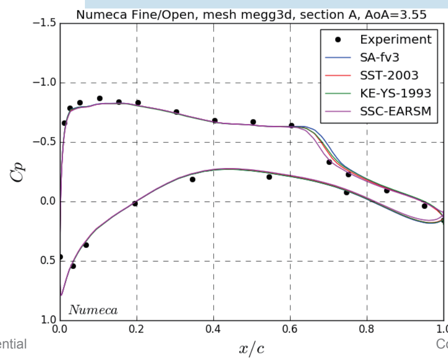

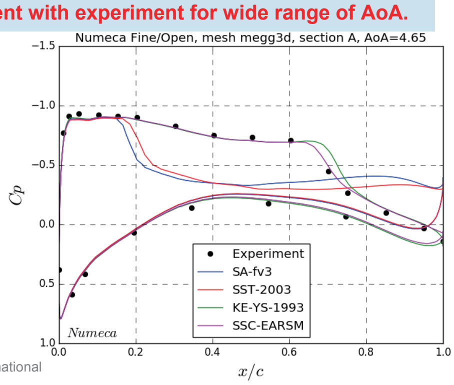

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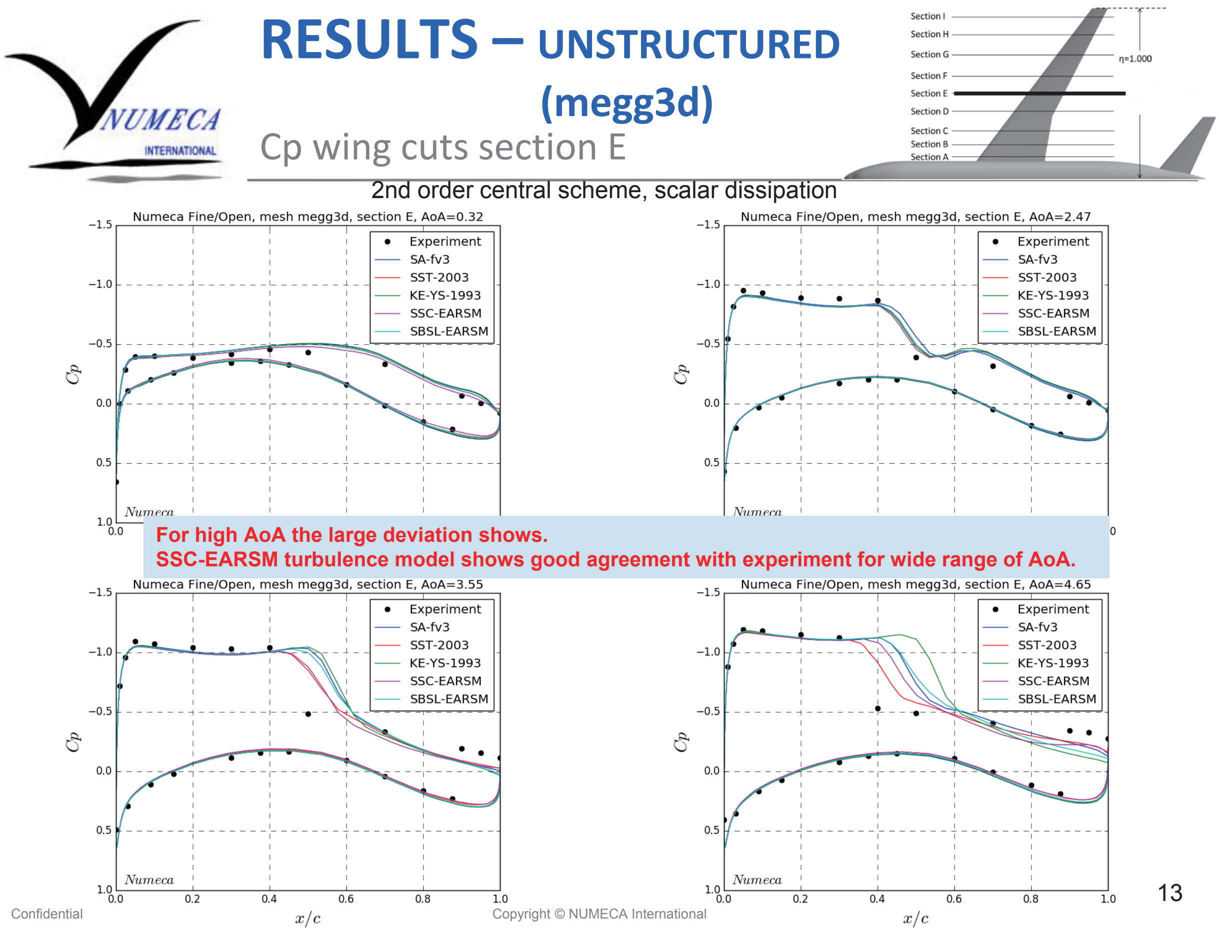

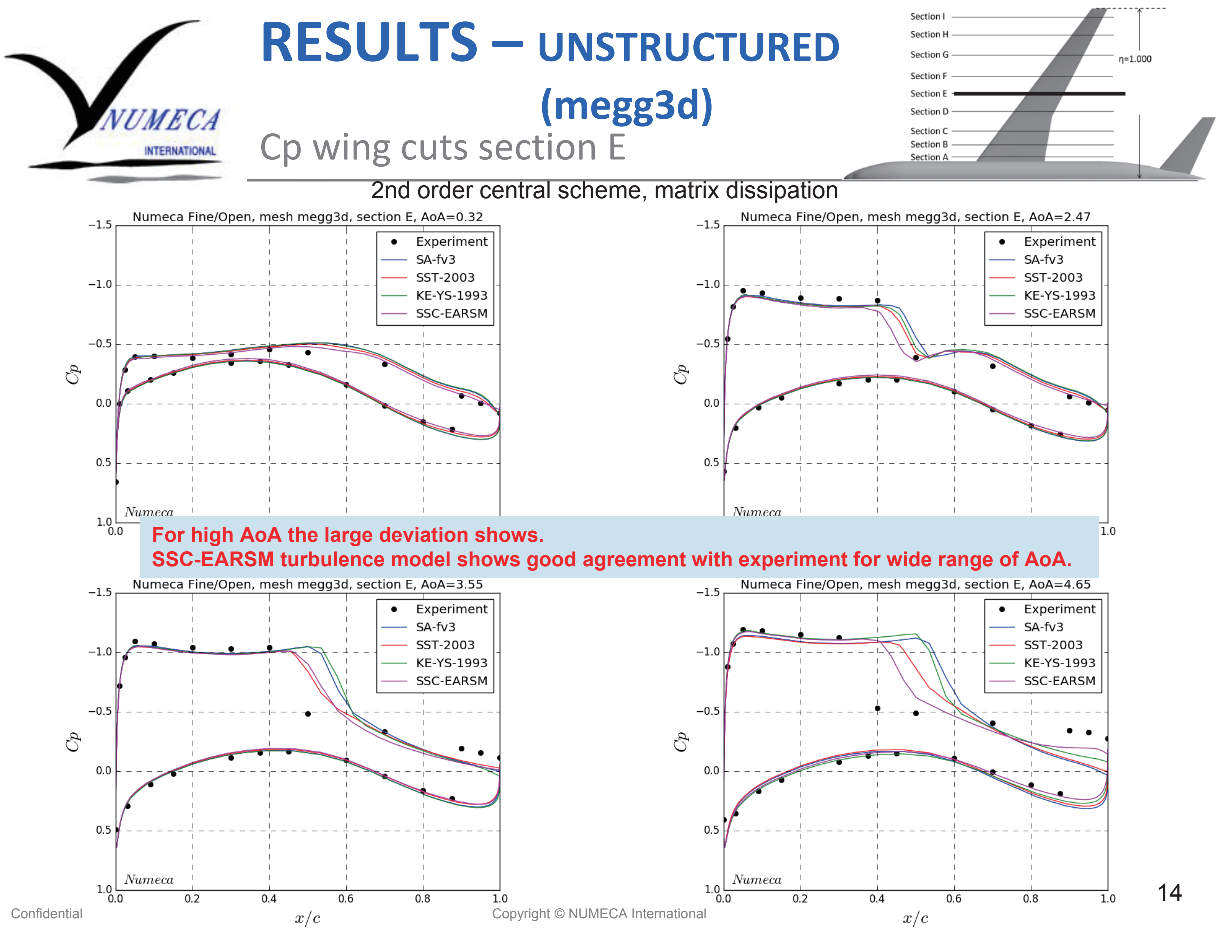

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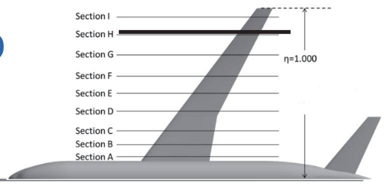
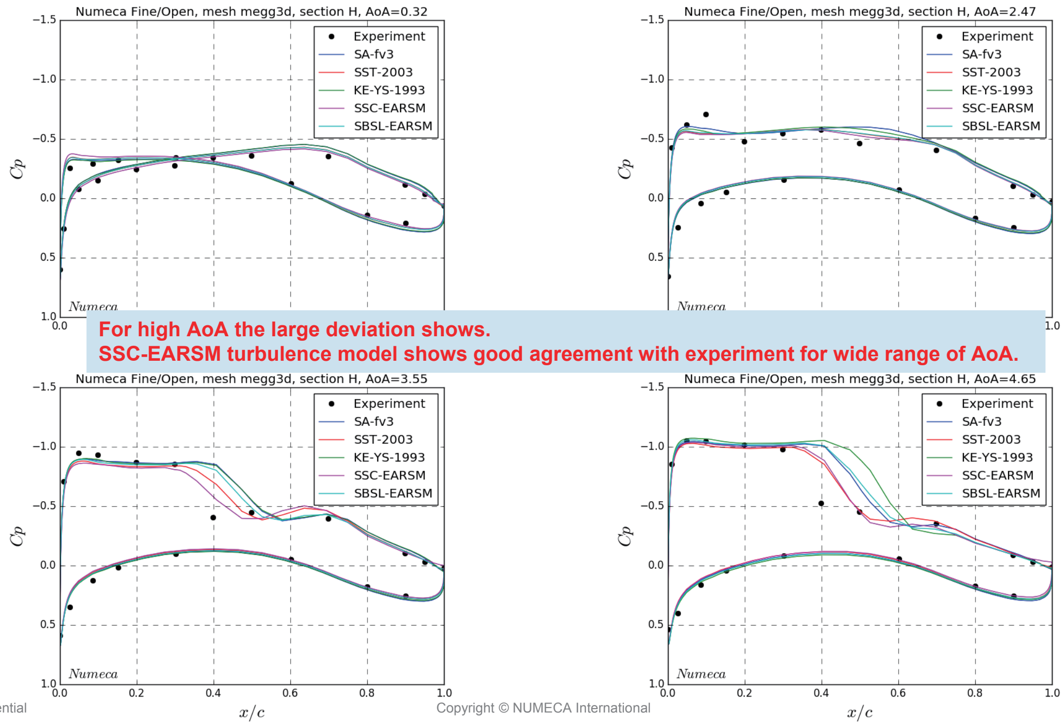
RESULTS – UNSTRUCTURED (megg3d)

Cp wing cuts section H



2nd order central scheme, scalar dissipation



For high AoA the large deviation shows.
SSC-EARSM turbulence model shows good agreement with experiment for wide range of AoA.

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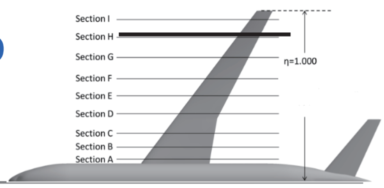
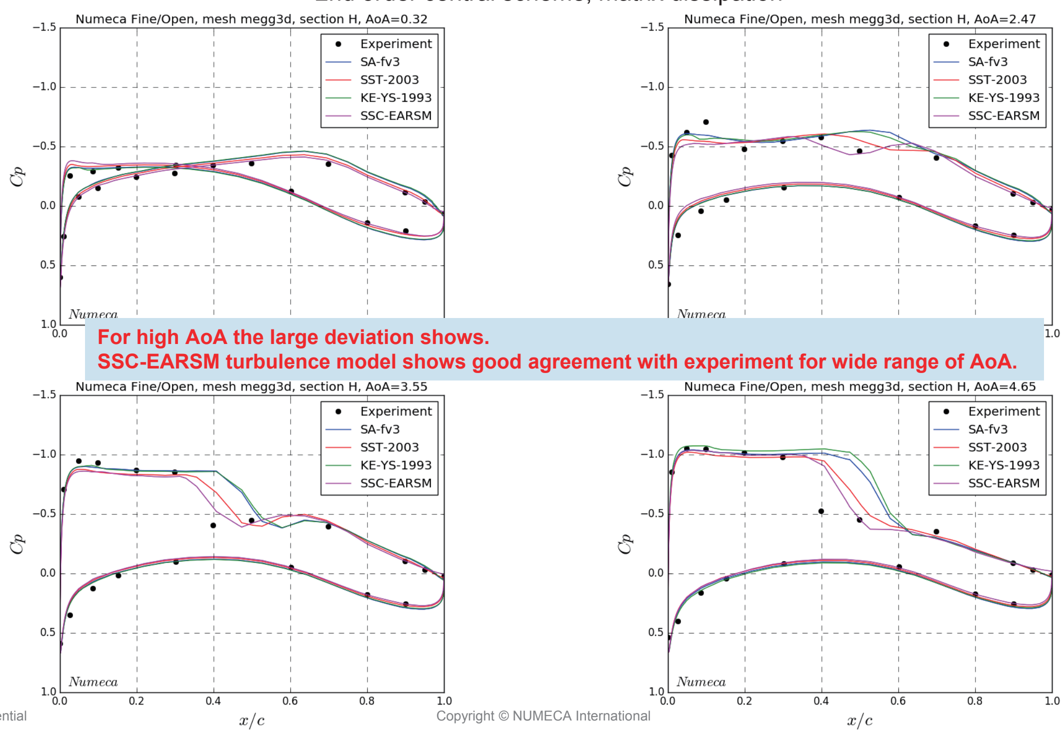
RESULTS – UNSTRUCTURED (megg3d)

Cp wing cuts section H



2nd order central scheme, matrix dissipation



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Results

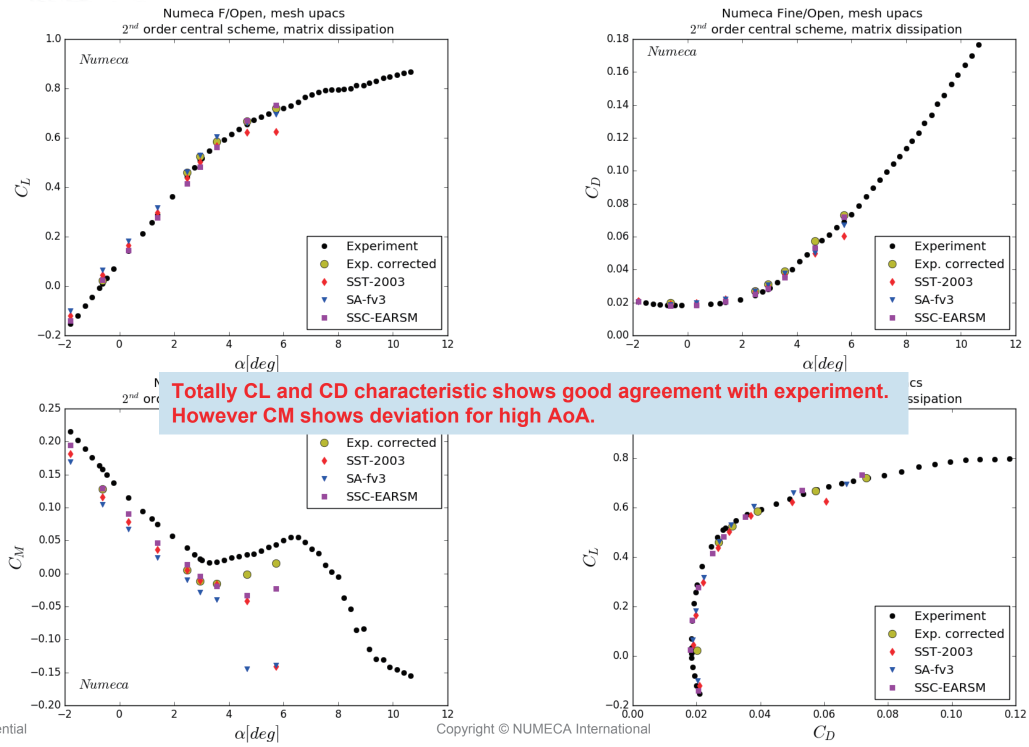
RESULTS
STRUCTURED(upacs) MESHES

Turbulence models:

- SA-fv3
- SST-2003
- SSC-EARSM

RESULTS – STRUCTURED(upacs)

Aerodynamics Forces



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Results

Wing Pressure Coefficient Cuts
AoA = 0.32, 2.47, 3.55, 4.65 deg.
Structured(upacs) meshes

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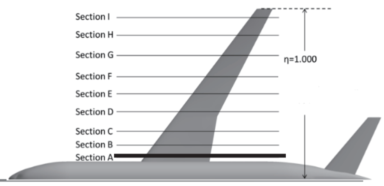
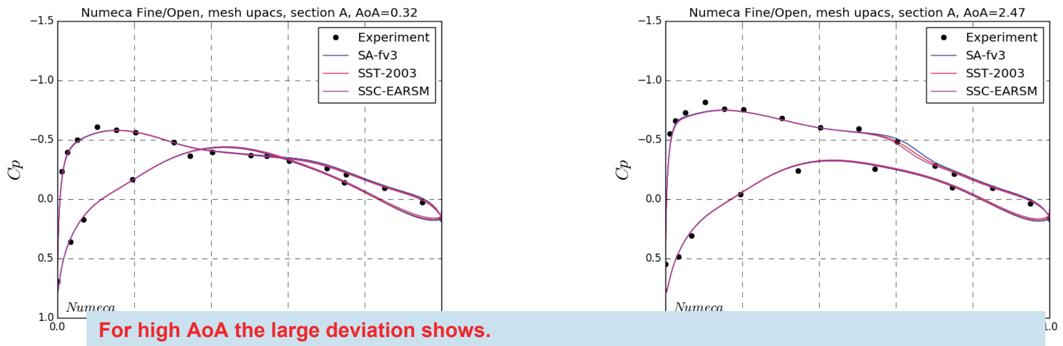
RESULTS - STRUCTURED (upacs)

Cp wing cuts section A





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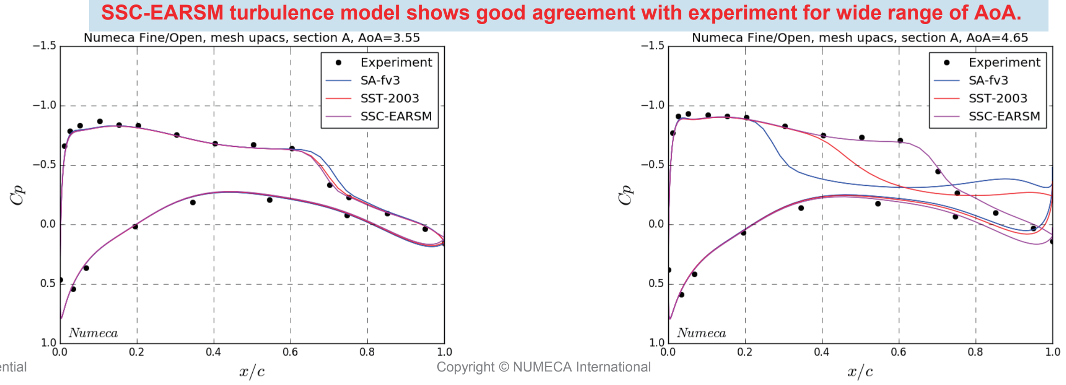

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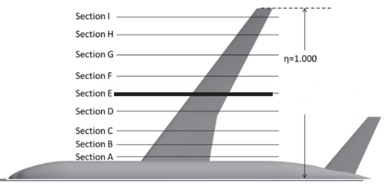
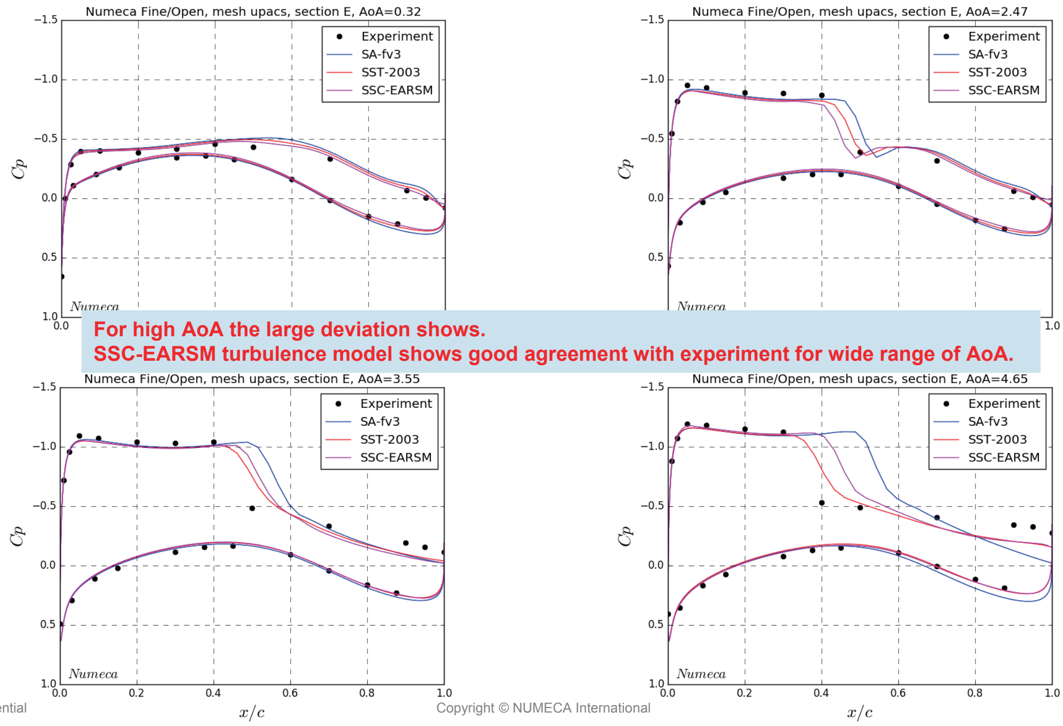
RESULTS - STRUCTURED (upacs)

Cp wing cuts section E





For high AoA the large deviation shows.
SSC-EARSM turbulence model shows good agreement with experiment for wide range of AoA.

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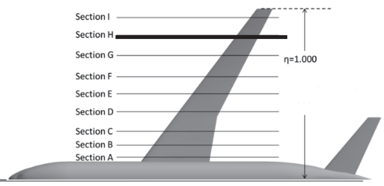
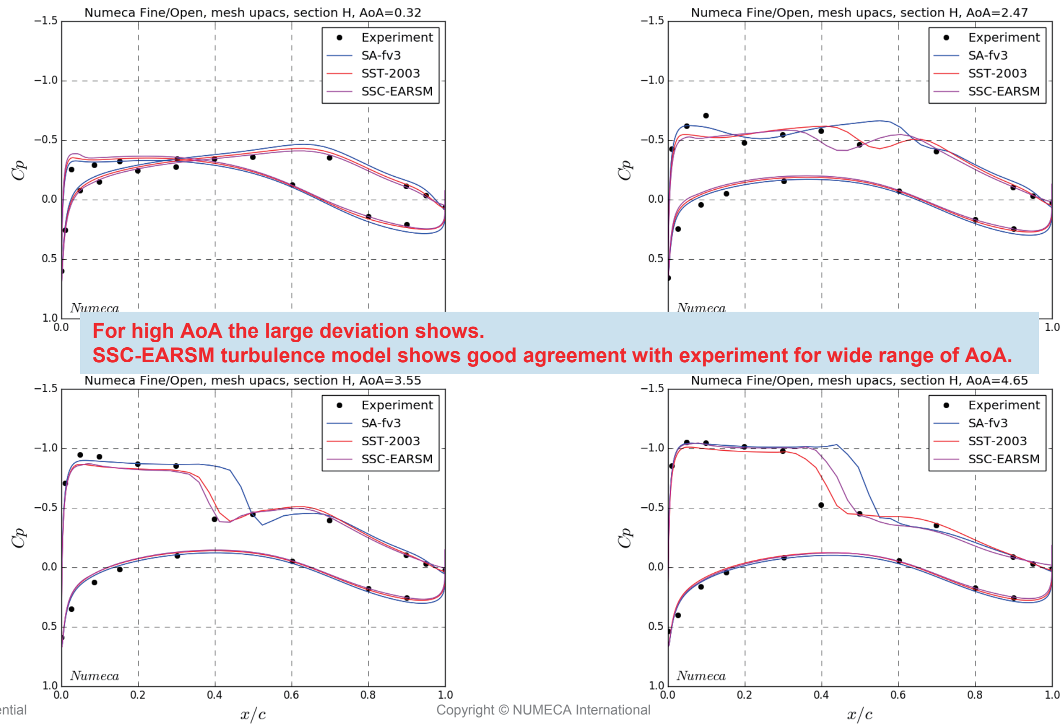
RESULTS - STRUCTURED (upacs)

Cp wing cuts section H





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Analysis of Results

Analysis of flow over wing suction side
At high angle of attack
AoA = 4.65 deg.
Structured(upacs) vs.
Unstructured(megg3d) meshes

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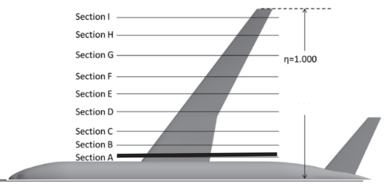
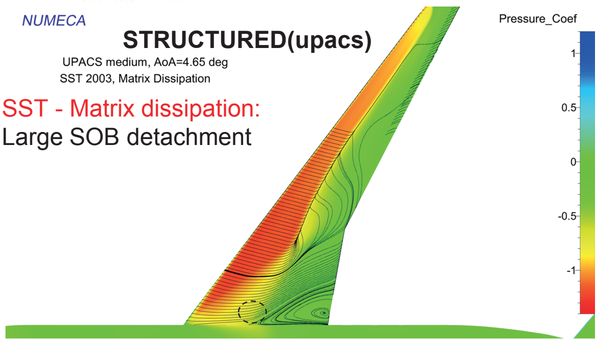
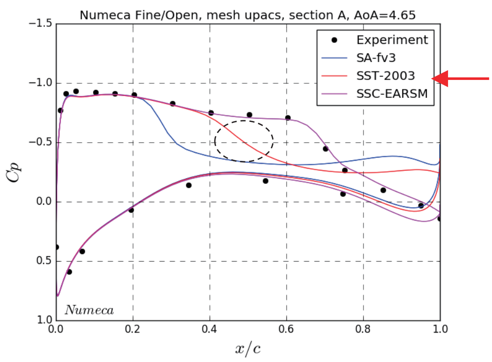
WING FLOW

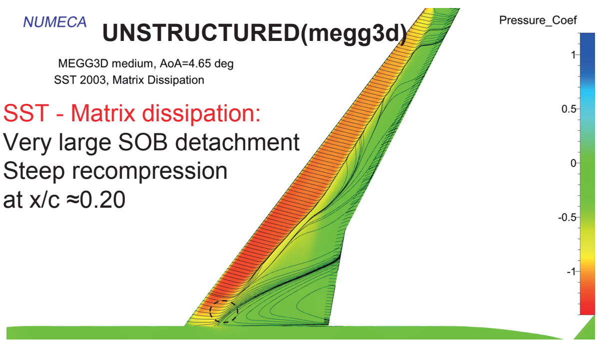
SST-2003, Mesh effect



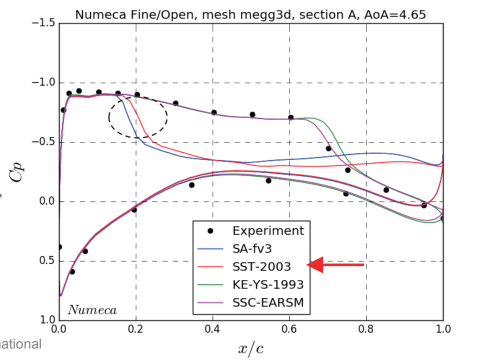


SST - Matrix dissipation:
Large SOB detachment





SST - Matrix dissipation:
Very large SOB detachment
Steep recompression
at x/c ≈0.20



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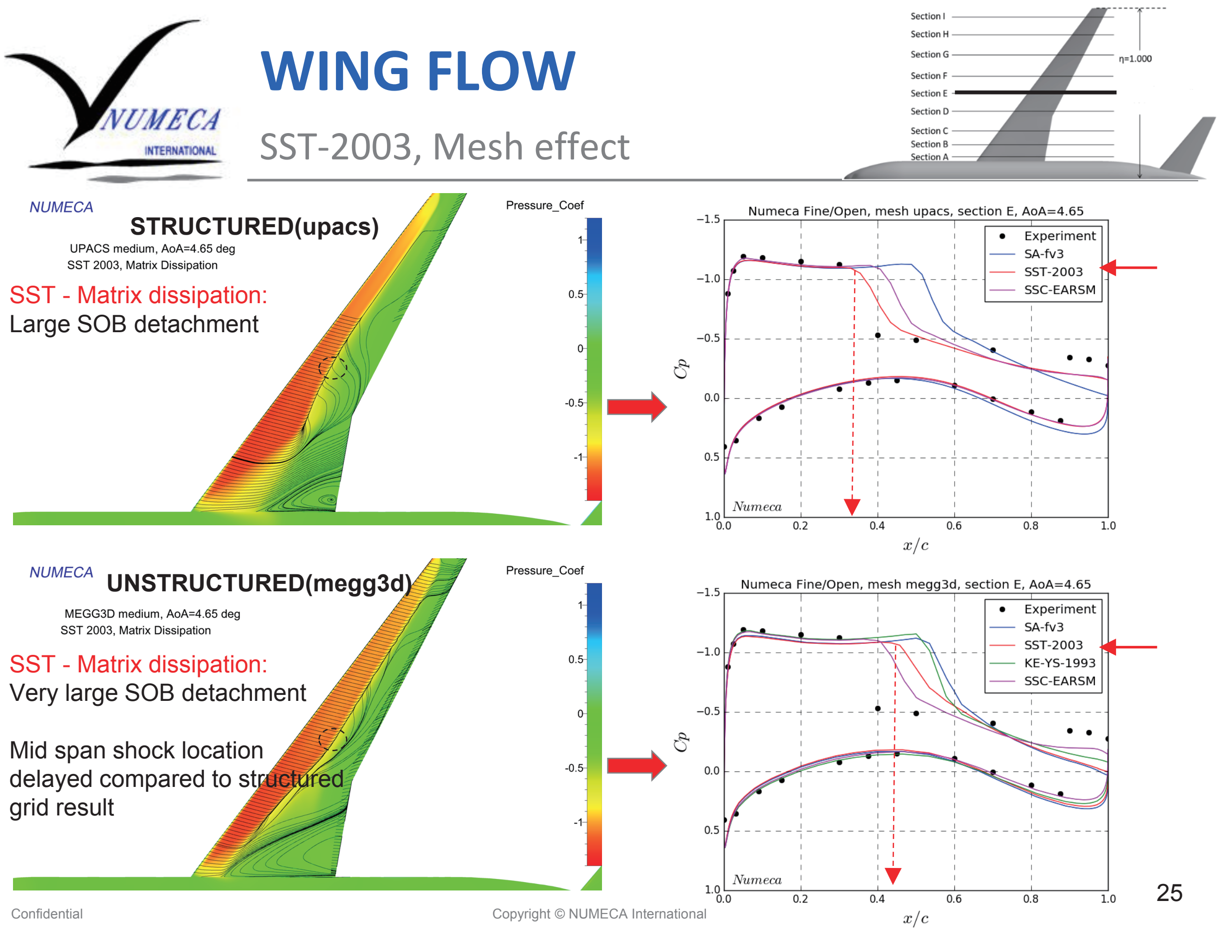

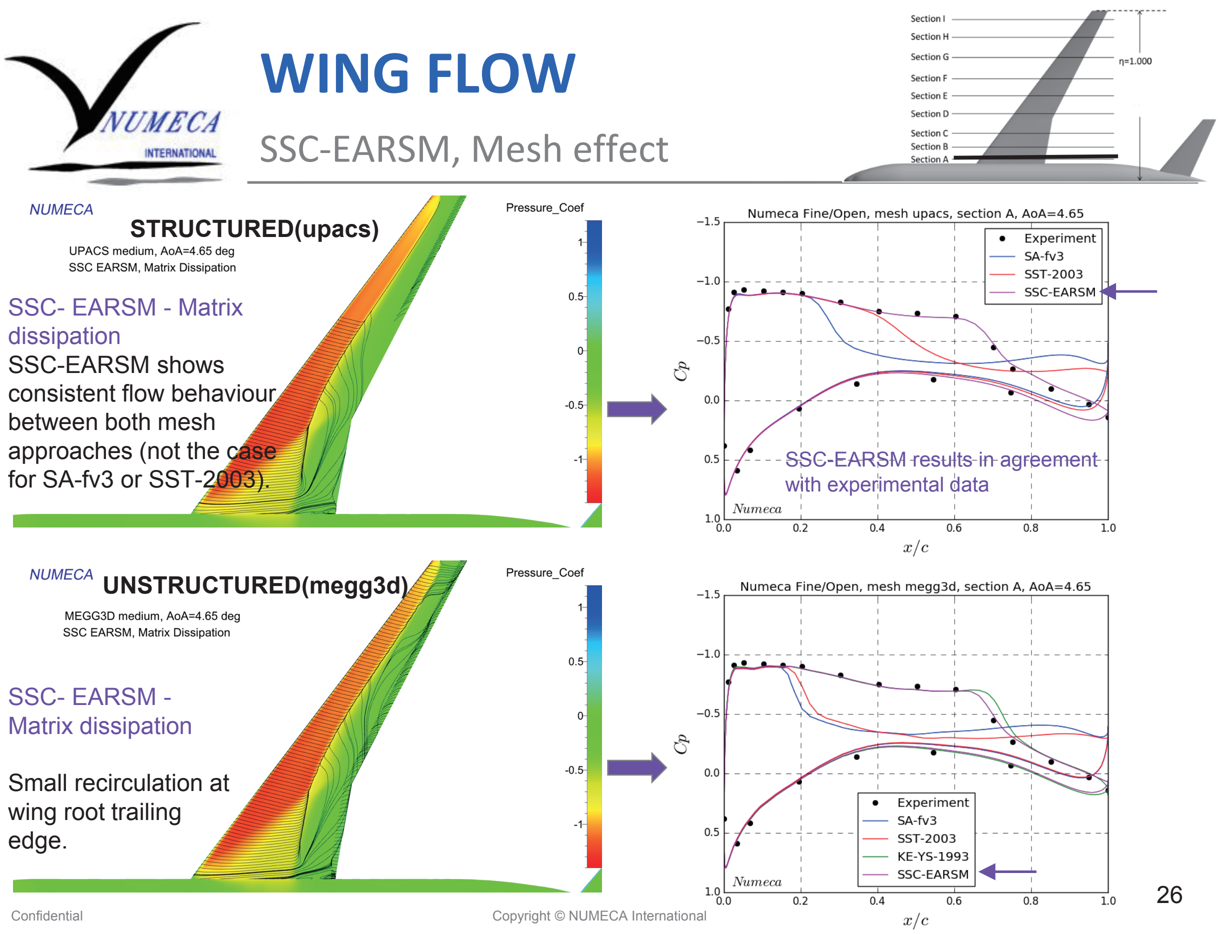

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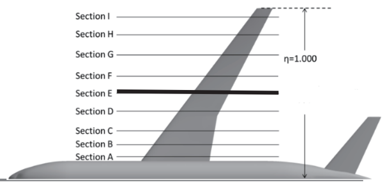
WING FLOW

SSC-EARSM, Mesh effect



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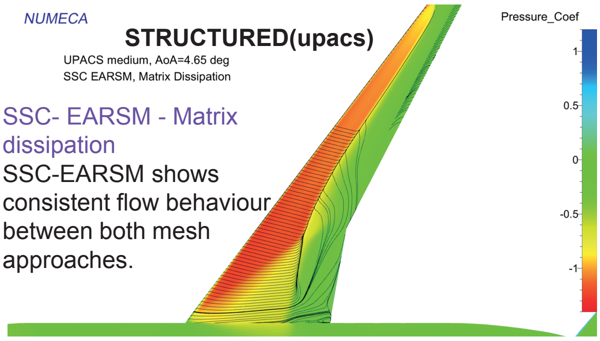
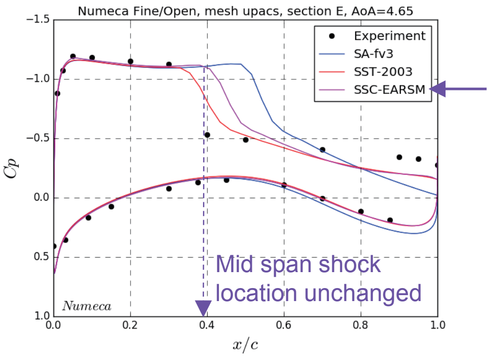
STRUCTURED(upacs)

UPACS medium, AoA=4.65 deg
SSC EARSM, Matrix Dissipation

SSC- EARSM - Matrix dissipation

SSC-EARSM shows consistent flow behaviour between both mesh approaches.





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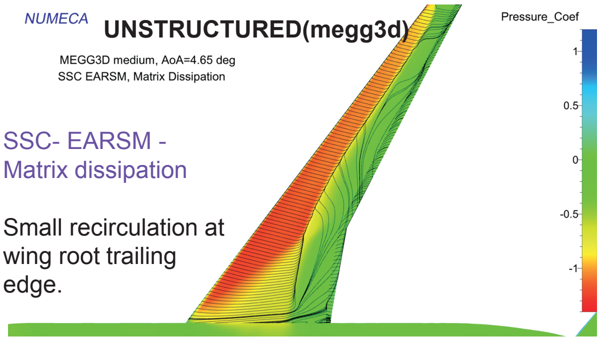
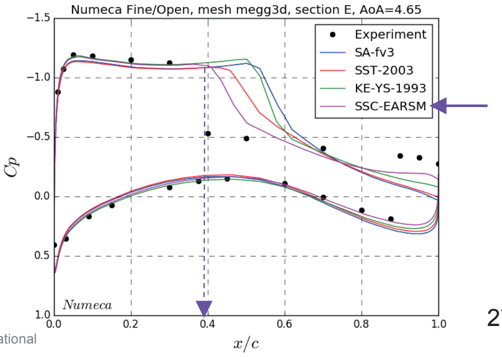
UNSTRUCTURED(megg3d)

MEGG3D medium, AoA=4.65 deg
SSC EARSM, Matrix Dissipation

SSC- EARSM - Matrix dissipation

Small recirculation at wing root trailing edge.





SUMMARY

Third Aerodynamic Prediction Challenge (APC-III)

- We performed 12 sets of CFD simulations using NUMECA FINE/Open solver.
- For high angle of attack (AoA), CFD results show large deviation for any sections.
- SSC-EARSM (Separation Sensitive Corrected Explicit Algebraic Reynolds Stress Model) turbulence model relatively shows good agreement with experiment even for high AoA. Moreover it hardly shows dependence on the mesh element.
- SSC-EARSM turbulence model was developed through the ANADE project (Advances in Numerical and Analytical tools for Detached flow prediction) under grant contract PITN-GA-289428.
- SSC-EARSM model is based on the SBSL-EARSM model of Menter et al.(2012) and designed with the aim of better predicting separated flows.
- We have shown that SSC-EARSM is better choice as a turbulence model for wide range of AoA and both structured and unstructured mesh.

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Content

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Appendix

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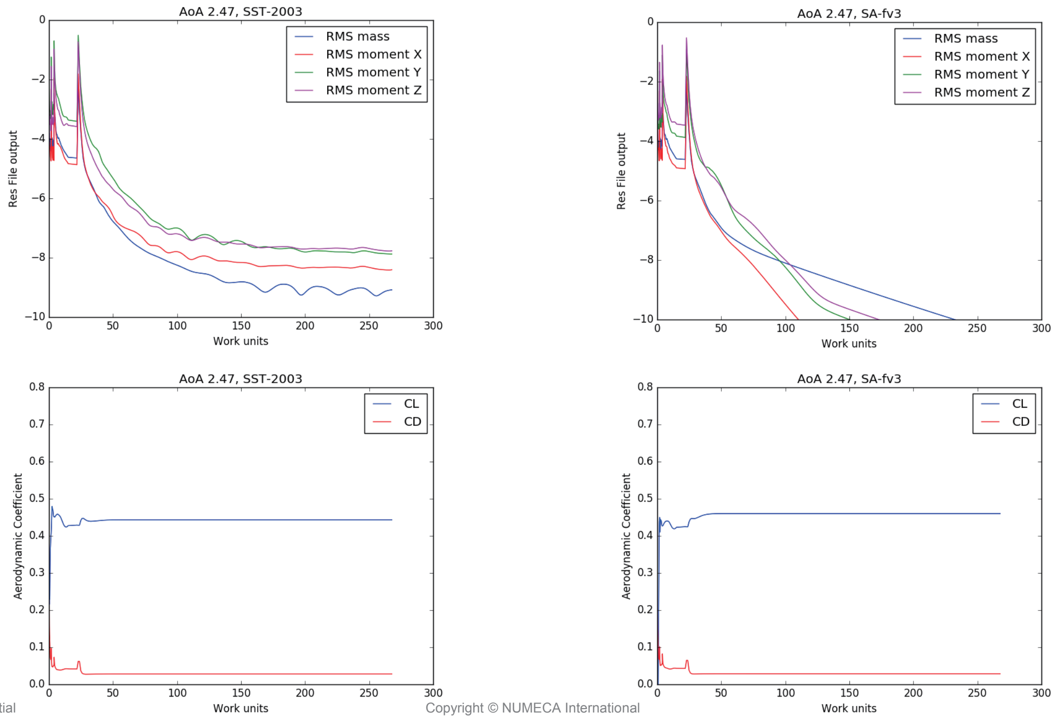
RESULTS – UNSTRUCTURED(megg3d)

Convergence history at AoA=2.47 deg. (scalar dissipation)



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APC-III

Analysis of Results

Analysis of flow over wing suction side
At high angle of attack
AoA = 4.65 deg.
Unstructured(megg3d) meshes

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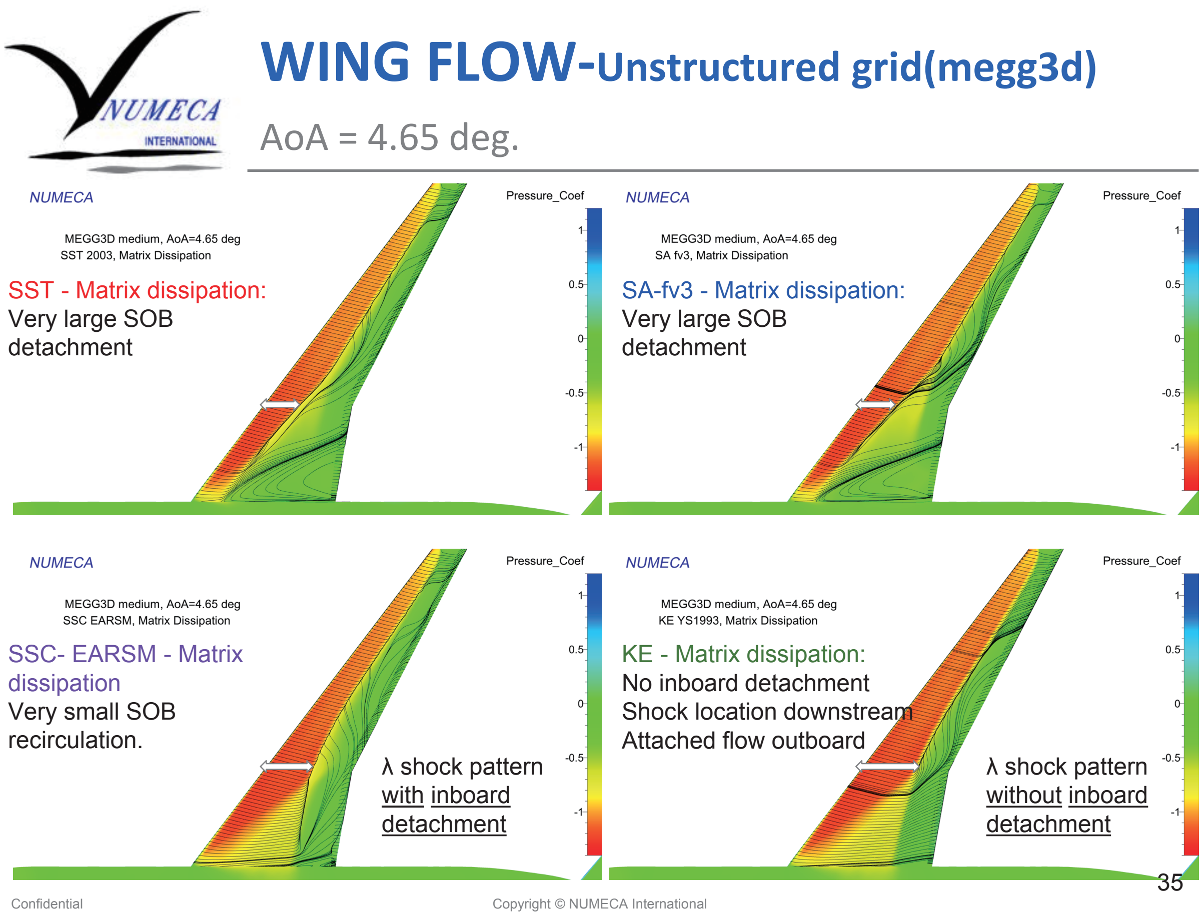

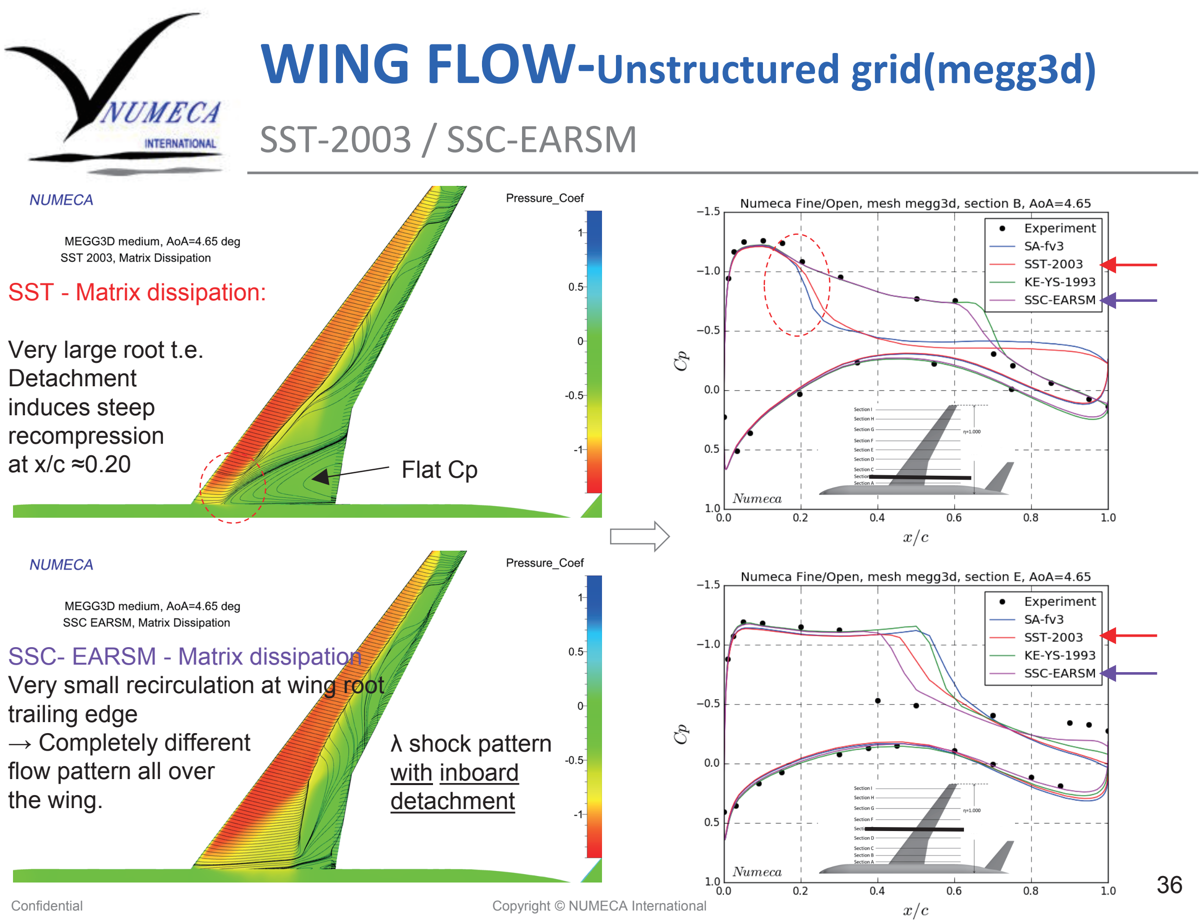

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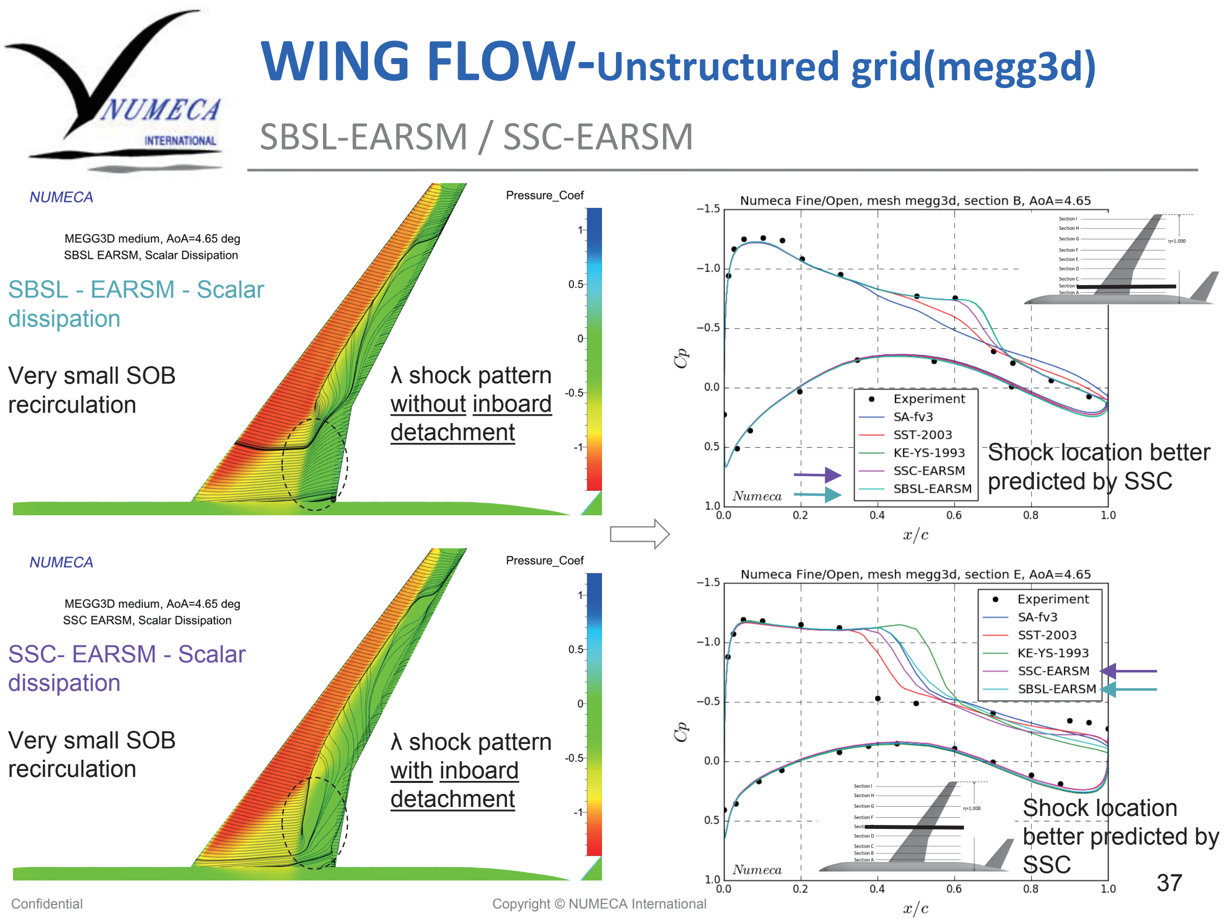

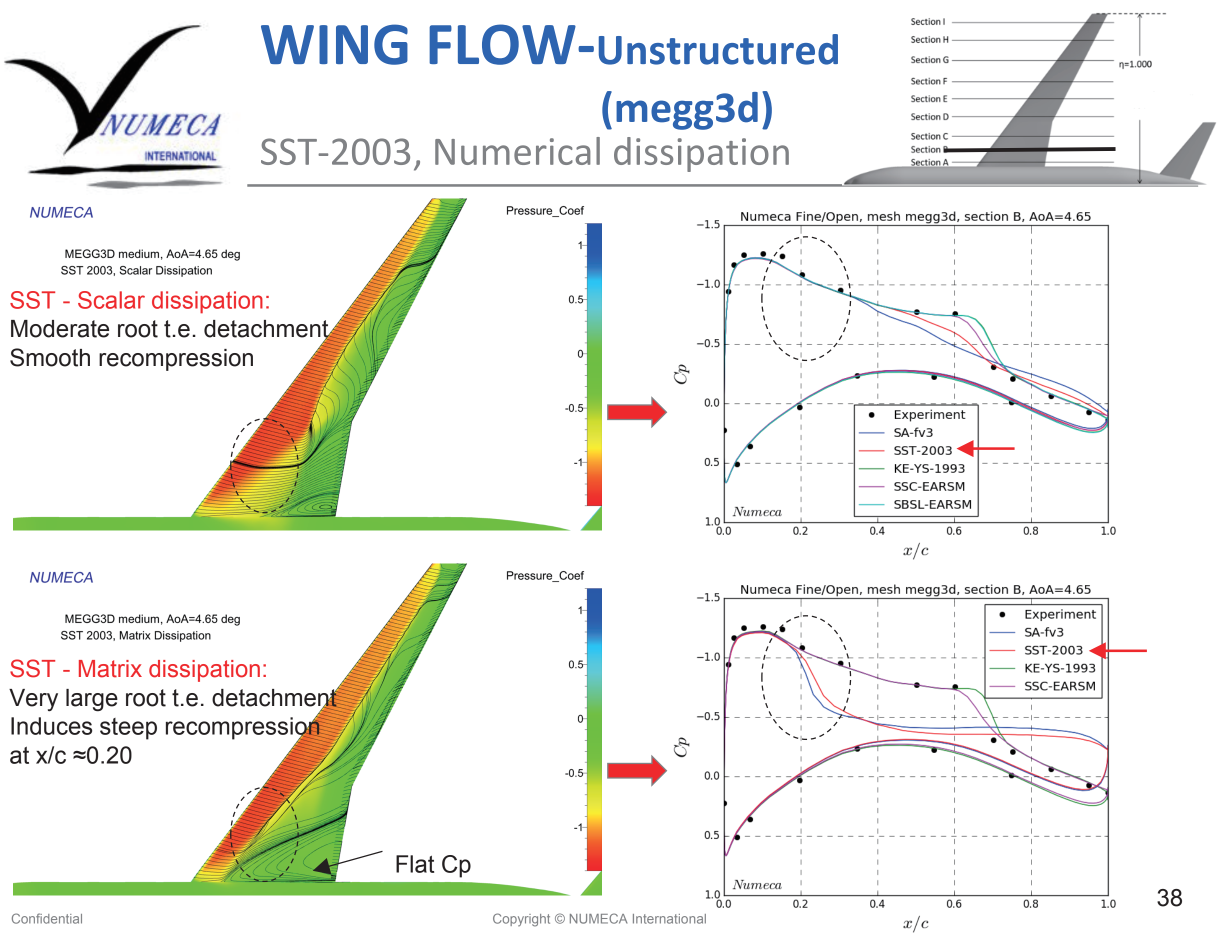

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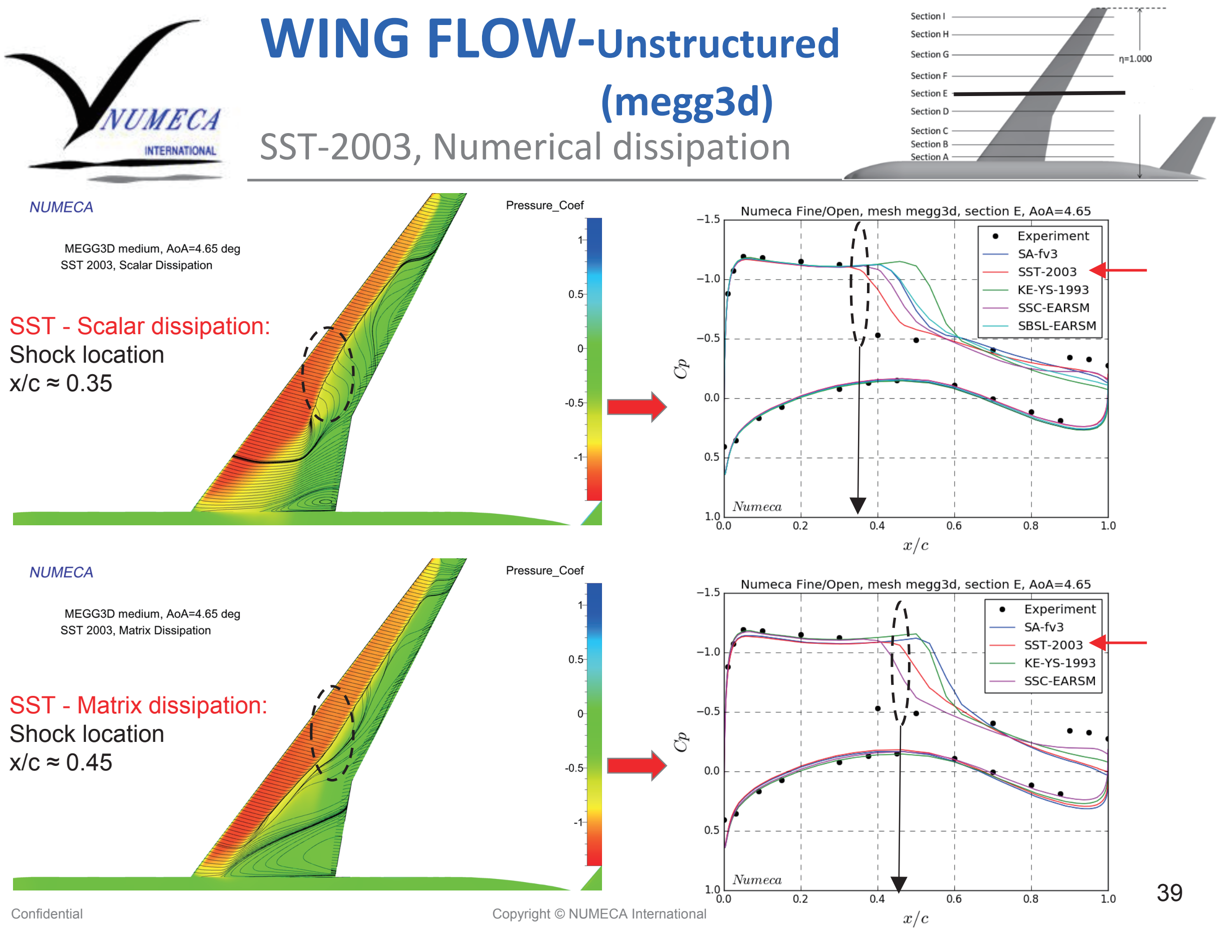

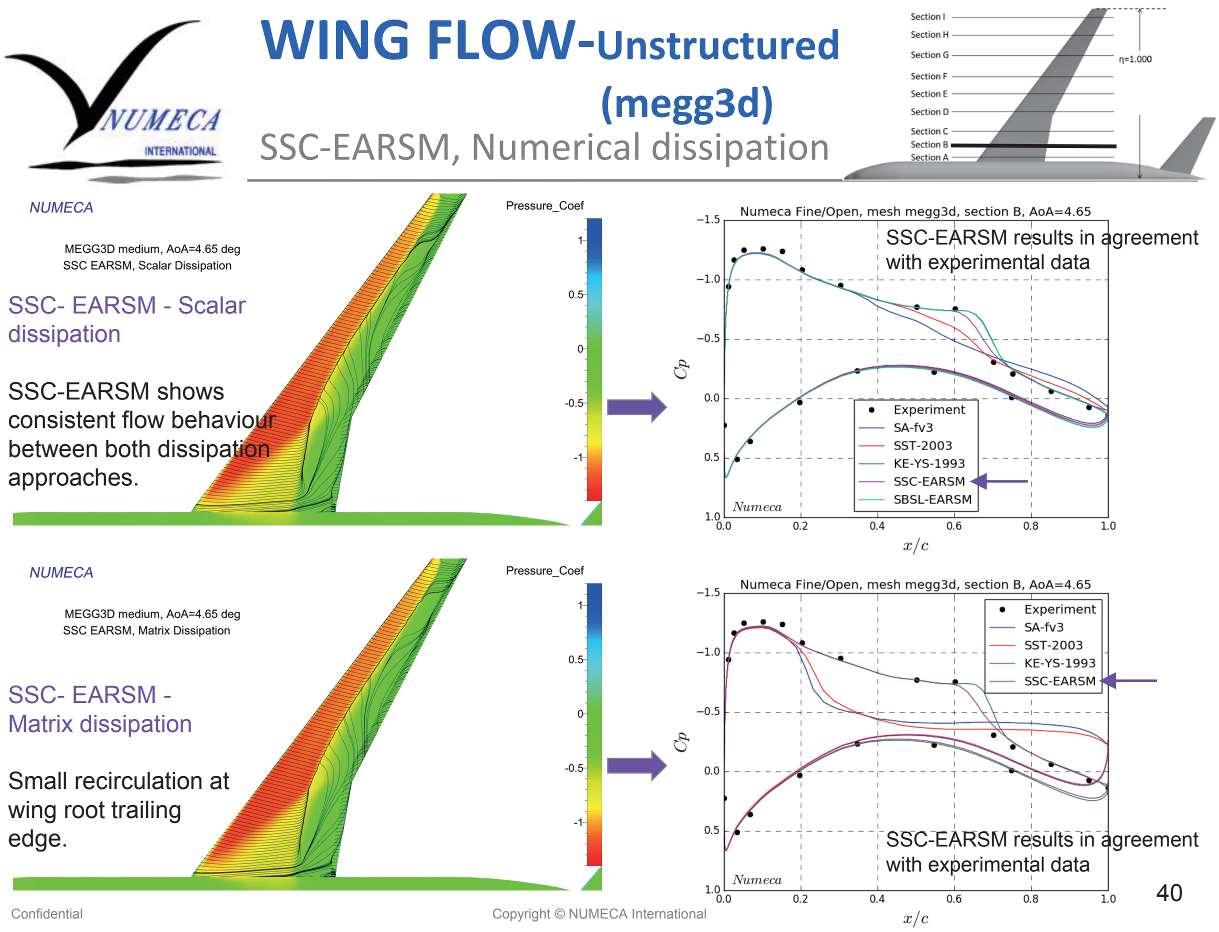

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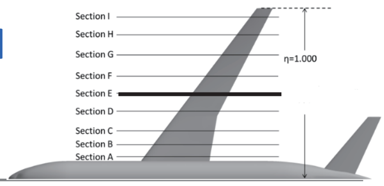
WING FLOW-Unstructured (megg3d)

SSC-EARSM, Numerical dissipation



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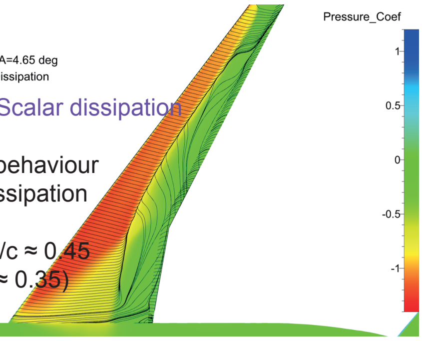
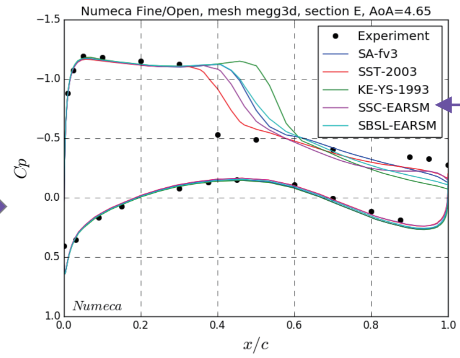
MEGG3D medium, AoA=4.65 deg
SSC EARSM, Scalar Dissipation

SSC- EARSM - Scalar dissipation

Consistent flow behaviour between both dissipation approaches.
Shock location x/c ≈ 0.45 (experiment x/c ≈ 0.35)





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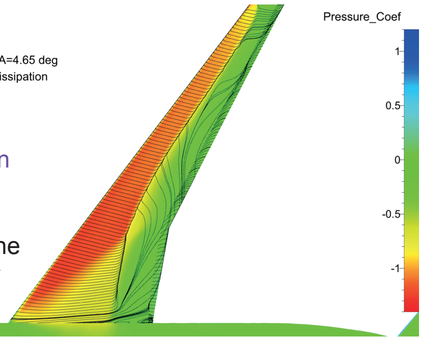
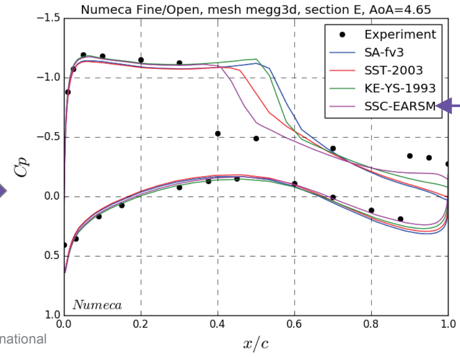
MEGG3D medium, AoA=4.65 deg
SSC EARSM, Matrix Dissipation

SSC- EARSM - Matrix dissipation

Same size of recirculation at the t.e. of wing-body intersection.





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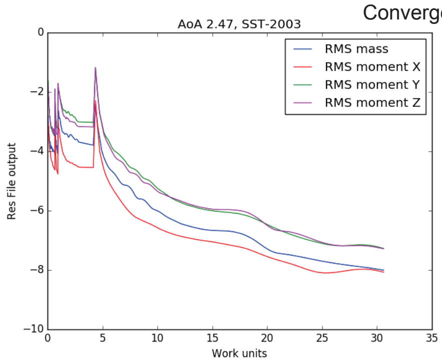
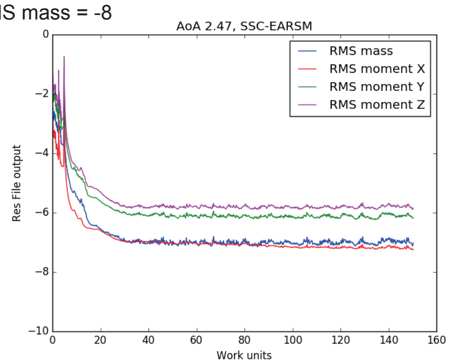
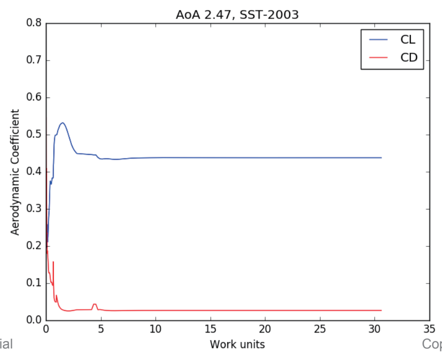
RESULTS – STRUCTURED(upacs)

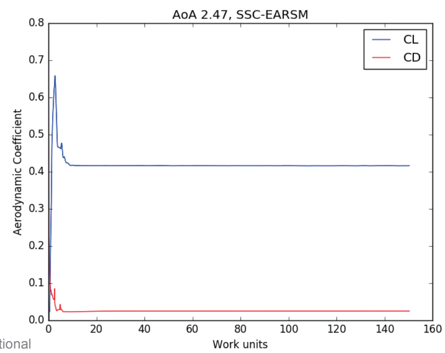
Convergence history at AoA=2.47 deg. (matrix dissipation)

Convergence criterium RMS mass = -8









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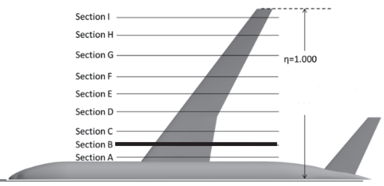
APC-III

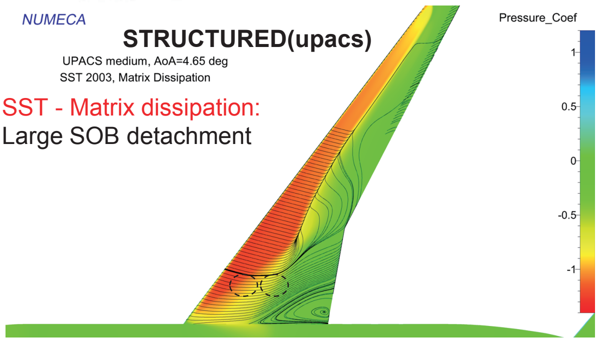
Analysis of Results

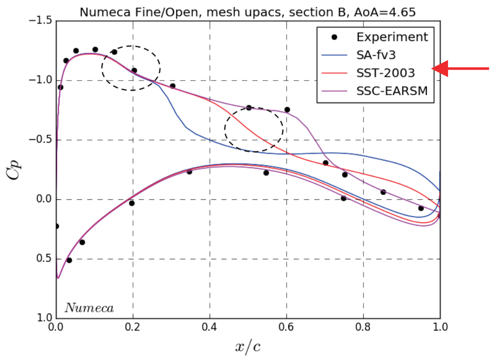
Analysis of flow over wing suction side
At high angle of attack
AoA = 4.65 deg.
Structured(upacs) vs.
Unstructured(megg3d) meshes

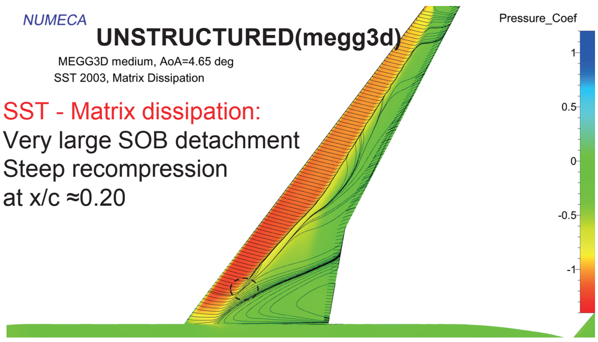
WING FLOW

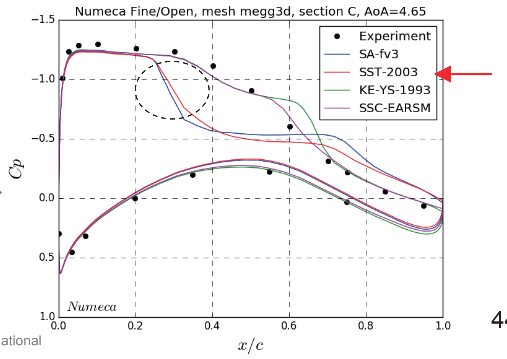
SST-2003, Mesh effect











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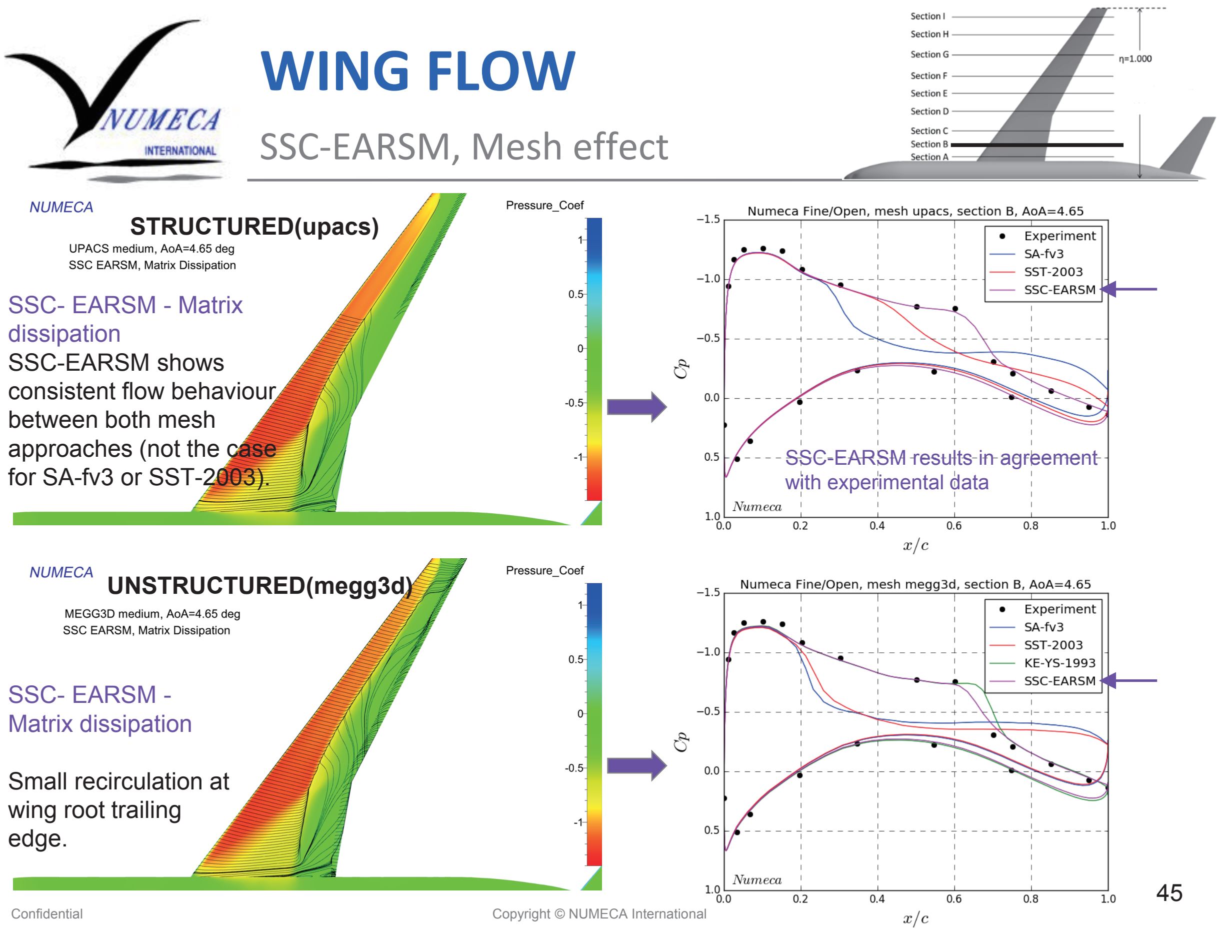

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