4th AIAA CFD Drag Prediction Workshop

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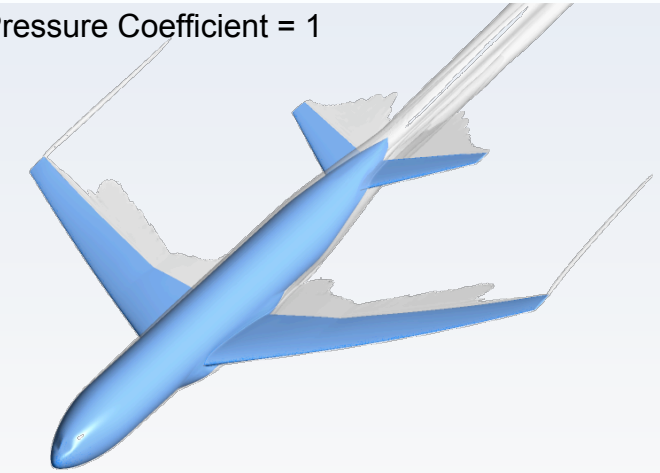
Outline

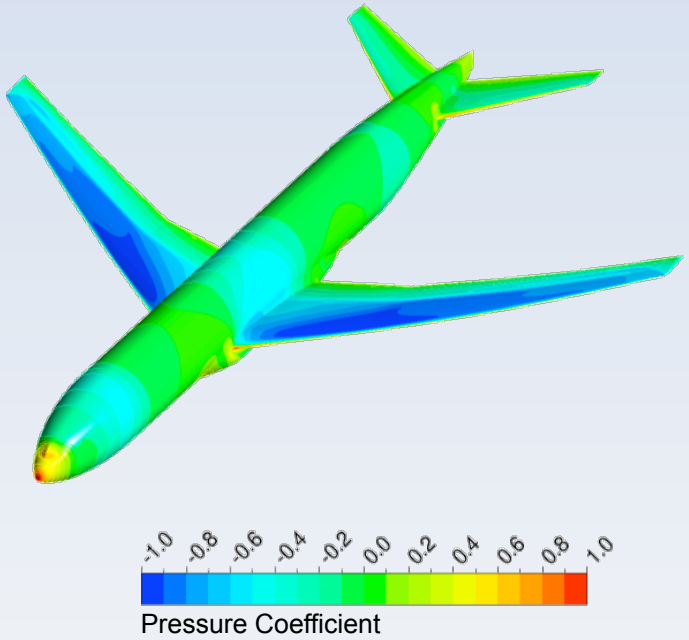
- Test cases
- Grid
- Setup
- Results
- Computational info
- Summary

Total Pressure Coefficient = 1



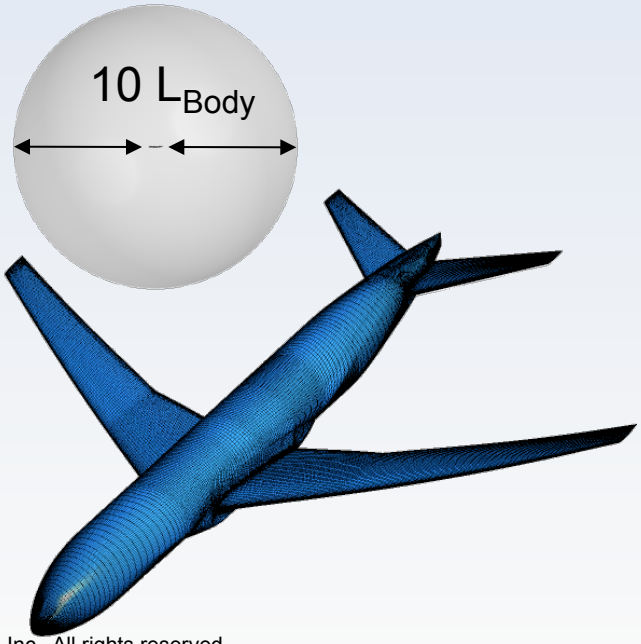
Test cases

- Case 1.1: Grid convergence study
  - Mach = 0.85, c_L = 0.500 (±0.001)
  - Chord Reynolds Number 5x10^6
  - Coarse, medium, fine, extra-fine
- Case 1.2: Downwash study
  - Mach = 0.85, c_L = 0.500 (±0.001)
  - Chord Reynolds Number 5x10^6
  - AoA 0.0°, 1.0°, 1.5°, 2.0°, 2.5°, 3.0°, 4.0°
  - i_H = -2°, 0°, +2° and tail off
- Case 3: Reynolds number study
  - Mach 0.85, c_L = 0.500 (±0.001)
  - Chord Reynolds Number 20x10^6
  - Medium



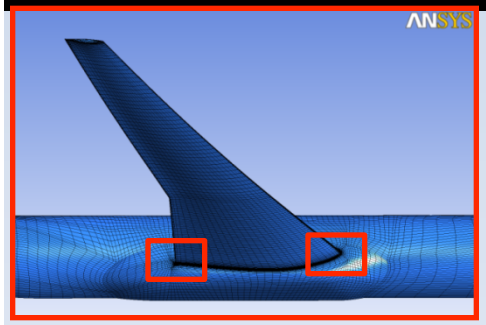
Grid

- ANSYS ICEM CFD
- Multiblock structured mesher
- Top-down meshing
- Hexahedral mesh

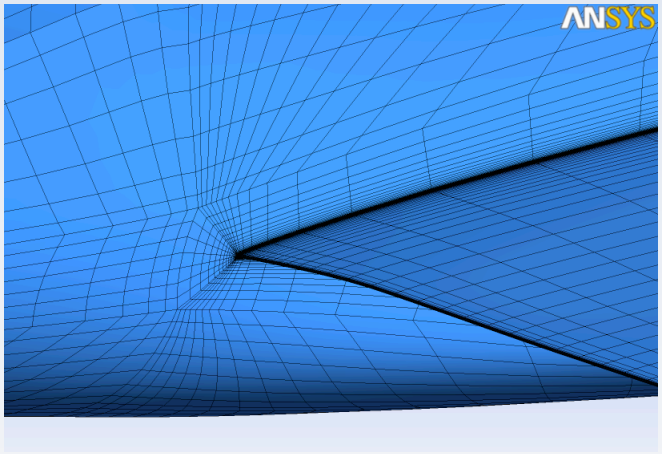


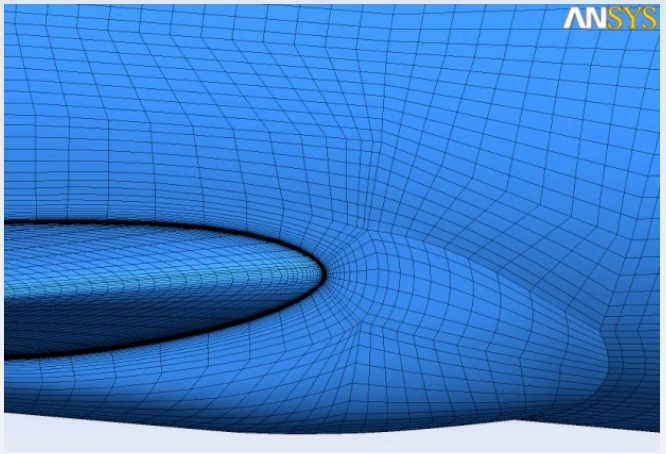
	Coarse	Medium	Fine	Extra-Fine
Nodes	3,592,043	10,951,602	36,159,816	104,991,542
Elements	3,516,705	10,793,559	35,808,564	104,273,186
Min. angle	14°	14°	12°	11°
Max. skewness	0.96	0.96	0.96	0.96
Max. volume change	11	10	12	14
Max. aspect ratio	62,000	61,000	65,000	65,000
# cells across TE	7	12	18	24

Grid - Coarse



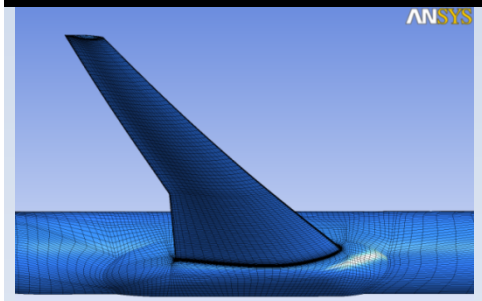
coarse



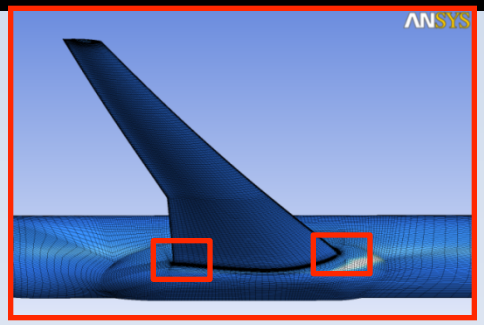


3,516,705 hexahedral cells
150,044 boundary faces

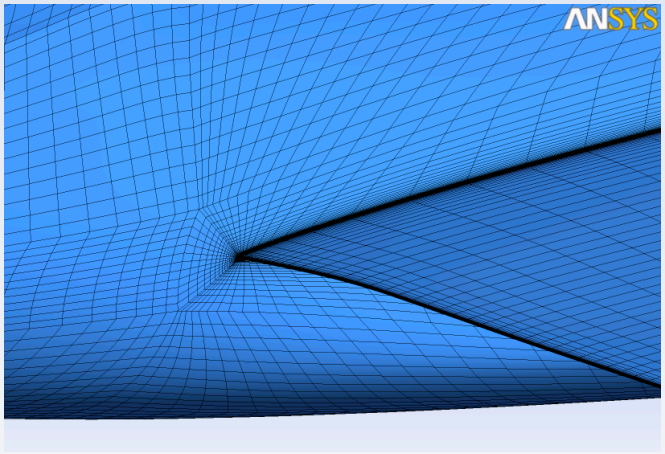
Grid - Medium

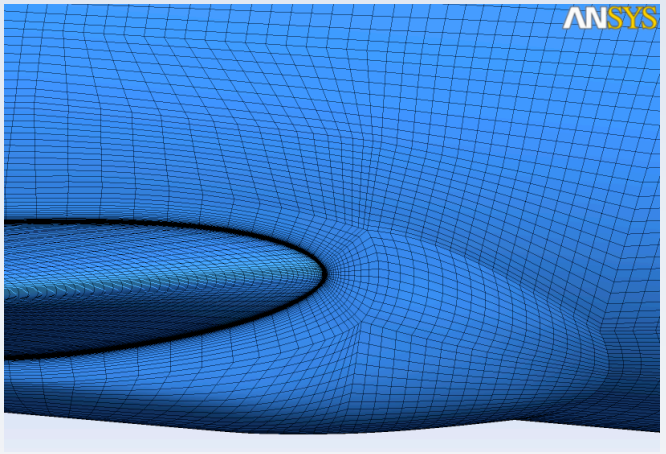


coarse



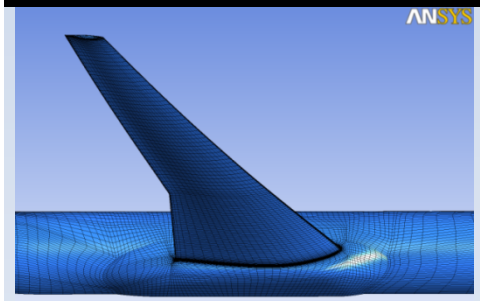
medium



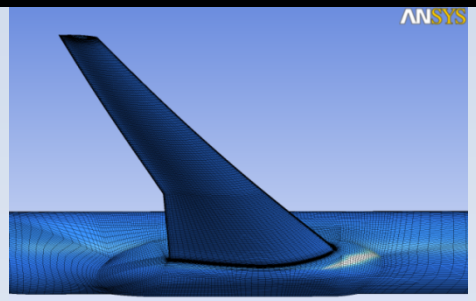


10,793,559 hexahedral cells
315,162 boundary faces

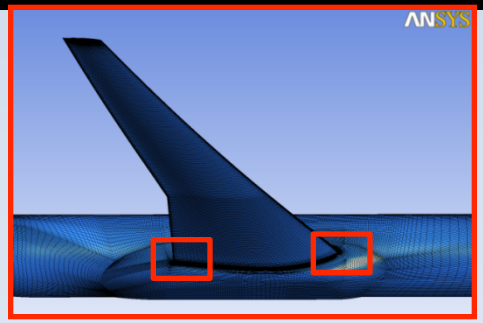
Grid - Fine



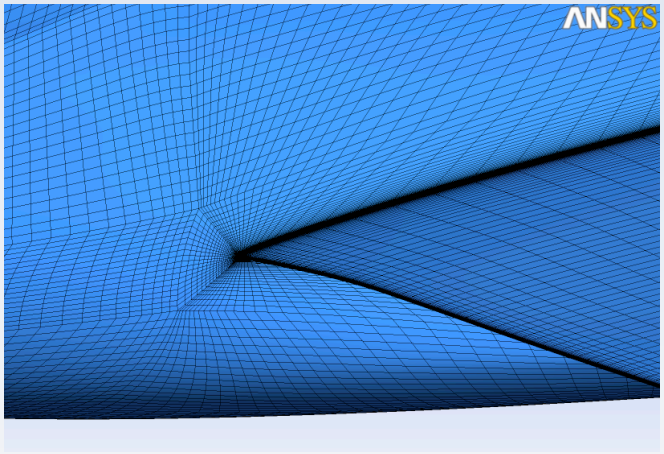
coarse

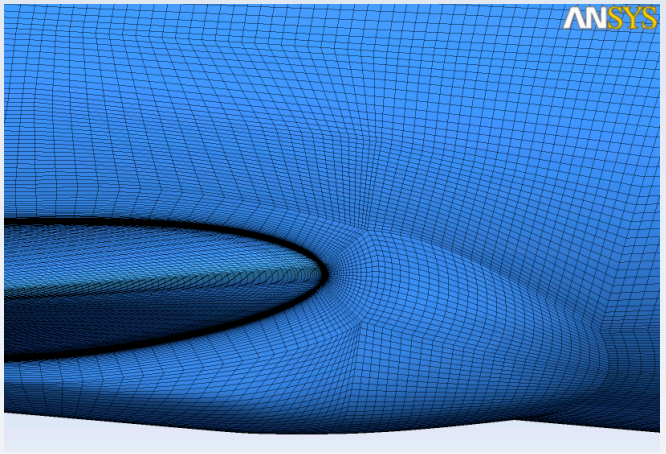


medium



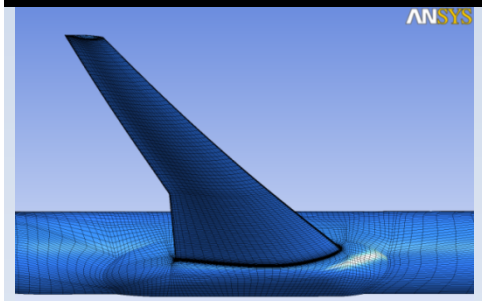
fine



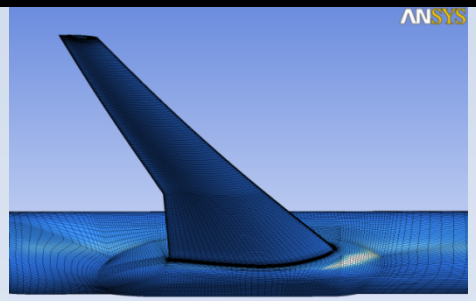


35,808,564 hexahedral cells
701,124 boundary faces

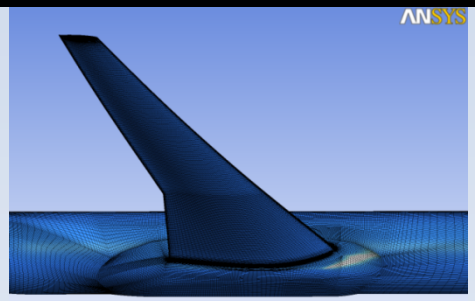
Grid – Extra-Fine



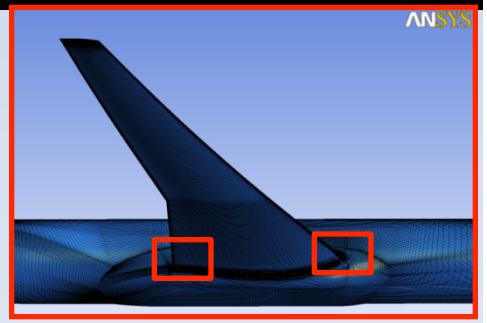
coarse



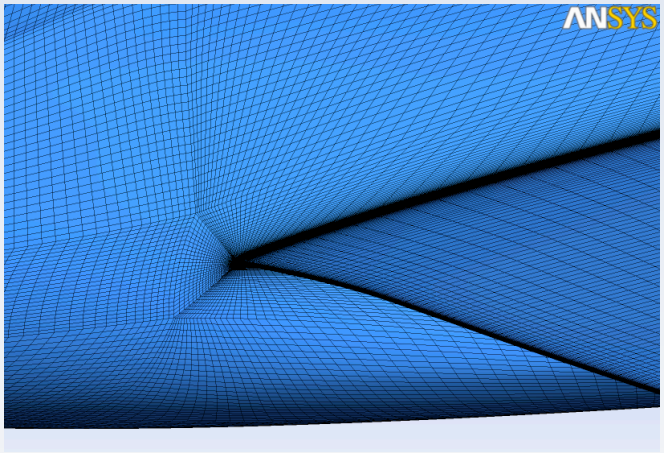
medium

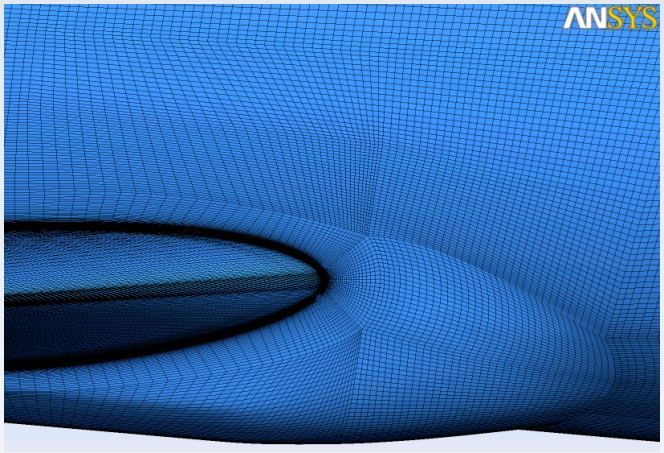


fine



extra-fine

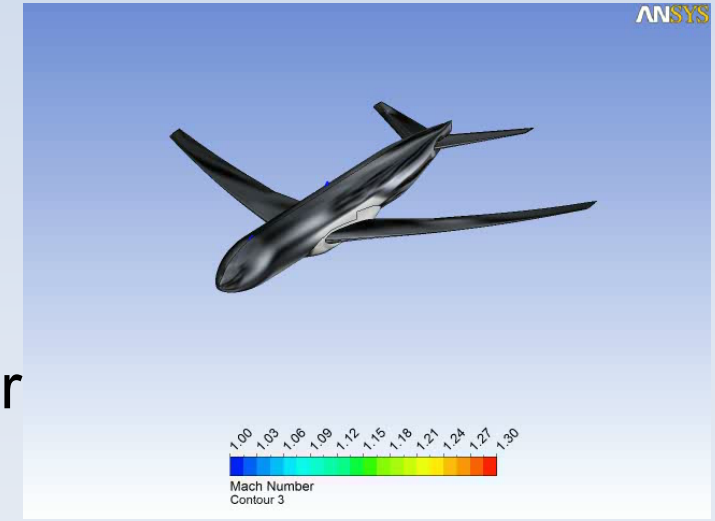


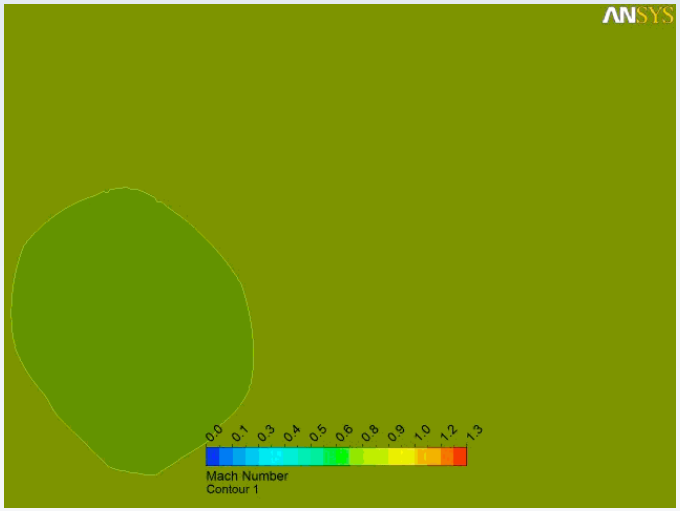


104,273,186 hexahedral cells
1,434,740 boundary faces

Setup - Solver

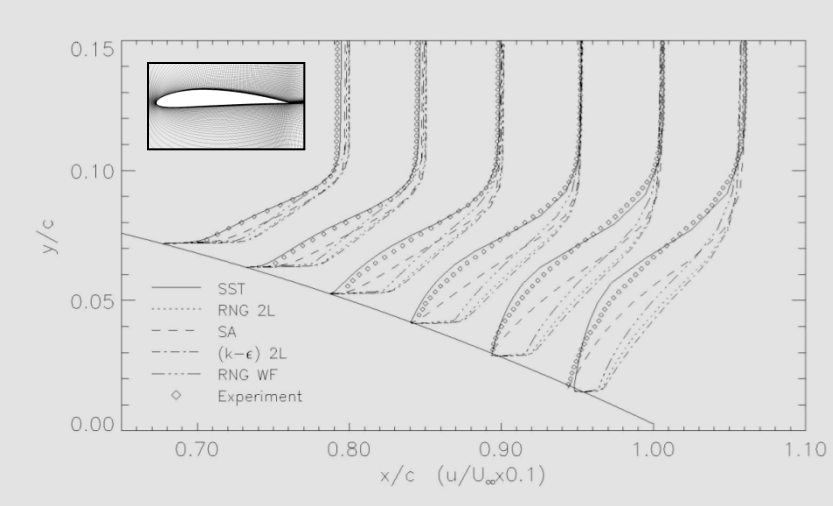
- ANSYS FLUENT 12
- Steady state
- Compressible (ideal gas)
- Density-based implicit coupled solver
- Spatial discretization: 2nd order
- Least-square cell-based gradient
- Flux Type: Roe-FDS
- Algebraic multigrid method
- Scalable parallelization
- Double precision

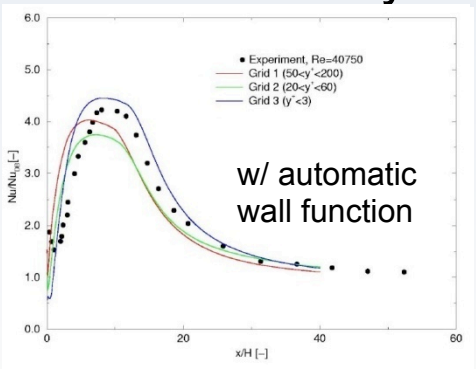


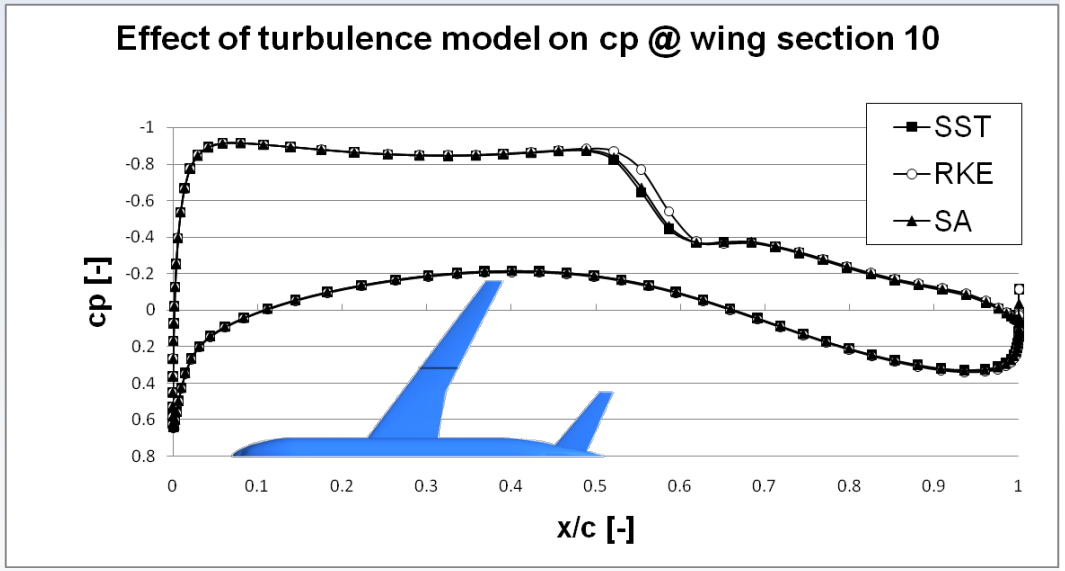


Setup - Model error

- SST model (Menter, 1994)
  - Blending of k-ε and k-ω model
  - Improved eddy viscosity formula
- Proper model for separated flows
- Automatic wall function
  - Less sensitive to y^+

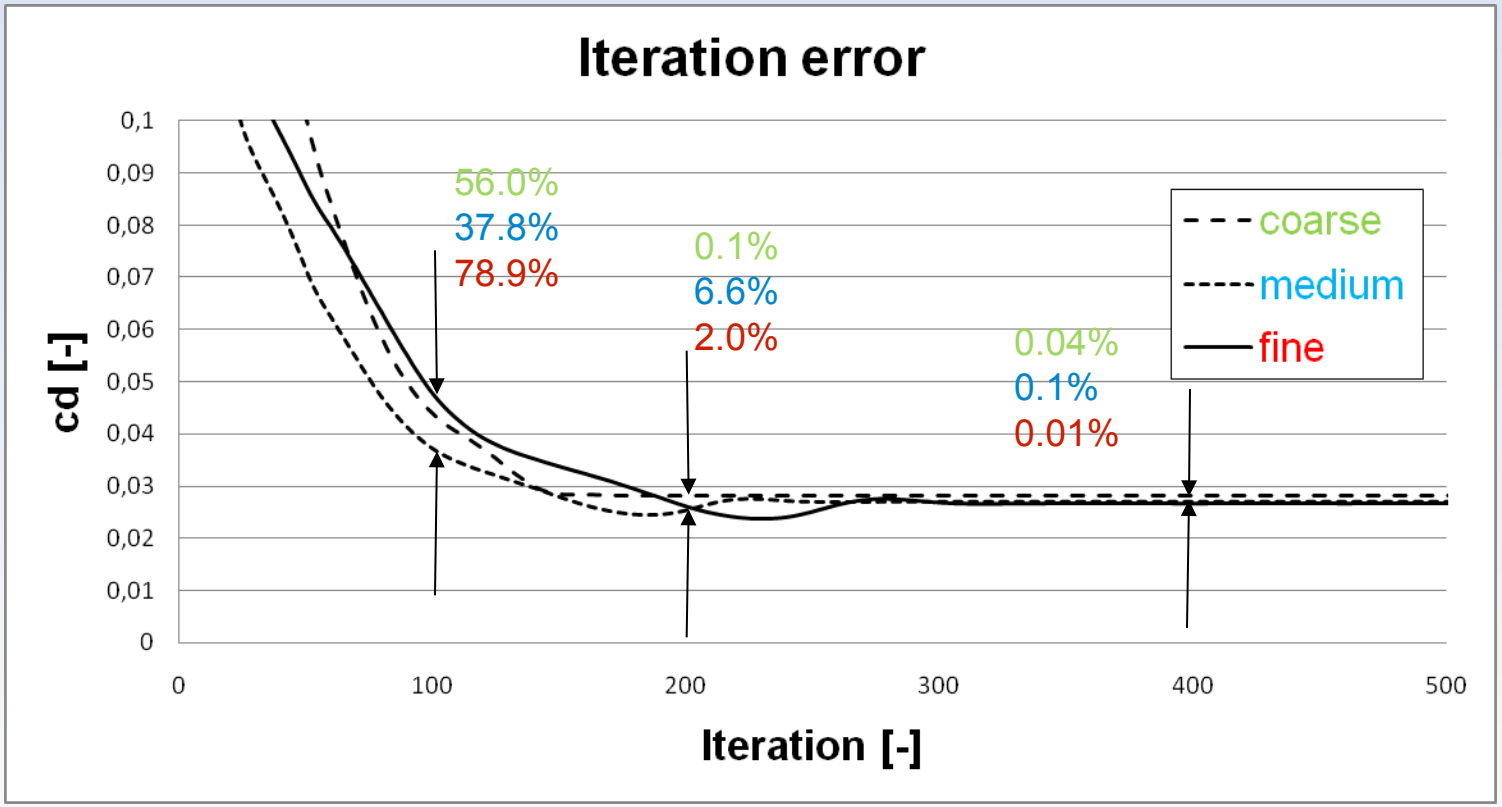






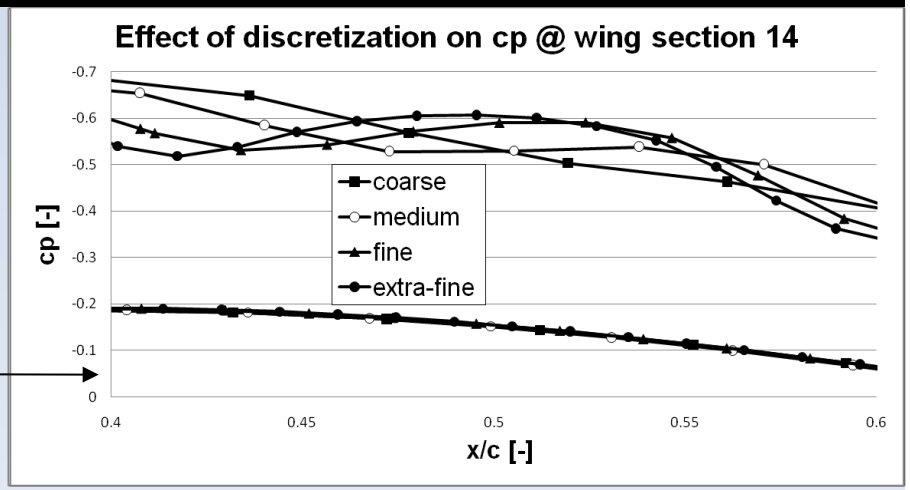
Results – Iteration error

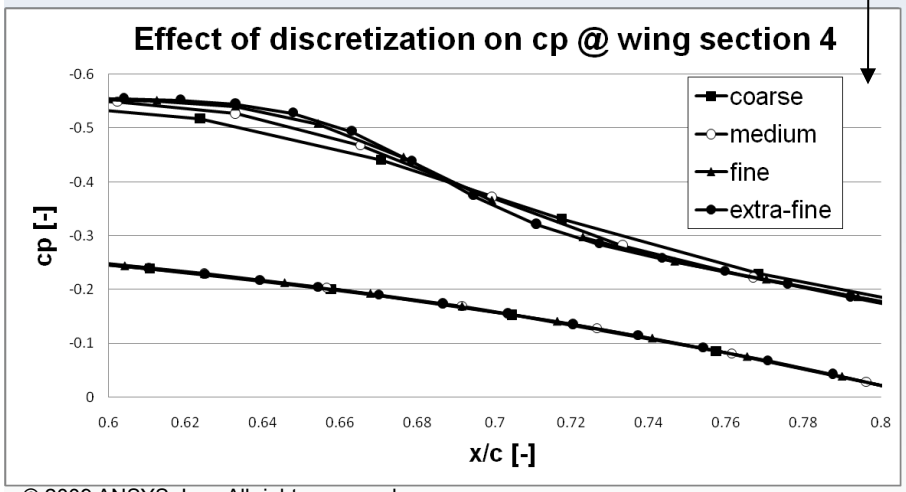
- 400 iterations for convergence (relative error ≤ 0.1%)
- Converged within 1 drag count

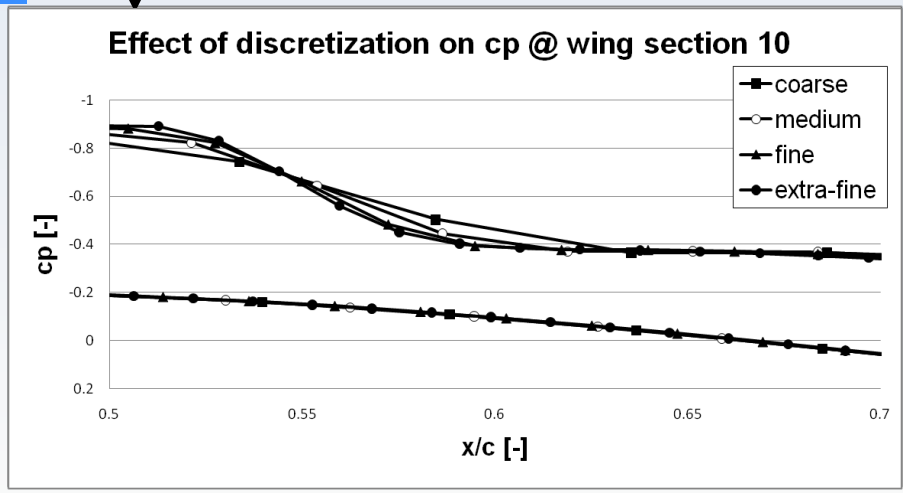


Results – Discretization error

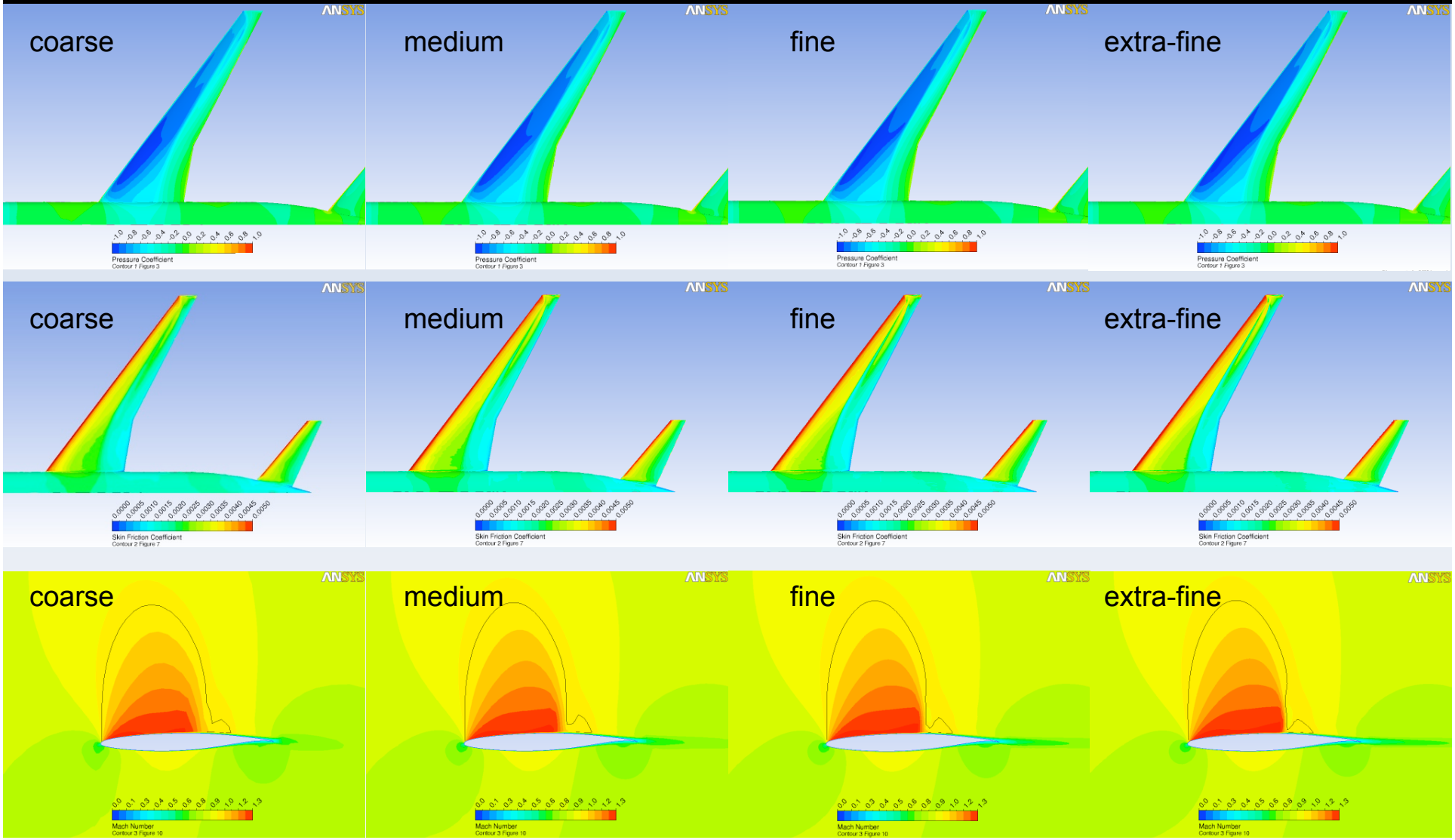
- Increasing discretization error with increasing distance to fuselage
- Fine and extra-fine results almost congruent



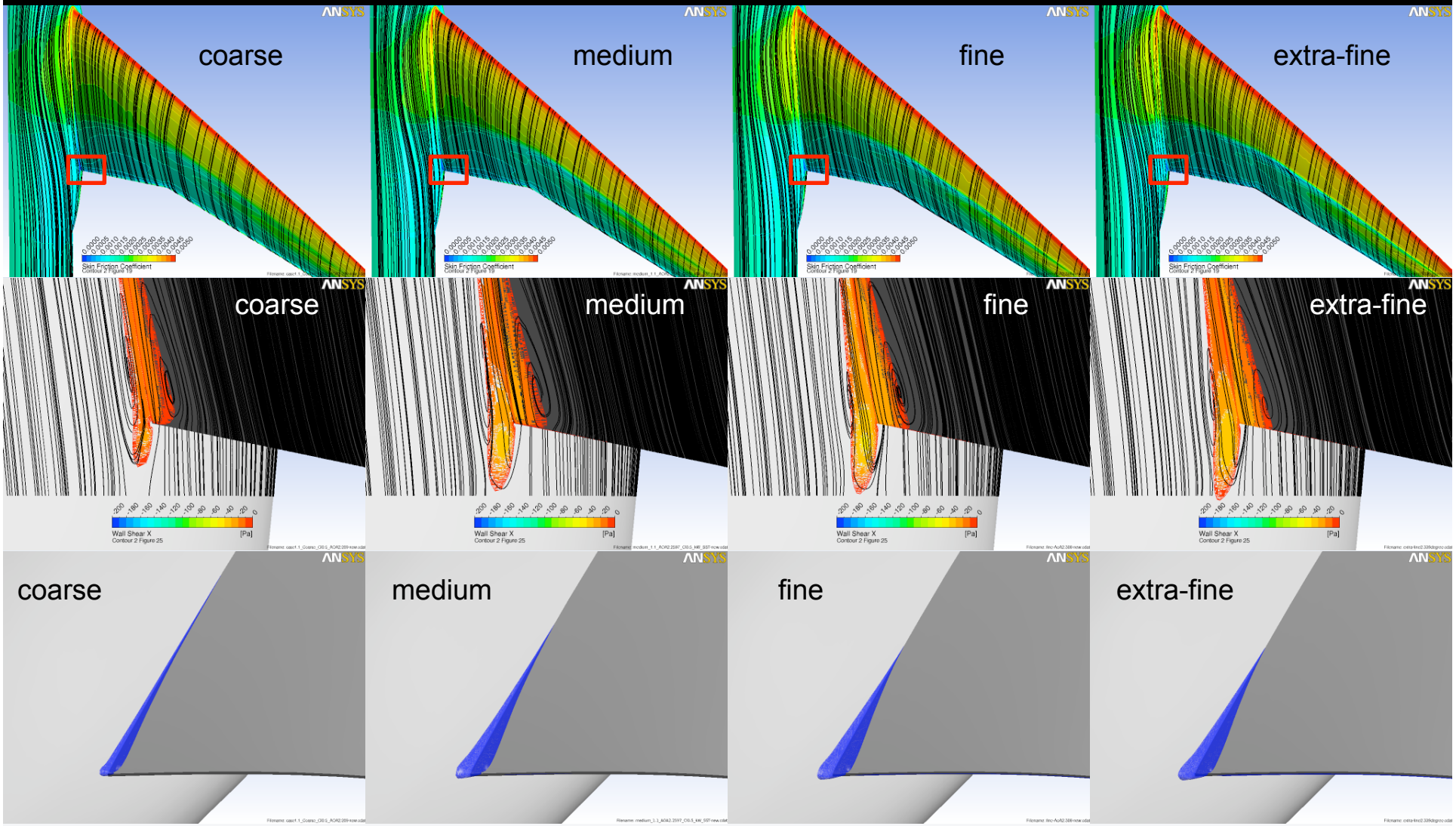




Results – Discretization error

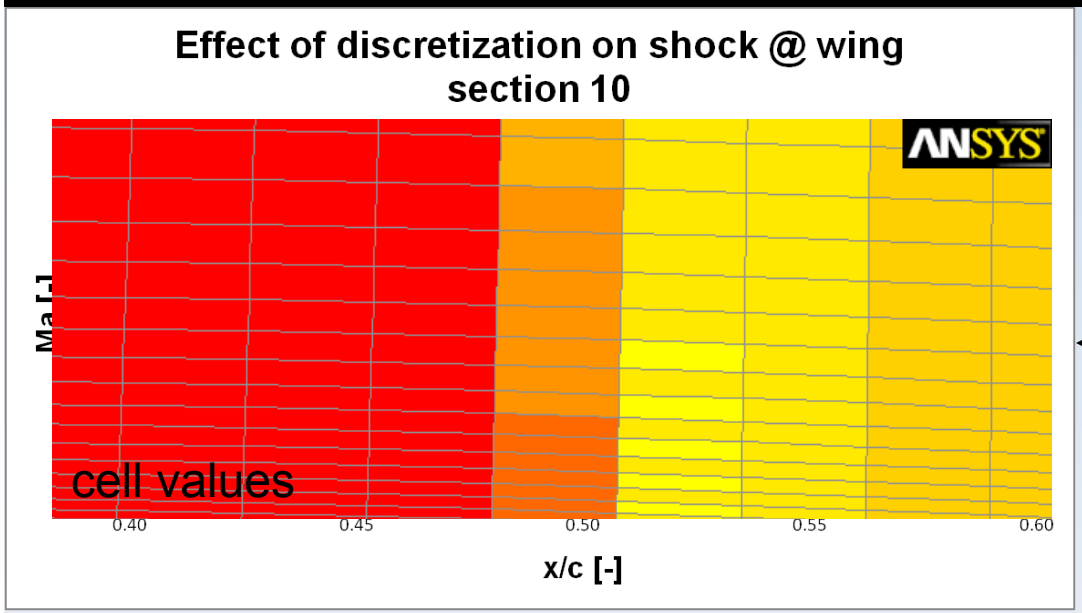


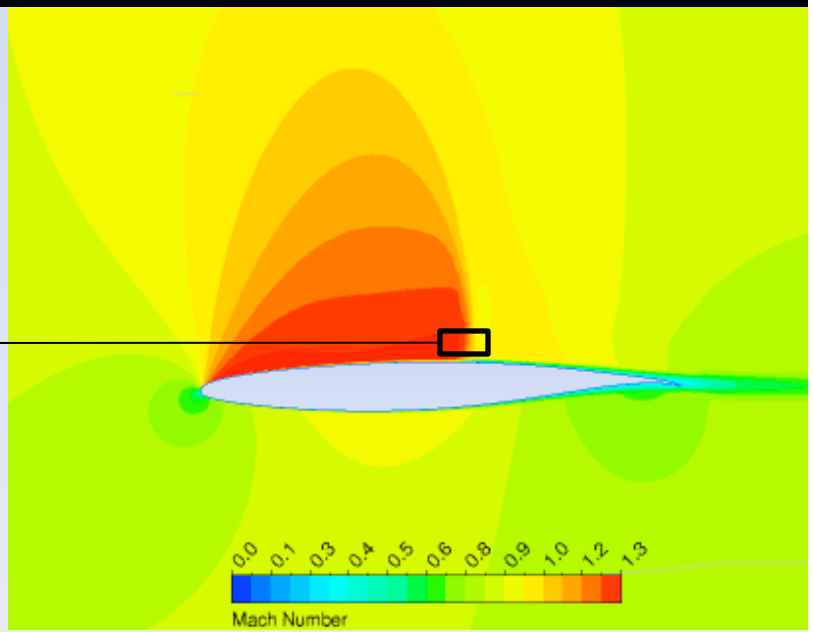
Results – Discretization error



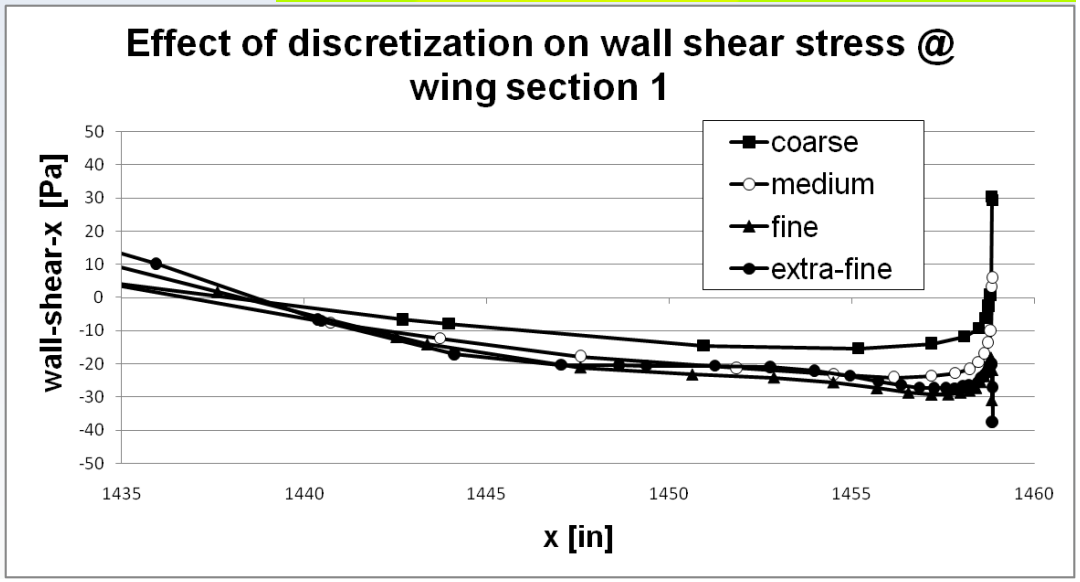
iso-surface of v_x = -10 m/s

Results – Discretization error





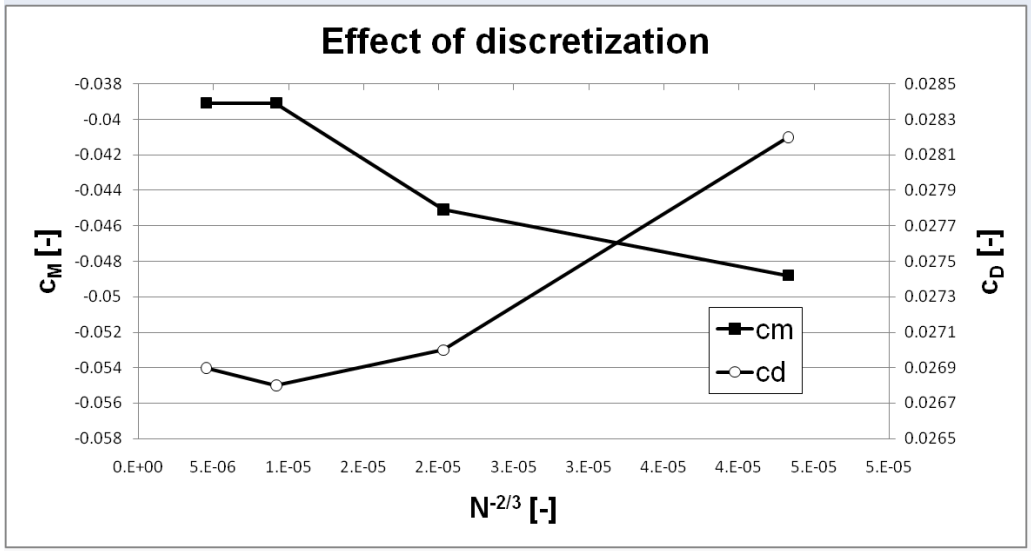
- Finer mesh leads to increased wall-shear-x-stresses and enlarged separation bubble



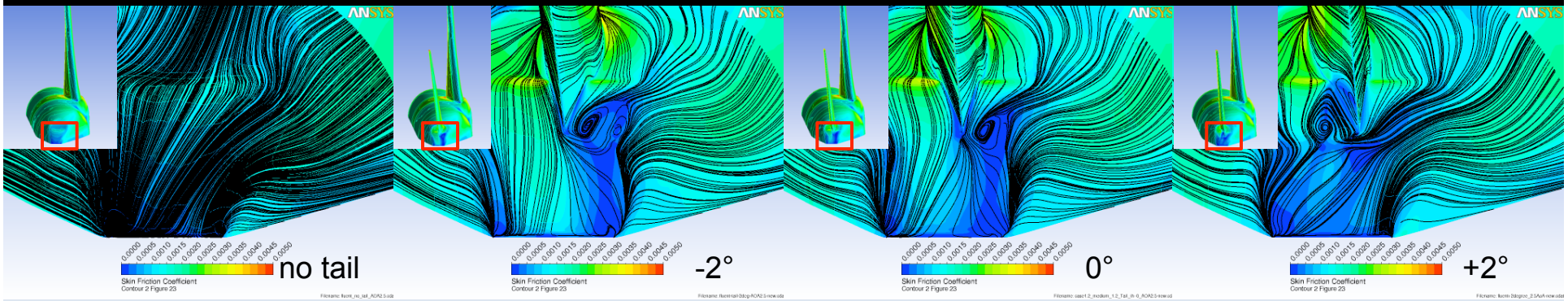
Results – Discretization error

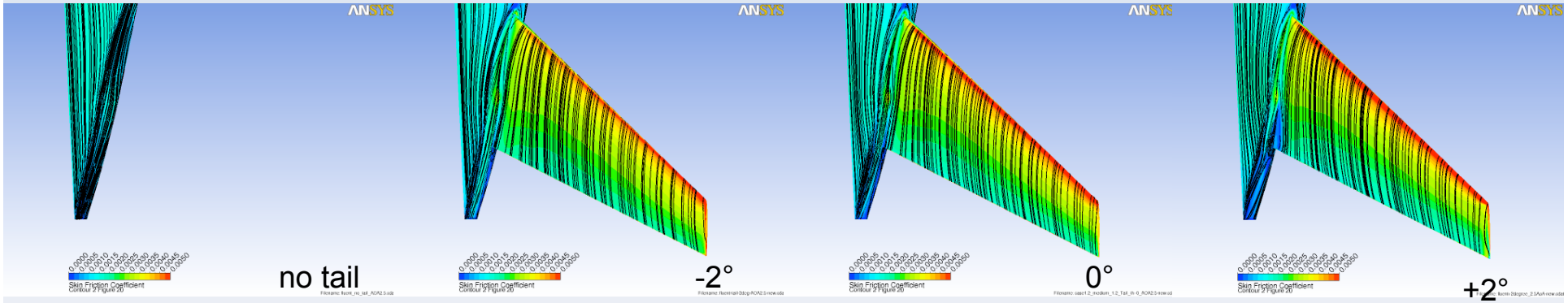
- c_L = 0.500 (±0.001)
- Re = $5x10^6$

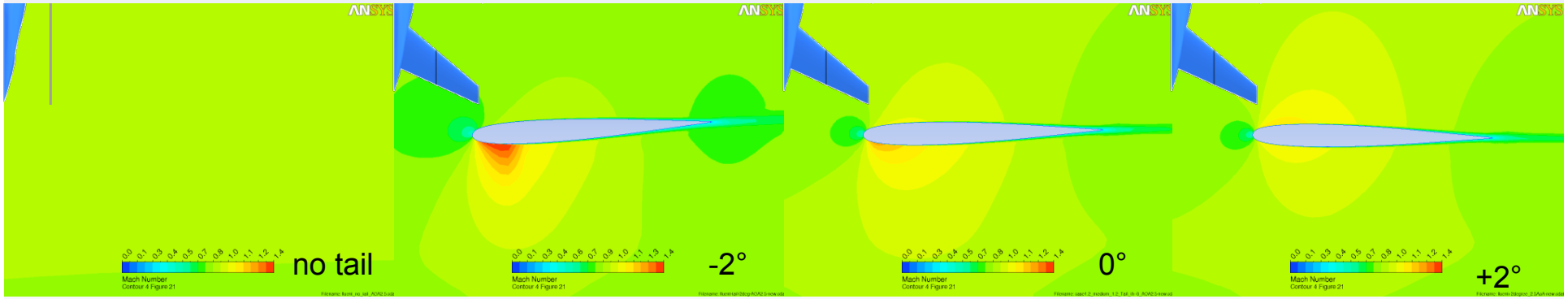
	Coarse	Medium	Fine	Extra-Fine
Nodes	3,592,043	10,951,602	36,159,816	104,991,542
Elements	3,516,705	10,793,559	35,808,564	104,273,186
AoA [°]	2.209	2.260	2.308	2.339
c_D	0.0282	0.0270	0.0268	0.0269
c_M	-0.0488	-0.0451	-0.0391	-0.0391
y^+_{avg}	0.358	0.242	0.163	0.110



Results – Downwash study

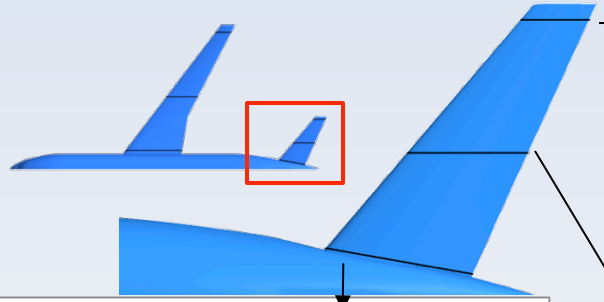


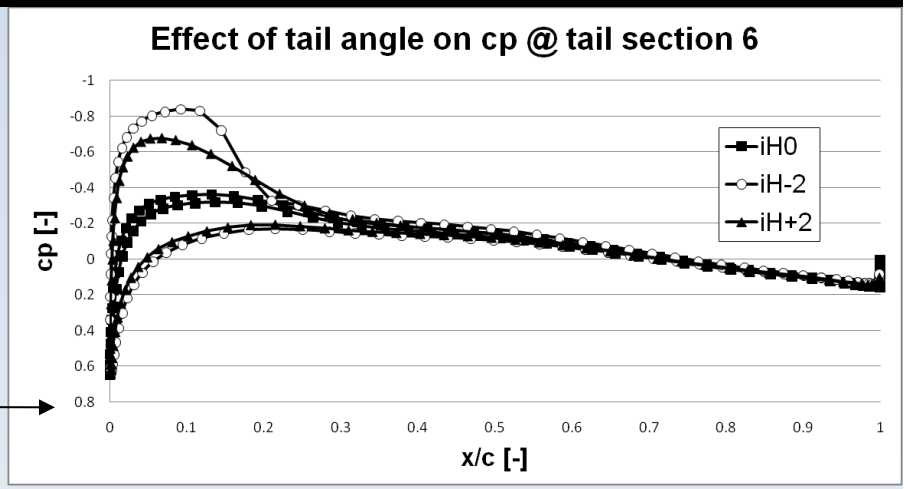


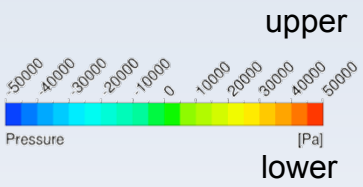


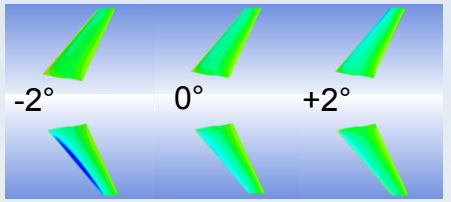
Results – Downwash study

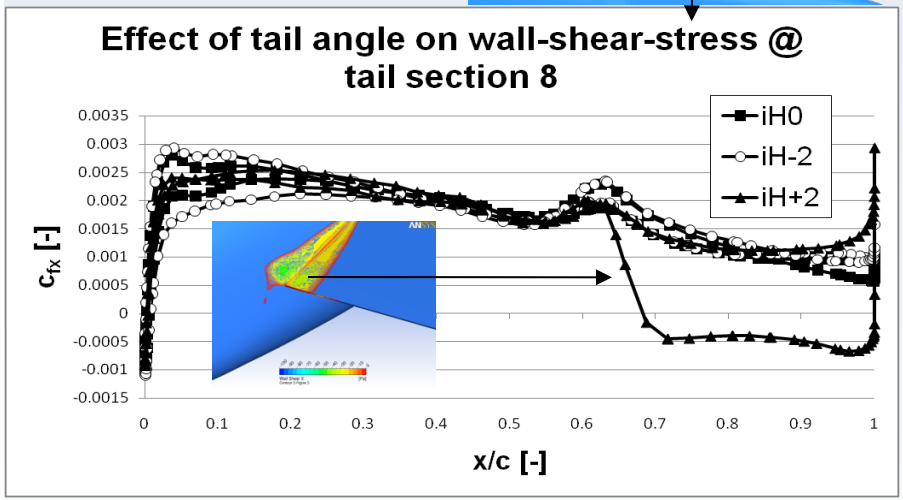
- TE separation on upper tail surface for iH=+2°
- Negative lift on tail for iH=-2° and 0°

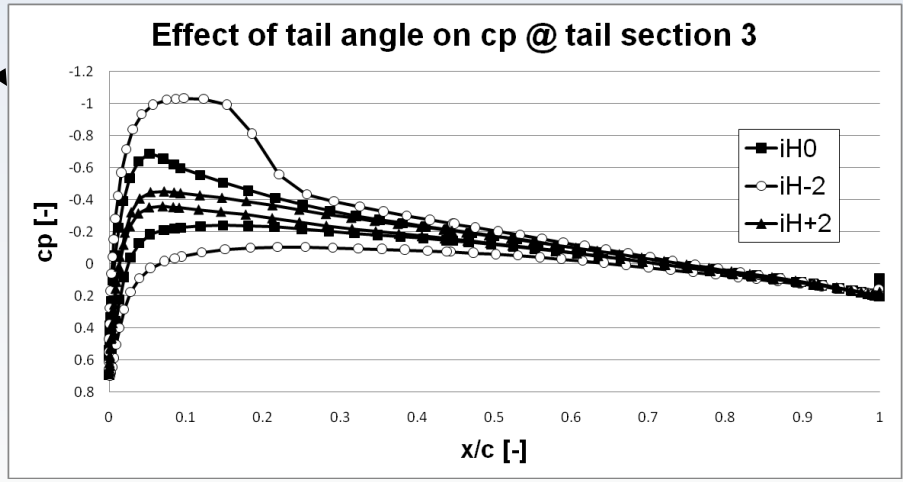




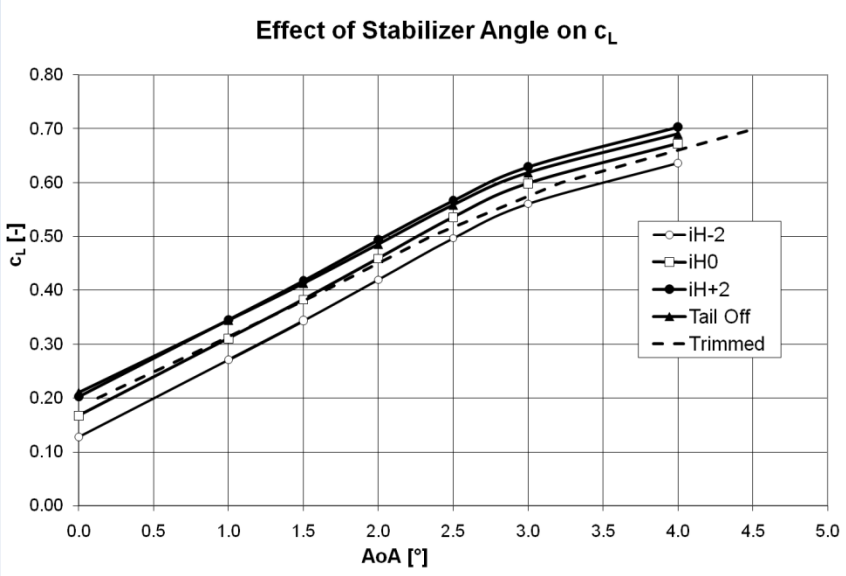


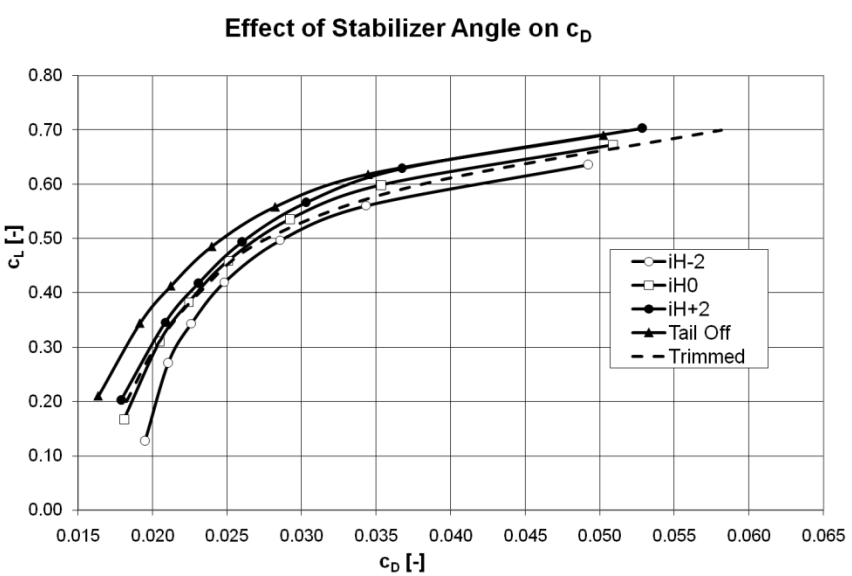


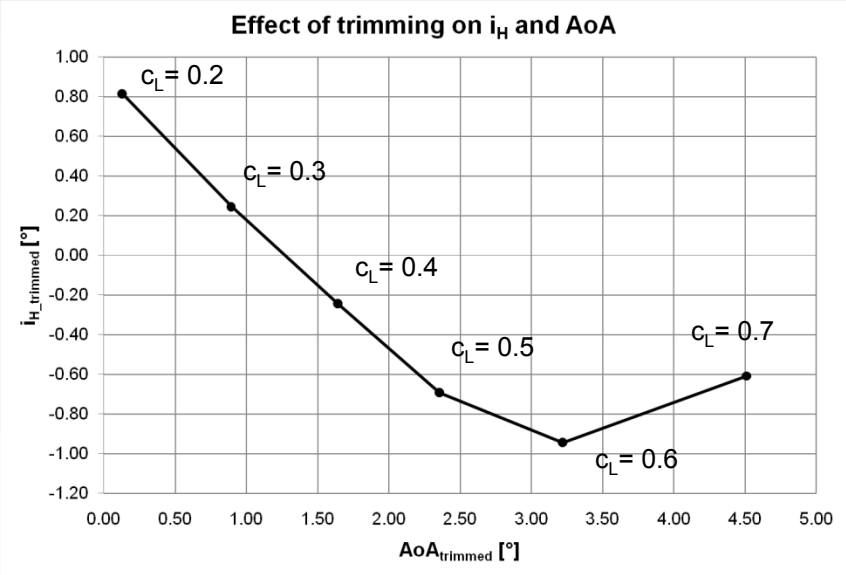


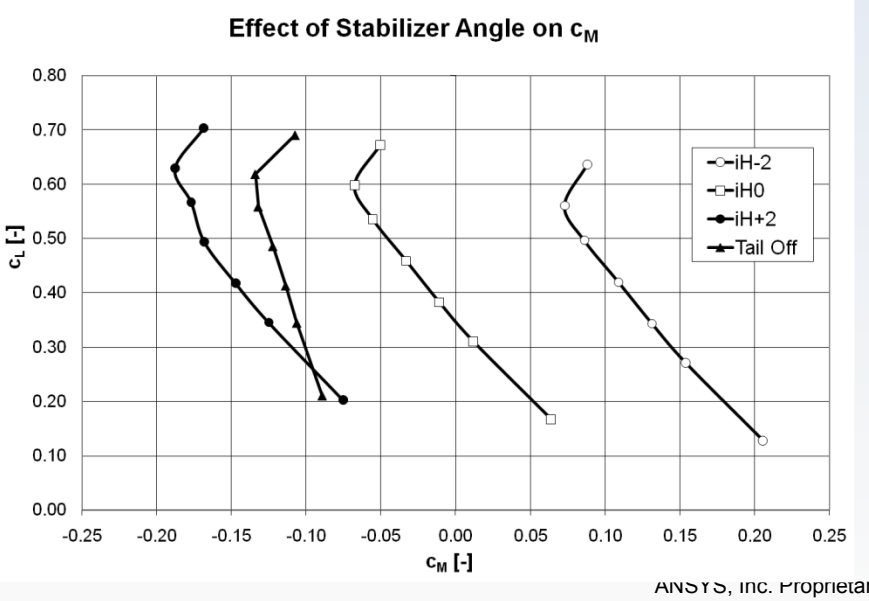


Results – Downwash study



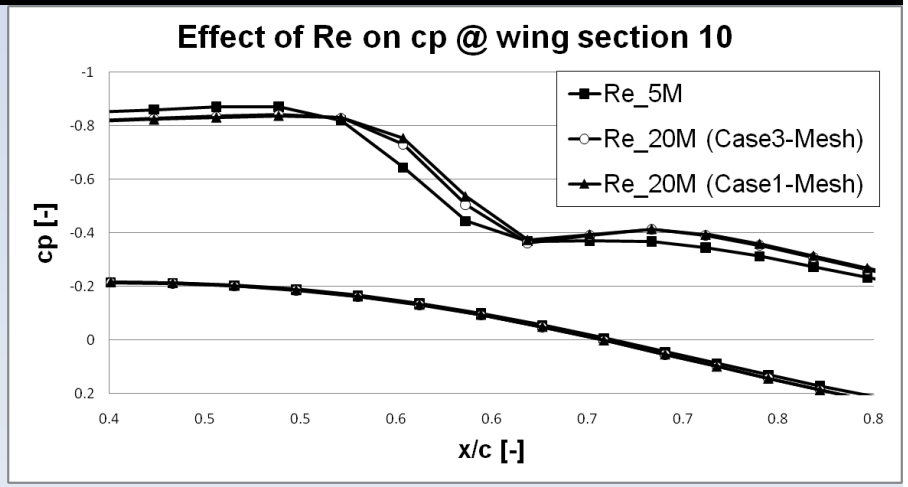




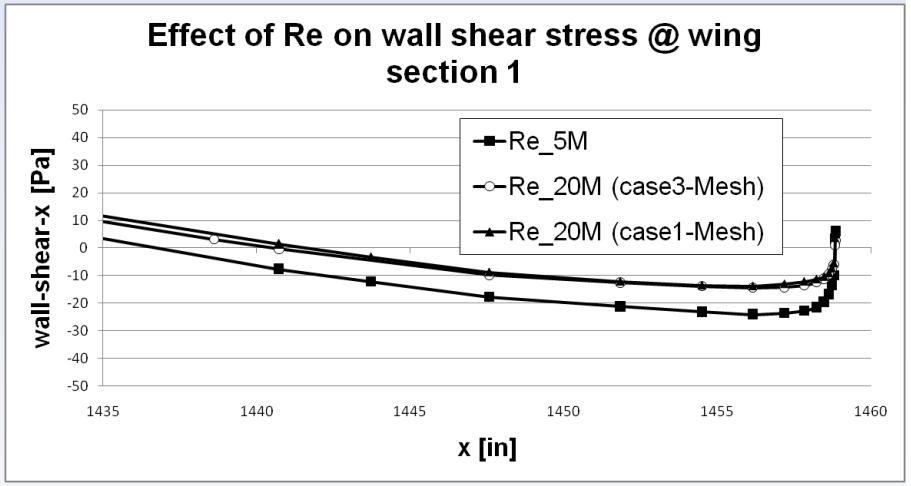


Results – Reynolds Number study

- Increased Reynolds number shifts shock towards TE
- Delayed TE separation and decreased wall shear stresses



	$Re=5x10^6$	$Re=20x10^6$ (Case1-Mesh)	$Re=20x10^6$ (Case3-Mesh)
Nodes	10,951,602	10,951,602	11,284,694
Elements	10,793,559	10,793,559	11,123,320
AoA [°]	2.2597	2.0210	2.0505
c_D	0.0270	0.0233	0.0235
c_M	-0.0451	-0.0507	-0.0507
y^+_{avg}	0.242	0.890	0.252



Computational Info

	Coarse	Medium	Medium (tail off)	Medium Re=20M	Fine	Extra-Fine
Elements	3,516,705	10,793,559	8,565,287	11,123,320	35,808,564	104,273,186
Wall clock time (500 it) [h]	3.4	3.5	2.5	2.9	2.0	3.8
CPU time (500 it) [h]	26.3	119.8	77.9	91.6	386.1	1131.1
RAM usage [GB]	16.3	47.8	43.8	51.6	199.2	549.7
CPU info	8 x AMD Opteron 2.3 GHz	32 x AMD Opteron 2.3 GHz			192 x AMD Opteron 2.3 GHz	244 x AMD Opteron 2.3 GHz
OS	SLE 10					

Summary

- Consistent and robust solver convergence
- Expected grid refinement trends are observed
  - At wing tip, grids are still not sufficiently refined
- In spite of new fairing, there are small separation bubbles on upper wing surface close to fuselage
- Blind study and unavailability of experimental data doesn't allow to comment on absolute accuracy
- Quick results even for extra-fine grid, but high RAM usage due to density-based implicit solver in double precision

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