AERODYNAMIC AND STATIC AEROELASTIC NUMERICAL SIMULATIONS FOR THE 6TH AIAA CFD DRAG PREDICTION WORKSHOP

6th AIAA CFD Drag Prediction Workshop - 2016

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Embraer S/A

Outline

INTRODUCTION

Considered Cases and solver setup

Considered four series of computations:

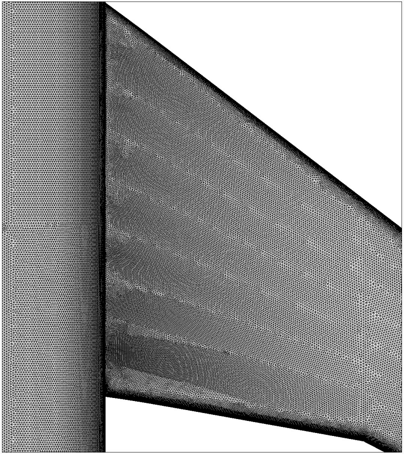
- Case 1: Verification study;
- Case 2: CRM Nacelle-Pylon Drag Increment;
- Case 3: CRM WB Static Aero-Elastic Effect;
- Case 5: CRM WB Coupled Aero-Structural Simulation;

Solver setup

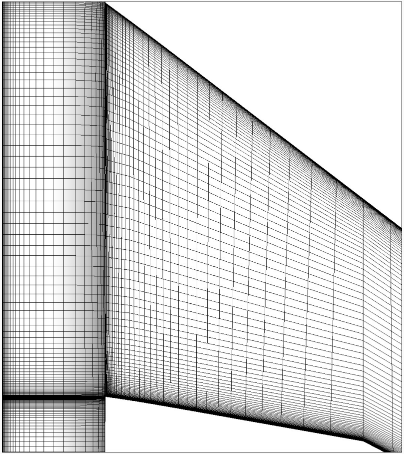
Solver	:	CFD++ (14.1.1)
Formulation	:	Pre-conditioned compressible RANS, perfect gas
Turbulence model	:	SST and SA (case 1 only)
Time integration	:	Point-implicit (SGS) / Algebraic multigrid
Spatial discretization	:	Finite volume, 2nd order
Polynomial type	:	Nodal-based
TVD limiter	:	Minmod compression 2

Grids

Grids @ Tiny level



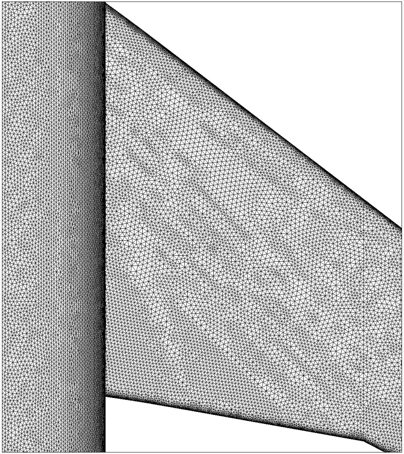
(a) CommonHybrid



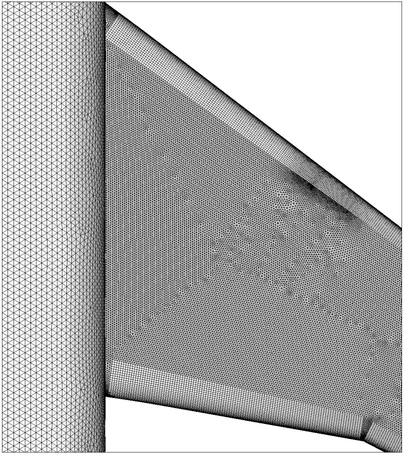
(b) CustomHexa

Grids

Grids @ Tiny level



(c) CustomHybrid-I



(d) CustomHybrid-A

Grids

Grid sizes in million (WB-AE275):

	Tiny		Fine	
	Nodes	Cells	Nodes	Cells
CommonHybrid	20.5	83.6	66.2	271.2
CustomHexa	20.3	20.0	70.3	69.6
CustomHybrid-A	9.4	19.7	23.9	72.6
CustomHybrid-I	8.0	20.3	25.7	68.6

We matched the gridding guidelines for number of cells!

NUMERICAL SIMULATIONS RESULTS

Case 1: Verification Study

Flow condition:

M	=	0.15
Re	=	6 million
AOA	=	10 degrees

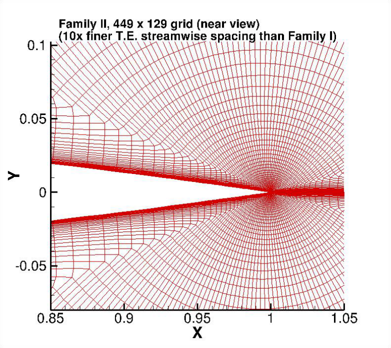
Grid:

NACA 0012

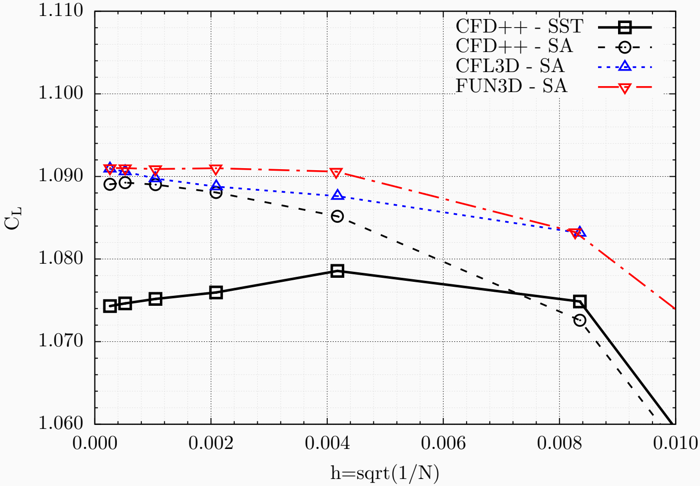
TMBWG Family II

Turbulence model:

SA and SST (CFD++)

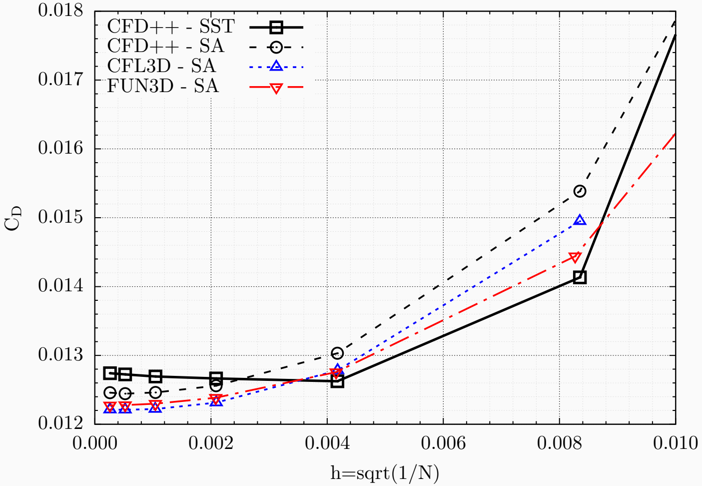


Grid convergence: Lift

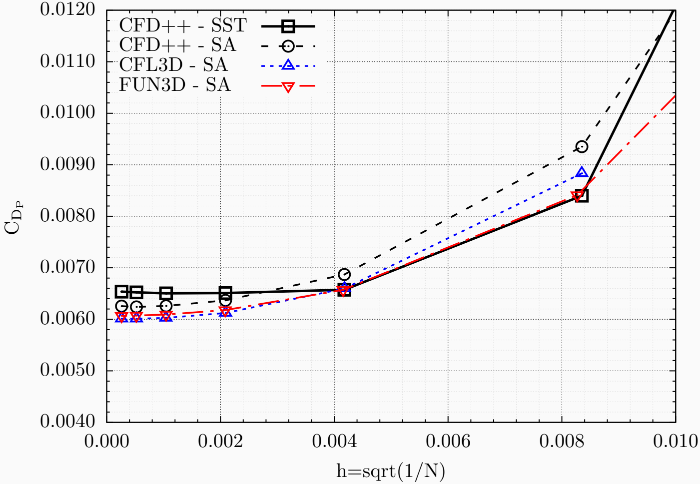


Case 1: Verification Study

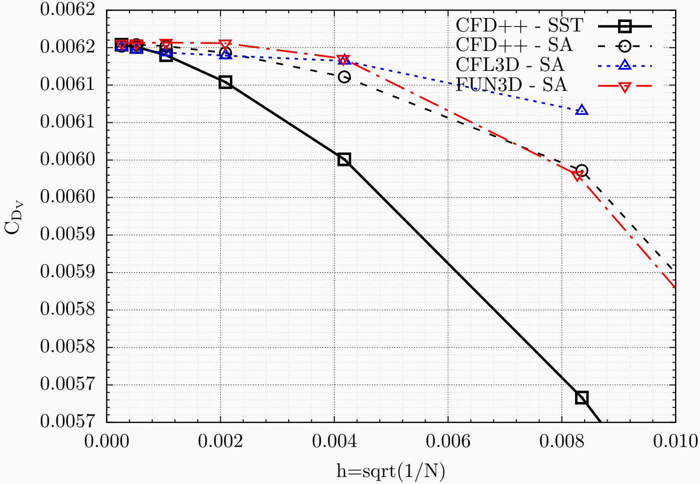
Grid convergence: Drag



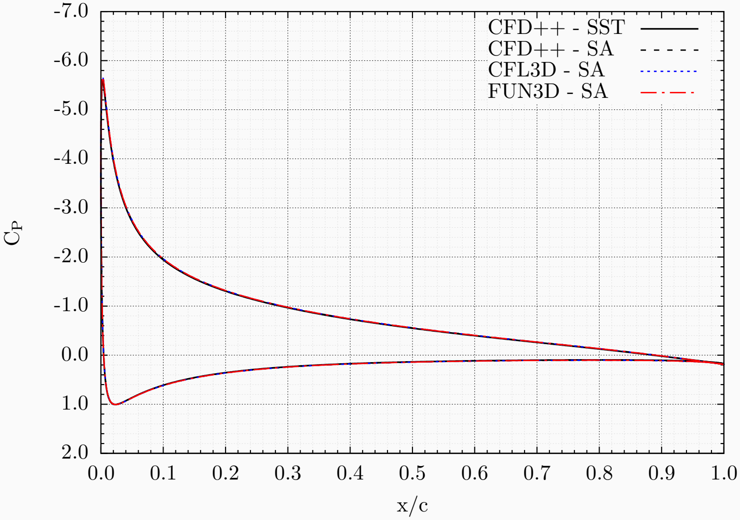
Grid convergence: Drag (pressure component)



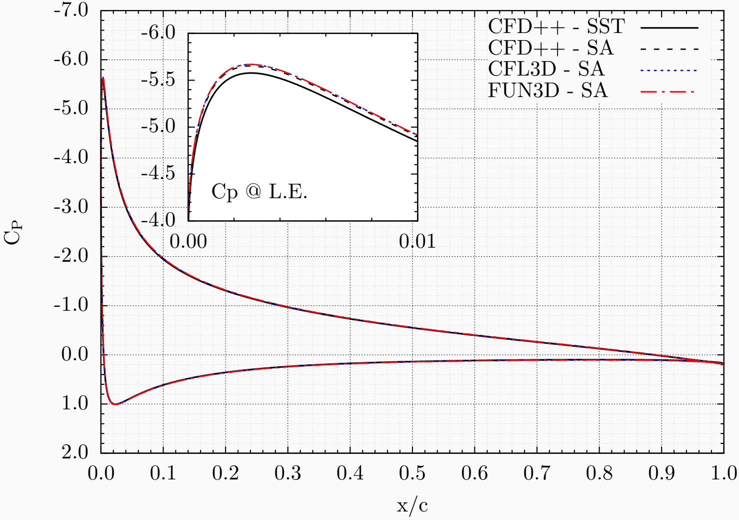
Grid convergence: Drag (viscous component)



Pressure distribution @ finest grid

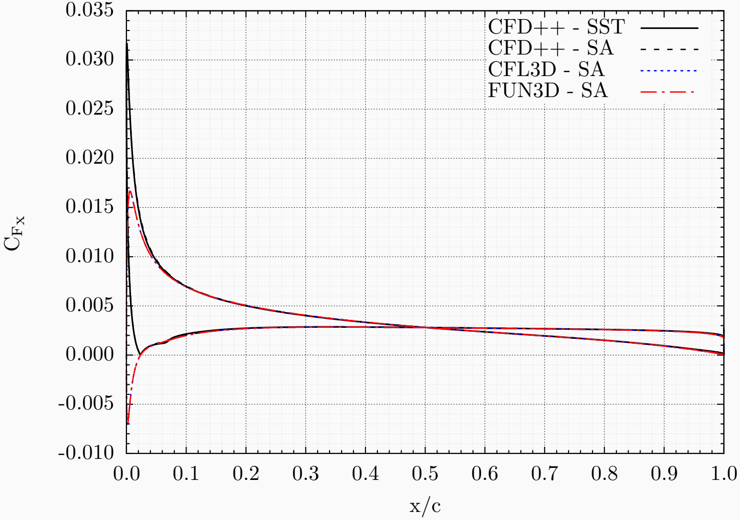


Pressure distribution @ finest grid



Case 1: Verification Study

Skin friction @ finest grid



Case 2: CRM Nacelle-Pylon Drag Increment

Flow condition:

M	=	0.85
Re	=	5 million
CL	=	0.50

Turbulence model:

SST (CFD++)

Grids:

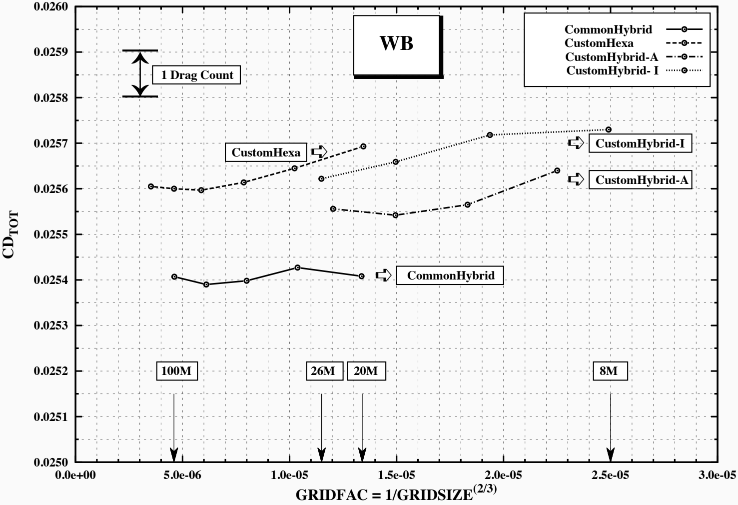
CommonHybrid	:	T,C,M,F
CustomHexa	:	T,C,M,F,X,U (WB only)
CustomHybrid-I	:	T,C,M,F
CustomHybrid-A	:	T,C,M,F

Geometry:

Aeroelastic deflection at the angle-of-attack 2.75 degrees

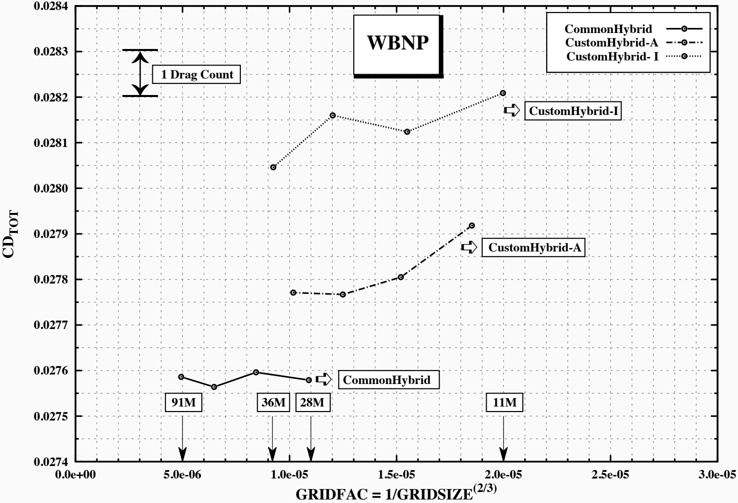
Case 2: CRM Nacelle-Pylon Drag Increment

Total drag convergence @ WB



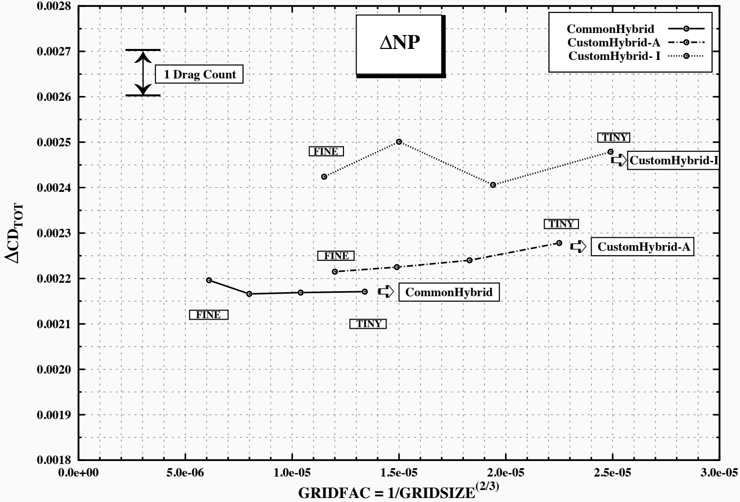
Case 2: CRM Nacelle-Pylon Drag Increment

Total drag convergence @ WBNP

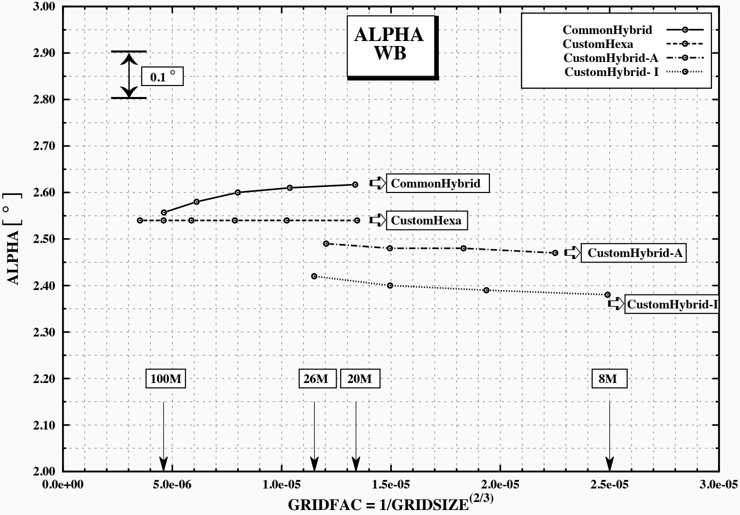


Case 2: CRM Nacelle-Pylon Drag Increment

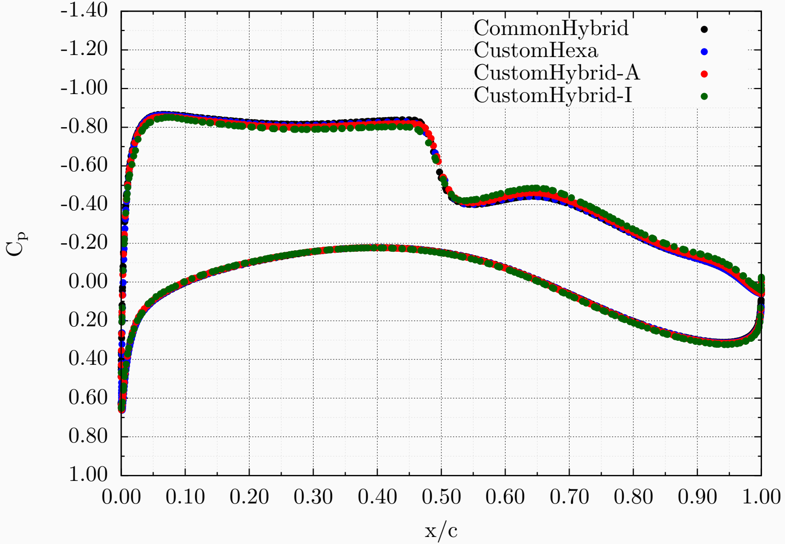
Delta NP drag convergence (WBNP-WB)



Angle of attack for each grid @ CL 0.50

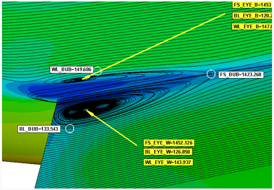


Pressure distribution @ wing section 11 (Fine grid)

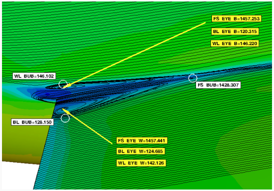


Case 2: CRM Nacelle-Pylon Drag Increment

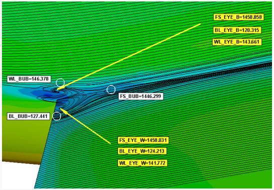
Side-of-body separation (SOB):



CommonHybrid (T)		
Nodes	:	≈ 20 mi
Cells	:	≈ 84 mi



CustomHexa (T)		
Nodes	:	≈ 20 mi
Cells	:	≈ 20 mi



CustomHybrid-I-A (F)		
Nodes	:	≈ 24 mi
Cells	:	≈ 73 mi

Case 3: CRM WB Static Aero-Elastic Effect

Flow condition:

M	=	0.85
Re	=	5 million
AOA	=	2.50 | 2.75 | 3.00 | 3.25 | 3.50 | 3.75 | 4.00 degrees
AE	=	2.50 | 2.75 | 3.00 | 3.25 | 3.50 | 3.75 | 4.00 degrees

Grids:

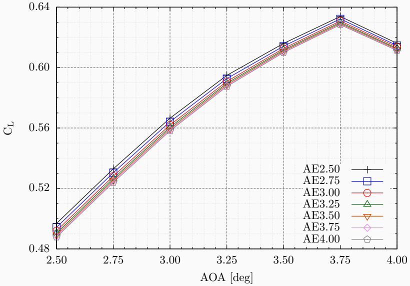
CommonHybrid	@ Medium level (45M nodes)
CustomHexa	@ Medium level (45M nodes)
CustomHybrid-A	@ Medium level (17M nodes)
CustomHybrid-I	@ Medium level (17M nodes)

Turbulence model:

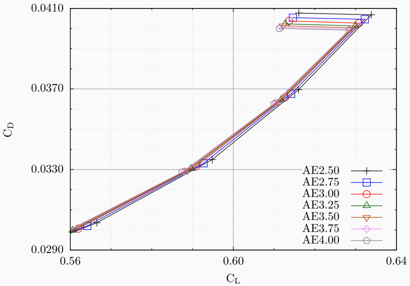
SST (CFD++)

Wing deformation effect on lift and drag polar

CustomHexa



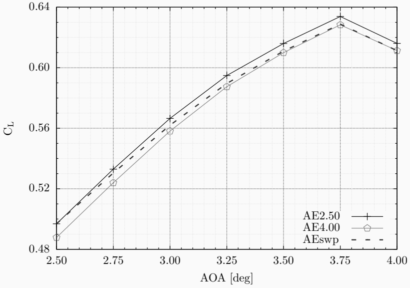
(a) Lift



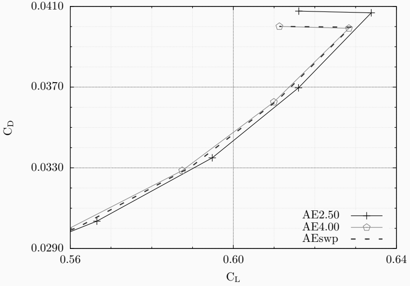
(b) Drag Polar

Wing deformation effect on lift and drag polar

CustomHexa



(a) Lift

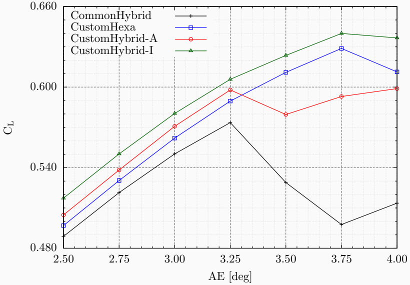


(b) Drag Polar

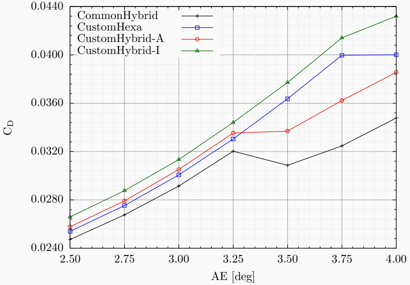
Increased AE $\rightarrow$ Decreased tip incidence $\rightarrow$ Decreased lift slope

Case 3: CRM WB Static Aero-Elastic Effect

Mesh effect on lift and drag

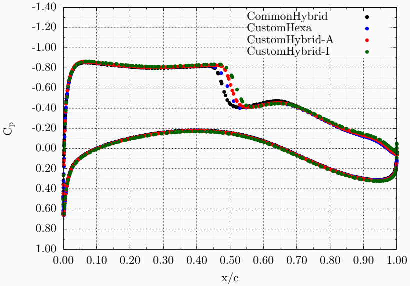


(a) Lift

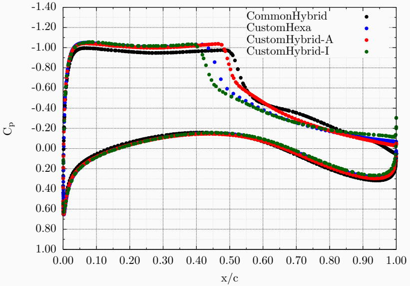


(b) Drag

Mesh and wing deformation effect on Cp distribution



(a) Wing Section 11 - AE2.50 - AOA=2.5°



(b) Wing Section 11 - AE4.00 - AOA=4.0°

Conclusion - Case 1

- Results for CFD++ SA are similar to CFL3D and FUN3D except for a shift in total drag;
- The difference comes mainly from the pressure drag component;
- The SST turbulence model generates different results in comparison to SA;

Conclusion - Case 2 and 3

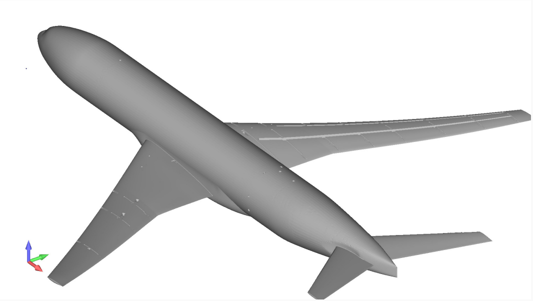
- Despite the difference in grid cells:
  - The CustomHybrid-A is only 1 to 2 dc away from CommonHybrib (WB and WBNP);
  - On the other hand, CustomHybrid-I generates differences in drag up to 5 dc for the same number of elements;
  - This result highlights the importance of the way the elements are distributed;
- The SOB separation seems to be more related to gridding strategy than to the grid size;
- The grid has a significant influence on predicting CD, CL and CP for higher AE deflections;

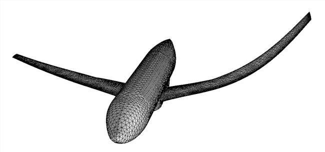
Case 5: WB Coupled Aero-Structural Sim.

- AERO Suite, CMSoft Inc.
  - Coupled fluid/structral/thermal analysis;
  - Euler, RANS, DES and LES;
  - ALE (Arbitrary Lagrangian Eulerian) 2nd-order Finite Volume solver;
  - Linear/non-linear structural analysis;
- Modal base obtained with MSC Nastran (linear structure);
- SA QCR-2013 up to wall;
- Quasi-static CL-driven fluid-structure simulation;

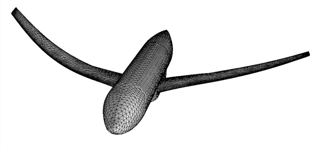
Case 5: WB Coupled Aero-Structural Sim.

WT solid FEM model 0.027:1 (*10 modes are considered*)

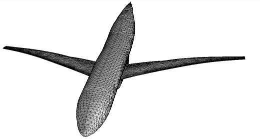




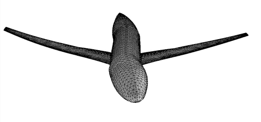
(c) 1st mode: 39.4 Hz



(d) 2nd mode: 41.0 Hz

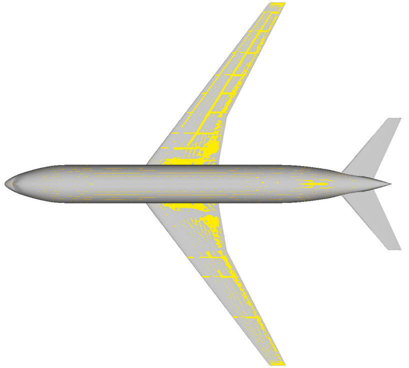


(a) 3rd mode: 39.4 Hz



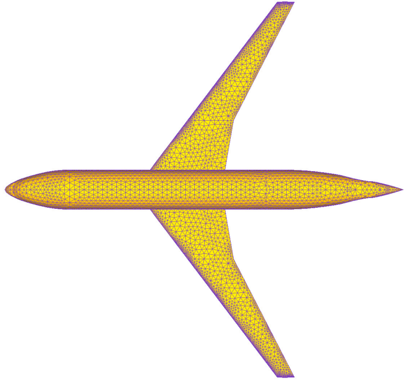
(b) 4th mode: 41.0 Hz

Case 5: WB Coupled Aero-Structural Sim.



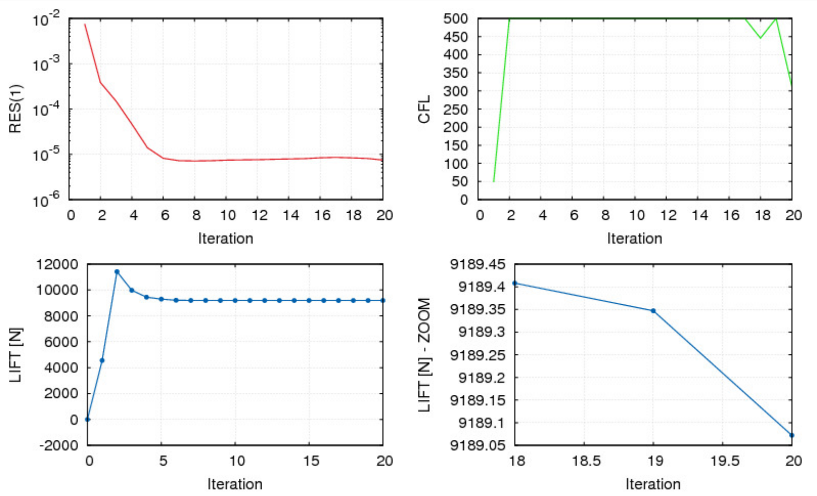
CFD medium (level 3)
mirrored custom-hexa
Mesh motion linear torsional spring analogy
$min(vol) = \mathcal{O}(10^{-21})m^3$

Dressing mesh 20k tri
AE0.0 loft

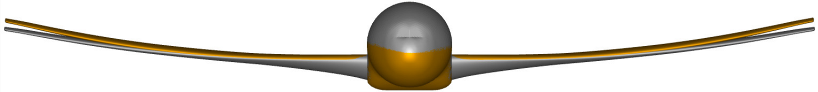


Case 5: WB Coupled Aero-Structural Sim.

Numerical convergence of coupled system.
Wall-clock 3 hours for 1500 partitions.



CASE 5: WB COUPLED AERO-STRUCTURAL SIM.



CRM NTF 0.027:1

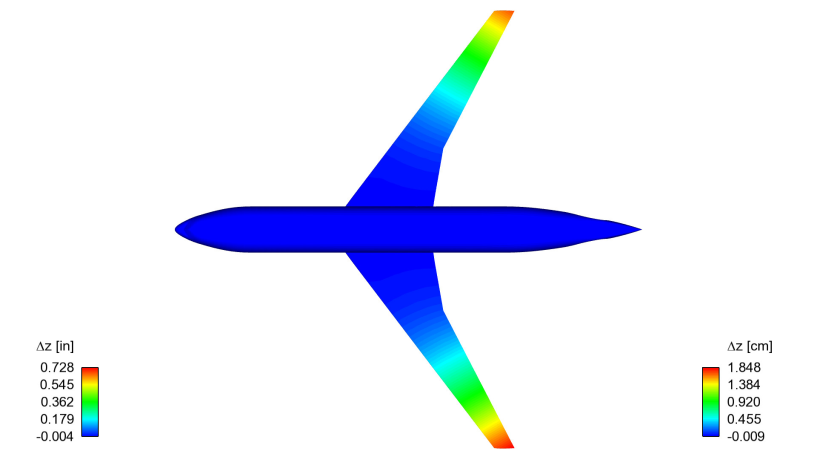
M 0.85 RE 5.0×10^6 α 2.5971°

CL 0.499989 CD 0.025412

Q 63.215 kPa, 1320 psf

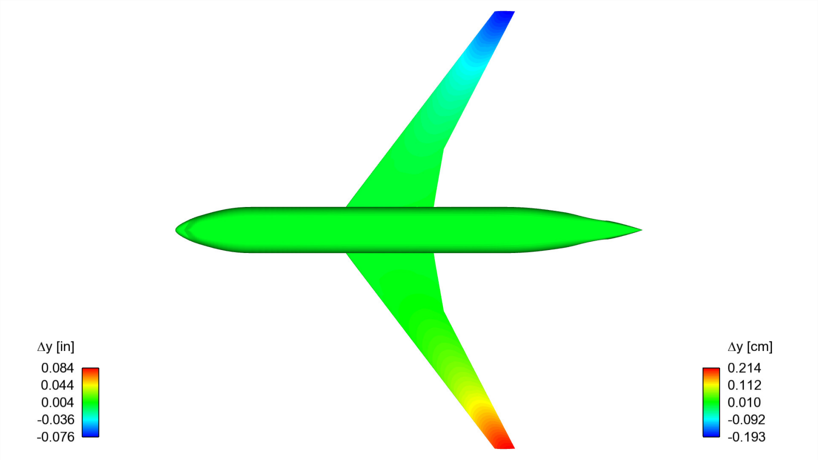
Case 5: WB Coupled Aero-Structural Sim.

Displacement Z



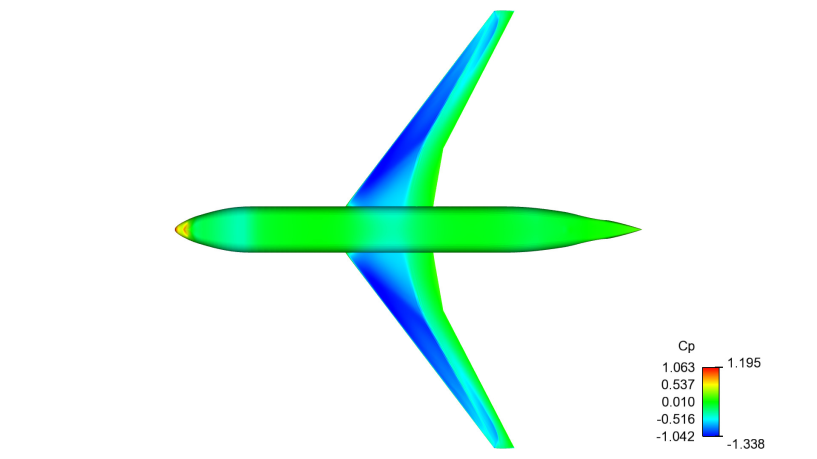
Case 5: WB Coupled Aero-Structural Sim.

Displacement Y



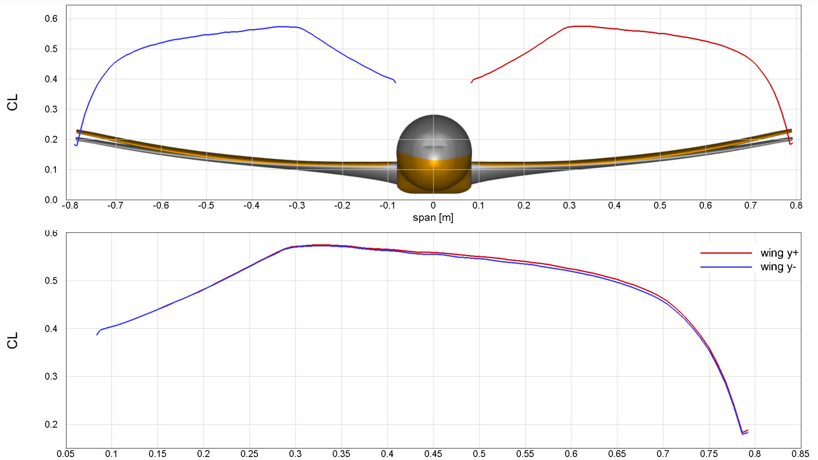
Case 5: WB Coupled Aero-Structural Sim.

Cp contours



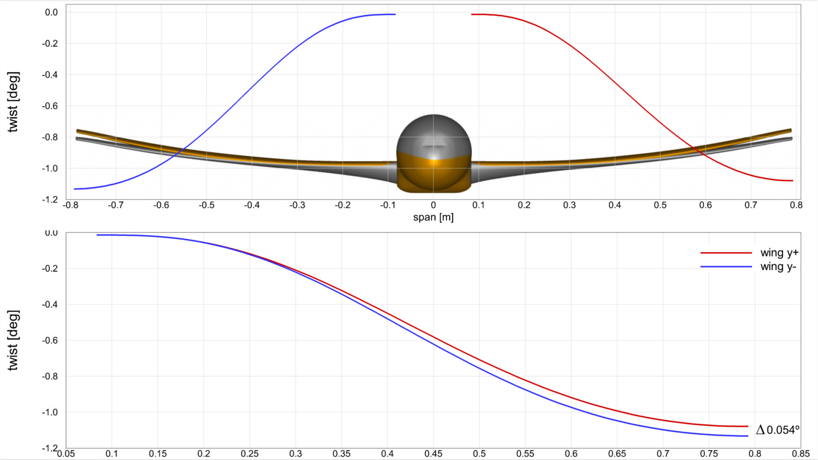
Case 5: WB Coupled Aero-Structural Sim.

CL vs span



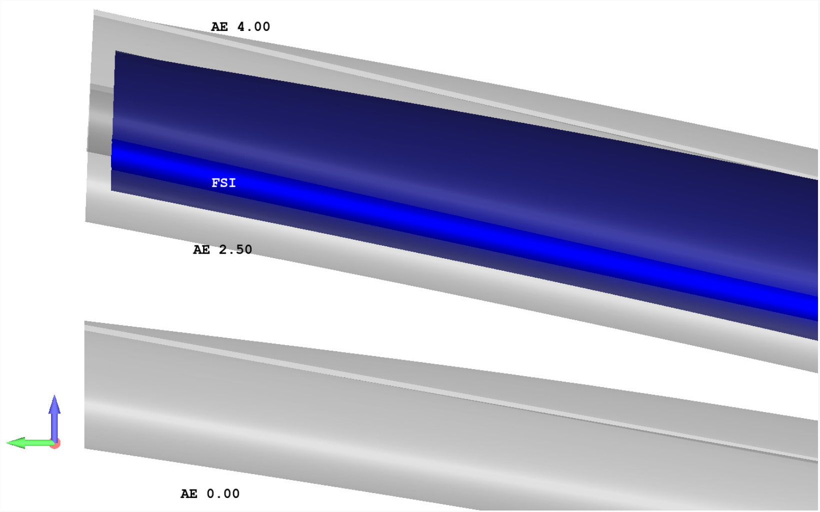
Case 5: WB Coupled Aero-Structural Sim.

Twist vs span



Case 5: WB Coupled Aero-Structural Sim.

Wing "shortening"



Conclusion - Case 5

- FEM is particular to the wind tunnel configuration;
- Flexibility effects play a major role in forces and moments prediction;
- Secondary geometric effects (“shortening”) are accounted for in coupled simulations;
- FSI methods are ready and feasible for complex flight-shape analysis, i.e. transonic flows, practical geometries and meshes.

Recommendations - Case 5

- Quantify wing bending vs wing twist effects;
- Shorten the span for provided static aero-elastic geometries;
- Improve FEM analysis header. Excess of 6GB for Nastran F06 file with only 10 modes;
- Improve case 5 website description/requirements: loft scale, FEM - wingbox vs WTT;
- Experiment mesh motion methods with hybrid tetra+prism meshes.

BONUS TRACK

The GMA – Automatic Mesh Generator

Replay file .tcl written on ICEMCFD:

- Read geometry
- Clean up
- Generate support entities (points and curves)
- Perform block cutting
- Calculate bunching
- Output grid

The GMA – Features

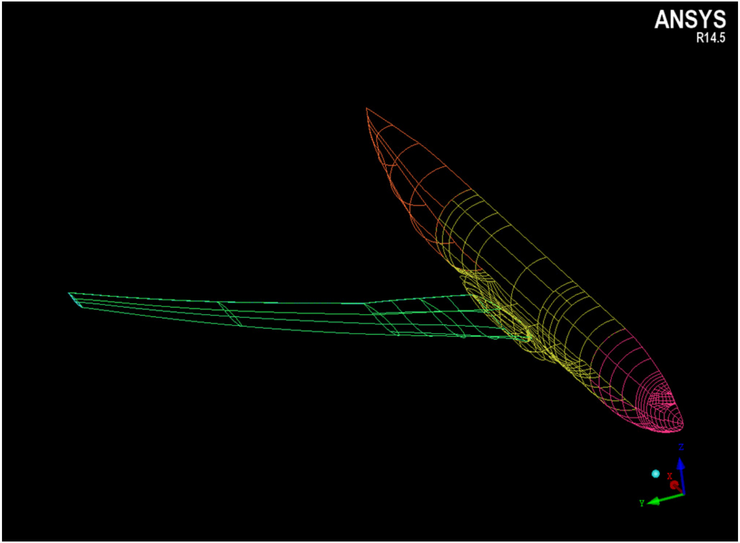
Features:

- Fast mesh generation
- High quality elements
- Consistency

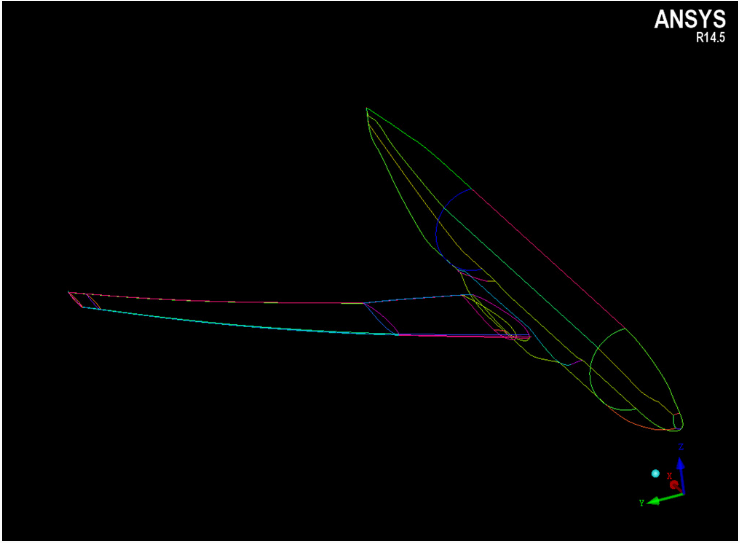
Adequate for:

- Refinement studies – whole airplane or particular region
- Accurate comparison between different geometries

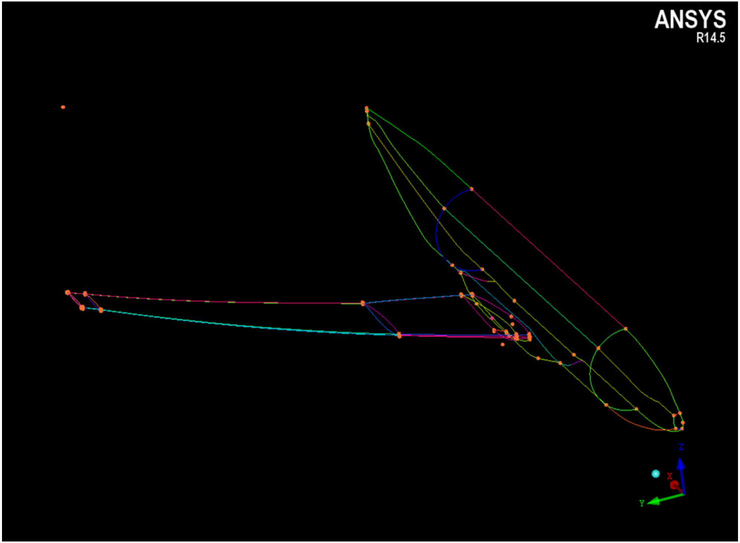
The GMA – Read Geometry



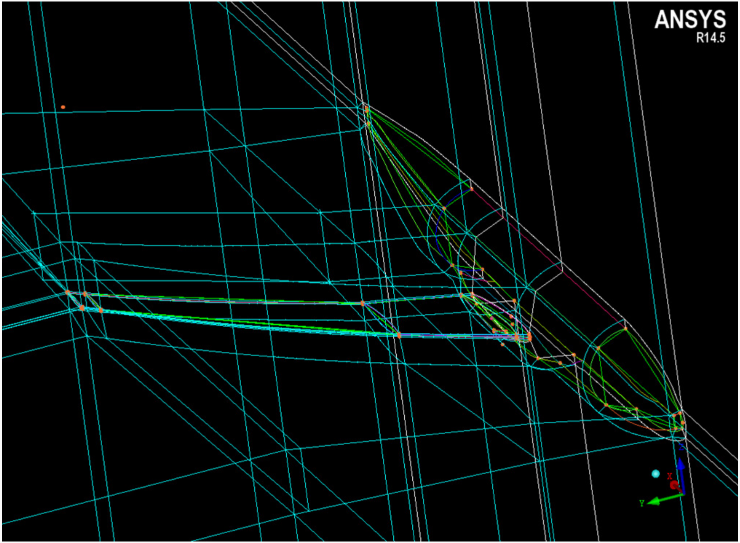
The GMA – Support Curves



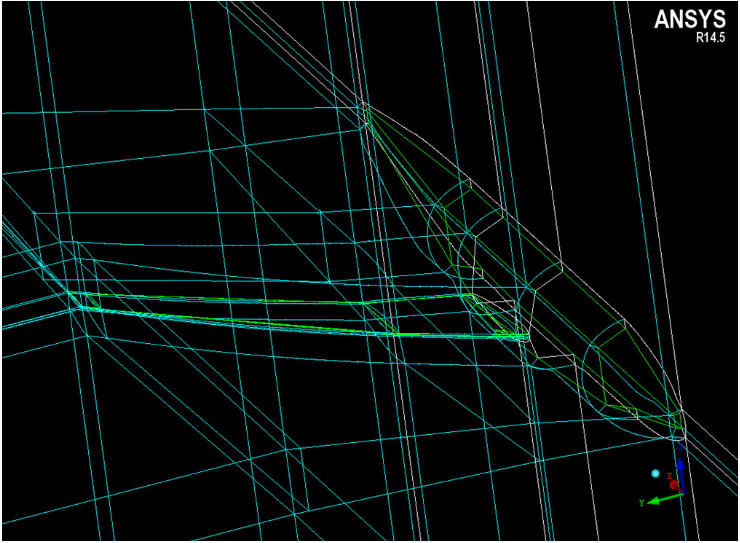
The GMA – Support Points



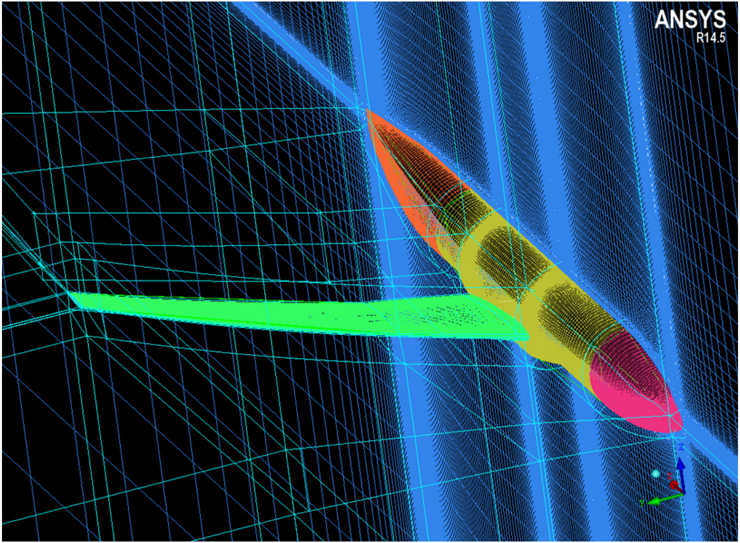
The GMA – Block Cutting



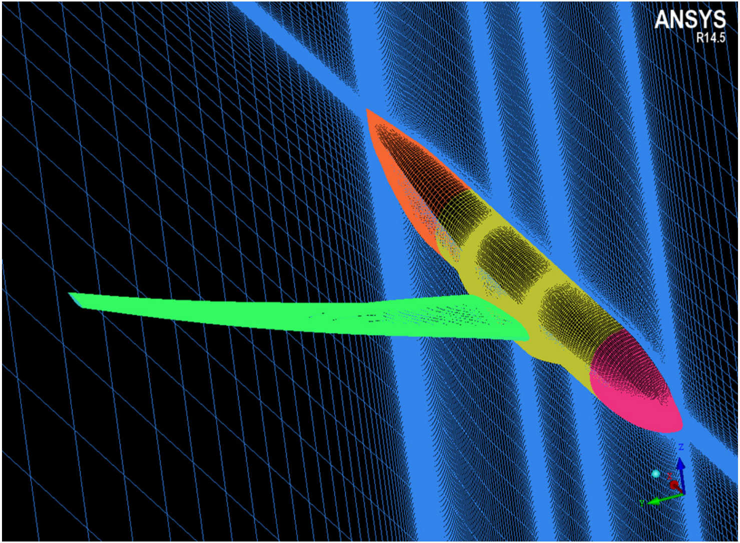
The GMA – Block Cutting - Edges Only



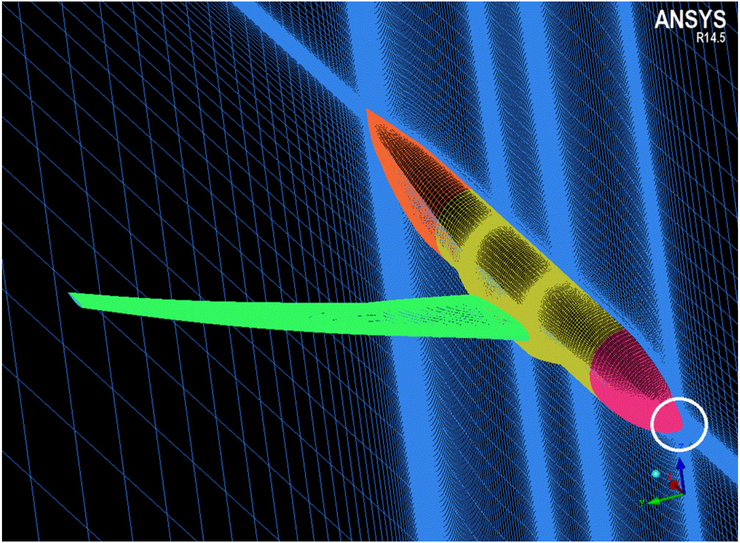
The GMA – Grid Generation



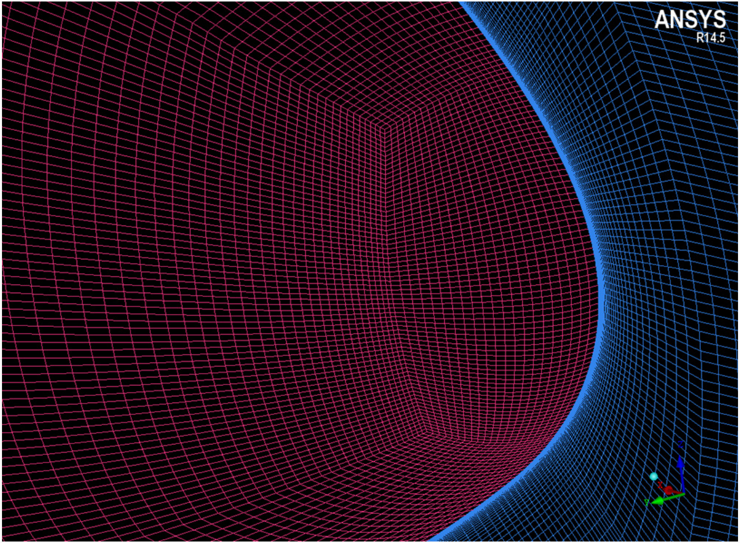
The GMA – Grid Generation



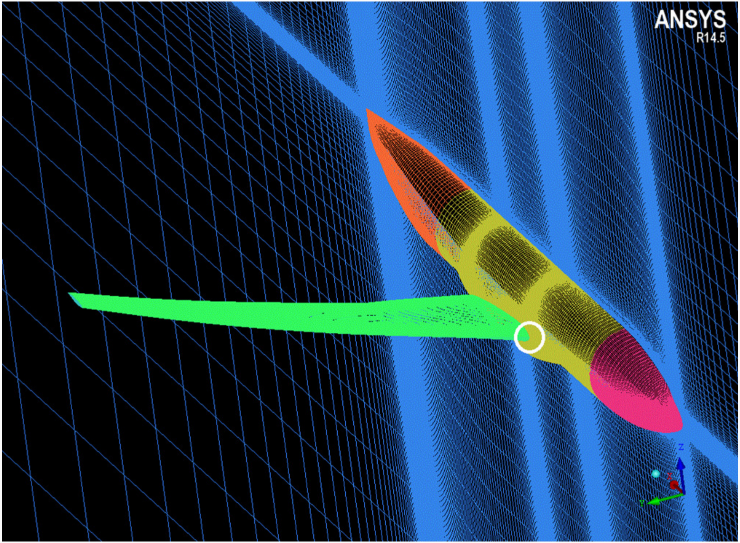
The GMA – Nose Detail



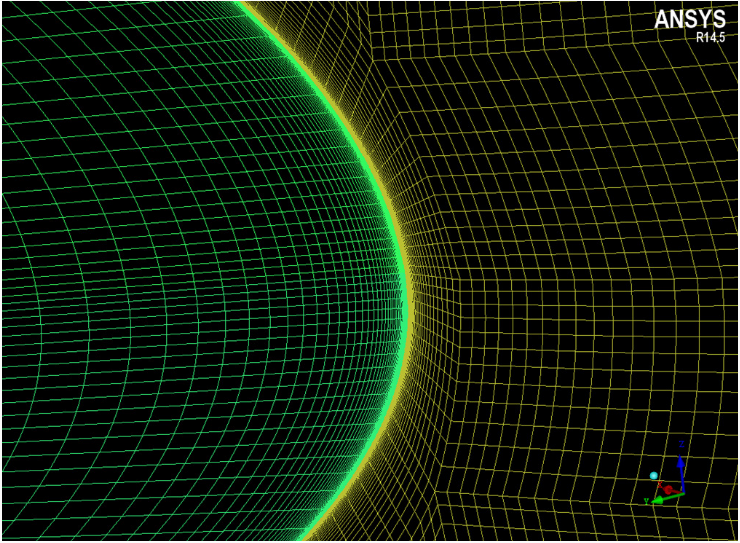
The GMA – Nose Detail



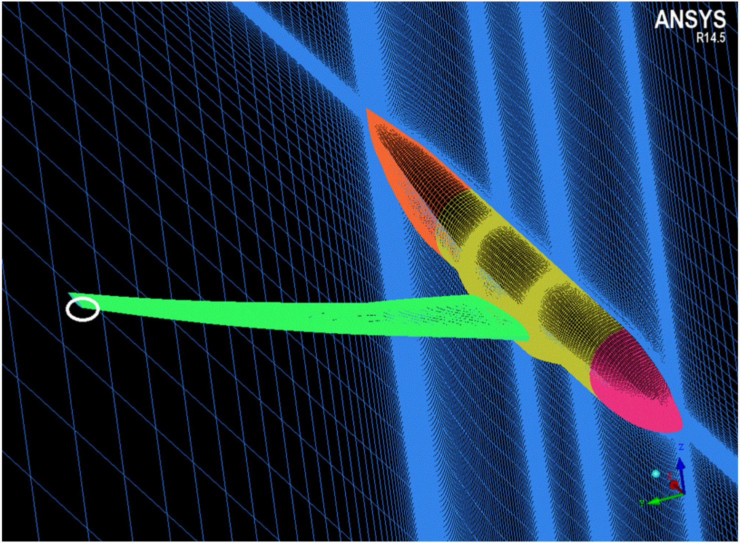
The GMA – Wing Fairing Intersection (LE)



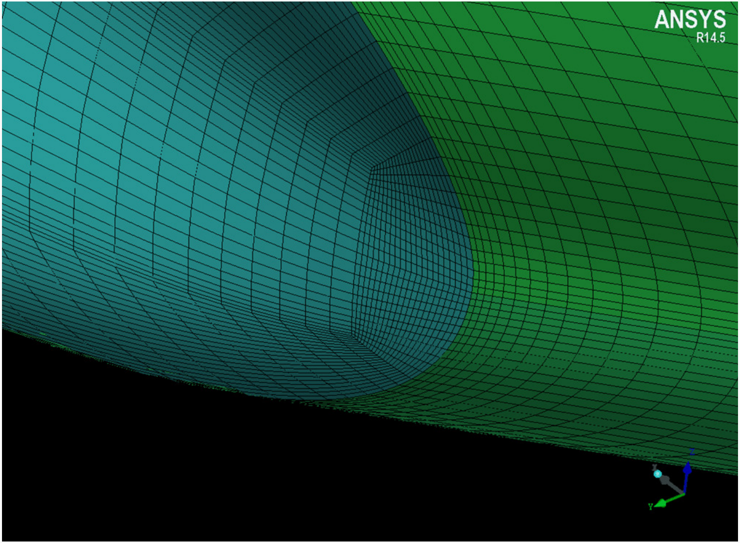
The GMA – Wing Fairing Intersection (LE)



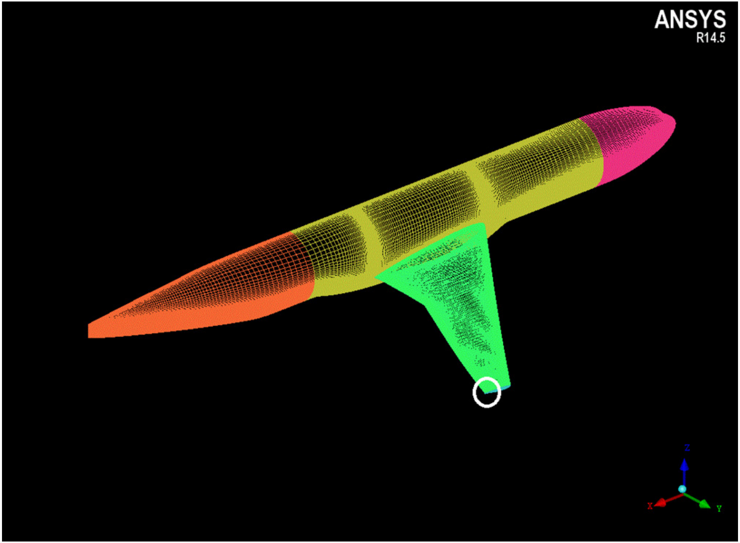
The GMA – Wing Tip (LE)



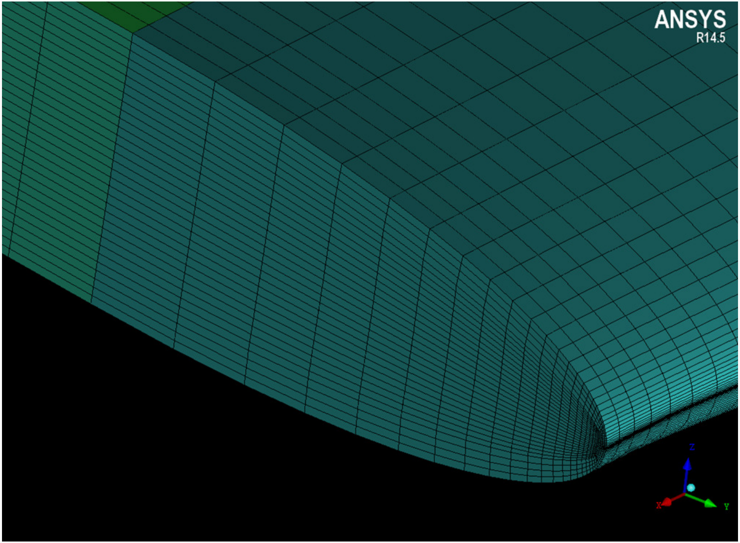
The GMA – Wing Tip (LE)



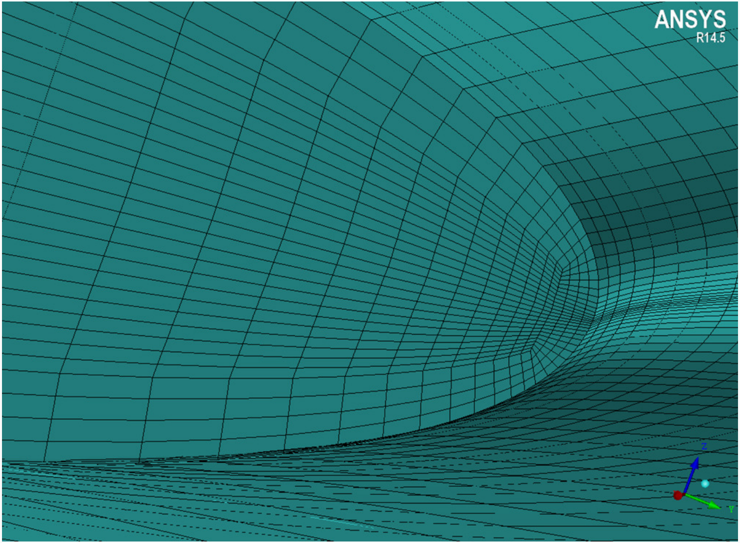
The GMA – Wing Tip (TE)



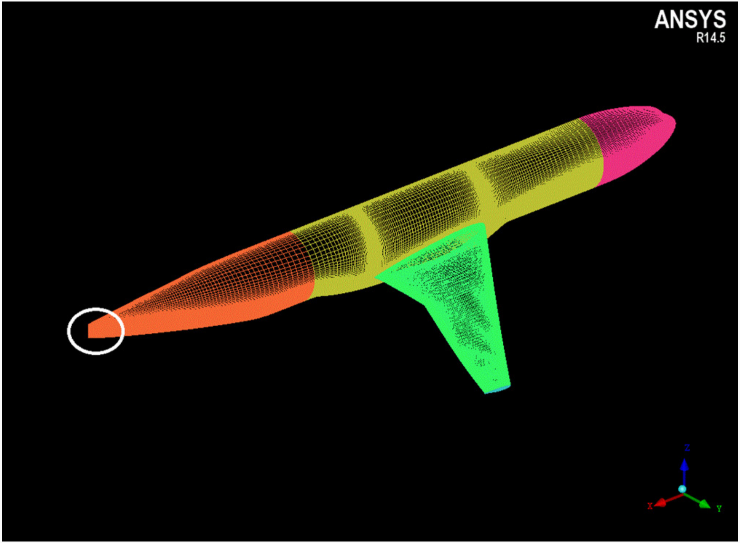
The GMA – Wing Tip (TE)



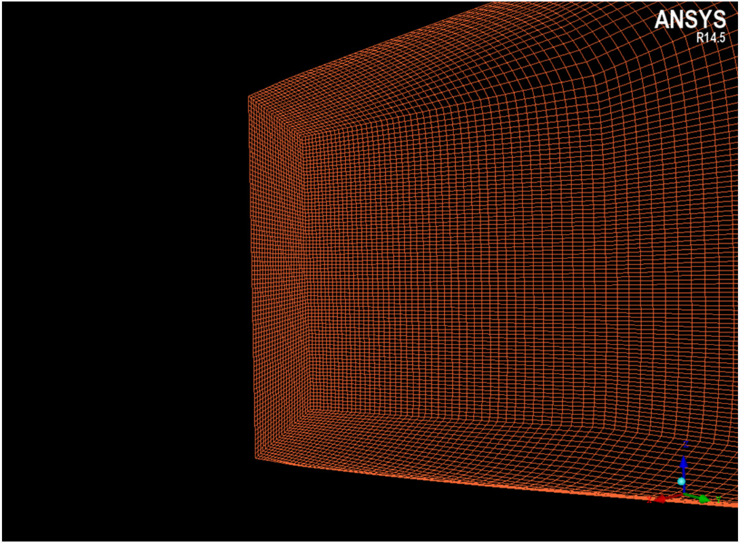
The GMA – Wing Tip (TE)



The GMA – Tail Cone



The GMA – Tail Cone



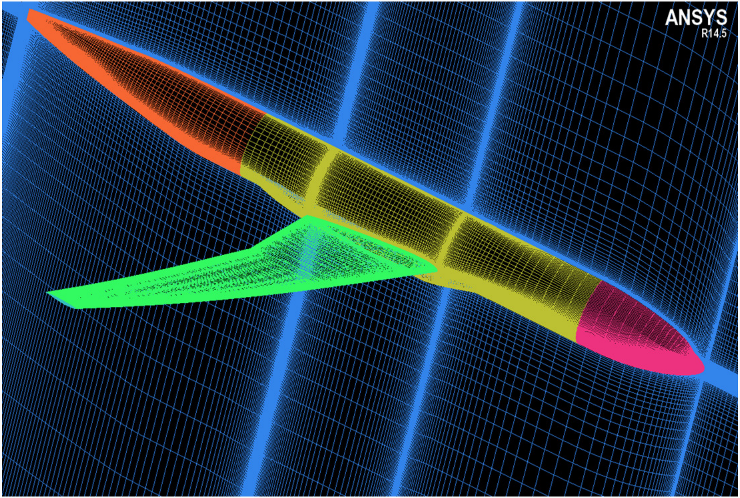
The GMA – Refinement Studies

The next slides show the grids for the cases:

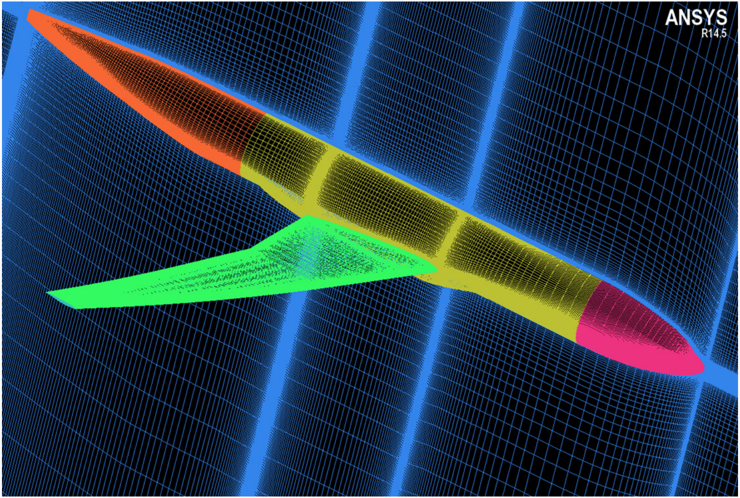
- Tiny (20 M)
- Coarse (30 M)
- Medium (45 M)
- Fine (70 M)
- Extra Fine (100 M)
- Ultra Fine (150 M)

Wing Deflection = 2.75 Deg

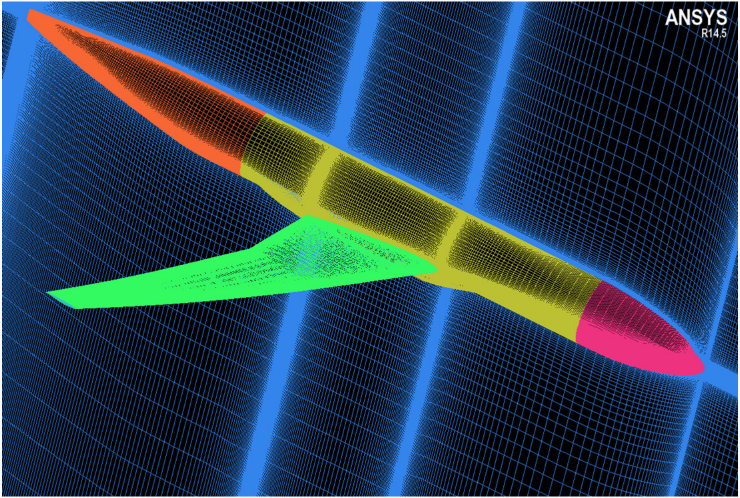
Tiny – 19,957,518 vol. cells



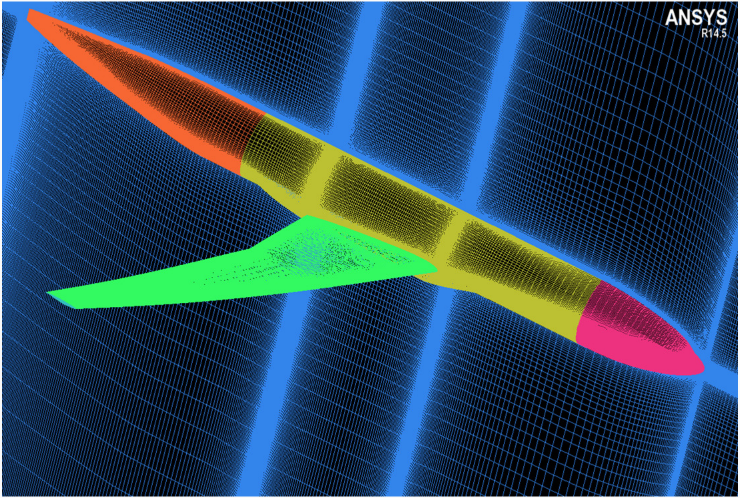
Coarse – 29,985,790 vol. cells



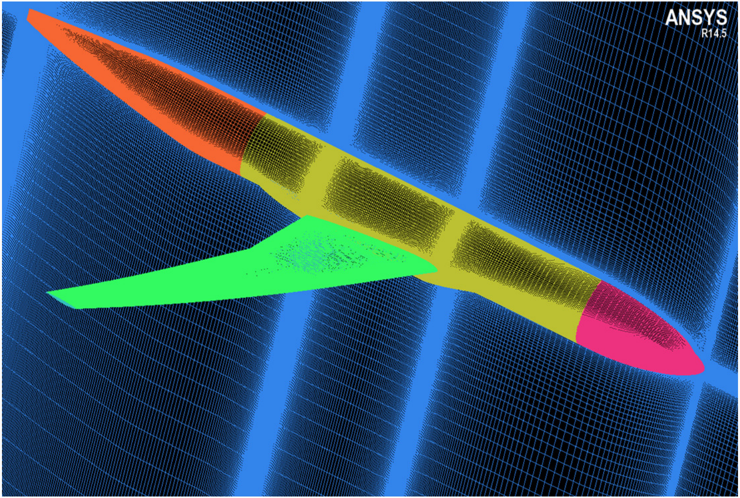
Medium – 44,930,430 vol. cells



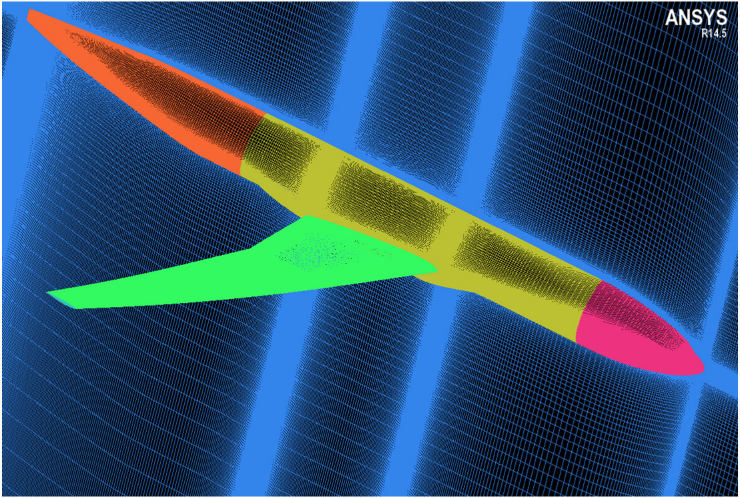
Fine – 69,994,449 vol. cells



Extra Fine – 100,984,026 vol. cells



Ultra Fine – 149,991,722 vol. cells

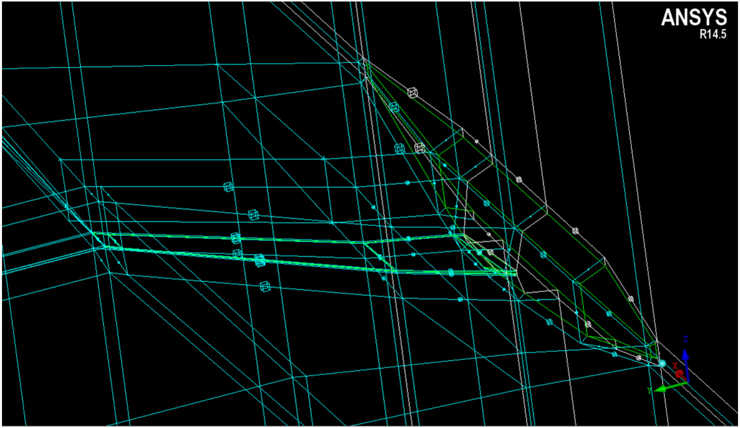


The GMA – Wing Deflecion Study

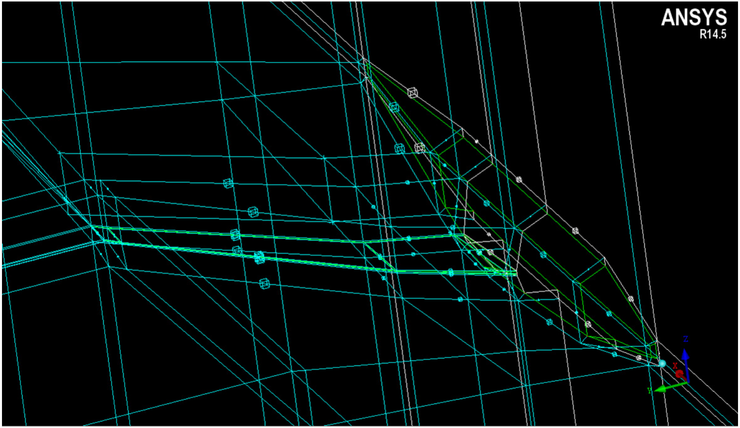
The next slides show the grids for the deflections

- 0.00 deg
- 2.50 deg
- 2.75 deg
- 3.00 deg
- 3.25 deg
- 3.50 deg
- 3.75 deg
- 4.00 deg

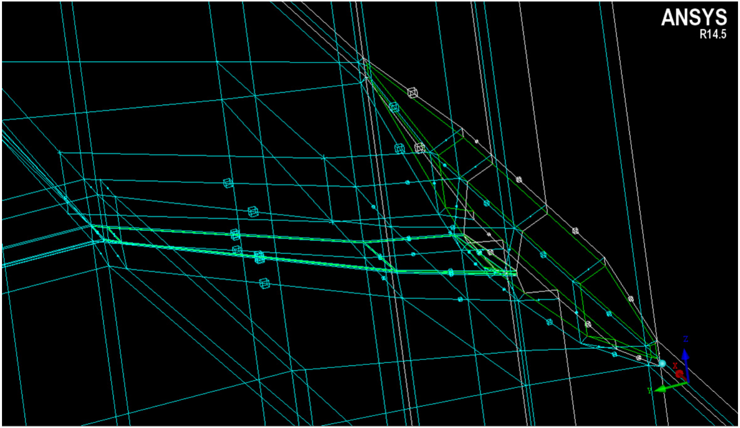
The GMA – Space Blocking – 0.00 deg



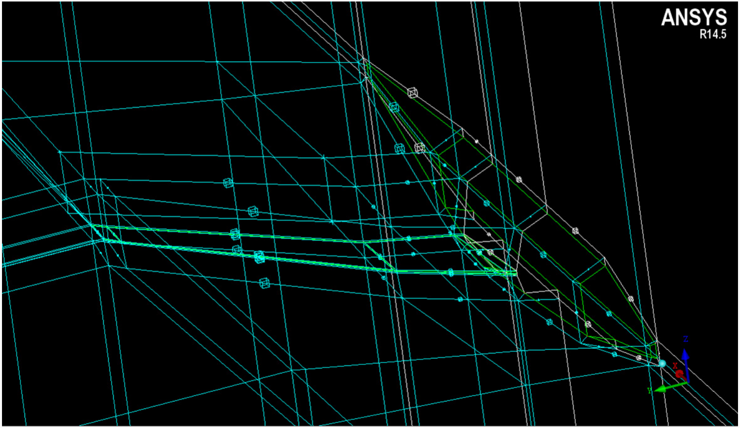
The GMA – Space Blocking – 2.50 deg



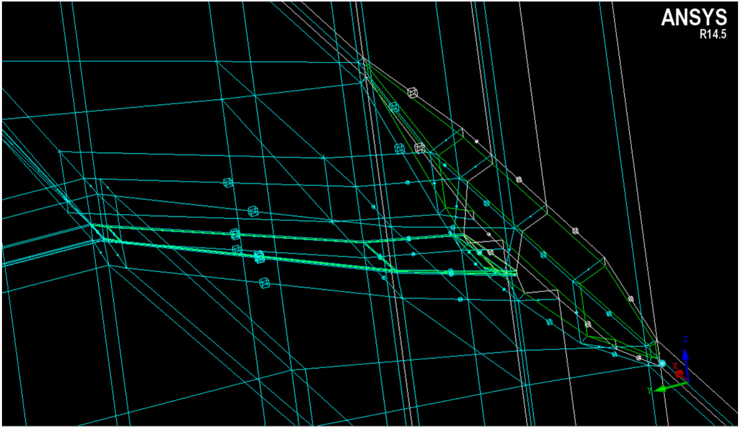
The GMA – Space Blocking – 2.75 deg



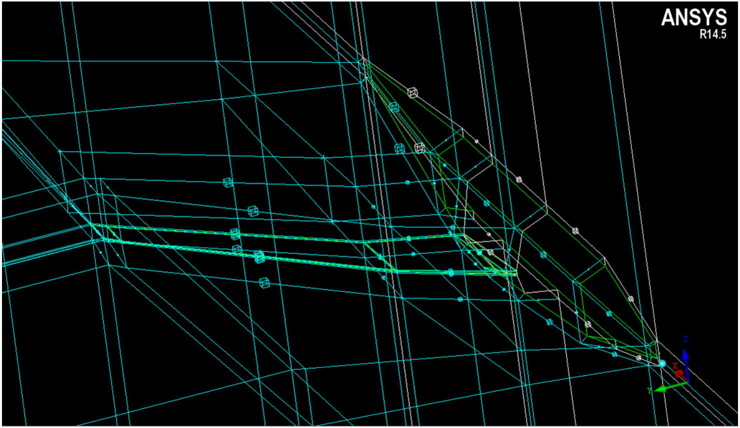
The GMA – Space Blocking – 3.00 deg



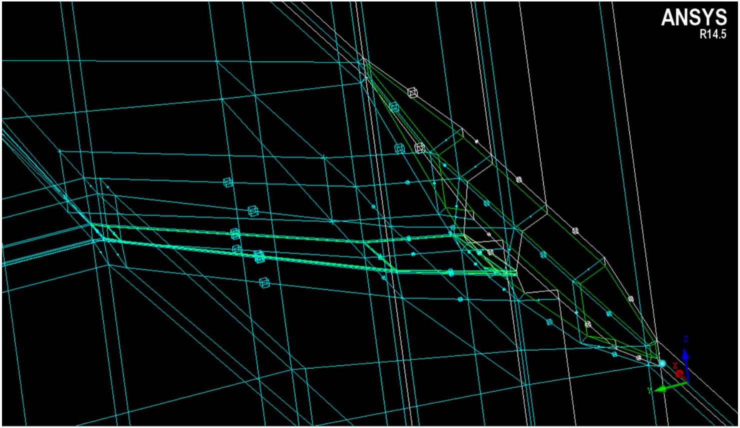
The GMA – Space Blocking – 3.25 deg



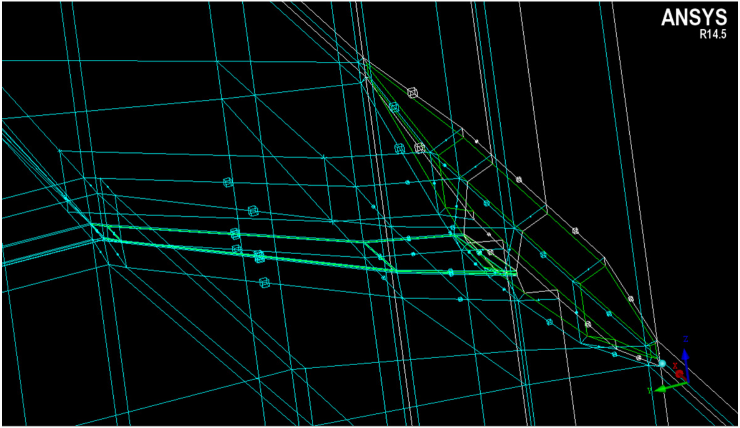
The GMA – Space Blocking – 3.50 deg



The GMA – Space Blocking – 3.75 deg



The GMA – Space Blocking – 4.00 deg



The GMA – General Comments

The grids requires basically two sizes for generation:

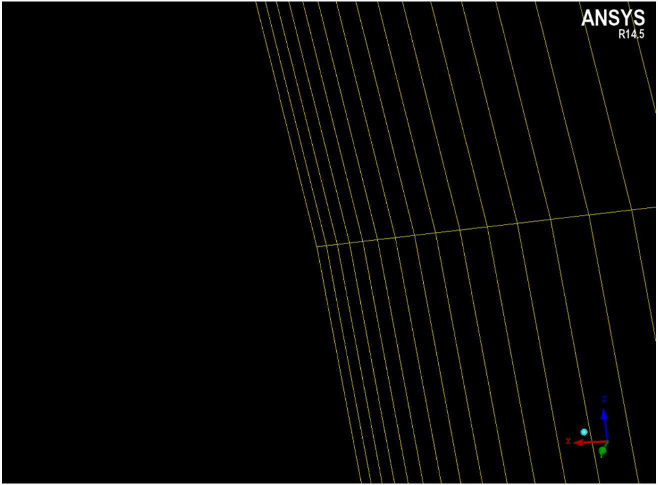
- BL first element
- Element at the leading edge (wing root)

All the rest of the grid is defined by prescribing growth ratios. Grids of other sizes can easily be obtained by changing these Grid parameters.

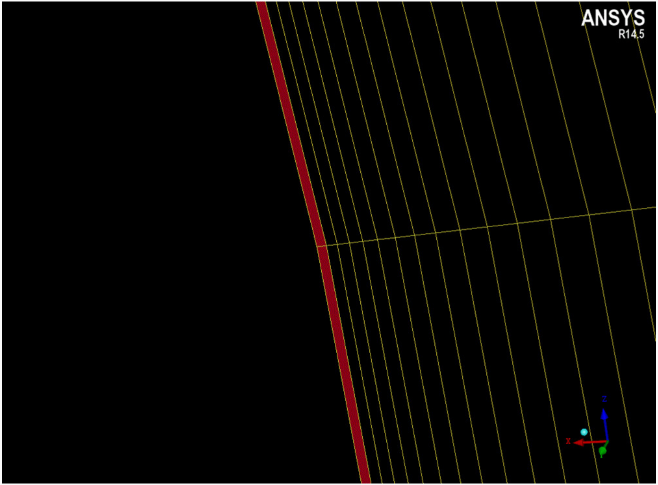
The GMA – Uniform Grid Elements at Surface

Investigation on how the number of uniform grid elements on surface influences drag calculation

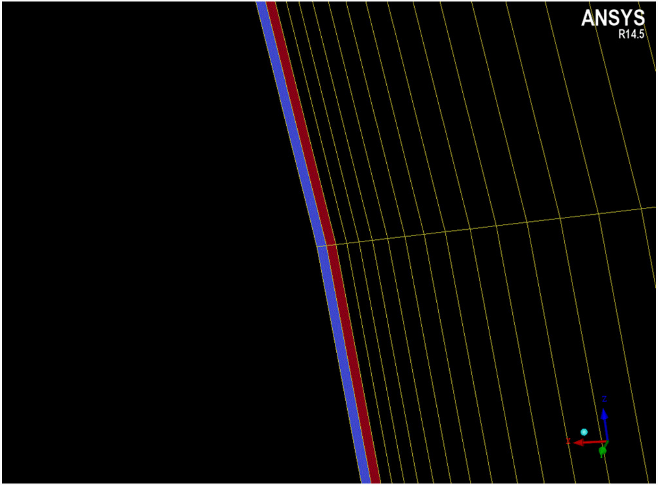
Insert Elements on BL



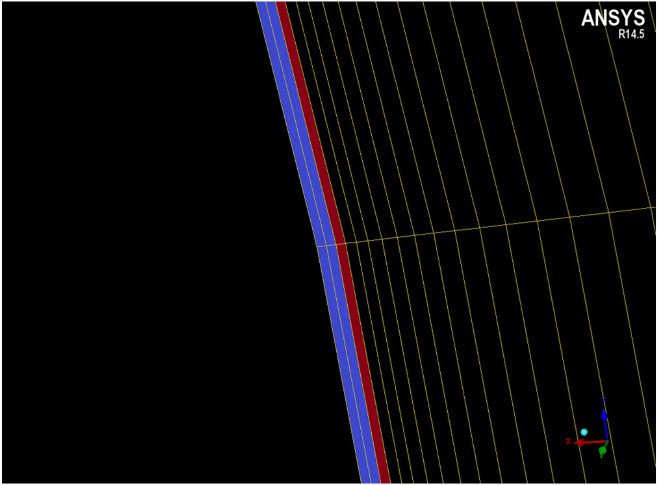
Insert Elements on BL



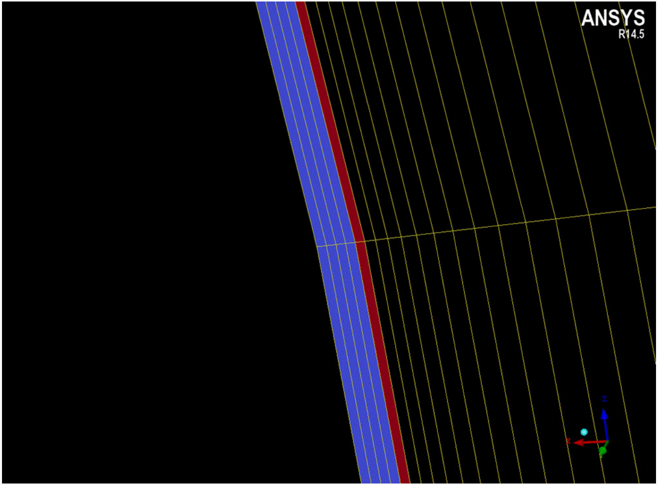
Insert Elements on BL



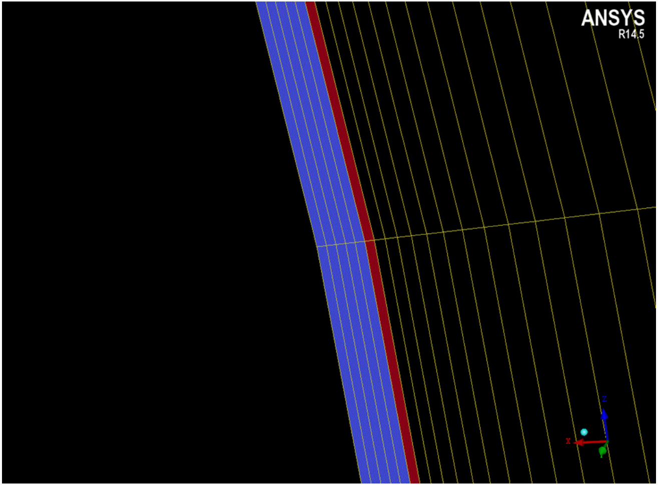
Insert Elements on BL



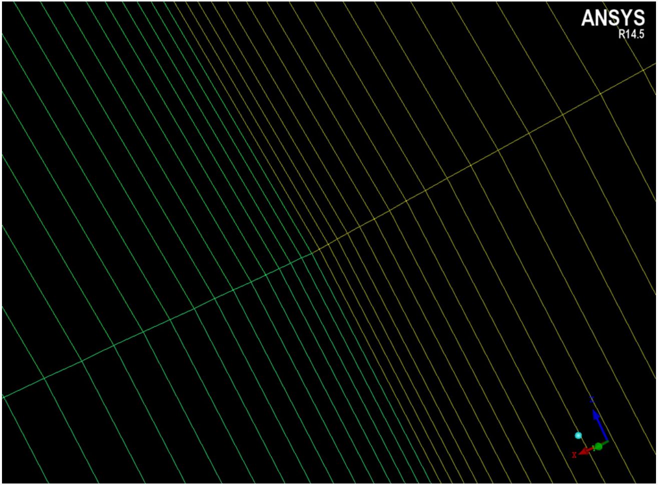
Insert Elements on BL



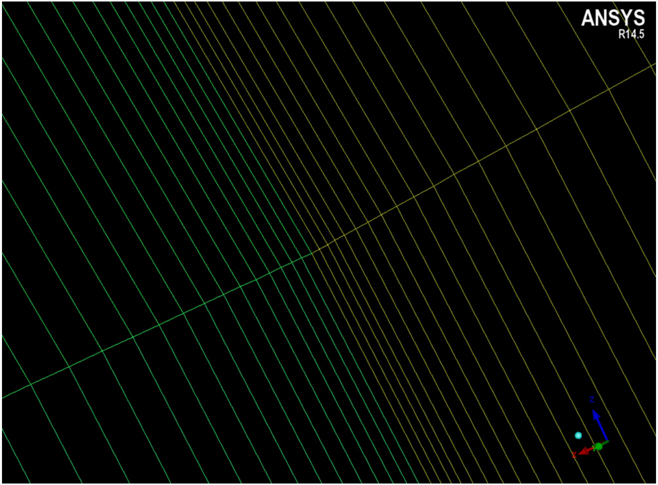
Insert Elements on BL



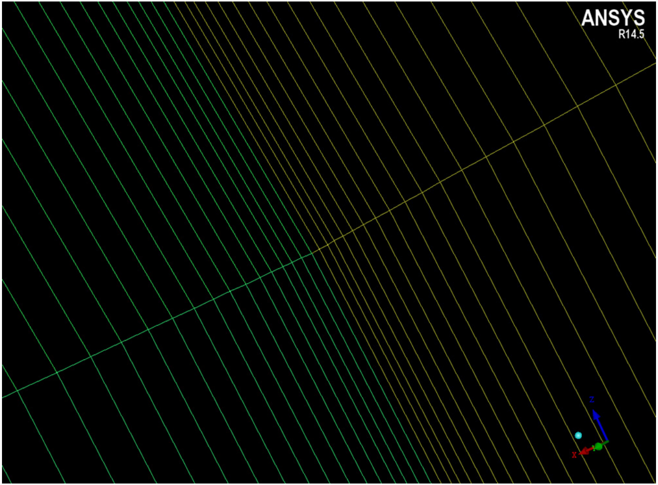
1 Elts @ BL – insert elmt – Wing Fus Intersection



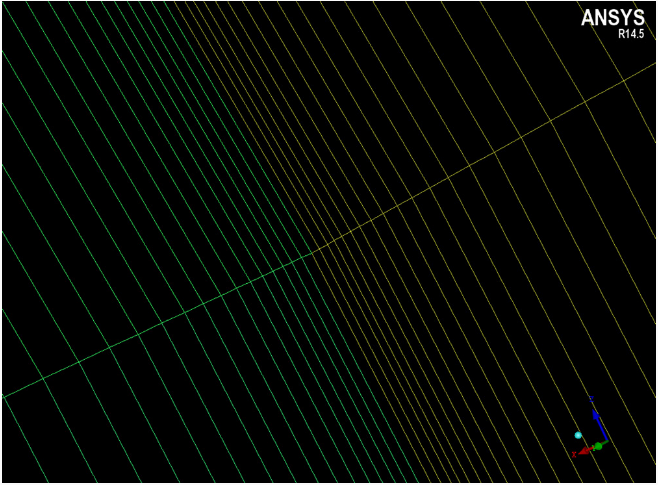
2 Elts @ BL – insert elmt – Wing Fus Intersection



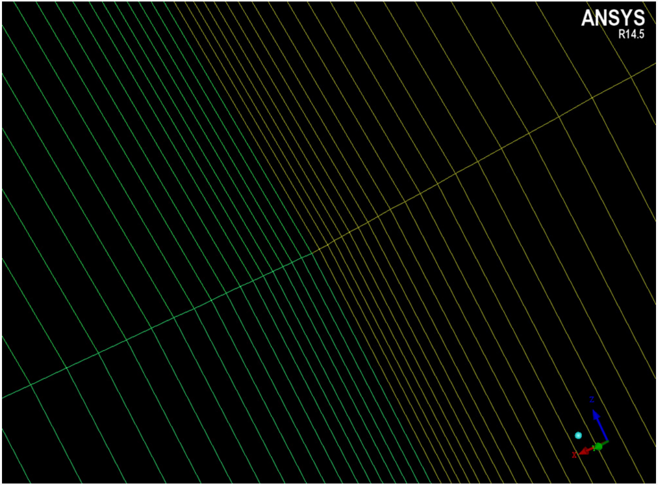
3 Elts @ BL – insert elmt – Wing Fus Intersection



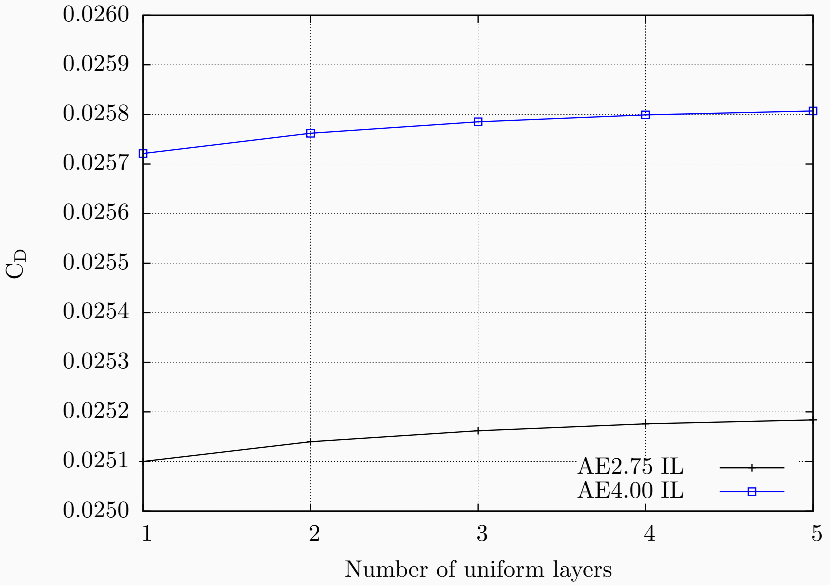
4 Elts @ BL – insert elmt – Wing Fus Intersection



5 Elts @ BL – insert elmt – Wing Fus Intersection



Drag Calculation - Inserting Layers



Uniform Grid Elements at Surface

- Uniform elements do influence calculation of absolute Drag (≈1 dc for 5 elements);
- Sistematic way of generating grids yields smoothness and allows comparison between runs;
- Delta drags do not differ for different aeroelastic deformations (differences match almost perfectly);

Next steps

- Extend GMA for WBPN

Thank you!

(Obrigado)