6th AIAA CFD Drag Prediction Workshop

Summary of results from the CFD++ software suite

Brian A. Edge

Metacomp Technologies, Inc.

June 2016

Corresponding Participant

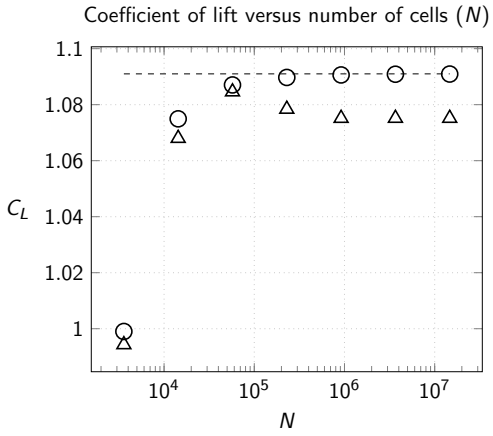
Name:	Brian Edge
Email:	edge@metacomptech.com
Phone:	(818) 735-4880
Address:	Metacomp Technologies, Inc. 28632-B Roadside Drive, Suite 255 Agoura Hills, CA 91301

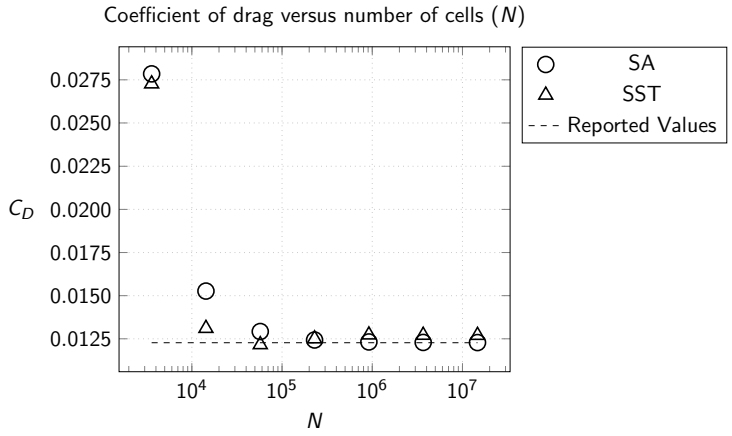
Metacomp Participation

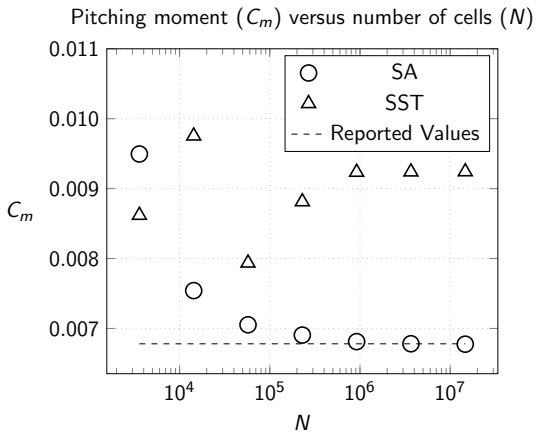
- Tasks Performed:
  1, 2, 3, and 5
- Software used:
  CFD++ Software Suite: CFD++, CSM++, MetaFSI, MIME
- CFD++ Basic Algorithms:
  - Unified unstructured higher-order TVD interpolation convection scheme
  - Cell- and vertex-based polynomial reconstruction
  - Positivity-preserving Riemann solver-based flux computation
  - Advanced algebraic multi-grid agglomeration linear solver

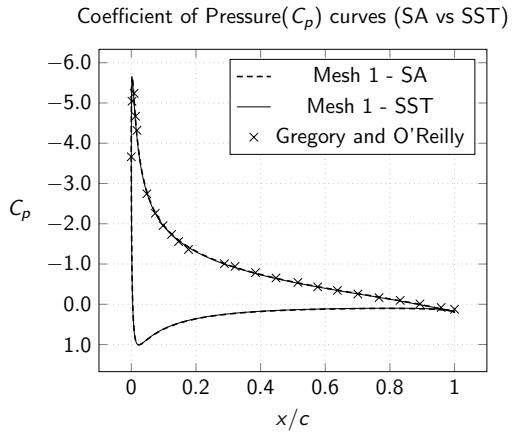
Task 1: Verification Study

Conditions:
Ma=0.15, Re=6 million, α=10 degrees, farfield ν_t/ν=0.2104









The dashed lines represents the infinitely-refined results obtained from 3 codes (FUN3D, CFL3D, and TAU).

Task 2: Drag Increment Study

Task 2: Drag Increment

- Two grids:
  - "unstructured_NASA_GeoLab.REV00"
  - "Boeing_Babcock_Unstructured_CC.REV00" grid families.

- Four turbulence models:
  - Linear Eddy Viscosity
    - Spalart-Allmaras
    - SST
  - Non-Linear Eddy Viscosity
    - Hellsten
    - SA-RC-QCR

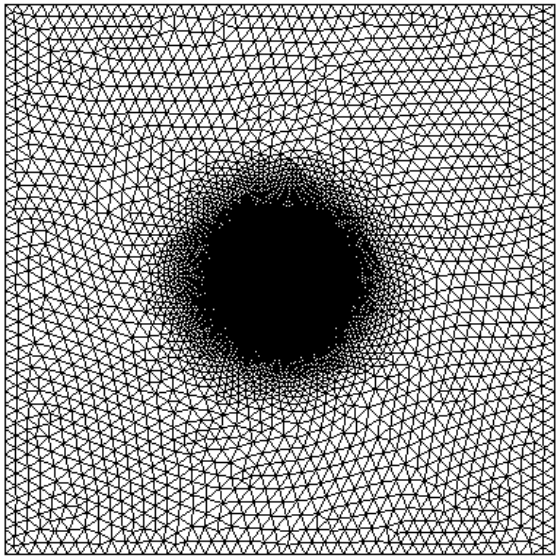
Task 2: Grid Comparison

Number of cells

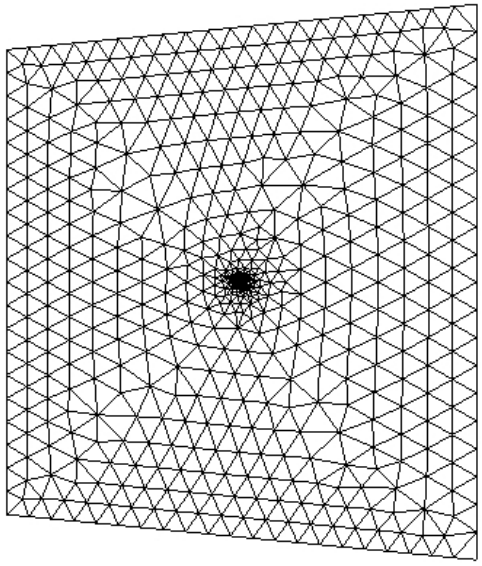
Grid	Grid Level	unstructured_NASA_GeoLab.REV00 WB	unstructured_NASA_GeoLab.REV00 WBNP	Boeing_Babcock_Unstructured_CC.REV00 WB	Boeing_Babcock_Unstructured_CC.REV00 WBNP
TINY	1	83,578,942	120,909,566	20,657,615	27,015,892
COARSE	2	122,816,245	178,924,829	26,271,819	35,271,269
MEDIUM	3	181,953,555	266,818,466	33,683,206	45,687,005
FINE	4	271,262,930	399,877,018	43,126,748	60,174,840
XTRAFINE	5	404,235,547	597,491,792	56,413,328	79,548,552
ULTRAFINE	6	606,531,721	**901,459,751**	71,169,688	**101,639,992**

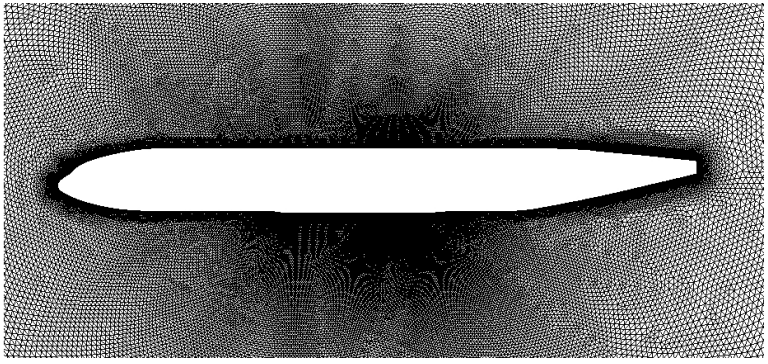
Task 2: Grid Comparison (Symmetry Plane)

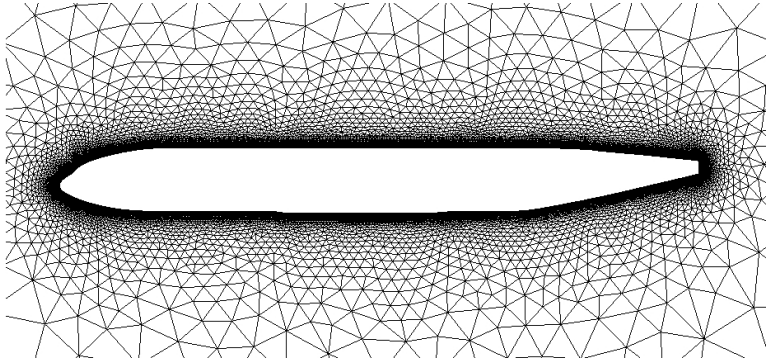
unstructured_NASA_GeoLab.REV00
Grid Level 1 (TINY)



Boeing_Babcock_Unstructured_CC.REV00
Grid Level 1 (TINY)

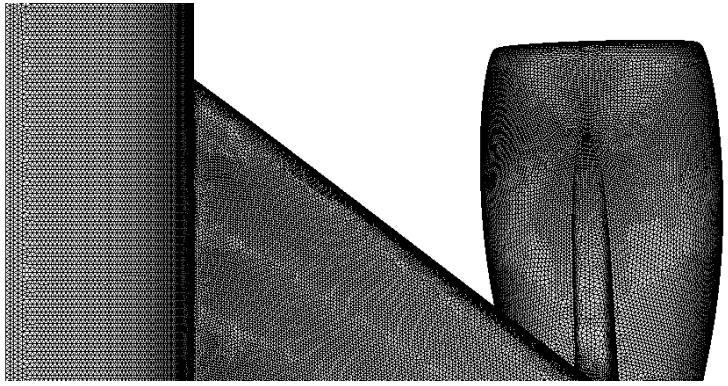


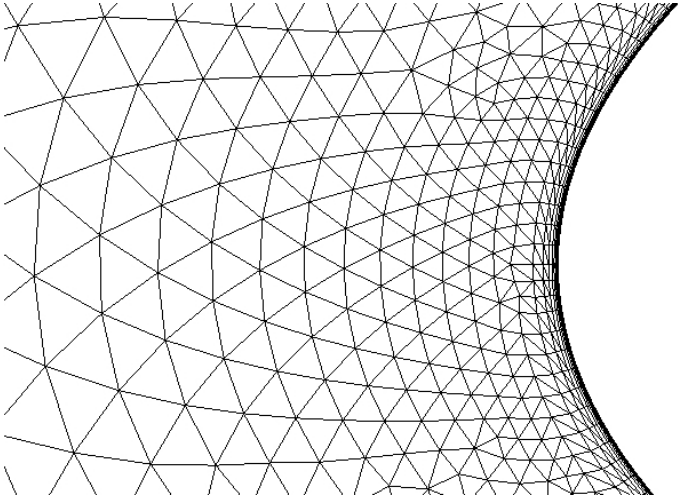




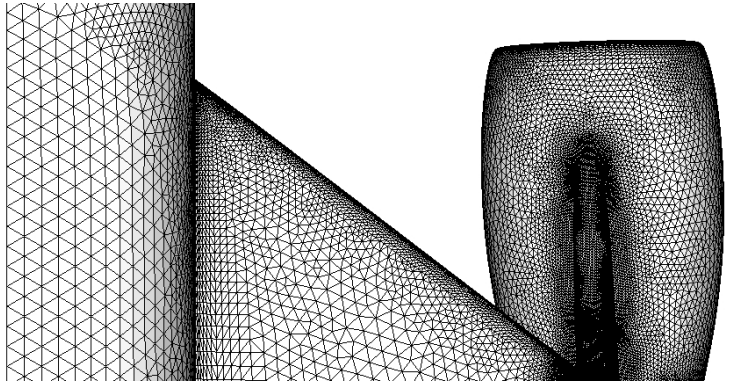
Task 2: Grid Comparison (Surface and Prism Layers)

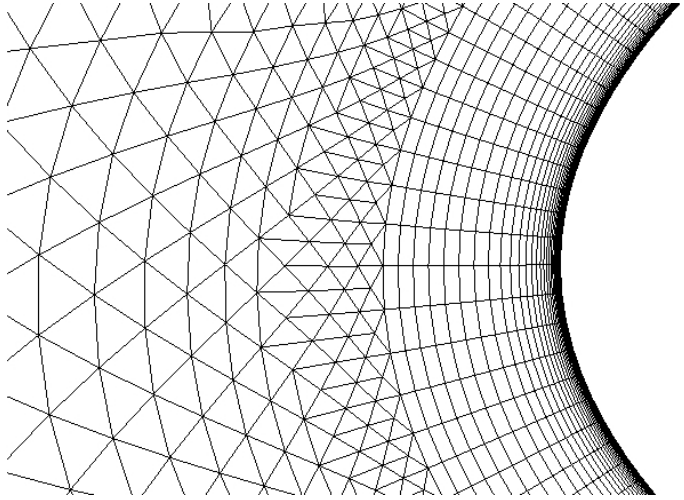
unstructured_NASA_GeoLab.REV00
Grid Level 1 (TINY)





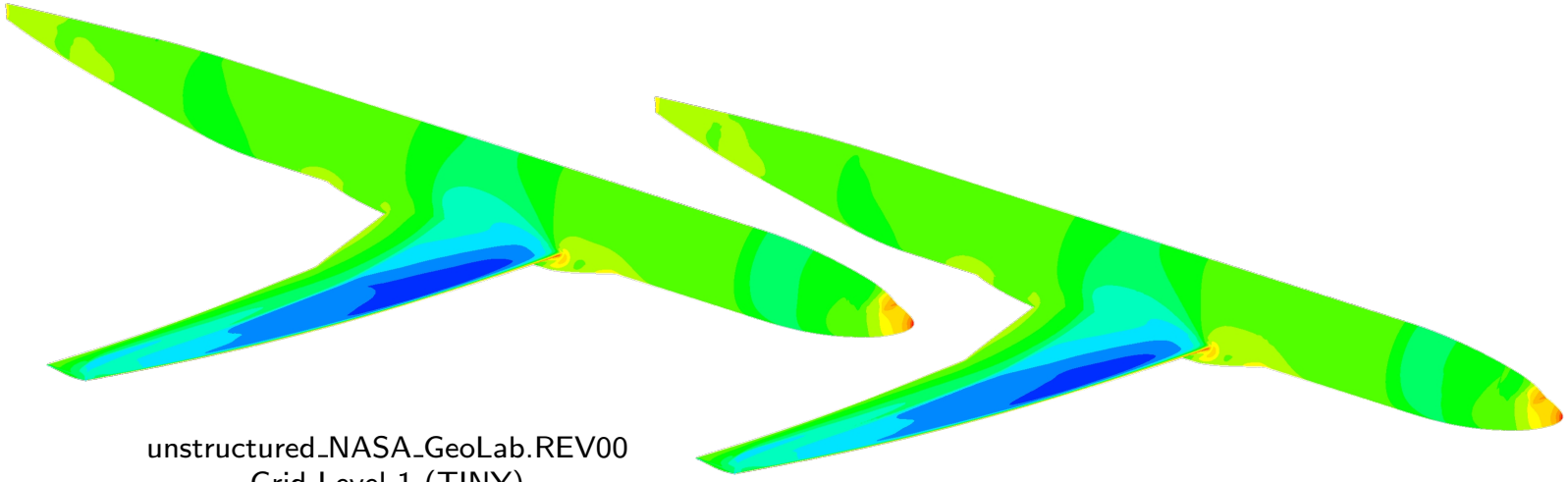
Boeing_Babcock_Unstructured_CC.REV00
Grid Level 1 (TINY)





Task 2: Grid Comparison

C_p contours on WB Geometry
Grid Level 6 (ULTRAFINE)

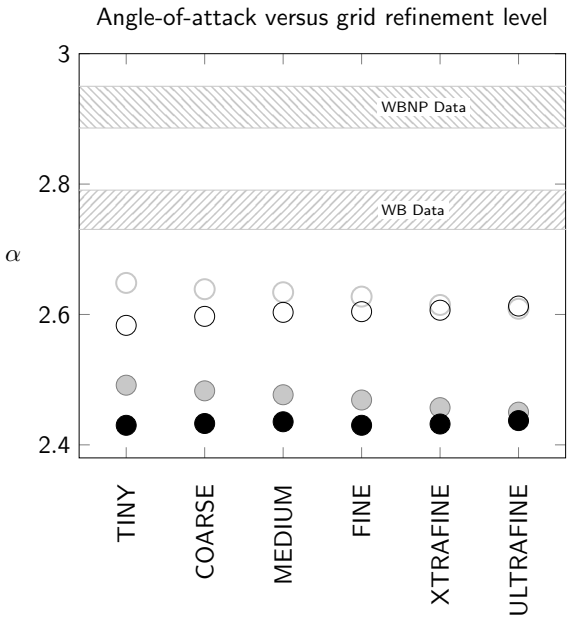


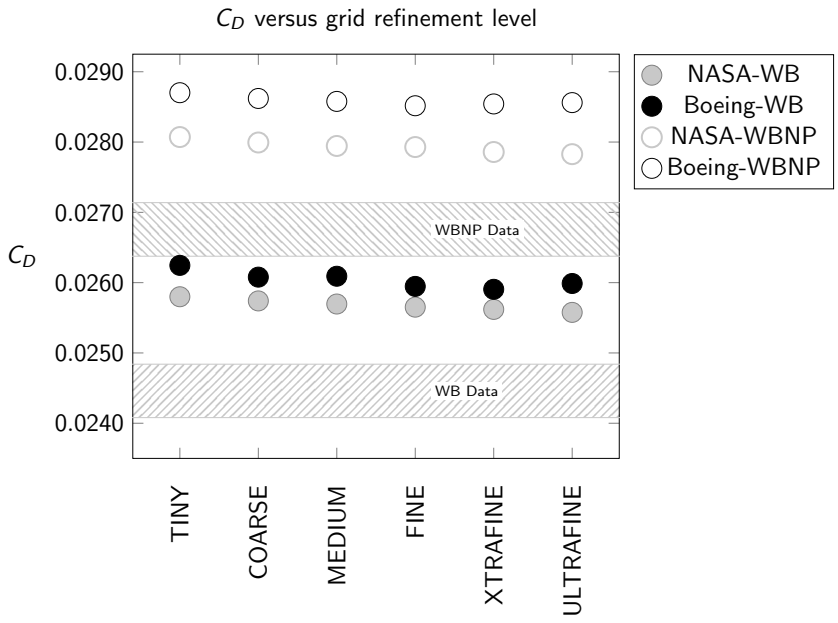
unstructured_NASA_GeoLab.REV00
Grid Level 1 (TINY)

Boeing_Babcock_Unstructured_CC.REV00
Grid Level 1 (TINY)

Task 2: Grid Comparison

Angle-of-Attack at $C_L = 0.5 \pm 0.0001$. Results were obtained using the Spalart-Allmaras turbulence model.





Task 2: Grid Computational Resource Needs

System Specs:
192 Intel(R) Xeon(R) E5-2620 v3 CPUs running at 2.40GHz,
InfiniBand interconnect 4X FDR 56GB/sec.

WB Geometry
"Boeing_Babcock_Unstructured_CC.REV00"

Grid	Grid Level	Run Time [h]	RAM [GB]
TINY	1	1.5	87
COARSE	2	1.8	108
MEDIUM	3	2.0	135
FINE	4	2.7	170
XTRAFINE	5	3.2	218
ULTRAFINE	6	3.8	272

For Comparison:
unstructured_NASA_GeoLab.REV00 (WB) - MEDIUM: 22.4 [h]

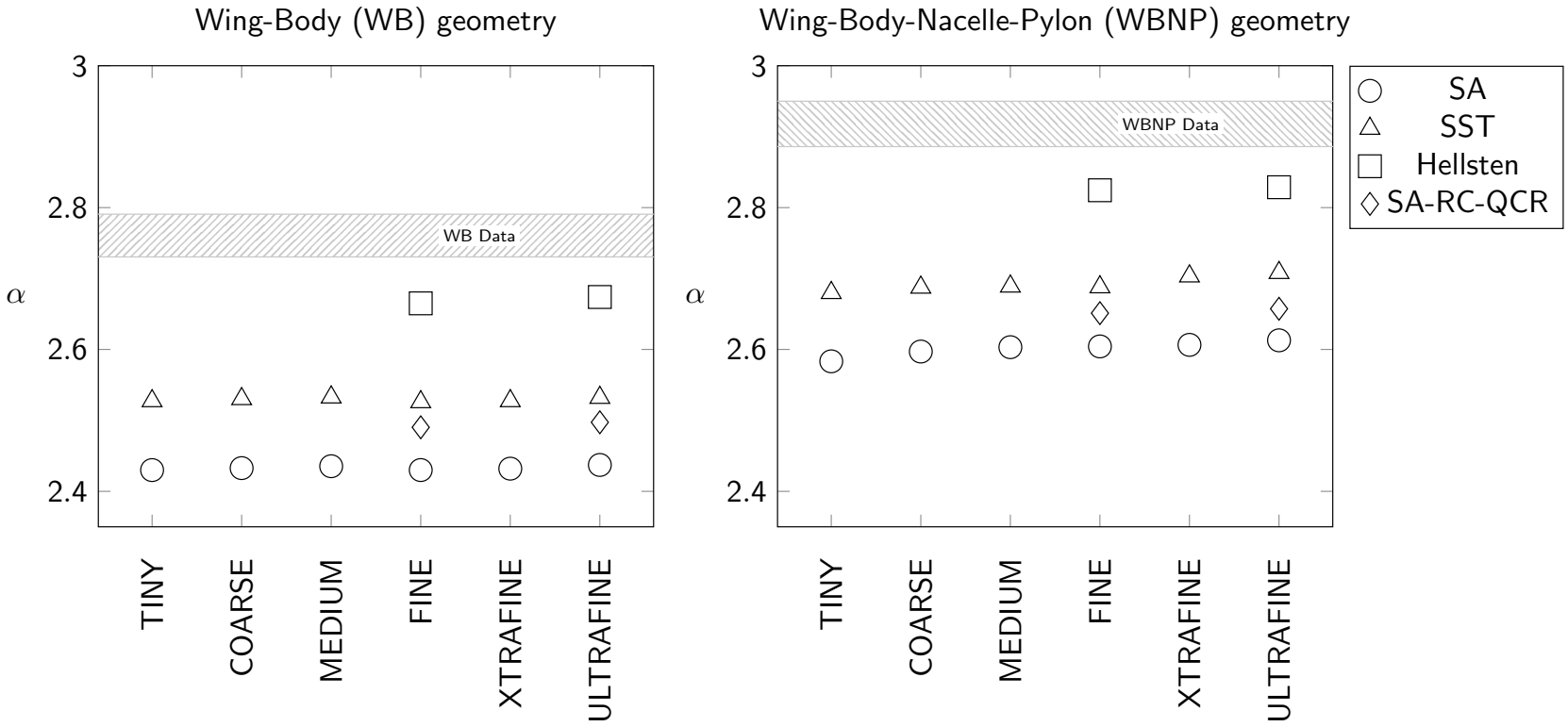
Task 2: Grid Comparison

Our decision: use the "Boeing_Babcock_Unstructured_CC.REV00" grid family for remaining studies.

- It provides "similar" results to the larger unstructured NASA grid
- It has fewer cells and requires less CPU resource

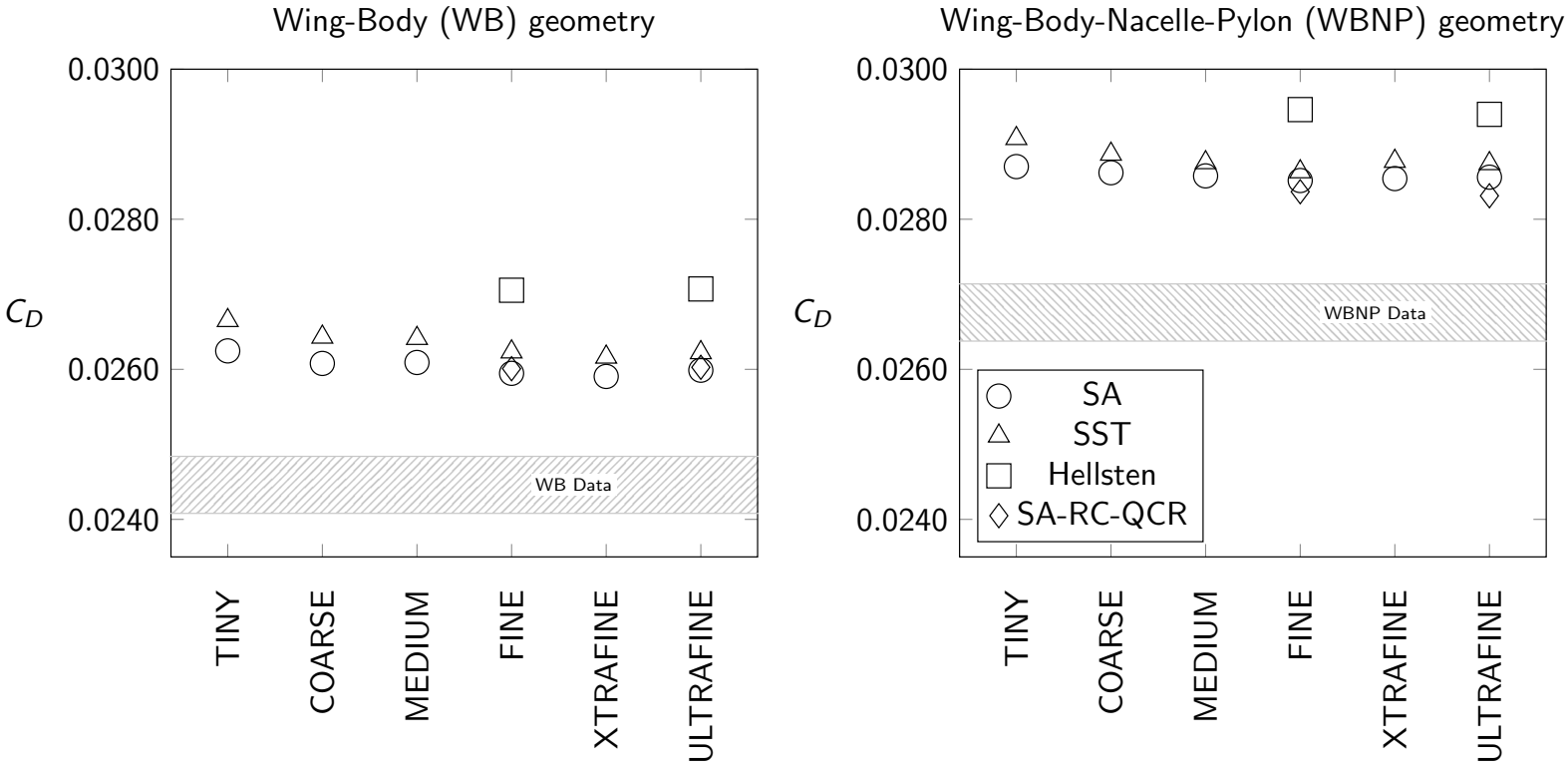
Task 2: Turbulence Model Comparison

Angle-of-Attack (α) versus grid refinement level.

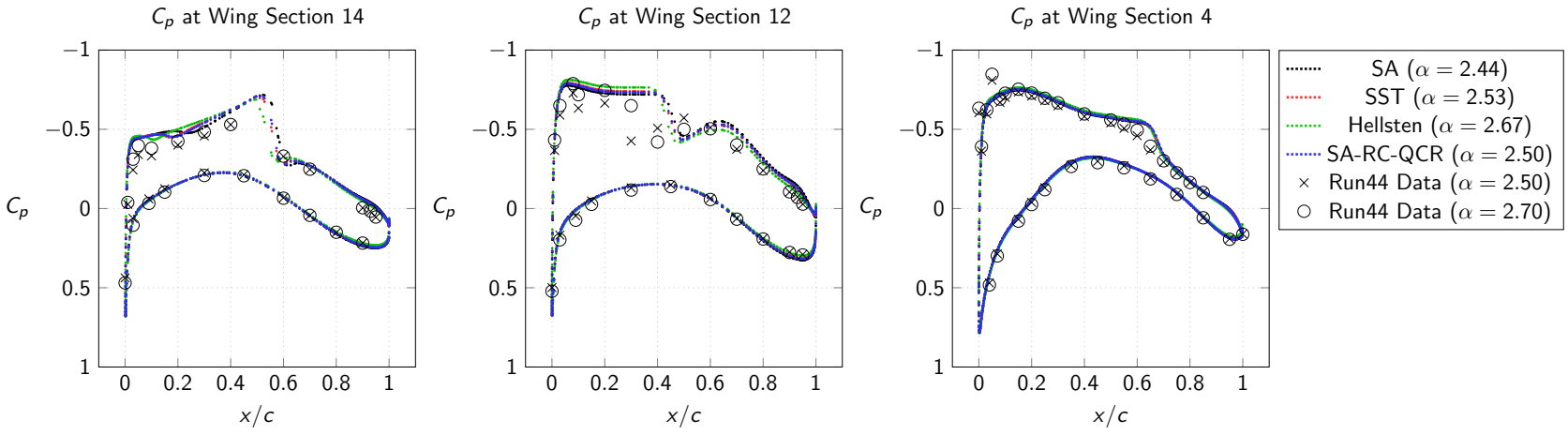


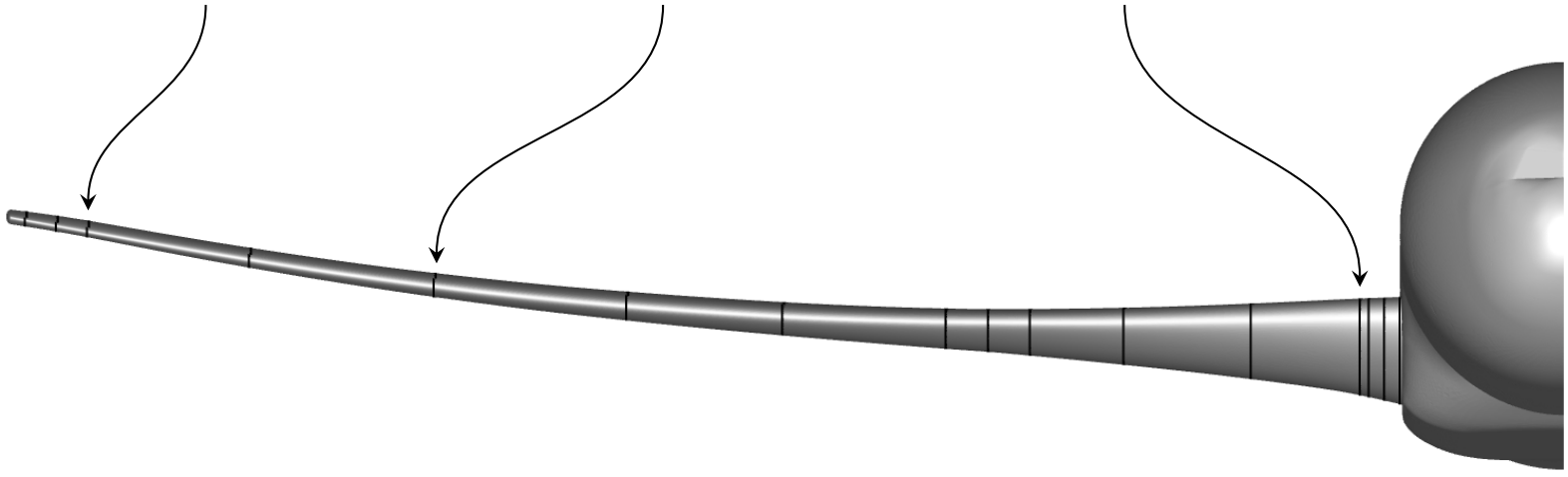
Task 2: Turbulence Model Comparison

C_D versus grid refinement level.



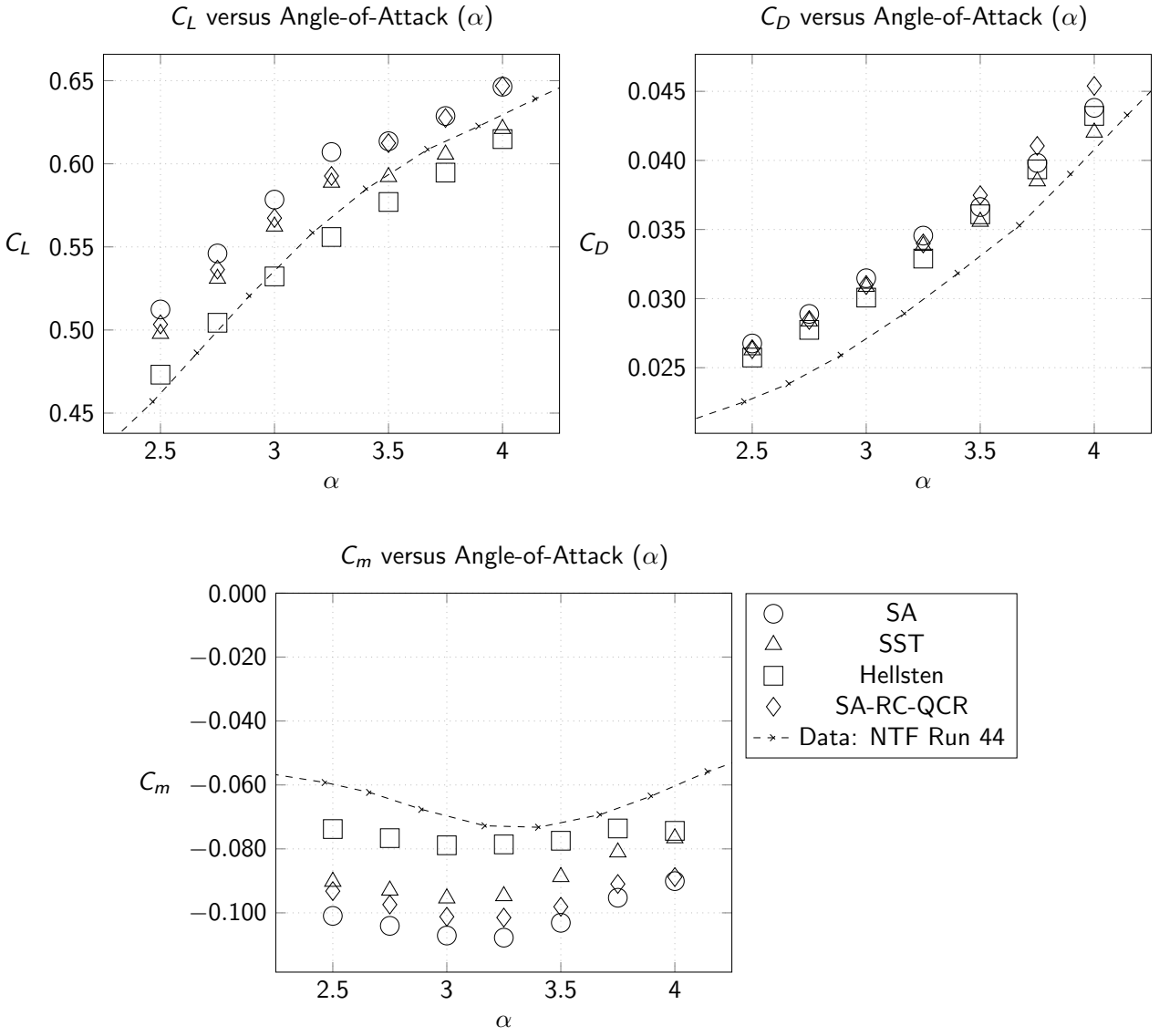
Task 2: Turbulence Model Comparison: C_p Curves



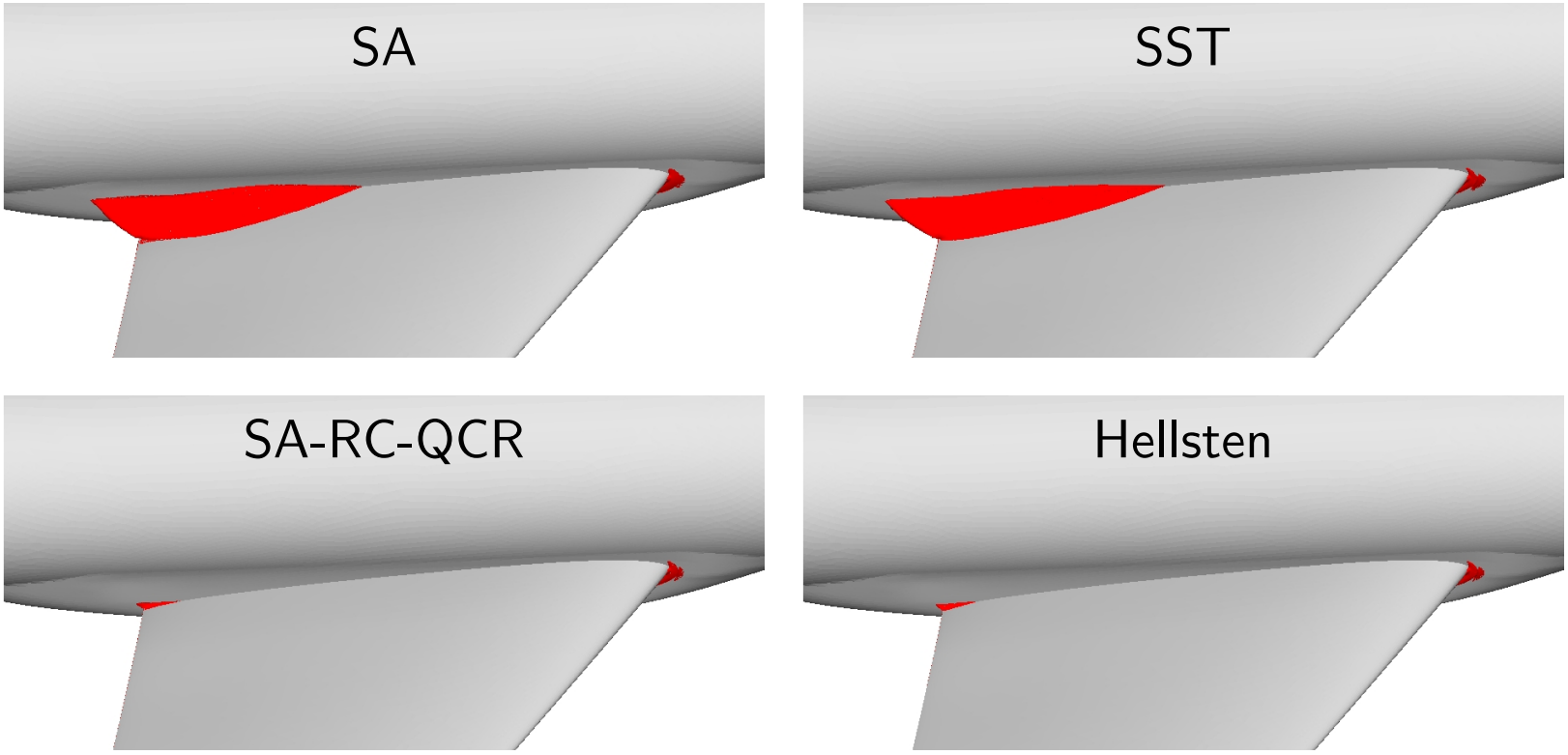


Task 3: Static Aero-Elastic Effect

Task 3: Results versus angle-of-attack (α)



Task 3: Isosurface of Separated Flow with different Turbulence Models ($\alpha = 3.75$)

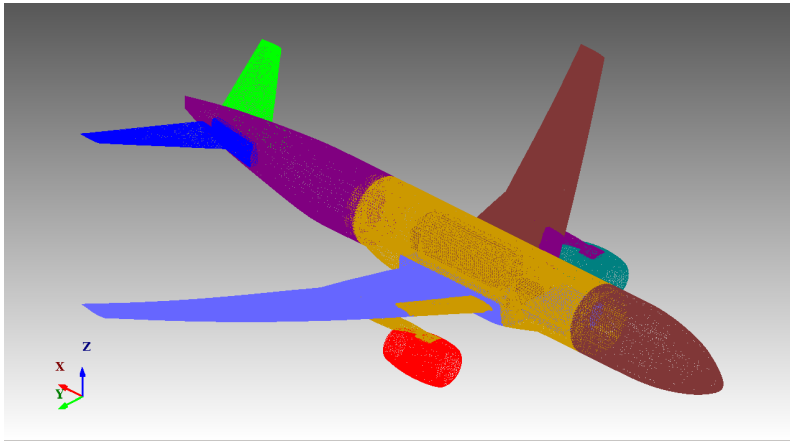


Task 5: Coupled Aero-Structural Simulation

Task 5: Summary of effort

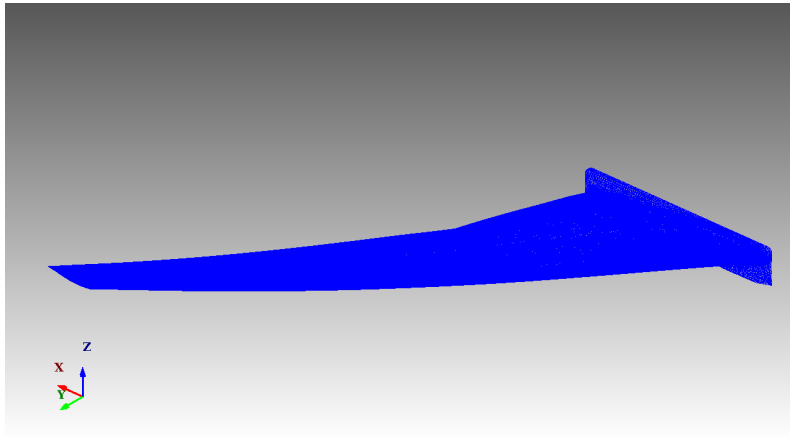
The CFD++ Software suite was used to predict aero-elastic deformation of the test model.

- FE model of the NTF wind tunnel geometry was obtained from CRM website
- Reduced the FE model to the wing only
- Simulated ETW run 182 test conditions (Ma=0.85, Re=5 million)



Full Model

4.0E6 Degrees of Freedom



Reduced Model

1.7E6 Degrees of Freedom

Task 5: Summary of effort

Differences from previous tasks:

- Simulation at model scale
- Mesh created with MIME
- Wall-distance-free Realizable $k - \epsilon$ model
- C_L-driver combined with coupled aero-elastic analysis

Task 5: Software Suite for Aero-elastic analysis

Aero-elastic calculations used four software components:

1. MIME

   unstructured mesh generation

2. CFD++

   general unstructured finite volume-based flow solver

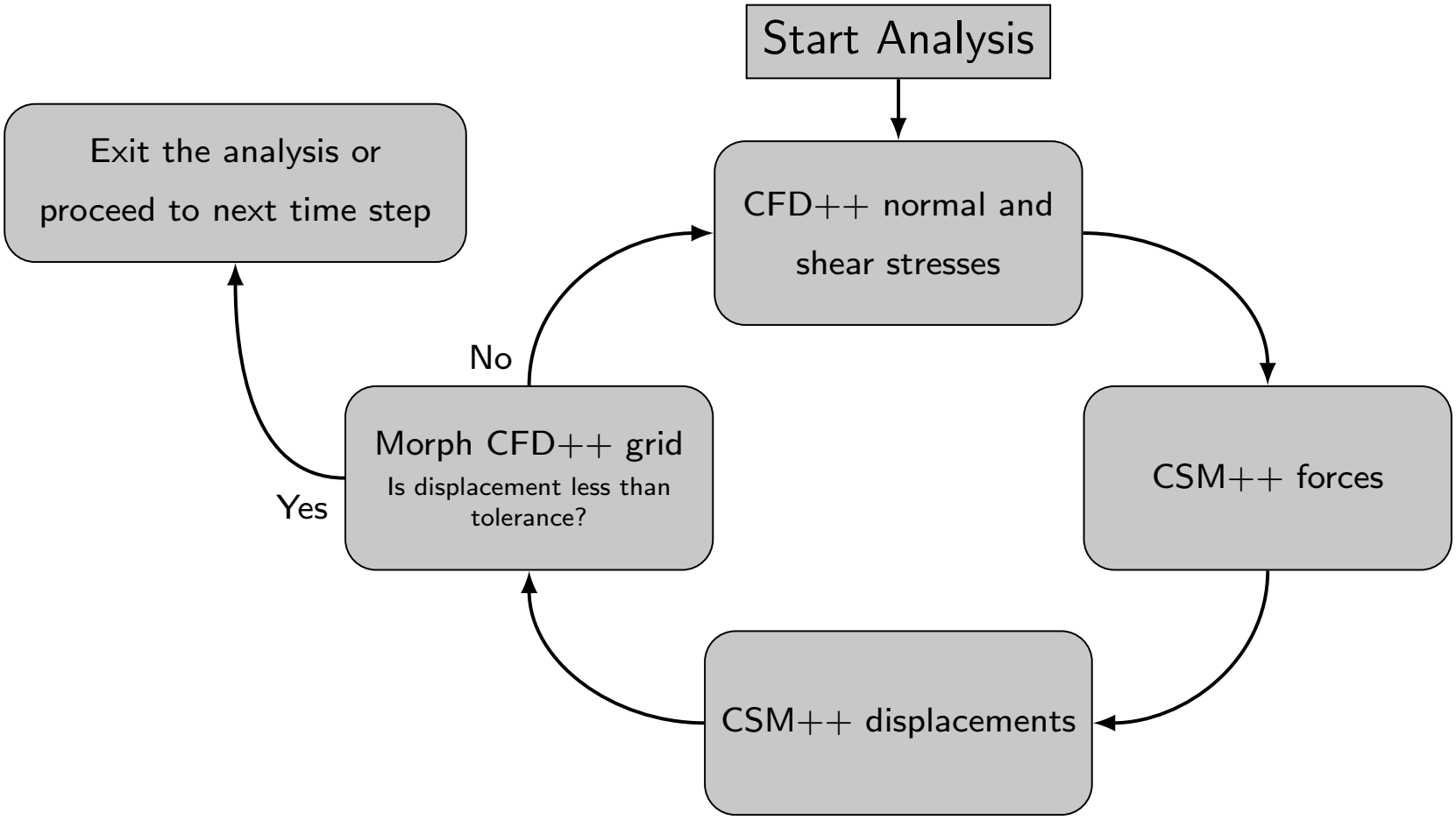
3. CSM++

   finite element-based structural solver that can be used to perform static, transient, and eigen-mode analyses.

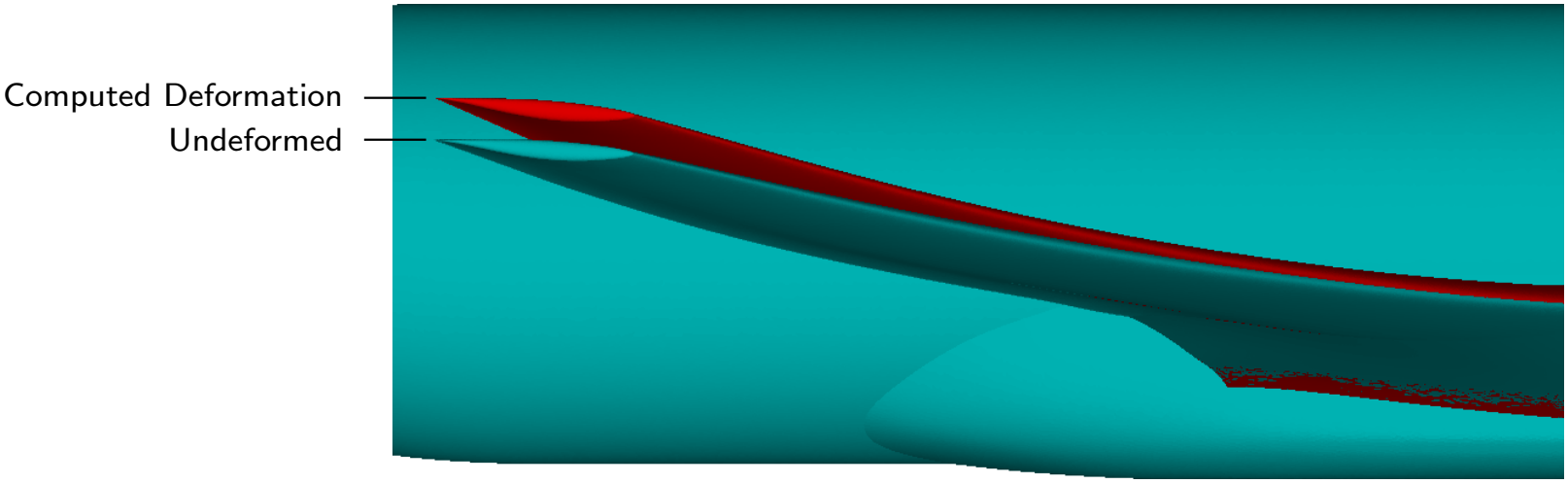
4. MetaFSI

   efficiently transfers loads and morphs the CFD++ grid to follow the CSM++ deformations.

Task 5: Aero-elastic analysis process



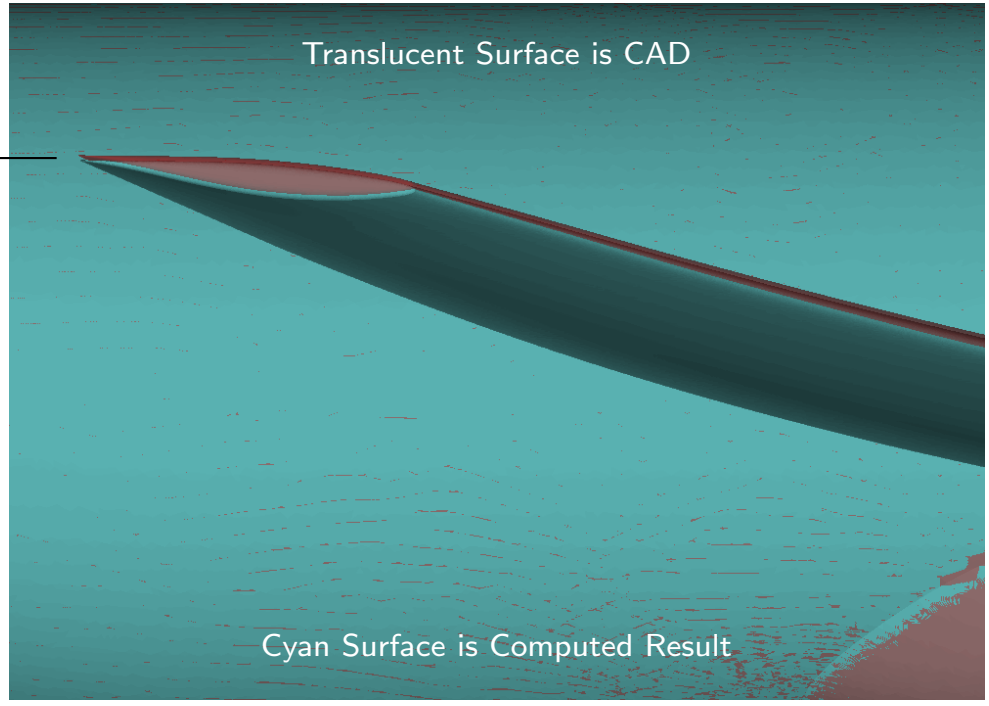
Task 5: Resulting deformation



Task 5: Resulting deformation closely matches AE2.75 CAD model

Computed bending is within 5% of the AE2.75 value

The offset at full scale is 1.18 inch



Closing Summary

- Task 1: Validation
  - CFD++ results show excellent agreement.
- Tasks 2 and 3:
  - CFD++ effectively handled all of the grids from the "unstructured_NASA_GeoLab.REV00" and the "Boeing_Babcock_Unstructured_CC.REV00" grid families.
  - Results were shown for a sample of the turbulence models available within CFD++.
- Task 5: Aero-elastic deformation
  - Demonstrated coupled aero-elastic analysis with CFD++ in co-simulation with CSM++ and MetaFSI.
  - Computed deformations closely matched experiment.

Thank You!

Name:	Brian Edge
Email:	edge@metacomptech.com
Phone:	(818) 735-4880
Address:	Metacomp Technologies, Inc. 28632-B Roadside Drive, Suite 255 Agoura Hills, CA 91301