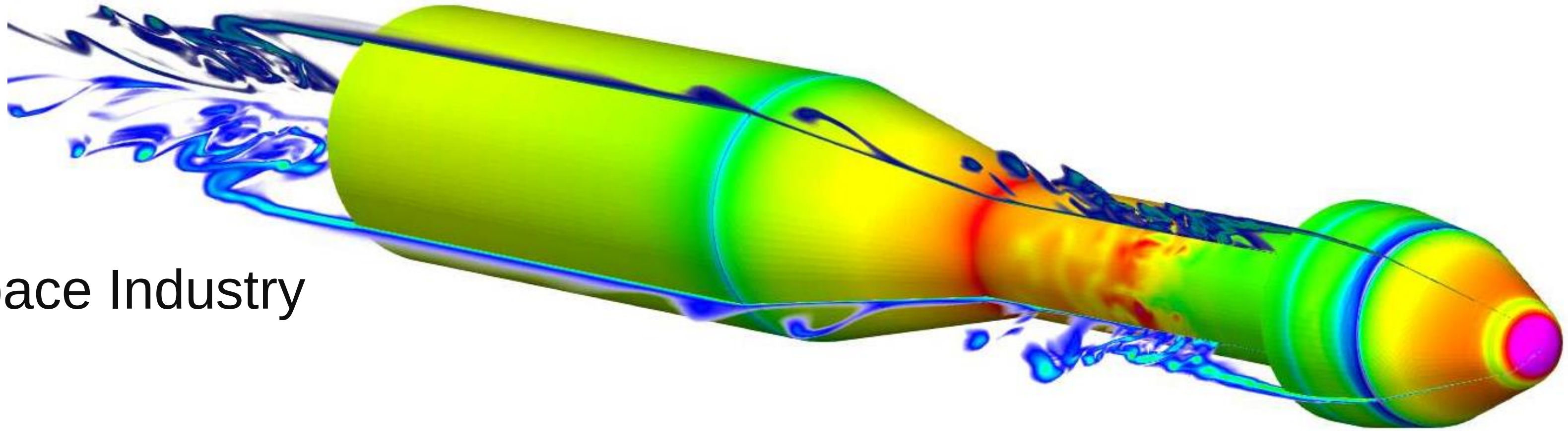
FOAM-U 2019



iconCFD® Transonic
A New Toolset for the Aerospace Industry

Prepared by:
Vincent Rivola - Presenter
Dr. Lucy Gagliardi – Transonic Product Leader

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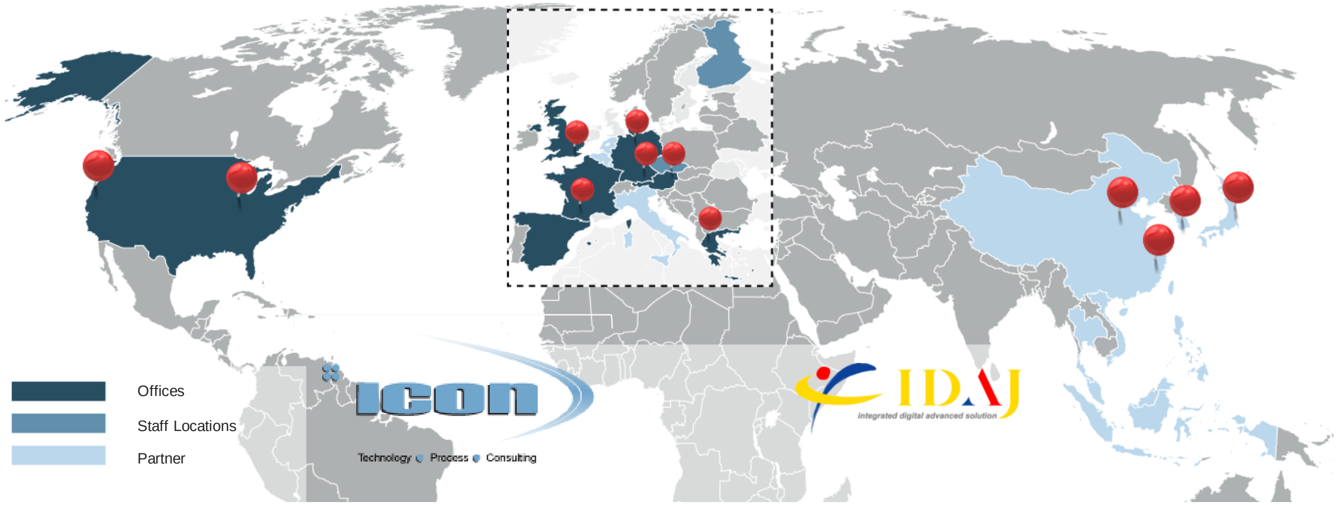
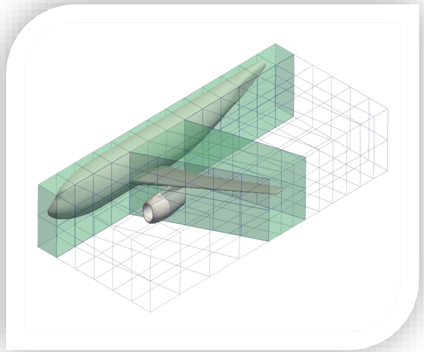
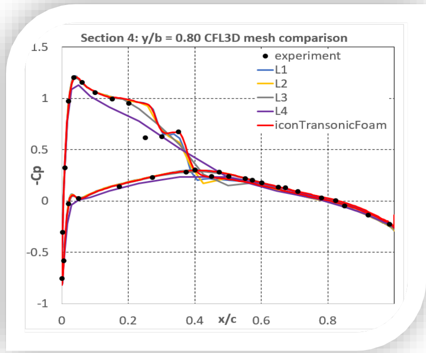
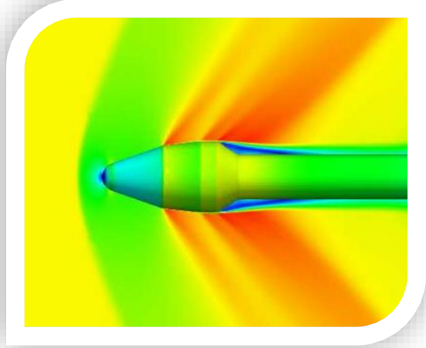


AGENDA

- Introduction - iconTransonicFoam
- Validation and Verification
- iconCFD Transonic Process
- Future work







iconCFD TRANSONIC

INTRODUCTION - iconTransonicFoam

- Solver developed in collaboration with ARA (UK).
- Solves the Navier-Stokes equations in a fully-implicit, density-based manner. The governing continuity, momentum and energy equations are treated as a fully coupled system, in conservative form this is:

$$\frac{\partial \vec{W}}{\partial t} + \nabla \cdot \vec{F}_T = 0$$

- The equations are linearised in time, providing the following system:

$$\frac{\partial \vec{W}}{\partial t} + \nabla \cdot \left(\bar{\bar{J}}_T^o \delta W \right) = -\nabla \cdot \vec{F}_T^o$$

$$\vec{W} = \begin{bmatrix} \rho \\ \rho \vec{U} \\ \rho E \end{bmatrix}, \qquad \vec{F}_T = (\vec{F}_c - \vec{F}_v),$$

$$\vec{F}_c = \begin{bmatrix} \rho \vec{U} \\ \rho \vec{U} \cdot \vec{U} + \bar{\bar{I}} p \\ \rho \vec{U} \cdot H \end{bmatrix},$$

$$\vec{F}_v = \begin{bmatrix} 0 \\ \bar{\bar{\tau}}_{eff} \\ \bar{\bar{\tau}}_{eff} \cdot \vec{U} + \kappa \nabla T \end{bmatrix}$$

$$\bar{\bar{J}}_T = \frac{\partial \vec{F}_T}{\partial \vec{W}}, \qquad \delta \vec{W} = \vec{W}^n - \vec{W}^o$$

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iconCFD TRANSONIC

INTRODUCTION - iconTransonicFoam

- The system is solved for the **variable $\delta\vec{W}$**, with each component of the matrix comprising of the block Jacobian tensor and the source terms comprising of the vector fluxes.

$$\left[\frac{\bar{\bar{I}}}{\partial t} + \nabla \cdot \bar{\bar{J}}_T^o\right] \boldsymbol{\delta\vec{W}} = -\nabla \cdot \vec{F}_T^o$$

$$\left[\bar{\bar{A}}\right] \quad \boldsymbol{x} \quad = \quad \vec{b}$$

- The system is discretised using a cell-centred finite volume approach.
- Convective fluxes use a 2nd order Roe formulation with Rebay-Van Leer flux limiter and modified Harten-Hyman entropy fix.
- Viscous fluxes use a 2nd order approximate central scheme with face gradient correction.
- Approximate formulations of the viscous and convective Jacobians are used.

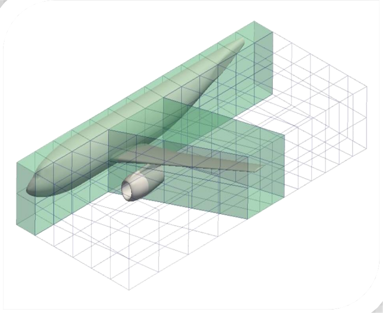
AGENDA

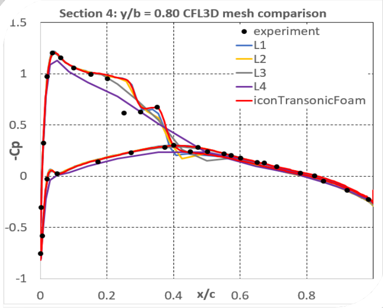
Introduction - iconTransonicFoam

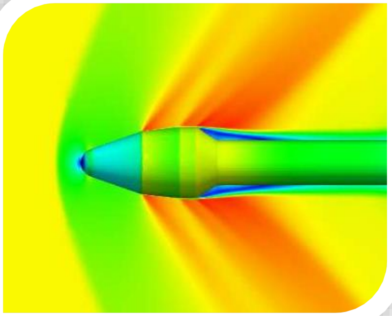
Validation and Verification

iconCFD Transonic Process

Further work





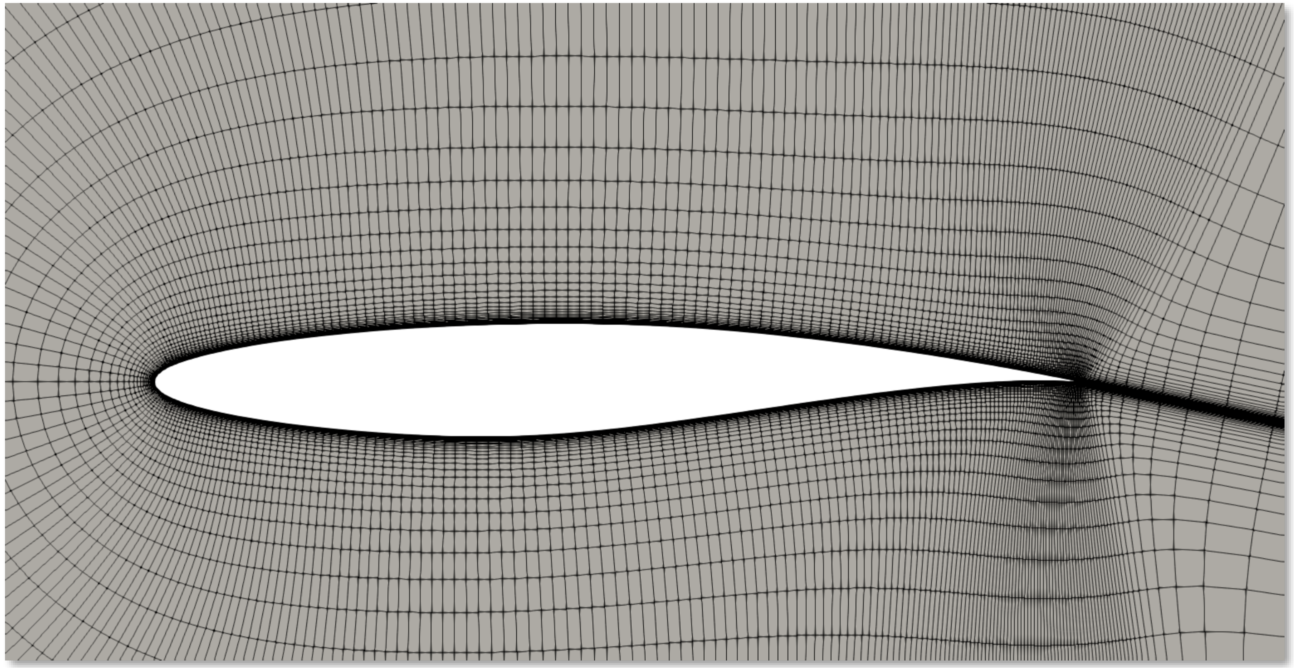


iconCFD TRANSONIC
VALIDATION/VERIFICATION → RAE2822

- RAE2822 2D Transonic aerofoil
- Experimental data from Cook et al. (AGARD-138)
- 2 cases considered:

Case*	M	Re	T0 (K)	α (°)
6	0.729	6,500,000	282	2.31
9	0.734	6,500,000	282	2.54

- Verification data from NASA (Wind3D), and EUROVAL project
- NPARC C-H structured mesh used for all cases
  - 23,552 cells
  - Average y+ ~ 1

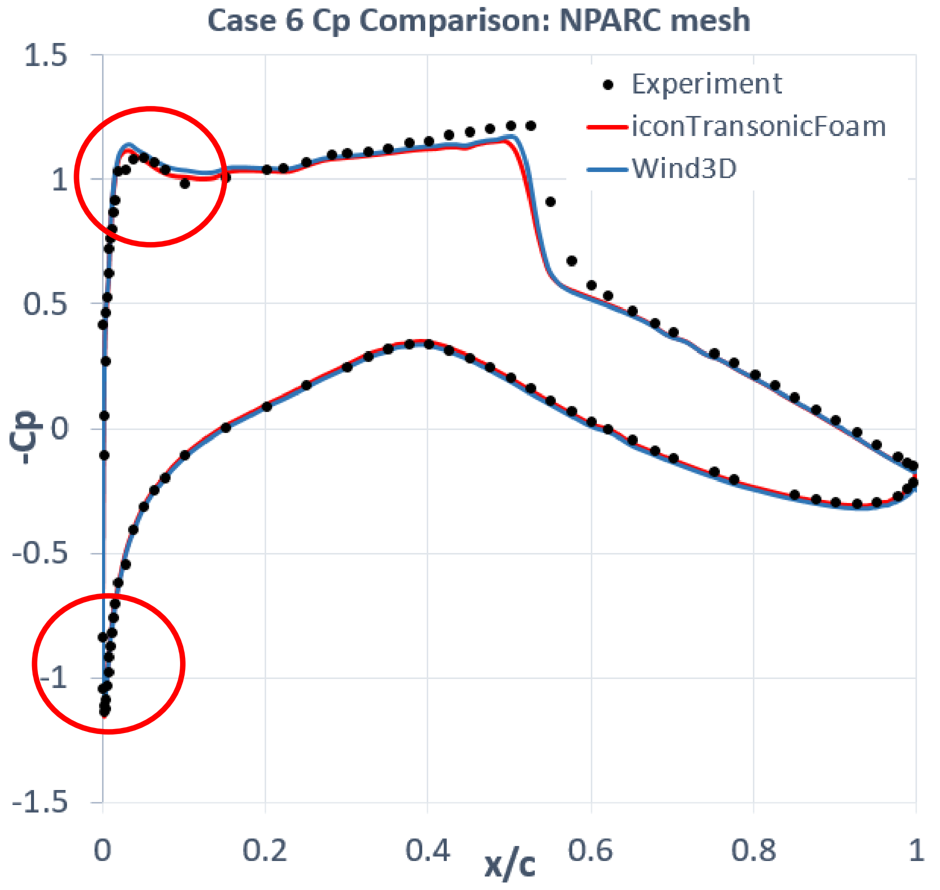


*corrected for WT effects

iconCFD TRANSONIC
VALIDATION/VERIFICATION → RAE2822

- Verification of Cp profile with data from NASA Wind3D code shows close agreement
- Suction peak and stagnation is predicted well compared to experimental results, although shock is slightly forward of experimental position.
- Force comparison is good with < 2 drag counts error to experiment.

Case	Lift			Drag		
	Pressure	Skin friction	Total	Pressure	Skin friction	Total
experiment	-	-	0.7340000	-	-	0.0127000
iconTransonicFoam	0.7113445	1.97E-05	0.7113642	0.0066840	0.0058293	0.0125133
Wind3D	0.7309260	3.63E-05	0.7309620	0.0062004	0.0059160	0.0121165



iconCFD TRANSONIC
VALIDATION/VERIFICATION → ONERA M6

- Classic validation test case for transonic flow
- Experimental data from Schmitt and Charpin (AGARD-AR-138) Test: 2308
- Test conditions:

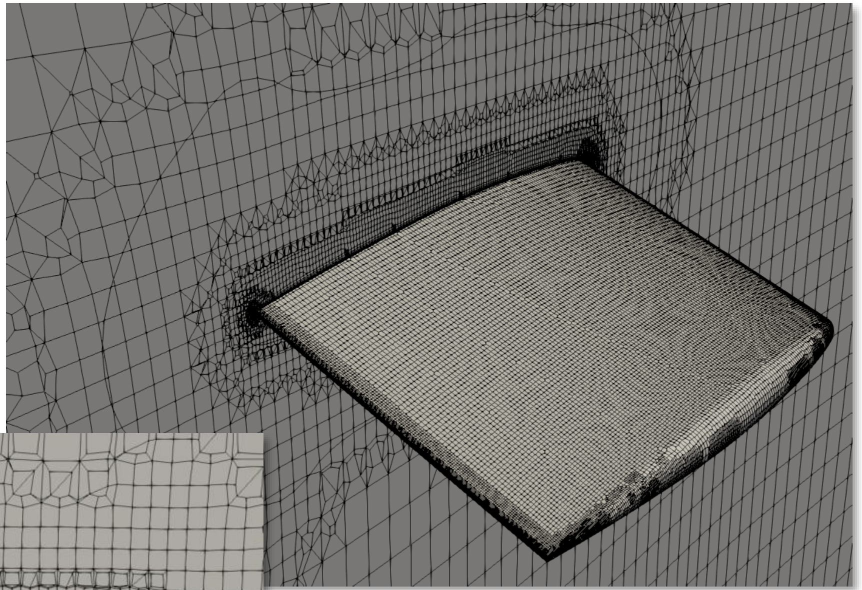
M	Re	T0 (K)	α (°)
0.8395	11,720,000	300	3.06

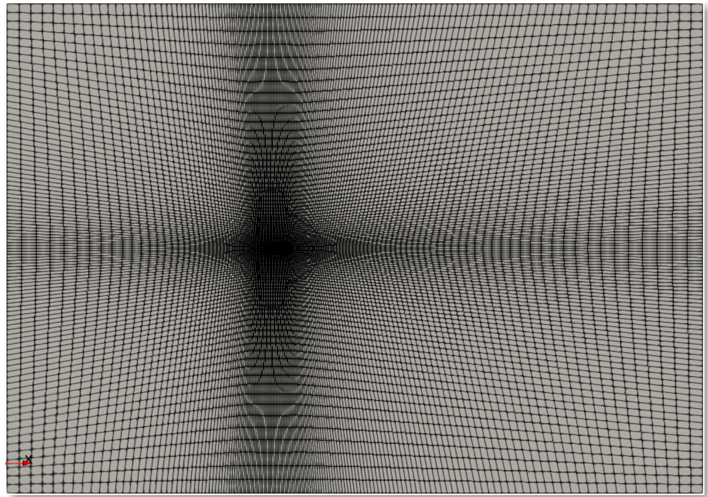
- Verification data obtained from AIAA SciTech 2018 sessions:
  "RANS solutions for benchmark configurations"
- 3 codes: CFL3D, USM3D and FUN3D
- Geometry modified for a sharp TE (iconCFD case with original geometry)
- Ref. solutions run with Spalart-Allmaras neg model (iconCFD uses std SA)
- 4 consistent grid levels, L1-4

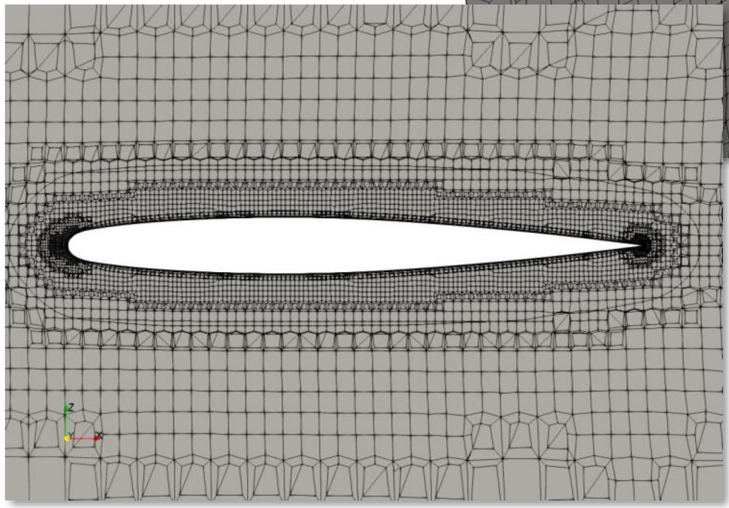
Mesh	nCells
L1	69,206,016
L2	8,650,752
L3	1,081,344
L4	135,168
iconHexMesh	2,890,072

iconCFD TRANSONIC
VALIDATION/VERIFICATION → ONERA M6

- *iconHexMesh* used to create mesh.
- *aeroBlockMesh* utility used to provide initial blocking and anisotropy framework around geometry.
- Hex-dominant mesh with full layer coverage and a y+ ~0.5
- Mesh size: ~2.89e6 cells



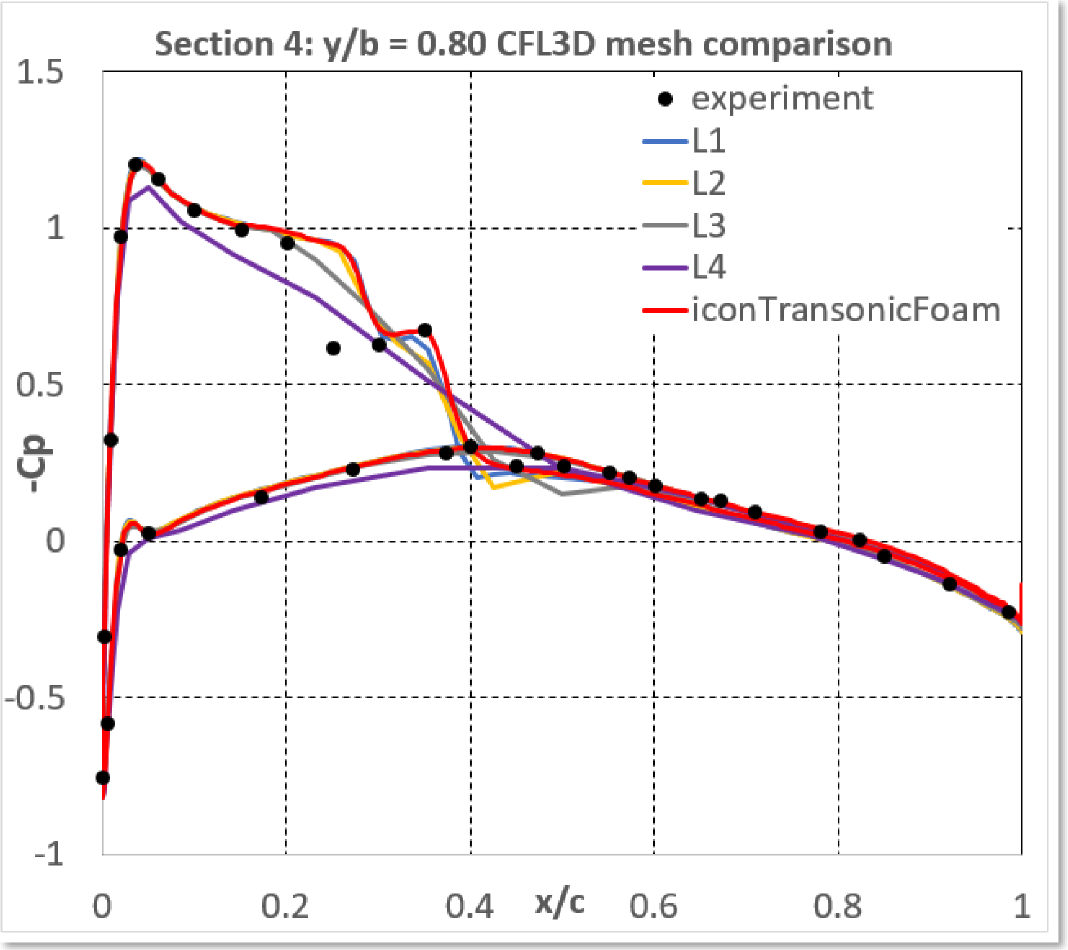




iconCFD TRANSONIC

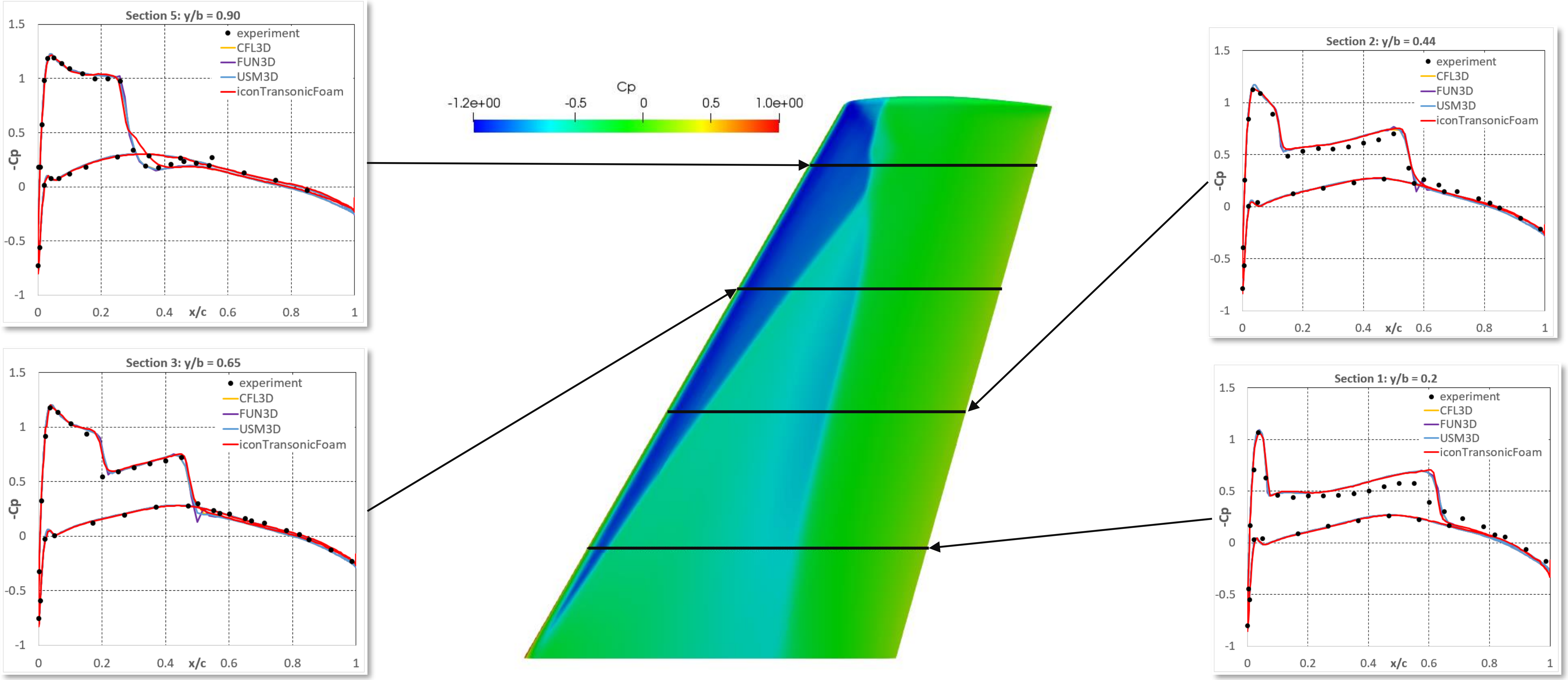
VALIDATION/VERIFICATION → ONERA M6

- Comparing to CFL3D on all four mesh levels showed that iconTransonicFoam provides results comparable to the L1 mesh.
- Further verification of iconTransonicFoam will only be performed with the L1 mesh.



iconCFD TRANSONIC

VALIDATION/VERIFICATION → ONERA M6



iconCFD TRANSONIC
VALIDATION/VERIFICATION → ONERA M6

- Comparison was also made to lift and drag coefficients for the L1 meshes
- Comparison is acceptable
- Slightly higher Cl and Cd than the AIAA SciTech data – correlates with Cp plots, particularly shock induced separation on outboard sections

Case	Mesh size (nCells)	Lift	Drag		
		Total	Pressure	Skin friction	Total
iconTransonicFoam	2,890,072	0.2741	0.01393	0.00411	0.01803
CFL3D (L1 struct.)	69,206,016	0.2693	0.01165	0.00530	0.01696
USM3D (L1 tet.)	69,206,016	0.2706	0.01174	0.00531	0.01705
USM3D (L1 tet-prism)	69,206,016	0.2693	0.01168	0.00530	0.01698
FUN3D (L1 tet-prism)	69,206,016	0.2695	0.01167	0.00528	0.01695

iconCFD TRANSONIC
VALIDATION/VERIFICATION → DPW2 DLR F6

- 2nd AIAA Drag Prediction workshop: DLR F6 Wing/Body/Nacelle/Pylon configuration.
- Case 2: drag polar, fully turbulent.

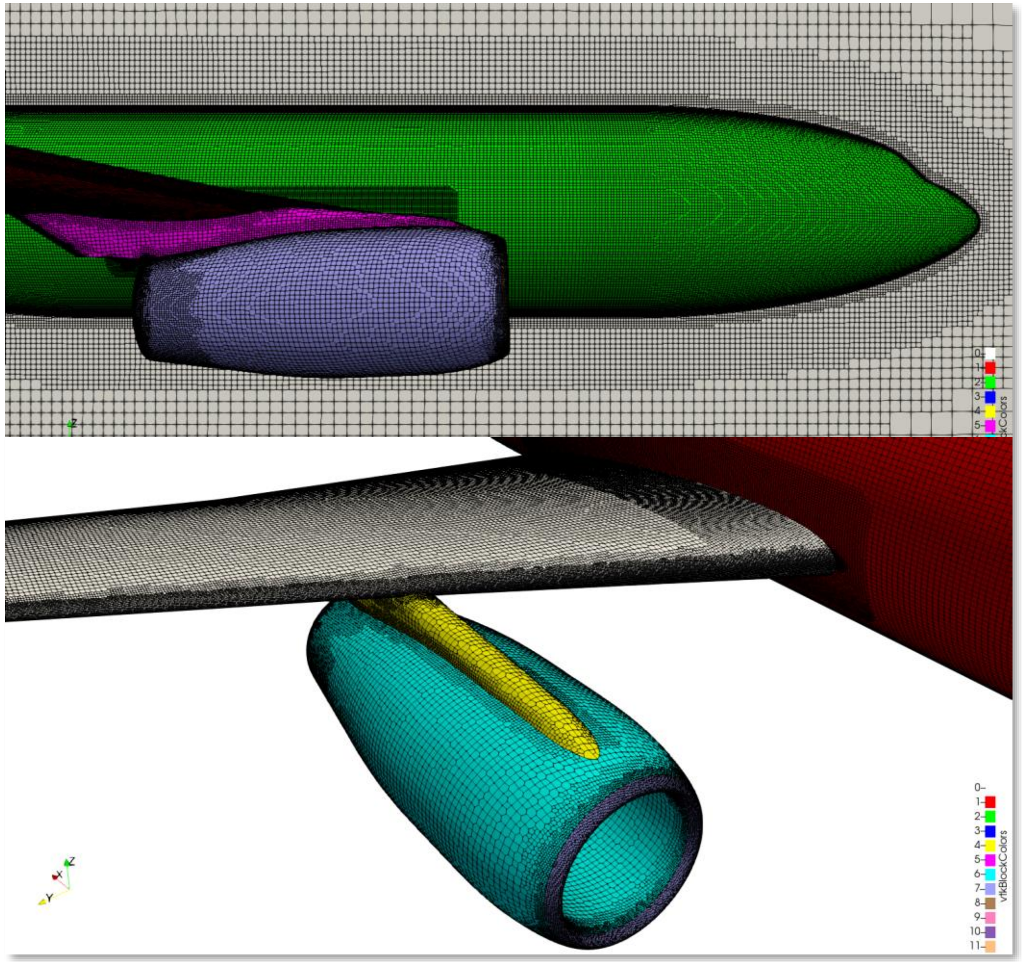
Case	M	Re	T0 (K)	α (°)
2	0.7500	3,000,000	305.09	-3, -2, -1.5, -1, 0, 1, 1.5

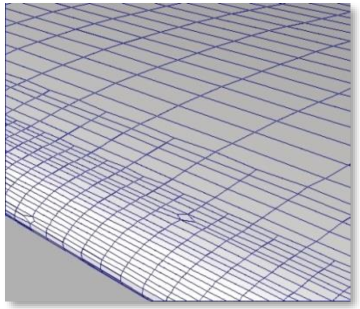
- Verification data from the workshop on “medium” sized grid, ~8e6 cells.
- Comparison with a number of well-established codes, including: CFL3D, Cobalt, eLSA, ENSOLV, FUN3D, and TAU.
- Experimental results taken from data provided to workshop candidates.

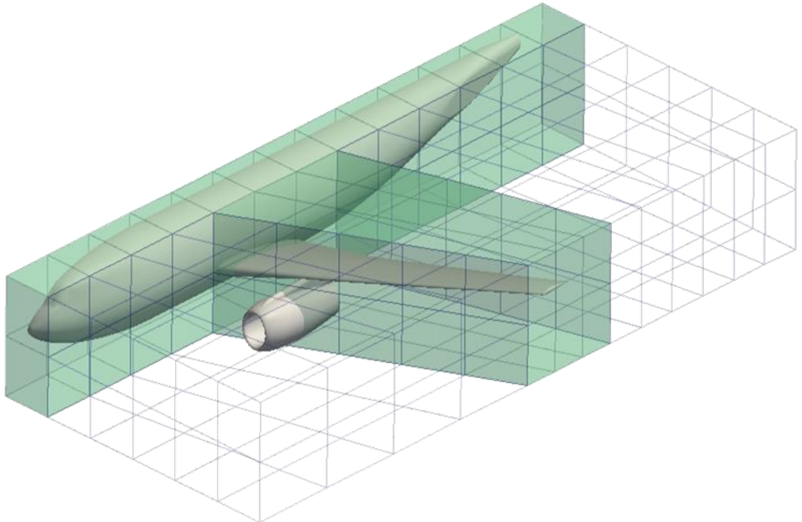
iconCFD TRANSONIC

VALIDATION/VERIFICATION → DPW2 DLR F6

- *iconHexMesh* used to create mesh with comparable size to “medium” grids.
- *aeroBlockMesh* utility used to provide initial blocking and anisotropy framework around geometry.
- Hex-dominant mesh with near full layer coverage
- Mesh size ~10.43e6 cells
- Average y+ ~0.5
- Fully turbulent

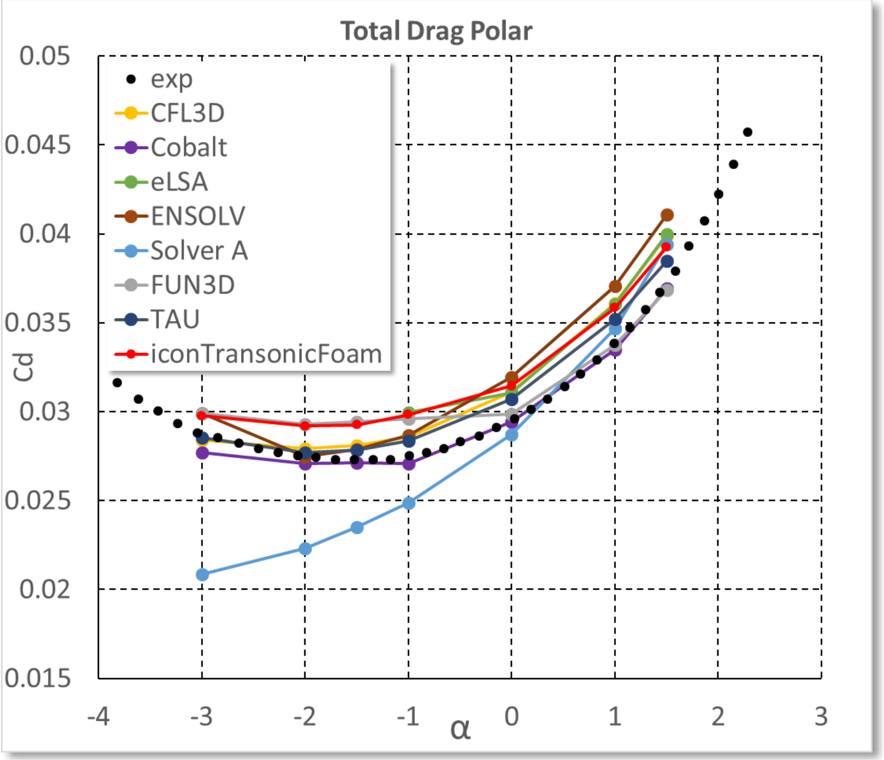


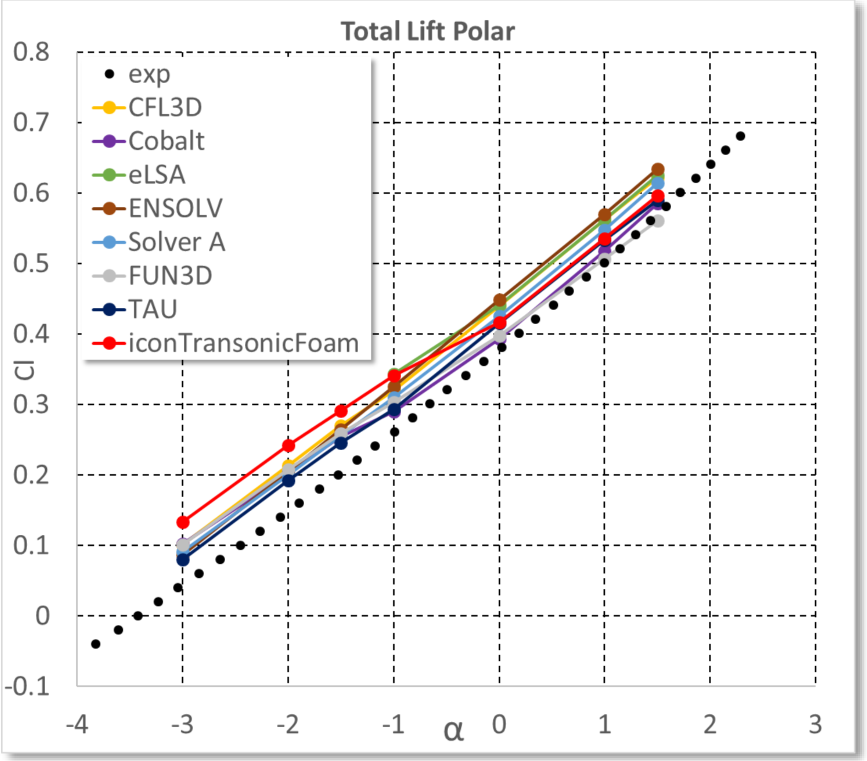


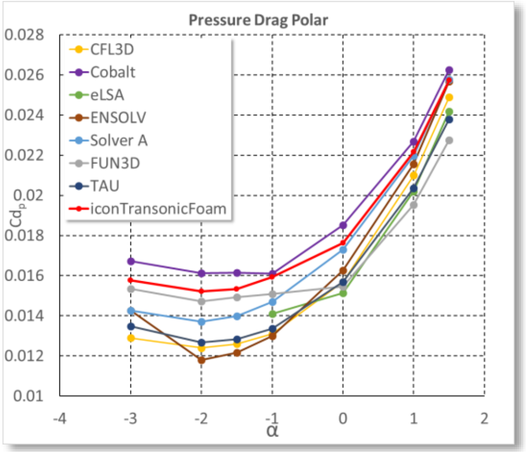


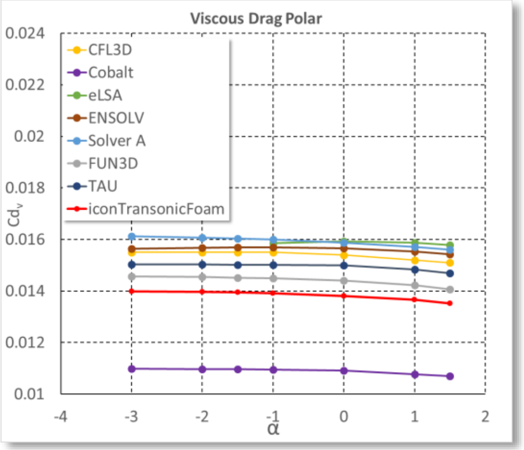
iconCFD TRANSONIC
VALIDATION/VERIFICATION → DPW2 DLR F6

- Force polar comparisons:
- FUN3D and Solver A also run fully turbulent









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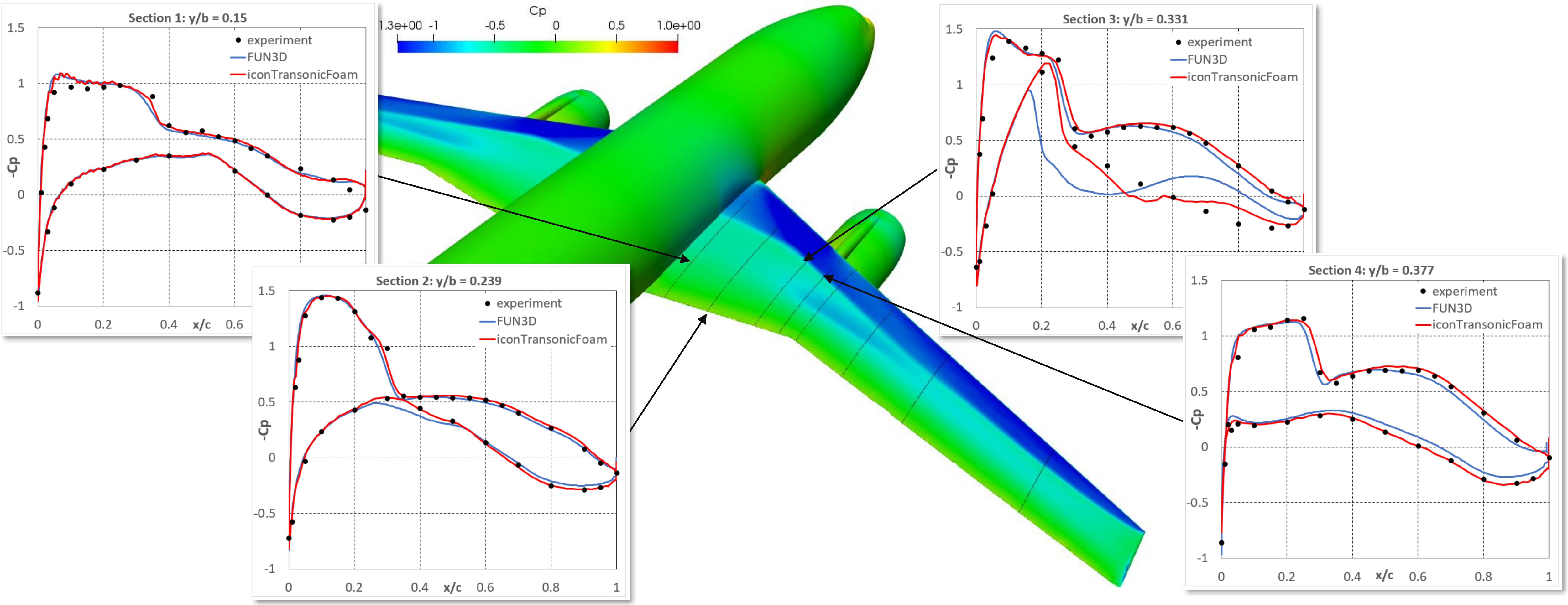
VALIDATION/VERIFICATION → DPW2 DLR F6



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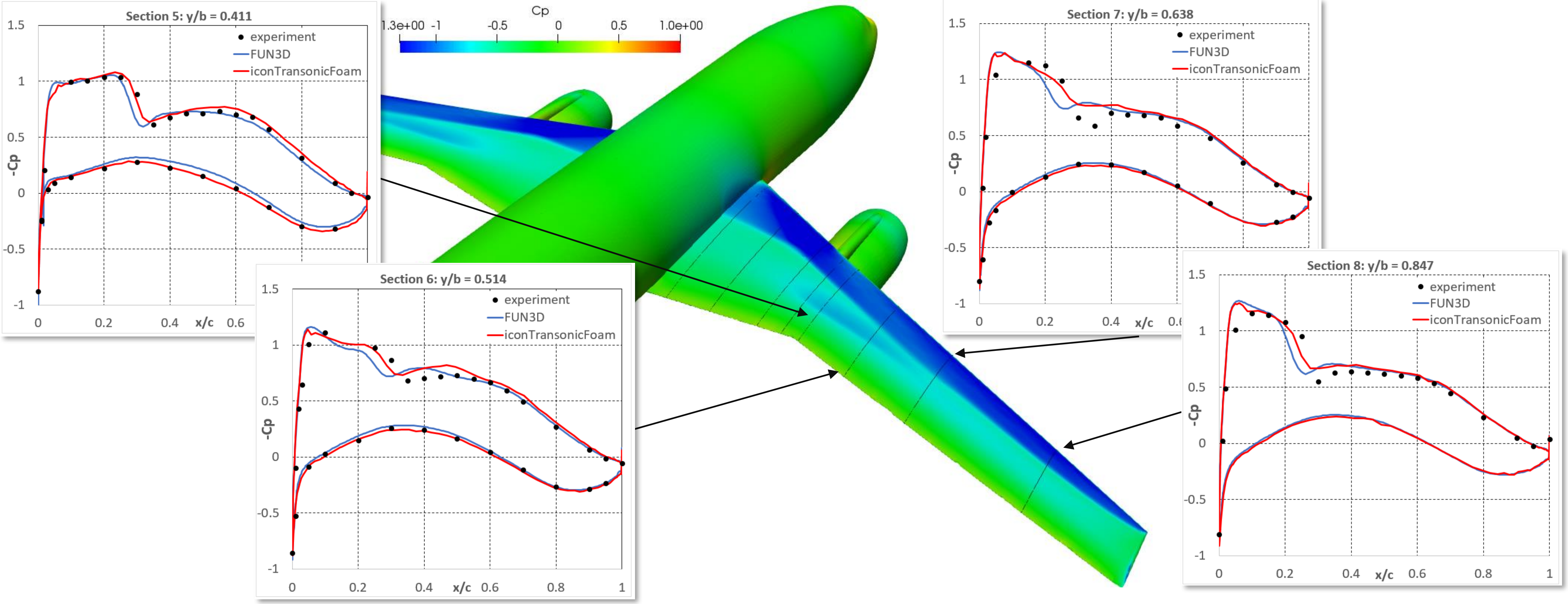
VALIDATION/VERIFICATION → DPW2 DLR F6



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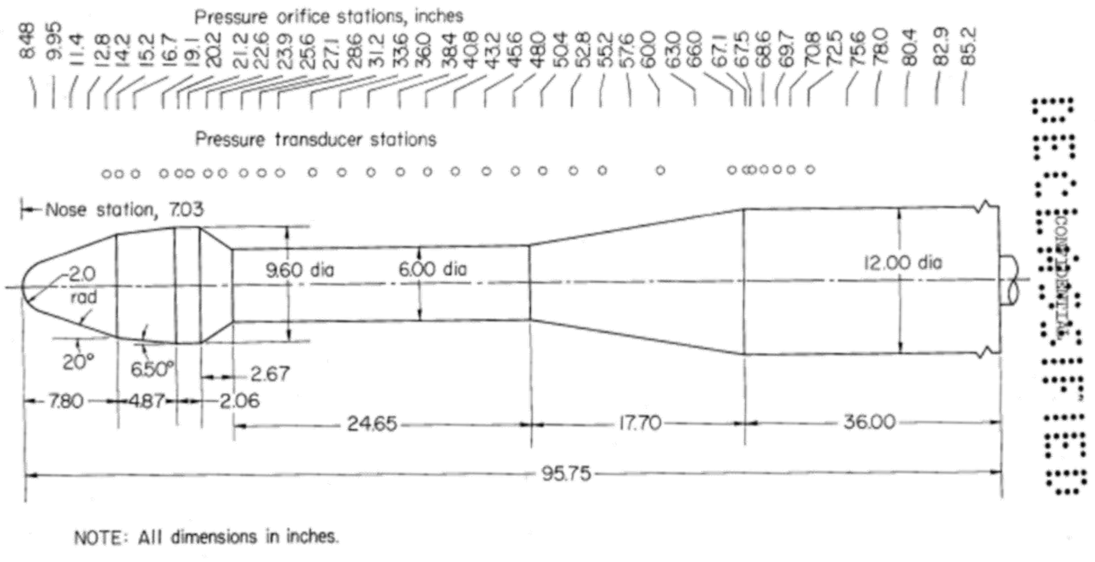
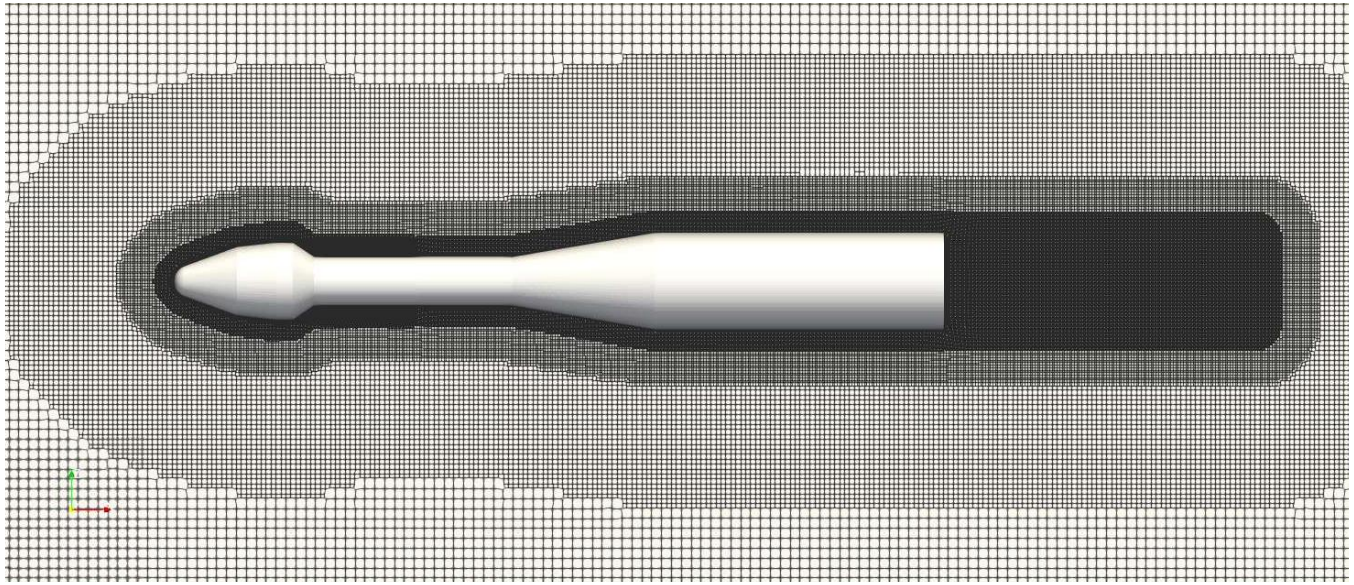
iconCFD TRANSONIC
VALIDATION – NASA TECH MEMO X778

- Model11 of the memo “Steady and fluctuating pressures at transonic speeds on hammerhead launch vehicles” is used as a validation case.



(a) Model 11

Figure 3.- Sketches of models showing pertinent dimensions and locations of the static-pressure orifices and pressure transducers.



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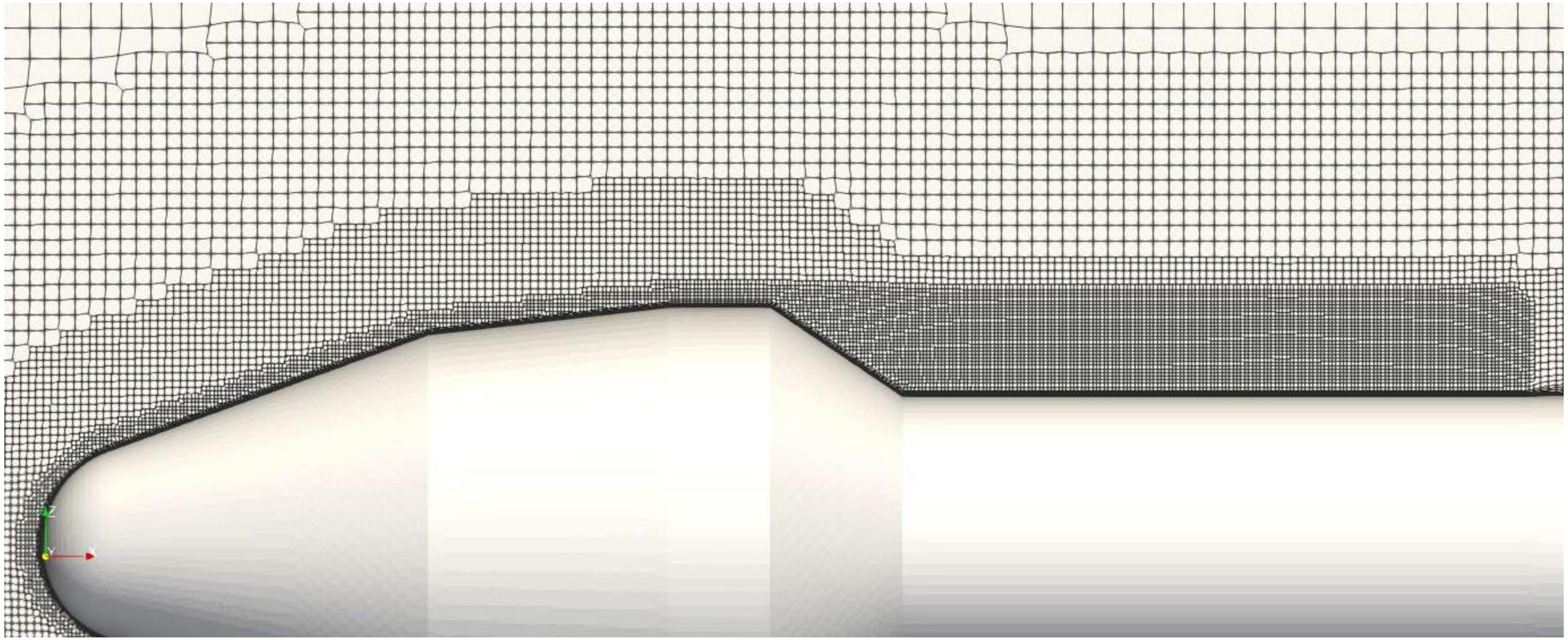
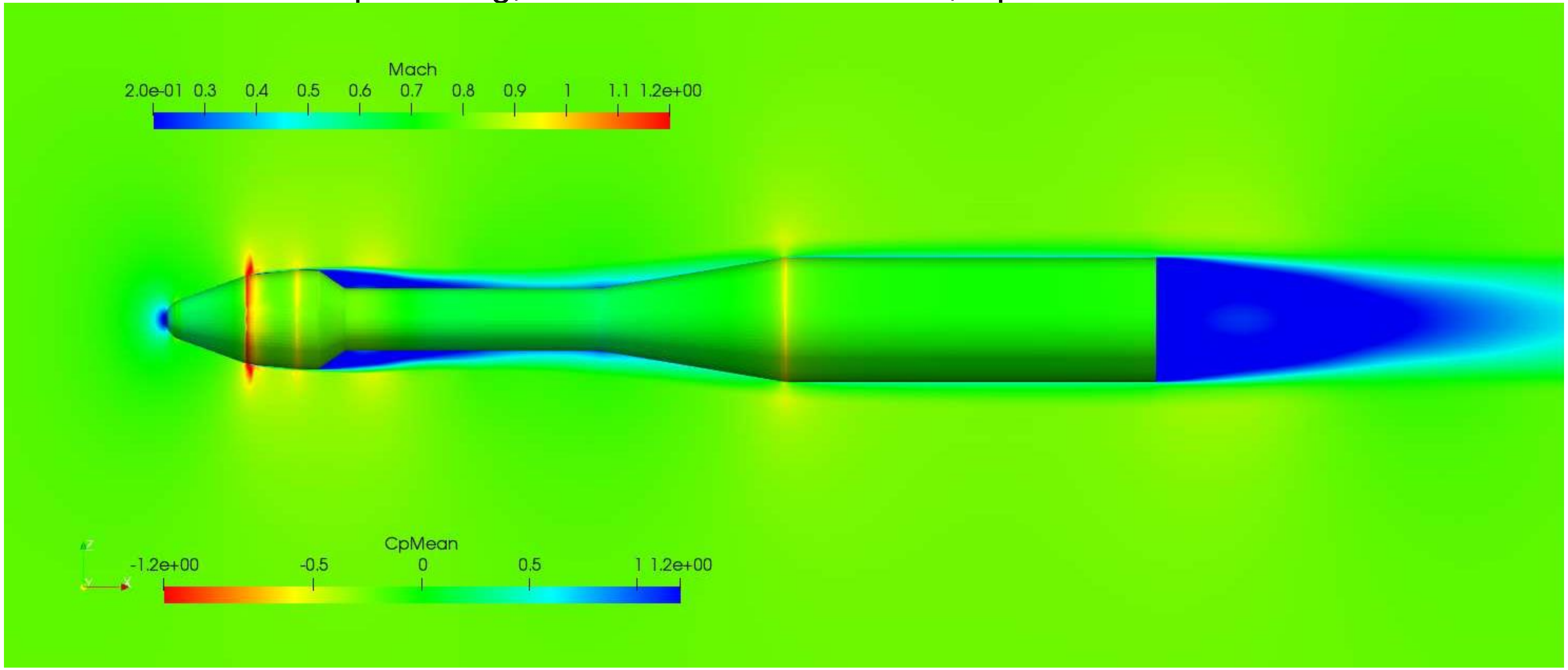
iconCFD TRANSONIC
VALIDATION – NASA TECH MEMO X778

- Mesh generation using iconHexMesh. Half domain contains 5M cells.



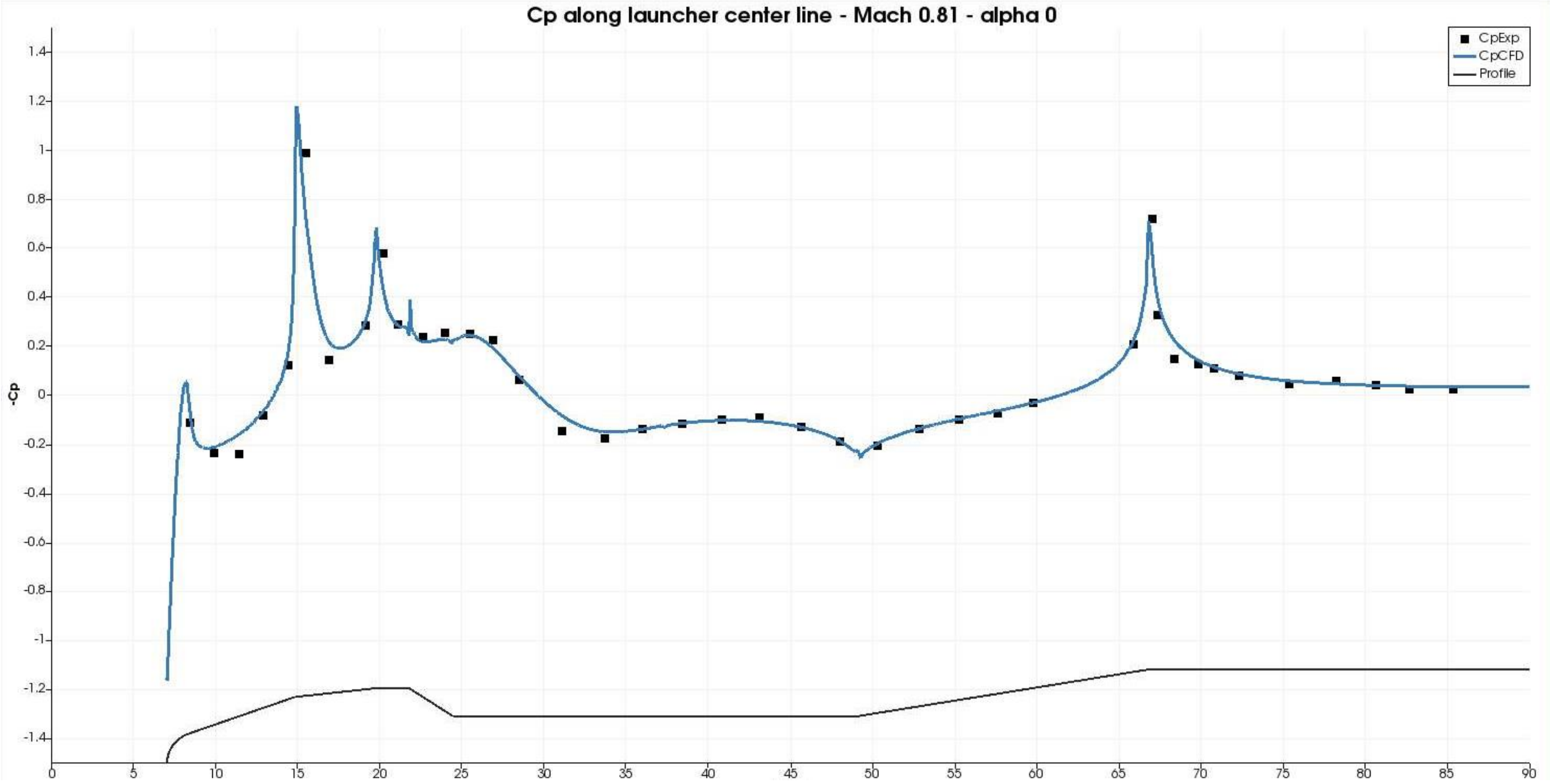
iconCFD TRANSONIC
VALIDATION – NASA TECH MEMO X778

- Mach 0.8 results and alpha 0deg, Mach number in the field, Cp at the wall:



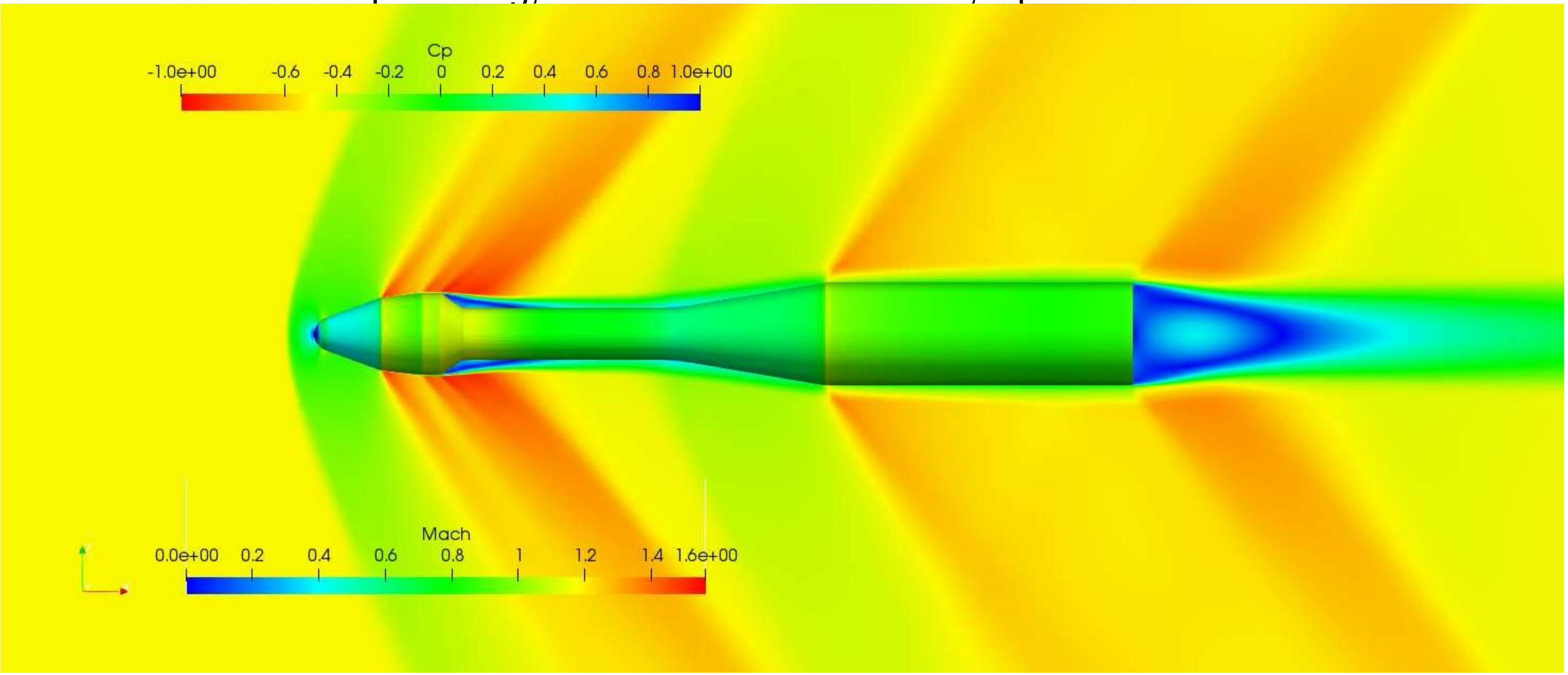
iconCFD TRANSONIC
VALIDATION – NASA TECH MEMO X778

- Mach 0.8 results and alpha 0deg, Cp at the wall along the symmetryPlane:



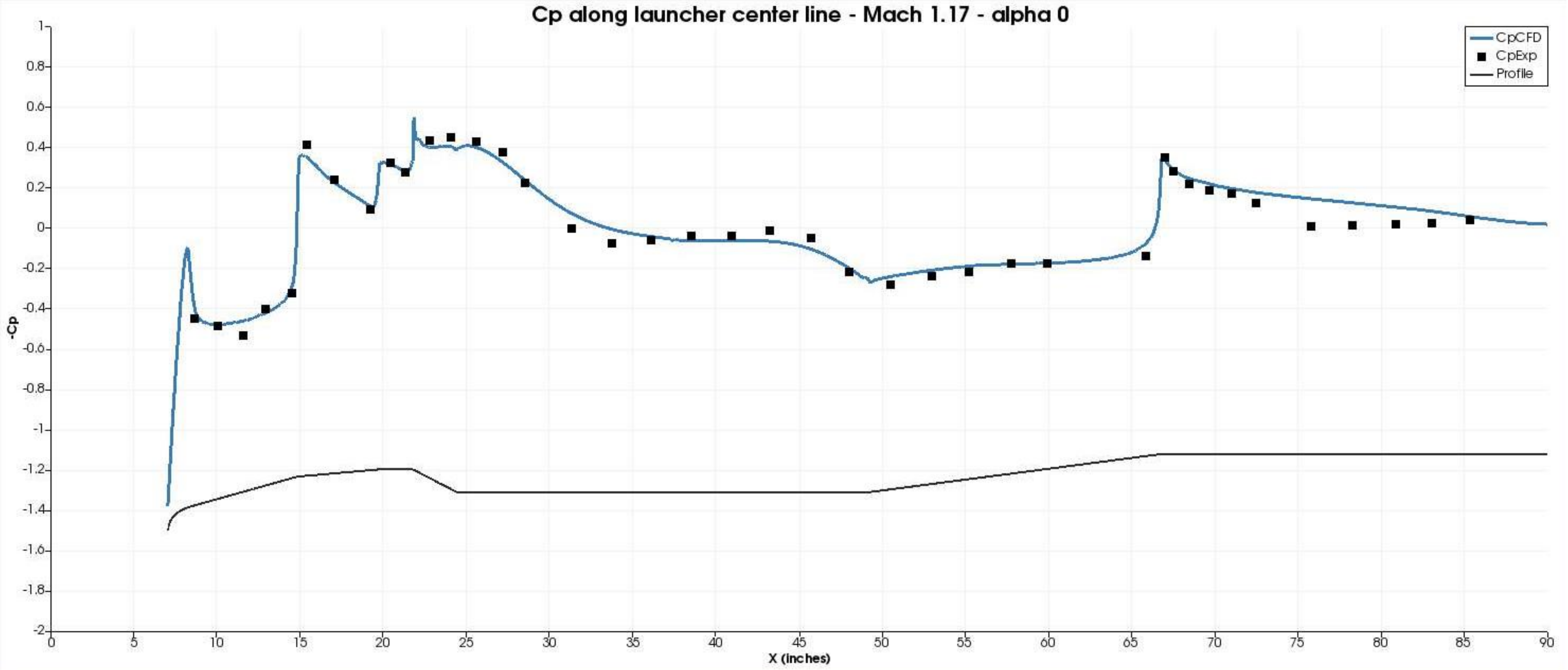
iconCFD TRANSONIC
VALIDATION – NASA TECH MEMO X778

- Mach 1.17 results and alpha 0deg, Mach number in the field, Cp at the wall:



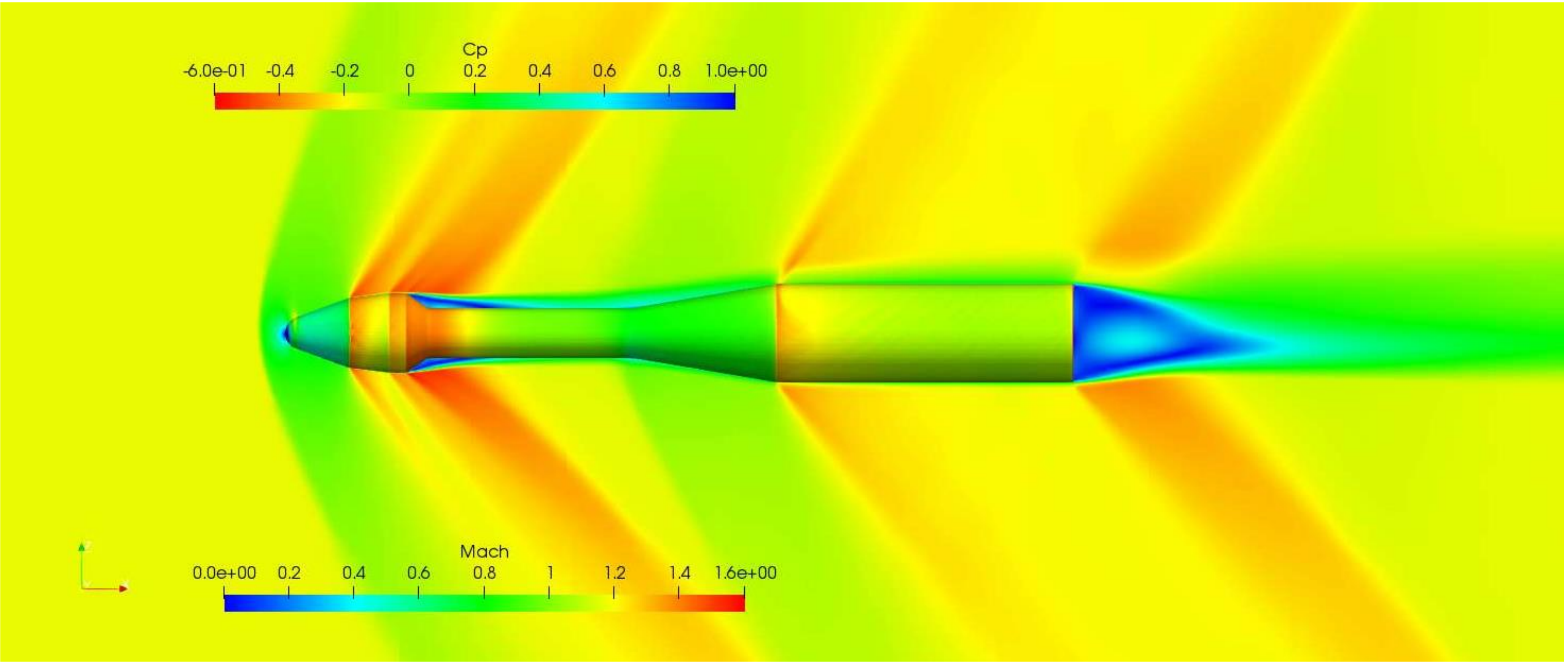
iconCFD TRANSONIC
VALIDATION – NASA TECH MEMO X778

- Mach 1.17 results and alpha 0deg, Cp at the wall along the symmetryPlane:



iconCFD TRANSONIC
VALIDATION – NASA TECH MEMO X778

- Mach 1.17 results and alpha 4deg, Mach number in the field, Cp at the wall:



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VALIDATION – NASA TECH MEMO X778

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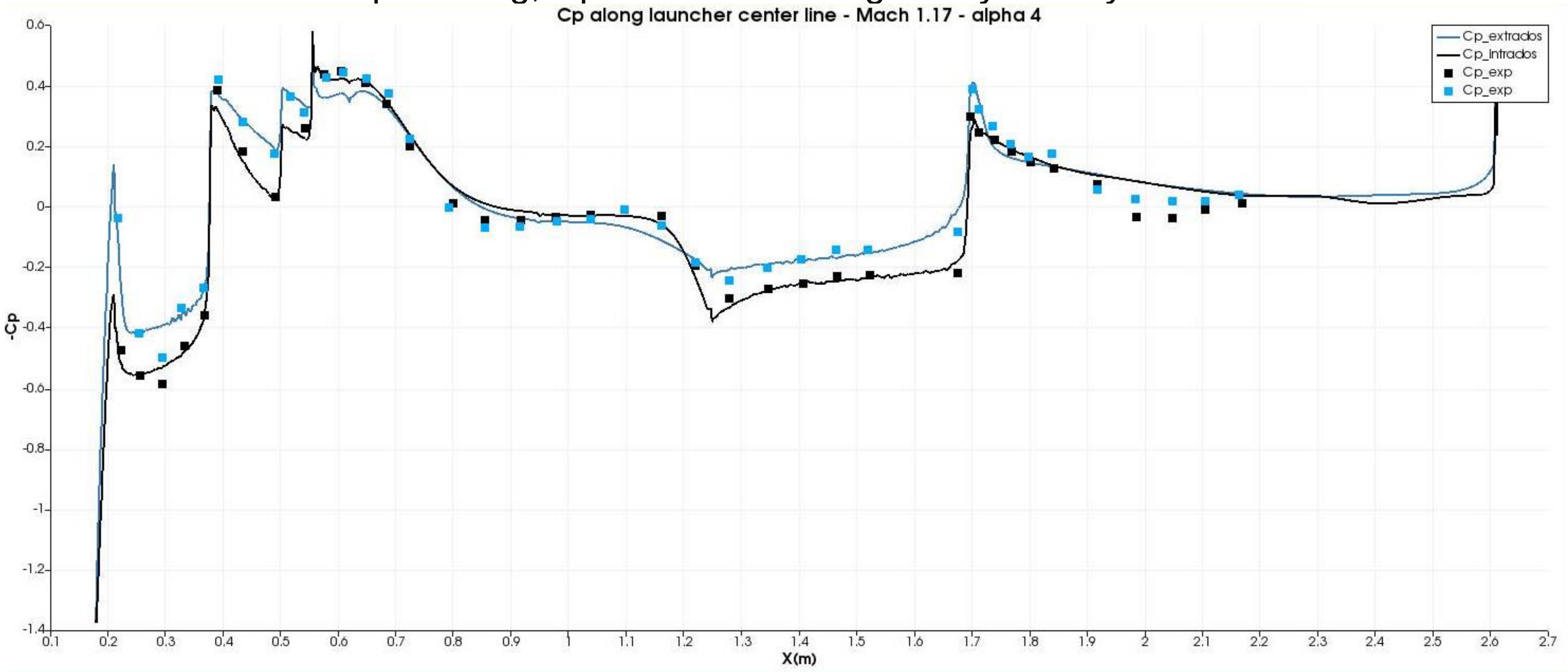
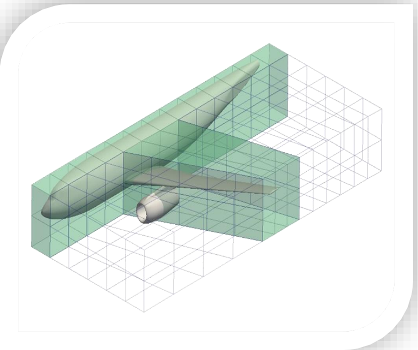


AGENDA

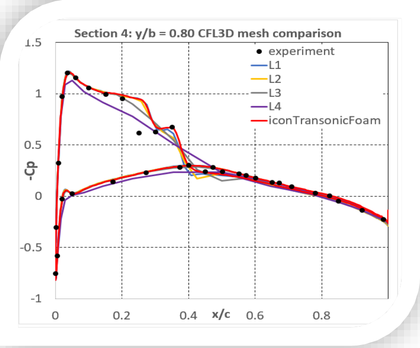


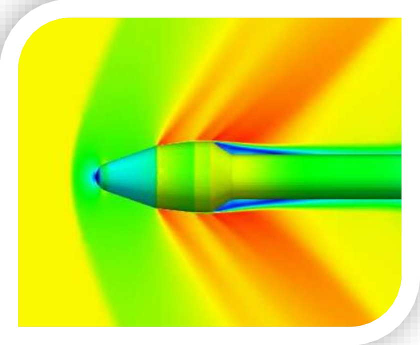
Introduction - iconTransonicFoam

Validation and Verification

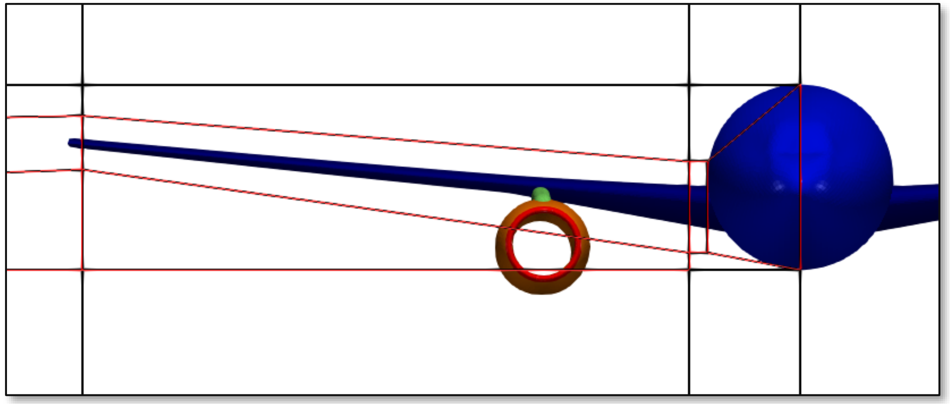
iconCFD Transonic Process

Further work

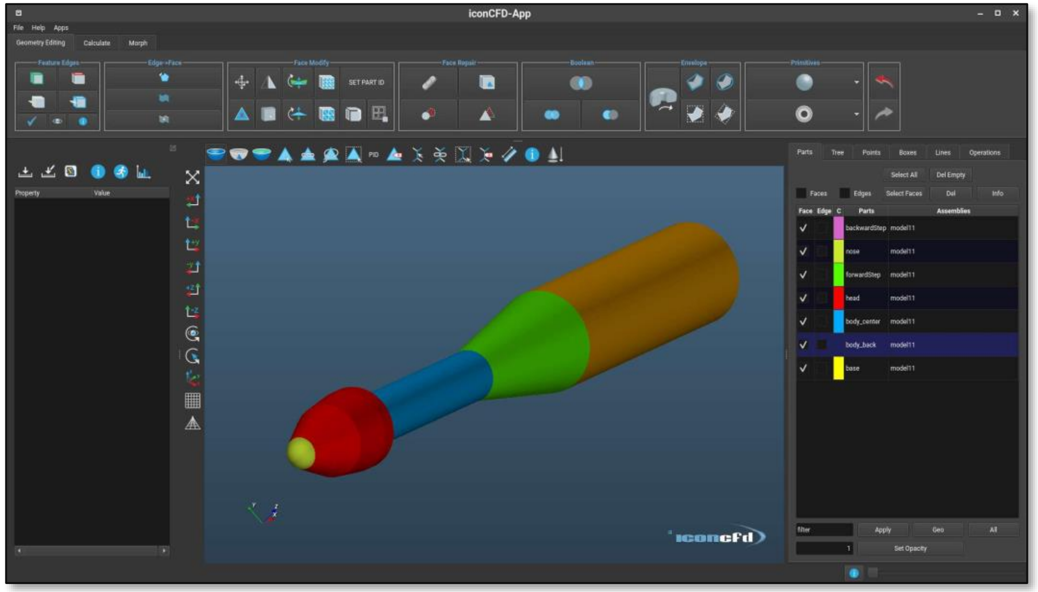




iconCFD TRANSONIC
PROCESS



- The iconCFD Transonic module is not simply a solver
- Other tools within the module include:
  - aeroBlockMesh
  - Function objects – on-the-fly post-processing modules
- Incorporated into the iconCFD workflow it can provide the user with a complete efficient, user-focused, automated process tailored to the aerospace industry.
  - Customisable App-based pre-processing
  - Geometry wrapping
  - Fully parallelised polyhedral meshing technology
  - Fully interactive generic post-processing viewer



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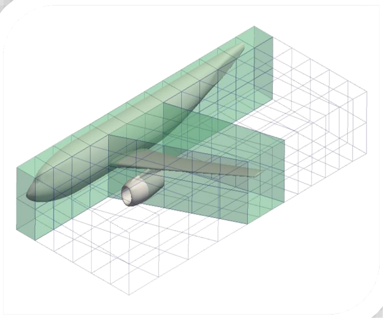
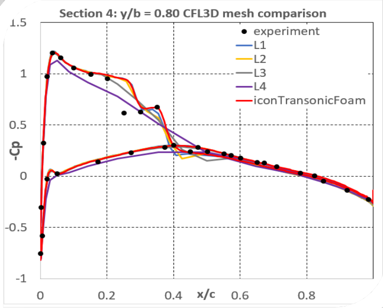
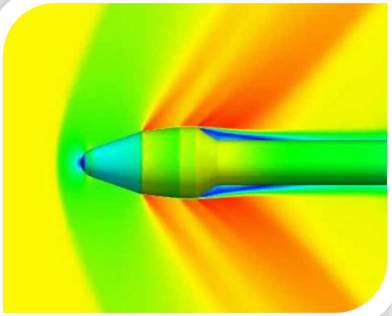
- **Further work**



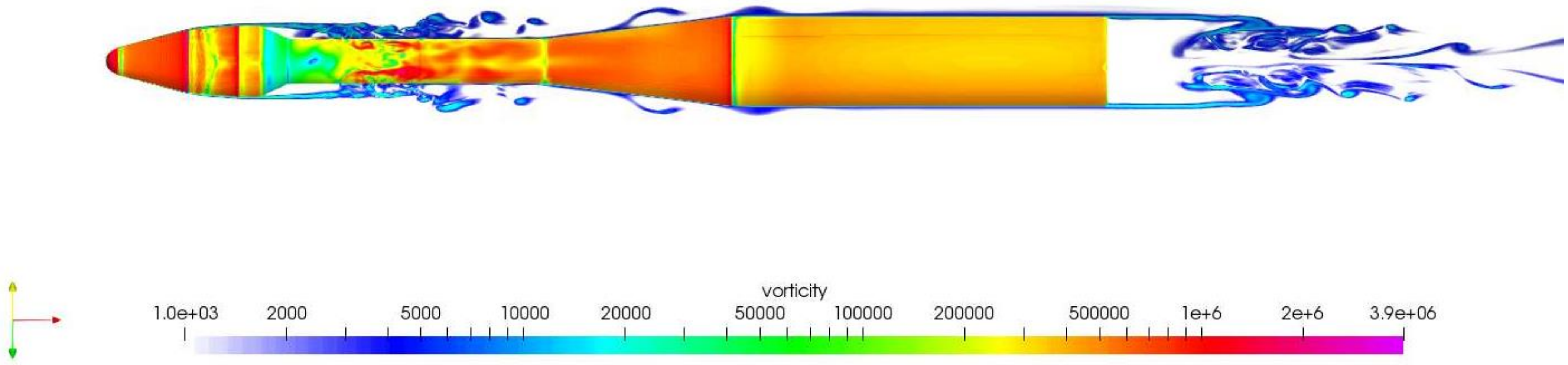




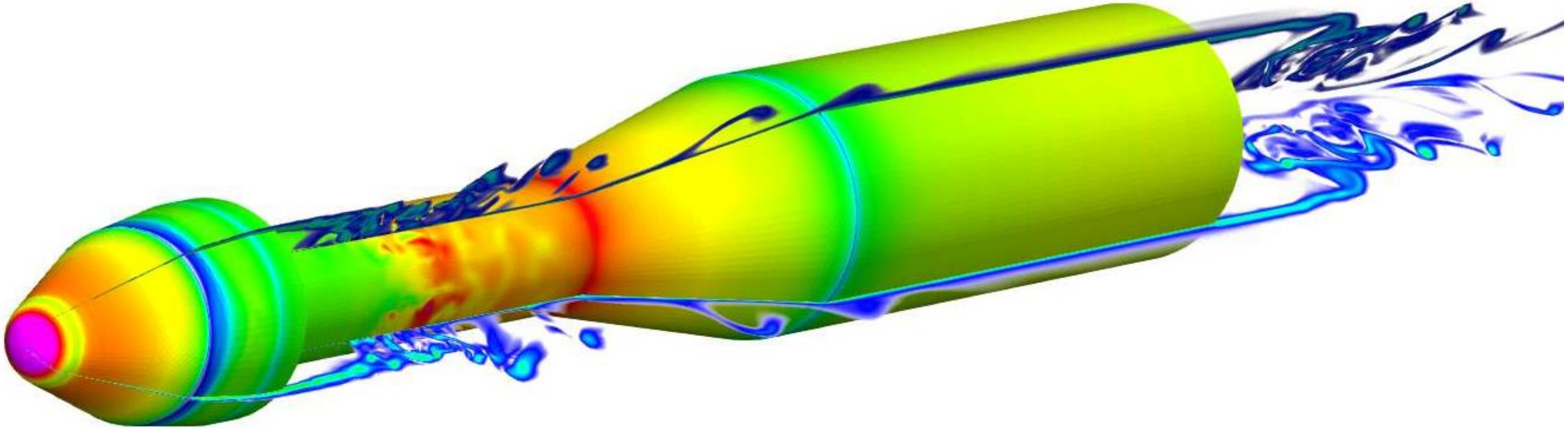
iconCFD TRANSONIC

EXTEND VALIDATION – NASA TECH MEMO X778

- Extend validation to transient data.
- DES simulation currently running



THANK YOU – ANY QUESTION?



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