Computational Aerodynamics Applications in Aerospace Engineering

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CONTRIBUTIONS

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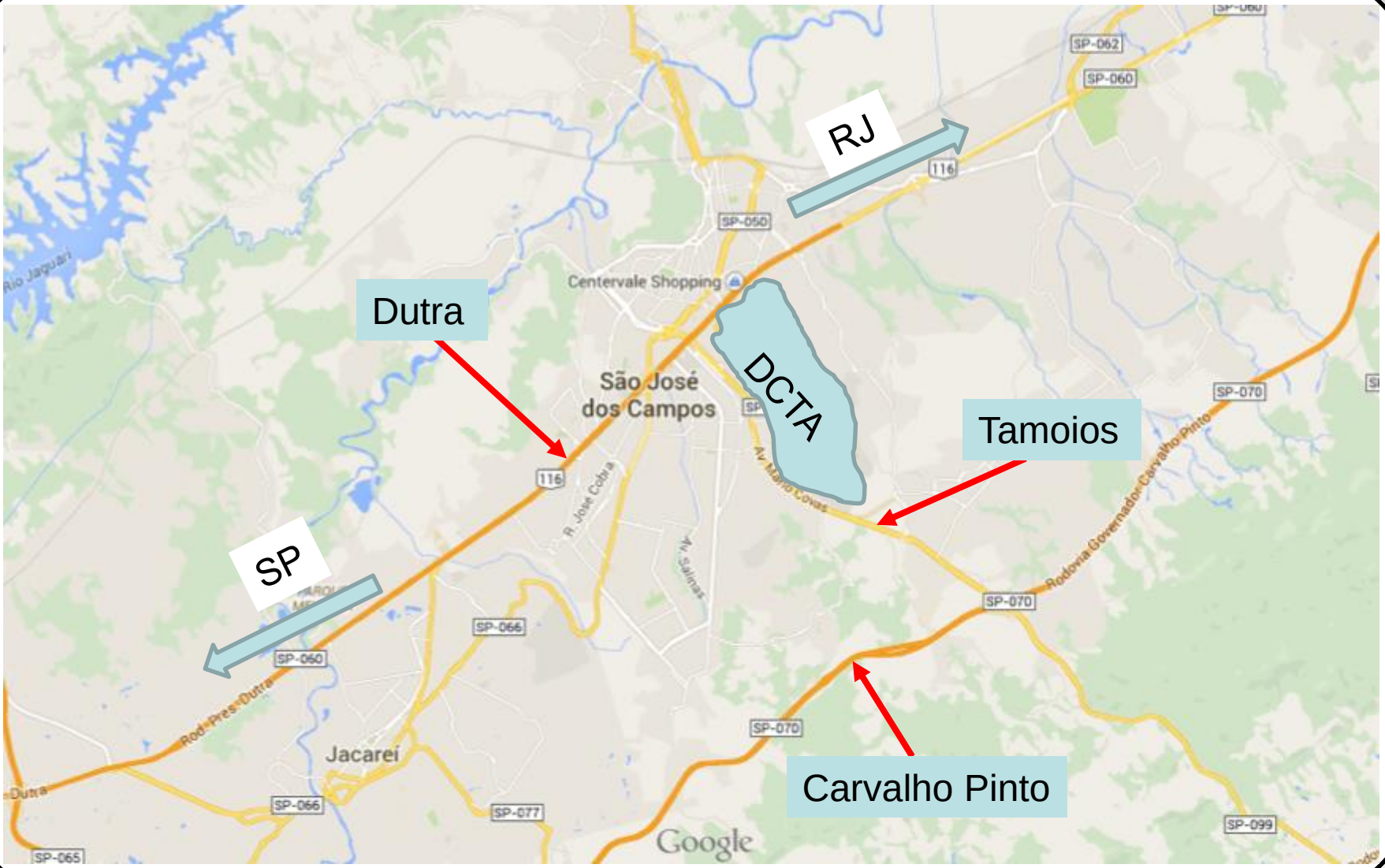
OUTLINE

- Background information
  - Location
  - DCTA and its Institutes
  - CFD laboratory
  - Research interests

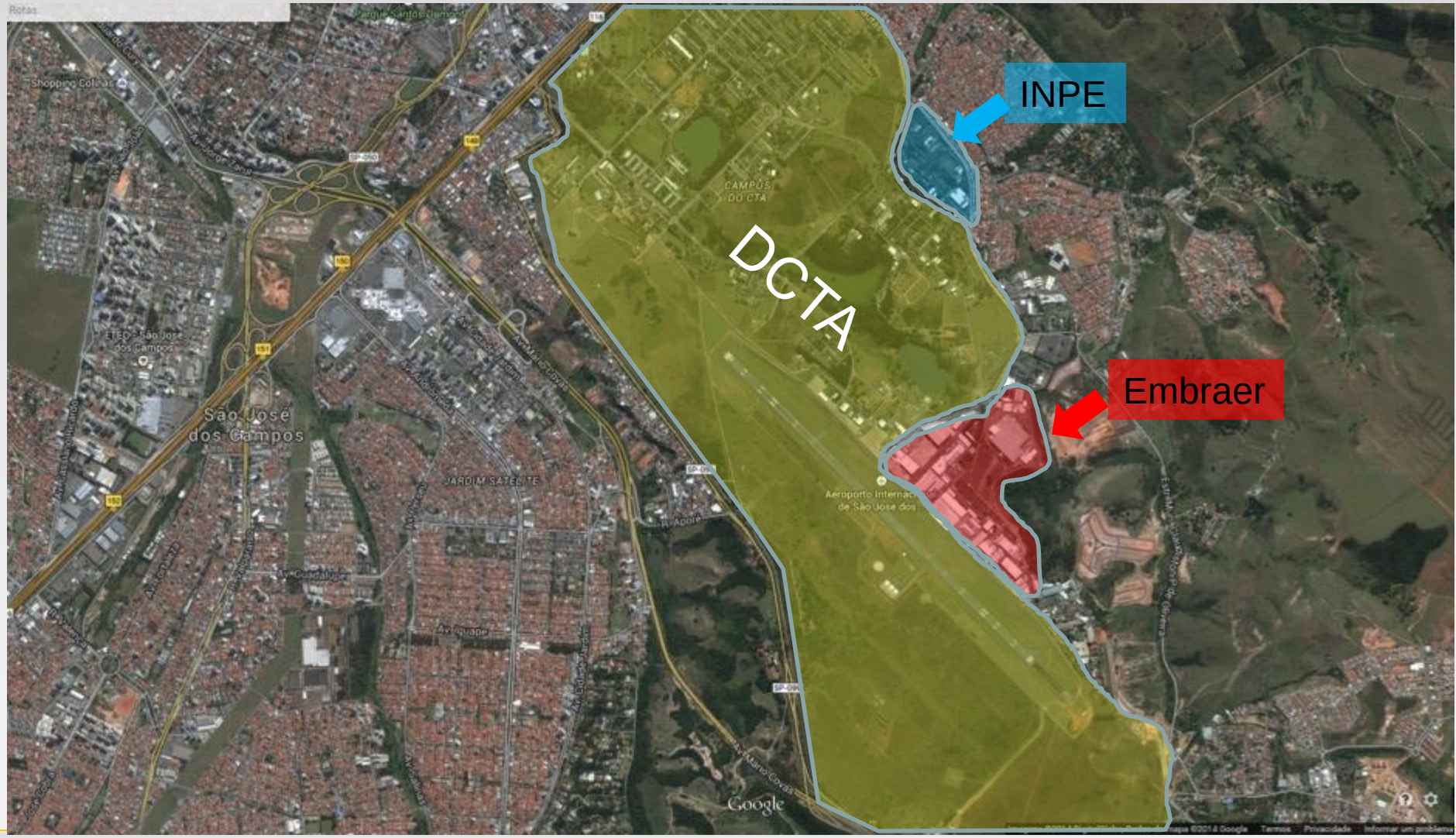
- Some representative results of our current work
- Concluding remarks

São José dos Campos

DCTA and its Institutes



DCTA and its Institutes



A BIT OF HISTORY

- CTA (currently DCTA) was created together ITA in the late 40's by (then) Col. Casimiro Montenegro Filho
- Instituto Tecnológico de Aeronáutica (ITA) is probably the most well-known institute in our center.
- DCTA is an organization of the Brazilian Air Force Command
- Our responsibility is to do research and to develop technology relevant for aerospace applications
- In particular case of IAE, the work is focused on systems which are to be fielded right now or in the near future
- In this context, our group's work is directed towards CFD applications and developments relevant to DCTA.

CFD Laboratory

- Researchers and/ or professors (5)
- Post-doctoral researchers (3)
- PhD students (5)
- MS students (16)
- Undergraduate students (4)

AREAS OF RESEARCH INTEREST

- Code Development and Verification-Validation
- Applied CFD and Turbulence Modeling
- LES and Aeroacoustics
- Aeroelasticity and Fluid-Structure Interaction
- High-Order CFD Methods
- High-Speed Flows (Hypersonics)
- Aerodynamic Optimization

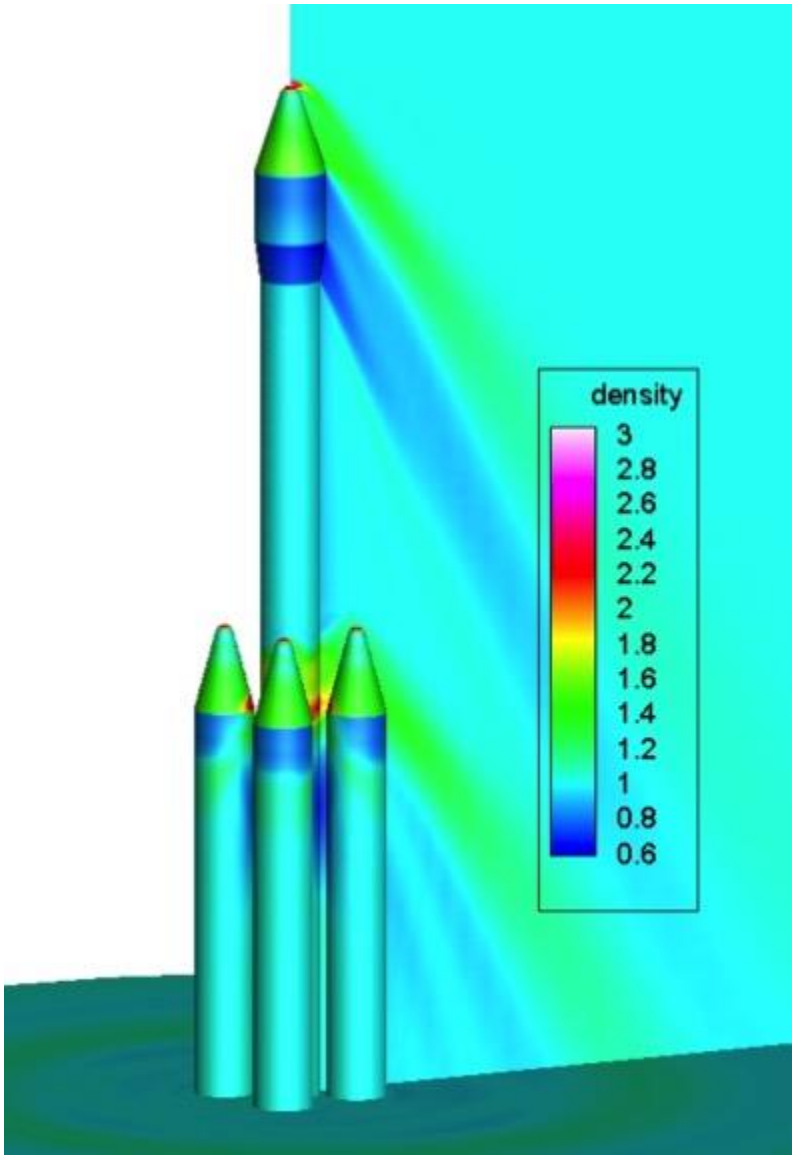
CODE DEVELOPMENT

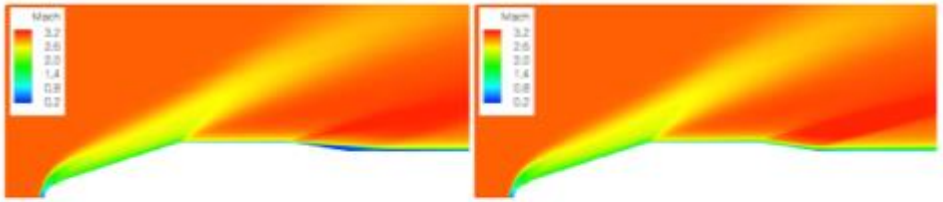
- Development of in-house software
  - BRU3D, v2.xx
    - Reynolds-averaged Navier-Stokes (RANS) formulation
    - Several turbulence models available (SA, low Reynolds Wilcox κ-ω, realizable κ-ε, SST, modified Craft-Launder RSM, stressBSL EARSM, Wallin-Johansson EARSM)
    - Finite Volume Method (FVM), cell centered, general unstructured grids
    - Spatial discretization: centered scheme (+ artificial dissipation) and Roe scheme
    - Temporal discretization: explicit Runge-Kutta schemes + point implicit solver
    - Convergence acceleration for steady state: local time stepping + agglomeration multigrid
    - Parallel code (MPI + OpenMP)

CODE DEVELOPMENT

- Development of in-house software
  - BRU3D, v3.0
    - C++, templates, CGNS, parallel I/O
    - General unstructured grids
    - High-order spatial discretization
    - MPI + OpenMP + CUDA
  - JAZzY, v1.0
    - Parallel compressible LES code (with MPI)
    - Structured meshes, CGNS+HDF5, parallel I/O
    - Standard and dynamic Smagorinsky sub-grid scale models
  - dsmcFOAM
    - Open-source C++ fluid dynamics toolbox OpenFOAM
    - Ballistic particle tracking
    - Probabilistic collisions
    - Quantum-kinetic chemistry model

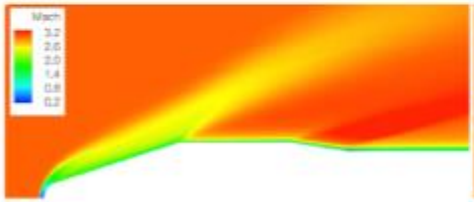
APPLIED CFD



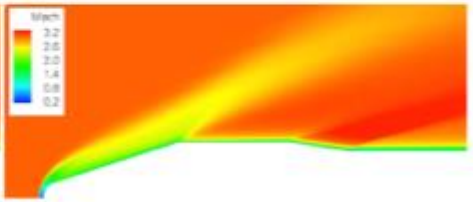


(a) Laminar (no turbulence closure).

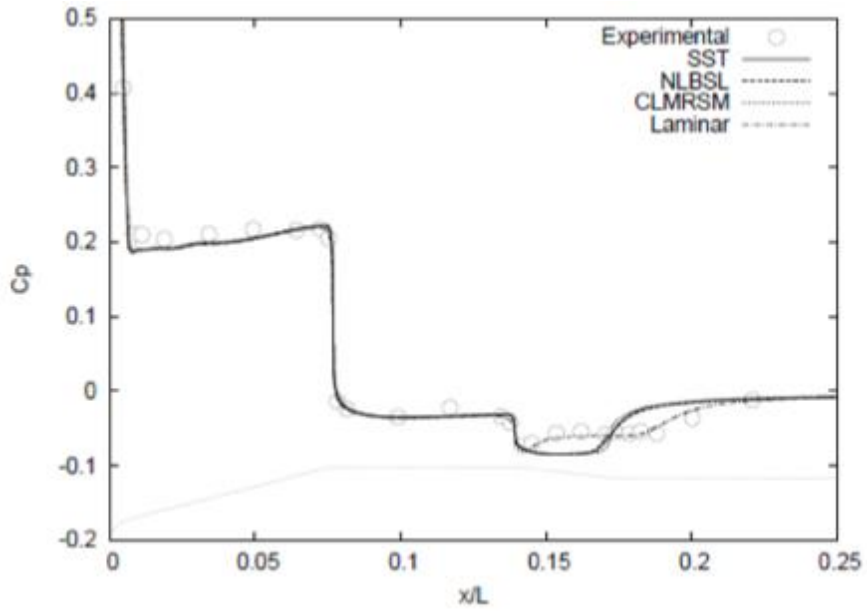
(b) SST.



(c) NLBSL.



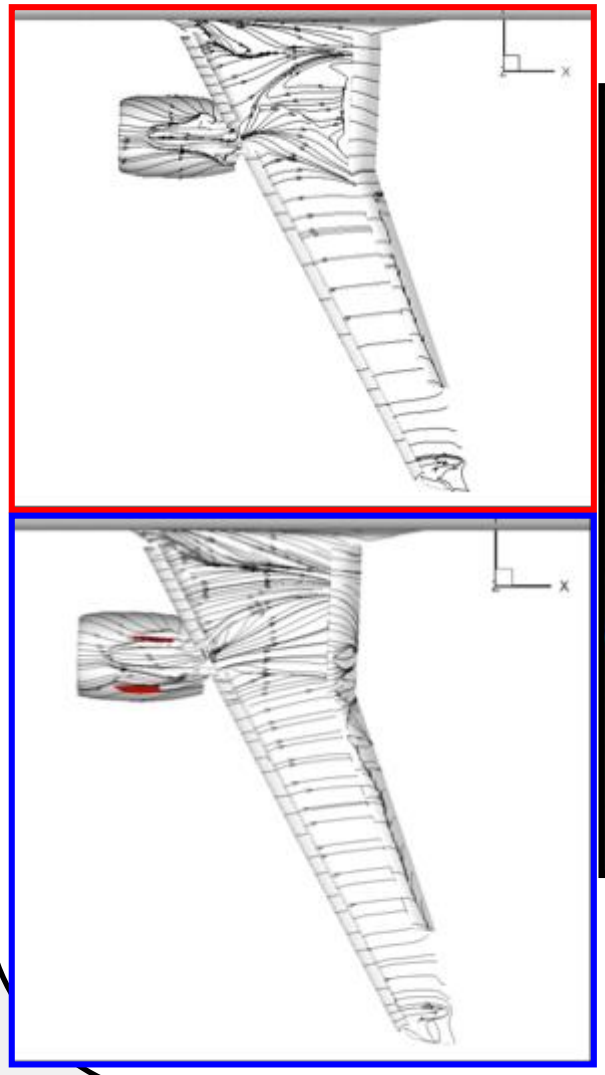
(d) CLMRSM.

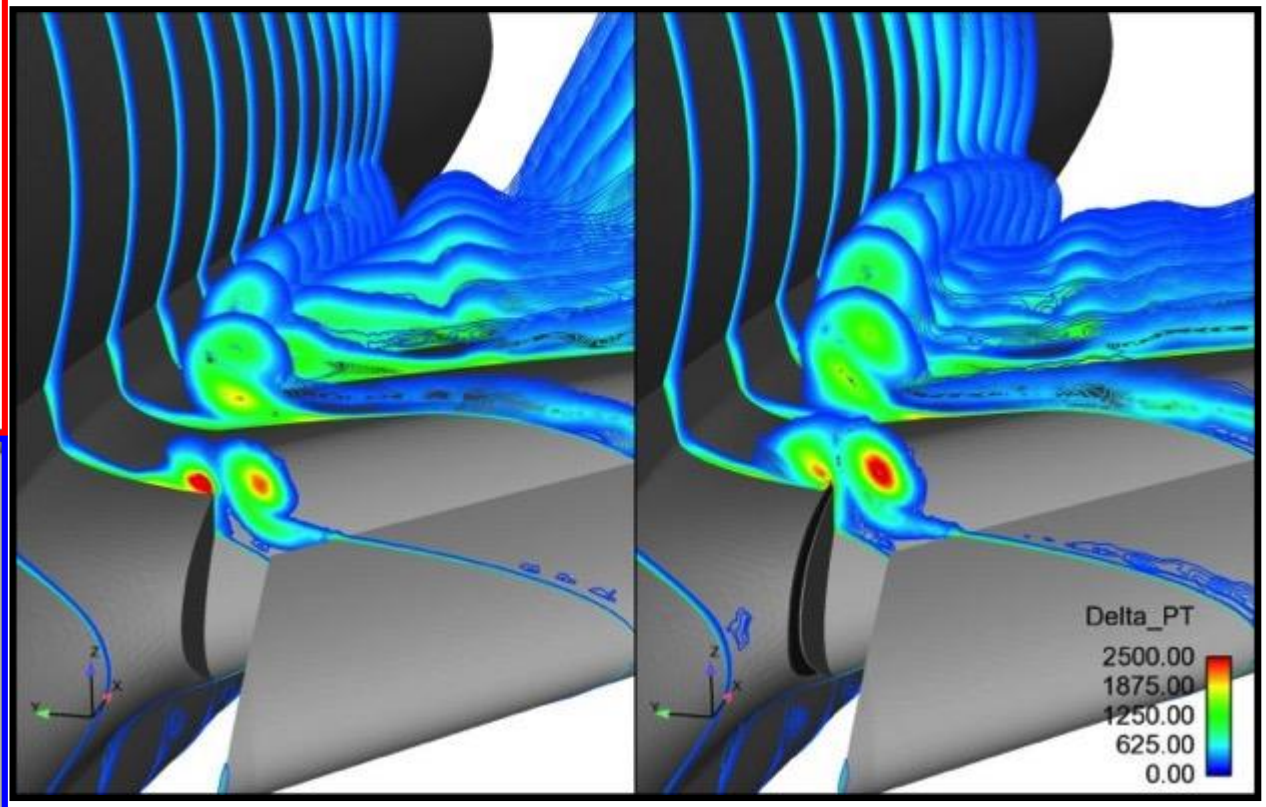


APPLIED CFD

RANS solutions used to improve the understanding of stall behavior.

Fence effect at Re = 3 X 10^6 , M = 0.25 and AoA = 15 deg

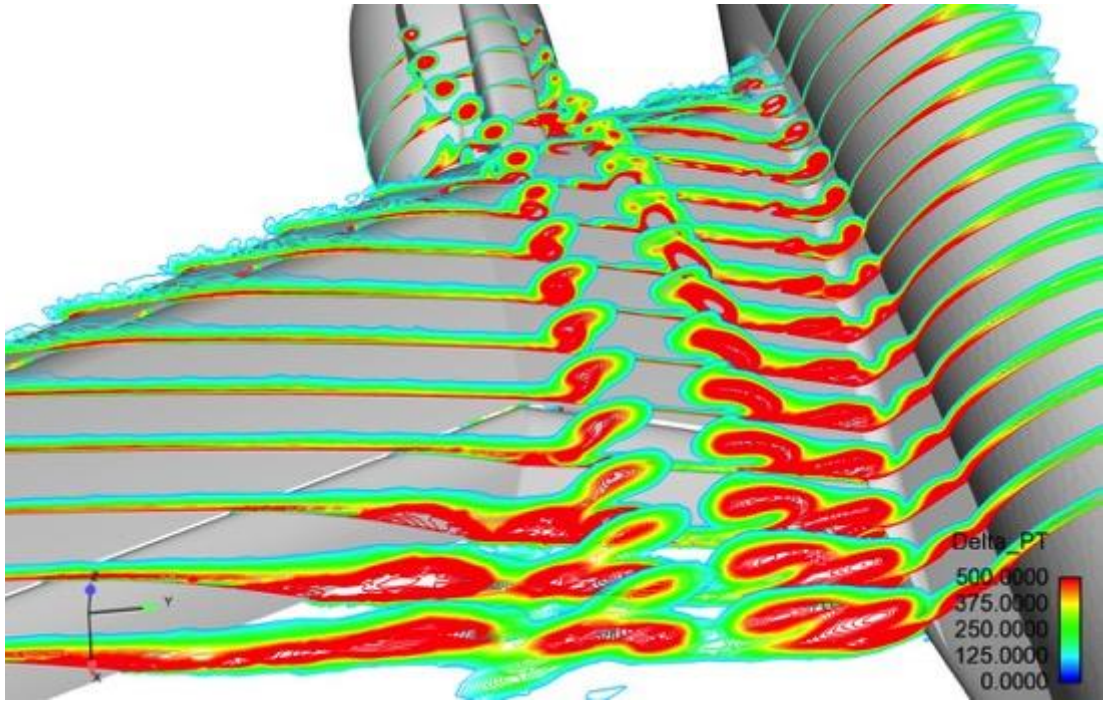


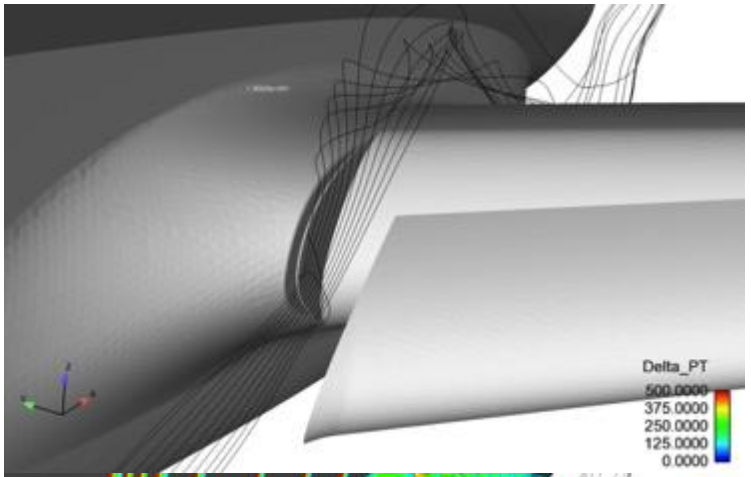


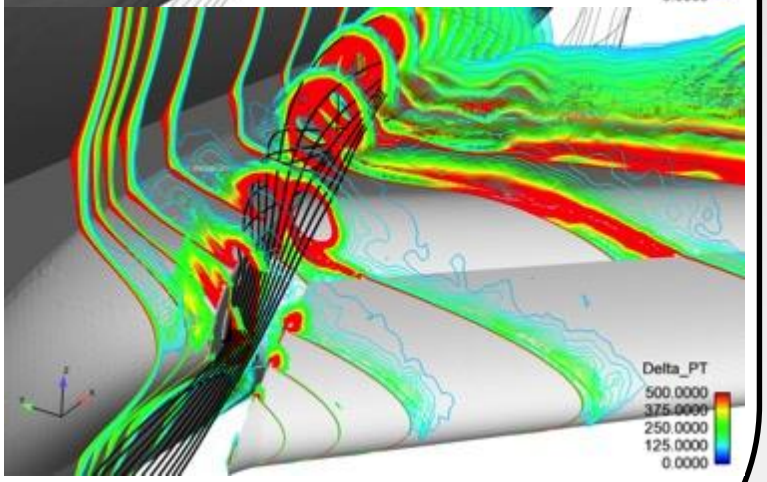
APPLIED CFD

RANS solutions used to improve the understanding of stall behavior.

Interaction between vortical structures and boundary layer.

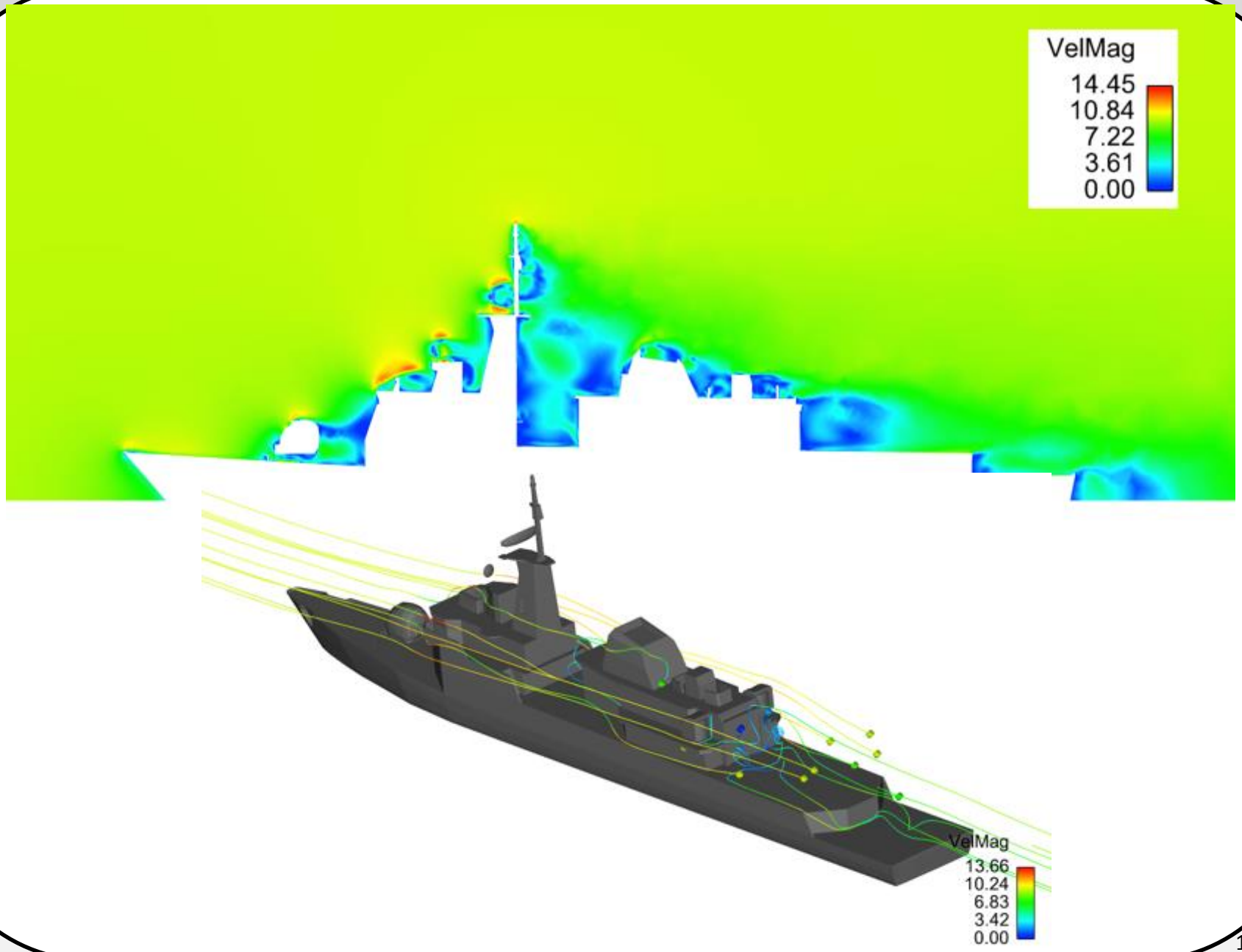






APPLIED CFD

APPLIED CFD

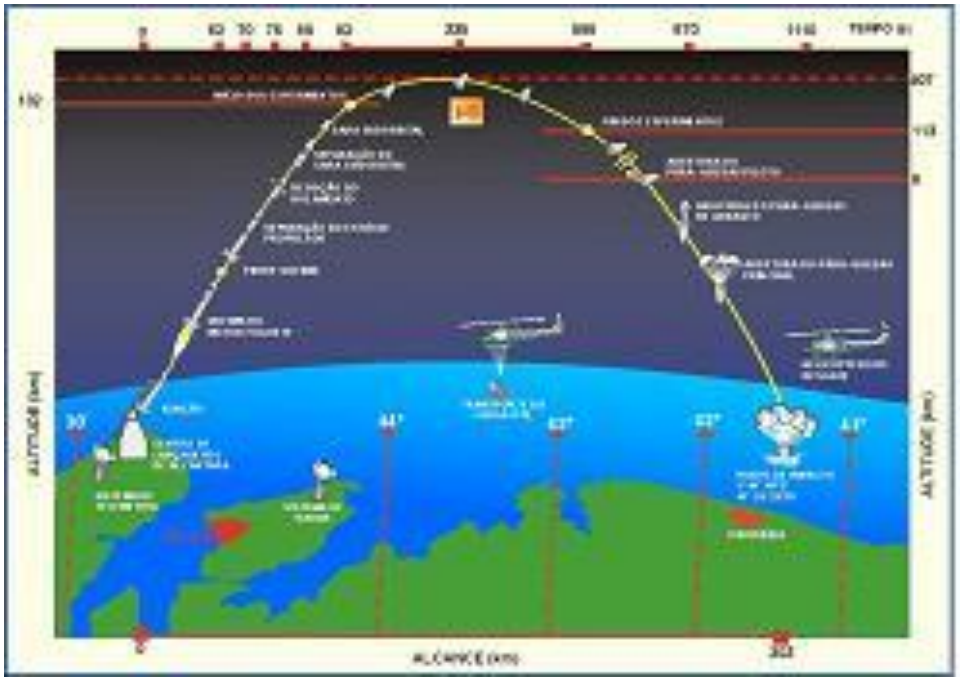


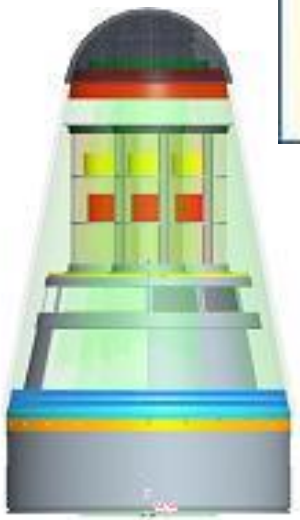
HYPERSONIC FLOWS

Numerical Investigation of Hypersonic Vehicles under Thermochemical Non-Equilibrium Conditions

The project includes the development of a space platform for experiments in microgravity, called Satélite de Reentrada Atmosférica (SARA)

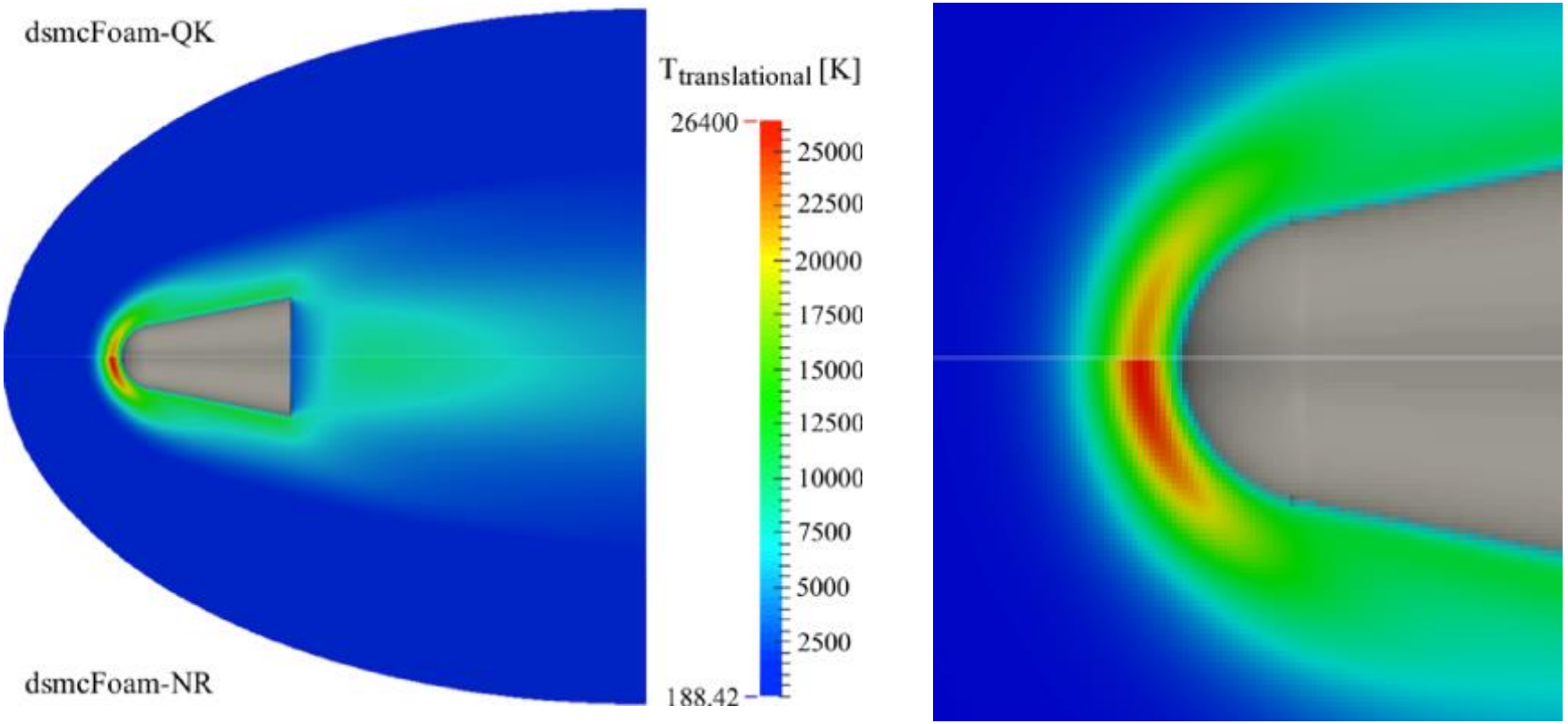
- Low circular orbit (300 km), 10 days max
- Reentry Simulation: 95 km altitude, Mach 28, vel. 28,000 km/h
- Suborbital SARA vehicle, 350 kg, launched through modified VS-40 sounding rocket





HYPERSONIC FLOWS

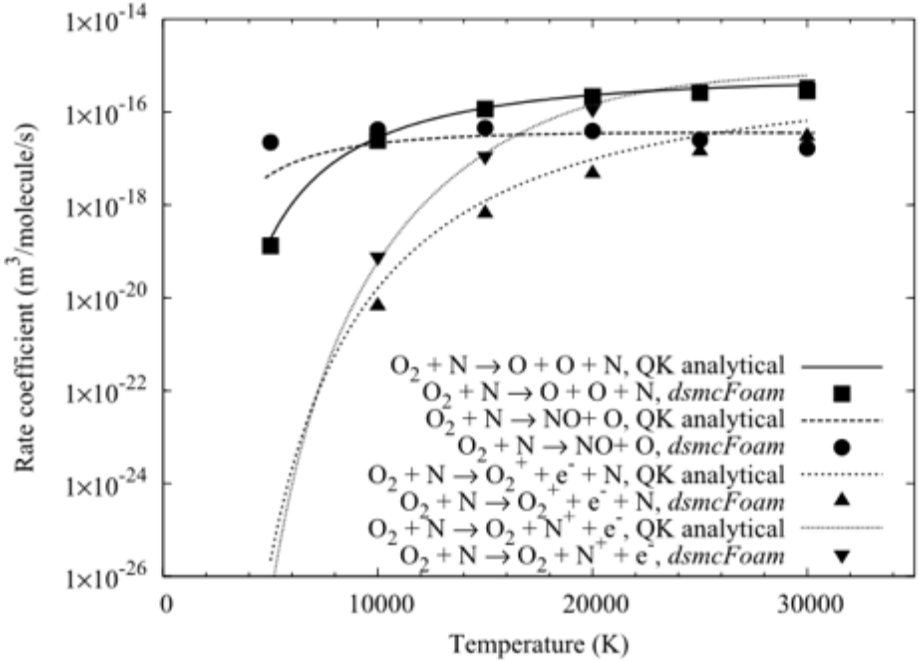
Suborbital SARA Vehicle

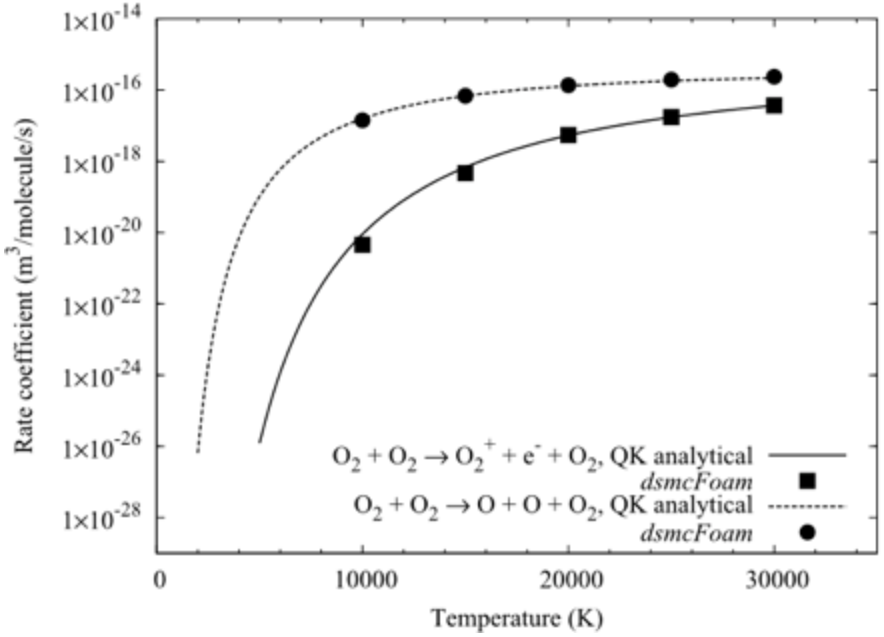


- Reentry condition – **95 km, 28,000 km/h, Mach 28**;
- **Reactive flow (QK) vs Non-reactive flow (NR)** – **DSMC technique**;
- "**Quantum Kinetic**" reaction model – 5 species and 19 reactions (dissociation and exchange reactions);
- **Overprediction** of shock wave **temperature** and **heat transfer**.

HYPERSONIC FLOWS

Implementation of ionization reactions
(reaction rates: dsmcFoam vs analytical solution)





Applications:

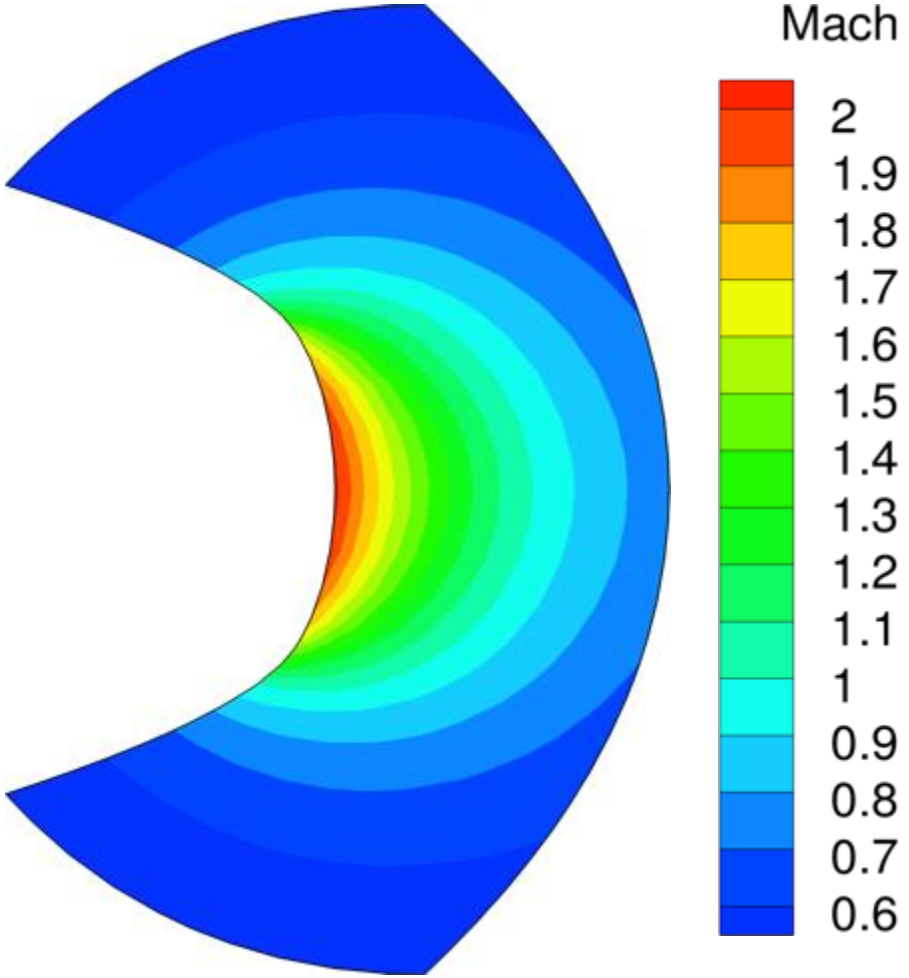
- - **Plasma formation** around reentry vehicles;
- - Development and design of reliable **thermal protection systems**;
- - Radio signal **blackout**;
- - Plasma **propulsion systems** for satellite altitude control.

HIGH-ORDER METHODS

Spectral Difference Method

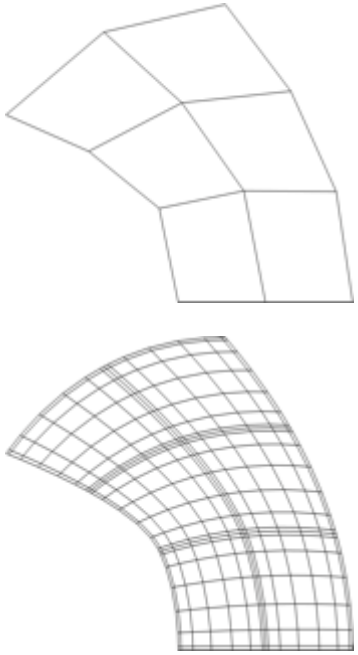
Development of High-Order Code

- Expectation of reduction in the man-hours required to achieve solution
- Compressible flows
- Work is mostly directed towards method development
- However, there are other issues which need effort
- High-order geometry representation and grid generation
- High-order visualization
- Robust solvers
- Robust discontinuity capturing method

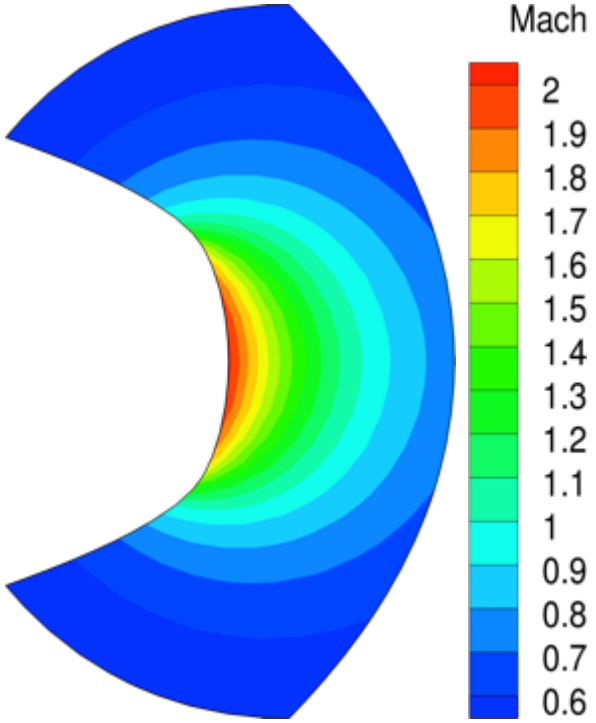


HIGH-ORDER METHODS

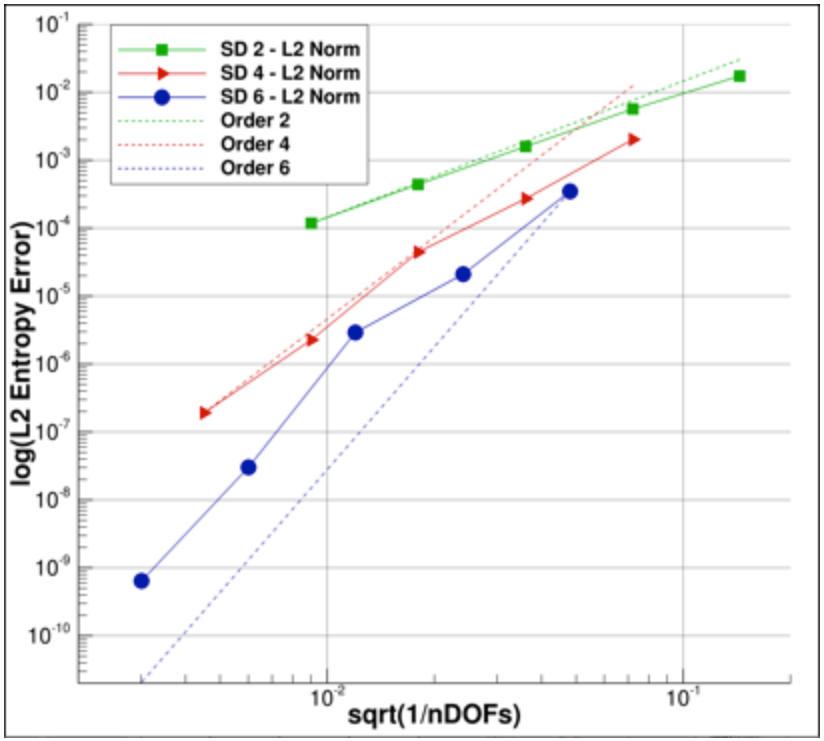
Ringleb Flow Problem



High-order geometry representation



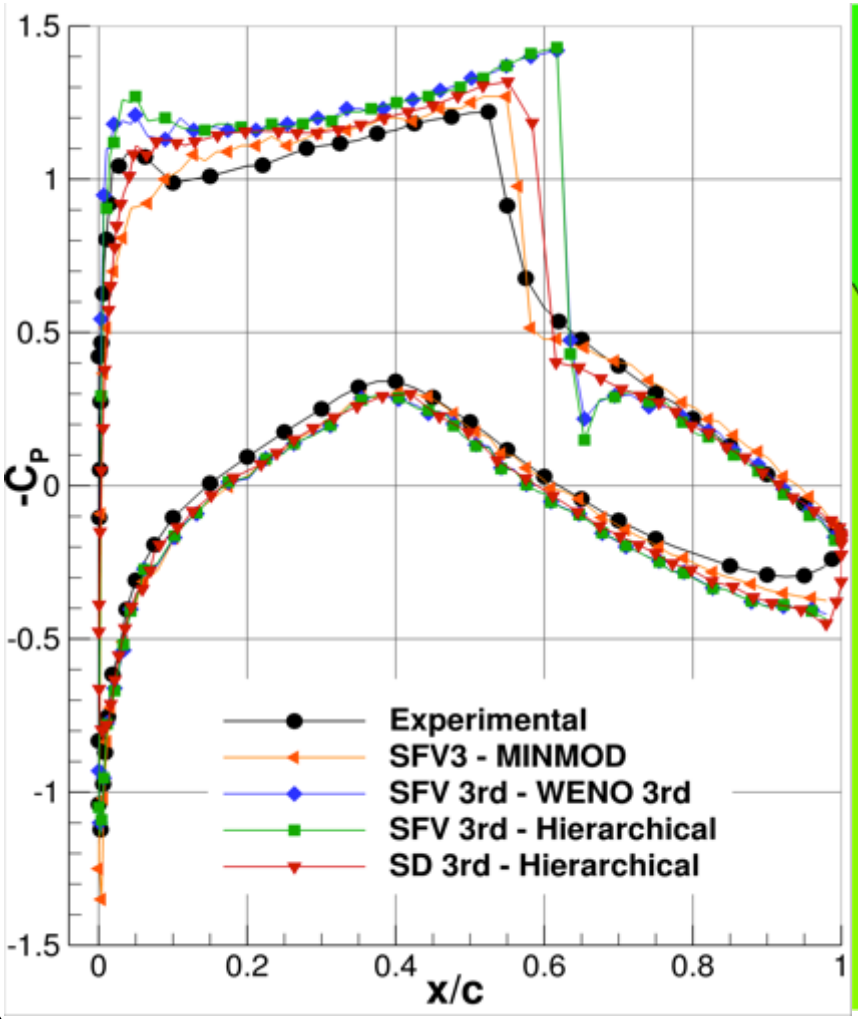
Entropy error = 3.88 X 10-4

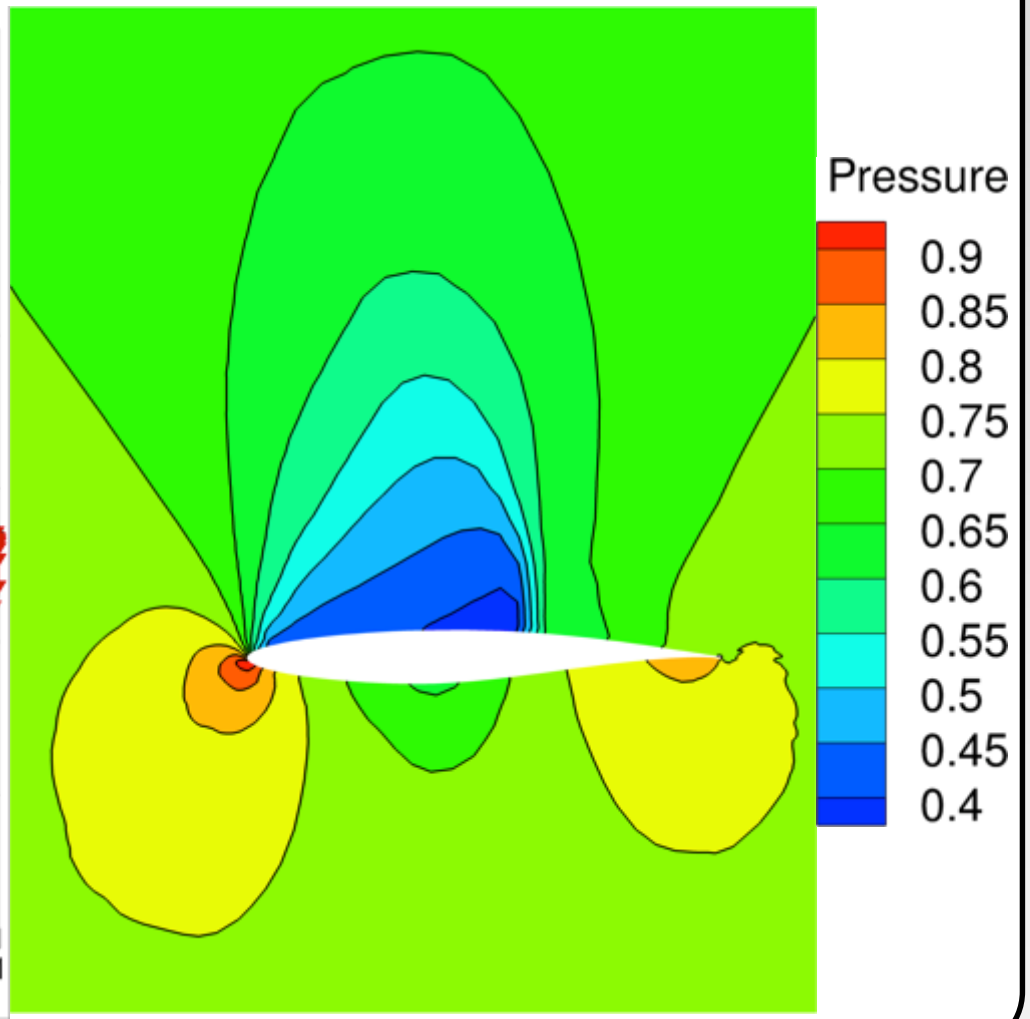


Close to ideal spatial convergence rate

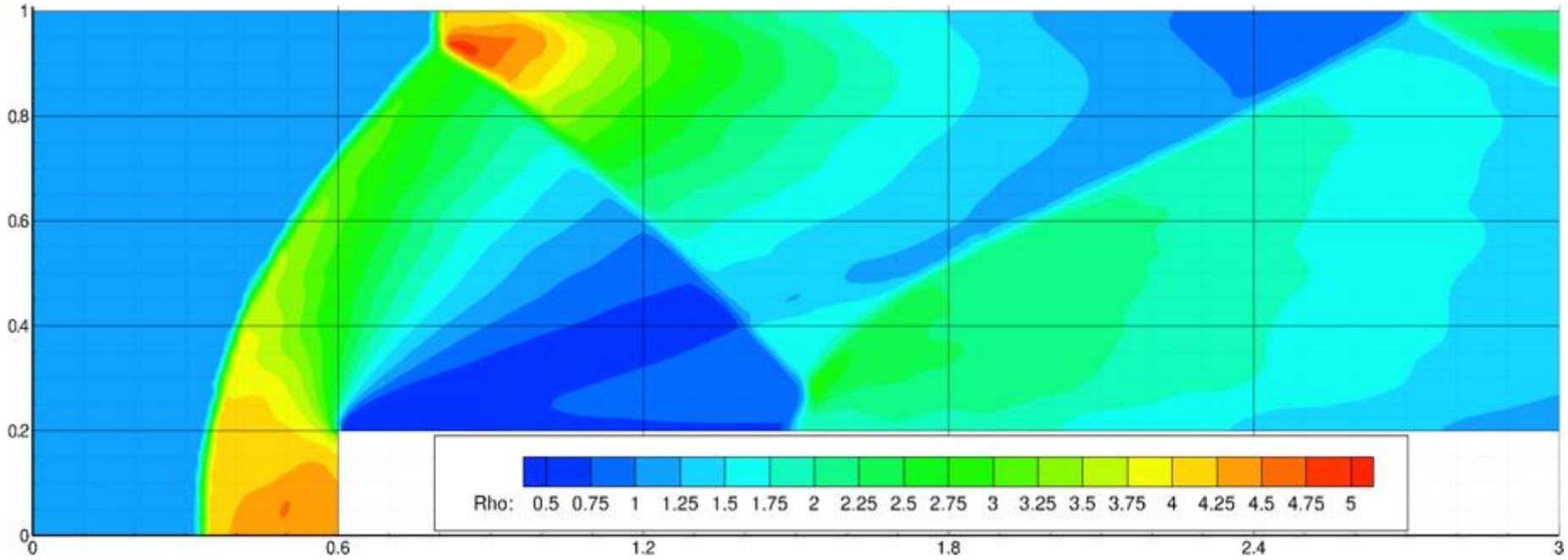
6^{th}-order formulation

HIGH-ORDER METHODS





HIGH-ORDER METHODS

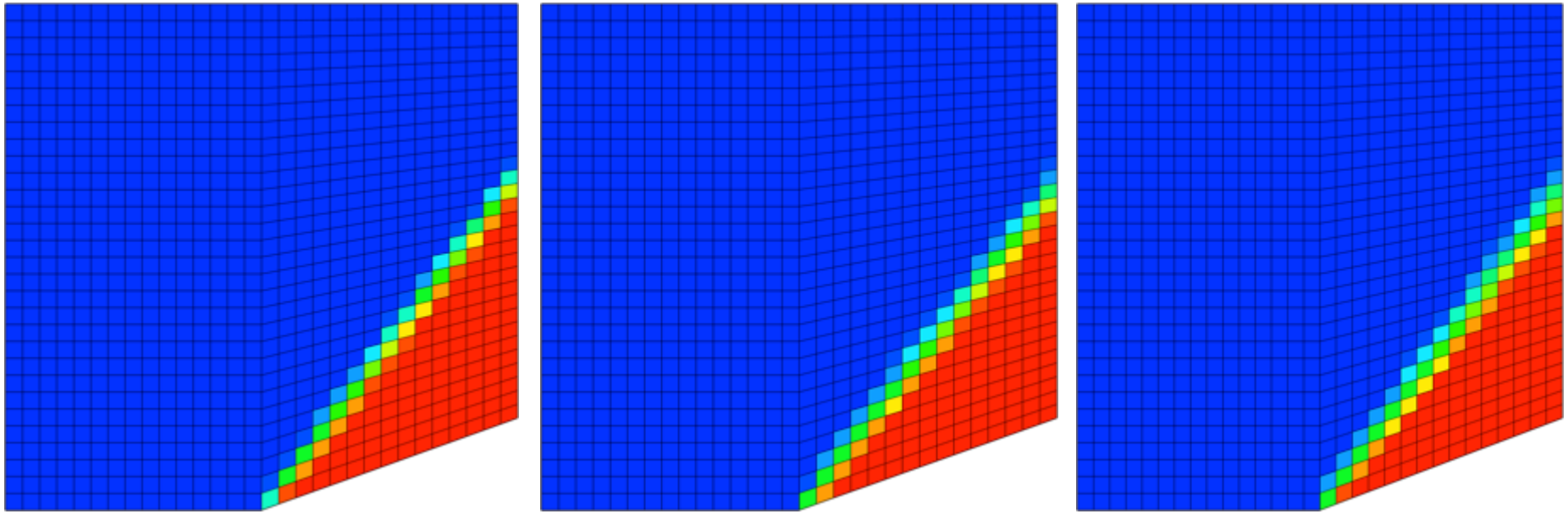


2nd order method on an unstructured grid of approximately 17,000 quadrilaterals

M = 3, transient computation until t = 4.0

Robustness to deal with strong shocks

HIGH-ORDER METHODS



2nd-order 3rd-order 4th-order

Mach = 2 flow over a wedge

Limiting process extendable to higher-order formulations

LES and AEROACOUSTICS

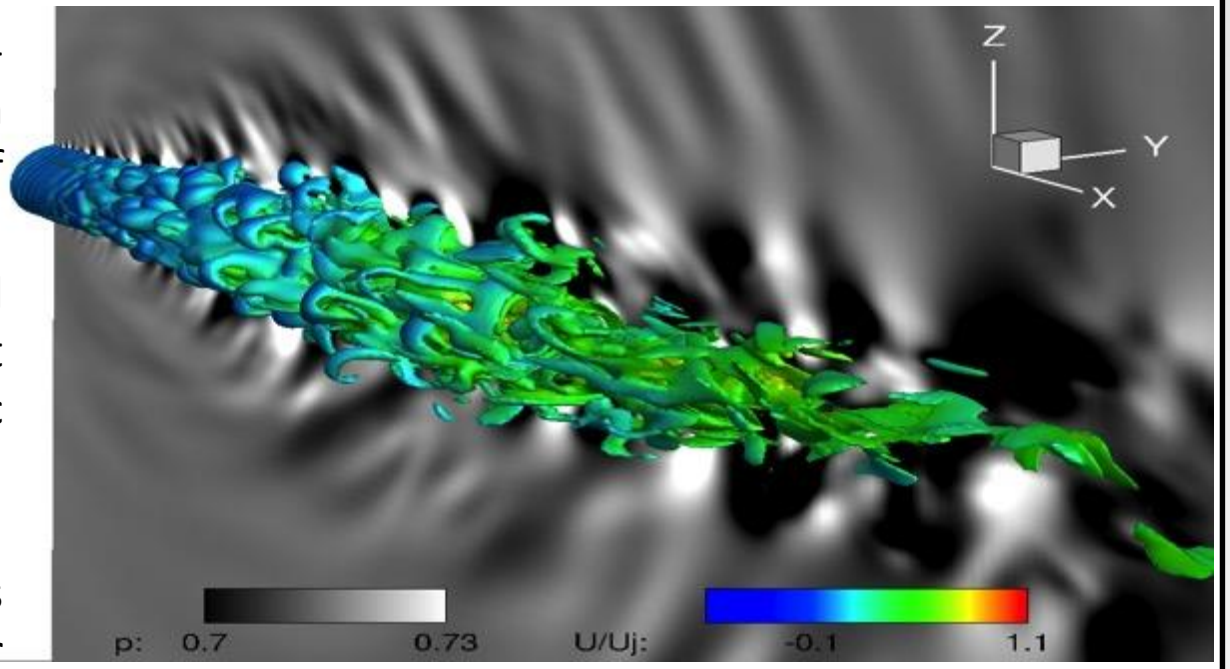
Large Eddy Simulation and Aeroacoustics of Perfectly Expanded Supersonic Jets

DEVELOPMENT OF A COMPRESSIBLE LES SOLVER

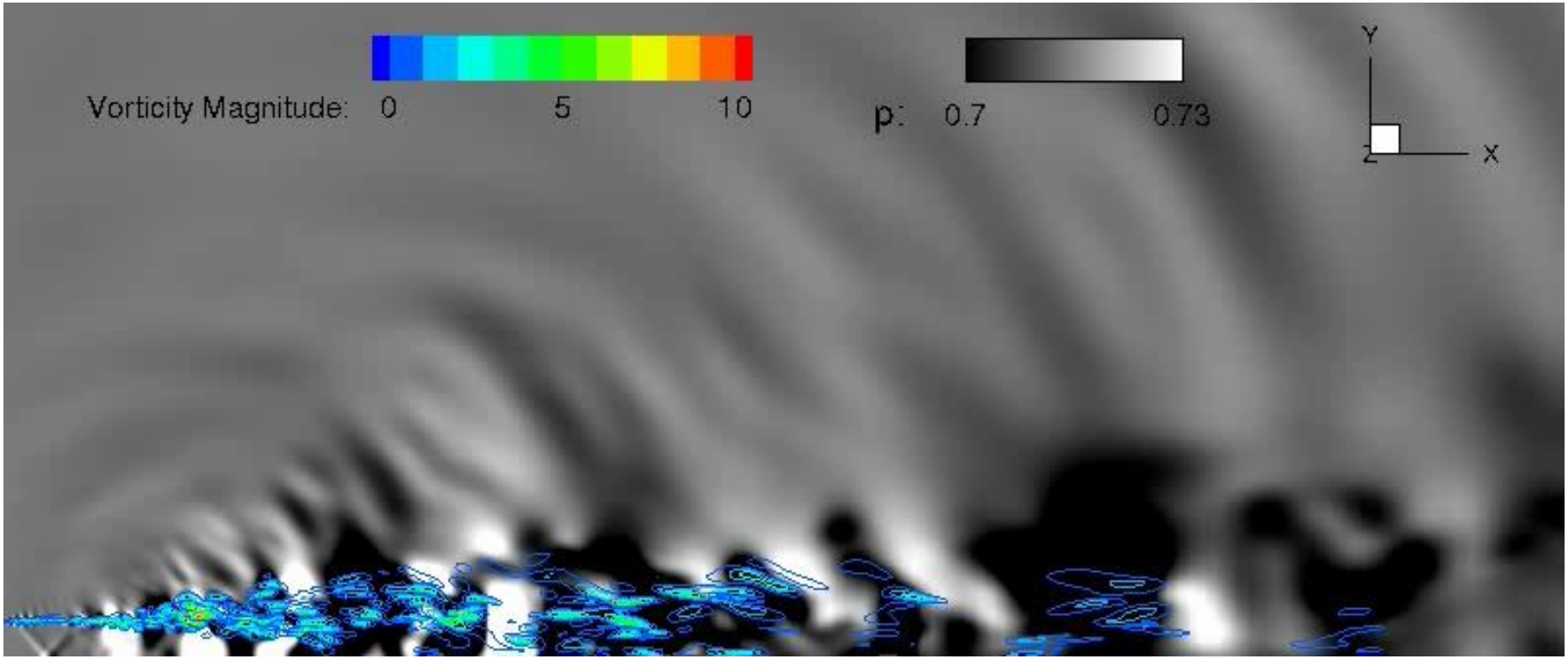
- Upgrade of a serial RANS solver to a parallel compressible LES solver.
- Perfectly expanded supersonic jet configurations.

NOISE PREDICTION AND PROPAGATION

- Development of physics-based noise prediction tools for analysis of aerodynamic noise sources.
- Fast multipole method (FMM) + boundary element method (BEM) for acoustic scattering.
- Fast multiple method (FMM) + Ffowcs Williams and Hawkings (FWH) for sound propagation.

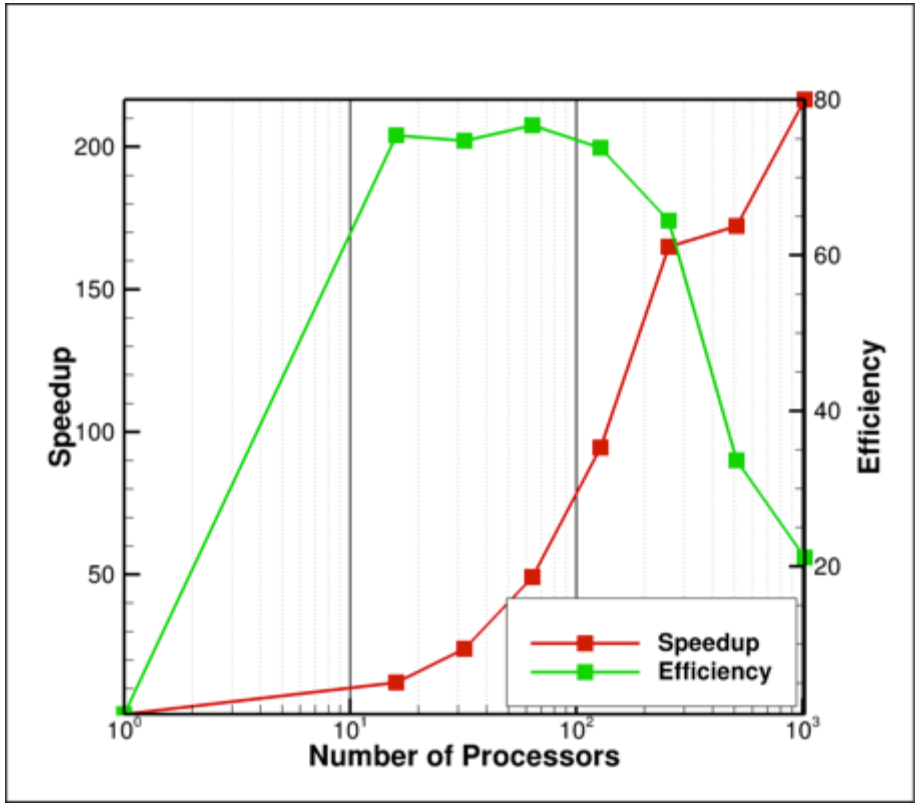


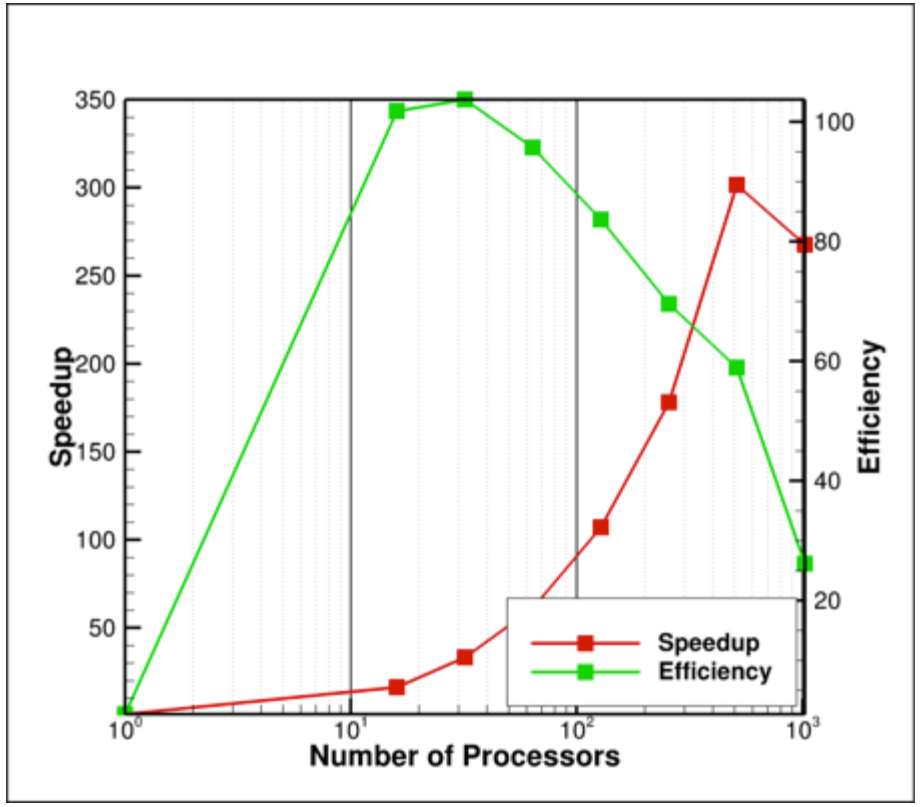
LES and AEROACOUSTICS



15 million mesh points: 150 days on CESUP (200 cores)
40 days on CEPID (1000 cores)

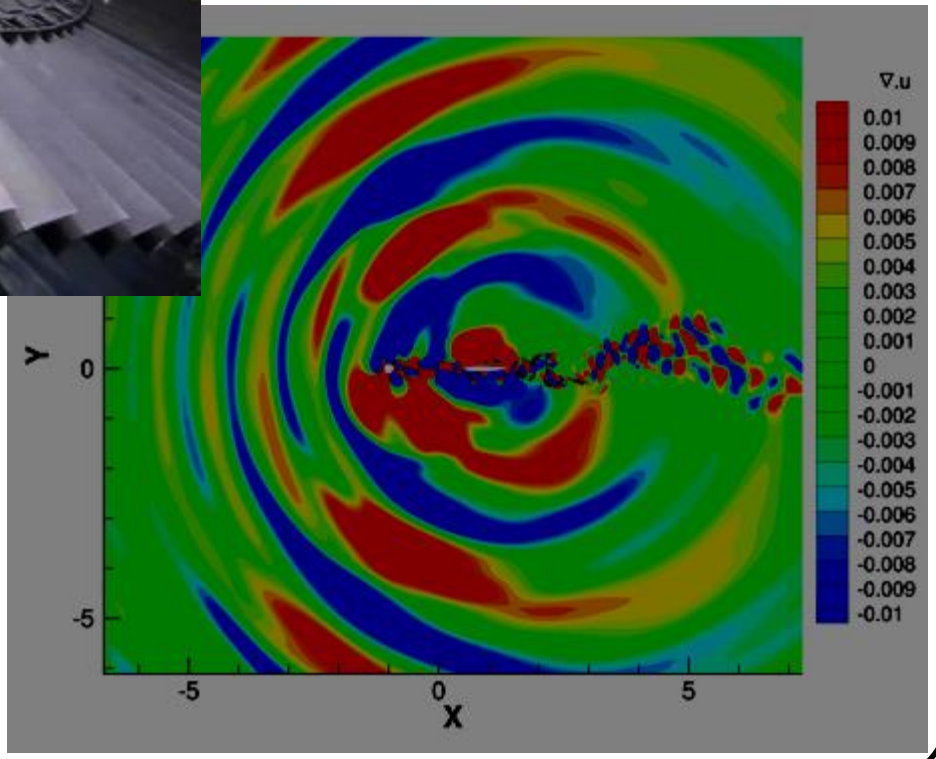
LES and AEROACOUSTICS





AIRFOIL NOISE

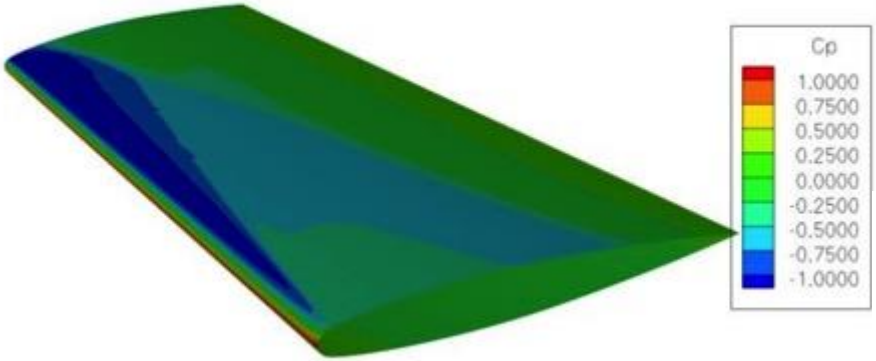
Airfoil Immersed in a Wake Vortex

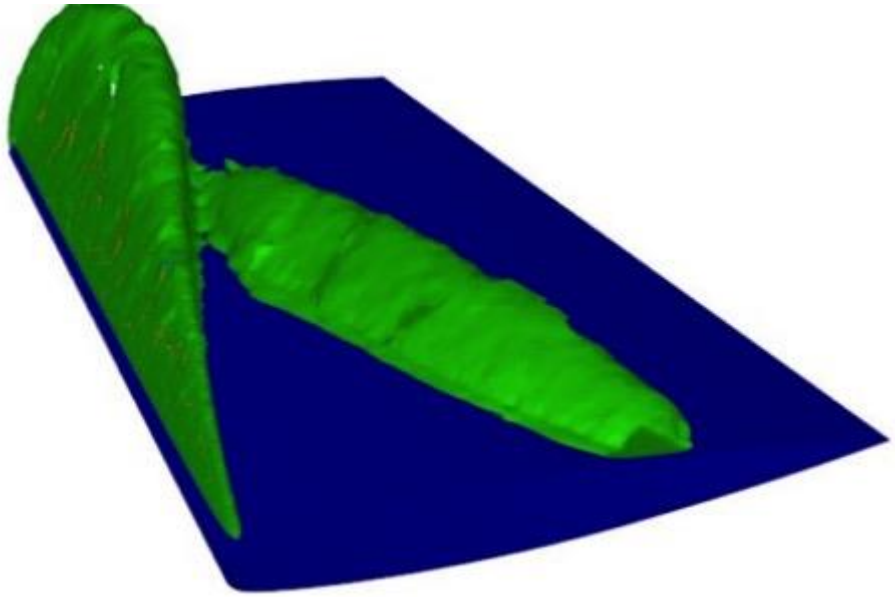


TURBULENT FLOW

Lambda Shock Formation

- All turbulence models (SA, SST and BSL-EARSM) were able to predict a lambda shock formation over the ONERA M6 wing upper surface
- Numerical results predict the shock merging location more inboard than experimental data

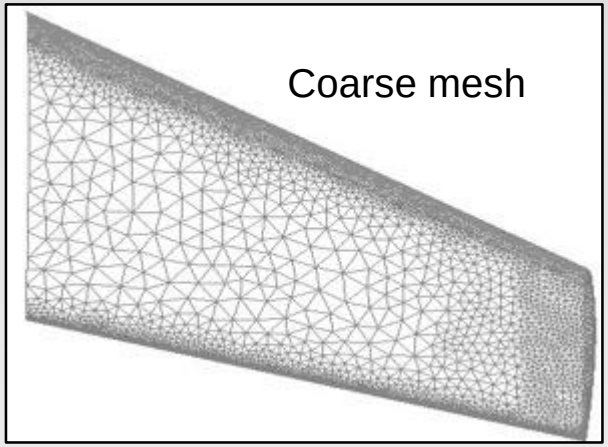


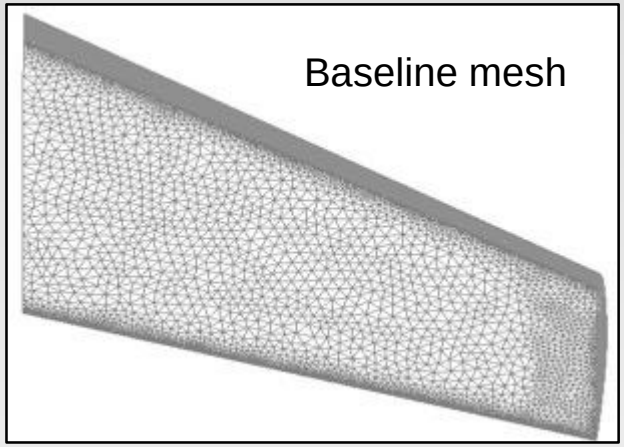


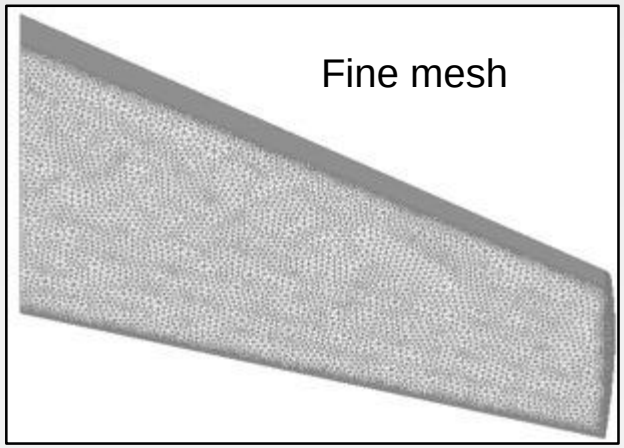
Flight conditions:
M = 0.84
AoA = 3.06 deg.
Re = 11.72 mi

Mesh Generation

- Surface mesh according to each mesh refinement level.

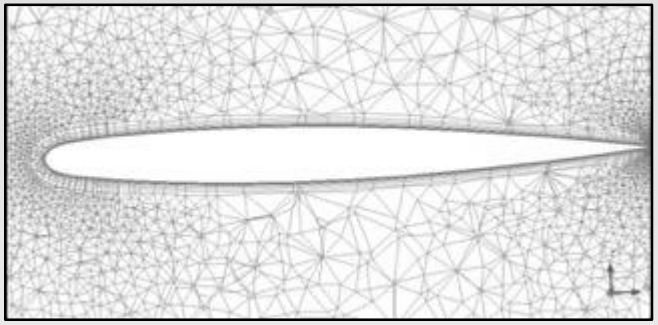




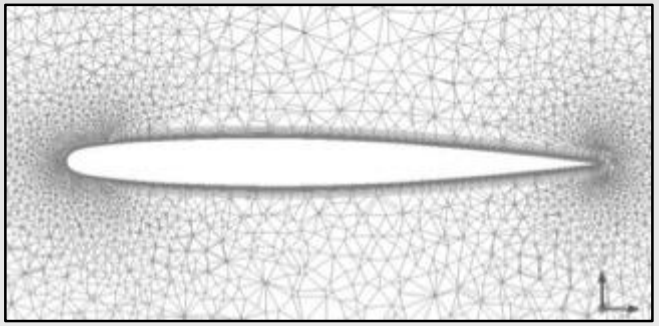


Mesh Generation

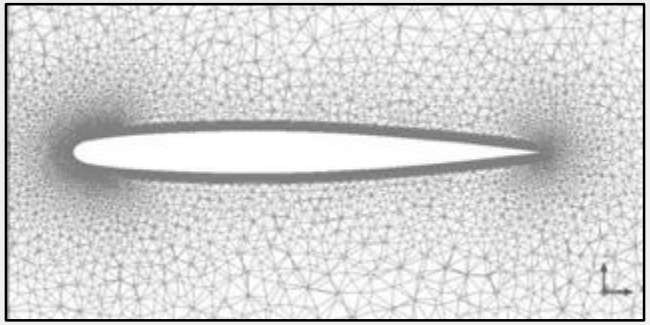
- Cut sections of the volumetric mesh located at the wing midspan position



Coarse mesh



Baseline mesh



Fine mesh

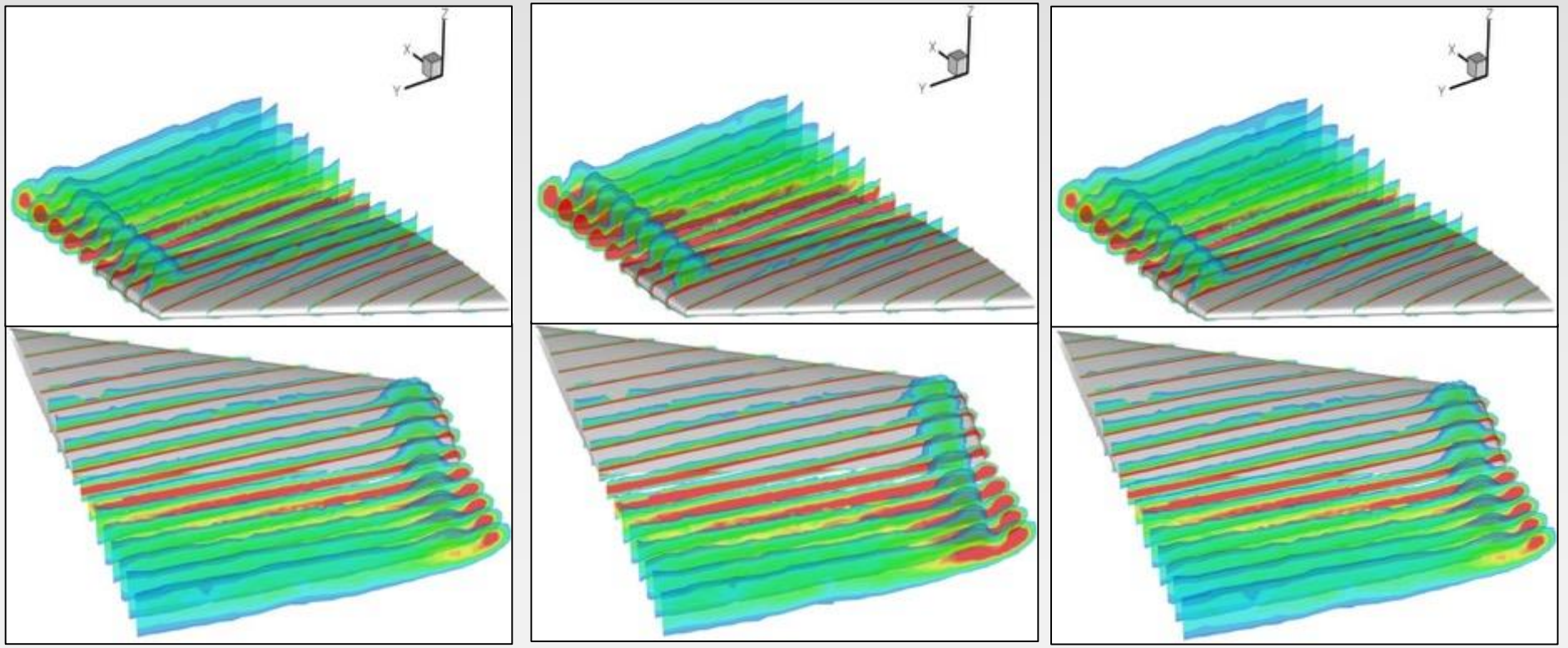
Wing Tip Vortex Visualization

Coarse Mesh

SA

SST

BSL-EARSM



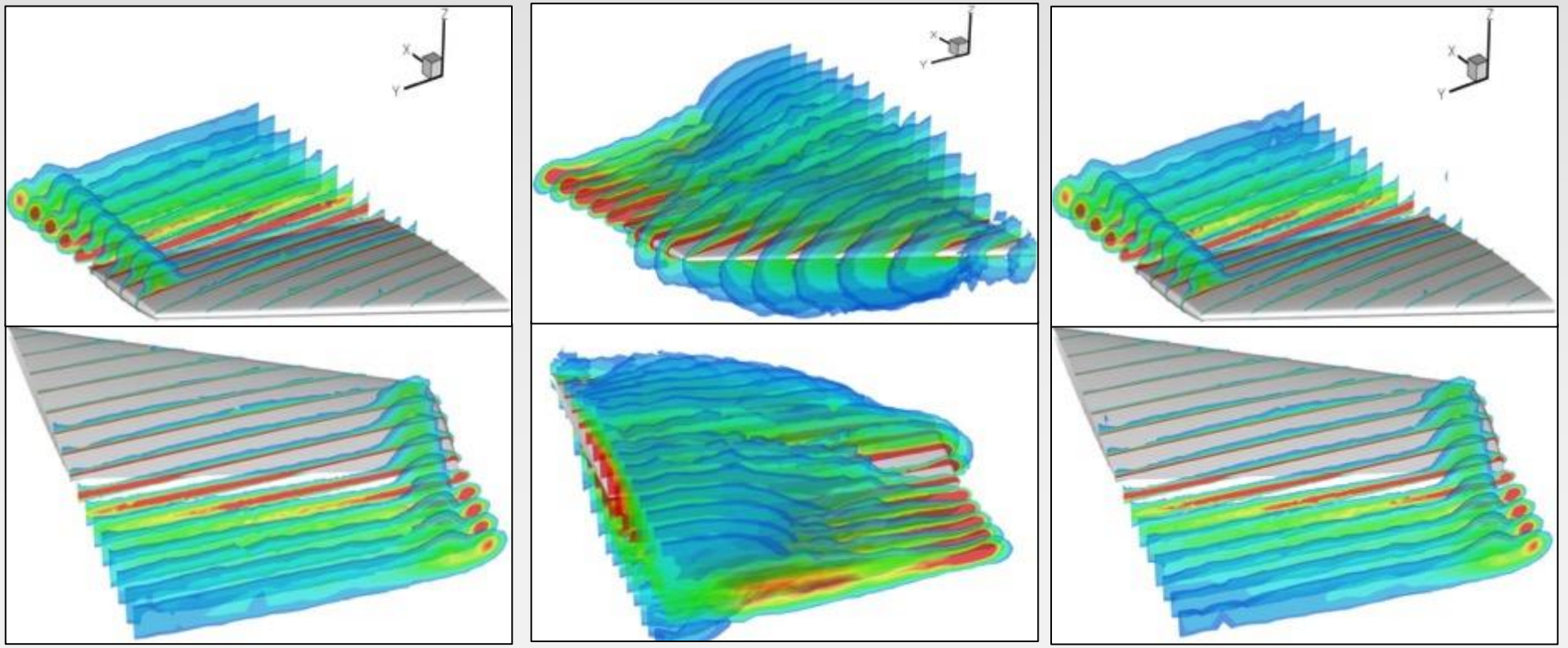
Wing Tip Vortex Visualization

Baseline Mesh

SA

SST

BSL-EARSM



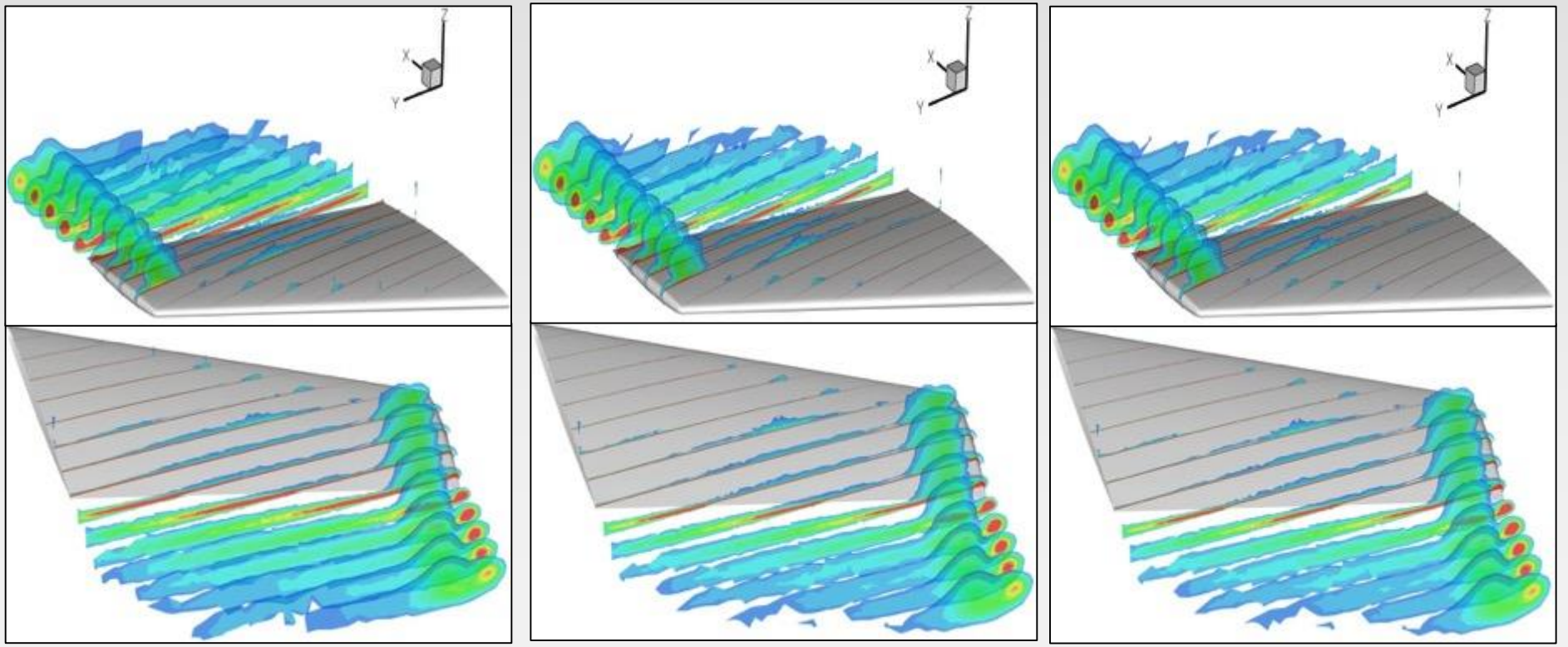
Wing Tip Vortex Visualization

Fine Mesh

SA

SST

BSL-EARSM



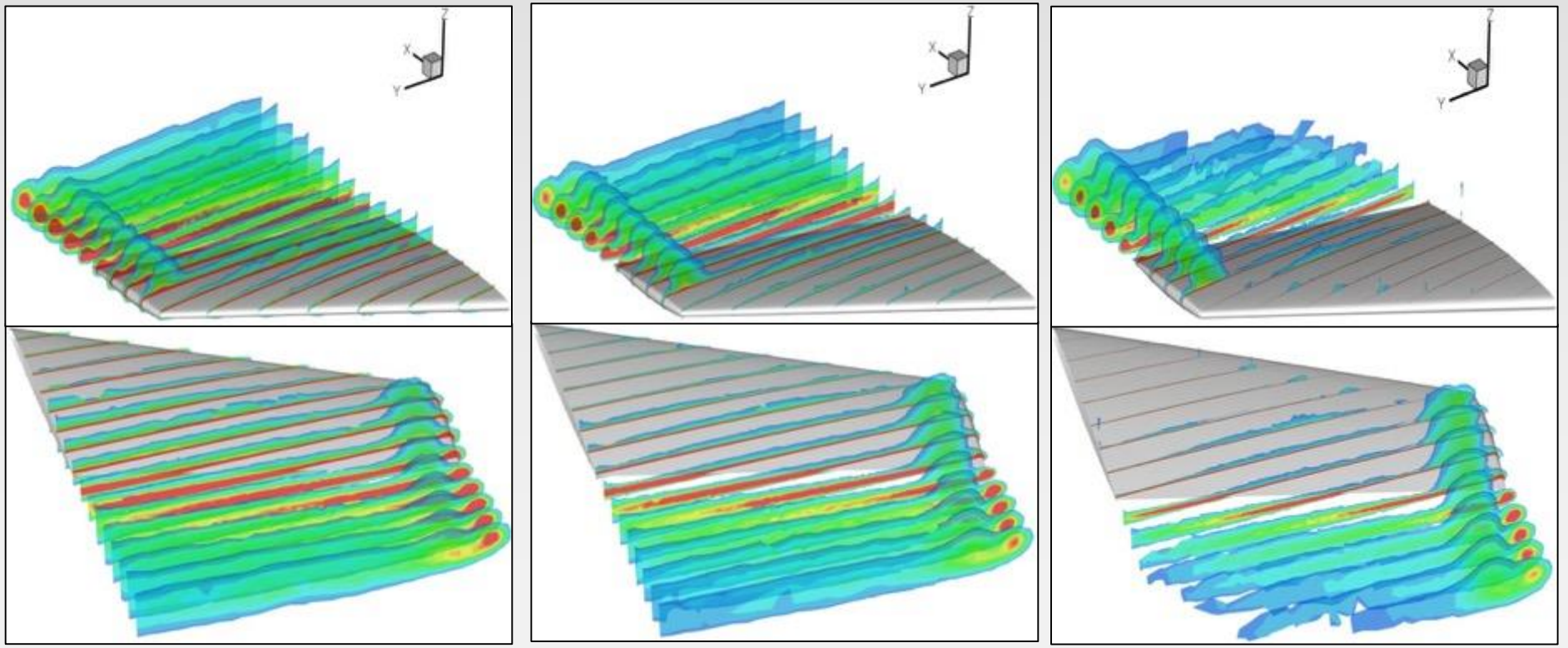
Wing Tip Vortex Visualization

SA Turbulence Model

Coarse Mesh

Baseline Mesh

Fine Mesh



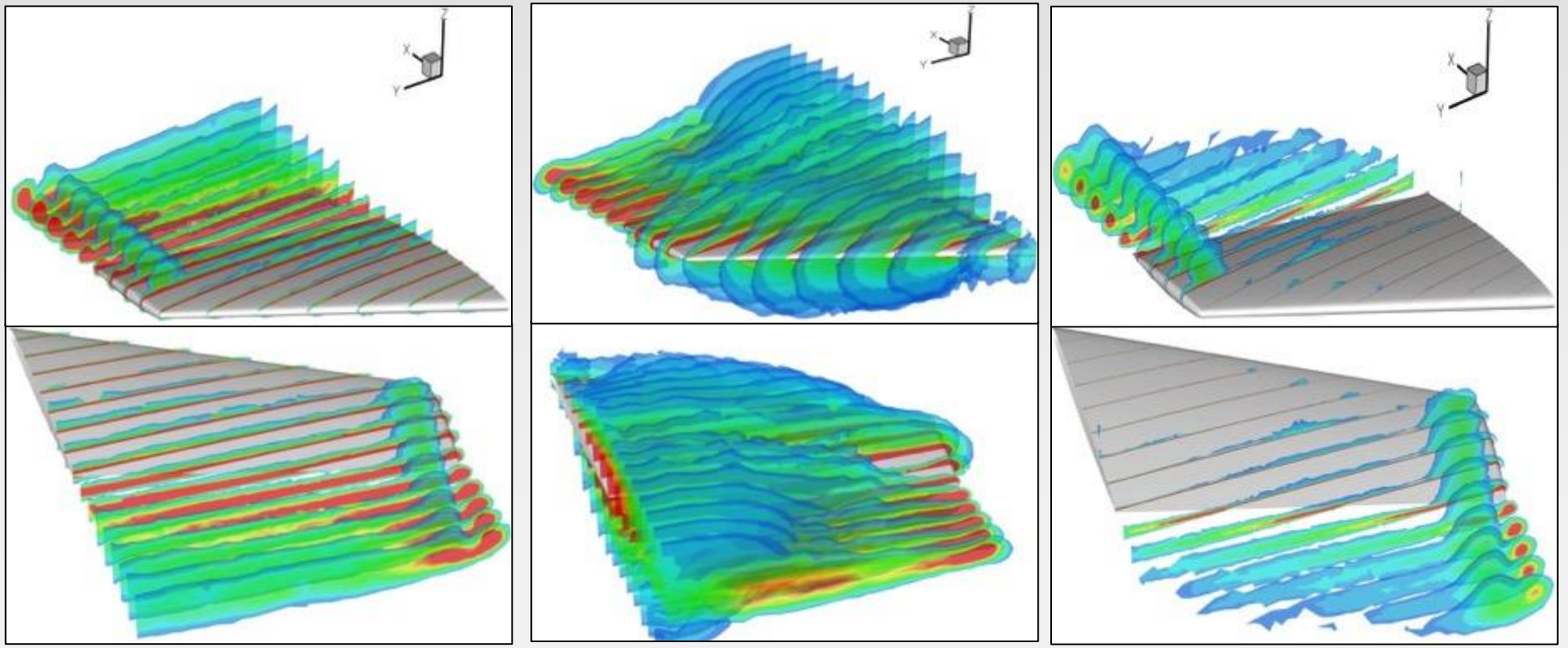
Wing Tip Vortex Visualization

SST Turbulence Model

Coarse Mesh

Baseline Mesh

Fine Mesh



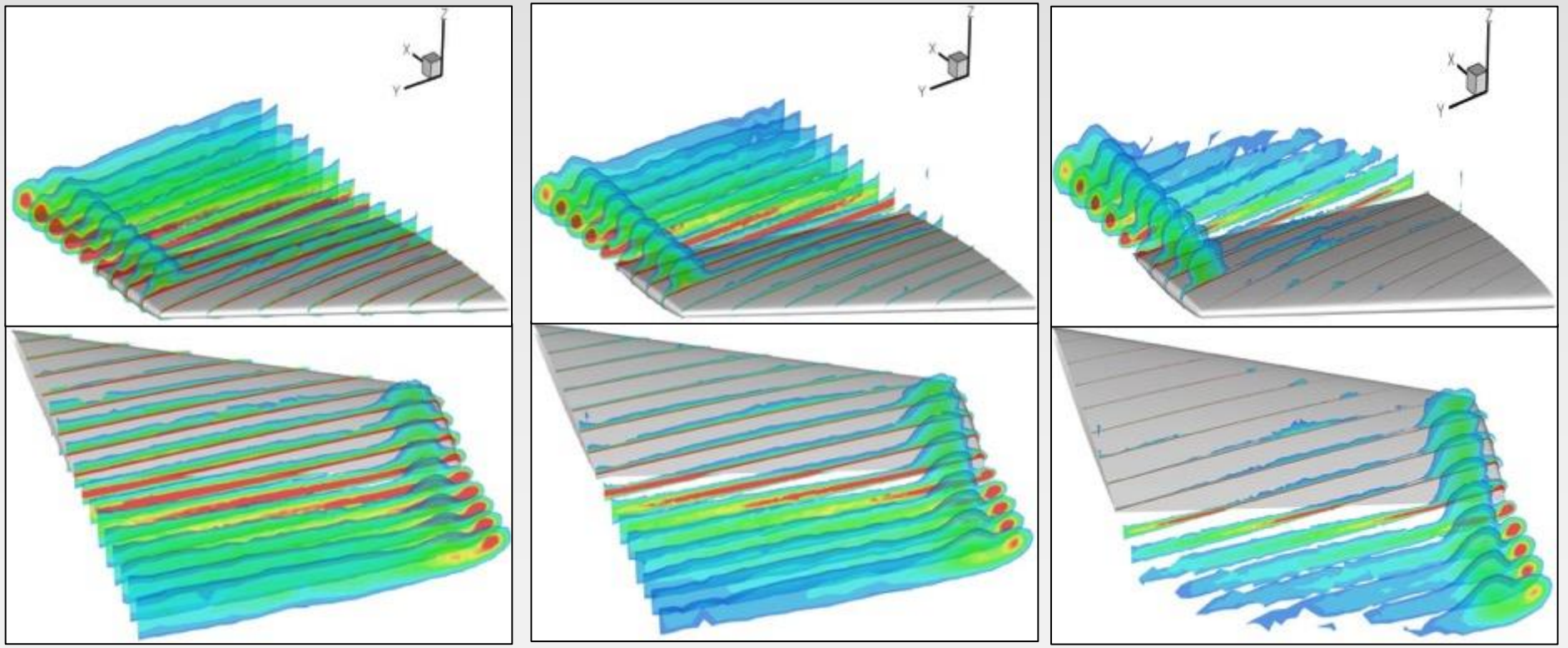
Wing Tip Vortex Visualization

BSL-EARSM Turbulence Model

Coarse Mesh

Baseline Mesh

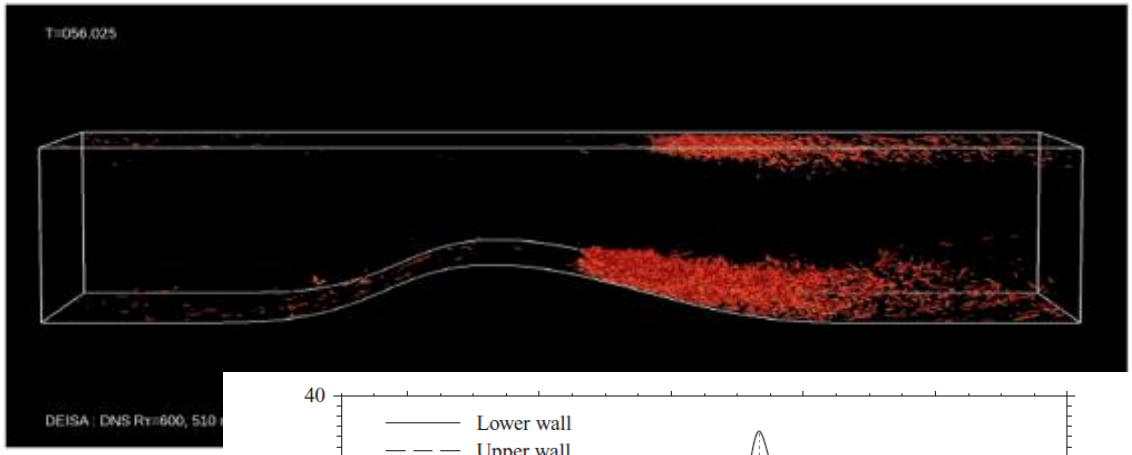
Fine Mesh

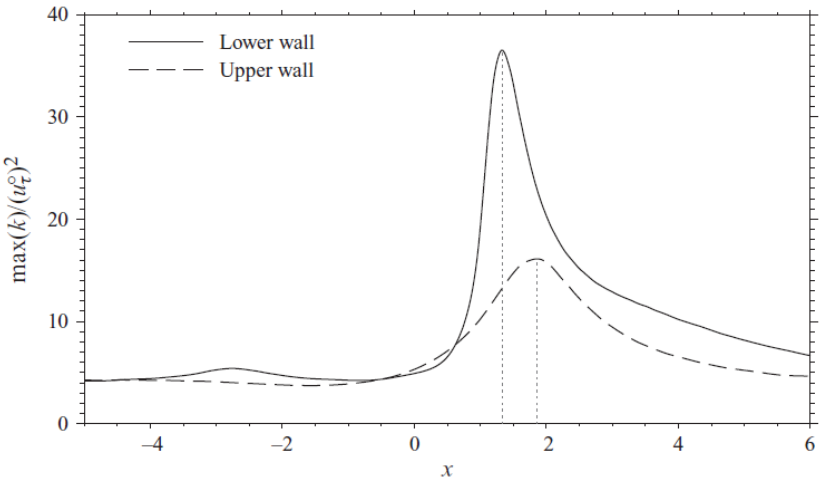


TURBULENT FLOW

Effects of Adverse Pressure Gradients

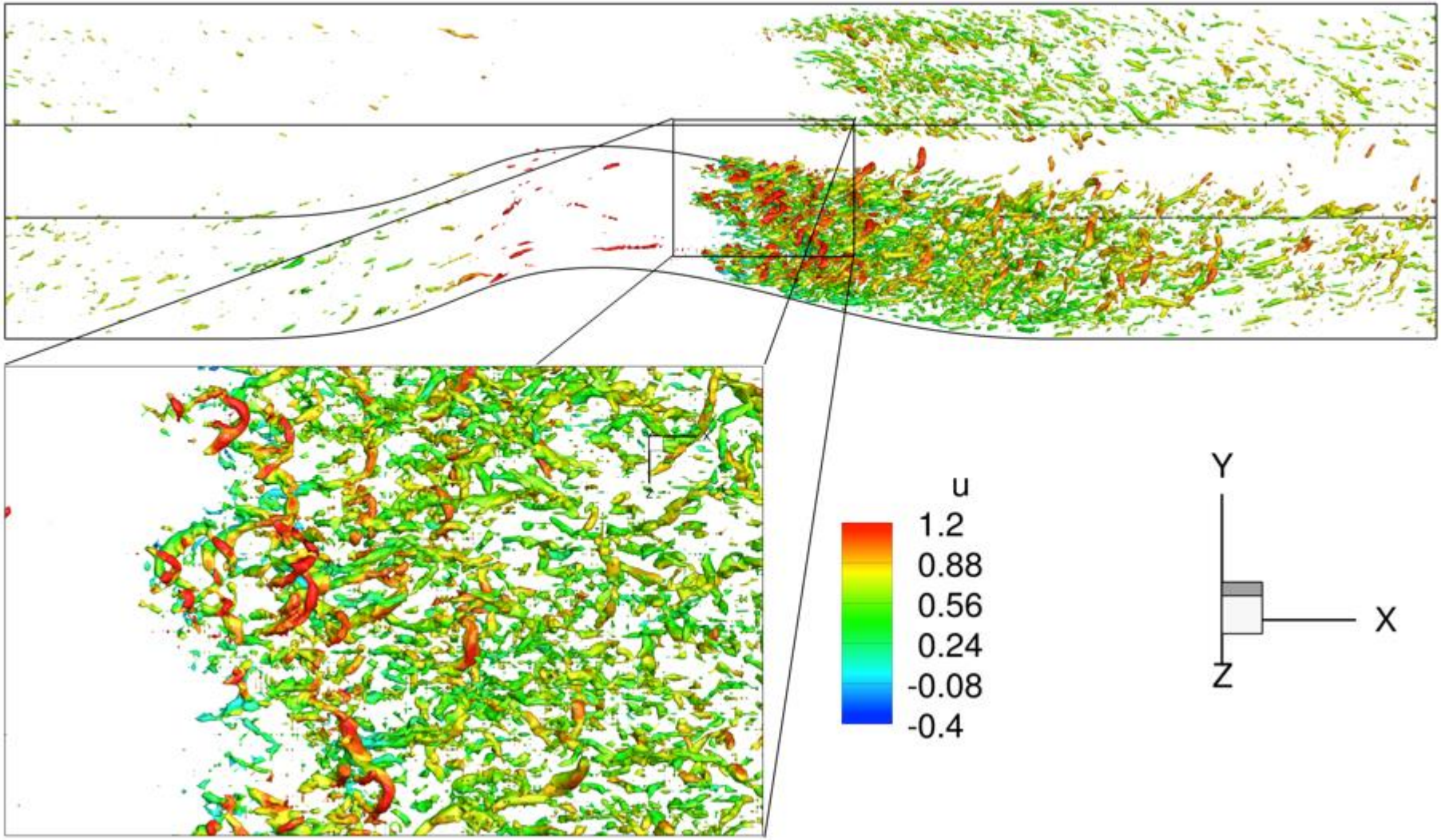
- Flow in a converging-diverging channel.
- New physical mechanism observed in APG regions
- Separation and reattachment points studied
- Streak instability (or streak bursting)





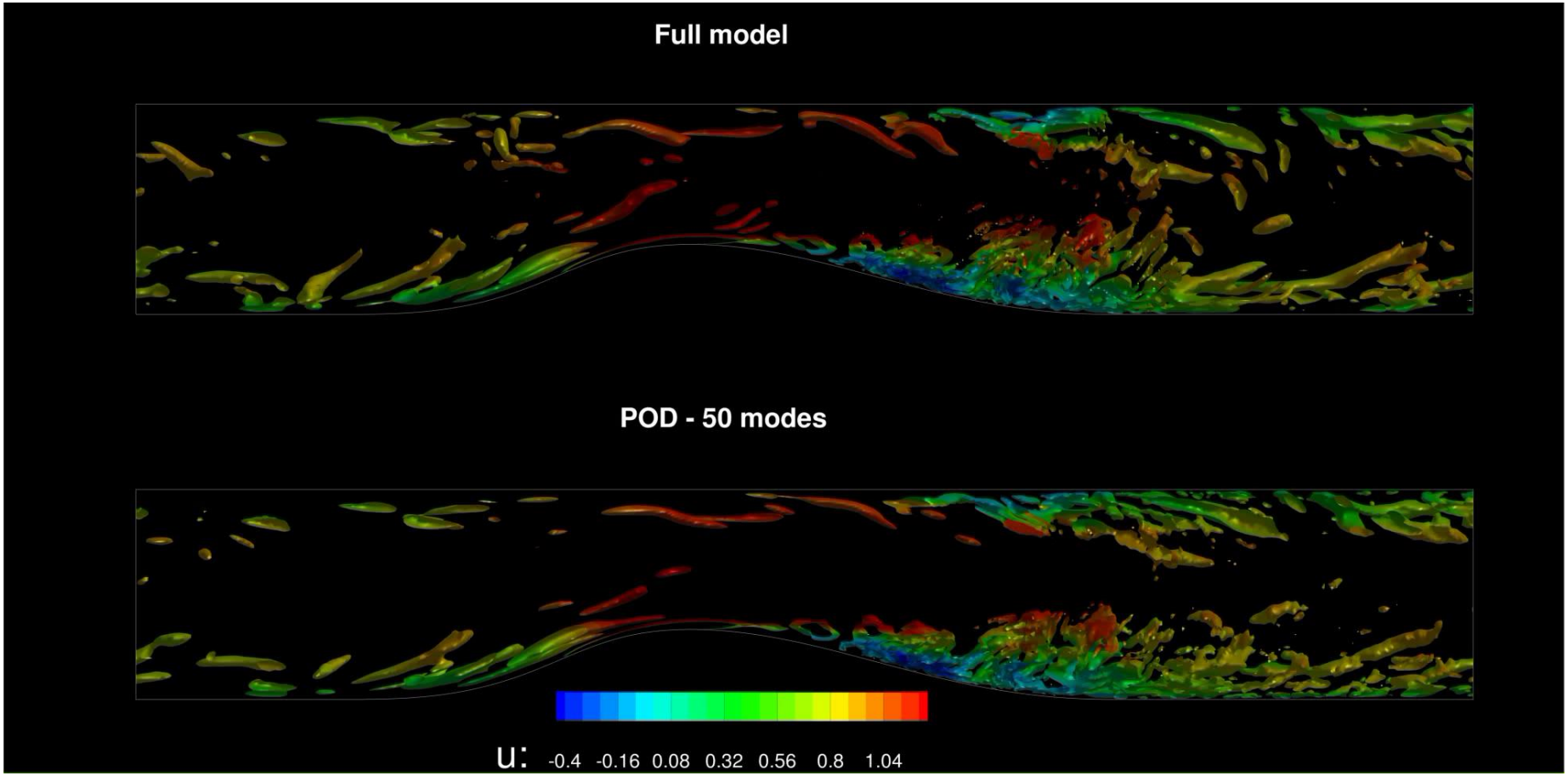
TURBULENT FLOW

Effects of Adverse Pressure Gradients



TURBULENT FLOW

Effects of Adverse Pressure Gradients
(need for reduced order models due to size of files involved)



CONCLUDING REMARKS

- I hope that this brief overview of part of our work was able to give some idea of the research/development performed.
- Recently, areas of turbulence modeling, either RANS or LES formulations, and high-order methods have been the most active ones.
- A great deal of the work here described is performed under a FAPESP RIDC project (center): CeMEAI (Center for Industrial Mathematics Applications).
- The availability of the computational resources at the CeMEAI RIDC is absolutely essential for our work.

THANK YOU