High Lift Prediction Workshop – 2

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Objectives

- Study grid convergence and Reynolds number effect
- Compare adaptive refinement to manual refinement

Outline

- Introduction to solver and adaptivity
- Results
  - Case 1
  - Case 2a and 2b
- Future work

Flow Solver

- PHASTA (Parallel Hierarchic Adaptive Stabilized Transient Analysis)
- Uses piecewise linear finite elements
- Can solve incompressible and compressible Navier-Stokes equations
- Turbulence models supported: RANS-SA, DES, LES
- Generalized-α implicit time integrator
- GMRES linear algebra solver
- Block diagonal pre-conditioner
- Highly scalable. Shown to scale up to 3M MPI processes for a 92 billion tetrahedral element mesh for a rudder geometry

Adaptivity

- Anisotropic adaptivity using Hessians of flow solution variables
- Ability to adapt boundary layers except in the thickness direction
- Simmetrix Inc.'s mesh adaptation software used
- Developed a combined approach to use PDE residuals for smallest mesh spacing and Hessians for relative scales and directions
- One adaptivity pass was achieved on an extra coarse mesh to get comparable mesh size to the coarse mesh

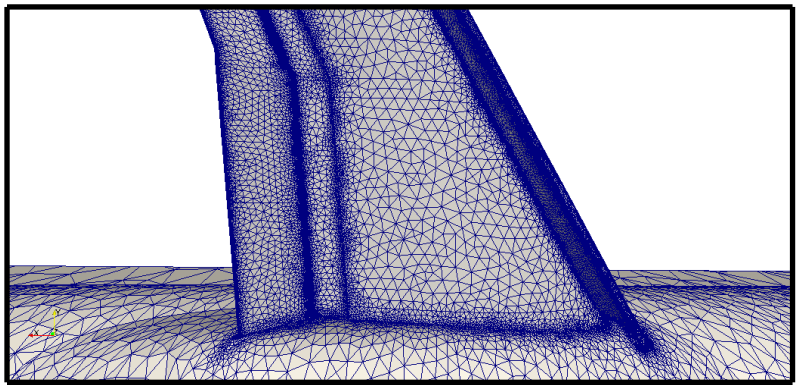
Case 1: Description

- Angles of attack: 7º and 16º
- Meshes:
  - Created using gridding guidelines given online
  - Unstructured, with mixed element boundary layers
  - Created in-house using MeshSim software by Simmetrix Inc.
- Mesh statistics:

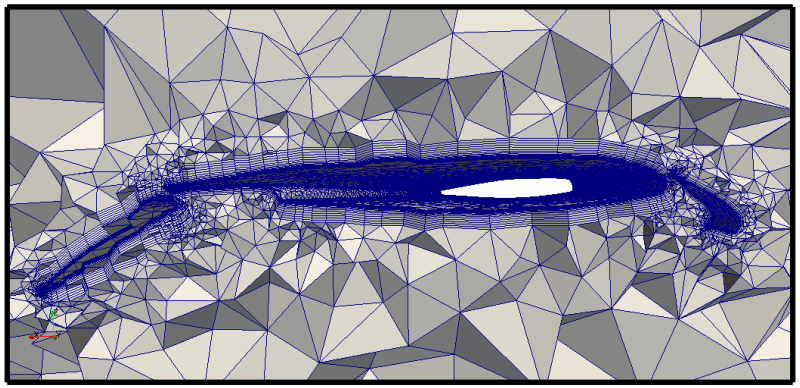
Meshes	# elements	# nodes
Coarse	32.2M	13.5M
Medium	91.5M	37.3M
Fine	288M	113M
Adapted (7º)	40M	14M
Adapted (16º)	35M	12M

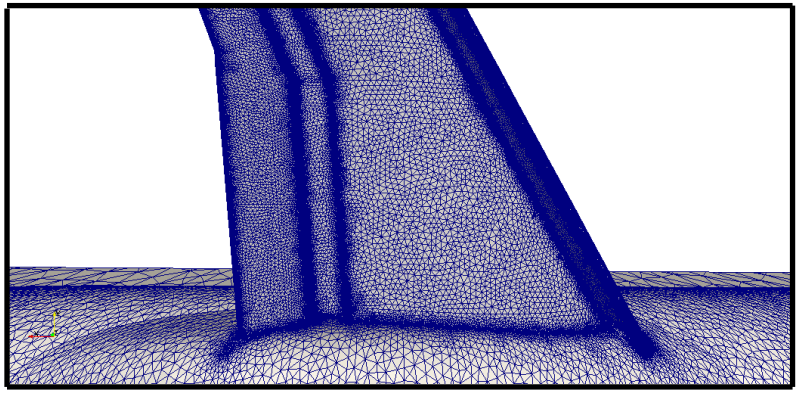
- Solved on 1k - 64k MPI processes on Janus supercomputer and Mira (BG/Q)

Case 1: Meshes



Coarse





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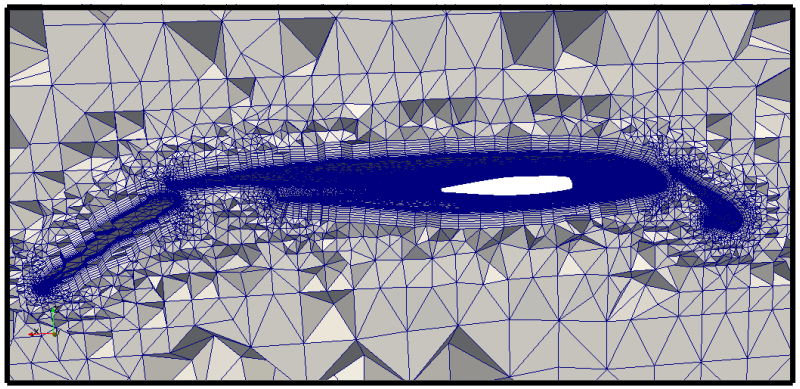
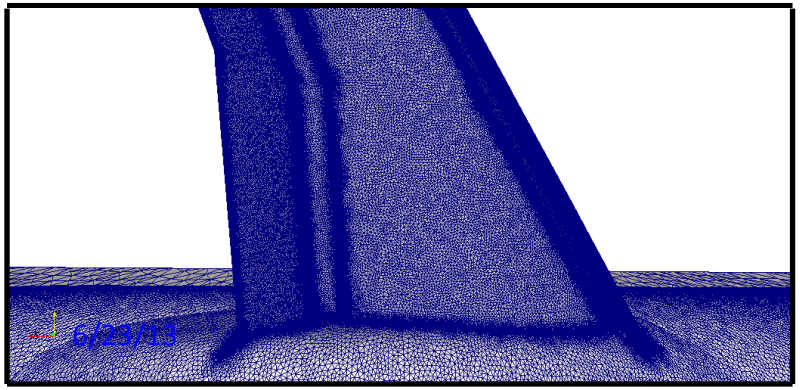
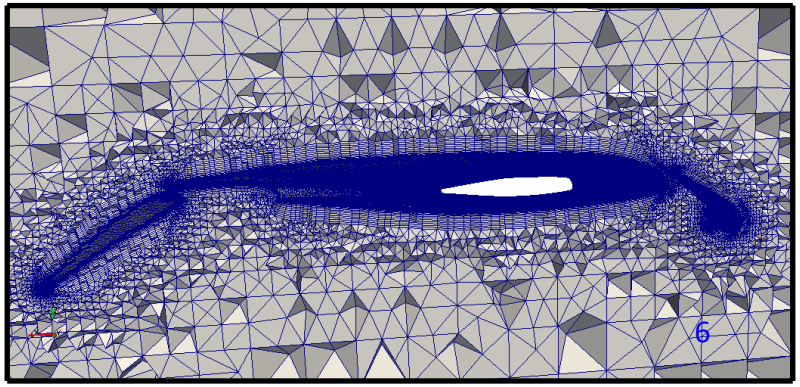
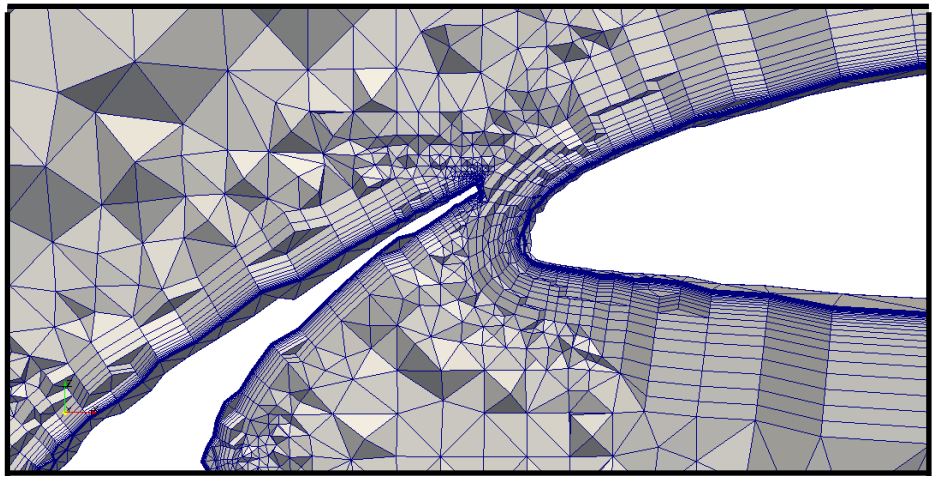


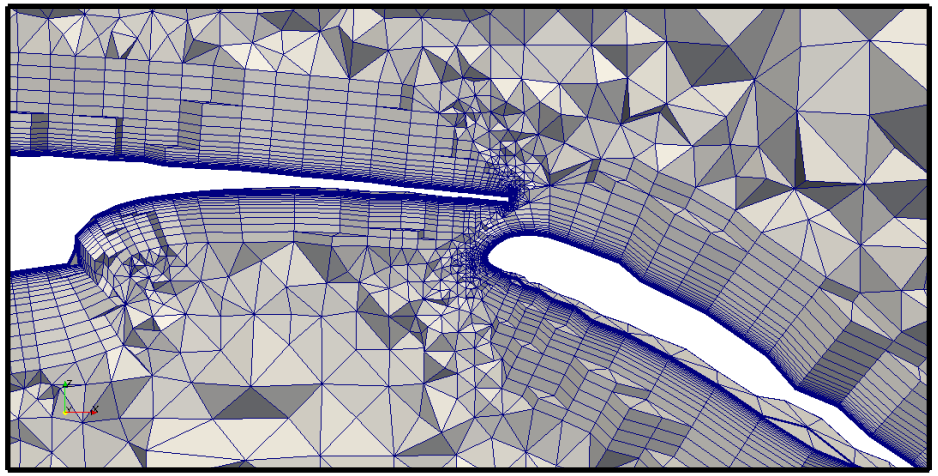


Fine

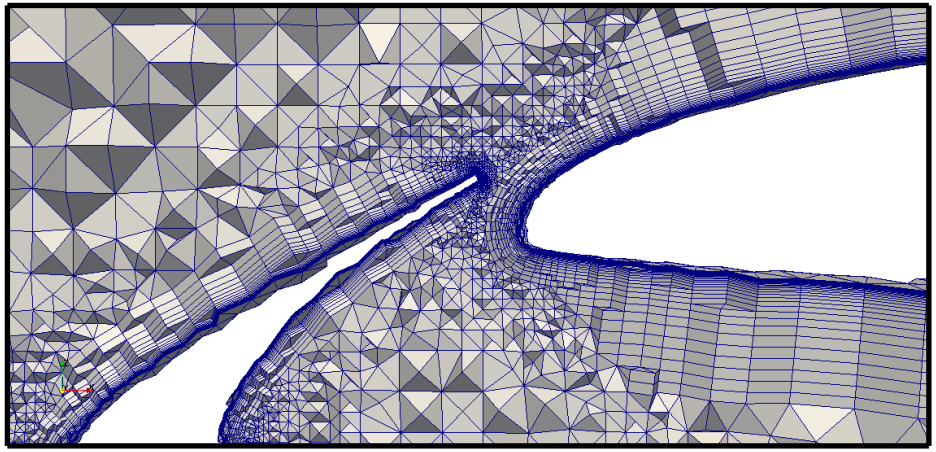


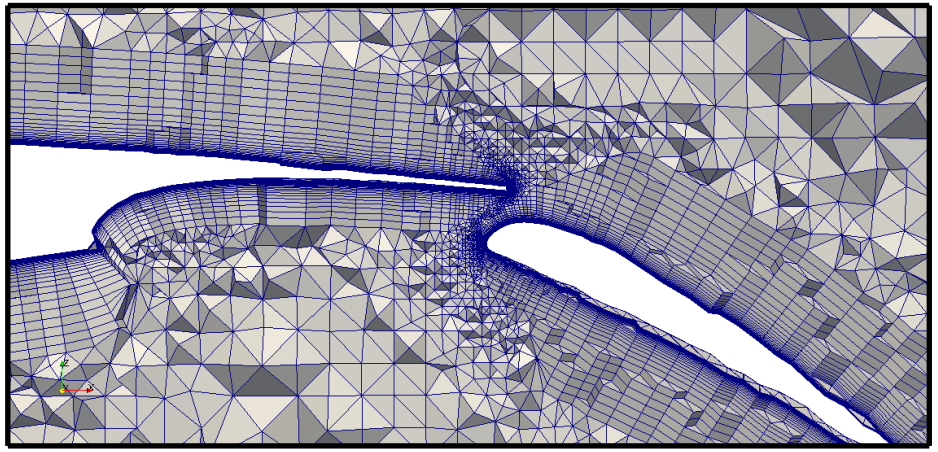
Case 1: Meshes





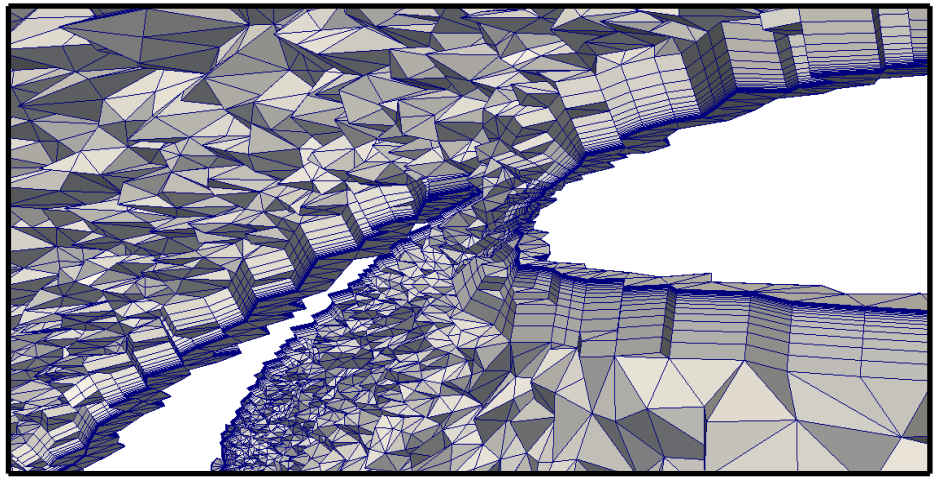
Zooms of the medium mesh

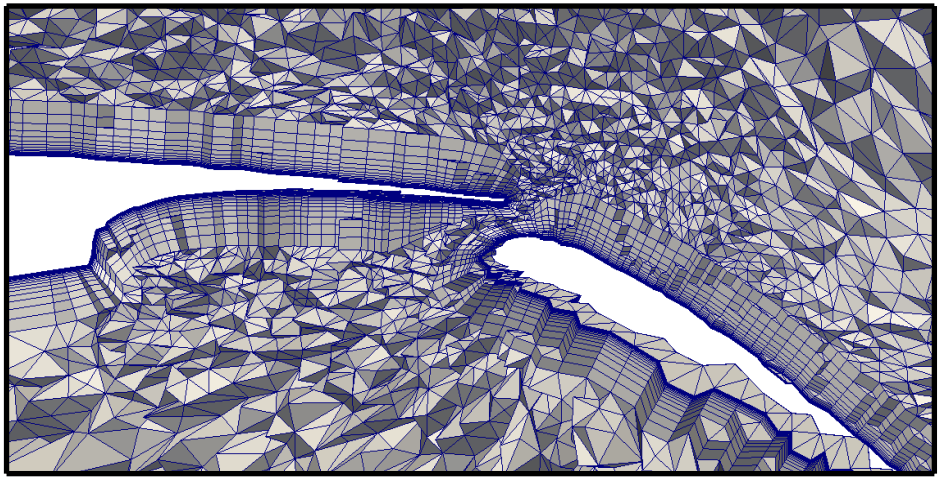




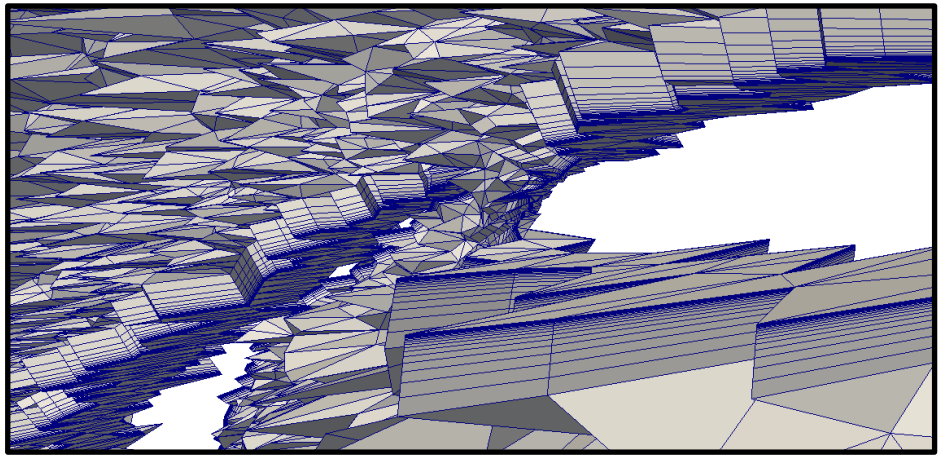
Zooms of the fine mesh

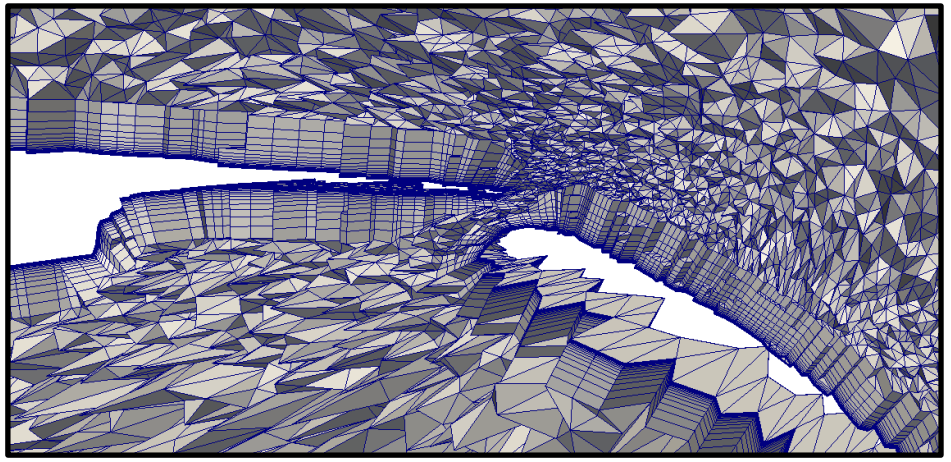
Case 1: Meshes





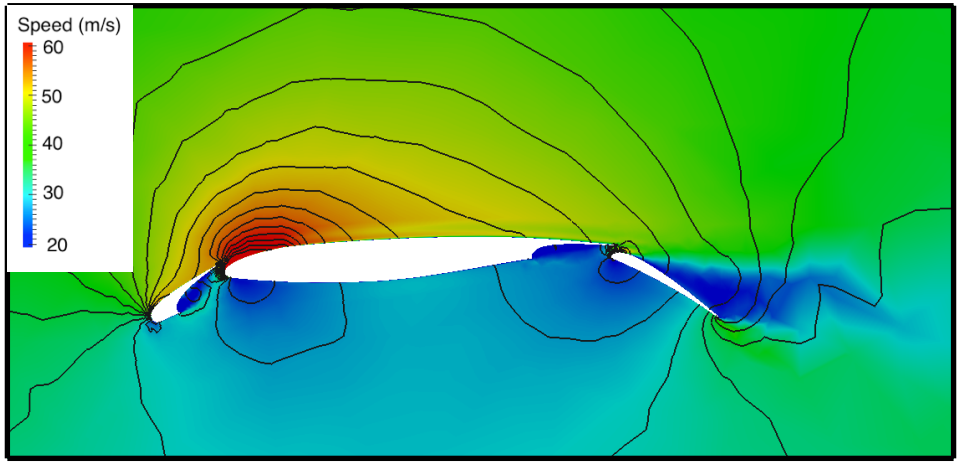
Zooms of the adapted mesh (7º)

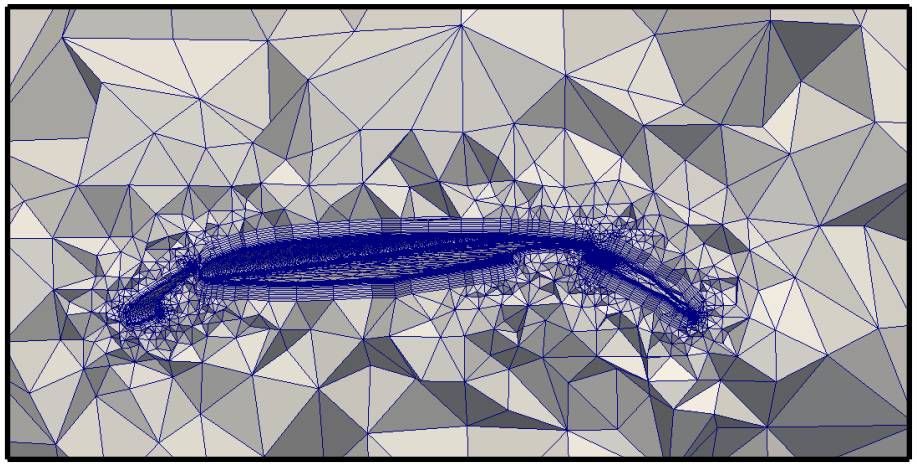




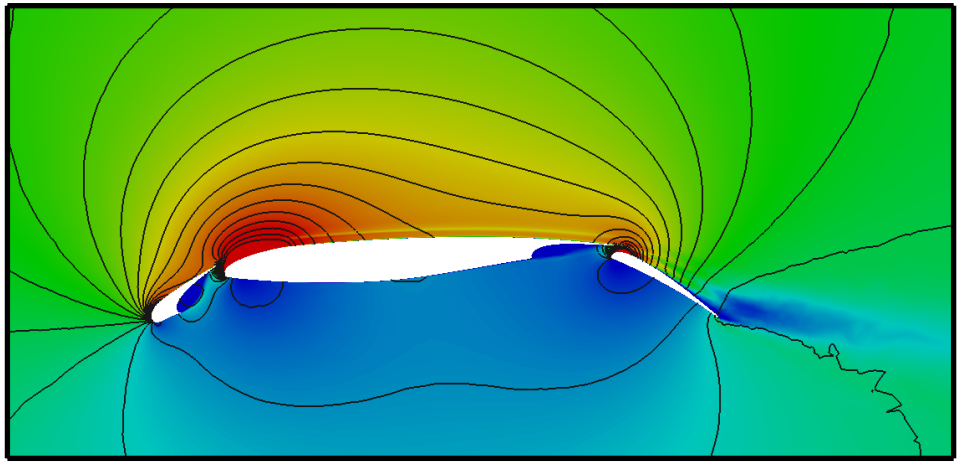
Zooms of the adapted mesh (16º)

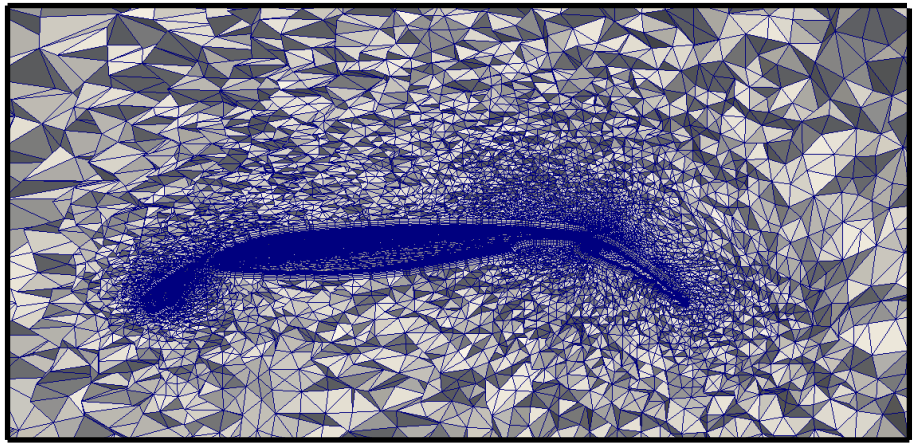
Case 1: Speed and Meshes





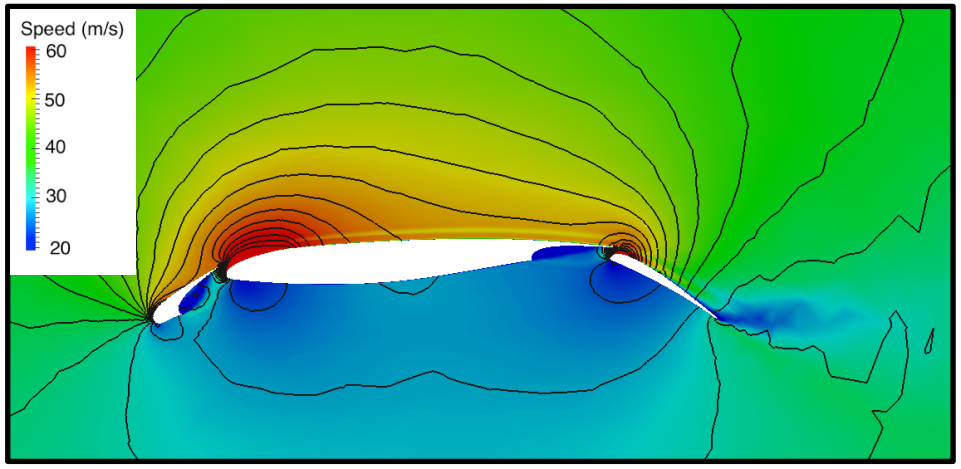
Coarse mesh

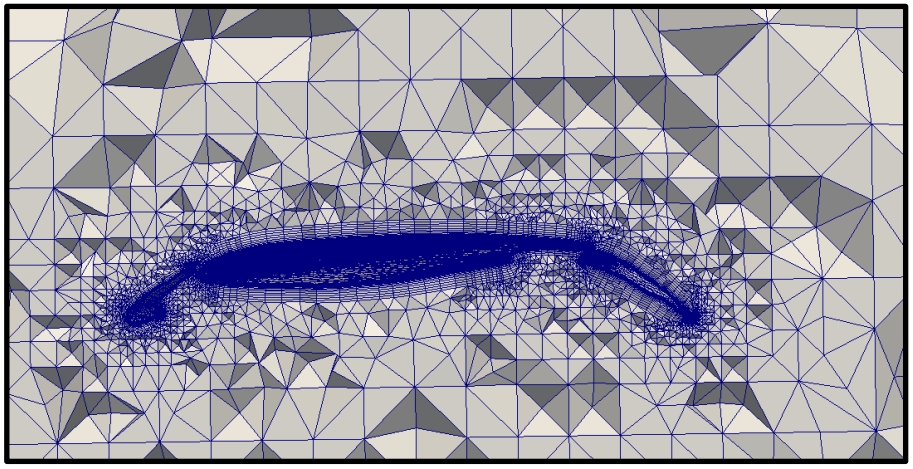




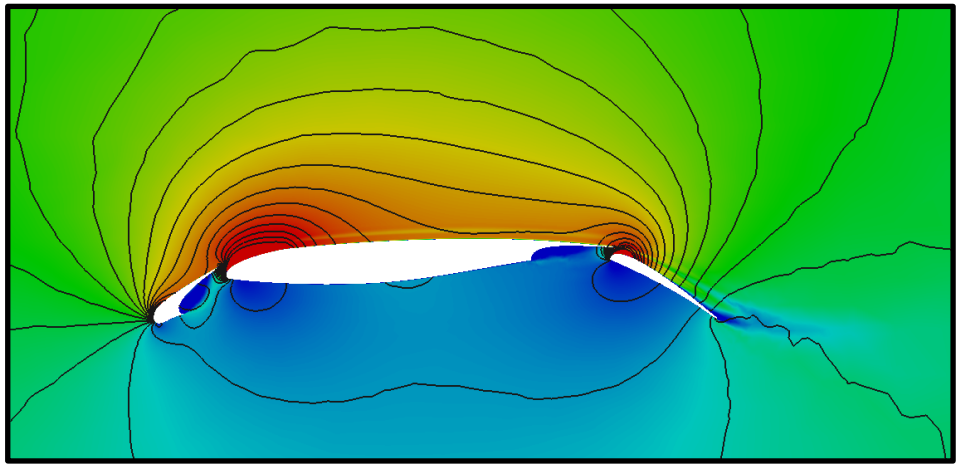
Adapted mesh

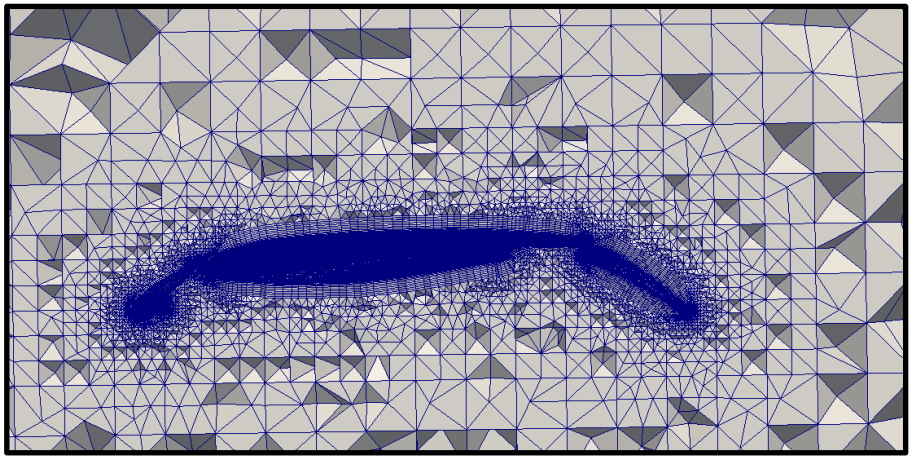
Case 1: Speed and Meshes





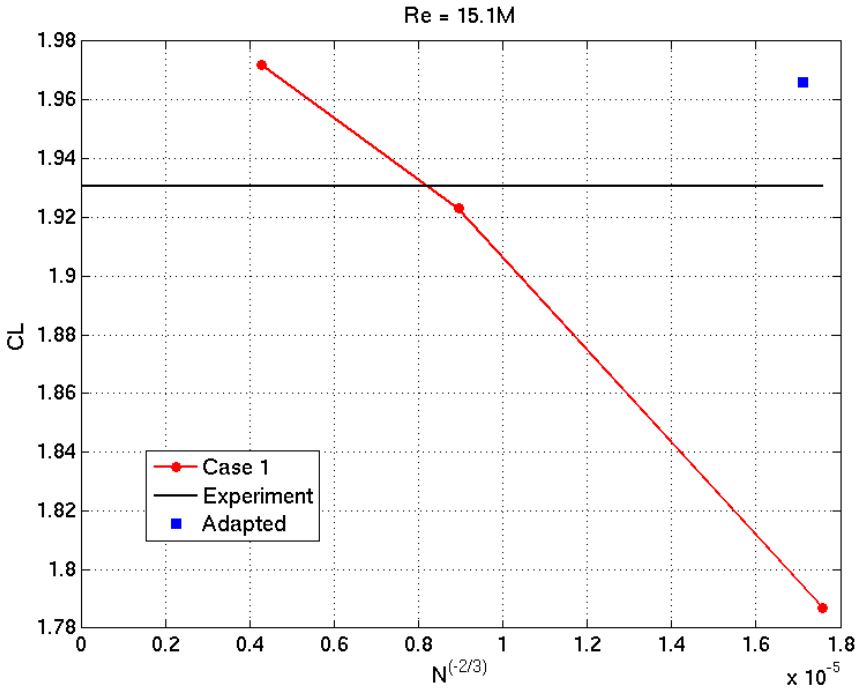
Medium mesh

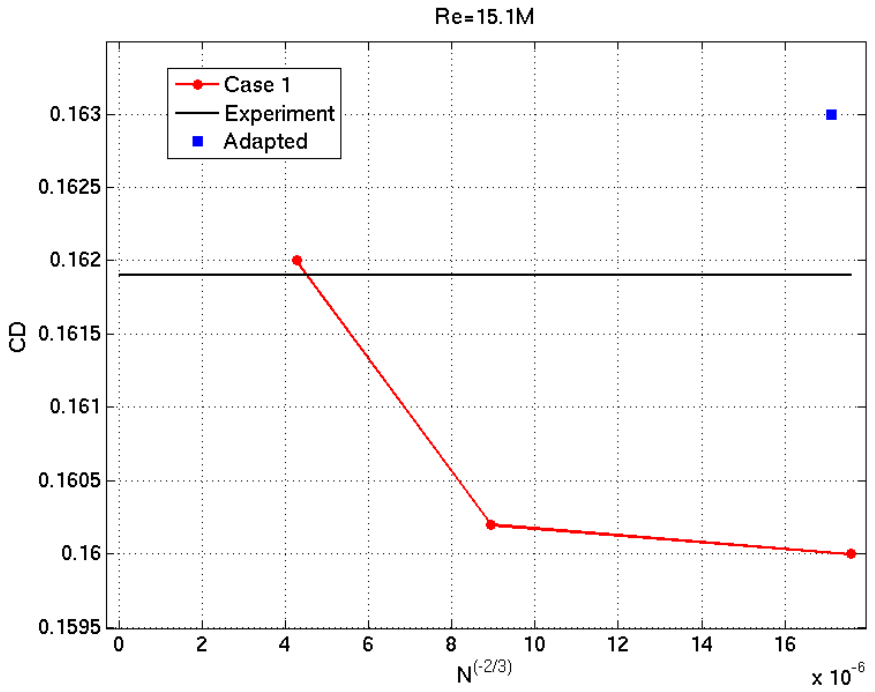




Fine mesh

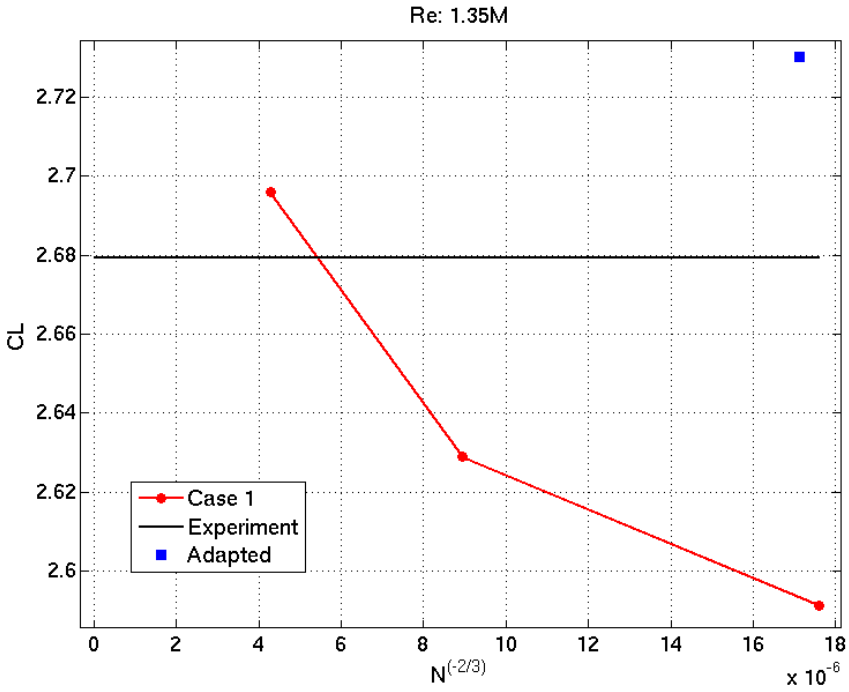
Case 1: Grid Convergence

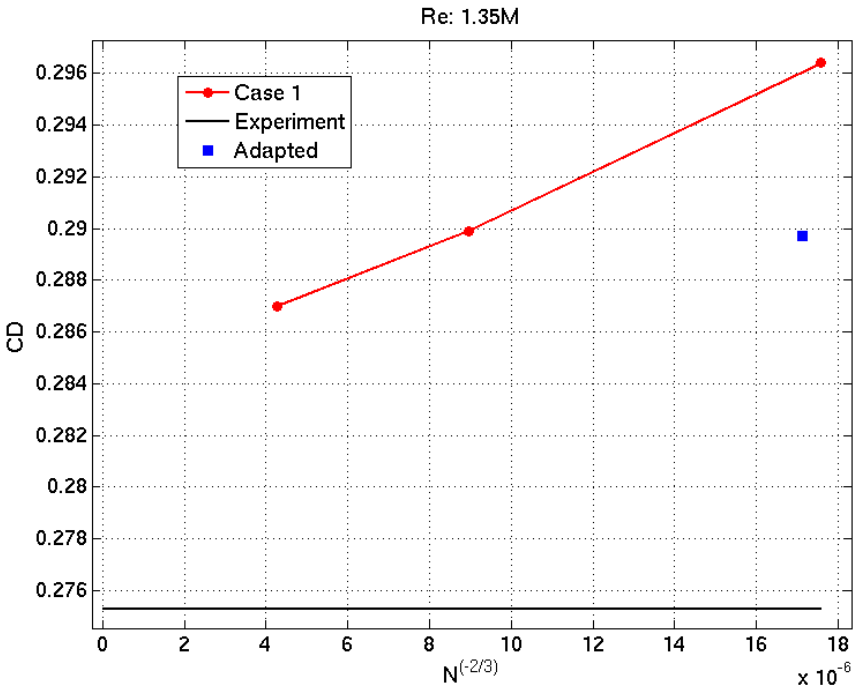




AoA = 7º

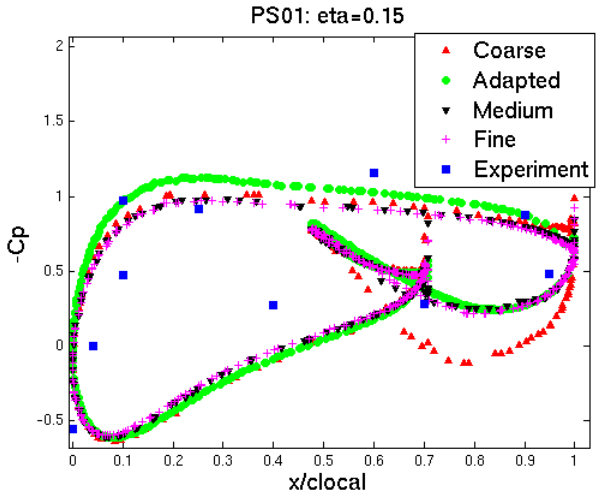
Case 1: Grid Convergence

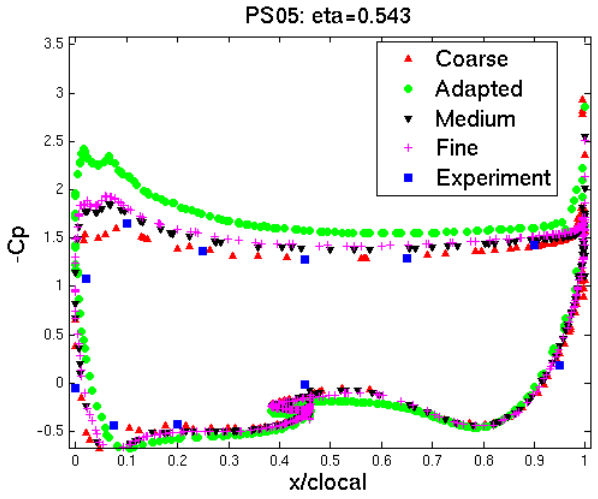


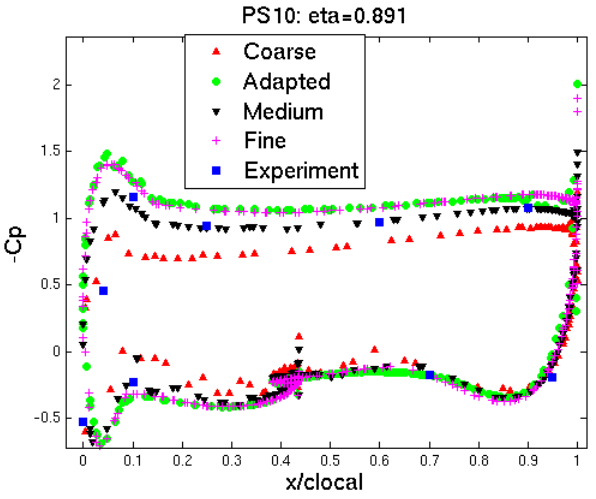


AoA = 16º

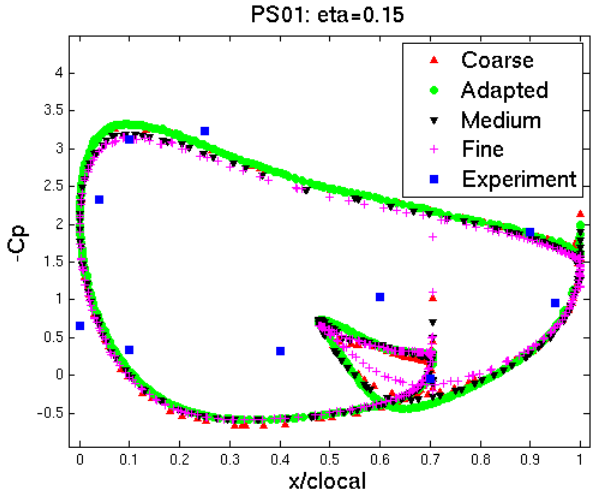
Case 1: C_p Plots

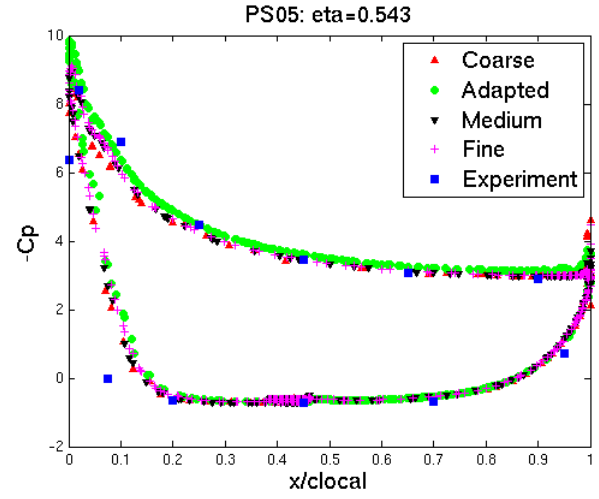


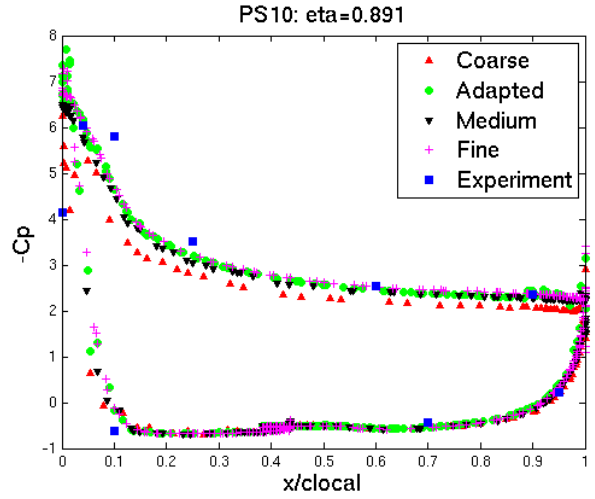




AoA = 7º (Slat element)

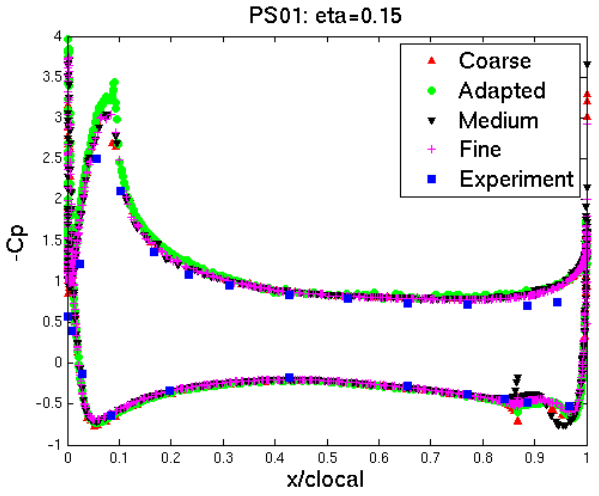


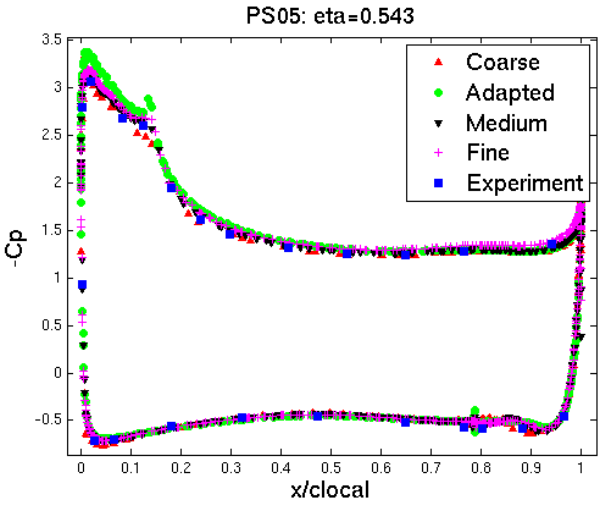


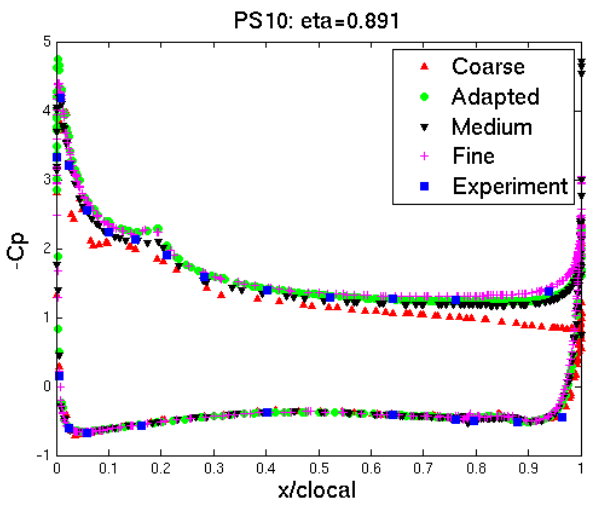


AoA = 16º (Slat element)

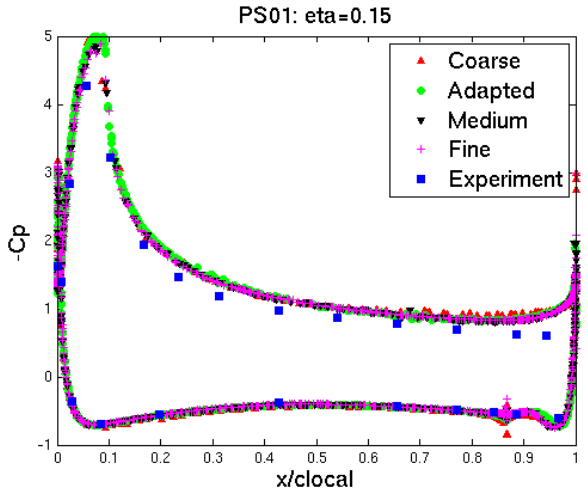
Case 1: C_p Plots

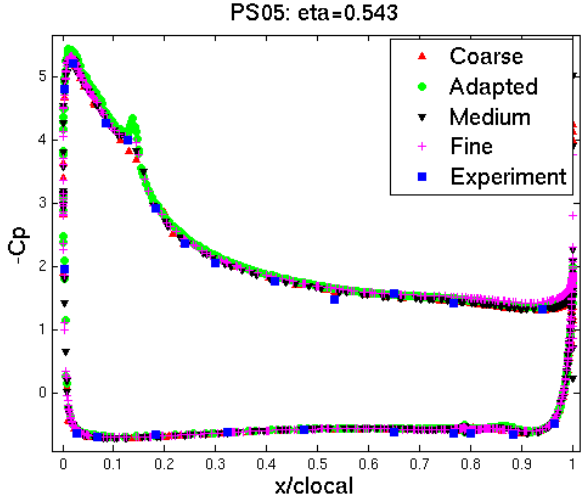


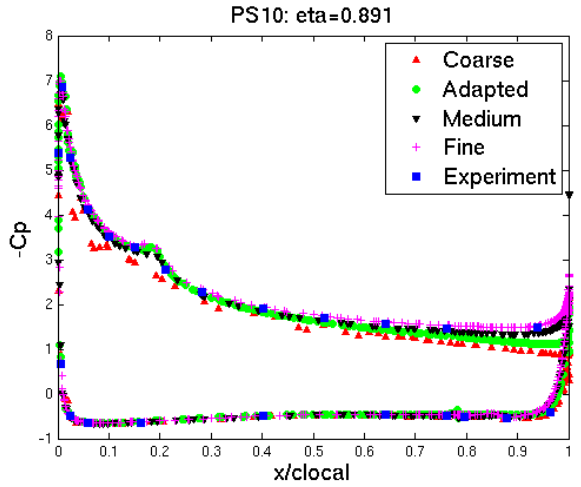




AoA = 7° (Main wing)

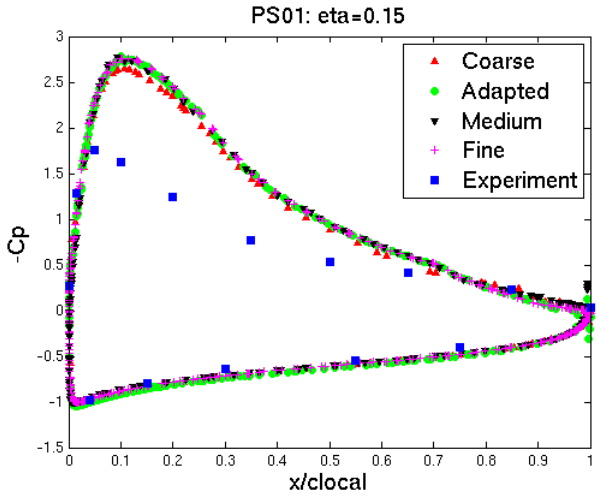


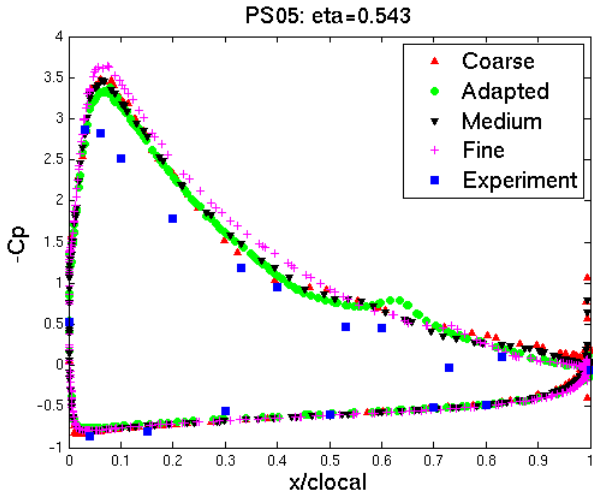


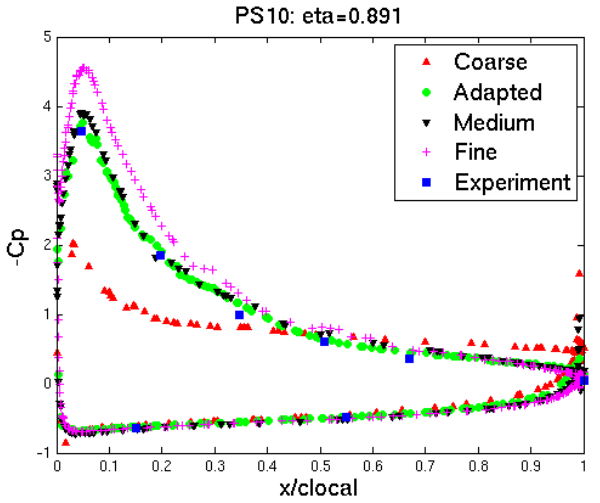


AoA = 16° (Main wing)

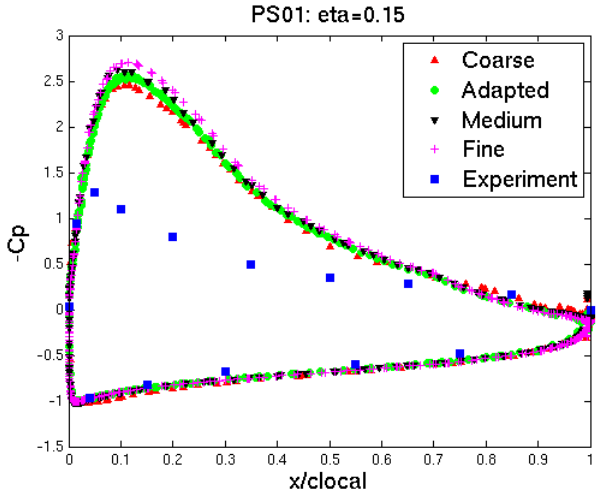
Case 1: C_p Plots

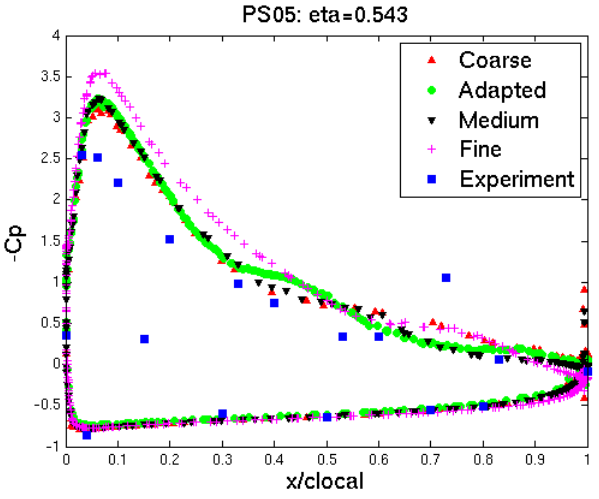


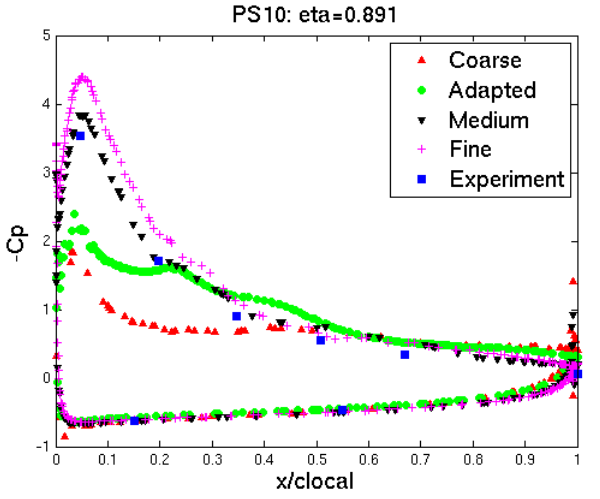




AoA = 7º (Flap element)

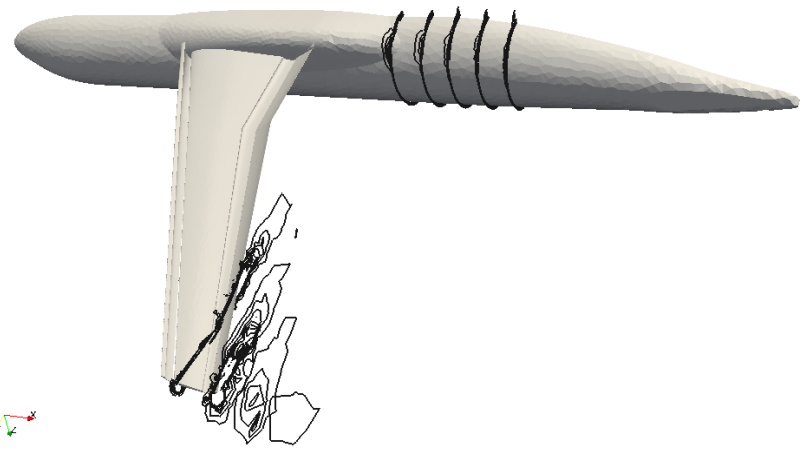




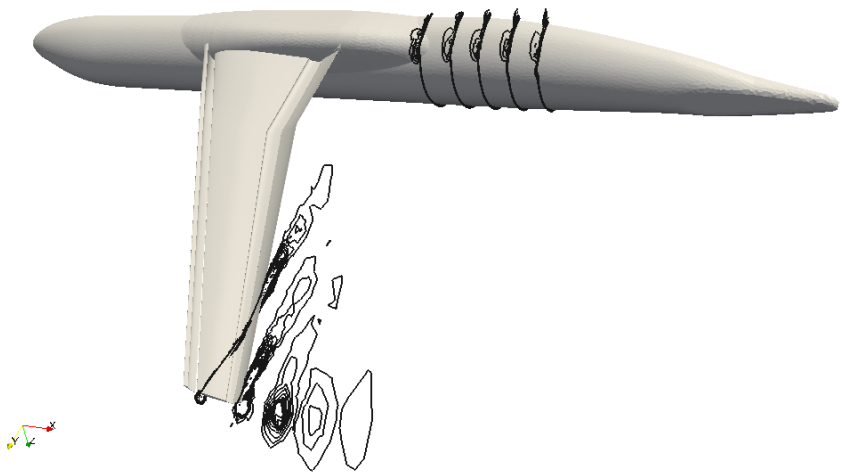


AoA = 16º (Flap element)

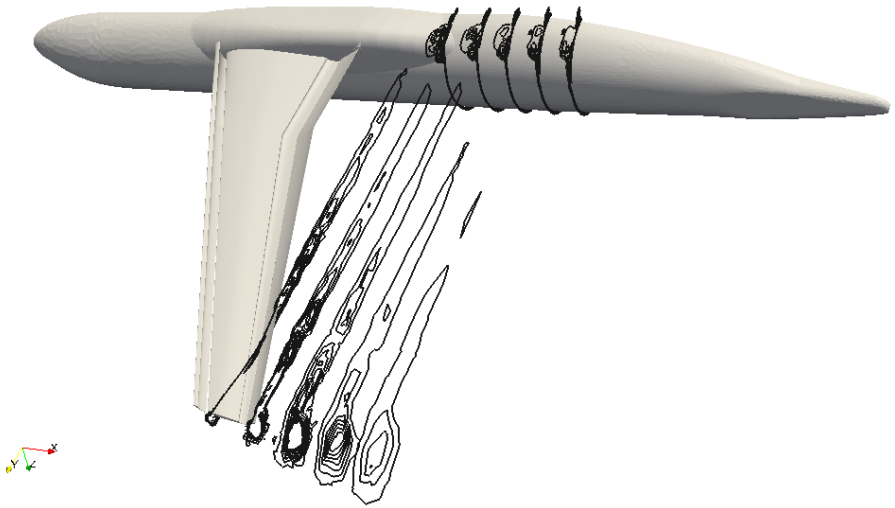
Case 1: Vorticity Contours



Coarse



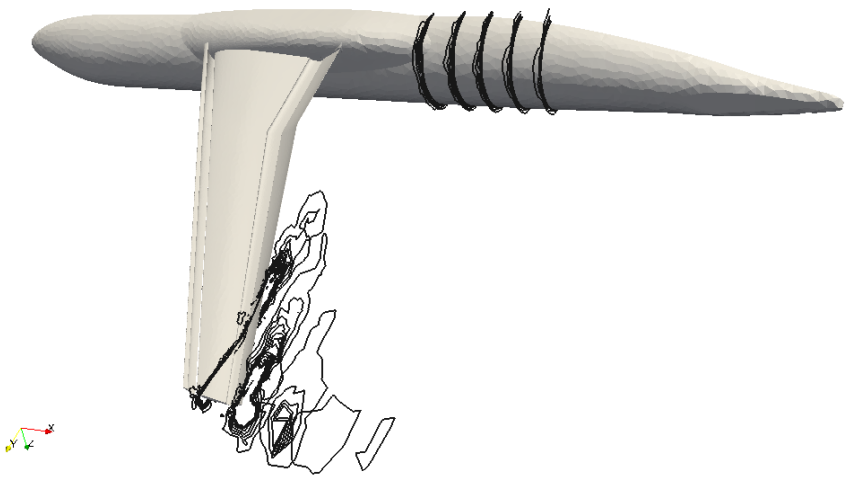
Medium



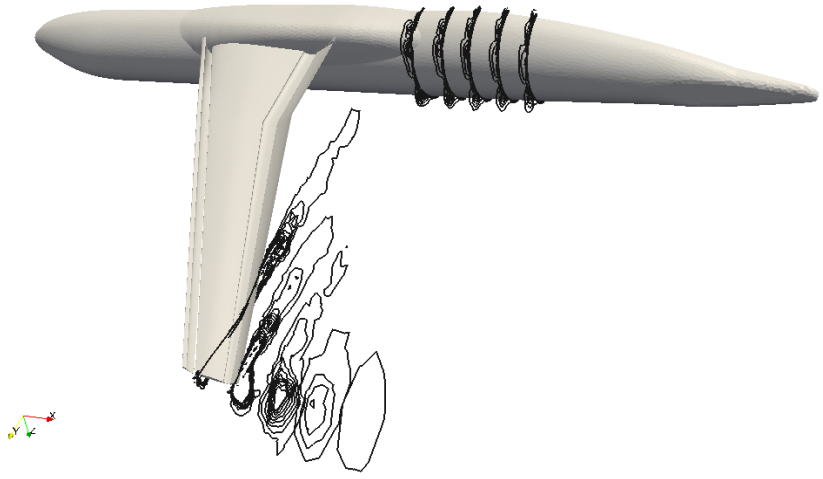
Adapted

AoA = 7°: vorticity contours on X planes

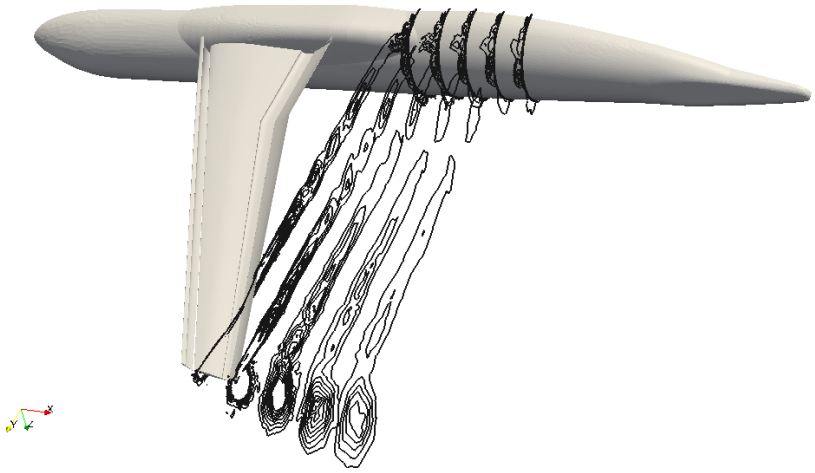
Case 1: Vorticity Contours



Coarse



Medium



Adapted

AoA = 16°: vorticity contours on X planes

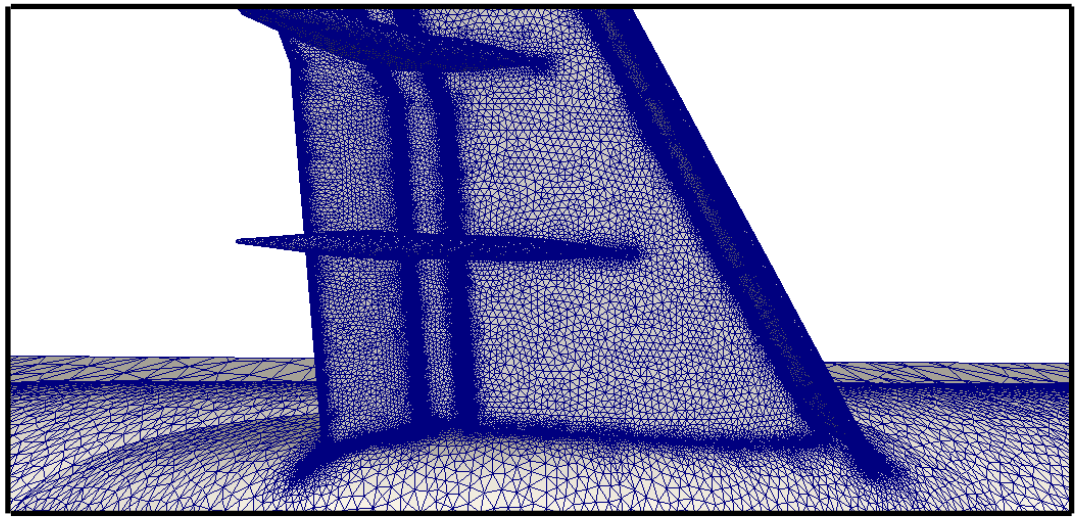
Case 1: Summary

- Reasonable agreement with the experiments
- Adaptivity overall does better near the tip and near the trailing edges in capturing the flow due to higher resolution compared to the coarse mesh, which is of comparable size.
- Flap element shows some difference in C_p values, especially near the root
- Adapted mesh overshoots C_p at some locations, second adaptivity pass usually removes this overshoot

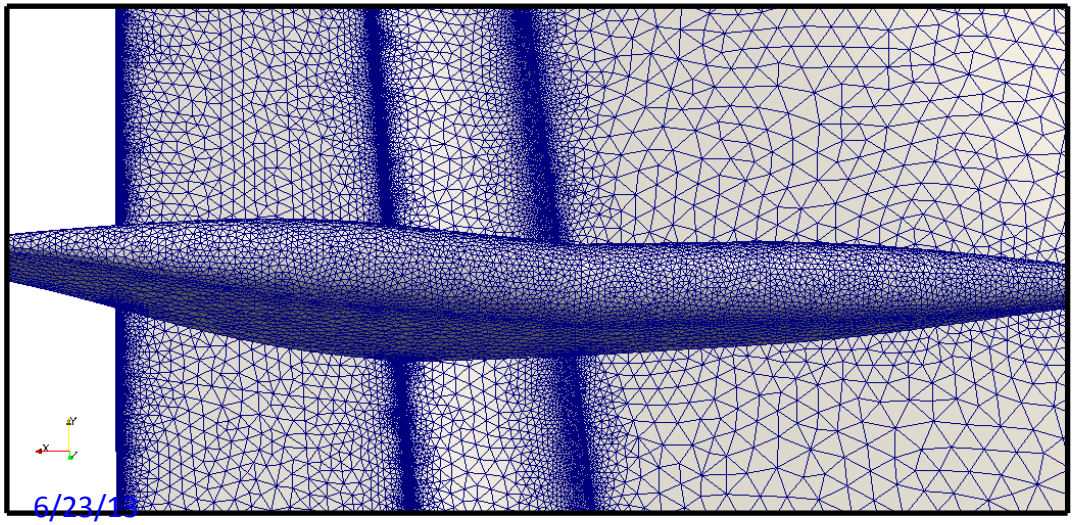
Case 2: Description

- Meshes:
  - Created using gridding guidelines given online
  - Unstructured, with mixed element boundary layers
  - Created in-house using MeshSim software by Simmetrix Inc.
- Mesh statistics:
  - Medium: 98M elements, 40M nodes
- Cases:
  - Case 2(a): Low Reynolds number = 1.35M
    - Angles of attack: 0, 7, 12, 16, 18.5, 19, 20, 21 (degrees)
  - Case 2(b): High Reynolds number = 15.1M
    - Angles of attack: 0, 7, 12, 16, 18.5, 20, 21, 22.4 (degrees)
- Solved on Mira BG/Q on 32k processors

Case 2: Mesh

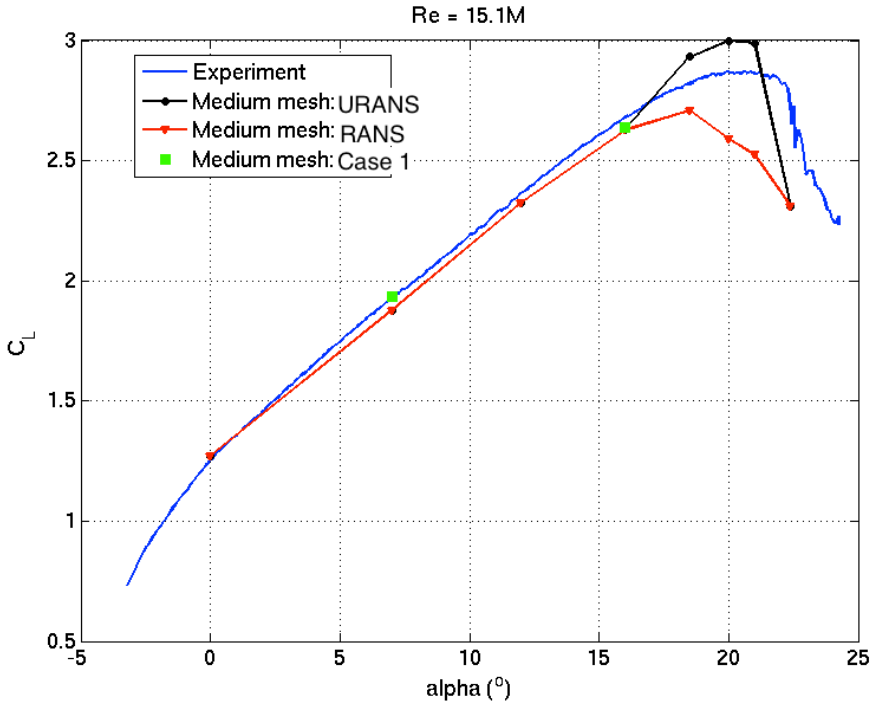


Mesh created with same attributes as for medium mesh in Case 1

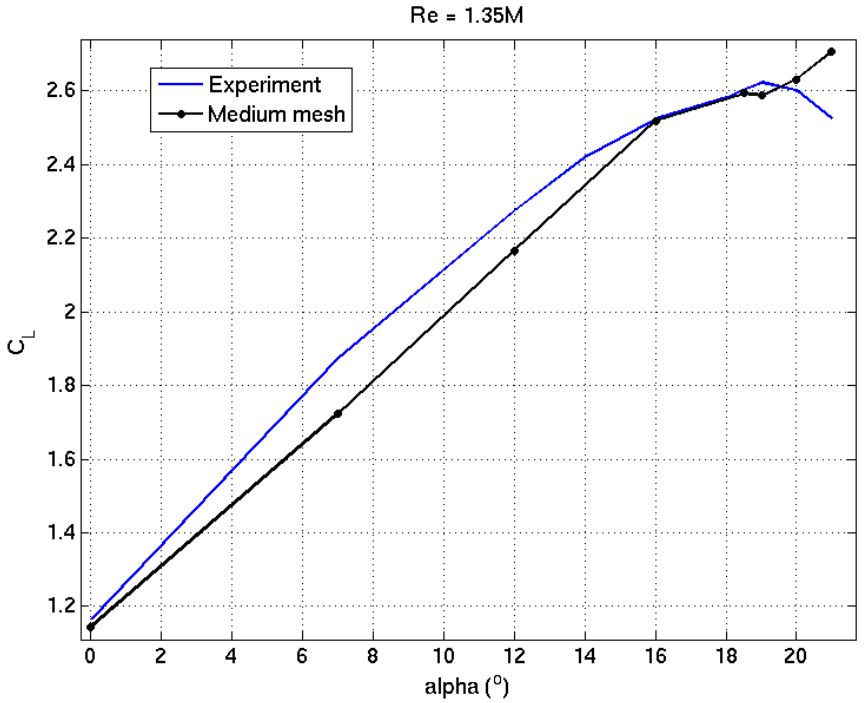


Zoom of the flap fairing

Case 2: Lift Curves

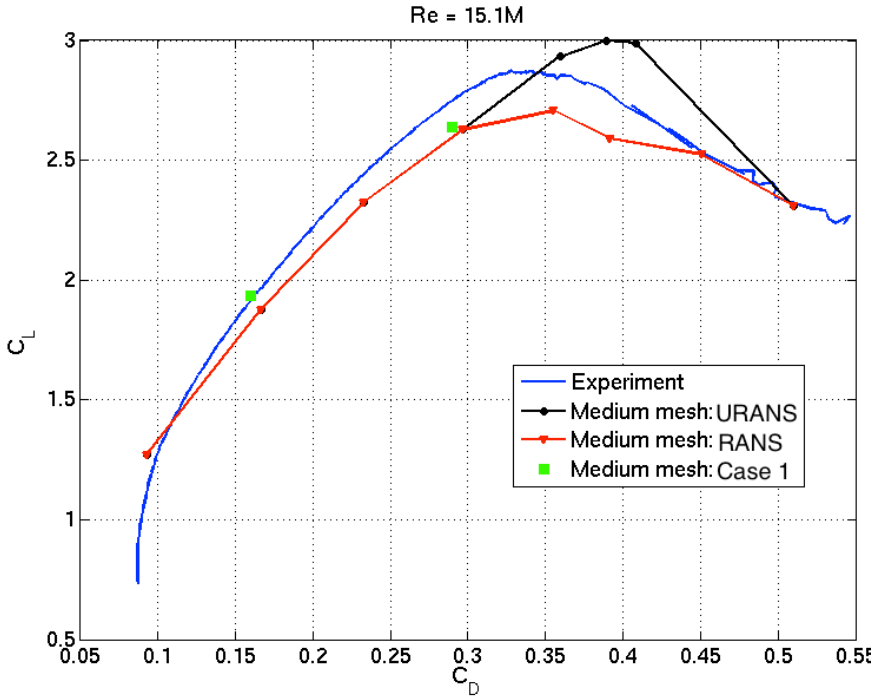


Reynolds number
15.1 Million

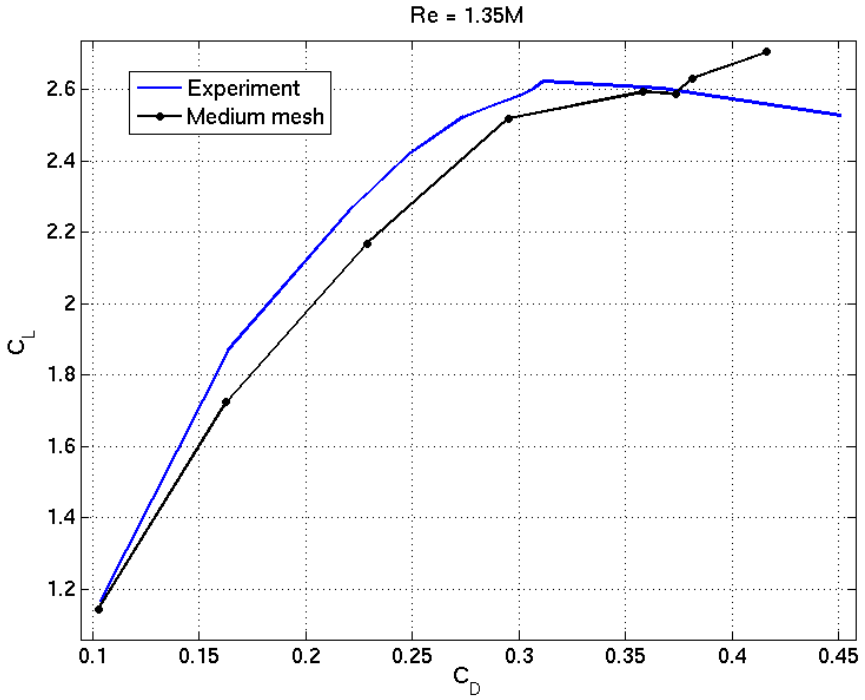


Reynolds number
1.35 Million

Case 2: Lift vs. Drag

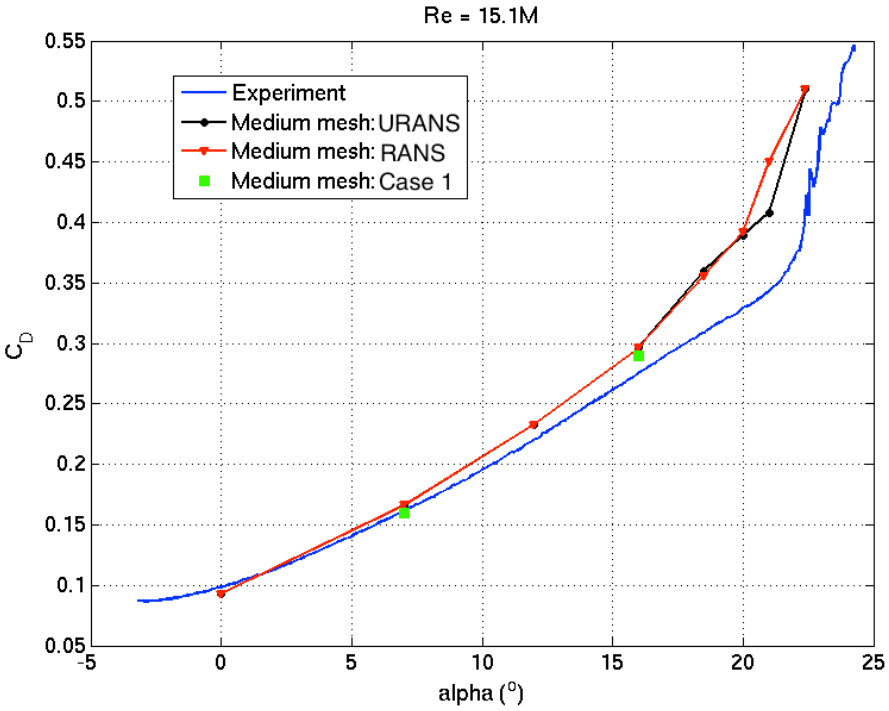


Reynolds number
15.1 Million

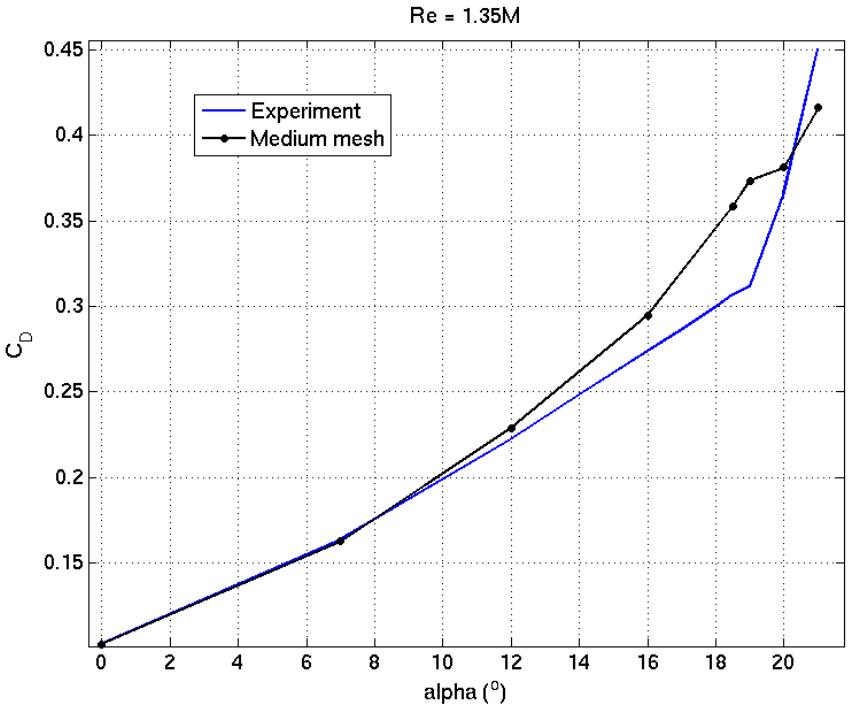


Reynolds number
1.35 Million

Case 2: Drag Curves

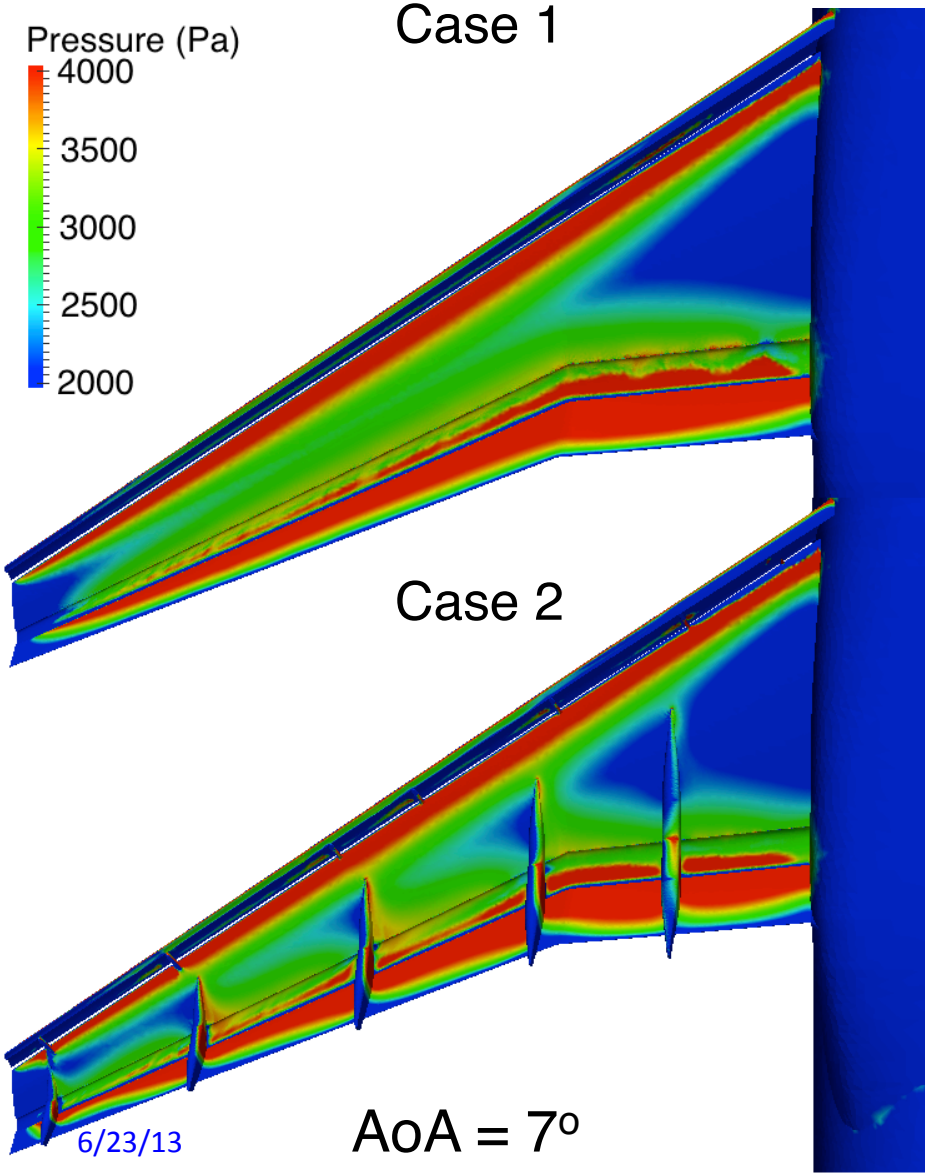


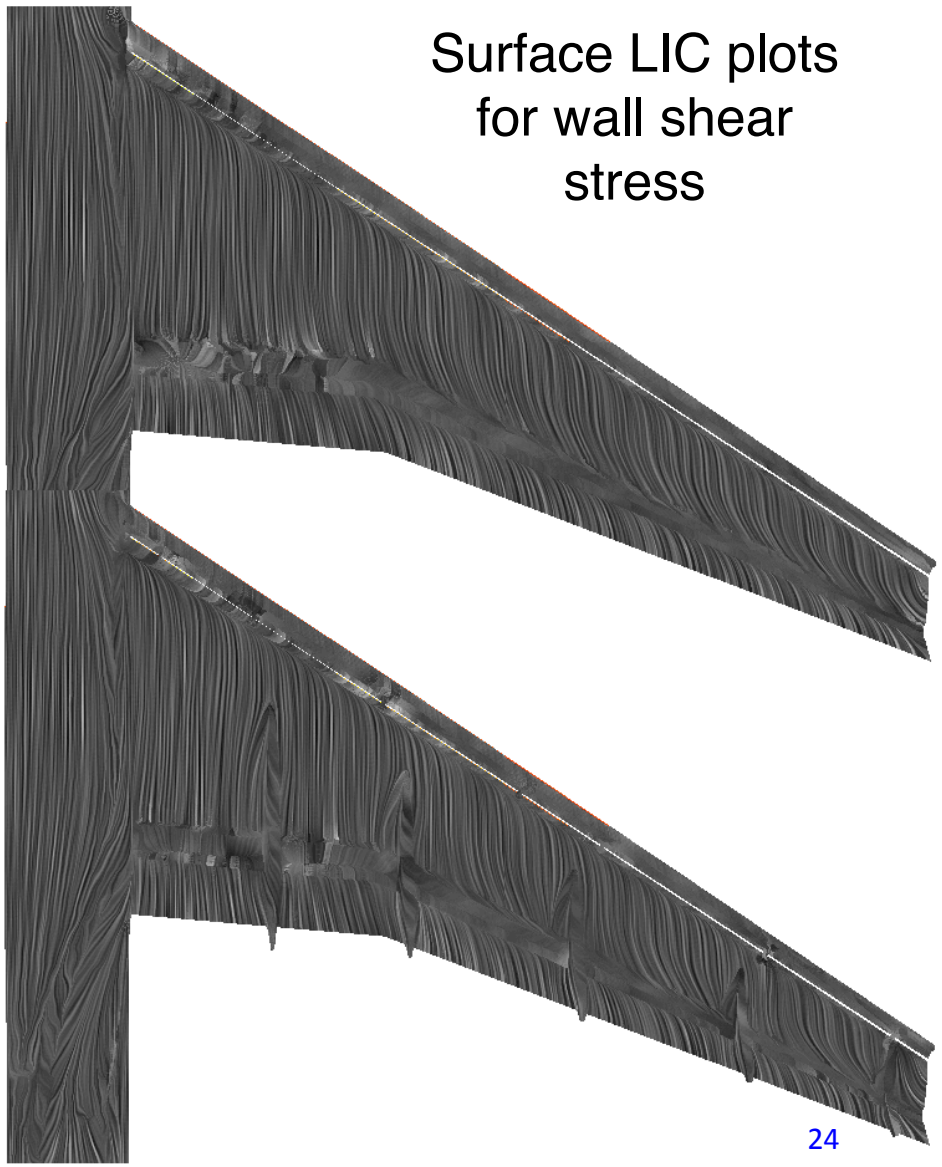
Reynolds number
15.1 Million



Reynolds number
1.35 Million

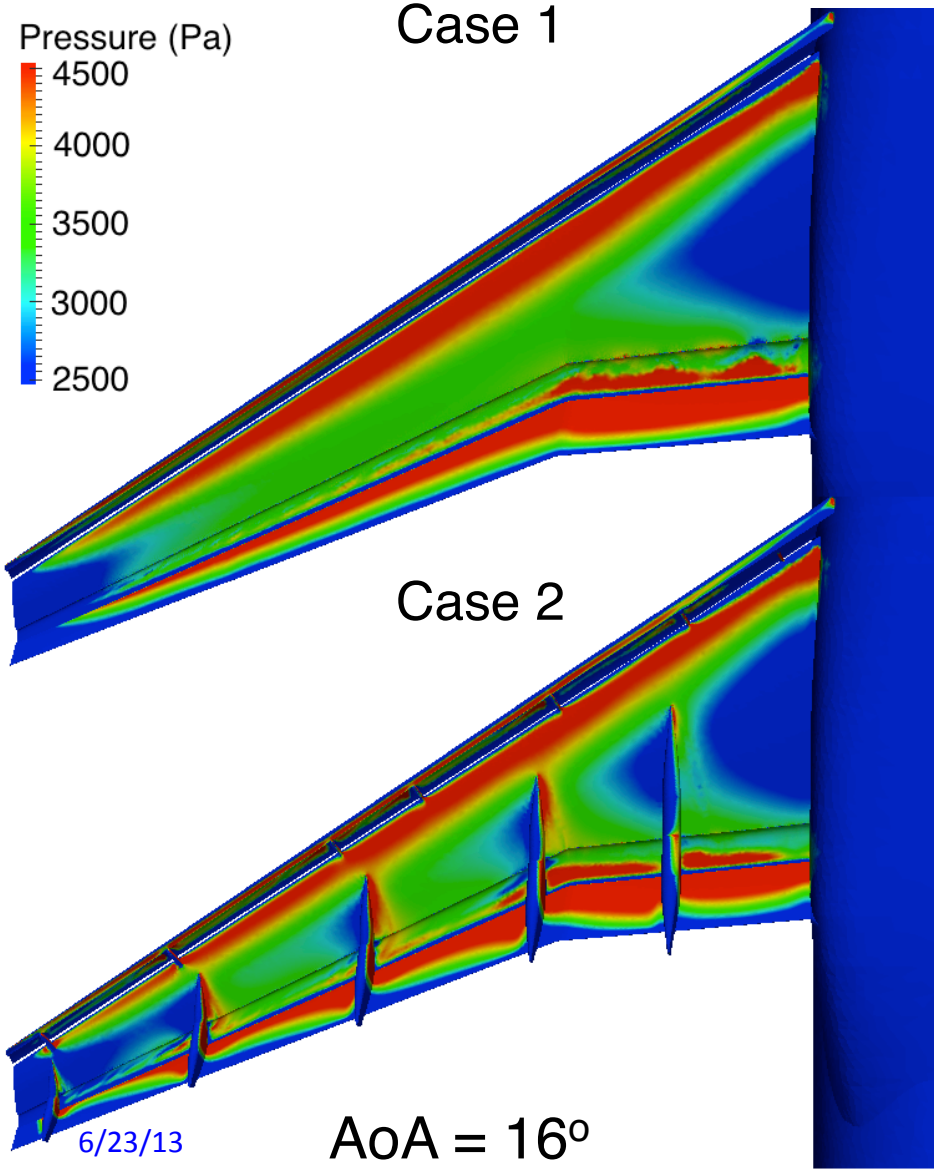
Case 2: Pressure and LIC

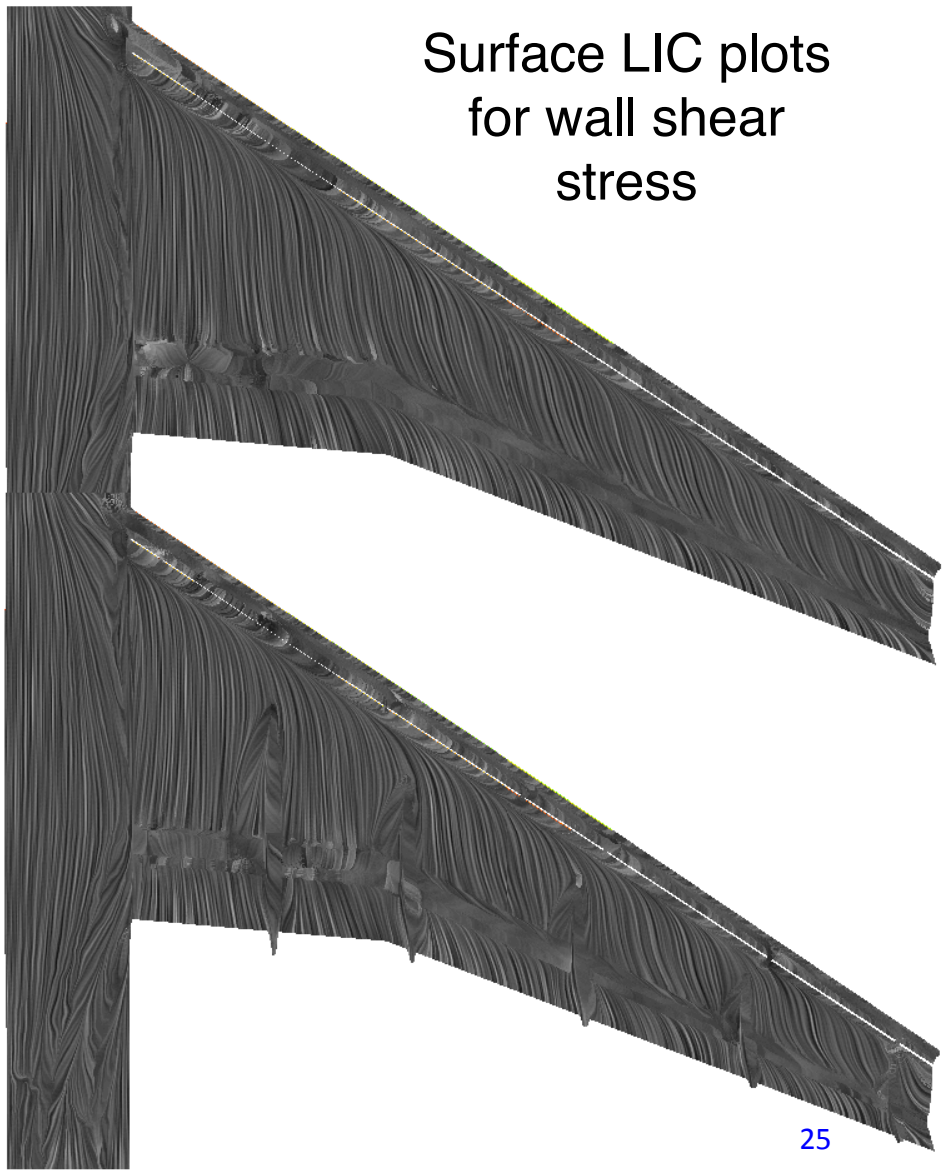




Surface LIC plots for wall shear stress

Case 2: Pressure and LIC





Surface LIC plots for wall shear stress

Case 2: Summary

- Overall reasonable agreement with the experimental data
- Higher angles of attack show sensitiveness to the time step size (steady vs. unsteady)
- Drag is over predicted at higher angles of attack.
- 21^{o} angle of attack is over predicting C_L for Re = 1.35M, going unsteady has not shown any improvement.

Future Work

- More adaptivity passes on Case 1, need to go parallel
- Adaptivity on case 2
- Running with DES…

THANK YOU!