

FUN3D Solutions for Nose Landing Gear

Veer N. Vatsa, David P. Lockard
And
Mehdi R. Khorrami



NASA Langley Research Center. Hampton. VA

Outline



- Objectives
- Numerical Method
- Configuration and Flow Conditions
- Grids
- Results
- Computational Resources
- Observations

Objectives



- Assess the applicability of an unstructured grid flow solver FUN3D for Nose Landing Gear configuration
- Examine grid and turbulence modeling sensitivity



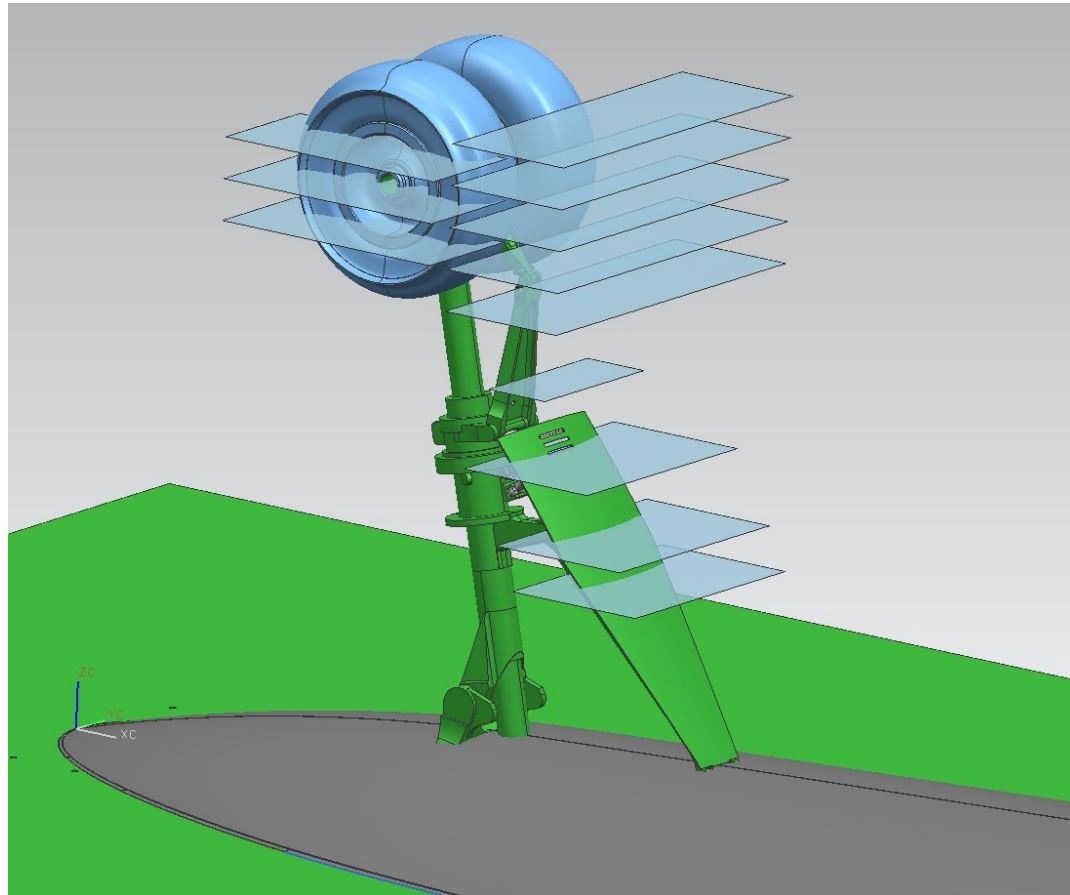
Numerical Method

- Equations solved
 - Unsteady Reynolds-averaged Navier-Stokes (URANS) equations
Fully unstructured node-based flow solver (FUN3D)
 - Turbulence models
 - Hybrid RANS/LES model (Ref. Lynch et al. AIAA Paper 2008-3854)
 - Modified Delayed Detached Eddy Simulation (MDDES) model
(Ref. Vatsa and Lockard AIAA Paper 2010-4001)
- Spatial and temporal discretizations
 - Roe's flux-difference splitting scheme without flux limiter
 - Optimized second-order backward difference (BDF2OPT) scheme
for temporal discretization: Dual-time stepping with 15 subiterations
- Boundary Conditions
 - Constant temperature, no-slip floor & gear
 - Inviscid side walls & ceiling
 - subsonic inflow/outflow for inlet and exit planes
 - Outlet pressure specified
 - Inlet total pressure and temperature specified

Configuration and Flow Conditions



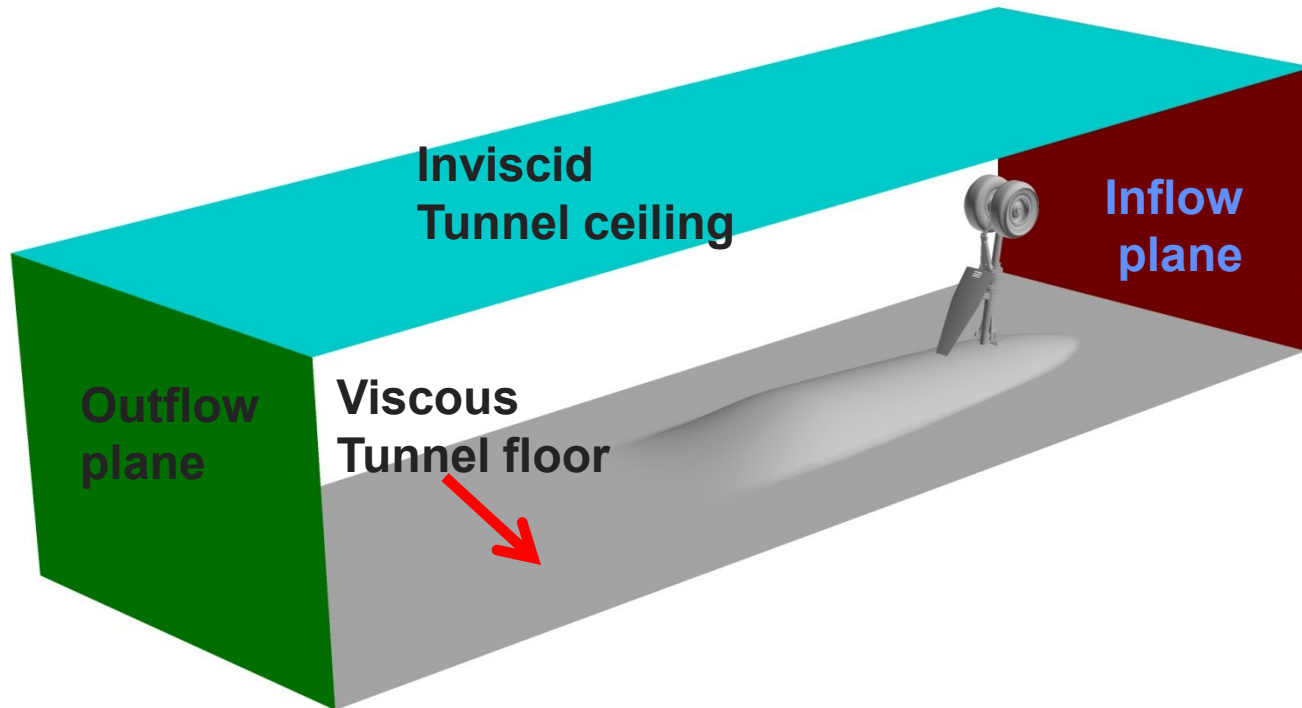
- $Re = 73,000$ based on post diameter
 - Flow code run in fully turbulent mode
- $M = 0.166$



Computational grids



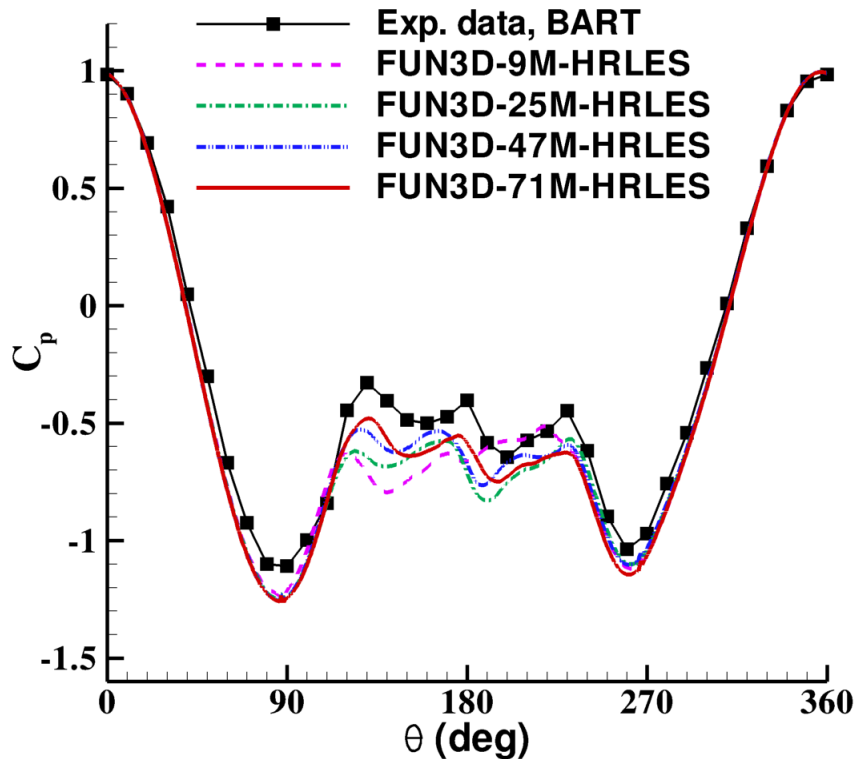
- Unstructured, mixed-element grids using VGRID
- Sequence of 3 successively refined grids: 9, 25 and 71 million nodes
- Locally enriched 47 million node grid



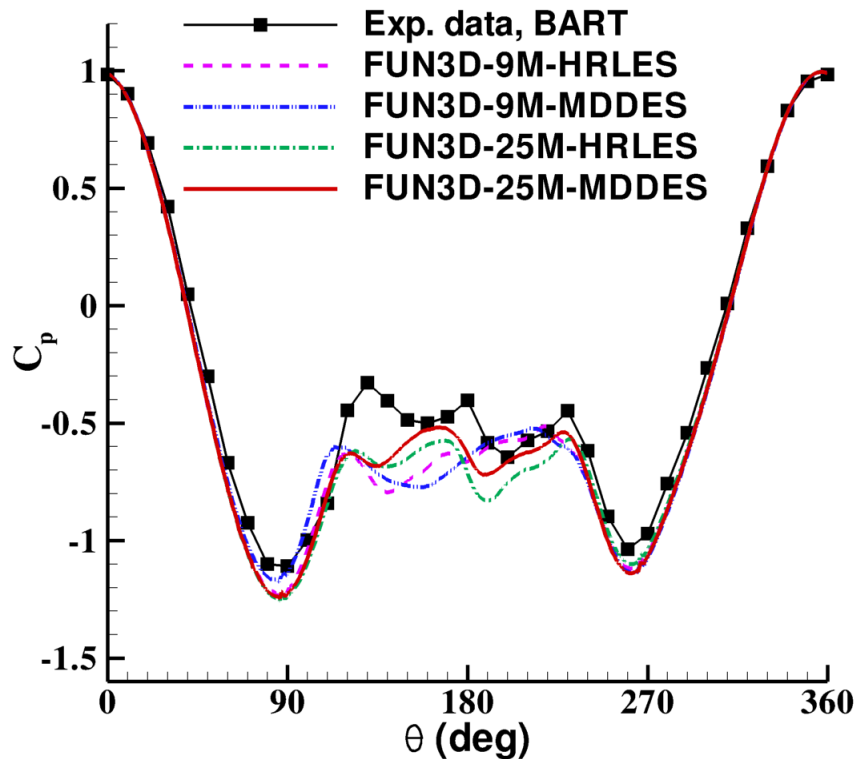
Results

- Time step
 - 4.92×10^{-6} seconds
- Number of time steps run
 - Total : minimum of 80,000 time steps
 - Sampling : Minimum of 50,000 time steps
- Convergence information
 - C_p and $C_{p_{rms}}$ checked after every 10,000 time steps

Surface Pressure comparisons (starboard wheel)

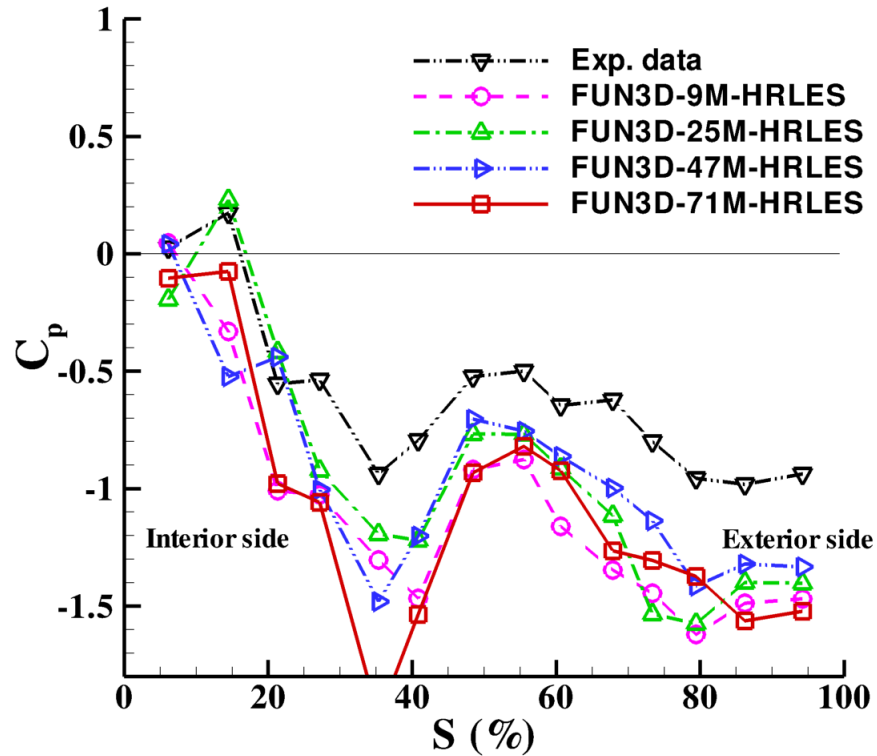


Grid sensitivity

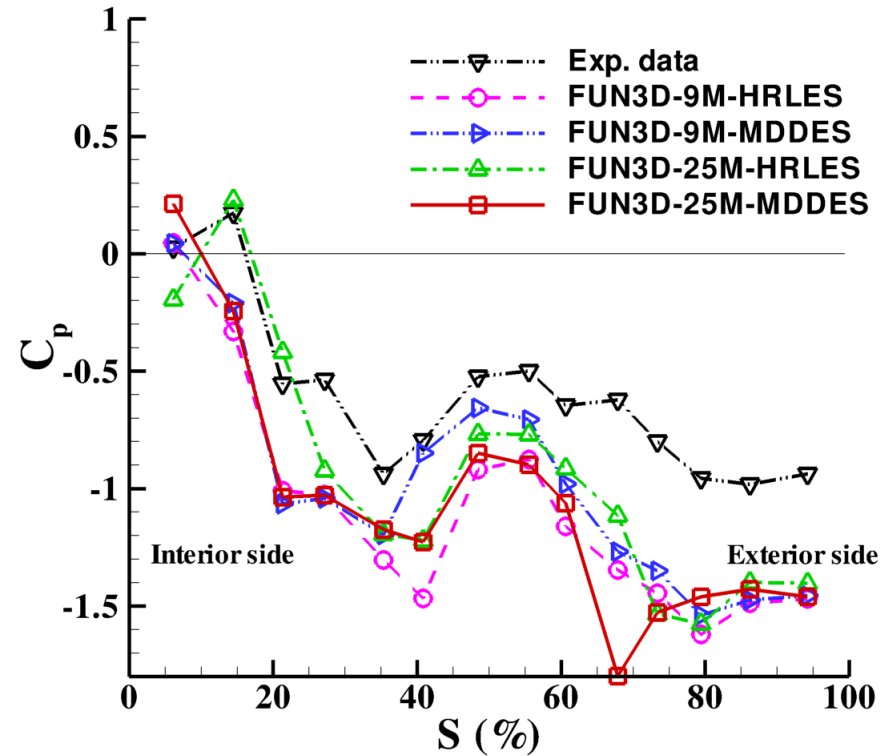


Turbulence modeling
sensitivity

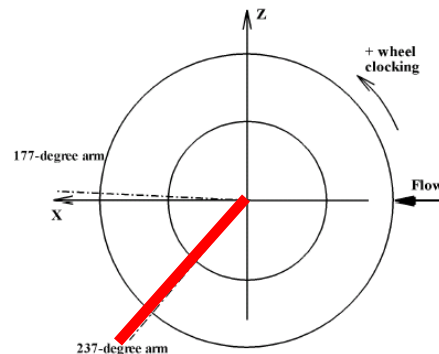
Surface Pressure comparisons (port wheel transverse cut at 237°)



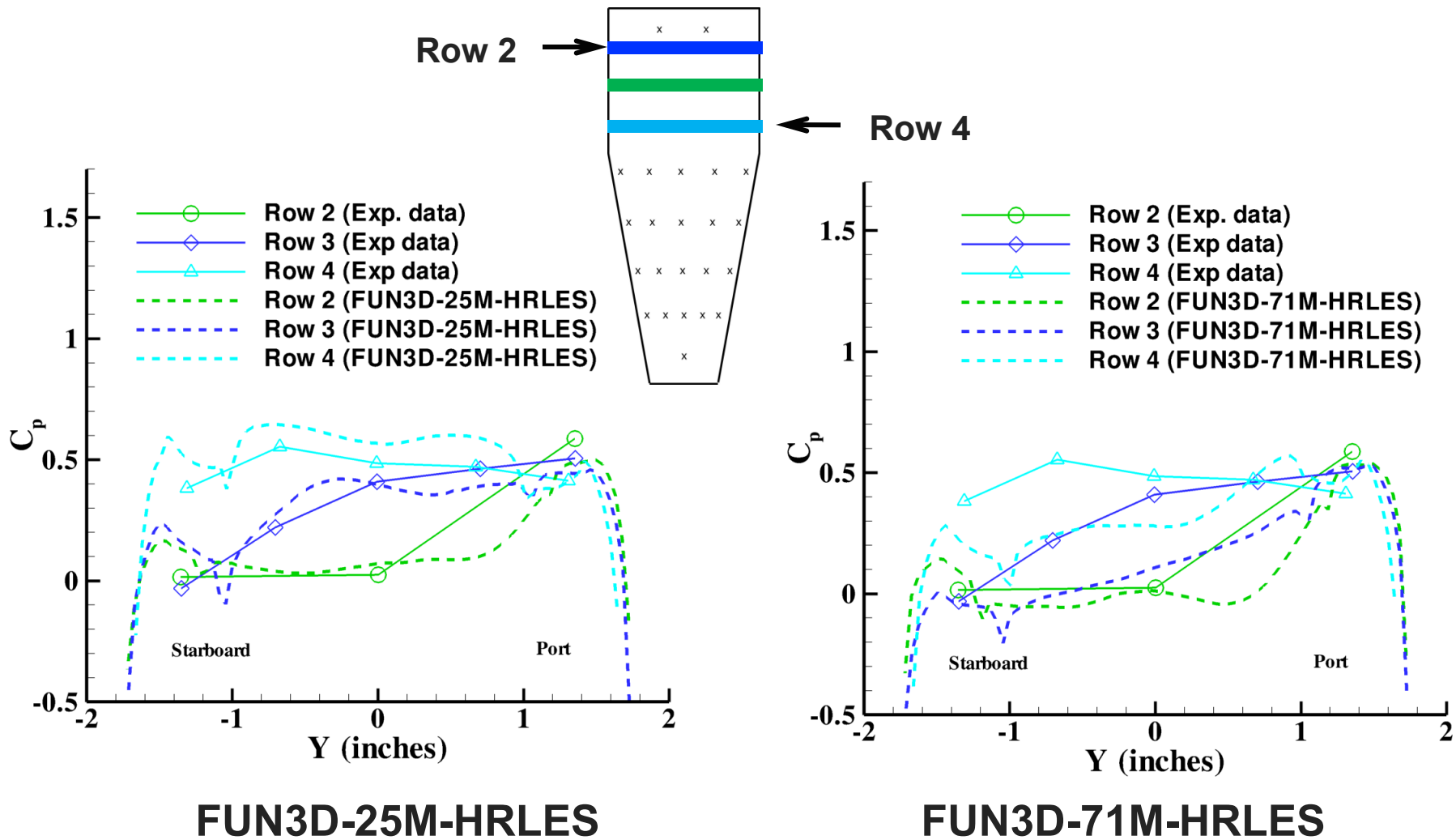
Grid sensitivity



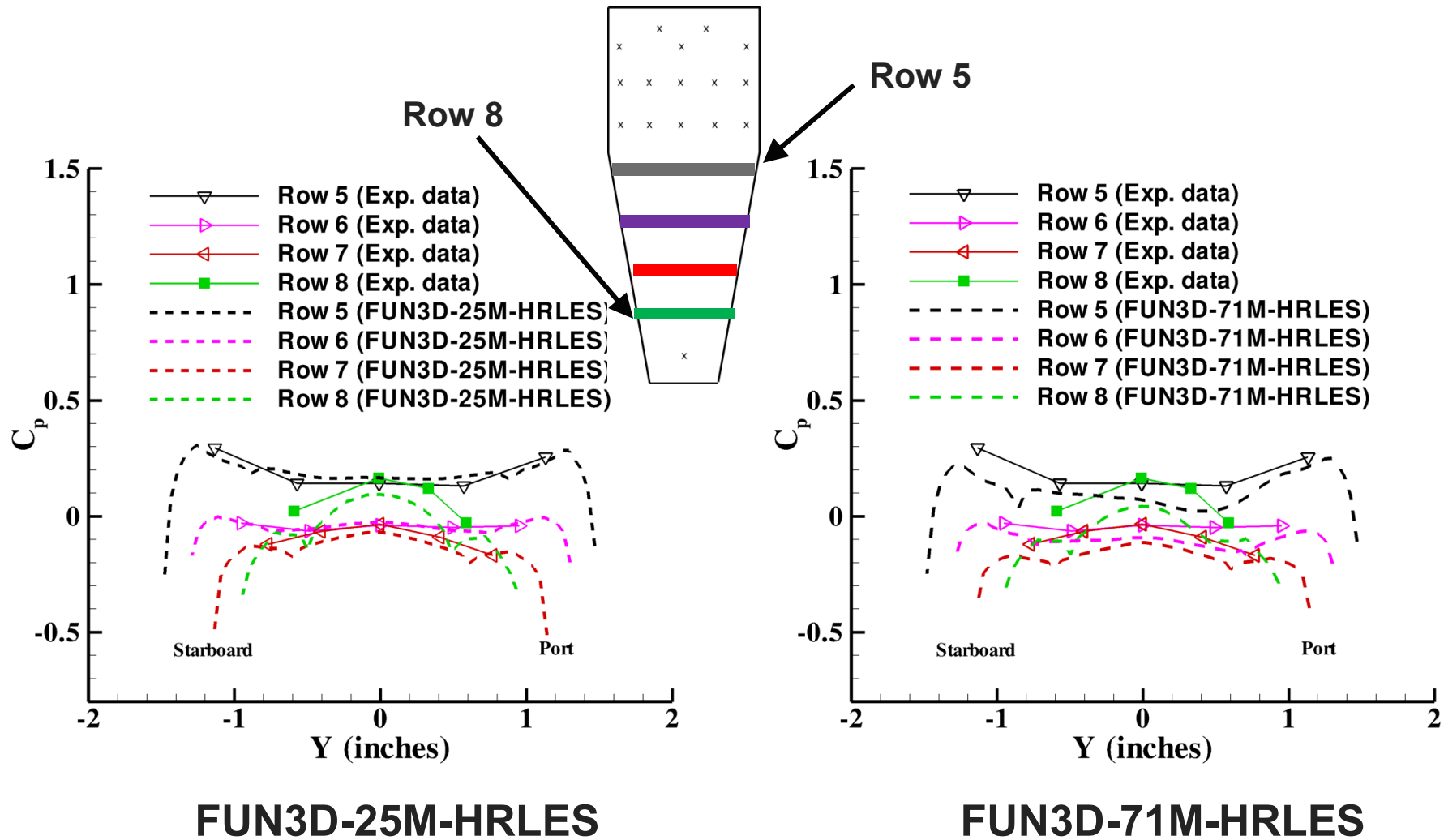
Turbulence modeling sensitivity



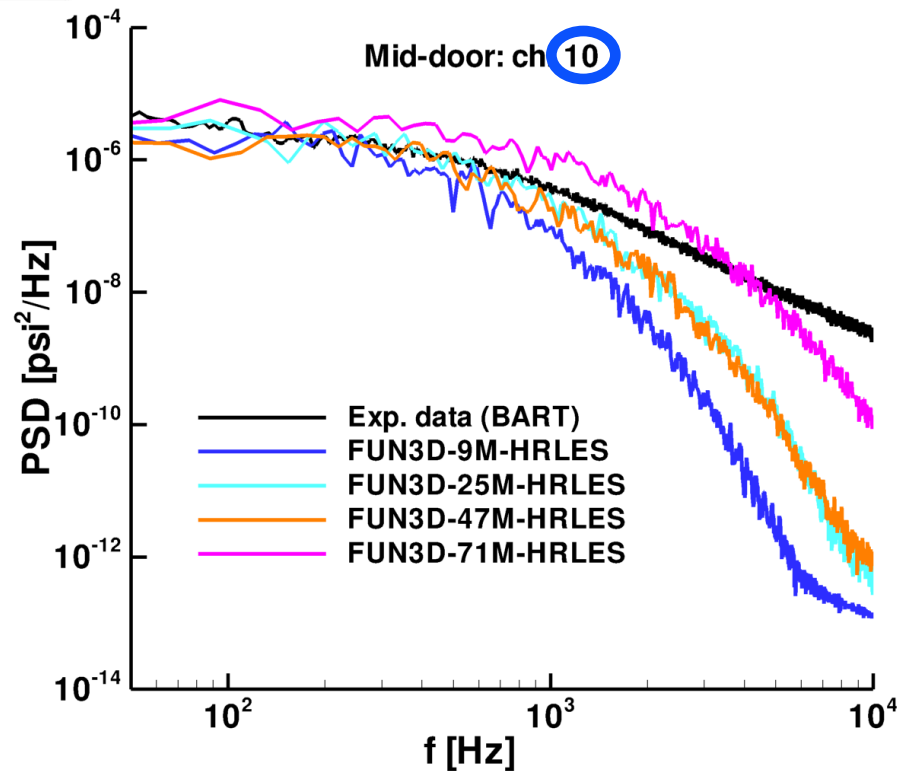
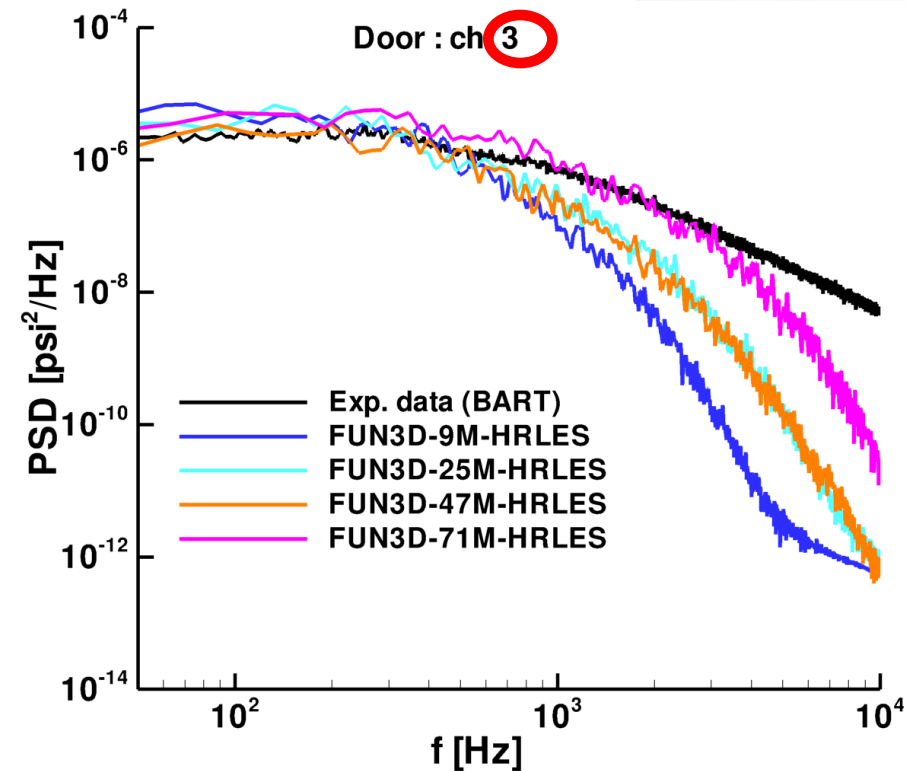
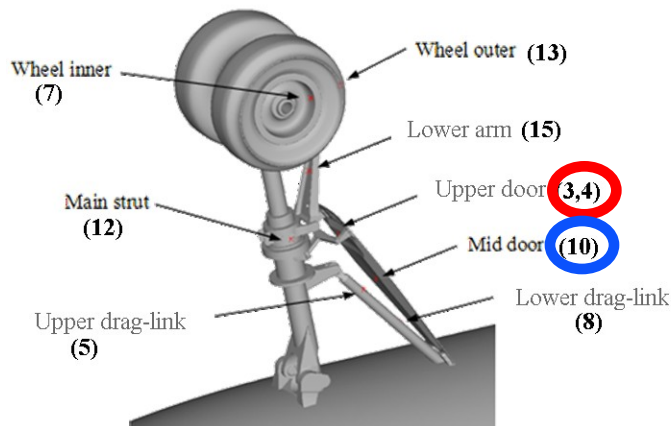
Surface Pressure comparisons at door (Rows 2-4)



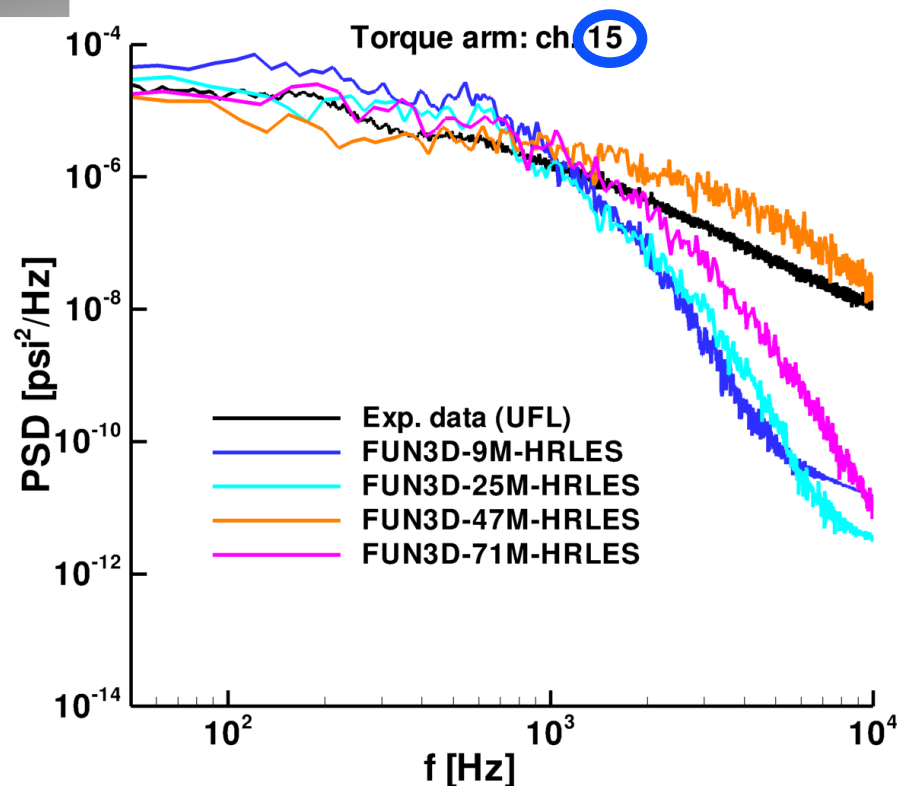
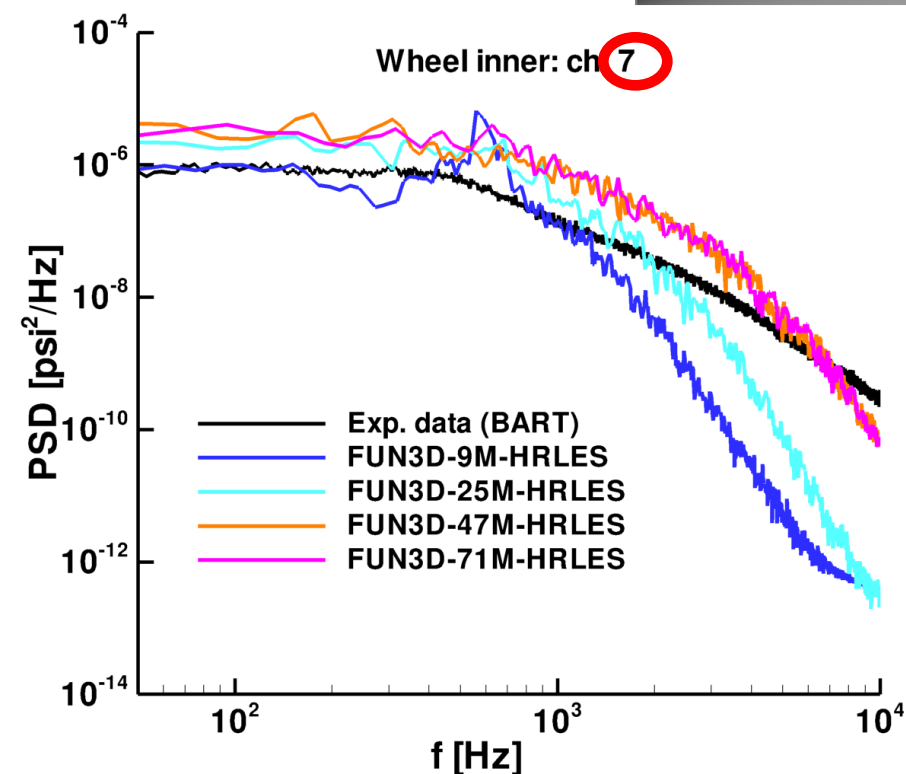
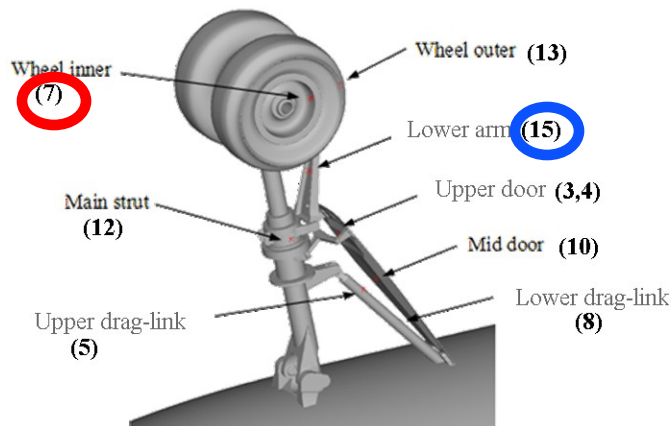
Surface Pressure comparisons at door (Rows-5-8)



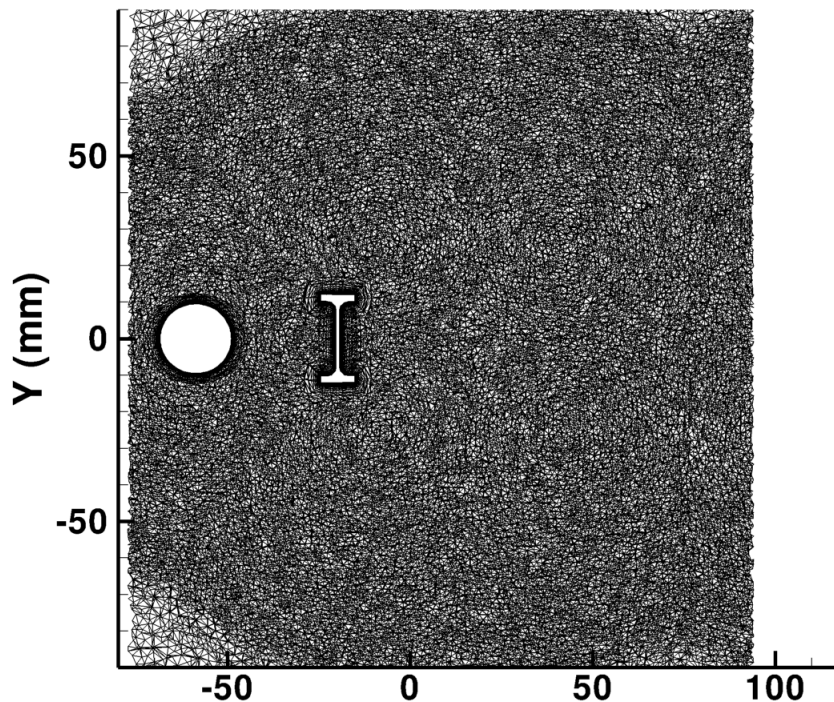
Power Spectral Density Comparisons



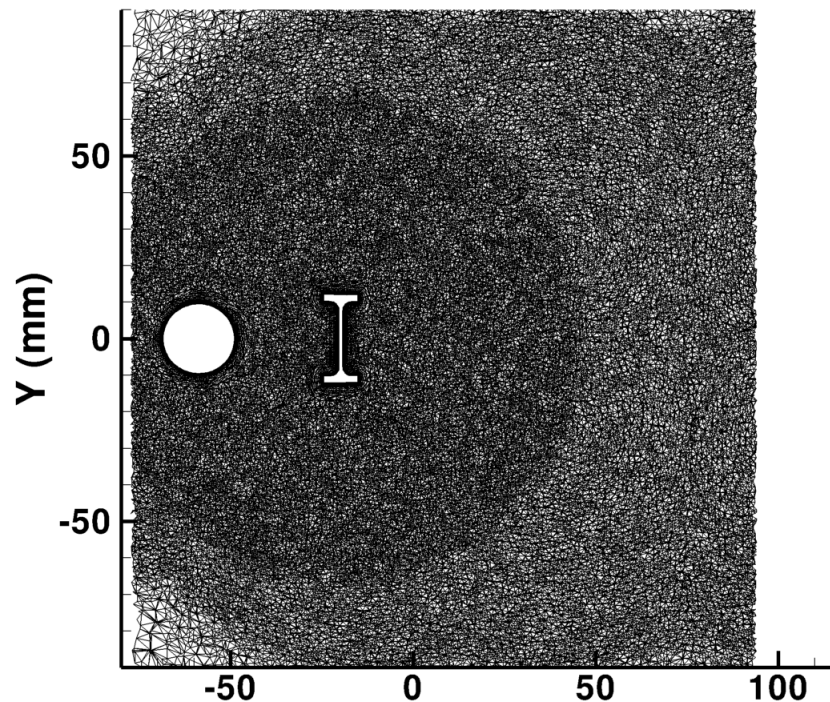
Power Spectral Density Comparisons ... (2)



Partial view of grid near torque-arm

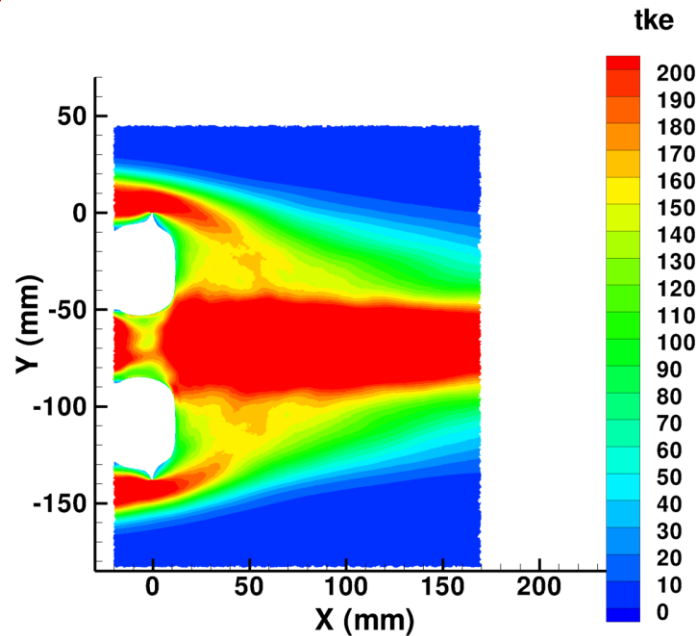


25 M node grid

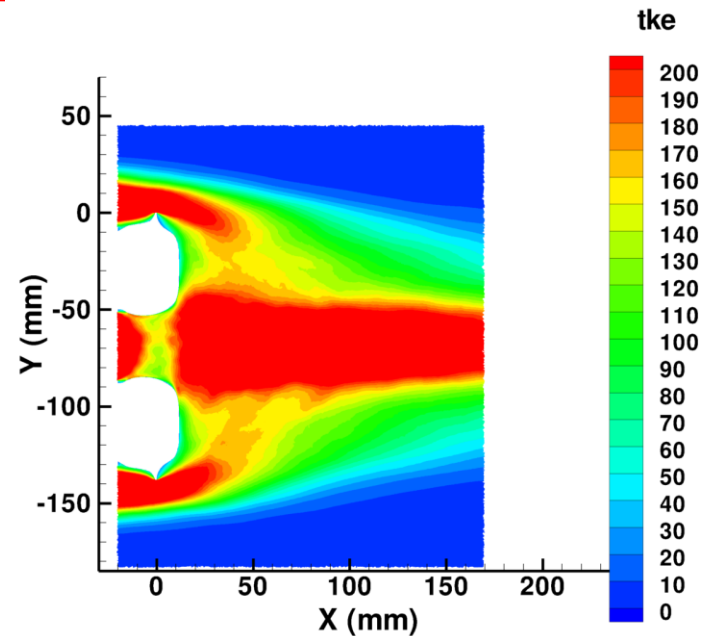


47 M node grid

2-D Turbulence Kinetic Energy at wheel wake centerline

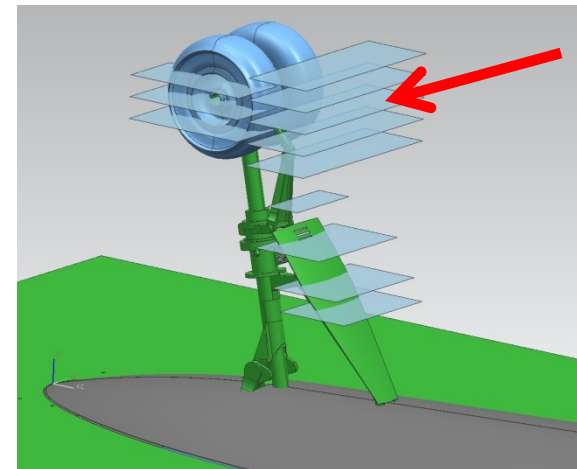
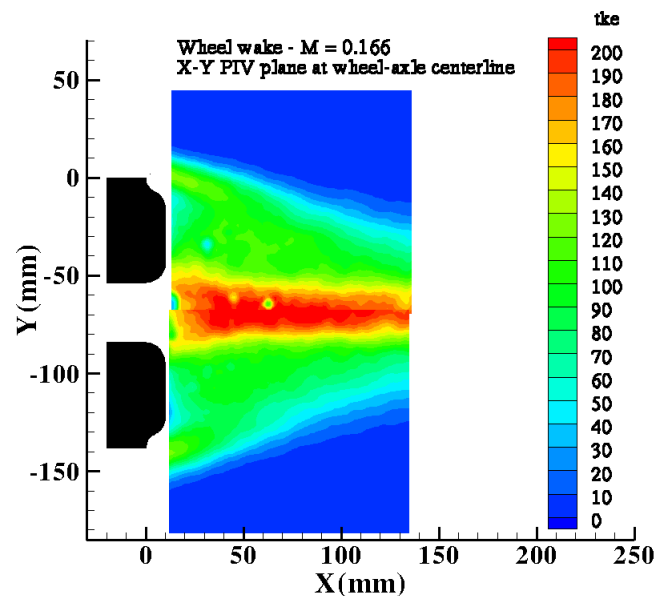


FUN3D-25M-HRLES

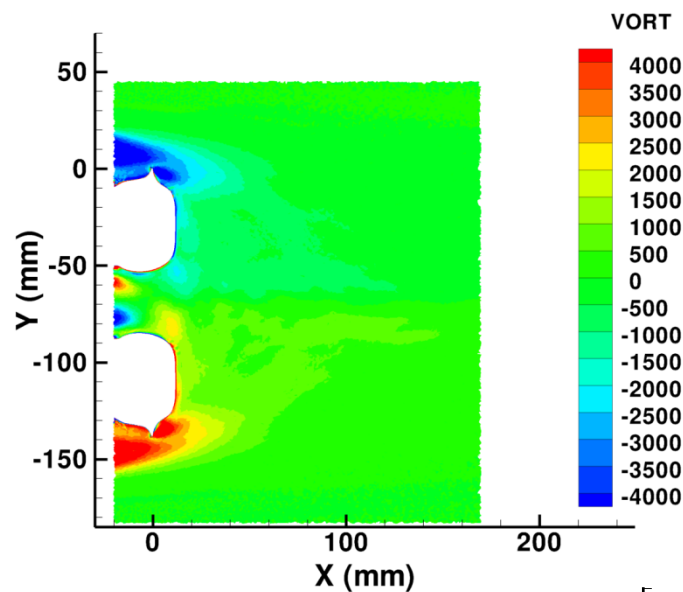


FUN3D-71M-HRLES

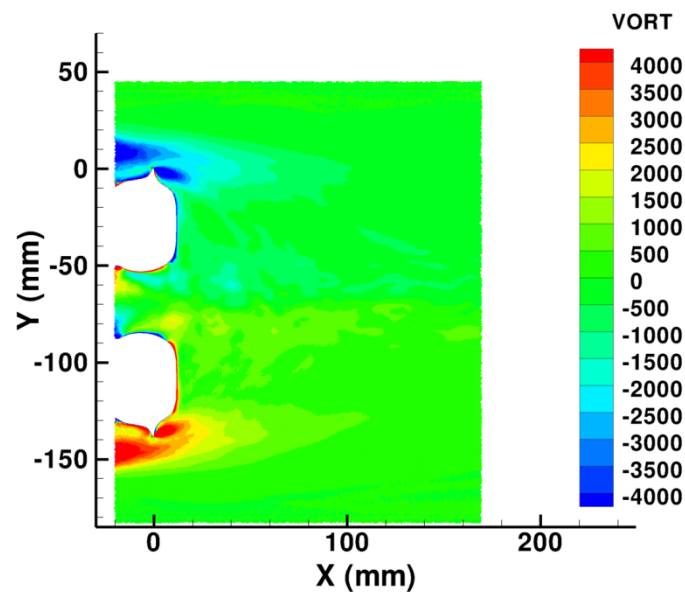
Exp. PIV data



Spanwise vorticity at wheel wake centerline

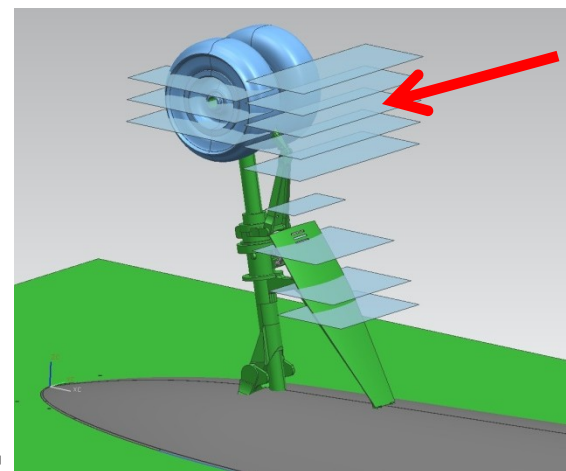
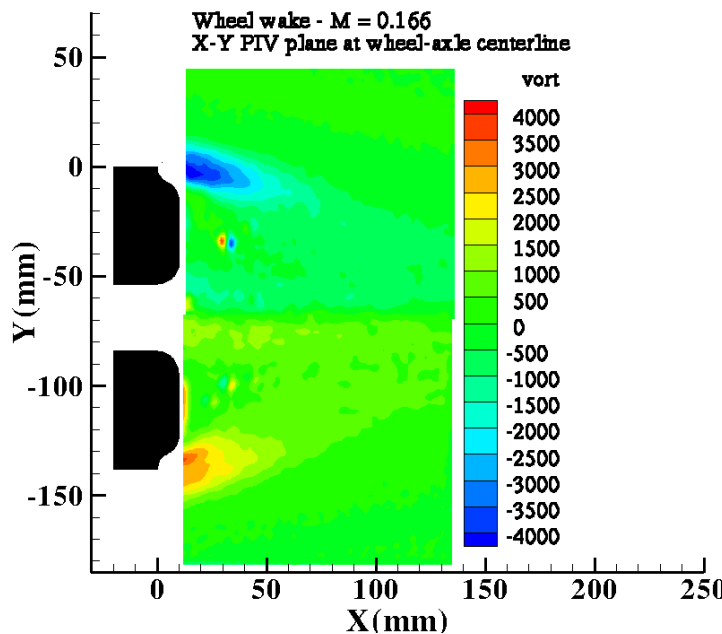


FUN3D-25M-HRLES

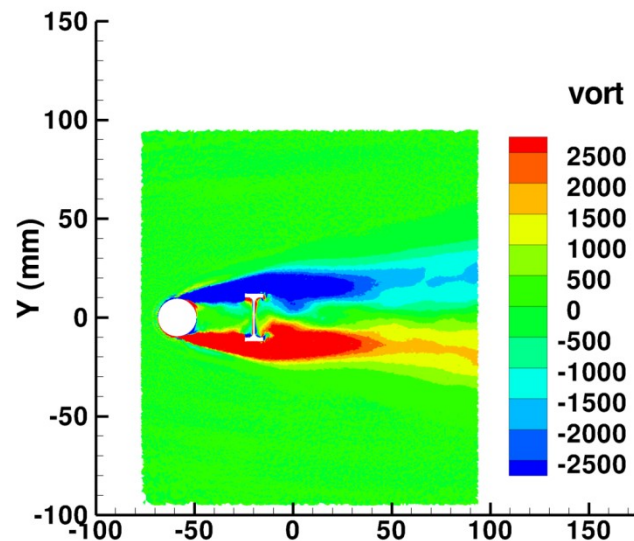
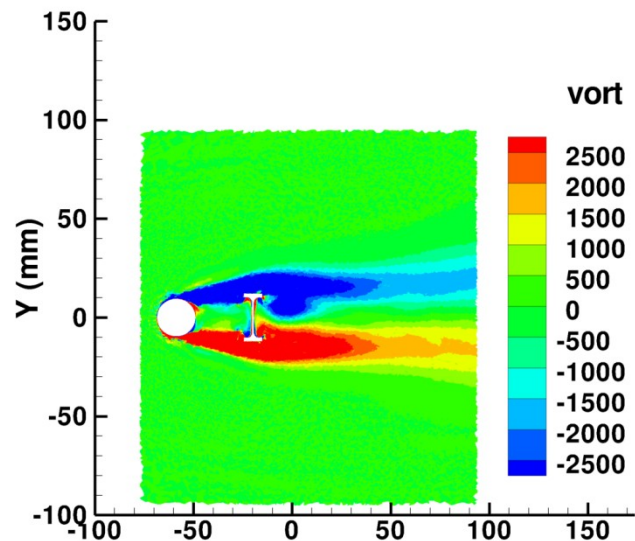


FUN3D-71M-HRLES

Exp. PIV data



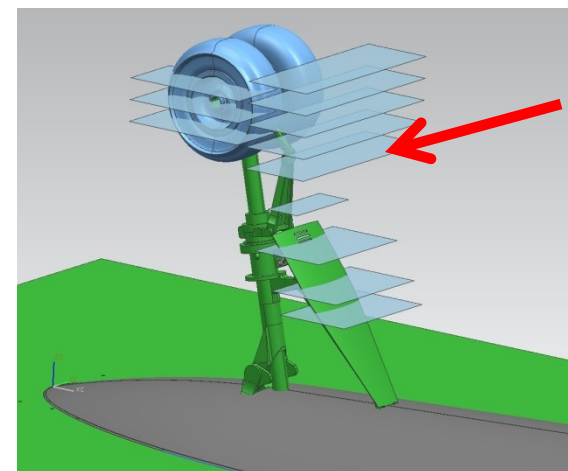
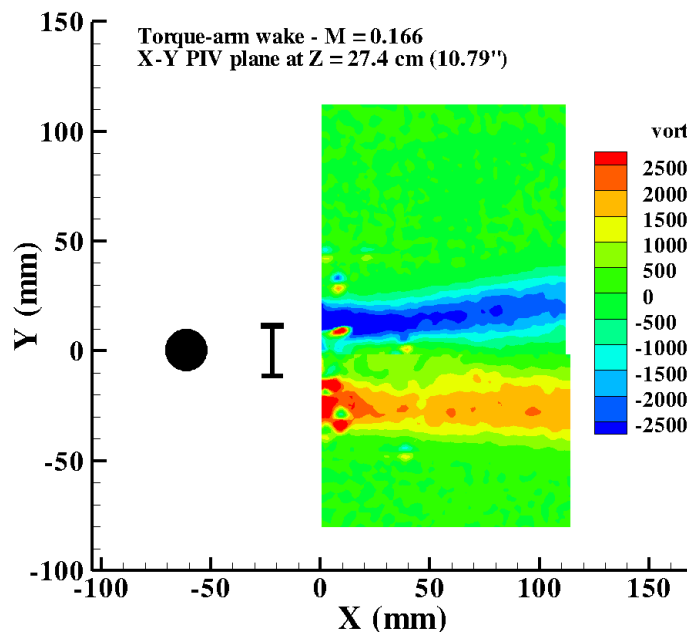
Spanwise vorticity at torque arm wake



FUN3D-25M-HRLES

FUN3D-71M-HRLES

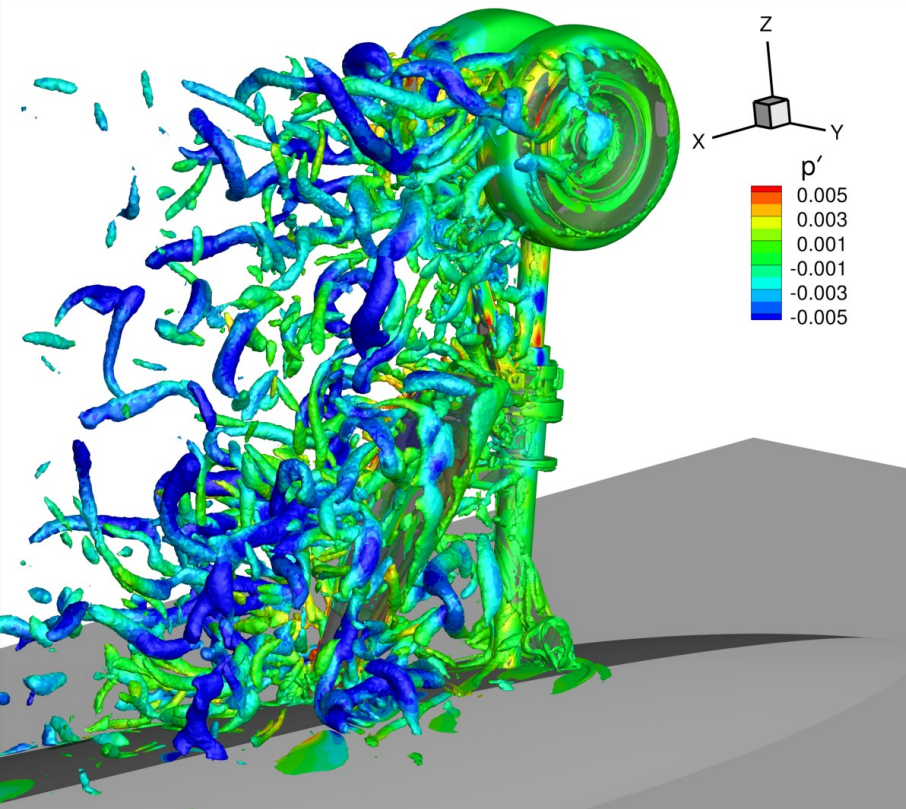
Exp. PIV data



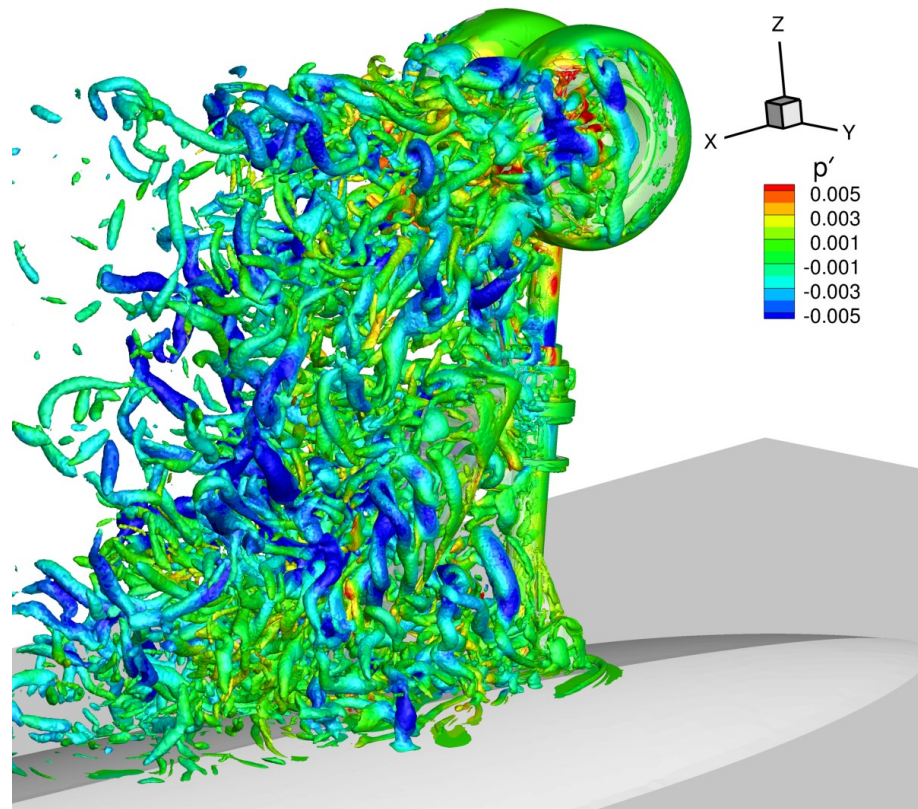
Iso-surfaces of Q-criterion



- Colored with perturbation pressure



FUN3D-9M-HRLES



FUN3D-25M-HRLES

Computational Resources



- Computer hardware
 - CPU: NAS Pleiades, 2 quad-core Xeon E5472 Harpertown cpu's/node, 1GB memory/core
 - Interconnect: Infiniband
- Resources (for 25 M nodes, HRLES case)
 - CPU (or wall clock) Time / time step : 33.8 secs. using 960 cores
 - Minimum of 80,000 time steps in simulation
 - Minimum of 50,000 time-steps for data sampling

- What did you learn?
 - Computational challenges
 - Significant computational effort for statistically meaningful results
 - Constructing suitable grids very challenging
 - New insights into the physics
 - Complex flow physics, difficult to simulate with fixed (non-adapting) grids
 - Manual, local refinement effective but tedious
 - Tunnel inflow/outflow b.c.'s could influence computations
 - Transition difficult to simulate, could impact flow on smaller components
 - Assessment of state-of-the-art based on your simulation for the problem category of interest
 - Encouraging results, solutions capture salient flow features
 - Uncertainty due to grids, transition and turbulence modeling
 - Recommendations for follow-on efforts
 - Need test data to quantify Reynolds number sensitivity
 - Need systematic grid refinement/adaptation studies, better turbulence/transition modeling