FUN3D Analyses in Support of the X-59 Pitot Probe Wind Tunnel Test

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Aeronautics Research Mission Directorate | 06/15/2023

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Illustration Credit: Lockheed Martin

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- Pretest CFD
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Introduction

- X-59 Pitot Probe tested in the 8x6 Supersonic Wind Tunnel at the NASA Glenn Research Center
- FUN3D simulations performed in support of the wind tunnel test
- Pretest CFD performed to evaluate sting effects on the measured pressure
- Post-test CFD simulations performed to:
  - Improve understanding of data
  - Assess prediction capabilities
  - Evaluate modeling techniques for pitot probe analyses
- This presentation provides a summary of FUN3D analyses performed for the X-59 pitot probe

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FUN3D Flow Solver

- FUN3D is a 3D, unstructured flow solver developed at the NASA Langley Research Center
  - Node-centered, finite volume Reynolds-averaged Navier-Stokes (RANS) solver
  - More information available at: https://fun3d.larc.nasa.gov/
- Roe scheme employed for inviscid flux calculations
- van Leer flux limiter employed for Mach > 0.8
- Spalart-Allmaras model with negative provisions, rotation correction (RC), and Quadratic Constitutive Relation (QCR-2000) employed for turbulence
- Simulations performed steady-state
  - Time-accurate simulations performed as part of port modeling study
- All simulations performed in “free air”

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Pretest CFD Analyses

- Goal: Assess the impact of the sting on the pressures measured by the X-59 pitot probe
- Perform simulations for probe w/ and w/o sting at lowest Mach number (M = 0.25)
- Grid refinement study included to improve confidence in predictions

Probe w/o Sting

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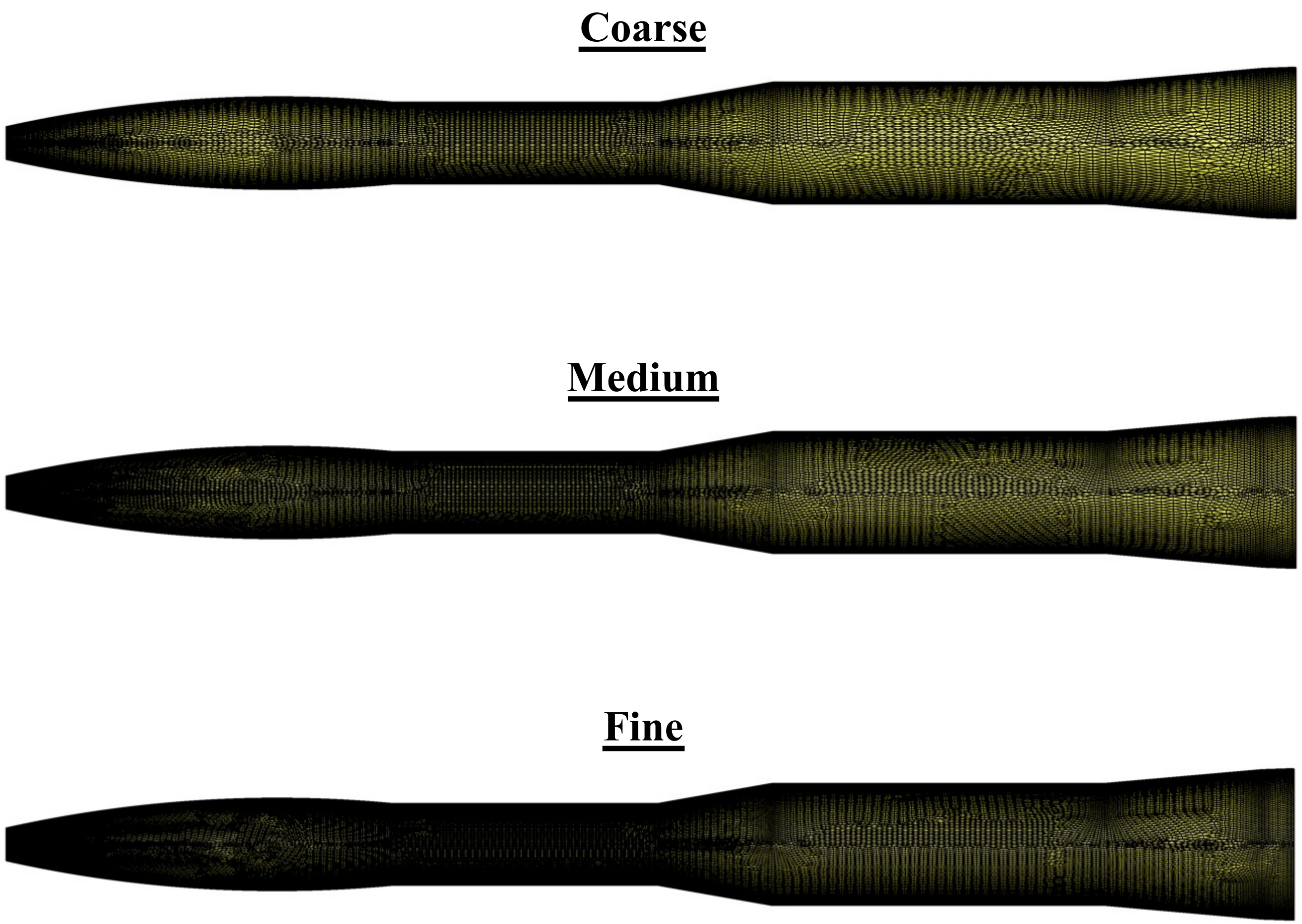
Grid Refinement Study

- Grids generated using HeldenMesh v3.03
- Refinement factor (h) chosen to provide ~2x refinement
    - Automatically scales all surface and volume sourcing
- y^+ scaled manually by same factor
- Same scaling applied to both sets of grids

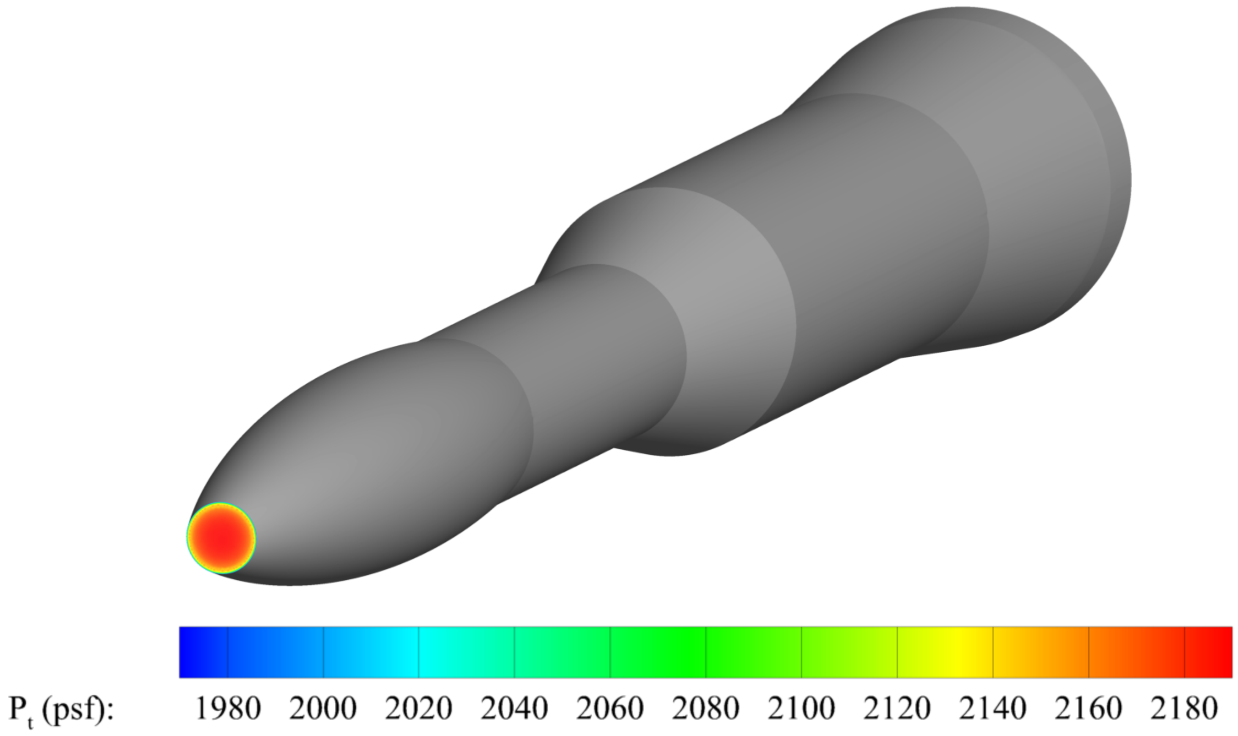
		h	y^+	Nodes $\times 10^{-6}$
W/O Sting	Coarse	1.000	1.000	0.567
	Medium	0.800	0.800	1.155
	Fine	0.650	0.650	2.289
W/ Sting	Coarse	1.000	1.000	1.986
	Medium	0.800	0.800	3.802
	Fine	0.650	0.650	7.140



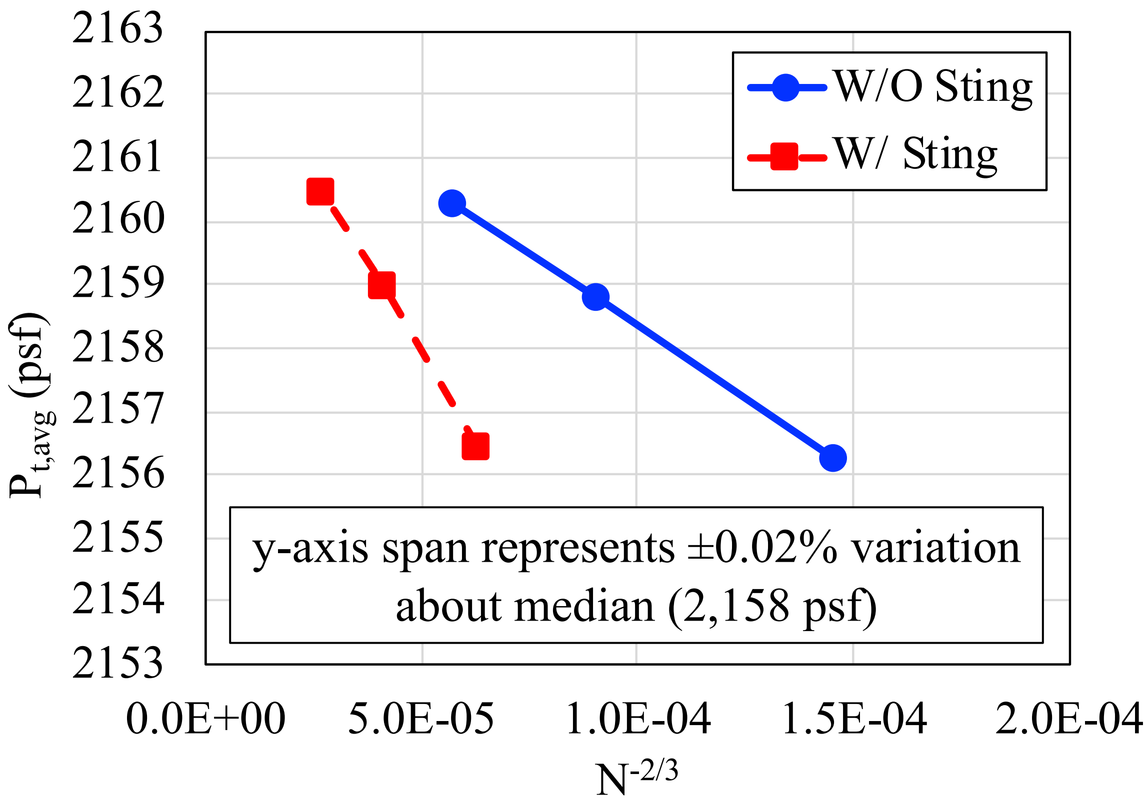
Sting Effects – Total Pressure

- Average total pressure computed at the probe tip
- Results show increasing total pressure with increasing grid refinement
- All grid refinements illustrate insignificant influence of sting

	W/O Sting	W/ Sting
	$P_{t,avg}$ (psf)	
Coarse	2156.237	2156.431
Medium	2158.776	2158.959
Fine	2160.266	2160.457



Mach 0.25, Re_D = 41,525, α, β = 0°



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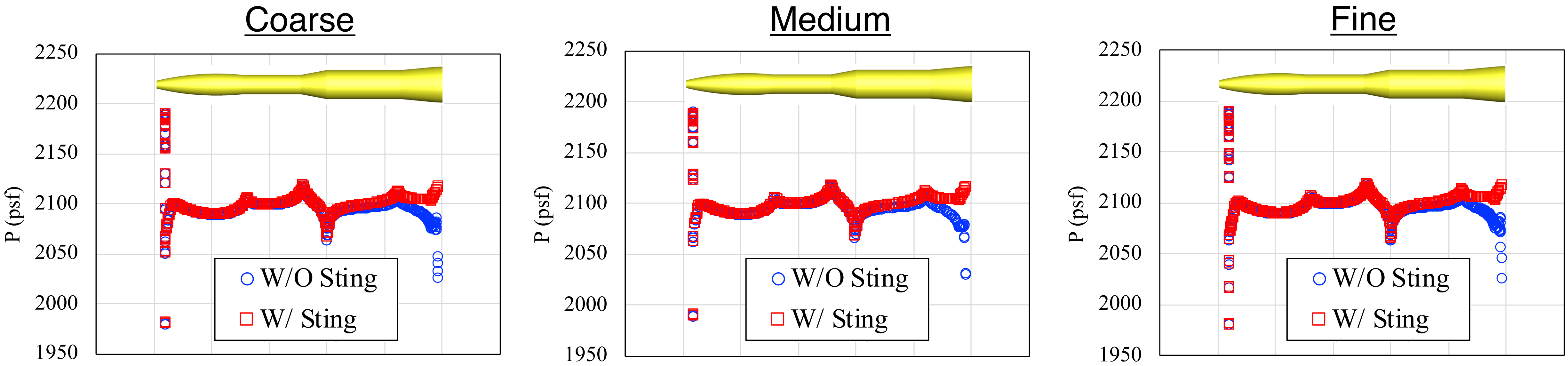
Sting Effects – Static Pressure

- Results show insignificant impact of sting on forward pressure with larger differences occurring downstream
- Differences potentially exaggerated due to blunt trailing edge of probe model

Mach 0.25, Re_D = 41,525, α, β = 0°



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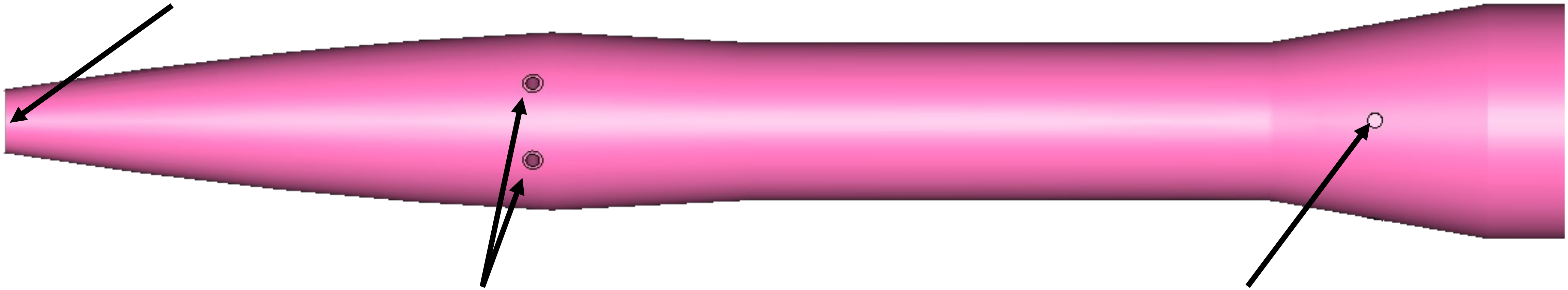
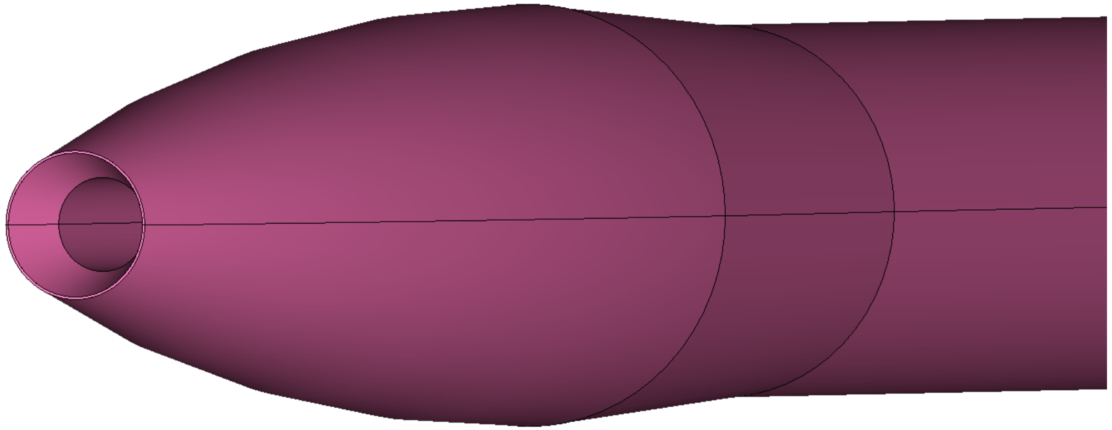
Post-test CFD Analyses

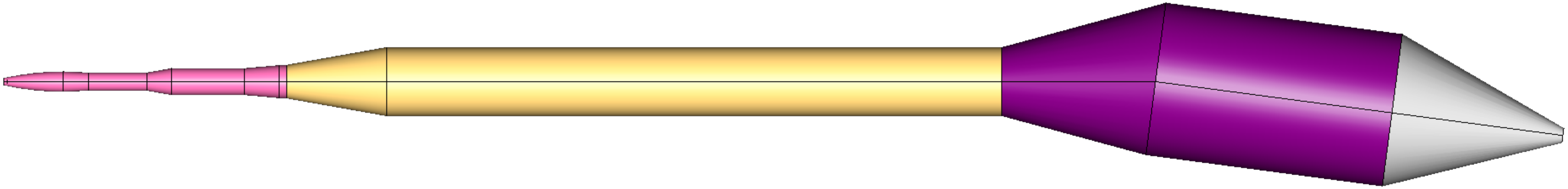
- Post-test CFD performed for comparisons to experimental data
- Six pressure values obtained from experiment
  - P1 = total pressure
  - P2-P5 = AOA/AOS pressure
  - P6 = manifolded static pressure



Geometry

- Probe OML obtained from laser scan of wind tunnel model
- Computational model includes cavity for total pressure port
  - Static ports not modeled
- Study performed to assess impact of cavity depth on predicted total pressure
  - Results showed that depths of 3, 5, and 7 internal diameters predict consistent total pressure
  - Cavity with depth of 5 internal diameters utilized for post-test CFD
- 8x6 sting included in computational model





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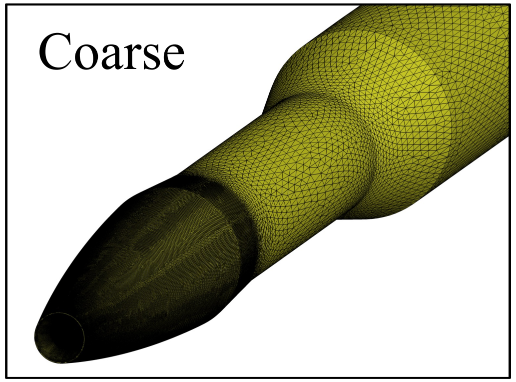
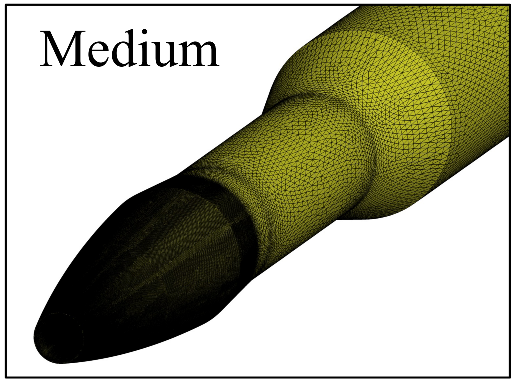
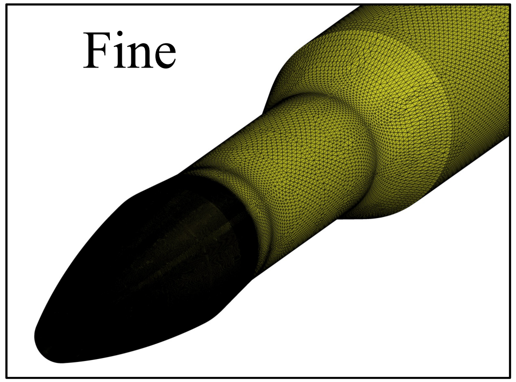
Grid Refinement Study

- Grids generated using HeldenMesh v3.03
- Refinement factor chosen to provide ~2x refinement
- y+ scaled manually by same factor

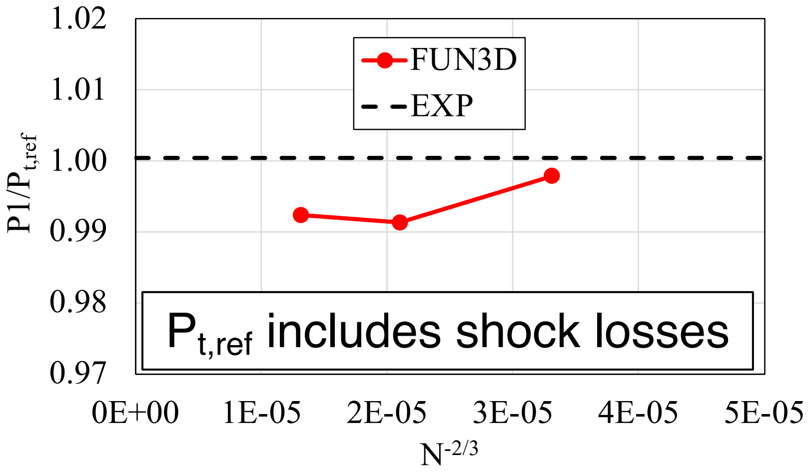
Grid	h	Y+	Nodes ×10^{-6}
Coarse	0.72	0.72	5.25
Medium	0.55	0.55	10.40
Fine	0.42	0.42	20.97

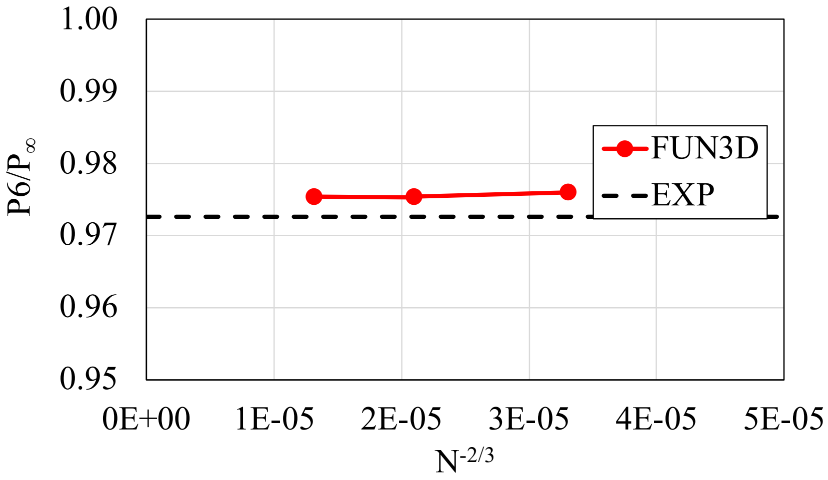


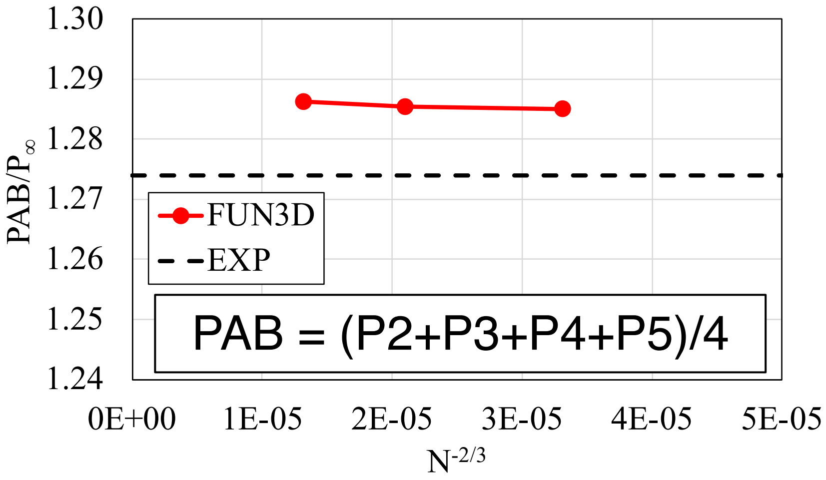




$\alpha = 0°$, $\phi = 0°$, M = 1.35, Sea Level







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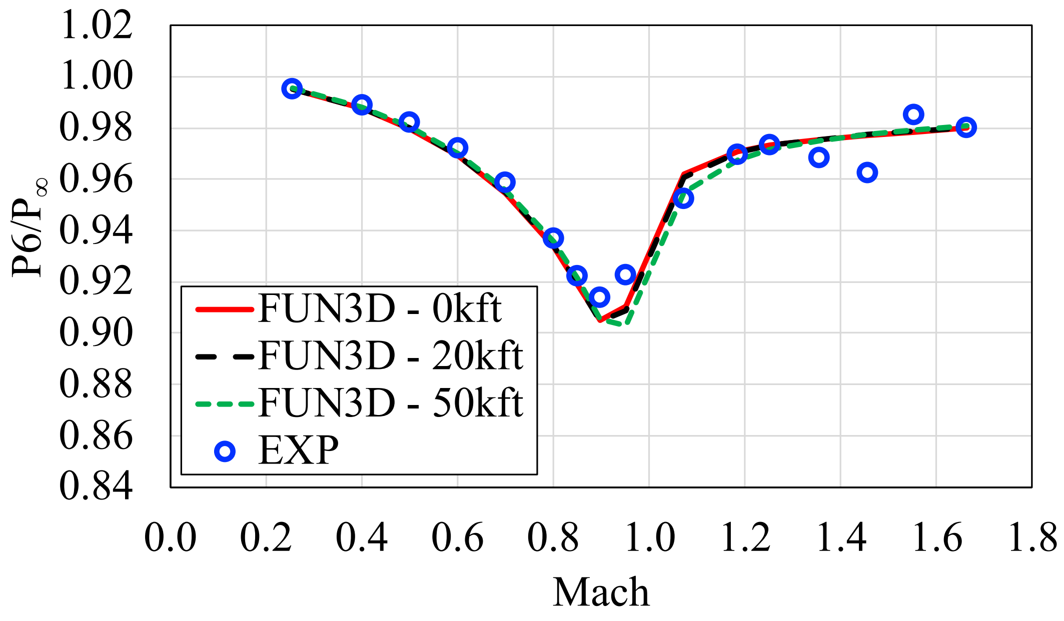
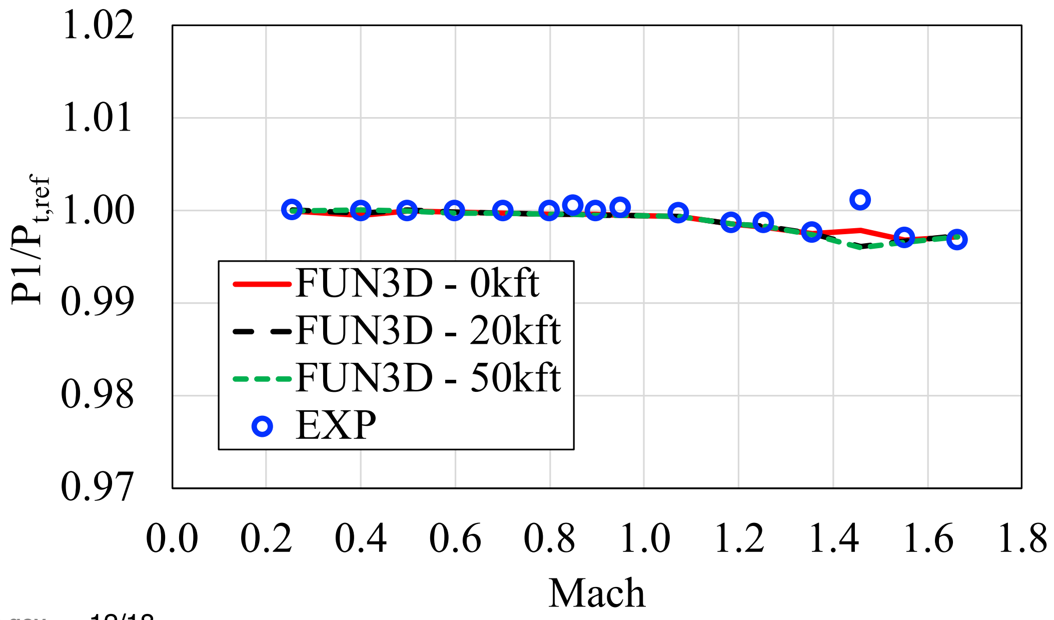
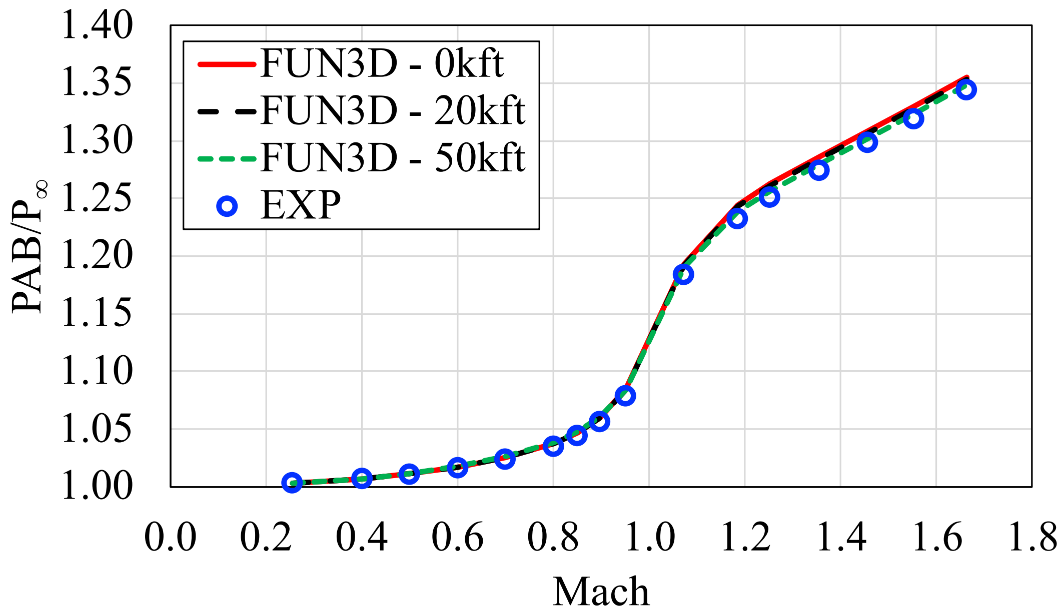
Mach Sweep Results – Altitude Study ($\alpha = 0°$, $\phi = 0°$)

- Altitude study performed to assess effects on predicted pressure
- Study considered altitudes of 0, 20000, and 50000 ft
- Results show minimal impact for altitudes considered
  - Small differences observed in PAB and P6 at 50000 ft







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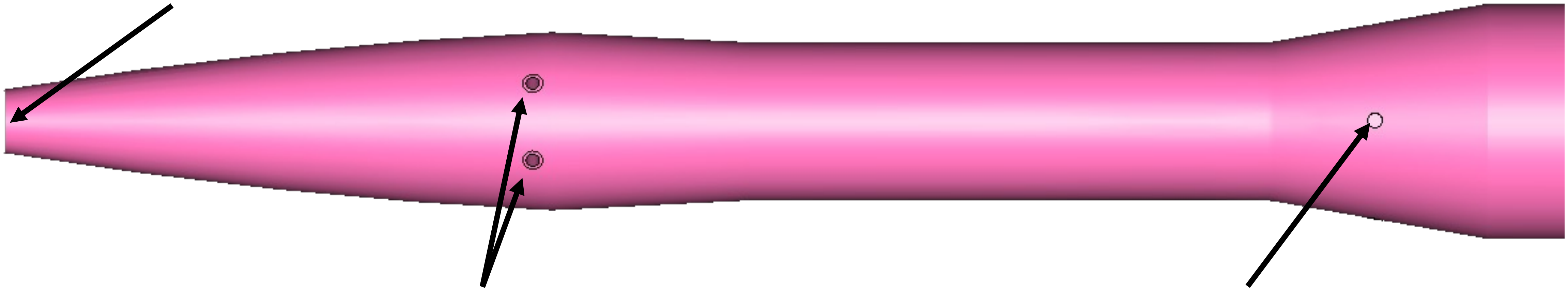
Modeling Ports – Geometry

- Study performed to assess impact of modeling static ports on predicted pressure
  - Four manifolded ports (forward)
  - Four independent ports (aft)
- Port diameters obtained from manufacturer
- Limited information for probe internals due to proprietary nature of probe
- Port locations obtained by hand-measurements of wind tunnel model



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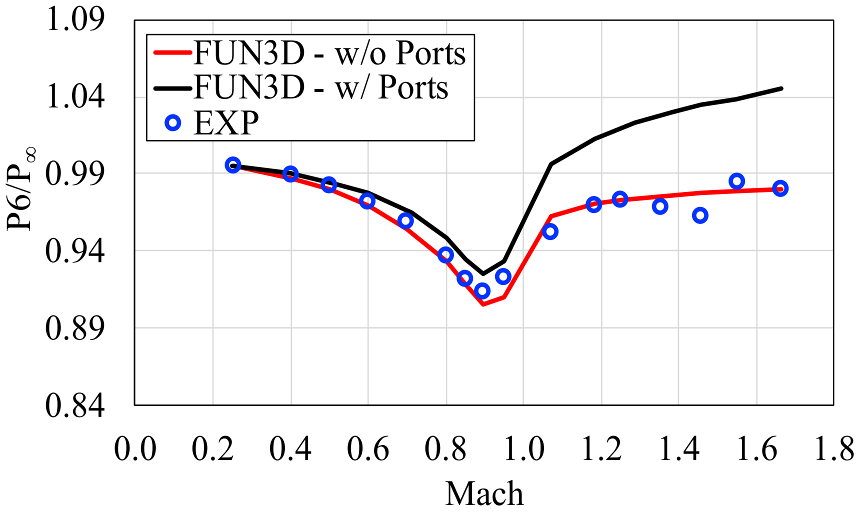
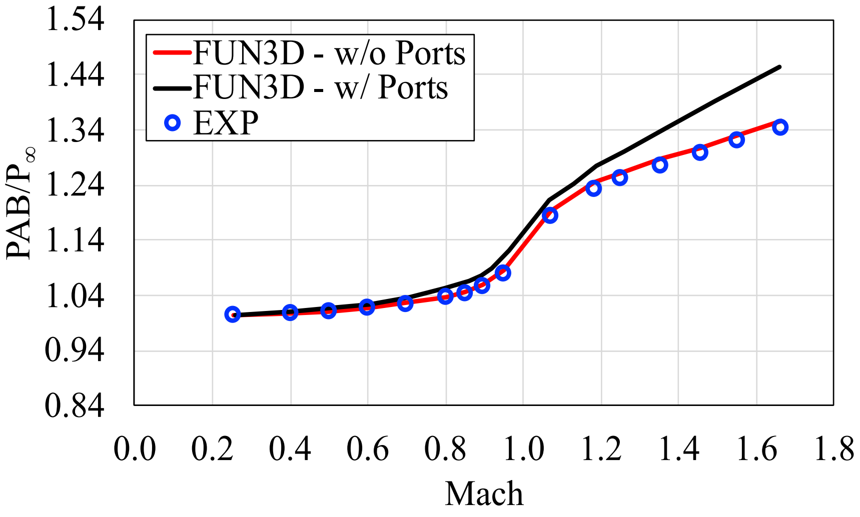
Modeling Ports – Mach Sweep Results

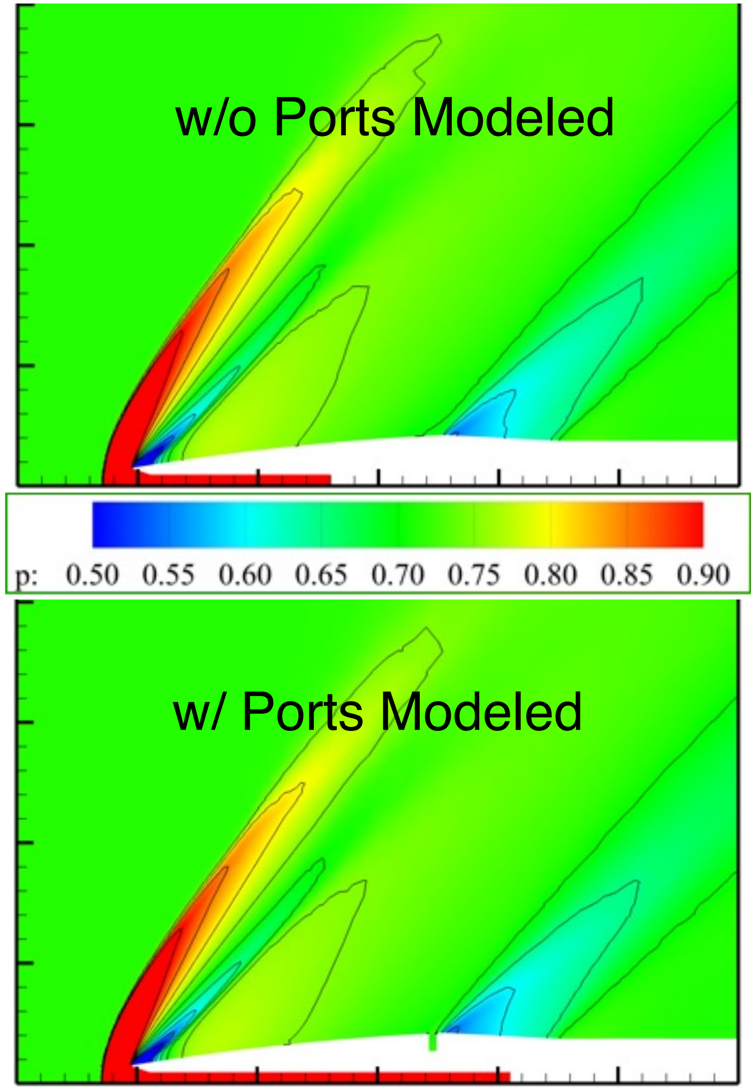
- Mach sweep results indicate that modeling ports results in higher pressure predictions
  - Observed for all ports
  - Differences shown to increase with Mach number
- Additionally, better agreement with experiment observed for model without ports
- Pressure contour plots illustrate favorable agreement between both models

$\alpha = 0°$, $\phi = 0°$, Sea Level





M = 1.35, $\alpha = 0°$, $\phi = 0°$, Sea Level



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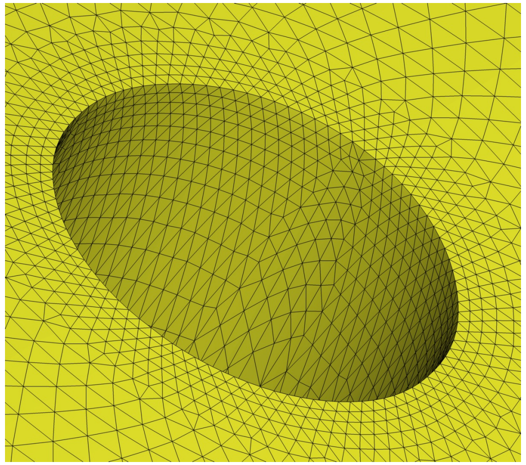
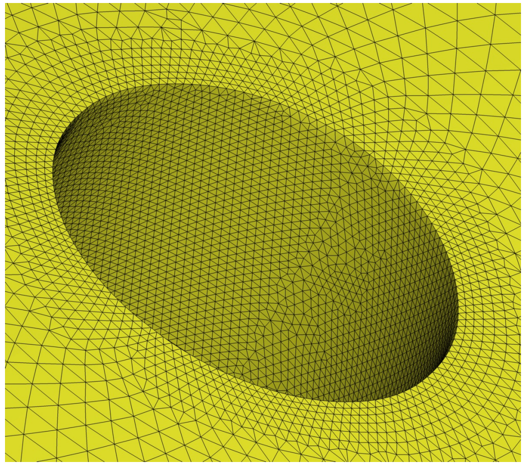
Modeling Ports – Port Refinement Study

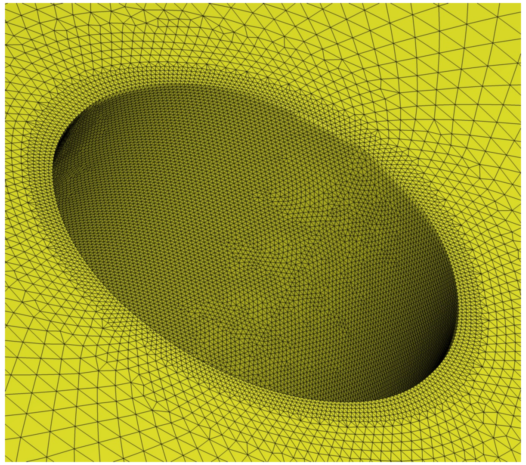
- Study performed to assess impact of port refinement on predicted pressures
- Port refinements consisting of 96, 140, and 270 points around the circumference considered
- Simulations performed at Mach 1.35 show good agreement between two finest grids
- Grid with 140 points around port circumference selected



96 points around circumference (baseline)

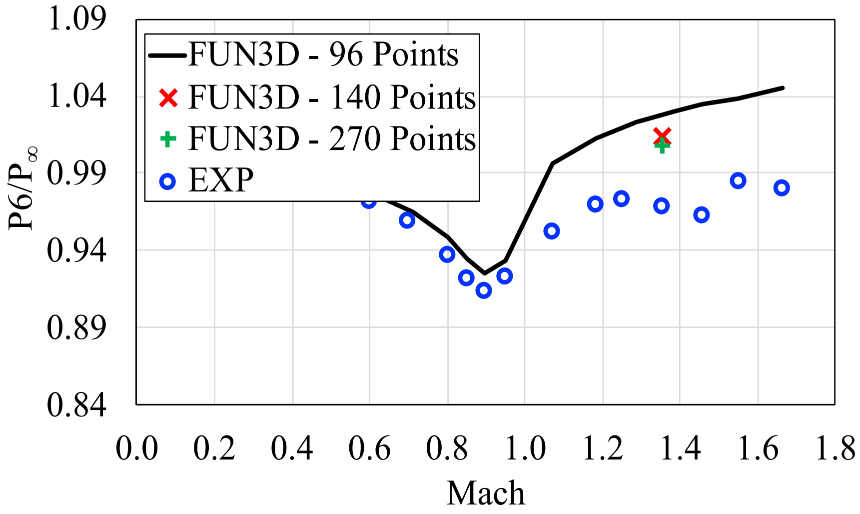


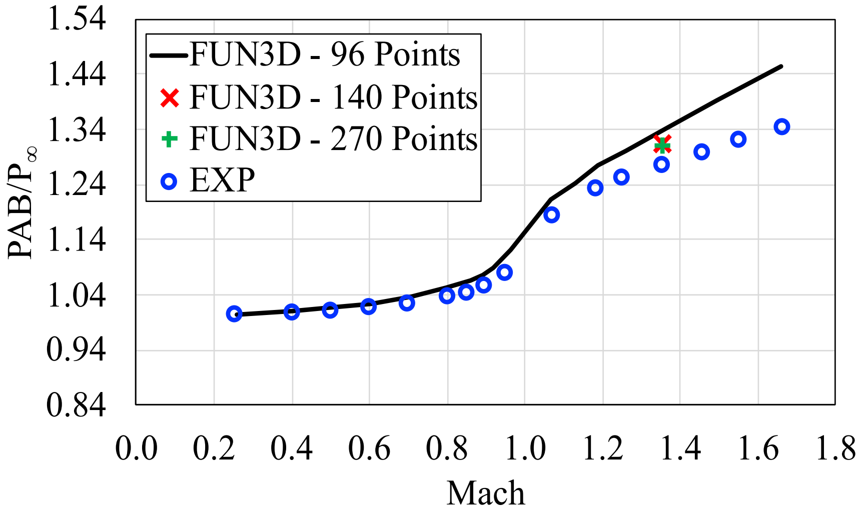
140 points around circumference



270 points around circumference

α = 0°, ϕ = 0°, Sea Level





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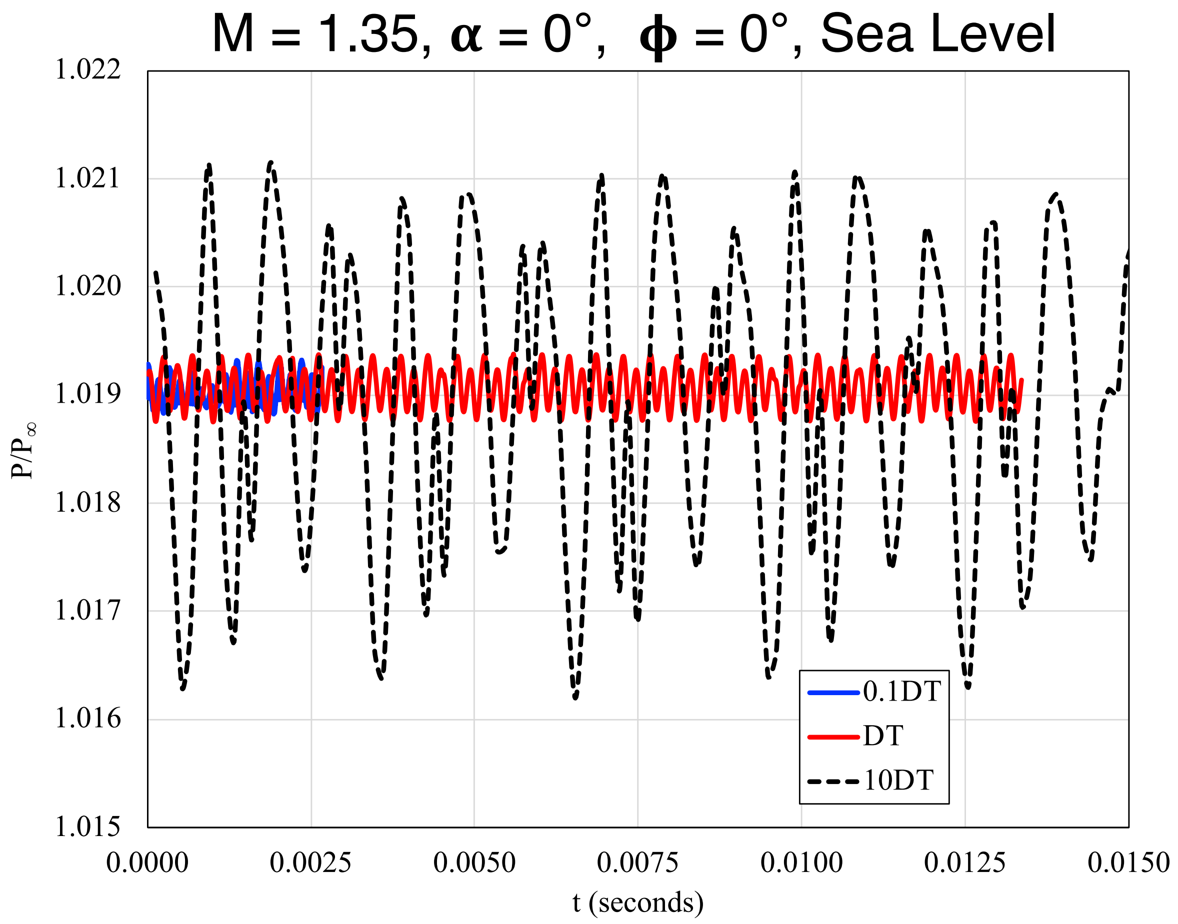
Modeling Ports – URANS

- URANS simulations performed for model with ports to assess any potential unsteadiness
- Baseline time step chosen to be 1/50th of approximate time needed to traverse length of port
  - Scaled by factor of 0.1 and 10 to assess impact of time step size
- Monitored static pressure in one of four manifolded ports to investigate unsteadiness
- Favorable agreement observed for two smallest time-step sizes with larger amplitude and lower frequency observed for the largest time step
- Time-averaged static pressure in good agreement for all time steps
- Additionally, time-averaged static pressure agrees favorably with RANS prediction

Case	Time Step (sec)	$(P/P_\infty)_{avg}$
0.1DT	1.34e-6	1.0190
DT	1.34e-5	1.0191
10DT	1.34e-4	1.0189
RANS	N/A	1.0189



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Summary

- FUN3D analyses performed in support of wind tunnel test of X-59 pitot probe
- Pretest CFD results illustrate insignificant impact of sting on predicted pressure
- Post-test CFD analyses included Mach sweep at $\alpha = 0°$, altitude study, and port modeling study
- Mach sweep illustrates favorable agreement between experiment and FUN3D for P1-P6
  - P6 scatter not captured in FUN3D predictions
- Altitude study results illustrate slight altitude effects at 50000 ft, with good agreement observed for 0 and 20000 ft
- Port modeling study shows that FUN3D predicts higher pressure (P2-P6) than observed in experiment when including the ports
- Efforts made to improve port predictions included a port refinement study and URANS analyses
- Port refinement study illustrated improved agreement with experiment as grid is refined
  - Predicted pressure still observed to be larger than that extracted from the surface
- URANS simulations show unsteadiness in ports but time-averaged results agree favorably with RANS prediction

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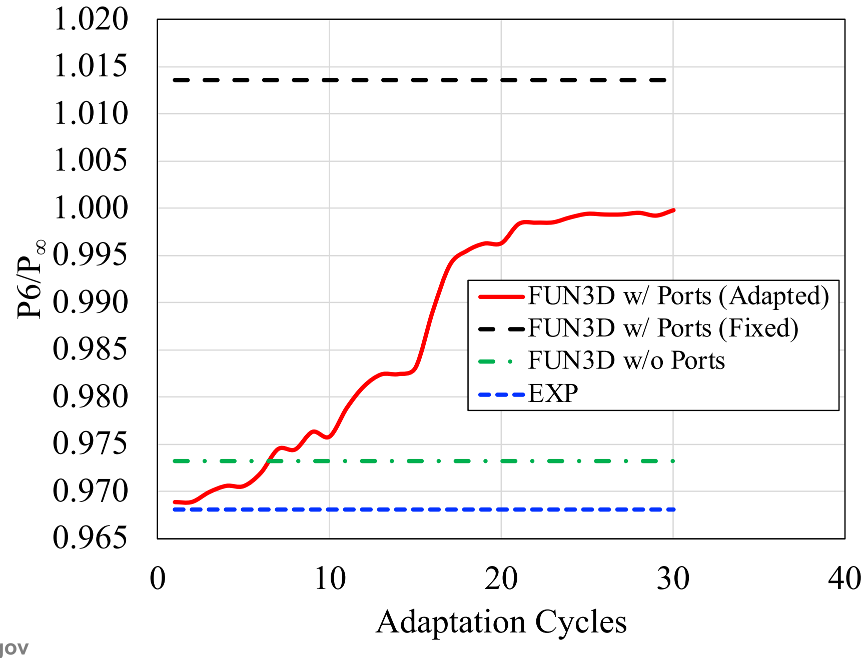
Modeling Ports – Grid Adaptation

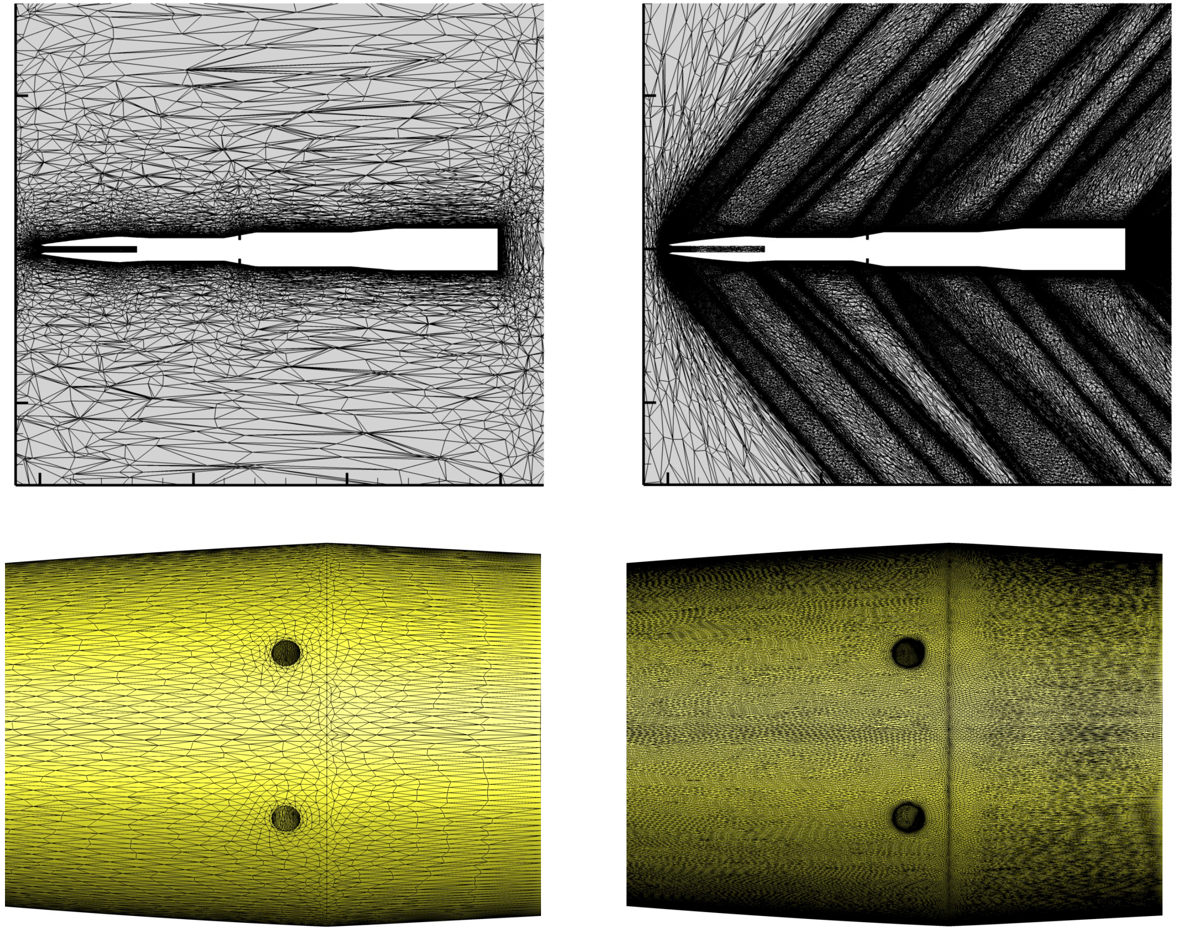
- Grid adaptation performed for Mach 1.35 to gain further insight into impact of grid refinement on port pressure
- Results show that adapted grid predictions closer to experiment than for the fixed grid
- Adapted grid still predicts higher pressure than observed in experiment

M = 1.35, α = 0°, ϕ = 0°, Sea Level



Starting Grid
355,497 Nodes

Final Grid
51,266,446 Nodes



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FUN3D Flow Solver

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  - More information available at: https://fun3d.larc.nasa.gov/
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- van Leer flux limiter employed for Mach > 0.8
- Spalart-Allmaras model with negative provisions, rotation correction (RC), and Quadratic Constitutive Relation (QCR-2000) employed for turbulence
- Sketch-2-Solution utilized for grid adaptation study
  - Internal grid adaptation capability
  - Both surface and volume grid adaptation
- Simulations performed steady-state
  - Time-accurate simulations performed as part of port modeling study