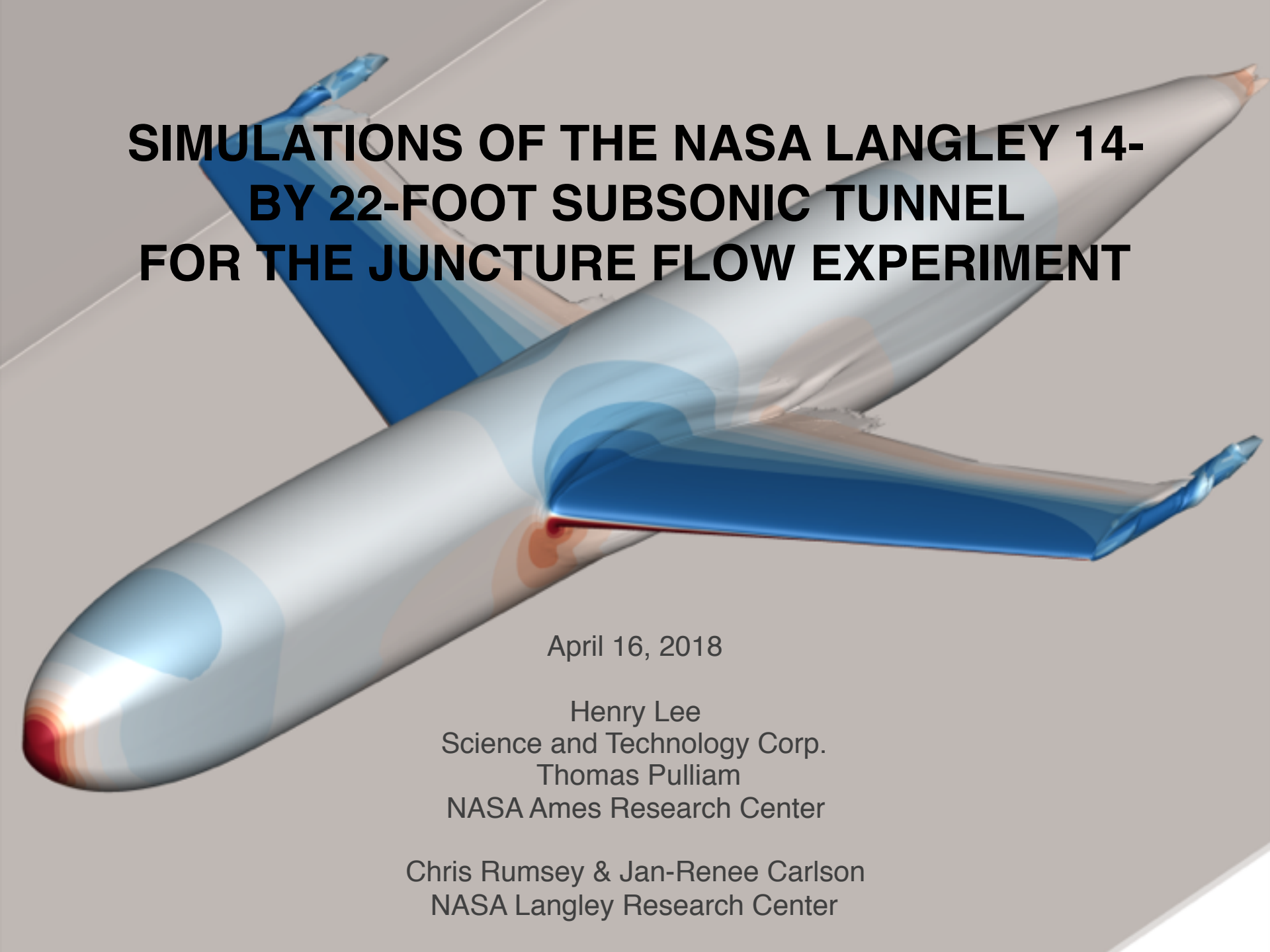

SIMULATIONS OF THE NASA LANGLEY 14-BY 22-FOOT SUBSONIC TUNNEL FOR THE JUNCTURE FLOW EXPERIMENT

April 16, 2018

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Science and Technology Corp.
Thomas Pulliam
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NASA Langley Research Center

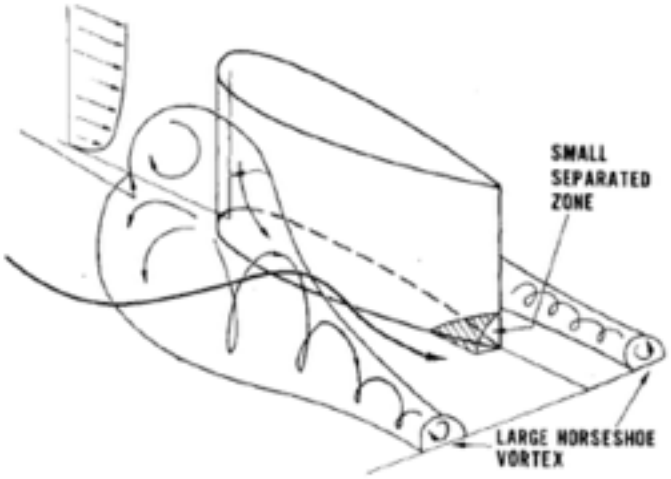
Juncture Flow Experiment

Sponsored by NASA's Transformative Aeronautics Concepts Program's Transformational Tools and Technologies (T^3) project

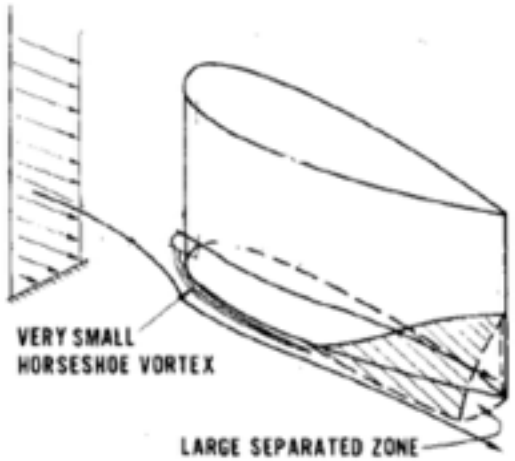
- Substantial effort to investigate the origin of separation bubbles found in wing-body juncture zones
- Primary goal is to gather validation level data, for future CFD code & turbulence model development
- Multi-year effort including several large-scale wind tunnel tests
  - First set of entries just finished: Nov 2017-April 2018
  - Planned Entries in 2019, 2020

Juncture Flow Physics

- Flow physics of juncture flows is complex
  - Several vortical structures coexist: e.g., Horseshoe Vortex (HSV), corner vortex, stress-induced vortex
  - Many factors: incoming boundary layer momentum thickness, wing bluntness, and wing sweep, etc



(a) thick boundary layer

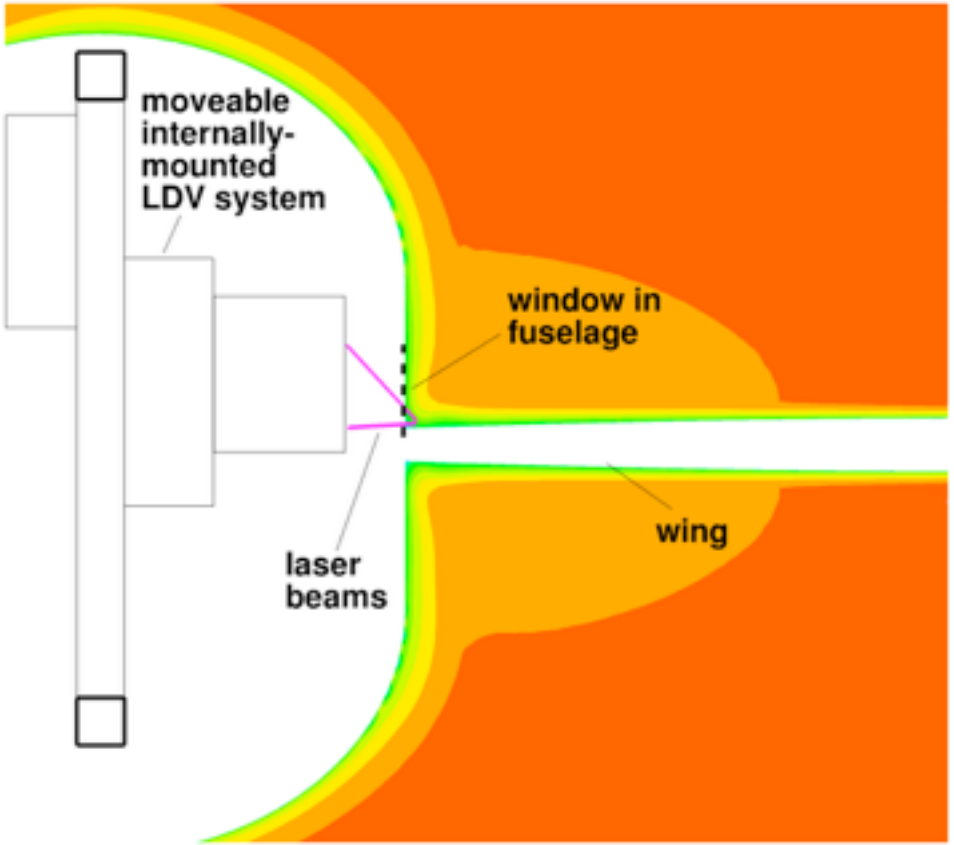


(b) thin boundary layer

Model proposed by Barber et al.

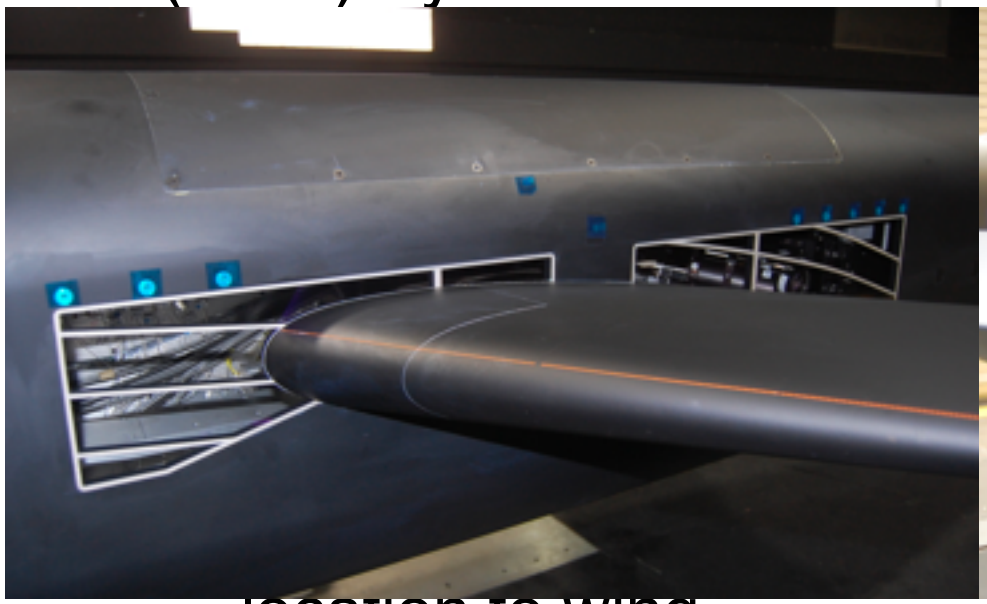
Juncture Flow LDV

- Use internal Laser Doppler Velocimetry (LDV) system
  - Mounted inside of the fuselage
  - Movable three-axis traverse system
  - Measure the flow field through window on fuselage
  - Closest possible location to wing-body juncture



Juncture Flow LDV

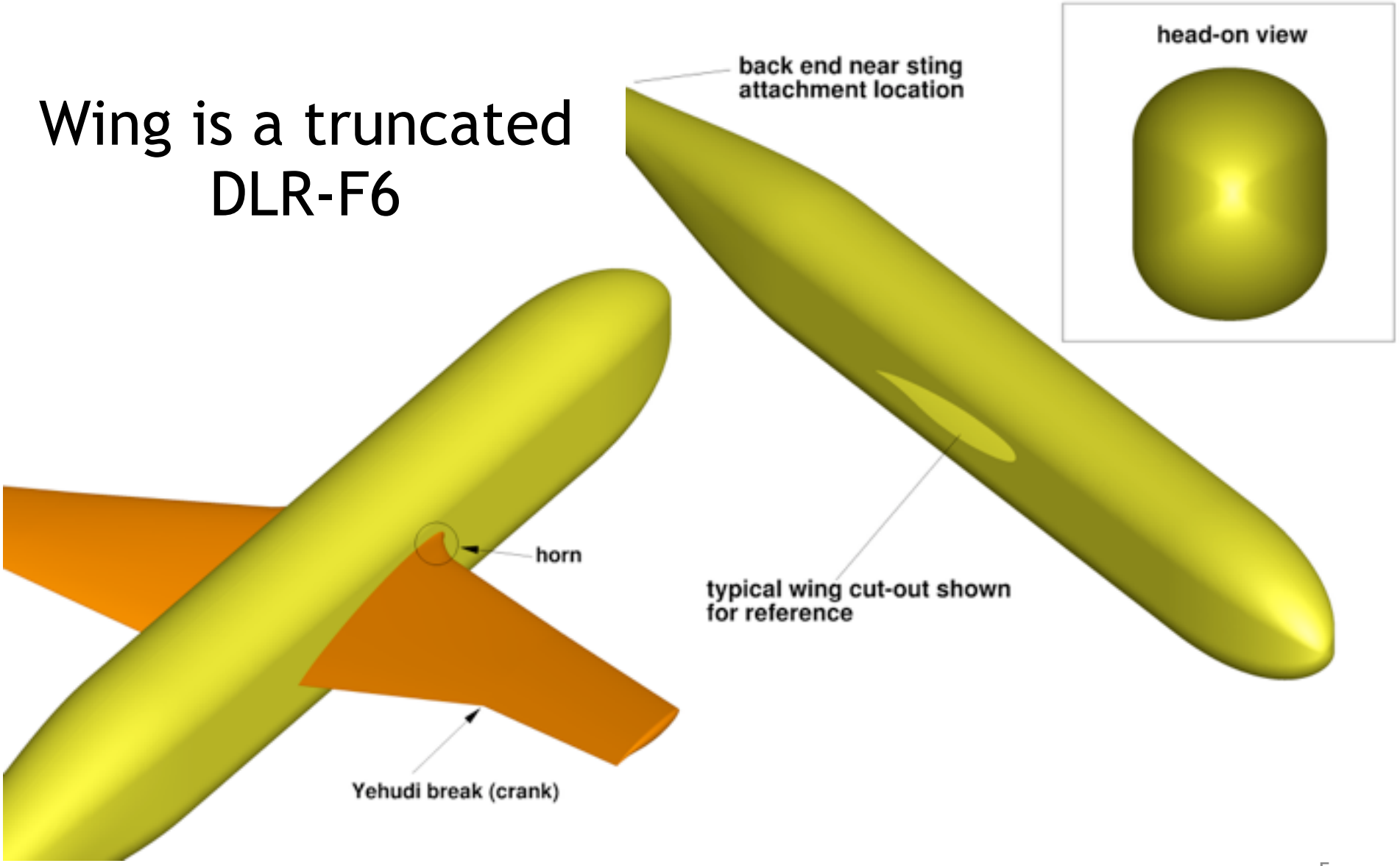
- Use internal Laser Doppler Velocimetry (LDV) system



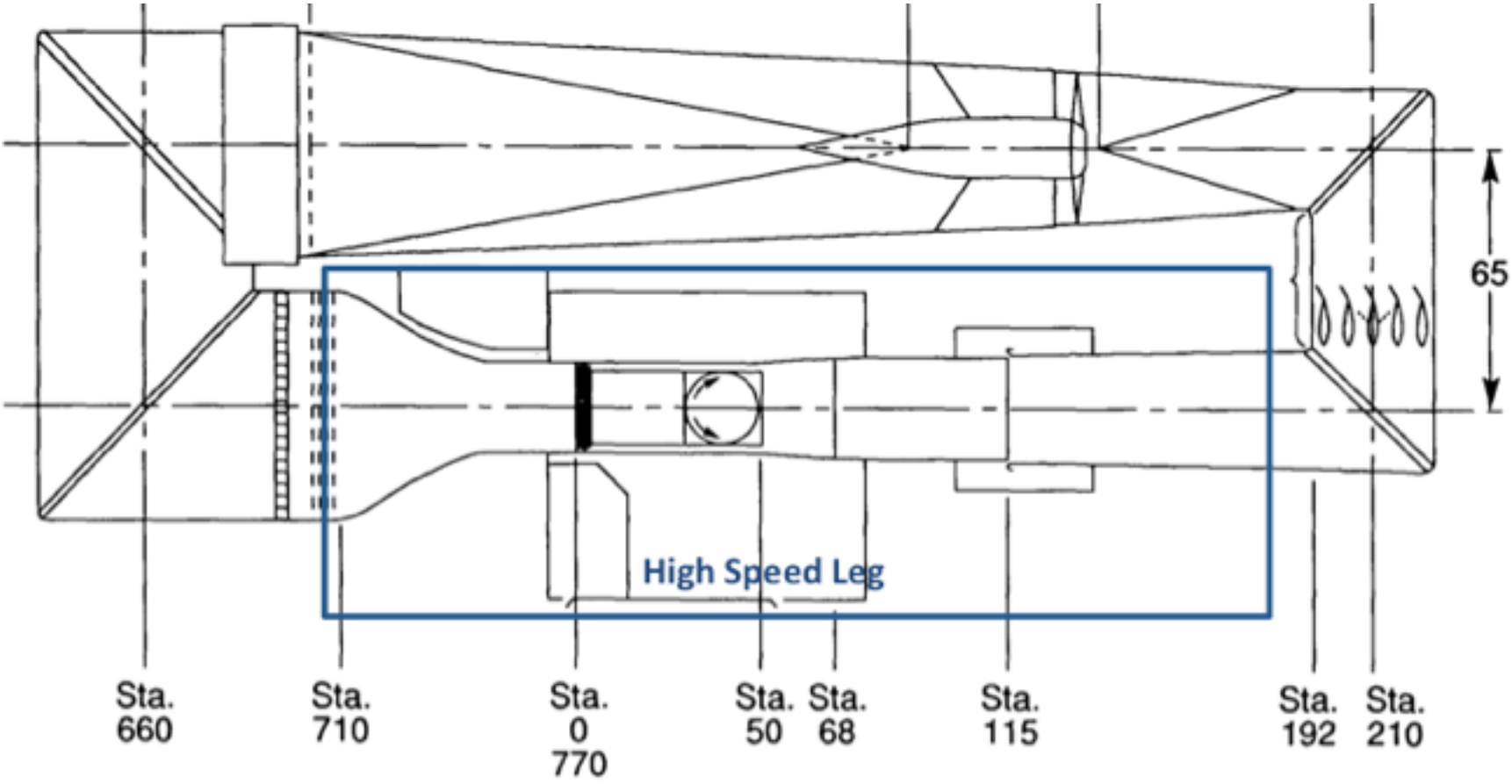
location to wing-body juncture

Juncture Flow Model Details

Wing is a truncated DLR-F6

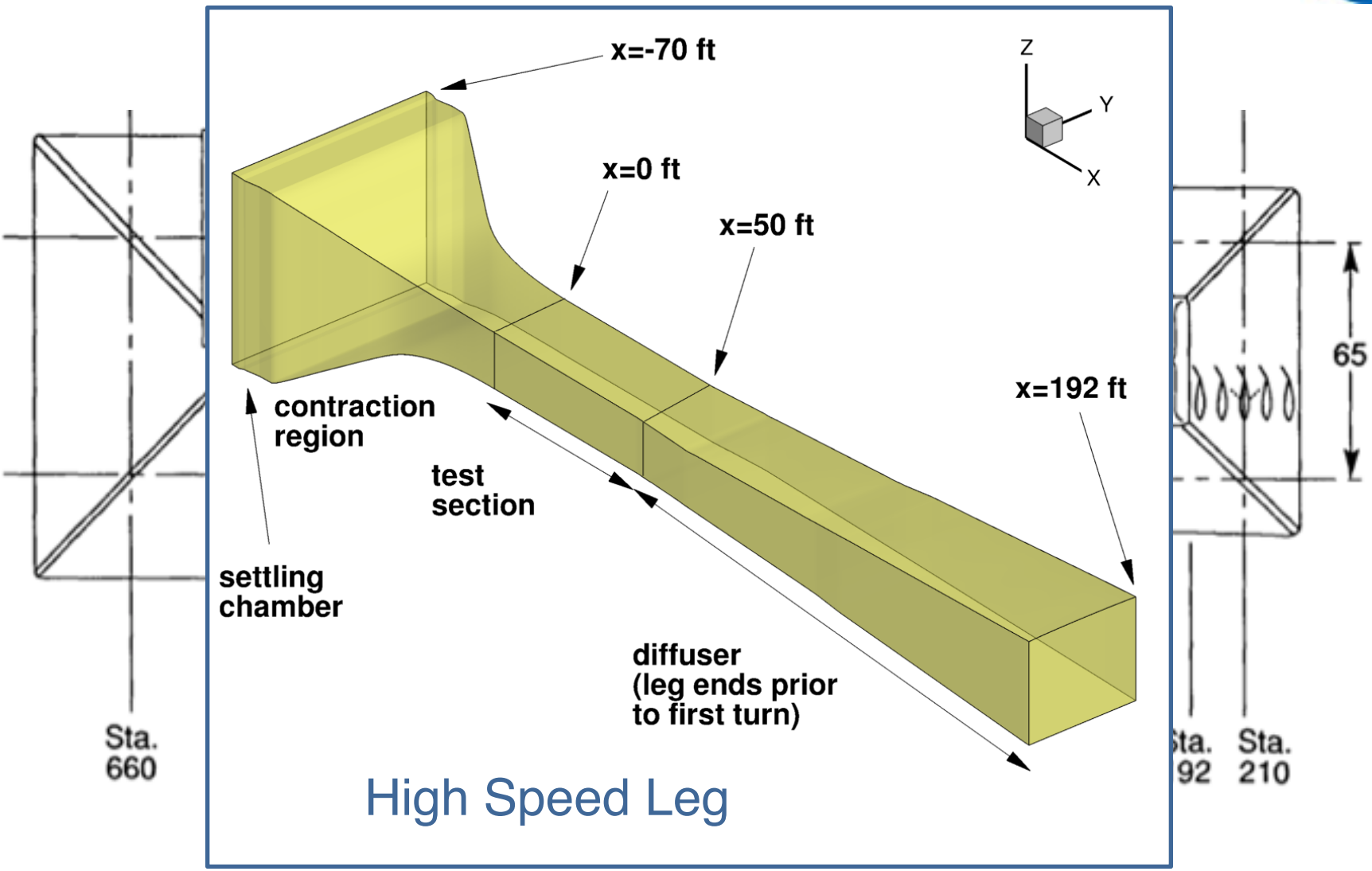


14x22 Wind Tunnel



Mach 0.2
Reynolds Number 2.4M

14x22 Wind Tunnel



Mach 0.2
Reynolds Number 2.4M

Introduction

- Juncture Flow (JF) Experiment
  - Heavy collaboration between CFD and WT design team
    - CFD used extensively in the experiment design
    - Companion CFD runs for all risk assessment experiments
  - Publications so far:
    - AIAA 2016-1557, AIAA 2017-4127, AIAA 2016-4126, NASA TM-2016-219348, etc
- Tasked to perform various parametric studies using CFD:
  - Effect of support hardware
  - Effect of wind tunnel walls on measurements

Introduction cont.

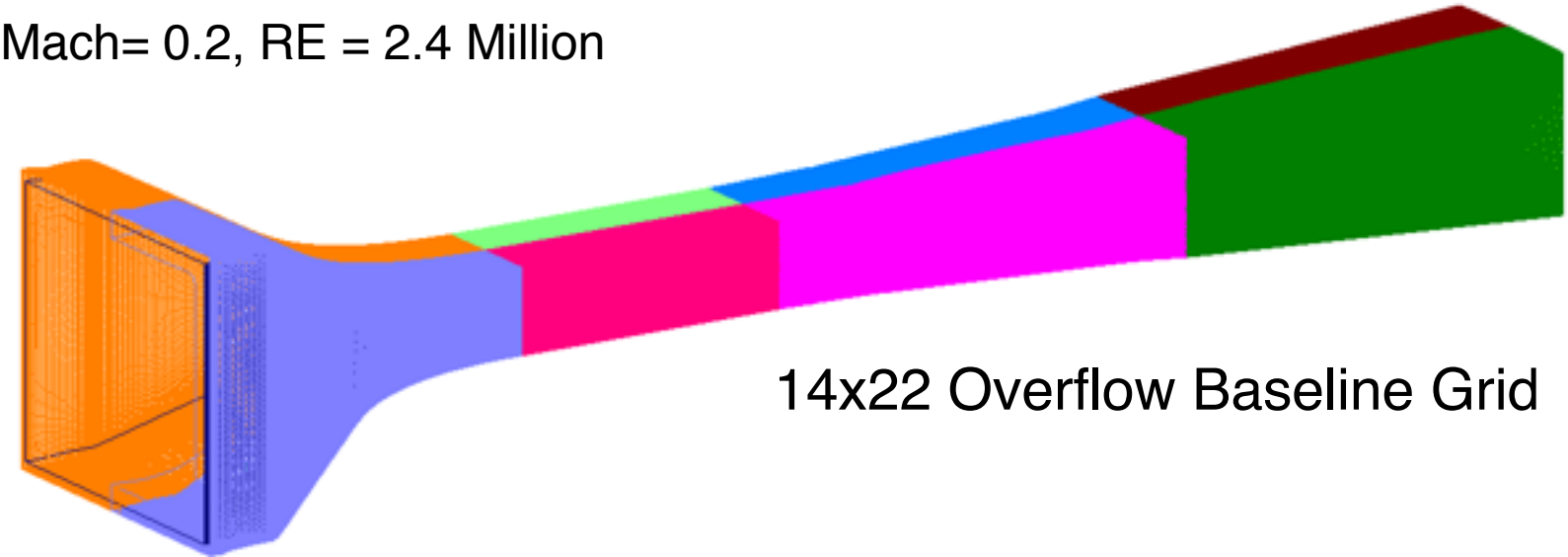
- CFD parametric studies approach:
  - Run 14x22 empty tunnel
    - Grid resolution study
    - Tunnel speed calculations
    - Solution acceleration approaches
  - Run 14x22 with JFM installed
    - Run with various support hardware included
    - Determine effect of wind tunnel walls

Introduction: Difficulties discovered

- CFD simulations of 14x22 empty tunnel
  - CFD tunnel is very sensitive to changes in back pressure
  - Long process:
    - Manual changes to back pressure
    - Slow to propagate downstream
  - Corner Separation
- CFD simulations with JFM installed
  - Determining tunnel speed - calibration point covered by model
  - Corner separation present in most cases
  - Tunnel speed is very sensitive
  - Inflow/Outflow BC issues

14x22 Empty Tunnel Studies

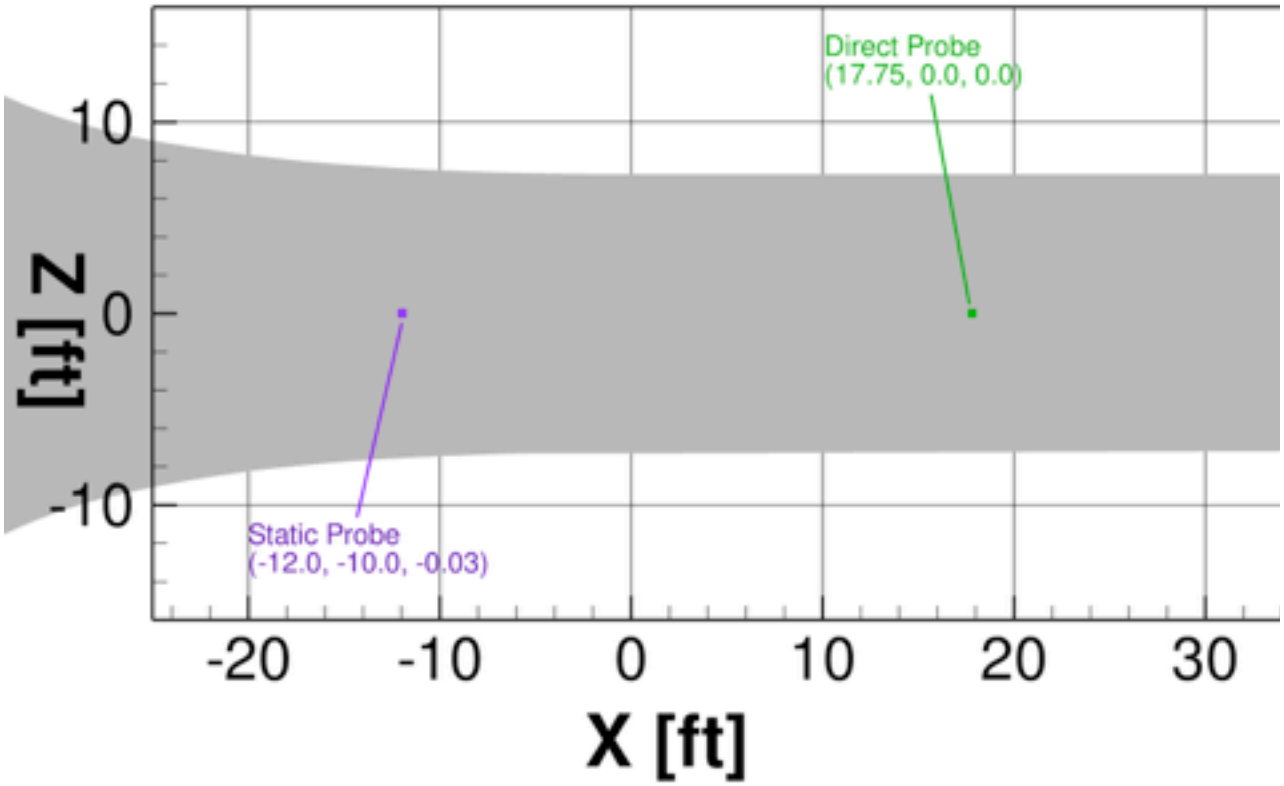
- Overset structured grids, built with Chimera Grid Tools
  - Coarse (9.3M), Medium (41.6M), Fine (118.7M)
- Overflow 2.2N
- 3rd-Order Roe upwind RHS, ARC3D Beam-Warming scalar pentadiagonal LHS
- Low-Mach preconditioning
- Spalart-Allmaras turbulence model + rotational correction + QCR
- Fully Turbulent, Steady State
- Inflow BC: Total Pressure/Temperature (P0, T0)
- Outflow BC: Back Pressure (Pratio = P0/Pexit)
- Mach= 0.2, RE = 2.4 Million



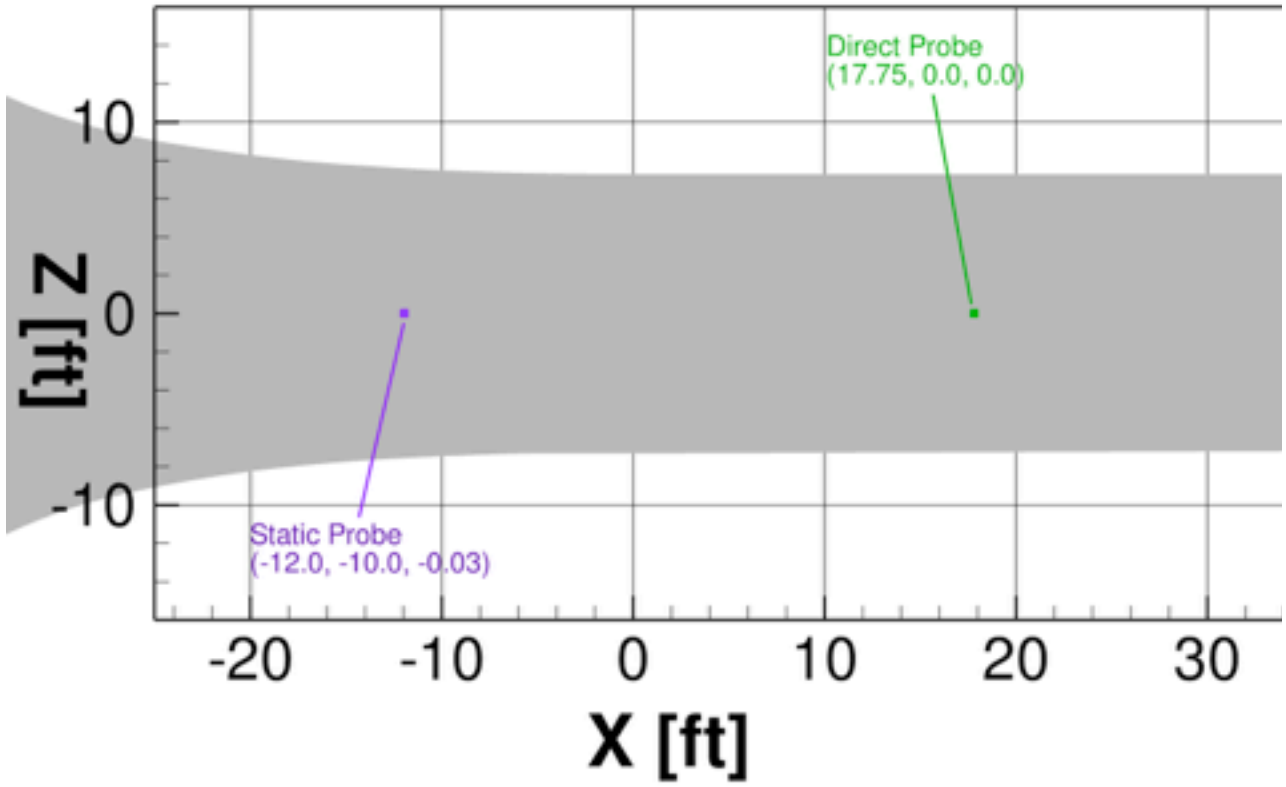
14x22 Overflow Baseline Grid

14x22 Tunnel Speed Calculation

- Tunnel Speed Calculation
  - Direct probe at (17.75,0.0,0.0)
    - Calibration point
    - Model is often located here
  - Calculated using wind tunnel method:
    - Uses total pressure & static pressure “probe” values from their locations
    - Calibrated equations -> tunnel speed



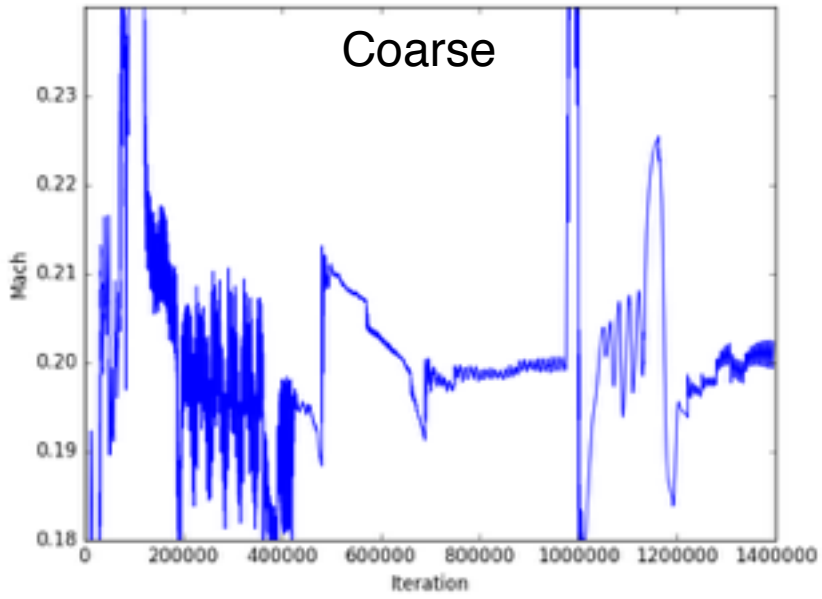
14x22 Tunnel Speed Calculation

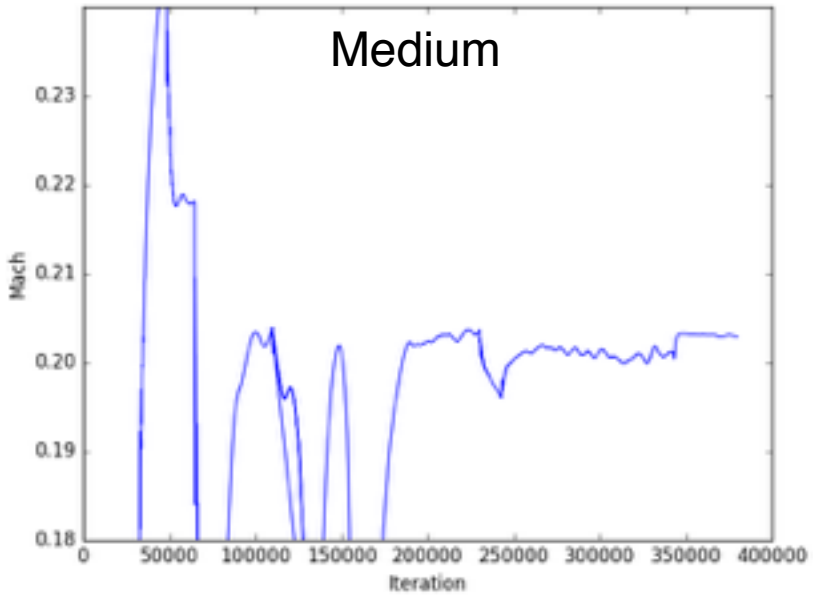


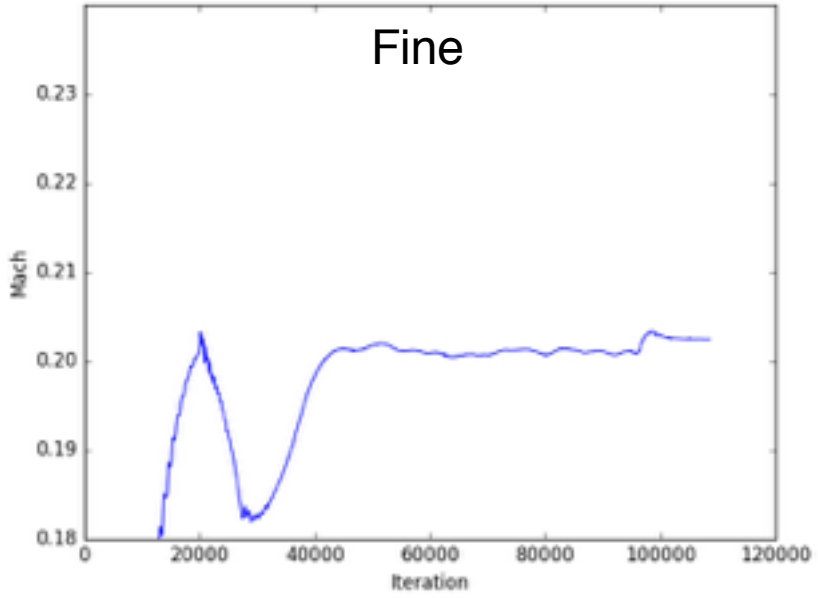
Grid	Calculated Mach	Direct Mach Probe
Coarse	0.2023	0.1995
Medium	0.2029	0.2004
Fine	0.2025	0.2000

Mach values are nearly identical: can calculate wind tunnel speeds using same method

14x22 Grid Refinement (Overflow)

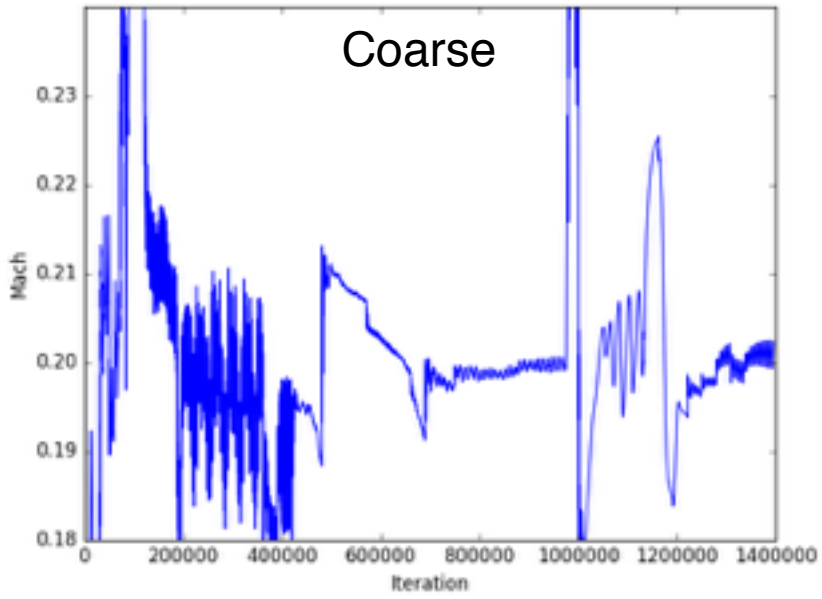


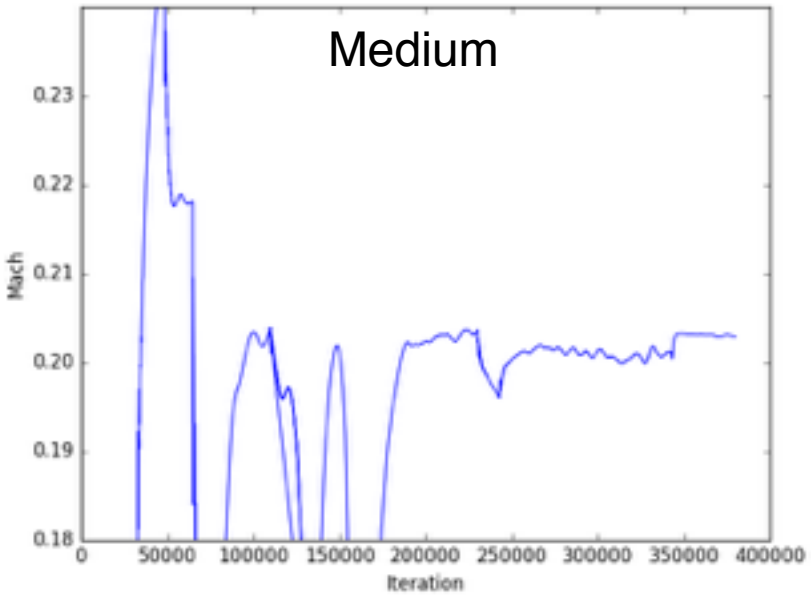


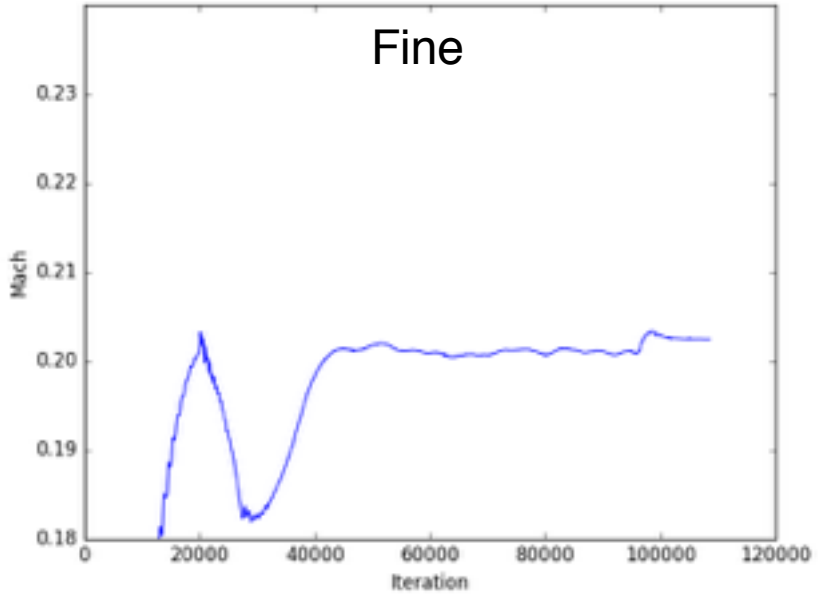


- Mach number of tunnel vs iteration
- Tunnel speed is calculated using pressure probes

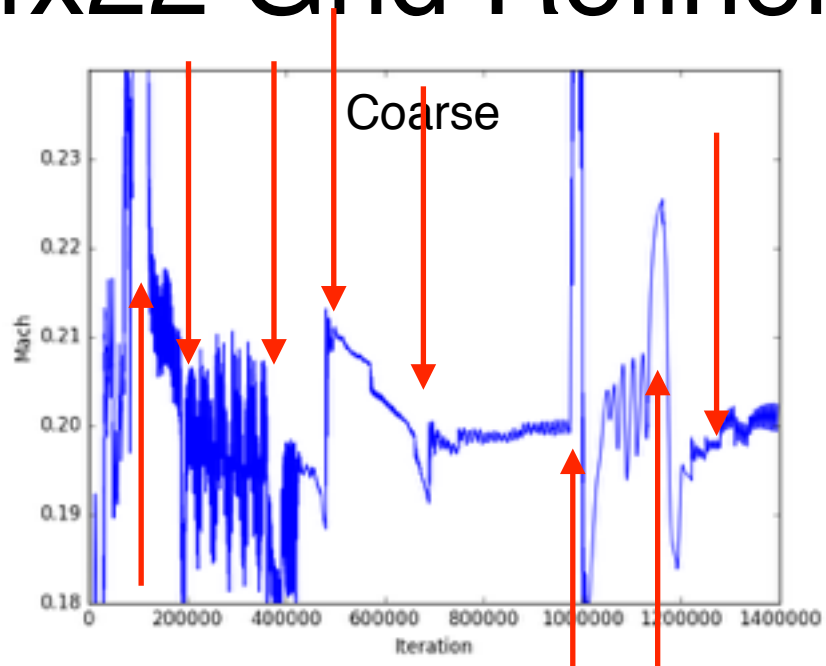
14x22 Grid Refinement (Overflow)

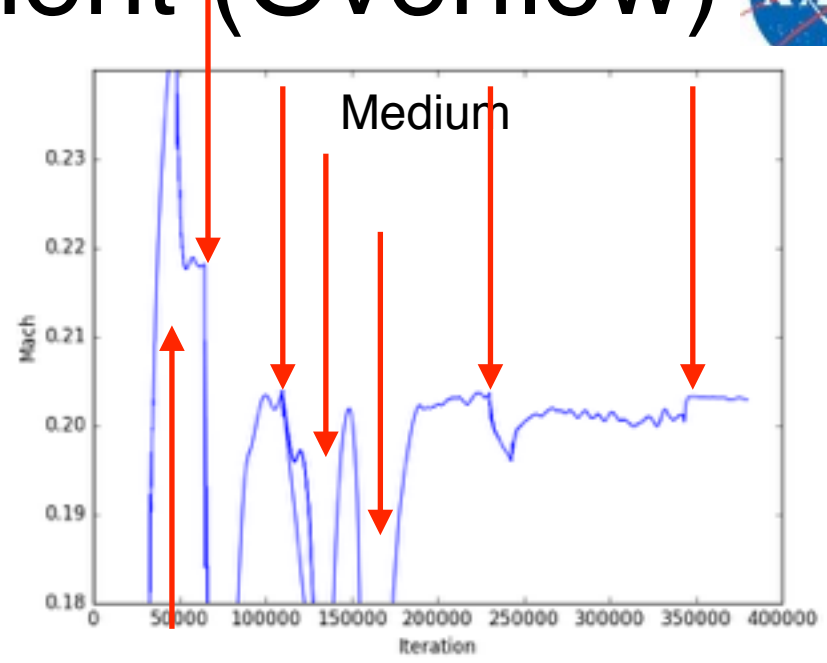


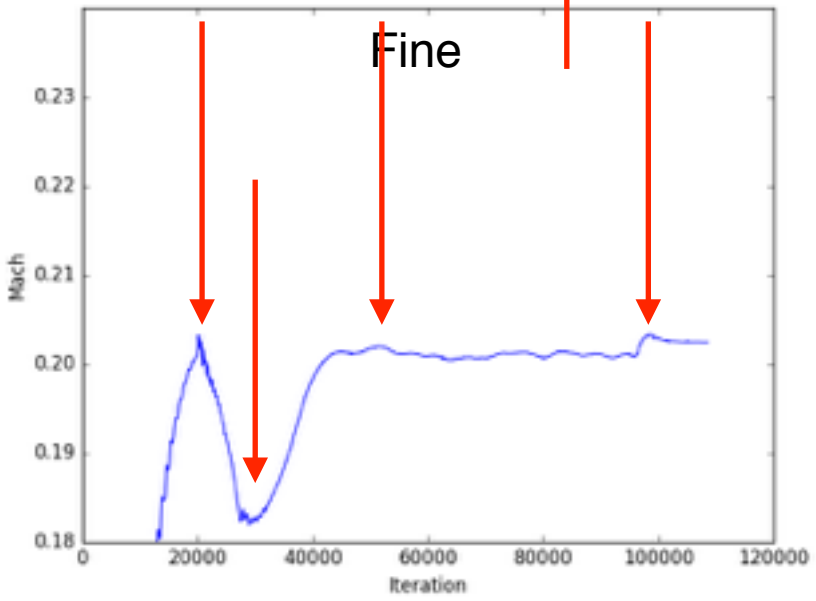




14x22 Grid Refinement (Overflow)

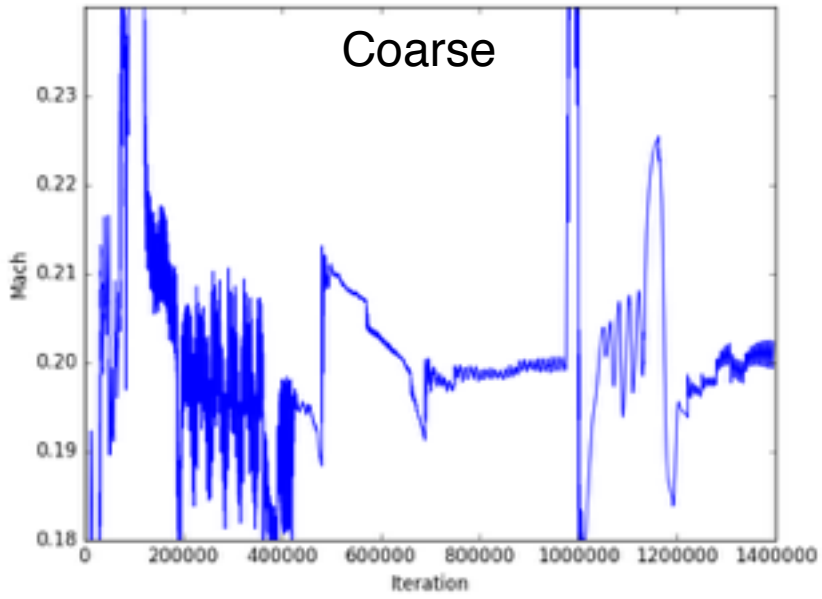


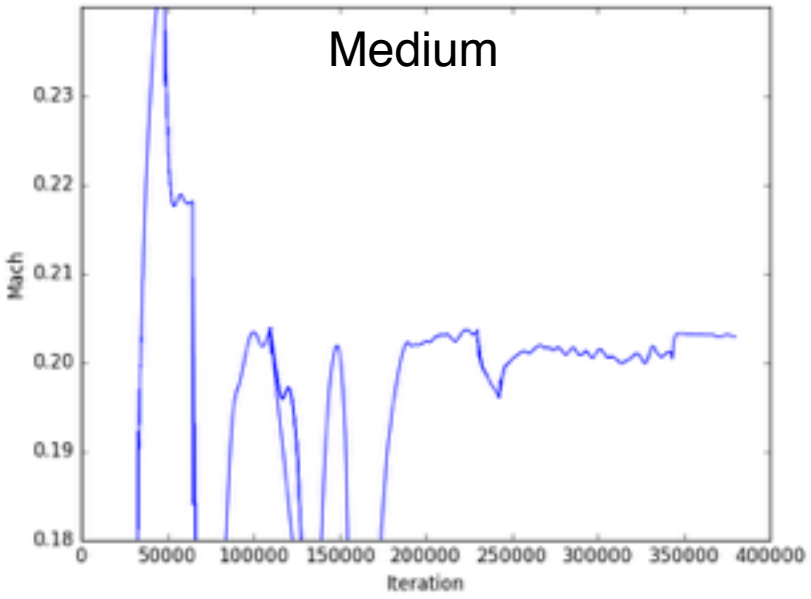


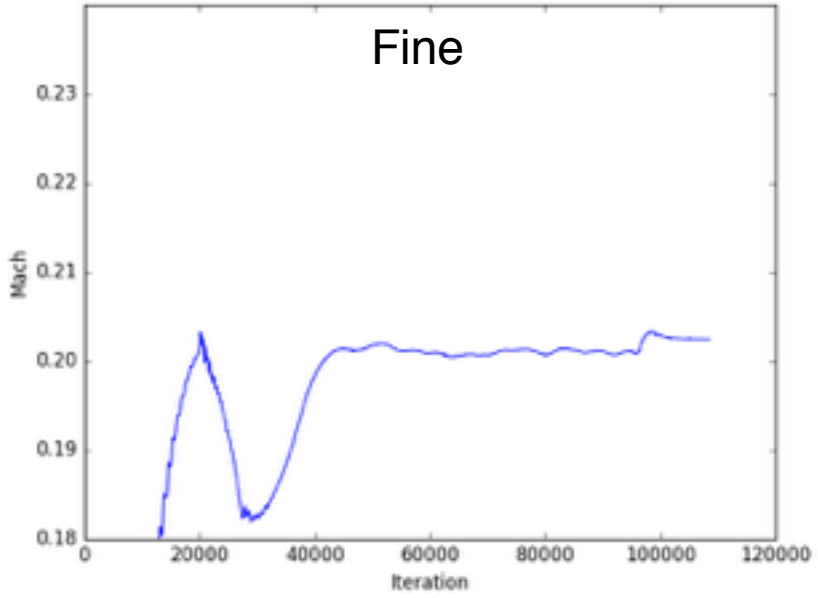


- Spikes/drops caused by manual changes in back pressure
- Each change required 10,000 steps to “settle”
- Solutions require 100,000 to 1,000,000+ steps!

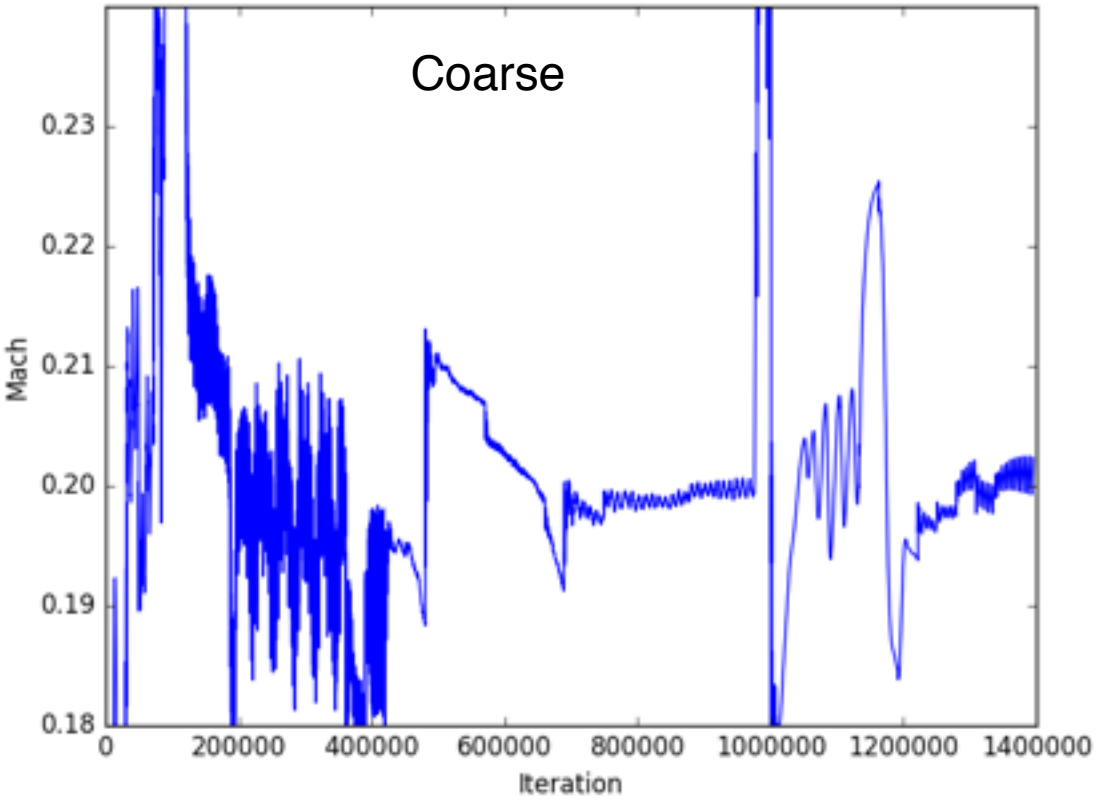
14x22 Grid Refinement (Overflow)

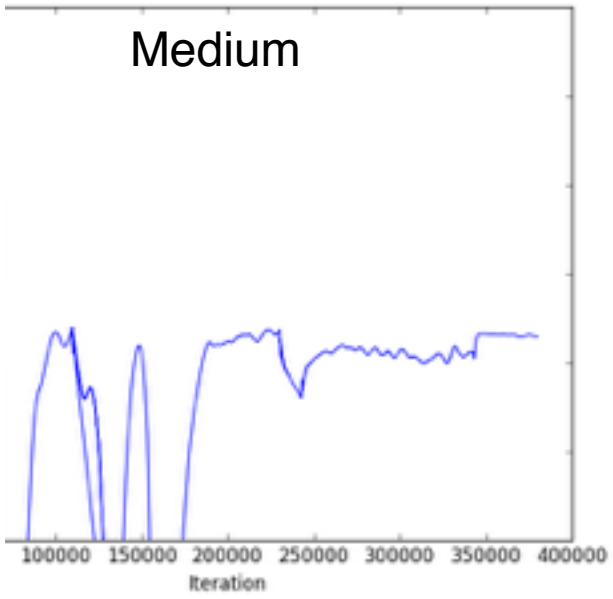


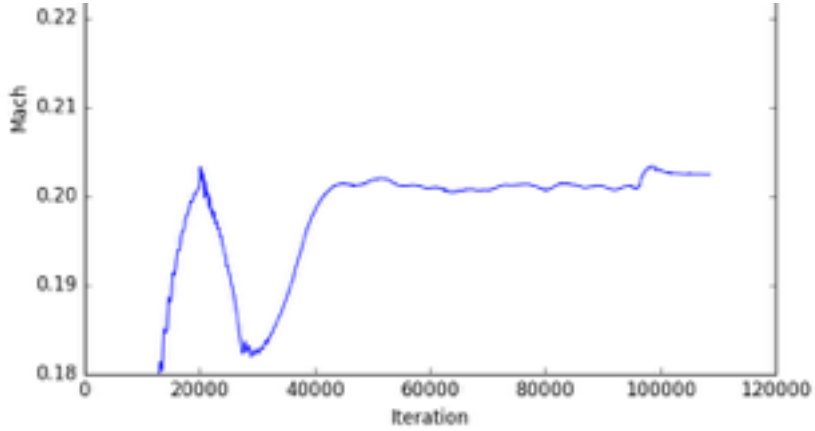




14x22 Grid Refinement (Overflow)

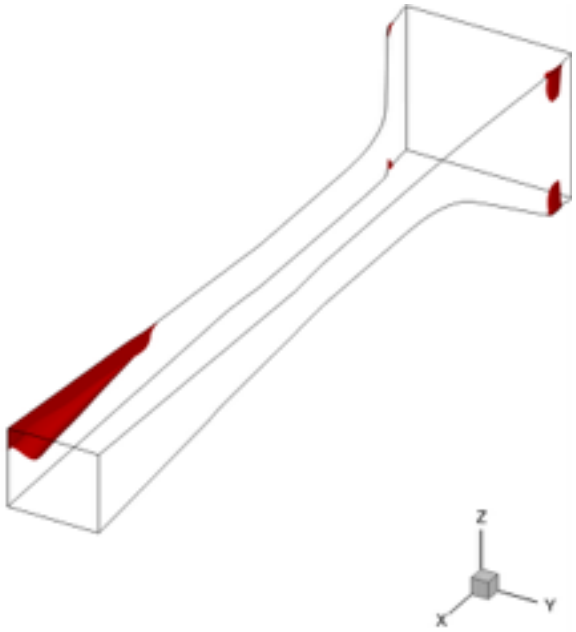




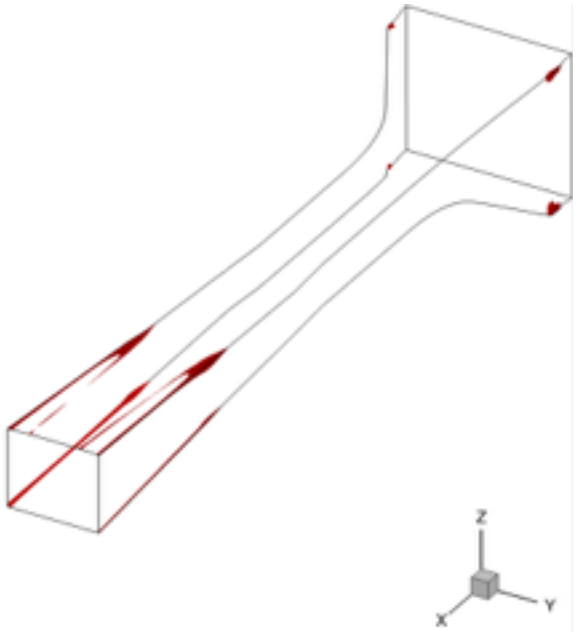


- Coarse grid tunnel speed was extremely noisy

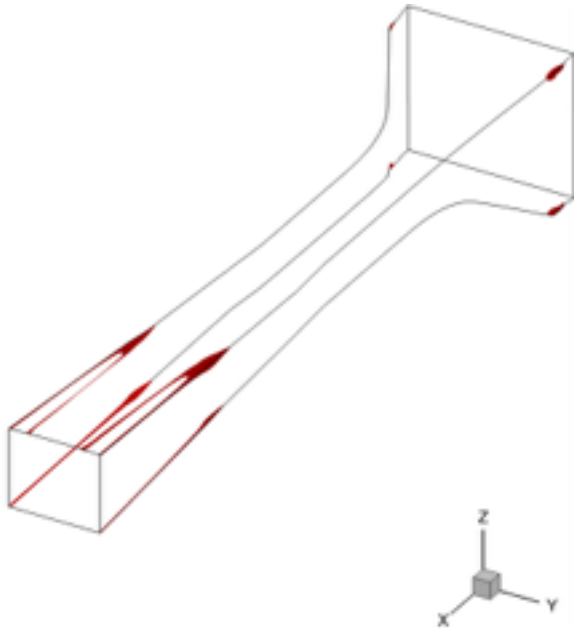
14x22 Grid Refinement



Coarse



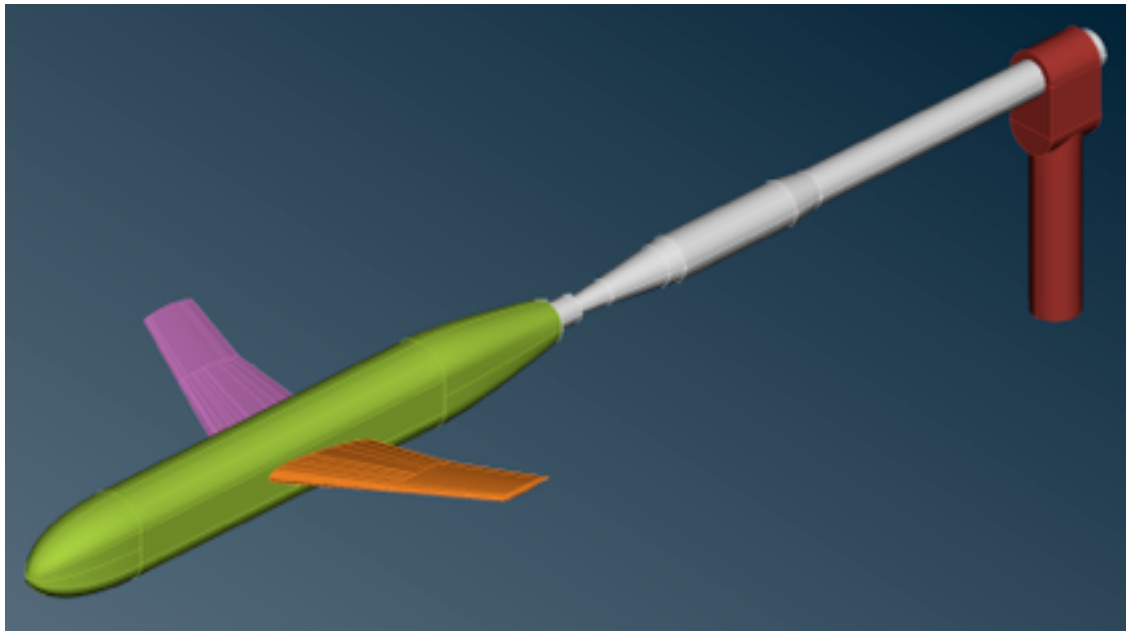
Medium



Fine

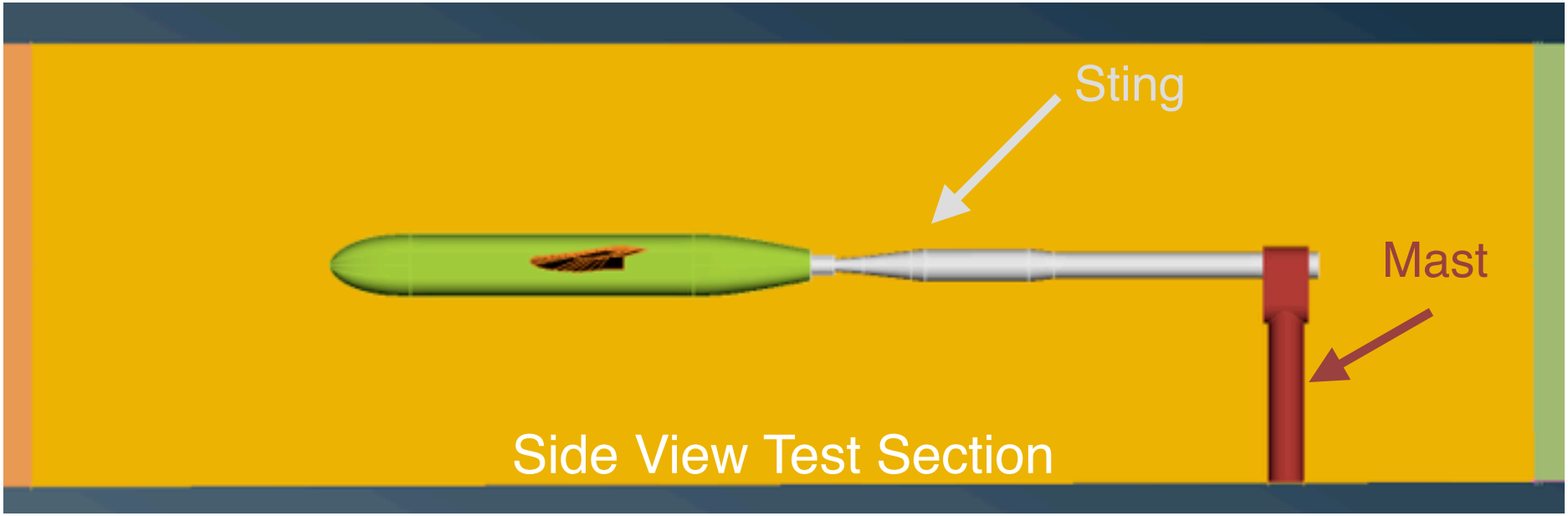
- Red isosurfaces - reverse flow
- Large diffuser separation in Coarse grid
- Tunnel Mach number was “noisy” due to corner separation

Juncture Flow Model with WT walls



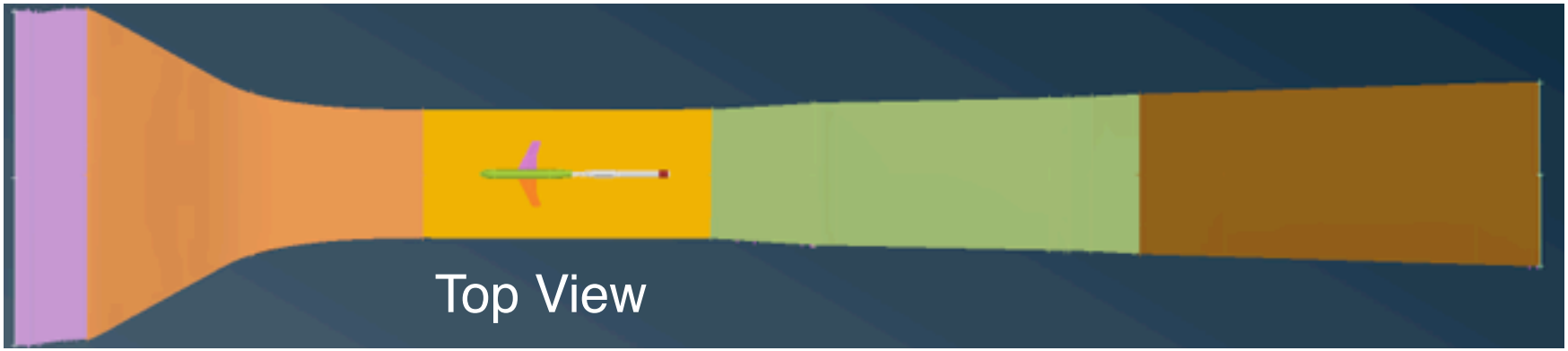
JFM 8% model with roll sting and mast

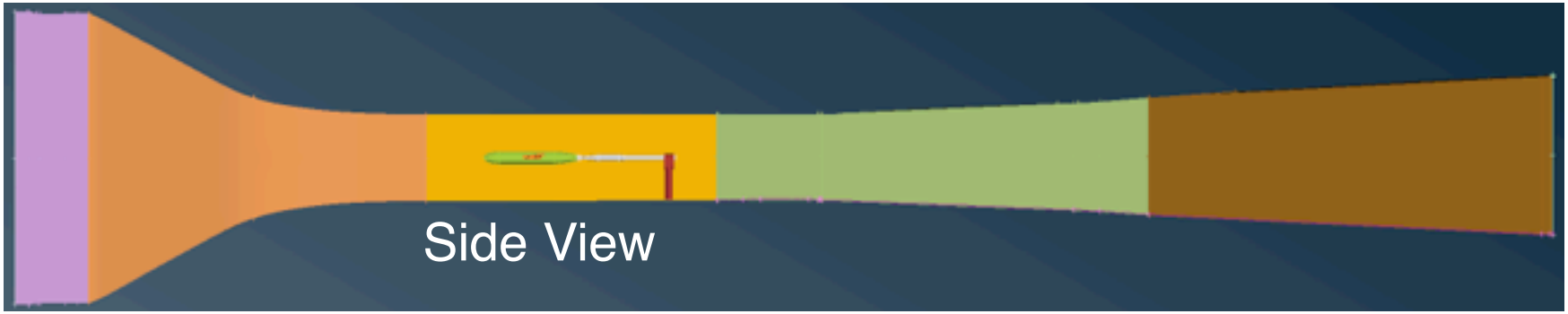
Using medium WT grid



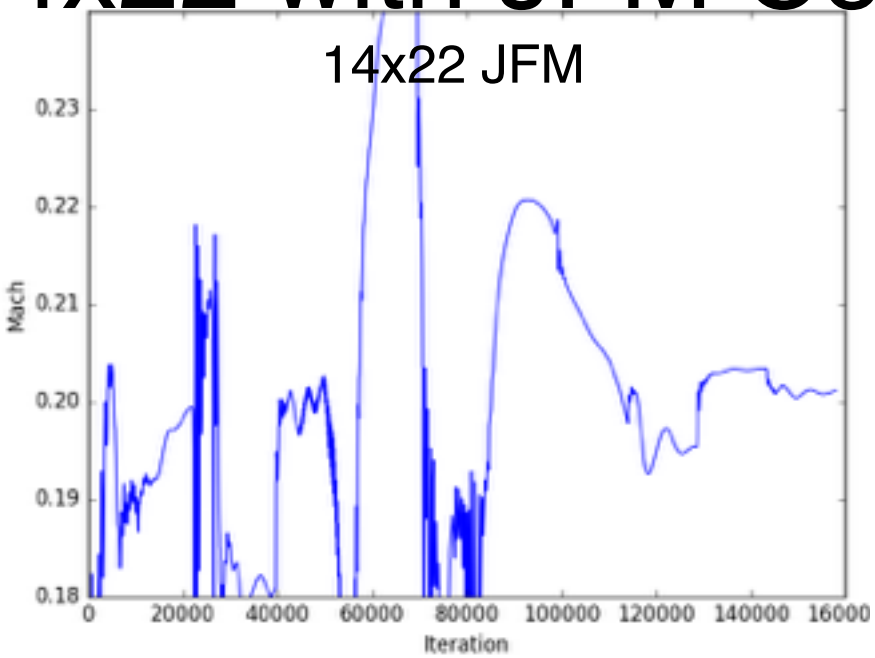
JFM 8% Conditions

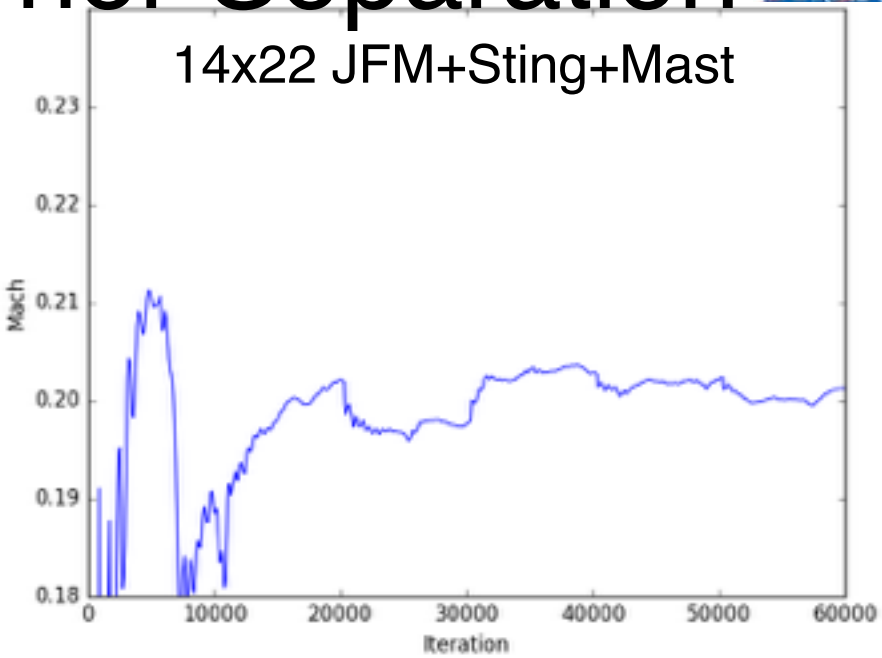
- RE = 2.4M based on yehudi break chord 21.97 inches
- T = 560 Rankine (hot day in the tunnel, Q~55)
- Mach = 0.2
- Process:
  - Speed calculation with WT walls computed with Static/Stagnation pressure probe calculations
  - Inflow BC: Stagnation T & P, Outflow BC: Pback ratio (iterated)

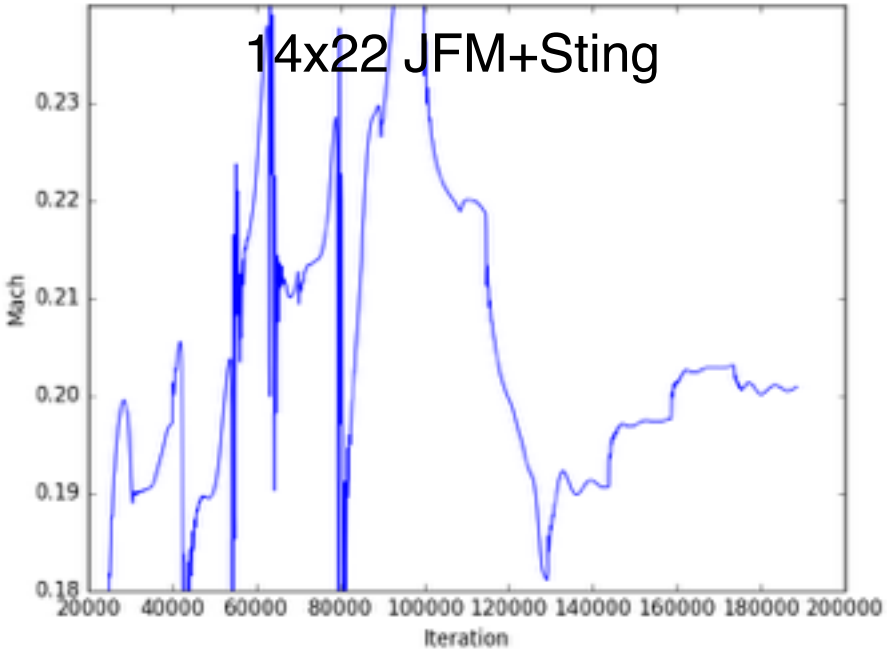




14x22 with JFM Corner Separation



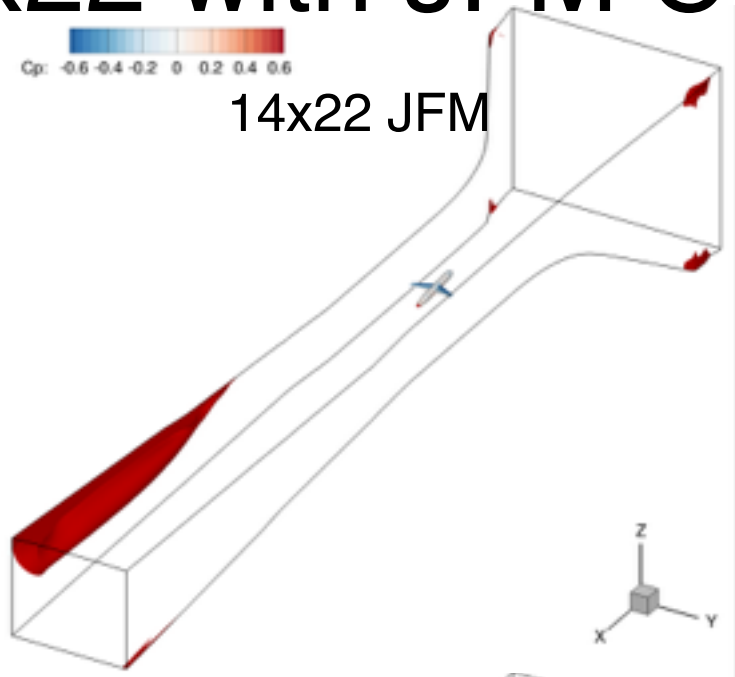


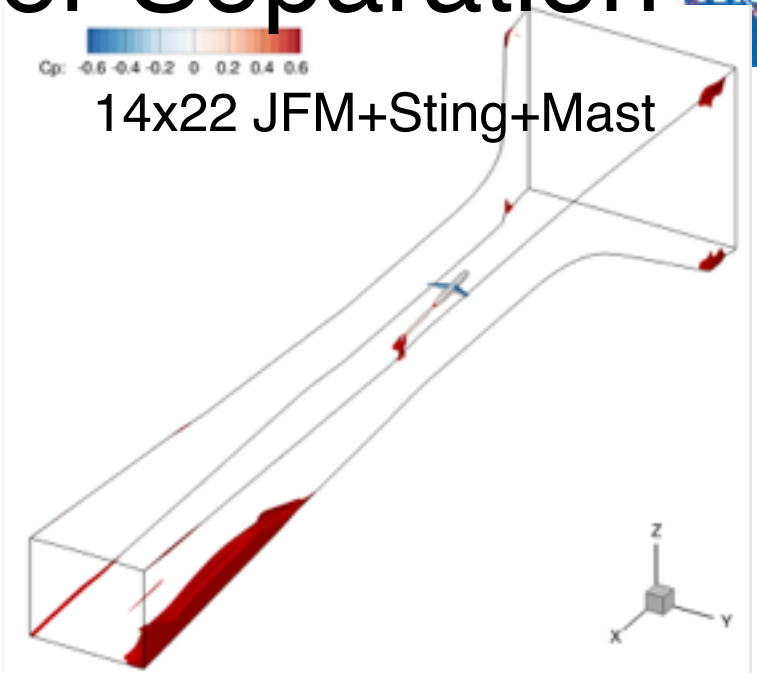


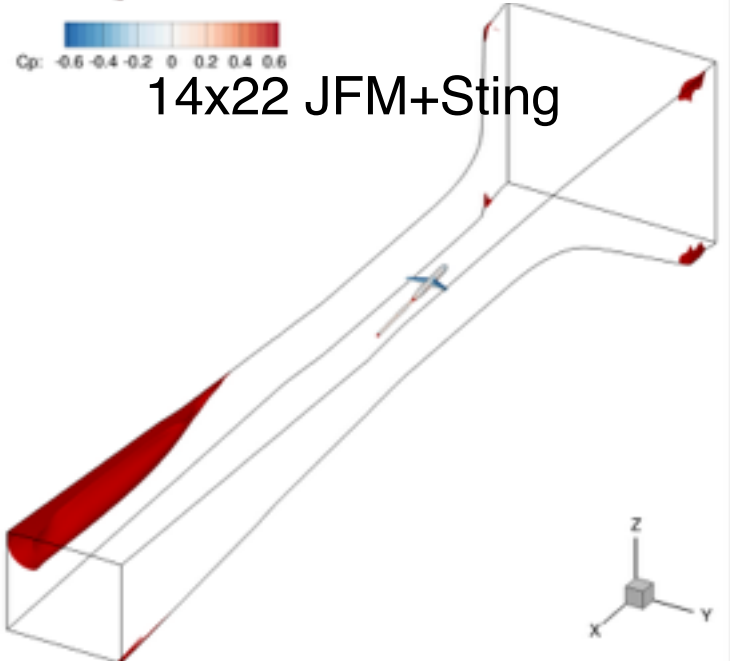
- Cases were very hard to converge
- Mach response to ratio changes were erratic

AOA 5 degrees

14x22 with JFM Corner Separation







- Most configurations at some +AOA had corner separation

AOA 5 degrees

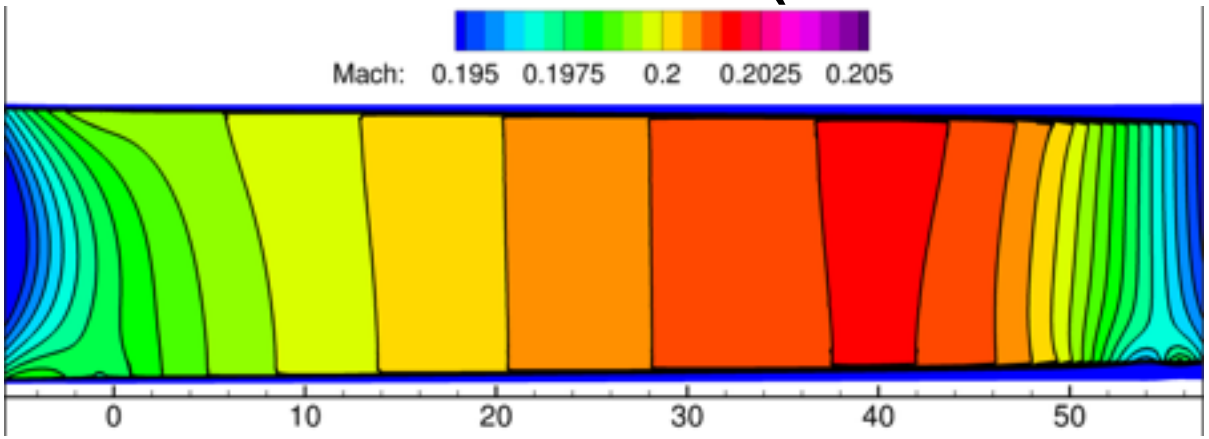
14x22 Inflow/Outflow BC's

- Inflow/Exit BC's are based on inviscid assumptions:
  - Running regions near BC inviscid may help speed up convergence
  - May reduce corner separation
- Blue sections are run as Inviscid
- Same exit pressure ratio (1.02188) used for both

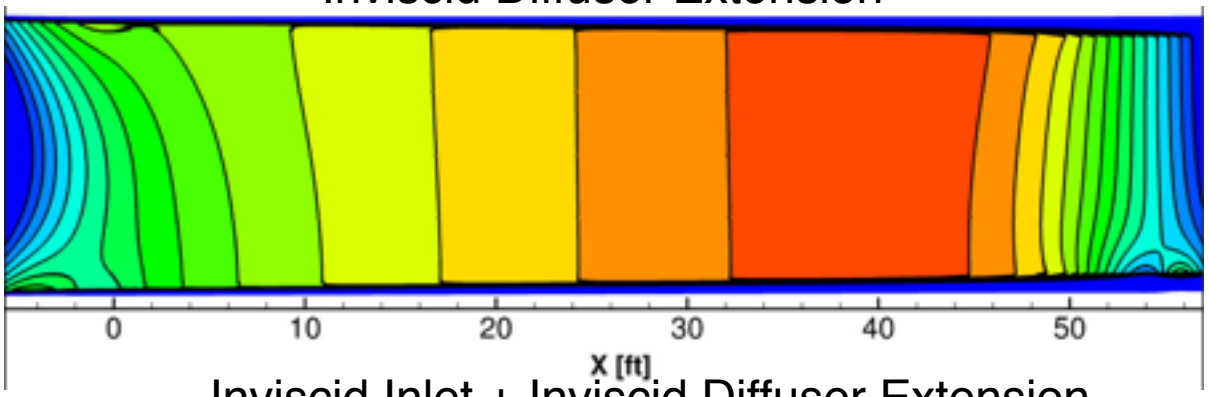
Inviscid Diffuser Extension

Inviscid Inlet + Inviscid Diffuser Extension

14x22 Inviscid BC's (Overflow)



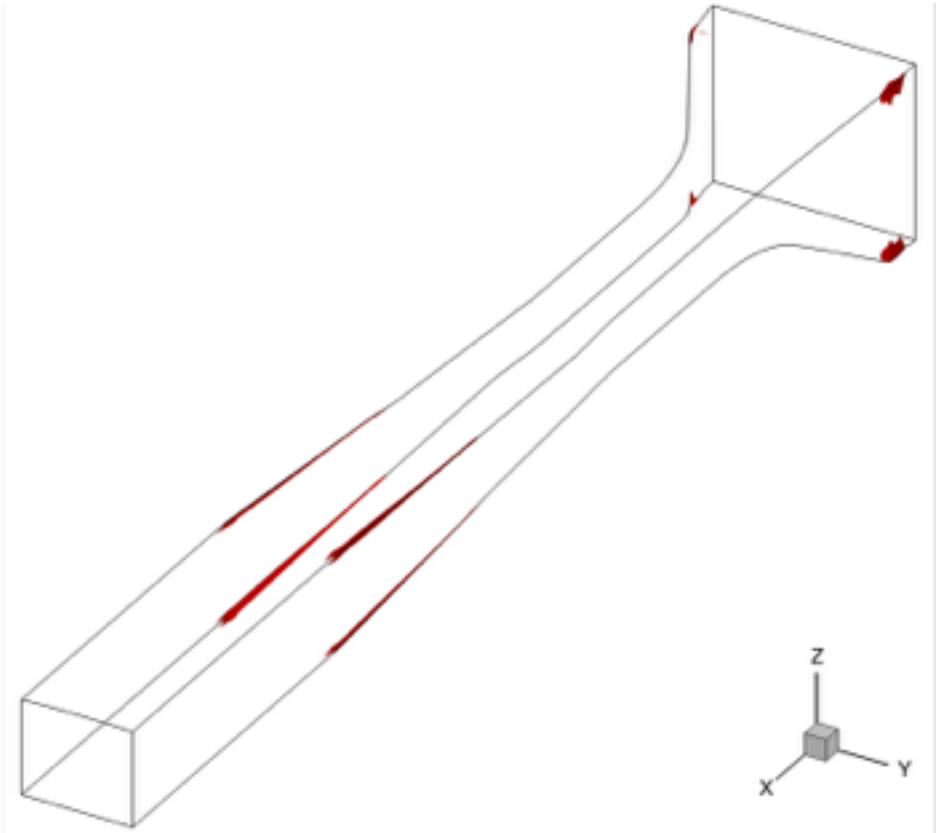
Inviscid Diffuser Extension



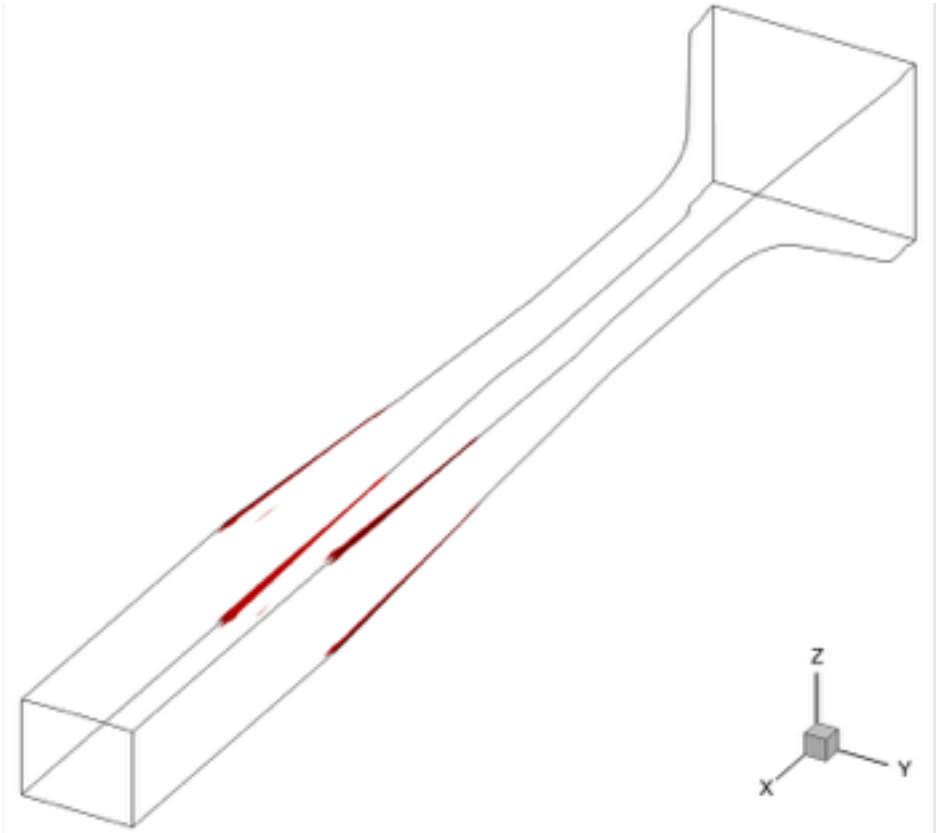
Inviscid Inlet + Inviscid Diffuser Extension

- Slice down middle of test section, mach contours
- Inviscid Inlet has a slightly lower speed in test section
- Very similar results

14x22 Inviscid BC's (Overflow)



Inviscid Diffuser Extension

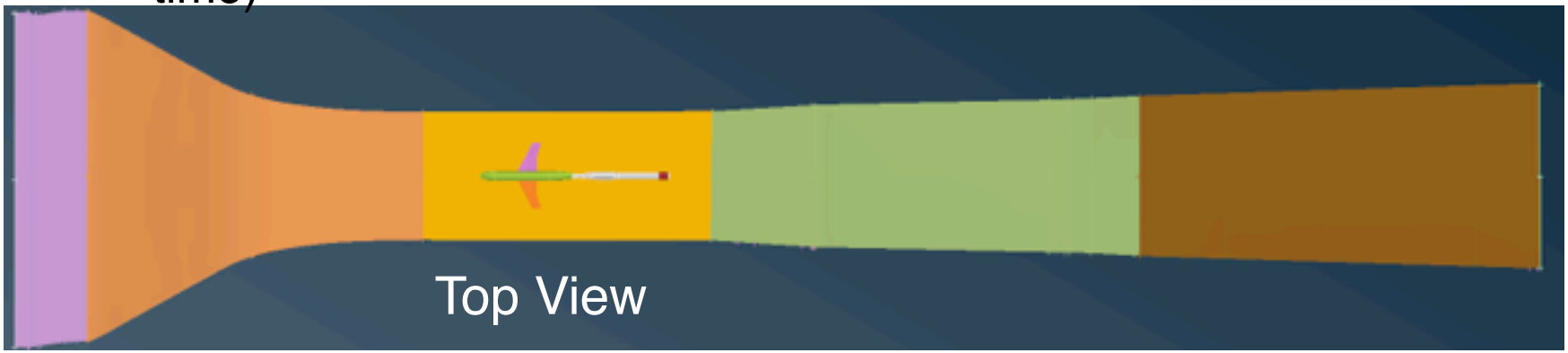


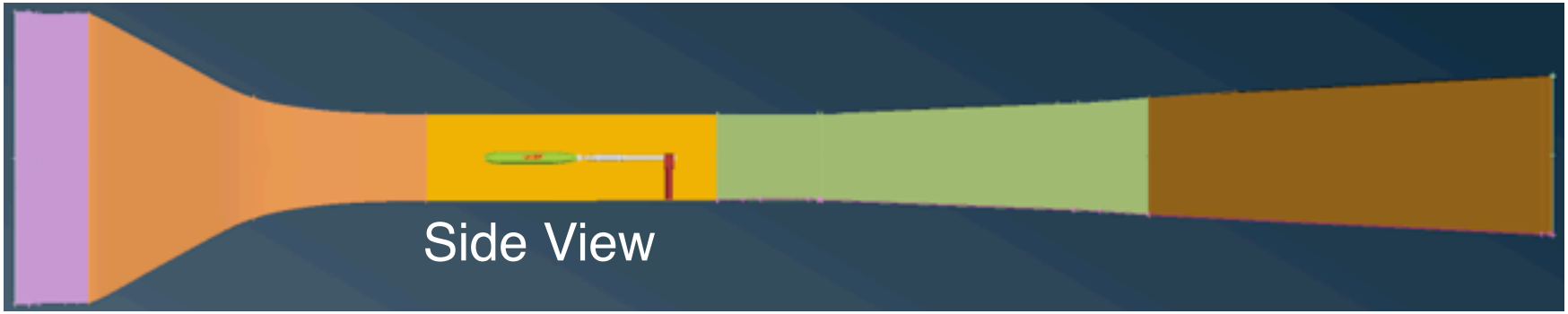
Inviscid Inlet + Inviscid Diffuser Extension

- Inviscid Inlet suppresses the separation present in the corners of the inlet
- Both suppress diffuser corner separation

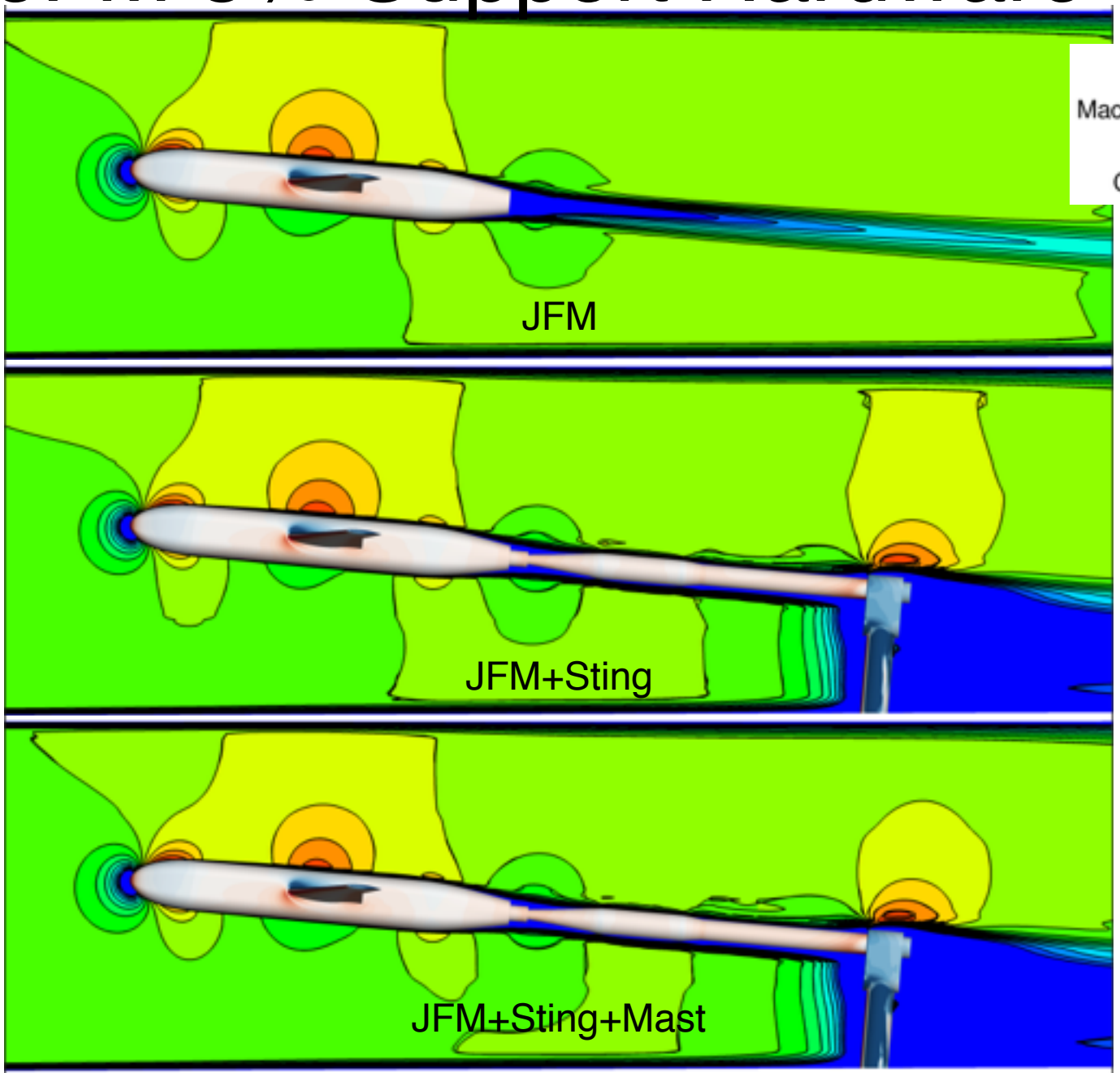
JFM 8% Installed in 14x22

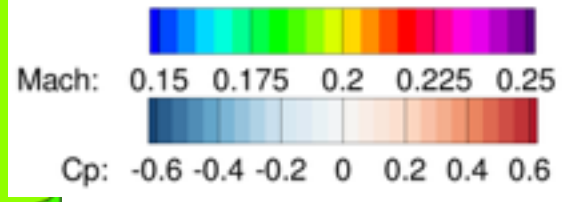
- Increment Analysis: Support Hardware, WT Extension
  - 14x22 WT: JFM, JFM+Sting, JFM+Sting+Mast (42-46M Grid points)
  - 14x22 WT Extended: JFM+Sting+Mast (84M-88M Grid Points) (Inviscid Diffuser)
  - 14x22 WT Extended with inviscid inlet & diffuser (didn't finish in time)





JFM 8% Support Hardware Effect



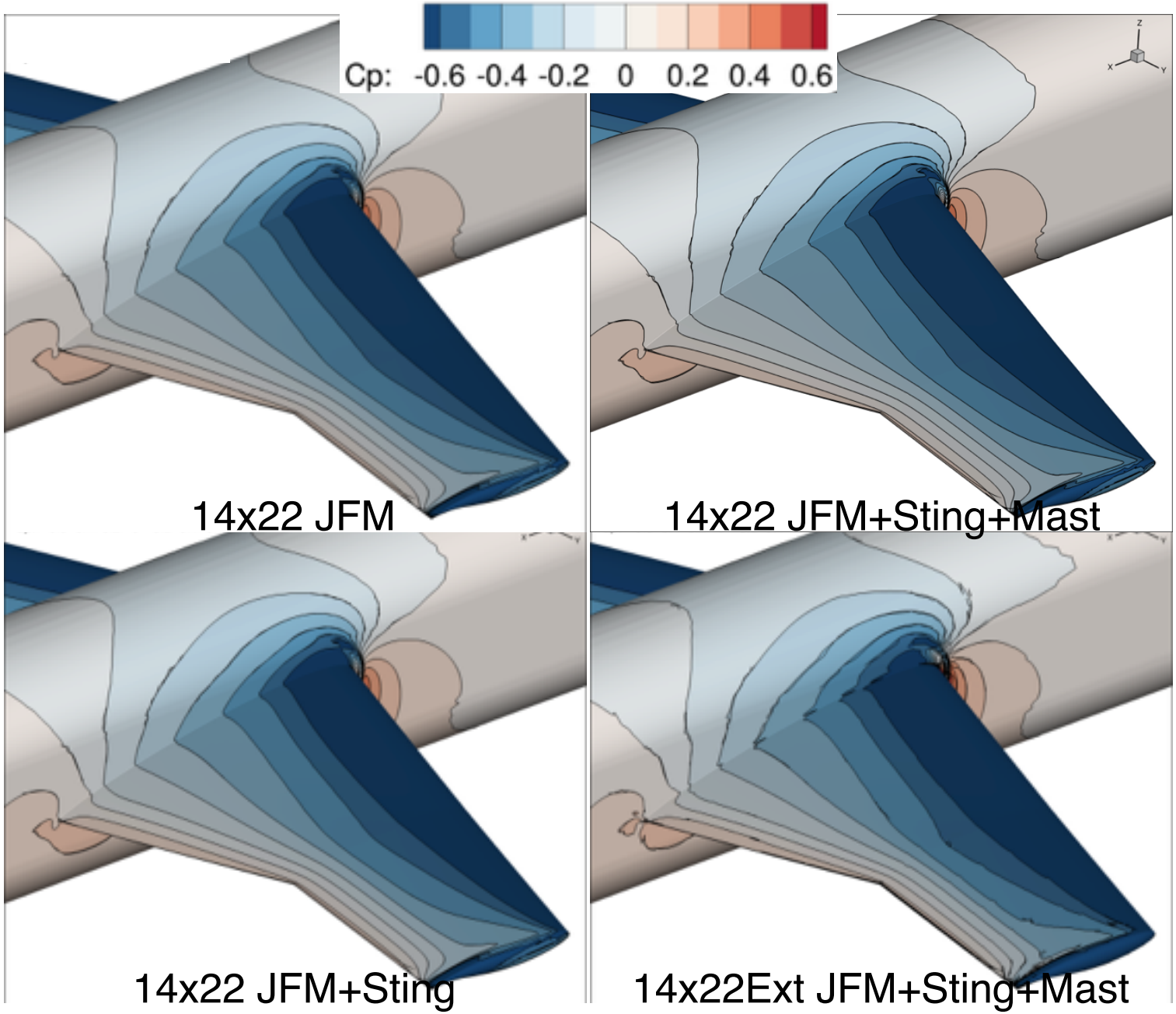


Effect of the support hardware on:

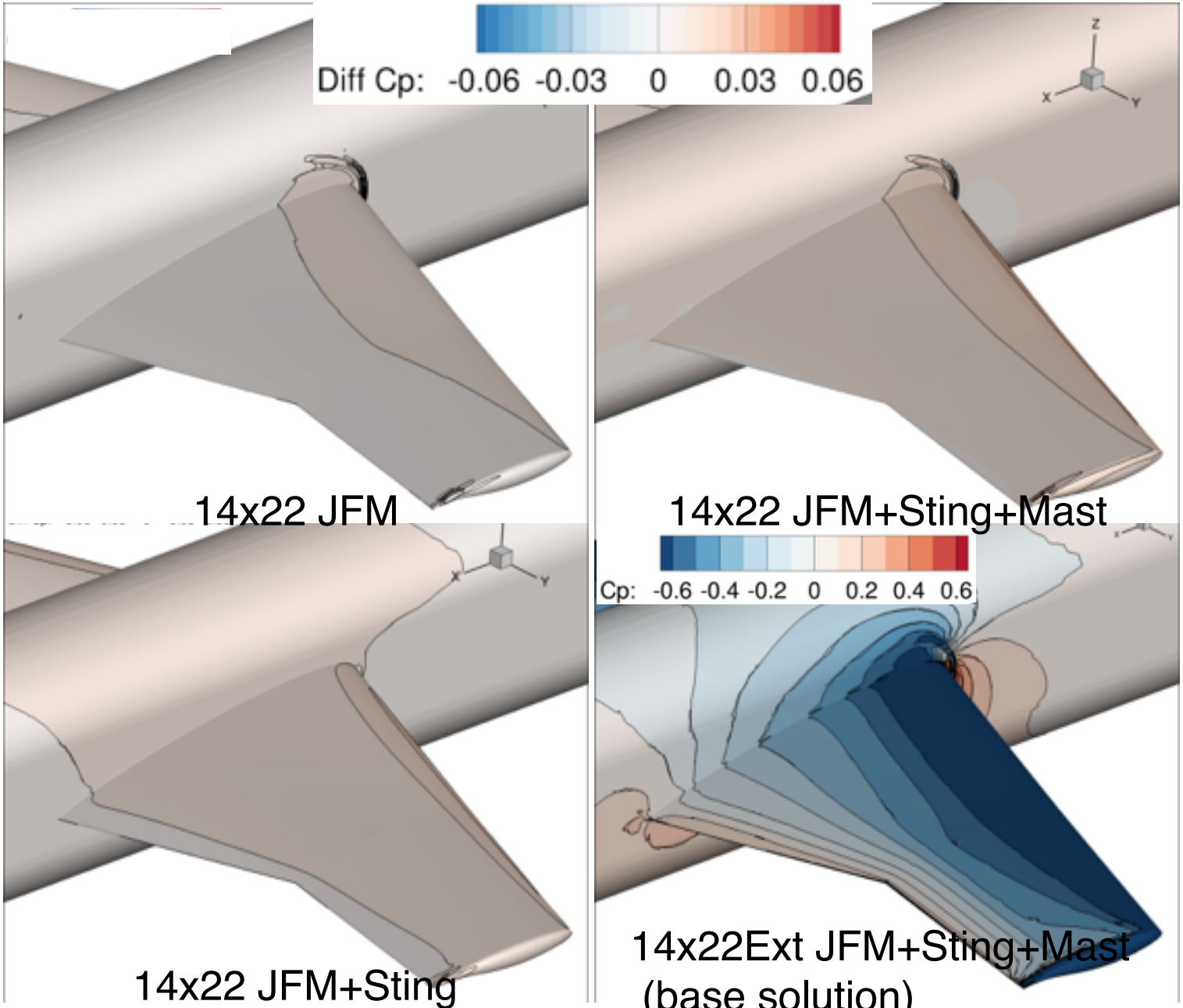
- Wing/Bubble
- Solution

All results at AOA 5 degrees

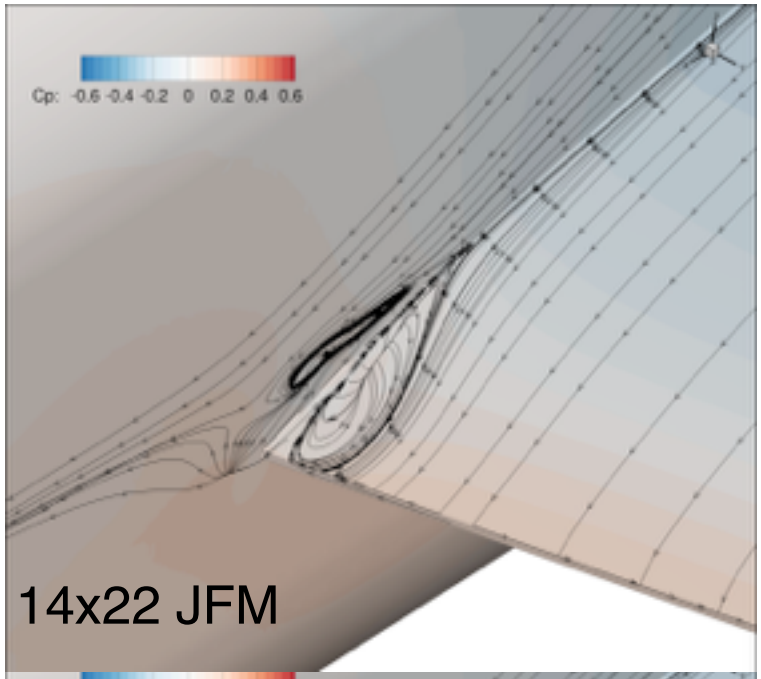
14x22 JFM Support Hardware Comparison α=5.0°

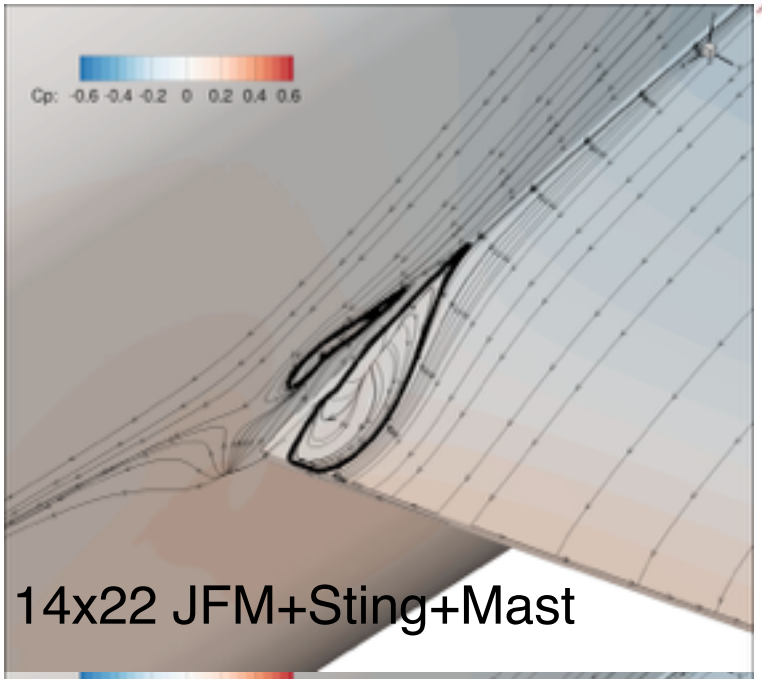


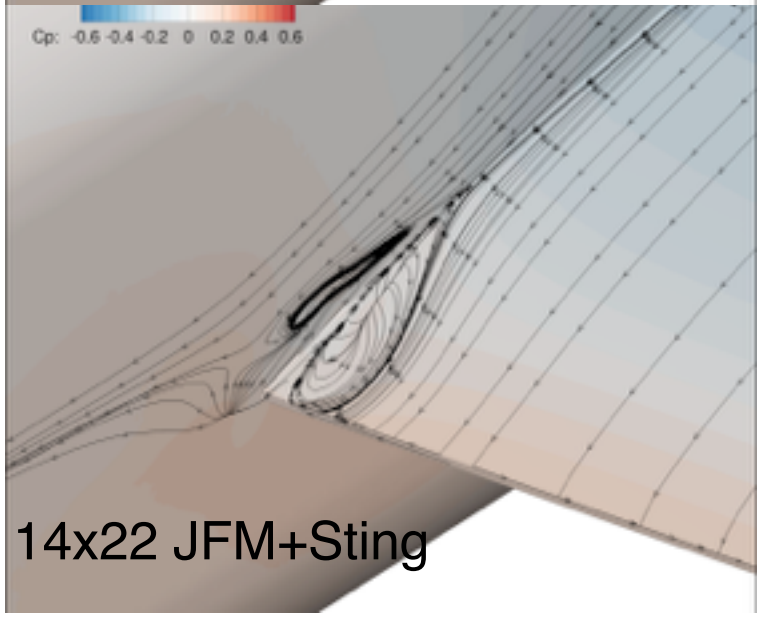
14x22 JFM ΔCp Comparison α=5.0°

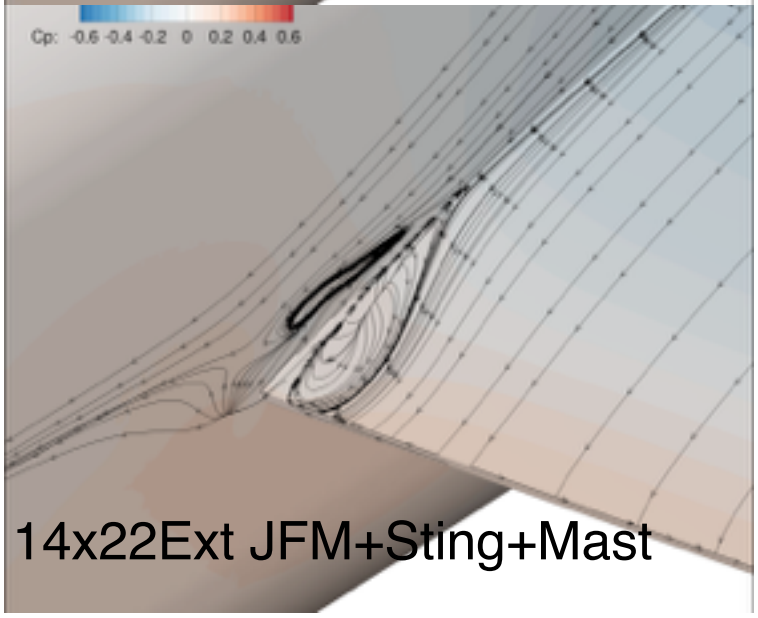


14x22 JFM Bubble Comparison α=5.0°



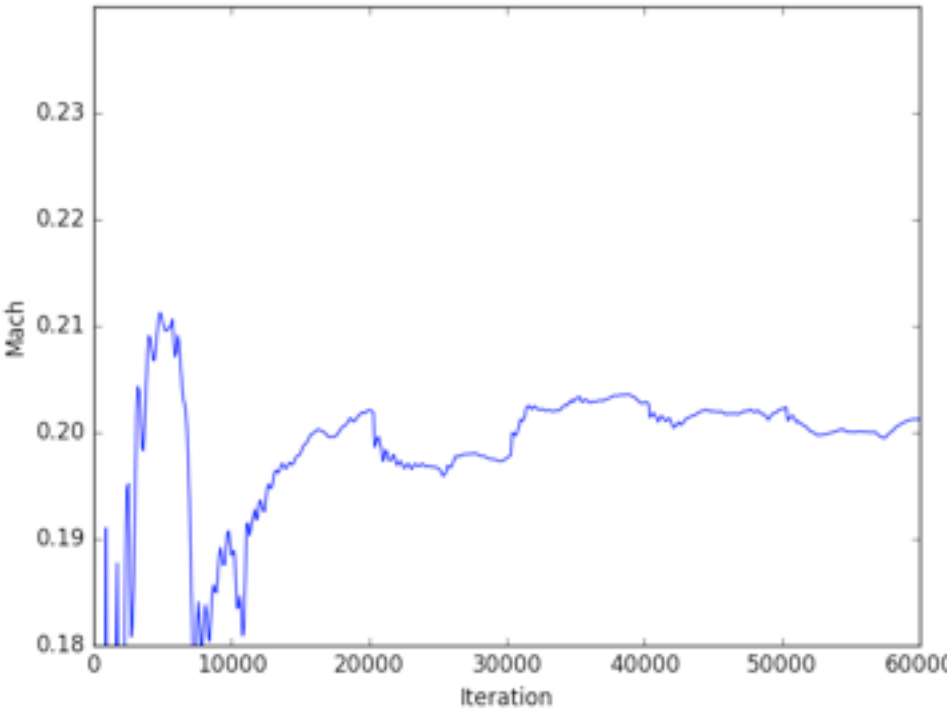




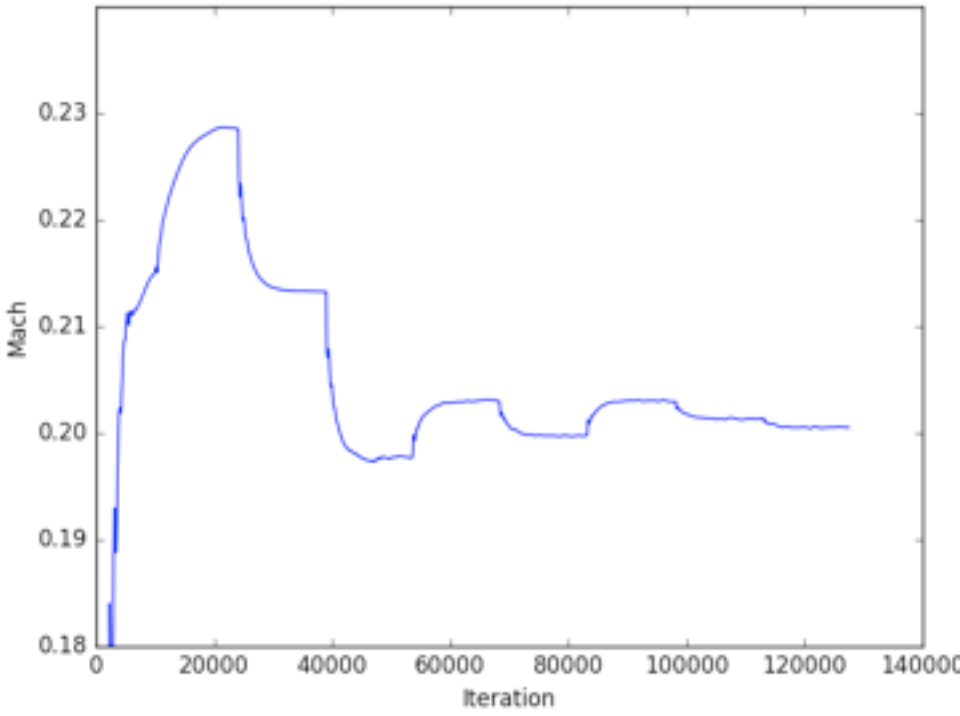


14x22 Tunnel Extension Effect

14x22 wo/Extension
JFM+Sting+Mast



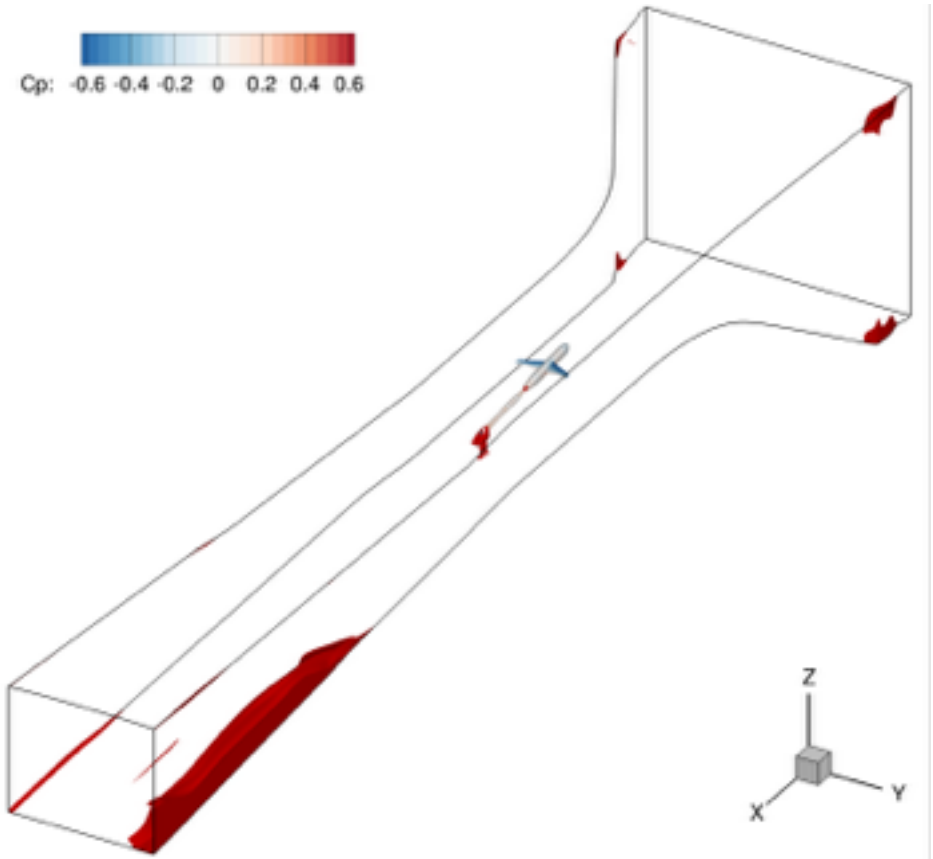
14x22 w/Extension
JFM+Sting+Mast



AOA 5 degrees

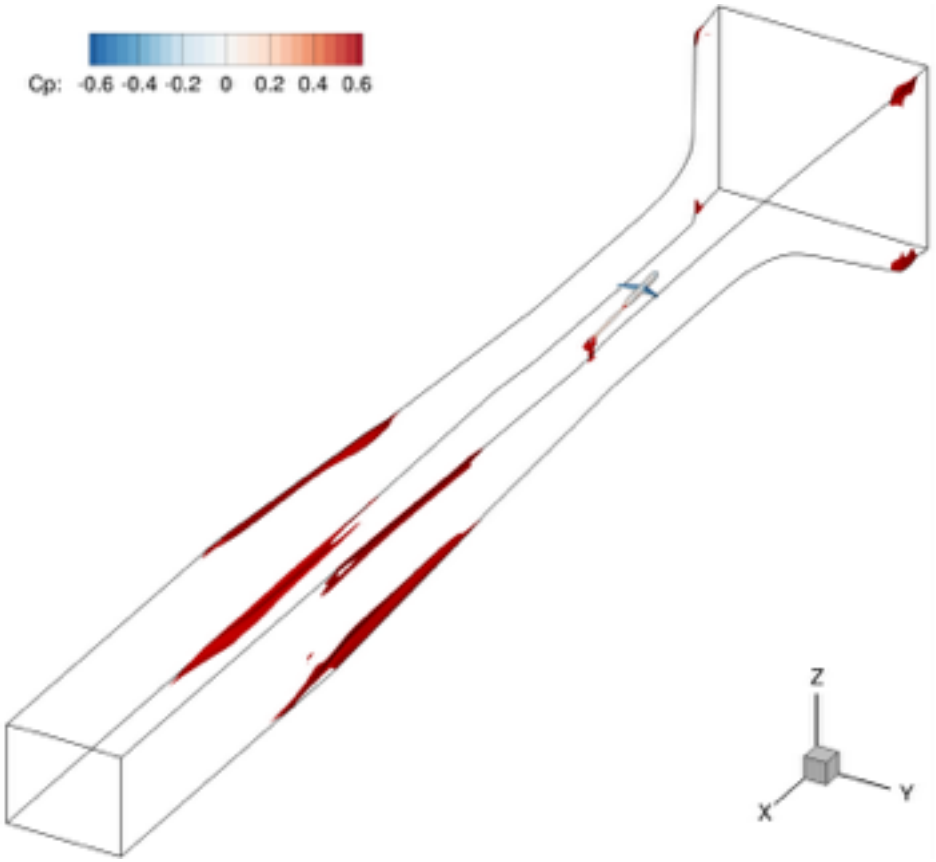
14x22 Tunnel Extension Effect

14x22 JFM+Sting+Mast



Pexit ratio = 1.0196

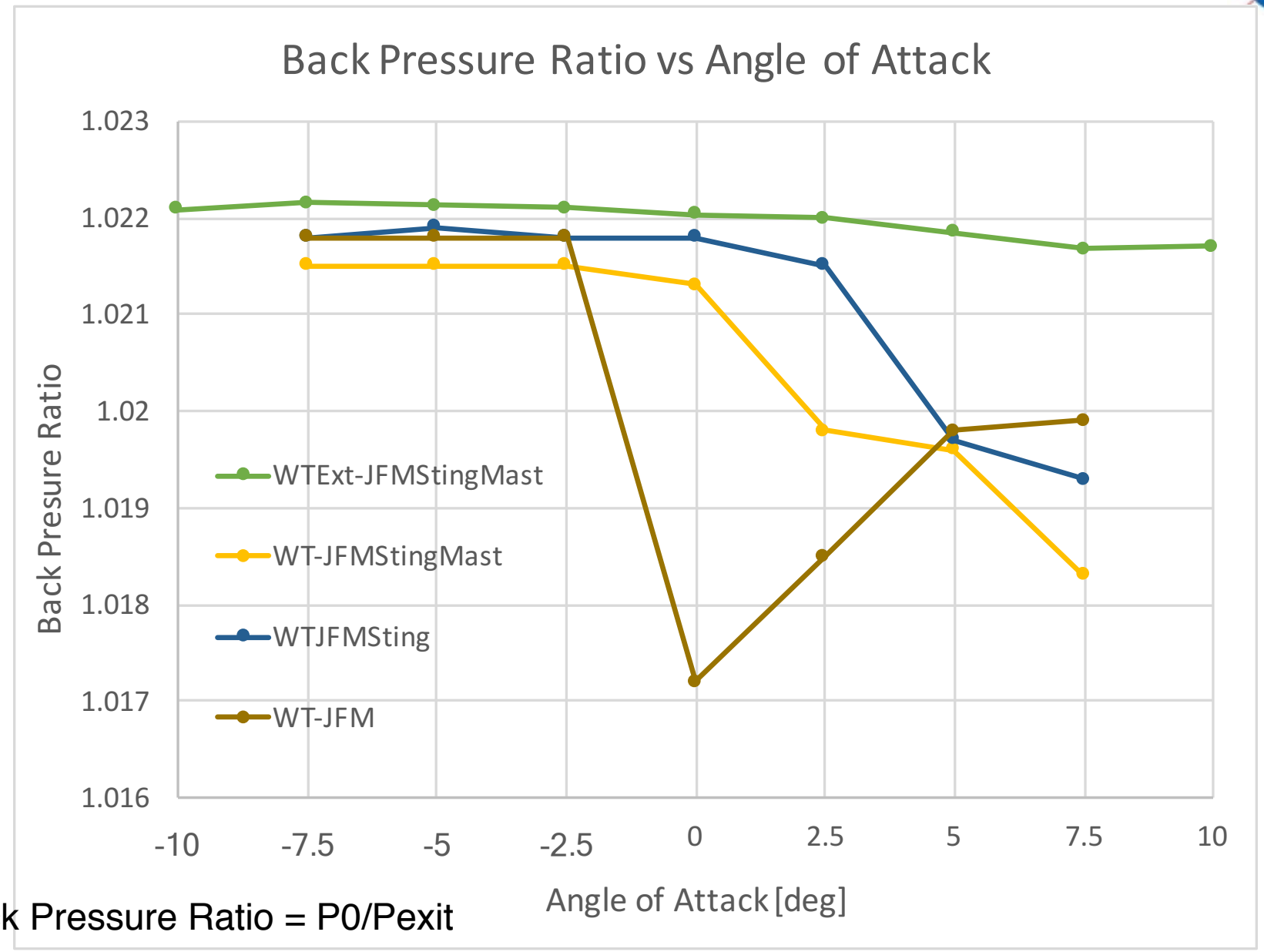
14x22 JFM+Sting+Mast w/Extension



Pexit ratio = 1.02185

AOA 5 degrees

14x22 Back Pressure Ratio Mach 0.2



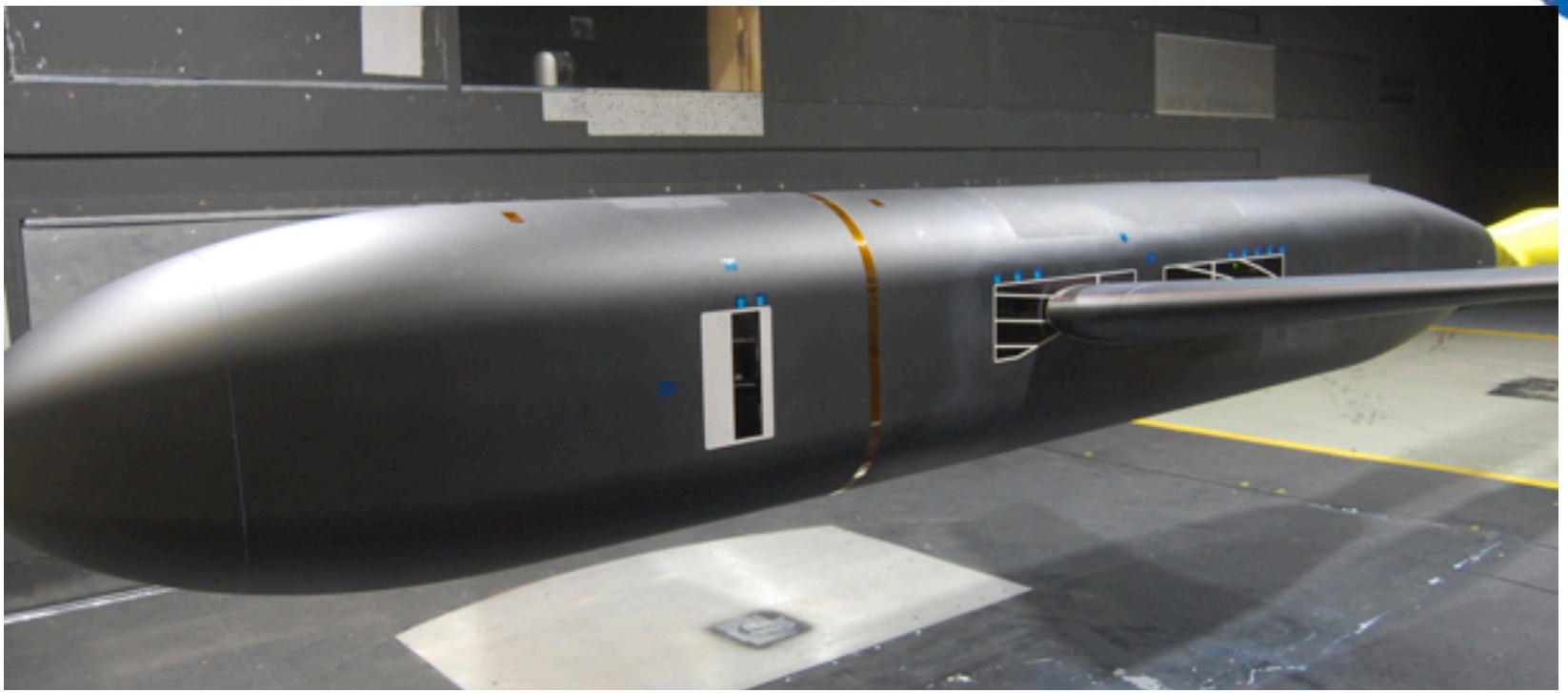
Back Pressure Ratio = P0/Pexit

14x22 8% JFM Increment Summary

- Support Hardware
  - Pressures were very similar for all results
  - Bubble size was insensitive to support hardware, and tunnel extension (preliminary result)

- 14x22 WT vs 14x22 WT with Inviscid Extension
  - Suppresses the corner separation in the diffuser
  - Back pressure does not need to be as high
  - Extension Exit Pressure ratio is closer to empty tunnel value (1.022)
  - Tunnel speed settles out much faster
- Need to still look at effect of adding Inviscid Inlet on JFM

Future Work



- Compare CFD WT to CFD Free Air
- Compare with WT data once available
  - Cp profiles, oil flows
  - Velocity & Reynolds stress profiles
- Automate back pressure ratio (PID controller)

Acknowledgements

NASA's Transformational Tools and Technologies (T^3) Project

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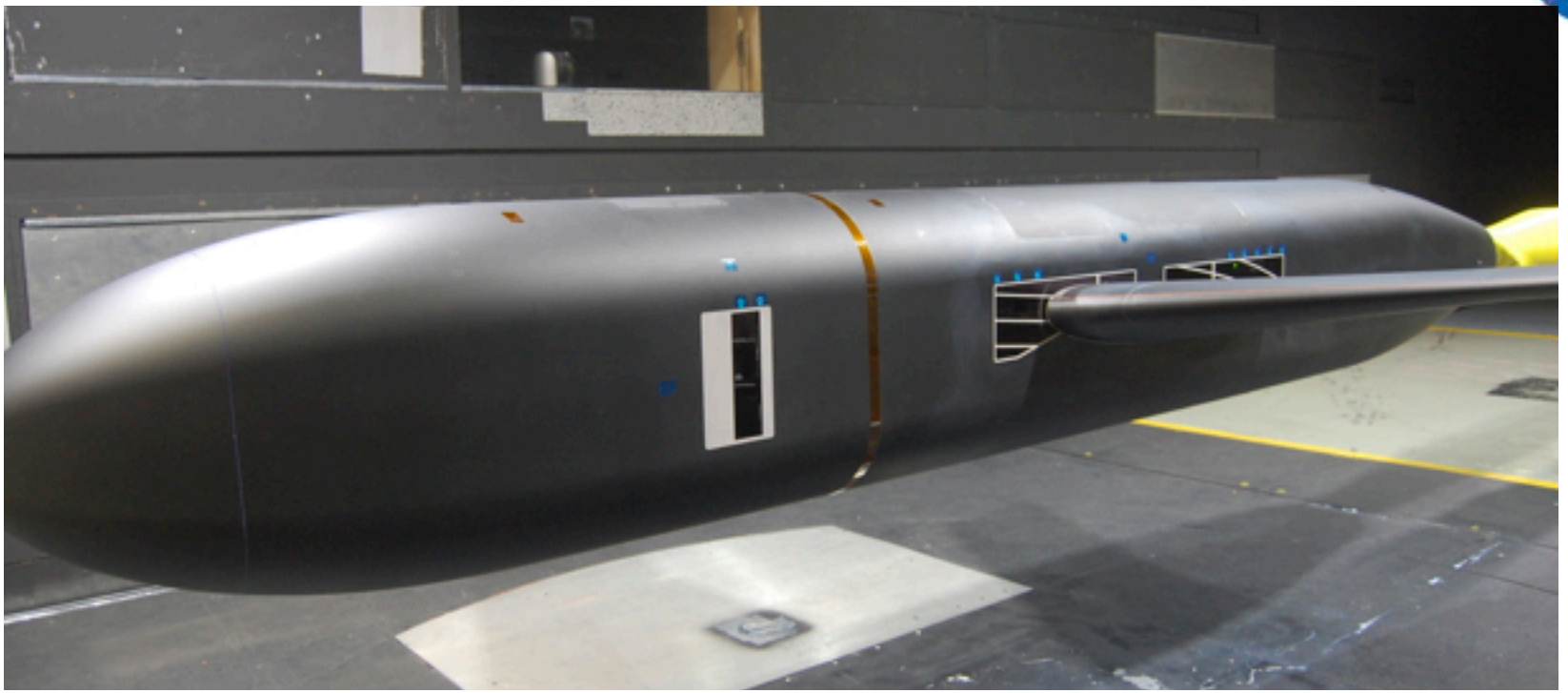
Bill Oberkampf

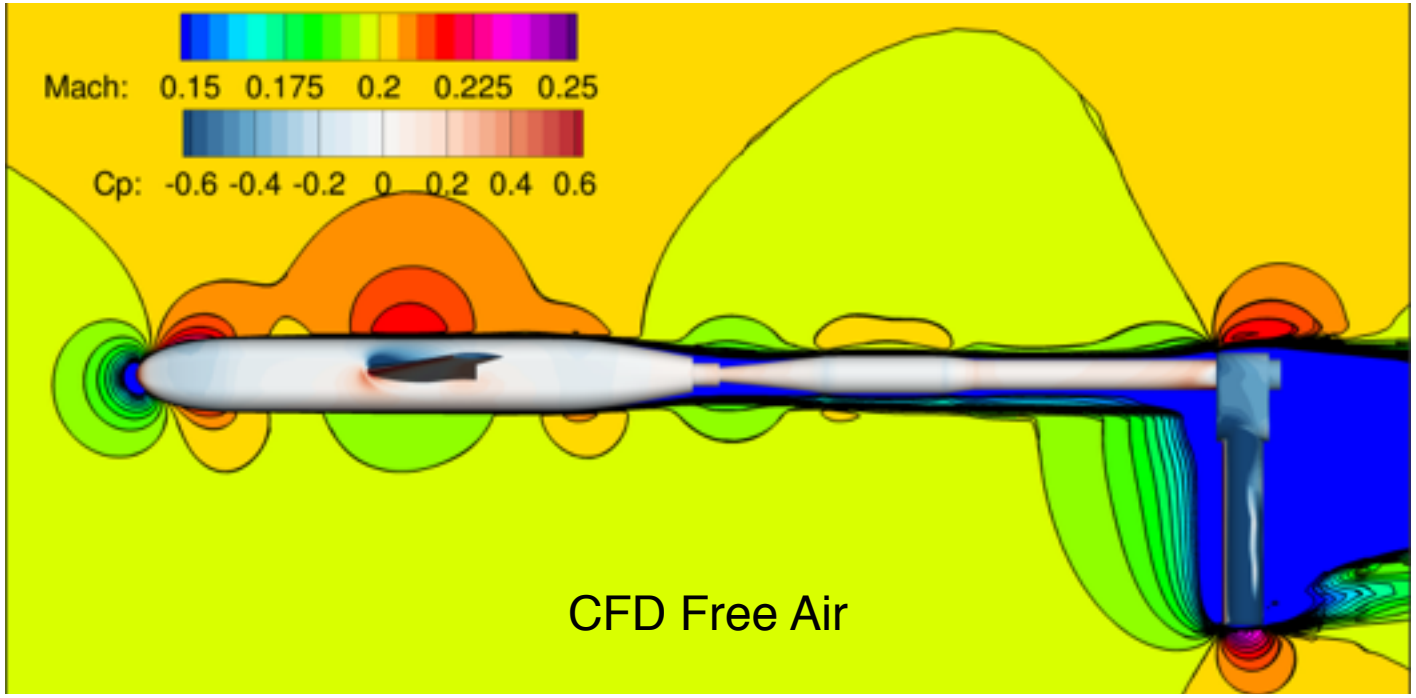
Discussion



- How else can we improve modeling with WT walls?

- What do we need to do to this dataset to best help CFD community improve their models?

Preliminary CFD Free Air vs CFD WT



AOA 5 degrees