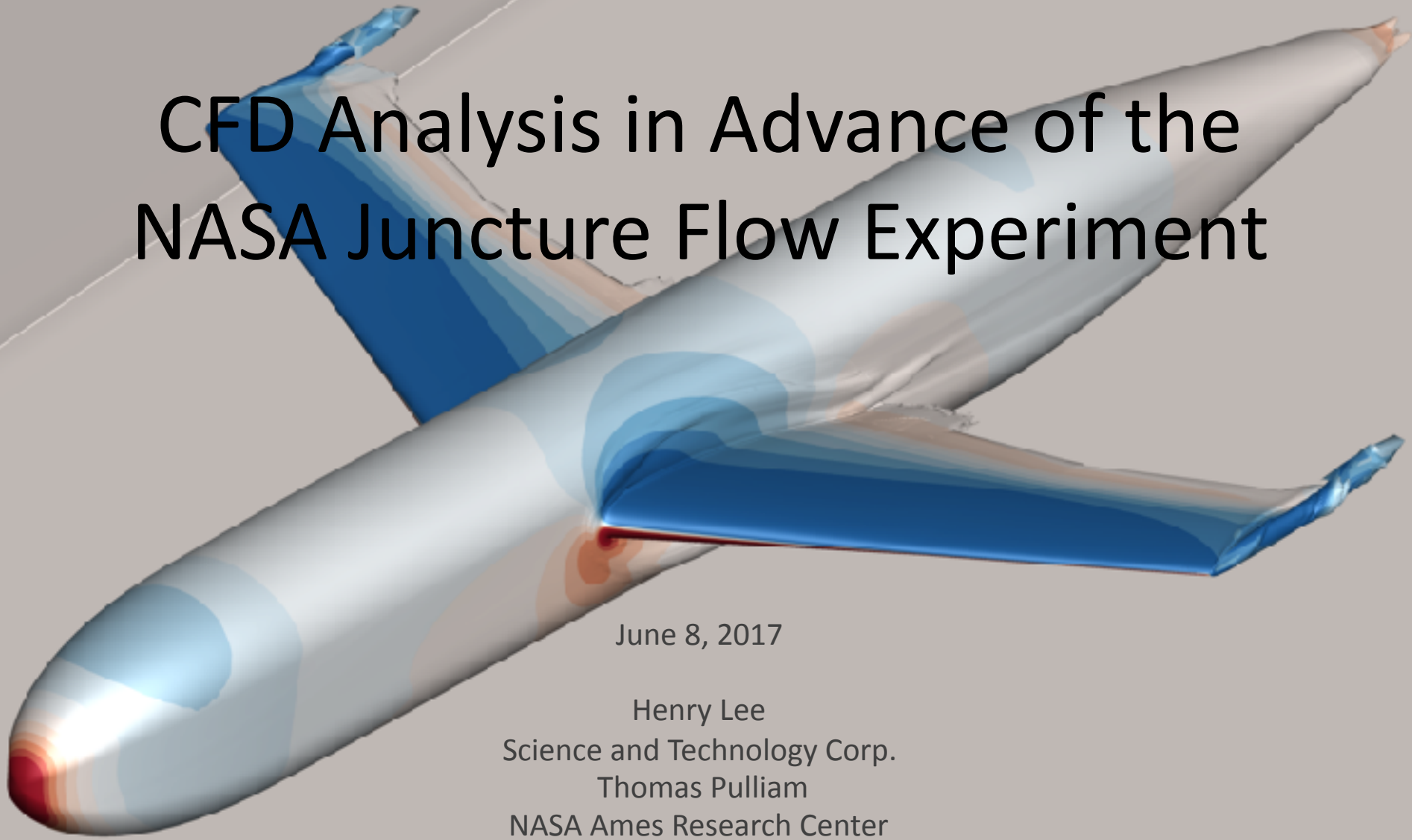
CFD Analysis in Advance of the NASA Juncture Flow Experiment



June 8, 2017

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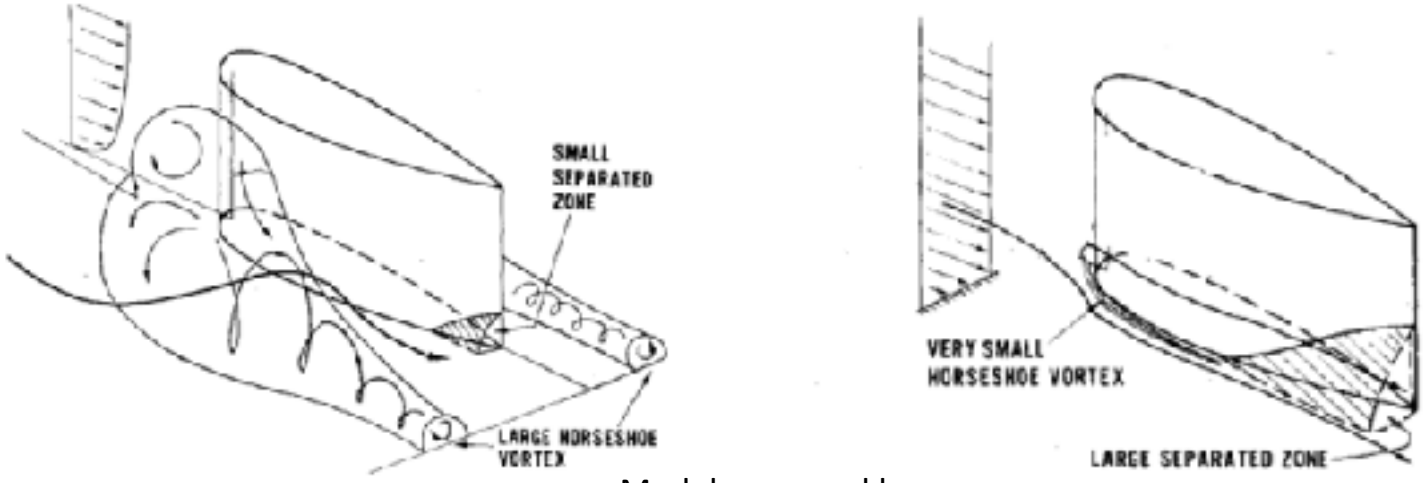
Outline

- Experiment Motivation, Goals, Model Design
- Wing Candidates
- Risk reduction experiments
  - NASA Ames Test Cell 2 (TC2) 32”x48” 3% semispan
  - Virginia Tech Stability Tunnel 6’ 2.5% fullspan
  - NASA Langley 14- by 22-Foot Subsonic Tunnel (14x22) 6% fullspan
- Results from 14x22 6% risk reduction
  - CFD Free Air
  - CFD with 14x22 WT walls
  - Risk Reduction Experiment: oil flow
- Observations and Upcoming Experiment

Juncture Flow

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
- Computational Fluid Dynamics (CFD) used in both design and support of risk reduction experiment



(a) thick boundary layer

Model proposed by Barber *et al.*

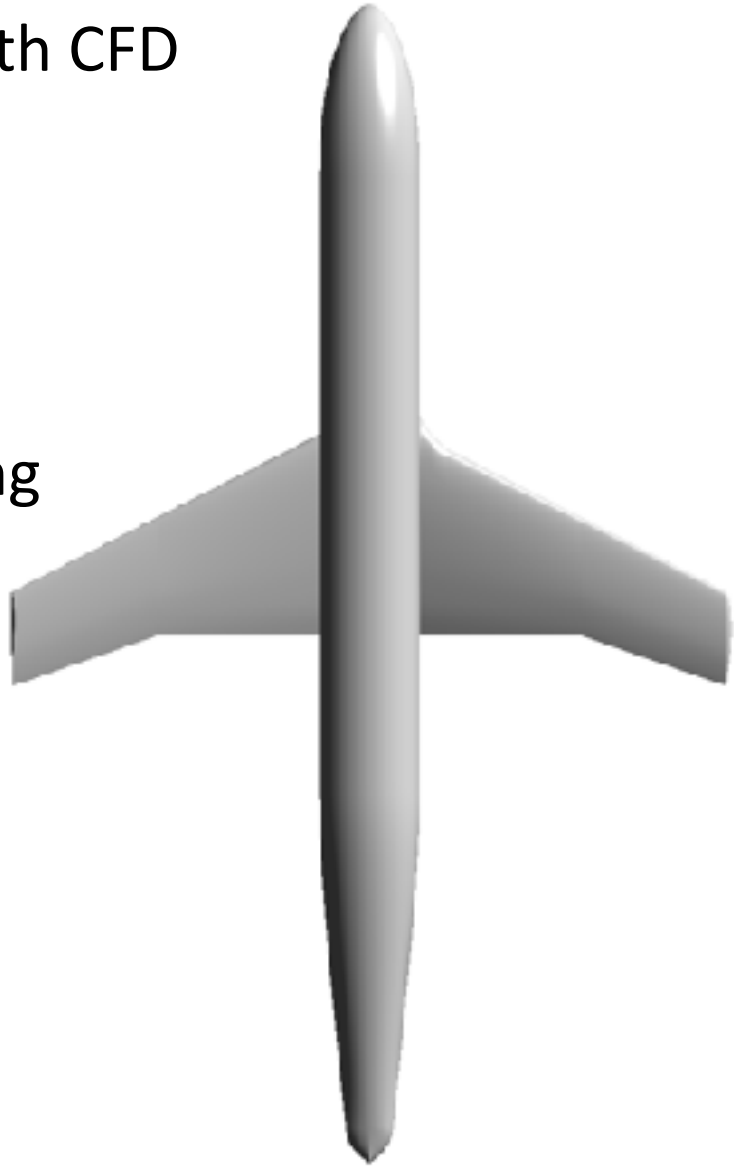
(b) thin boundary layer

Juncture Flow Experiment

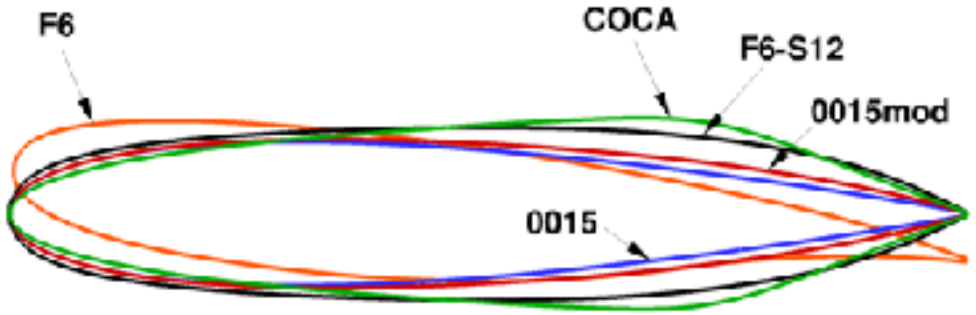
- Design Goals
  - Observe onset and growth of side of body separation
  - Separation: None —> small separation —> large separation
  - Collect validation quality data: improve turbulence models, etc
- LDV system placed inside fuselage: closer measurements
- Planar fuselage side wall
- 8% model (~16 ft long, 11 ft wide), based on CRM full scale

Juncture Flow Model Design

- Preliminary model design done with CFD
  - Overflow 2.2L: SARC-QCR2000
  - FUN3D: SARC-QCR2000
- Evaluated 20+ wing candidates
- Committee down-selected the wing candidates
- Selected 6 wing candidates that combined satisfied the goals
- Risk reduction experiment tests proposed: further evaluate 6 wing candidates



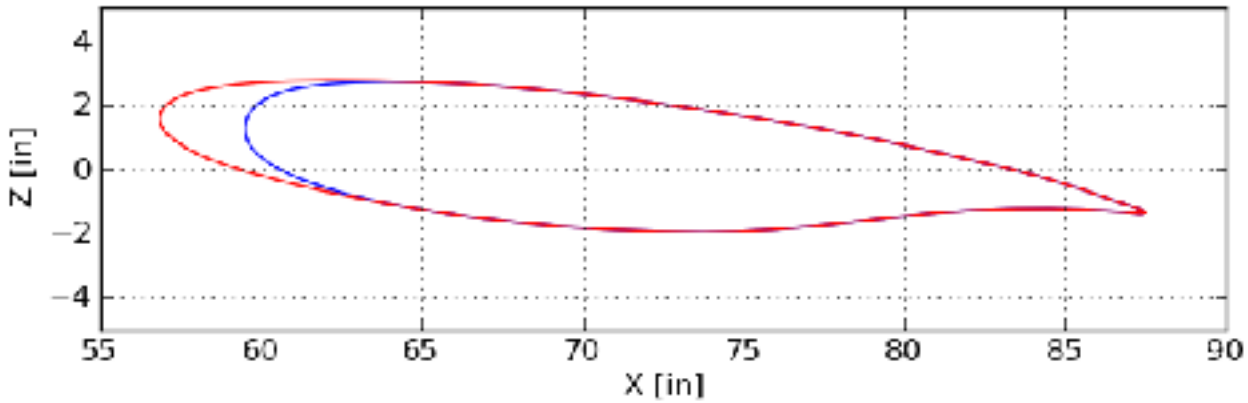
Wing Candidates



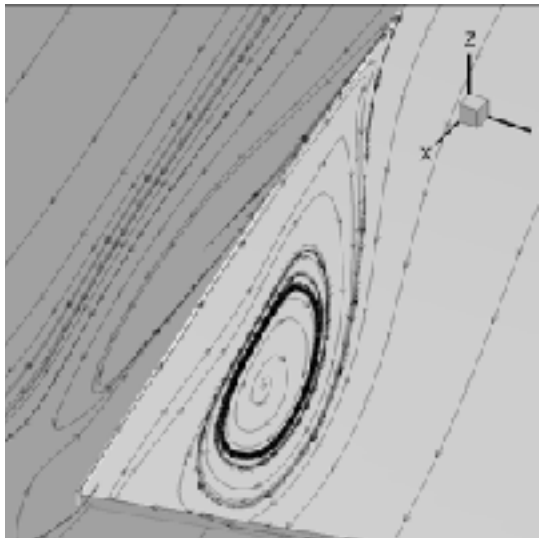
6 Wing candidates

- DLR-F6 no horn
  - Used in DPW3
  - Showed side of body separation
- DLR-F6: with LE horn
- NACA 0015 with horn: symmetric wing
- NACA 0015mod: slightly steeper pressure recovery
- F6S12: symmetric F6 variant
- COCA
  - Coder-Campbell design
  - CDISC/skin-friction constraints

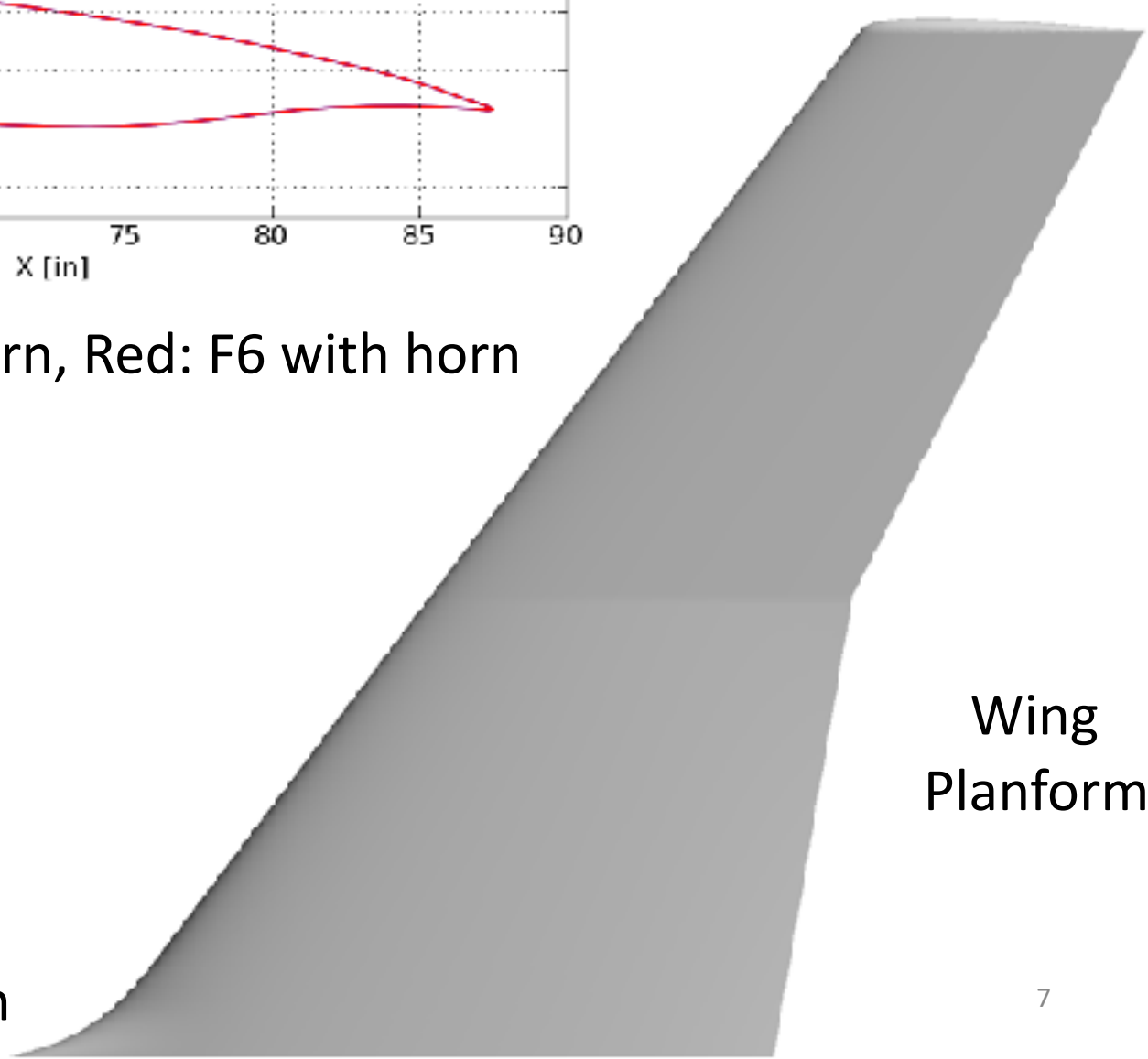
DLR-F6



Blue: F6 without horn, Red: F6 with horn

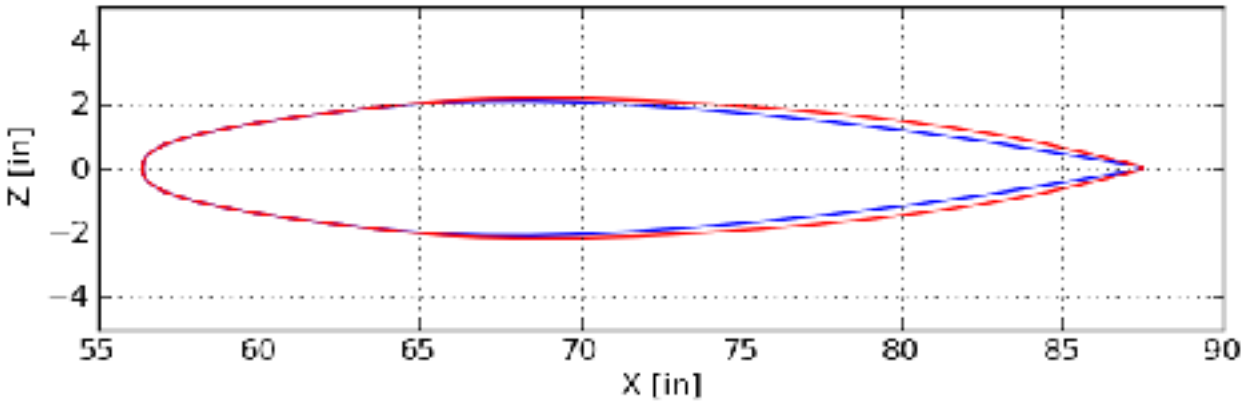


Side of Body Separation



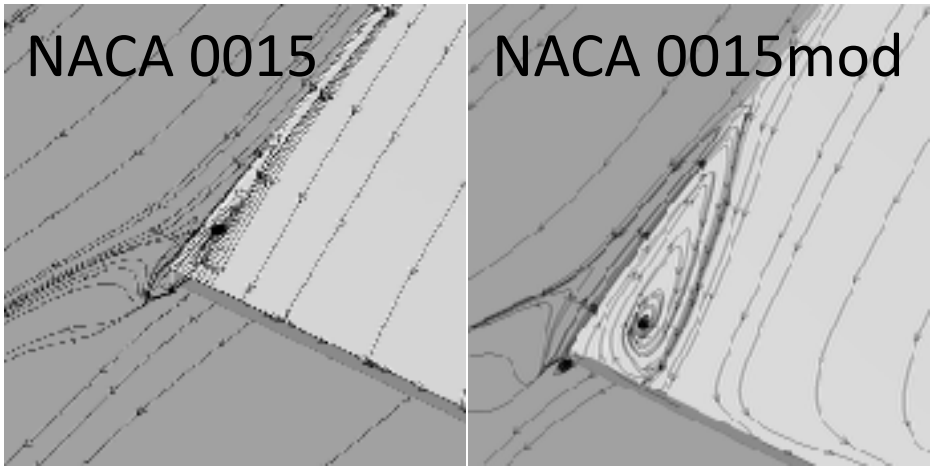
Wing Planform

NACA 0015 — NACA 0015mod

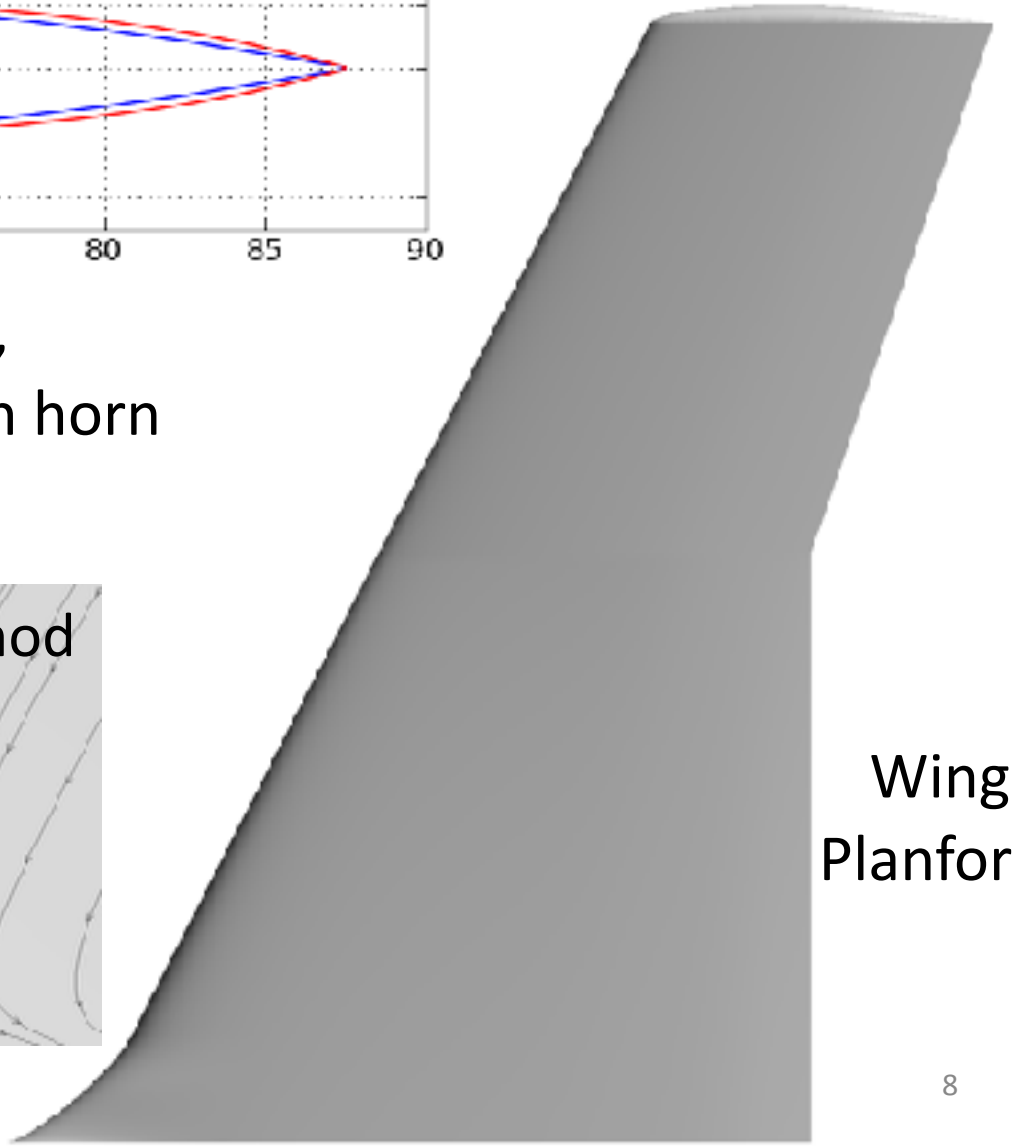


Blue: NACA 0015 w/horn,

Red: NACA 0015mod with horn

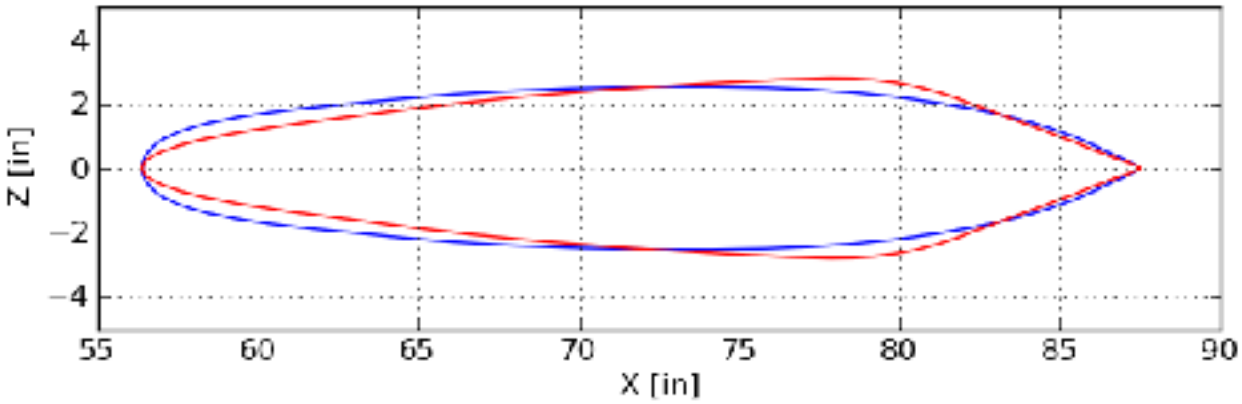


Side of Body Separation

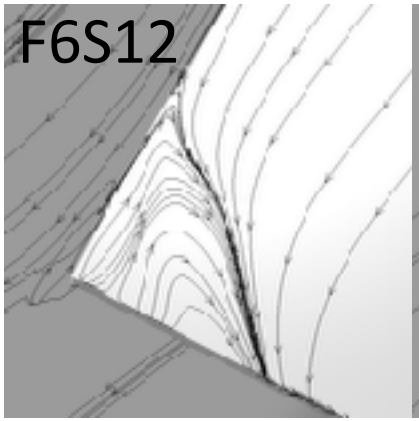


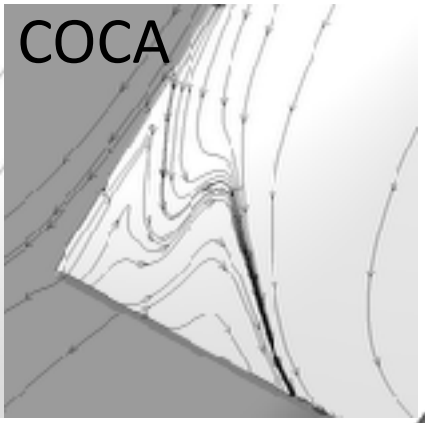
Wing Planform

F6S12 — COCA

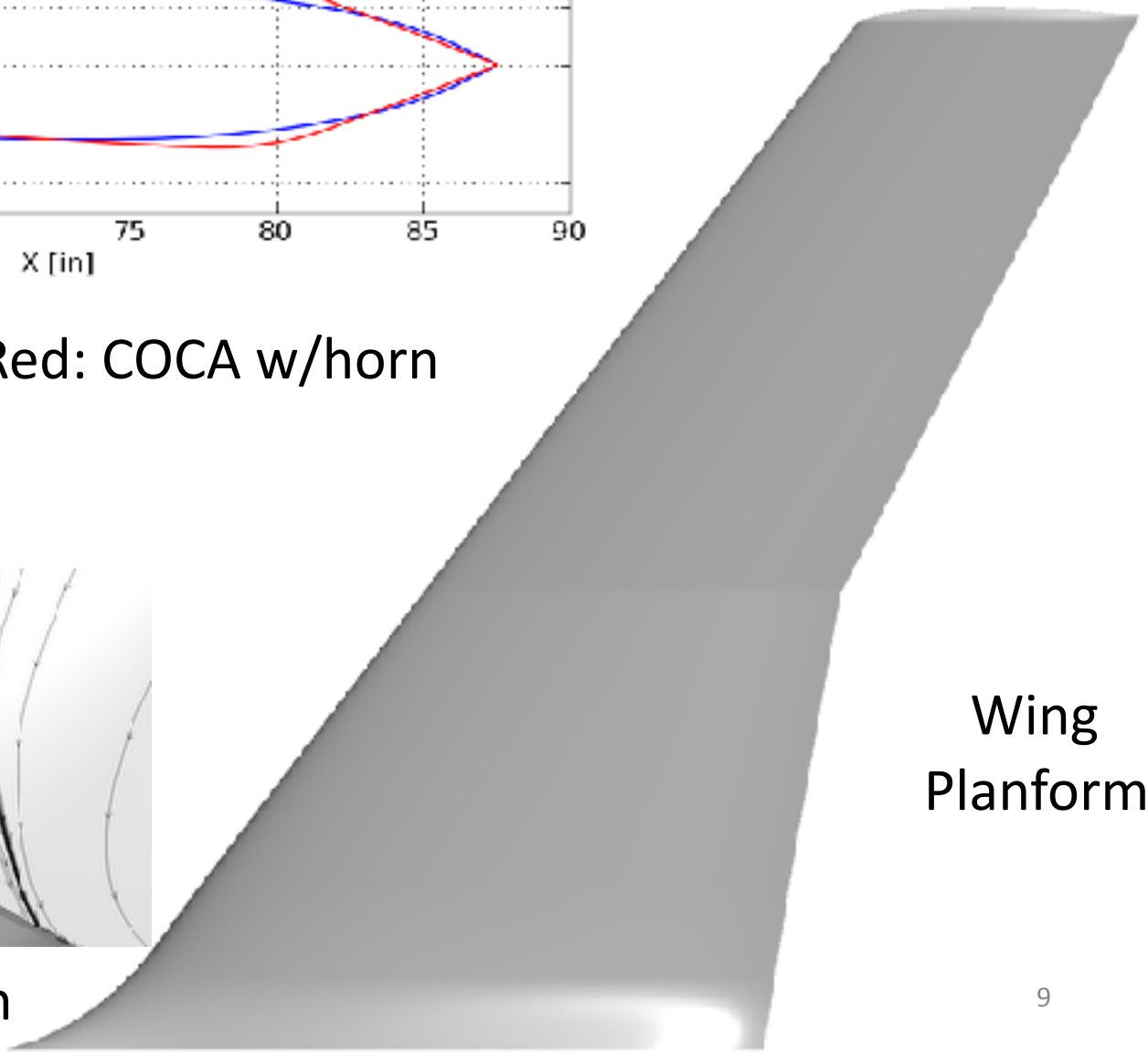


Blue: F6S12 w/horn, Red: COCA w/horn





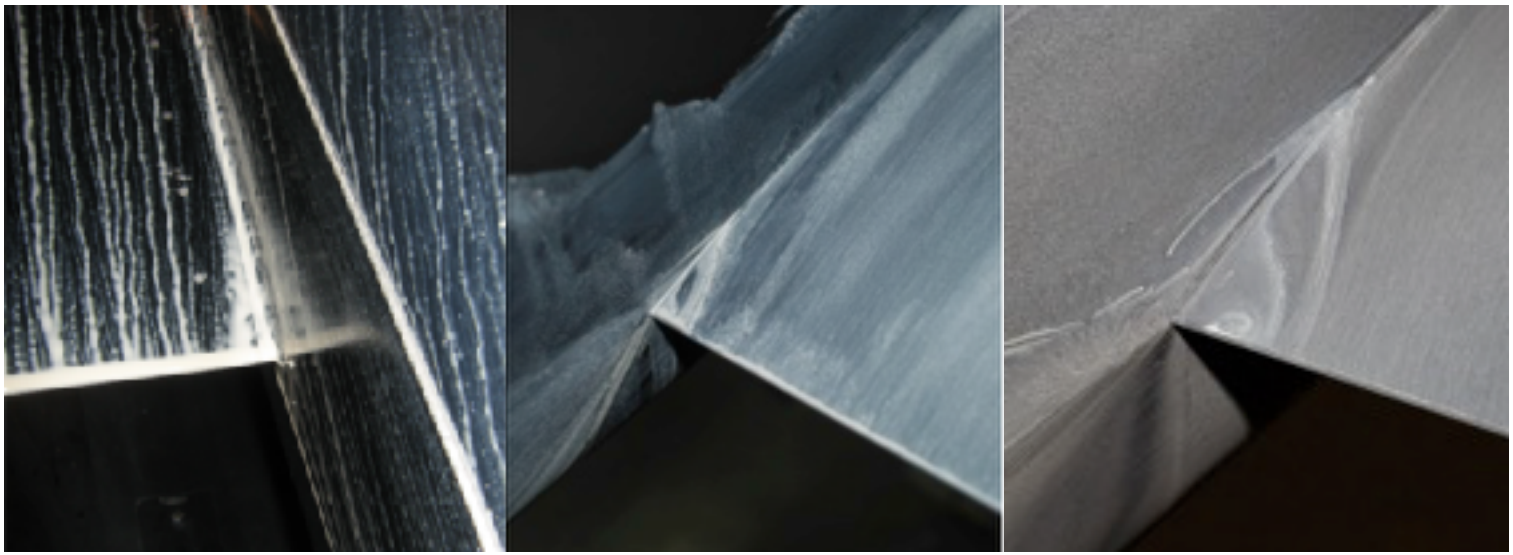
Side of Body Separation



Wing Planform

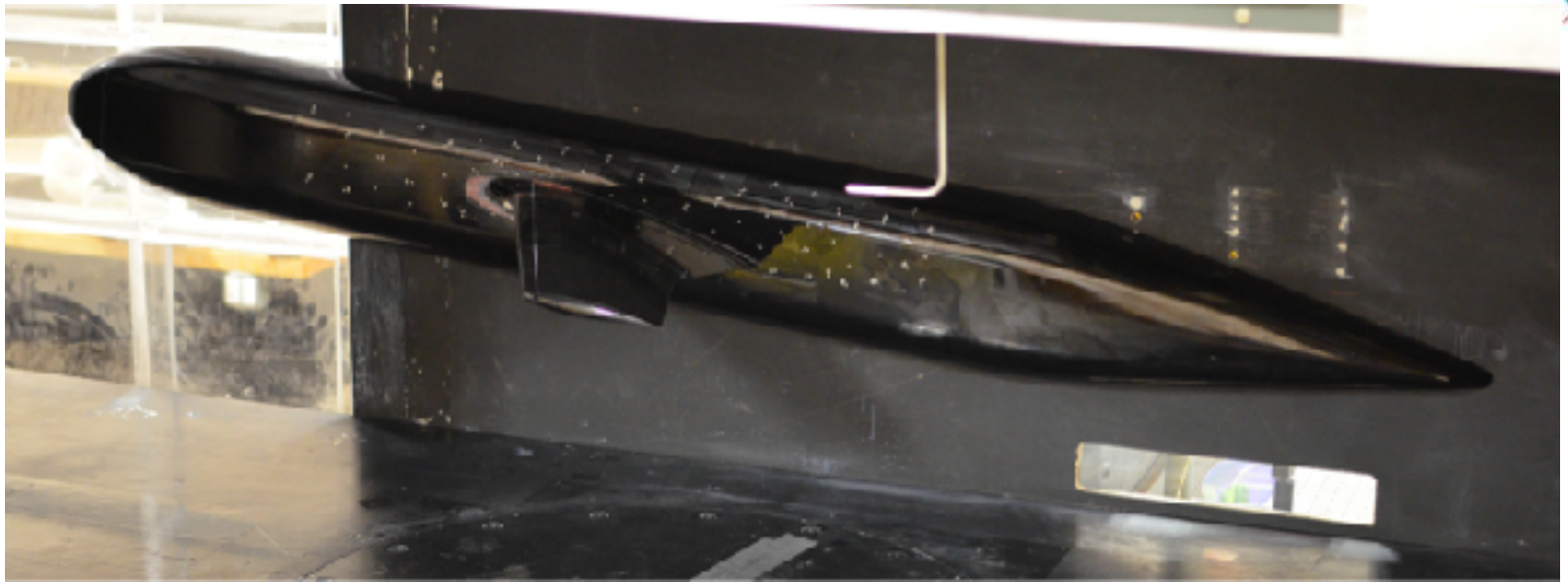
Risk Reduction Tests

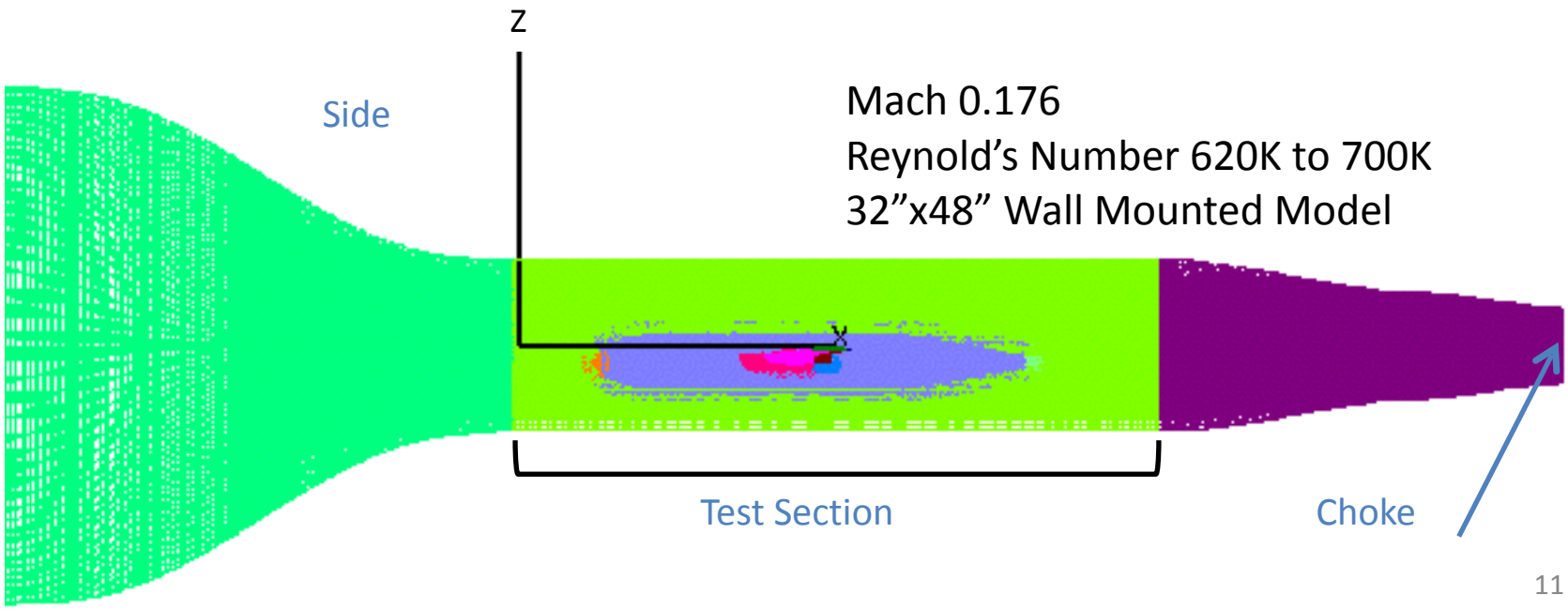
- Series of risk reduction tests
  - Ames TC2 3% wall mounted model, low RE
  - Virginia Tech 2.5% fullspan low RE
  - Langley 14x22 6% fullspan high RE
- CFD solutions were run concurrently with all tests



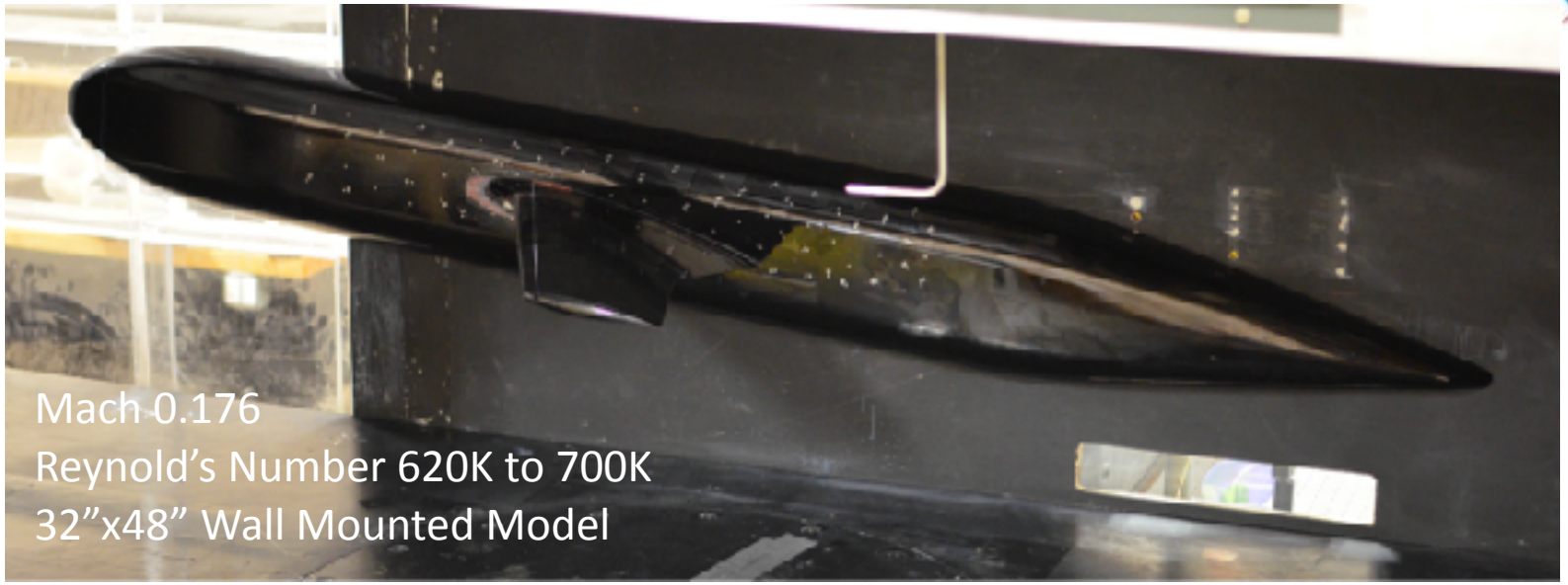
TC2 VA Tech 14x22

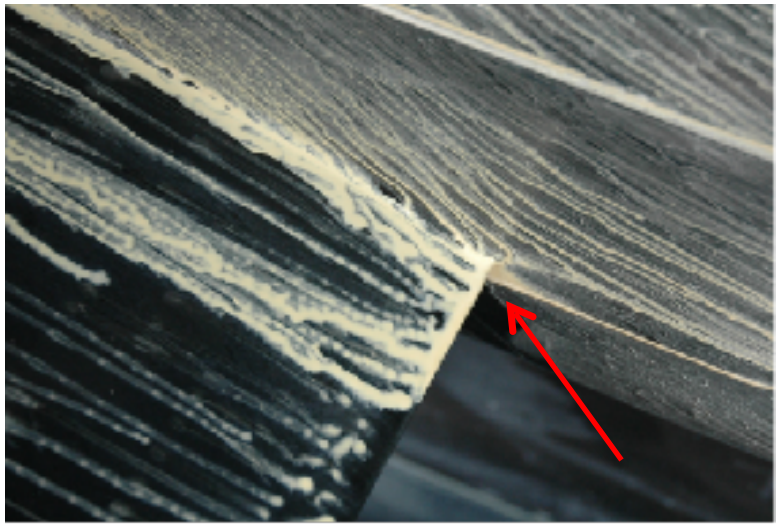
Model in TC2 and CFD Geometry



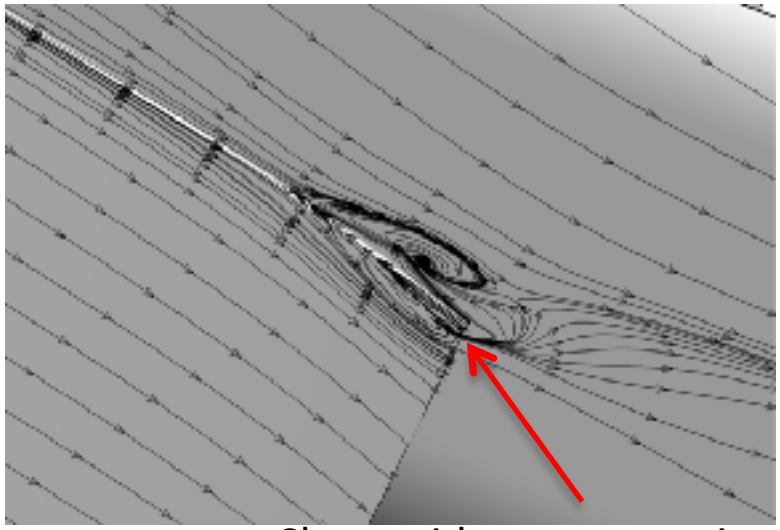


TC2 Risk Reduction





Small hint of separation



Clear evidence separation

Determined Wall Mounted model is not ideal for this test

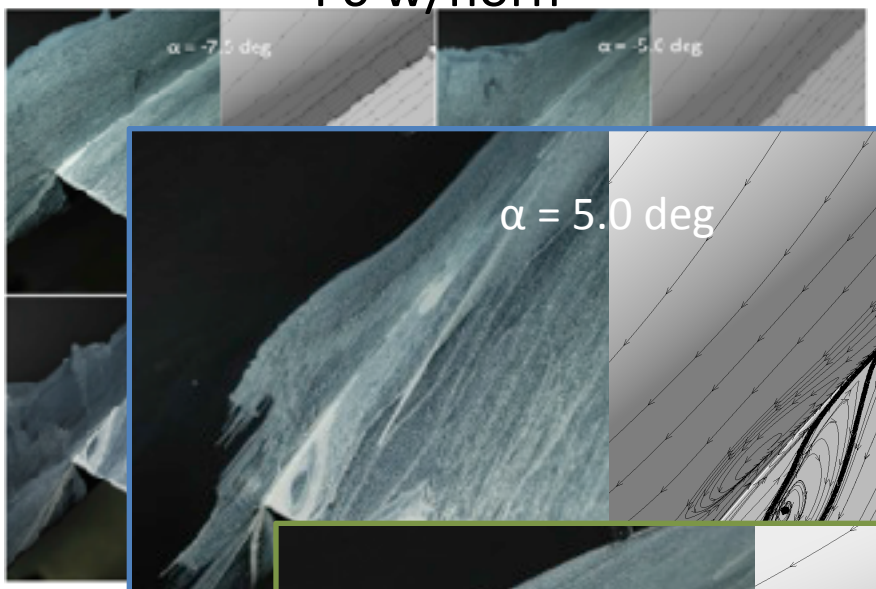
Results published in AIAA Paper 2016-1558

Virginia Tech 2.5% Full Span Test

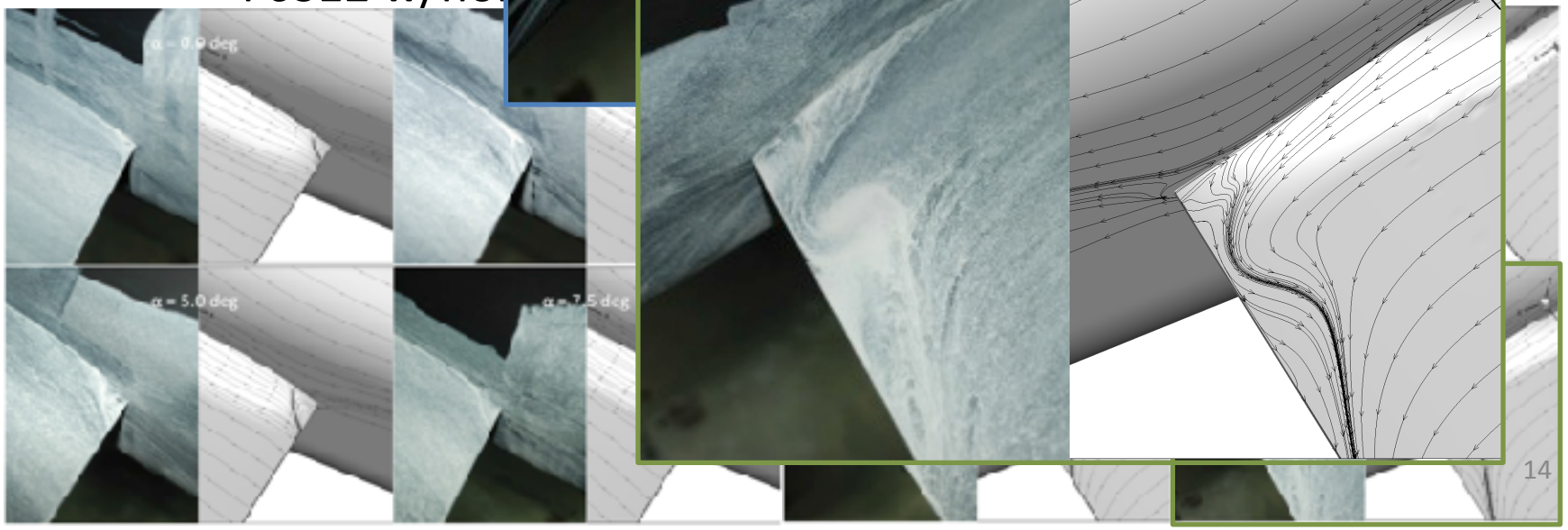
Mach 0.176, Reynolds Number of 620K, 6’ Test Section

VT Tunnel Risk Reduction

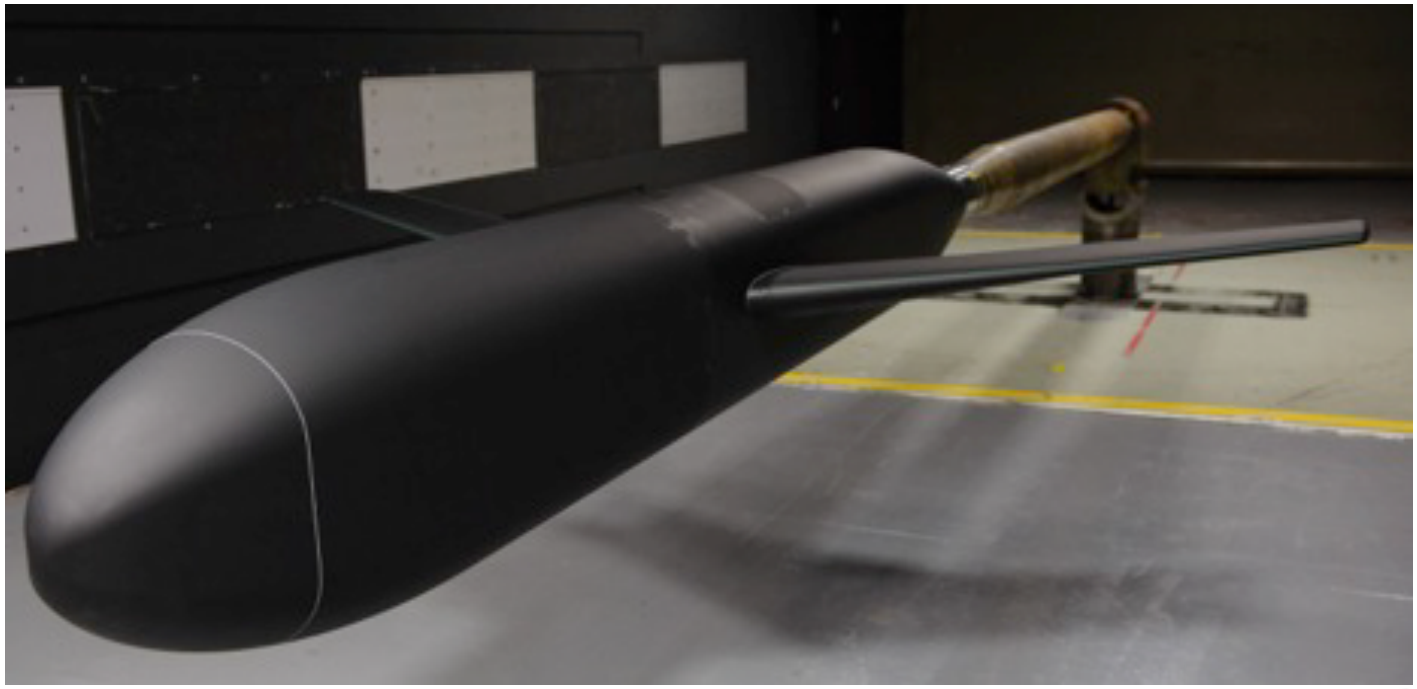
F6 w/horn

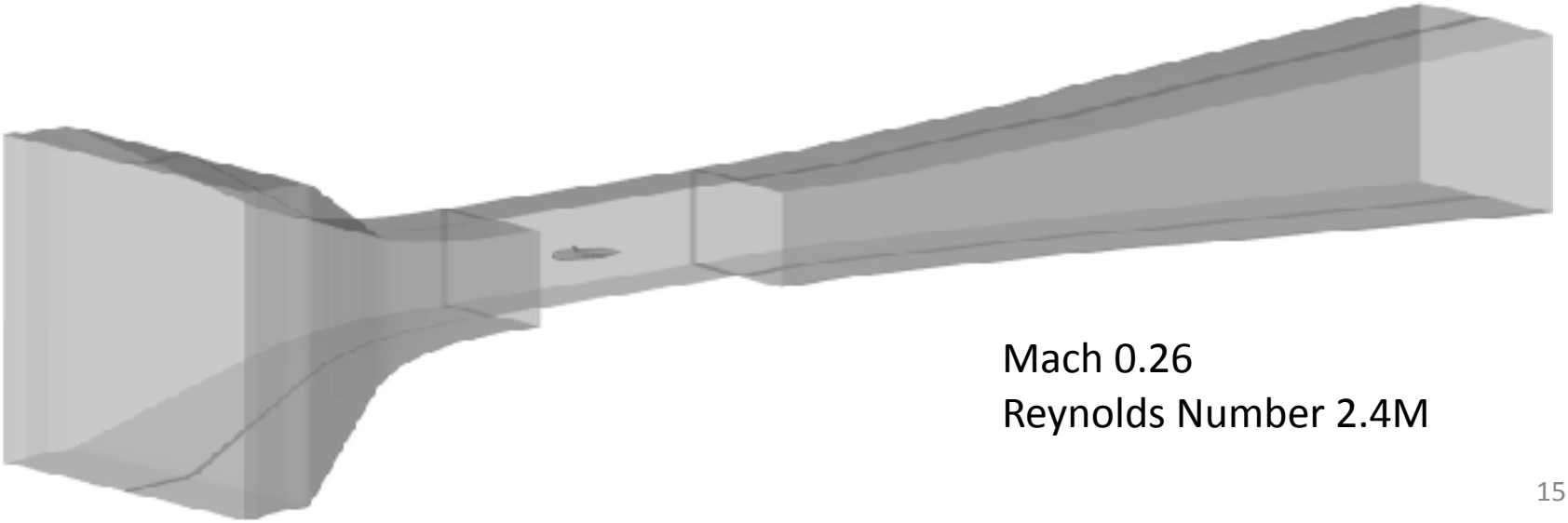


F6S12 w/hor



14x22 6% Risk Reduction Test





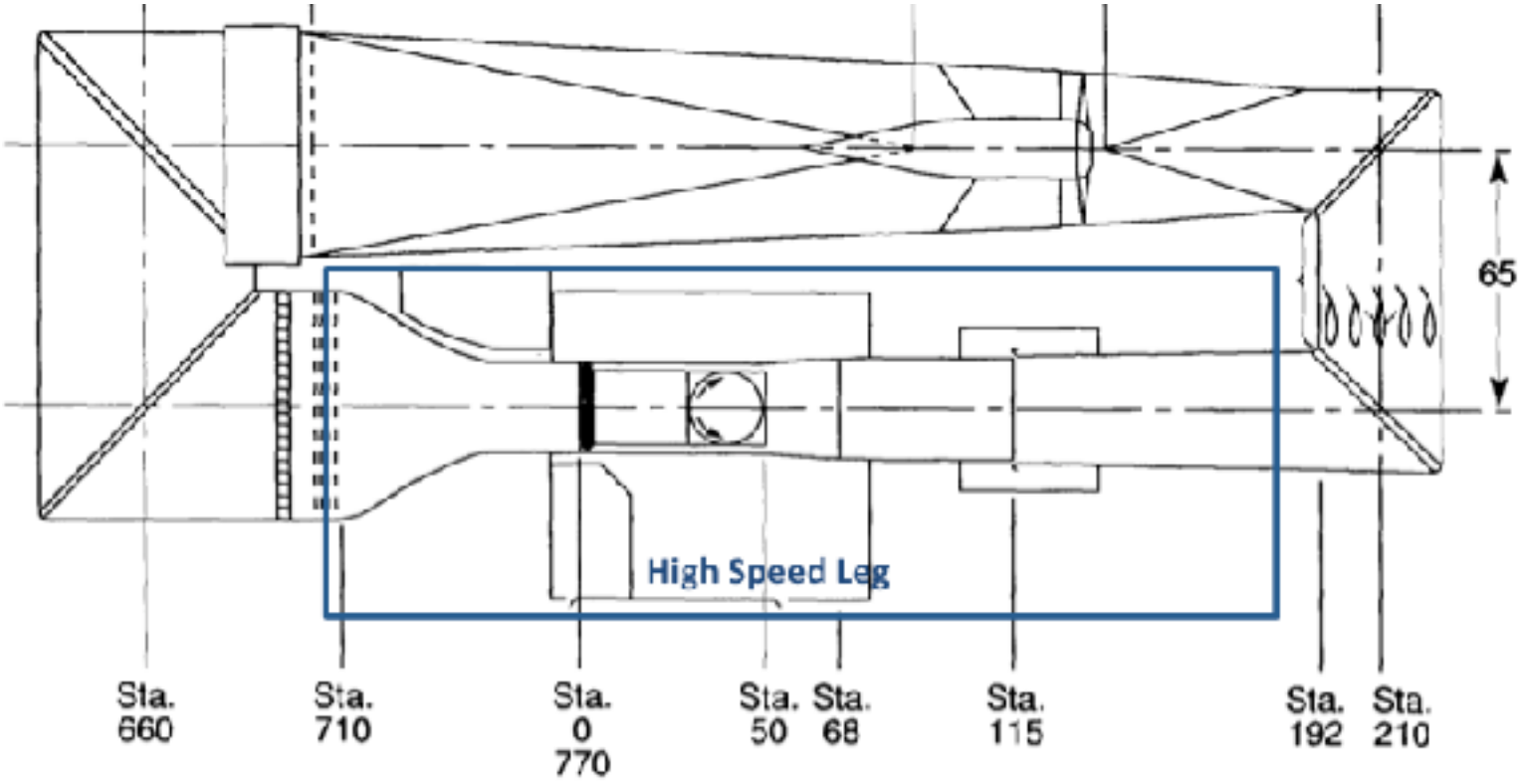
Mach 0.26
Reynolds Number 2.4M

14x22 6% Risk Reduction Setup

- Three data sources
  - Experiment
  - CFD in Free Air
  - CFD with 14x22 wind tunnel walls
- Comparisons: oil flow vs streamlines
- Additional results for α = -10.0 — 10.0 degrees in paper
- Additional experimental results in NASA TM–219348

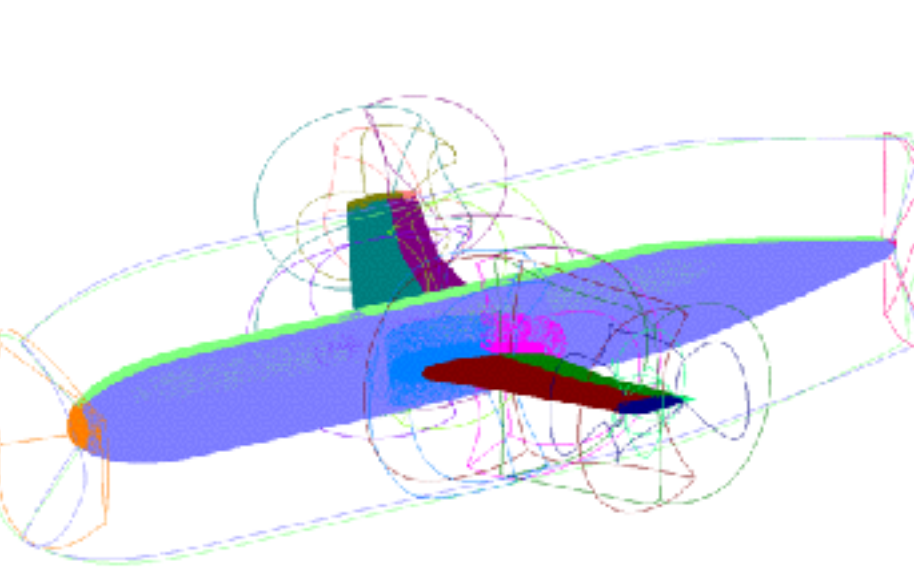
NASA Langley 14- by 22-Foot Subsonic Tunnel

- 14.5 ft high by 21.75 ft wide test section
- Closed-circuit wind tunnel
- Blue box represents high speed leg
- RE = 2.4 million, Mach 0.26

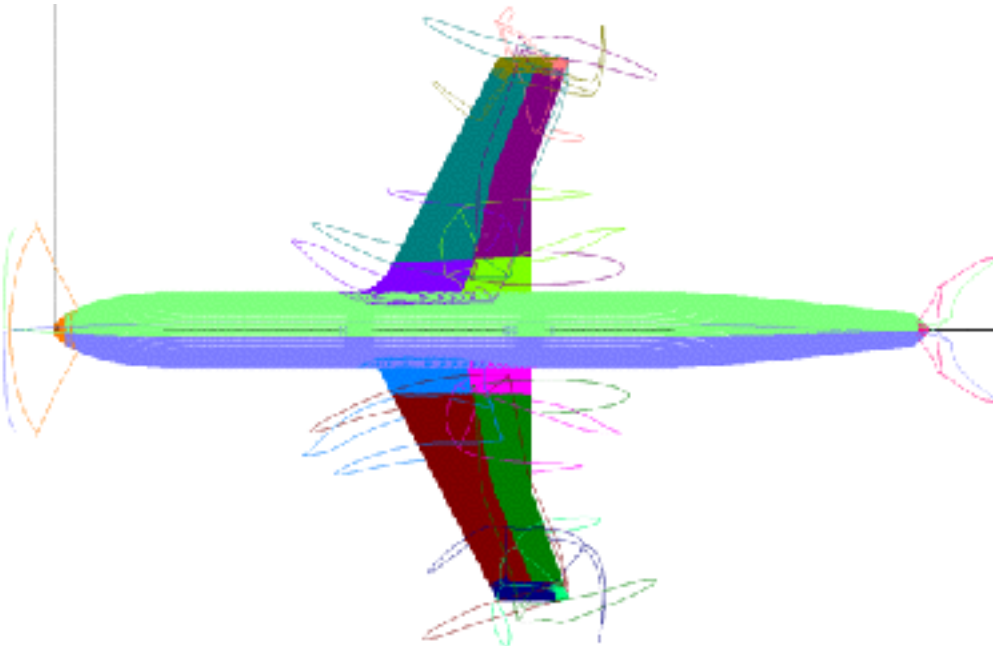


Juncture Flow Model Grids

- Grids created based on best practices, as defined by AIAA workshops (DPW, HiLift, etc)
- Grid resolution study was performed early on to establish grid guidelines for all cases



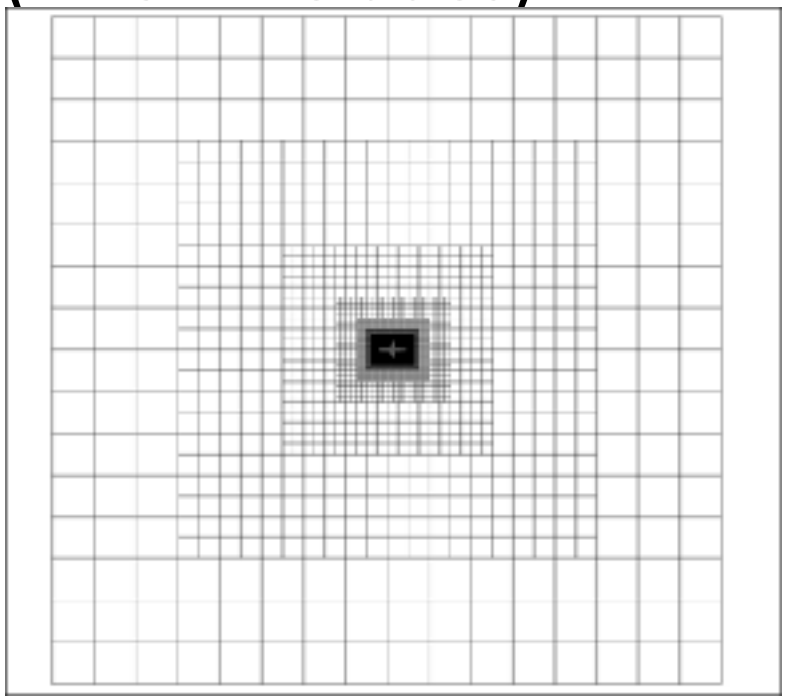
JFM Grids ISO-view

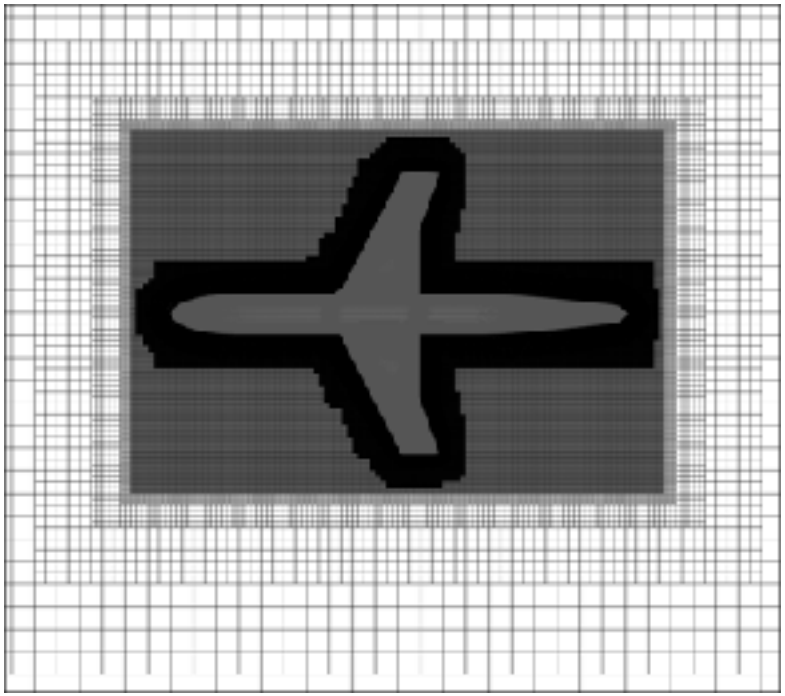


JFM Grids Top-view

JFM Free Air Cases

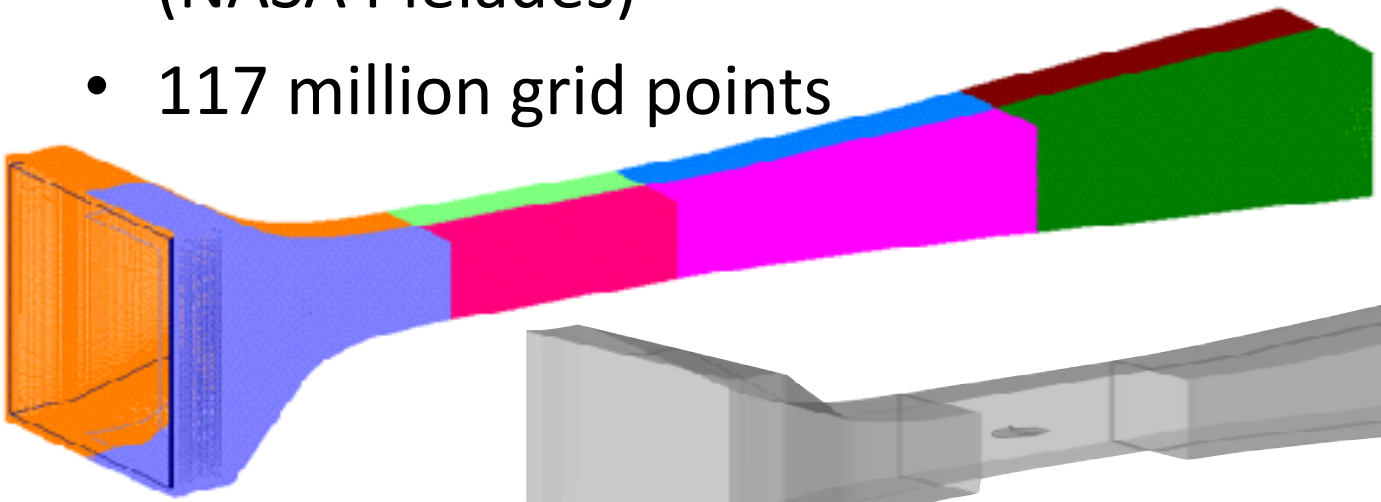
- JFM grids, imbedded in Overflow's off body grids
- Fairfield at 100 chord lengths away
- 108 Million grid points
- 420 Intel Broadwell cores, 12 hours wall time (NASA Pleiades)



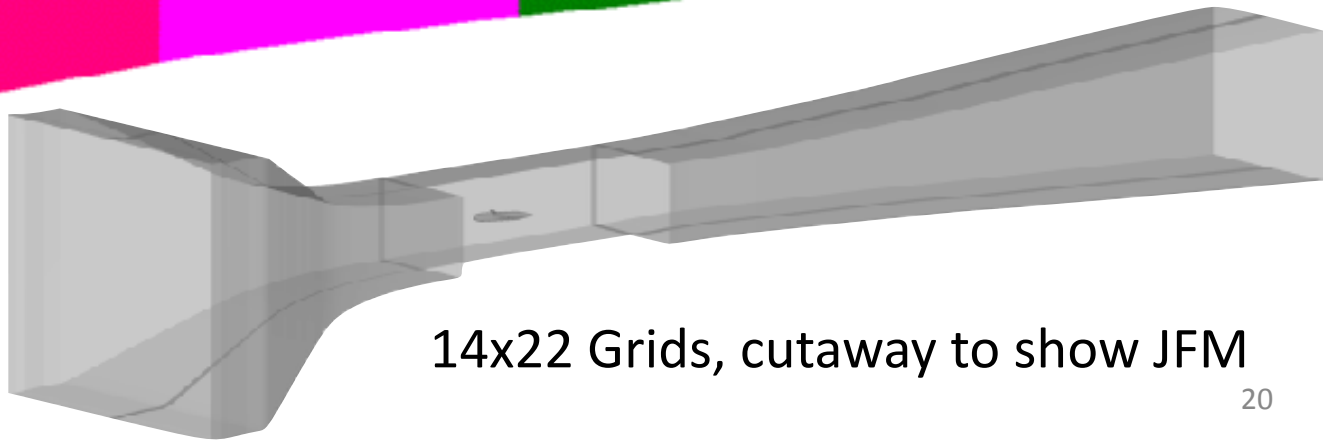


JFM Wind Tunnel Cases

- JFM grids, installed in the 14x22 wind tunnel grids
- Inflow BC: Stagnation pressure/temperature
- Outflow BC: Back pressure iterated to match tunnel speed.
- 1200 Intel Ivy Bridge cores, 60-120 hours wall time (NASA Pleiades)
- 117 million grid points



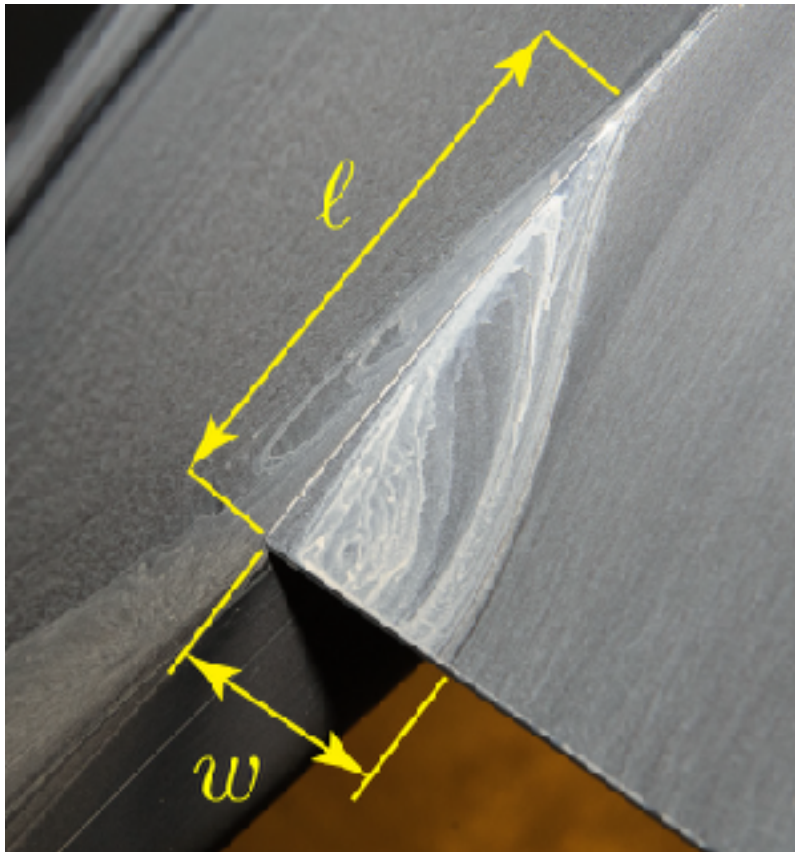
14x22 Grid



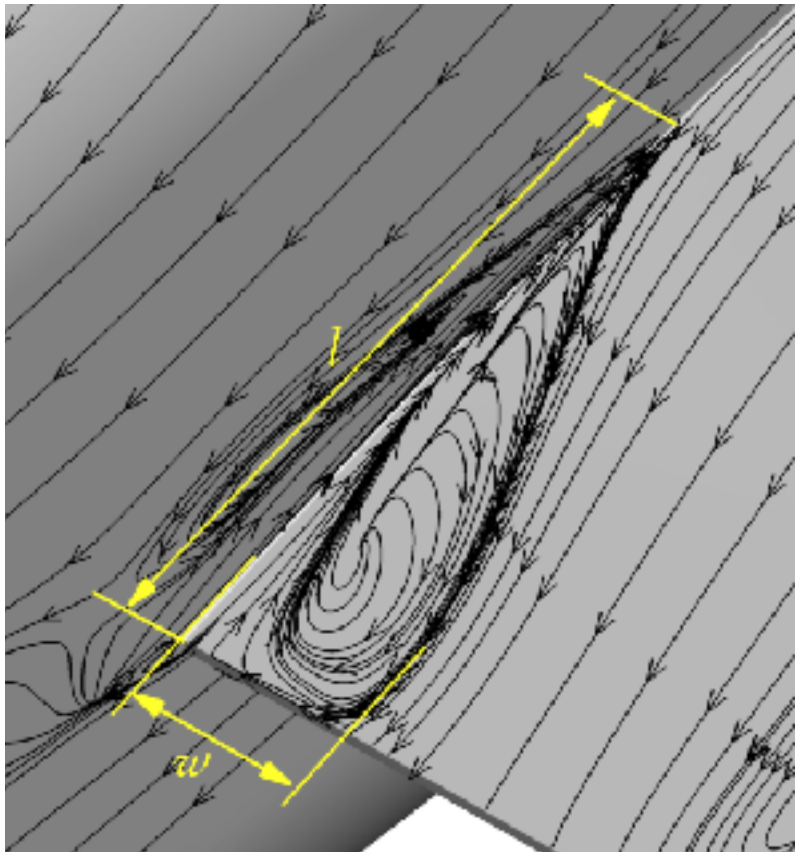
14x22 Grids, cutaway to show JFM

SOB Bubble Size Definitions

Experiment Oil Flow



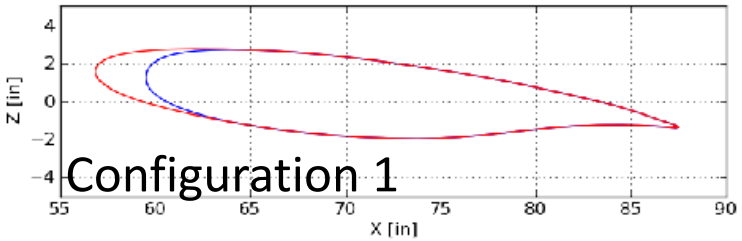
CFD Surface Streamlines

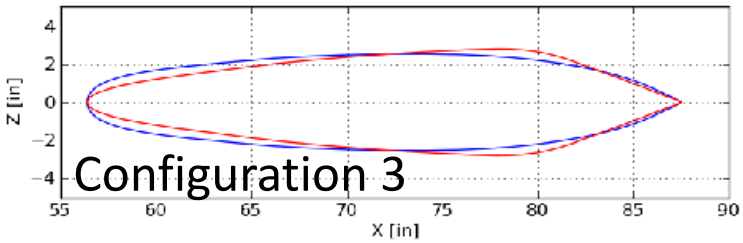


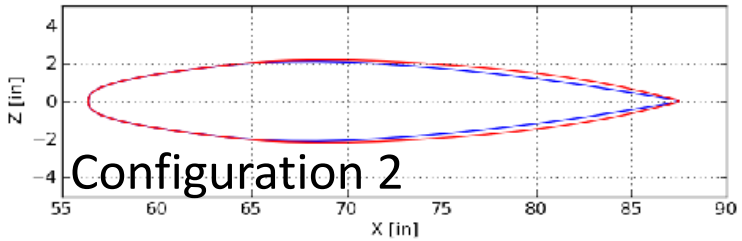
length ℓ and width w bubble size definitions

Wing Configurations

Configuration	Port Wing	Starboard Wing	Data
1	F6 no horn	F6 w/horn	Exp, CFD Free Air, CFD WT
2	NACA 0015 w/horn	NACA 0015mod w/horn	Exp, CFD Free Air, CFD WT
3	F6S12 w/horn	COCA w/horn	Exp, CFD Free Air





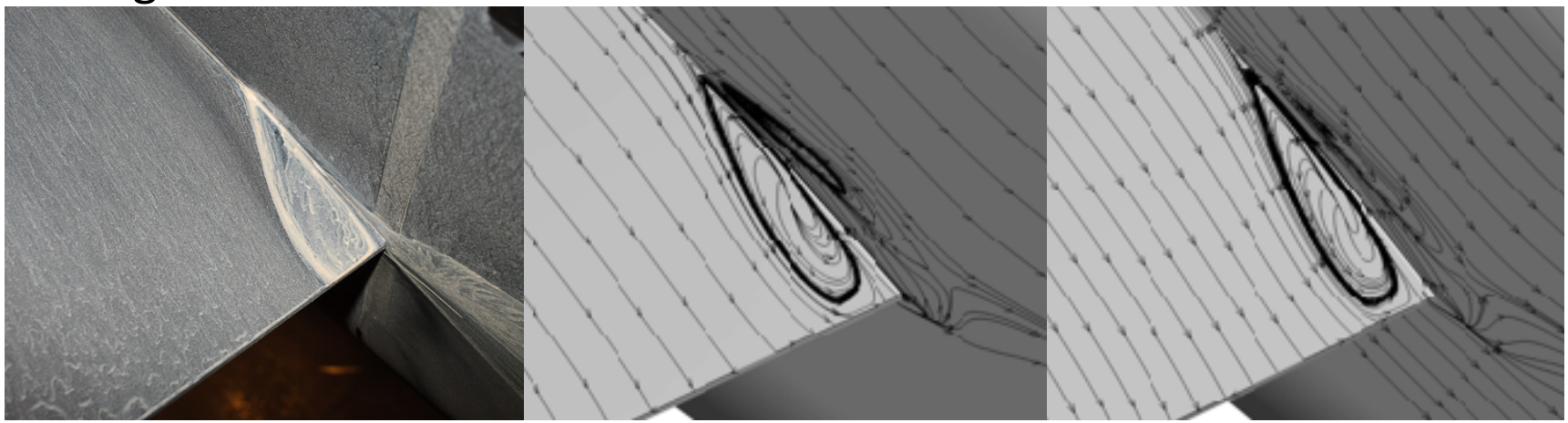


— Port Wing (blue)

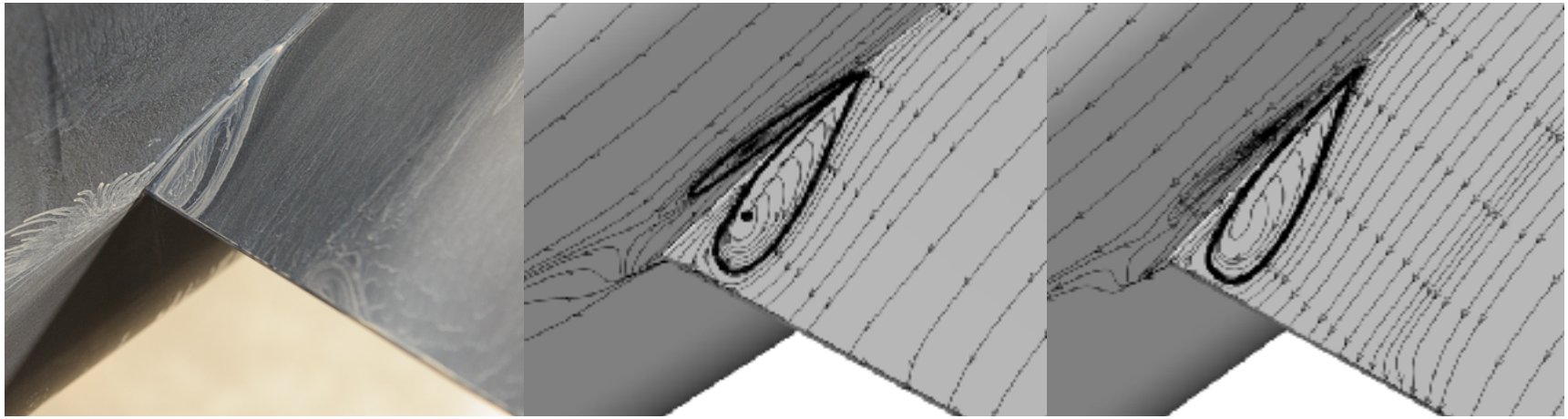
— Starboard Wing (red)

Configuration 1: F6 no horn—F6 w/horn, α=5.0°

Port Wing: F6 no horn



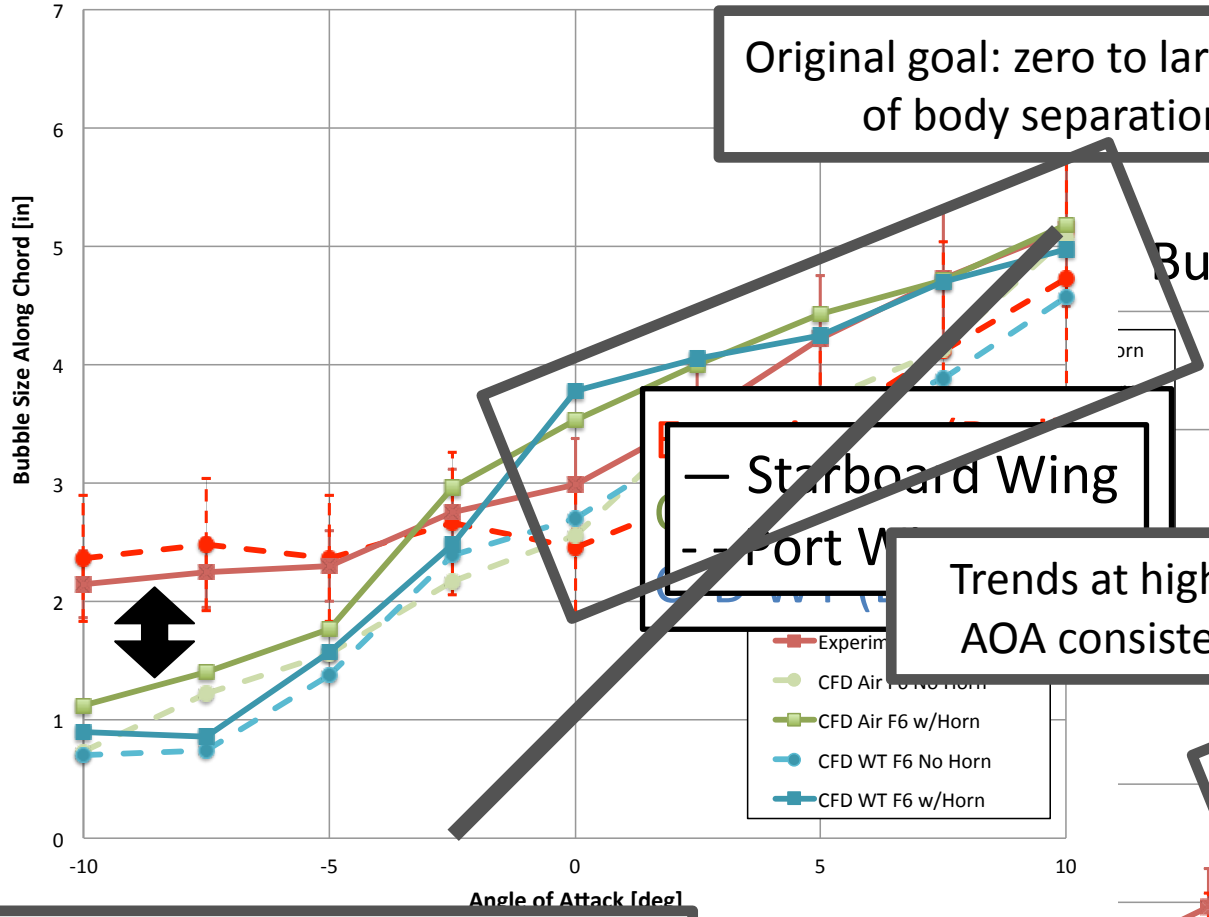
Starboard Wing: F6 w/horn



Experiment CFD Free Air CFD WT

Configuration 1: F6 no horn—F6 w/horn

Bubble Length Comparison

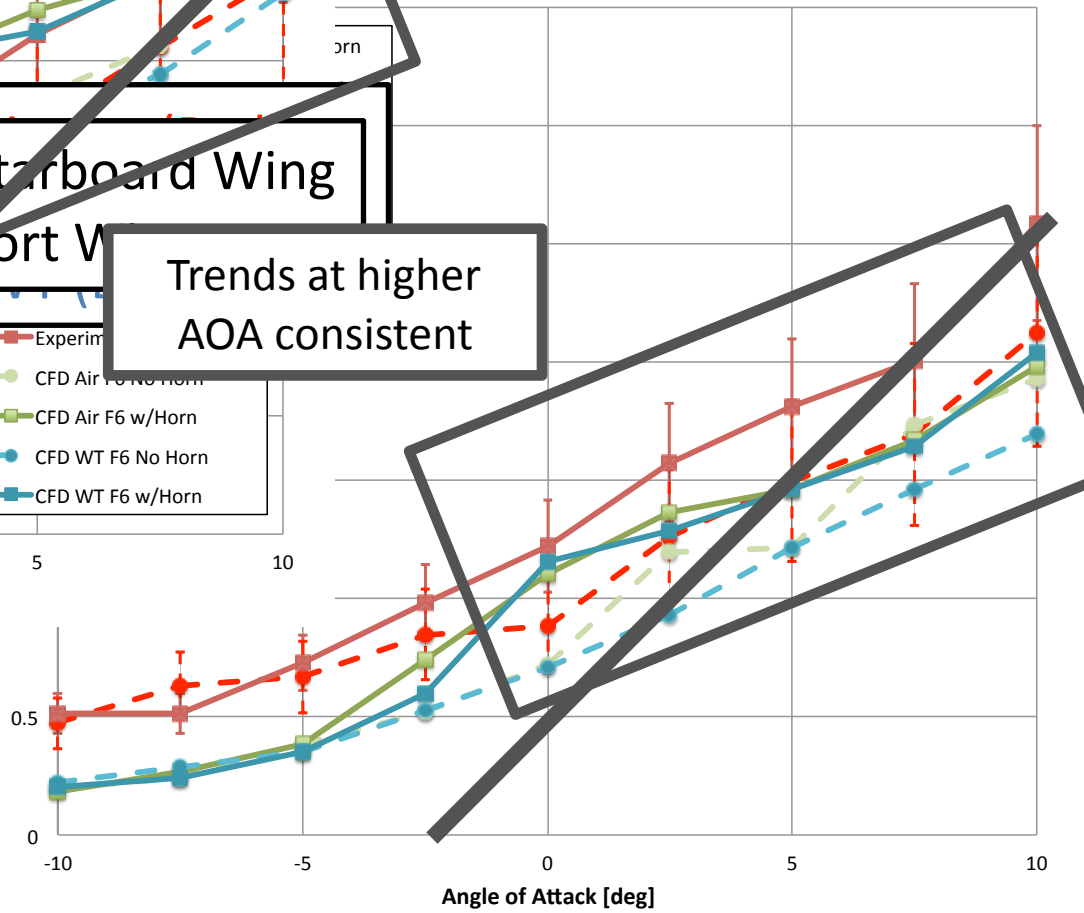


Original goal: zero to large side of body separation

— Starboard Wing

Trends at higher AOA consistent

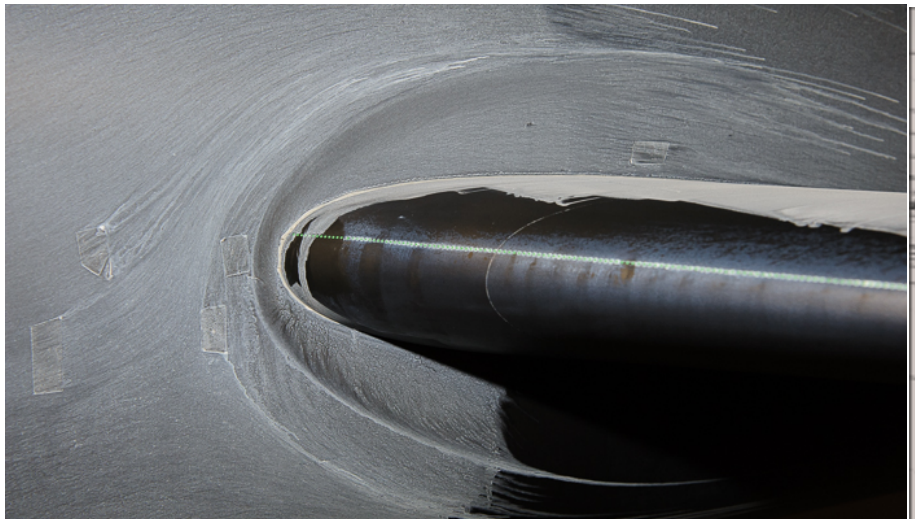
Bubble Width Comparison

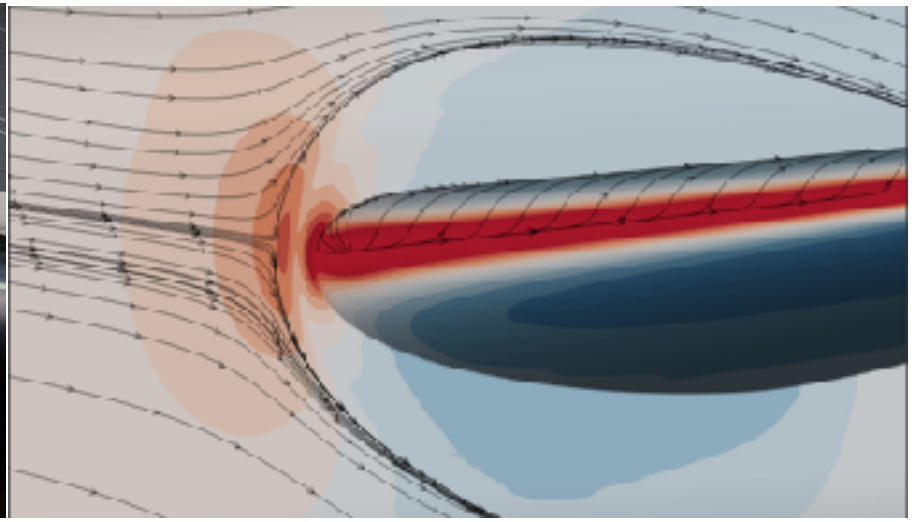


Larger difference between CFD and WT Data at lower AOA. Bubble size doesn't go to zero

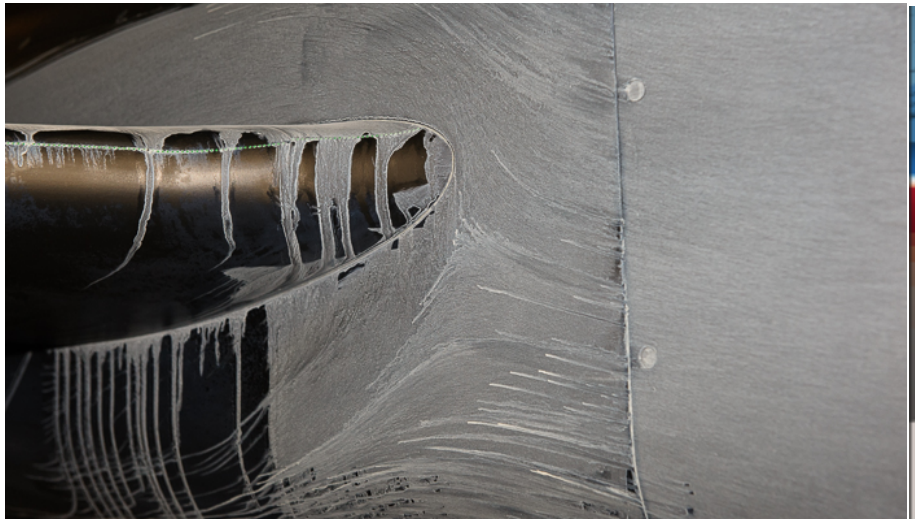
Configuration 1: F6 no horn—F6 w/horn, α=5.0° LE

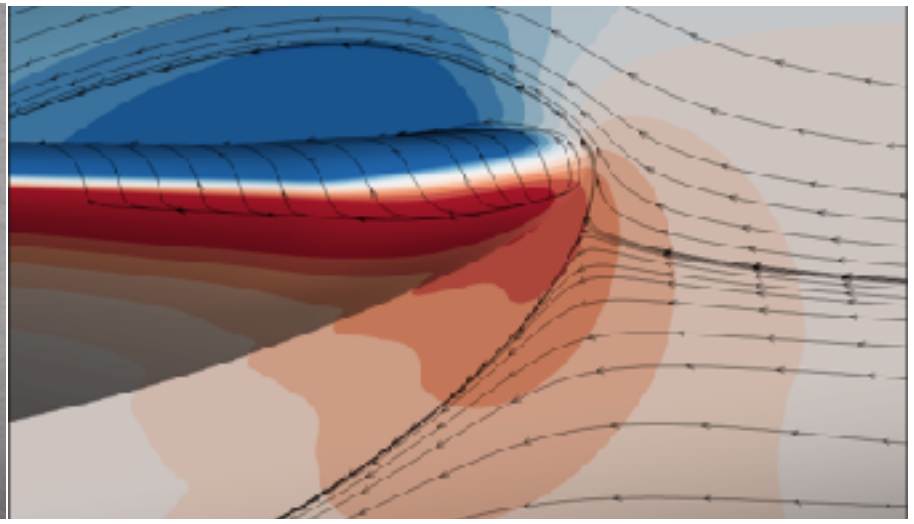
Port Wing: F6 no horn





Starboard Wing: F6 w/horn



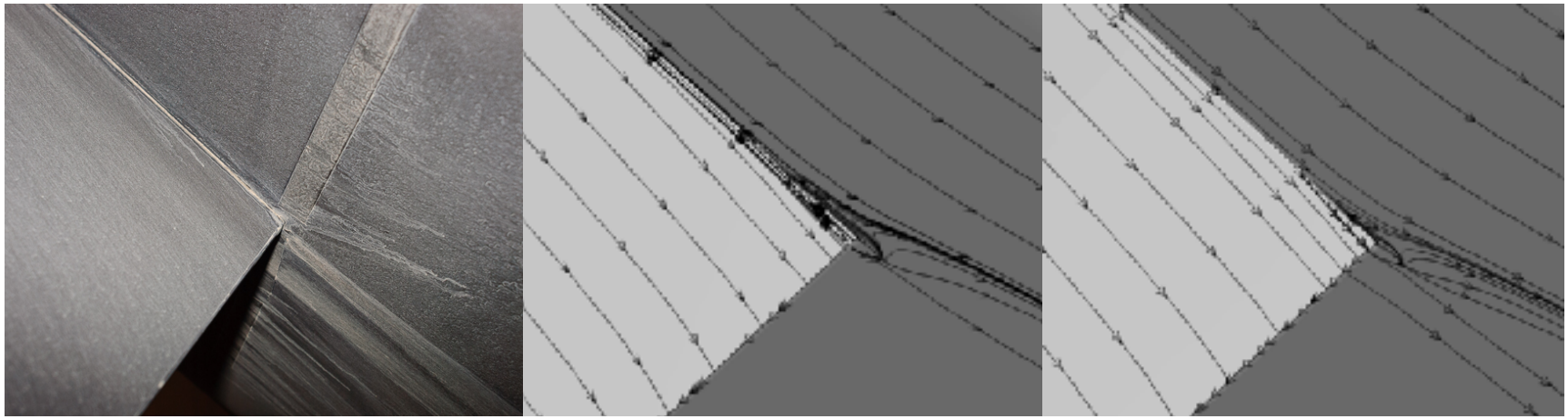


Experiment

CFD WT

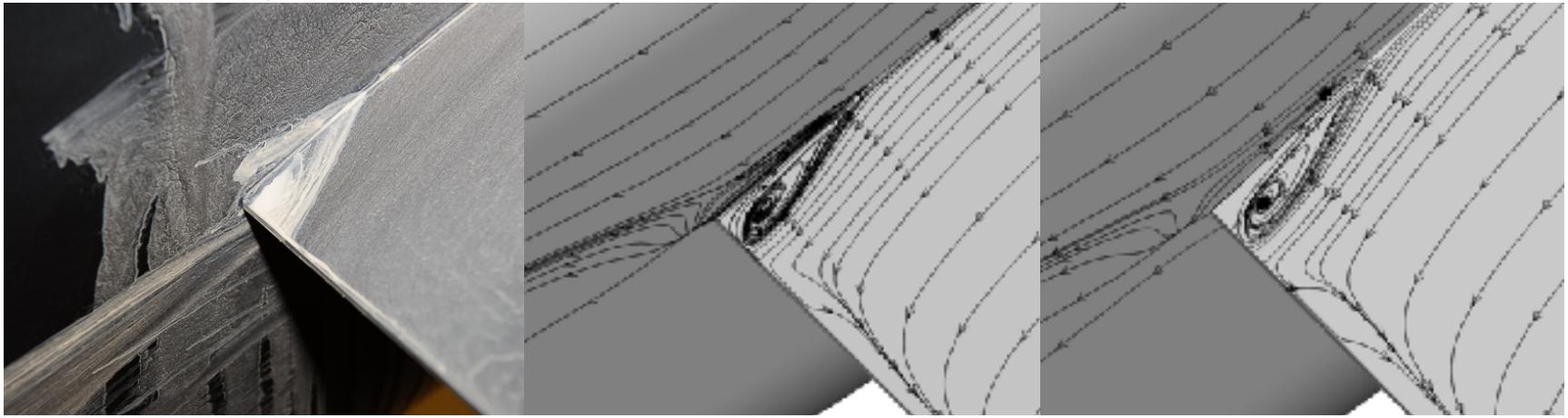
Configuration 2: NACA 0015—NACA 0015mod, α=5.0°

Port Wing: NACA 0015 w/horn



*Was run without horn

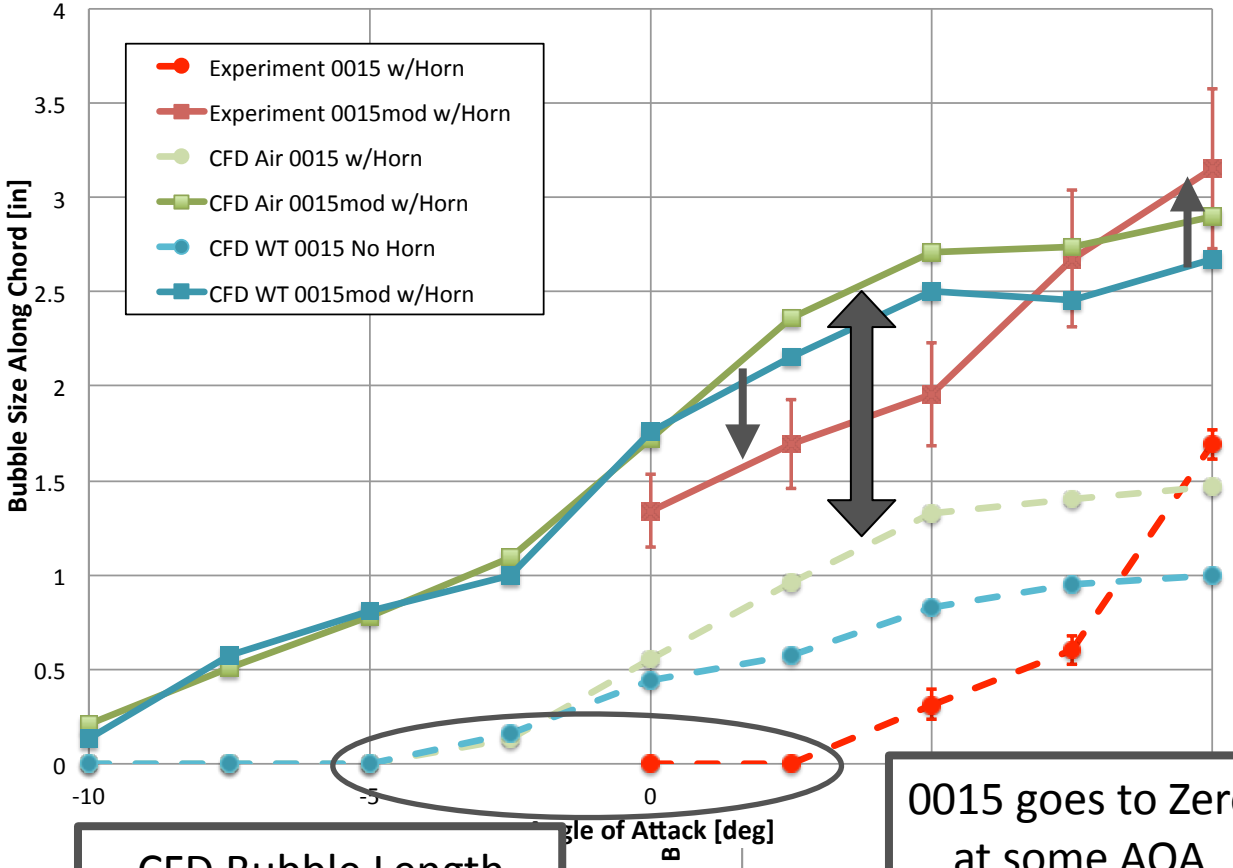
Starboard Wing: NACA 0015mod w/horn



Experiment CFD Free Air CFD WT

Configuration 2: NACA0015—NACA0015mod

Bubble Length Comparison

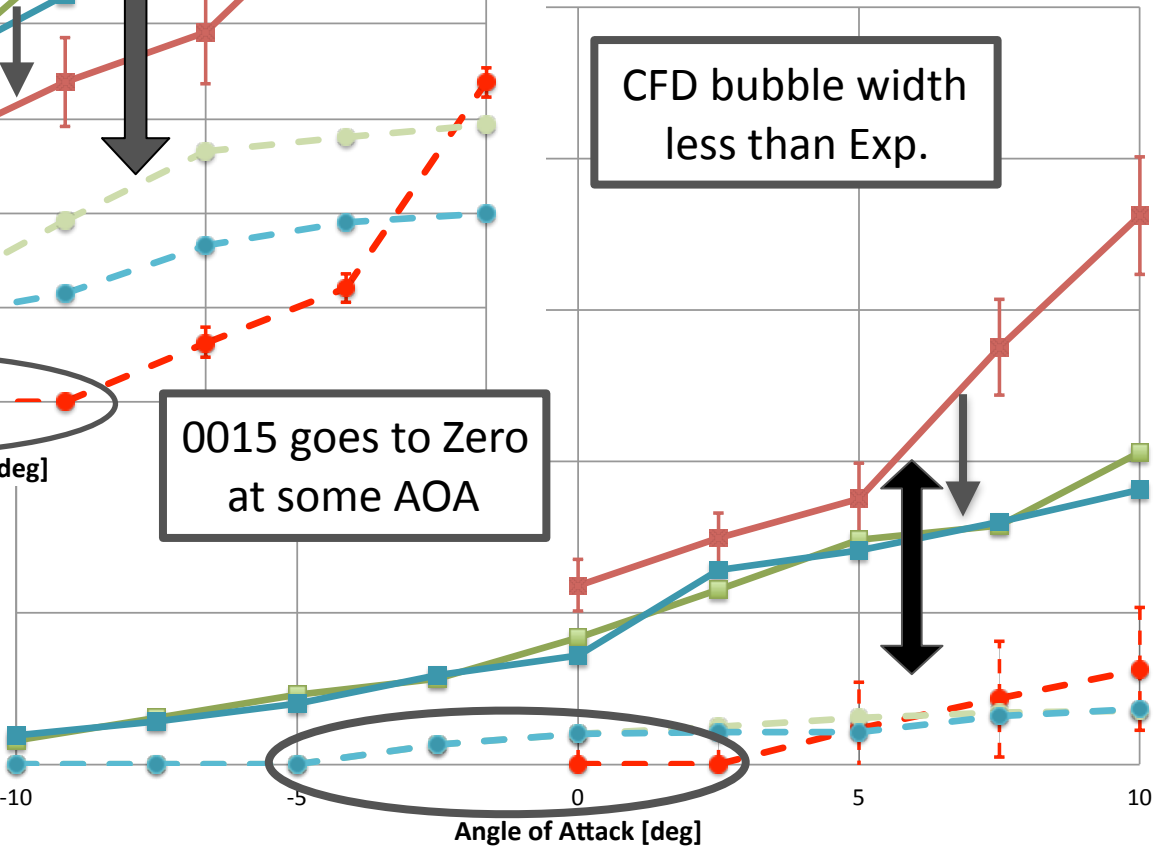


CFD Bubble Length slightly larger than Exp. at lower alpha, under predicts at high alpha

ween
mod
wing consistent

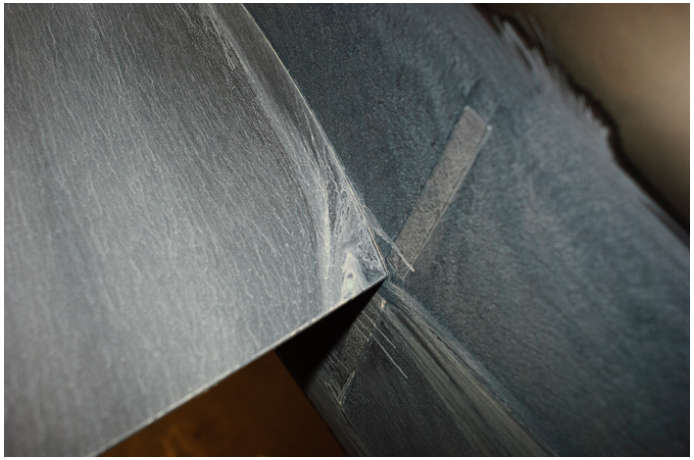
0015 goes to Zero at some AOA

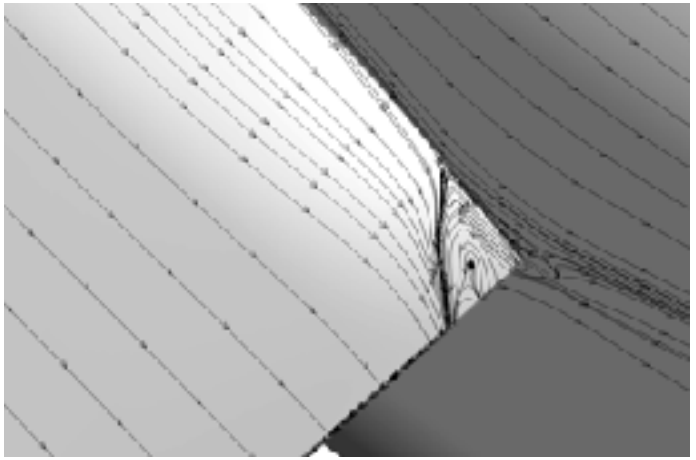
Bubble Width Comparison



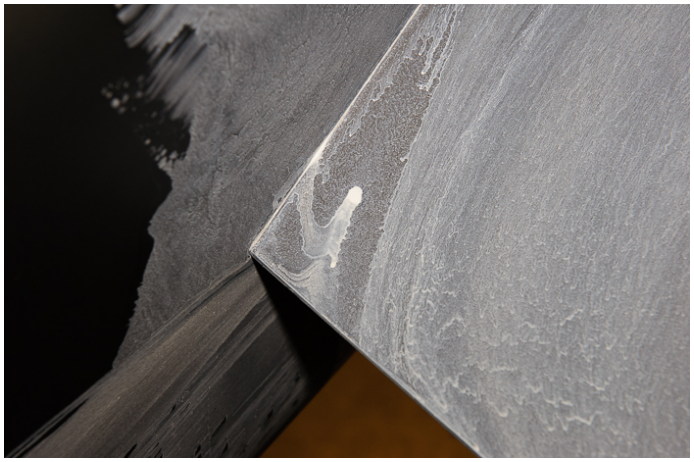
Configuration 3: F6S12—COCA, α=5.0°

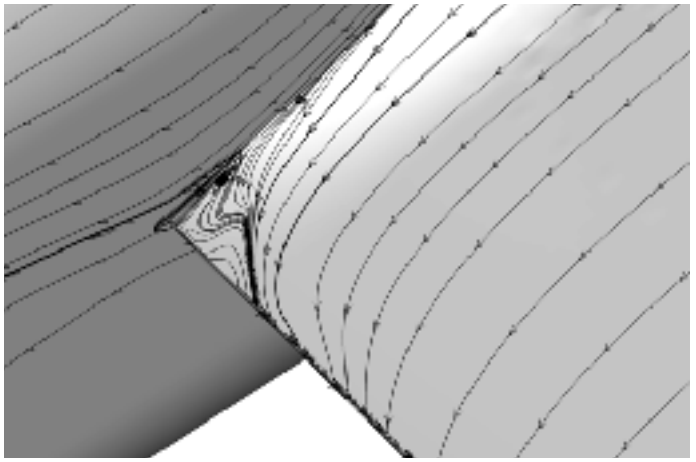
Port Wing: F6S12 w/horn





Starboard Wing: COCA w/horn





Experiment

CFD Free Air

Wing Evaluations

- Trends between CFD and Experiment are very good

- F6 showed medium to large side of body separations
- NACA 0015 showed none to small separation
- NACA 0015mod showed small to medium separation
- COCA wing and F6S12 ruled out
- LE-horn indicates smaller LE horseshoe vortex

Conclusions and Upcoming

- Performed wing design evaluations with CFD
- Performed companion CFD risk assessments with the risk reduction experiments
- CFD design and analysis, combined with experimental risk assessment experiments, results in high confidence in selecting the final models
- Committee used all the data to select the final configurations:
  - F6 (primary)
  - 0015 (secondary)

- Fuselage Model & Wing models delivered May 2017

- Tunnel entry 1: November 2017
- Tunnel entry 2: March 2018

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