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Computational Evaluation of Inlet Distortion on an Ejector Powered Hybrid Wing Body at Takeoff and Landing Conditions

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Engineering, Operations & Technology
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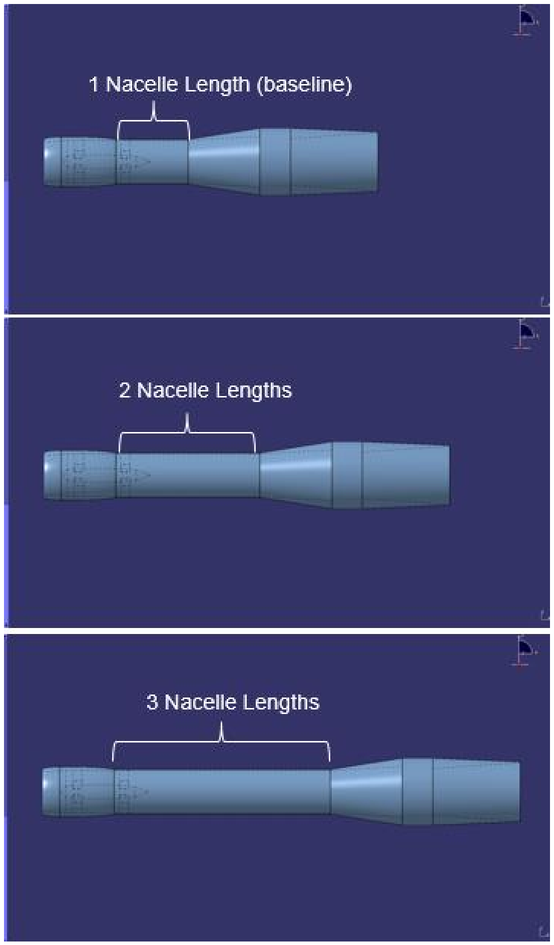
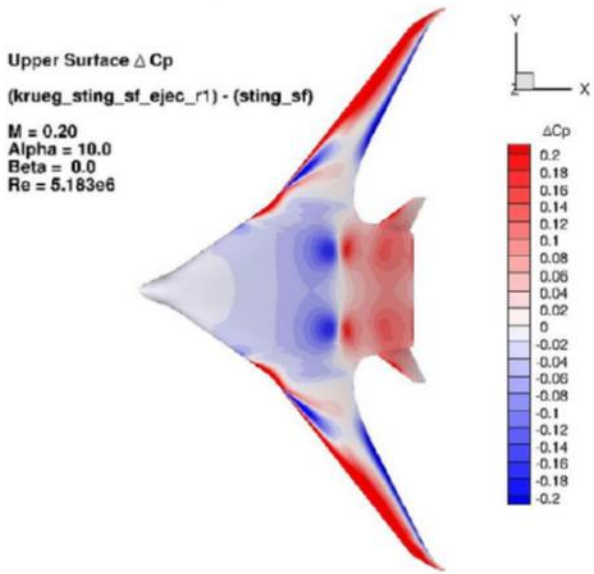
Introduction

- **Due to the aft, upper surface engine location on the Hybrid Wing Body (HWB) planform, there is potential to shed vorticity and separated wakes into the engine when the vehicle is operated at off-design conditions and corners of the envelope required for engine and airplane certification**
- **CFD simulations were performed of the full-scale reference propulsion system, operating at a range of inlet flow rates, flight speeds, altitudes, angles of attack, and angles of sideslip to identify the conditions which produce the largest distortion and lowest pressure recovery**
- **Pretest CFD was performed by NASA and Boeing, using multiple CFD codes**
  - Model integration
  - Characterize inlet flow distortion patterns
  - Help define the wind tunnel test matrix
- **CFD was also performed post-test; when compared with test data, it was possible to make comparisons between measured model-scale and predicted full-scale distortion levels.**

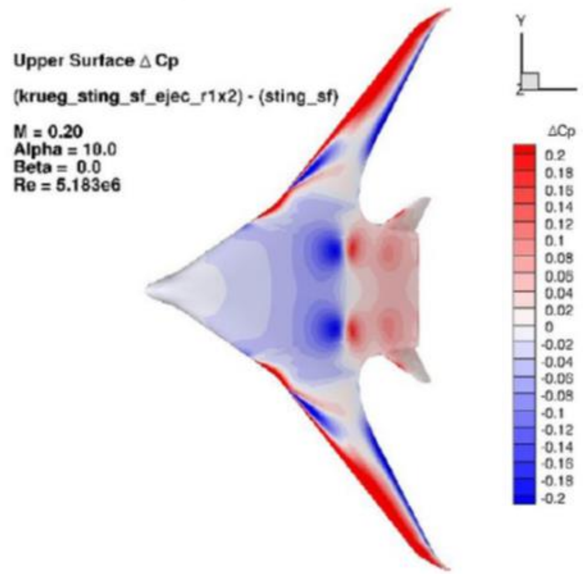
Pre-Test CFD for Model Integration: Ejector Sizing



Ejector Rev1



Ejector Rev1 Ext2

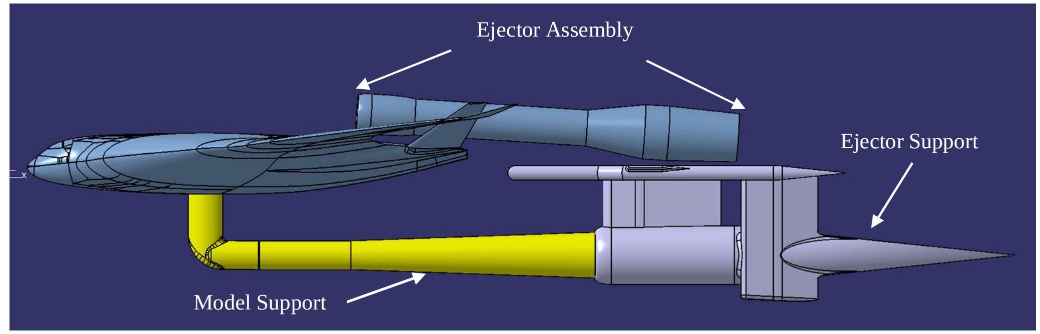


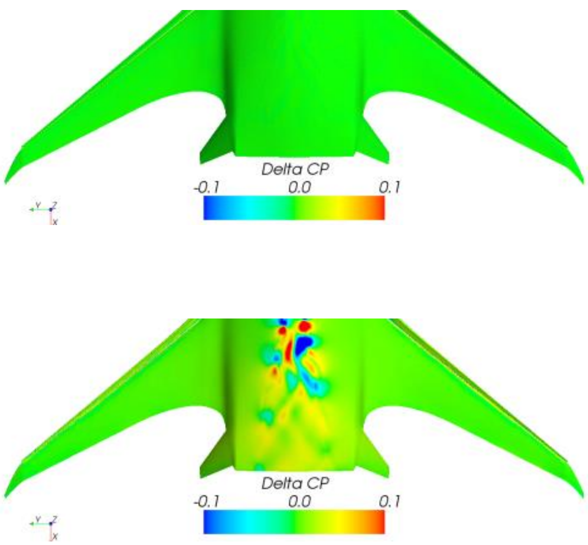
CFD Analysis was used to size the constant-area duct in the ejector

- CFD results plot the difference in Cp with the ejector present and absent
- A longer constant-area duct in the ejector minimizes the ejectorsôeffect on pressure distributions on the body

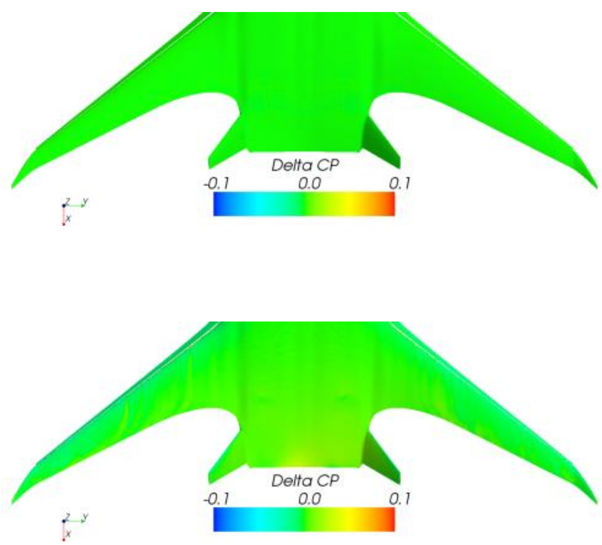
Pre-Test CFD for Model Integration: Influence of Support Stand

- Ejector support had negligible effects on the flowfield through the ejector assembly
- Top surface of the wing appeared unaffected by the ejector support
- Ejector support primarily influenced the underside of the wing body

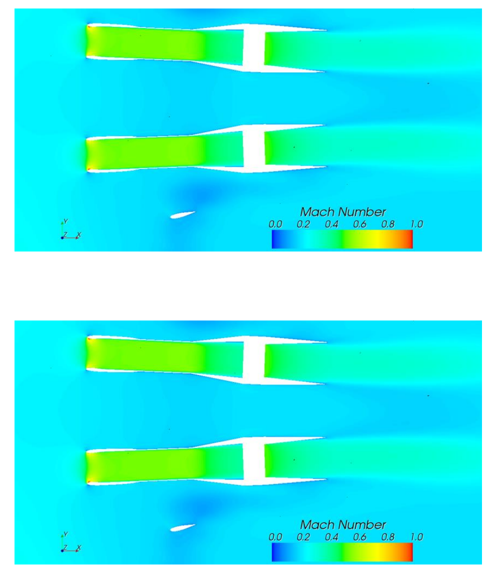




Bottom View



Top View



Ejector Flowfield

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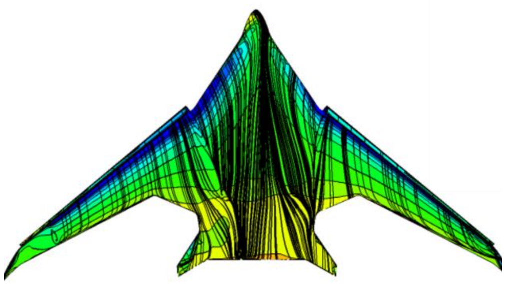
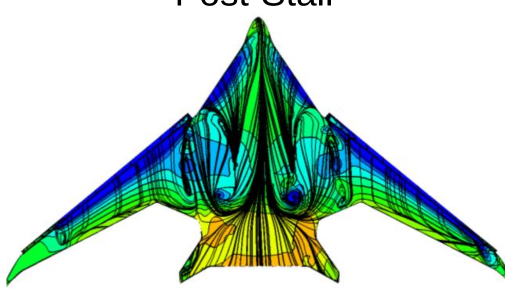
Pre-Test CFD Model Scale Inlet Distortion Study: Surface Cp Contours

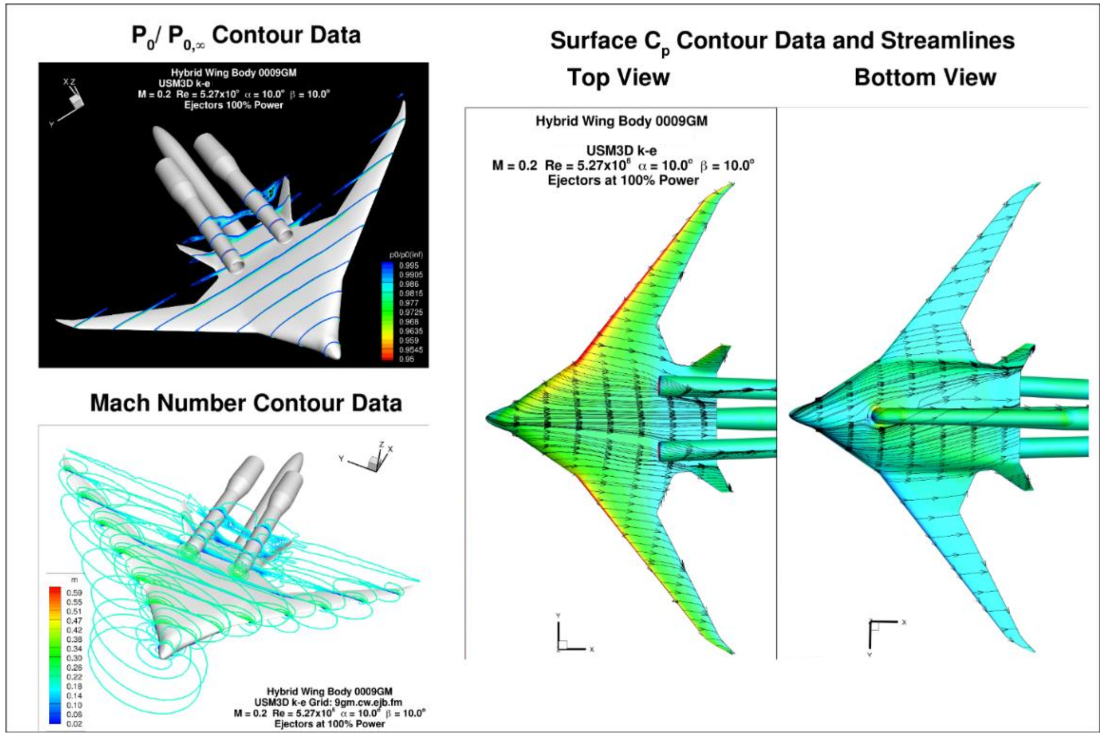
- At low freestream conditions (MN < 0.065) ejector has significant interaction with body
- Higher power cases cause higher suction off of body near inlet of ejector

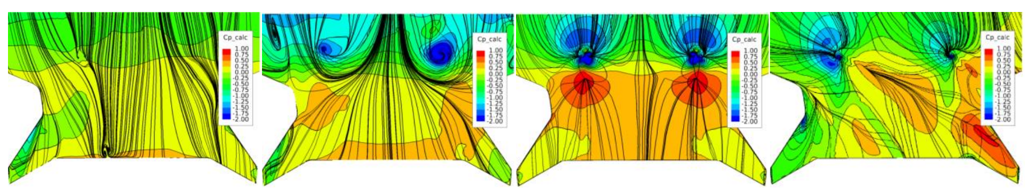
Pre-Stall



Post-Stall



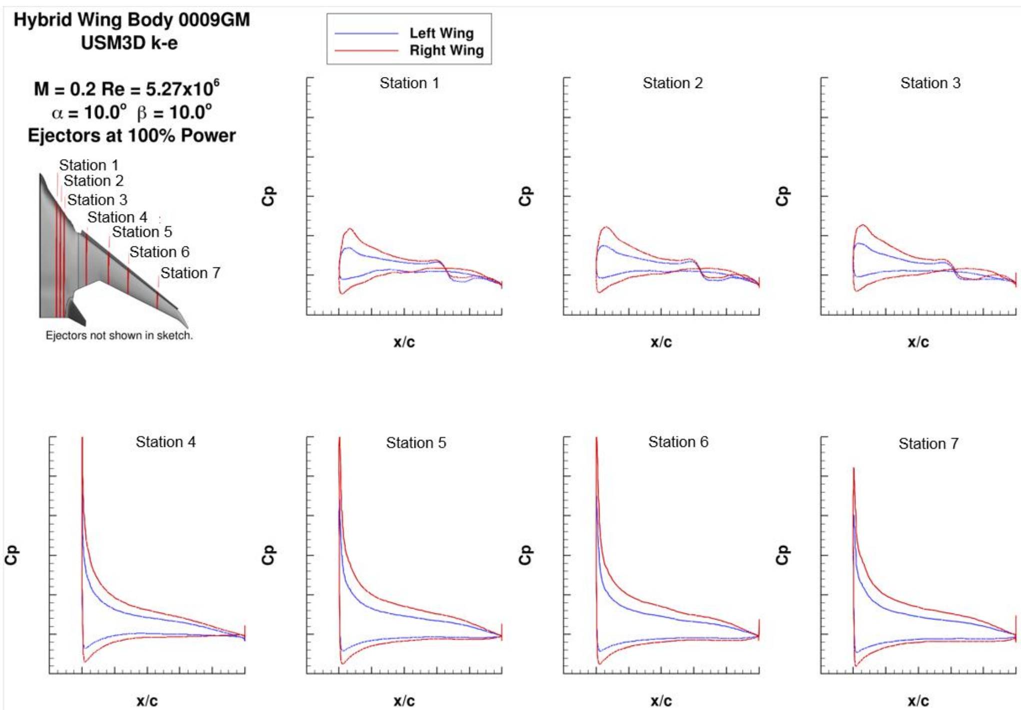


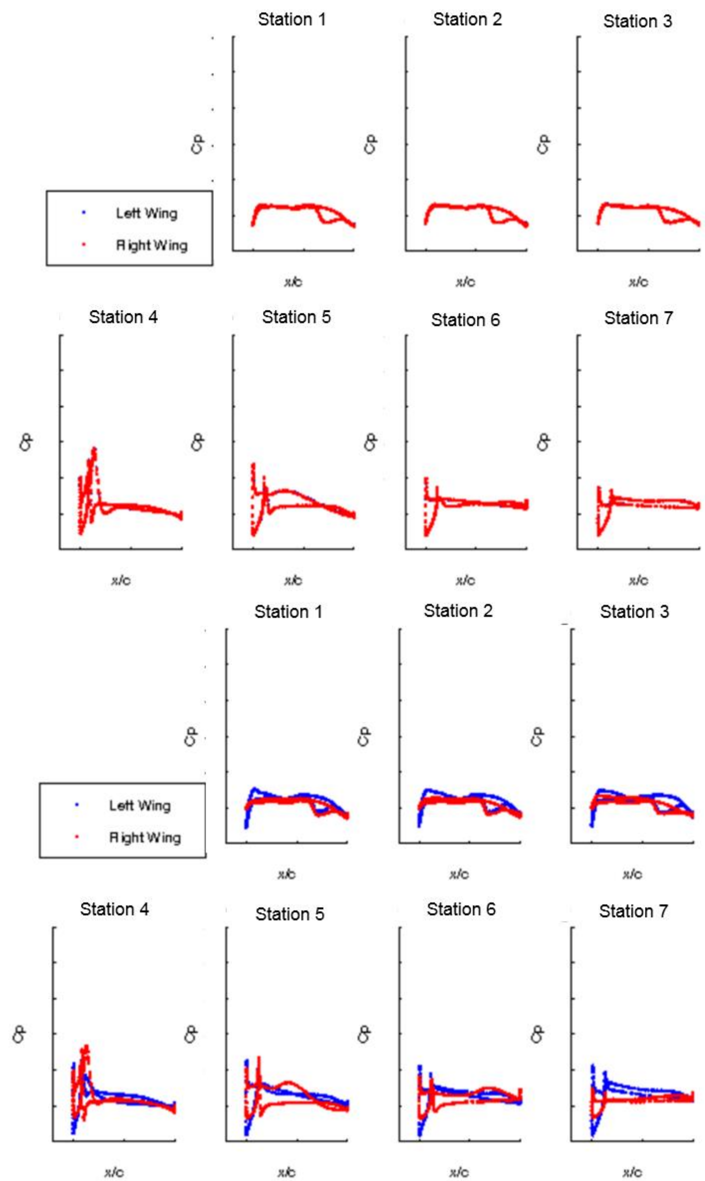


Pre-Stall | Post-Stall | Runway High Power | High Crosswind

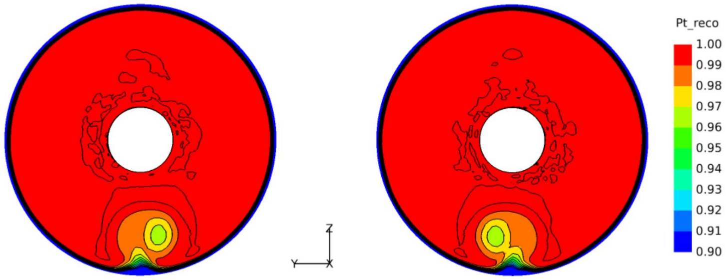
Pre-Test CFD Model Scale Inlet Distortion Study: Pressure Tap Predictions

- Minimal Scatter between left, right, and center pressure measurements for cases with low distortion and low power
- Scatter of pressure measurements increases as distortion increases

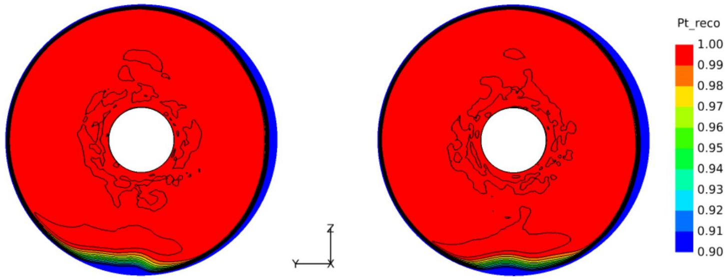




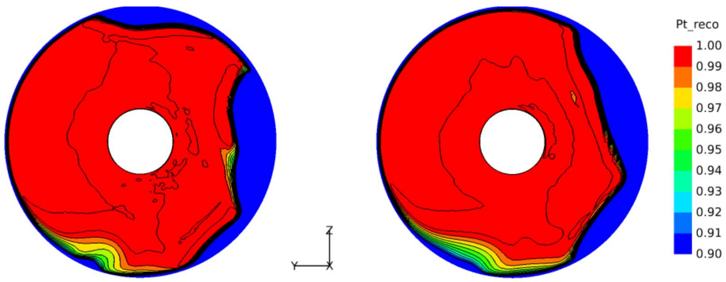
Pre-Test CFD Model Scale Inlet Distortion Study: Total Pressure Recovery Contours



Low ɓ, MN 0.05

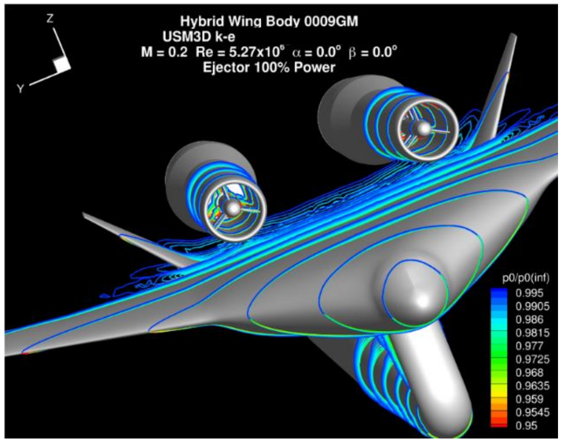


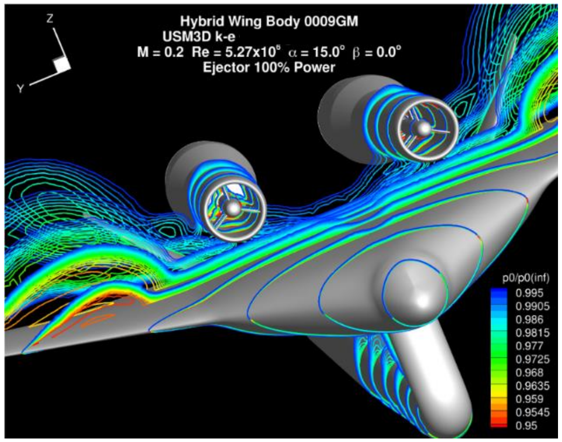
Moderate ɓ, MN 0.10



High ɓ, MN 0.0645

- ĭ ñGroundòvortex off of HWB body is ingested at MN 0.05
- ĭ At high ɓ, significant distortion is seen
- ĭ Wing vortex shedding at moderate Ŭ does not appear to interact with inlets





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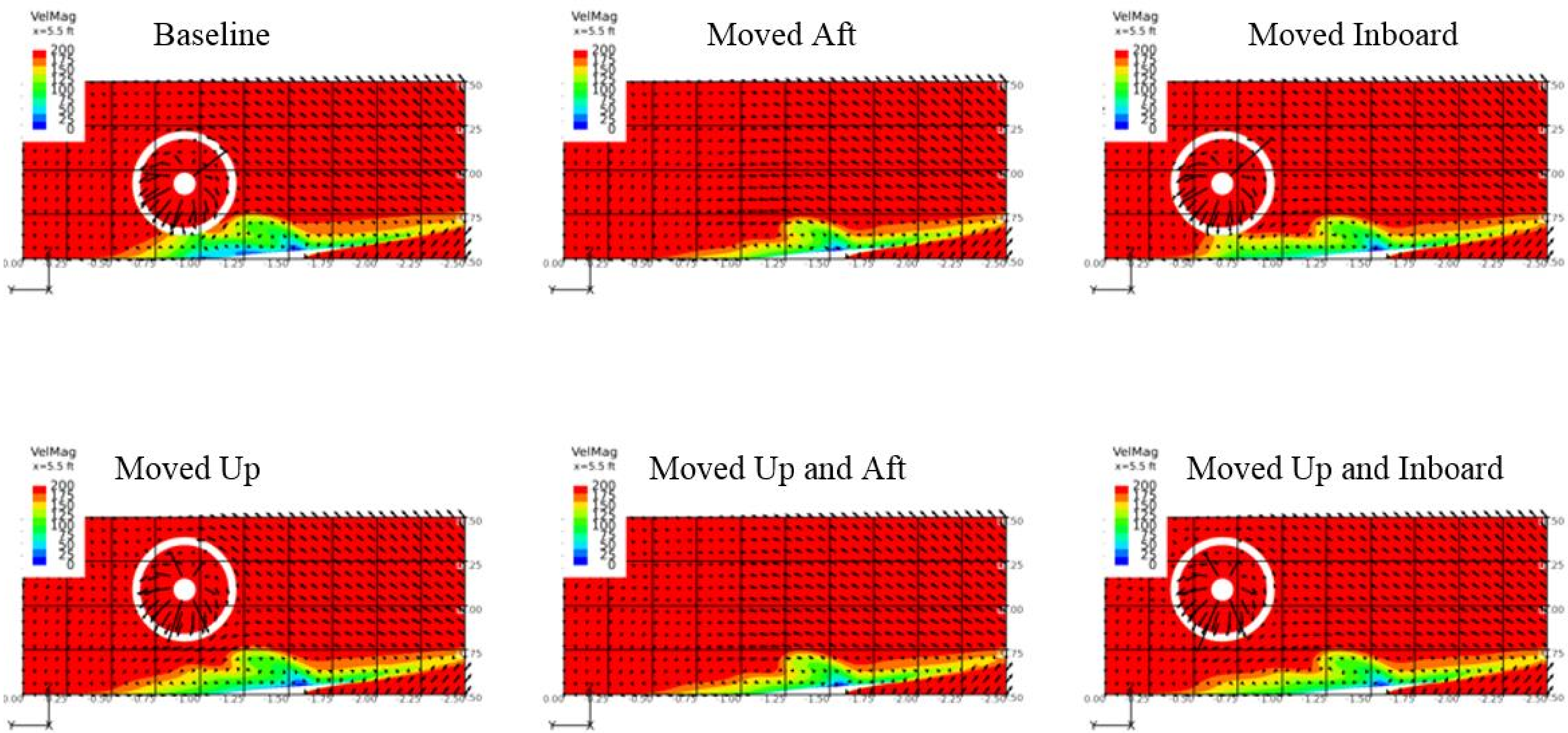
Pre-Test CFD Model Scale Inlet Distortion Study: Nacelle Placement Study

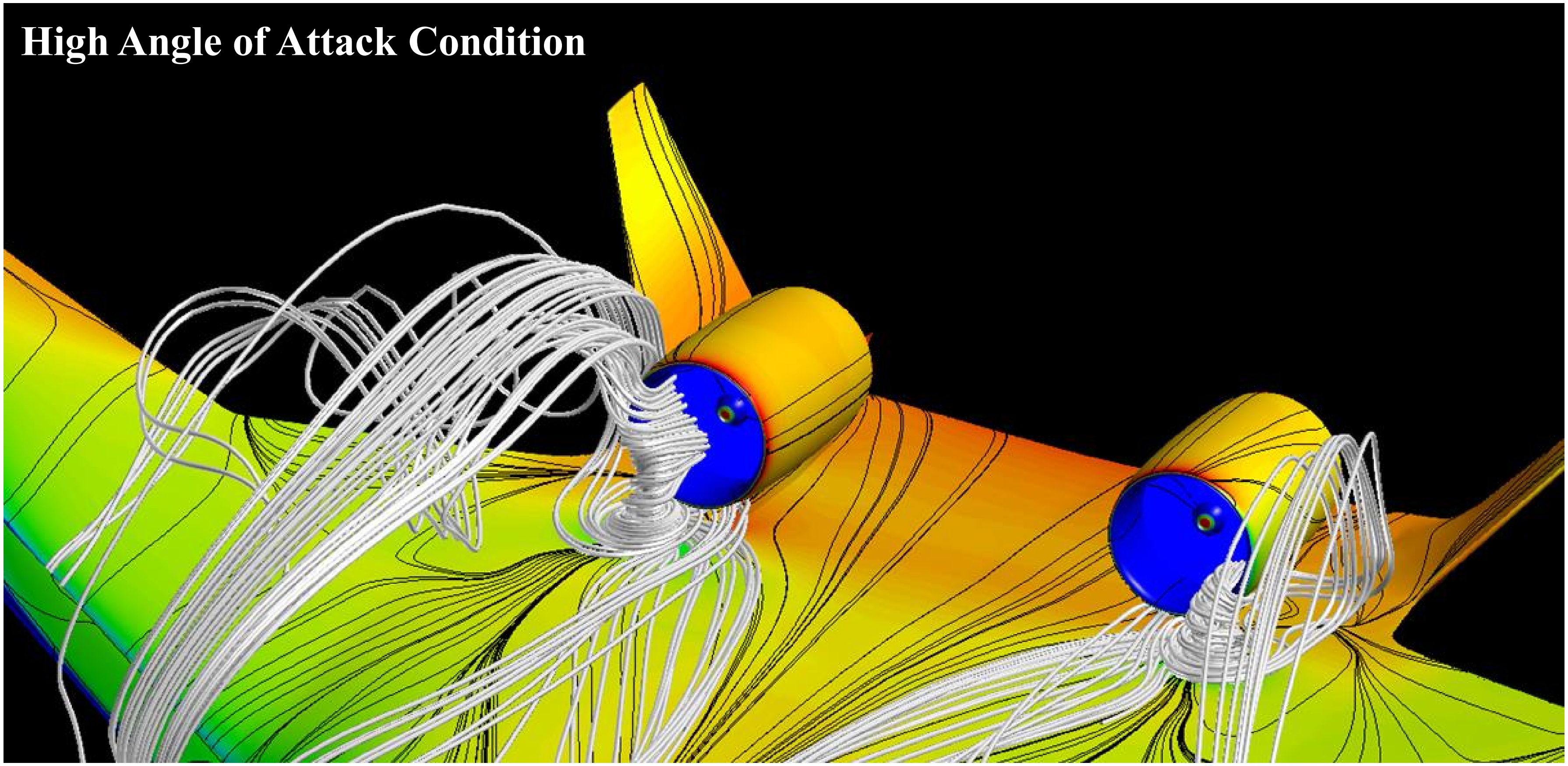
Slight preference for moving inlet

- Up
- Aft, or
- Up, aft, and inboard together



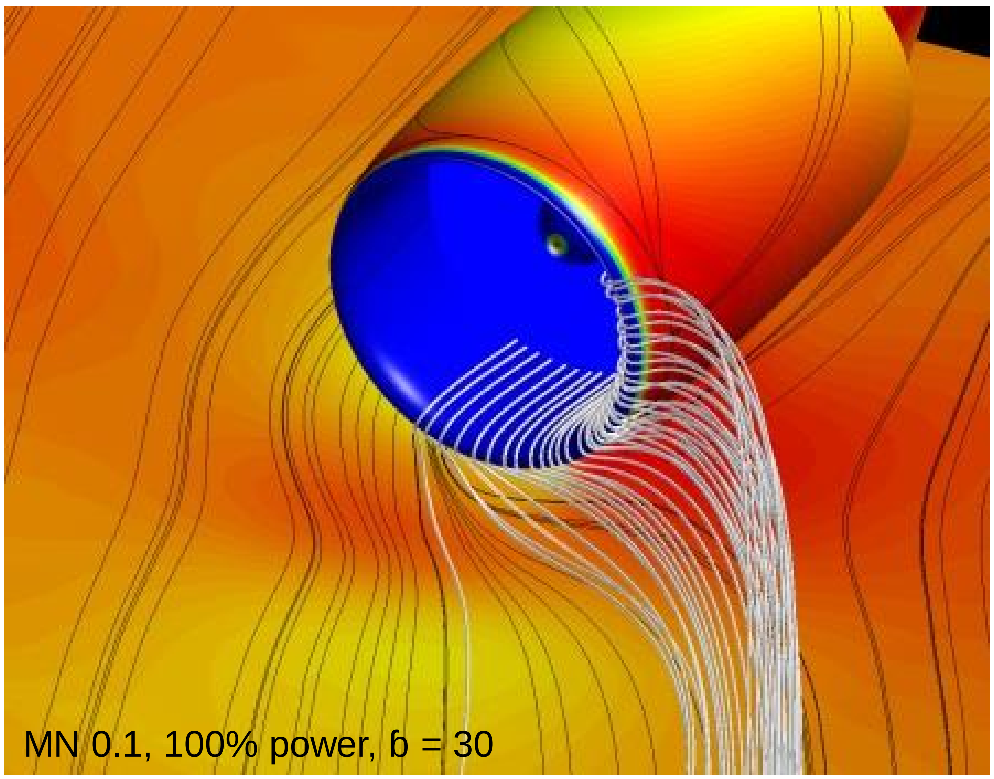
Pre-Test CFD Full Scale Inlet Distortion Study: Vortex Ingestion from the Leading Edge of the Body

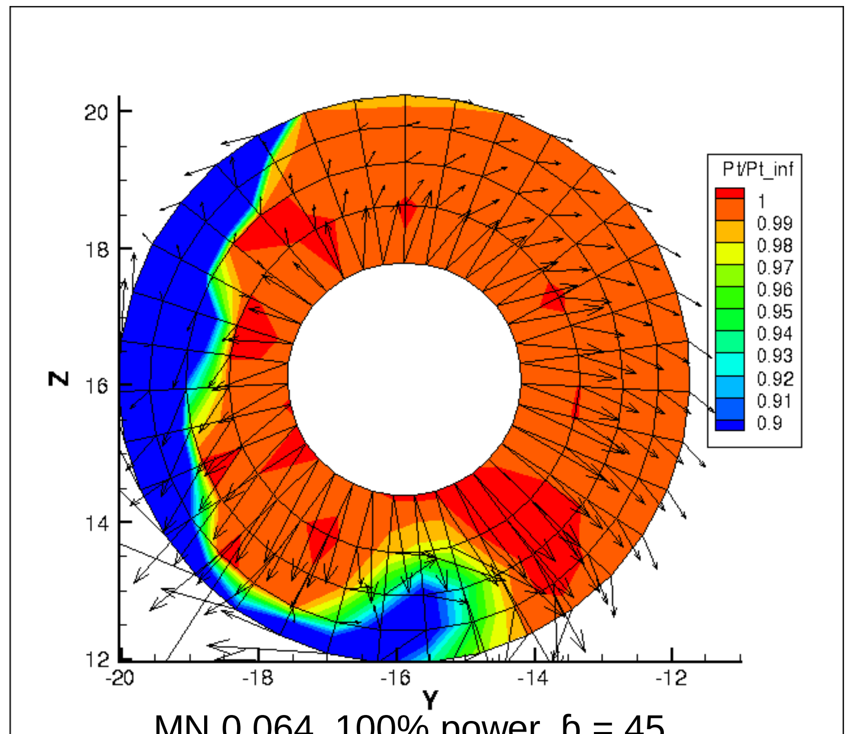
- A risk to engine operability is the ingestion of a vortex originating from the leading edge of the body of the HWB at high angles of attack with or without sideslip



Pre-Test CFD Full Scale Inlet Distortion Study: Effect of Crosswind on Lip Separation

- A concern for engine operability is lip separation and total pressure loss on the windward side of the inlet for a high angle of crosswind condition
- This was deemed to be the most challenging flow regime, and is not acceptable for the engine

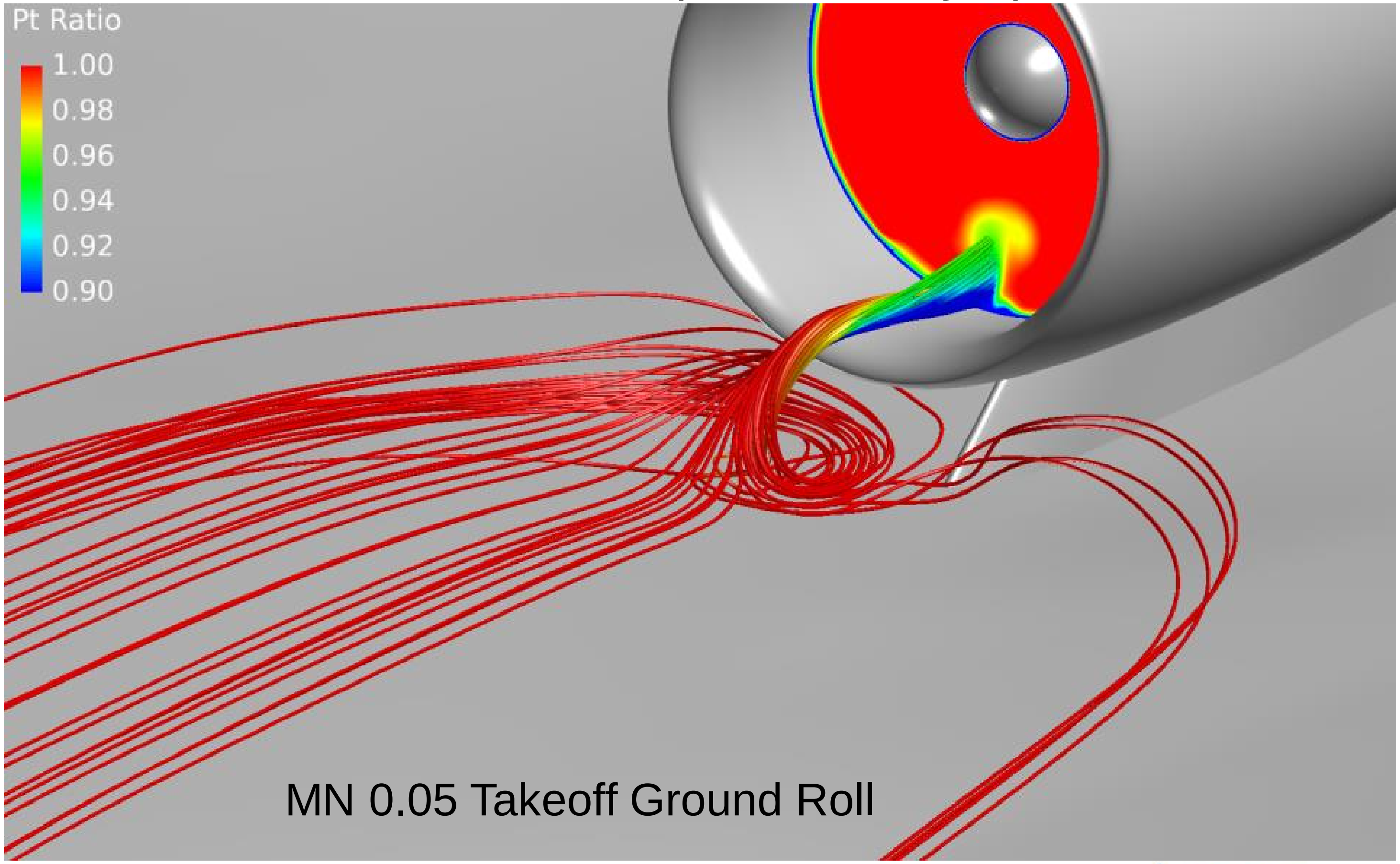

MN 0.1, 100% power, β = 30



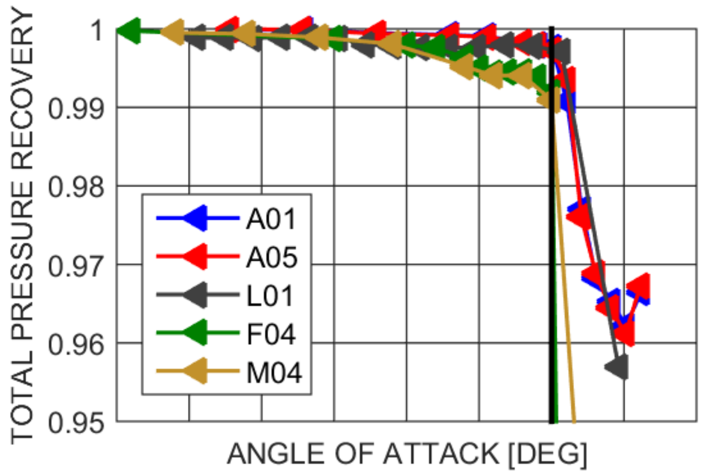
MN 0.064, 100% power, β = 45

Pre-Test CFD Full Scale Inlet Distortion Study: Low Speed Vortex Ingestion off the Body

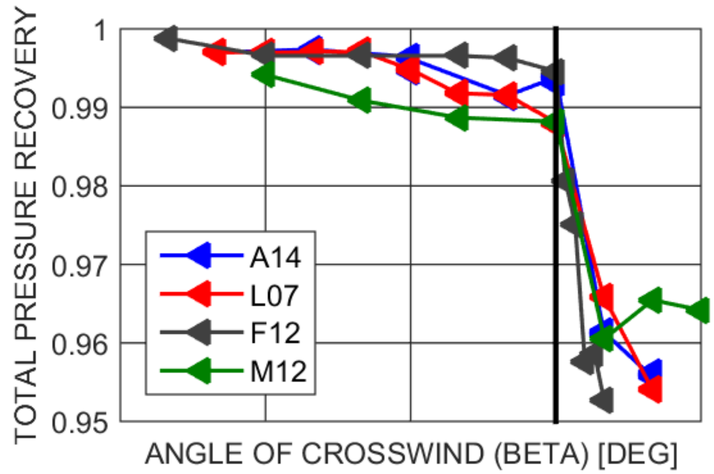
- A concern for integrating engines above the body is the ingestion of a vortex off of the body which manifests at high power, low mach number conditions, such as low speed runway operations



CFD and Wind Tunnel Data Comparison: Angle of Attack and Angle of Crosswind Pressure Recovery



Code	Purpose
A01	α Sweep test data at NFAC
A05	α Sweep test data at NFAC
L01	α Sweep test data at NASA Langley
F04	Full Scale Inlet CFD
M04	Model Scale Posttest CFD

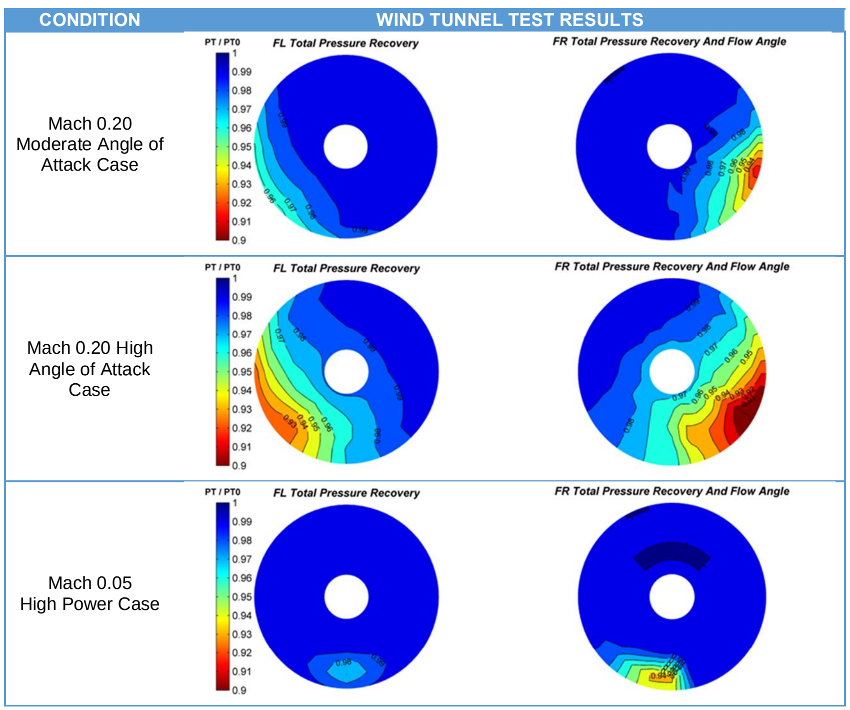


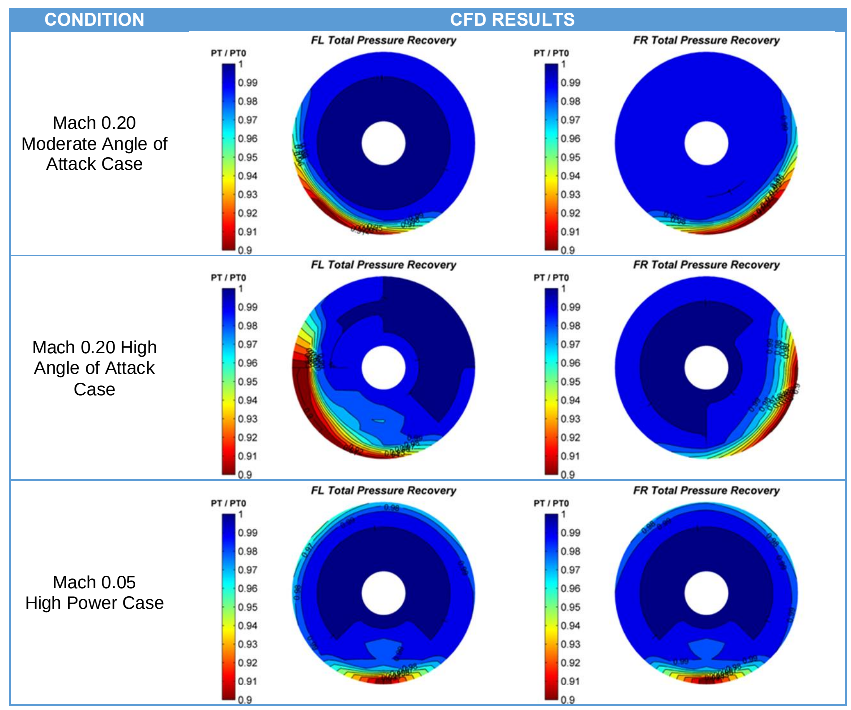
Code	Purpose
A14	β Sweep test data at NFAC
L07	β Sweep test data at NASA Langley
F12	Full Scale Inlet CFD
M12	Model Scale Posttest CFD

- In general, the CFD did not manage to predict flow transition at the same conditions as the wind tunnel.
- There is a Reynolds number effect that results in the stall or separation angle of attack for the wing to be different between the model and full scale.
- When conditions were matched in terms of flow phenomena, CFD predictions were close to the total pressure recovery levels seen in the wind tunnel

CFD and Wind Tunnel Data Comparison: Post-Test CFD Model Scale Inlet Distortion Study

- Qualitative agreement in terms of total pressure levels between experiment and CFD
- The level of distortion seen in the wind tunnel tests near wing stall or high sideslip conditions were within the level of distortion provided to Pratt & Whitney for the PSC inlet fan compatibility assessment
- A further discussion of the comparison between CFD and wind tunnel test results is in Ref. 1





Conclusions

- CFD of the full-scale reference inlet was performed to predict inlet distortion levels and provide data for engine company operability assessment
- Pretest CFD was also run in a collaborative effort between Boeing and NASA to characterize inlet flow distortion and provide insight for test planning
- Boeing and NASA also performed CFD to help determine the size and layout of ejector hardware
- The model-scale ejector hardware was designed and built to measure inlet distortion levels via the ejector campaign
- Subsequent to collecting data, CFD was run on the post-test model-scale ejector
- Therefore, it was possible to make comparisons between experimental data and CFD to make projections of distortion levels for the full-scale configuration

References

1) Carter, Melissa B. et al., "Experimental Evaluation of Inlet Distortion on an Ejector Powered Hybrid Wing Body at Take-off and Landing Conditions," AIAA Science and Technology Forum and Exposition 2016. (submitted for publication)

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