A-10 ANALYSIS USING THE HPCMP CREATE™-AV KESTREL PRODUCT UTILIZING THE FIREBOLT PROPULSION COMPONENT

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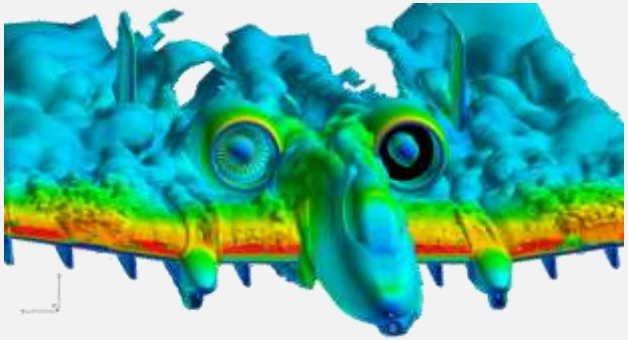

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Background

- *A-10 single seat tactical aircraft*
- *Two TF34-GE-100 high bypass turbofans mounted above and behind inboard section of wing*
  - *Flow quality over the wing must be maintained*
  - *Distorted flow over wing likely to be ingested by engine and cause stability issues*
- *A-10 mission requires operation of aircraft at high AOA and AOSS*
- *To mitigate distorted flow over wing, A-10 currently uses a movable slat on the inboard wing leading edge*
- *To reduce maintenance cost, SPO interested in replacing movable slat with fixed geometry on wing inboard leading edge*
- *Several candidate geometries tested on 10% scale model in AEDC 16T wind tunnel*

Purpose/Outline

- *Summarize the use of CREATE™-AV Kestrel with Firebolt propulsion component in analyzing the A-10*
- *Tunnel scale simulations*
  - *Baseline Wing*
  - *Modified Wing*
- *Flight scale simulations (Baseline wing only)*
  - *Using Firebolt Cap 1 (0-D engine model)*
  - *Using Firebolt Cap 2 (full annulus turbomachinery)*
- *Flight scale store separation simulations using Firebolt Cap 1 to simulate propulsion effects*
  - *Baseline and modified wing using all unstructured meshes*
  - *Baseline wing using NBOB capability*
- *Conclusions*

CREATE™ Overview

- *Computational Research and Engineering Acquisition Tools and Environments (CREATE™)*
  - *DOD HPCMP program to improve acquisition timeline, cost, and performance through the use of CSE tools*
  - *Covers ships (SHIPS), aircraft (AV), antenna design and analysis (RF), meshing (MG)*
  - *CREATE-AV*
    - *Kestrel – fixed wing*
    - *Helios – rotary wing*
    - *DaVinci – conceptual design*

Kestrel - Firebolt Overview

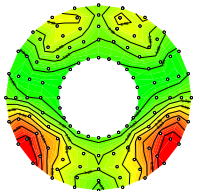
- ***Kestrel:*** *High-fidelity simulation tool used to model aircraft flow-field behavior*
- ***Firebolt:*** *Modular propulsion component*
  - *FB Cap 1: Low-order (0-D) steady-state or transient engine models (cycle decks)*
  - *FB Cap 2: High-fidelity full annulus rotating turbomachinery*
- *Kestrel - Firebolt combination provides virtual system to simulate integrated airframe-inlet-propulsion system dynamic performance*
  - *Maneuvering aircraft*
  - *Complex unsteady inlet distortion*

Airframe/Inlet/Engine Integration

CFD Inlet Predictions

Wind Tunnel Tests

AIP Distortion Patterns



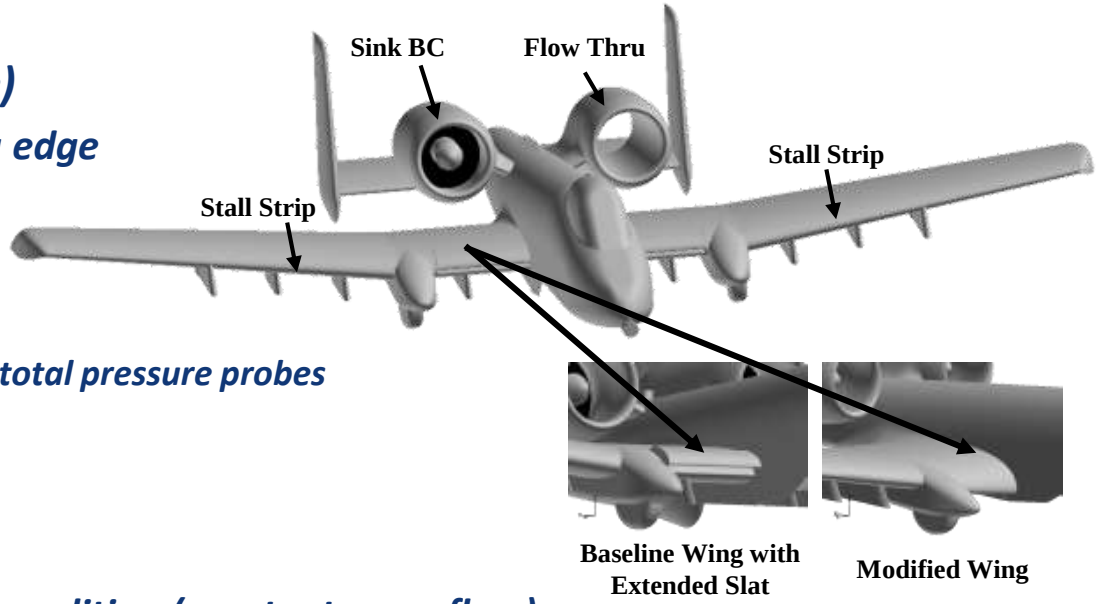
Distortion Screen Tests

Flight Test Verification

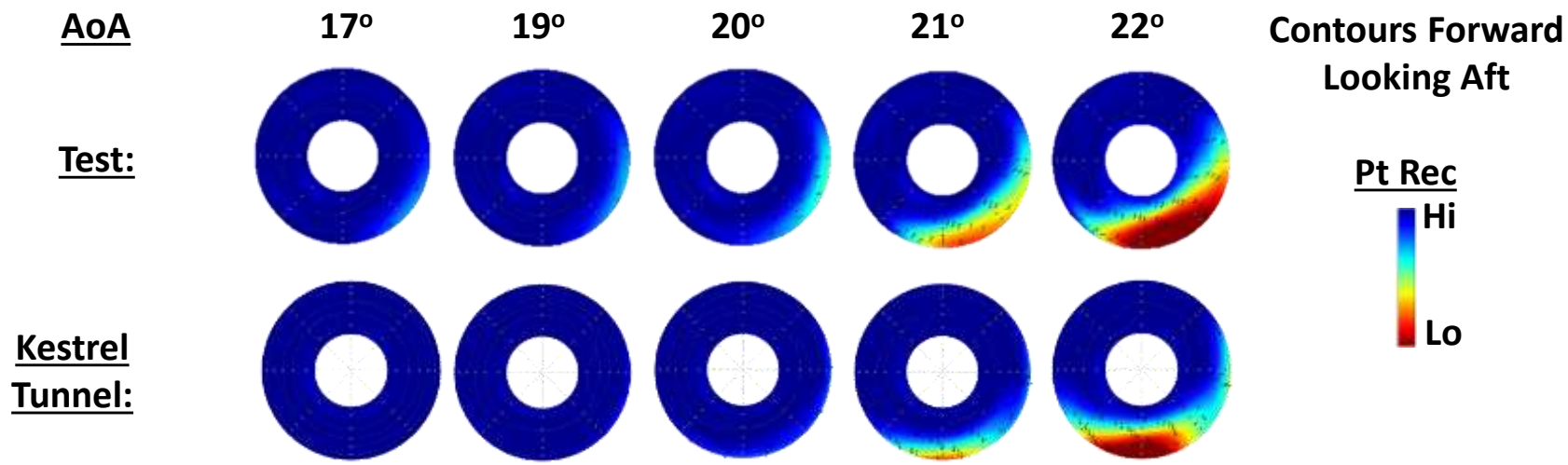
- *Historical Process*
  - *Scale model testing of airframe and inlet in wind tunnel*
  - *Reduce wind tunnel results to AIP distortion patterns*
  - *Engine stability testing with distortion patterns*
  - *First time airframe/inlet/engine are coupled is at flight test*
- *Kestrel with Firebolt*
  - *Enables integration of airframe/inlet/engine simulations*
  - *Allow discovery of possible integration issues early in weapon system design cycle*
  - *Impact weapon system development*
    - *Schedule*
    - *Cost*

Tunnel Scale Simulations

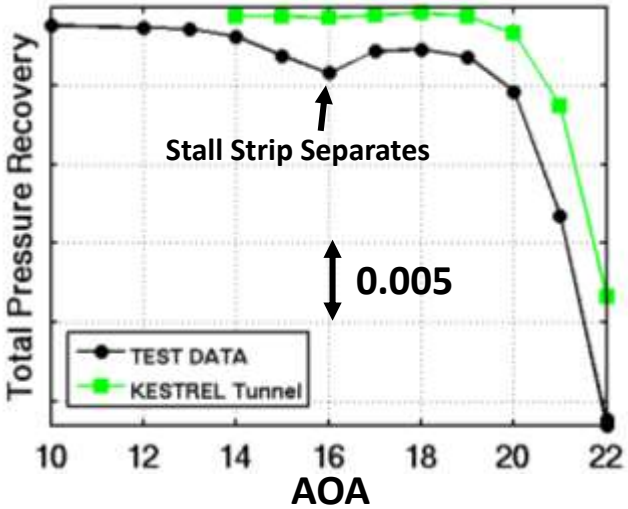
- *Wind tunnel geometry (10% Scale)*
  - *Replaceable inboard wing leading edge*
  - *Port nacelle: flow through*
  - *Starboard nacelle*
    - *Connected to calibrated ejector*
    - *40-probe rake with high response total pressure probes*
- *CFD tunnel geometry (10% Scale)*
  - *No sting or ejector body modeled*
  - *Port nacelle: flow through*
  - *Starboard nacelle: sink boundary condition (constant mass flow)*
- *CFD tunnel simulations*
  - *Mesh: 30 million cells*
  - *HLLE+ inviscid flux scheme*
  - *Spalart-Allmaras Delayed Detached Eddy Simulation (SA-DDES) turbulence model*
  - *1×10^{-4} sec. time step*
  - *Typical solution: 20,000 iterations*
    - *Time-averaged over 15,000 iterations (1.5 sec)*
    - *36 hours on 512 cores*



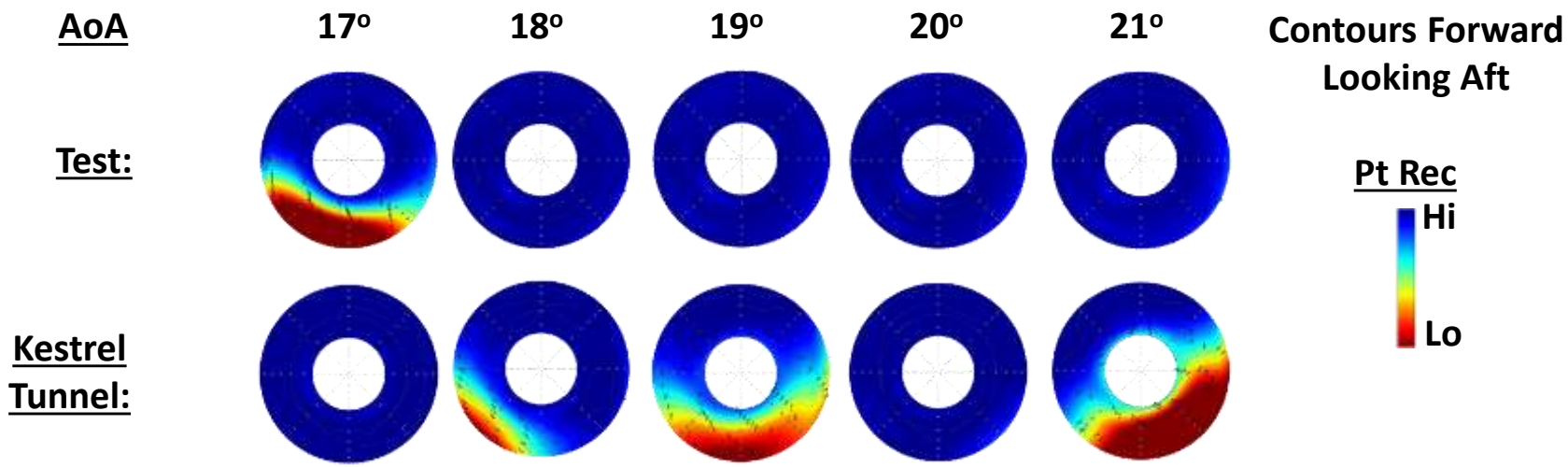
Tunnel Scale: Baseline Results



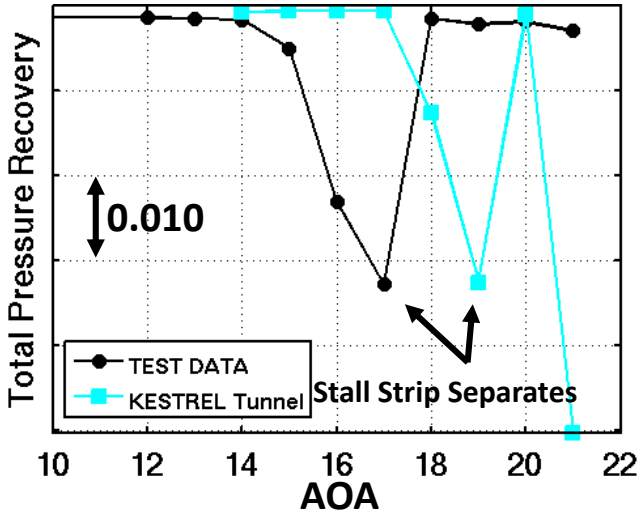
Baseline Wing with Extended Slat



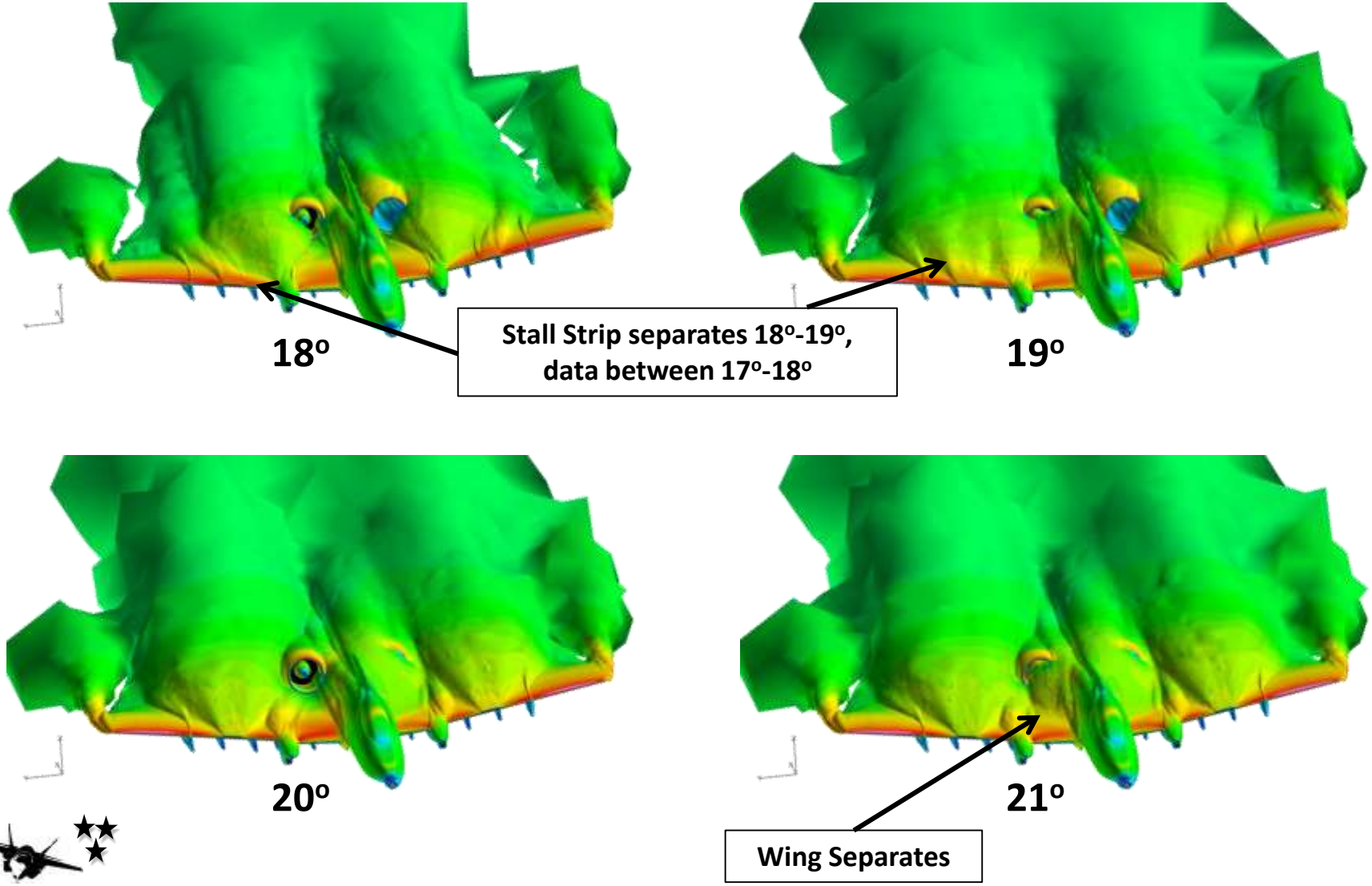
Tunnel Scale: Modified Results



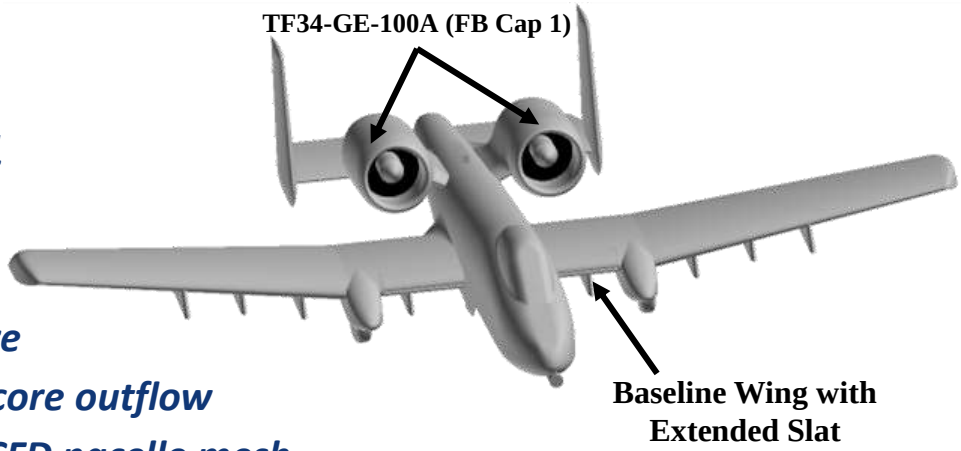
Modified Wing



Tunnel Scale: Modified Results

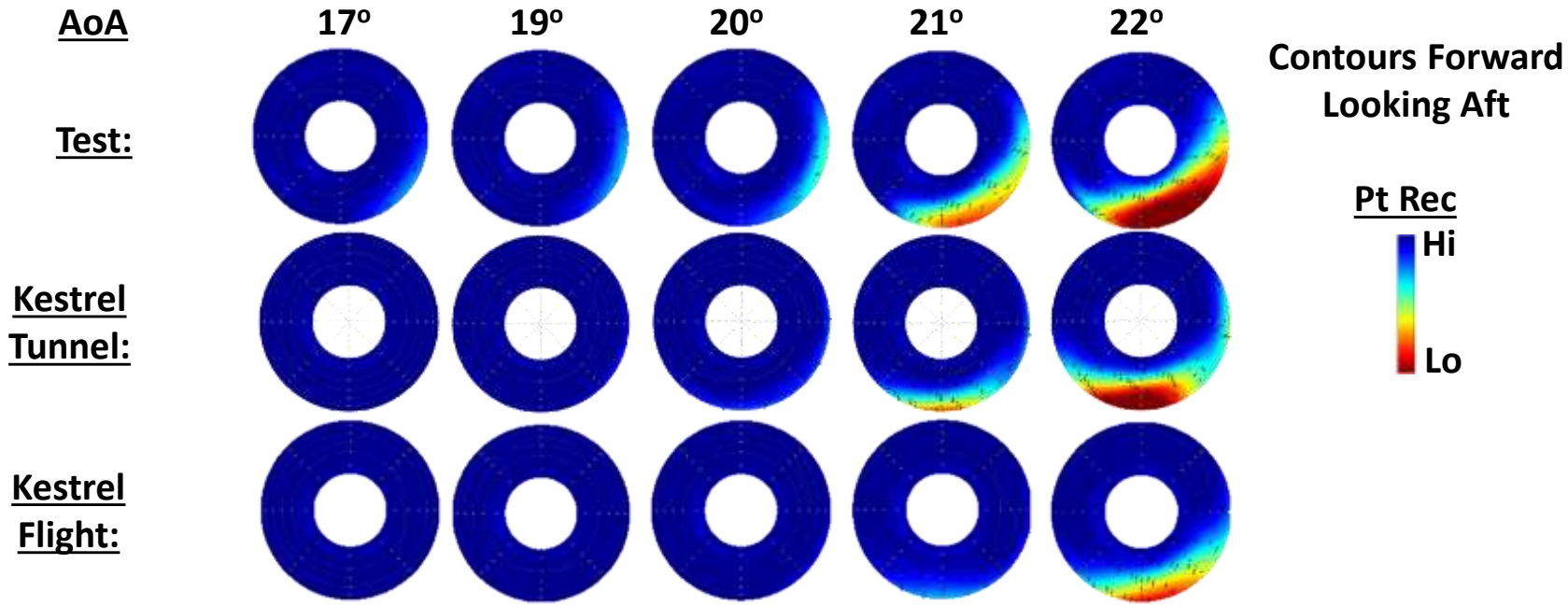


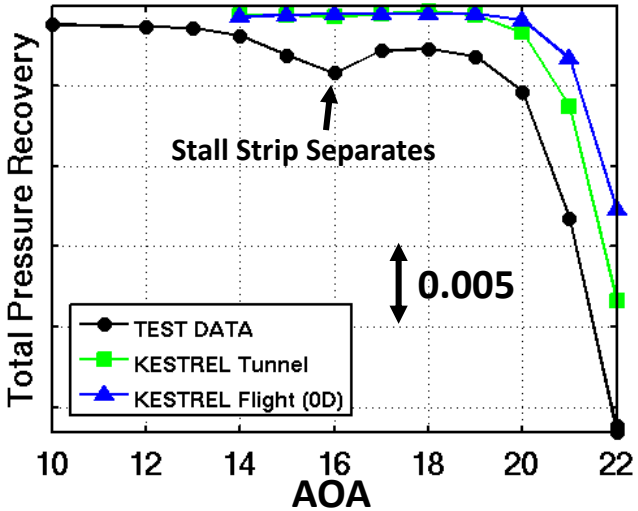
Flight Scale FB Cap 1 Simulations



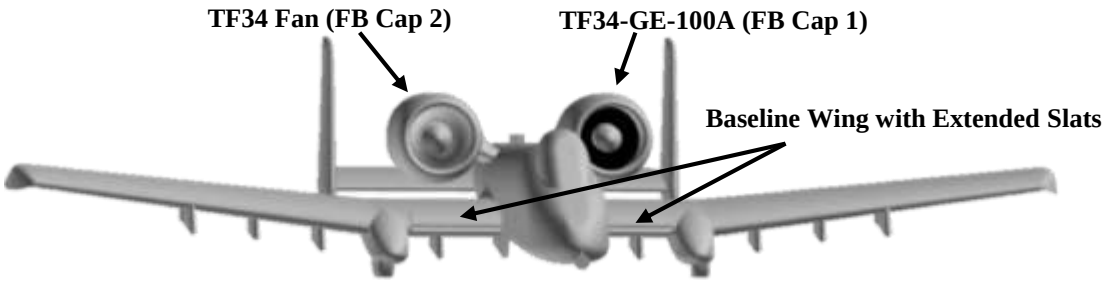
- CFD flight scale geometry
  - Port/Starboard nacelle: Firebolt Cap 1 TF34-GE-100A 0-D engine model
    - Modified standalone engine model to be incorporated in Firebolt architecture
    - Engine model inflow, bypass outflow, core outflow associated with boundary patches in CFD nacelle mesh
- CFD flight scale simulations
  - Mesh: 30 million cells
  - HLLE+ inviscid flux scheme
  - Spalart-Allmaras Delayed Detached Eddy Simulation (SA-DDES) turbulence model
  - $1x10^{-4}$ sec. time step
  - Each engine PLA set to 80° to match tunnel nacelle scaled mass flow rates
  - Typical solution: 20,000 iterations
    - Time-averaged over 15,000 iterations (1.5 sec)
    - 36 hours on 512 cores

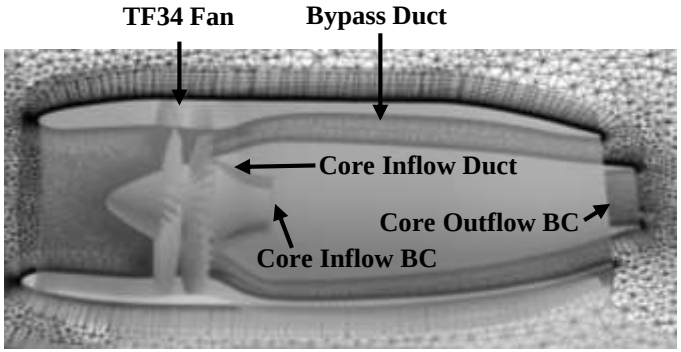
Flight Scale FB Cap 1 Results

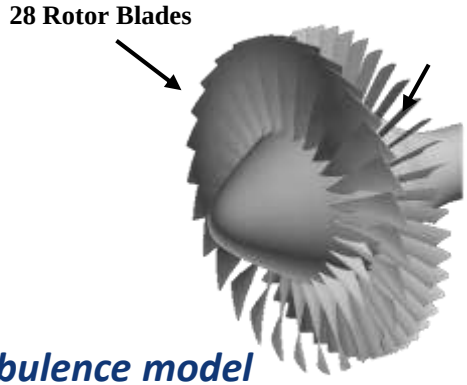




Flight Scale FB Cap 2 Simulations

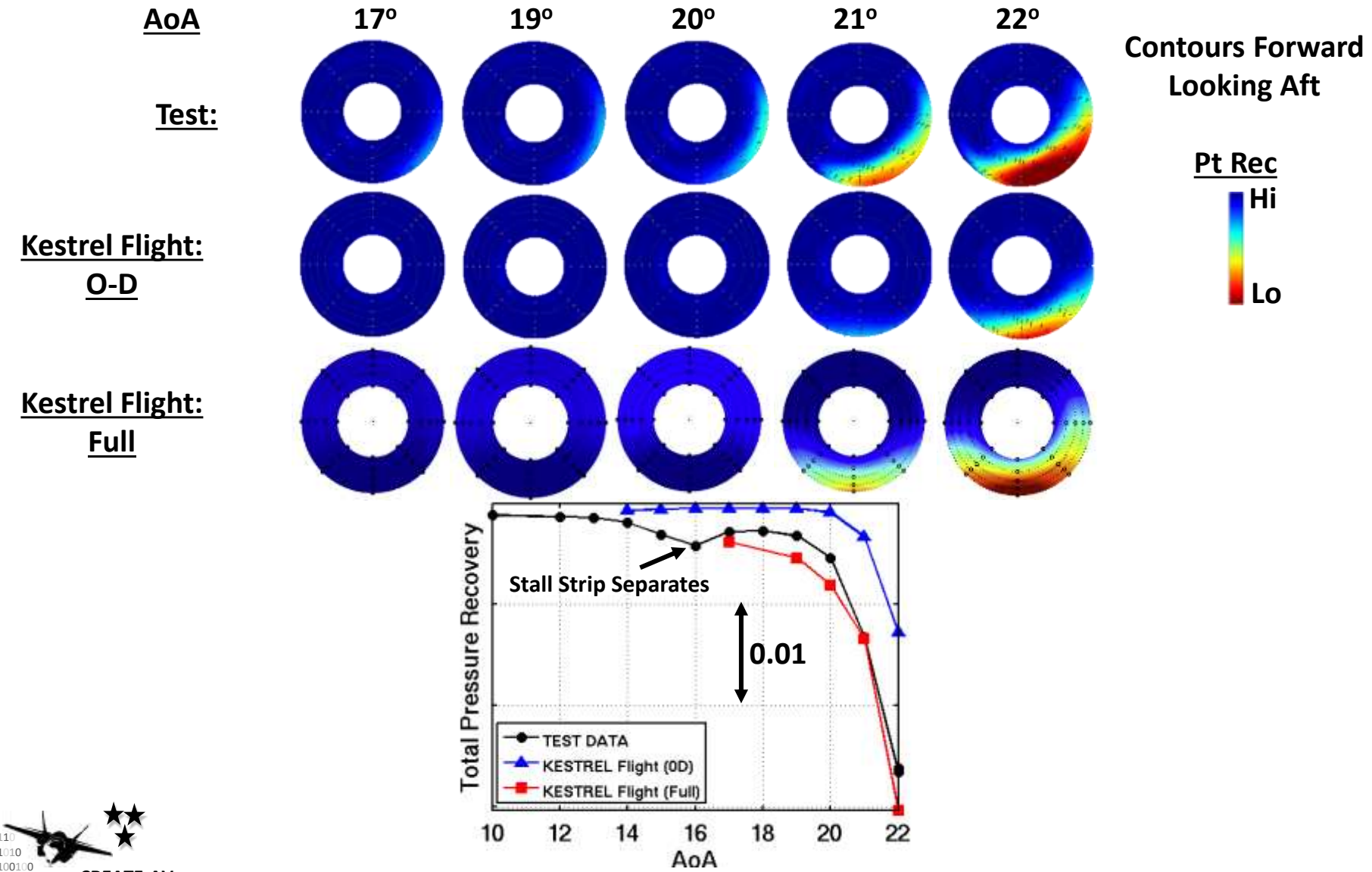






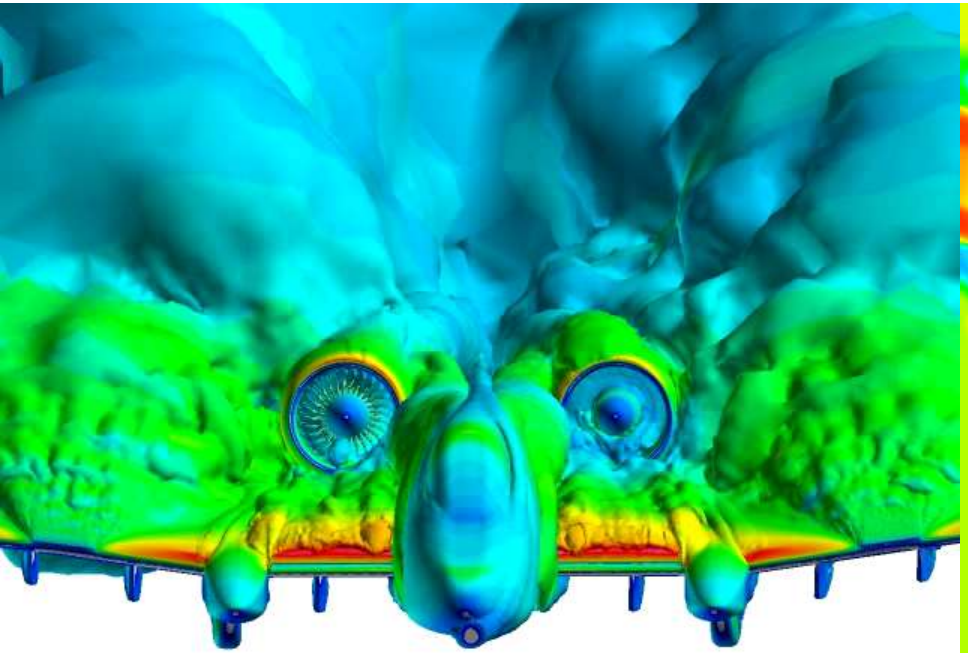
- *CFD flight scale geometry*
  - *Port Nacelle: FB Cap 1 - TF34-GE-100A 0-D engine model*
  - *Starboard Nacelle: FB Cap 2 - TF34 rotating turbomachinery fan*
    - *Core inflow/outflow boundaries set from 0-D model*
- *CFD flight scale simulations*
  - *Mesh: 105 million cells (A-10: 30 million, TF34 Fan: 75 million)*
  - *HLLE+ inviscid flux scheme*
  - *Spalart-Allmaras Delayed Detached Eddy Simulation (SA-DDES) turbulence model*
  - *5×10^{-6} sec. time step*
  - *0-D engine PLA set to 80°*
  - *TF34 fan set to 6500 RPM (matches 0-D engine model fan speed)*
- *Typical solution: ~15 rotor revolutions (720 cores)*
  - *~10 rotor revolutions at "quasi-steady" state*
  - *14 sec/iter, 2000 iter/revolution, 3.5 revolutions/day, 4-6 days/solutions*

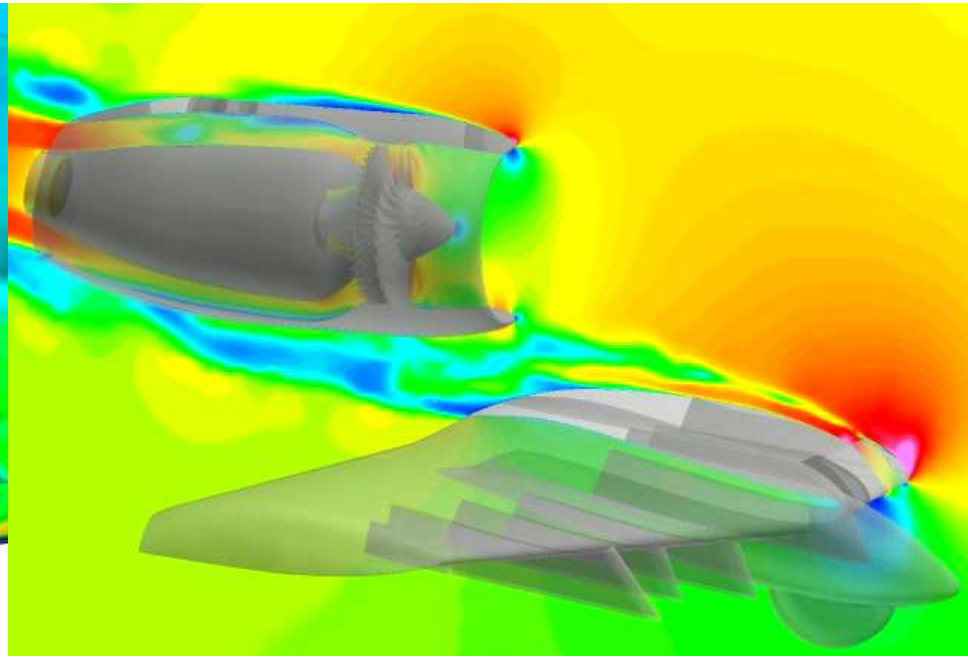
Flight Scale: FB Cap 2 CFD Results



Flight Scale: FB Cap 2 CFD Results

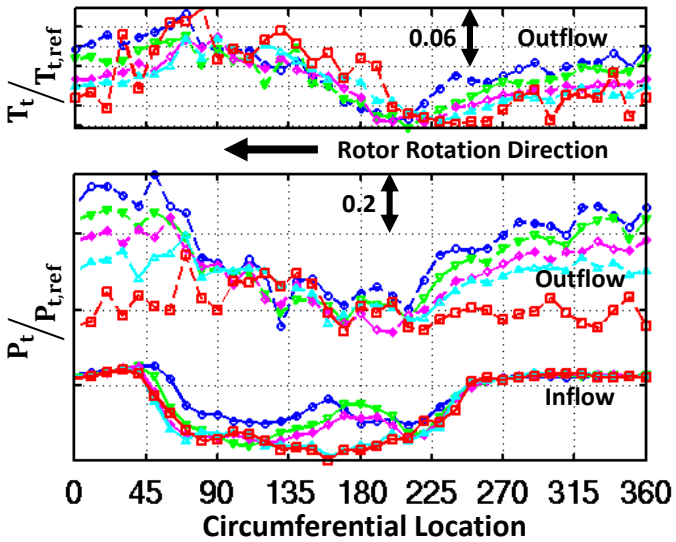
21° AOA – 10 Rotor Revolutions

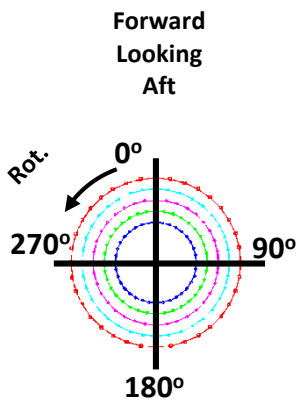


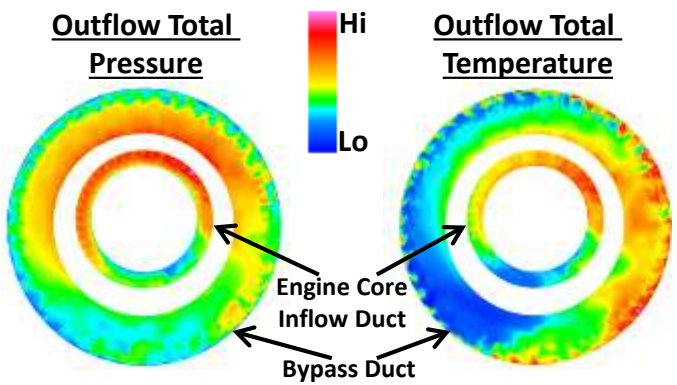


Flight Scale: FB Cap 2 CFD Results

Instantaneous Circumferential Total Pressure and Total Temperature

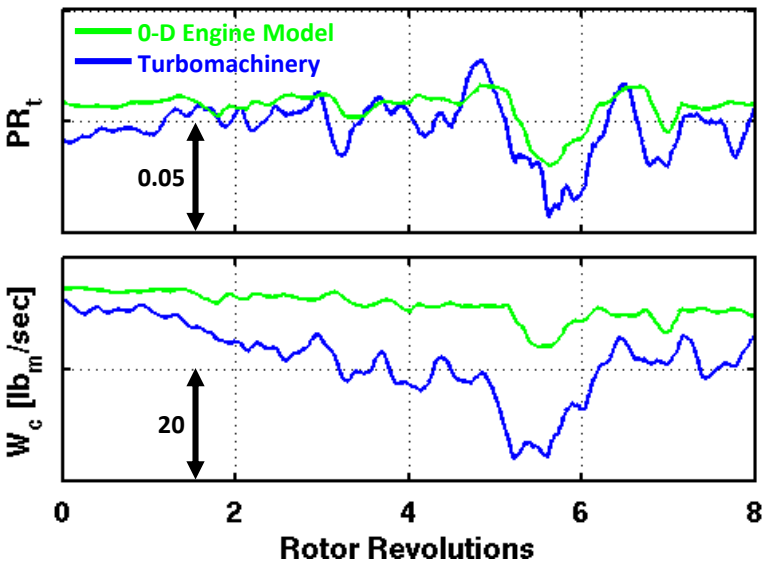




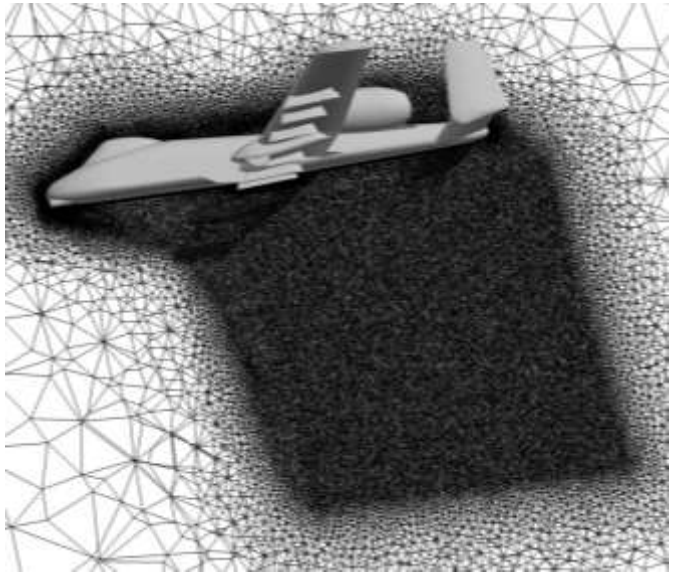


21° AOA

0-D Engine Model vs. CFD Fan Performance Comparison



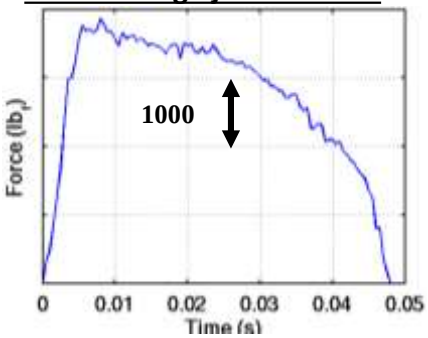
Fuel Tank Store Separation Simulations



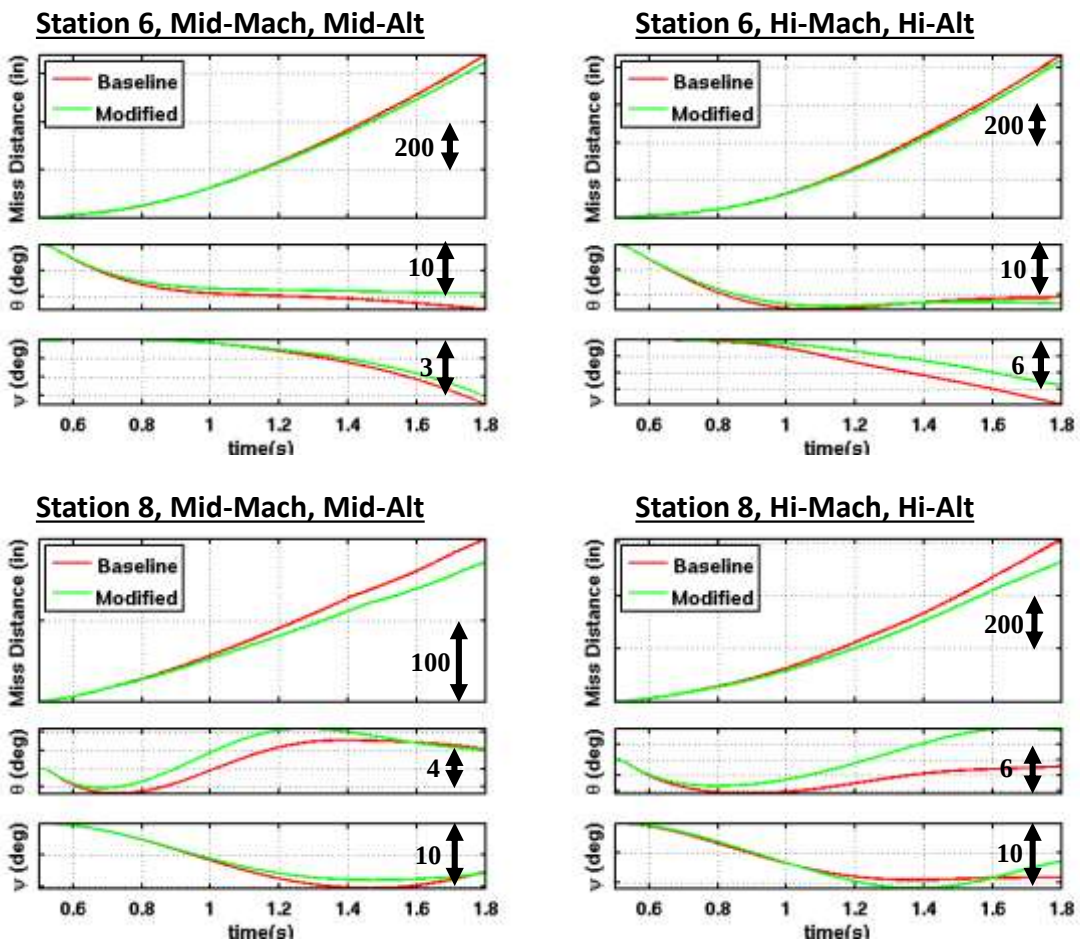
- *Proposed wing modification in close proximity to several store pylons*
- *Compare store separation characteristics for baseline and modified wing*
  - *Empty 600-gallon fuel tank store*
  - *Two pylons; Two separate Flight conditions*
  - *Overset meshes and 6DOF*
- *A-10 mesh*
  - *Slat retracted due to flight conditions of drop*
  - *Used FB Cap 1 TF34-GE-100A 0-D engine model at 80º PLA*
  - *Controlled unstructured volume mesh under aircraft in region of drop: 37 million cells*
- *Empty 600-gallon fuel tank mesh*
  - *7.5 million cells*
  - *Included mass, moments of inertia, CG, and forward lug ejector forces*
- *Typical solution: 18,000 iterations*
  - *13,000 iterations after drop (1.3 sec)*
  - *48 hours on 512 cores*

600-gallon Fuel Tank Surface Mesh

Forward Lug Ejector Forces



Fuel Tank Store Separation: CFD Results



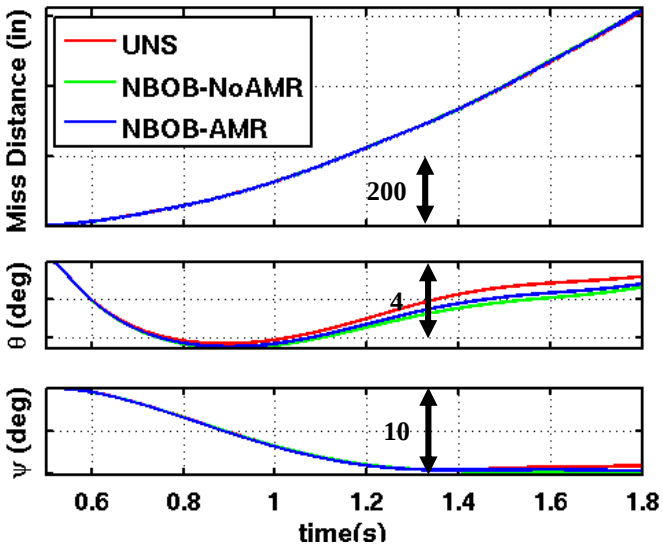
Pylon @ wing/fuselage join

Pylon directly under modified wing section

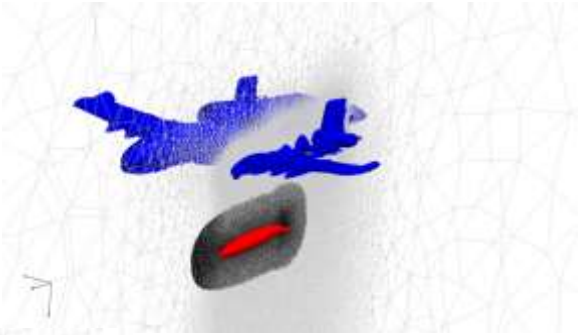
NBOB Fuel Tank Store Separation: CFD Simulation

- *NBOB Benefits*
  - *Easier mesh generation*
  - *Better capture wake and off-body flow-field characteristics*
- *Trimmed UNS mesh cells more than 15 inches from the surface*
  - *Orig Baseline A-10: 37 million; Trimmed Baseline A-10: 22 million*
  - *Orig Tank: 7.5 million; Trimmed Tank: 5.5 million*
- *Ran NBOB cases with/without AMR*
  - *Solution mesh refinement every 250 iterations for case with AMR*
- *Cartesian solver*
  - *Initial Cartesian grid: 37 million cells (with/without AMR)*
  - *Without AMR final Cartesian grid: 48 million cells (geometric refinement)*
  - *With AMR final Cartesian grid: 183 million cells (geometric/solution refinement)*
- *Solutions Times*
  - *All UNS: 10.5 sec/iter*
  - *NBOB without AMR: 8.5 sec/iter*
  - *NBOB with AMR 11.5 sec/iter*

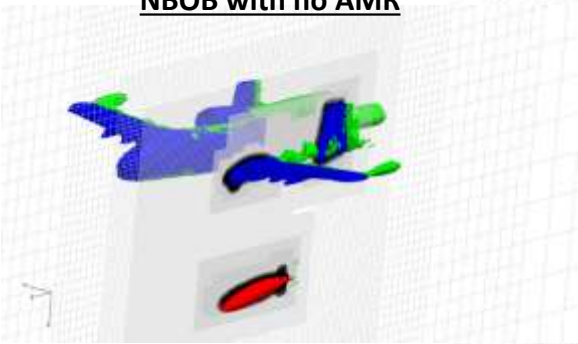
NBOB Fuel Tank Store Separation: CFD Results



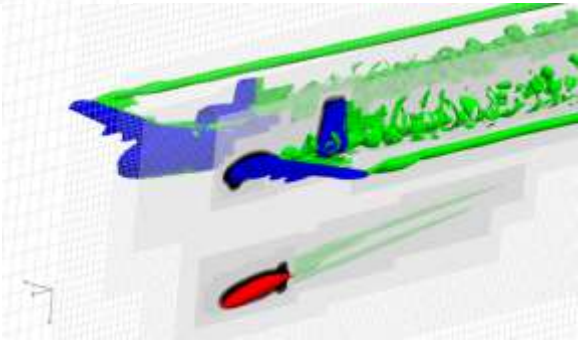
Unstructured



NBOB with no AMR



NBOB with AMR



Conclusions

- *Assisted and added value to A-10 wind tunnel test program with Kestrel - Firebolt*
- *Modeled A-10 wind tunnel test geometry for the baseline wing and one proposed wing modification*
- *Included propulsion effects via the 0-D TF34-GE-100A engine model using FB Cap 1*
- *Demonstrated A-10 full aircraft with full annulus TF34 rotating turbomachinery fan using FB Cap 2*
- *Demonstrated store separation characteristics for baseline and proposed wing modification with full unstructured mesh system and NBOB mesh system*
- *Provided feedback to developers to improve Kestrel-Firebolt*

Acknowledgements:

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Questions?