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

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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

- **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

CFD Inlet Predictions  Wind Tunnel Tests  AIP Distortion Patterns  Distortion Screen Tests

1.20
1.18
1.16
1.14
1.12
1.10
1.08
1.06
1.04
1.02
1.00
0.98
0.96
0.94
0.92
0.90
1.00
1.00
1.00
1.00
1.00
1.02
1.02
1.02
1.02
1.02
1.04
1.04
1.04
1.04
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
  - HLL+ inviscid flux scheme
  - Spalart-Allmaras Delayed Detached Eddy Simulation (SA-DDES) turbulence model
  - $1 \times 10^{-4}$ 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

AoA

17°  19°  20°  21°  22°  Contours Forward Looking Aft

Test:

Kestrel Tunnel:

Baseline Wing with Extended Slat

Stall Strip Separates

Total Pressure Recovery

AOA

0.005
**Tunnel Scale: Modified Results**

### Test:
- **Kestrel Tunnel**
- **Stall Strip Separates**

### Contours Forward Looking Aft
- **Pt Rec**
  - Hi
  - Lo

### AoA
- 17°
- 18°
- 19°
- 20°
- 21°

### Modified Wing

### Graph:
- **Total Pressure Recovery**
  - **TEST DATA**
  - **KESTREL Tunnel**

- **Stall Strip Separates**
- **0.010**

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**Tunnel Scale: Modified Results**

Stall Strip separates 18°-19°, data between 17°-18°

Wing Separates

18°

19°

20°

21°
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
  - $1 \times 10^{-4}$ sec. time step
  - Each engine PLA set to $80^\circ$ 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

<table>
<thead>
<tr>
<th>AoA</th>
<th>17°</th>
<th>19°</th>
<th>20°</th>
<th>21°</th>
<th>22°</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test:</strong></td>
<td><img src="image1" alt="Contour 17°" /></td>
<td><img src="image2" alt="Contour 19°" /></td>
<td><img src="image3" alt="Contour 20°" /></td>
<td><img src="image4" alt="Contour 21°" /></td>
<td><img src="image5" alt="Contour 22°" /></td>
</tr>
<tr>
<td><strong>Kestrel Tunnel:</strong></td>
<td><img src="image6" alt="Kestrel Tunnel 17°" /></td>
<td><img src="image7" alt="Kestrel Tunnel 19°" /></td>
<td><img src="image8" alt="Kestrel Tunnel 20°" /></td>
<td><img src="image9" alt="Kestrel Tunnel 21°" /></td>
<td><img src="image10" alt="Kestrel Tunnel 22°" /></td>
</tr>
<tr>
<td><strong>Kestrel Flight:</strong></td>
<td><img src="image11" alt="Kestrel Flight 17°" /></td>
<td><img src="image12" alt="Kestrel Flight 19°" /></td>
<td><img src="image13" alt="Kestrel Flight 20°" /></td>
<td><img src="image14" alt="Kestrel Flight 21°" /></td>
<td><img src="image15" alt="Kestrel Flight 22°" /></td>
</tr>
</tbody>
</table>

**Contours Forward Looking Aft**

- **Pt Rec**
  - Hi
  - Lo

**Stall Strip Separates**

- Total Pressure Recovery
- AOA
- 0.005

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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
  - $5 \times 10^{-6}$ 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

AoA

17°  19°  20°  21°  22°

Test:

Contours Forward Looking Aft

Pt Rec
Hi
Lo

Kestrel Flight: O-D

Kestrel Flight: Full

Stall Strip Separates

0.01

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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

Outflow Total Pressure
Outflow Total Temperature

Engine Core
Inflow Duct
Bypass Duct

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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 80° 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
**Fuel Tank Store Separation: CFD Results**

Station 6, Mid-Mach, Mid-Alt

- Baseline
- Modified

Station 6, Hi-Mach, Hi-Alt

- Baseline
- Modified

Station 8, Mid-Mach, Mid-Alt

- Baseline
- Modified

Station 8, Hi-Mach, Hi-Alt

- Baseline
- Modified

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

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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?