Computational Flow Field in Energy Efficient Engine (EEE)

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Kenji Miki, Jeff Moder, Meng-Sing Liou
NASA Glenn Research Center

Acknowledge: Christopher Heath, Thomas Wey, Tsan-Hsing Shih, Clarence Chang, Kumud Ajmani, Francisco Guzman
Motivation

- Future propulsion systems will be of increasingly higher bypass ratio from larger fans combined with much smaller cores
- Important to understand core engine component interactions, such as combustor-turbine interactions

From “Deposition With Hot Streaks in an Uncooled Turbine Vane Passage”, B. Casaday, et al J. Turbomach, 2013 Vol. 136 (Permission from Prof. Bons and thanks to Dr. Mike Dunn @ OSU)

- Designing high-pressure turbines (HPTs) for peak temperatures at the combustor exit ➔ More cooling air ➔ Less cycle efficiency
- Designing HPTs for the mean exit-temperature at the combustor exit ➔ More local hot spots (hot streaks) ➔ Less gas turbine durability
- CFD should give some design guidelines
Features of Open National Combustion Code (OpenNCC)

- OpenNCC is the releasable version of the National Combustion Code (NCC), which has been continuously updated for more than two decades at NASA Glenn Research Center (GRC)

- Main Features
  - Numerics: Jameson-Schmidt-Turkel (JST) scheme and Roe's upwind scheme, and *advection upstream splitting method (AUSM)* (1-3)
  - Turbulence: Cubic non-linear k-ε (4) model with the wall function, Low-Re model
  - Combustion: Reduced chemical kinetic, low dimensional manifold, Linear Eddy Model (LEM) (5)
  - Spray: Lagrangian liquid phase model (6-8)
  - Other features: Low-Mach preconditioning, *transition model* (9), unstructured mesh, adaptive mesh refinement (AMR) (10), massively parallel computing (with almost perfectly linear scalability achieved for non-spray cases up to 4000 central processing units)

**Selected reference**
Energy Efficient Engine (E³) – GE design, 80s -

<table>
<thead>
<tr>
<th>Case</th>
<th>Numerics</th>
<th>Steady?</th>
<th>Spray</th>
<th>Fuel</th>
<th>Chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>JST/AUSM</td>
<td>Yes</td>
<td>Gas</td>
<td>C12H23</td>
<td>one-step</td>
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<tr>
<td>2</td>
<td>JST/AUSM</td>
<td>Yes</td>
<td>Liquid</td>
<td>C11H21</td>
<td>14 species-18 reactions</td>
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<tr>
<td>3</td>
<td>JST/AUSM</td>
<td>No</td>
<td>Liquid</td>
<td>C11H21</td>
<td>14 species-18 reactions</td>
</tr>
</tbody>
</table>

- One-cup (12 degree) E³ geometry\(^{(1)}\) is considered
- Tetrahedral mesh (~9.5M) is generated by Cubit (AMR is off)
- Used 960 processors of Pleiades at NASA Advanced Supercomputing facility
- Non-linear k-ε model and finite-rate chemistry
- Taken into consideration is the simulated sea level takeoff condition (SLTO)

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<tbody>
<tr>
<td></td>
<td>2.52</td>
<td>720</td>
<td>0.26</td>
<td>0.00364</td>
<td>0.014</td>
<td>0.5</td>
<td>520</td>
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</tbody>
</table>

Unsteady Flow Fields (axial velocity)

- Dilution airflow and swirling airflow interact and oscillate back and forth.
- There is a recirculation zone at the top of the dilution hole, enhancing the oscillation.
Processing Vortex Core (PVC)

- PVC greatly impacts on the particle motion and the combustion dynamics.
Temperature field is not uniform at the combustor exit and lots of hot/cold “spots”.
### Averaged Temperature Profiles

<table>
<thead>
<tr>
<th>Case 3</th>
<th>JST</th>
<th>AUSM</th>
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<tr>
<td>(Liquid, Detailed Chem.)</td>
<td><img src="image1" alt="JST Case 3" /></td>
<td><img src="image2" alt="AUSM Case 3" /></td>
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<tr>
<td>(Gas, one-step chem.)</td>
<td><img src="image3" alt="JST Case 3" /></td>
<td><img src="image4" alt="AUSM Case 3" /></td>
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</table>

- The flame is not attached to both fuel domes using the liquid spray.

<table>
<thead>
<tr>
<th>Case 2</th>
<th>JST</th>
<th>AUSM</th>
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<tr>
<td>(Liquid, Detailed Chem.)</td>
<td><img src="image5" alt="JST Case 2" /></td>
<td><img src="image6" alt="AUSM Case 2" /></td>
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<tr>
<td>(Liquid, Detailed Chem.)</td>
<td><img src="image7" alt="JST Case 2" /></td>
<td><img src="image8" alt="AUSM Case 2" /></td>
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</table>

<table>
<thead>
<tr>
<th>Case 1</th>
<th>JST</th>
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<td>(Gas, one-step chem.)</td>
<td><img src="image9" alt="JST Case 1" /></td>
<td><img src="image10" alt="AUSM Case 1" /></td>
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<tr>
<td>(Gas, one-step chem.)</td>
<td><img src="image11" alt="JST Case 1" /></td>
<td><img src="image12" alt="AUSM Case 1" /></td>
</tr>
</tbody>
</table>

T (K)  
600  
2400
• JST (red) and AUSM (blue) shows some difference, especially near the bottom wall.
• Bi-modal distribution is successfully captured by using the liquid-spray injection.
• We are planning to turn on the adaptive mesh refinement, and turbulence-chemistry interaction (e.g., LEM), and consider the combustor-turbine interaction.
Thank you!

Acknowledgement

- Supported by NASA's Transformational Tools and Technologies project
- Simulations conducted NASA Advanced Supercomputing (NAS) Pleiades computers
- Grid Generation conducted with Cubit (Sandia National Labs)
- Flow Viz was conducted with Visit (Lawrence Livermore National Labs)