Fuel Sensitivity of Gas Emissions, Lean Blowout and Combustion Dynamics for a 9-point LDI Combustor

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Introduction

- NASA has been investigating the use of synthetic fuel on aircraft combustors for decades.
- Advanced Air Transport Technology (AATT) Program
  - 50%/50% alternative fuel/jet-A blended
  - 80% NOx emissions reduction of ICAO CAEP 6.
- Environmentally Responsible Aviation (ERA)
  - 75% NOx reductions
  - 50%/50% Rentech/Jet-A blended.
- Alternative fuels tested recently:
  - hydrotreated tallow (HRJ),
  - direct sugar fermentation (Amyris AMJ-710)
  - Fischer-Tropsch processes (Rentech).
National Jet Fuels Combustion Program (NJFCP)

- highly-coordinated, involving several government agencies, universities, industry partners and international collaborations
- focused on the impacts of fuel compositions and physical properties on aviation engine combustor operability
  - lean blowout
  - high altitude ignition
  - cold start
- The fuels under investigation
  - Category C fuels are bended fuels, with unconventional properties, composition or distillation curves
OBJECTIVE

• Compare behavior of test fuels C1 and C3 to average Jet A (A2)
• A lean-burn combustor
  • 9-point Lean Direct Injection (LDI)
  • Short fuel-air mixture preparation time
• High pressure and high temperature conditions (T3 = 575 K to 825 K, P3 = 689 to 1723 kPa)
• Gas emissions and combustion dynamics
  • Near Lean blow-out, NOx emissions, combustion dynamics, ignition.
Experimental Set Up

- NASA Glenn Research Center's CE-5 test facility
- Ceramic liners, rectangular cuboid, (7.6 cm X 7.6 cm X 46 cm)
- Inlet air temperature up to 830 K and inlet air pressure up to 2400 kPa or 24 bar.
- Standard gas-analysis procedure, SAE-ARP1256D
- Three dynamic pressure sampling locations
Test Hardware

- Two 9-point Swirl-Venturi Lean Direct Injection (SV-LDI) injector configurations
- A lean burn concept
- Three fuel circuits
- Local fuel air equivalence ratios were similar among the nine fuel air mixers for most conditions
2015 test

- Fuel:
  - random batch of Jet-A, A2, C1, C3.
- Injector configuration:
  - Co-rotating pilot

2016 test

- Fuel:
  - A2 and C1
- Injector configuration,
  - Counter-rotating pilot
Fuels Properties

- A2, (POSF 10325), “average/nominal” Jet-A
  - high molecular weight duel-component iso-paraffin
  - low cetane number
  - long ignition delay time
  - 80% fuel distilled at a temperature of 35°C lower, faster vaporazation rate.

- C1, (POSF 11498)
  - high molecular weight duel-component iso-paraffin
  - low cetane number
  - long ignition delay time
  - 80% fuel distilled at a temperature of 35°C lower, faster vaporazation rate.

- C3, (POSF 12341)
  - high viscosity (upper specification limit at -20°C)
  - look at the effect of atomization

<table>
<thead>
<tr>
<th>Properties</th>
<th>A2 (w/ average properties)</th>
<th>C1 highly-branched iso-paraffins</th>
<th>C3 (64% A-3; 36% Amyris farnesane (C15 iso-paraffin))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall composition</td>
<td>Petroleum Jet A</td>
<td>Gevo ATJ; C12/C16</td>
<td></td>
</tr>
<tr>
<td>Viscosity, -20 °C (cSt)</td>
<td>4.5</td>
<td>4.9</td>
<td>8.0</td>
</tr>
<tr>
<td>Cetane number</td>
<td>48.3</td>
<td>17.1</td>
<td>47</td>
</tr>
<tr>
<td>Distillation (°C), 90%</td>
<td>244</td>
<td>228</td>
<td>245</td>
</tr>
<tr>
<td>80%</td>
<td>230</td>
<td>195</td>
<td>243</td>
</tr>
<tr>
<td>50%</td>
<td>205</td>
<td>182</td>
<td>230</td>
</tr>
</tbody>
</table>
Results - NO\textsubscript{x} emissions

- A random batch of Jet-A, C3 about the same as A2.
- C1 lower NOx emissions
  - 12% EI lower at T3 of 725 K,
  - 5% EI lower at T3 of 825 K.

- Possible explanation for Lower NOx with C1
  - Longer ignition delay time, low cetane number
  - Faster vaporization rate.

- NOx emissions do not appear to correlate with Cetane Number.
  - Current testing shows similar NOx emissions for C1 (DCN=16) and A2 (DCN=48)
  - Previous HRJ (Cetane Index =69) testing showed similar NOx emissions as Jet-A
Results-ignition

- The C1 fuel was hard to ignite.
- Auto-ignition temperature for A2 is about 700k.
- One successful C1 ignition (P3=1379 kPa, T3=810 K, phi=0.49)
- Also tried fueling the center (pilot) mixer with A2 (instead of C1) at lower T3 and P3 conditions, but no successful ignition.

<table>
<thead>
<tr>
<th>Fuel used</th>
<th>P_3 (kPa)</th>
<th>T_3 (K)</th>
<th>DP%</th>
<th>Φ (Pilot)</th>
<th>Φ (Main1)</th>
<th>Φ (Main2)</th>
<th>Φ (total)</th>
<th>Successful ignition</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1 only</td>
<td>1723</td>
<td>727</td>
<td>2</td>
<td>0.96</td>
<td>0.37</td>
<td>0.37</td>
<td>0.43</td>
<td>NO</td>
</tr>
<tr>
<td>C1 only</td>
<td>1034</td>
<td>727</td>
<td>2</td>
<td>0.96</td>
<td>0.36</td>
<td>0.36</td>
<td>0.42</td>
<td>NO</td>
</tr>
<tr>
<td>C1 only</td>
<td>1379</td>
<td>810</td>
<td>3</td>
<td>0.97</td>
<td>0.37</td>
<td>0.37</td>
<td>0.44</td>
<td>NO</td>
</tr>
<tr>
<td>C1 only</td>
<td>1379</td>
<td>810</td>
<td>3</td>
<td>0.97</td>
<td>0.43</td>
<td>0.43</td>
<td>0.49</td>
<td>YES</td>
</tr>
<tr>
<td>Pilot A2/ Main C1</td>
<td>862</td>
<td>672</td>
<td>2</td>
<td>1.05</td>
<td>0.37</td>
<td>0.37</td>
<td>0.44</td>
<td>NO</td>
</tr>
<tr>
<td>Pilot A2/ Main C2</td>
<td>862</td>
<td>672</td>
<td>2</td>
<td>1.67</td>
<td>0.37</td>
<td>0.37</td>
<td>0.51</td>
<td>NO</td>
</tr>
</tbody>
</table>
Results - Near lean blow-out

- CO curves for fuel evenly distributed.

- The C1 flame blows out at a calculated adiabatic flame temperature 25 K higher than the A2 fuel.

- Near LBO results are independent of T3, inlet air temperature
Low power conditions, high PILOT $\Phi$ OF 0.68

- CO curves vary with combustor design

- Rich burn or lean burn with relatively higher pilot fuel air ratio tend to stay lite even at lower fuel air ratio and at high CO emissions conditions

- C3 has higher CO emissions than C1 and A2 at similar adiabatic flame temperature.
  - high viscosity property of C3
  - the fuel injector may produce larger fuel drop sizes relative to A2 and C1
Combustion Dynamics

a) 2015 data

a) 2016 data
Conclusion

- **Two tests series were completed**
  - Used a 9-point LDI combustor
  - Measured gaseous emissions and combustion dynamics

- **C1**
  - Long ignition delay time. Faster vaporization rate than A2
  - Promotes better fuel air mixing and lower NO\textsubscript{x} emissions
  - C1 blows out at a flame temperature 25 K higher than A2

- **C3**
  - High in viscosity. Larger size fuel droplets and slower vaporization rate
  - No NO\textsubscript{x} emissions differences observed
  - At low power, higher CO emissions observed

- **No combustion dynamics difference observed between the three fuels.**
Acknowledgments

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Questions and Comments