Liquid Burner Development for Powerplant Fire Test

Yi-Huan Kao, Michael Knadler, Samir Tambe
and
San-Mou Jeng
School of Aerospace Systems
University of Cincinnati
November 16-17, 2011
Project Objective:

- Develop the operating settings for NexGen burner for powerplant fire tests
  - NexGen burner should simulate previously FAA approved liquid burners
  - NexGen burner should be robust and repeatable

Approach:

- Fire test results from NexGen burner operated at the same heat flux and temperatures
- Derive the NexGen burner settings future work
  - Comparison of fire test results from different burners (Park, NexGen and ISO)
NexGen Burner

Both fuel and air rate can be accurately metered and controlled.

Uninsulated Cone (Inconel 661)

Modified Turbulator (Four 1”x3/4” tabs)

12”x12”

4”x4”
Conclusions from previous work (1)

Turbulator with four 1”x 3/4” tabs creates better and more stable air/fuel mixing and provides:

– Higher and more uniform flame temperatures
– More repeatable flames
– We recommend these tabs to be added to NexGen burner design
Conclusions from previous work (2)

Burner flame temperature and heat flux is very sensitive to the fuel flow rate, but not as sensitive to the air flow rate.

**Air Sensitivity**

**Fuel Sensitivity**

![Graphs showing the relationship between temperature and airflow rate or jet-A change](image-url)
Conclusions from previous work (3)

For the same flame, temperature indicated by smaller TCs was around 100 F higher.
Current Study

• Fire tests using burner settings with the same measured temperature and heat flux
  – Different air flow rate
  – Different thermocouple size

• Test samples and methods
  – Small size Sample (4”x4”x1/4” AL6061) and Large size Sample (12”x12”x1/4” AL6061)
  – Back side TCs to monitor the temperature history and post-test inspection
Test Rig #1 and TC Locations for 4”x4” Sample

Test Piece (4”x4”)
Test Main Frame
Adapter
Back Holder

TC Location @ Rear Side

TC1
TC2
TC3

1”

3”
4”

3”

- Test Sample: 4”x4”
- Exposure Area: 3”x3”
Test Rig #2 and TC Locations for 12”x12” Sample

Test Sample: 12”x12”
Exposure Area: 11”x11”
## Test Conditions and Calibration Data (Small Sample)

<table>
<thead>
<tr>
<th>Small</th>
<th>Test Conditions</th>
<th>Calibration Data</th>
<th>Burnthrough Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test #</td>
<td>Fuel (GPH)</td>
<td>Air (SCFM)</td>
</tr>
<tr>
<td><strong>Fuel Leaner Case</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(<strong>(\phi=0.74)</strong>)</td>
<td>#1</td>
<td>2.20</td>
<td>67.6</td>
</tr>
<tr>
<td></td>
<td>#2</td>
<td>2.20</td>
<td>67.6</td>
</tr>
<tr>
<td><strong>Baseline Case</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(<strong>(\phi=0.80)</strong>)</td>
<td>#3</td>
<td>2.25</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>#4</td>
<td>2.25</td>
<td>64</td>
</tr>
<tr>
<td><strong>Fuel Richer Case</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(<strong>(\phi=0.87)</strong>)</td>
<td>#5</td>
<td>2.25</td>
<td>58.6</td>
</tr>
<tr>
<td></td>
<td>#6</td>
<td>2.25</td>
<td>58.6</td>
</tr>
<tr>
<td><strong>All tests were terminated at 17 min</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Ambient Temp.=80~90 F, w/o forced convection*
Test Results: Small Sample

![Graphs showing test results for Fuel Leaner, Baseline, and Fuel Richer conditions across different tests. The graphs depict temperature versus test time for each condition and test number.](image-url)
Test Results: Small Sample (after 17mins)

\[ \Phi = 0.74 \text{ (undamaged)} \]

\[ \Phi = 0.80 \text{ (surface melted)} \]

\[ \Phi = 0.87 \text{ (burned through \@ 17 min)} \]
Test Conditions and Calibration Data (Large Sample)

<table>
<thead>
<tr>
<th>Large</th>
<th>Test Conditions</th>
<th>Calibration Data</th>
<th>Burnthrough Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test #</td>
<td>Fuel (GPH)</td>
<td>Air (SCFM)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Leaner Case ((\phi=0.76))</td>
<td>#1</td>
<td>2.25</td>
<td>67.6</td>
</tr>
<tr>
<td></td>
<td>#2</td>
<td>2.25</td>
<td>67.6</td>
</tr>
<tr>
<td>Baseline Case ((\phi=0.82))</td>
<td>#3</td>
<td>2.25</td>
<td>62.2</td>
</tr>
<tr>
<td></td>
<td>#4</td>
<td>2.25</td>
<td>62.2</td>
</tr>
<tr>
<td>Fuel Richer Case ((\phi=0.88))</td>
<td>#5</td>
<td>2.25</td>
<td>57.7</td>
</tr>
<tr>
<td></td>
<td>#6</td>
<td>2.25</td>
<td>57.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Ambient Temp.=80~90 F, w/o forced convection
Tests 1, 3, 5, 6 conducted up to burn through
Tests 2, 4 terminated at 10 min
Test Results: Large Sample
Test Results: Large Sample (after 10mins)

- $\Phi = 0.76$ (undamaged)
- $\Phi = 0.82$ (surface melted)
- $\Phi = 0.88$ (burned through)

Burnthrough

- @ 15 mins
- @ 11.5 mins
- @ 10 mins
# Test Conditions and Calibration Data (Diff. TCs)

<table>
<thead>
<tr>
<th></th>
<th>Test Conditions</th>
<th>Calibration Data</th>
<th>Burnthrough Time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Large</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Test #</td>
<td>Fuel (GPH)</td>
<td>Temp. (F)</td>
</tr>
<tr>
<td><strong>Small TCs</strong></td>
<td>#1</td>
<td>2.14</td>
<td>1907.9</td>
</tr>
<tr>
<td>($\phi=0.8$: baseline)</td>
<td></td>
<td>60.4</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td>1918.8</td>
<td>9.0</td>
<td>-</td>
</tr>
<tr>
<td><strong>Big TCs</strong></td>
<td>#3</td>
<td>2.25</td>
<td>1919.8</td>
</tr>
<tr>
<td>($\phi=0.82$: baseline)</td>
<td></td>
<td>62.2</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td>1919.6</td>
<td>9.4</td>
<td>-</td>
</tr>
</tbody>
</table>

*Ambient Temp.=80~90 F, w/o forced convection

---

## Thermocouple Dimension Information

<table>
<thead>
<tr>
<th></th>
<th>Bead (inch)</th>
<th>Wire (inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Big</strong></td>
<td>0.033</td>
<td>0.020 (AWG 24)</td>
</tr>
<tr>
<td><strong>Small</strong></td>
<td>0.020</td>
<td>0.012 (AWG 28)</td>
</tr>
</tbody>
</table>

K-Type, bare bead, ¼” inch exposed wire

*AC 20-135: thermocouple wire: AWG 20~30 (0.0100~0.0253 inch)
Test Results – Different TCs

![Graph showing temperature over test time for different TCs]
Test Results_Diff. TCs(after 10mins)

Big TCs, (surface melted)

Burnthrough

@ 11.5 mins

Small TCs, (undamaged)

Survive

until 15 mins
Conclusion

- Tests were conducted at flames with different air/fuel ratios but the same heat flux and temperature calibrations:
  - More damage was observed for the fuel richer test condition as compared to the fuel leaner condition.

- Small test samples had less damage as compared to the large test samples.

- Tests results are sensitive to TC sizes in calibration process:
  - The temperature measured by small TCs could reach target temperature at lesser fuel flow rate resulting in lower heat flux.
  - Test sample could survive longer under the flame calibrated by small TCs.
Recommendations

• Both air and fuel flow rates for a liquid burner should be precisely controlled and metered

• Current Fire Test guidelines do not require reporting the fuel and air flow rates. For future tests we recommend
  – Fuel and air flow rates to be documented
  – Guidelines should include precise air and fuel flow rate settings

• The range of recommended thermocouple size should be made narrower to limit the effect of different thermocouple sizes