Fuel Actuator Development and Testing

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Outline

Background/Motivation

NASA GRC Active Combustion Control Research Program Chronology

Brief Description of NASA GRC’s High Bandwidth (HB) Fuel Modulator Characterization Capabilities

HB Characterization Rig
Test Configurations; Procedures/Tests

Conventional Rich-Burn Combustor Application
Specification/Procurement of a HB Fuel Modulator (GTV)
Characterization/Validation Results

Advanced Lean-Burning Combustor Prototype Application
Characterization/Validation Results

Conclusions

Future Work
NASA’s Aeronautics Goals: Reduction in Fuel Burn
Reduction in Noise
Reduction in Emissions

Lean-burning Combustors

Significantly reduce emissions
Thermo-acoustic instabilities have been observed

Technology Enabler: Active Combustion Instability Control (ACC)
**NASA GRC ACC Chronology**

- **2000**
  - Conventional Rich-Burning Combustor (CRBC)
  - ACC Control Development
  - Development of Characterization Rig
  - Procurement of the Georgia Tech Valve (GTV)
  - Characterization of the GTV for CRBC Use

- **2004**
  - Validation of Characterized GTV Performance (in operation with CRBC)
Lean-Burning Combustor (LBC)

2006

Small Flow Number (pilot) fuel modulator development

Characterization of the GTV for LBC Use

2010

Validation of Characterized GTV Performance (in operation with LBC)
Characterizing Candidate Fuel Modulators

Test in situ with combustion rig?

NO!

Design and build a dedicated Rig that can approximate the combustion rig testing.
Characterization Rig Test Section

- Accumulator ensures a constant pressure working fluid supply
- Injection orifice approximates fuel injector
- Simulated Combustor accepts pressurized air to approximate the backpressure downstream of injector
- Plumbing connection between Test Candidate and injection orifice can accommodate insertion of additional tube length

Max Working Pressure: 600 psig
Working Fluid: Cleveland City Water (non-combustible)

Testing

Configurations

Establish Flow Condition
\[ \dot{m}, P_4, (F_{N_{\text{inj}}}) \]

Engage Mean Flow Control;
Issue Modulation Commands
\( \text{ASin}(2\pi ft) \text{ issued discretely for } f \in \{100, 200, 300, \ldots, 1000\} \text{ Hz with } A \text{ fixed} \)
(Time History, PSD’s, & Discretized FR)

Sinusoidal Sweep
Range: 100 to 1000 Hz
Performed logarithmically
70 second duration
(Bode plots – ‘qualitative’)

Procedure/Tests
The Conventional Rich-Burning Combustor (CRBC)

- Built as a collaborative effort with UTRC & PW
- Single nozzle combustor designed to emulate a PW prototype engine having an observed instability (550 Hz)

Defined Operating Conditions for the Conventional Rich-Burn Combustion Rig

<table>
<thead>
<tr>
<th>FN_i</th>
<th>FN_m</th>
<th>( \dot{m} ) (pph)</th>
<th>P_4 (psig)</th>
</tr>
</thead>
<tbody>
<tr>
<td>110</td>
<td>23</td>
<td>500</td>
<td>200</td>
</tr>
<tr>
<td>110</td>
<td>23</td>
<td>375</td>
<td>200</td>
</tr>
<tr>
<td>110</td>
<td>23</td>
<td>250</td>
<td>200</td>
</tr>
</tbody>
</table>

Tube Length (L): 18”
Specifications for a Modulator Design as Coupled to a Combustor Platform

Bandwidth: $\geq 600$ Hz

$P_{\text{fuel max}} = 600$ psig

$m_{\text{max}} = 500$ pph

$P_{\text{comb max}} \approx 300$ psi

$T_{\text{amb}} \approx 300$ F

$L \geq 12''$ ; $\frac{1}{4}''$ ID

Flow Number (FN) = \[ \frac{m}{\sqrt{P_{\text{dstrm}} - P_{\text{comb}}}} \] \[ (\text{pph}) \] \[ (\text{psi}^{0.5}) \]

FN: 110 (CRBC main fuel flow)
The Georgia Tech Valve (GTV)

Initial Design Specifications for GTV
(based on CRBC operational conditions)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Mean Fuel Flow Rate</td>
<td>500 pph</td>
</tr>
<tr>
<td>Maximum Inlet pressure</td>
<td>600 psi</td>
</tr>
<tr>
<td>Maximum Pressure Drop</td>
<td>300 psi</td>
</tr>
<tr>
<td>Modulation Authority</td>
<td>+/- 40% of the Mean Flow</td>
</tr>
<tr>
<td>Minimum Bandwidth</td>
<td>600 Hz</td>
</tr>
<tr>
<td>Working Fluid</td>
<td>Liquid Jet Fuel</td>
</tr>
<tr>
<td>Working Temperature</td>
<td>400 °F</td>
</tr>
</tbody>
</table>
Results

Characterization Rig: Long Config w/ Combustor Data

Discrete Normalized Frequency Response

- Predicted Performance
  - 4 vpp
  - 8 vpp

- Pvdnstr: 6 vpp
- mdot = 300 pph
- Tube Length = 18”
The Lean-Burning Combustor (LBC)

Tube Length: 26”

Defined Operating Conditions for the Lean-Burn Advanced Combustor Prototype

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>m, (pph)</th>
<th>P_4 (psig)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>8</td>
<td>75</td>
<td>250</td>
</tr>
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<td>8</td>
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</tr>
<tr>
<td>8</td>
<td>8</td>
<td>25</td>
<td>166</td>
</tr>
</tbody>
</table>
Results

Characterization Rig: Long Config w/ Combustor Data

Discrete Frequency Response

Predicted Performance
- 25 pph
- 75 pph
- 60 pph

Tube Length = 26”

“Performance Evaluation of a High Bandwidth Liquid Fuel Modulation Valve for Active Combustion Control”
AIAA ASM January 2012
Future Work

• New modulation concepts are being developed that are more appropriately sized for the encountered applications.

Active Signal Technologies/Moog
-- Magnetostrictive-actuated poppet valve
-- Flow number range: 3 to 5
-- Expected March 2012

Jansen Aircraft System Controls (JASC)
-- Partners: UTRC, Parker Hannifin, Avior Controls, Dynac Labs
-- Rotary/translating spool
-- Flow number range: 3 to 8
-- Expected June 2013

• Efforts underway to improve predictive fidelity of the characterization data
  ➢ Modeling (fluidic system, including acoustics)
  ➢ Using fuel as a working fluid.
Conclusions

• Characterization rig designed and developed for evaluating high bandwidth fuel modulators
• The Georgia Tech Valve (GTV) was evaluated for use as a fuel modulator for 2 distinct combustor platforms
  ➢ characterization and CRBC data agreed well; good authority predicted, success was achieved.
  ➢ characterization and LBC data agreed well for middle frequencies; poor performance predicted, poor performance attained.
• Several fuel modulator concepts for lean-burn (pilot) application are under development
• The characterization rig will be used to screen the performance of these concepts prior to use in combustion testing

Acknowledgement

The authors wish to acknowledge Dr. Daniel Paxson for his consultation on issues surrounding the optimization of the GTV for off-nominal design operation and for his modeling efforts that supported our active combustion control research.