**Title and Subtitle:**
Adiabatic Compression Sensitivity of AF-M315E (Briefing Charts)

**Authors:**
Phu Quach, Adam Brand, and Greg Warmoth

**Abstract:**
The Air Force Research Laboratory developed monopropellant, AF-M315E, has been selected for demonstration under the NASA sponsored Green Propellant Infusion Mission (GPIM) program. As the propulsion system developed by Aerojet-Rocketdyne for this propellant advances in maturity, studies have been undertaken to address the knowledge gaps in the adiabatic compression sensitivity of the propellant as it relates to the system parameters for this mission. Of particular interest is the sensitivity of the propellant at elevated temperatures and the resulting system peak pressures and dynamic response characteristics. For this study, an adiabatic compression U-tube apparatus was used to determine the driving pressure threshold levels of the propellant at elevated temperatures. These tests simulate the worst-case scenario resulting from a rapid closure or opening of valves in a propellant feed line in situ. The results of these tests are presented as a preliminary assessment on the margin of safety for the propellant.
Outline

➤ GPIM Mission
➤ Background
➤ Experimental methods
➤ Results
➤ Conclusions
Ball assembled a cross-cutting team of US experts for GPIM.
Background

• Rapid isentropic compression of entrained gas bubbles
• Closure or opening of valves
• External mechanical shock
• Gas introduced by thermal decomp., during priming, or high Q pumping
• Bubble collapse increases local temp. & exothermic decomp.

\[
\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma - 1}{\gamma}}
\]

\(T = \text{Temperature [K]}
\)

\(P = \text{Pressure [psi]}
\)

\(\gamma = \text{ratio of specific heats}
\)
Purpose of Study

- Pressure/temperature threshold initiation levels
- Sensitivity of thermally damaged propellant
  - Thermal soak-back from cat. preheat
- Characterize dynamic response
- Waterhammer effect
**AF-M315E Formulation**

AF-M315E Monopropellants Produced From Energetic Ionic Liquids

\[
\begin{align*}
\text{Hydroxyethylhydrazinium Nitrate (HEHN)} & : [\text{HOCH}_2\text{CH}_2\text{N}_2\text{H}_4]^+ [\text{NO}_3^-] \\
\text{Hydroxylammonium Nitrate (HAN)} & : [\text{NH}_3\text{OH}]^+ [\text{NO}_3^-]
\end{align*}
\]

<table>
<thead>
<tr>
<th>Properties</th>
<th>AF-M315E</th>
<th>Hydrazine</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{Isp}_{\text{vac}} ) [lbf-sec/lbm] ((e = 50:1 \quad Pc = 300 \text{ psi}))</td>
<td>266 (theo.) 250 (del.)</td>
<td>242</td>
</tr>
<tr>
<td>Density [g/cc]</td>
<td>1.465</td>
<td>1.021</td>
</tr>
<tr>
<td>Vapor Pressure [torr]</td>
<td>&lt; 0.1 (w/o H\textsubscript{2}O)</td>
<td>14.3</td>
</tr>
<tr>
<td>Melt point [°C]</td>
<td>&lt; -22</td>
<td>1</td>
</tr>
</tbody>
</table>

Distribution A: Approved for public release; distribution unlimited
## Safety Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal stability</td>
<td>0.43% weight loss per 24 hours at 75 °C</td>
</tr>
<tr>
<td>Unconfined ignition response</td>
<td>No explosive response</td>
</tr>
<tr>
<td>Impact sensitivity [Olin Mathiesen drop weight]</td>
<td>60 kg-cm</td>
</tr>
<tr>
<td>Friction sensitivity [Julius Peters sliding friction]</td>
<td>300 N</td>
</tr>
<tr>
<td>Detonability [NOL card gap at 0 cards]</td>
<td>Negative (&lt; 24 cards)</td>
</tr>
<tr>
<td>Electrostatic discharge sensitivity</td>
<td>Insensitive to static spark discharge (1J)</td>
</tr>
<tr>
<td>Vapor toxicity</td>
<td>Low hazard (No Self-Contained Breathing Apparatus)</td>
</tr>
<tr>
<td>Vapor pressure</td>
<td>&lt; 0.1 torr</td>
</tr>
</tbody>
</table>

Distribution A: Approved for public release; distribution unlimited
Procedure and P&ID

Procedure

- 3 mL in Ti-3Al2.5V U-tube
- Tube immersed in bath for 20 minutes
- Fast pressurization (GN2) with burst disc
- Compression rates of 80k to 140k psi / second
- LabView sampled at 25 kHz for 5 seconds
MATLAB Characterization

Terminology
- Max Pressure
- Settling Pressure
- Peak Time
- Rise Time
- Settling Time
- Compression Rate
# Summary of AF-M315E

## Adiabatic Compressions

<table>
<thead>
<tr>
<th>Temperature [°C]</th>
<th>Pressure [psi]</th>
<th>POS</th>
<th>NEG</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>300</td>
<td>0</td>
<td>19</td>
</tr>
<tr>
<td>25</td>
<td>350</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>25</td>
<td>400</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>25</td>
<td>500</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>25</td>
<td>1500</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>60</td>
<td>300</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>90</td>
<td>300</td>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td>90</td>
<td>350</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>90</td>
<td>400</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>250</td>
<td>0</td>
<td>19</td>
</tr>
<tr>
<td>100</td>
<td>300</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>400</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
Waterhammer Effect

\[ f_n = \frac{1}{2\pi} \sqrt{\frac{K}{W}} \]

- \( f_n \) = undamped natural frequency [Hz]
- \( K \) = bulk modulus [psig]
- \( W \) = weight [lb]

K = 2.2 \times 10^9 \text{ Pa} 
K = 5.7 \times 10^9 \text{ Pa}

Distribution A: Approved for public release; distribution unlimited
AF-M315E Adiabatic Compressions

Distribution A: Approved for public release; distribution unlimited
Characteristic Times

Distribution A: Approved for public release; distribution unlimited
## Parameter Averages

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Water 300 psi</th>
<th>AF-M315E 300 psi</th>
<th>AF-M315E 250 psi</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum Pressure [psi]</strong></td>
<td>797 829</td>
<td>840 833</td>
<td>718</td>
</tr>
<tr>
<td><strong>Settling Pressure [psi]</strong></td>
<td>313 318</td>
<td>314 313</td>
<td>253</td>
</tr>
<tr>
<td><strong>Peak Time [ms]</strong></td>
<td>5.41 7.04</td>
<td>7.35 6.39</td>
<td>7.53</td>
</tr>
<tr>
<td><strong>Rise Time [ms]</strong></td>
<td>2.04 2.37</td>
<td>2.75 2.80</td>
<td>3.31</td>
</tr>
<tr>
<td><strong>Settling Time [ms]</strong></td>
<td>28.75 27.04</td>
<td>67.37 72.23</td>
<td>87.61</td>
</tr>
<tr>
<td><strong>Compression Rate [psi / s]</strong></td>
<td>153805</td>
<td>133916</td>
<td>111852</td>
</tr>
<tr>
<td><strong>Est. Adiabatic Temp. [°C]</strong></td>
<td>-- 444</td>
<td>526 597</td>
<td>568</td>
</tr>
</tbody>
</table>

\[
\frac{T_2}{T_1} = \left( \frac{P_2}{P_1} \right)^{\gamma - 1} \\
T = \text{Temperature [K]} \\
P = \text{Pressure [psi]} \\
\gamma = \text{ratio of specific heats}
\]

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Summary

- No positive responses at:
  - 300 psi, 25 °C to 90 °C
  - 250 psi, 100 °C
- Bulk modulus explains dynamic behavior
- Peak pressure not largely dependent on temperature
- Peak and rise time not functions of temperature
- Settling time drastically increased with temperature
Acknowledgements

• AFRL
  • Adam Brand, Greg Warmoth, and Claude Merrill
• NASA Goddard Space Flight Center
  • Stephen McKim and Caitlin Baucha
Hazards of Thermally Damaged Propellant

**Thermal Management of 5-lbf Thruster is Problematic**

- Thermal soak back from catalyst pre-heat operations causes the thruster propellant valve and propellant to heat

- AFRL to test hazards of heated propellant in contact with titanium to determine a maximum safe temperature (30 minutes)

- Primary concerns are adiabatic compression and impact sensitivity

- Aerojet to provide all test materials needed under the CRADA such as heating mantles and burst discs to allow testing in titanium to simulate valve seat material and system tubing

**AFRL conducting adiabatic compression on propellant heated in situ to determine an acceptable temperature and driving pressure for safe operation**

Ruptured Steel U-Tube