Ignition methods for ADN-based liquid monopropellants

M. Negri, C. Hendrich, M. Wilhelm, D. Freudenmann, H. K. Ciezki @ DLR, Lampoldshausen
L. Gediminas, L. Adelöw @ FOI, Tumba
T. Bartok, R.-J. Koopmans, S. Schuh @ FOTEC, Vienna
C. Scharlemann @ FHWN, Wiener Neustadt
Y. Batonneau, R. Beauchet, C. Maleix, R. Brahmi, C. Kappenstein @ IC2MP (CNRS), Poitiers
M. Schwентенвейн @ Lithoz, Vienna
Ignition has always been a challenging issue...

... many different solutions were found...
Ignition of Green propellants

... up to now ADN-Based Propellants are ignited through a preheated catalyst...

... but other kind of igniter may also work...
Advantages of ADN liquid monopropellants compared to hydrazine:

• **Lower** overall life cycle cost due to simplified handling
• **Higher** overall performance ($I_{sp}$)
• **Higher** volumetric specific impulse

Baseline ADN-based liquid monopropellants

• LMP-103S: ADN, Methanol, Water, Ammonia
• FLP-106: ADN, MMF, Water

![Monopropellant Comparison Chart](chart.png)

NASA CEA, frozen vacuum expansion, $p_c = 10$ bar, $\varepsilon = 40$
Rheform - Replacement of hydrazine for orbital and launcher propulsion systems

Rheform aims at replacing the carcinogenic and toxic hydrazine in propulsion applications

Rheform is founded from the European’s Union Horizon 2020 programme

Rheform will run from 01.01.2015 to 31.12.2017

Rheform project coordinator: Michele Negri
Rheform goals

1. Replacing hydrazine by adapting the baseline propellants (LMP-103S and FLP-106) to obtain a combustion temperature compatible with currently existing materials available in Europe (ITAR-Free)

2. Development of a cold-start capable ignition system to replace hydrazine in the whole operational area
   - New catalytic igniter
   - Thermal igniter

3. Verification of the technology within thruster demonstrator(s) to reach a Technology Readiness Level of 5
Rheform Flowchart

WP2
Definition of Requirements

WP3
Propellant Development and Preliminary Testing

WP4 + WP5
Ignition Systems Development and Testing
- Catalytic Igniter
- Thermal Igniter

WP6 + WP7
Optimized Igniters
- Thruster Demonstrators Development and Testing
- Thrusters TRL5

WP8
Commercial Development Plan

WP1 + WP9
Management and Dissemination
Investigation of catalysts as ignition system

by Lithoz, IC2MP and FHWN/FOTEC
Catalytic ignition – typical questions

- Production
  - What base material?
  - Dimensions?
  - Machine settings?
  - Inner structure?

- Testing
  - Washcoating procedure?
  - Best active phase?
  - Thermal shock resistance?
  - Ignitibility?
  - Steady state performance?
  - Transient performance?
  - Preheating?
Catalytic ignition – research methods

- Design catalysts for ignition investigated in several ways
  - theoretical considerations
  - experimental investigation
  - numerical assessment

\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho U) = \dot{S}_M
\]

\[
D_c \left( \frac{d^2 C}{dx^2} \right) = \frac{2k_1 C}{r}
\]
Why Thermal Ignition?

Currently ADN based system use a preheated catalyst igniter.  
1 N thruster $\rightarrow$ 10 W, 30 min.

Possible **advantages** of thermal igniters:

- **Cold start capable $\rightarrow$ Prompt ignition** (no preheating phase)
- Better suitable for **larger thrusters** (100 - 500 N)
Preliminary tests on thermal ignition

- Resistive Ignition
- Laser Ignition, H2/O2 torch ignition
Resistive ignition - Experimental setup

• Electric discharge through a drop of propellant
• Three 1000 µF capacitors in series
• Voltage range: 60 V and 350 V
• Voltage and current measured during discharge
• Electrode shapes:
  • flat lower / slightly curved upper electrode
  • pointy upper electrode / bowl shaped lower electrode
• Electrode materials:
  • Mild steel
  • Tungsten
• Propellants:
  • FLP-106
  • LMP-103S
Resistive ignition - Results 1

$t_0 + 0.5 \text{ ms}$

$t_0 + 1.0 \text{ ms}$

$t_0 + 1.5 \text{ ms}$

$t_0 + 2.0 \text{ ms}$

$t_0 + 2.5 \text{ ms}$

$\text{Splashing}$

$t_0 + 3.0 \text{ ms}$
Resistive ignition - Results 2

LMP-103 (tests 192)  FLP-106 (test 194)  NaCl/H2O (test 195)

• The 2 propellants and the salt solution showed very similar behaviors
• The spark were generated by electric arc NOT by decomposition of the propellant
Resistive Ignition - Discussion

• 150 tests conducted
• Most of the tests with 2 µL drops
• No ignition was observed
• In 20 tests a spark was observed
  • Large discharge current was measured
  • Spark generated through electric arc
• Splashing and separation of the drop from electrodes
  → measured current lower than expected
• Electric discharge cause evaporation of volatile components in propellants

• In previous tests conducted at FOI resistive ignition worked well – Wingborg et al. AIAA-2005-4468 (2005)
Laser Ignition - Experimental Setup

- Nd:YAG pulsed laser (Quantel)
  - 10 ns pulse
  - 100 mJ (FLP-106) → enough to generate a plasma in air
  - 320 mJ (LMP-103S)
- High speed camera (Photron SA1.1)
  - 300 000 fps
  - 128 x 64 pixels
- Acoustic levitator (tec5)
- Drops volume 3-5 µL
- Propellant tested:
  - FLP-106
    - + 11.5 % H2O
    - + 15.7 % H2O
    - + 27.7 % H2O
  - LMP-103S
    - + 5.8 % H2O
    - + 17.4 % H2O
Laser ignition of ADN-based propellants
# Laser ignition - Results 1

<table>
<thead>
<tr>
<th>Time (µs)</th>
<th>LMP-103S</th>
<th>LMP-103S + 5.8% H2O</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_0 - 6$ µs</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>$t_0$</td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>$t_0 + 3$ µs</td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
<tr>
<td>$t_0 + 6$ µs</td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
</tr>
<tr>
<td>$t_0 + 12$ µs</td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
</tr>
<tr>
<td>$t_0 + 21$ µs</td>
<td><img src="image11.png" alt="Image" /></td>
<td><img src="image12.png" alt="Image" /></td>
</tr>
<tr>
<td>$t_0 + 30$ µs</td>
<td><img src="image13.png" alt="Image" /></td>
<td><img src="image14.png" alt="Image" /></td>
</tr>
<tr>
<td>$t_0 + 60$ µs</td>
<td><img src="image15.png" alt="Image" /></td>
<td><img src="image16.png" alt="Image" /></td>
</tr>
<tr>
<td>$t_0 + 120$ µs</td>
<td><img src="image17.png" alt="Image" /></td>
<td><img src="image18.png" alt="Image" /></td>
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Laser ignition - Results 2

<table>
<thead>
<tr>
<th>Time</th>
<th>Image</th>
<th>Time</th>
<th>Image</th>
<th>Time</th>
<th>Image</th>
<th>Time</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_0 - 6 \mu s$</td>
<td><img src="FLP-106.png" alt="Image" /></td>
<td>$t_0$</td>
<td><img src="t_0.png" alt="Image" /></td>
<td>$t_0 + 3 \mu s$</td>
<td><img src="t_0+3.png" alt="Image" /></td>
<td>$t_0 + 6 \mu s$</td>
<td><img src="t_0+6.png" alt="Image" /></td>
</tr>
<tr>
<td>$t_0 + 12 \mu s$</td>
<td><img src="t_0+12.png" alt="Image" /></td>
<td>$t_0 + 21 \mu s$</td>
<td><img src="t_0+21.png" alt="Image" /></td>
<td>$t_0 + 30 \mu s$</td>
<td><img src="t_0+30.png" alt="Image" /></td>
<td>$t_0 + 60 \mu s$</td>
<td><img src="t_0+60.png" alt="Image" /></td>
</tr>
</tbody>
</table>

FLP-106

FLP-106 + 11.5% H2O
Laser ignition - Discussion

- The plasma spark generated by the laser lead to a disintegration of the droplet.

- Light emission from drop after the laser pulse → No clear trend was recognized

- The diagnostic technique used during the tests (high speed shadowgraphy) did not allow determining the causes of light emission.

- Ignition was not clearly identified

<table>
<thead>
<tr>
<th>Propellant</th>
<th>Number of bright frames after $t_0$</th>
<th>Time length of bright light emission [μs]</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLP-106</td>
<td>5</td>
<td>17</td>
</tr>
<tr>
<td>FLP-106</td>
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<td>17</td>
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<td>7</td>
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<tr>
<td>FLP-106</td>
<td>11</td>
<td>37</td>
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<tr>
<td>FLP-106</td>
<td>28</td>
<td>93</td>
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<tr>
<td>FLP-106 + 11.5% $\text{H}_2\text{O}$</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>FLP-106 + 11.5% $\text{H}_2\text{O}$</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>FLP-106 + 15.7% $\text{H}_2\text{O}$</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>FLP-106 + 15.7% $\text{H}_2\text{O}$</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>FLP-106 + 15.7% $\text{H}_2\text{O}$</td>
<td>8</td>
<td>27</td>
</tr>
<tr>
<td>FLP-106 + 27.7% $\text{H}_2\text{O}$</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>FLP-106 + 27.7% $\text{H}_2\text{O}$</td>
<td>9</td>
<td>30</td>
</tr>
<tr>
<td>FLP-106 + 27.7% $\text{H}_2\text{O}$</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>LMP-103S</td>
<td>12</td>
<td>40</td>
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<tr>
<td>LMP-103S</td>
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<td>43</td>
</tr>
<tr>
<td>LMP-103S</td>
<td>15</td>
<td>50</td>
</tr>
<tr>
<td>LMP-103S + 5.8% $\text{H}_2\text{O}$</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>LMP-103S + 5.8% $\text{H}_2\text{O}$</td>
<td>12</td>
<td>40</td>
</tr>
<tr>
<td>LMP-103S + 17.4% $\text{H}_2\text{O}$</td>
<td>8</td>
<td>27</td>
</tr>
<tr>
<td>LMP-103S + 17.4% $\text{H}_2\text{O}$</td>
<td>13</td>
<td>43</td>
</tr>
</tbody>
</table>
Atomization and thermal ignition

μShowerhead ASL1  μShowerhead ASL2  Swirl 3
Ignition demonstrator with torch igniter

- H2/O2 torch igniter → possibility to regulate the power of the igniter
Acknowledgments

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