Cryogenic System Development for LOX/Hydrocarbon Propulsion Research

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Agenda

• Introduction
  – Background
  – Motivation
  – cSETR

• Cryogenic System
  – Methane Condensation System
  – Delivery System
  – Data Acquisition and Control

• Safety considerations

• Testing

• Conclusions and Future Work
Introduction: Background

Current Propulsion Systems

Used propellants:
• Liquid Oxygen (LOX)
• Liquid Hydrogen (LH₂)
• Monomethyl Hydrazine (MMH)
• Nitrogen Tetroxide (NTO)

Disadvantages

• Carcinogenic, toxic, corrosive and hypergolic (MMH and NTO)
• Leaks, High flammability limits, low ignition energy and boiling point 20K (LH₂)
Introduction: Motivation

Space systems safety
• Design to avoid hazards
• Stringent safety and energy programs
• Protect ground personnel and onboard astronauts

Methane vs. Hydrogen
• Higher liquid density (425/70 [kg/m\(^3\)])
• Warmer storage temperature (~108K/20K)
• Smaller flammability limits (5.4-59.2/4.65-94 [mol\%])

Consequences
• Design, operation and handling costs are elevated

Advantages
• Less production energy
• Higher tank storage (V,T)
• Relatively lower safety precautions
Introduction: cSETR

Liquid Methane Research
- Ignition physics
- Heat transfer thrust chambers
- Injector dynamics

Potential applications
- NASA Lunar ascent engine
- Mars in-situ resource utilizations
Introduction: cSETR

Opportunity areas

- Reliable Ignition
- High heat load management
- Fast response
- Associate components life
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Cryogenic system

Methane condensation system

- cSETR needs of Liquid Methane: 1 to 25 L
- Make in-house Liquid Methane with a heat exchanger
- Liquid nitrogen as cooling fluid (77K boiling point)
- Operating pressure of 1MPa
- Vertical thermocouple array as level gauge
Cryogenic system

Methane condensation system

Heat transfer-energy model:
• Condense 10 L (4.3 kg) Methane
• 3800 kJ (17 kg liquid nitrogen)

Multi-resistive heat transfer model:
• Log mean temperature difference
• 18 m coil (1/4” diameter)
• 2.5 L/hr condensation rate

\[ Q = \dot{m} \cdot \int_{T_1}^{T_2} C_v \, dT \]

\[ Q = U \cdot A \cdot \Delta T \]

Where:
\[ U = \frac{1}{h_{\text{Natural}}} + \frac{\ln \left( \frac{D_0}{D_i} \right)}{2 \pi kl} + \frac{1}{h_{\text{Forced}}} \]
Cryogenic system

Methane condensation system

Proof of concept
- 1L cryogenic Dewar
- 1m Stainless Steel (1/8” diameter) coil
- Weight change over time
Cryogenic system

Methane condensation system

Second generation condenser
- 2.5 m (1/4” diameter) coil
- 2L condenser
- Third generation condenser in development
Cryogenic system

Delivery system

- Deliver cryogenic LOX and Methane to test articles
- Powers up to 100N LOX/CH4 thrusters with 368 ISP
- Maximum pressure 1310 KPa (190 PSI)
- LOX compatible materials
Cryogenic system

Delivery system

- Liquid nitrogen chill down system
- Gas nitrogen purge system
- 25μ filter for LOX and 40 μ for LN2 and LCH4
Cryogenic system

Delivery system

• Actuated valves, flow meters, pressure transducers and temperature diodes
• Pressure relief valves and ventilation system
Cryogenic system

Controls system

- Allow for remote operation and monitor the delivery system
- Redundant capacity for diagnostics of critical parameters (temperature and pressure)
- Incorporate an auxiliary mode capable of controlling the feed system components without an electronic controller
- Incorporate an emergency procedure to abort any experimentation if the test article becomes a hazard
- Record all the data generated by the sensors and the transducers

<table>
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<tr>
<th>System</th>
<th>Classification</th>
<th>Hardware</th>
<th>Electrical Requirements</th>
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<tbody>
<tr>
<td>Cryogenic Feed System</td>
<td>Control</td>
<td>10 Solenoid valves</td>
<td>Excitation: 120 V AC</td>
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<td>2 Pressure transducers</td>
<td>Excitation: 10 VDC</td>
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<td>2 Cryogenic Temperature sensors</td>
<td>Output: 0-30 mV</td>
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<td>2 Cryogenic Flow meters</td>
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<tr>
<td>Multipurpose Optically Accessible Combustor</td>
<td>Measurement</td>
<td>1 Pressure transducer</td>
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<td>2 Thermocouples</td>
<td>Output: 0-30 mV</td>
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<td>2 Gas Flow meters</td>
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<tr>
<td>Multipurpose Altitude Simulation System</td>
<td>Measurement</td>
<td>2 Pressure transducers</td>
<td>Excitation: 12 VDC</td>
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<tr>
<td></td>
<td></td>
<td>1 Pirani Vacuum Gage</td>
<td>Output: 0-5 V</td>
</tr>
<tr>
<td>Torch Igniter</td>
<td>Control</td>
<td>2 Solenoid valves</td>
<td>Excitation: 24 V DC</td>
</tr>
<tr>
<td>Spark Exciter</td>
<td>Measurement</td>
<td>2 Gas Flow meters</td>
<td>Excitation: 12 VDC</td>
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<tr>
<td></td>
<td>Control</td>
<td>1 Voltage Transformer</td>
<td>Power: 12 VDC</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>Output Control: 5 VDC</td>
</tr>
</tbody>
</table>
Cryogenic system

Controls system

- Back Up power supply (30 minutes)
- Industrial computer with 2 hard drives of 500 GB
- 16 relay output channels
- 24 analog input channels
- Expandable to 12 PCI cards
- Modular patch panels
- Controlled via LabVIEW GUI
Cryogenic system

Controls system

Cryogenic Fuel Feed System

Torch Ignition System

cSETR Goddard Laboratory Bunker Instrumentation and Controls - Cryogenic Delivery System

Auxiliary Controls

SV Output

LV Output
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Safety Considerations

Cryogenics’ Potential hazards

• Physiological
  – Frostbite, asphyxiation, hypothermia, death

• Over pressure

• Materials and components damage

• Fire and Explosions
  – LOX systems
Safety Considerations

Safe operation

- Remote testing
- Projectile-proof bunker
- Cryogenics training
- PPE
- Written procedures and hazards analysis
- Dry runs
- Testing with supervision
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Testing

- All testing is performed remotely from a control room
- A minimum of 3 personnel is required, a test director, a test operator and a safety operator
- Pre-test is conducted in three major phases. Functional testing, pressure testing, propellant line fill
- Operability and delivery are in expected performance
- The system has been pressure tested at a maximum pressure of 344 kPa (50PSI) using gas Nitrogen and 206 kPa (30 PSI) on a gas Oxygen/Methane test
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Conclusions

• A propulsion research system has been built and developed at the cSETR facilities at UTEP
• Produces up to 2L Liquid Methane
• Remotely tested gaseous fuels (Oxygen/Methane)
• Ambient and altitude testing (up to 85000 ft) capabilities
• Steady State and pulsing operation of 100 N class thrusters
• Strict safety policies to ensure personal wellness and facilities integrity
Conclusions and Future Work

Future Work

• Future testing includes chilled methane/Gas Oxygen, gas methane/LOX and finally LCH4/LOX
• Future condenser to operate at high pressures (1 Mpa – 145 PSI), produce 25L and collect the generated data
• Perform a non dimensional analysis to compare condensers’ design and performance, characterizing the process with a non dimensional parameter
Questions?