Cryogenic Propulsion for the Titan Orbiter Polar Surveyor

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Cryogenic Propulsion for Planetary Science Missions

- Why is liquid hydrogen (LH2) useful?
- LH2+LO2 Storage
- Subcooling Technique
  - Thermodynamic Cryogen Subcooler (TCS)
  - Launch Pad Cryocoolers
- Current Work
  - Missions of Interest: Any mission that requires high ΔV and high delivered and high returned mass to and from planets, moons, asteroids, comets with lower spacecraft wet mass.
  - Examples:
    - Titan Orbital Polar Surveyor (TOPS)
    - Europa or Enceladus Missions
    - Lunar Sample Return Mission
    - Comet and Asteroid Missions
  - Hardware: Subcooling using launchpad cryocooler demonstration
- Roadmap
- Summary
Why LH2+LO2 vs Hypergols (MMH+NTO)

- LH2+LO2 provides the highest specific impulse of any practical chemical propulsion system.
- For the TOPS Mission this means a 44% reduction in launched mass. This mission can be completed using an Atlas Launch Vehicle using LH2+LO2 but not with MMH+NTO.
- LH2+LO2 can enable missions that deliver/recover substantially larger masses to/from the target destinations, or launch the mission on smaller and cheaper launch vehicles, or both.
- LH2+LO2 can be also be used to reach the surfaces of atmosphere less planetary bodies without exposing the target bodies to hazardous and toxic hypergols, *eg. Europa or Enceladus*.
- If required the LH2+LO2 could also provide an alternative to heavier batteries with the use of fuel cells, *eg. shadowed regions of the moon.*
TOPS Launch Vehicle Performance

<table>
<thead>
<tr>
<th></th>
<th>LH2+LO2 - HGA</th>
<th>MMH+NTO - HGA</th>
<th>LH2+LO2 - LaserComm</th>
<th>MMH+NTO - LaserComm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Delta - V</td>
<td>5887</td>
<td>5887</td>
<td>5887</td>
<td>5887</td>
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<tr>
<td>Dry Mass - Nominal [Kg]</td>
<td>739</td>
<td>878</td>
<td>739</td>
<td>878</td>
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<tr>
<td>Dry Mass - With Variable Dry Mass Contingency [Kg]</td>
<td>880</td>
<td>1053</td>
<td>880</td>
<td>1053</td>
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<tr>
<td>Launch Mass with Variable Dry Mass Contingency [Kg]</td>
<td>3174</td>
<td>5587</td>
<td>2947</td>
<td>5266</td>
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<tr>
<td>AV 431 - Separated Launch Limit [Kg]</td>
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<td>2827</td>
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<tr>
<td>AV 431 - Separated Launch Mass Margin [%]</td>
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<td>-49</td>
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<td>-46</td>
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<tr>
<td>AV 541 - Separated Launch Limit [Kg]</td>
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<td>AV 541 - Separated Launch Mass Margin [%]</td>
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<td>-44</td>
<td>5</td>
<td>-41</td>
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<tr>
<td>AV 551 - Separated Launch Limit [Kg]</td>
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<td>AV 551 - Separated Launch Mass Margin [%]</td>
<td>8</td>
<td>-39</td>
<td>16</td>
<td>-35</td>
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</table>

Includes a 25% Dry Mass Margin
Combination of Smart Cryogenic Design with Subcooling and Lowering Solar Flux (artificially and naturally) allows long term storage of LH2+LO2 for Planetary Science propulsion
Pre-Launch Isobaric Subcooling for Storage

- **Objective**: Delay venting of the cryogen as long as possible.
- **Fluid Conditioning**
  - Engine Start Box High End (SBHE)
  - Fluid at Normal Boiling Point (N)
  - Isobaric Subcooling (B)
    - Proposed fluid conditioning method
- **Physics**
  - Substantially lower heat flux in-space than in-atmosphere exploited or enhanced
    - Dominant in-space load < 0.25 W/m²
    - Dominant in-atmosphere load > 63 W/m²
  - Available heat capacity of the stored cryogen - Unexploited
    - Heat Capacity from N to SBHE = 18.2 KJ/Kg
    - Heat Capacity from B (@ T=16 K) to SBHE = 55.0 KJ/Kg
  - Isobaric Subcooling to 16 K allows hydrogen to absorb ~ 3x the energy before venting has to be initiated => hold time before venting for isobaric subcooling is ~ 3x
- **RL-10s operated with densified hydrogen**
- **Other Engines would have to be qualified**

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Subcooling Demonstration

Vacuum Shell simulating load responsive MLI to be used for TRL 6-7 Demonstrations

Cryogen Tank
TRL 5: LN2
TRL 6: LNe
TRL 7: LH2

Fill/Vent Lines

G10 Isolator

Transfer Lines

Subcooling Dewar
And Cryocooler
490 N LH2+LO2 Engine

Joint GSFC+MSFC Development Effort
Roadmap
Summary: Cryogenic Propulsion for Planetary Science Missions

- Cryogenic LH2+LO2 Propulsion provides high specific impulse chemical propulsion for planetary science exploration.
- Provide high ΔV and high delivered and high returned mass to and from planets, moons, asteroids, comets with lower spacecraft wet mass.
- For the TOPS mission, subcooled LH2+LO2 reduces launched spacecraft mass by 43% and allows for launch on an Atlas launch vehicle. The same mission cannot be performed using a MMH+NTO propulsion and an Atlas launch vehicle.
- Subcooling cryogenic propellants on the launch pad enables multi-year storage of LH2+LO2 without adding launched mass for LH2+LO2 storage.