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 Misson
  - 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>
<td>2827</td>
<td>2827</td>
</tr>
<tr>
<td>AV 431 - Separated Launch Mass Margin [%]</td>
<td>-11</td>
<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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<tr>
<td>AV 541 - Separated Launch Mass Margin [%]</td>
<td>-2</td>
<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>3430</td>
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<tr>
<td>AV 551 - Separated Launch Mass Margin [%]</td>
<td>8</td>
<td>-39</td>
<td>16</td>
<td>-35</td>
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</tbody>
</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

Pre-launch Subcooling using launch pad subcoolers or a thermodynamic cryogen subcooler
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

8/20/2015
490 N LH2+LO2 Engine

Joint GSFC+MSFC Development Effort
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.