

Cryogenic Propulsion for the Titan Orbiter Polar Surveyor



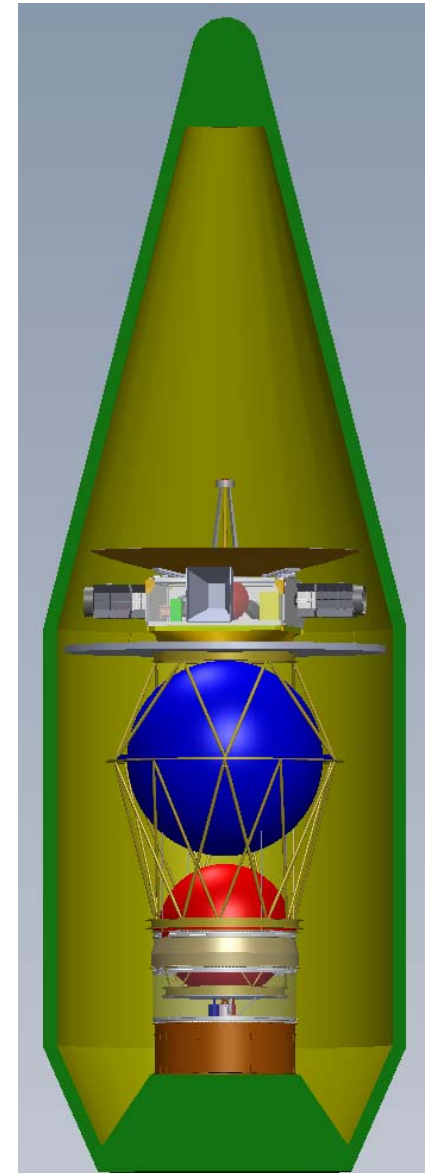
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Cryogenic Propulsion for Planetary Science Missions

- 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

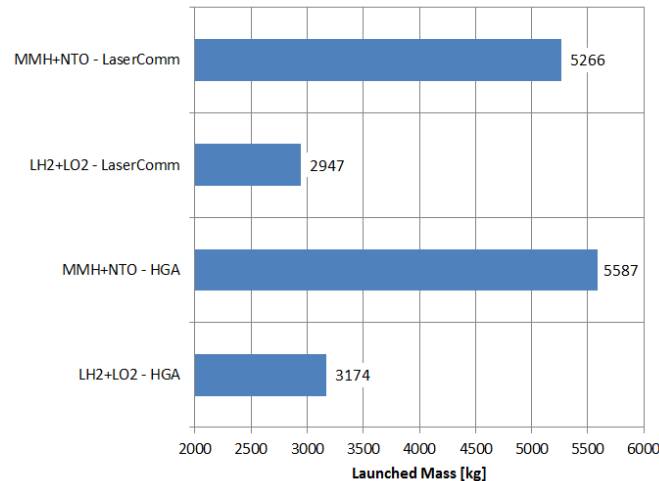




Why LH2+LO2 vs Hypergols (MMH+NTO)



TOPS Launched Mass - Various Configurations



- **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 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.*

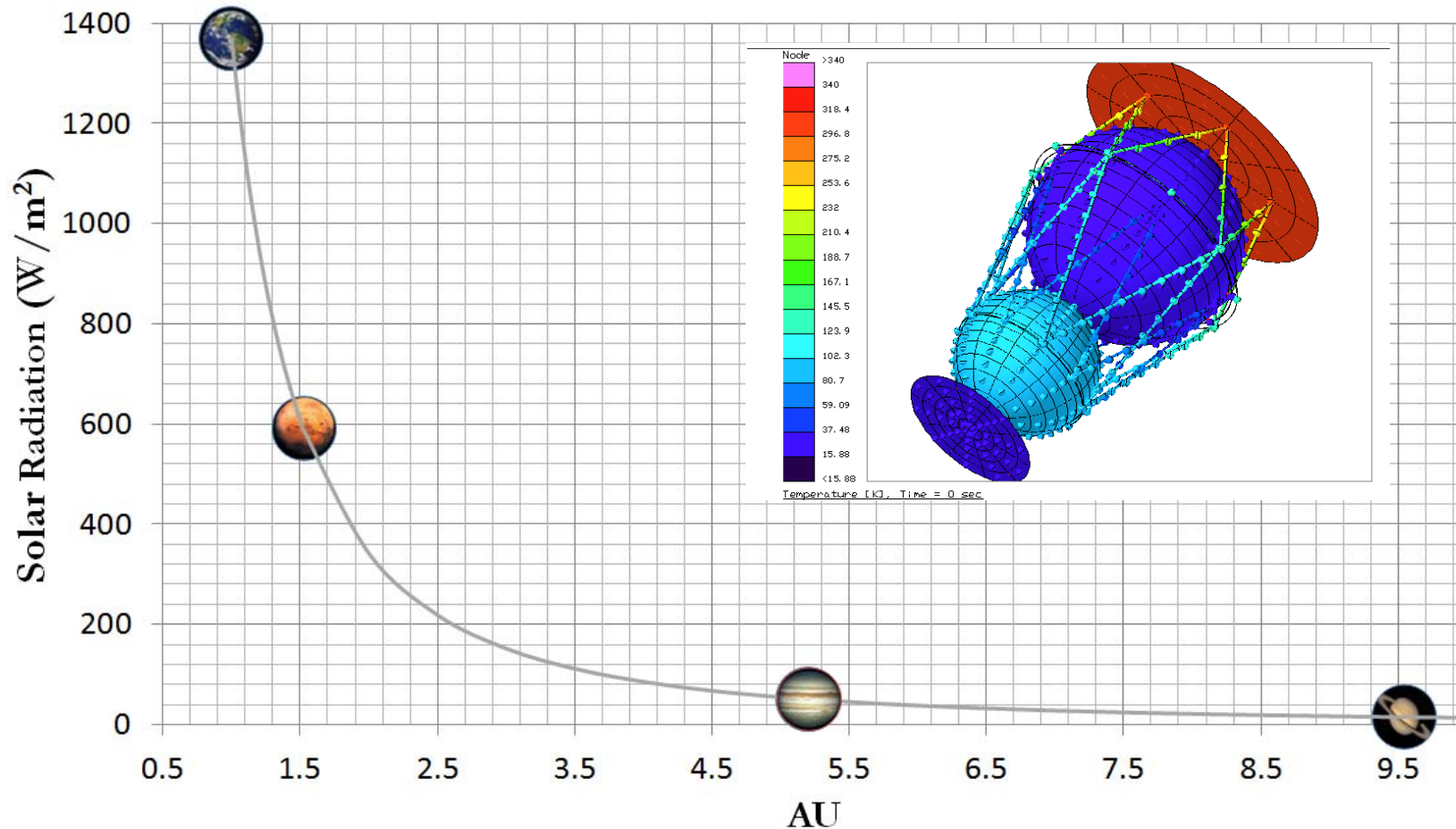


TOPS Launch Vehicle Performance

	LH2+LO2 - HGA	MMH+NTO - HGA	LH2+LO2 - LaserComm	MMH+NTO - LaserComm
Total Delta - V	5887	5887	5887	5887
Dry Mass - Nominal [Kg]	739	878	739	878
Dry Mass - With Variable Dry Mass Contingency [Kg]	880	1053	880	1053
Launch Mass with Variable Dry Mass Contingency [Kg]	3174	5587	2947	5266
AV 431 - Separated Launch Limit [Kg]	2827	2827	2827	2827
AV 431 - Separated Launch Mass Margin [%]	-11	-49	-4	-46
AV 541 - Separated Launch Limit [Kg]	3105	3105	3105	3105
AV 541 - Separated Launch Mass Margin [%]	-2	-44	5	-41
AV 551 - Separated Launch Limit [Kg]	3430	3430	3430	3430
AV 551 - Separated Launch Mass Margin [%]	8	-39	16	-35

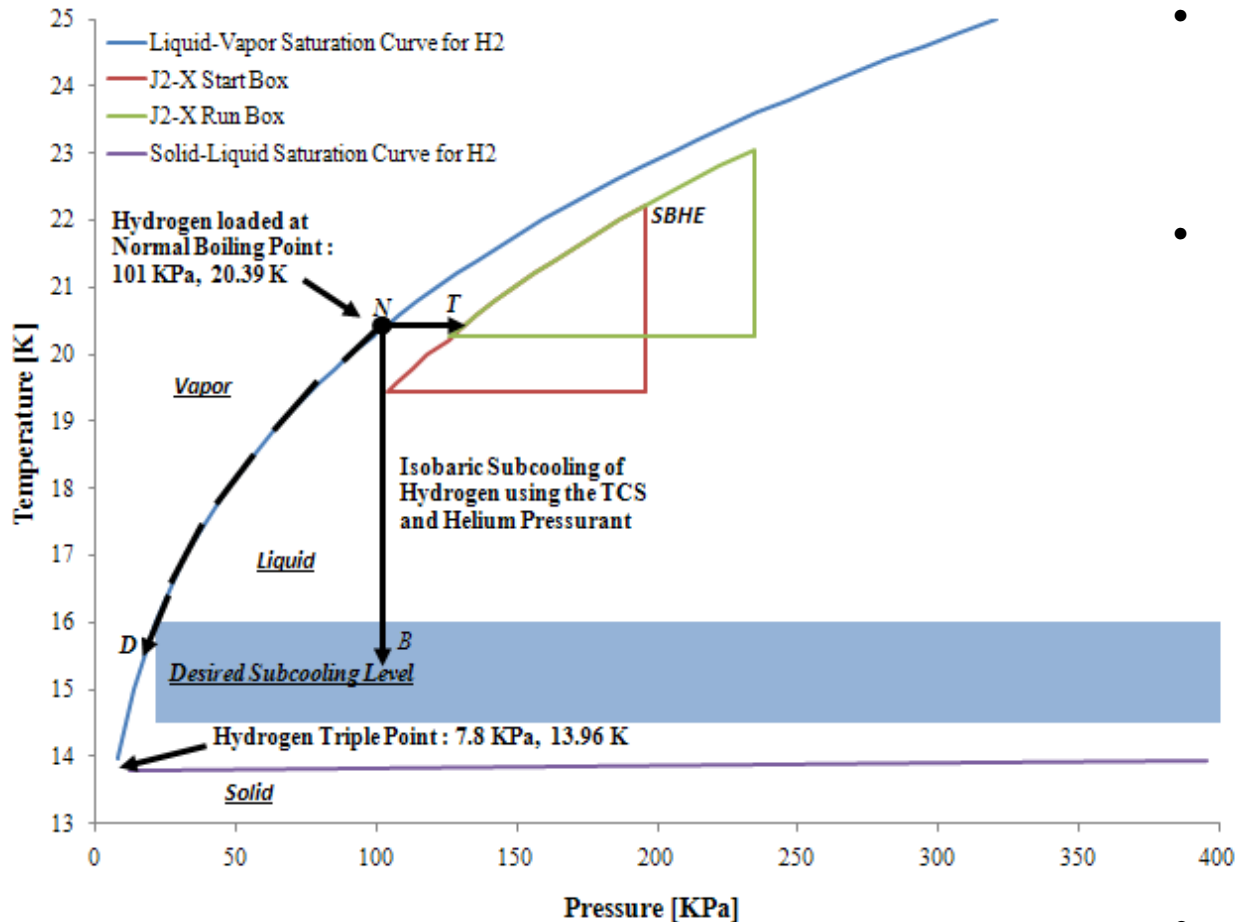
Includes a 25% Dry Mass Margin

LH2+LO2 Storage



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

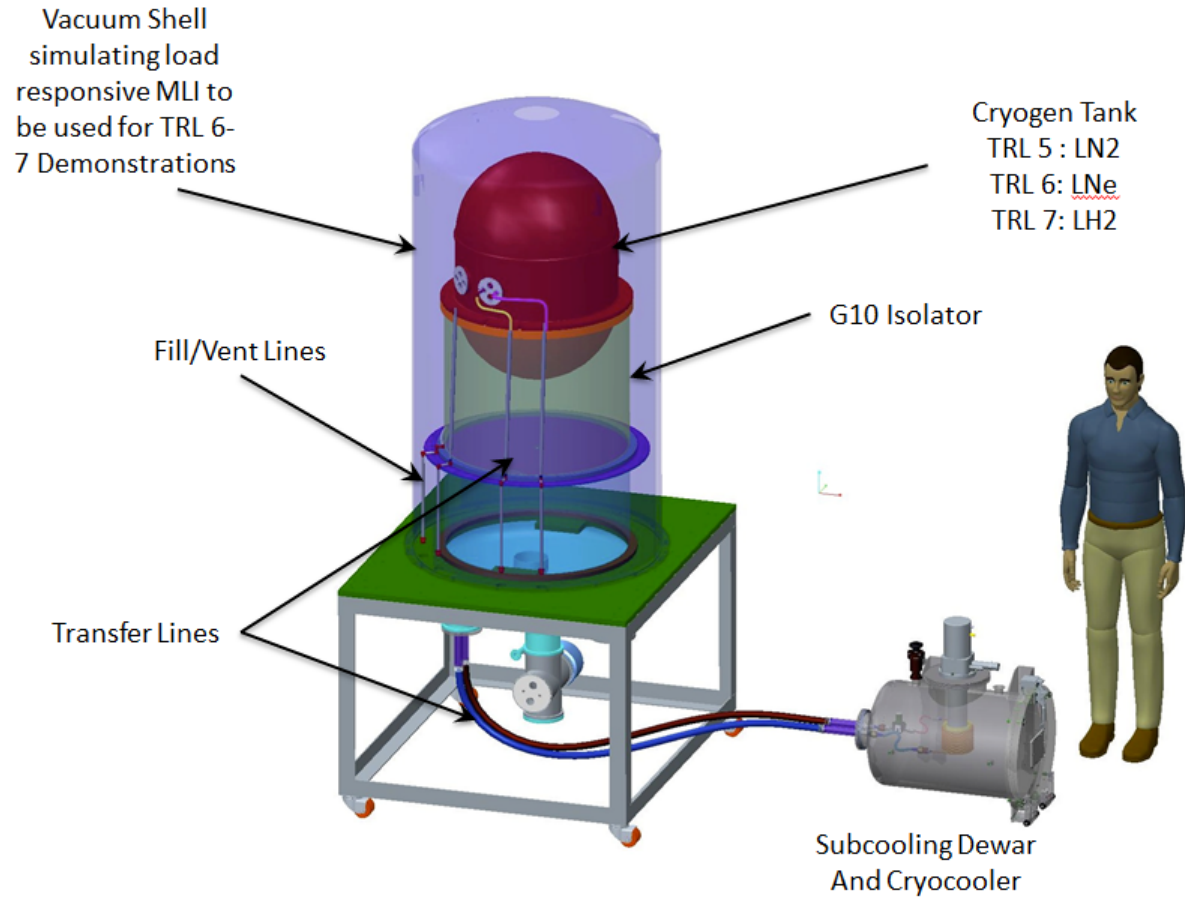
Pre-Launch Isobaric Subcooling for Storage



- RL-10s operated with densified hydrogen
- Other Engines would have to be qualified

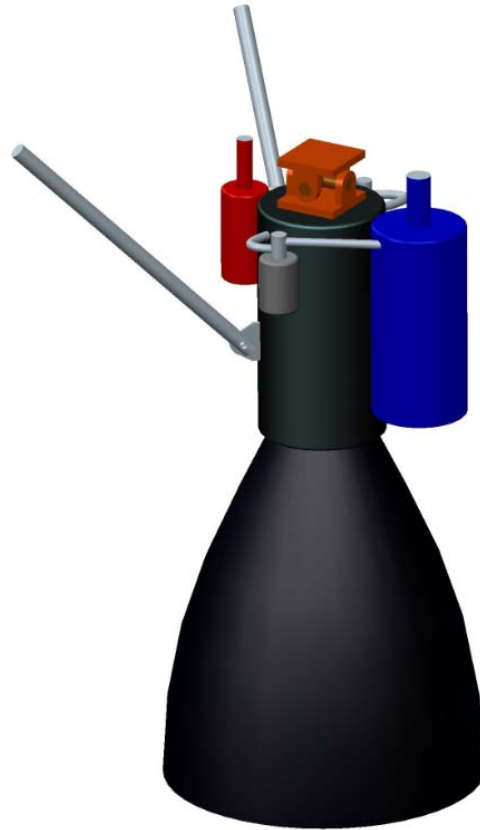
- **Objective:** Delay venting of the cryogen as long as possible.
- **Fluid Conditioning**
 - Engine Start Box High End (SBHE)
 - Fluid at Normal Boiling Point (N)
 - Isobaric Subcooling (B)
 - Proposed fluid conditioning method
- **Physics**
 - Substantially lower heat flux in-space than in-atmosphere 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
- Pre-launch Subcooling using launch pad subcoolers or a thermodynamic cryogen subcooler

Subcooling Demonstration



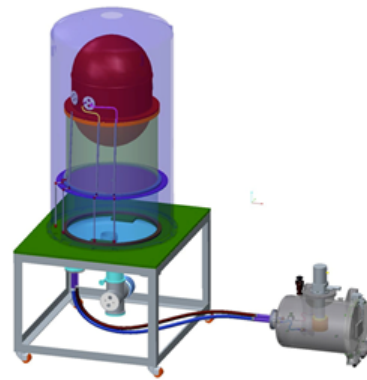


490 N LH2+LO2 Engine

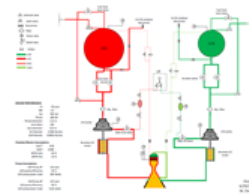


JOINT GSFC+MSFC Development Effort

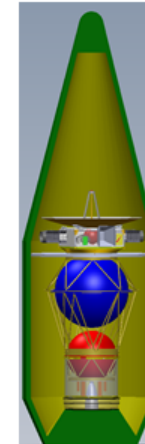
Roadmap



2015: TRL 5



2017: TRL 6



2022: TRL 9

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

