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A SysML Trade Study of a Large-Scale Liquid Hydrogen Storage Tank with Zero Boiloff

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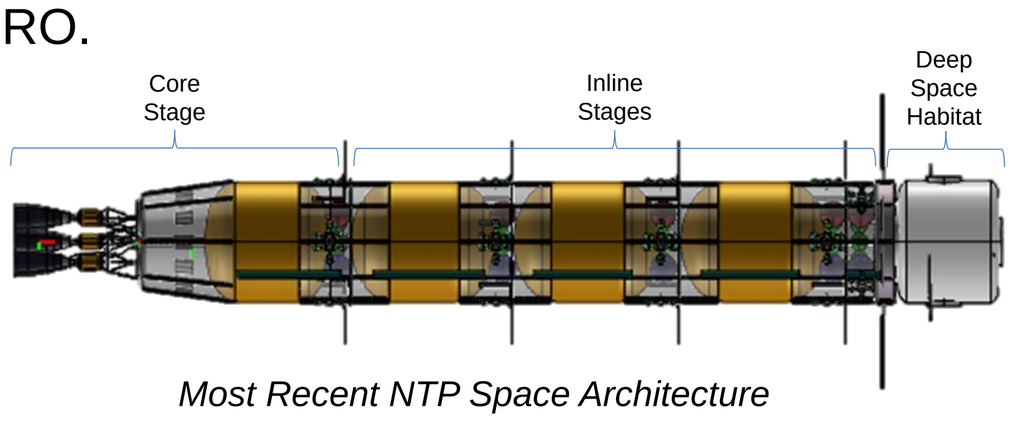
Introduction

NASA is designing a Nuclear Thermal Propulsion (NTP) space architecture using liquid hydrogen (LH_2) propellant that is capable of high thrust and ISP, but the LH_2 must be stored at 20K at 1atm to stay liquid. NASA has achieved zero boiloff conditions for a 18m^3 tank of LH_2 on Earth but is it possible in a Near Rectilinear Halo Orbit (NRHO) in space?

Objective

Mass is the largest driving cost of space travel. A significant amount of mass will have to be allocated to the thermal control system to ensure the hydrogen stays liquid. Cryocoolers scale differently depending on the thermodynamic cycle. Three types of cryocoolers will be compared when looking at a scaled up NTP inline LH_2 propellant tank in NRO.

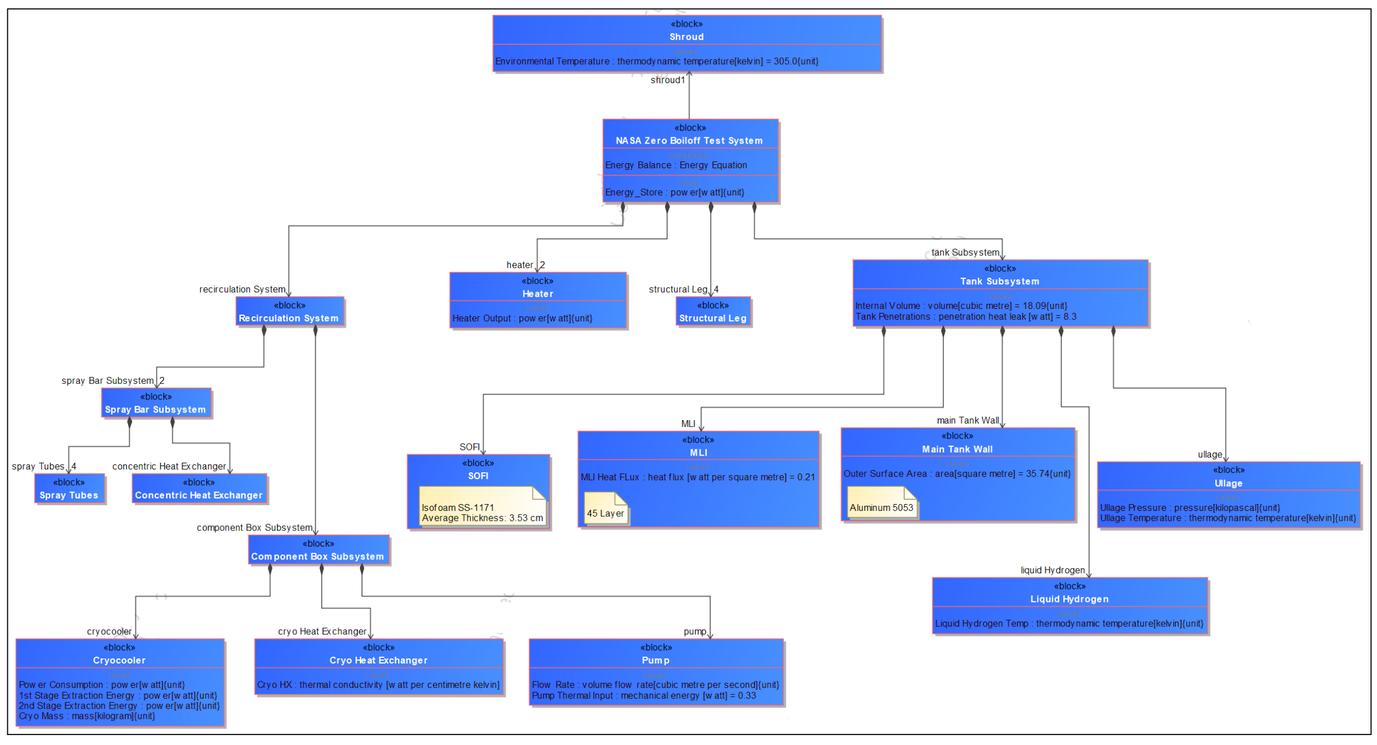


Most Recent NTP Space Architecture

Methodology

Systems Modeling Language (SysML) and MATLAB was used to model NASA's zero boiloff experiment[2]. Values from the test are plugged into the model and then scaled up to a 278m^3 tank. An environmental hot case at NRHO yielded the follow values:

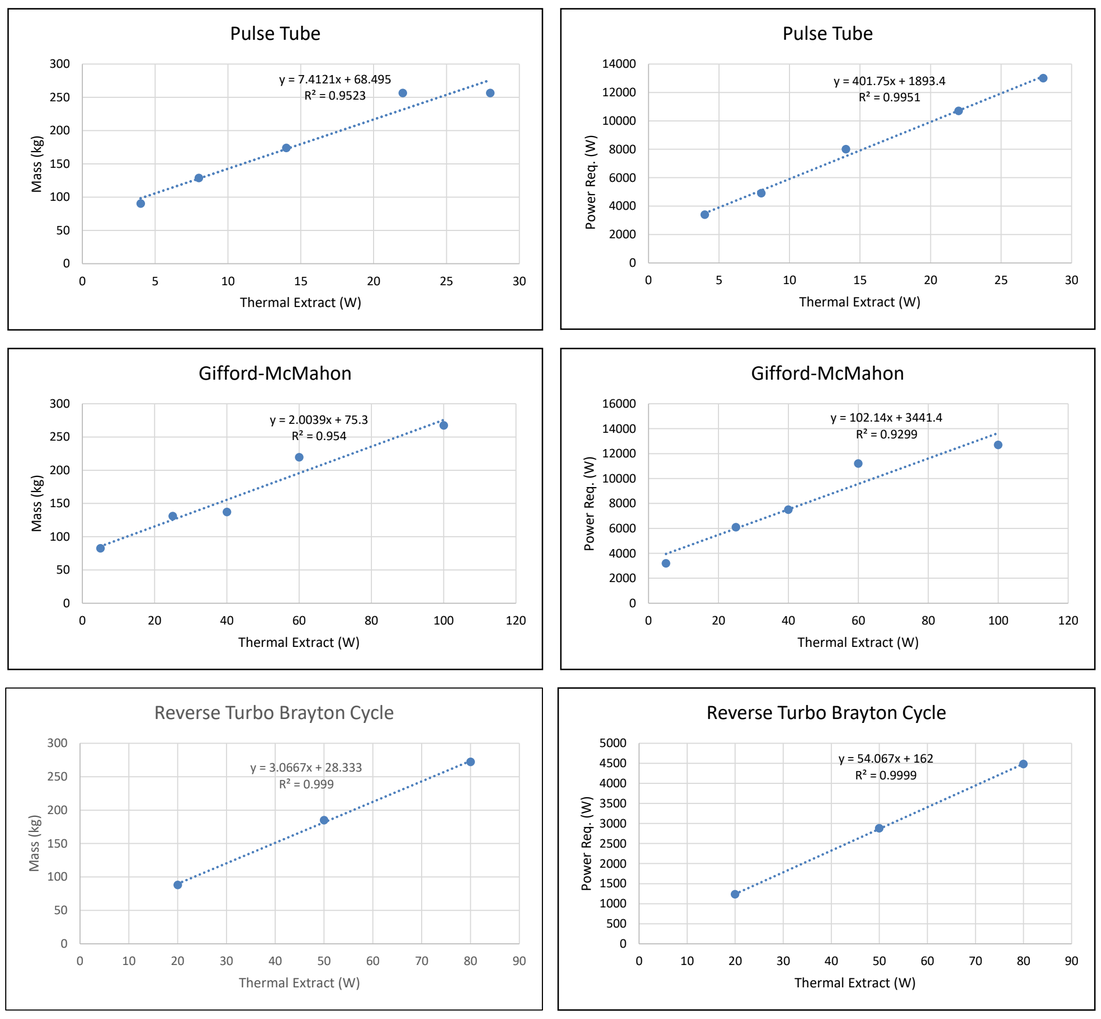
	Earth	Moon	Sun
Inferred Radiation	0.0317 W	127 W	
Planetary Albedo	0.0676 W	41.3 W	
Direct Solar			590 W
Total	0.0993 W	168.3 W	758.4 W



Block Definition Diagram of multipurpose hydrogen test bed in SysML

Results

The heat leak from the scaled up tank increased from 26.5W to 758.4W. Given the data below, the Gifford McMahon (GM) proved more mass efficient than the Pulse Tube (PT) and Reverse Brayton (RTBC) with masses of 1595kg, 2354kg and 5690kg respectfully. However, RTBC is most appealing when power required is factored in. RTBC, GM and PT require 41kW, 81kW and 306kW respectively.



Reverse Turbo Brayton Cycle, Gifford McMahon and Pulse Tube cryocooler mass & power required as a function of thermal extract[1].

Path Forward

Radiators, broad area cooling and reactor outputs are the next steps for creating a higher fidelity NTP zero boiloff model.

Acknowledgements

Thanks to Dr. Dale Thomas for direction and guidance on this work.

Ref[1]: ***World Leaders in Cryorefrigeration. (n.d.). Retrieved August, 2018, from http://www.cryomech.com/***

Ref[2]: ***Hastings, L. J., Bryant, C. B., Flachbart, R. H., Holt, K. A., Johnson, E., Hedayat, A., . . . Plachta, D. W. (2010). Large-Scale Demonstration of Liquid Hydrogen Storage With Zero Boiloff for In-Space Applications.***

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NASA