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M1Or4B-06: Composite cryogenic hydrogen insulated lightweight lined storage (C-CHILL)

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The Composite Cryogenic Hydrogen Insulated Lined (C-CHILL) Storage System, developed by Dynovas, addresses the need for advanced reusable liquid hydrogen storage. The C-CHILL system is engineered to support spacecraft, surface systems, and hydrogen aircraft requiring long-duration cryogenic hydrogen storage. Leveraging a Type IV composite overwrapped pressure vessel (COPV) with a carbon fiber vacuum jacket, the C-CHILL system provides a 25%-60% weight reduction compared to traditional metallic tanks.

The design of the C-CHILL system focuses on material selection for the 3 main components of a Type IV COPV: composite overwrap, port boss, and permeation liner. The main technical challenges are the compatibility between these components at cryogenic temperatures, differences in thermal strain between unlike materials, tank permeability to LH2, and bond strength under cryogenic conditions between sealing surfaces. To address these issues, a carbon nano tube (CNT) resin has been selected to reduce the effects of microcracking in the carbon fiber filament wound overwrap. This additive is expected to increase the durability of the composite overwrap to the LH2 environment. The use of a carbon fiber overwrap necessitates careful material selection for the port boss and liner because the difference in thermal strain between components needs to be minimized. After evaluating more traditional tank metals like 300 series stainless steel and aluminum alloys, invar was selected as the boss material for its high dimensional stability because it negates any concerns of the port boss "shrinking"during temperature differentials. Liner material selection requires it to have a low CTE, low LH2 permeability, a high bond strength under cryogenic conditions, and it must be compatible with rotational molding, Dynovas's liner manufacturing method of choice. Based on these requirements, polyetheretherketone (PEEK) was found to be the best suited liner material because it has the lowest CTE of the low hydrogen permeability, roto-moldable materials. It also has superior mechanical properties compared to similar inert plastics and has a legacy of use with cryogenic hydrogen. Dynovas has conducted permeability testing and lap shear tests to confirm viability of PEEK as a liner material. Dynovas'next phase of prototyping focuses on manufacturing PEEK liners and winding prototype articles for the upcoming full-scale burst tests.

The C-CHILL system is currently at TRL 4, and Dynovas plans to demonstrate TRL 6 in 2025, with a goals that include:
1. Optimize Hydrogen Compatibility: Engineer a storage system specifically designed for liquid hydrogen compatibility, addressing all challenges presented from the LH2 environment.
2. Reduce Parasitic Permeation: Limit hydrogen permeation rates to less than $1x10^{-3}$ sccm/m^2, ensuring compliance with NASA's leakage requirements for long-duration missions.
3. Demonstrate Thermal and Pressure Cycle Durability: Demonstrate the system's ability to survive over 10,000 thermal cycles between 20°K and 327°K and more than 5,000 pressure cycles at cryogenic temperatures under an operating range of 150-300 psi.
4. Validate Vacuum Insulation Stability: Develop a vacuum insulation layer capable of maintaining pressures below 10 millitorr for extended durations, with rapid re-evacuation in under 1 hour to ensure operational reliability.
5. Showcase Scalability: Provide a modular system for diverse cryogenic applications, supporting storage sizes from current 20 L prototypes to planned production models of 100 L, 700 L, and 1400 L tanks.

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