CYPRESS

CrYogenic Performance REfueling Safety System

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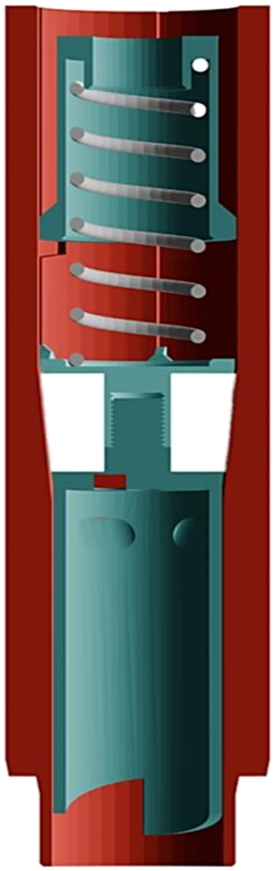


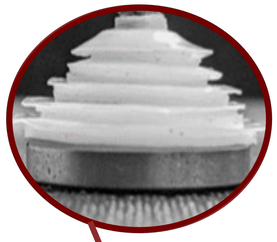
LH2 Transfer for Artemis

The repeatable, quick, safe transfer of liquid hydrogen in terrestrial, lunar, and cis-lunar environments is critical to the success of the Artemis missions. Current LH2 couplers require extensive purging, are cumbersome to handle, and cost prohibitive.

By combining cryogenically conformable polymer gaskets with 3D printed metal alloys, we can create a coupler that enables purge-less connecting and disconnecting of LH2 transfer lines at reduced weight and cost.

Conformable Cold Seals

Plug seals formed by stacking PTFE discs and spacer rings create a multi-surface seal that conforms to the valve seat at 20K.



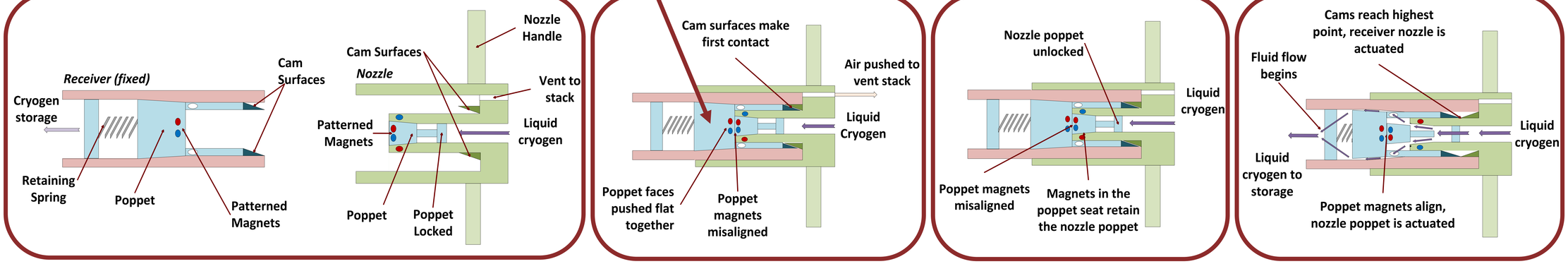
Initial testing in pressure relief valves showed minimal leakage after contamination with foreign object debris [3].

Anti-Icing Design

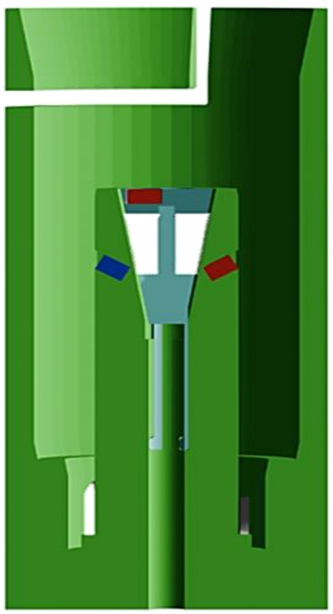
Al6061-RAM2 has a thermal conductivity of 7.5 W/m-K at 20 K, like SS304, but with only 1/3 the density—cutting component weight by 60% and chill-in cryogen losses by 30% [1][2].

Additive manufacturing enables complex designs without machining costs [5]. Vacuum jacketing and thermal standoffs limit heat leak to ~7.8 W per component, comparable to bayonet couplers at 8.8 W [4].

Mechanical Schematic



(1) Uncoupled | **(2) Operator Slides Nozzle Over Receiver** | **(3) Operator Begins Rotation of Nozzle** | **(4) Haptic Feedback Indicates Complete rotation** | **(5) Coupled**



Inherent Safety Features

Nozzle locking mechanism redundantly retains nozzle poppet while uncoupled to ensure fluid flow only begins during proper coupling.

Paired cam surfaces and patterned magnets actuate poppets only in the presence of the corresponding CYPRESS component to inhibit tampering and improper coupling.

Purge-Less Concept

Mechanical tolerancing ensures air is pushed out of the system during coupling, traveling to the vent stack through the vent lines. This creates a purge-less design for rapid transfer and system simplicity.

A purge feature for lunar dust mitigation utilizing the Leidenfrost dusting effect is possible.

Implementation Plan

Advancement through TRL 3 during HULC 2025.

TRL 4 achieved via LN2 testing in partnership with NASA Armstrong and Marshall Summer 2025.

Planned TRL 5 via LH2 testing at HYPER Center in partnership with DOE HYPER-Fuel project in 2026.

TRL 6-9 involving testing in space environment and flight testing in next two years.

Acknowledgements: NASA Armstrong & Marshall Centers

[1] M Shenton et al 2024 *IOP Conf. Ser.: Mater. Sci. Eng.* 1301 012171
[2] Ekin, Jack W. 2006 *Experimental Techniques for Low-Temperature Measurements: Cryostat Design, Material Properties, and Superconductor Critical-Current Testing* (New York: Oxford University Press)
[3] Wood, M, and J W Leachman 2024 *IOP Conf. Ser.: Mater. Sci. Eng.* 1301 012034
[4] Flynn T M 2005 *Cryogenic Engineering* (Boca Raton: CRC Press)
[5] Fedotowsky T M et al AL6061-RAM2 Development and Hot-Fire Testing using Additive Manufacturing Laser Powder Directed Energy Deposition for Liquid Rocket Engine Channel-Cooled Nozzles In: *AIAA SciTech Forum* 2024 doi: 10.2514/6.2024-0994