Cryogenic Orbital Siphoning System
CROSS

Faculty Advisor - Dr. Mohammed Alabsi

Vaishnavi Adusumilli | Mohamed Eladawy
Kyle Luis | Pierce Rubenstein

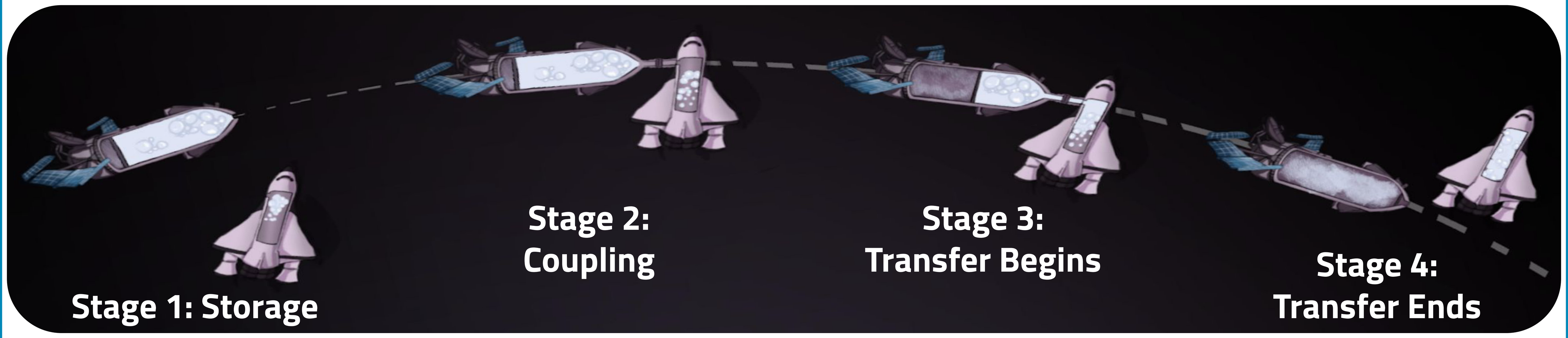
Objective and Solution

To perform the distributed launch mission structure for Artemis and future deep-space missions, it is critical to produce a reliable, low-loss, and low-complexity propellant storage and transfer system optimized for microgravity. While current propellant tanks primarily utilize passive liquid acquisition devices and helium pressurization methods, environmental differences and evolving needs have created a desire to explore new alternatives.

CROSS aims to reinvent the propellant storage tank by combining old ideas with a unique innovation.

- Controlled boil-off of cryogenic fuel provides pressure stabilization without the need for helium pressurant
- Piston within storage tank provides adjustable volume control for slosh reduction and prevents fuel contamination
- Autogenous pressurant ramping provides ample force to propel the piston for fuel transfer

Concept of Operations



Stage 1: Storage
- CROSS pre-pressurized before installation to payload vehicle
- Valve minimally opened for limited flow of propellant to CVAPS
- CROSS stays pressurized over time

Stage 2: Coupling
- Signals from the destination vessel are sent to the instrument system
- Automated couplers activate between destination vessel and CROSS

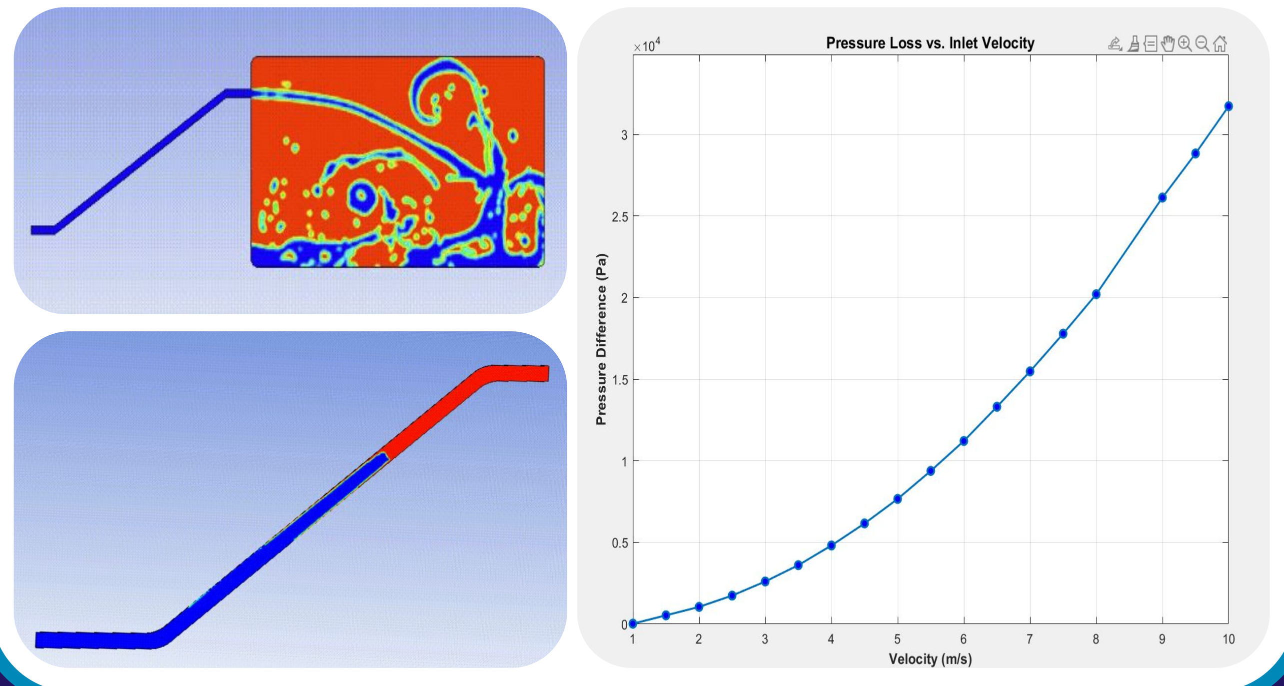
Stage 3: Transfer Begins
- Valve opens further to allow increased flow to CVAPS
- Increased rate of vaporization heightens gas pressure
- Piston begins to move in the direction of the exit point

Stage 4: Transfer Ends
- Pressure equalizes at the end of piston stroke
- CROSS is now filled with gas
- Destination vessel supply is now fully replenished
- CROSS disengages from destination vessel

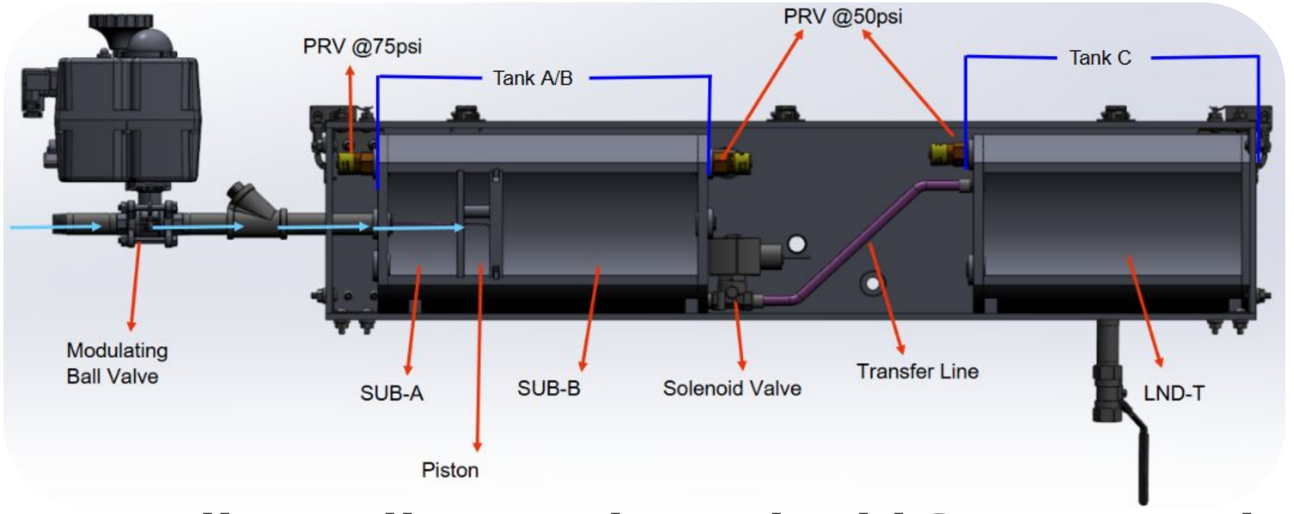
CROSS Simulation

PULSE Apparatus Verification
- Provide preliminary pressure differential readings
- Verify pressure loss effects on transfer speed
- Visualize transfer line fluid behavior
- Iterative simulations from ranging flow velocities

Fluid Behavior
- Turbulence modeled within destination tank
- Turbulent dissipation studied from flow simulation
- LN_2's, severely complex nature in simulation requiring severe parameter refinement



Experimental Validation



Propellant Ullage-Driven Liquid Storage and Expulsion (PULSE) Test Bench:

Pressure Differential Control Scheme
- Requires multiple pressure readings for comparison between tank compartments
- Gradual increase in pressure for LN_2 expulsion within adequate time frame

Pneumatic-Based Piston System
- Minimizes mechanical complexity
- Separates states of matter
- Reduced maintenance and risk of failure

PULSE Testing Goals
- Validate the CROSS design by demonstrating the viability of combining positive expulsion systems with autogenous pressurization methods
- Determination of experimental siphon ratio to better calculate theoretical CROSS expulsion efficiency

CROSS Design

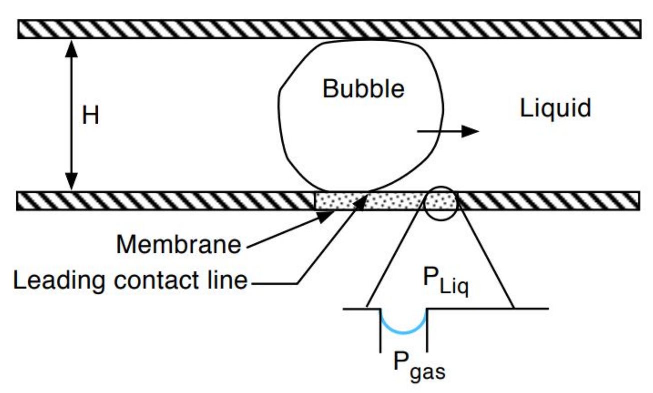
The Cryogenic Orbital Siphoning System utilizes a thermodynamic cycle to control boil-off within the storage tank, redirecting it to the other side of a piston to be used as a positive expulsion device. The key features include:

Expulsion Mechanism
- Pneumatic Pressure Control Piston
- Pressurization through Thermodynamic Cycling

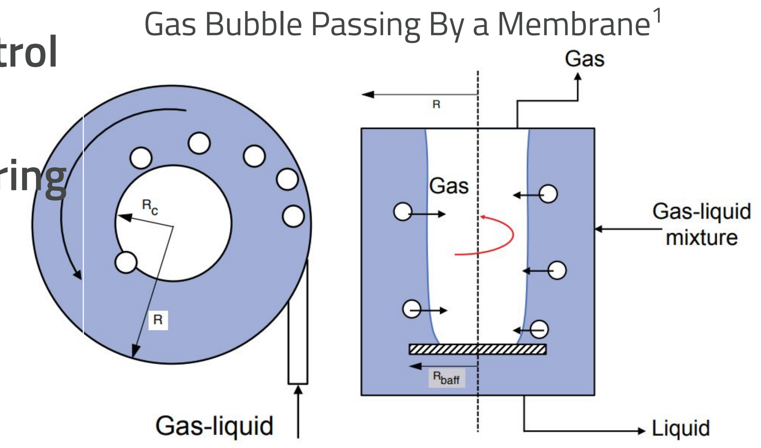
CVAPS Subsystem
- Heated Gradient Lines
- Heating Element For Vapor Saturation
- Single-Phase Compressor
- Expansion Tank For Pressure Storage

Phase Separation for Liquid Propellant Transfer
- Siphoning Loop to Isolate Phases
- Centrifugal Cyclonic Separator

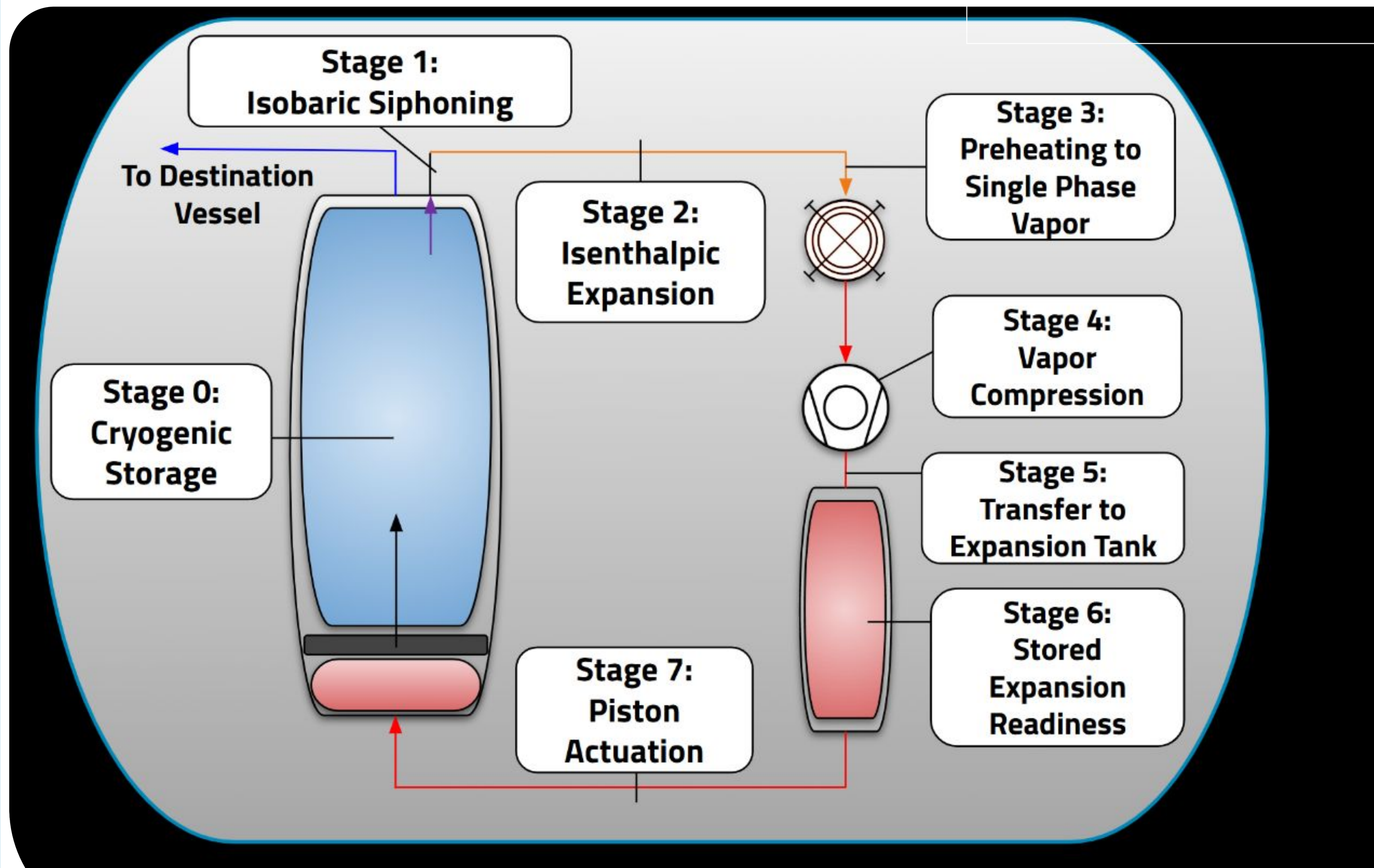
Automation and Feedback
- Pressure Sensing in Main Storage Units
- Automated Valve Control for System Response
- Maintains Boil-off During Storage
- Reduces Manual Intervention and Error



Gas Bubble Passing By a Membrane[1]

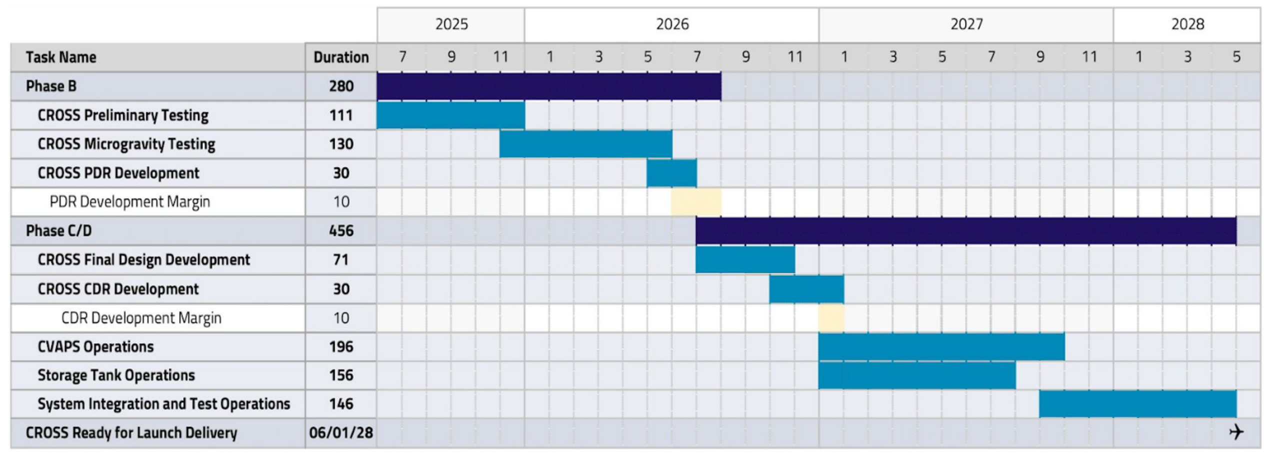


Schematic Of A Cyclonic Separator[1]



Pressure-Volume Relationships	
Stage 0	P_0, V_0
Stage 1	$P_1 < P_0, V_1$
Stage 2	$P_2 = P_1, V_1$ $\Delta h = 0$ (throttling)
Stage 3	$P_3 > P_4, V_3$
Stage 4	$P_4 V_4^{\gamma}$ = Constant $\gamma \sim 1.42$
Stage 5	$P_5 = P_4, V_5$
Stage 6	$P_6 < P_5, V_6 = V_5$
Stage 7	$P_7 < P_6, V_7$

Path to Flight



CROSS Mechanism Costs	Mechanical Subsystem	Electrical Subsystem	Thermal Subsystem	Software Subsystem
	$16,644,000	$151,000	$40,000	$17,000
Additional Costs	Wrap Costs	Facility Costs	PULSE-2 Costs	Employee Salaries
	$5,498,000	$5,056,000	$1,668,000	$19,800,000

Overall Totals	CROSS Mechanism	Mechanism + Testing	Full Adoption Costs
	$16,852,000	$27,405,000	$48,874,000
Inflation Adjusted Totals	$28,678,000	$46,638,000	$83,172,000

Acknowledgements and References

We would like to thank HuLC for their support of this project. We would also like to thank Dr. Anthony Lau and Dr. Ardeshir Tabrizi for their guidance and feedback.

This project was supported by the New Jersey Space Grant Consortium.

[1]Balasubramaniam, R., Ramé, E., & Motil, B. J. (2019). Microgravity liquid-gas two-phase flow: Review of pressure drop and heat transfer correlations and guidelines for equipment operability (NASA/TM–2019-220147). National Aeronautics and Space Administration. https://ntrs.nasa.gov/api/citations/20190001795/downloads/20190001795.pdf

[2]Megson, T. H. G. (2007). Aircraft structures for engineering students (4th ed.). Elsevier.

[3]National Aeronautics and Space Administration. (2005). External tank thermal protection system (NASA Fact Sheet). NASA Marshall Space Flight Center. https://www.nasa.gov/wp-content/uploads/2016/08/114022main_tps_fs.pdf