AggieSat Laboratory

Next-generation Cryogenic Transfer and Autonomous Refueling (NeCTAR)

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Project Manager: *Kamalika Bose (UG, MXET)*

Chief Engineer: *Thomas Lopez, B.S. (UG. ESET)*

06/25/25

Personnel

Thermals, Mechanics, and Structures
Lead: Kai Elmore, (G, AERO)
Ryan Chacko, (UG, AERO)
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Electrical Power Subsystem
Lead: Pallavi Gokul, (UG, CPEN)
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Command and Data Handling
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Dynamics
Lead: Gage Wallace, (UG, AERO)
Sri Dhriti Kuram, (UG, CHEN)
Jaret Pinkerton, (UG, MXET)
Siquan (Cindy) Qiu, (UG, AERO)

Key
UG -Undergraduate
G - Graduate

AERO - Aerospace Engineering
CHEN - Chemical Engineering
CPEN - Computer Engineering
CPSC - Computer Science
ECEN - Electrical Engineering
ENGR - General Engineering
ESET - Electronic Systems and Engineering Technologies
MEEN - Mechanical Engineering
MXET - Mechatronics Engineering

AggieSat Laboratory

- *"The AggieSat Laboratory Student Space Program trains university students in systems engineering through hands-on experience in the design, building, testing, and operation of space-related systems."*
- Largest student-led university satellite program in the country
- 8 simultaneous projects this year
- AggieSat6 – oldest project
- NeCTAR – youngest project

Presenting: *Kamalika Bose (Project Manager)*

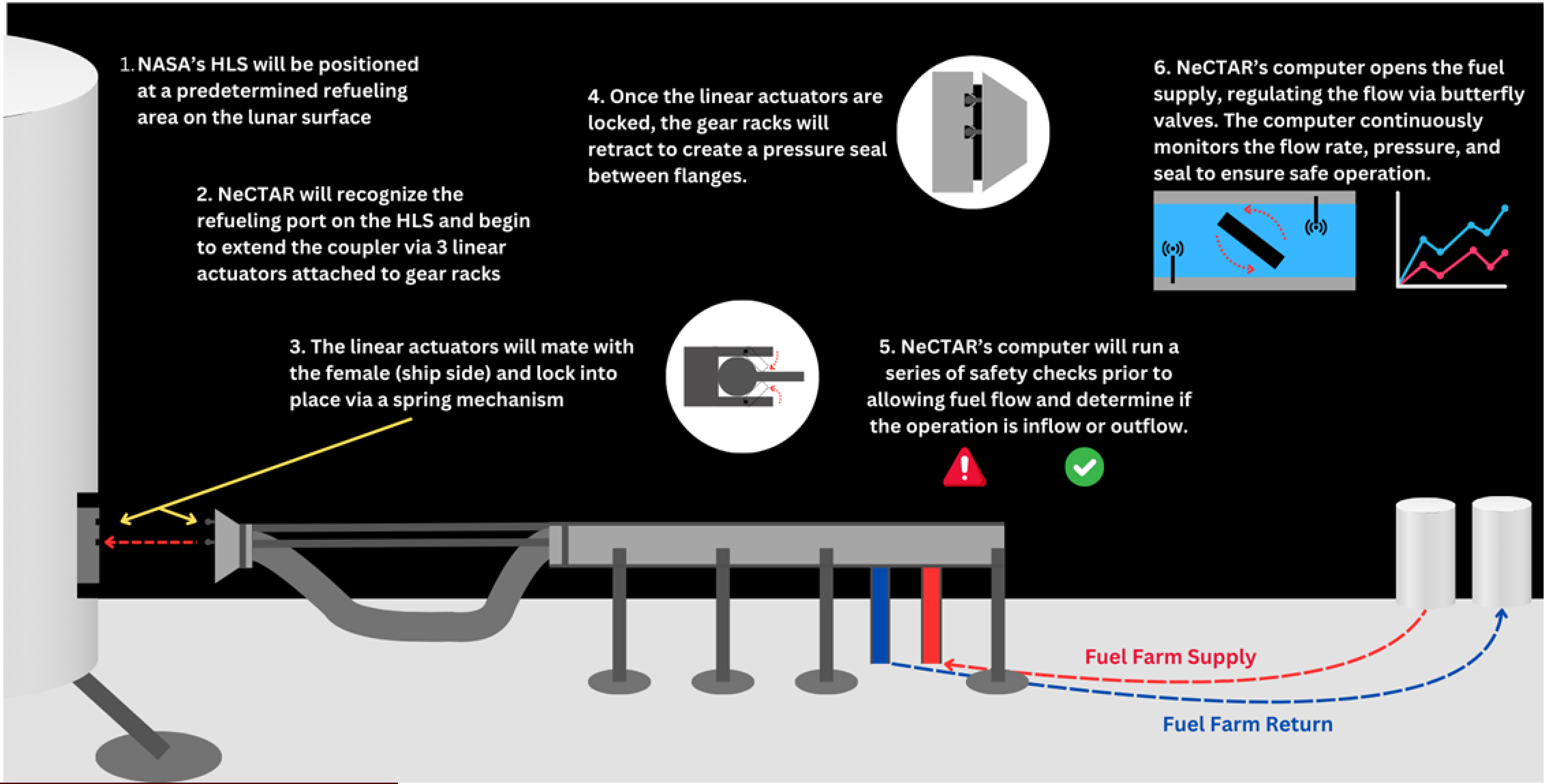
Cryogenic Refueling Challenges in Space

- Unstable fluid behavior
  - Cryogens form globules that disrupt steady flow
- Thermal and Material Stress
  - Brittleness, cracking, and vapor lock
- Contamination and Safety Risks
  - Leaks, pressure spikes, and residual gases
  - Potential issues heightened by regolith from PSI
- Current Limitations
  - Existing systems are poorly equipped for long-duration mission or autonomous operations

Presenting: *Kamalika Bose (Project Manager)*

NECTAR

CONCEPT OF OPERATIONS



Presenting: *Kamalika Bose (Project Manager)*

Thermal, Mechanics, and Structures (TMS)

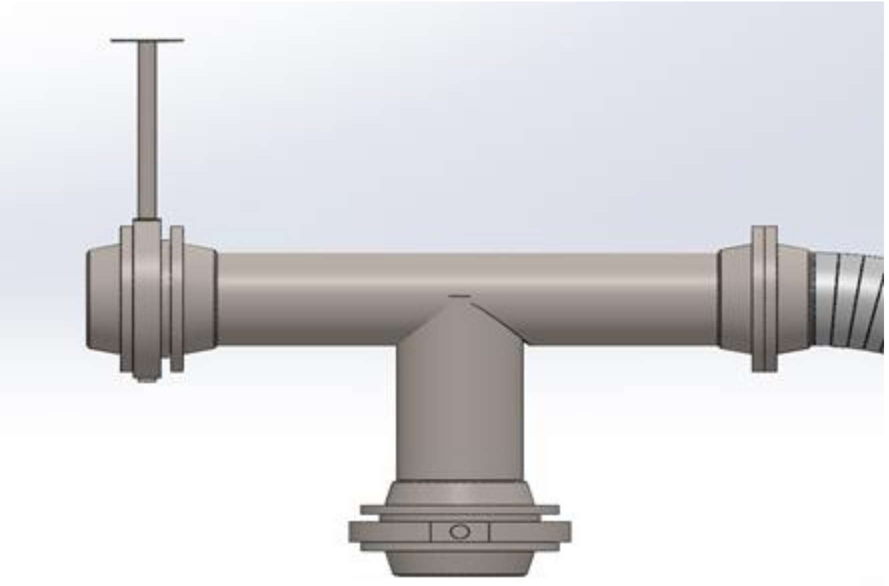
- Pipe–Coupler System
  - Main pipe: 316L, vacuum-jacketed
  - Anchoring: Dual brackets, floating standoffs
  - Flange: TZM, 37.5°, recessed 3.5 mm
  - Interface: Chamfered, self-aligning
  - Seal: Passive axial, spring-energized
  - Main seal: Dual PTFE/Elgiloy, cryo-rated
  - Sensors: TIG ports, cryo-isolated feeds

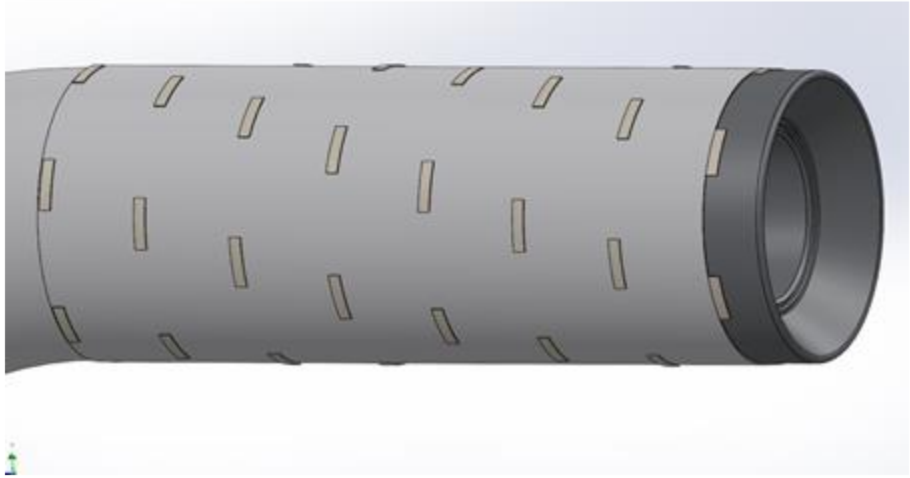
- Materials & Components
  - Pipe: Orbital-welded 316L
  - Flange: Ground TZM (<6.35 μm)
  - Seals: Spring-energized PTFE/Elgiloy, 10k+ cycles
  - Iris:
  - Hose: 316L braid, PCTFE-lined
  - Gears: Maraging Steel 18Ni-300, cryo-rated

Thermal, Mechanics, and Structures (TMS)

- Bidirectional Fluid Transfer
  - Mirrored flanges, dual-groove seals
  - ¼-turn cryo butterfly valves (Bray 2021)
  - Electric rotary drives, sequenced via CDH
  - FSM controls: fill, drain, purge
  - One valve open at a time (no overlap)
  - Check valves prevent backflow

- Dust Mitigation
  - Iris shutter covers seal face (NASA TP–20220018746)
  - YBCO Meissner layer (~8 mm repulsion)
  - Multi-layer encapsulation coating (SiO_2/parylene/alumina) (GCD–SCT–4158C)
  - 148 V electrostatic deflection rings
  - No exposed elastomers



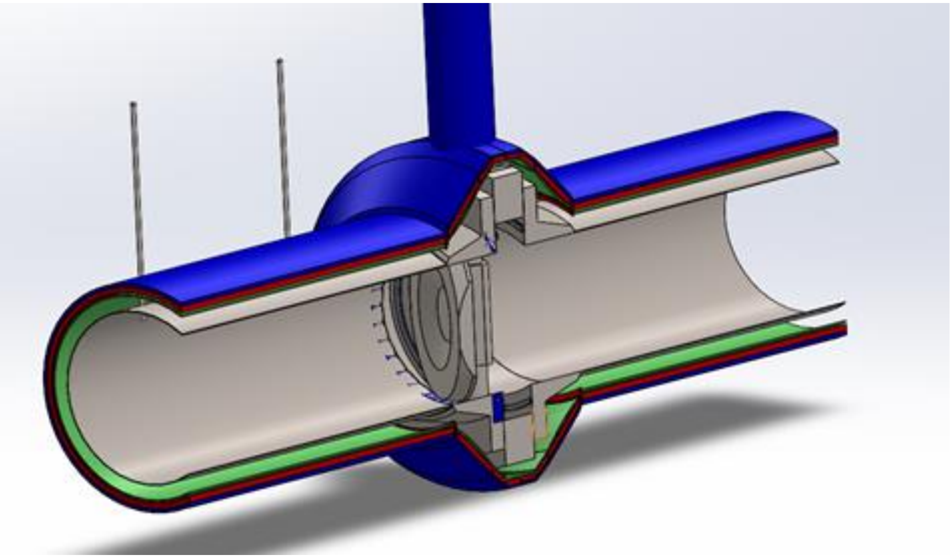


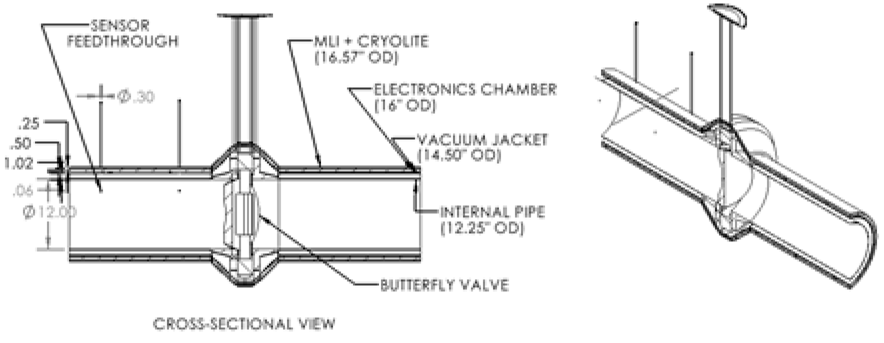
Presenting: *Ryan Chacko (TMS)*

Thermal, Mechanics, and Structures

- Actuation System
  - Triple rack-pinion (5.7 ft, >1565 lb-ft each)
  - Gears: Maraging Steel 18Ni-300 (NASA TM–20160009123)
  - Fatigue >620 MPa, 10^7+ cycles
  - Preload + limit switches = no backlash
  - CDH logs torque/drift; ML flags anomalies
  - Fully enclosed from regolith, thermal swings

- Overall Characteristics
  - PTFE/Elgiloy O-rings, spring-energized (NASA-STD-5017)
  - Operates –193 °C to +120 °C; bakeout 125 °C (ASTM E595)
  - MAWP 186 psi; burst >800 psi (NASA-STD-5001B)
  - Leak-before-burst logic; internal threads/seals
  - FSM autonomy, retry logic, manual override
  - 1" radial vacuum jacket (⅛" thick), electronics chamber, then MLI/cryolite shell





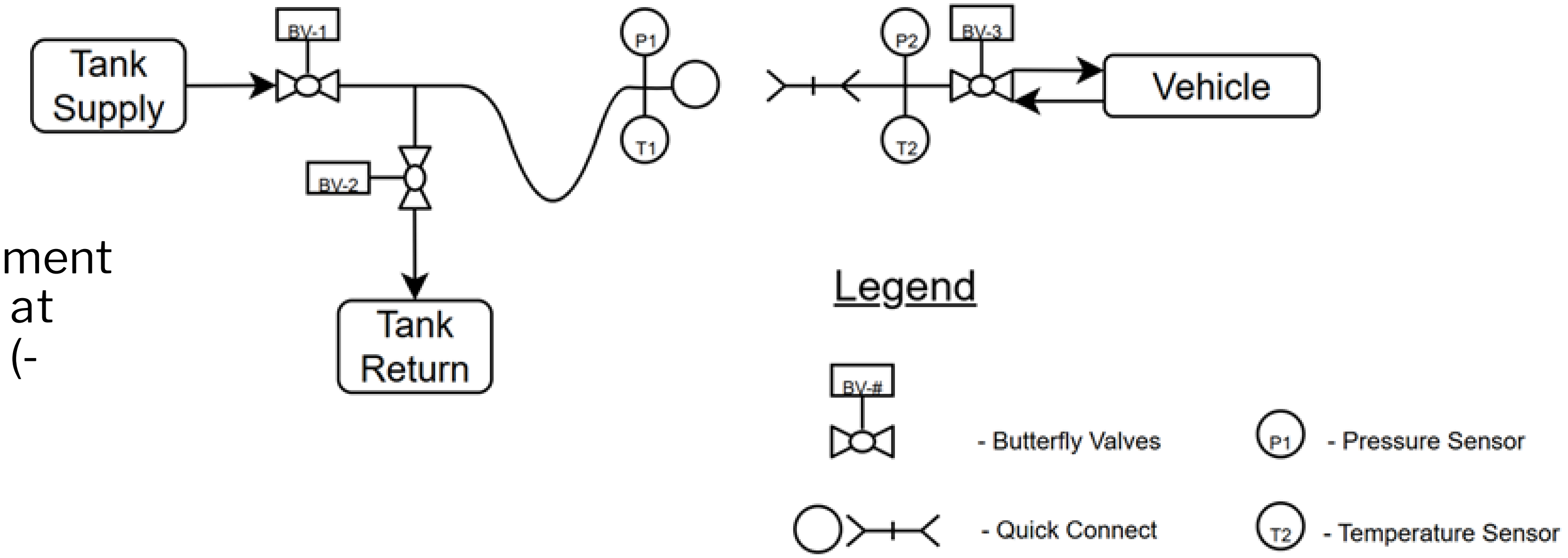
CROSS-SECTIONAL VIEW

ISOMETRIC CROSS-SECTIONAL VIEW

Dynamics (DYN) - Pipeline System

- Components
  - 1/8” thickness & 12” DIA concentric pipes
  - Dual ¼-turn butterfly valves
  - 12” single braided stainless steel hose
  - 37.5° flared flange connection
  - Spring-energized PTFE O-rings

- Material
  - 316L stainless steel
    - exhibits cryo-enhancement of strength properties at ultra-low temperature (-452°F/~-269°C)



Presenting: *Cindy Qiu (DYN)*

Dynamics (DYN) - Insulation System

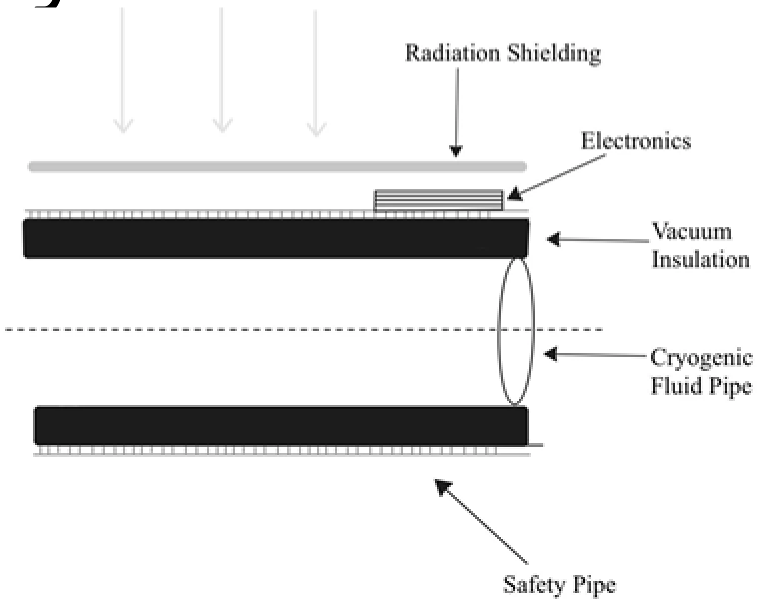
- Design
  - Vacuum jacketed piping
  - Cryolite/MLI

- Cryolite
  - Thickness: 25mm

- Outer layer: Aluminized Beta Cloth (Dunmore)
  - Thickness: 0.020 cm
  - Past flights: EOIM-3, ISS

- Reflector layer: Double Aluminized Mylar (Dunmore)
  - Thickness: 0.0064 - 0.127 mm
  - Past flights: Apollo Lunar Module CGSS, Apollo 9

- Spacer: Dacron Netting (Apex Mills)
  - Thickness: 0.16mm ± 0.01mm
  - Past flight: Perseverance rover



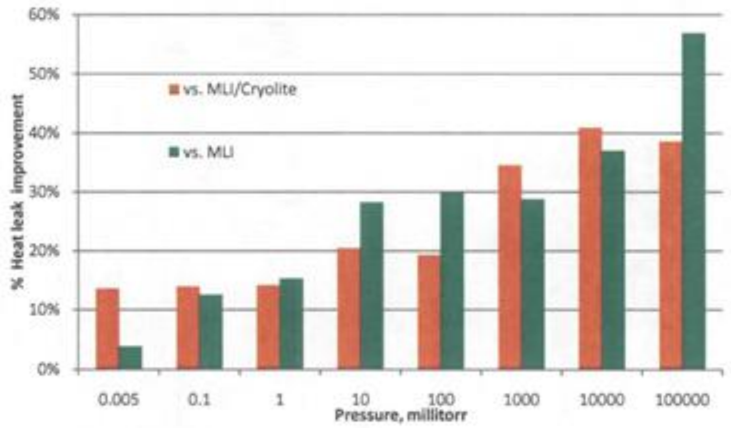
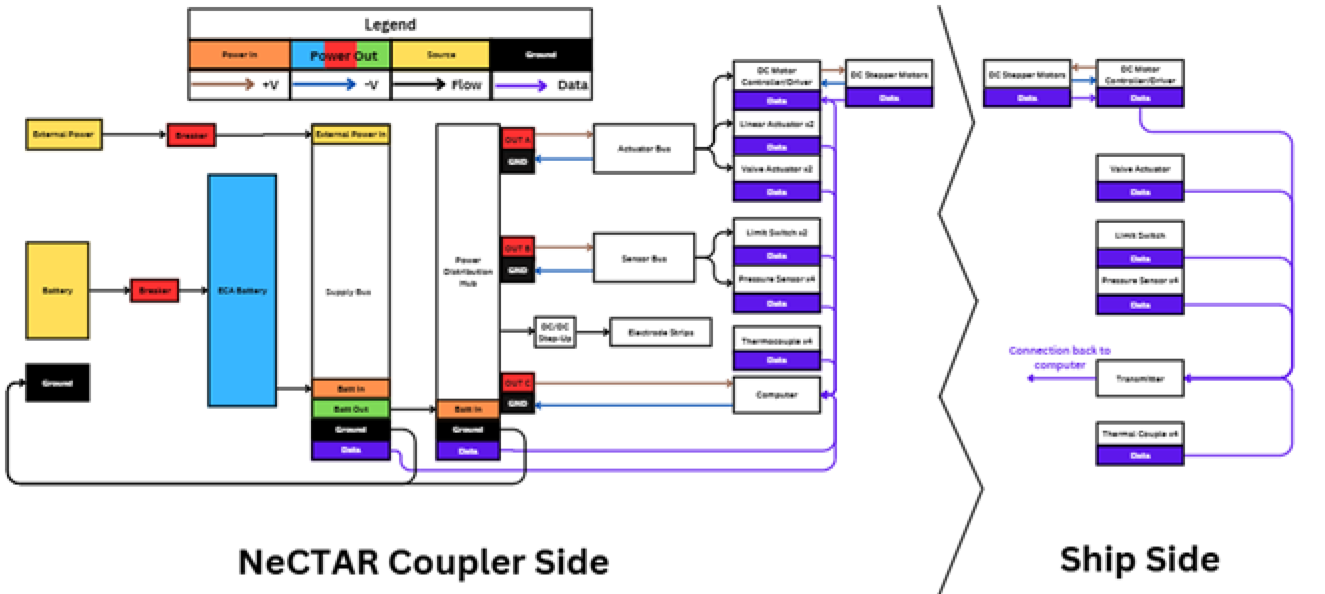


Figure 5. Percent improvement in heat leakage rate for the Cryolite/MLI composite.

Presenting: _Cindy Qiu (DYN)_

Electrical Power Subsystem (EPS)



Power Budget								
System	Component	Manufacturer	Model	Power (W)	Voltage (V)	Current (A)	Quantity	Total Power (W)
Sensor Array	Temperature Sensor	Lake Shore Cryogenics	Cernox-HT (CO)	N/A	N/A	N/A	8	0
	Pressure Sensor	PCB Piezotronics	102M81A (15-30V)	0.56	28	0.02	8	4.48
	Limit Switches	Sensata Technologies	4AT64	112	28	4	3	336
Actuators	Valve Actuators	Lin Engineering	5718L-01P	67.2	24	2.8	3	201.6
	Linear Actuators	Lin Engineering	8718L-08P-Y05-A0-A24F	369.6	48	7.7	6	2217.6
Dust Protection	Electrode Sheets	MSE Supplies	MSE PRO High Conductivity Carbon Nanotube Film	22.5	300	0.075	1	22.5
	H-Bridge			0			1	0
Transmitters/Recievers	Transponder	L3Harris	CXS-1000	19.6	28	0.7	1	19.6
	Transmitter	ISISPACE	S-Band Transmitter	30	20	1.5	1	30
Stepper Motor Controller/Driver	Driver/Controller	Lin Engineering	R256	48	24	2	9	432
Vacuum Solonoid Valves	Solonoid	Sintered Metal Corporation	XSA NC Straight Solonoid Valve	4.5	12	0.375	5	22.5
Total Wattage:			3286.28					

EPS Key Features:

- Shore power and grounding capability
- Staging for power efficiency and organization across components
- Electrodynamic dust shield to prevent damage from lunar PSI
- Buck convertors to provide ample voltage for motors and the dust shield

EPS Sensor Array and COM:

- Lake Shore Cryogenic Temperature Sensors
- PCB Piezotronics Pressure Sensors
- Sensata Technologies Limit Switches
- L3 Harris CXS-1000 Transponder
- ISISpace S-Band Transmitter

EPS Mechanical:

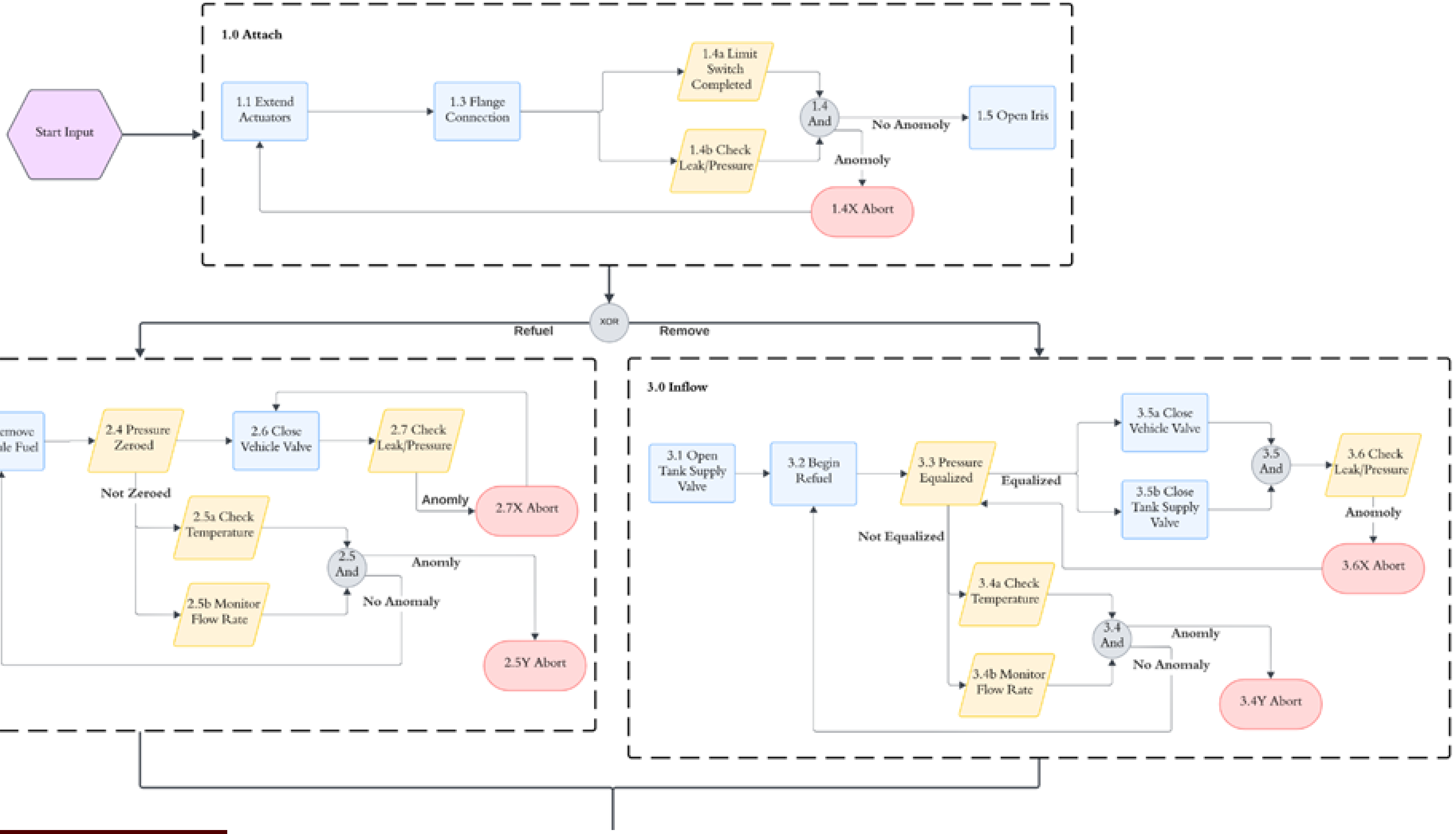
- Lin Engineering Linear Actuators
- Lin Engineering Valve Actuators
- Lin Engineering Driver/Controller
- Sintered Metal Corporation Solenoids

EPS Dust Shield:

- MSE Supplies Electrode Sheets
- H-Bridge

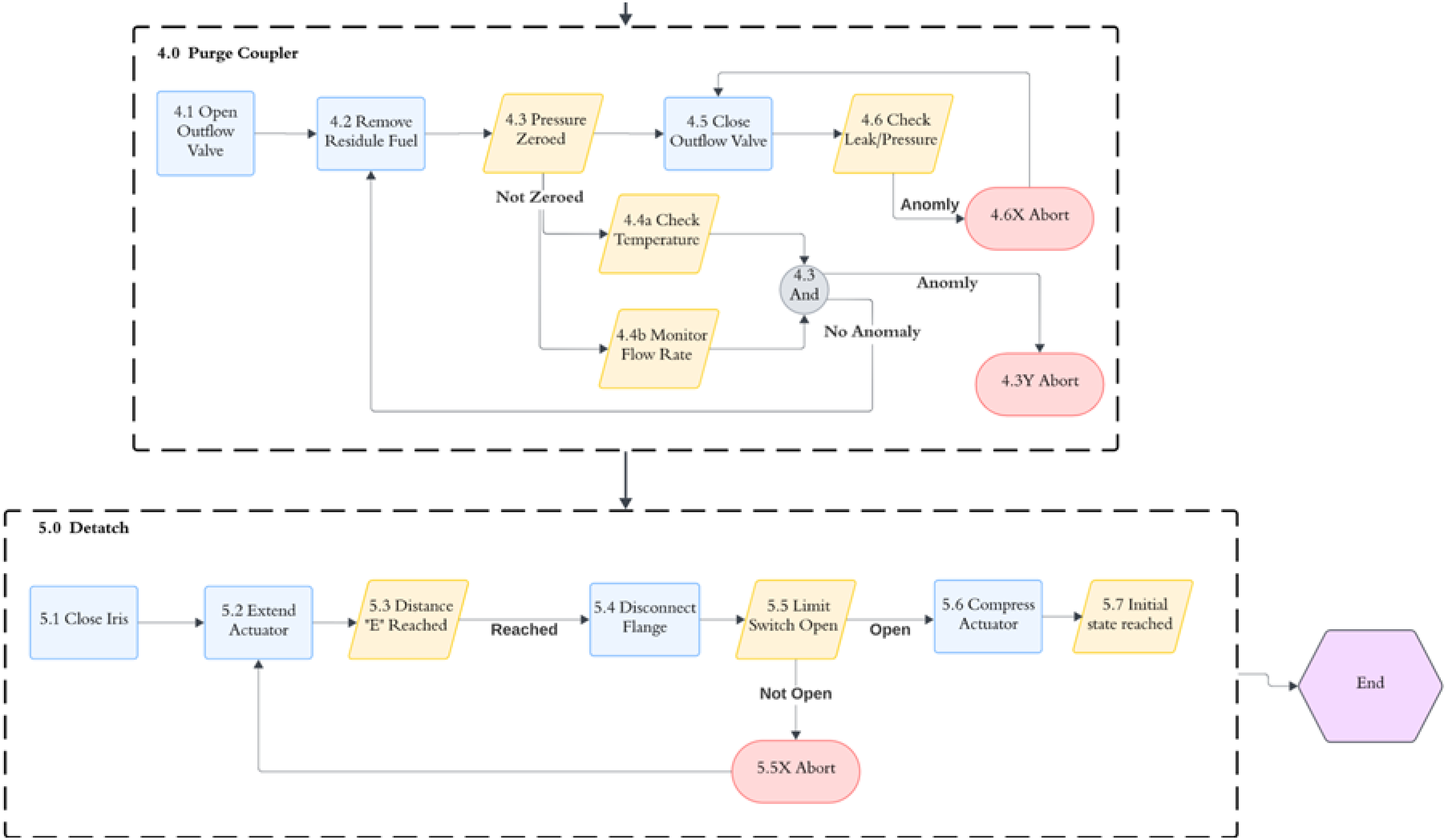
***Presenting:** Thomas Lopez (Chief Engineer)*

Command and Data Handling (CDH)



Presenting: *Thomas Lopez (Chief Engineer)*

Command and Data Handling (CDH)



Presenting: Thomas Lopez (Chief Engineer)

Analysis and Verification Tools

- TMS and DYN
  - NASA's Integrated Coupled Loads Analysis
  - Surface Mating Analysis (Docking Standards / Cross-Interface Integration)
  - NASA Structural Analysis (NASTRAN)
  - Generalized Fluid System Simulation Program (GFSSP)

- EPS
  - NASA's Integrated Power System Verification Testing
  - Computational Electromagnetics Laboratory

- CDH
  - Communication Systems Simulation Laboratory (CSSL)
  - V&V through standard functional testing

System Merit

- Performance
  - Adheres to HuLC constraints and guidelines
  - Applies an innovative approach towards current refueling processes to reduce risk and increase efficiency
- Technology Readiness
  - System Level Testing Completion - TRL 6
  - Complete System Validation - TRL 7
- Risk
  - Low risk solution providing enhanced safety with the elimination of human error
  - Anticipated risks were analyzed, and mitigation strategies were developed
- Programmatic Implementation
  - Provides a standardized refueling process applicable to NASA’s HLS intended for long term usage on the lunar surface
  - Intended to be implemented with pre-existing lunar infrastructure to include fuel storage, pipelines, and a dedicated refueling location on the lunar surface

NECTAR		Severity				
System Risk Matrix		Insignificant	Minor	Moderate	Major	Severe
Likelihood	Almost Certain					
	Likely					
	Possible			2		
	Unlikely		4		3	1
	Rare					5

1: Ruptured fuel line
2: Misaligned coupling
3: Seized valve
4: Seal degradation
5: Vapor lock

Costing

- Total estimated cost of NeCTAR's lifetime development, launch, and operations is $59.63M
  - Technology Maturation: $1.2M
  - Development and Integration: $11.1M
  - Mission Infusion Costs: $1.0M
  - Launch Costs: $25M
  - Surface Operations: $21.3M over 10 years averaging $2.13M/year
- Values calculated with NASA's Cost Estimating Handbook (CEH)

Design, Development, Test, and Evaluation (DDT&E) Schedule

Phase	Milestone	Timeline
Concept Design & Proposal	Initial design phase, trade studies	Completed (2024–2025)
Development & Testing	Component procurement, subsystem integration, environmental testing	2025–2030
Flight Readiness Review (FRR)	TRL 7 confirmation, pre-launch qualification and system certification	Q4 2030
Launch Integration	Manifest selection and physical integration into a lunar cargo delivery mission (e.g., CLPS or Artemis)	Q1 2031
Lunar Launch & Delivery	Launch and surface delivery via cargo lander	Q2 2031

Design, Development, Test, and Evaluation (DDT&E) Schedule

Phase	Milestone	Timeline
Surface Deployment & Commissioning	Initial power-up, diagnostics, and sensor calibration	Q2–Q3 2031
Autonomous Operations Phase	Bi-directional cryogenic transfer in support of HLS refueling	2031–2041
Midlife Assessment	Performance check, firmware updates, long-term diagnostic	2036 (Year 5)
End-of-Life / Transition	Evaluation of hardware integrity or replacement by next-gen system	2041+

***Presenting:** Kamalika Bose (Project Manager)*

Key Takeaways

1. NeCTAR implements a five state CDH architecture that allows for autonomous refueling operations.
2. NeCTAR addresses unstable fluid behavior by using a vacuum-jacketed, concentric flow path with cryo-rated seals and precise actuation.
3. NeCTAR actuators allow for increased reliability through use of simple mechanics.
4. Dust mitigation is addressed by the implementation of an electrodynamic dust shield that repels regolith and minimizes lunar PSI.
5. Thermal heat transfer is minimized by utilizing multilayer insulation (MLI), and cryo-compatible materials.

Thank you for listening!