



COSMIC Capstone Challenge: Final Briefing

**PackNanoSat, NC State University:
ORBTT – Orbital Refueling
By Internal Tank Transfer**

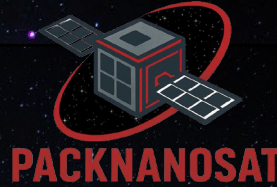
Students: Mason Stimach, Nick Lawton, Will Busse,
Colby Harrell, Aiden Hayes
Advisor: Felix Ewere
Mentor: Uchechukwu Agwu

April 16, 2026

Agenda

1. Introduction
2. Mission Overview
3. Mission Analysis
4. Subsystems
5. Risk and Innovation
6. Path Forward

Team Overview



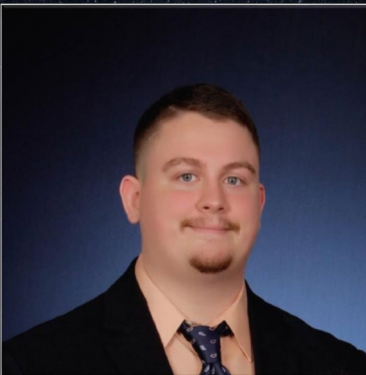
Mason Stimach
Project Manager



Nick Lawton
Docking Lead



Will Busse
Track System Lead



Colby Harrell
Missional Analysis Lead



Aiden Hayes
Docking Port Design



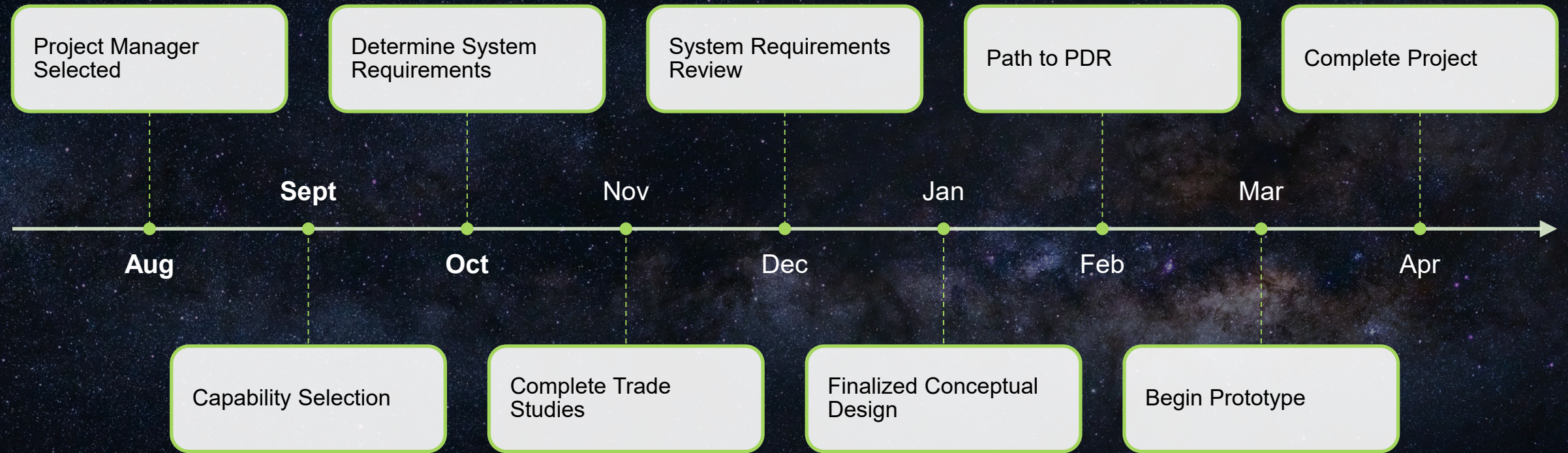
Felix Ewere
Advisor

Executive Summary

- Problem Identified:
 - No in-orbit refueling capability for client satellites
 - SSO satellites in LEO present the highest ΔV opportunity
- Solution:
 - Replaceable propellant tanks with track-based internal transfer system
 - Modified docking interface for clients
 - Up to 18 ORUs \rightarrow 100–120 m/s ΔV (~600 kg sats)
- Impact:
 - Autonomous satellite refueling
 - Extends mission lifetimes and reduce orbital debris
 - Enables modular ISAM architecture
- Status:
 - Final CAD complete
 - Initial prototype in development

Program Management

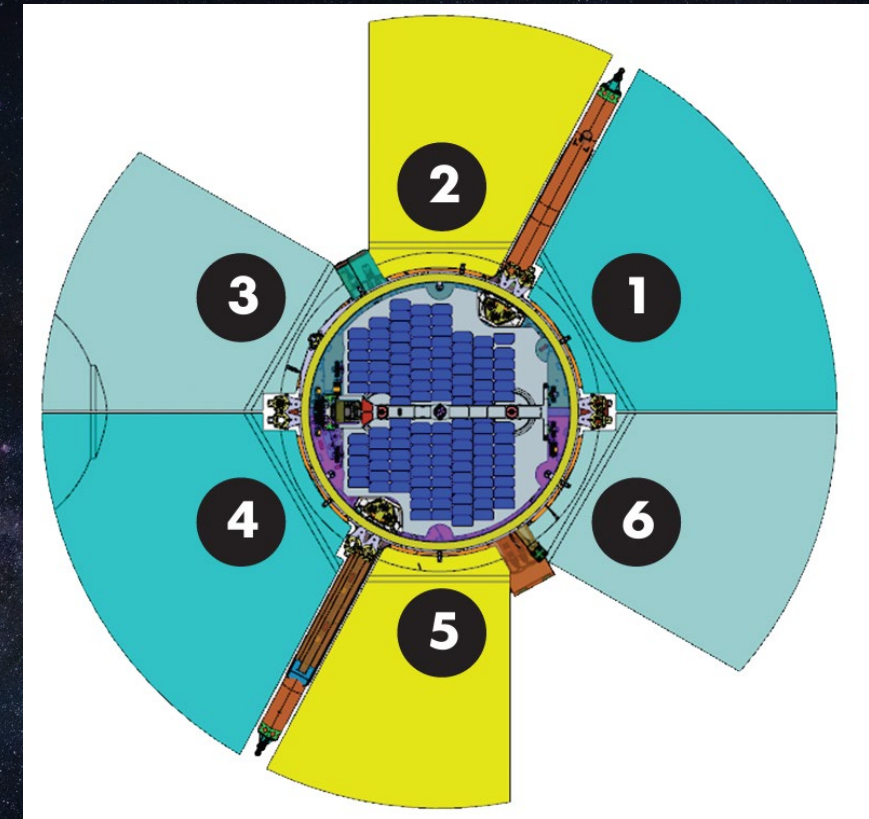
2.4 Program Management Milestones



Advancing Missions

1.4 Advancing High-Value Missions

- Supports On-Orbit Servicing & Refueling
 - Demonstrates a practical approach to satellite life extension
- Advances Modular Spacecraft Design
 - Supports future standardized and serviceable satellite systems
- Enables Scalable ISAM Infrastructure
 - Supports long-term LEO infrastructure development
- Leverages Existing Host Platforms
 - Designed around ESPASStar servicing vehicle



ESPASStar Platform

References: NASA (Chato – On-Orbit Refueling), NASA STMD (Autonomous Servicing), Kohut (Modular Spacecraft), COSMIC C3 Packet

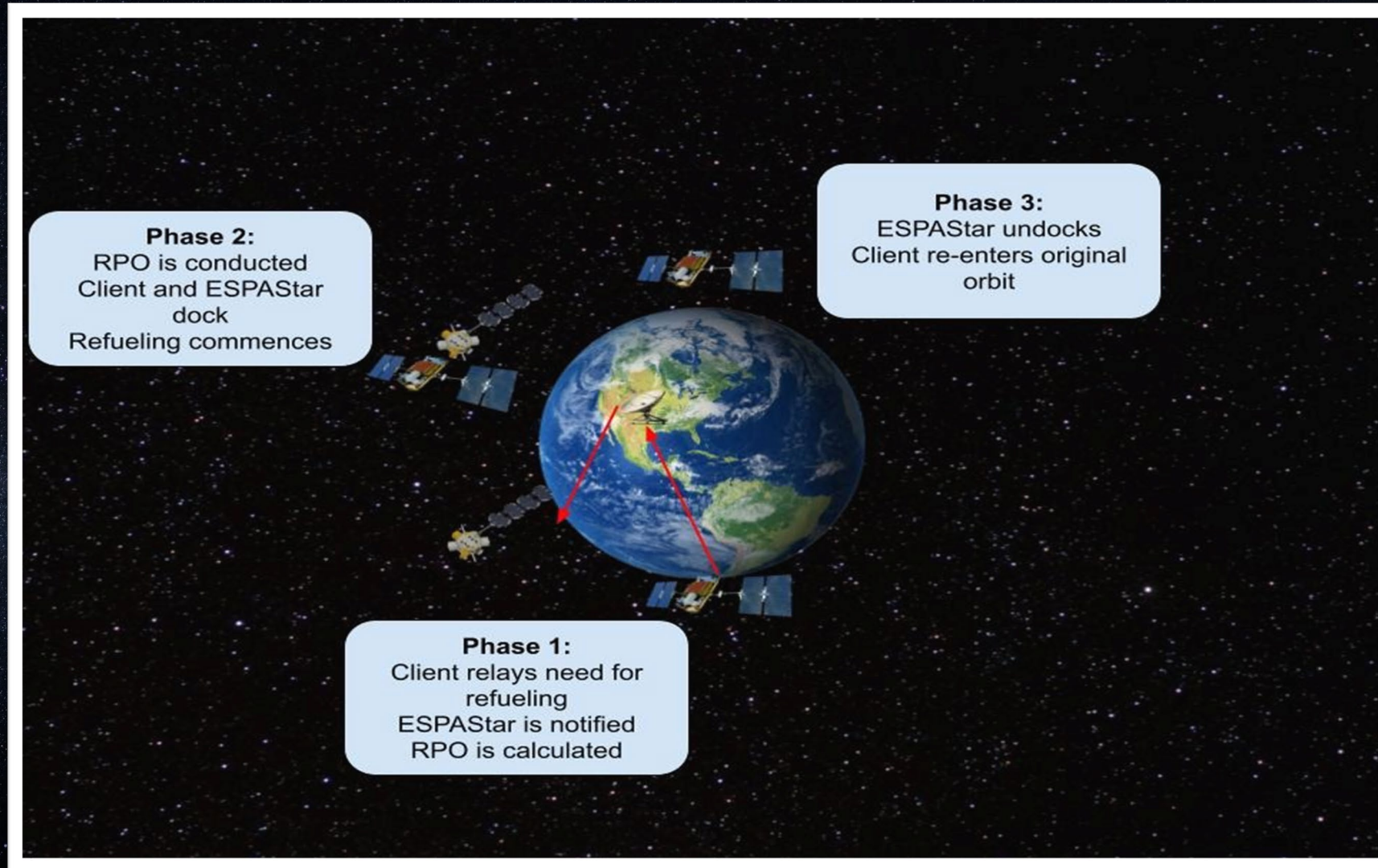
Impact

1.1 Impact

- Extends Satellite Mission Lifetimes
 - Provides +100–120 m/s ΔV for ~600 kg satellites
 - Delays fuel-limited end-of-life
- Enables Scalable Servicing
 - Multi-client capability (up to 18 ORUs)
 - Supports growing SSO/LEO constellations
- Reduces Cost & Launch Demand
 - Avoids full satellite replacement
 - Enables refueling vs. rebuild
- Reduces Orbital Debris
 - Fewer satellites retired prematurely
 - Supports sustainable LEO operations

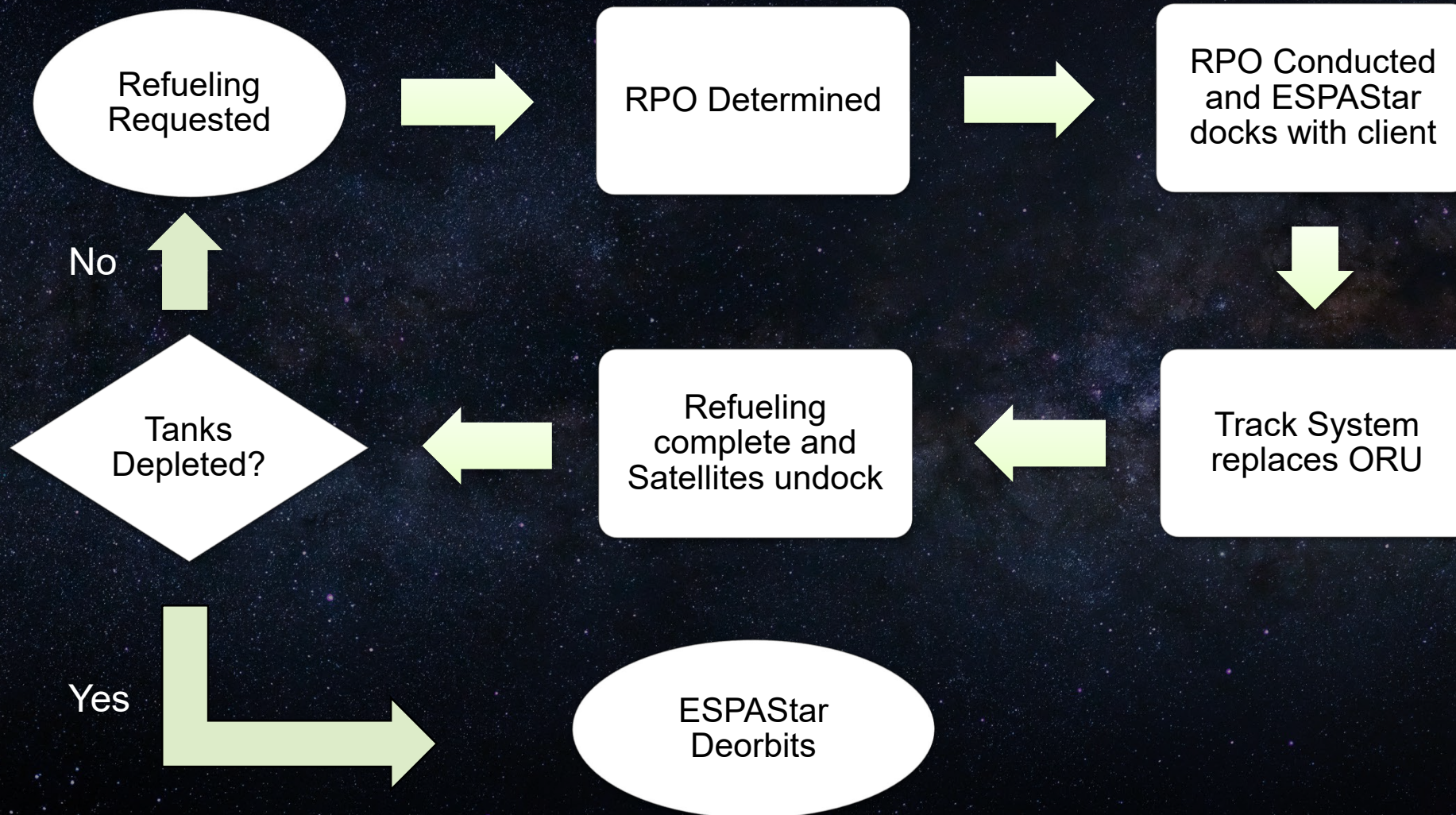
CONOPS

2.2 Storyboard



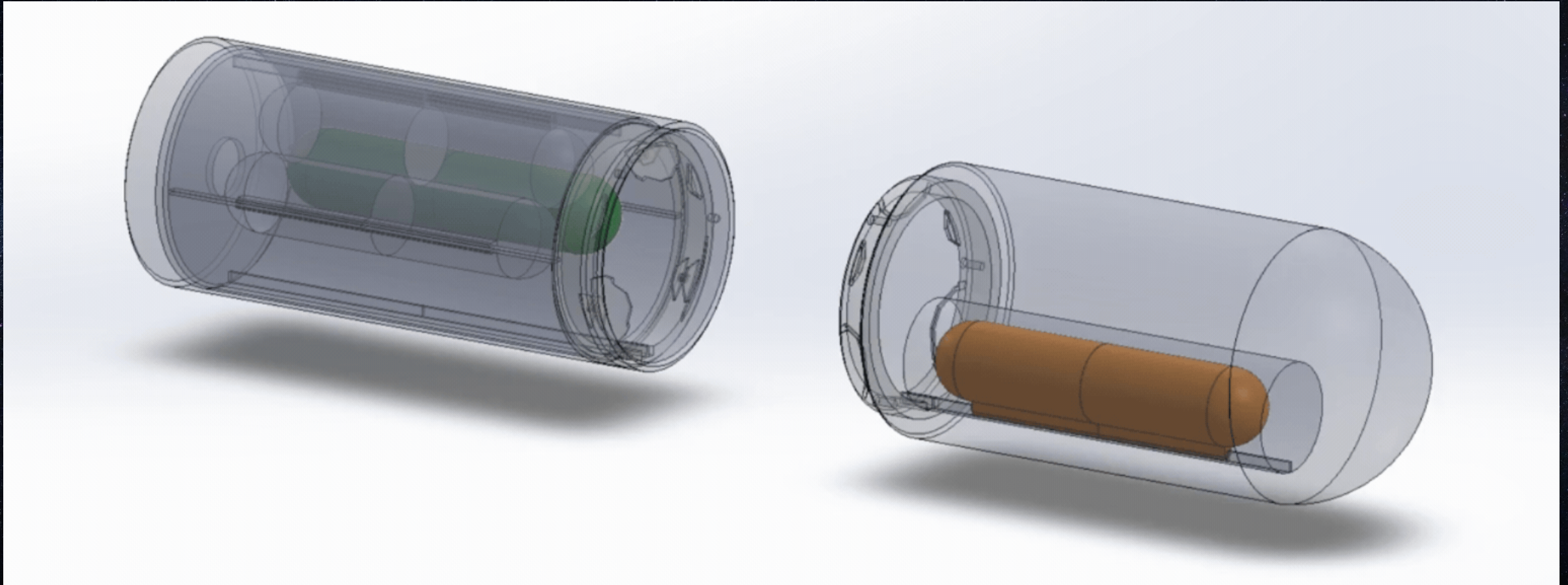
Mission Plan

2.2 Storyboard



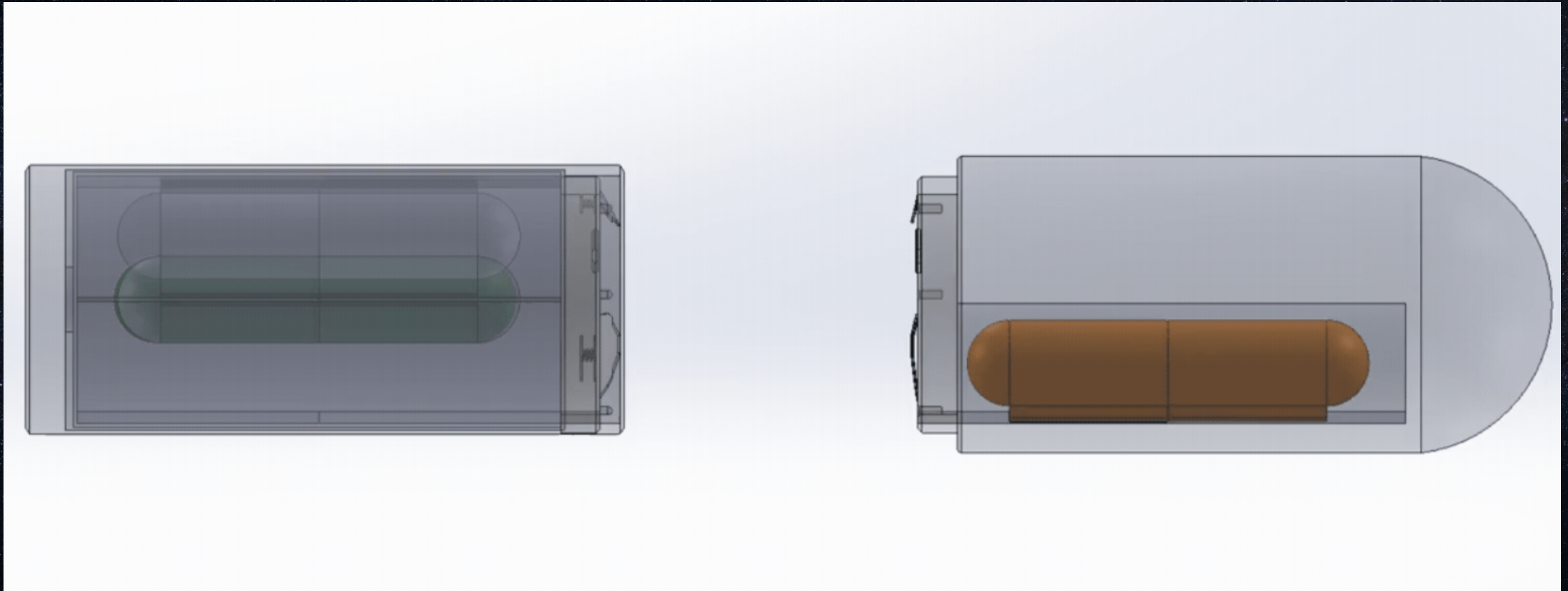
Animation of Refueling Sequence

2.1 - Animation



Animation of Refueling Sequence

2.1 - Animation



Requirements and Orbit Selection

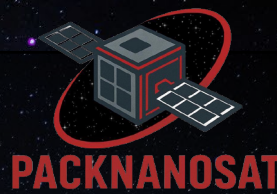
3.4 Trade Studies

- Operating Requirements
 - The ESPASat ORU shall lengthen a client's satellite lifetime by 5 years
 - The ESPASat shall prevent orbital debris accumulation by 1 satellite per servicing
- 5 Year Countdown Rule
- SSO Satellites in LEO ~800 km
 - High populated orbit for imaging and tracking satellites
 - Less ΔV for RPO if no plane change is required
 - Satellites and tank sizes comparable to nominally selected designs
 - Lower impacts of drag on station keeping



Satellites in LEO in an SSO

Reference Satellite Selection



3.4 Trade Studies

Satellite Name	Total Mass (kg)	Original Propellant mass (kg)	Thruster Type	Specific Impulse and Thrust Output	Estimated ΔV per refuel for original fuel amount and 30L Refuel
EO-1	588 kg	22.3 kg	Hydrazine Monopropellant	$I_{SP} = 220$ m/s $T = 4$ N	Original: 85 m/s New: 117.62 m/s
CALIPSO	635 kg	28 kg	Hydrazine Monopropellant	$I_{SP} = 220$ m/s $T = 4$ N	Original: 97.3 m/s New: 106.25 m/s
SMOS	670 kg	28 kg	Hydrazine Monopropellant	$I_{SP} = 220$ m/s $T = 4$ N	Original: 92.1 m/s New: 100.59 m/s

Economic Considerations

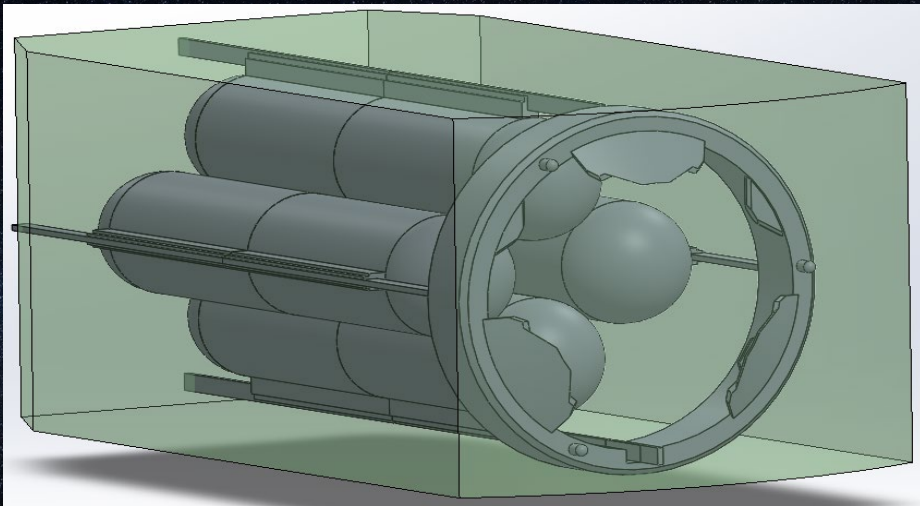
1.2 Feasibility

- Launch weight: ~1333.5 kg
- Falcon 9 has a launch cost of \$74 million and a maximum payload of 22,800 kg
 - Assuming a linear relationship between cost and size, the ride share would be around \$3,250/kg
- Launch cost: ~\$4.4 million per launch
 - We need to charge \$250,000 per refuel to breakeven
 - \$350,000 with 40% markup
- EO-1 launch cost: ~\$2.275 million
- Refueling client satellites would be ~85% cheaper

- End of Life Considerations
 - Revenue: \$6.3 million
 - Deorbit the ESPASat

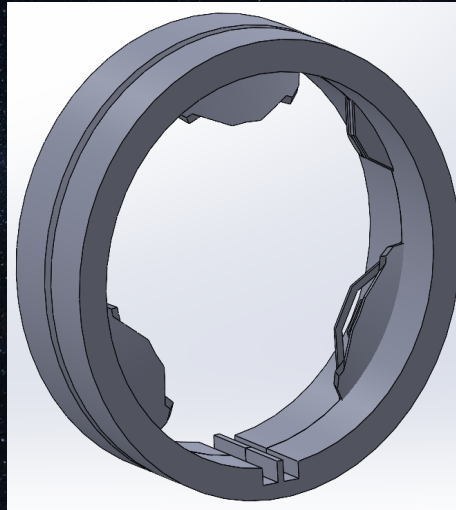
Docking Mechanism Design

3.1 - Required Elements



Assembly with the rotary tank & track system

- The opening at the bottom of the docking port will allow for tank traversal into the client satellite.



Assembly of male and female ports together



Female docking port



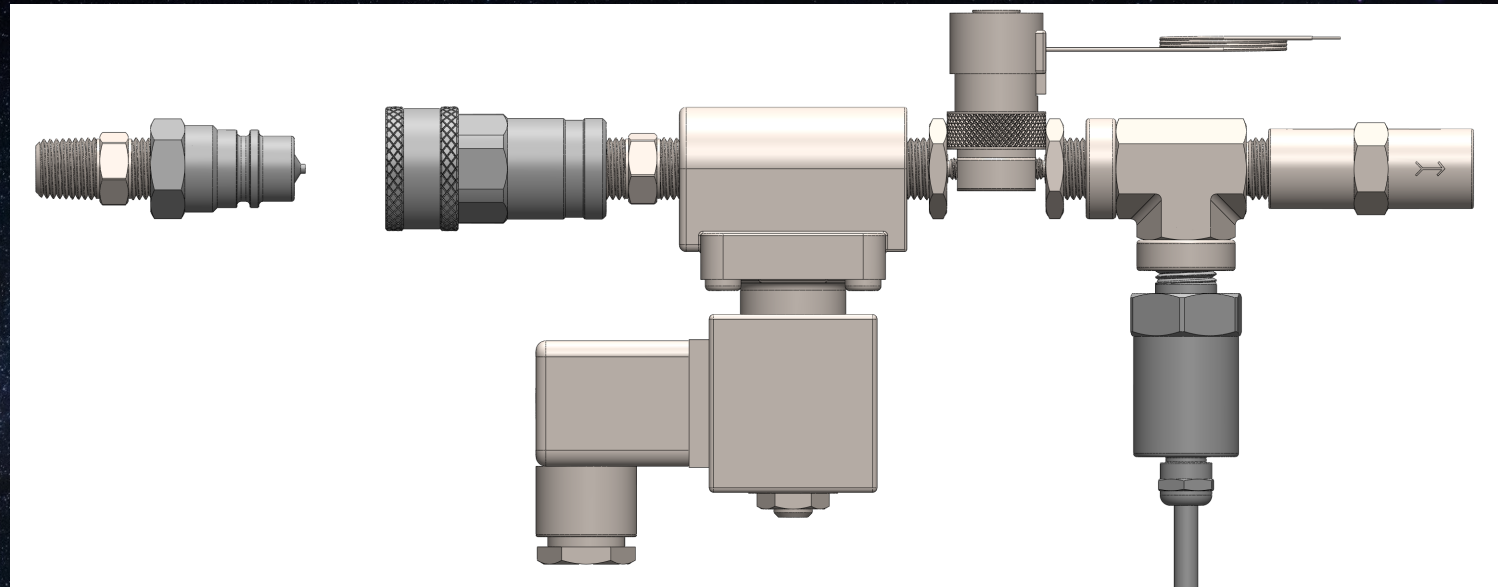
Male docking port

Docking port assembly with tank system

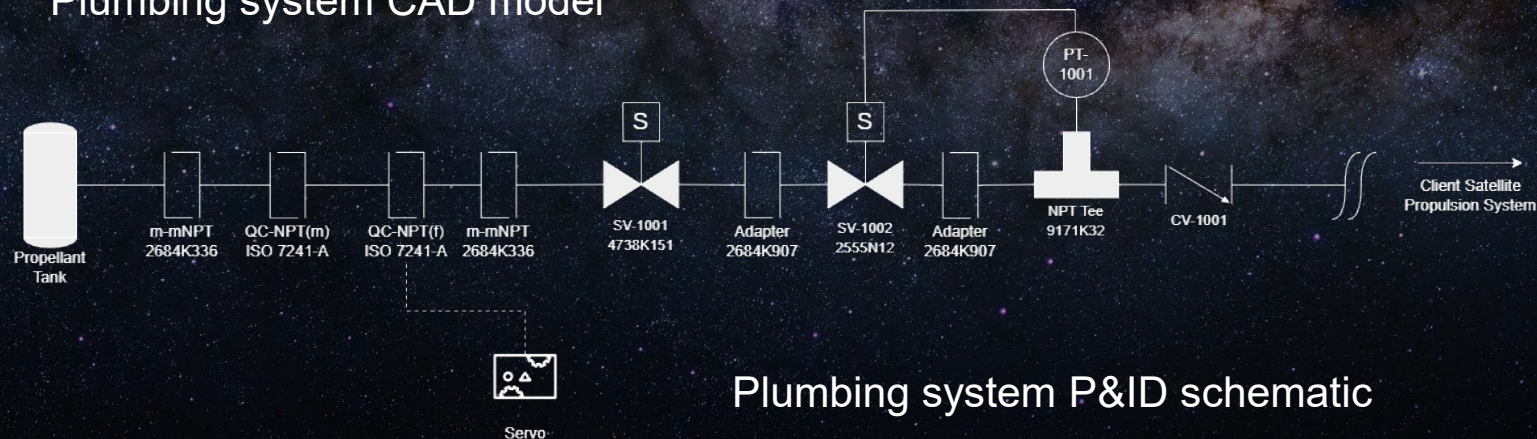
Client Satellite Required Plumbing Design

3.1 - Required Elements

- Quick Connects (QC) to attach/detach ORU to client
 - Auto-sealing QCs
- Solenoid run valve
- Solenoid flow control valve
 - Pressure transducer feedback loop
- Check valve for safety



Plumbing system CAD model



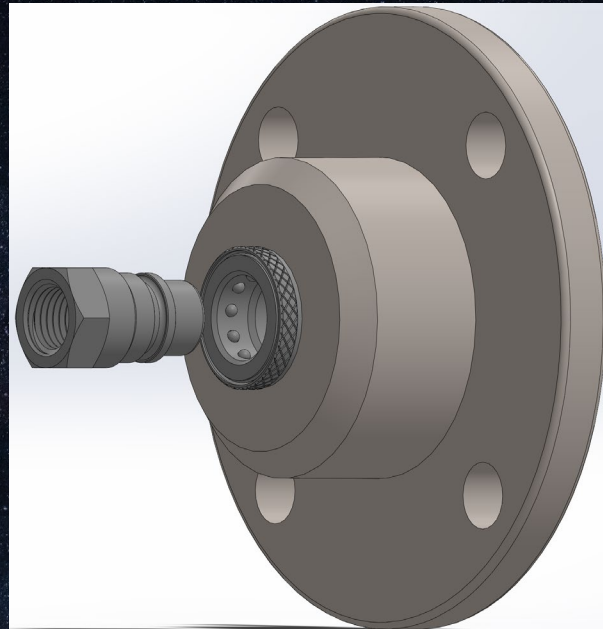
Plumbing system P&ID schematic

Client satellite's design requirements to enable use of ORUs

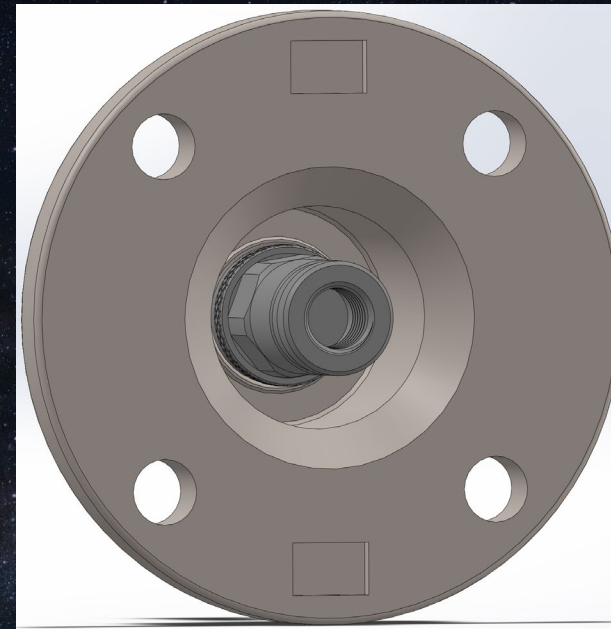
Quick Coupler Actuator Design

3.1 - Required Elements

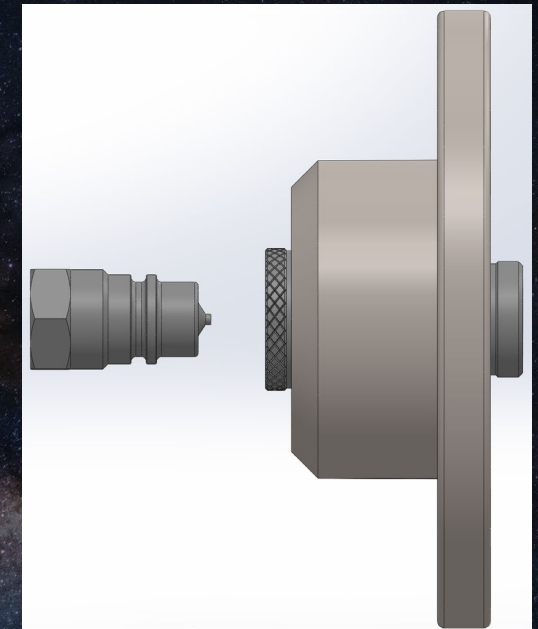
- Dual linear actuation of QCs
- Actuator plate pushes the QC jacket forward
- Internal spring in QC returns system to neutral, locked position
- Linear actuators are fixed to client satellite's plumbing system



Rotated view of actuator plate



Back view of plate



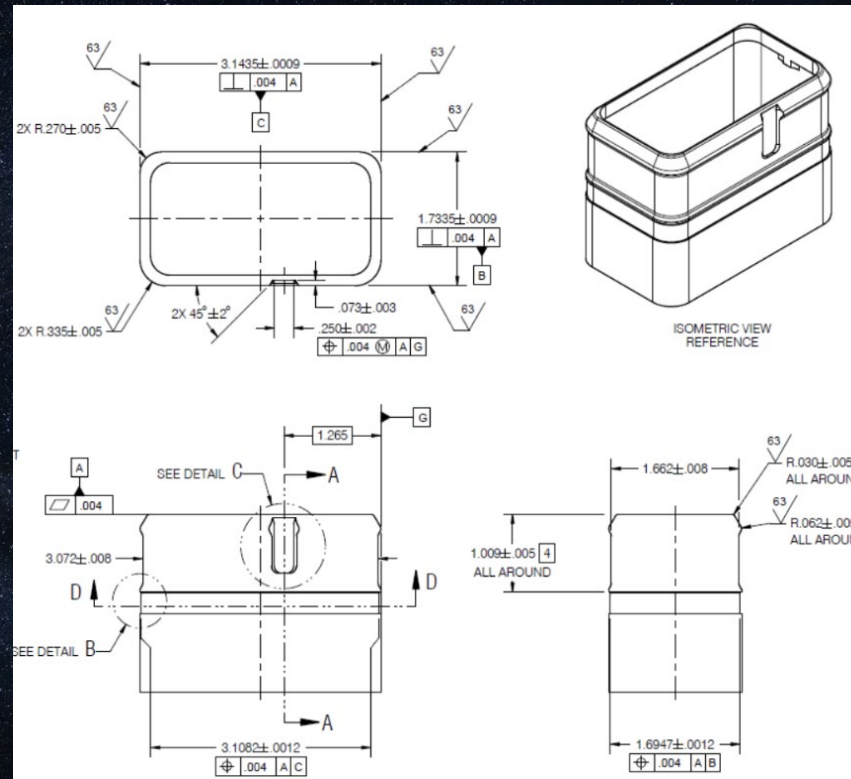
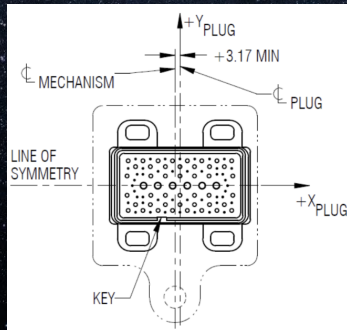
Side view of plate

Removal and attachment process for ORU

Electronic Connection & Data Transfer

3.1 - Required Elements

- IDSS compliant bulkheads
- Bulkheads rest on the docking port female and male sides
- At a 10Hz update rate, the system requires 2.64 kbps
- Using UART, which can achieve 115 kbps, we are well under budget



IDSS bulkhead requirements

Data Point	Bytes
Motor updates	9
Tank attachment status	7
ORU track mechanism status	8
Background health	5
Packet header & CRC	4
Total	33

Data Budget

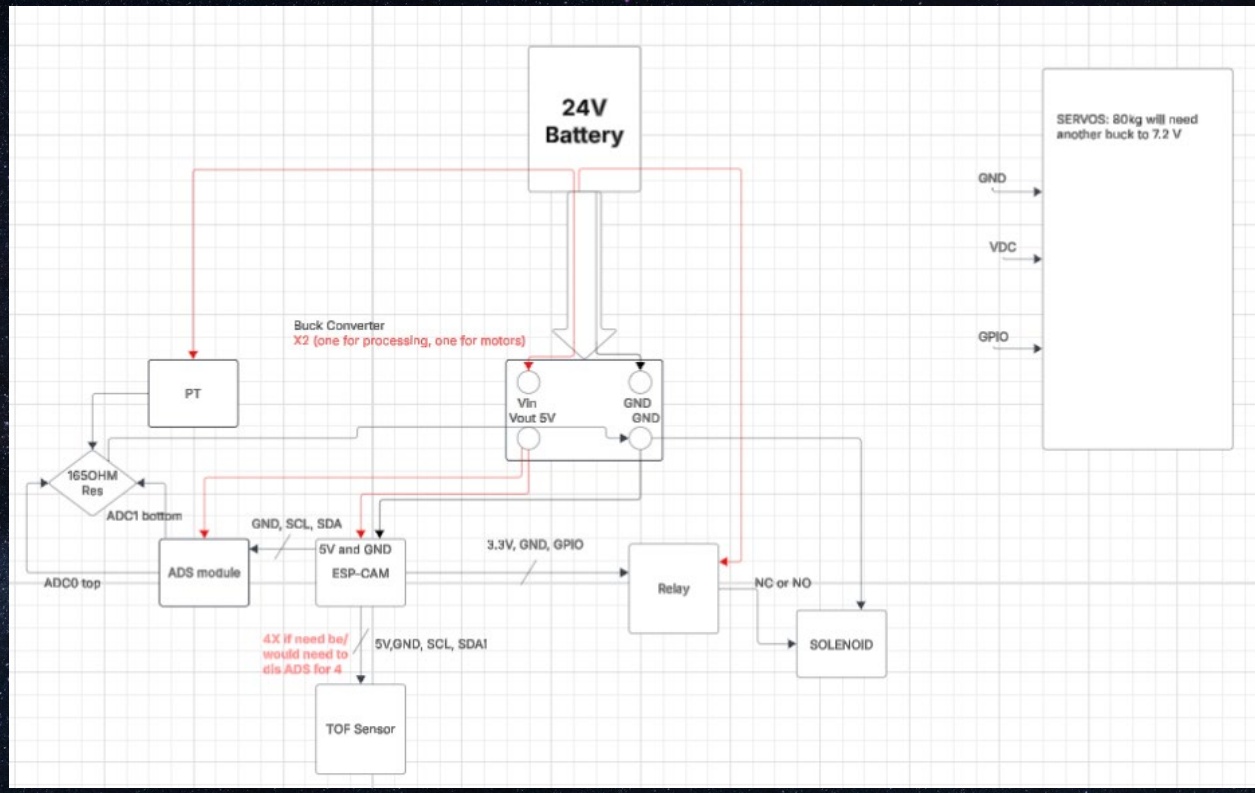


PACKNANOSAT

Client Required Electronics Design

3.1 - Required Elements

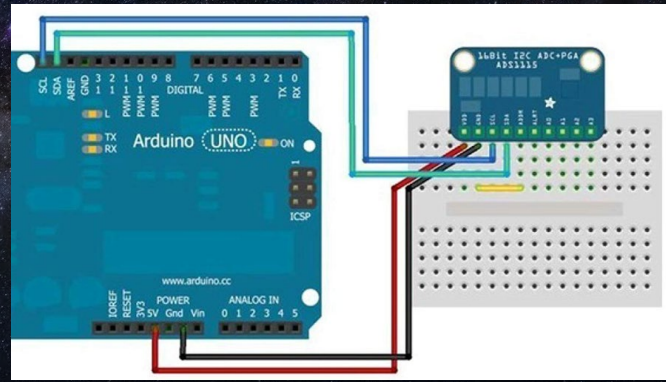
- Using an ESP32-CAM module as main controller
- PCA9685 for I2C control
- 2x Servos (40 & 80kg)
- Solenoid run valve
- Flow control valve
- Pressure transducer



Electronics Schematic of Docking System



ESP32-CAM



I2C Controller

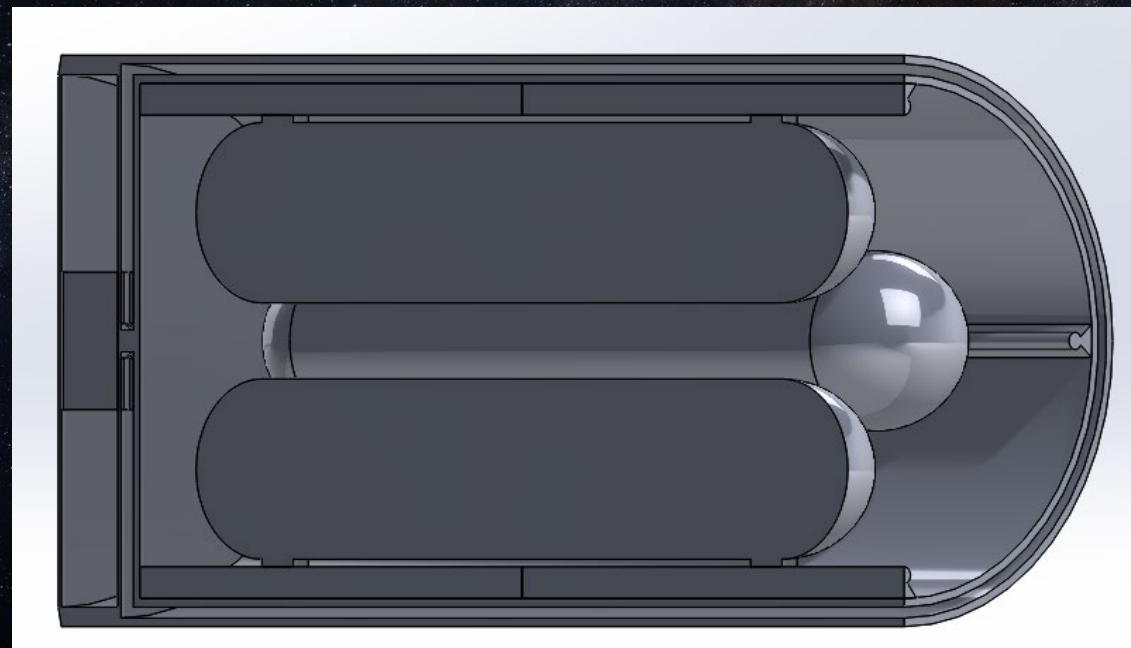
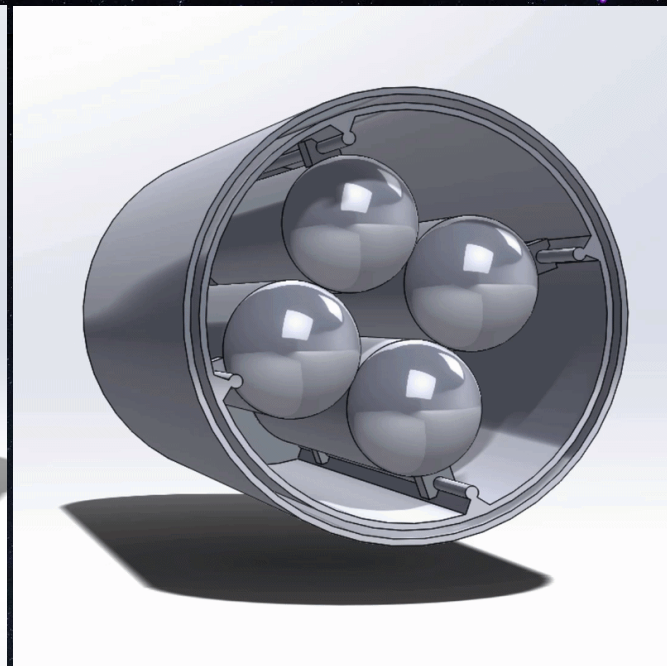
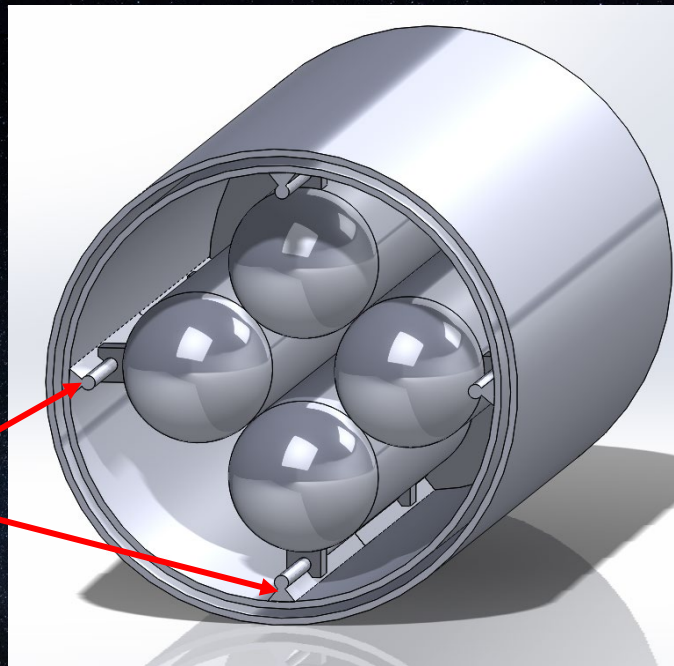
Electronics required to control the ORU transfer and plumbing system

ORU System Design

3.1 - Required Elements

- Rotary Design
 - Linear rails keep fuel tanks in place and aligned with docked client satellite
 - Crawlers using gears along the rails move and retrieve tanks
 - Allows for minimally complex storage of multiple fuel tanks
 - Only needs rotary counterbalance by ESPASStar

Can store 3x30L fuel replacement tanks per bay in the ESPASStar



Tank Mechanism Chart

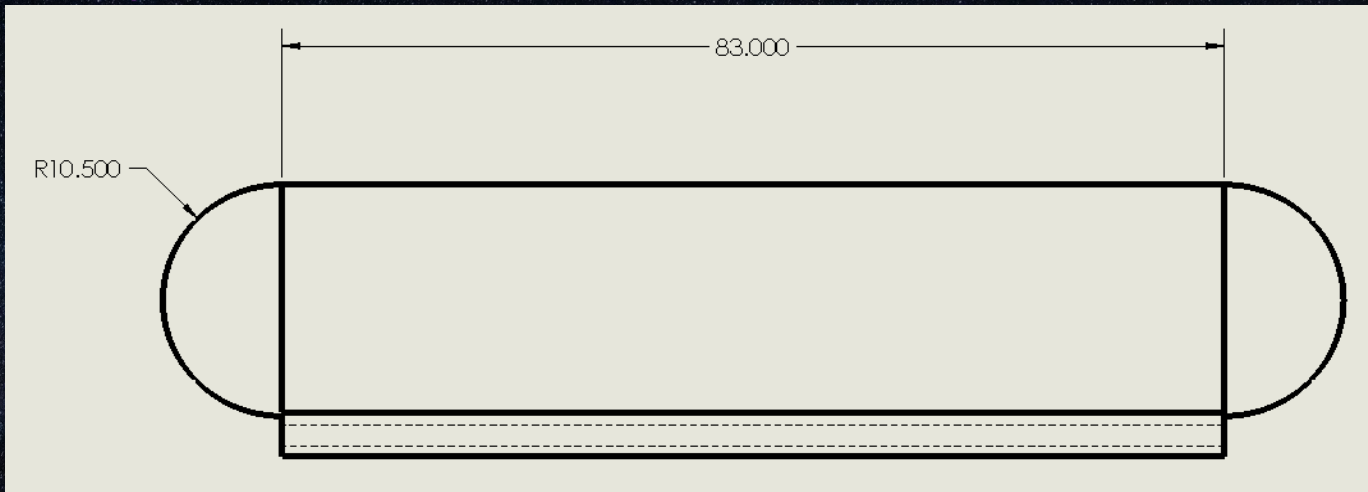
3.4 - Trade Studies

	Robotic Arm	Rotary	Shipping Container
Simplicity	1	4	2
Refuelability	4	3	3
Ease of Implementation	2	4	4
Total	7	11	9

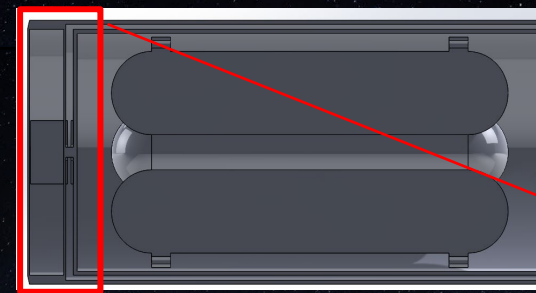
Rotary Design selected for tank mechanism due to simplicity

Rotary ORU Design

3.1 - Required Elements



- Tanks are 83cm cylinder with 21cm diameter end caps
- Assuming wall thickness of 0.5cm
- Total internal tank volume of 30.264 L
- Hydrazine fuel used due to known reliability and widespread use



1. Brushless DC motor used to rotate internal drum
2. Space for hardware mounting for motor controllers, onboard computers, and electrical management
3. Reflective optical encoder with magnetic sensing for precise motor control and alignment



Tank Material Chart

3.4 - Trade Studies

- For Hydrazine typically stored at 25 bar, we assumed ultimate pressure of 5 MPa (50 bar) for a F.O.S. of 2
- Need material that can then withstand a hoop and longitudinal stress of 100 MPa and 500 MPa respectively for our tank configuration

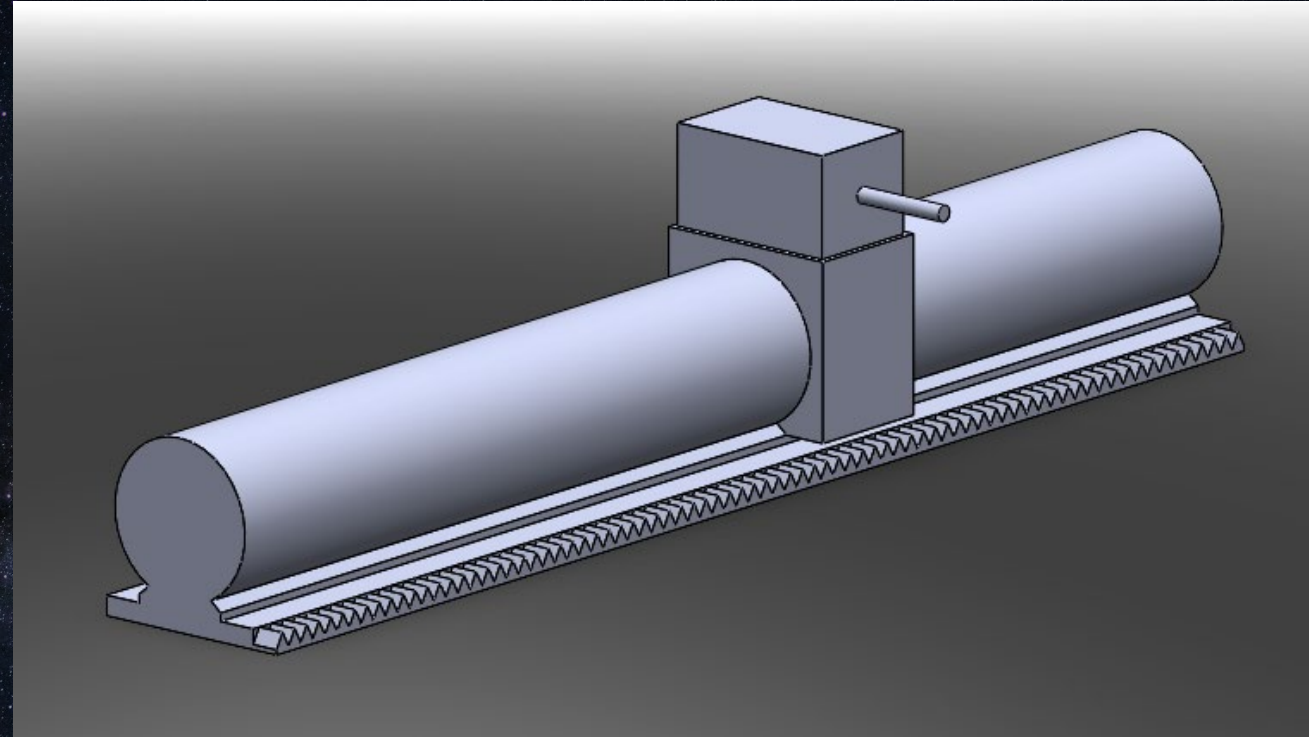
	Ti-6A1-4V	Aluminum-Lithium 2195/2090	Carbon Fiber Composites
Yield Strength	5	4	3
Weight/Density	2	4	5
Manufacturable	4	2	1
Total	11	10	9

Ti-6A1-4V Titanium Alloy selected for tank material due to strength and industry usage with hydrazine

Tank Crawler Design Concept

3.1 - Required Elements

- Crawler to attach to and retain tanks within the ORU
- Once client is docked, crawler will push or retrieve tanks
- One crawler per track
- Crawler Components:
 - Mounted to linear rail like the tanks
 - Mounted brushless motor on top
 - Gear meshes with rack gear on base of linear rail
 - Gears lock in place to keep tank stationary and supplies force to push tank onto client satellite



Communication System

3.3 Data Handling and Comms

- System Requirements
 - Communication system shall be able to downlink telemetry, SOH, and experimental data.
 - The ground station(s) shall support automated command execution.
 - The data handling system shall collect, process, and transmit system health and operational data.

- Operational Concept
 - Primarily autonomous system:
 - No real-time downlink needed - Operations are executed autonomously with event-based telemetry.
 - Minimal operator Involvement - Ground station provides command uplink and health monitoring.

 - Low data rate communication:
 - Docking and transfer status
 - ORU position
 - Pressure and valve states

Link margin	12.6	dB
Required Link Margin	6	dB

Most Important Technology Gaps

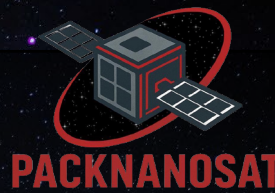
4.2 Tech Gap Assessment

- ORU Transfer System (Rotary/Rails)
 - [TRL 3]
- Docking & Mechanical Interface
 - [TRL 5-6]
- Client Satellite Plumbing Interface
 - [TRL 3]
- Autonomous Control & Operations
 - [TRL 3-4]
- Data Handling & Communications
 - [TRL 7–8]

9	Actual System Proven in Operational Environment
8	System Complete and Qualified
7	System Prototype Demonstration in Operational Environment
6	Technology Demonstrated in Relevant Environment
5	Technology Validated in Relevant Environment
4	Technology Validated in Lab
3	Experimental Proof of Concept
2	Technology Concept Formulated
1	Basic Principles Observed

Risks

3.2 Risks



Risk	Impact	Mitigation
Orbital Debris / Collision	-Loss of vehicle or client satellite -Mission failure	-Analysis & collision avoidance -Station keeping and deorbit plan
Failure to Rendezvous	-Waste of propellant -Loss of servicing opportunity	-Pre-mission orbit planning -Incremental approach with abort capability
Docking / Transfer Failure	-Damage to ORU or client interface -Loss of functionality	-Alignment guides & tolerance design -Redundant latching and safe modes
Propellant Interface / Leak	-Loss of propellant -Contamination or system failure	-Leak-proof standardized interfaces -Ground testing and validation
Autonomous Operation Failure	-Incorrect sequence or system fault -Potential system damage	-Fault detection, isolation, and recovery

Most Innovative Concepts Considered

4.1 Innovative Concepts

- Robotic Arm-Based Tank Transfer
 - Use of robotic manipulators to remove and install propellant tanks
 - High flexibility for handling multiple client configurations
 - Rejected due to complexity, mass, and control challenges
- Direct Fluid Transfer Refueling
 - Continuous propellant transfer between servicer and client
 - Eliminates need for replaceable tanks
 - Rejected due to sealing, contamination risk, and interface complexity
- Linear “Container-Style” Transfer Mechanism
 - Bidirectional translation system to grab and replace tanks
 - Rejected due to alignment sensitivity and increased structural complexity

Biggest Challenges Encountered

4.3 Biggest Challenges

- Rotary ORU Transfer System
 - Challenge: Alignment, jamming, and reliable tank positioning
 - Result: Iterated design to improve guidance and mechanical reliability
- Docking & Interface Standardization
 - Challenge: Compatibility across multiple client satellites
 - Result: Utilized an existing connection design with modified interface
- Team Continuity and Project Transition
 - Challenge: Significant reduction in team size late in the project
 - Result: Reallocated responsibilities and prioritized core system development

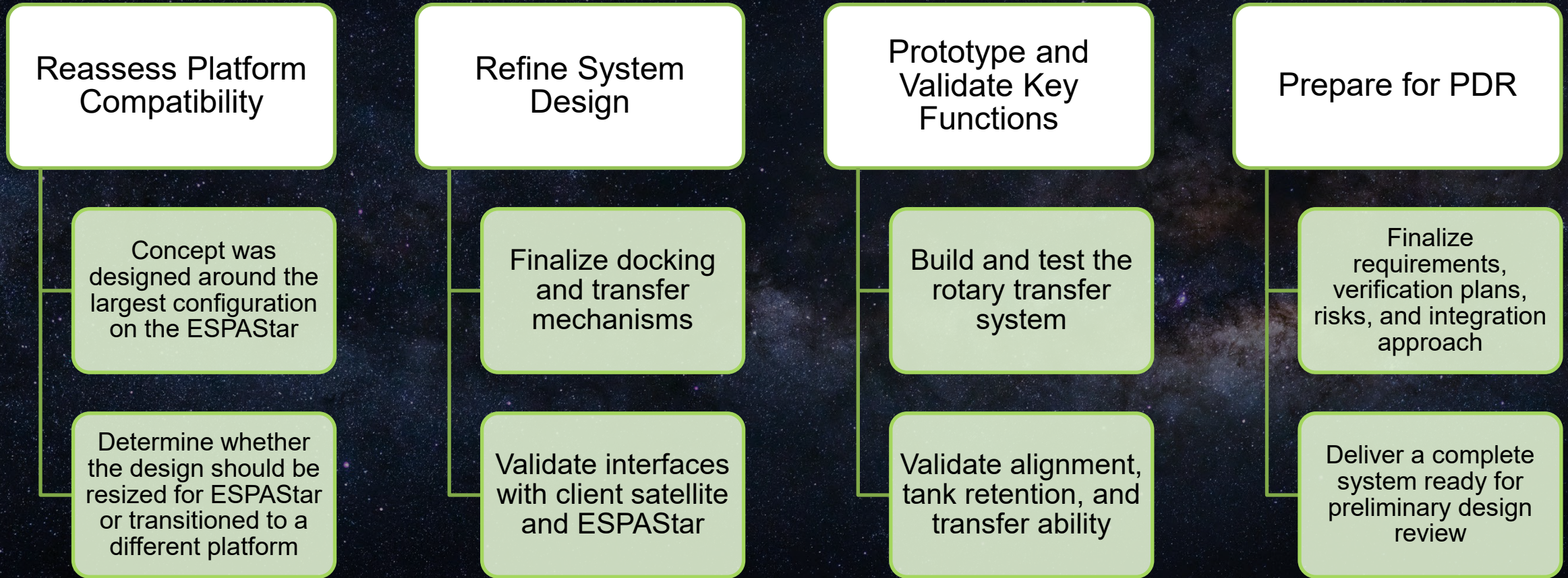
Paper

5.2 Paper

- Important Paper Characteristics
 - Abstract Length - 224 words
 - Paper Length – 15 pages
 - Number of References – 20
- Potential Publishing Locations:
 - Conference:
 - AIAA SciTech
 - AIAA Student Conference
 - Journal:
 - SAE International Journal of Aerospace

Path to PDR

2.3 Path to Preliminary Design Review



Conclusion

- Problem Addressed

- No current capability for in-orbit refueling in LEO.
- Fuel limits drive premature mission end and orbital debris.

- Our Solution

- Modular ORU tank exchange system.
- Rotary internal transfer mechanism.
- Up to 18 ORUs → 100–120 m/s ΔV per client.

- Lessons Learned

- Simplicity in mechanical design is critical for reliability.
- Early definition of interfaces and requirements is essential.
- Strong coordination across subteams.

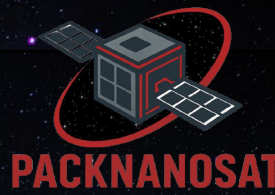
- Path Forward

- Prototype validation and integrated testing.
- Host vehicle integration refinement.
- Standardization of client interfaces.

Questions?

Backup Slides

Communication System



Transmitter Information			
Frequency	2.2	GHz	S-Band
Utilized Bandwidth	0.0125	MHz	May be radio limited but is also limited by frequency license policy. Generally UHF max allocation $\leq 100\text{kHz}$, S-band max allocation $\leq 5\text{ MHz}$
Wavelength	0.136269299	m	Typically express in nm, but use m for calculations only
Bit rate	0.256	Mbps	Using value inputted into the Data Budget. This is modulation dependent but: UHF is usually 9600bps or 19.2kbps. S-band is usually $< 1\text{Mbps}$. X-band is usually $< 100\text{Mbps}$.
Transmit Power	5.0	W	