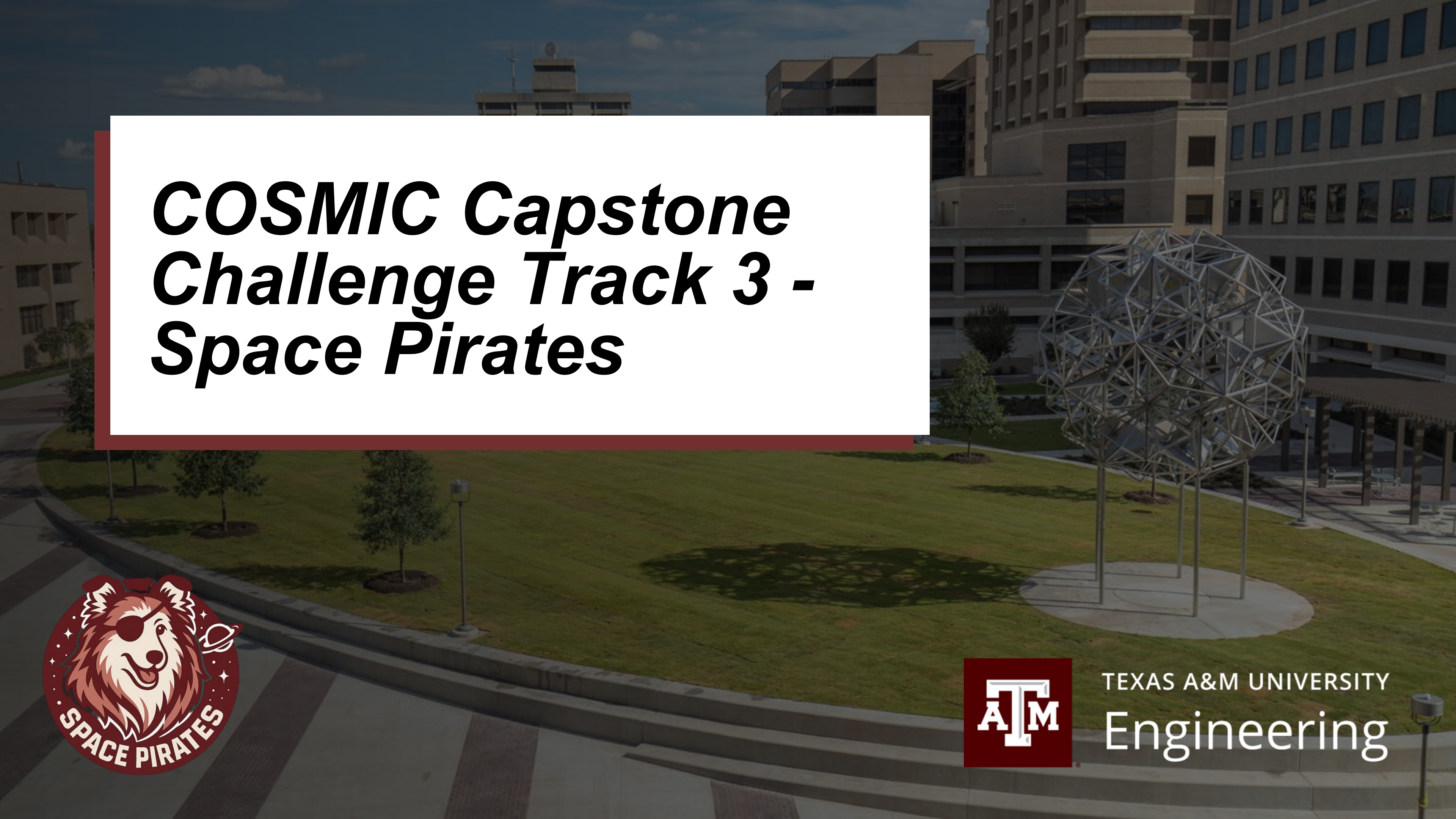


# COSMIC Capstone Challenge Track 3 - Space Pirates

SPACE PIRATES

TEXAS A&M UNIVERSITY
Engineering

# Meet the Crew

**Project Manager -** Dominic Escamilla

**Chief Engineer -** Shawn Lattner

**Structures -** Jacob Bustamante, David Limbert

**PP&T -** Eliud Garcia, Luke Logan

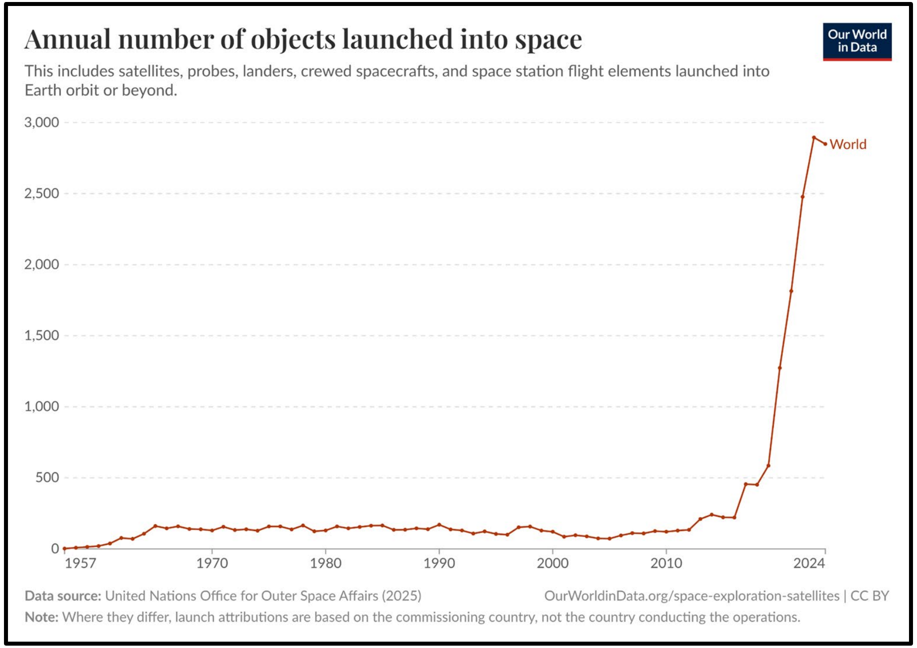
**Computer Systems -** Calvin Schroeder

**Attitude/GNC -** Carson Capps, Juan Pena, Nate Rodriguez

# Mission Overview

# Background and Motivation

- Exponentially increasing satellite population in LEO
  - Starlink, Kuiper, etc.
- No current/past way to service satellites in orbit efficiently
  - NASA OSAM-1 cancelled
- Projected 50,000+ in LEO
- SPARROW (**S**pacecraft **P**latform for **A**utonomous **R**epair **R**efuel and **O**rbital **W**ork)
- **Inclination Target: [50, 71.6]°**
- **Altitude Target: [500, 650] km**



Annual number of objects launched into space

This includes satellites, probes, landers, crewed spacecrafts, and space station flight elements launched into Earth orbit or beyond.

**Data source:** United Nations Office for Outer Space Affairs (2025) OurWorldinData.org/space-exploration-satellites | CC BY

**Note:** Where they differ, launch attributions are based on the commissioning country, not the country conducting the operations.

"Annual Number of Objects Launched into Space." *Our World in Data*, ourworldindata.org/grapher/yearly-number-of-objects-launched-into-outer-space?country=~OWID_WRL. Accessed 27 Oct. 2025

# *Design Process Overview*

## What?

- SPARROW will perform *Critical Servicing Functions (CSF)* on client satellites
    - Extend lifetimes
    - Upgrade
    - Repair
    - Refuel
    - Data transfer
    - Orbital maneuvering

## How?

- CSF will be performed by modular payloads
    - Hot-swappable
    - Customizable
    - Scalable
- Different clients require different payload
- **Robotic arm(s)** = main payload

# Stakeholders → Needs

- Most important stakeholders needs the design must meet:
    - Must comply with DoD and regulatory licensing guidelines
        - Launch safety protocols
        - Debris mitigation
        - Ground tracking permission
    - Must fit inside a payload bus of a designated launch provider
    - Must be able to dock/grapple/refuel/repair serviceable clients.

| # | Stakeholder | Needs (Musts) |
|---|---|---|
| **1** | Department of Defense | Compliance with DoD launch and safety standards/protocol |
| **2** | Launch Provider | Compliance with launch provider protocols/documentation/sizing |
| **3** | Satellite Companies (Clients) | Compliance with interfaces (docking, refueling, repair) servicing operations (orbit, rendezvous) |
| **4** | Regulatory Licensing (FAA/ FCC/ NOAA/ ITAR) | Compliance with air and space regulations, i.e. orbital debris mitigation, ground tracking |
| **5** | Mission Operations & Autonomy Team | Full operational breakdown including ConOps, mode diagrams, autonomy limits, simulation verifications, etc. |

# Goals (Success Criteria)

- **Autonomy**
  - ≥ 90 % anomaly resolution success in simulation
  - ≥ 2 autonomous client servicing operations per mission
- **Critical Servicing Function**
  - ≥ 2 distinct critical servicing functions demonstrated
  - ≥ 200 m/s ΔV capability for client repositioning
  - ≥ 90 % debris removal success rate
  - Demonstrated augmentation (Yes/No basis)
  - ≥ 200 L usable stowage for replacement parts

# System Requirements

**SYS 4.00)** The spacecraft shall include components, equipment, and sensors to perform proximity operations on various client satellites.

**SYS 6.00)** The spacecraft shall be fully autonomous and require no human-in-the-loop intervention for the duration of the mission.

**SYS 7.00)** The spacecraft shall feature > 80 % modularity across the spacecraft structure, subsystems, and payloads.

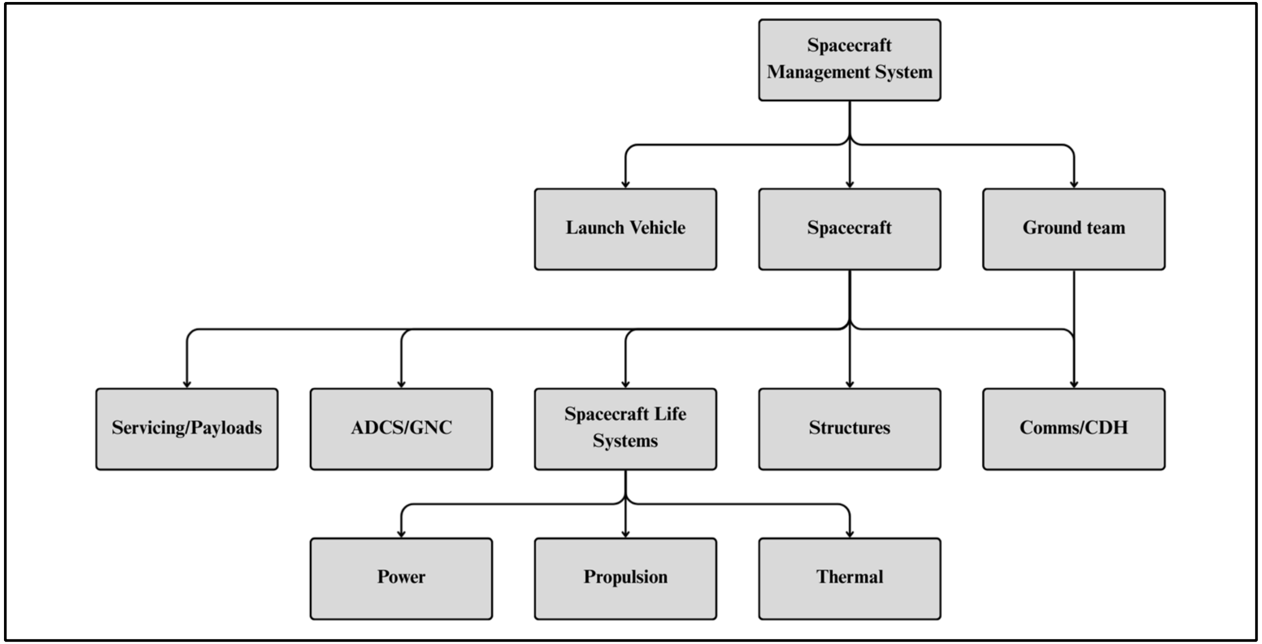
**SYS 8.00)** The spacecraft shall have > 50 % of its structures reconfigurable at any point during its lifecycle.

**SYS 15.00)** The spacecraft shall autonomously execute collision-avoidance maneuvers to maintain > 10 m clearance between all spacecraft surfaces and nearby client satellites or orbital debris.

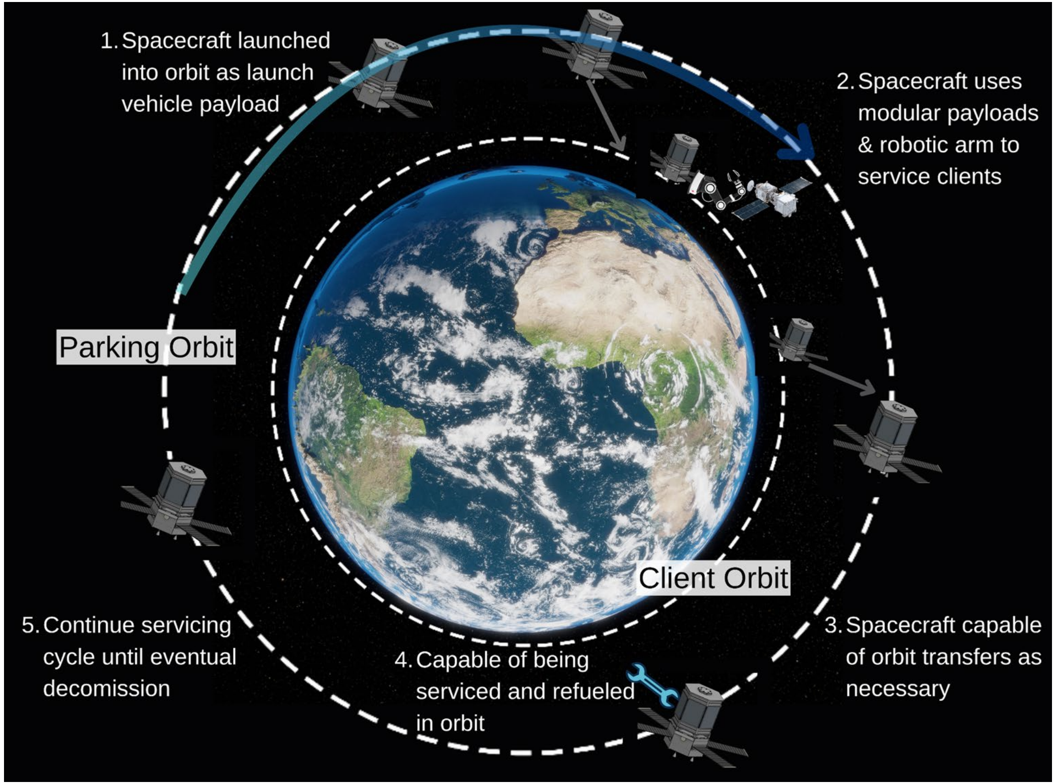
# System Concept and Architecture

# System Architecture

- Three phase operation
- Four subteams
    - Attitude/GNC
    - SLS/PP&T
    - Structures
    - C&DH/Comms
- Commercial launch vehicle

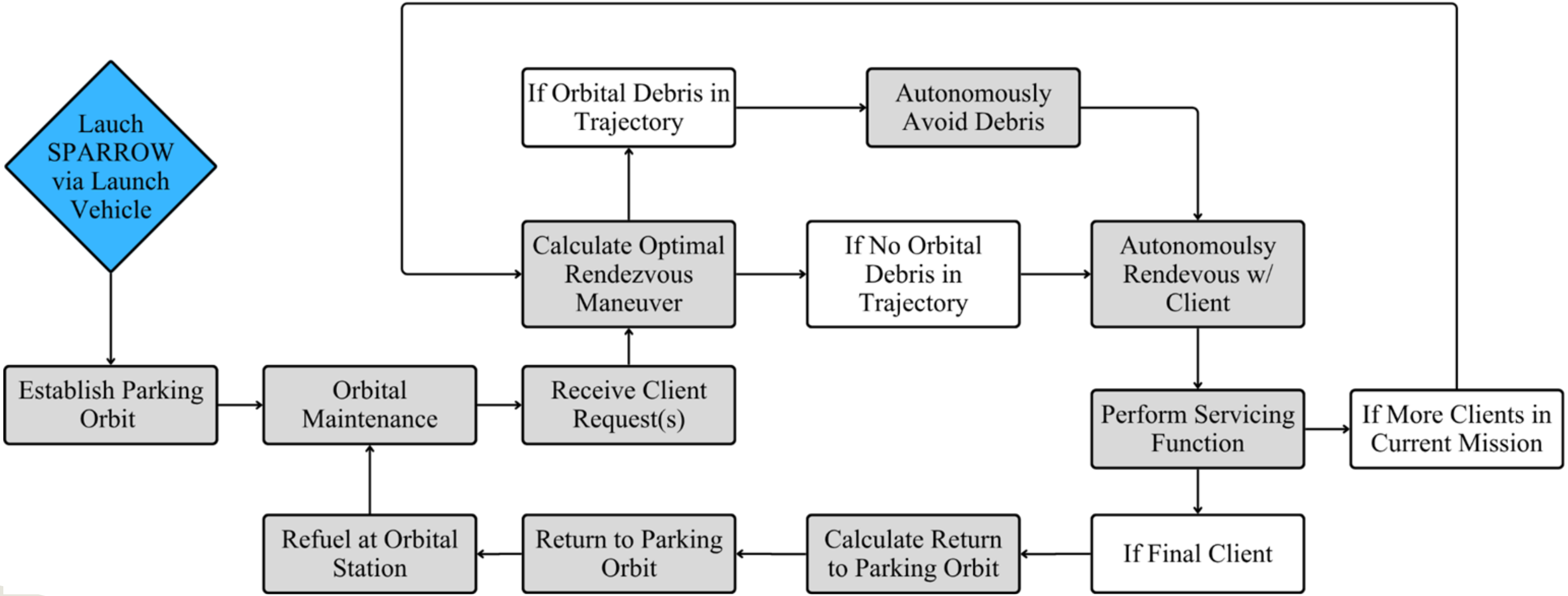


# ConOps


1. Spacecraft launched into orbit as launch vehicle payload
2. Spacecraft uses modular payloads & robotic arm to service clients
3. Spacecraft capable of orbit transfers as necessary
4. Capable of being serviced and refueled in orbit
5. Continue servicing cycle until eventual decomission

*Presenter: Dominic Escamilla*

# Functional Flow Block Diagram



Lauch SPARROW via Launch Vehicle

Establish Parking Orbit

Orbital Maintenance

Receive Client Request(s)

Calculate Optimal Rendezvous Maneuver

If Orbital Debris in Trajectory

Autonomously Avoid Debris

If No Orbital Debris in Trajectory

Autonomoulsy Rendevous w/ Client

Perform Servicing Function

If More Clients in Current Mission

If Final Client

Calculate Return to Parking Orbit

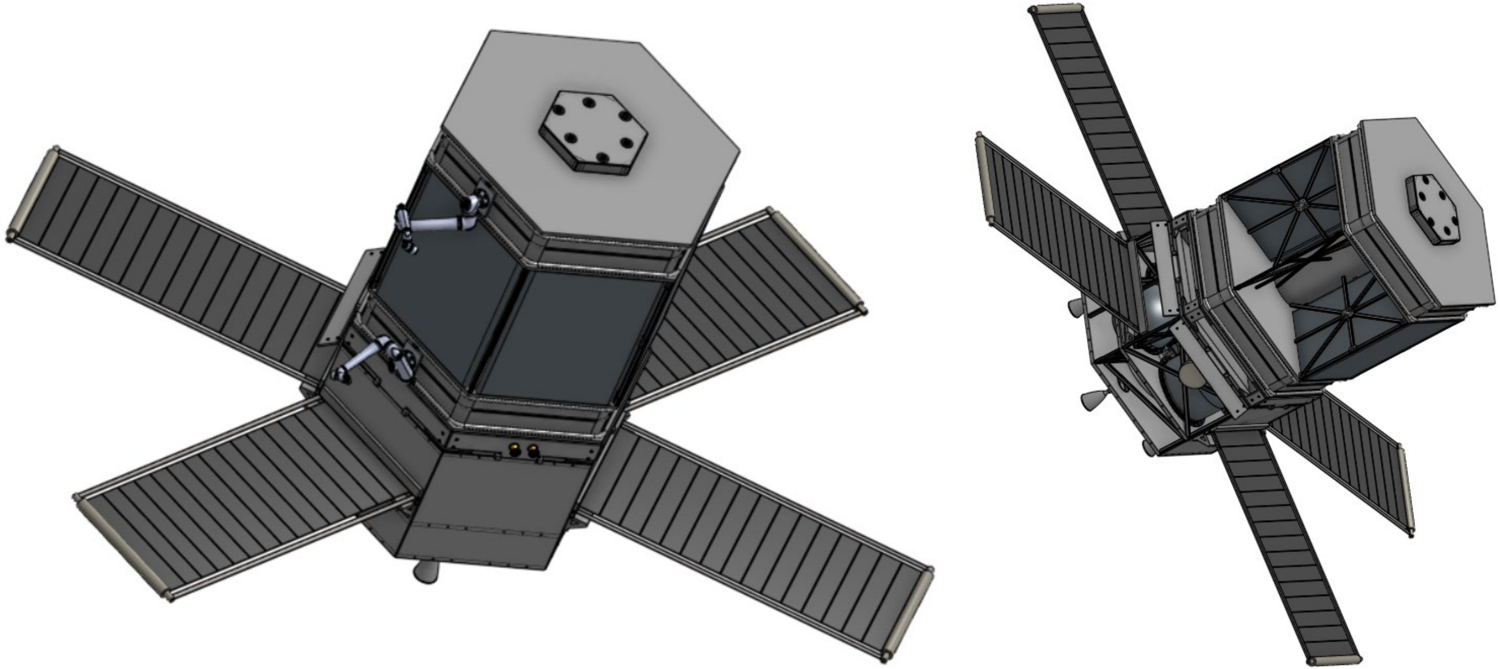
Return to Parking Orbit

Refuel at Orbital Station

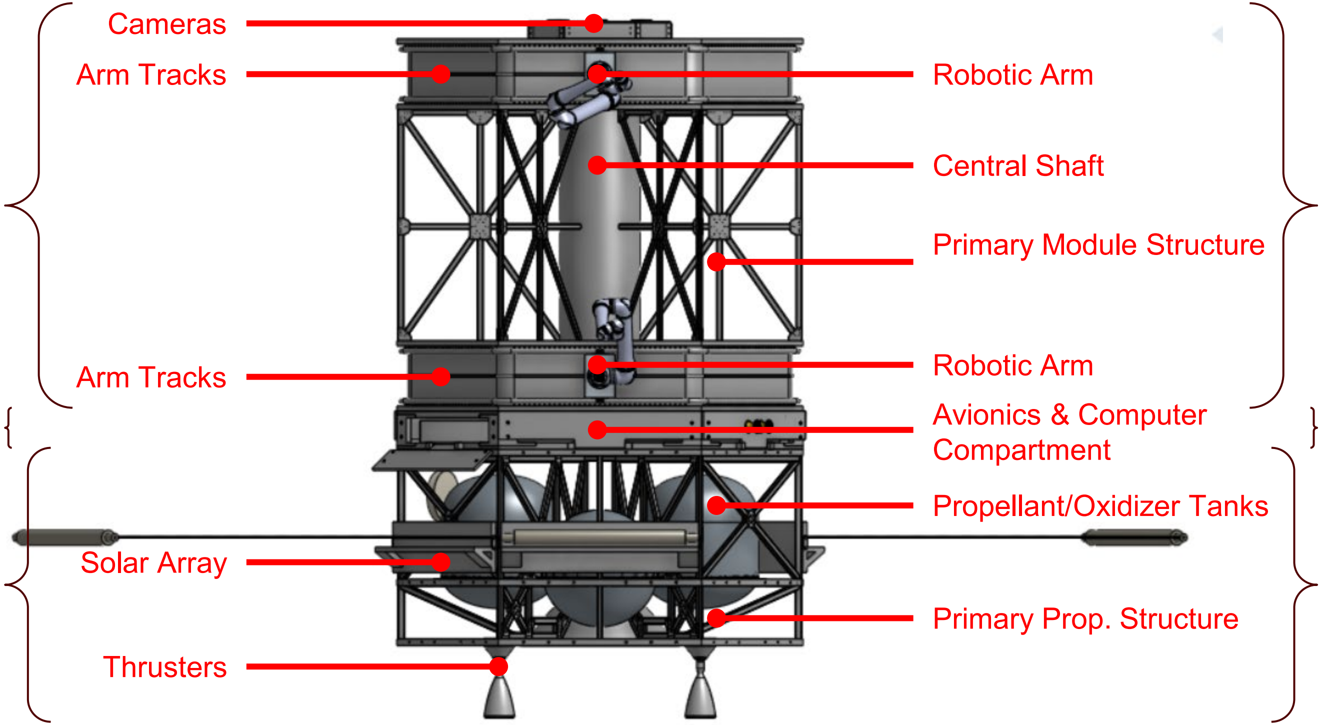
# SPARROW

**S**pacecraft **P**latform for **A**utonomous **R**epair **R**efuel and **O**rbital **W**ork

# SPARROW Overview



# Main Spacecraft Bus



Servicing Module Structure

Cameras

Arm Tracks

Robotic Arm

Central Shaft

Primary Module Structure

Arm Tracks

Robotic Arm

Avionics & Computer Compartment

Avionic & Comp. Structure

Propellant/Oxidizer Tanks

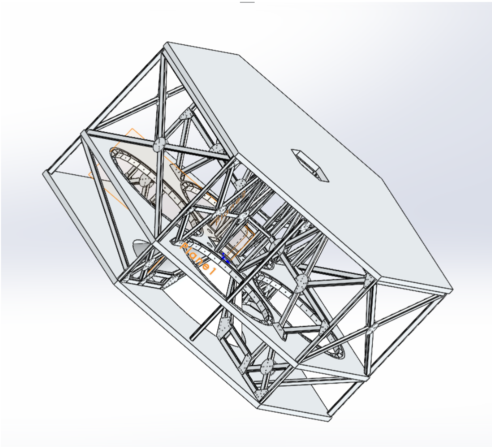
Propulsions Structure

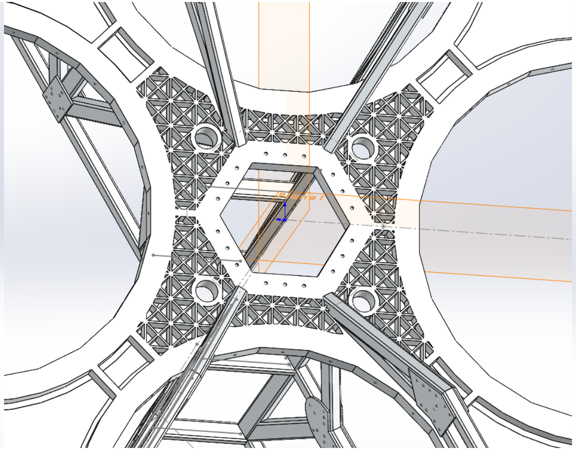
Solar Array

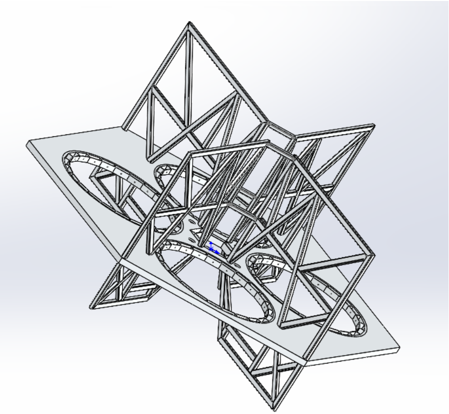
Primary Prop. Structure

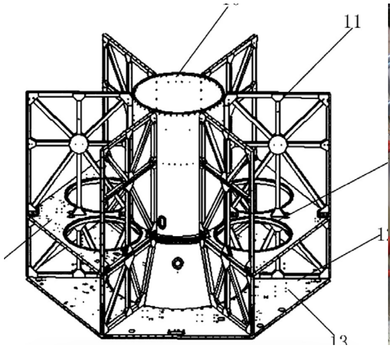
Thrusters

# Propulsion Structure

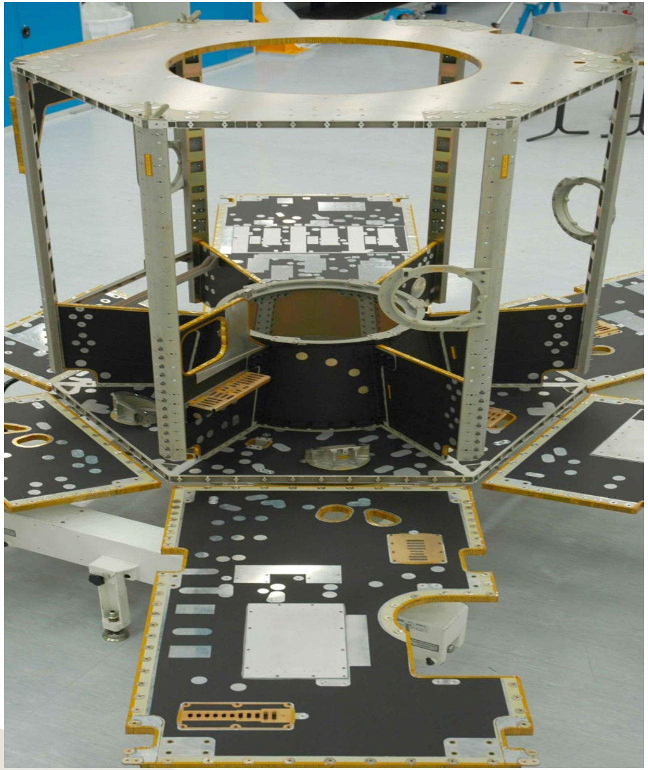


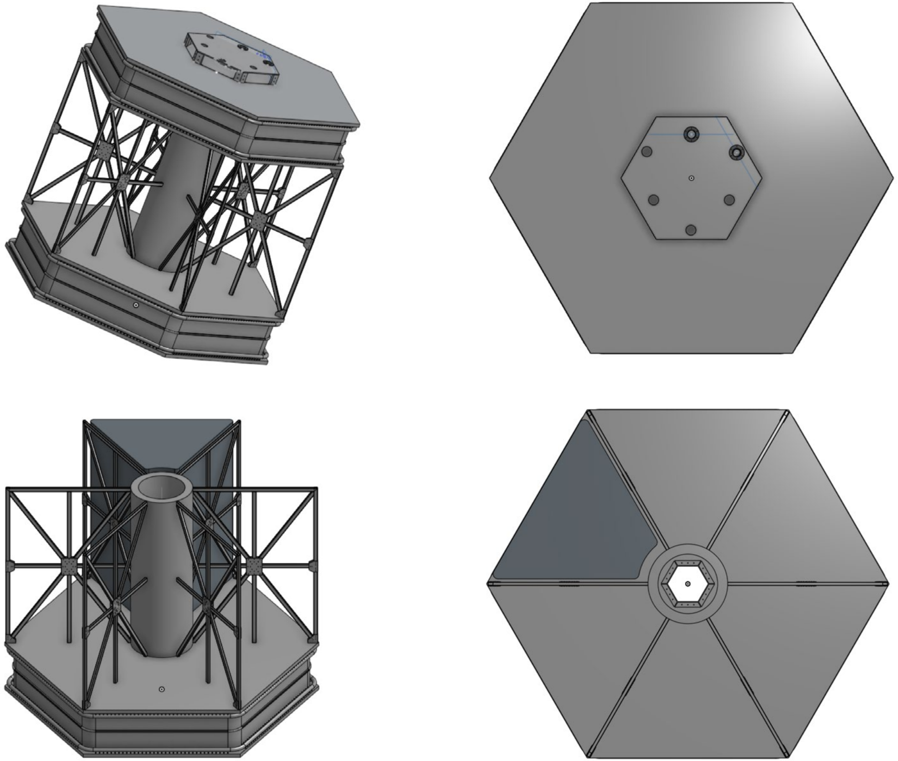




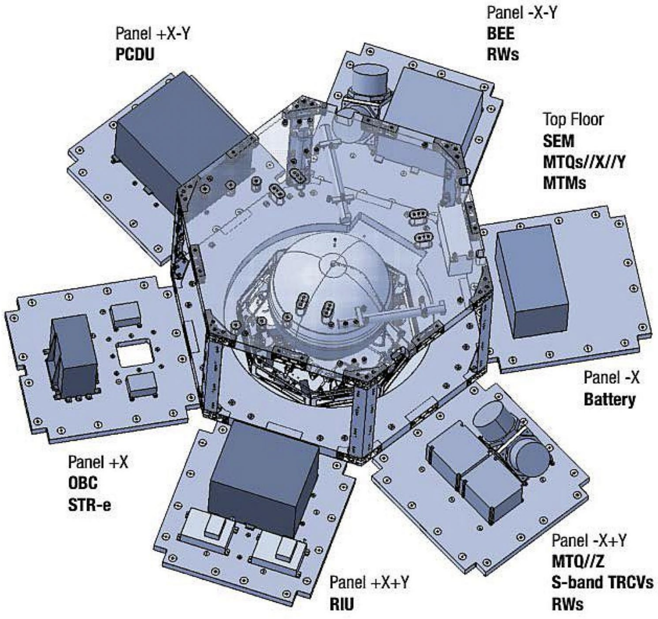


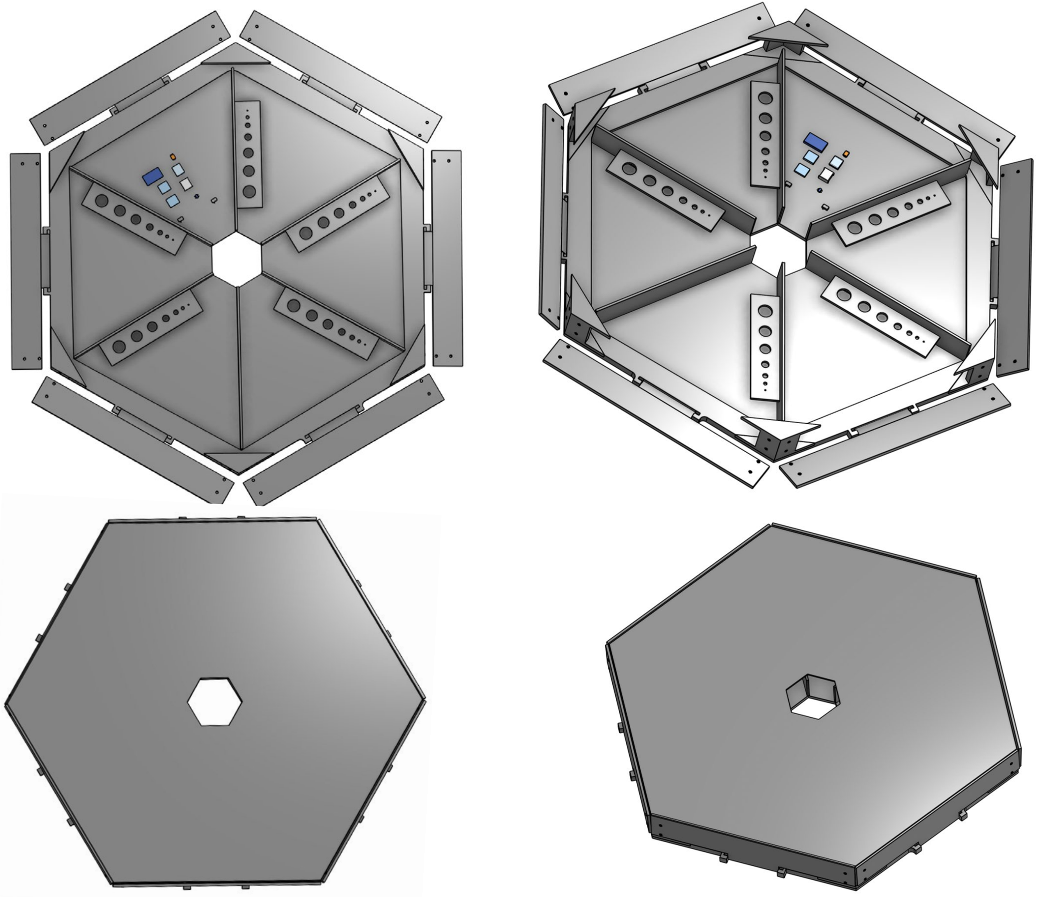
# Modular Payload Structure

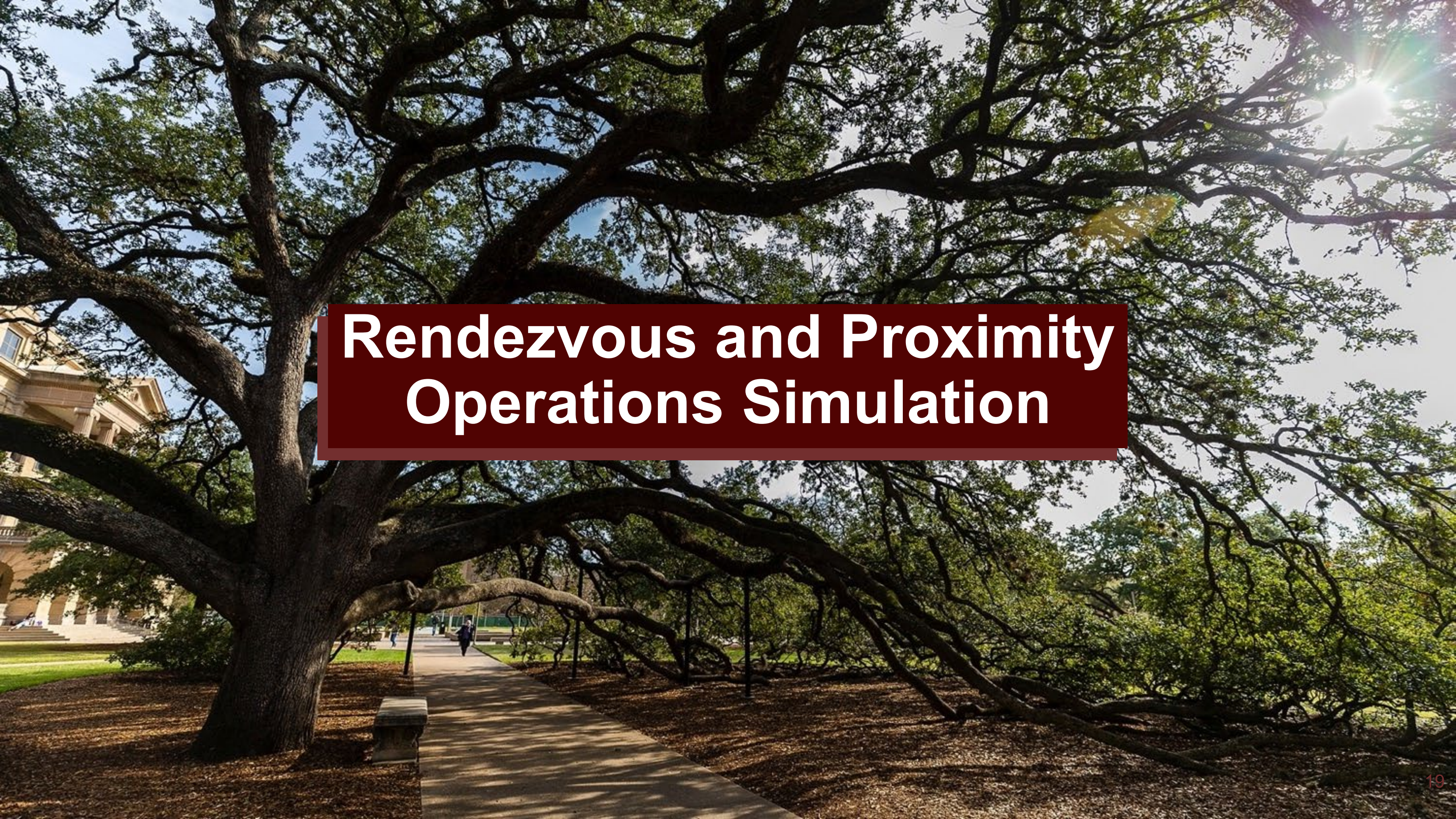




# Electronics Bay







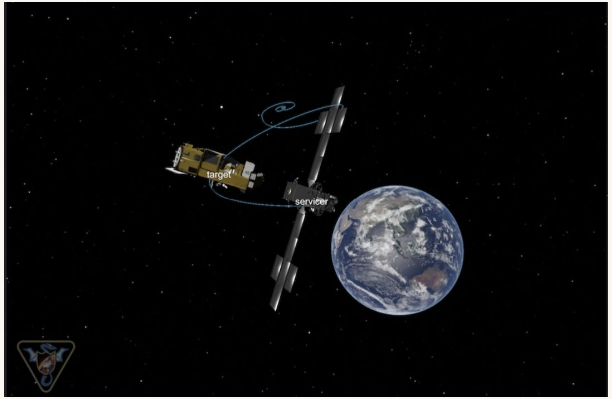
# Rendezvous and Proximity Operations Simulation

# GNC Verification & Validation Plan

**Simulation Strategy:**

We will utilize astrodynamics simulation software Basilisk for GNC system validation.

- **Truth Model:** 6-DOF Rigid Body Dynamics.
- **Nav Model:** Corrupted by sensor noise specified in sensor datasheets.



User Guide — Basilisk 2.8.41 documentation

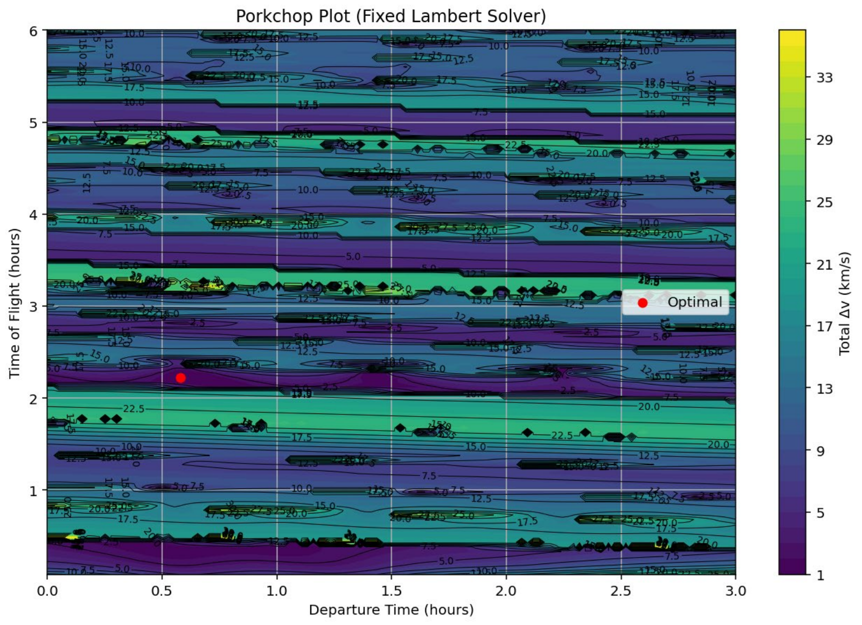
## Pass/Fail Criteria

| Metric | Requirement | Result |
|---|---|---|
| Position Estimation | < 0.05m | Pass |
| Angular rate error | $< 3\sigma$ | Pass |
| Attitude Error | $< 3\sigma$ | Pass |

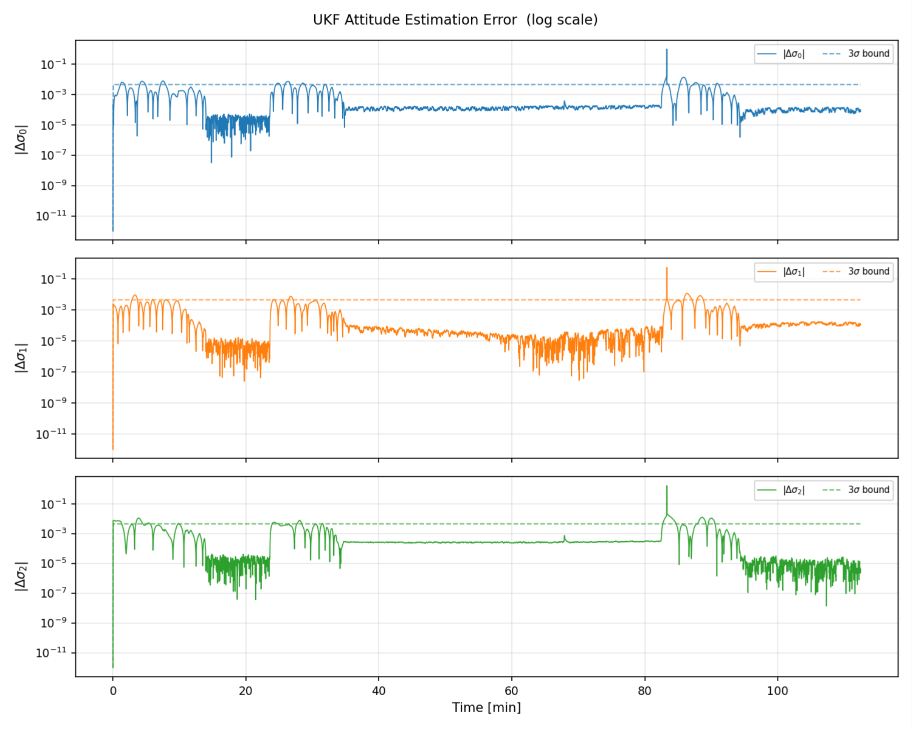
# Determination of Optimal Maneuvers

**Process Summary:**

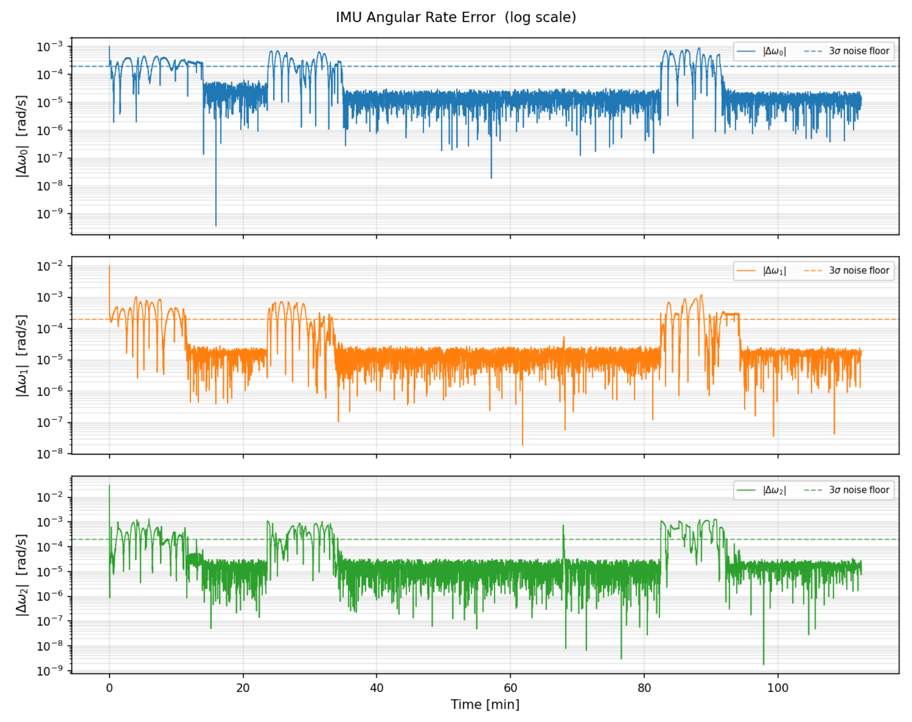
- We first propagate SPARROW and client satellite for a determined departure time
- For each departure time and a range of time of flight, we solve Lambert's problem ot obtain the transfer-orbit velocity vectors
- Using results, we can create porkchop plot (shown on the right), and we can determine the minimum delta V departure time and time of flight
- We compute the required impulses using the difference between Lambert's velocities and initial velocity vectors



# Error Plots



UKF Attitude Estimation Error (log scale)
$|\Delta\sigma_0|$
$|\Delta\sigma_1|$
$|\Delta\sigma_2|$
$3\sigma$ bound
$10^{-1}$
$10^{-3}$
$10^{-5}$
$10^{-7}$
$10^{-9}$
$10^{-11}$
0
20
40
60
80
100
Time [min]



IMU Angular Rate Error (log scale)
$|\Delta\omega_0|$ [rad/s]
$|\Delta\omega_1|$ [rad/s]
$|\Delta\omega_2|$ [rad/s]
$|\Delta\omega_0|$
$|\Delta\omega_1|$
$|\Delta\omega_2|$
$3\sigma$ noise floor
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-5}$
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
0
20
40
60
80
100
Time [min]

# Demo Video

# Sizing and Trade Studies

# Structures

## Satellite Structure Subteam

*David Limbert, Jacob Bustamante, Dominic Escamilla*

TEXAS A&M UNIVERSITY
Engineering

# Subsystem Requirements and Sizing

## Structures Requirements

**STRC 1.00)** The structure shall withstand first mode frequencies > 150 and 50 Hz in both the longitudinal and lateral axes respectively.

**STRC 2.00)** The structure shall comply with size constraints of the launch vehicle payload.

**STRC 3.00)** The structure shall have a mass < the maximum allowable payload mass of the launch vehicle

## Preliminary Sizing

Based on a max payload of ~150 kg:

- Structures should be around 150 kg
    - Based on 20% of the Dry mass of the spacecraft.

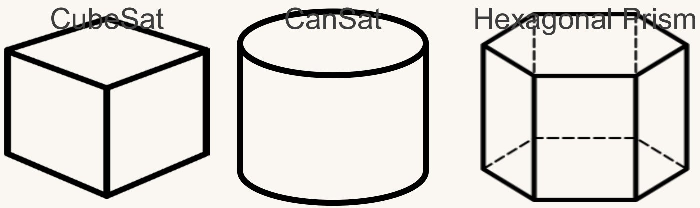
# *Material Trade Study*

- In a vacuum, titanium seems to be the best material, but cost and machinability makes it hard to use at a large scale.
- Most important criteria that should be considered is stiffness, compressive strength, concentrated stress tolerance, and corrosion resistance.
- Stainless Steel and Titanium stand out

| | **Materials Trade Study** | | | |
|---|---|---|---|---|
| **Criteria** | Aluminum | Stainless Steel | Titanium | CFRP Composites |
| Stiffness | 3 | 2 | 4 | 5 |
| Density | 4 | 1 | 3 | 5 |
| Tensile Strength | 3 | 3 | 4 | 5 |
| Compressive Strength | 2 | 4 | 5 | 3 |
| Concentrated Stress Tolerance | 3 | 4 | 5 | 1 |
| Fracture Toughness | 3 | 5 | 5 | 3 |
| Thermal Expansion | 3 | 2 | 4 | 5 |
| Heat Load Capacity | 2 | 5 | 4 | 3 |
| Corrosion Resistance | 2 | 4 | 5 | 2 |
| Ductility | 4 | 5 | 3 | 1 |
| Machinability | 5 | 3 | 2 | 2 |
| Cost | 5 | 4 | 1 | 2 |
| **Averages** | 3.25 | 3.50 | 3.75 | 3.08 |

# Shape Trade Study

- Best choice is a Hexagonal Shaped Satellite
    - Allows for better modularity (more faces).
    - Allows for easy integration.



|  | Shape Trade Study |  |  |
|---|---|---|---|
| **Criteria** | CubeSat | CanSat | Hexagon |
| Structural Stiffness | 3 | 5 | 4 |
| Manufacturability | 5 | 3 | 4 |
| Internal Volume Efficiency | 5 | 3 | 4 |
| Ease of Integration (subsystems) | 4 | 2 | 5 |
| Cost | 3 | 4 | 4 |
| Thermal Uniformity | 4 | 5 | 4 |
| **Averages** | 4 | 3.666666667 | 4.166666667 |

# Propulsion, Power, Thermal

**PP&T Subteam**

*Eliud Garcia, Shawn Lattner, Luke Logan*

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Engineering

# Subsystem Requirements

## Propulsion Requirements

**PROP 1.00)** The propulsion system shall carry 4000 m/s of deltaV required to maneuver to any satellite within the designated orbital servicing regime.

**PROP 2.00)** The propulsion subsystem shall feature a propulsion system capable of refiring the thrusters >10 times per mission to successfully transfer itself to a client and return to the spacecraft's parking orbit.

## Power Requirements

**POW 1.00)** The power system shall be capable of providing a constant power output of >7 kW for full operation of the spacecraft for the duration of the life cycle.

**POW 2.00)** The power system shall provide sufficient power to the essential functions of the spacecraft during eclipses and other power outages for > 3 hours.

**POW 3.00)** The power system shall be capable of managing and allocating the power draw to the spacecraft subsystems with automated priority sensing to sustain 120% of the power need.

## Thermal Requirements

**THM 1.00)** The thermal systems shall be capable of keeping all subsystems within their operational temperature range with a <5 K design margin

**THM 2.00)** Thermal subsystems shall reject all excess heat from the spacecraft.

*Presenter: Shawn Lattner*

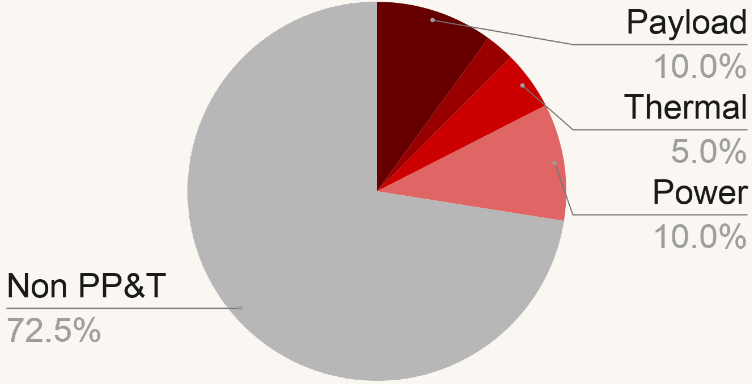
# PP&T Sizing

Payload ~ 150 kg @ 10% dry mass = ~1500kg dry mass spacecraft

Propulsion system @ 2.5% dry mass → 37.5 kg

Power @ 10 % dry mass → 150 kg

Thermal @ 5% dry mass → 75 kg



# Equations

**Rocket Equation:** $\Delta V = V_e \ln\left(\frac{M_i}{M_{bo}}\right)$

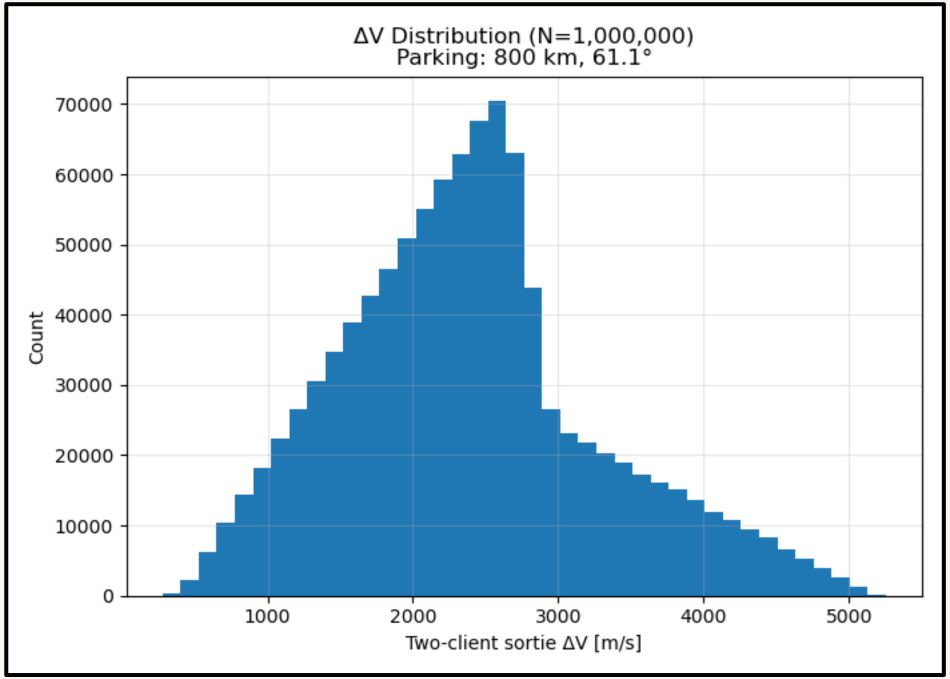
- $\Delta V$ → Change in velocity
- $V_e$ → Nozzle exit velocity
- $M_i$ → initial mass
- $M_{bo}$ → burnout mass

**Solar Panel Power:** $P = AG\eta\cos\theta$

- P → Power output
- A → Solar panel area
- G → Incident solar irradiance
- θ → Angle between sunlight and panel normal

# *Delta-V Requirement*

- **System Goals**
  - ≥ 2 autonomous client servicing operations per mission
  - ≥ 200 m/s ΔV capability for client repositioning
- **2 Client Monte Carlo Simulation ΔV Results**
  - Mean ~ 2400 m/s
  - P90 ~ 3700 m/s
  - P99 ~ 4700 m/s



# *Propulsion*

- Chemical:
  - Solid
  - Hybrid
  - Liquid
- Electric:
  - Electrothermal
  - Electrostatic
  - Electromagnetic
- Nuclear:
  - Fusion Rocket
  - Thermal Rocket
- Solar Sail
- **Winner** → Chemical
  - Maneuverable
  - Reliable
  - High thrust
  - Lowest mission time

| | Propulsion Trade Study | | | |
|---|---|---|---|---|
| **Criteria** | Chemical | Electric | Nuclear | Solar Sail |
| Specific Impulse (Isp) | 2 | 4 | 3 | 4 |
| Thrust | 5 | 3 | 4 | 1 |
| Maneuvering | 5 | 2 | 3 | 1 |
| System Mass & Volume | 3 | 3 | 2 | 3 |
| Fuel Mass | 2 | 4 | 4 | 5 |
| Power Requirements | 5 | 1 | 4 | 5 |
| Complexity & Integration Risk | 4 | 4 | 2 | 2 |
| Servicing & Docking | 4 | 3 | 2 | 1 |
| Autonomy & Reliability | 5 | 4 | 2 | 2 |
| Tech Readiness Level | 5 | 5 | 1 | 1 |
| Cost & Scalability | 5 | 4 | 2 | 2 |
| **Averages** | 4.09 | 3.36 | 2.64 | 2.45 |

# *Power*

- No power = no mission
- Generate the required power for nominal operations
- Energy Storage to survive eclipses
- Regulate, Control, and distribute power to all components
- **Winner** → Solar
  - Reliable
  - Highly modular

| | Power Trade Study | | |
|---|---|---|---|
| **Criteria** | Fuel Cells | RTG | Solar Panels + Battery |
| Continuous Power Criteria | 3 | 2 | 3 |
| Eclipse Performance | 4 | 5 | 3 |
| Specific Power | 2 | 2 | 4 |
| Complexity | 4 | 4 | 5 |
| Reliability | 3 | 4 | 4 |
| Energy Storage | 2 | 2 | 5 |
| Degradation | 4 | 5 | 3 |
| Autonomy | 4 | 4 | 4 |
| Cost & Scalability | 2 | 2 | 5 |
| Modularity | 3 | 3 | 5 |
| **Averages** | 3.10 | 3.30 | 4.10 |

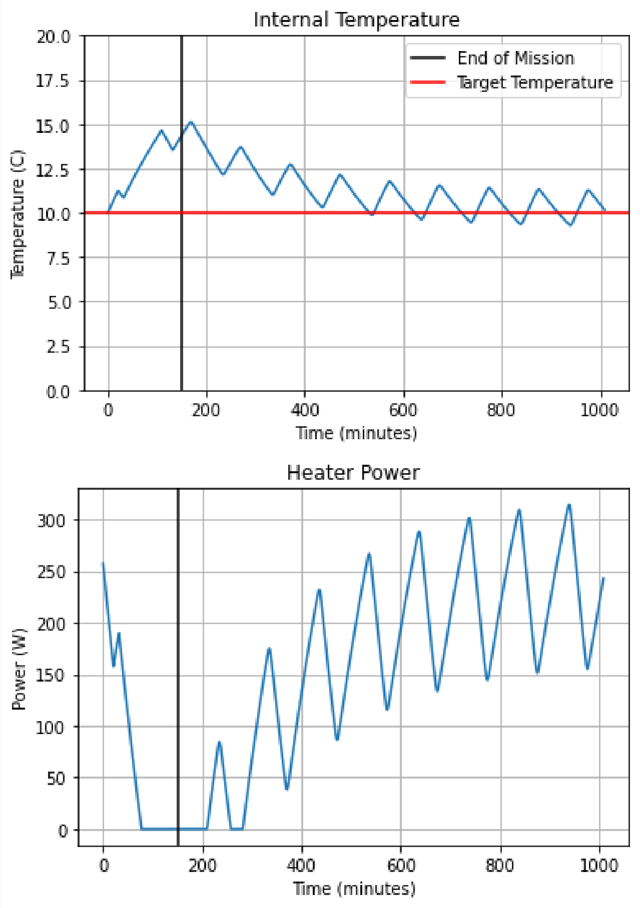
# *Thermal*

- **Active** - use mechanical, electrical, or fluid loops to transport and control heat
  - Heaters
  - Pumped fluid loops
  - Thermoelectric coolers
- **Passive** - rely on material properties, surface coatings, and thermal geometry design to control heat flow by radiation and conduction
  - Thermal washers
  - Multi-layer insulation
  - Phase change material
- **Too close to call**
  - Default to component requirements

| | **Thermal Trade Study** | |
|---|---|---|
| **Criteria** | Passive | Active |
| Control Authority | 1 | 5 |
| Adaptability | 2 | 5 |
| Eclipse Performance | 3 | 5 |
| Mass & Volume | 5 | 2 |
| Power Usage | 5 | 3 |
| Complexity | 5 | 2 |
| Reliability | 4 | 3 |
| Modularity | 5 | 5 |
| Cost & Scalability | 3 | 2 |
| **Averages** | 3.67 | 3.56 |

# *Thermal Simulations*

- Simulates servicing mission and return to parking orbit
- Internal Temperature must be between 0℃ and 20℃
- Proportional Controller to maintain an internal temperature of approximately 10℃



# Computer Systems

## Communications and C&DH Subteam

*Calvin Schroeder*

TEXAS A&M UNIVERSITY
Engineering

# Subsystem Requirements

## Communications Requirements

**COMM 1.00)** The communications system shall be able to reconnect to ground station within 2 hours of disconnect.

**COMM 2.00)** The communications system shall be capable of receiving information on client satellites and their repair needs at least daily.

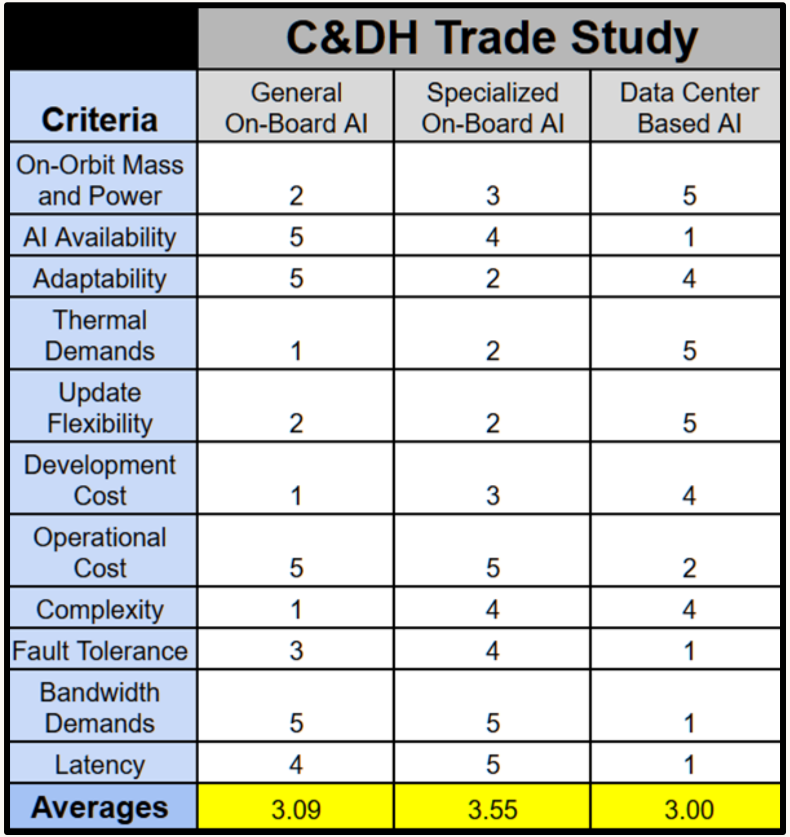
## Command and Data Handling Requirements

**CDS 1.00)** The C&DH system shall be capable of 200 TOPS minimum for artificial intelligence computations.

**CDS 2.00)** The C&DH system shall be capable of interfacing with the command and data handling systems of at least half of the client satellites using compatible communications protocols.

# Command and Data Handling

- On-board vs ground-based AI
- RAM size
- Groundbreaking AI
- Unacceptable latency
- Unprecedented failsafes



| | C&DH Trade Study | | |
|---|---|---|---|
| **Criteria** | General On-Board AI | Specialized On-Board AI | Data Center Based AI |
| On-Orbit Mass and Power | 2 | 3 | 5 |
| AI Availability | 5 | 4 | 1 |
| Adaptability | 5 | 2 | 4 |
| Thermal Demands | 1 | 2 | 5 |
| Update Flexibility | 2 | 2 | 5 |
| Development Cost | 1 | 3 | 4 |
| Operational Cost | 5 | 5 | 2 |
| Complexity | 1 | 4 | 4 |
| Fault Tolerance | 3 | 4 | 1 |
| Bandwidth Demands | 5 | 5 | 1 |
| Latency | 4 | 5 | 1 |
| **Averages** | 3.09 | 3.55 | 3.00 |

# *Communications*

- Ground vs in-space comms
- Heavily dependent on AI
- Ground AI requires optical

| | **Communications Trade Study** | | | |
|---|---|---|---|---|
| **Criteria** | RF/RF | RF/Optical | Optical/RF | Optical/Optical |
| Bandwidth | 3 | 4 | 4 | 5 |
| Weight | 2 | 3 | 3 | 4 |
| Signal Loss | 5 | 4 | 1 | 1 |
| Infrastructure | 5 | 2 | 3 | 1 |
| Pointing Demands | 4 | 3 | 2 | 1 |
| Redundancy Failsafe | 5 | 1 | 1 | 5 |
| Frequencies | 3 | 4 | 4 | 5 |
| Cost | 4 | 2 | 2 | 1 |
| Security | 3 | 3 | 5 | 5 |
| **Averages** | 3.78 | 2.89 | 2.78 | 3.11 |

# Sizing

- Heavily dependent on computing location
- Space computing
    - C&DH: 45 kg, 145 W
    - Comms: 45 kg, 200 W
- Comms and C&DH 6% of dry mass
- Comms 23% of power budget
- C&DH 17% of power budget

$$P_t = 332.93 \ln\left(P_{pl}\right) - 1046.6$$

# Attitude/GNC Systems

## Guidance, Navigation, and Control Subteam

*Carson Capps, Juan Pena Gomez, Nate Rodriguez*

TEXAS A&M UNIVERSITY
Engineering

# Subsystem Requirements

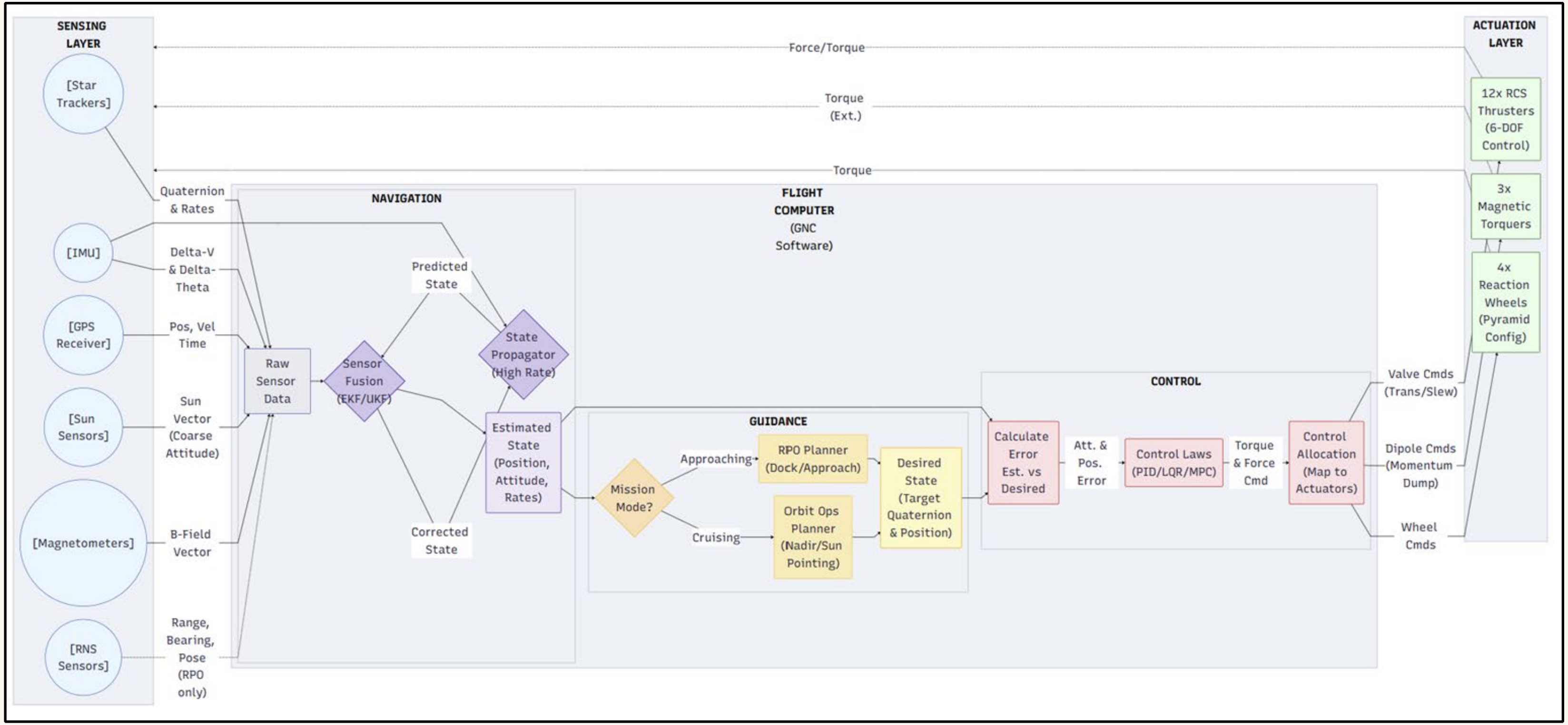
## ADCS Requirements

**ADCS 1.00)** The ADCS shall determine the spacecrafts relative navigation state with an accuracy of ≤ 0.05 meters for position, ≤ 0.01 meters/second for velocity, and ≤ 0.5 degrees for attitude.

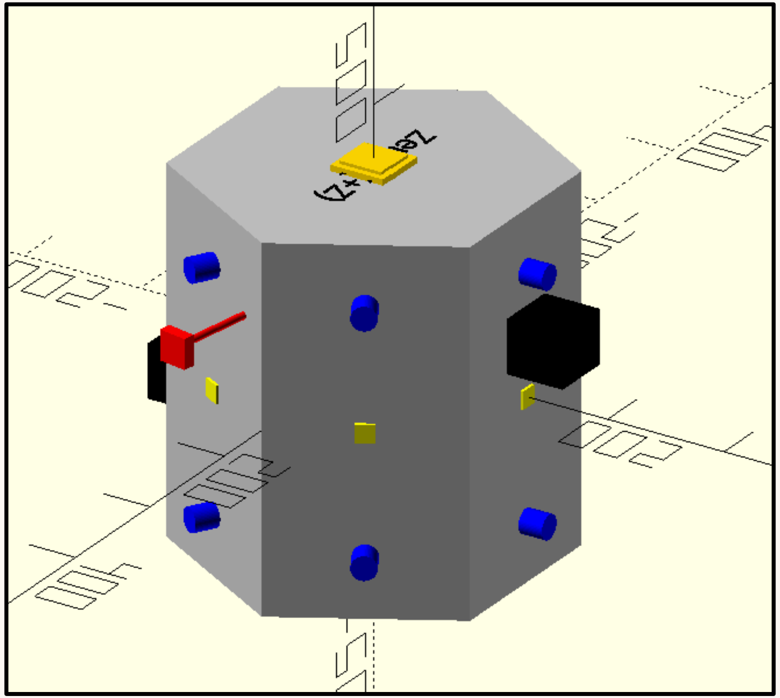
**ADCS 2.00)** The ADCS shall determine the attitude rates of the spacecraft with an accuracy of ≤ 0.01 degrees/second

**ADCS 3.00)** The ADCS shall control the spacecraft with an error less than ≤ 0.1 degrees for attitude, ≤ 0.1 meters for position, and ≤ 0.01 meters/second for velocity.

# *ADCS Architecture*



# Basic ADCS Architecture

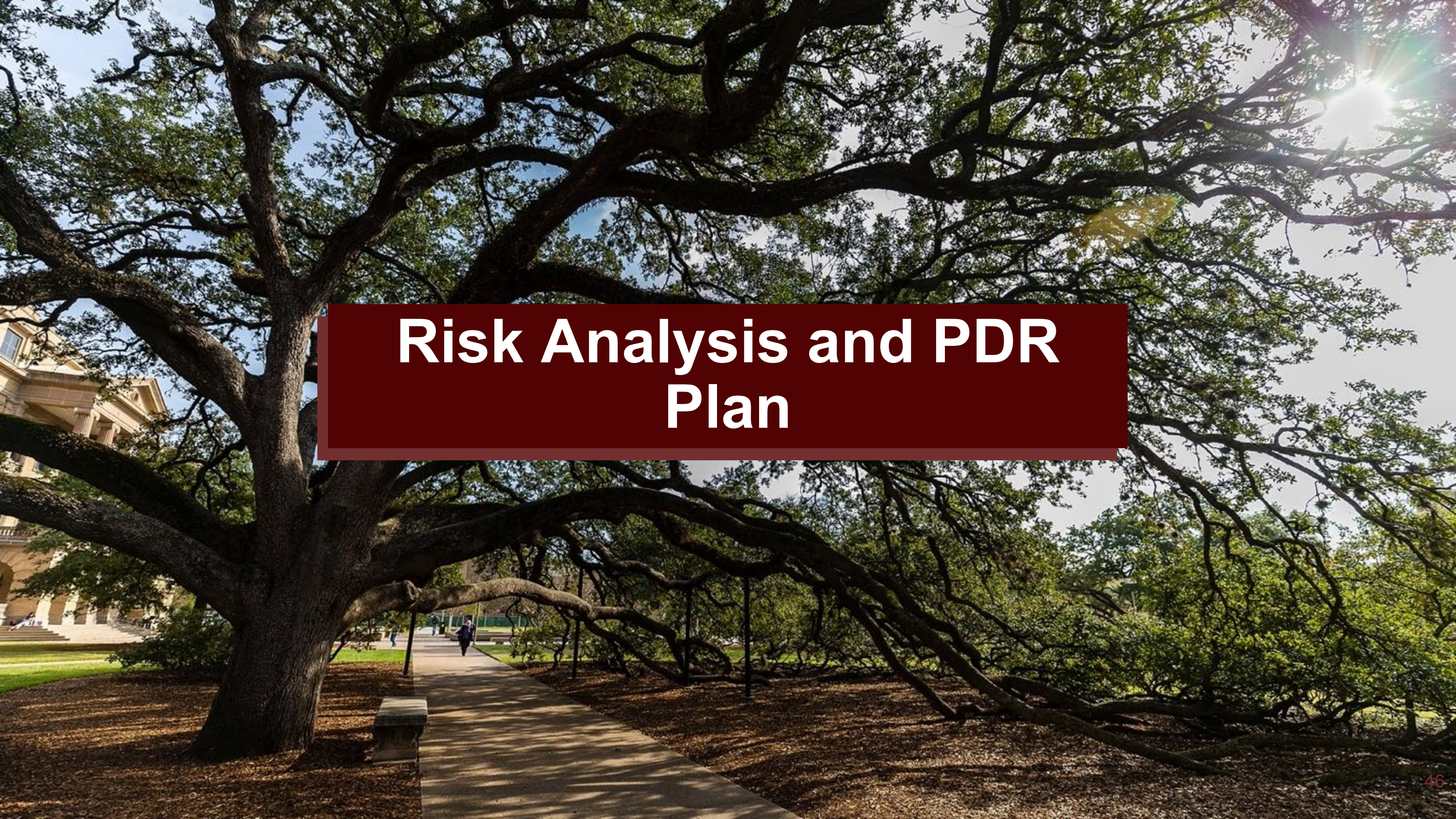


**Sensor Legend:**

⬛ Star Tracker
🟨 Sun Sensor
🟥 Magnetometer
🟧 GPS Receiver
🟦 RCS Thruster

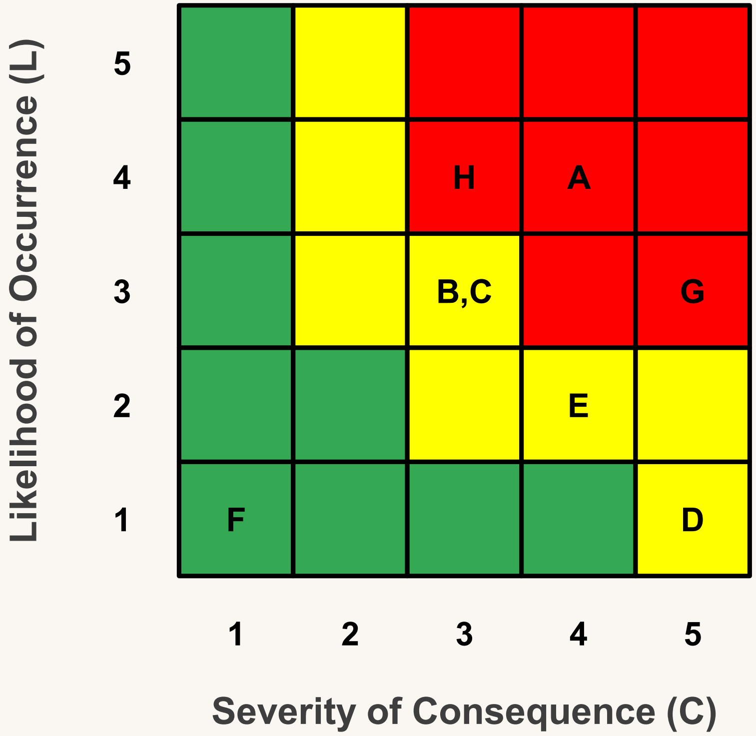
## Notes:

- Scale exaggerated for visualization
- Internal components (IMU, Reaction Wheels, Magnetic Torquers) not visualized



# Risk Analysis and PDR Plan

# Risk Analysis



| Likelihood of Occurrence (L) | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 5 | 🟩 | 🟨 | 🟥 | 🟥 | 🟥 |
| 4 | 🟩 | 🟨 | 🟥 H | 🟥 A | 🟥 |
| 3 | 🟩 | 🟨 | 🟨 B,C | 🟥 | 🟥 G |
| 2 | 🟩 | 🟩 | 🟨 | 🟨 E | 🟨 |
| 1 | 🟩 F | 🟩 | 🟩 | 🟩 | 🟨 D |

Severity of Consequence (C)

A. Thruster reaches qualification life
B. ROSA mechanism failure
C. RCS failure during proximity ops
D. Structure fail under launch loads
E. Micrometeorites pierce solar panels, thermal layers, etc.
F. Prolonged loss of ground station communication
G. AI decision making anomaly
H. Sensor degradation

# Mitigation Strategies

- Utilize four thrusters to distribute burn time across multiple engines, requiring less firing time for the same delta-V and prop mass costs.
- Optimize delta-V costs when performing orbital maneuvers.

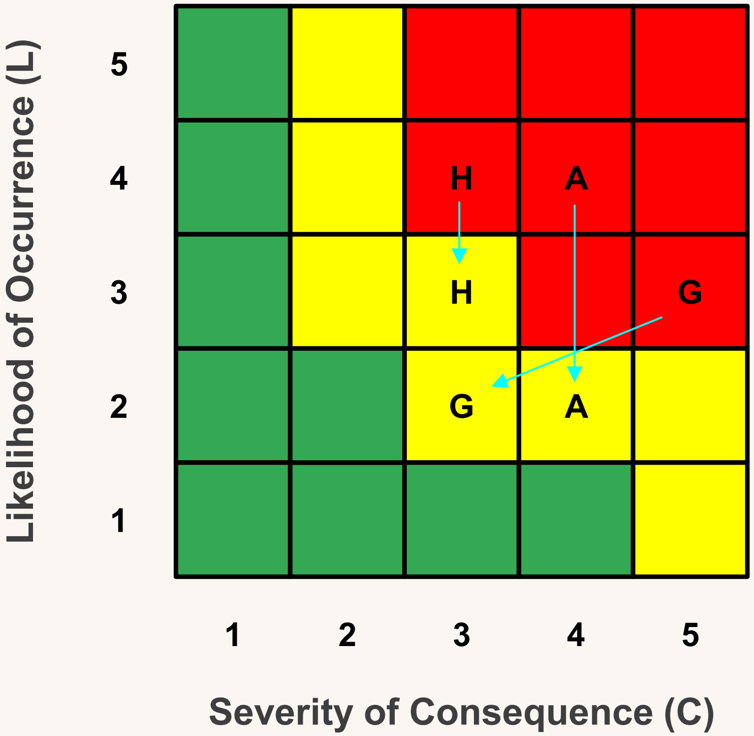
G)

- Train AI models using hard-coded fault simulations.
- Include fallback AI modes and redundant AI computer.

H)

- Include sensor redundancy and modular interfaces that allow for seamless component hot swapping between mission

# Post-Mitigation Risk Analysis



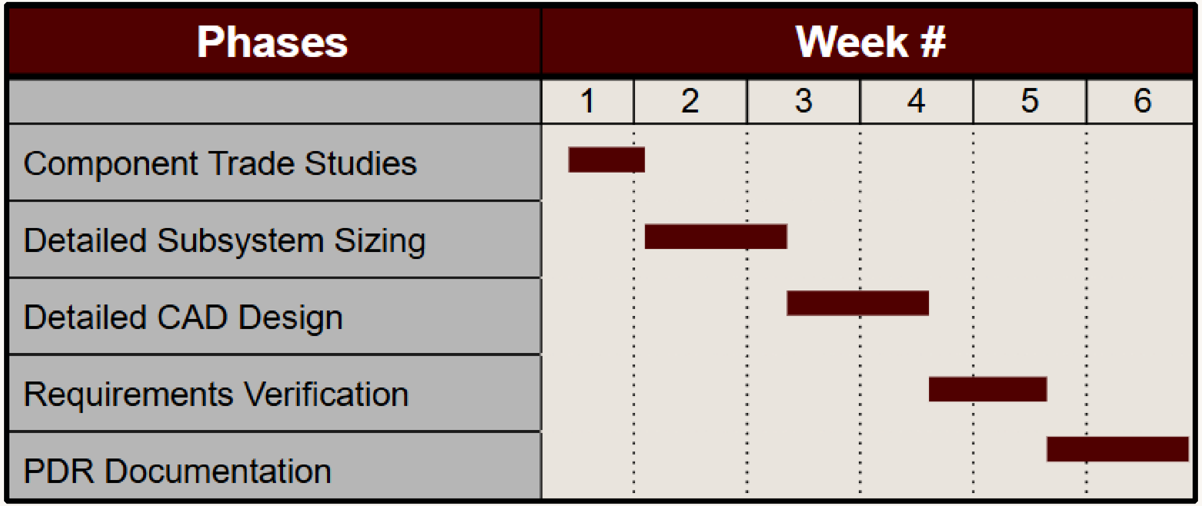
A) Thruster reaches qualification life.

G) AI decision making anomaly

H) Sensor degradation

# PDR Plan

- 6 week plan from presentation
- 5 distinct phases
- Focuses on selecting parts, sizing, V&V
- Need to upsize launch fairing



# Lessons Learned

# Innovative Concepts

- Robotic Arms opn Circumferential Tracks (Pursued)
  - Allows for full, 360° authority around spacecraft
  - Able to access multiple servicing locations
  - Highly flexible for servicing
- Orbital Docking station (Not Pursued)
  - Gas station/garage in orbit with modular part swapping capability
  - Outside project scope, would increase complexity significantly
- Fully modular payload compartments (Pursued)
  - Clients can send modular compartments to SPARROW with needed tools/interfaces
  - Hot-swappable end effectors, tools, parts, etc.
  - Major driver of spacecraft architecture
  - Highly flexible and scalable

# Technology Gap

- AI Requirement
  - Needed for decision making, diagnostics, navigation, client servicing
  - Current AI lacks full-system autonomy
  - Main priority of technological advances
- Autonomous Robotic Arm
  - High precision end effectors, pressure-sensing capabilities
  - Advancements needed in dexterity, sensing, and control
- High-powered Onboard Computer
  - Improvements needed on data processing, autonomous capabilities, and environmental protection
  - High reliability is a must

# Biggest Challenges

- Size Constraints
  - Sizing components, subsystems
  - Limited flexibility due to launch vehicle constraints
- High Modularity
  - Ultimate driver of SPARROW design
  - Modular bins for components, tools, etc.
  - Many different options explored
- System-Level Integration
  - Placement of sensors, solar panels, cameras, etc.
  - Systems engineering and design

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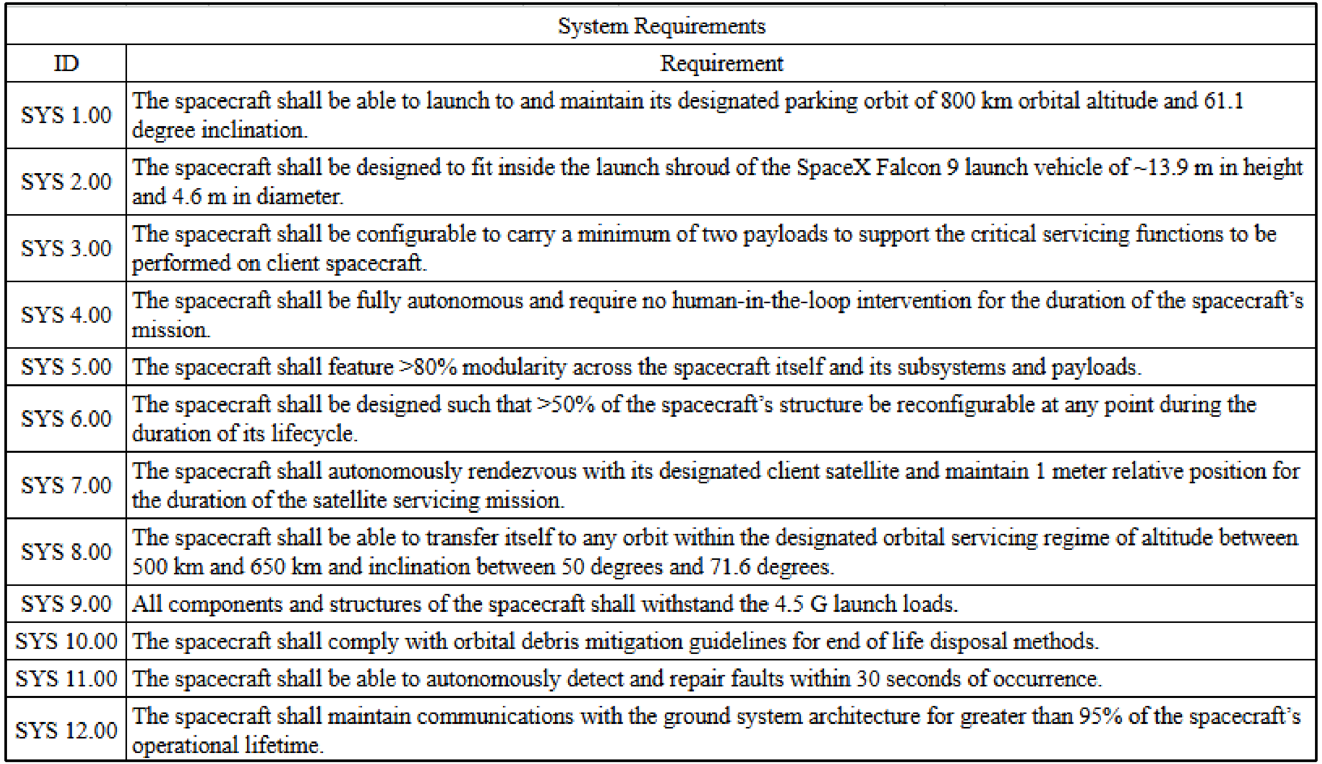
# THANK YOU

SPACE PIRATES

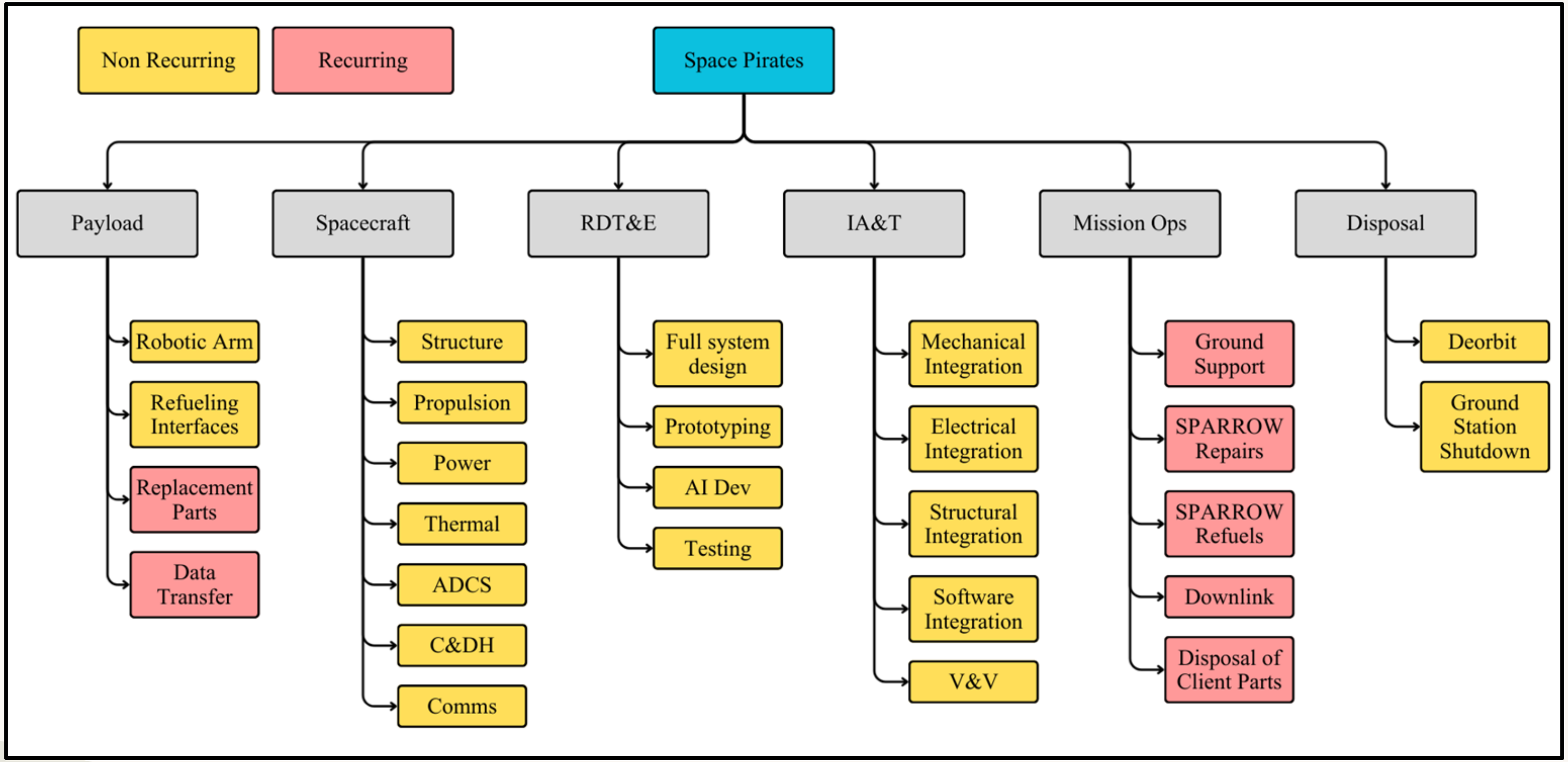
# Extra Slides

# Full System Requirements Table



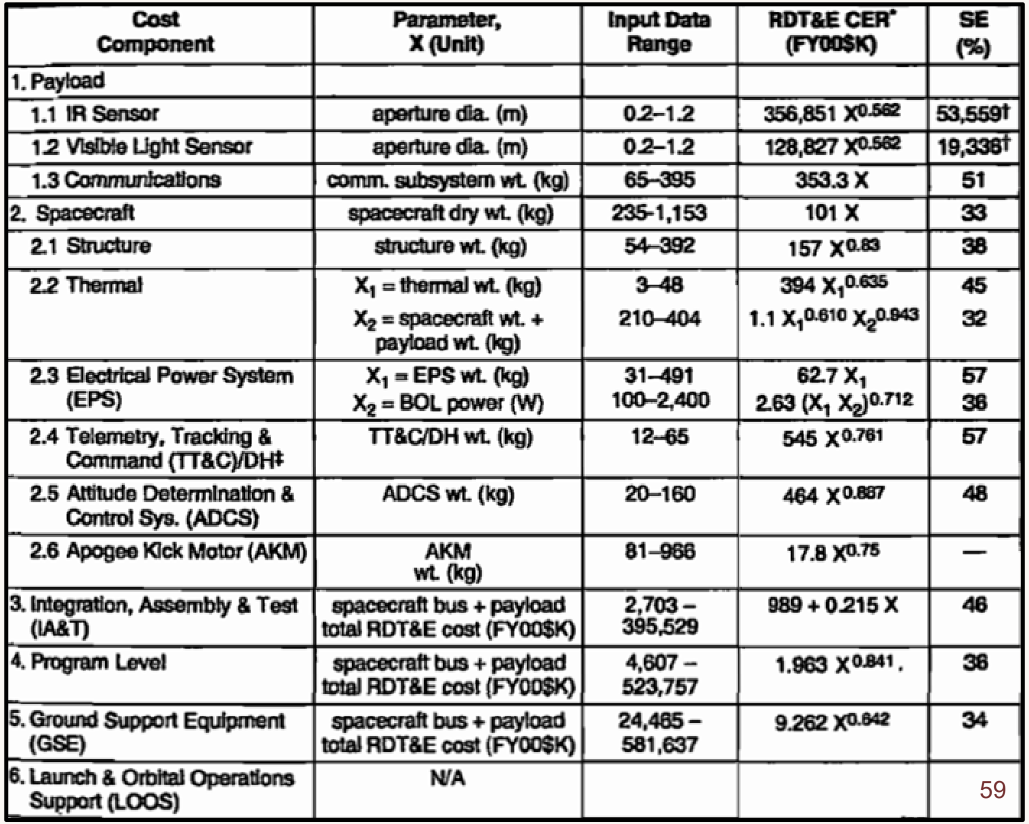
| System Requirements | |
|---|---|
| ID | Requirement |
| SYS 1.00 | The spacecraft shall be able to launch to and maintain its designated parking orbit of 800 km orbital altitude and 61.1 degree inclination. |
| SYS 2.00 | The spacecraft shall be designed to fit inside the launch shroud of the SpaceX Falcon 9 launch vehicle of ~13.9 m in height and 4.6 m in diameter. |
| SYS 3.00 | The spacecraft shall be configurable to carry a minimum of two payloads to support the critical servicing functions to be performed on client spacecraft. |
| SYS 4.00 | The spacecraft shall be fully autonomous and require no human-in-the-loop intervention for the duration of the spacecraft's mission. |
| SYS 5.00 | The spacecraft shall feature >80% modularity across the spacecraft itself and its subsystems and payloads. |
| SYS 6.00 | The spacecraft shall be designed such that >50% of the spacecraft's structure be reconfigurable at any point during the duration of its lifecycle. |
| SYS 7.00 | The spacecraft shall autonomously rendezvous with its designated client satellite and maintain 1 meter relative position for the duration of the satellite servicing mission. |
| SYS 8.00 | The spacecraft shall be able to transfer itself to any orbit within the designated orbital servicing regime of altitude between 500 km and 650 km and inclination between 50 degrees and 71.6 degrees. |
| SYS 9.00 | All components and structures of the spacecraft shall withstand the 4.5 G launch loads. |
| SYS 10.00 | The spacecraft shall comply with orbital debris mitigation guidelines for end of life disposal methods. |
| SYS 11.00 | The spacecraft shall be able to autonomously detect and repair faults within 30 seconds of occurrence. |
| SYS 12.00 | The spacecraft shall maintain communications with the ground system architecture for greater than 95% of the spacecraft's operational lifetime. |

# Work Breakdown Structure (WBS)



# Estimated Cost Table (Pt 1)

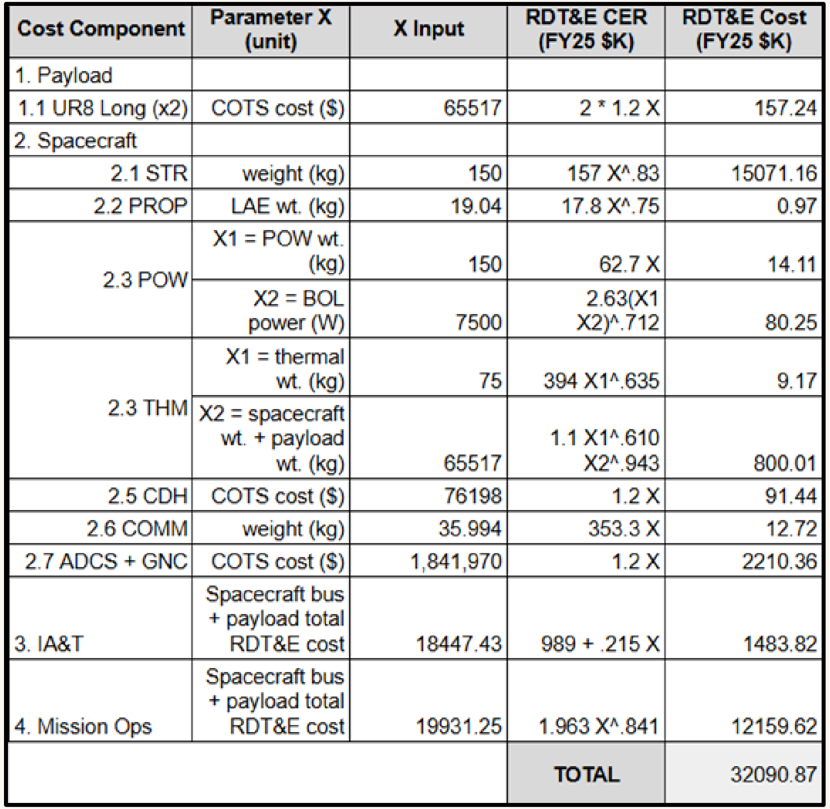
- Leverage (old) SMAD **Table 20-4**
- X parameters based on estimates + known component masses



| Cost Component | Parameter, X (Unit) | Input Data Range | RDT&E CER[*] (FY00$K) | SE (%) |
|---|---|---|---|---|
| 1. Payload | | | | |
| 1.1 IR Sensor | aperture dia. (m) | 0.2–1.2 | $356{,}851\ X^{0.562}$ | 53,559[†] |
| 1.2 Visible Light Sensor | aperture dia. (m) | 0.2–1.2 | $128{,}827\ X^{0.562}$ | 19,336[†] |
| 1.3 Communications | comm. subsystem wt. (kg) | 65–395 | $353.3\ X$ | 51 |
| 2. Spacecraft | spacecraft dry wt. (kg) | 235-1,153 | $101\ X$ | 33 |
| 2.1 Structure | structure wt. (kg) | 54–392 | $157\ X^{0.83}$ | 38 |
| 2.2 Thermal | $X_1$ = thermal wt. (kg)<br>$X_2$ = spacecraft wt. + payload wt. (kg) | 3–48<br>210–404 | $394\ X_1^{0.635}$<br>$1.1\ X_1^{0.610}\ X_2^{0.943}$ | 45<br>32 |
| 2.3 Electrical Power System (EPS) | $X_1$ = EPS wt. (kg)<br>$X_2$ = BOL power (W) | 31–491<br>100–2,400 | $62.7\ X_1$<br>$2.63\ (X_1\ X_2)^{0.712}$ | 57<br>36 |
| 2.4 Telemetry, Tracking & Command (TT&C)/DH[‡] | TT&C/DH wt. (kg) | 12–65 | $545\ X^{0.761}$ | 57 |
| 2.5 Attitude Determination & Control Sys. (ADCS) | ADCS wt. (kg) | 20–160 | $464\ X^{0.867}$ | 48 |
| 2.6 Apogee Kick Motor (AKM) | AKM wt. (kg) | 81–966 | $17.8\ X^{0.75}$ | — |
| 3. Integration, Assembly & Test (IA&T) | spacecraft bus + payload total RDT&E cost (FY00$K) | 2,703 – 395,529 | $989 + 0.215\ X$ | 46 |
| 4. Program Level | spacecraft bus + payload total RDT&E cost (FY00$K) | 4,607 – 523,757 | $1.963\ X^{0.841}$, | 36 |
| 5. Ground Support Equipment (GSE) | spacecraft bus + payload total RDT&E cost (FY00$K) | 24,465 – 581,637 | $9.262\ X^{0.642}$ | 34 |
| 6. Launch & Orbital Operations Support (LOOS) | N/A | | | |

# Estimated Cost Table (Pt 2)

- ~32 million in RDT&E costs
- COTS increased by 20% for integration costs
- Starship launch cost not factored in
  - Adds ~$70 million per launch



| Cost Component | Parameter X (unit) | X Input | RDT&E CER (FY25 $K) | RDT&E Cost (FY25 $K) |
|---|---|---|---|---|
| 1. Payload | | | | |
| 1.1 UR8 Long (x2) | COTS cost ($) | 65517 | 2 * 1.2 X | 157.24 |
| 2. Spacecraft | | | | |
| 2.1 STR | weight (kg) | 150 | 157 X^.83 | 15071.16 |
| 2.2 PROP | LAE wt. (kg) | 19.04 | 17.8 X^.75 | 0.97 |
| 2.3 POW | X1 = POW wt. (kg) | 150 | 62.7 X | 14.11 |
| | X2 = BOL power (W) | 7500 | 2.63(X1 X2)^.712 | 80.25 |
| 2.3 THM | X1 = thermal wt. (kg) | 75 | 394 X1^.635 | 9.17 |
| | X2 = spacecraft wt. + payload wt. (kg) | 65517 | 1.1 X1^.610 X2^.943 | 800.01 |
| 2.5 CDH | COTS cost ($) | 76198 | 1.2 X | 91.44 |
| 2.6 COMM | weight (kg) | 35.994 | 353.3 X | 12.72 |
| 2.7 ADCS + GNC | COTS cost ($) | 1,841,970 | 1.2 X | 2210.36 |
| 3. IA&T | Spacecraft bus + payload total RDT&E cost | 18447.43 | 989 + .215 X | 1483.82 |
| 4. Mission Ops | Spacecraft bus + payload total RDT&E cost | 19931.25 | 1.963 X^.841 | 12159.62 |
| | | | **TOTAL** | 32090.87 |

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