ARAPAIMA

Application for RSO Automated Proximity Analysis and IMAging (ARAPAIMA): Development of a Nanosat-based Space Situational Awareness Mission

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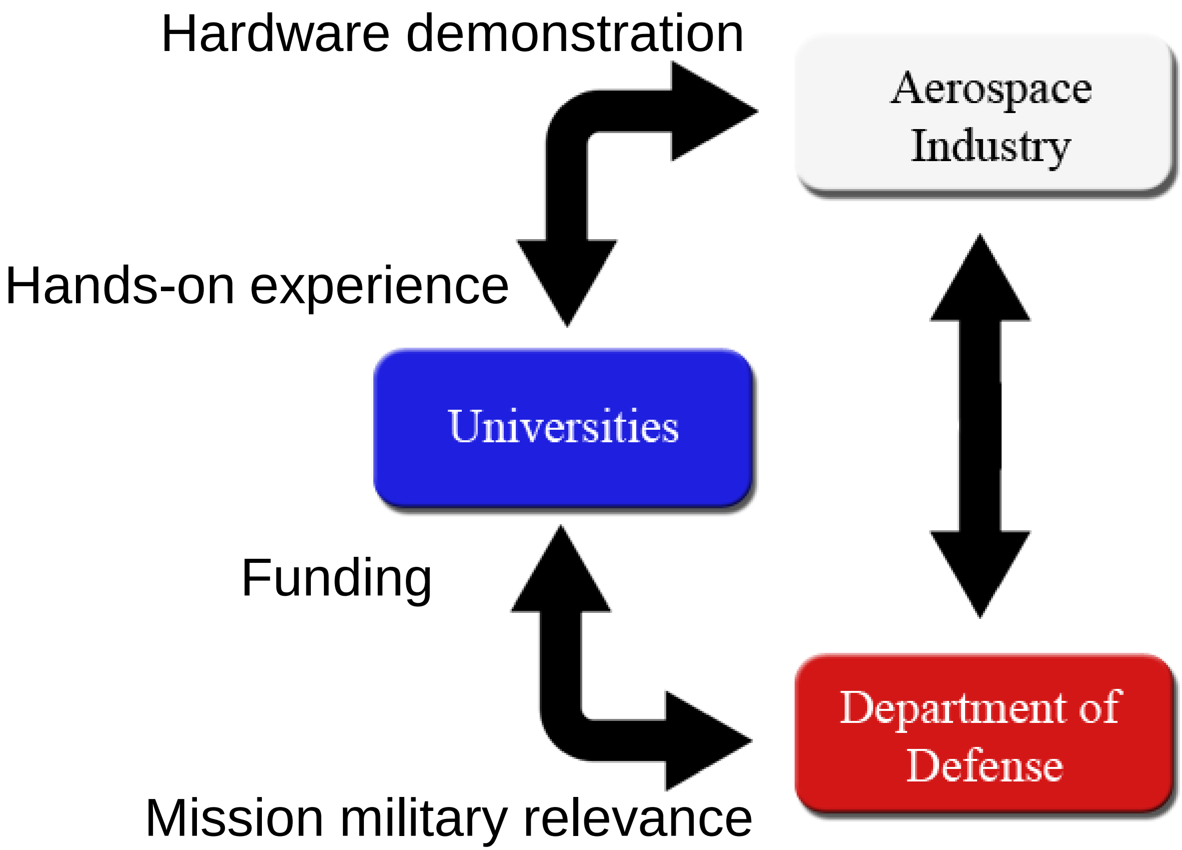
Overview

- Introduction
- Mission success criteria
- Concept of operations
- 6U Cubesat design
- Subsystems
- Conclusions

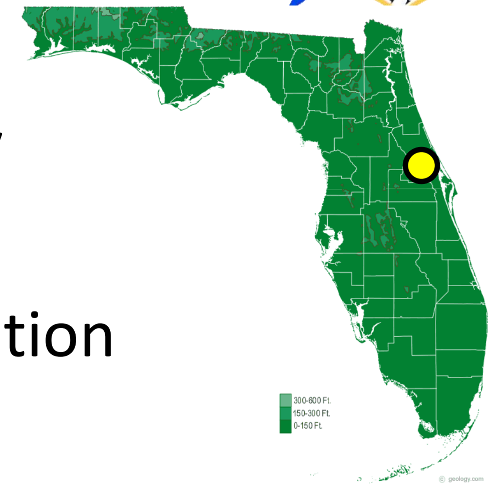
University NanoSat Program

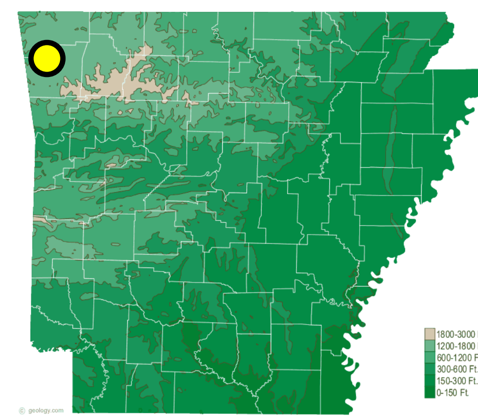


Advancing capabilities in U.S. space superiority

Team

- Embry-Riddle Aeronautical University
  - “Prime Contractor”
  - Overall design procurement and integration
  - PI: Bogdan Udrea
- University of Arkansas
  - Nanosat propulsion system
  - Co-I: Adam Huang
- Red Sky Research LLC
  - Science
  - Co-I: Mikey Nayak





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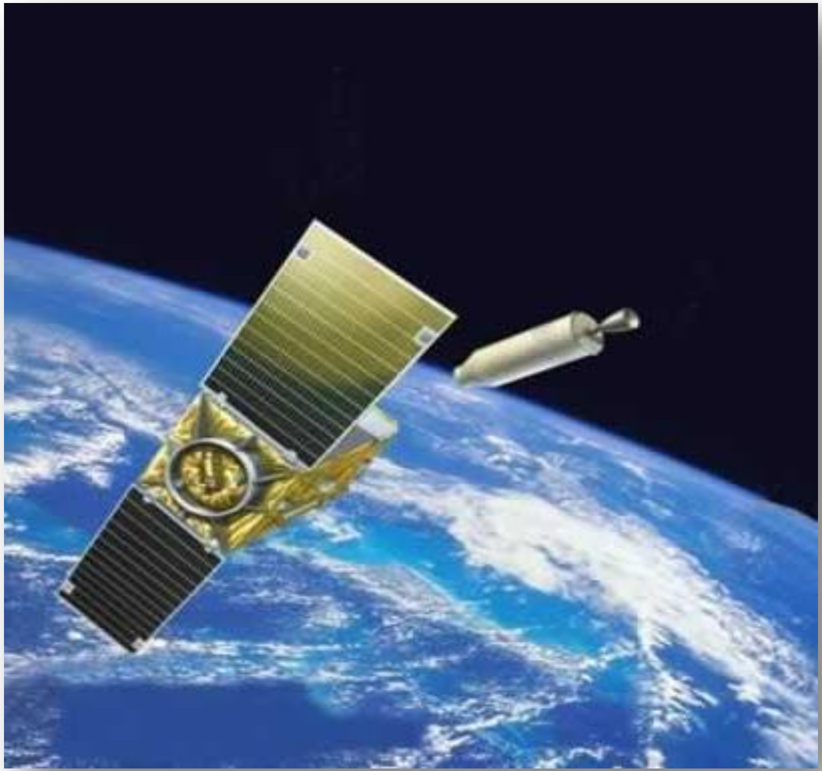
Military Relevance

Addresses 3 of 15 prioritized USAF space capabilities:

4. Space situational awareness
8. Satellite operations
10. Offensive space control

Advances Rendezvous & Proximity Ops (RPO) technology



XSS-11 autonomous proximity operations.
(Image from spacetoday.org)

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Mission Overview

ARAPAIMA is a 6U cubesat which autonomously maneuvers in close proximity to a Resident Space Object (RSO) for visible, IR, and 3D imaging.

Mission objectives:

- Determine the 3-D shape of the RSO without previous knowledge
- Autonomously navigate and safely maneuver in close proximity to the RSO, in low earth orbit
- Estimate the attitude state of the RSO by remote observation

Science Problem Statement

- Perform relevant space-based SSA with a nanosat
- Without a priori knowledge of RSO shape or attitude:
  - Assess the capability of the visual and visual-aided navigation algorithms to:
    1. Extract 3D shape knowledge of the RSO
    2. Estimate the attitude state of the RSO
  - Perform infrared radiometry science
- Execute near-optimal trajectories to maximize space-based surveillance of the RSO in low earth orbit
- Validate on-board autonomous relative trajectory
  - Planning
  - Control
  - Execution

Mission Success Criteria

- **Minimum success**

  Take an unresolved image of the RSO and downlink it to the ground station.

- **Full success**

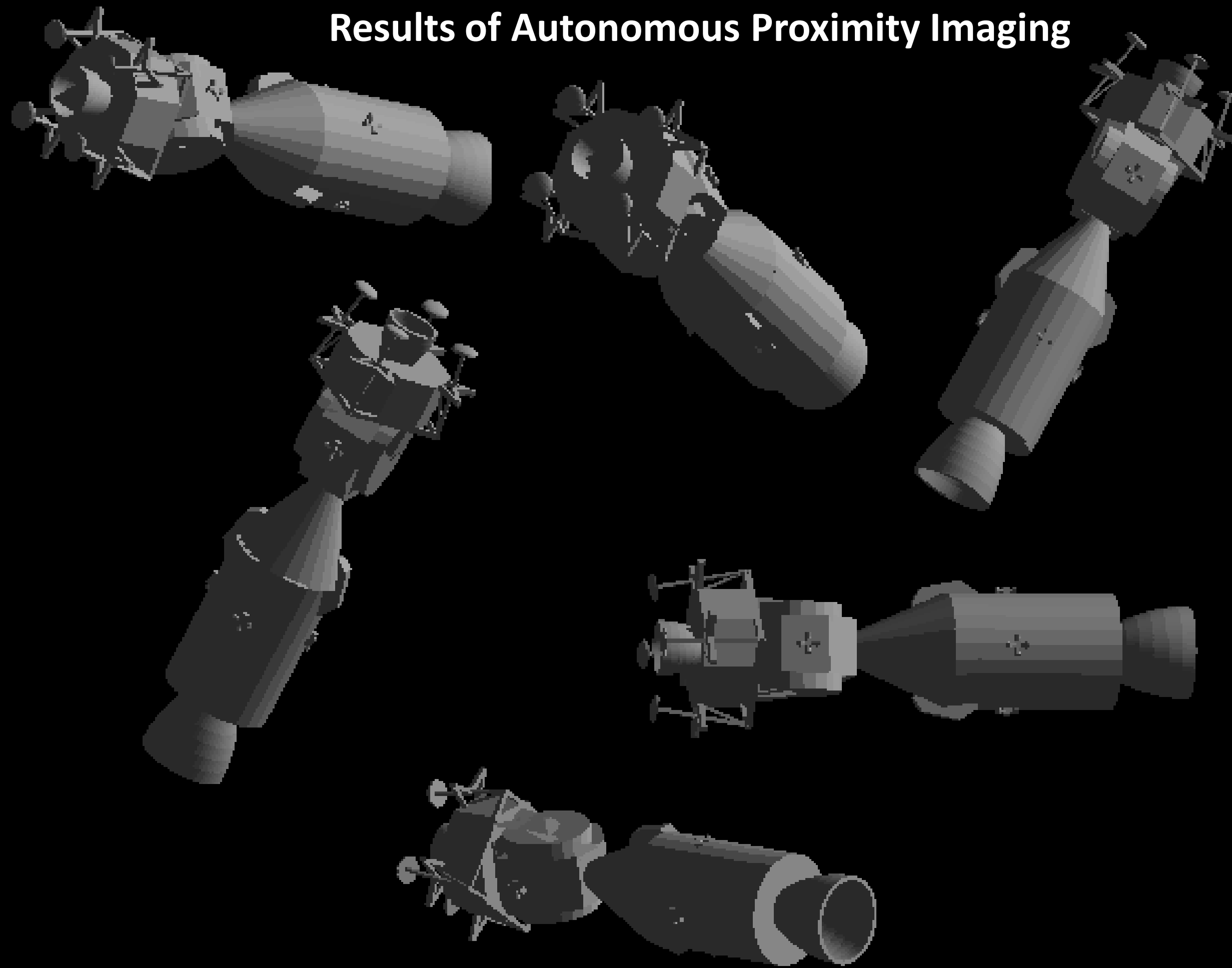
  Maneuver into the proximity of the RSO, with preloaded commands, and take an image in which the RSO occupies at least 15% of the pixels of the visible and IR spectrum cameras.

- **Extended mission success**

  On-board planning and execution of maneuvers to acquire a relative orbit with respect to the RSO and use the LRF to generate a 3D point cloud.

Imaging Results - Simulation

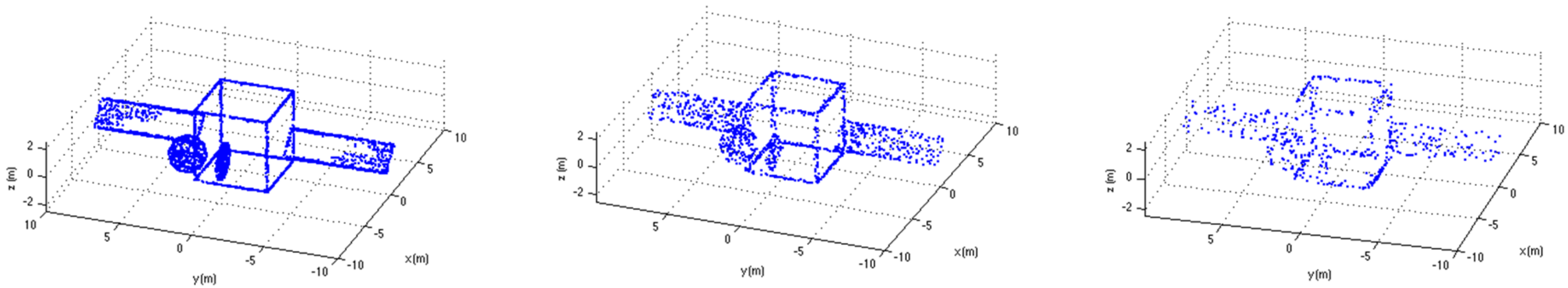
Results of Autonomous Proximity Imaging



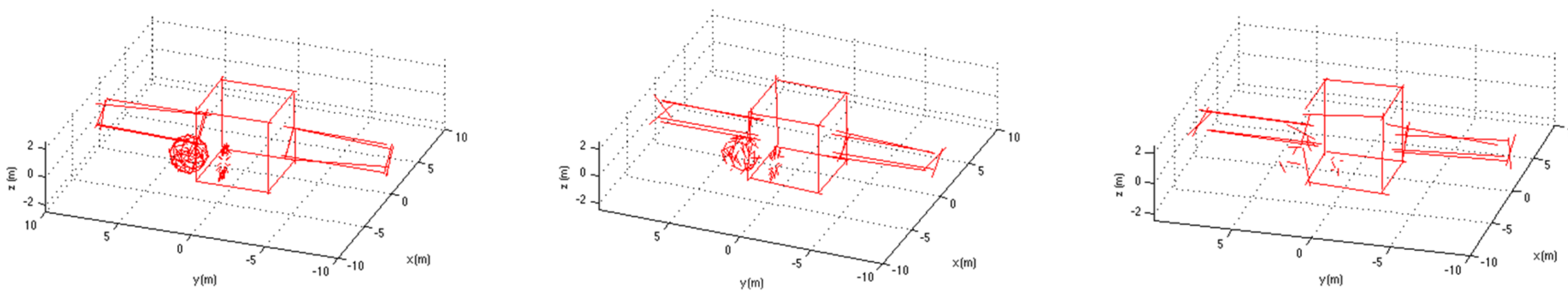
Unknown RSO: Upper stage with attachment of interest

3D Imaging Results - Simulation

With robust RSO attitude solution, LRF-only sensor can recover shape knowledge of unknown RSO.



LRF-only point clouds: 89,000 / 11,000 / 3,500 strikes



Shape reconstruction after: 32 / 12 / 4 hours of surveillance

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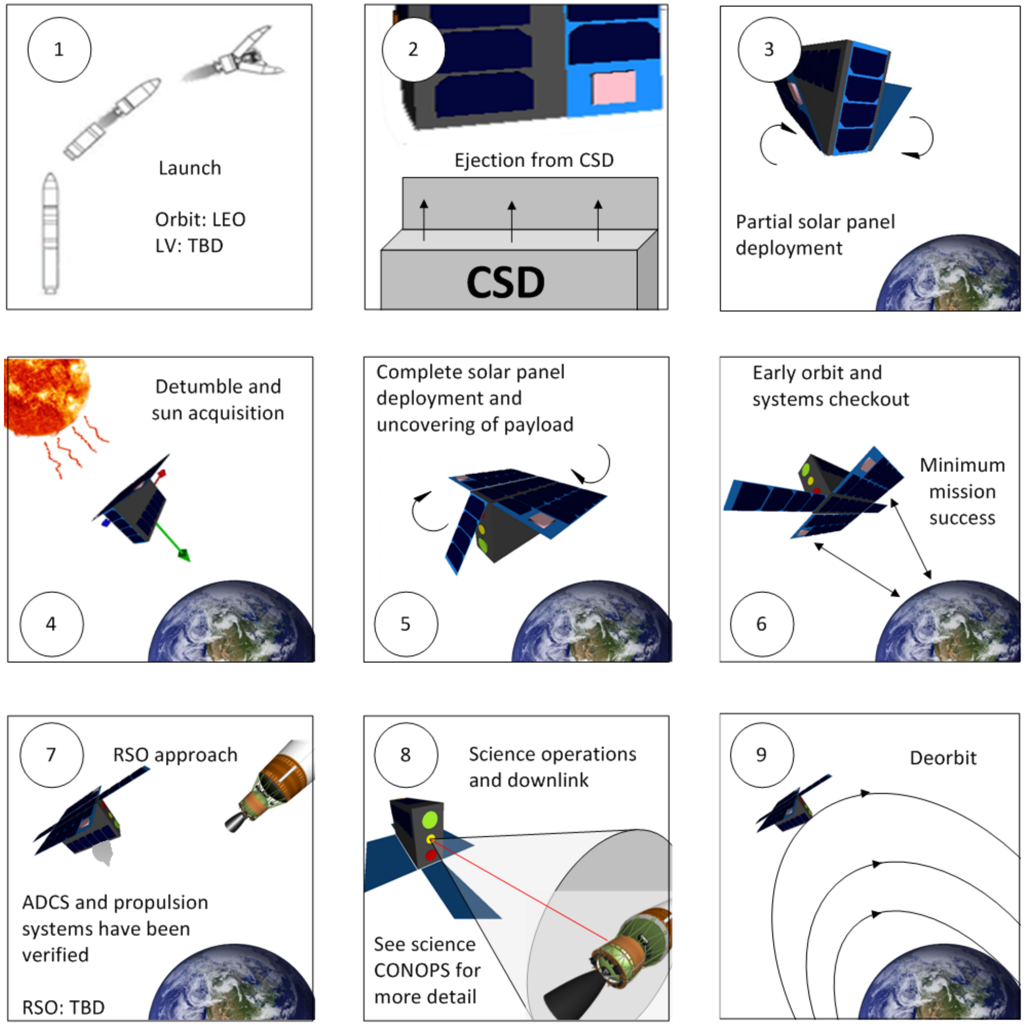
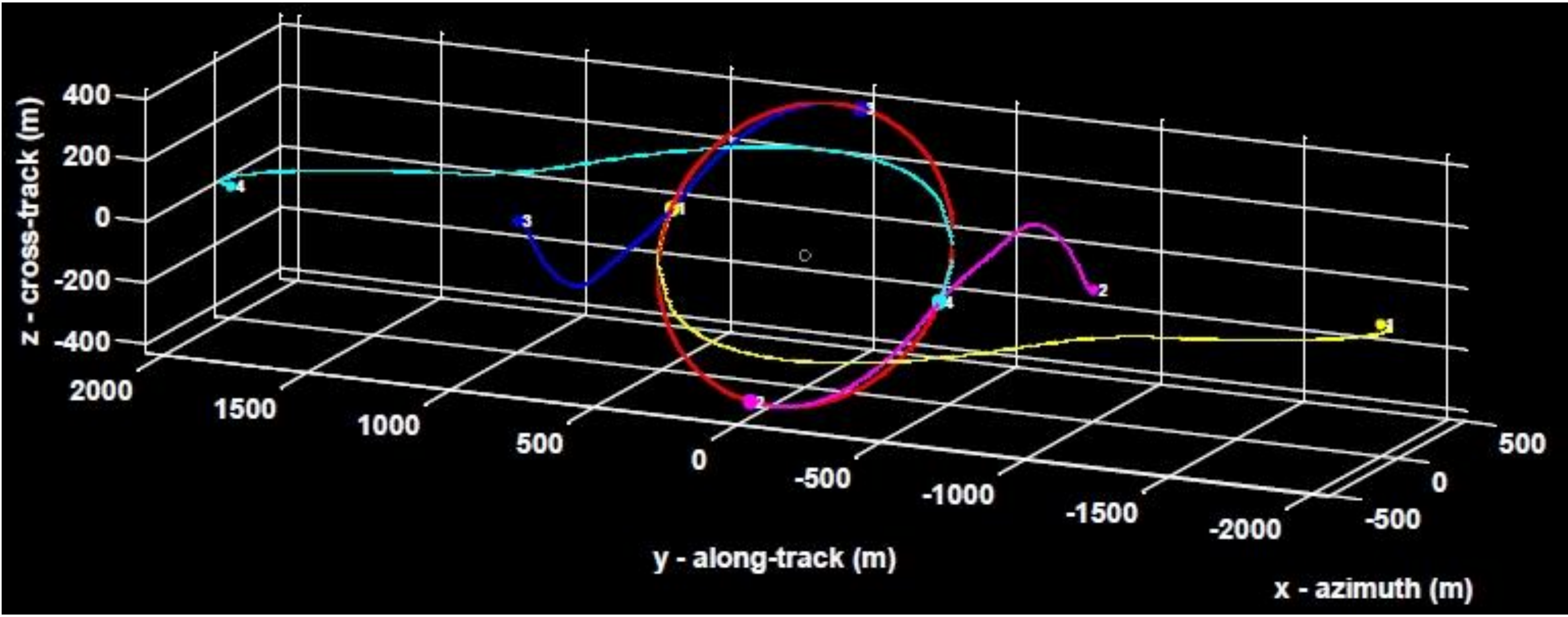
Overall Concept of Operations

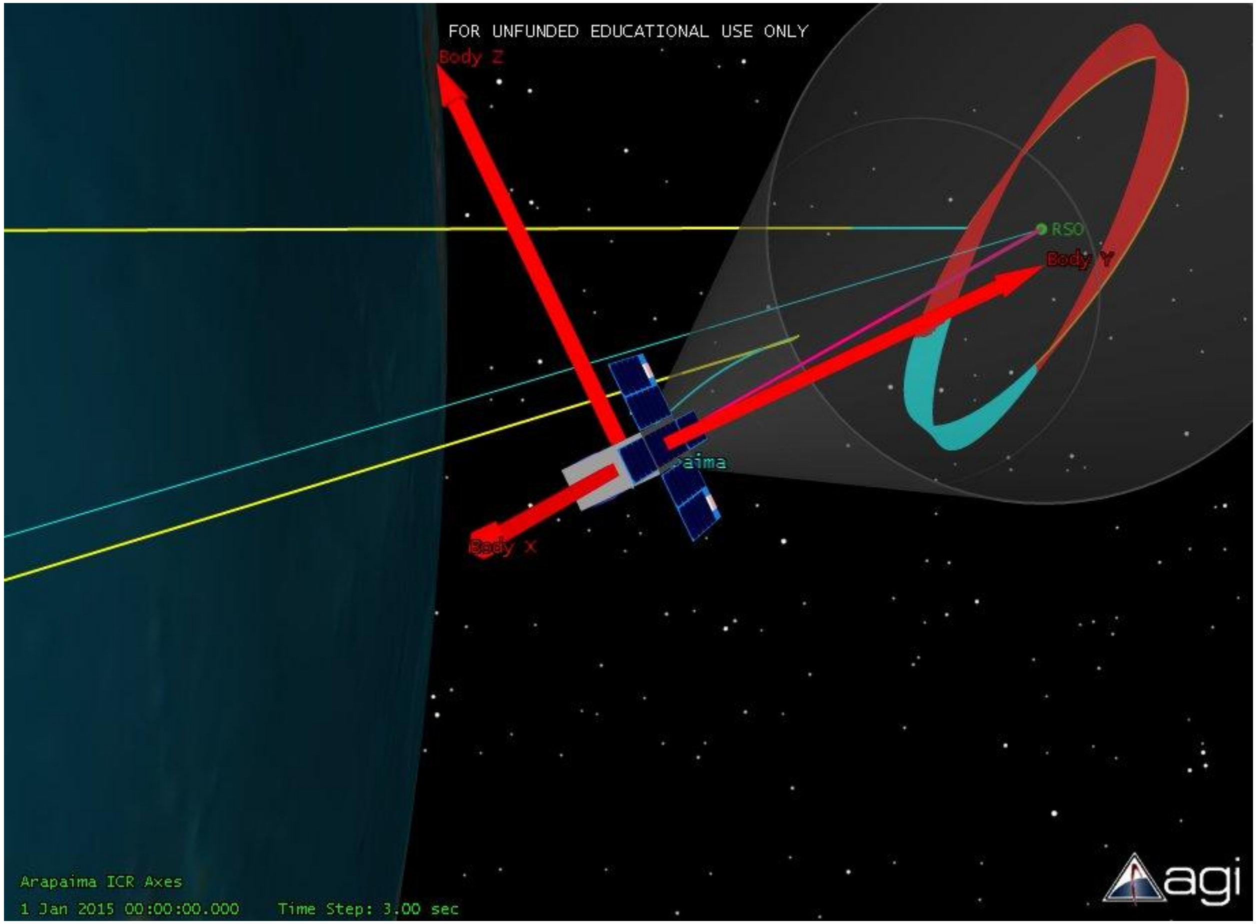


Relative Orbit Acquisition (1/2)



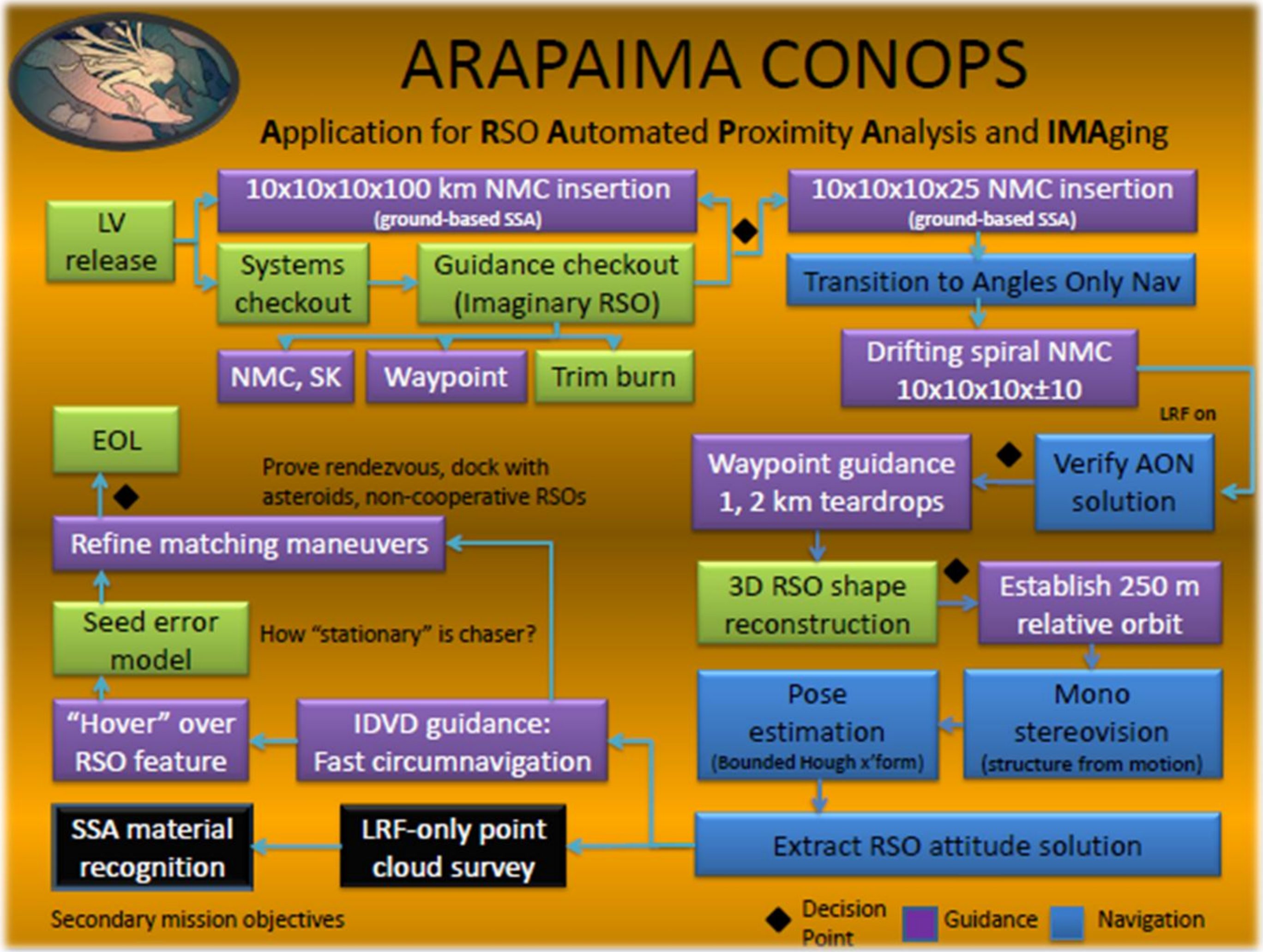
Propellant optimal trajectories for acquisition of a circular relative orbit. (Each color represents a different initial in-track distance.)

Relative Orbit Acquisition (2/2)



ARAPAIMA prior to maneuver to 250m relative orbit

Science Concept of Operations



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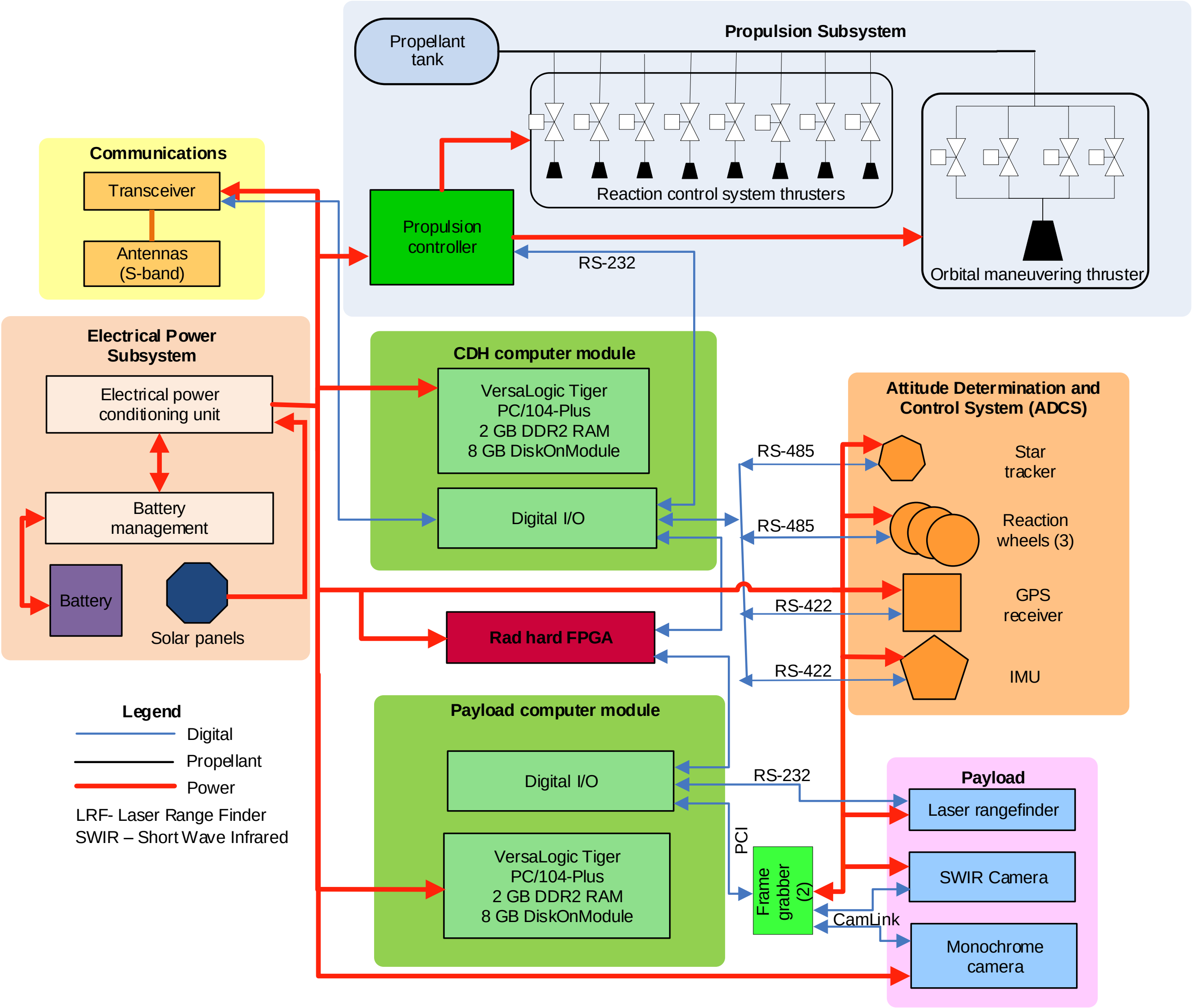
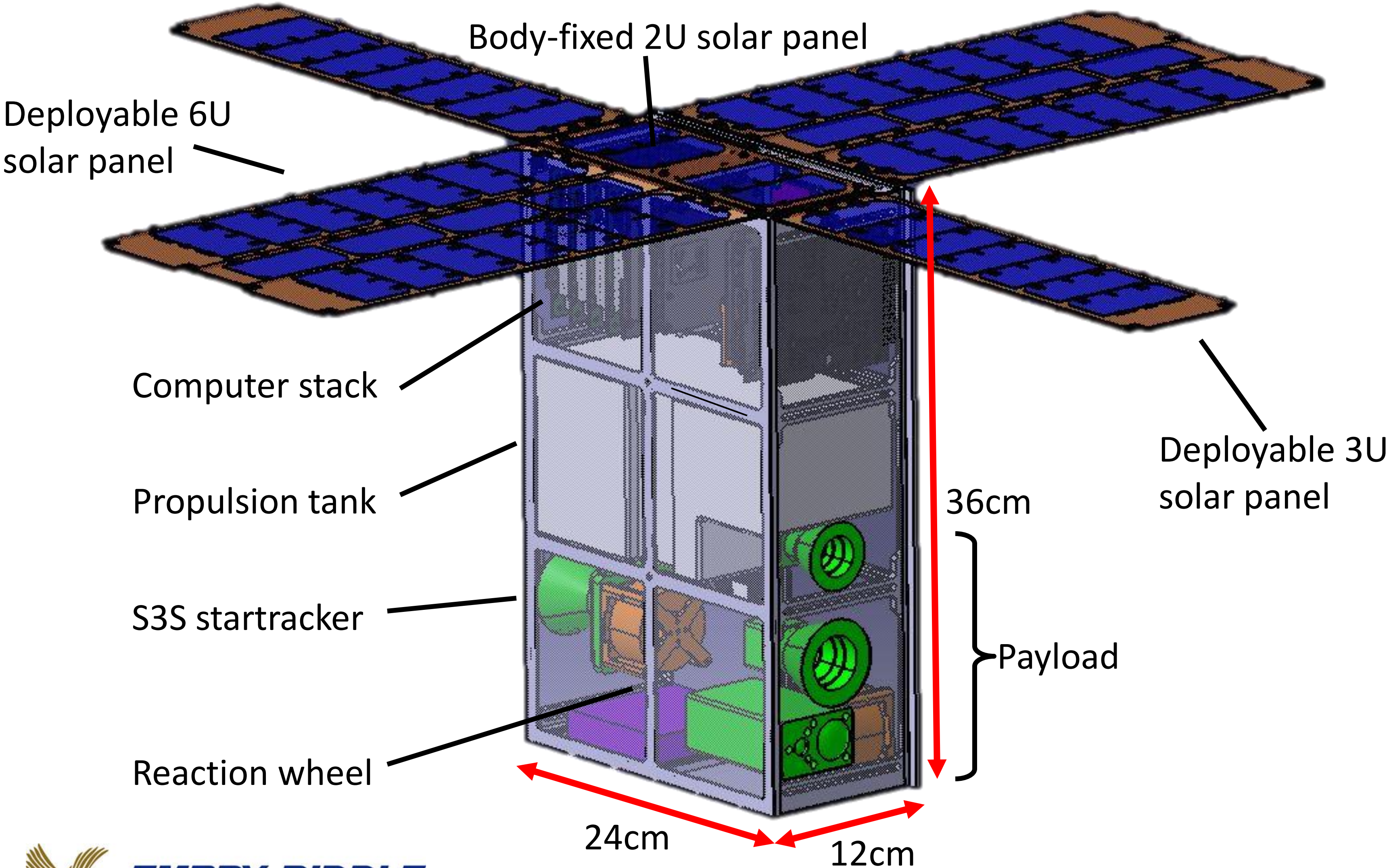
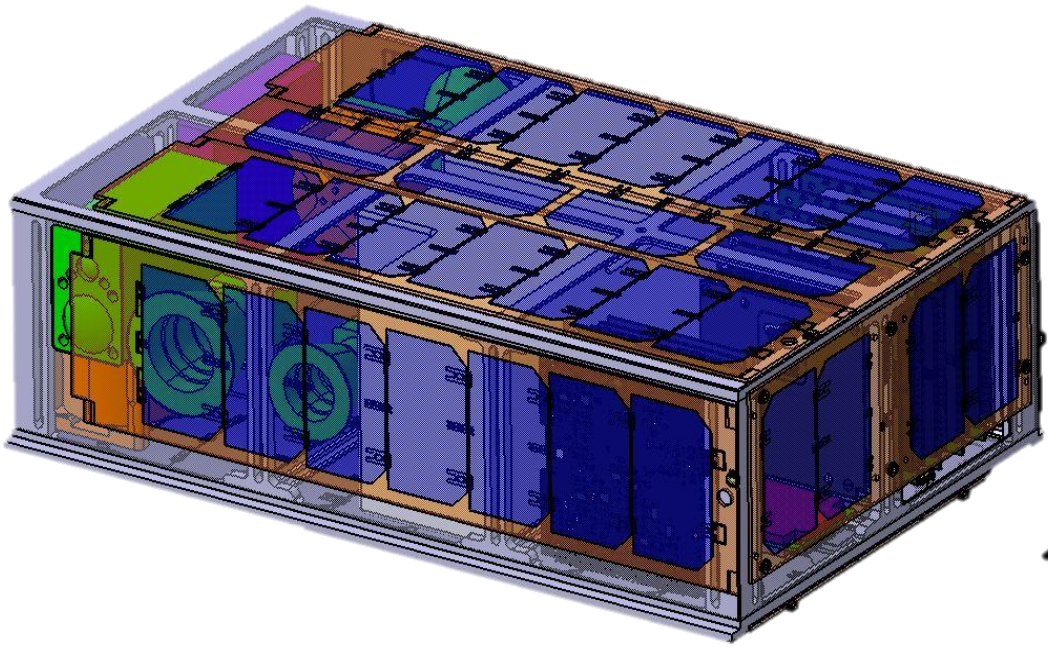
ARAPAIMA Functional Diagram

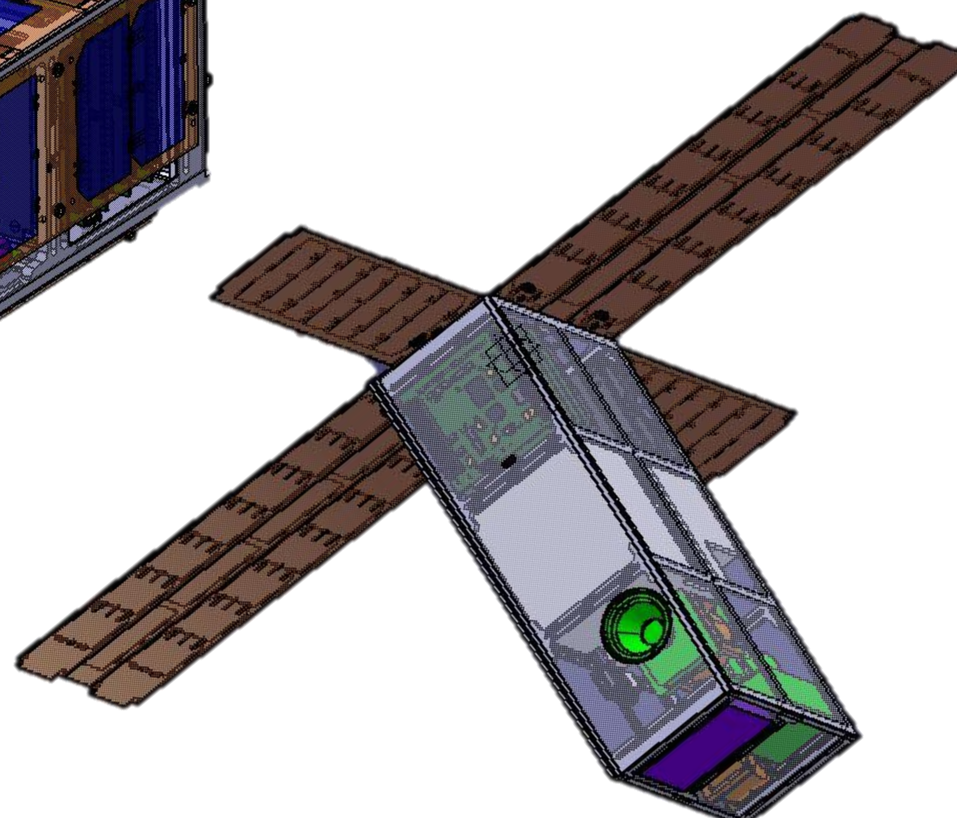


ARAPAIMA Cubesat



Structures: Model





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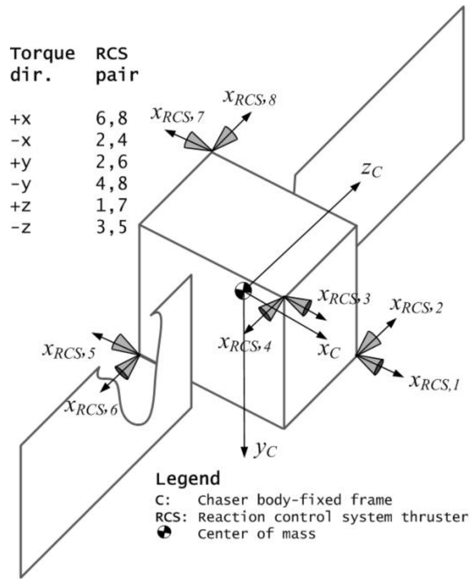
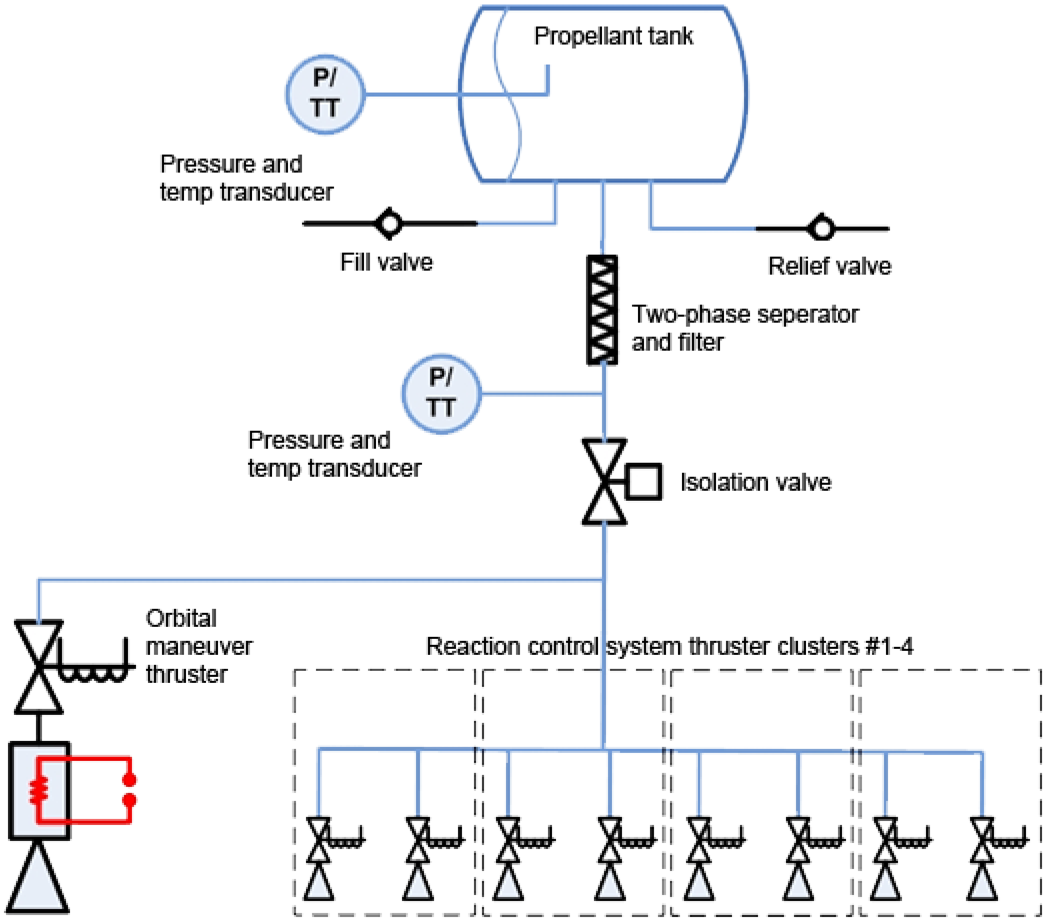
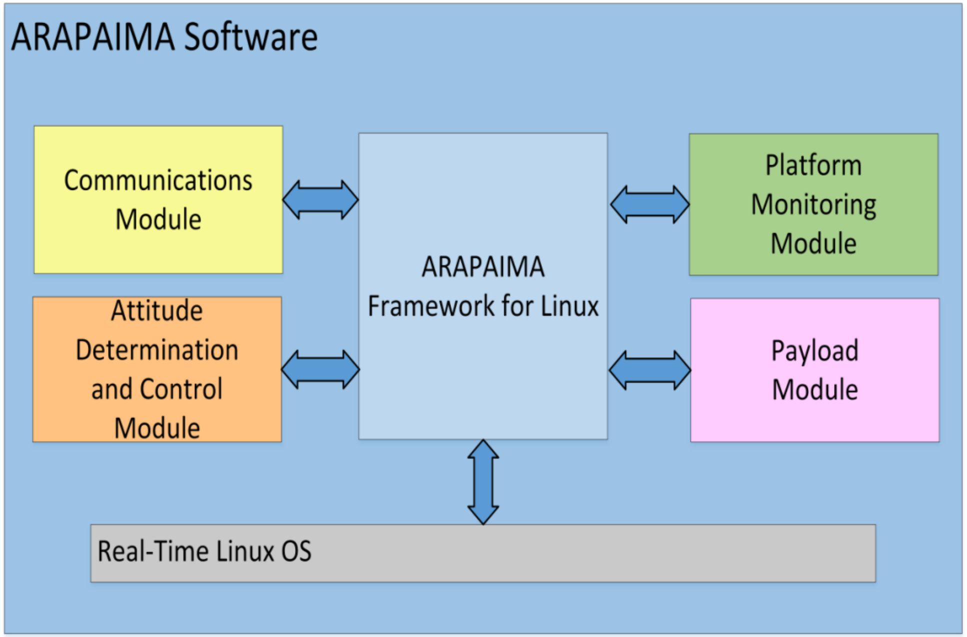
Propulsion System

- HFC-236fa, $I_{sp} = 47s$
- 100mN OMT
- 8 x 10mN RCS thrusters in 4 clusters





On-Board Computer

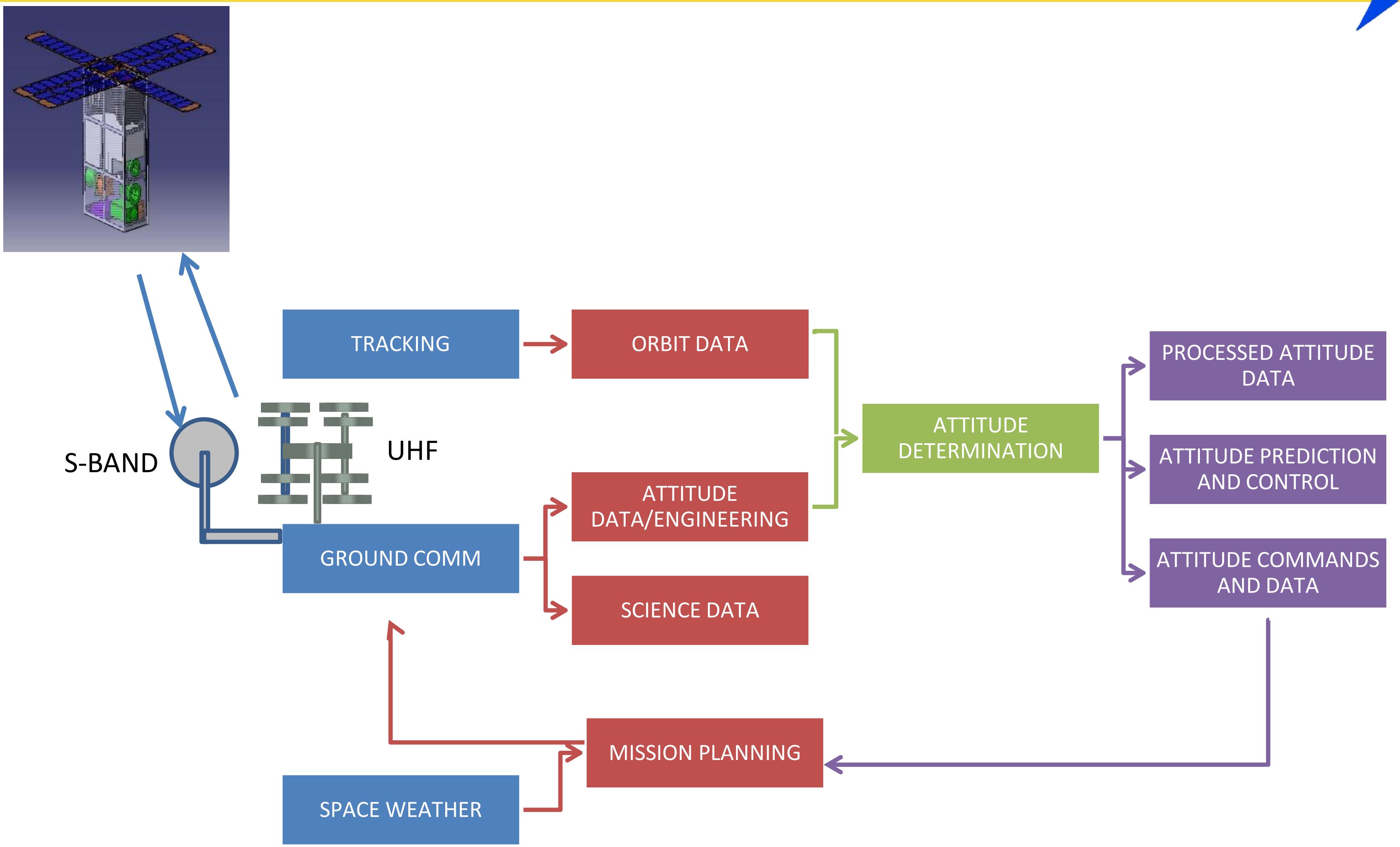


- Two independent Versalogic C/104 Tiger boards
- Manages all subsystems including payload.
- Payload independence ensures payload has enough data resources to be mission effective without conflicting with other subsystems

Communications

- Basic Information
  - Set elevation mask: 10 degrees
  - Propagation range: 2880 km
- Modulations:
  - Uplink: GFSK (2 bits per symbol)
  - Downlink: O-QPSK
- Data Rates
  - Uplink: 9600 bps
  - Downlink: 1.3 Mbps
- Frequencies
  - Uplink: 450 MHz (UHF)
  - Downlink: 2.25 GHz (S-band)
- Uplink Budget:
  - Carrier to Noise Ratio: 54.85 dB-Hz
  - Data Link Margin achieved: 9.03 dB
- Downlink Budget:
  - Carrier to Noise Ratio: 71.19 dB-Hz
  - Data Link Margin achieved: 6.35 dB

Ground Operations

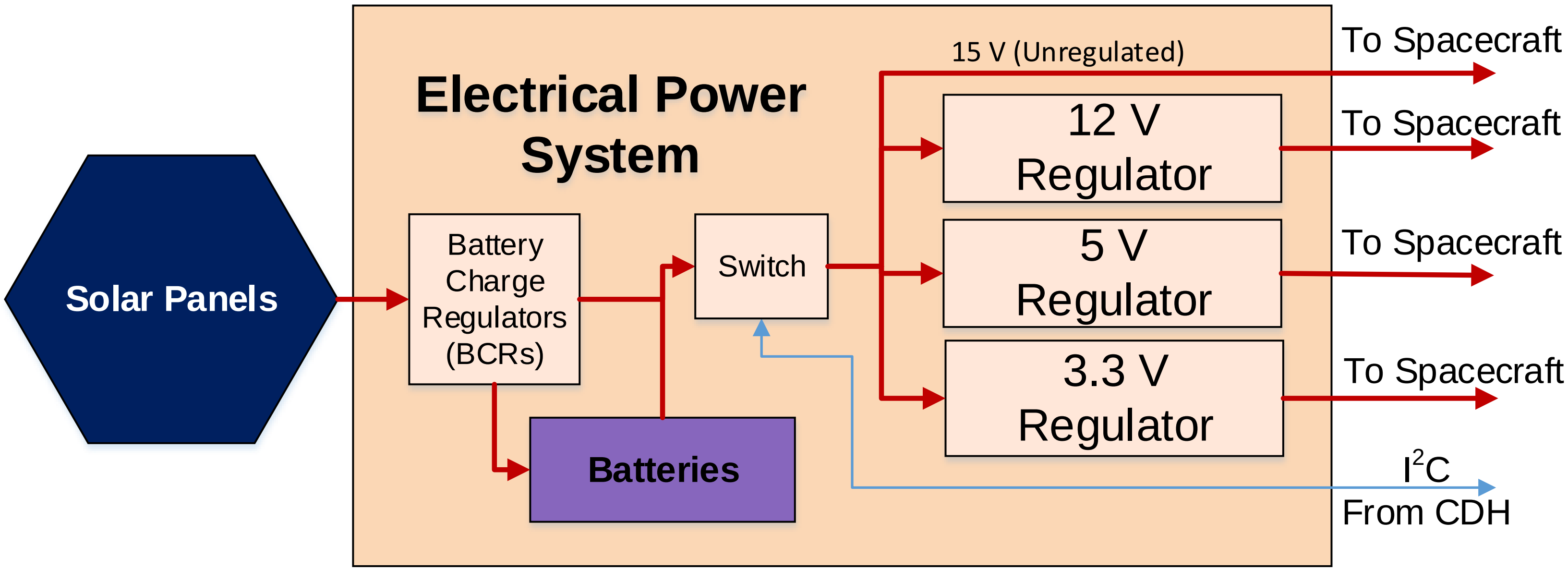


Thermal

- Static Analysis Performed:
  - Single and 6 node analysis
  - Rectangular shape w/o solar panel configuration
  - More simple and understandable
  - Examined using extreme IR and albedo values
- Results:
  - Hot Case ~85˚ ±1˚ C
  - Cold Case ~ 11˚ ±1˚ C

- Results are shown with an 11 ˚ C margin

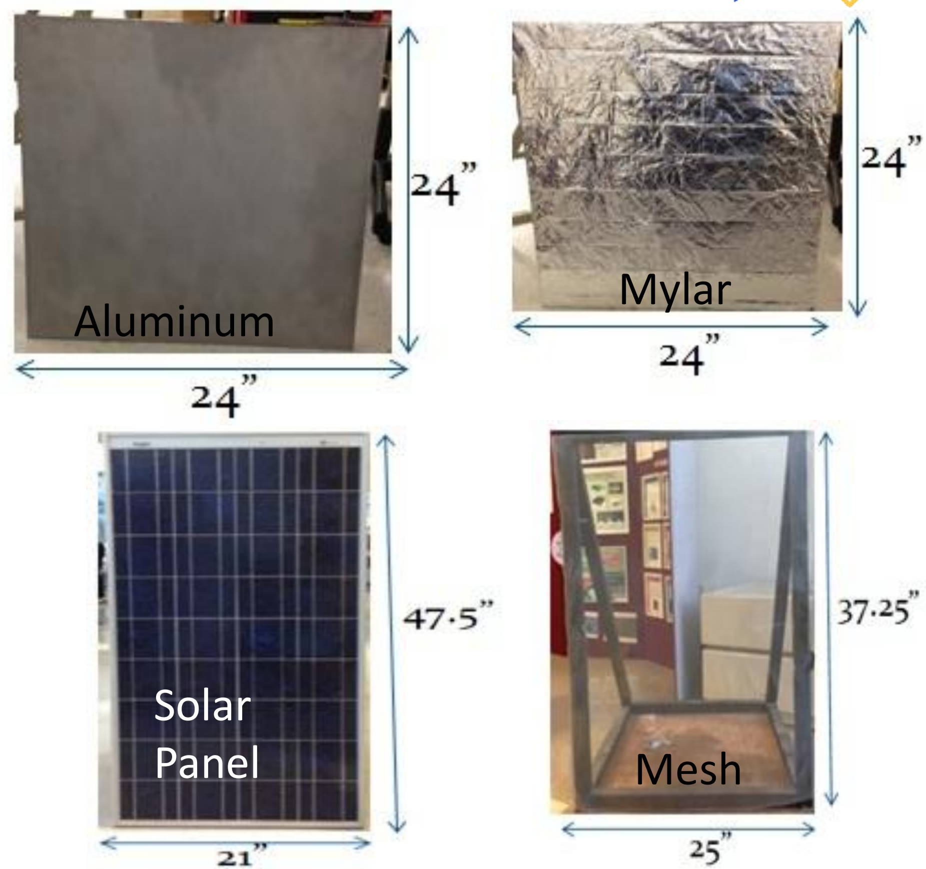
Electrical Power System

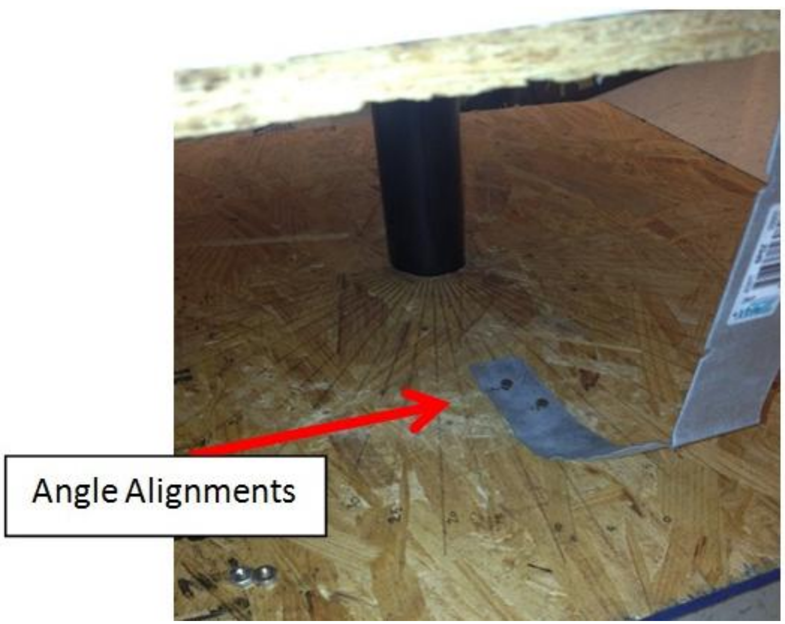


- Solar panels provide power for both system and charging of battery
- All power is routed through switch controlled by on board computer
- Three supply voltages of 12V (Direct from battery), 5V, and 3.3V
- Silicon Solar panels and Lithium Ion batteries are best choices so far

Payload Testing

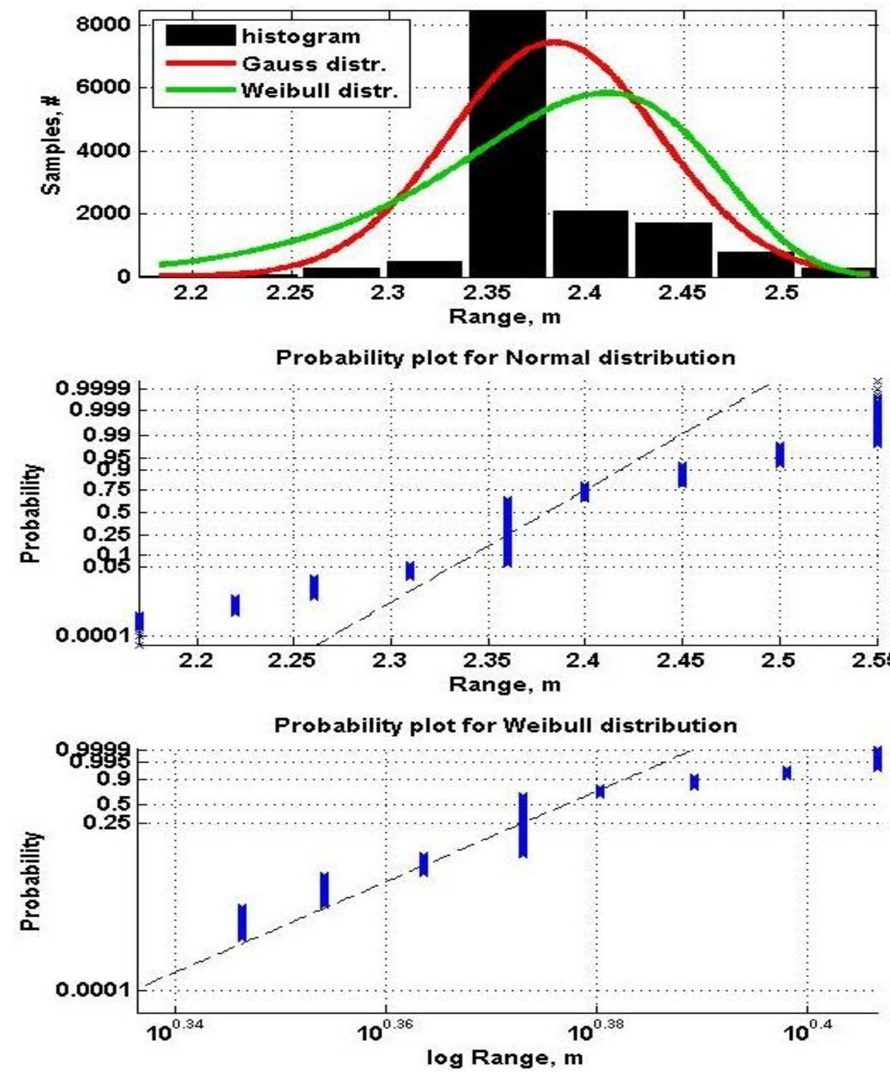
- Testing:
  - Aluminum plate, solar panel, Mylar, fine steel mesh
  - Incidence angles: 0 °- 45°
  - Distance: 5m - 30m
  - Varying light conditions





Payload Emulator Test Results

- Analyzed using Gaussian and Weibull distribution
- Bloom imaging
- Error characterization for LRF modeling:
  - Pulse dilation
  - Influence of the material reflectance



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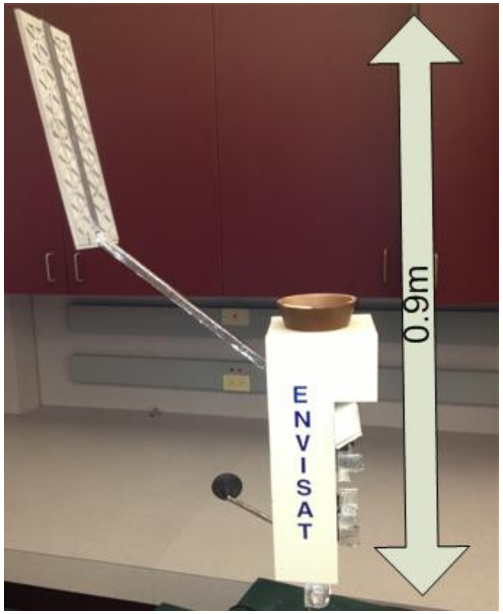
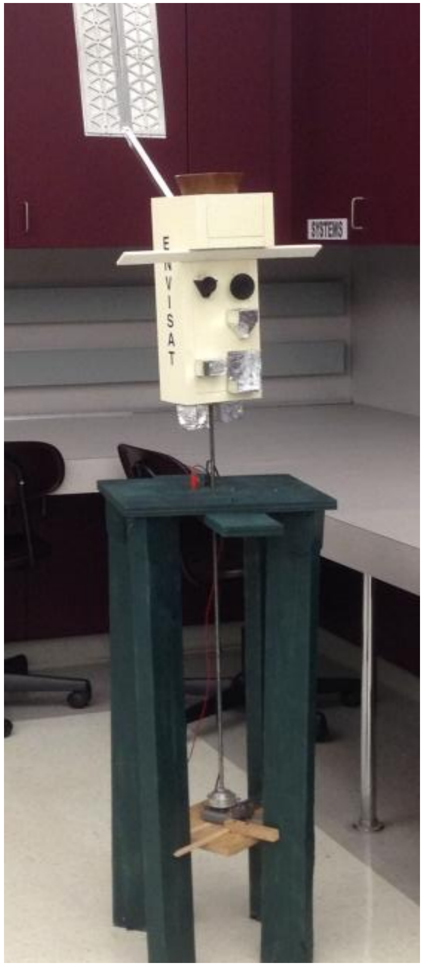
Further Testing

- The next step is to use the payload emulator to simulate point clouds and images of moving models.
- Models include, Envisat, X37-b, Delta IV upper stage, among others.
- This testing allows for not only testing of the individual components but also the payload as a whole





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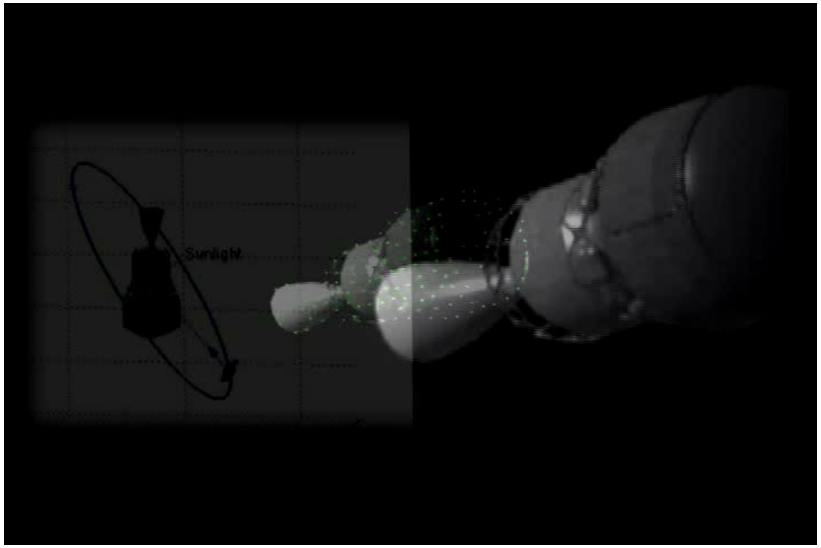
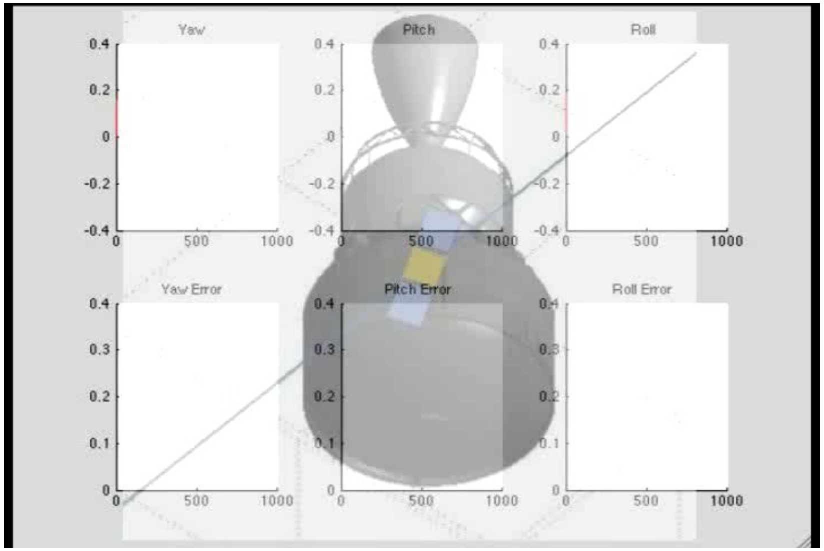
Science

Feature Detection



Roll, Pitch, & Yaw Approximations

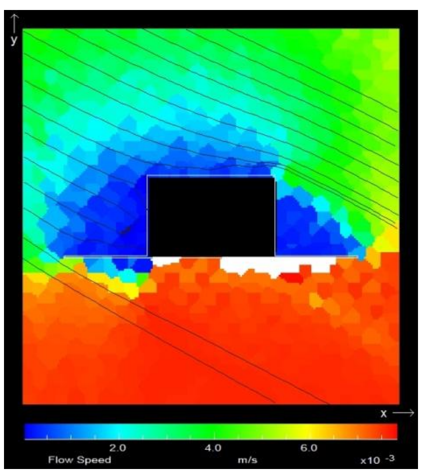


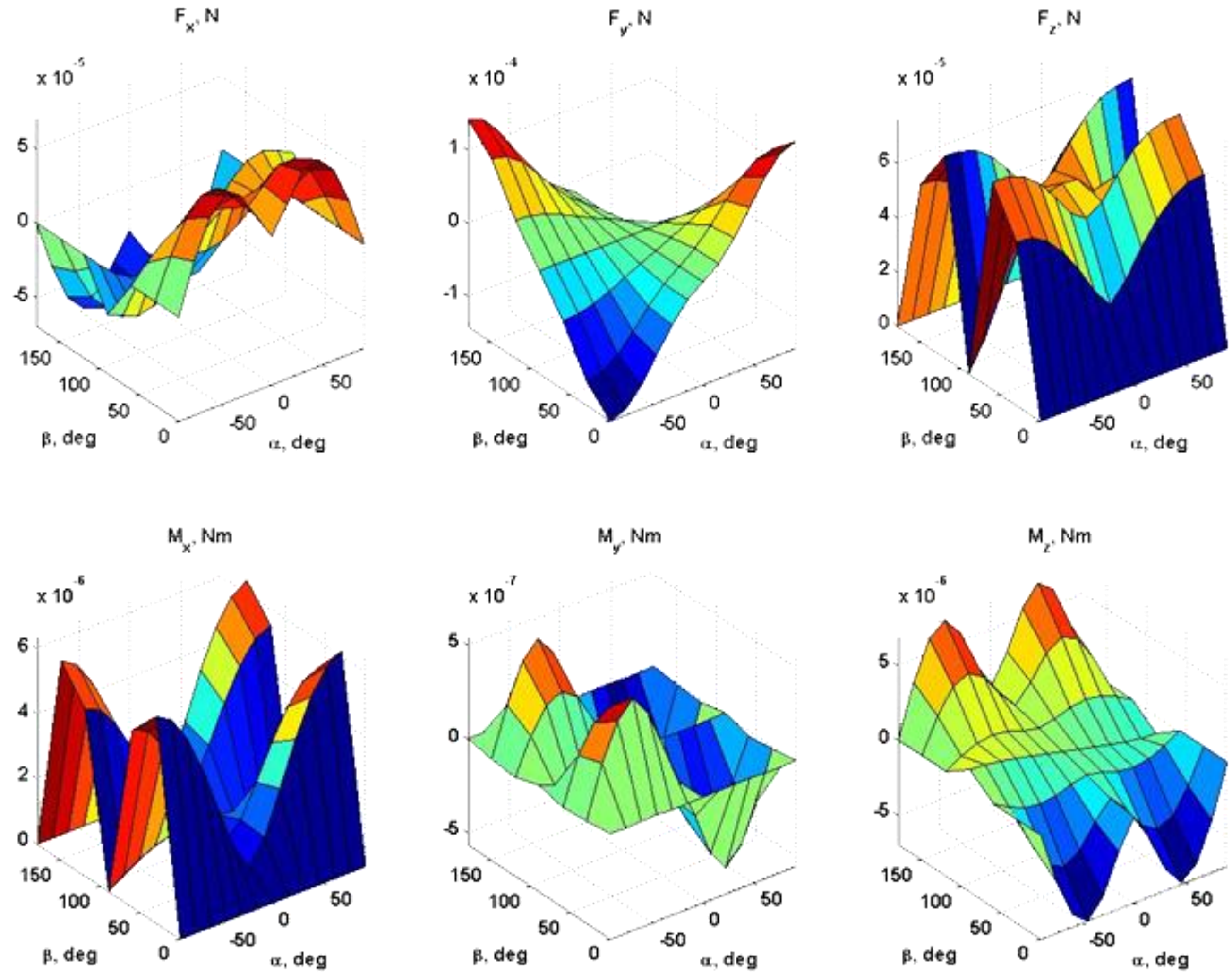
Attitude Dynamics Modeling

- External disturbance torques:
  - Aerodynamic
  - Gravity gradient
  - Residual magnetic moment
  - Solar radiation pressure
- Internal disturbance torques:
  - Reaction wheel imbalance
  - Propellant slosh
  - Solar panel vibration
  - Orbital maneuver thruster misalignment

Aerodynamic Disturbance Torques

- Direct simulation Monte Carlo (DS3V)
- Parameters:
  - O – 94%, N – 6%, T=1491K, $n=3.8\times10^{14}\#/m^3$,
  - v=7.6km/s,
  - mfp=27.33km





Conclusions/Project Timeline

	Review	Months from Kickoff	Date	Expectations (Mechanical, Electrical, Software)
✓	System Concept	2	12 Mar 13	Mission concept
✓	System Requirements	4	30 Apr 13	CAD model, electrical board concept, software/hardware identified
	Preliminary Design	8	16 Aug 13	Physical model, breadboards, high-level block diagram
	Critical Design	14-16	Feb-Apr 14	Refined CAD, elegant breadboard, software 1.0
	Engineering Design	20	Aug 14	Engineering unit, flight-ready configuration board, software 2.0
	Flight Competition	25	Jan 15	Flight CAD, flight-ready configuration board tested, software 3.0

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Questions?