space structures laboratory

CoreSat – Conceptual Design Review

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January 3rd, 2017

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Outline

- **Requirements and System Overview**
- **Sub-system descriptions**
  - Avionics
  - Structures
  - ADACS
  - EPS
  - RF/Comms.
  - Rendezvous and docking
- **Integration and test plan**
- **Spacecraft operations**
- **Future plan (AE105 projects)**

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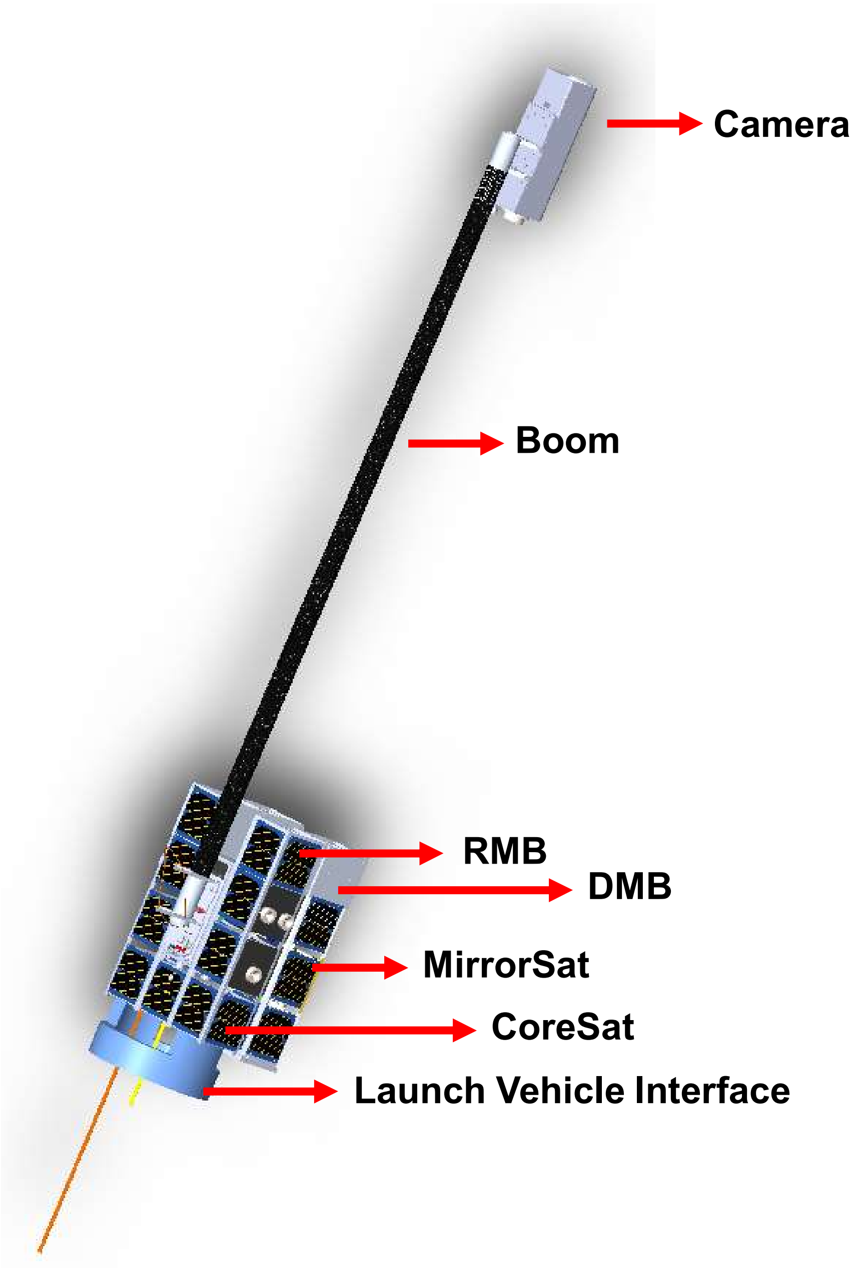
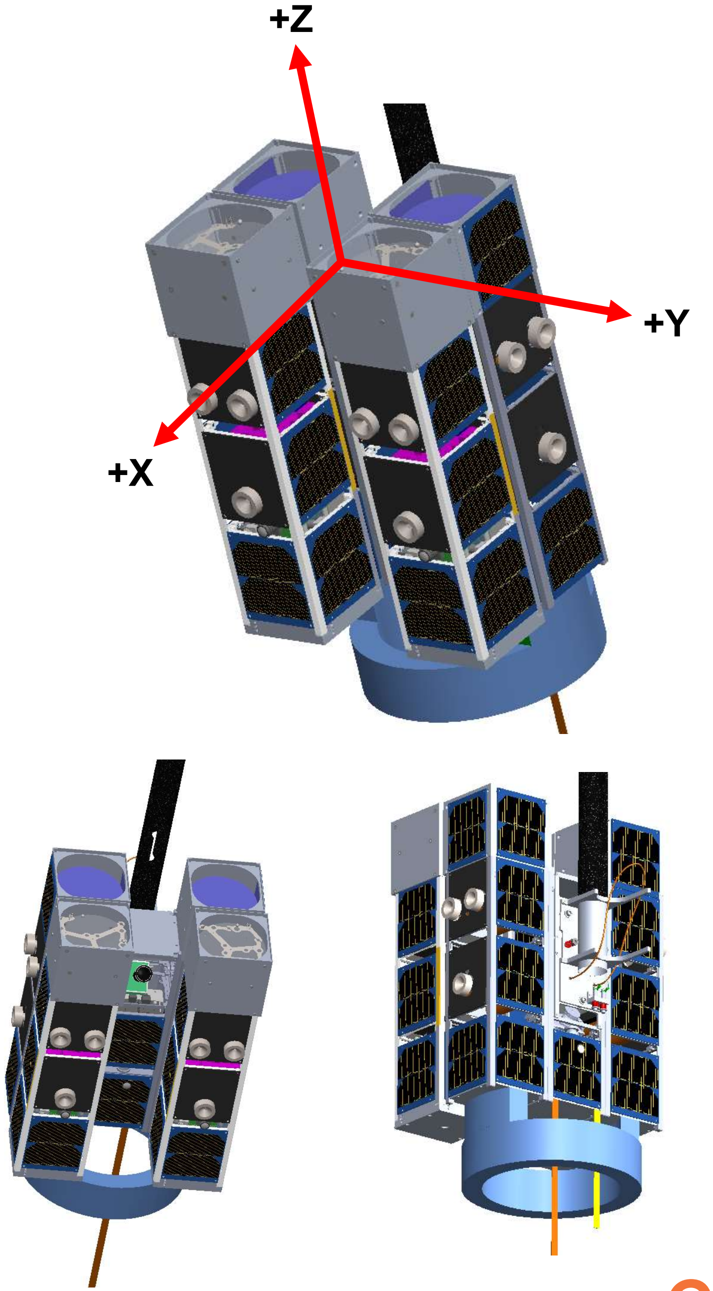
Spacecraft Overview





Orbit and Deployment Chronology

Piggy-back on PSLV: LEO orbit, h<1000km, as low as possible

t = 0
- Launch
- Detach from launcher and orbit verification

2 orbits
- Turn on satellite: - turn on critical systems
  - switch from battery to solar panels

4 orbits
- Verify and stabilize satellite: - power, communications
  - spin rate, temperature, attitude
  - camera (dark measurement)

8 orbits
- Telescope deployement: - 1st stage boom deployment
  - 2nd stage boom deployment
  - Unrestrain DM1, DM2, RM1, RM2

9 orbits
- Adjust and stabilize satellite attitude
- Point spacecraft to first target

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Orbit and Deployment Chronology

9 orbit	• Image stars, Moon and Earth with reference mirrors (0.3º FoV) • Check ADCS drift requirement (0.1º 3σ)
10-12 orbits	• Begin calibration for the fixed+deformable mirrors compact configuration with target stars. •Image stars, Moon and Earth in full compact configuration
13-14 orbit	•(Fire MirrorSat 1 frangibolt) •(Spin reaction wheels of the MirrorSat 1) •(Switch off MirrorSat 1 ADCS and) undock MirrorSat 1 •Redock MirrorSat 1 on the same CoreSat face and redo imaging •Undock MirrorSat 1 •Carry out CoreSat 90° spin and capture MirrorSat 1
14-15 orbit	•(Fire MirrorSat 2 frangibolt) •(Spin reaction wheels of the MirrorSat 2) •(Switch off MirrorSat 2 ADCS and) undock MirrorSat 2 •Redock MirrorSat 2 on the same CoreSat face and redo imaging •Undock MirrorSat 2 •Carry out CoreSat 90° spin and capture MirrorSat 2

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Orbit and Deployment Chronology

15 orbit	•Check docking success and attitude
16 orbits	• Begin calibration for the fixed+deformable mirrors wide configuration with target stars. •Image stars, Moon and Earth in full wide configuration
17-18 orbits	•Turn on ADCS of MirrorSat 1 •Undock MirrorSat 1 •Fire thruster of MirrorSat 1 and go away
18.5 orbit	•Redock MirrorSat 1 using LIDAR and nadir sensors
19-20 orbits	•Turn on ADCS of MirrorSat 2 •Undock MirrorSat 2 •Fire thruster of MirrorSat 2 and go away
20.5 orbit	•Redock MirrorSat 2 using LIDAR and nadir sensors

System Engineering

CoreSat Requirements

ADCS

- **Pointing accuracy:** error < 0.1º 3σ all axes
- **Attitude stability:** drift < 0.02º 3σ for 600s all axes during payload operation
- **Slew rate: >** 3º/s 3σ during rendez-vous maneuvers
- **Pointing direction:** able to operate with Sun > 20º off optical (Z) axis

Directly linked to:

Mission objective 1: 1 star image, 80% encircled energy

Mission objective 2: autonomous docking and reconfiguration

Communication with Ground

- **Frequency range:** VHF U/L (1.2 kbps) & UHF D/L (9.6 kbps)

System Engineering

CoreSat Requirements, Interfaces

Payload/CoreSat Interface

	Mechanical	**Electrical**
Camera	Provide hold-downs for launch	5W at 5V power and I2C com (image data)
Boom	Support kinematic mount	Separation device: >2V and >1.5 A
Reference mirror boxes	Support reference mirror boxes	2 W power at 5V

Launcher/CoreSat Interface

•**Accomodation:** PSLV compatible launch interface

System Engineering

CoreSat Requirements, Interfaces

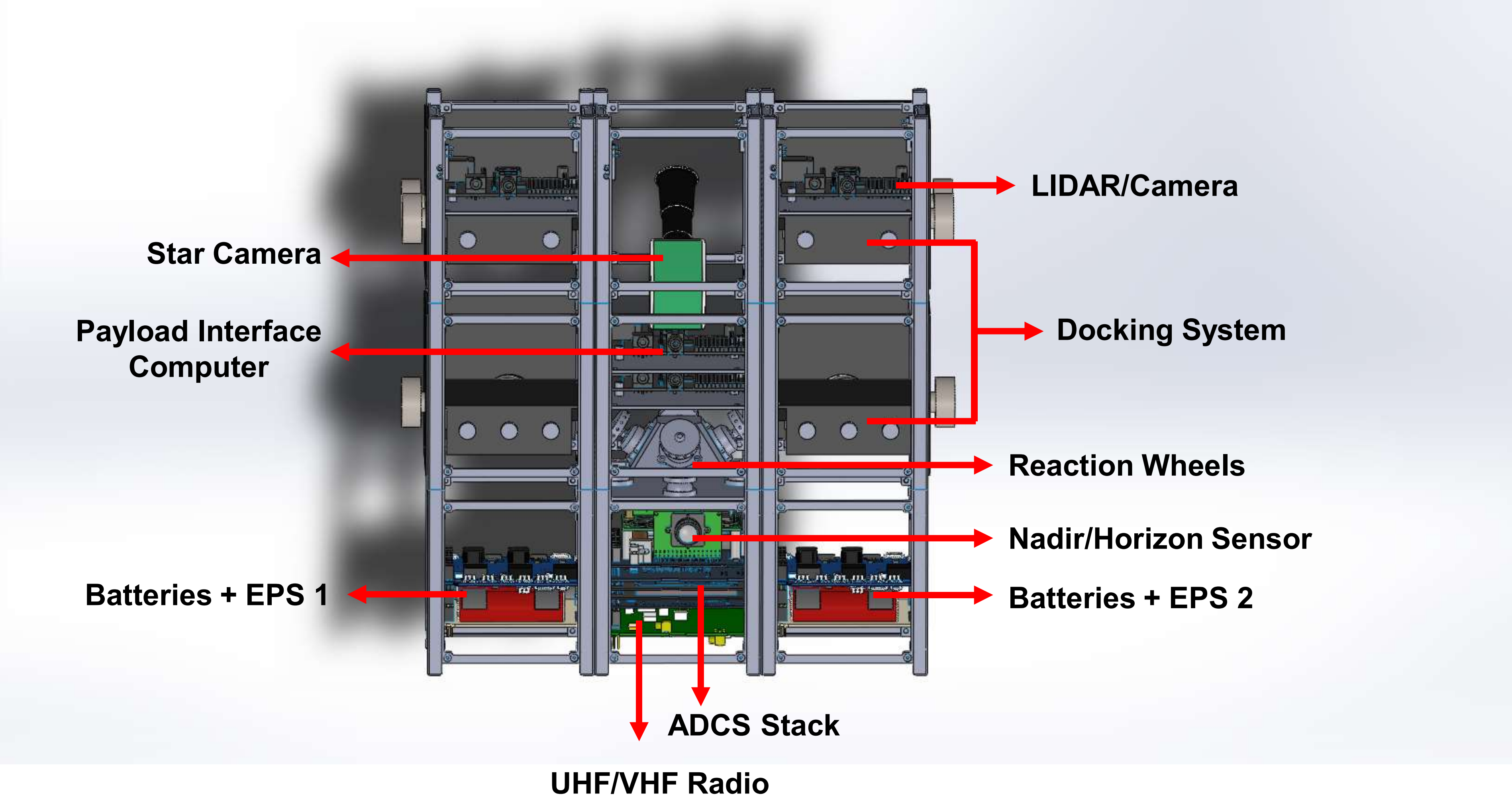
MirrorSats/CoreSat Interface

Mechanical	Electrical
Provide hold-down for launch	5W at 5V power to both docked MirrorSats
Provide CoreSat docking mechanism	Communication with MirrorSats via Wi-Fi
	Independently sense MirrorSats during RDV/docking

System engineering team (near future plan):

Update and review of interface control document for the CoreSat.

CoreSat Overview



Notes

- Star Camera mounted at 45° from z-axis
- Sun-sensor and nadir sensor to be provided unobstructed view between solar panels
- Not available for RDV

Not Shown

- Frangibolts
- Antenna deployment mechanism
- GPS antenna

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Mass Properties

Sub-System	Quantity	Mass (g)
Chassis	1	260
1U Solar Panels	19	313
Surface Structural Panels	12	511
Docking Units	4	1700
LIDAR/Camera (RDV electronics)	2	400
ADCS Stack	1	300
Reaction Wheels	1	1000
Star Camera	1	166
EPS + Batteries	2	900
UHF/VHF Radio	1	85
Payload Interface Board	1	200
UHF, VHF Antennas and Deployment Mechanism	1	250
Launch Interface	1	600
Launch Interface Mounts	2	300
CoreSat Total		**6985**
MirrorSat	2	12200
Camera	1	3500
Rigid Mirror Box	2	1000
Deformable Mirror Box	2	800
Boom + Camera Interface + CoreSat Interface	1	600
Total System Mass		**25085**

$$I = \begin{bmatrix} 8.469 & 0.003 & -0.406 \\ 0.003 & 8.365 & 0.009 \\ -0.406 & 0.009 & 0.354 \end{bmatrix} kg.m^2$$

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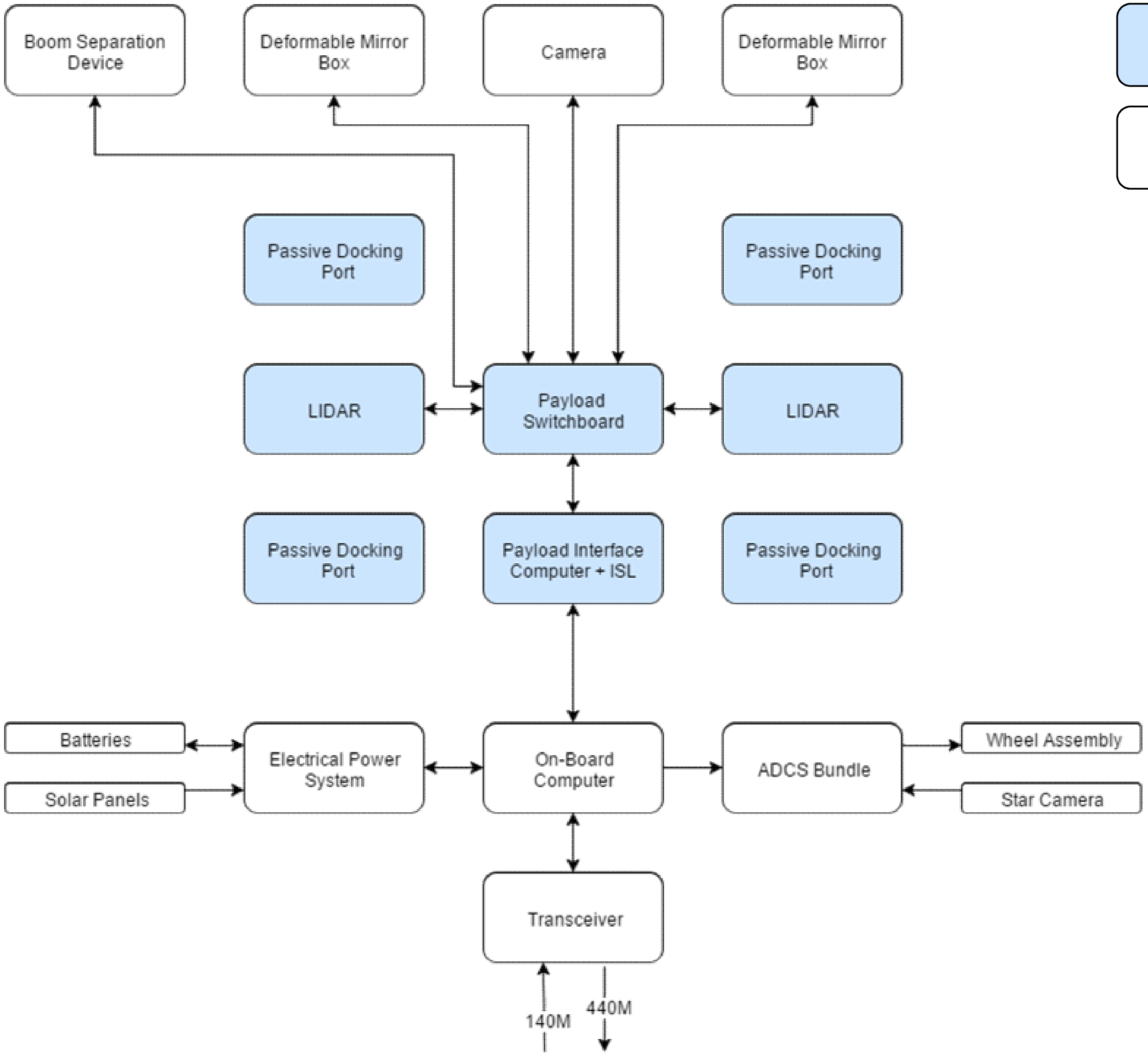
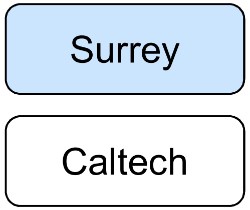
Avionics – Block Diagram





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Avionics – Hardware Diagram

Provides an interface with the payloads
Surrey

On-Board Computer (OBC)
Integrates components to:
- Provide communication with the ground
- Command ADCS unit
- Regulate EPS
- Transfer commands to payload via the Switchboard/Payload interface computer

RF team
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ADCS team
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EPS team
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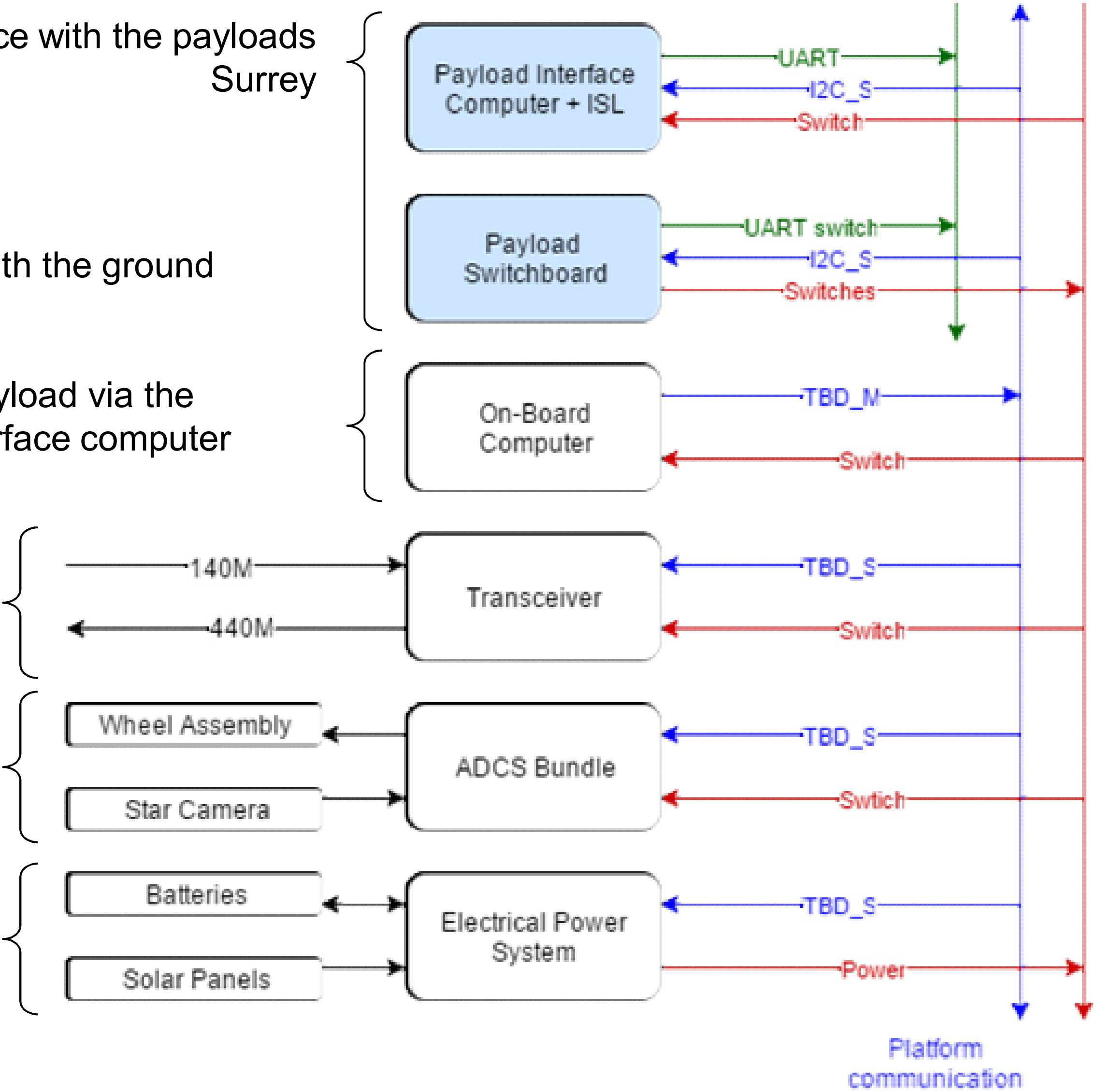

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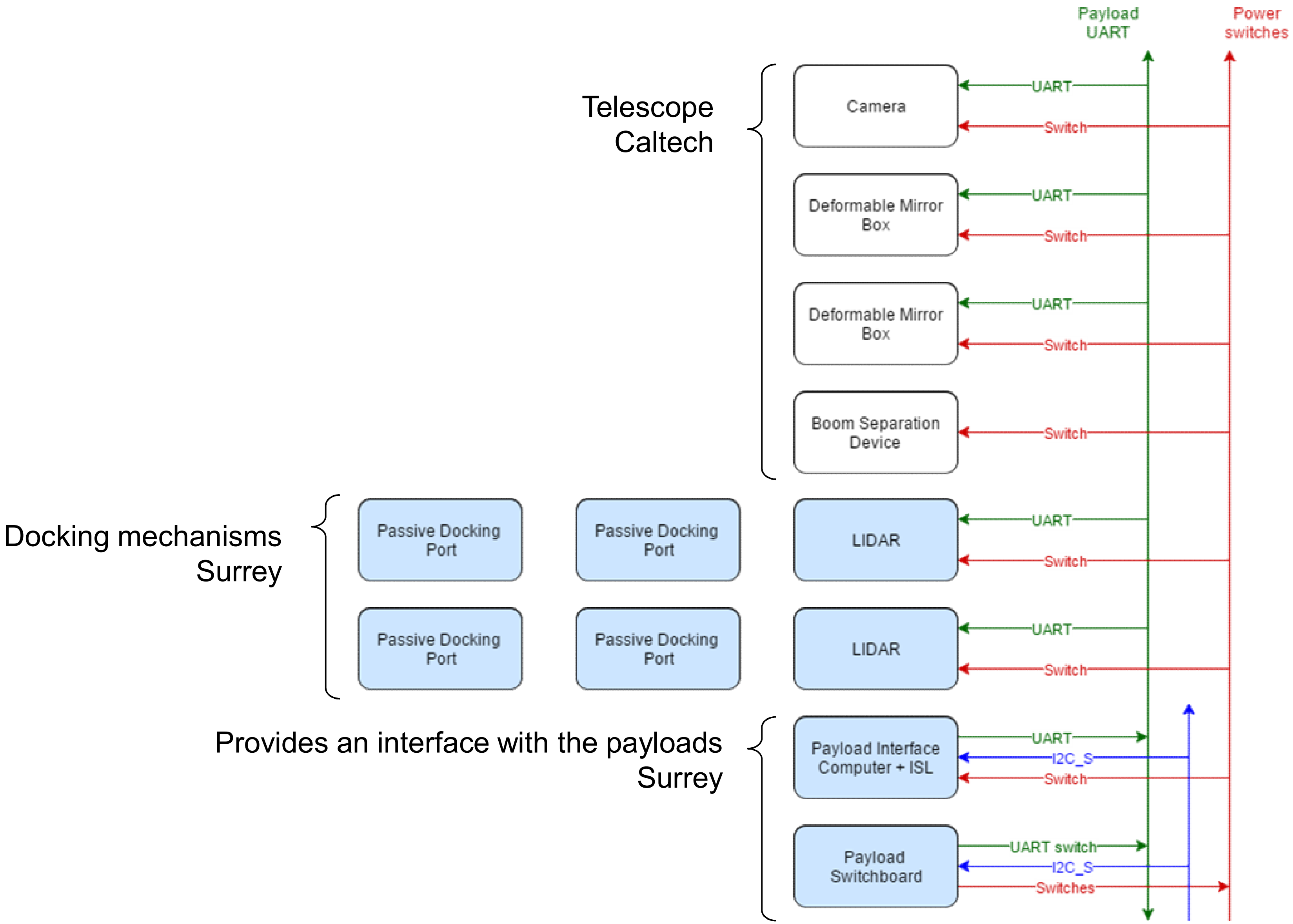
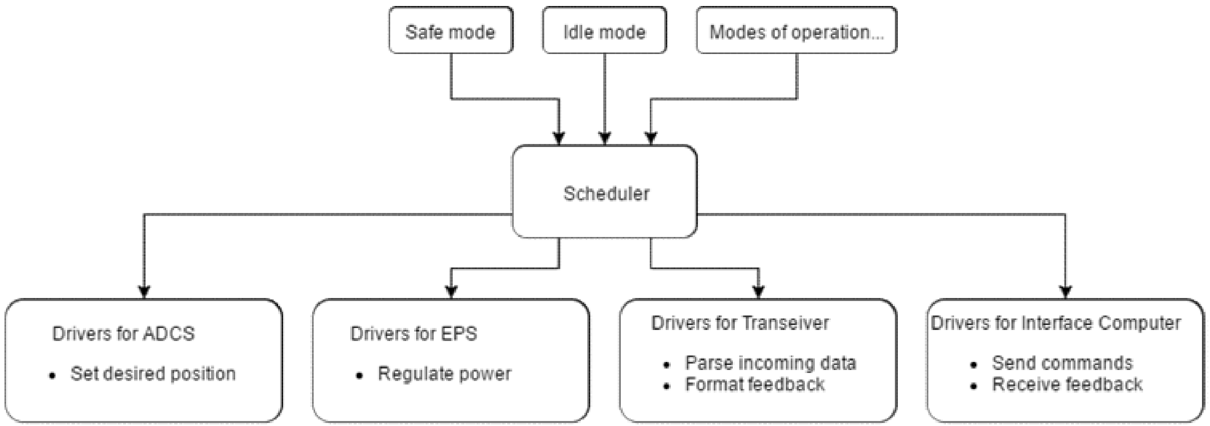
Avionics – Hardware Diagram



Avionics – Software

- Software for Payload Interface Computer provided by Surrey
- Software for OBC



- Each payload (ADCS, EPS, RF/Comms, Payload Interface Computer) defines its commands and schemes to operate it to write **Drivers**
- System engineering team defines the modes of operation and the state of the payloads for each
- **Scheduler**
  - Checks the functionality of the satellite and triggers safe mode if needed
  - Checks for incoming commands from the ground and feedback to be sent
  - Sends commands to different payloads according to incoming messages

CoreSat Structure

Fabrication plan

- **Preliminary design of custom chassis based on current information of internal modules, docking system and volume requirements**
- **Adjust the design to the modifications of other subsystems occurring in the meantime**
- **CAD design of the structure and FEM design for modal analysis**
- **Key design considerations**
  - Compatible with CubeSat form-factor for various sub-systems
  - Allows maximum area for solar panels
  - Aperture for nadir/horizon sensors, sun-sensors, star camera
  - Clearances for avoiding interference during docking

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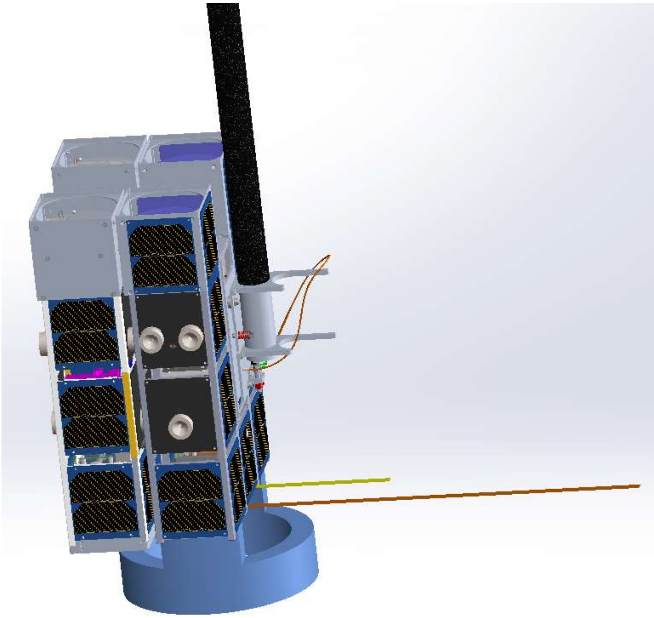
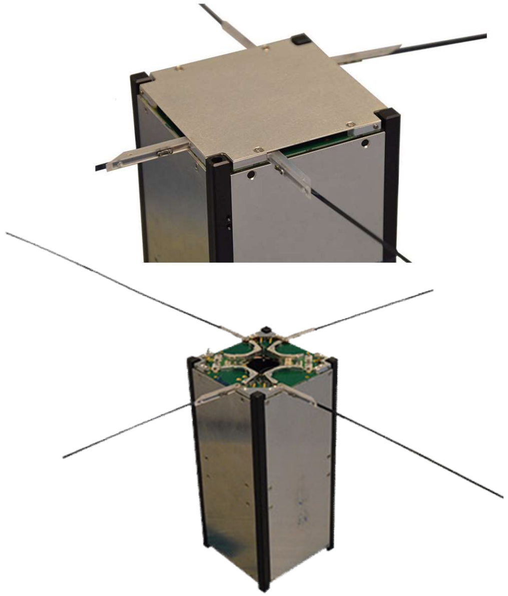
Antenna and Launch Vehicle Interface

Antenna mounting

- Better orientation with ground station
- No interference with MirrorSats
- Deployment mechanism fits in the gap between the launch vehicle interface and the chassis





ISIS Hybrid Deployable Antenna

ISRO's IBL230V2
Mounting diameter: 230 mm
Mass: 0.6 kg

Launch Vehicle Interface

- Select launch vehicle interface (IBL230V2)
- Select/design the mounting part based on clearance requirements

ADCS Requirements

3 main requirements:

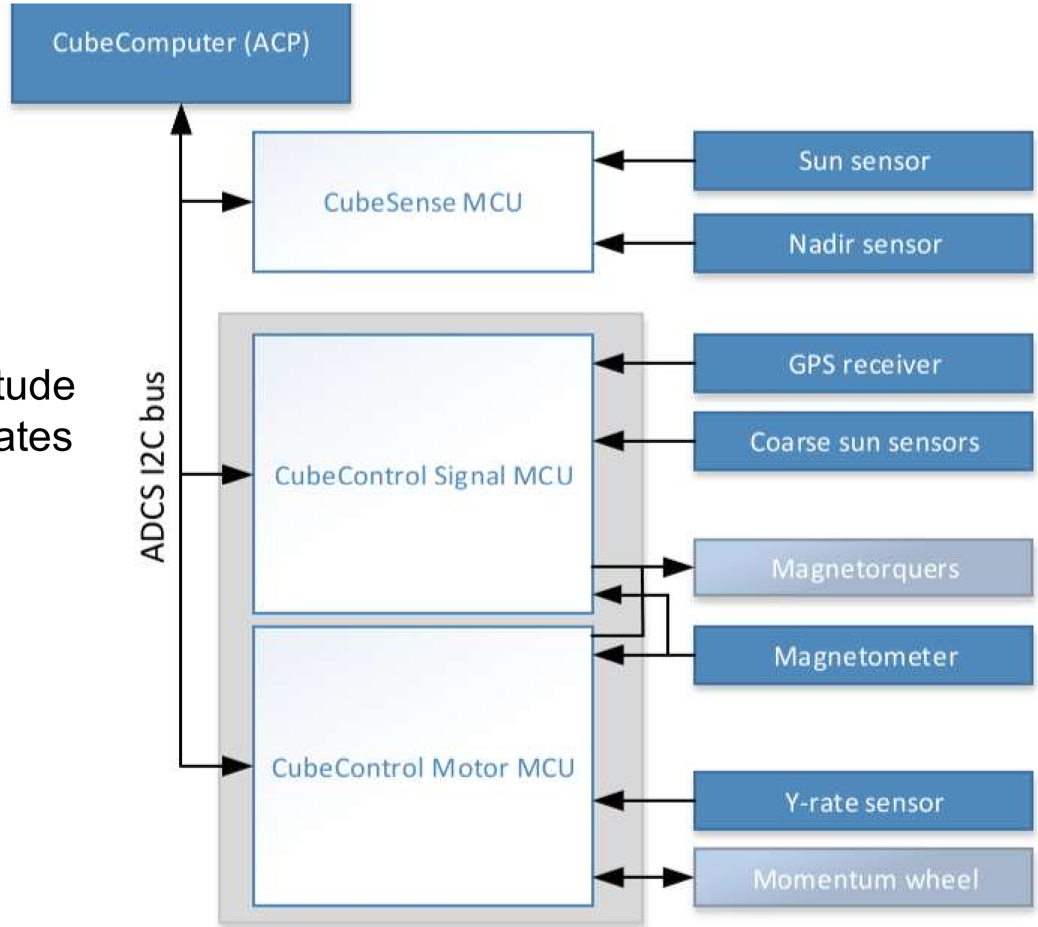
- Pointing accuracy: pointing error all axes < 0.1° 3σ
- Attitude stability: angular drift < 0.02°/s for 600s during payload operations
- RDV manoeuvers: slew rate > 3°/s

Stellenbosch System Overview

Sensors
- Coarse sun sensors, coarse attitude
- Sun sensor, attitude
- Nadir sensor, coarse attitude
- Rate gyro, angular rate
- Magnetometer (boom deployed), attitude
- Star camera, precision attitude and rates
- GPS receiver, position

Actuators
- Magnetotorquer (x3)
- Momemtum wheels (x3)

Computers
- CubeComputer
- CubeSense MCU
- CubeControl Signal MCU
- CubeControl Motor MCU



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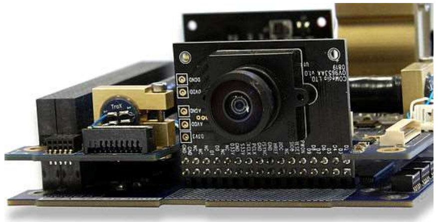
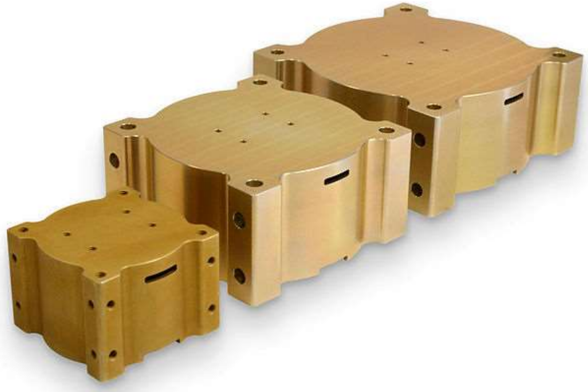
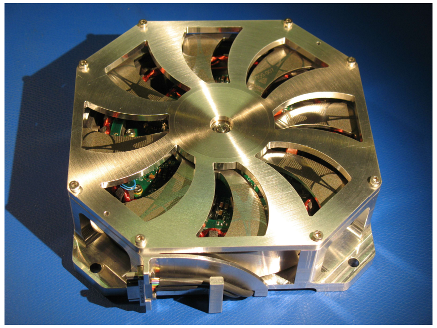
Stellenbosch System Overview



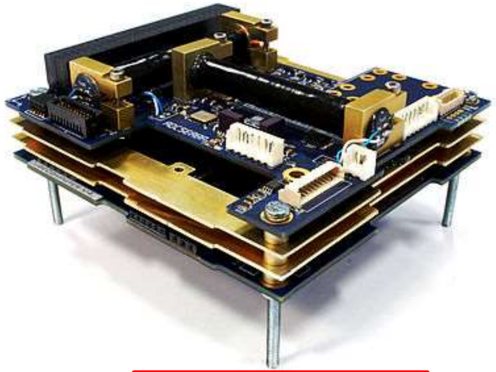
Cube Sense



Cube Wheels



Sinclair Wheel



Cube Control

- **CubeComputer**
  - 32-bit ARM Cortex M3
  - Low power (200 mW @ 48 MHz)
  - Radiation tolerant
    - FPGA-based EDAC
    - SEL protection circuits
- **CubeCamera (no details available)**
  - Similar camera flown on SumbandilaSat

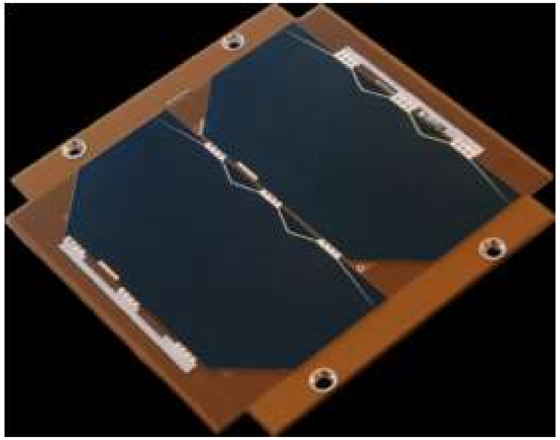
Cube Computer

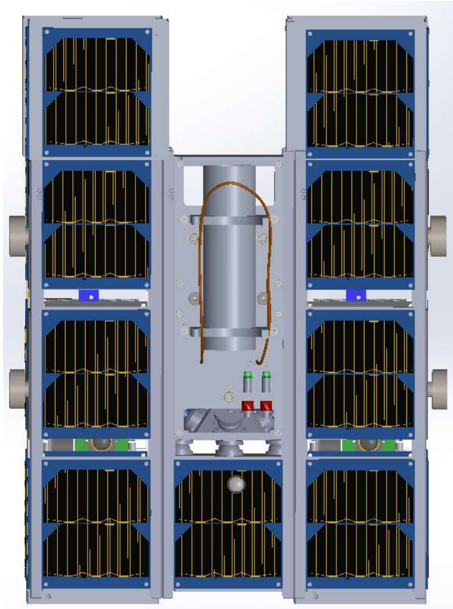
Disturbance Torques

- **Main External Torques**
  - Gravity Gradient $$T_g \approx \frac{3\mu_\oplus}{2R^3}\left|I_z - I_y\right| \approx 15\cdot 10^{-6}\ Nm$$
  - Atmospheric Drag $$T_a \approx \left(c_{pa} - c_g\right)\frac{1}{2}\rho C_D A v^2 \approx 0.08\cdot 10^{-6}\ Nm$$
  - Magnetic $$T_m \approx mB \approx 49\cdot 10^{-6}\ Nm$$
  - Solar Pressure $$T_{srp} \approx \left(c_{ps} - c_g\right)\frac{F_s}{c}A_s\left(1+\rho\right) \approx 0.2\cdot 10^{-6}\ Nm$$
- **Internal Disturbances**
  - Reaction Wheels Vibrations

EPS – Solar Panels

- COTS GOMSpace NanoPower P110 series with AzurSpace 3G30A triple junction cells or
- CubeSat Kit PMDSAS solar panels with SpectroLab UTJ cells
- 2.35 W orbit-averaged power (OAP) per panel in 6am-6pm polar sun-synchronous orbit
- Possible strategy: Whenever not in science phase and not in eclipse, orient –X face towards the sun (OAP: 21.15 W, assuming solar panels on the mirror boxes, narrow config.)
- MirrorSats receive power only in 'wide' configuration (total OAP: 35.25 W)
- In the 'narrow' configuration, CoreSat transfers power to the MirrorSats
- Panel deployment possible from –X





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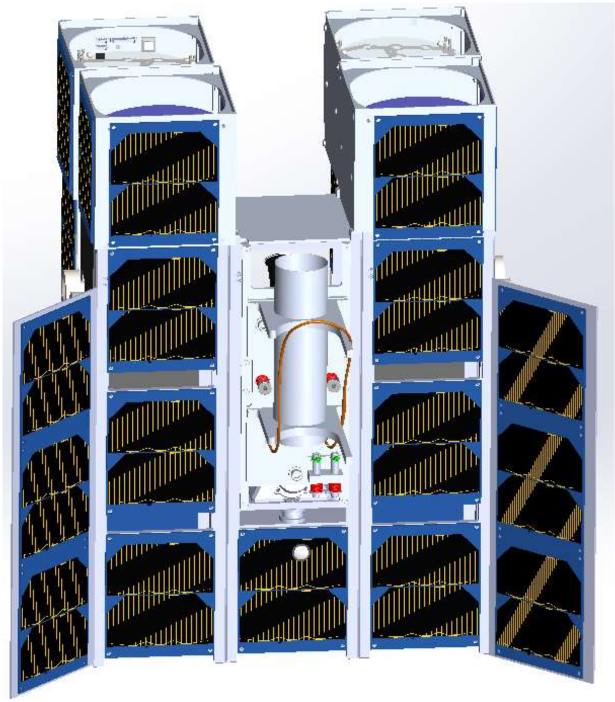
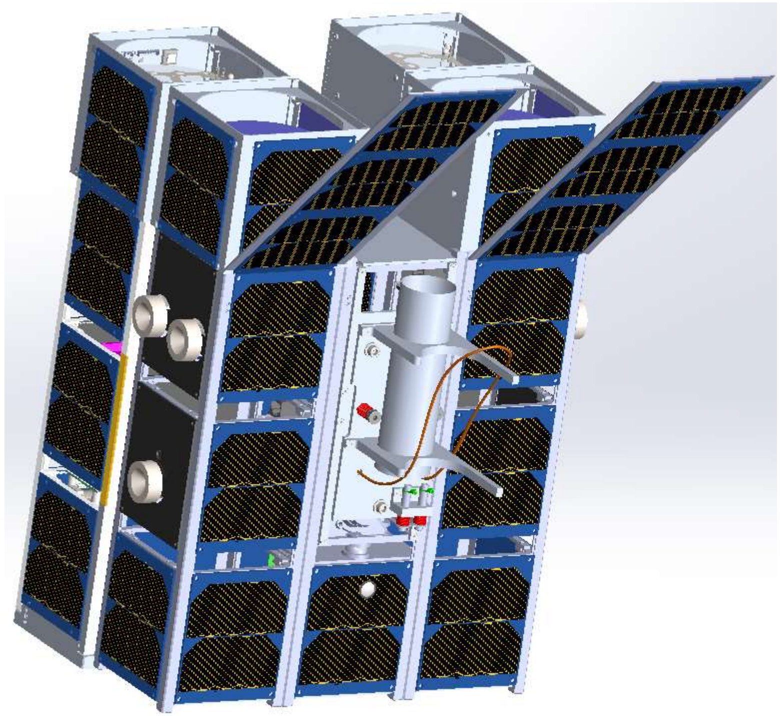
Deployable Panels



- 45 deg angle to avoid docking interference
- Narrow: 31.1 W
- Wide: 35.25 W



- 45 deg angle to avoid blocking RMB
- Narrow: 26.4 W
- Wide: 40.5 W

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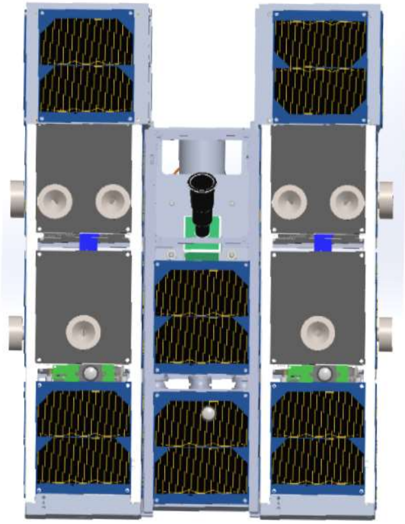
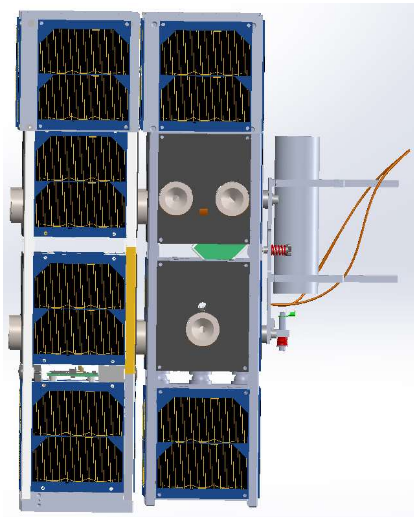
Power Output from Other Faces

+X	Narrow	Wide
CoreSat + MirrorSat	14.1/23.5 W	28.2/37.6 W
With extra 3U units	14.1/23.5 W	28.2/37.6 W



+Y/-Y	Narrow	Wide
CoreSat + MirrorSat	14.1 W	4.7/9.4 W
With extra 3U units	21.15 W	11.75/16.45 W



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Power Budget

Sub-System	Peak Power (W)	Qty.	Total Peak Power (W)
MirrorSat Charging (MC)	5	2	10
ADCS (stack + wheels, no GPS)	8	1	8
Star Camera (SC)	1	1	1
Frangibolts	9	4 (1)	9
OBC1	3.5	2	7
Camera	5	1	5
Rigid Mirror Payload	2	2	4
Payload Interface Computer (PIC)	7	1	7
WiFi	1	2	2
LIDAR + LEDs	2.5	2 (1)	2.5
Comms. Radio	2.4	1	2.4
EPS (95% eff.)	0.75	1	1.5
Boom Deployment	4	1	4

Operating Modes

1. Boom deployment
2. Detumbling
3. Frangibolt release
4. Nominal consumption
5. Ground communication
6. Science operations
7. Docking maneuvers

Nominal Consumption: EPS + ADCS = 9.5 W
Science Operation Peak: EPS + ADCS + PIC + Camera + RMP + SC = 26.5 W
Docking Peak: EPS + ADCS + PIC + LIDAR + WiFi + SC = 22 W

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EPS – Boards

- **Two EPS/Battery sets (+Y and –Y)**
- **3 ports with MPPT**
  - PVCP1: External charging port
  - PVCP2: Y panel
  - PVCP3: X Panel
- **GOMSpace NanoPower P31u X 2**
- **Integrated battery/Panasonic 18650B**
- **Battery heater?**
- **Distribute load across 2 EPS units?**

RF Communications

- **Existing solution**
  - Surrey ground station
  - ISIS TRXUV VHF/UHF Transceiver
  - Deployable monopole antennas similar to STRaND-1 satellite
  - Surrey's Saratoga data transfer protocol
- **Open issues**
  - Antenna placement
  - What hardware and software can we obtain from Surrey
  - Need to propose data sizes, rates, formats
  - Need to file for frequency allocation

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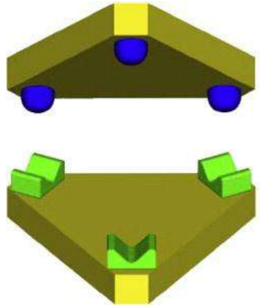
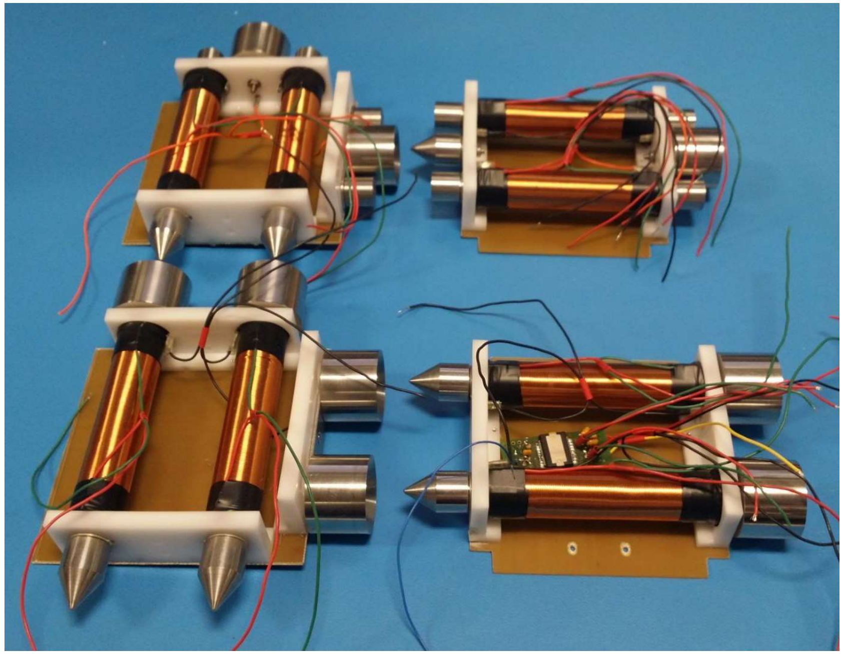
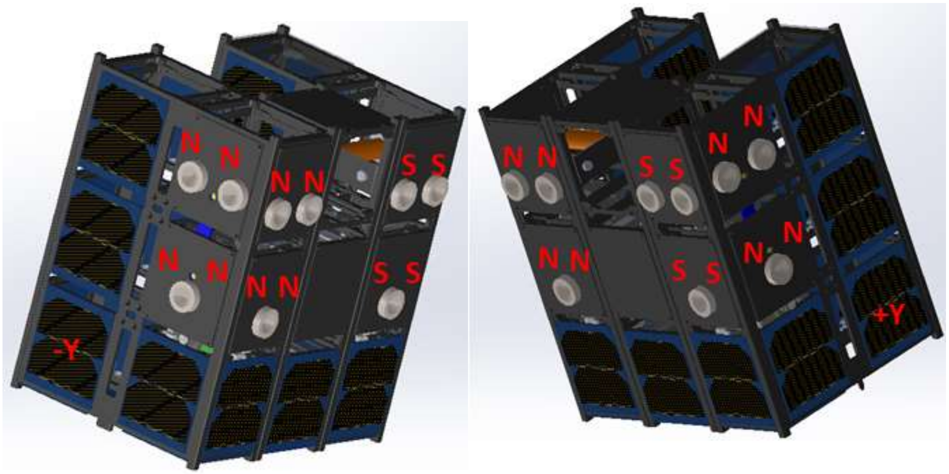
Sub-systems Description

- **Rendezvous and docking**
- Composed of 4 permanent magnets on the coresat coupled with 3 « probe and drogue » (60º cone and 45º cup) and 4 electromagnets on the MirrorSats
- Use Kelvin Clamp principle
- Monitored by earth sensor and LIDAR





CoreSat magnets polarities



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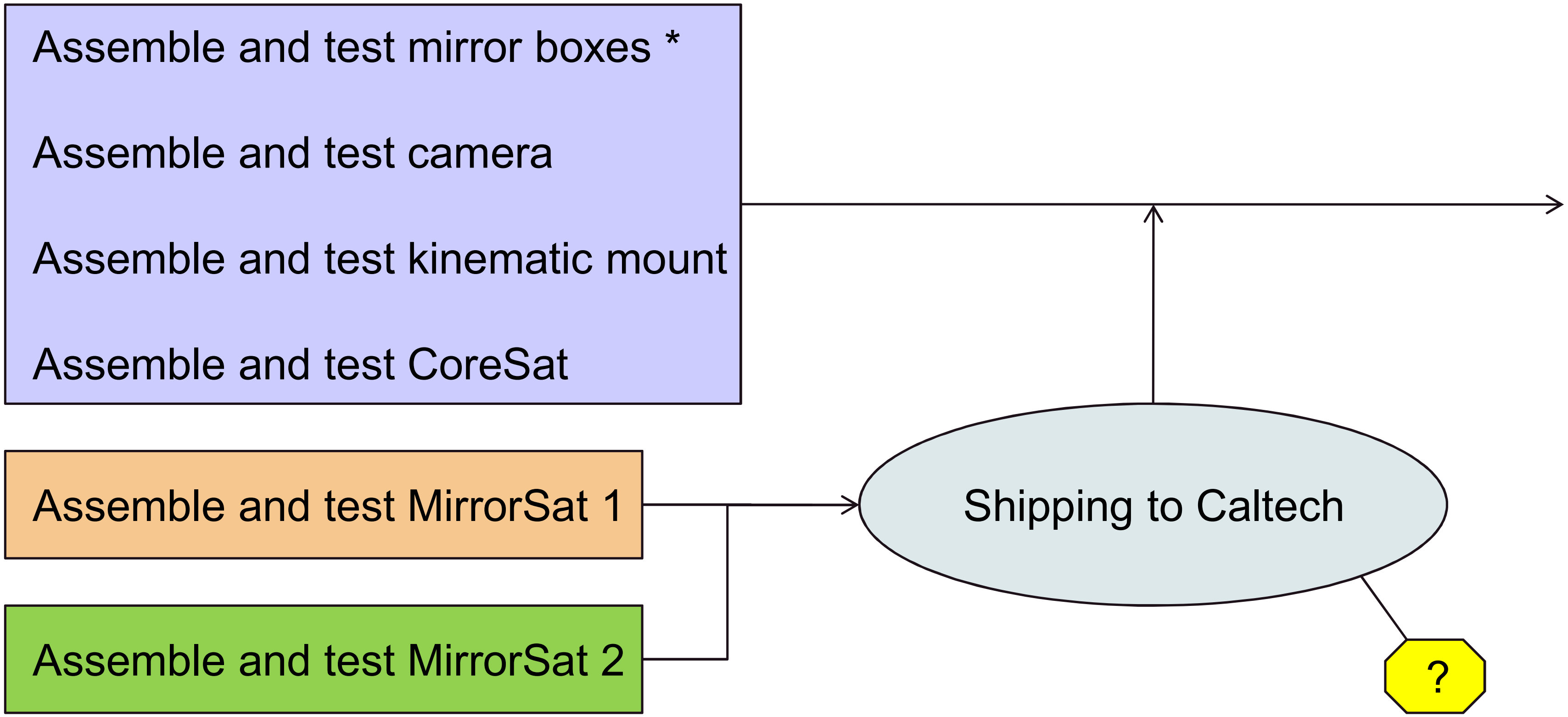
Integration and Test Plan: Spacecraft



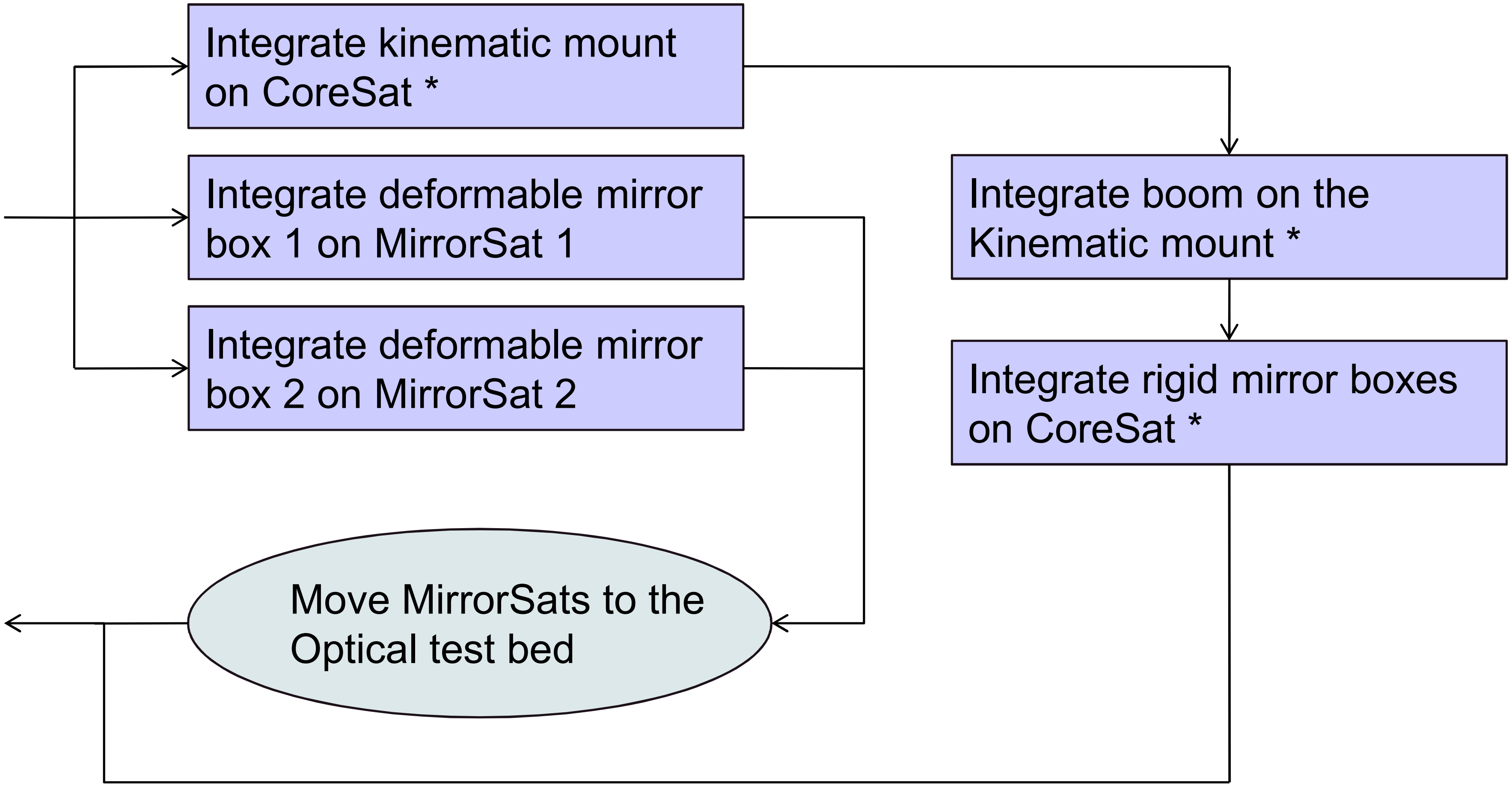
Location:

- USA, Caltech (SSL clean room)
- UK, University of Surrey
- India, IIST

? Important points to address first

*Without separation device cable

Integration and Test Plan: Spacecraft



*On the optical test bed

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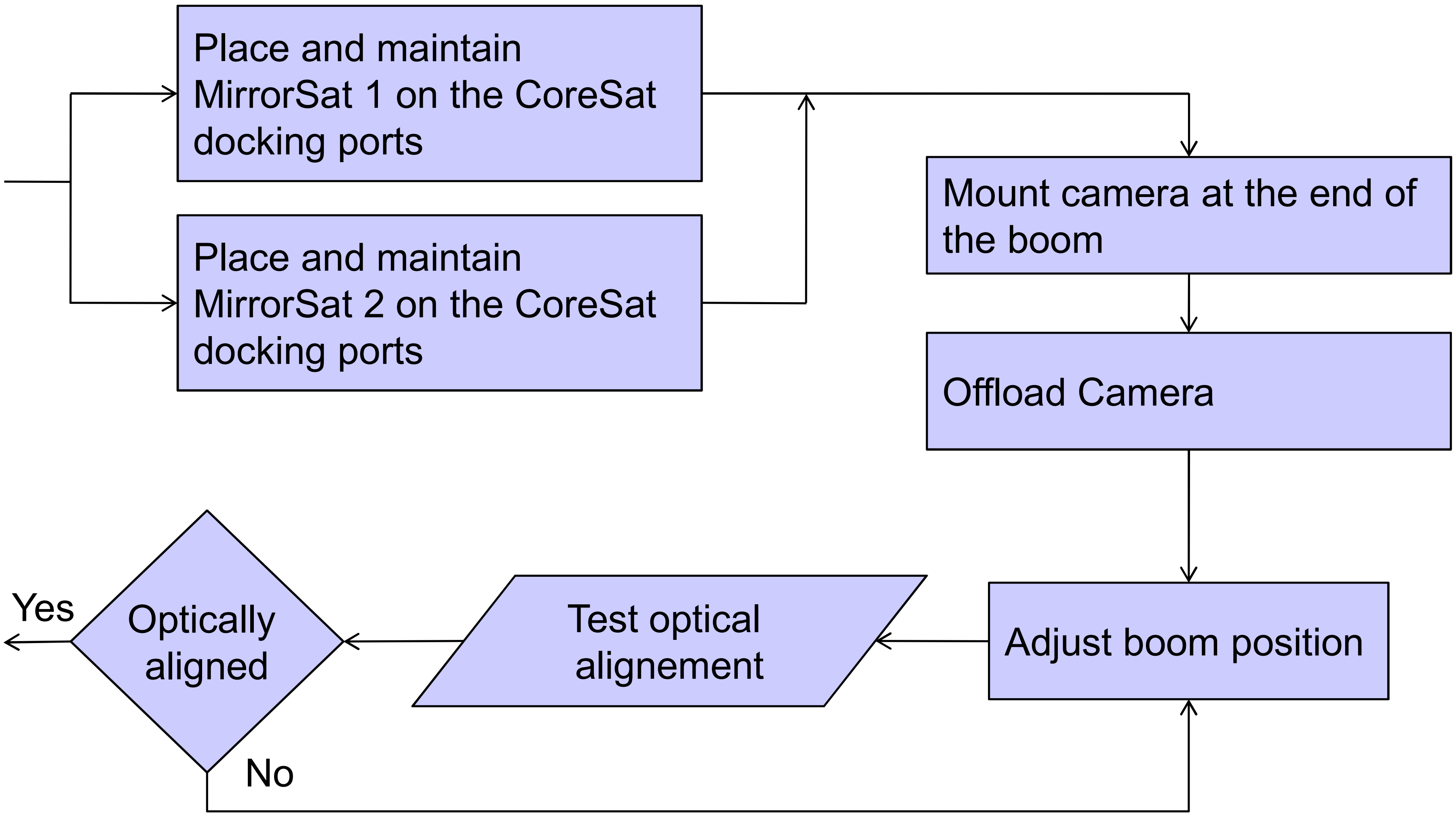
Integration and Test Plan: Spacecraft



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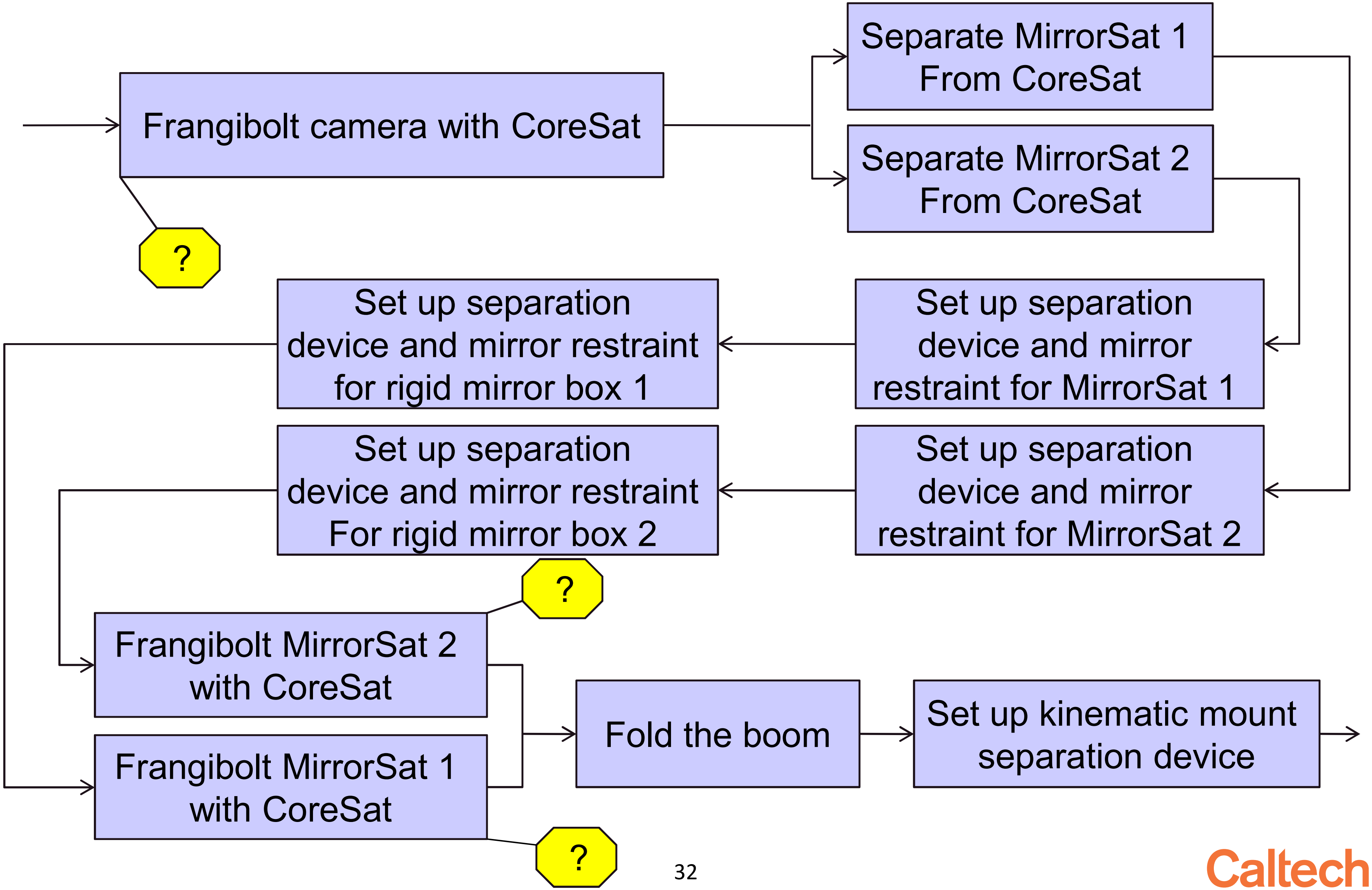
Integration and Test Plan: Spacecraft



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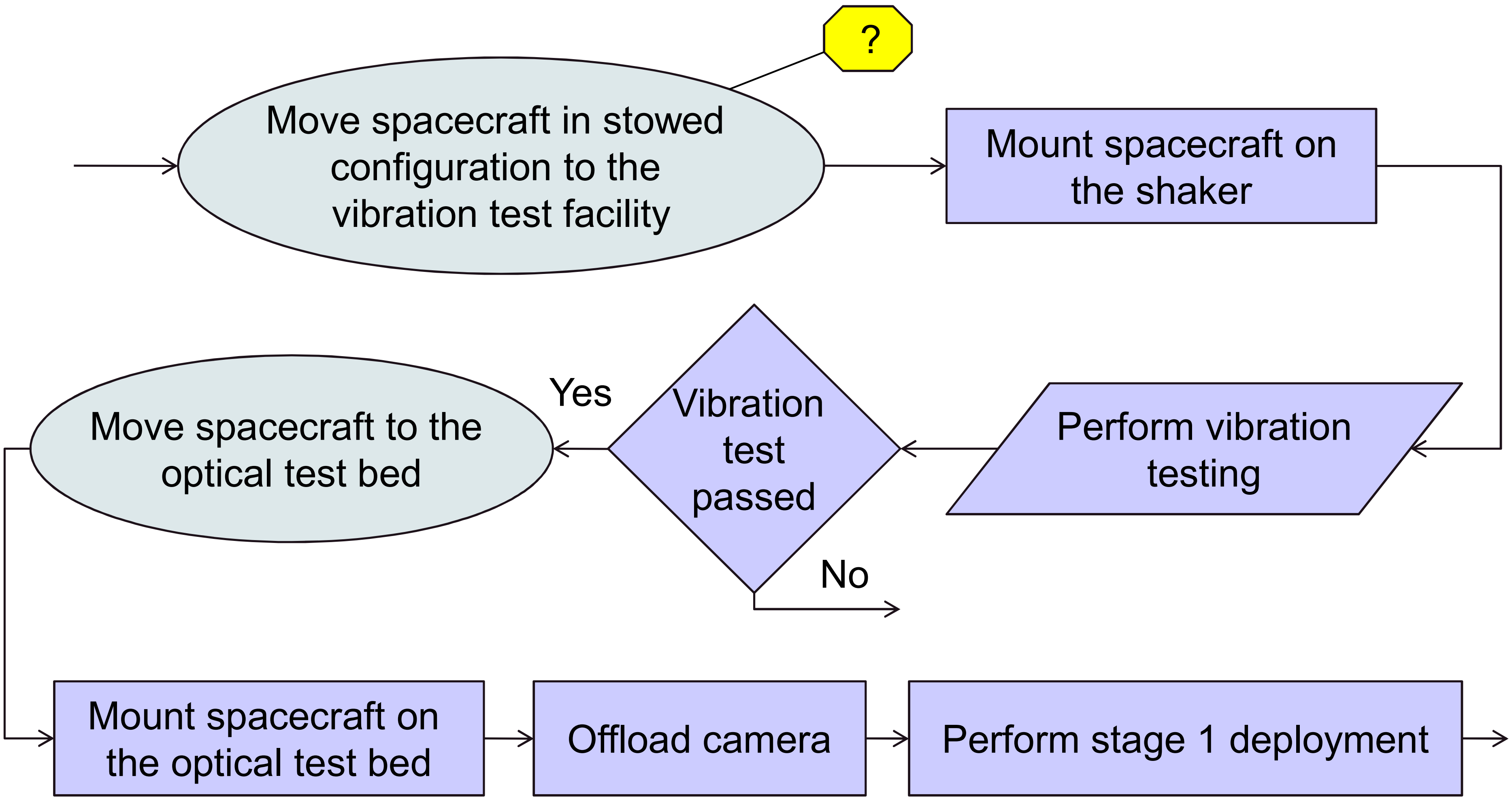

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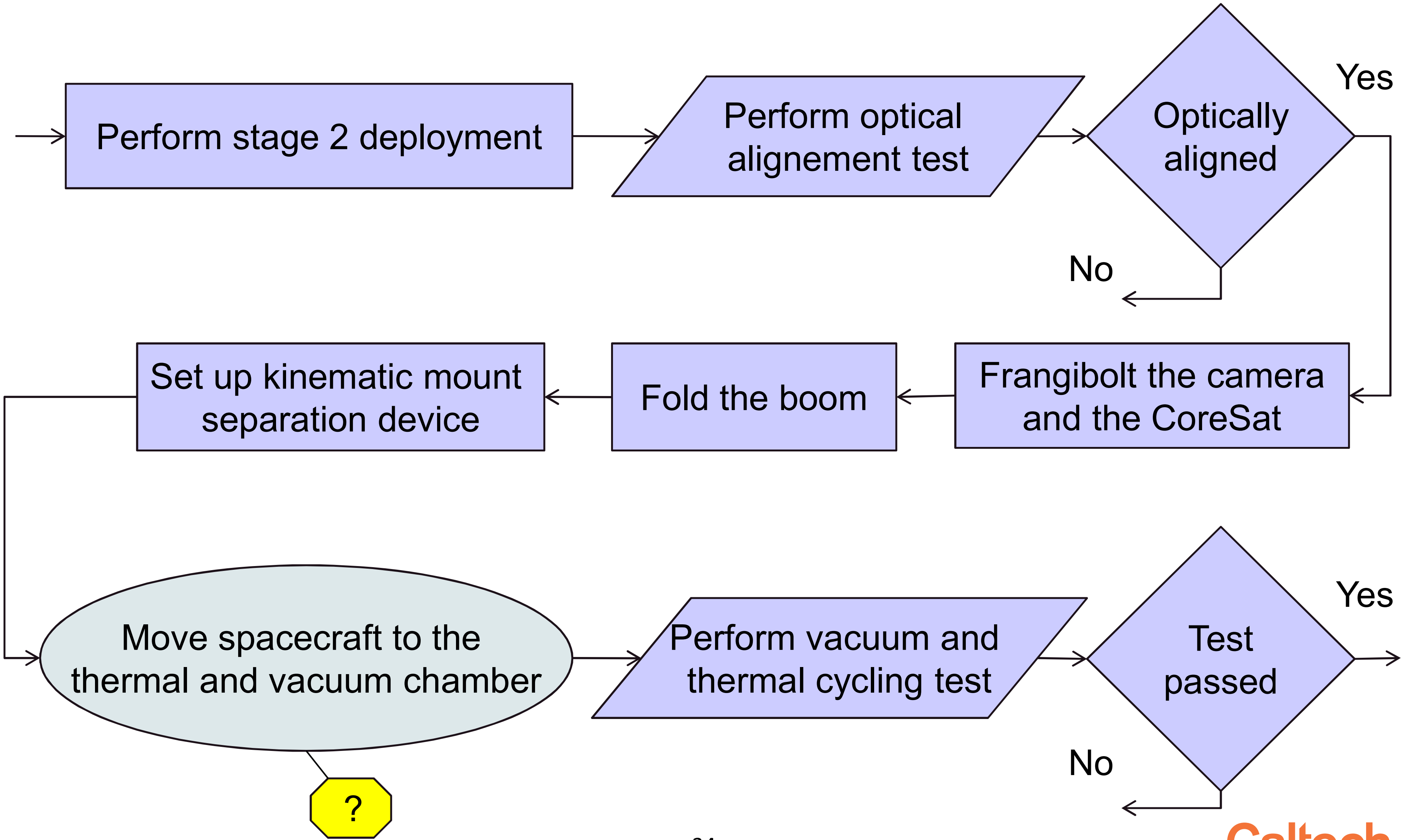

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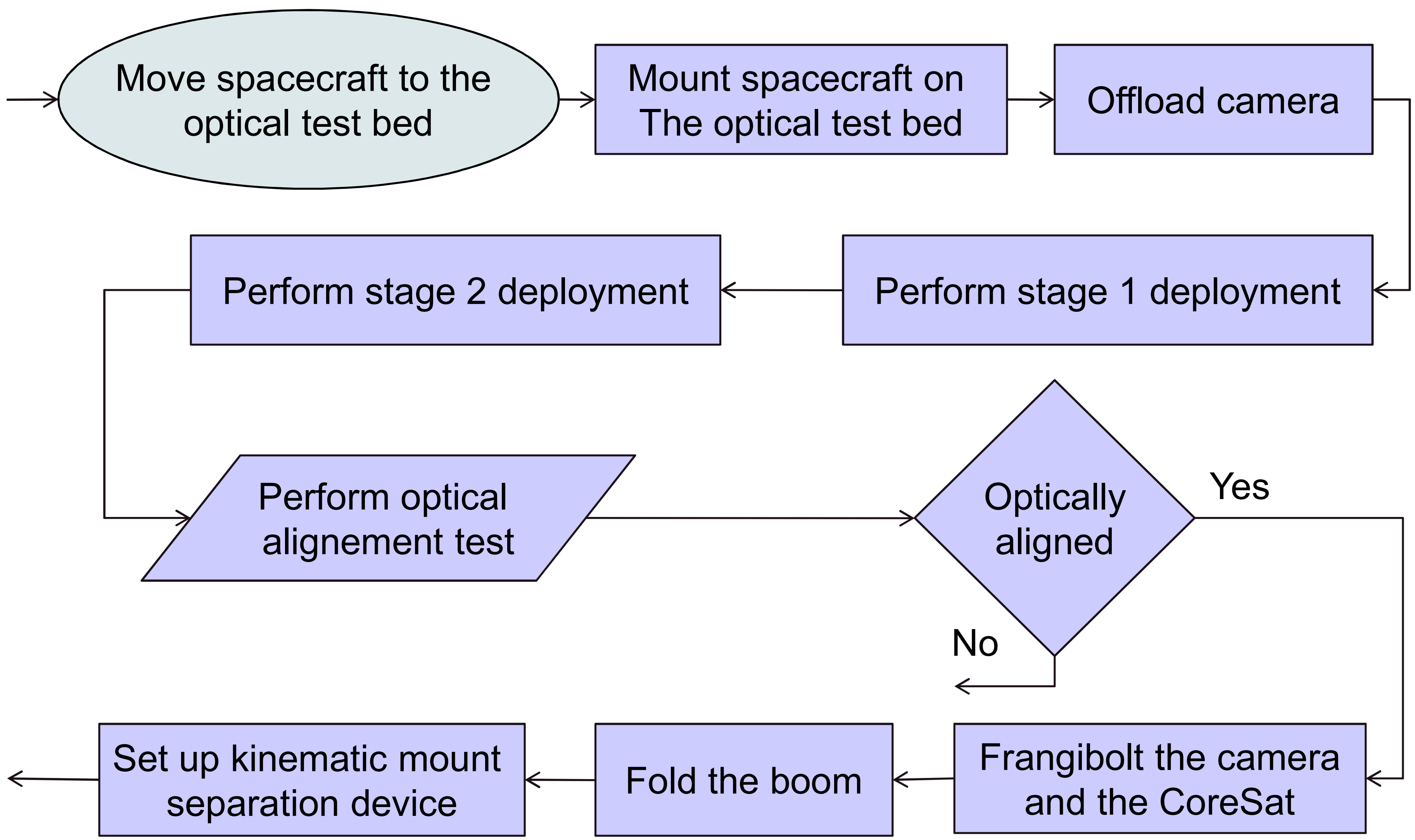

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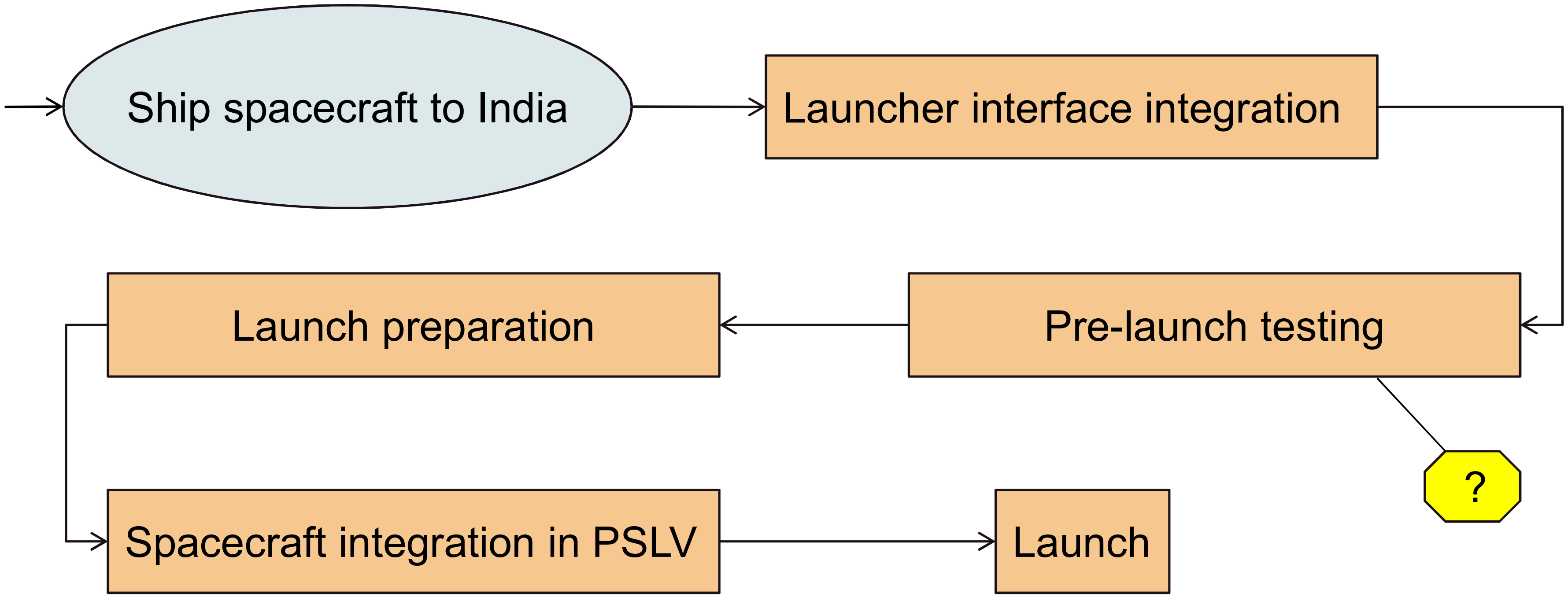
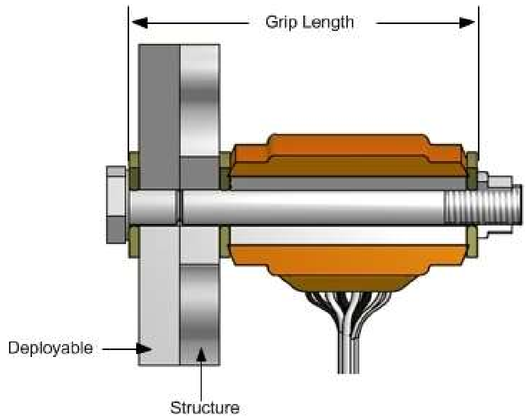
Integration and Test Plan: Spacecraft

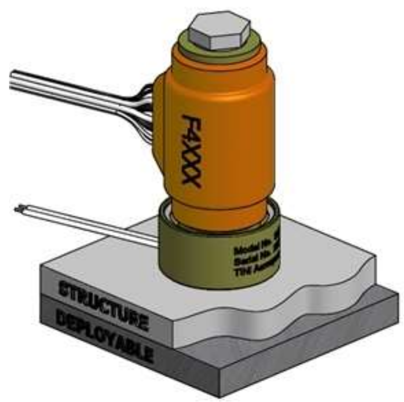


Integration and Test Plan: Spacecraft

- **Question raised by this test plan** ?

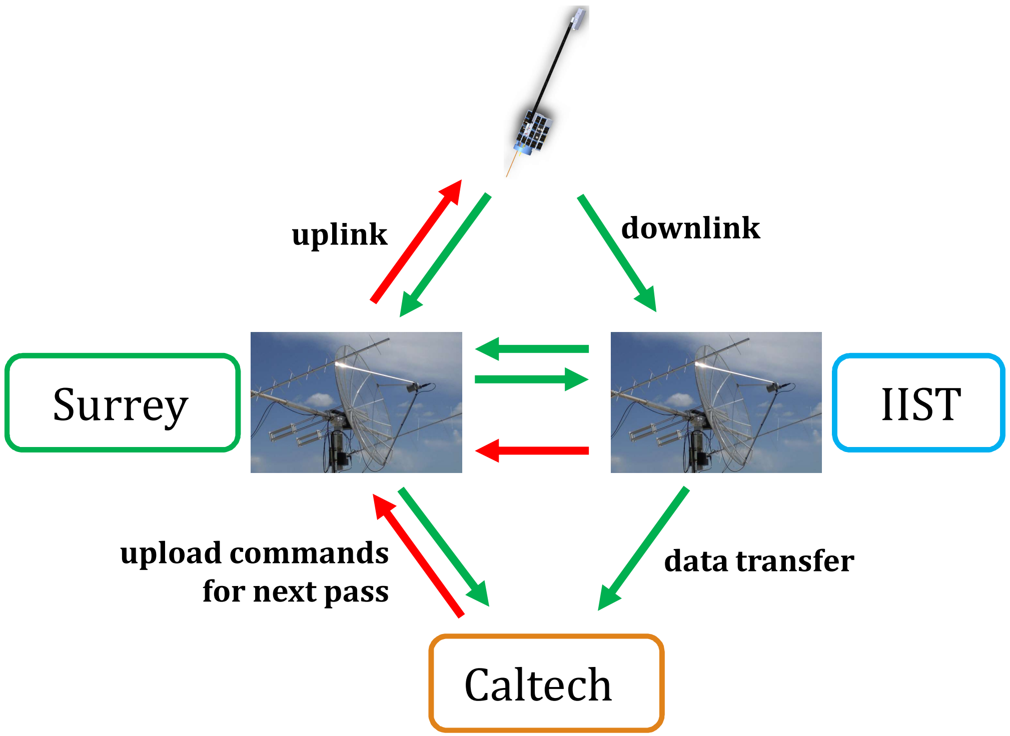
- Where should we do the testing? The optical test bed is at Caltech.
- Can we have access to external test facilities? (shaker, vacuum chamber, electromagnetic chamber)
- Are we re-testing in India if the final assembly is made in Caltech?
- How do we assemble the frangibolts? Need to take care of clearances to mount them.





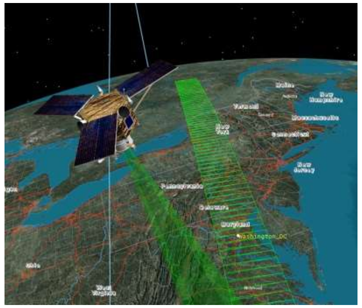
Spacecraft Operations

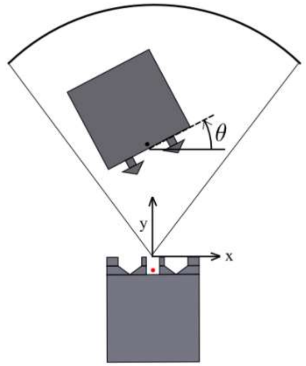
- **Primary ground station at University of Surrey, operated jointly by personnel from Caltech and IIST**
- **Downlink-only ground station at IIST**



Next Steps: System Engineering

- **Develop an orbital model of the spacecaft using AGI STK software**
  - Feed in to EPS and ADCS teams
- **Determine upper bounds on the docking maneuver clearance needed (no-go volume around the CoreSat)**
  - Simplified model with fixed magnetic fields, focus on translational data
- **Update interface control documents, maintain power budget and mass budget, verify requirements**
  - System engineering meeting at the beginning of every AE105 presentation
- **Elaborate CoreSat integration and test plan**
  - Communicate integration requirements to subsystem teams





Next Steps – Structures

Divide in three sub-tasks and possibly three sub-groups

- **Task 1: Structural design**
- **Task 2: Antenna positioning and mounting**
- **Task 3: Lunch Vehicle Interface**

Task 1 Involves CAD design based on sub-system requirements and mass / volume requirements and subsequent FEM modal analysis; a plan will be developed for fabrication of the custom chassis compatible with the CubeSat form-factor

Task 2 involves the positioning of the antenna for communication, without negative interaction with other moving components (i.e. docking, boom deployment)

Task 3 involves the selection of a launch vehicle interface (LVI) and an interface between the LVI and the spacecraft

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Next Steps – ADCS

- **Generate requirements for various operational modes**
- **Analyze magnetic torque disturbances**
- **Preliminary component selection**
- **Detailed ADCS analysis**
- **Create Hardware Test Plan**

Next Steps – EPS

- **Develop orbit simulator to estimate orbit averaged power for few candidate orbits**
- **Study various COTS solar panel, EPS and battery solutions**
- **Estimate power consumption for various operation modes**
- **Trade-off fixed vs deployable panels**
- **Develop test procedures for solar panels, batteries and EPS**
- **Deliverables**
  - Final design of the power system
  - CONOPS for various mission scenarios
  - Arrangement of solar cells on the outer surface

Next Steps – Avionics and RF

- **Avionics**
  - Component selection and trade-off (if necessary) for OBC
  - Board design, Wiring – Interface between OBC and systems
  - FlatSat – Design and integration of components
  - Software – Write drivers for each system
  - Software – Write scheduler

- **RF**
  - Component selection and trade-off (if necessary)
  - Hardware procurement
  - Select data sizes, rates, formats
  - Testing of integrated comms system

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Questions?

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