Outline

2:00 pm: Introduction & Welcome
2:15 pm: Camera
2:45 pm: Boom
3:15 pm: Mirror Boxes
3:45 pm: On-board Software
4:15 pm: Electronics
Mission Overview

Maria Sakovsky
Motivation: Building Large Space Telescopes

• Mirror dia. of current and planned space telescopes limited by constraints of a single launch
  – Hubble (1990): Ø 2.4 m
  – JWST (2018): Ø 6.5 m
  – HDST (2030+): Ø 11.7 m

• New paradigms needed for Ø 30 m+ segmented primary:
  – Autonomous assembly in orbit
  – Active ultralight mirror segments

• Active mirrors relax tolerances for assembly and manufacturing, correct thermal distortions
• Modular, robust, low-cost architecture
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AAReST Objectives

• Demonstrate key technologies:
  – Autonomous assembly and reconfiguration of modular spacecraft carrying mirror segments
  – Active, lightweight deformable mirrors operating as segments in a primary

• Operate for as long as necessary to accomplish the objectives (~90 days)

• Gather engineering data to enable development of the next system
AAReST Spacecraft
AAReST Spacecraft

CoreSat
Power, Comm., Telescope ADCS
Caltech
AAReST Spacecraft

MirrorSat (×1)
Reconfigurable free-flyers
U. of Surrey

CoreSat
Power, Comm., Telescope ADCS
Caltech

MirrorSat (×1)
Reconfigurable free-flyers
IIST
AAReST Spacecraft

MirrorSat (×1)  
Reconfigurable free-flyers  
_U. of Surrey_

CoreSat  
Power, Comm., Telescope ADCS  
_Caltech_

Deformable Mirrors (×2)  
Active mirror segments  
_Caltech_

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Fixed figure mirror segments
Caltech

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Deployable Boom
Composite structure provides 1.2 m focal length
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Camera
Imaging, Wavefront Sensing and Control
Caltech

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Composite structure provides 1.2 m focal length
Caltech

**Camera**
Imaging, Wavefront Sensing and Control
Caltech

| **MirrorSat (×1)** | **Launch Volume:** 46 × 34 × 30 cm | **Prime focus telescope:** 465 nm – 615 nm | **UHF down** | **Ref. orbits:**
<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mass:</strong> &lt;40 kg</td>
<td>0.34° field of view</td>
<td>1.2 m focal length</td>
<td>VHF up</td>
<td>~650 km SSO</td>
</tr>
<tr>
<td><strong>Prime focus telescope:</strong> 465 nm – 615 nm</td>
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<td><strong>UHF down</strong></td>
<td><strong>Ref. orbits:</strong></td>
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<tr>
<td><strong>UHF down</strong></td>
<td><strong>VHF up</strong></td>
<td><strong>Ref. orbits:</strong> ~650 km SSO</td>
<td><strong>ISS (400 km, 52 deg. incl.)</strong></td>
<td></td>
</tr>
</tbody>
</table>

[Image of the system components and specifications]
Mission Requirements

- **Minimum mission**
  1. Produce one focused image from a deformable mirror
     - 80% encircled energy radius from point source < 25 µm
  2. Perform at least one in-flight autonomous spacecraft reconfiguration maneuver to demonstrate space assembly capability

- **Extended mission**
  1. Produce one focused image from a deformable mirror after reconfiguration
  2. Coalign images to improve SNR and demonstrate precursor to co-phasing
  3. Produce at least two images of other sources (e.g. Earth and Moon) for outreach purposes
## Concept of Operations


Launch in a compact, stowed volume
- 46 cm × 34 cm × 30 cm
## Concept of Operations

|---|-----------|-------------------------|-----------------------------------|--------------------|--------------------------------------|---------------------|

- Turn on, verify satellite components
- Stabilize attitude, temperature

- Deploy boom in two stages:
  1. Boom segments unfold
  2. Camera is released
- Uncage deformable mirrors
## Concept of Operations

<table>
<thead>
<tr>
<th></th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Launch</td>
<td>Telescope Deployment</td>
<td>Telescope Calibration &amp; Imaging</td>
<td>Reconfiguration</td>
<td>Telescope Recalibration &amp; Imaging</td>
<td>Extended Mission</td>
</tr>
</tbody>
</table>

- Telescope points to a bright reference star
- Calibrate:
  - Segment tip/tilt/piston
  - Deformable mirror surface figure
- Camera provides feedback for segment calibration
Concept of Operations

|----|-----------|--------------------------|-----------------------------------|-------------------|------------------------------------|---------------------|

- MirrorSats release from CoreSat (one at a time)
- Fly out ~1 m
- Re-dock into “wide” configuration
Concept of Operations

1. Launch
2. Telescope Deployment
3. Telescope Calibration & Imaging
4. Reconfiguration
5. Telescope Recalibration & Imaging
6. Extended Mission

- Telescope points to a bright reference star
- Calibrate:
  - Segment tip/tilt/piston
  - Deformable mirror surface figure
- Camera provides feedback for segment calibration
## Concept of Operations

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<td>Extended Mission</td>
</tr>
</tbody>
</table>

- Co-align star images from different segments to improve SNR
  - Pre-cursor to co-phasing
- Produce images of extended sources (e.g. Moon, Earth) for outreach
AAReST Optical Overview

- Field of View: 0.34°
- Optical bandwidth: 465-615 nm (540 nm center)

Deformable Mirror (DM) \( \varnothing 0.1 \text{ m} \times 2 \)
Reference Mirror (RM) \( \varnothing 0.1 \text{ m} \times 2 \)

- \( \varnothing 0.405 \text{ m} \) aperture (narrow), \( f/D = 2.87 \)
- \( \varnothing 0.530 \text{ m} \) aperture (wide), \( f/D = 2.19 \)

M1 focal length: 1.163 m
Telescope Alignment and Control

- **Actuators:**
  - 3 rigid body motion (RBM) actuators per segment
  - 41 piezoelectric actuators per deformable mirror

- **Sensors:**
  - Image plane camera
  - Shack-Hartmann Wavefront Sensors (SHWS)

Feedback from image plane controls segment tip/tilt

Feedback from wavefront sensors controls deformable mirror figure and piston
Telescope Alignment and Control

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- **Sensors:**
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Team Responsibilities

• Caltech
  – Deformable mirrors
  – Telescope system
  – Boom
  – CoreSat

• University of Surrey
  – MirrorSat x1
  – Docking system
  – Mission ops

• Indian Institute of Space Science and Technology
  – MirrorSat x1

• JPL
  – Class instructors
  – Project management
Caltech Team

- Ae105 class designs, builds, analyzes, tests components
- Ae205 class provides mentorship and guidance
- JPL class instructors, project manager
- JPL provides mirror manufacturing facilities
- Postdocs, upper-year grad students, SURF students provide focused support
Outline

2:00 pm: Introduction & Welcome

2:15 pm: Camera

2:45 pm: Boom

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3:45 pm: On-board Software

4:15 pm: Electronics
AAReST Camera Team

Frederick Berl
Carlos Gonzalez
Kimberly Liu
Erika Schibber
William Yu

Mentor: Maria Sakovsky
Camera
Project Workflow

Goals:
Integrate the mechanical, optical and electronic components of the camera

Goal:
Create assembly and test procedures

Goal:
Test the camera to verify it work as expected and won’t break during launch

Camera Parts
- Quality Check
- Assembly
- Test Procedure

Camera Proto Flight Model
- Baseline Optical Test
- Thermal Cycling
- Optical Test
- Vibration Test
- Optical Test
- Signal to Noise Ratio Test
- Tested Camera
The Camera

prime focus

Collimator lens group

Cube B/S 1

SHWS 1

Imaging lens group

SHWS 2

Cube B/S 2

Light Shield

Pupil Mask

Beam-splitters

SHWS

Mask

Mask motor

Imaging lens

Imaging detector

Electronics Mount

Baffle

BIC

Collimator lens

Frangibolt interface

Boom Interface
Project Workflow

- Camera Parts
- Quality Check
- Assembly
- Test Procedure
- Camera Proto Flight Model
  - Baseline Optical Test
  - Thermal Cycling
  - Optical Test
  - Vibration Test
  - Optical Test
  - Signal to Noise Ratio Test
- Tested Camera
Assembly and Quality Check: Tasks

- Design assembly procedures
  - Created a set of comprehensive procedures
    - Cleaning, RTV application, and Assembly/Clean room procedures

- Quality Checking
  - Measured every part and checked if it was within specifications
  - Made sure parts fit together
    - Sent out parts that very clearly weren’t within spec to be fixed (i.e. parts that didn’t fit together)

- Camera Assembly
  - Fully assemble all available parts in the clean room using the relevant procedures
Assembly and Quality Check: RTV Test and Cleaning

Procedures are in place to apply RTV silicone, as well as to clean the parts and minimize their exposure to dust.
Mask Test

- Mask mechanism verification
  - ✔ Verify mask is rotated by stepper motor
  - ✔ Design limit switch mechanism
  - ▲ Find consistent mask rotation step sequence

- Stepper motor does not have enough torque to affect limit switch
  - ○ Using two strips of conducting tape

- Mask jams occasionally during rotation
  - ○ Postpone test until bearing is inserted
Assembly and Quality Check: Assembled Camera
## Mass Budget

### Camera Team Mass Budget

<table>
<thead>
<tr>
<th>Component</th>
<th>As Designed (g)</th>
<th>Margin (%)</th>
<th>As Designed + Margin (g)</th>
<th>Measured (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metrology Plate</td>
<td>482</td>
<td>5</td>
<td>506</td>
<td>458</td>
</tr>
<tr>
<td>Collimator, Focal Group, and Beam Splitters</td>
<td>1238</td>
<td>5</td>
<td>1300</td>
<td>1148</td>
</tr>
<tr>
<td>Lens Mounts (4x)</td>
<td>320</td>
<td>5</td>
<td>336</td>
<td>304</td>
</tr>
<tr>
<td>Electronics Package (Al)</td>
<td>253</td>
<td>30</td>
<td>327</td>
<td>252</td>
</tr>
<tr>
<td>Fasteners &amp; Wiring</td>
<td>181</td>
<td>20</td>
<td>217</td>
<td>181</td>
</tr>
<tr>
<td>SHWS Board and Mount (2x)</td>
<td>308</td>
<td>5</td>
<td>323</td>
<td>302</td>
</tr>
<tr>
<td>Light Shielding and Baffle</td>
<td>155</td>
<td>5</td>
<td>163</td>
<td>150</td>
</tr>
<tr>
<td>Boom Inspection Camera</td>
<td>17</td>
<td>5</td>
<td>18</td>
<td>17</td>
</tr>
<tr>
<td>Image Detector w/ Mount</td>
<td>45</td>
<td>5</td>
<td>48</td>
<td>44</td>
</tr>
<tr>
<td>Mask and Motor Assembly (Al)</td>
<td>48</td>
<td>5</td>
<td>51</td>
<td>54</td>
</tr>
<tr>
<td>Frangibolt and Boom Bracket (Al)</td>
<td>218</td>
<td>5</td>
<td>229</td>
<td>218</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3263</strong></td>
<td></td>
<td><strong>3517</strong></td>
<td><strong>3128</strong></td>
</tr>
</tbody>
</table>
## Assembly and Quality Check: Deviations from test-as-you-fly

### Cleaning Procedures

<table>
<thead>
<tr>
<th>Item</th>
<th>Reason</th>
<th>Impact</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isopropyl Alcohol leaves residue</td>
<td>The IPA was meant to be dried with compressed air</td>
<td>Low</td>
<td>Dry with compressed air/nitrogen</td>
</tr>
</tbody>
</table>

### Assembly Procedures

<table>
<thead>
<tr>
<th>Item</th>
<th>Reason</th>
<th>Impact</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolt stuck in titanium plate (lens barrel assembly)</td>
<td>Defective bolt snapped while torqueing</td>
<td>Low</td>
<td>Glue long rod to the bolt unscrew it</td>
</tr>
<tr>
<td>Beam splitters not properly mounted</td>
<td>One detent does not screw in all the way</td>
<td>Low</td>
<td>Get a new detent</td>
</tr>
<tr>
<td>RTV spacer on lens R3 (Spacer AARC6)</td>
<td>Lens was loose</td>
<td>Low</td>
<td>Send barrel back to shop</td>
</tr>
</tbody>
</table>
Project Workflow

- Camera Parts
- Quality Check
- Assembly
- Test Procedure
- Camera Proto Flight Model
- Baseline Optical Test
- Thermal Cycling
- Optical Test
- Vibration Test
- Optical Test
- Signal to Noise Ratio Test
- Tested Camera
Thermal: Tasks

- Design test procedures
  - ✓ Research effects of condensation and ambient pressure
  - ✓ Finish procedures document
- Thermal testing
  - ▲ Preliminary tests
  - ▲ Full test
  - ✓ Post-test structural/optical verification
Thermal: Setup

- **Equipment:**
  - Instron 500 Series Environmental Chamber
    - Not under vacuum
    - Possibility of condensation

- **Set up:**
  - Vacuum bag
    - Tape seal
    - Nitrogen purge
  - Two thermocouples
Thermal: Test Procedure

- Two low level preliminary tests
- 2 hour dwell time
- 3°C/min ramp rate
- Finish with bake at 30°C to eliminate condensation
Thermal: Test Procedure

Plan:

Room Temp → 40°C → -30°C → 30°C → Room Temp

Actual:

Room Temp → 40°C → 0°C → 40°C → Room Temp

- Thermal lag: ~ 0.15°C/min
  1 hour dwell time
- Thermocouples show 5°C gradient across camera
- Slow conducting nitrogen in bag

Plan vs Actual

Temperature (°C) vs Time (min)

Test Plan: Blue line
Thermocouple 1: Red line
Thermocouple 2: Green line
Thermal: Optical Test Setup

- Collimating Lens
- Refocusing Lenses
- Mirror Simulating Mask
- Point Source
- Camera
Thermal: Optical Test

Imaging Detector Spot Size Comparison

<table>
<thead>
<tr>
<th></th>
<th>Simulated</th>
<th>Pre-thermal</th>
<th>Post-thermal</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 x 260 um</td>
<td>~350 x 230 um</td>
<td>~350 x 230 um</td>
<td></td>
</tr>
</tbody>
</table>
Thermal: Optical Test

SHWS Spot Number Comparison

<table>
<thead>
<tr>
<th></th>
<th>Predicted</th>
<th>Pre Thermal</th>
<th>Post Thermal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirror 1</td>
<td>~153</td>
<td>153</td>
<td>151</td>
</tr>
<tr>
<td>Mirror 2</td>
<td>~153</td>
<td>152</td>
<td>153</td>
</tr>
</tbody>
</table>

SHWS Spot Size Comparison
- Diffraction limited = 4 pixels diameter
- Measured = ~4-5 pixel diameter
## Thermal: P/F Criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Heating/cooling rates</td>
<td>Out of Spec</td>
</tr>
<tr>
<td>• No signs of condensation on interior of vacuum bag</td>
<td>Some condensation, no adverse effects noted</td>
</tr>
<tr>
<td>• No obvious physical damage</td>
<td>Pass</td>
</tr>
<tr>
<td>• No loose parts</td>
<td>Pass</td>
</tr>
<tr>
<td>• Optical performance meets the requirements</td>
<td>Pass</td>
</tr>
</tbody>
</table>
Project Workflow

Camera Parts
- Quality Check
- Assembly

Test Procedure
- Camera Proto Flight Model
- Baseline Optical Test
- Thermal Cycling
- Optical Test
- Vibration Test
- Optical Test
- Signal to Noise Ratio Test
- Tested Camera
Vibration Testing: Tasks

• Test preparation
  ✓ Create procedures document
  ✓ Manufacture camera mounts

• Vibration tests
  ▲ Set up and run vibration test
  ▲ Post-test optical verification
Vibration Testing: Instruments

Vibration X to camera X

- Lens barrel 1: triaxial
- Lens barrel 2: uniaxial
- SHWS: uniaxial
- Interface plate: triaxial

Vibration X to camera Y

- Lens barrel 1: triaxial
- Lens barrel 2: uniaxial
- Mask: uniaxial
- Interface plate: triaxial
Vibration Testing: Test Sequence and Input Profiles

White Noise → -12 dB → White Noise → -6 dB → -3 dB → White Noise → Full Level → White Noise

Minimum Workmanship - ASD

- ASD values for different levels of attenuation:
  - 6.8 grms
  - 4.8 grms
  - 3.4 grms
  - 1.7 grms

3 dB/oct
Vibration Testing: Checks

Run

Pre-Run

- Spectrum
- Torque

Post-Run

Signature
- Frequency shift < 5%
- Amplitude shift < 10%

Accelerometers
- Signal
- Correct polarization
- No saturation

Torque
- No change

Visual Inspection
- Failures (e.g. corners, lenses area)

Optical Test
# Vibration Test: Flight Deviations from test-as-you-fly

<table>
<thead>
<tr>
<th>Item</th>
<th>Reason</th>
<th>Impact</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronic boards not included</td>
<td>PCB and other electronics not ready yet</td>
<td>Low</td>
<td>Dummy PCBs to be used</td>
</tr>
<tr>
<td>Boundary conditions do not match flight</td>
<td>One plane of contact during test</td>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>Vibration table has strong resonance at 1500 Hz</td>
<td>Vibration table needs maintenance</td>
<td>High</td>
<td>Postpone test for maintenance</td>
</tr>
<tr>
<td>Vibration table produces large Y- and Z-axis vibrations</td>
<td>Vibration table needs maintenance</td>
<td>High</td>
<td>Postpone test for maintenance</td>
</tr>
</tbody>
</table>
Project Workflow

Camera Parts

Quality Check

Assembly

Test Procedure

Camera Proto Flight Model

Baseline Optical Test

Thermal Cycling

Optical Test

Vibration Test

Optical Test

Signal to Noise Ratio Test

Tested Camera
Signal to Noise Ratio Test

**Goal:** Verify SNR > 100 for the camera

**How?** Use a calibrated photodiode to measure intensity of white light source and adjust until it matches our expected star.
Signal to Noise Ratio: Setup

1. Align mirrors
2. Align photodiode at prime focus
3. Red Laser → White Light Source
4. Vary intensity white light until desired voltage is reached
5. Photodiode → Camera
6. Take picture and calculate SNR
Signal to Noise Ratio: Setup

1. Align mirrors
2. Align photodiode at prime focus
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5. Photodiode → Camera
6. Take picture and calculate SNR

AAReST Rigid Mirror

Flat Mirror

Point Source

Beam-splitter

Prime Focus

Calibrated Photodiode
Signal to Noise Ratio: Setup

1. Align mirrors
2. Align photodiode at prime focus
3. Red Laser → White Light Source
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- AAReST Rigid Mirror
- Flat Mirror
- Point Source
- Beam-splitter
- Prime Focus
- Calibrated Photodiode
Signal to Noise Ratio: Setup

1. Align mirrors
2. Align photodiode at prime focus
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5. Photodiode $\rightarrow$ Camera
6. Take picture and calculate SNR

Diagram:
- AAReST Rigid Mirror
- Flat Mirror
- Beam-splitter
- Prime Focus
- Calibrated Photodiode
Signal to Noise Ratio: Setup

1. Align mirrors
2. Align photodiode at prime focus
3. Red Laser → White Light Source
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5. Photodiode → Camera
6. Take picture and calculate SNR

Desired Voltage: 2.6 mV
Filtered Voltage: 1.8 mV
Signal to Noise Ratio: Setup

1. Align mirrors
2. Align photodiode at prime focus
3. Red Laser \(\rightarrow\) White Light Source
4. Vary intensity white light until desired voltage is reached
5. Photodiode \(\rightarrow\) Camera
6. Take picture and calculate SNR

AAReST Rigid Mirror

Flat Mirror
Signal to Noise Ratio: Setup

1. Align mirrors
2. Align photodiode at prime focus
3. Red Laser → White Light Source
4. Vary intensity white light until desired voltage is reached
5. Photodiode → Camera
6. Take picture and calculate SNR

Picture and SNR Calculation!
SNR Calculation

Test deviations:
- Light not point source
  - Mask blocks larger beams from image detector
- Incorrect intensity: light source too dim

SNR Calculation

\[
SNR = \frac{\text{mean}(\text{Signal} - \text{Background})}{\text{RMS(Background)}}
\]

<table>
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<tr>
<td>SNR &gt; 100</td>
<td>51.89</td>
</tr>
</tbody>
</table>
# Summary: Status of Tests

<table>
<thead>
<tr>
<th>Test</th>
<th>Comments</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Baseline</td>
<td>New camera images consistent with previous</td>
<td>Pass</td>
</tr>
<tr>
<td>Thermal</td>
<td>Thermal lag</td>
<td>Need to improve setup</td>
</tr>
<tr>
<td>Mechanical</td>
<td>Reliable step sequence</td>
<td>Missing bearing</td>
</tr>
<tr>
<td>Vibration</td>
<td>No vibration modes of table in test frequency range</td>
<td>Vibration table out of service</td>
</tr>
<tr>
<td>SNR</td>
<td>Point light source intensity</td>
<td>Inadequate optical fiber</td>
</tr>
</tbody>
</table>

![Status Colors](https://example.com/status_colors.png)
Summary: Future Work

- Thermal testing w/ new setup
- Vibration testing w/ fixed table
- SNR measurement w/ correct light intensity
- Integrate electronics
- Integrate light shielding
- Finalize external interfaces
- Integration to satellite
Thank you!

Questions?
Outline

2:00 pm: Introduction & Welcome
2:15 pm: Camera
2:45 pm: Boom
3:15 pm: Mirror Boxes
3:45 pm: On-board Software
4:15 pm: Electronics
Boom Subsystem Validation

Team

Fabien Royer
Federico Presutti
Joaquin Garcia-Suarez
Thomas Peterson

Mentor:
Christophe Leclerc
Boom Subsystem
Boom Subsystem Overview

Introduction

• The hinged composite boom is responsible for bearing and deploying the camera
• Newest boom designed last year; some features to be retested

Team Responsibilities:

• Validate structural integrity and proper deployment of boom subsystem
• Ensure repeatability of boom alignment for optical applications
• Define structural details of boom connection to CoreSat
Tasks Overview

Boom-mount connection design

Stage 2 Deployment Testing

Vibration Testing

Accuracy Testing
Boom-Mount Interface Design

Objective: design the final connection to survive LEO conditions

Deal with **CTE mismatch**
- Stresses arise at the interface due to different deformations of the materials
- Operation thermal conditions: **+60°C to -60°C**

Our choice: **LOCTITE EA 9394 AERO**
- Epoxy Paste Adhesive
  (Known as Hysol EA 9394)

- Appropriate thermal and mechanical properties and low outgassing
Design of Boom-Mount Fixation

Testing structural integrity of the connection:
- Prepared connection sample for test (following bonding procedure)
- Used environmental chamber to test thermal cycle
- Mechanical load applied

Conclusions:
- Expected mechanical and thermal loads do not trigger failure
Stage 2 Deployment Test

Objectives:
• Ensure a reliable and repeatable stage 2 deployment
• Track deterioration and wear of the composite boom
• Determine maximum acceleration due to deployment
Stage 2 Deployment Testing

<table>
<thead>
<tr>
<th>Part</th>
<th>Mass (kg)</th>
<th>2014</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera</td>
<td>2.98</td>
<td>3.43</td>
<td></td>
</tr>
<tr>
<td>CoreSat</td>
<td>27.74</td>
<td>27.74</td>
<td></td>
</tr>
</tbody>
</table>

Updates to experimental setup:

- Increase camera mass to account for new weight requirements
- Increase mandrel diameter with 3D printed piece to fit new boom design

CoreSat mass model

Camera mass model
Stage 2 Deployment Results

• Boom deterioration:
  – Tests will be performed preflight; need to be sure tests will not compromise boom and deployment
  – First sign of wear of the composite matrix after the third test (3 cycles folding/deployment)
  – By seventh test, no cracks had formed on the boom, but more visible signs of wear on the matrix

• Repetitive deployment pattern:
  – In agreement with previous tests (2014)
  – In disagreement with computer simulations; needs updating
Stage 2 Deployment Results

- Maximum accelerations on camera:
  - About 1g
  - Loads due to deployment are expected to be smaller than those during launch
  - Ex: at least 2g axial and lateral shocks expected from Delta IV rocket launch
Boom Natural Frequencies

- Discrete Fourier Transform of acceleration profile was used to analyze boom natural frequencies.
- Need to avoid disturbances from satellite components inducing vibrations at natural frequencies (e.g. reaction wheel).

<table>
<thead>
<tr>
<th>Observed Frequency (Hz)</th>
<th>Inferred Corresponding Mode</th>
<th>Approximate Decay Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Torsion around boom axis + bending in xz plane</td>
<td>5</td>
</tr>
<tr>
<td>11</td>
<td>Torsion higher mode</td>
<td>5</td>
</tr>
<tr>
<td>13</td>
<td>Bending in xz plane</td>
<td>20</td>
</tr>
</tbody>
</table>

• Discrete Fourier Transform of acceleration profile was used to analyze boom natural frequencies.
• Need to avoid disturbances from satellite components inducing vibrations at natural frequencies (e.g. reaction wheel).
Vibration Testing Objectives

- Survive launch vibration phase
  - Acceptance level test (10 gRMS, 30g peak)

- Accurate position of the camera
  - Vibration induced displacements of the adjustable components

- Separation device functional
  - Evolution of the Vectran cable tension

- System undamaged
  - Structural integrity and mechanical response

Random vibration input direction:
- X-axis
- Y-axis
Testing setup and interface

- FARO Arm
- Camera
- Shaker
- Boom
- Kinematic mount
- Interface
Results: observations

Thorough visual inspection

Stroke of the separation device: Tension of the Vectran cable

Faro arm measurements: relative displacements

Accelerometers: Structural integrity

Transfer function overlay top collar mount

Frequency (Hz)
Quantitative results

<table>
<thead>
<tr>
<th>Stroke X-axis test (mm)</th>
<th>Stroke Y-axis test (mm)</th>
<th>Relative loss of stroke X-axis test (%)</th>
<th>Relative loss of stroke Y-axis test (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.58</td>
<td>7.08</td>
<td>16.9</td>
<td>6.2</td>
</tr>
</tbody>
</table>

• Requirement: final stroke > 3mm

Displacements Y-axis testing

<table>
<thead>
<tr>
<th>Mandrel axis linear displacement (mm)</th>
<th>dx: 0.032, dz:0.009 (dy: 0.052)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mandrel axis angular displacement (°)</td>
<td>0.037</td>
</tr>
<tr>
<td>Camera displacement (modulus) (mm)</td>
<td>0.9 mm</td>
</tr>
</tbody>
</table>
Accuracy Testing Criteria

- Verify the **repeatability** of camera alignment, after the boom is folded and stored for some time.
- If the boom is aligned during assembly, will it still be aligned after deployment?

**Camera Tolerances**

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Focal length</td>
<td>1163 ± 1mm</td>
</tr>
<tr>
<td>Maximum admissible lateral offset</td>
<td>± 3 mm</td>
</tr>
<tr>
<td>Maximum admissible angular offset</td>
<td>± 1°</td>
</tr>
</tbody>
</table>
Accuracy Testing Methods

- **Challenge:** Boom is 1.5 meters long and flexible; we need to measure position with millimeter accuracy and without touching it.
- **Solution:** FARO Arm measuring device with optical scanning tool.

Simulated storing the boom for seven months in folded configuration by aging process – 2000 seconds at 96°C

**Procedure:**
1. Scan the camera end of the boom
2. Scan the coresat end of the boom
3. Fit each point cloud to a cylinder in matlab
4. Determine the position of the camera end relative to the coresat end
5. See how the position changes after folding and aging
Accuracy Testing Results

<table>
<thead>
<tr>
<th>Description</th>
<th>Length Change</th>
<th>Lateral Change</th>
<th>Angular Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirement</td>
<td>± 1 mm</td>
<td>± 3 mm</td>
<td>± 1°</td>
</tr>
<tr>
<td>Folding</td>
<td>0.1 mm</td>
<td>0.5 mm</td>
<td>0.1°</td>
</tr>
<tr>
<td>Aging</td>
<td>3.0 mm</td>
<td>1.0 mm</td>
<td>0.2°</td>
</tr>
</tbody>
</table>

- Axial displacement after aging is larger than expected – 3 mm elongation
- Could be a problem with our measurement system or with the boom itself
- Needs further investigation
Conclusions

• Found a reliable method of performing the boom-mount connections

• Changes in boom do not affect maximum acceleration experienced by boom during stage 2 deployment

• Repeatable pattern of natural frequencies observed in stage 2 deployment

• Kinematic mount validated under vibration environment

• Validated the accuracy of the boom position after folding and storage
Future work

• Analysis of the vibration modes and comparison with the simulations
• Stage 1 and stage 2 deployment tests with aged booms
• Repeat the Stage 2 deployment computer simulation adding constraints to match experimental results
• Error quantification for the vibration test results
• Vibration test of the full system (full boom in launch configuration)
• Investigate large axial displacement of the boom after aging
Thanks for your attention
Any questions?
Outline

2:00 pm: Introduction & Welcome
2:15 pm: Camera
2:45 pm: Boom
3:15 pm: Mirror Boxes
3:45 pm: On-board Software
4:15 pm: Electronics
Mirror Box

Jake Larson, Sheila Murthy, Catherine Pavlov, Tyler Okamoto, Anand Kumar

Mentor: Serena Ferraro
Rigid Mirror Boxes

Deformable Mirror Boxes
Project Overview

Key Purposes of Mirror Boxes:

• House mirrors and electronics
• Restrain mirrors during launch
• Provide rigid body rotation and axial motion of the mirrors

Mirror Boxes Objectives:

• Develop assembly methods and documentation
• Design and manufacture Mirror Box parts
• Test epoxy and picomotor limit switches
• Perform vibration testing with proto-flight components
• Future work: Perform optical and mechanical testing on both boxes
Mirror Boxes Overview

Rigid

- Mirrors & Mounts
- Picomotors
- Electronics

Deformable

- Launch Restraint System
- Frame

Dimensions:
- 105mm
- 106mm
- 105.6mm
Mirror Box Assembly

- Both boxes are assembled using similar procedures which integrate the three primary subsystems of the boxes.
- These procedures are codified in assembly documents.
Assembly overview

1. Mirror plate + mirror
2. Reference plate + picomotors
3. Mirror plate + reference plate connected via Vectran™ tensioning
4. Electronics boards mounted on base plate
5. Mirror assembly and walls attached to base plate
6. Optical encoder mounts attached to base plate
Securing the Mirrors

Rigid

Attached at three raised pads with epoxy

Deformable

Attached to mounting posts with magnet & ball bearing pinches
Designed and Manufactured Components

- Optical Encoder Bracket
  - Picomotor optical encoder

- Shaft & Clamp Inserts
  - Launch restraint & separation devices

- Representative Mirror Mass
  - Vibration testing

- Optical Mirror Mask
  - Rigid mirror alignment

- Separation Device Lid
  - Contain Vectran after deployment
Limit Switch Test

• Picomotors provide **13 N** of force when translating
• Need a fail-safe mechanism to restrain over-actuation
• Nano-miniature Top-Actuated Tact Switch
• Determined force needed to activate switch to ensure they were up to spec
• Mean depression force: **1.02 N**
• Overall Std. Dev: **.09 N**
• The switches were within the force range provided by the manufacturer of **1N +/- 25%**
Epoxy Bond Test

- Rigid Mirror Box: Mirror is glued to mirror plate
- Peak Acceptance: 40g -> \( \sim 42\text{N} \) on each pad
- Epoxy Name: Loctite EA 9394 AERO
- Tensile test
  - Failure at \( 88.8\text{N} \)
  - Debonding from mirror surface

- Limitations: Outgassing properties of 1.5%
- Need to take this strength and compare it with vibration results
Vibration Testing: Test Sequence and Input Profiles

- White Noise
- White Noise
- White Noise
- White Noise
- Full Level

Minimum Workmanship - ASD

- 6.8 grms
- 4.8 grms
- 3.4 grms
- 1.7 grms

3 dB/oct
Substituting the Mirror

Vibration Testing

Aluminum Mass Screwed to Mirror Plate

Flight

Rigid Mirror Epoxied to Pads on Mirror Plate
Substitute Mirror Mass Design and Manufacture

- Mass: 323.5g
- Density comparable to Zerodur
- \( \frac{3}{4} \)" aluminum rectangular block
- Secured to mirror plate via 2-56 1" long screws
- Dimensions large enough to secure to mirror plate spare holes and small enough to fit within box
- Milled down to size and drilled holes
# Deviations From Test As You Fly (TAYF)

<table>
<thead>
<tr>
<th>Proto-Flight Boxes</th>
<th>Flight Boxes</th>
<th>Impact</th>
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</thead>
<tbody>
<tr>
<td>Aluminum Mirror Mass</td>
<td>Actual Rigid Mirror</td>
<td>High</td>
</tr>
<tr>
<td>Screws attach rigid mirror to mirror plate</td>
<td>Epoxy bond applied between mirror and mirror plate</td>
<td>High</td>
</tr>
<tr>
<td>Picomotors have large RJ45 network wires and are not vacuum-compatible</td>
<td>Picomotors will have encoded Kapton® and will use a vacuum-compatible model</td>
<td>Medium</td>
</tr>
<tr>
<td>No additional sensing equipment</td>
<td>Temperature Sensors with wiring</td>
<td>Medium</td>
</tr>
<tr>
<td>Manually Cut Glass Fiber Boards</td>
<td>Electronics PCBs</td>
<td>Low</td>
</tr>
<tr>
<td>Optical Encoder Brackets</td>
<td>Optical Encoder Brackets with PCB and Encoder</td>
<td>Low</td>
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</tbody>
</table>
Accelerometer Placement

- The signal was input in the Y direction
- Accelerometers recorded:
  - All 3 axial responses of the mirror mass
  - All 3 axial responses of interface plate (control)
  - Vertical Z axis of reference plate
  - Input Y axis of the reference plate
- Accelerometer locations chosen to identify accelerational load particular to mirror mass from that of entire system
Ch4: Reference Plate Z-Axis White Noise Test 1 Results

- 20% shift in resonance frequency after the -12dB test
- These shifts continued after -6dB, signalling **structural changes in the test article**
- Inspected the time history and PSDs for more information
Ch4: Reference Plate Z -6 dB Test 1 Results

- The vertical axis of the reference plate experienced unexpectedly large amplification
  - Max acceleration: 122.67 g
  - GRMS: 7.85
- Cross-Coupled Response
- First Mode of a Thin Plate
- Continued the search for answers with the mirror mass...

![Graph showing power spectral density for Channel 4](image)
Ch6 & Ch7: Mirror Mass Y & Z-Axis -6 dB Test 1 Results

- Mirror Mass vertical and input axes responses were one-sided
  - Upon visual inspection, the mirror mass was loose, and was slapping the reference plate and walls/wires
What does a “loose mirror mass” mean, and how do we fix it?

- The Rigid Mirror will be attached to the Mirror Plate using epoxy

- For vibration testing purposes, the **Mirror Mass** is attached to the **Mirror plate** using **screws**

- Improper securement of the mass appeared a likely cause of the unexpected test results

- To eliminate the excess spacing between the Mirror Plate and Mirror Mass, washers were added to the corner screws, along with **foam** between the two pieces
Ch4: Reference Plate Z-Axis White Noise Test 2 Results

- All screws were confirmed secure with a torque wrench
- After properly securing the mirror mass, the reference plate had acceptable, smaller frequency shifts
Ch4: Reference Plate Z -6 dB Test 2 Results

- After securing the reference plate, the amplification was lessened
  - Max acceleration: 84.46g (122.67g)
  - GRMS: 7.97 (7.85)
- Preliminary projections from this data raise possible concerns about the epoxy bond strength
- Solutions include increasing pad size for larger bond area
Ch6 & Ch7: Mirror Mass Y & Z-Axis -6 dB Test 2 Results

- Mirror Mass Response now displayed expected two-sided peaking
- Upon visual inspection, box displayed no signs of structural failure
Vibration Testing Conclusions

- Potential to exceed bonding strength at full level loading
- Box structure withstands very high peak loading
- Shaker table needs to be fixed so Y and Z axis can be accurately assessed
Rigid Mirror Mask Design and Manufacture

- After Vibration Testing, need to optically align the mirror for a “true assembly”
- Need to maintain mirror position during optical alignment
  - Box is rotated to apply epoxy to underside of mirror
- Designed and manufactured a mask to secure the mirror during optical testing and assembly
Summary of Tasks

Completed Work
- Designed and manufactured components
- Limit switch and Epoxy Bond Test
- Assembly of both boxes
- Assembly documents
- Rigid box vibration testing in y
- Rigid box optical testing preparation

Future Work
- Vibration testing of rigid mirror in x and z
- Vibration testing of deformable mirror box
- Complete assemblies with real mirrors
- Optical testing and alignment verification
- Separation device mechanism test
Concluding Remarks

The Mirror Boxes have progressed from CAD models to real, assembled equipment and undergone a first round of vibration testing.
Backup Slides
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<td>Background Learning</td>
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<td>Limit Switches Testing</td>
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<td>4-Apr</td>
<td>11-Apr</td>
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<td>2-May</td>
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<td>Standard Parts List &amp; Order</td>
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<td>Base Plate Design &amp; Machining</td>
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<td>Rigid Mirror Box Assembly Document</td>
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<tr>
<td>Vibration Testing - Rigid</td>
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</table>
Assembly Documents

AAReST Deformable MirrorBox Assembly Document

Seena Ferraro
Project Supervisor, California Institute of Technology

Jake Larson and Catherine Pavlov
Rigid MirrorBox Members, California Institute of Technology

These instructions detail the recommended assembly method for the Deformable MirrorBox for the AAReST project. This includes assembling the base electronics plate, assembling the reference plate, and assembling the mirror plate. For the MirrorBox containing the rigid mirrors, please see the Rigid MirrorBox Assembly Document.

AAReST Rigid MirrorBox Assembly Document

Seena Ferraro
Project Supervisor, California Institute of Technology

Anand Kumar, Sheila Murthy, and Tyler Okamoto
Rigid MirrorBox Members, California Institute of Technology

These instructions detail the recommended assembly method for the Rigid MirrorBox for the AAReST project. This includes assembling the base electronics plate, assembling the reference plate, and assembling the mirror plate. Special steps are required in order to mount and calibrate the optical assembly before the RTV silicone can be applied. For the MirrorBox containing the deformable mirrors, please see the Deformable MirrorBox Assembly Document.
Reference Plate Subsystem

- Need to limit axial excitation of Deformable Mirror
- Soft silicone pads are epoxied to the pillars
- Shims are placed below the pillars to ensure equal compression of the material at all locations,
Tensioning the Vectran for Assembly

- The Launch Restraint and Separation devices secure and release the mirror during and after launch.
- The mirror is secured with Vectran Cable, tensioned to 200N.
- The mirror is released by activation if a NiChrome wire severing mechanism, burning and cutting the cable.
Tensioning the Vectran for Assembly

Mirror held in 90 deg. position, same as optical test

Stopper
Tensioning Vectran for Assembly

1. Carefully and slowly load 20 Kg to tension vectran

2. Fix Clamp

3. Remove Stopper
Reference Plate Lid

- After vectran is cut, there will be loose vectran cable
- Lid designed to keep vectran pieces contained after mirror deployment, as well as protect surroundings from heat and current in burnwire
Transfer Function for Mirror Mass Z Axis Run 1

Channel 7 RV Transfer Function Overlays

Transfer Function [sqrt(g^2/Hz)]

Frequency [Hz]
Transfer Function for Mirror Mass Z Axis Run 2
Second Set of Rigid Box Vibration Test Results

-12 dB test had normal accelerations (right?)

Assembly flaw identified during -6 dB test
- Rattling noise in box: a picomotor is too close to adjacent spring tube pin
- Spring tube couldn’t fully tighten to reference plate
- **Solution**: either shorten pin insert or change position
Outline

2:00 pm: Introduction & Welcome
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3:45 pm: On-board Software
4:15 pm: Electronics
AAReST
Onboard Software (OBSW)

Gautham Sholingar
Abbas Tutcuoglu
Arjun Sadanand
Daniel Pastor
Juliana Kew

Mentors:
Thibaud Talon
Yuchen Wei
High-Level Overview

Main Objectives

- 1x focused image from Deformable Mirror (DM)
- ≥2 images of other sources

**Camera**

- Capture image and perform analysis
- Control **mirror alignment**

**Mirror**

- Reflects/focuses light onto camera via 2 Rigid & 2 Deformable Mirrors
- Receives command from camera to **adjust mirrors**
Agenda – Mirror OBSW

1. High Level Overview
2. Mirror Positioning
3. Communications
4. Results and Future Work
Project Tasks - Mirror

**Task I: Software**
- Implement algorithm to **minimize** Root Mean Square (RMS) error of mirror position ( <40 nm )
- Test implementation using Google Testing Framework

**Task II: Comm. Protocols**
- Implement wireless communication protocol between mirrors and camera
- Monitor device health using thermal sensors

**Task III: Hardware**
- Manufacture **reliable encoder**
Mirror Actuation

- Each mirror controlled by **3 picomotors**
- Each DM additionally controlled by **41 electrodes**
- Use **picomotors** to enable **tip, tilt and piston motion** for the rigid and deformable mirrors

- Picomotor behavior is a **stochastic process**.
- How to **estimate** shaft head location?

**Forward Step**
\[ \Delta z = 28 \text{nm} \pm 6 \text{nm} \]

**Backward Step**
\[ \Delta z = -40 \text{nm} \pm 8 \text{nm} \]
Need for Encoders

Encoders help estimate mirror position within an interval.
Challenges with Encoder

Encoder Strip

- Encoder strip (right) tailored to use on **flat surfaces**

- Consisting of **3 layers** → glossy top layer **delaminates** upon curving

- **Previous solution:** Tested position estimation algorithms in a **simulator** using Google Testing Framework

- **Permanent solution:** Achieved curvature at **elevated temperatures**
Final Result

- **Step 1**: Exact position unknown → **Calibrate** encoder
- **Step 2**: Receive desired location from camera team → calculate how many **interval-jumps** to be made
- **Step 3**: Adjust for stochastic variation to minimize RMS error in a **deterministic way** → calculates no. of **picomotor steps** needed

---

**Calibrate**

**Desired Displacement**: 750nm

Move $\lceil \frac{750}{212} \rceil = 3$ intervals

$+424$ nm

$+636$ nm

$+848$ nm
Objective: Establish a robust Wireless communication system between the Mirror MCUs and Camera CPU using Xbee wireless radio modules.
Xbee Communications

- Mirror restraint deployment signal
- Mirror actuator voltages
- Picomotor commands

- Picomotor shaft position as estimated by encoders
- Telemetry

---

Deformable mirror 1
Rigid mirror 1
Rigid mirror 2
Deformable mirror 2
Xbee Communications Testbed

Currently using a RS-232 to USB interface to relay data to a computer terminal.
Xbee Communications

- Communication packets:
  - Application Programming Interface (API) mode enables data verification, checksums and point-to-point communication

- Interface Control Document (ICD) created to explain message types and protocol

- Current progress: Two-way communication established between 1 Master Xbee and 2 End-Point Xbee modules

<table>
<thead>
<tr>
<th>0x05</th>
<th>0xA7BB01</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 byte address</td>
<td>3 bytes of data</td>
</tr>
</tbody>
</table>
Hardware Monitoring

**MCU’s connected hardware**
- Thermal Sensors
- High Voltage Board

**Why read off temperature?**
- Hardware could overheat
- Temperature monitoring required for thermal control

**Needs protocol to communicate with MCU (ATMega 1284):**
- Inter-Integrated Circuit (I2C)
- Serial-Peripheral Interface Bus (SPI)

**Caution:** protocols require robust error handling [e.g. due to other interfering communication processes]
Thermal Sensor Testing

Two thermal sensors [I2C]
- MCP9801 [Conduction-based]
- TMP006 [Radiation-based]

Testing
- Reliable testing difficult due to environmental conditions

Observations
- Currently require **contact** between thermal sensors and targets
- Need to **calibrate** sensor measurements
Results

Software-Level

- Implemented algorithm to lower RMS error under 40nm
- Tested simulator using Google-Testing framework
- Established Xbee communication between 1x master and up to 2x slaves
- Tested health monitoring via I2C with thermal sensors

Hardware-Level

- Manufactured a reliable encoder via heat treatment
- Tested wireless picomotor actuation
Future Work

- Actuate a combination of 3 picomotors to achieve tip, tilt and piston functionality
- Test calibration and position estimation using picomotors
- Integrate 4 End-Point Xbee modules and implement protocol for messages
- Close the loop to demonstrate camera image correction using picomotor actuation
AAReST OBSW: Camera
Outline

1. Background & Motivation
2. Task Overview & Progress
3. Hardware Constraints
4. Future Work
Camera Hardware

- Camera Hardware
- Flight CPU
- Ground Console
- Xbee
- Other electronics (temperature sensor, power management,...)
- Flight Configuration
- Mirror Boxes

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Camera Task Overview

Task I
- Implement and improve spot centering algorithm
- Establish bidirectional communication with mirrors
- Test all functionality

Task II
- Design and test hardware monitor functions

Task III
- Design and test shape correction algorithms
Software Architecture

- **C++ Functions** that are used for operations
  - Spot Location

- **Libraries**
  - Collection of functions depending on purpose
    - Image Processing

- **Drivers**
  - Low-level functions to communicate directly with hardware
    - Camera Drivers

**Manufacturer API, Linux run-time libraries**
Testing Environment

OBSW Testing & Verification

- Google Test Framework
  - Overarching testing environment

Test Scripts

- Scripts that test functionality of code
  - Test all possible use cases
  - Use cases derived from Interface Control Documents

Programs

- List of functions that are used during operations
Task I: Centering Algorithm Introduction

AAReST has four mirrors
• Two rigid, two deformable
• Upon deployment, telescope needs to be aligned
  1. Calibrate picomotor motion via spot displacement
  2. Align optical axes of rigid mirrors
  3. Align optical axes of deformable mirrors
  4. Final iteration
Task I: Centering Algorithm Development

Designed and wrote software to:
- Take images
- Filter images
- Locate and track spots on sensor
- Send actuation commands to the mirrors
- Implement error handling

Generated Interface Control Documents (ICD)
- Clearly defines software interface and functionality

Note: Spots are from saturated laser source. These are much larger than expected in flight.
Task I: Centering Algorithm Testing

Tested spot location and tracking algorithms:

• Tested expected cases
  – 4 normal spots
  – Square-shaped spot

• Tested fringe cases
  – Spot on the edge
  – Defocused image (expected in space)

• Resolved encountered bugs
  – All tests now passed
Task I: XBee Communications

• Wrote drivers for Xbee communication between flight CPU and mirror MCUs
  – Implemented as C++ class using the open source C library libxbee

• Designed and implemented communication software
  – Used communication protocol set by mirror software team

• Tested and verified wireless communication link with mirror MCU
  – Verified data exchange by C program
Task II: Hardware Monitoring

Software

Hardware health needs to be monitored

• 5 sites for temperature monitoring
  – External temperature sensors are accessed via I2C

• Implemented status monitoring for imaging camera
  – All parameters are accessed via camera API
Task II: Hardware Monitoring Software Testing

Hardware error handling

• Ensure break in camera communication is properly handled

• Designed and implemented error handling function
  – Need to test by disconnecting camera during communication
Task III: Shape Correction Algorithm

- Use Shack-Hartmann wavefront sensors (SHWS)
- Given known effect for each deformable mirror + voltage constraint, compute required voltages to minimize voltages.
Task III: Shape Correction Progress

• Provided with already written code
  – Get an image
  – Compute the errors
  – Solve the linear programming problem

• Updated to work with current code

• Wrapped into C++ Objects
Hardware Constraints

Shape correction algorithms tested with previously taken images
- Baumer camera unavailable for use
- Software test with SHWS under way

Software not yet tested with all four mirrors
- Lab currently has two rigid mirrors
- Deformable mirror still in development
Future Work

Durability tests
• Run camera for an extended period and ensure proper operation

Verify functionality of final centering algorithm
• Use four mirrors
• Test on flight hardware

Verify functionality of shape correction algorithms
• Perform unit-test with flight hardware
Acknowledgements:

• Thibaud, Yuchen, Kathryn

Questions?
Outline

2:00 pm: Introduction & Welcome
2:15 pm: Camera
2:45 pm: Boom
3:15 pm: Mirror Boxes
3:45 pm: On-board Software
4:15 pm: Electronics
AAReST Electronics Team

Andre Sukernik   Saumya Vij

Mentors
Ashish Goel
Stephen Bongiorno
AAReST Electronics

Camera
Saumya

Mirror Box
Andre
Mirror Box Electronics

Andre Sukernik

Mentors
Ashish Goel
Stephen Bongiorno
Outline

• System Overview
• Project Objectives
• Design Overview
• Printed Circuit Boards
• Schedule
Outline

- System Overview
- Project Objectives
- Design Overview
- Printed Circuit Boards
- Schedule
Mirror System Overview

Power System

- Mirror Bias 100V
- Mirror Control Variable
- Picomotor Power 150V
- Low Voltage 5V & more

Deformable Mirror Array Proof of Concept
Mirror System Overview

Power System

Drive Picomotors

Mirror Bias 100V

Mirror Control Variable

Picomotor Power 150V

Low Voltage 5V & more

Deformable Mirror Array Proof of Concept
Mirror System Overview

Power System

Drive Picomotors

Driver Circuit x3

Deformable Mirror Array Proof of Concept
Mirror System Overview

Power System

Drive Picomotors

Communicate

Driver Circuit x3

Deformable Mirror Array Proof of Concept
Mirror System Overview

- Power System
- Drive Picomotors
- Communicate

- MCU
- ADC
- Limit Current
- Picomotor Feedback
- I2C / SPI / GPIO
- Temperature Sensors
- Activate Separation

Deformable Mirror Array Proof of Concept
Mirror System Overview

Multiplexer Board

High Voltage Board

MCU Board
Project Objectives

• Select components

• Convert high level diagrams into detailed schematics

• Layout printed circuit boards

• Focus on 2 boards – High Voltage, MCU
Outline

• System Overview
• *Project Objectives*
• Design Overview
• Printed Circuit Boards
• Schedule
Outline

• System Overview

• Project Objectives

• Design Overview

• Printed Circuit Boards

• Schedule
Power Distribution

- Voltage Regulators
- Current Limiting Switch x3
- USB BUS
- Control Switch
- Separation Device Power
- Fixed 100V Supply
- Variable HV Supply
- Fixed 150V Supply

MCU Board

HV Board
Power Distribution

- Voltage Regulators
- Current Limiting Switch x3
- USB Bus
- Control Switch
- Separation Device Power
- Fixed 100V Supply
- Variable HV Supply
- Fixed 150V Supply

HV Board
MCU Board

2.8V 3.3V
5V 12V

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Power Control & Monitoring

- MCU Board
- ADC
- Current Switch 1
  - Fixed 100V Supply
  - Variable HV Supply
  - Fixed 150V Supply
- USB BUS
- BUS
- EN
- MCU Board
- HV Board
- Current Switch 2
- Current Switch 3
- Fixed 150V Supply
Power Control & Monitoring

- MCU Board
  - ADC
  - MCU
  - Current Switch 1
- HV Board
  - Fixed 100V Supply
  - Variable HV Supply
  - Fixed 150V Supply

Connections:
- USB BUS
- BUS
- EN
- Current Switch 1
Picomotor Control

MCU

Level Shifter

I/O Expander

150V Supply

Picomotor Driver

Encoder
Outline

• System Overview

• Project Objectives

• Design Overview

• Printed Circuit Boards

• Schedule
Outline

- System Overview
- Project Objectives
- Design Overview
- Printed Circuit Boards
- Schedule
Existing Components

Multiplexer Board

Variable Supply

150V Supply

100V Supply

Picomotor Driver
Component Adaptation Example

Variable Supply

- Remove mounting holes
- Add monitoring capability
- Minor functional changes
MCU PCB

Separation Device

USB 5V
MCU PCB

- Xbee
- Current Limiters
- Separation Device
- Encoder Connector
- Step Up Converter
- Step Down Converters
- MCU
- USB 5V

MCU PCB Diagram
MCU PCB

- Xbee
- Current Limiters
- Encoder Connector
- Step Up Converter
- Step Down Converters
- MCU
High Voltage PCB

150V

100V

Variable

Picomotor Drivers
High Voltage PCB

150V

100V

Variable

Picomotor Drivers
High Voltage PCB
Presentation Outline

- System Overview
- Project Objectives
- Design Overview
- *Printed Circuit Boards*
- Schedule
Presentation Outline

• System Overview

• Project Objectives

• Design Overview

• Printed Circuit Boards

• Schedule
Camera Electronics

Saumya Vij

Mentors:
Ashish Goel
Stephen Bongiorno
Outline

• Overview of camera electronics
• Task list
• Details of each task completed
• Schedule/Future work
Camera CAD Model

3 circuit boards in the camera
- **Support board for baumer camera**
- **SHWS (Shack-Hartmann Wavefront Sensor) board**
  - LVDS (Low Voltage Differential Signal) switch
  - Mask motor driver
- **Motherboard**
  - Telescope CPU daughter board
  - XBee daughter board
  - Connectors for peripherals
Task List

• Ramp up on camera, previous work done & EAGLE tool for PCB layout
• LVDS (Low Voltage Differential Signal) switch selection, ordering & testing
• PCB design & layout
  - Motherboard
  - SHWS module board
• PCB fabrication
• PCB testing
Task List

- Ramp up on camera, previous work done & EAGLE tool for PCB layout
- LVDS (Low Voltage Differential Signal) switch selection, ordering & testing
- PCB design & layout
  - Motherboard
  - SHWS module board
- PCB fabrication
- PCB testing
LVDS Switch Testing

✓ Phase 1: Direct testing
✓ Phase 2: Crosstalk characterization
✓ Phase 3: Testing with 1 SHWS and Baumer camera
  • Phase 4: Testing with 2 SHWS and Baumer camera
    - 2nd SHWS damaged during testing
    - Testing be completed after we receive the 2nd SHWS back from repair

Results
  • Positive - meets requirements
  • Very low cross-talk noise
  • Successfully switches at required rate (@ 2 Hz) between ON & OFF state of 1 SHWS
Task List

• Ramp up on camera, previous work done & EAGLE tool for PCB layout
• LVDS (Low Voltage Differential Signal) switch selection, ordering & testing
• PCB design & layout
  • Motherboard
  • SHWS module board
• PCB fabrication
• PCB testing
On Flight Placement of Boards

OPTICS

12 lines of I2C to 3 temperature sensors
8 Lines to Mask Motor & Contact detectors

Baumer Flex cable from SHWS 1
Baumer Flex cable from SHWS 2

USB from Imaging & Boom inspection camera

SHWS BOARD

Baumer Flex Cable
Headers

MOTHERBOARD

12 V
XBEE

SUPPORT BOARD

BAUMER CAMERA

Power (12V)
GigE

Chassis

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Connectors

- Need to have a mechanical locking feature for vibration resilient connection
- Insulating material should be low-outgassing

ITT Cannon MDM Series for I2C and Mask Motor driver

JST BM03B SRSS For Baumer camera connection

LUSBA11100 for all USB connections – Like a regular USB type A connector but with locking
Task List

• Ramp up on camera, previous work done & EAGLE tool for PCB layout
• LVDS (Low Voltage Differential Signal) switch selection, ordering & testing
• PCB design & layout
  • Motherboard
  • SHWS module board
• PCB fabrication
• PCB testing
Motherboard Design

Actual Dev board size

Requirement for AAReST

165 mm

135 mm

75 mm

65 mm
Motherboard - Layout of Components

Components:
- 22 + 2 pin headers to interact with SHWS
- USB B & USB C to communicate with imaging & boom inspection cameras
- Power management circuit
- GigE for baumer camera
- 2 push buttons
- SD card
- XBee module
- JTAG headers
- CPU daughter board
Motherboard – Final Look

- Final board with completed routing
- 4 layer board
- Has been sent for fabrication
Task List

- Ramp up on camera, previous work done & EAGLE tool for PCB layout
- LVDS (Low Voltage Differential Signal) switch selection, ordering & testing
- PCB design & layout
  - Motherboard
  - SHWS module board
- PCB fabrication
- PCB testing
SHWS – Layout of Components

Components:
• 22 + 2 pin headers to interact with MB
• USBA to communicate with spacecraft
• 2 Hirose Plugs to receive SHWS signals
• 1 Hirose Receptacle for Baumer camera
• 21 pin MDM connector for mask motor, contact detectors, 3 temperature sensors
• 4 LVDS switches
• Mask motor driver circuit
SHWS Board

- Current board
- 4 layer board
- Some changes being made before sending it out for fabrication
AAReST Electronics

Thank you for your attention!

Questions

Andre Sukernik

Mentors:

Ashish Goel

Stephen Bongiorno

Saumya Vij

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