Concept of Operations (ConOps) Documentation & Camera Pointing Evaluation Tool

Ian Brownstein, Aaditya Chaphalkar, Chris Zheng

Mentors: Tony Freeman and Dan Scharf
Concept of Operations (ConOps) Document

- Useful introduction to AAReST for incoming team members
- Centralized reference for current group members
- A way to make sure teams have a consensus on mission and subsystem goals and objectives, while also providing a space to record their progress
- ‘Living’ document to consolidate essential project information
  - Up to date mass and power budget, mission requirements, subsystem requirements, mission plan, etc.
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## Risk Table

<table>
<thead>
<tr>
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<th>Pre-Flight Risk Reduction</th>
<th>Software Fix</th>
<th>Hardware Fix</th>
<th>Rescue Likelihood</th>
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<td>Restraint strap does not burn</td>
<td>Insufficient power</td>
<td>Boom does not deploy – mission failure</td>
<td>Unlikely</td>
<td>Test power intake</td>
<td>Turn off non-operational non-essential parts, turn the spacecraft to get more power</td>
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## Risk Table

### Phase – Preoperational: Boom Deployment

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<td>Test power intake</td>
<td></td>
<td>Turn off non-operational non-essential parts, turn spacecraft to get more power</td>
<td>Very likely</td>
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<tr>
<td>Hinges do not unfold</td>
<td>Mechanical fault</td>
<td>Boom will not stay in alignment, unable to align with mirrors and take an image – mission failure of some L1 goals (can still reconfigure)</td>
<td>Unlikely</td>
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<tr>
<td>Hinges damaged</td>
<td></td>
<td>Test durability (shake tests, etc)</td>
<td>Unlikely</td>
<td></td>
<td>If boom can still stay stuff, attempt to shake the boom to deploy, otherwise no fix</td>
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#### Preoperational: Boom Deployment

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<td></td>
</tr>
<tr>
<td><strong>Hinges do not unfold</strong></td>
<td>Insufficient strength</td>
<td>Boom does not deploy or boom becomes too tall in some L1 goals (can still reconfigure)</td>
<td>Unlikely</td>
<td>Test durability</td>
<td>Shock the spacecraft to attempt to shake the boom loose by pulsing thrusters or reaction wheels</td>
<td>Unlikely</td>
<td></td>
</tr>
<tr>
<td><strong>Hinges damaged</strong></td>
<td>Unlikely</td>
<td>Test durability (shake tests, etc)</td>
<td>Unlikely</td>
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<td>Unlikely</td>
<td>Test deployment with strap</td>
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</table>

**“If” is the fault**

**Example:** “Hinges do not unfold”
Risk Table

“Due to” is the reason for the fault, can have many per fault

Example:
- Insufficient strain
- Hinges damaged
- Boom-CoreSat friction too great
- Boom-strap friction too great
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<tr>
<th>If</th>
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<td>burn</td>
<td>power</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mechanical</td>
<td></td>
</tr>
<tr>
<td></td>
<td>fault</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>strain</td>
<td></td>
</tr>
<tr>
<td></td>
<td>damaged</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Boom-CoreSat</td>
<td></td>
</tr>
<tr>
<td></td>
<td>friction too</td>
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<tr>
<td></td>
<td>Hinges not fully</td>
<td></td>
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<tr>
<td></td>
<td>deployed</td>
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</table>

“Then” is the consequence from the fault

Example:
Boom does not deploy or boom does not stay in alignment, thus unable to align with mirrors and take an image — mission failure of L1 goals (cannot image or reconfigure)
“Likelihood” is the risk Categories: Very likely, Likely, Unlikely

Example: Hinges having insufficient strain is “Unlikely” because we will have done testing to prove this.

Need to validate “likelihood”
“Pre-flight Risk Reduction” are tests, design changes, etc. to determine likelihood and make the fault less likely.

Example:
Hinges should be tested for deployment in nominal cases, and also off nominal cases, such as after heavy launch vibrations.

<table>
<thead>
<tr>
<th>Pre-flight Risk Reduction</th>
<th>Software Fix</th>
<th>Hardware Fix</th>
<th>Rescue Likelihood</th>
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<tr>
<td>Test power intake</td>
<td></td>
<td></td>
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“Software Fix” and “Hardware Fix” are contingency operations for during the mission.

Example:

- If boom does not deploy due to friction, then shock the spacecraft with its thrusters and reaction wheels to force a boom deployment.
- If boom does not deploy due to a crack, then we have not developed a contingency plan.

No contingency plan: red flag!
**Risk Table**

“Rescue Likelihood” is how likely we will recover from the fault. Categories: Very likely, Likely, Unlikely

**Example:**
- If boom does not deploy due to friction, then shocking the spacecraft is a “very likely” fix.
- If boom does not deploy due to a crack or mechanical failure, then we are “unlikely” to fix it.
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Preoperational: Boom Deployment Continued
Recommendations

• Continue to identify and reduce risks and incorporate them into the document maintaining a centralized record
  – Reduce number of single point failures
• Prioritize robust launch simulation tests for all hardware in its launch configuration (shake tests)
• Consider utilizing the boom inspection camera to measure the relation between the camera and spacecraft positions over time
• Develop better configuration management to help address the issues of workers separated temporally (year to year turnover) as well as spatially (Pasadena and Surrey)
Camera Pointing Capability Evaluation

• Goal: Develop an evaluation tool to assess camera jitter due to reaction wheels disturbances incorporating the relevant flexible modes of the boom

• Camera Requirements:
  – Jitter: <0.02°/s
  – Pointing accuracy: <0.10°
  – Duration: ≥600s
Overview of Tool

Developed close-looped Simulink model of entire spacecraft

- Allocator using pseudo-inverse
- Comprehensive reaction wheel model
- Reaction wheel disturbance model with variable phasing capability
- Spacecraft dynamics based on simplified FE model
- Jitter determination through performance output
- Second order sensor transfer function
Simulink Model

PID Controller

Allocator

Reaction wheel model

Reaction wheel disturbances

Rigid body plant

Flexible modes transfer function

Camera jitter evaluation

Sensor Noise

Sensor transfer function
Simulink Model

PID Controller
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Reaction wheel disturbances
Rigid body plant
Flexible modes
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Simulink Model

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Sensor transfer function
Major Unit Tests Performed

- Reaction wheel model
- Disturbance model output check
- Sensor transfer function comparison to manufacturer data
Simulation Verification

Unit test system feed reaction wheel disturbance sinusoid to flexible modes and seek to match analytic predication

\[ \sum T(\omega; t) = \sum A(\omega) \cdot \sin(\omega t + \varphi) \]

Flexible Modes, \( G(j\omega) \)

\[ \psi (\omega; t) = B(\omega) \cdot \sin(\omega t + \theta) \]
Simulation Verification

Reaction Wheel Disturbance Model

\[ |T(\omega_o, t)| = N \cdot T(\omega_o, t) \cdot \sin(\beta) \cdot |G(j\omega_o)| \]

Bode Plot: Flexible Modes, No Rigid Body

\[ |\psi(\omega_o, t)| = N \cdot |T(\omega_o, t)| \cdot \sin(\beta) \cdot |G(j\omega_o)| \]
Simulation Verification

\( \omega_o = 7.1 \text{Hz} \)

\( N = 4 \)

\(|T(\omega_o, t)| = 0.54 \text{ mNm} \)

\( \beta = 56.31^\circ \)

\(|G(j\omega)| = -2.55 \text{ dB} \)

\[ \therefore |\psi(\omega_o, t)| = 1.3 \text{ mrad} \]

**Results are as expected**

\[ |\psi(\omega_o, t)| = N \cdot |T(\omega_o, t)| \cdot \sin(\beta) \cdot |G(j\omega_o)| \]
Sample Results

Output angles at cameras vs. time

Reaction wheel speeds vs. time

Jitter vs. time

Commanded torque for wheel 4
Sample Results

Within Reaction Wheel Specifications

Approaching Requirements

Violates Requirements
Moving Forward

• Develop model and implement reaction wheel isolation transfer function
  – Work currently being performed by Surrey

• Obtain and update the reaction wheel disturbance model
  – Current data was taken on a unbalanced wheel

• Deterministic sweep of reaction wheel speeds with random disturbance phasing to determine wheel speeds where camera requirements met
Questions?
Boom Subsystem

Sandra Fang, Arturo Mateos, Yuchen Wei, Michael Williamson
Mentor: Lee Wilson
Camera

Boom

CoreSat

Caltech
What is the Boom?

**Lay-up consists of**
- Plain-weave AstroQuartz
- Unidirectional carbon fiber

**Lay-up sequence**
- General: $[\pm 45_{AQ} / 0_{3\ CF} / \pm 45_{AQ}]$
- At hinges: $[\pm 45_{AQ} / 0_{3\ CF} / 90_{CF} / \pm 45_{AQ}]$
- Locally reinforced at hinges with $[90]$ plies to ensure proper deployment

---

Lay-up sequence ensuring proper deployment.
What does it do?

Stage 1 deployment

Stowed configuration

Stage 2 deployment

Deployed configuration
What does it *did* we do?

1. Characterize boom deployment with **experiments** and **simulations**
2. Design **restraints** and **interfaces** (boom/camera/CoreSats)
What does it did we do?

1. Characterize boom deployment with **experiments** and **simulations**
2. Design **restraints** and **interfaces** (boom/camera/CoreSats)

**Stage 1**
- **Deployment**
  - **Stowed configuration**

**Stage 2**
- **Deployment**
  - **Deployed configuration**
Critical Tasks

1. Characterize boom deployment with experiments and simulations
2. Design restraints and interfaces (boom/camera/CoreSats)
Stage 2 Deployment Test

**Objective**
- Characterize large-displacement behavior of the boom
- Study accelerations during boom deployment

**Method**
- Prepare an experimental setup modeling end masses and inertias
  - Simulate deployment in space via gravity offload

---

[Diagram of experimental setup showing CoreSat (30 kg), Camera (2.8 kg), Boom (1.45 m)]
Stage 2 Deployment Test - Setup

- Gravity offload system suspends boom and end masses from J-rail with rollers
  - Displacement constrained in y-axis
- Boom has manufacturing defects affecting accelerations
Stage 2 Deployment Test
Results: low accelerations

- Low accelerations compared to those experienced during launch.

For reference:

Delta IV rocket

axial load factors: [-2g, 6g]
lateral load factors: [-2g, 2g]
Stage 2 Deployment Simulation

Motivation

- Limitation of ground testing facility to simulate micro-G environment
- Examine material thermal effects on in-orbit deployment

Objective

- Develop high fidelity finite element model
- Capture whole deployment process in detail
Hinge Characterization

**Objective:** Provide quantitative comparison between *simulations* and *measured* behavior of hinge to validate model

- Perform *quasi-static deployment* experiments
- Develop *finite element model* for single-hinge experiments
- Compare moment-angle profiles

- Design and calibrate new apparatus with better boundary conditions

---

**Experiment - deployment**  
[32x speed]

**Simulation - folding**  
[1x speed]
Hinge Characterization

- **Hinges locked** before reaching deployed configuration
  - Quasi-static + Manufacturing Defects = prevented deployment
  - Manufacturing process has been improved
- **Estimated moment-angle profile** for this boom/hinge design
  - Steady-state moment region (0.1 Nm)
  - High snap-back moment to overcome (~0.7 Nm)
  - Small peak at ~30 degrees (0.3 Nm)
  - When hinge is latched, it is in a highly stable configuration
**Restraints and Interfaces**

**Objective:** Secure boom to spacecraft during launch and in-orbit

- Design **kinematic mounts** to allow for camera adjustment relative to the coresat
  - Corrects for misalignments in the construction satellite
- Design **release mechanism** for Stage 1 deployment

---

Core Sat kinematic mount (with restraint strap)

Camera kinematic mount
Kinematic Mount

- Cone and 3 flat configuration
- contact points with four 100 tpi ball tipped screws
  - Allows rotation of the adjustable plate around x, y, and z axes
Key Features

- Three pre-load springs maintain contact during adjustment
- Clamp down nuts provide holding force after adjustment
Kinematic Mount

Key Features

- Three pre-load springs maintain contact during adjustment

- Clamp down nuts provide holding force after adjustment
Release Mechanism

- **Vectran cable** ties down boom in stowed configuration
- **Nichrome wire** looped around tie down cable between pairs of terminals
- When heated, n ichrome wire cuts through the vectran cable due to spring preload

Based on design outlined in *A Nichrome Burn Wire Release Mechanism for CubeSats* by Thurn et al.
Completed Tasks

**Boom deployment tests**
- Modeled masses with accurate weights and intertias
- Assembled test rig
- Performed Stage 2 deployment experiment

**Single-hinge characterization**
- Improved experimental set-up with boundary conditions
- Estimated moment-angle profile

**FEM Simulation**
- Developed full-boom and single-hinge simulations
- Obtained preliminary results for stage-2 deployment

**Restraints and Interfaces**
- Designed kinematic mounts
- Designed burn wire release mechanism
Future Work

**Boom deployment tests**
- Perform Stage1/Stage2 deployment experiments
- Analyze acceleration for all degrees of freedom

**Single-hinge characterization**
- Perform multiple-folding experiments
- Perform storage experiments

**FEM Simulation**
- Expand boom & single-hinge simulation to deployment phase
- Modify FEM model according to experimental results
- Incorporate thermal properties of material into model

**Restraints and Interfaces**
- Prototype kinematic mounts and burn wire release mechanism
- Integrate prototypes into deployment tests
Questions?
Mirror Team: Vibrational and Thermal Testing

Erin Evans, Christian Kettenbeil, Akshay Sridhar, Yuchen Wei
Mentor: John Steeves
Motivation

Lightweight, Deformable Mirrors

Acoustic / Vibration

Thermal
Acoustics

- Analysis showed that launch survivability is a concern with current configuration.
Acoustic Experiments

- Mirror
- Laser
- Microphone
- Vibrometer
- Amplifier
- DAQ
- Analog Signal
- Input
Test-Bed Validation

![Graph showing displacement vs frequency with modes and comparison between acoustic testing, previous experiment, and FEM results.]

- **Mode 1**: Acoustic Testing = 60, Previous Experiment = 63, FEM = 73
- **Mode 2**: Acoustic Testing = 81, Previous Experiment = 74, FEM = 78
- **Mode 3**: Acoustic Testing = 201, Previous Experiment = 200, FEM = 203

**Legend**: Acoustic Testing, Previous Experiment, FEM
Mirror Restraint System – Concept

- Deformable Mirror Package
- Restraint Plate
- Restraint Peg
- Metal Pillar
- Damping Material
- Silicone Rubber
- Silicone Foam
- Styrene

- Break the Symmetric Mode of the Mirror
- Pillars act as damping element in restraint system
Mirror Restraint System – Analysis & Design

Analysis

• Analysis has predicted that restraint system can inhibit the acoustic vibration greatly (reduce 90% of the peak deflection magnitude)

Design

• Developed (with Mirror Test Team) mirror package prototype & test bed with restraint system

Implementation

• Performed mirror acoustic loading experiment with restraint system
Mirror Restraint System – Analysis & Design

Analysis

• Analysis has predicted that restraint system can inhibit the acoustic vibration greatly (reduce 90% of the peak deflection magnitude)

Design

• Developed (with Mirror Test Team) mirror package prototype & test bed with restraint system

Implementation

• Performed mirror acoustic loading experiment with restraint system
Restraint System Test

W/O Restraint

\[ OASPL = 122\text{dB} \]
\[ u_{max} = 0.14 \text{ mm} \]
Restraint System Test

\[ u_{\text{max}} = 0.015 \text{ mm} \]

\[ u_{\text{max}} = 0.14 \text{ mm} \]
Summary & Future Work

• Design, Manufacturing, Assembly and Validation of an acoustic test-bed
• Observed high deflections in current configuration
• Designed a restraint system that reduces the deflections by an order of magnitude
• Measurement of surface curvatures for different restraint configurations using optical techniques
• Increase SPL capability by use of an enclosure
Mirror Thermal Stability Testing

- **Problem**: Mirror deformation sensitive to temperature changes

- **Goal**: Build test platform that can operate at -50°C and 10^-5 torr

- **Method**: Set up vacuum chamber, build mirror cooling circuit, set up optical array for data collection
Cooling System Layout

Heat Exchanger

Heat Sink

27 V/28 A Power Supply

Cold In

Warm Out

27 V/28 A Power Supply

Hot In

Cold In

H-bridge

Fuse

Fuses

Feedthroughs

Temp. Controller

9 V/.66 A Power Supply

Radiation Shield

Mirror

Copper Springs
Cooling System Performance

- Vacuum: $10^{-5}$ torr in 3.5 hours.
- Water cooled heat sink can reach 10°C.
- Cooling plate temp of -20°C in 20 min.
- Reached 0°C on mirror surface with TEC temp of -20°C.
Data Acquisition

- Need to characterize mirror deformation as function of temperature
- Lens array set up to use point source to illuminate mirror
- Reflected waveform captured using Shack Hartmann wavefront sensor
Preliminary Results

Wavefront Error Plot

Y-Coordinate [mm]
X-Coordinate [mm]

Wavefront error: Comparison of mirror shape with that of a flat surface (processed into curvatures)

Zernike Coefficient – De-focus Metric

Mode 5 of interest

Caltech
Summary and Future Work

- Designed, commissioned experimental setup to test deformable mirrors at -20°C and 10-5 torr.
- Confirmed ability to capture mirror deformations with temperature
  - Concept - secondary radiation shield to improve mirror temperature profile if necessary
  - Characterise mirror deformation as a function of temperature
  - Compare different mirror designs – layer thickness specifications
Questions?
AAReST Camera Design

Spencer Freeman, Maria Sakovsky
Mentor: Manan Arya
Overview

1. System Definition
2. Requirements
3. Prototype
4. Flight Camera Design
5. Future Work
System Definition

Light from M1

Collimator

Boom Inspection Camera (BIC)

Lens

2x Cube B/S

SHWS Detector

SHWS Driver

Mask Motor

Telescope

CPU

ZigBee Transceiver

I²C to S/C

Wireless to RMx, DMx

SHWS Detector

Imaging Lens

Imaging Detector

Imaging Detector Driver
Task Overview

- **Camera Prototype**
  - SHWS mount prototype
  - SHWS alignment
  - Imaging and collimator groups

- **Flight camera design**
  - Mount optics
  - Package camera hardware and electronics
Requirements

Functional
- Work with reconfigurable primary mirror
- Provide feedback during primary mirror calibration
- Science imaging

Performance
- 80% encircled energy radius < 90% diffraction-limited EE radius
- 0.3° full field-of-view
- Bandwidth: 465 – 615 nm
- SNR > 100

Constraints
- Mass < 4kg
- Volume (excluding boom interface) < 10cm × 10cm × 35cm
- Power < 5W
Prototype: SHWS

- Consists of a microlens array (MLA) and CMOS detector
- Objective: Develop procedure for aligning MLA and detector (tip, tilt, piston)

Prototype: SHWS Mount

• Solution: Off the shelf kinematic mount + design modifications to hold 2 components rigidly in place
Prototype: SHWS Alignment

- Point source and collimating lens to generate plane wavefront for alignment
- Alignment verified with off-the-shelf SHWS
Prototype: SHWS Alignment

1. Threshold and clean up image
2. Extract spot locations (x)
3. Compute location of reference grid (o)
4. Wavefront slope is the difference between the two locations
5. Plot slopes to correct misalignment
Prototype: SHWS Alignment

Misaligned

Adjusted for tip and tilt
Prototype: SHWS Conclusion

1. Alignment process developed (know effects of tip, tilt, piston)
2. SHWS currently coarsely aligned
3. Interferometer needed for fine alignment
## Prototype: Power Budget

<table>
<thead>
<tr>
<th>Part</th>
<th>Peak (W)</th>
<th>Nominal (W)</th>
<th>MODE 1</th>
<th>MODE 2</th>
<th>MODE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telescope CPU</td>
<td>0.600</td>
<td>0.450</td>
<td>0.600</td>
<td>0.600</td>
<td>0.600</td>
</tr>
<tr>
<td>Imaging Detector</td>
<td>0.735</td>
<td>0.300</td>
<td>0</td>
<td>0.735</td>
<td>0</td>
</tr>
<tr>
<td>SHWS</td>
<td>2.400 x 2</td>
<td>1.800 x 2</td>
<td>2.400 +1.800</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Boom inspection camera</td>
<td>0.218</td>
<td>0.150</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wireless module</td>
<td>0.144</td>
<td>~0</td>
<td>0.144</td>
<td>0.144</td>
<td>0.144</td>
</tr>
<tr>
<td>Mask</td>
<td>0.600</td>
<td>0.600</td>
<td>0</td>
<td>0</td>
<td>0.600</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7.097</strong></td>
<td><strong>5.100</strong></td>
<td><strong>4.944</strong></td>
<td><strong>1.479</strong></td>
<td><strong>1.344</strong></td>
</tr>
</tbody>
</table>

- Mode 1: Wavefront sensing
- Mode 2: Imaging
- Mode 3: Mirror reconfiguration
Flight Camera Design

- Optical redesign required new mechanical design
- Physical Requirements
  - Mass: 4 kg
  - Envelope: 10x10x30 cm
- Current best estimate:
  - Mass: 2.94 kg
  - Envelope: 9.8x9.5x26.5 cm
Lens Groups

- Designed tangential interfaces
  - Minimize stress concentrations
  - Radially self-centering
- Radial tabs prevent decenter due to shocks
Prototype: Lens Groups

- Collimator and imaging groups assembled
- Point source at the prime focus of the collimator used for alignment
- See small spot at the end of the imaging lens as expected
• MLA fixed, detector adjusts in tip/tilt and piston
• Alignment process based on prototype SHWS
Beam Splitters

- 6 DoF constrained by flexures
  - Cannot bond due to CTE mismatch over large surface area
Mask

- Two positions for Compact and Wide Configurations
- Actuated by off-axis motor and spur gear
- Controlled by limit switch and hard-stop
Stray Light/Electronics Shield

- Makes use of triple-bounce interface for stray light blocking
- Minimum 1 mm thick Aluminum radiation shield
Requirements

Functional
• Work with reconfigurable primary mirror – Dynamic Mask
• Provide feedback during primary mirror calibration - SHWS
• Science imaging – Entire Subsystem

Performance
• 80% encircled energy radius < 90% diffraction-limited EE radius
• 0.3° full field-of-view
• Bandwidth: 465 – 615 nm
• SNR > 100

Constraints
• Mass < 4kg – CBE < 3kg
• Volume (excluding boom interface) < 10cm × 10cm × 35cm - Met
• Power < 5W – CBE ~ 4.9 W maximum
Future Work

• Prototype
  – Fine SHWS alignment
  – Integration with testbed

• Flight Camera Design
  – Thermal analysis
  – Boom inspection camera
  – Design for manufacturability
Questions?
Optical Testbed

Garima Gupta, Manuel Martinez
Mentor: Marie Laslandes
Simulating the entire optical system
Overview

• Primary Goal
  – To provide a setup in which the different components of the telescope could be tested as a whole

• Objectives
  – To model the optical components of the spacecraft
  – To simulate the observation of a distant star
Basic Setup

Spacecraft Interface Plate
Mirror(s) Being Tested
Source
Beam Splitter
AAReST Camera
Flat Mirror
Tasks

Design & Construct
- Flat Mirror Mount
- Spacecraft Interface Plate
- Reference Mirror Mount

Integrate & Test
- Flat Mirror Calibration
- Component Alignment

Validate
- Ray-Tracing
- Camera Image Analysis
Design & Construct

Flat Mirror Mount
Design & Construct

Flat Mirror Mount

Spacecraft Interface Plate
Design & Construct

Flat Mirror Mount

Mirror Segment Mount

Spacecraft Interface Plate
Design & Construct
Flat Mirror Mount

Purpose: to mount the large flat mirror (acquired from JPL) used for auto-collimation
Design & Construct
Spacecraft Interface Plate

Purpose: to simulate the mechanical interface with the spacecraft
Design & Construct
Spacecraft Interface Plate

Narrow Configuration

Wide Configuration
Design & Construct
Mirror Segment Mount

Purpose: to mount the reference and deformable mirrors to the spacecraft interface plate (with the ability to tip and tilt)
Integrate & Test
Flat Mirror Calibration

- Setup
  - Newton Fringes
  - Images taken at different positions on mirror

![Diagram of a setup with a monochromatic green lamp, optical flat, and fringes formed on the upper surface.](image)
Integrate & Test
Flat Mirror Calibration

Example Measurements


Measurements on Studied Mirror

Position A

Position B
Integrate & Test
Flat Mirror Calibration

Image Processing

- Qualitative: All fringes look straight by eye
- Quantitative
  - Detect edges, fit lines, measure deviation between edges and lines
  - Problem: Low contrast
  - Exploring Spatial Fourier Transform Approach
Integrate & Test
Component Alignment

• Goal: Align the different breadboard elements
  – Numerous coupled degrees of freedom
  – Need to define protocol for an efficient and effective alignment

• Two different situations (protocols):
  1. Breadboard alignment with on-axis mirror
     • Define the optical axis
  2. Integrate segments in AAReST configuration
Integrate & Test
Component Alignment – Protocol 1

- **Source & Beam Splitter**
  - Illuminate the interface plate
- **Mirror Segment & Flat Mirror**
  - Adjust Piston/Tip/Tilt to have return spot focusing on initial source
- **Camera**
  - Position on the optical axis, at the focal plane
Integrate & Test
Component Alignment – Protocol 1

Tip/tilt adjusted  Camera on focal plane  Tip/tilt and piston adjusted
Integrate & Test
Component Alignment – Protocol 2
Integrate & Test
Component Alignment – Protocol 2

• After protocol 1
  – optical axis is defined
• Move mirror segment to a particular AAReST configuration
  – The other components previously aligned must not be moved
  – Adjust piston, tip & tilt to position the spot on the camera
Validate

- Ray-tracing software gives expected image based on mirror configuration
- Comparing the actual image to the expected image is used to validate configuration and alignment

Simulated spot obtained for a single reference mirror

Measured spot after alignment of the reference mirror
Conclusion

• All components needed to perform tests on the in-flight subsystems: manufactured and tested

• Alignment protocols have been developed

• Therefore, the testbed is ready to accommodate the different subsystems to analyze the overall behavior of the telescope
  – More precise alignment needed for the camera to be integrated
Questions?
Camera & Mirrors
Hardware and Software

Ilana Gat, Casey Handmer, Yamuna Phal, Thibaud Talon

Mentors: Mélanie Delapierre, Heather Duckworth
Mirror Hardware + MCU
Camera Hardware + CPU
ZigBee
Mirror Hardware + MCU
Caltech
Mirror Hardware + MCU

Camera Hardware + CPU

ZigBee

Mirror Hardware + MCU

Caltech
Atmel MPU

- Purchased off-the-shelf Evaluation board for in-lab setup
  - Good for testing and writing software
  - Too large with too many unused connections for in-flight
- Will try to use the CPU board for in-flight
- Will design new main board for in-flight setup

Camera Hardware

Camera CPU

- Shack-Hartmann Sensor1
- Shack-Hartmann Sensor2
- Image Detector

S/C CPU

PC
Camera Hardware

- Purchased off-the-shelf UART to USB 3.0 Converter
  - Good for in-lab testing
  - Too bulky and requires too much power for in-flight
- Will use main converter chip + crystal oscillator for in-flight setup
Components Purchased:
- Camera CPU
- UART to USB Converter
- 2 x ZigBee

Components to be Designed:
- Camera Main Board
- UART to USB Converter with crystal oscillator
Camera Software

Q/ How do we go from an image to corrective commands to the mirrors?

- Started with image processing for the image detector
- Compiled and works for a computer
- Compiled and works for the Camera CPU !!!
ZigBee Hardware

Requirements:
- Easy to use out of the box
  - Minimal programming needed
- Minimal hardware to be designed for in-flight
- Used previously in space
- Performs well with radiation
- Low cost
- Low power

XBee satisfies all of these!!

XBee = hardware
ZigBee = network protocol

Antenna Options:
- Chip: Bad because XBee inside metal box
- Wire Whip: Bad because attached to XBee inside metal box
- U.FL Connector: Fragile
- RPSMA: Just right!
ZigBee Communication

Requirements:
• Easy to use out of the box
  • Minimal programming needed
• Minimal hardware to be designed for in-flight
• Used previously in space
• Performs well with radiation
• Low cost
• Low power

XBee satisfies all of these!!

XBee = hardware
ZigBee = network protocol
XBee Communication: IT WORKS!!!

- XBees currently talk with both connected to computer
- Next step:
  - Connect End Device to mirror CPU
  - Connect Coordinator to Camera CPU
  - Program ZigBee network for in-flight
ZIGBEE
CAMERA CPU
TRANSLATION MODES
MIRROR MCU
UART
THERMOCOUPLE + LNA
Analog MULTIPLEXER
SWITCHING BOARD
I²C
D/A CONVERTER
HV AMPLIFIER
SPI

Mirror - Task

- Weight: 14.9 kg (31 lb)
- Power Consumption: 680 W
Mirror - HV board

How do you design a HV board which is NOT 14.9 kg and 680 W?

- ATMEL stamp from INSPIRE mission
- SPI-I\(^2\)C-UART interfaces
- Digital output only – DAC needed

**LAB PROTOTYPE (TESTED)** | **POWER RATING**
--- | ---
HV BOARD | 0.4 W (NO LOAD)
HV BOARD - MUX | 0.8 W (FULL LOAD)
HV BOARD - TRANSLATION MODES | 1.2 W (FULL LOAD)
Mirror Picomotors

- Anticipate ‘set and forget’ usage
- Require 1kHz waveform at ~120V
- Attempt to leverage existing HVB architecture failed
- HVB latency/response time too slow under load
- Need picomotor-specific signal generator
Mirror Multiplexer

- Multiplexing concept

---

Need too much power

<table>
<thead>
<tr>
<th>Actuator</th>
<th>+500V</th>
<th>-500V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actuator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actuator</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

+500V ↑ -500V

-500V ↑ -500V

-500V
Mirror Multiplexer

- How does it work? Actuators behave as capacitors

Loop over all 41 channels in 1s (24 ms / channel)

<table>
<thead>
<tr>
<th>Set Voltage</th>
<th>On</th>
<th>Wait</th>
<th>Off</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 ms</td>
<td>2.5 ms</td>
<td>1-10 ms</td>
<td>2.5 ms</td>
</tr>
</tbody>
</table>

Mirror software

• Translated the former code
• Created low level functions to transfer data through I\(^2\)C and SPI
• Developed feedback for testing
• Integrated and tested for all 41 channels with the HV board
Summary

Camera
- In-lab CPU purchased
- Shack-Hartmann USB 3.0 compatibility implemented
- First image analysis programs designed - tested

ZigBee
- XBee hardware selected
- Communication established

Mirror
- HV board - lab breadboard complete
- Lab prototype designed - implemented - tested
Future Work

Camera
- In-flight main-board design
- Continue writing software package for in-flight use

ZigBee
- Connect XBees to in-lab mirror and camera CPUs
- Program XBees to communicate with in-lab setup

Mirror
- HV driving picomotors
- Finalize in-flight design
Questions?