AAReST
Mission Overview

John Baker
September 9th, 2013
The Vision
Review Objective

Objective:

• Demonstrate the readiness to proceed to a flight technology Project CDR.
  – Does the preliminary design appear feasible?
  – What concerns do you have that we need to address as we go to PDR?
Review Outline

1. Mission Overview (20 mins)
2. Spacecraft Design (60 mins)
3. Telescope Design (160 mins)
   a) Mirrors
   b) Camera
   c) Boom
   d) Telescope System Performance
   e) Test and Calibration
4. System Summary, Launch Vehicle, Project Plan (15 mins)
5. Discussion (15 mins)
Team Responsibilities

- NanoSat and MirrorCraft
- Docking system
- Integrated spacecraft & mission ops
- Deformable mirrors
- Telescope system
- Optical focus algorithm

System integration & Testing
Mission operations
Launch
Class instructors
Manufacturing facilities
Project Approach

• Partner with Univ of Surrey for spacecraft development
  – Use proven cubesat elements with some new technology and some redundancy to ensure we can accomplish the objectives
• Well defined objectives and short duration mission with clear goals for an extended mission
• Keep spacecraft to payload interfaces simple
• Automate telescope to maximum extent possible
• AE105 classes do design, analysis, test and operations tasks as the Project matures. JPL instructors teach the class.
• Caltech grad and SURF students do research and technology development for the telescope
• JPL provides class instructors, access to the Micro Devices Lab (MDL) and other facilities as requested.
AAReST Mission Objectives

• Accomplish two key experiments in LEO by demonstrating new technologies for
  1. Autonomous rendezvous and docking with small spacecraft for telescope re-configuration
  2. A low-cost active deformable mirror (one star image with 80% encircled energy)
• Operate as long as necessary to accomplish the objectives (90 days) post commissioning
• Accomplish the mission inexpensively for a 2015 launch
• Gather engineering data that enables the next system development
Extended Mission Objectives

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 (eg Earth and Moon) for outreach purposes.

- Requirements flowed down to the subsystem level last year
- Surrey will discuss spacecraft system and subsystem requirements and updates
- Telescope requirements will be discussed in each presentation along with updates.
Spacecraft & Payload Elements

1. MirrorCraft (x2) – 3U cubesats with deformable mirrors on top with rendezvous and docking capability
2. CoreSat – main spacecraft with primary power, communications, primary ACS, docking capability

Payload

1. Mirror assemblies – 2 active deformable mirrors, 2 fixed glass reference mirrors with tip/tilt positioning
2. Instrumentation package – Telescope optics, detectors, wave front sensor, aperture mask
3. Boom – 1.2m deployable composite
Operation timeline

Pre-launch & Launch

Deployment → Calibration → Imaging → Reconfiguration → Calibration → Imaging → Extended mission

Desorbit

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Deployment

- Launch
- Detach from launcher & Verify orbit

- Turn on satellite
  - Turn on low voltage then high voltage
  - Switch from battery to solar power

- Verify and stabilize satellite
  - Power, Thrusters, Communications
  - Tumble rate, Temperature, Attitude
  - Camera functioning (dark measurement)

- Telescope deployment
  - 1\textsuperscript{st} stage boom deployment
  - 2\textsuperscript{nd} stage boom deployment (+ camera)
  - Mirror covers deployment
  - Uncage DM1 and DM2

- Adjust and stabilize satellite attitude
1. Power up MirrorCraft1
Verify thrusters, T, communication and attitude control

2. Undock MC1: free-flyer
Check MC1 properties
Move MC1

3. Rotate spacecraft

4. Capture and lock MC1
Check spacecraft
Power up MirrorCraft2
Check MC2 properties

5. Undock MC2: free-flyer
Move MC2

6. Rotate spacecraft

7. Capture and lock MC2
Check spacecraft
Payload Block Diagram

Camera Package

Deformable Mirror

Reference Mirror

Reference Mirror

Deformable Mirror

MirrorCraft

CoreSat

MirrorCraft

Zigbee

High Voltage Switch

High Voltage

Controller

Controller

Controller

Controller

USB

Pwr

USB

Pwr

USB

Pwr

I2C

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Spacecraft Communications

TELESCOPE CPU
- Store & Compute position, size, shape, SNR, EE for each spot => Piston/Tip/Tilt of each segment
- Store & Compute WF slope for each segment
  ⇒ Voltage maps of each DM
- Store data

Science detector images
- SH detector images
- Camera state variables (mask config, T, status, ...)
- Inspection camera images
- Boom state variables (T)
- Mirrors state variables (T, V, config, status, ...)
- S/C status (attitude, attitude rate, config, ...)

S/C CPU
- Required data
- Orders

Earth

RM Board (x2)
- \( PTT_{RM1} \)
- \( PTT_{RM2} \)

DM Board (x2)
- \( V_{DM1} \)
- \( V_{DM2} \)
- \( PTT_{DM1} \)
- \( PTT_{DM2} \)
Primary spacecraft and payload ops will be run by Univ of Surrey
- Existing comm and ops infrastructure
- Includes spacecraft commanding and health monitoring
- Outreach

Remote payload monitoring will be done at Caltech
- Initial mirror calibration
- Mission planning (target selection)
- Engineering data analysis and reduction
- Outreach
Accomplishments in the Past Year

• Active mirror technology has been further matured in the lab.
• Preliminary spacecraft, telescope and ops concept have been refined
  – Total mass of 40kg is well within secondary launch capability
• 2012-13 AE105 class performed
  – Boom deployment tests and development
  – Refined optical system design
  – Refined Thermal analysis (2 orbit conditions)
• Spacecraft to payload interfaces are simple, with a lot of heritage from STRaND-1 which has flown.
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5. Discussion (15 mins)
Deformable Mirrors

Keith Patterson (task lead, presenting)
Marie Laslandes (optimization, testing)
Kristina Hogstrom (thermal)
Erin Evans (thermal)
September 9th, 2013
Relevant Assemblies

DM1  RM1  DM2  RM2  Lid
Problem Description

• Develop & design deformable mirror assembly
  – Key Characteristics
    • Thin, flexible, low areal density
    • Identical manufacturing process
    • Actively controlled
  – Key Challenges
    • Large strokes (10’s to 100’s microns)
    • Nanometer precision
    • Volume, power constraints
    • Launch survival
Deformable Mirrors

• Relevant requirements
  – Nominal radius of curvature 2.4 m
  – Deployable mirror cover(s), no debris
  – USB interface to mirrorcraft
  – Zigbee wireless interface to camera
  – 2W power (continuous) for each mirror
  – Functions in both wide and compact configurations
  – Deformation stable long enough for exposures (~50ms)
  – Capable of surviving between -40C and 80C
  – Capable of operating between -20C and 20C
  – Capable of correcting its manufactured shape error (~5 um RMS)
  – Capable of correcting its thermal imbalance (~20 um P-V)
  – Additional OAP stroke (microns RMS surface):
    defocus: 2; astigmatism: 1.2; coma: 0.2
  – Typical reflecting coating roughness < 15nm RMS
General Concept

• Thin laminate
  – Polished glass wafers
  – Piezo polymer coating
• Bimorph actuation
  – In-plane strains create mirror curvature
  – Thin, low areal density
• Actuation patterns
  – Independent regions for fitting of mirror surface shapes
Mirror Fabrication Process

1. Polished glass wafer (~225um)
2. Slump at ~650C over quartz mold*
3. Coat Cr+Al laminate (~3um total)*
4. Roughen mirror backside with HF vapor
5. Sputter ground layer (Ti+Au+Ti, 10+50+10nm)
6. Spin coat + bake piezo layers 140C (20um)
7. Sputter blanket electrode (Ti+Au, 10+10nm)
8. Evaporate electrode pattern (Au, 100nm)
9. Pole active material layer to 100 V/um
10. Ion mill etch back blanket electrode
11. Wirebond electrodes and mount mirror onto PCB

*These steps may involve additional processes or materials not explicitly listed in the original list.
Mirror Mounting

- Tiny Au wirebonds connect mirror electrodes to PCB pads (via holes)
- Kinematic mounting to PCB
  - Spheres pinch mirror in 3 places, preloaded and aligned using a magnetic field


Vibrational Behavior

Substrate: Glass

<table>
<thead>
<tr>
<th>Experiment</th>
<th>FEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damping Ratio, $\zeta$</td>
<td>0.12 (0.12)</td>
</tr>
<tr>
<td>Mode 1</td>
<td>63 Hz/3800 RPM</td>
</tr>
<tr>
<td>Mode 2</td>
<td>74 Hz/4500 RPM</td>
</tr>
<tr>
<td>Mode 3</td>
<td>220 Hz/ 13000 RPM</td>
</tr>
</tbody>
</table>

NOTE: Possible resonances at wheel speeds!
Launch Survival

- Mirror mass is ~4 grams (0.5 kg/m^2)
- Acoustics are most concerning
  - Delta IV-Heavy acoustic loads (conservative case)
  - Clamping points have critical stresses
- **Decision: require mirror launch restraint**

Bending stress failure @ 7 m\(^{-1}\)

![Diagram showing acoustic pressure and curvature over frequency](image-url)
Launch Restraint Concept

- Screw actuators lower mirror onto spring loaded restraint plate
- Restraint plate has small, soft pillars mounted to it to press on mirror underside
- Closed lid presses down from above with large soft pad (not shown)
- After lid is opened, mirror lifted from pads by actuators, restraint plate released
DM Package Block Diagram

Deformable Mirror

Mirror Board

Multiplexer 1

Multiplexer 2

Controller + Amplifier

Channels 1-80

Channels 1-40

Channels 41-80

Screw Actuators (3)

Piezo driver signals

D/M

S/C

+5V

Data

Data

GND

5V USB I/F

D/M CAM

Zigbee Wireless I/F

+5V

GND

Data

Data

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RM Package Block Diagram

- Rigid (reference) Mirror
- Screw Actuators (3)
- Controller + Amplifier
- Zigbee Wireless I/F
- D/M CAM
- +5V, Data, GND
- D/M
- S/C
- 5V USB I/F

Piezo driver signals
Current Configuration

Controller+amplifier board
Multiplexers
Gimbal base
Mirror board
Limit switches (7)
Actuators (3)
Mirror casing (white paint)

CAD

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Sensors and Actuators

• Sensors
  – Thermopile remote temperature sensors underneath mirror to monitor temperature, TBD locations
  – Thermocouples on PCB’s
  – Gimbal limit switches

• Actuators
  – ~40-80 mirror channels
  – 3 piezo screw actuators
  – Optional use of propellant heaters under mirrorbox
  – Gimbal range of motion:

<table>
<thead>
<tr>
<th>Mirror Position</th>
<th>Relative Piston (mm)</th>
<th>Tip (deg)</th>
<th>Tilt (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>0</td>
<td>2.855</td>
<td>0</td>
</tr>
<tr>
<td>Compact</td>
<td>2.9</td>
<td>2.855</td>
<td>2.855</td>
</tr>
<tr>
<td>Wide</td>
<td>8.7*</td>
<td>5.695</td>
<td>0</td>
</tr>
</tbody>
</table>

*without step height in wide configuration
41 Channel Lab Prototype

- Upgrade from previous 16 channel design
- Marie’s optimized “Notre Dame” actuation pattern
- Process improvements still ongoing
  - Reliability
  - Quality

![Prototype Images]

Example influence function measurements

A
B
C
D
E
F

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Major Components (Mirror assembly)

- Mirror board
  - Mirror
  - PCB
  - Launch restraint system
- Gimbal
  - 3 Newport Picomotors (8301-UHV)
- Multiplexer boards
  - Panasonic AQV258 PhotoMOS relays (1 per channel)
  - Maxim MAX6956AAX+ LED driver IC’s
- Controller board
  - M/C options
    - Rascal micro (Atmel ARM9)
    - MBED M/C (ARM Cortex-M3)
  - Apex/Cirrus HV Opamp (PA89A)
  - EMCO (AH06N-5T, AH06-5T) DC-HV DC converters
  - Zigbee wireless (TI CC2520)
Piezo Polymer Material Data

- Material characterization
  - Data from
    - JPL polymer lab (TMA, DMA, DSC, TGA)
    - Caltech material testing (Instron, optical measurements)
    - Sandia report on PVDF in space (DMA, piezo measurement)
  - Large variation in properties across temperatures

![Graphs showing thermal and mechanical data for piezo polymer material.](attachment:image)
Piezo Polymer Material Data

- CTE varies from 50 ppm/K to >200 ppm/K
- When cold, stiffness increases, but piezo coeff decreases
- Actuation stress fairly flat, optimal peak ~-40C
- Mirror stroke (for defocus mode)
  - +/-40 microns at 20C, +/- 60 microns at -40C
- Thermal balance
  - Thermal expansion overrides piezo range in <10C
  - Tuned balancing of mirror can extend operational range
  - Example designs below
  - * indicates curve used for performance analysis

Glass substrate

Glass substrate

Tunable reflective layer

Piezo polymer

Estimated CTE

Estimated Piezo Range (+/- 25MV/m)

Importance of Thermal Balance

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Additional Piezo Polymer Properties

• Critical temperatures
  – Tg: -40°C, glass transition (ill-defined)
  – Tc: +110°C, Curie
  – Tm: >140°C, melting
  – Td: >400°C, decomposition

• No moisture absorption (<0.01%)

• Viscoelasticity
  – Stiff for a polymer but still viscoelastic
  – Creep master curve to be measured
  – Good news: glass substrate will dominate shape over time and maintain molded shape
Thermal Traces: 11am/11pm SSO

The Model:

- Planetshine on
- Albedo on
- Sunshield (white paint, black chrome)
- .5 W generated/circuit board
- Temperatures between -10C and +10C
- Some radial thermal gradient present (due to board heat)
- Want surface temperature and emissivity underneath mirrors as uniform as possible to minimize gradients
Cold Case: No Power

The Model:
• 11 AM 11 PM Sun-synchronous orbit
• Planetshine on
• Albedo on
• Sunshield (white paint, black chrome)
• 0 W generated/circuit board
• Drops down to -60°C
  – Need to ensure mirror survival here
  – Can improve conduction to mirrorcraft
• Minor thermal gradient
Sun Pointed (Lost Control) – “Hot” Case

The Model:

- 11 AM 11 PM Sun-synchronous orbit
- Planetshine on
- Albedo on
- Sunshield (white paint, black chrome)
- .5 W generated/circuit board
- Telescope orbits with mirrors facing the sun
- Mirrors warm but still within survival range
- Solar irradiance may reflect into camera if mirrors are aligned -> BAD
Interfaces

• Mechanical
  – Mirrorbox bolts on top of 3U ISIS structure

• Electrical
  – 5V USB interface to mirrorcraft
  – Zigbee wireless to camera

• Thermal
  – Conductive contact with mirrorcraft
  – TBD survival heaters
  – Shielded from sun by lid/baffle(s)
Development Functional Tests

- **Optical**
  - Demonstration of 16-channel and 41-channel prototypes

- **Electrical**
  - Multiplexer prototype tested to +/-500V in air
  - Future: HV boards in partial vacuum

- **Thermal**
  - Piezopolymer survival (1 hour)
    - Retained functionality down to -70C and >90C
  - Future: thermal cycling of mirror package, shape hysteresis/creep
  - Future: thermal cycling of electronics

- **Mechanical**
  - Future test: launch restraint acoustic testing
Performance Tests

• Optical
  – 16 channel Si prototype
    • Achieved 2 waves RMS error in lab environment
  – 41 channel glass prototype
    • Some shorted channels, testing ongoing
    • Future: demonstrate diffraction-limited reproduction of OAP shapes

• Electrical
  • Future: amplifier power efficiency, peak power

• Thermal
  • Future
    • Mirror thermal shape stability and actuator stroke confirmation

16”x20” Vacuum chamber

Peltier coolers

Test mirror

6” laser window
Assembly and Integration

• Assembly
  – Critical step is wirebonding mirror to board
  – Boards mount into casing using brackets
  – Wirebonded flat flex cables between boards to minimize cabling volume/weight

• Integration
  – DM/RM individual unit assemblies shipped to Surrey
  – Assemble modules onto M/C and Coresat
  – Test communication to controllers
  – Verify mirror functionality of all channels (visual inspection)
  – Verify gimbal actuation
  – Lower mirror gimbals, clamp lid and restrain mirrors
Functional Library

• Commands:
  – activateGimbal()
  – resetController()
  – standby()
  – setVoltages(voltages)
  – driveActuator(id, cycles, forward_reverse)

• Queries:
  – getTemperatures()
  – getChannelStates()
  – getGimbalStates()
Conclusion

• Mirror box design
  — Packaging scheme laid out
  — Mirror restraint system concept needs testing
  — Design trade on sun shield/baffle needed

• Preliminary analysis and testing completed
  — Vibration work suggests launch restraint needed
    • Concept needs testing
  — Possible mirror resonance at high wheel speeds
  — Thermal numbers look reasonable so far
    • Good mirror thermal balancing is critical to optical performance
    • Mirror survival heater would be good to include
    • Uniform surface temperature below mirror will aid in thermal gradient reduction

• (System performance modeling coming in later slides)

• Mirror prototypes built and performance tested in ambient
  — Have not yet achieved diffraction-limited but getting closer
  — Improvements to glass slumping and piezo coating methods ongoing
  — Mirrors were functional after thermal survival tests (-70C, +90C)
  — Need to test optical performance with thermal cycling (chamber is being built)

• Controller/amplifier electronics needs breadboard testing
  — Power consumption numbers need to be verified

• Electronics/communication interfaces to M/C and Camera need more definition
Acknowledgements

• John Steeves, Jim Breckinridge (Caltech)
• Namiko Yamamoto, Risaku Toda, Victor White, Harish Manohara, Andrew Shapiro, Bill Warner (JPL)
• Past Ae105 classes
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Camera Requirements

• Functional
  – Work with 1.16m focal length segmented primary mirror
  – Provide feedback during primary mirror calibration
    • Deformable mirror (DM1 & DM2) shape
    • Primary mirror segment positions (tip and tilt)
  – Science imaging

• Performance
  – 80% encircled energy radius < 90% diffraction-limited EE radius
  – 0.3° (18 arcmin) full field-of-view
  – SNR > 100

• Constraints
  – Mass < 4kg
  – Volume (excluding boom interface) < 10cm × 10cm × 35cm
  – Power < 5W
Configuration

Primary Mirror (M1)

Adjustable mask

Dichroic beamsplitter (DBS)

Imaging lens

Collimator

Filters

Shack-Hartmann wavefront sensor (SHWS)

Imaging detector

Camera

DM1

RM1

RM2

DM2
• Designed using Zemax to minimize spot radius at image and wavefront error at pupil conjugate
• Designed for manufacturability
  – Cheaply available Schott glasses
  – Minimum RoC = 32mm
  – No cemented doublets for thermal performance
Optical Bandpass

![Graph showing transmission, reflectivity, and efficiency over wavelength (nm).]

- WS (370-494nm)
- Pointing (516-750nm)
- Imaging (522-545nm)
- DBS Transmission
- DBS Reflectivity
- Narrow-band filter Transmission
- Sensor QE
- Primary Mirror Reflectivity
Mechanical Configuration

- Collimator
- Collimator beamsplitter (DBS)
- Dichroic beamsplitter (DBS)
- Mask
- Imaging lens
- Stray-light baffles
- Boom interface
- Focal plane assembly
- Bench plate
- Telescope CPU
- Boom inspection camera
- SHWS
Mechanical Configuration

- The exterior will be wrapped in MLI for thermal stability
- The electronics box will be painted white

- Dimensions exclude the boom mount
Mask Configuration

- Static pupil mask
- Stepper motor
- Filter wheel

Extended pupil, Wideband
Compact pupil, Wideband
Compact pupil, Narrowband
Extended pupil, Narrowband
Camera Electronics

Imaging detector

- MT9P031 driver
  - Aptina MT9P031 CMOS sensor
- KAI-16070 driver
  - TruSense KAI-16070 CCD sensor
- MT9D112 driver
  - Aptina MT9D112 CMOS sensor

Telescope CPU

- mbed LPC1768 (ARM Cortex M3)

- SPI

- I^2C

- I^2C to S/C

- Mask driver

- Thermistors xN

- Temperature sensor driver

- Mask driver

- VN101504 Hall-effect sensor x4

- Faulhaber ADM 1220 S Stepper motor

To RMx, DMx
Camera Electronics

• Camera receives 5V power from S/C
  – Hardware limited to 5W max draw
• External $I^2C$ connection to S/C
• Internal $I^2C$ bus
  – Master: Telescope CPU
  – Slaves: imaging detector, SHWS, mask, BIC, etc.
Incident optical wavefront

- Microlens array
  - 500µm-pitch gives 88 samples over each primary mirror segment

- TruSense KAI-16070 interline CCD
  - 36.0mm × 23.9mm, 4864 × 3232 pixels (15.7MP)
  - 7.4µm square pixels
  - 48% QE at λ = 500nm
  - 12 electrons rms read noise
Imaging Detector

• Aptina MT9P031 CMOS
  – 2592 × 1944 pixels (5MP)
  – 2.2µm square pixels oversample the Ø14.2µm spot from a single primary mirror segment
  – 5.70mm × 4.28mm, 7.13mm diagonal
  – 0.3 degree (18 arcmin) field-of-view (diagonal)
  – 64% QE at λ = 500nm
### Camera Data Transmission

- **Imaging detector:** 3 types of images
  - **Focused point source**
    - Number of useful pixels: < 800
    - Compression method: Location and intensity of each useful pixel
    - Example image
  - **Unfocused point source**
    - Number of useful pixels: ~800K
    - Compression method: JPEG
    - Example image
  - **Extended source**
    - Number of useful pixels: ~5M
    - Compression method: JPEG
    - Example image

- **SHWS:** \{x,y\} centroid location for each subaperture spot
Telescope Command List

- beginTelescopeCheckout()
  - takeDarkFieldMeasurements()
  - checkoutMask()
  - checkoutMirrorSegment(segment_name)
- beginSegmentBlindSearch()
  - adjustMirrorSegmentPointing(segment_name, tip, tilt)
  - captureImage(exposure_time)
- beginCoarseCalibration()
  - coarseCalibrateSegment(segment_name)
  - adjustMirrorSegmentPiston(segment_name, piston)
- beginFineCalibration()
  - fineCalibrateSegment(segment_name)
  - takeWavefrontData(exposure_time)
  - deformableMirrorVoltages(segment_name, v[0:42])
- capturePointSourceImage(exposure_time)
- captureExtendedSourceImage(exposure_time)
- takeTemperatureData()
- captureBoomInspectionCamImage()
- switchMaskState(mask_state)
- .... Low-level commands not included!

Camera checkout commands

Mirror segment blind search and tip, tilt adjustment

Mirror segment voltage adjustment

Diagnostic and telemetry commands
Optical Analysis

• Spot diagrams and encircled energy analysis performed using Zemax
  – For a diffraction-limited, single Ø10cm mirror, 90% encircled energy radius = 13µm
  – Require 80% encircled energy radius < 13µm

• Require SNR > 100 for both SHWS and imaging detector
Encircled Energy Analysis

Diffraction 90% encircled energy = 13µm
On-axis 80% encircled energy = 10µm
Imaging detector pixel size
Geometric Spot Diagrams

- Grid is 400µm across
- Spot diagrams are presented using a superposition of the wide and compact pupil modes
- Imaging-band wavelengths: 522-545nm shown

2.2µm pixel size
SHWS SNR Calculations

- SHWS design informs the limiting photon count
- For a 50ms exposure with 100nm bandwidth around $\lambda=500\text{nm}$, we need a flux of $10^6$ photons/cm$^2$/s to achieve SNR = 100
- Corresponds to apparent magnitude $\sim$1.5-1.8

$$SNR = \frac{N}{N_{ron} + N_{poisson}}$$

$$N_{poisson} = \sqrt{N}$$

$$N = FT_{int} \eta \left( \frac{A_{mirror}}{n_{lenslets}} \right)$$

$$\eta = \eta_{mirror} \times (\eta_{lens})^4 \times (QE) = 0.42e^-/photon$$

$$T_{int} = 50\text{ms}, A_{mirror} = \pi(4.5\text{cm})^2, n_{lenslets} = 88$$

$$N_{ron} = n_{pixels} \times 12e^-/pixel = 195.1e^-$$

$$F = 2.6 \times 10^6\text{photons/cm}^2/\text{s}$$
• 1000mW and 400mW thermal loads model sensors
• Operating range for sensors and electronics: -50°C to 70°C
• Lower noise at colder temperatures
• Interior of camera: black paint; exterior: MLI; top: white
• Titanium case, glass lenses
Thermal Modeling Results

Profile during eclipse
Thermal Modeling Results

Profile in sunlight

Temperature [°C], Time = 24000 sec
# Camera Mass Budget

<table>
<thead>
<tr>
<th>Part</th>
<th>Mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lenses, filters, DBS</td>
<td>300</td>
</tr>
<tr>
<td>Lens mounts</td>
<td>300</td>
</tr>
<tr>
<td>Mask mechanism</td>
<td>150</td>
</tr>
<tr>
<td>Sensors</td>
<td>400</td>
</tr>
<tr>
<td>Structure</td>
<td>1000</td>
</tr>
<tr>
<td>Fasteners &amp; Wiring</td>
<td>300</td>
</tr>
<tr>
<td>Insulation</td>
<td>50</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2500</strong></td>
</tr>
<tr>
<td><strong>Margin (37.5%)</strong></td>
<td><strong>1500</strong></td>
</tr>
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## Camera Power Budget

<table>
<thead>
<tr>
<th>Part</th>
<th>Peak (W)</th>
<th>Nominal (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telescope CPU</td>
<td>0.600</td>
<td>0.450</td>
</tr>
<tr>
<td>Imaging detector</td>
<td>0.381</td>
<td>0.262</td>
</tr>
<tr>
<td>SHWS</td>
<td>1.600</td>
<td>1.000</td>
</tr>
<tr>
<td>Boom inspection camera</td>
<td>0.218</td>
<td>0.150</td>
</tr>
<tr>
<td>Wireless module</td>
<td>0.128</td>
<td>0.100</td>
</tr>
<tr>
<td>Mask</td>
<td>0.600</td>
<td>0.600</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3.527</strong></td>
<td><strong>2.562</strong></td>
</tr>
</tbody>
</table>
Interfaces

- Mechanical
  - 3-point kinematic interface to boom mount
- Electrical
  - Data and 5V power over I²C connection to S/C
- Wireless
  - 2.4GHz ZigBee communication to DM1, DM2, RM1, RM2
- Thermal
  - MLI exterior, white-painted top
  - Conduction to/from boom mount
- Optical
  - f/11.4 converging light beams from 4 primary mirror segments
  - 0.3 degree full field-of-view
Fabrication, Assembly & Integration

• To be contracted out:
  – Lens manufacturing
  – Lens group assembly

• To be done at Caltech:
  – Fabrication and assembly of camera
  – Initial alignment with primary mirror and boom

• To be done at Surrey:
  – Final alignment and integration with the boom and S/C
Optical Testing

- Test with polychromatic point source at the M1 prime focus
- Science detector requirements
  - 80% encircled energy radius < 90% diffraction-limited EE radius
  - Full field-of-view = 0.3°
- Tests to be performed in thermal chamber to characterize temperature effects
Future Work

• Mechanical and optical prototyping
• Optical element manufacturing and testing
• Command hardware development and testing
  – Telescope CPU
  – Various hardware drivers
• Software development
1. Mission Overview (20 mins)
2. Spacecraft Design (60 mins)
3. Telescope Design (160 mins)
   a) Mirrors
   b) Camera
   c) Boom
   d) Telescope System Performance
   e) Test and Calibration
4. System Summary, Launch Vehicle, Project Plan (15 mins)
5. Discussion (15 mins)
Problem Definition

• Design and fabricate a deployable boom suitable for the AAReST S/C
  – Key Characteristics
    • Lightweight and compact
    • Self-Deploying (utilizes strain energy for self-deployment)
  – Key Challenges
    • Maintaining optical-quality tolerances during telescope operation
      – Stiffness, deployment error & thermal issues
    • Controlling deployment process (forces on instruments)
Boom Requirements

• Functional
  – Package into a tight launch configuration for volume conservation
  – Deploy to final imaging state once in orbit
  – Accommodate a 1.16m focal length for the AAReST Telescope

• Performance
  – Boom deployment shall not impart rates greater than the control authority of the S/C ACS.
  – Static elongation of boom shall be no more than 500 μm in order to maintain telescope focus (can be accommodated by rigid body actuators on mirrors)
    • 50 μm axial displacement during calibration and imaging (depth of focus of imaging system)
  – Static lateral boom deflections shall be less than 2mm
    • 200 μm/s during imaging (avoid image smearing during calibration & imaging)
  – Avoid coupling between S/C ACS system in imaging mode
Boom Architecture
• Boom wrapped around S/C via folding tape-spring hinges
  – 4 hinges in total
  – $L_{tot} = 1.35\text{m}, \, D = 38\text{mm}, \, m = 80\text{g}$
  – Rigidly attached to S/C and instrumentation package
• Two-stage deployment process

Root
Camera Package

Stage 1
Stage 2
**Hinge Design**

- **Materials**
  - Combination of plain-weave fiberglass (60 μm thick) and unidirectional carbon fiber (90 μm thick)
  - \([+/45_f/0_c/+/45_f]\) lay-up
  - 210μm total thickness
  - 38mm diameter

- **Cutting pattern**
  - “Dog-bone” hinge cutting pattern
  - \(D = 15\) mm, \(L = 90\) mm, \(SW = 8\) mm

- Structural optimization techniques used to develop design

*Based off of Mallikarachchi, H.M.Y.C. and Pellegrino, S. (2008-2012)*
Boom Design

- Dimensions:
  - Width: 0.34m
  - Height 1: 0.31m
  - Height 2: 0.22m
Boom Design

Dimensions:
- Height: 0.58m
- Width: 0.29m
- Depth: 0.44m
Boom Design

1.35m

1.16m
**Fabrication Process**

1. Lay-up fiberglass (FG) and carbon fiber (CF) up to $2\pi D_{\text{mandrel}}$.

2. Roll onto cylindrical mandrel up to $\pi D_{\text{mandrel}}$.

3. Vacuum bag, autoclave cure & remove from mandrel.

4. Cut hinges in appropriate locations.

5. 9/16/2013
Deployment
First Stage Deployment

- First stage deployment initiated by burn wire (wrapped around folded boom)
- 2 hinges deploy, 2 remain folded at 90°
  - Compliant nature of boom accommodates small errors in deployment
- High velocity but low energy due to low mass of boom
  - Maximum torque applied to S/C = 0.4Nm
Second Stage Deployment

- Rate controlled deployment in order to minimize shock loading on instruments
  - Spool/cable system with stepper motor
- Deployment initiated by release of instrumentation package from S/C (frangible nut)
- Stiffness ratio of hinges designed to ensure collision avoidance between Camera and S/C
  - “Outward then up” motion
Deployment Control

- Required to ensure 2\textsuperscript{nd} stage deployment remains quasi-static
- Cable spool driven by brushless DC motor (CDA-InterCorp)
  - 52Nmm max torque
  - < 2W input
  - 80g total mass
Deployment Control

• Required to ensure 2\textsuperscript{nd} stage deployment remains quasi-static
• Cable spool driven by brushless DC motor (CDA-InterCorp)
  - 52Nmm max torque
  - < 2W input
  - 80g total mass
Cable Retraction

- Cable will become slack once mirror cover is deployed (after 2\textsuperscript{nd} stage deployment)
  - Slack cable could potentially obstruct optical path
- Long, low stiffness spring located inside boom
  - Fixed at camera package
  - Metal bead provides hard-stop during deployment
  - Cable retracted once mirror lid deploys
Structural Modeling
Structural Model

- Structural dynamics modeled using Abaqus Standard/CAE 6.12
- Boom: shell elastic elements
- S/C & Camera: 3D continuum elements
- 4kg Camera, 30kg S/C
- Boom properties defined using general shell section (ABD matrix – determined experimentally)
- Free boundary conditions
Structural Model

<table>
<thead>
<tr>
<th>Mode</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bending (yz-plane)</td>
</tr>
<tr>
<td>2</td>
<td>Bending (xz-plane)</td>
</tr>
<tr>
<td>3</td>
<td>Torsion</td>
</tr>
</tbody>
</table>

Note: Bending modes measured experimentally in order to validate model (fixed/free BCs)
Disturbance Analysis

- Reaction wheel provided by Surrey for characterization
- Jitter due to imbalances measured using 6DOF load cell
  - Used as boundary conditions for structural model
- Camera displacements/rotations calculated as a function of wheel speed

\[ M(\omega) = \sum_i A_i \omega^2 \sin(2\pi h_i \omega) \]

- Note: Data collected for a non-isolated, unbalanced wheel (worst-case scenario)

Based on Masterson et. al (2001)
Disturbance Analysis

- Torque imbalances applied to Coresat structure
- Loading due to three orthogonal wheels modeled
- Maximum deviations from optical axis determined (displacements and rotations)
  - Information fed into optical model

### Wheel Speed (rpm) | Displacements | Rotations
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amplitude (μm)</td>
<td>Rate (μm/s)</td>
</tr>
<tr>
<td>500</td>
<td>8</td>
<td>130</td>
</tr>
<tr>
<td>750</td>
<td>14</td>
<td>225</td>
</tr>
<tr>
<td>1000</td>
<td>30</td>
<td>480</td>
</tr>
</tbody>
</table>
Disturbance Analysis

- Torque imbalances applied to Coresat structure
- Loading due to three orthogonal wheels modeled
- Maximum deviations from optical axis determined (displacements and rotations)
  - Information fed into optical model

**Recommendation:** Keep wheel speeds less than 750rpm while imaging

<table>
<thead>
<tr>
<th>Wheel Speed (rpm)</th>
<th>Displacements</th>
<th>Rotations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
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<td>225</td>
</tr>
<tr>
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<td>30</td>
<td>480</td>
</tr>
</tbody>
</table>
Thermal Model
## Thermal Model

<table>
<thead>
<tr>
<th>AAReST</th>
<th>External Surface</th>
<th>Material</th>
<th>Internal Heat Load</th>
<th>Heat Max and Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirror Crafts (x2)</td>
<td>Solar Panels (sides), Black Paint (bottom)</td>
<td>Aluminum</td>
<td>6W/Craft</td>
<td>-</td>
</tr>
<tr>
<td>Core Craft</td>
<td>Solar Panels (sides), Black Paint (bottom)</td>
<td>Aluminum</td>
<td>18W</td>
<td>-</td>
</tr>
<tr>
<td>Mirror Boxes (x4)</td>
<td>White Paint (outside), Black Paint (inside)</td>
<td>Aluminum</td>
<td>2W/Mirror</td>
<td>Range: dT&lt;30K (+/- 15°C)</td>
</tr>
<tr>
<td>Mirrors</td>
<td>Aluminum Out, Black Under Side</td>
<td>Glass/Pyrex</td>
<td>No Heat</td>
<td>Range: dT&lt;30K (+/- 15°C)</td>
</tr>
<tr>
<td>Camera</td>
<td>MLI/White Paint/Black Paint</td>
<td>Titanium (6AL-4V)</td>
<td>Hot: 400 &amp; 1000 mW</td>
<td>Range: -50 to 70 °C</td>
</tr>
<tr>
<td>Boom</td>
<td>Black Paint</td>
<td>Carbon Fiber (orthotropic)</td>
<td>No Heat</td>
<td>-</td>
</tr>
<tr>
<td>Sun shield</td>
<td>Black Chrome/White Paint</td>
<td>Aluminum</td>
<td>No Heat</td>
<td>-</td>
</tr>
</tbody>
</table>
## Thermal Model

<table>
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<td>-</td>
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<td>Aluminum</td>
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<td>Mirrors</td>
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<tr>
<td>Camera</td>
<td>MLI/ White Paint/ Black Paint</td>
<td>Titanium (6AL-4V)</td>
<td>Hot: 400 &amp; 1000 mW Sensors</td>
<td>Range: -50 to 70 °C</td>
</tr>
<tr>
<td>Boom</td>
<td>Black Paint</td>
<td>Carbon Fiber (orthotropic)</td>
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</tr>
<tr>
<td>Sun shield</td>
<td>Black Chrome/ White Paint</td>
<td>Aluminum</td>
<td>No Heat</td>
<td>-</td>
</tr>
</tbody>
</table>
• Boom thermal profiles determined for Sun-Synch orbit (11am-11pm)
  – Determined assuming black paint across boom surface (worst-case scenario)
  – Significant circumferential gradient due to solar loading
• Deflections due to thermal profiles obtained via FEA
  – Hot (full sun) and cold (eclipse) profiles studied
Preliminary values of axial and circumferential CTE measured using 3D-DIC

- Tests performed in Thermal Chamber over a 65°C operating range
- **Axial:** \( \alpha_{11} = \sim 1.0 \text{ppm/}^\circ\text{C} \) (dominated by carbon fibers)
- **Circum:** \( \alpha_{22} = 21 \text{ppm/}^\circ\text{C} \) (dominated by fiberglass & epoxy resin)

- **Note:** Deflections are stable for approximately half the orbit
  - Below 2mm requirement
  - Produces a shift of the image on the focal plane

**CTE Measurements**

<table>
<thead>
<tr>
<th>Case</th>
<th>Axial Deflection (( \mu \text{m} ))</th>
<th>Lateral Deflection (( \mu \text{m} ))</th>
<th>Rotation (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot</td>
<td>25</td>
<td>625</td>
<td>0.04</td>
</tr>
<tr>
<td>Cold</td>
<td>-127</td>
<td>97</td>
<td>0.006</td>
</tr>
</tbody>
</table>
Interfaces
Interface to S/C

- Boom epoxied onto attachment collar
  - Collar pressure fit into S/C fitting then bolted in place
- S/C Fitting bolted into ISIS Cubesat frame
- May need to incorporate a secondary adapter plate in order to correct for errors introduced during assembly
Interface to Camera

- Kinematic mount used to provide alignment between Camera and Boom
  - Camera: V-grooves mounted at 120°
  - Boom Fitting: Matching spherical-tip cones
- Preloaded using surrounding bolt holes
## Boom Mass Budget

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boom</td>
<td>0.08</td>
</tr>
<tr>
<td>S/C Fitting</td>
<td>0.10</td>
</tr>
<tr>
<td>Camera Fitting</td>
<td>0.18</td>
</tr>
<tr>
<td>Cabling (electronic)</td>
<td>0.10</td>
</tr>
<tr>
<td>Burn wire</td>
<td>0.02</td>
</tr>
<tr>
<td>Motor/Spindle</td>
<td>0.10</td>
</tr>
<tr>
<td>Cabling (deployment)</td>
<td>0.02</td>
</tr>
<tr>
<td>Retraction Mechanism</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0.65</strong></td>
</tr>
</tbody>
</table>
Future Work

• Utilize cyanate ester resin
  – Improved thermal properties
  – Low outgassing

• Quantify viscoelasticity of boom material

• Monitor damage of hinges due to multiple folding/deployment processes

• Further refinement of manufacturing techniques

• Study flexible structure interaction with ACS
Review Outline

1. Mission Overview (20 mins)
2. Spacecraft Design (60 mins)
3. Telescope Design (160 mins)
   a) Mirrors
   b) Camera
   c) Boom
   d) Telescope System Performance
   e) Test and Calibration
4. System Summary, Launch Vehicle, Project Plan (15 mins)
5. Discussion (15 mins)
Performance Analysis

Keith Patterson
September 9th, 2013
Error sources:

- Camera CTE
- Boom deflections $(dX, dY, dZ)$
- Mirror shape errors, temperature, thermal bending

$\theta_x, \theta_y, \theta_z$
Error Sources

RBM: rigid body motion
WFE: wavefront error

Primary Mirror
- Manufacturing & Integration
  - RBM: rigid body motion
    - Shape errors
  - Environment
    - RBM: rigid body motion
      - Shape errors
- Environment
  - RBM: rigid body motion
    - Piston, Tip, Tilt correction
    - Residual error
  - Residual WFE
- Deformable Mirror correction
  - Pointing stability & jitter
  - Drift

Boom
- Manufacturing & Integration
  - RBM: rigid body motion
    - Vibrations
  - Environment
    - Residual WFE

Camera
- Design
  - WFE
- Manufacturing & Integration
  - WFE
- Environment
  - WFE

Initial Calibration Imaging
Performance Analysis Model

System Performance: Monte Carlo

MATLAB: Monte Carlo trial

new trial

MATLAB: Shack-Hartmann sampling

MATLAB: Piston (focus) adjustment

Spot diagram

Spot sizes

Diffraction-limited?

Converged?

no

yes

no

yes

MATLAB: actuator models from Abaqus FEM

actuator commands

MATLAB: optimization algorithm

pupil image wavefront

system perturbations

CODE V: ray trace

9/16/2013

AAReST Preliminary Design Review
Error Sources

Initial

Calibration

Imaging

Primary Mirror

- Manufacturing & Integration
  - RBM
    - Shape errors
  - Environment
    - RBM
      - Shape errors

Boom

- Manufacturing & Integration
  - RBM
    - Vibrations
- Environment
  - RBM
    - WFE

Camera

- Design
  - WFE
- Manufacturing & Integration
  - WFE
- Environment
  - WFE

RBM: rigid body motion
WFE: wavefront error

Included in model

Final error on image

Residual error

Piston, Tip, Tilt correction

Deformable Mirror correction

Residual WFE

Pointing stability & jitter

Drift
Error Budget Values

• Mirror temperature: -20C to +20C

• Camera temperature: -20C to +20C

• Mirror initial shape bounds (surface amplitudes, non-normalized, microns, +/-):
  – Z4 = .002; astigmatism_0
  – Z5 = .005; defocus
  – Z6 = .002; astigmatism_45
  – Z7 = .001; trefoil_x
  – Z8 = .001; coma_x
  – Z9 = .001; coma_y
  – Z10 = .001; trefoil_y
  – Z11 = .0005; tetrafoil_y
  – Z12 = .0005; 2_astigmatism_0
  – Z13 = .001; spherical
  – Z14 = .0005; 2_astigmatism_45
  – Z15 = .0005; tetrafoil_y
  – Z16:66 = .0001; higher order modes

• Boom deflection bounds (+/-):
  – X: 0.625 mm
  – Y: 0.625 mm
  – Z: 0.127 mm
  – Tip: 0.04 deg
  – Tilt: 0.04 deg
Example Performance Trial

- Initial Exit Pupil WFE Map (µm), Best Focus
- Current Exit Pupil WFE Map (µm), Best Focus
- Spot Diagram
- RMS Geometric Spot Size
- Initial Shack-Hartmann WFE (µm)
- Shack-Hartmann WFE (µm)
- Actuator Values
- Shack-Hartmann RMS WFE
Performance Results (Compact)

89% diffraction-limited
Performance Results (Wide)

72% diffraction-limited
System Performance Take-aways

- Mirror initial shape quality, astigmatism stroke, and operating temperatures are critical
- Low Shack-Hartmann sampling degrades camera spot size performance but increases SH SNR
- Non-common path errors and bandpass differences between detector and SH can degrade camera spot performance
- Boom deflection and alignment is of secondary importance compared to mirror quality
- Needed additions to model (future work)
  - Spacecraft pointing model (Newton-Euler)
  - Pointing controller
  - Mirror tip tilt controller
  - Camera optics manufacturing and integration errors
1. Mission Overview (20 mins)
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4. System Summary, Launch Vehicle, Project Plan (15 mins)
5. Discussion (15 mins)
Objectives

• Assembly segments/boom/camera
  – Verify mechanical interfaces
  – Optical alignment

• Optical performance validation
  – Validate calibration process

• Functioning
  – Mechanism
  – Electronic
  – Control & Algorithm
  – Communications
Test bed - requirements

- Generation of a large collimated beam
  - Auto-collimation technique
  - Only test 2 segments at a time

- Space-craft simulator
  - Mechanical interfaces
  - Communications
  - Power supply
Test-bed - Design

Φ 350 mm flat mirror
Surface quality λ/10

Polychromatic source,
at M1 focal plane

Primary Mirror
Beam Splitter
Spacecraft interface plate
Camera Package
Boom
Reference Mirrors alignment

- Mount segment on spacecraft interface plate
- Piston, Tip, Tilt each mirror

Criteria:
PSF size, shape and location

Φ 350 mm flat mirror

Spacecraft interface
• Position camera: adjust translation and rotation according to prime focus

Criteria:
- PSF: 80% of EE on 13um
- WFE < λ/20 rms
Deformable Mirror 1 alignment

- Mount DM1 in narrow configuration
- Illuminate RM1&DM1: tilt source, translate flat mirror
- Piston, Tip, Tilt DM

Criteria:
- PSF size and location
- Measurable WFE
Deformable Mirror 1 correction

- Control law from Influence Function measurement
- Reference wave-front: flat
- Correction of initial shape error
  - Will validate mirror control
  - Voltages minimizing the WFE to be recorded to approximate off-axis shape during operations

Criteria:
PSF: 80% of EE on 13um
WFE < λ/20 rms

Φ 350 mm flat mirror

Spacecraft interface
Deformable Mirror 2

- Mount DM2 in narrow configuration
- Illuminate RM2&DM2: tilt source, translate flat mirror
- Repeat DM alignment and correction
- Repeat for DM1&2 in wide configuration

Φ 350 mm flat mirror
• With RM1&2 illuminated
• Attach unconstrained boom to spacecraft interface plate
• Link boom to camera without straining the boom
  – Adjust mounting to keep optimal distance between primary mirror and camera
• Criteria:
  PSF : 80% of EE on 13um
  WFE < $\lambda/20$ rms

Φ 350 mm flat mirror
Telescope calibration process

- Reference Mirror process:

- Align RM1
- Align RM2
- Align DM1
- Correct DM1
- Align DM2
- Correct DM2
Telescope calibration process

- Deformable Mirror process:

[Diagram showing the processes and decisions for Telescope calibration]
Test telescope calibration

- With any aligned configuration (2 segments)

- Validate overall calibration process: introduce an expected perturbation (values from model and testing)
  - Camera temperature: translate camera
  - Boom deflection: translate/rotate camera
  - Segment misalignment: piston, tip, tilt segments

- Criteria: performance after calibration
  PSF: 80% of EE on 13um
  WFE < \( \lambda/20 \) rms
In-flight calibration: reference star

- Point telescope to reference star
  - bright star
  - near Zodiac
  - ±3 months from sun
In-flight calibration

- Star camera: pointing knowledge
  - If star disappear from FoV during process, stop and wait (or repoint)

Point reference star

Align RM1
Blind search, spot positioning and focusing (~1/4 orbit)

Align RM2 (~1/4 orbit)

Align DM1
Offset Voltages, Blind search, spot positioning and focusing (~1/4 orbit)

Correct DM1
Minimize WFE using new control law (~1/8 orbit)

Recalibrate DM1
Measure Influence Functions => new control law (~1/4 orbit)

WFE < \lambda/20 ?

No

Yes

Correct DM1
Minimize WFE using control law defined during ground calibration (~1/8 orbit)

Align DM2 (~1/4 orbit)

Correct DM2
Same than DM1 (~1/8 to 1 orbit)
In-flight calibration (~1-2 orbit) -> Record image on science detector (4 spots) (1 min)

no -> Expected optical performance?

yes -> Switch to narrow-band filter (1 min)

no -> 80% of Encircled Energy on 13 um?

yes -> Meet requirement

no -> Fine refocusing (segments’ piston) (10 min)

Record image on science detector (4 spots) (1 min)
Imaging (extended)

• Co-align segments
  – Adjust each segment tip/tilt to superimpose spots
  – Fine refocusing: adjust segments’ piston
  – Possibly: adjust DM1&2 shapes
  – Record image of the combined spot on science camera

• Extended source imaging
  – Calibrate on a star near the moon and then point at the moon

• Co-phase segments
  – If technique demonstrated on Earth
Conclusion and future work

• Integration and test plans defined
  – Optical elements
  – Mechanical interfaces
  – Control algorithm

• Integration on S/C
  – Ship segments in individual boxes and camera attached to deployed boom
  – Assemble on spacecraft
  – Optical test with same set-up to validate performance
  – Overall environmental testing

• Operation scheme defined, to be validated and refined with testing

• Start breadboard this year
  – Test-bed optical elements: white source, large flat mirror
  – Space-craft simulator: define interfaces
Review Outline

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Launch Vehicle Options

• Multiple opportunities now exist for small secondary payloads (<40kg)
  – Secondary launches on EELVs
  – ISS Cargo and jettison through the JEM airlock
• Orbit needs to be constrained to LEO (<650km) for communication performance and to de-orbit post mission.
  – No preferred inclination
• Looking for a low-cost/free ride share
  – NASA Earth science mission
  – NASA Space Technology Program mission
  – KSC LSP offers the CLI Program where NASA covers the launch cost.
• Used Delta-IV H for launch environments
# Telescope Mass & Power Summary

<table>
<thead>
<tr>
<th>Component</th>
<th>#</th>
<th>Unit Mass (kg)</th>
<th>Total Mass (kg)</th>
<th>Unit Peak Power (W)</th>
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<td><strong>Total</strong></td>
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<td><strong>14.64</strong></td>
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Data Rates/Volume

• Daily Data Volume
  – Best case: 3600s*9.6kb/s = 34.56Mb
  – Worst case: 17Mb

• Telescope data volume (per day-16 orbits)
  – Camera image: 15.7Mp (10 bits/pixel)
  – Windowing data reduction (50x50): 4 * 2500*10 = 100 kb
  – SHWFS: 5Mp (12 bits/pixel)
  – SHWFS data reduction: 4 * 88 Bytes * 12 bits/byte = 2816 bits
  – Telemetry (temps, state): 9600 bits
  – TOTAL: 10 images*100kb + 10*2816 + 9600 = 1.038Mb

  – Well within the available data downlink volume constraints

9/16/2013

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Plan

• Develop element prototypes and test Projects
  – Will include flight-like controllers, optics and mechanisms.

• Potential list of student Projects
  – Optical breadboard with two mirrors
    • Includes thermal testing of structure
  – Mirror Thermal and acoustics testing
  – Camera breadboard
  – Continue boom development

• Will be refined with the AE105 class instructors (Davis, Freeman, Scharf)
## Schedule

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**Schedule Notes:**
- **AAReST Preliminary Design Review:** 9/16/2013
- **Launch:** 9/2015
- **Ship:** 10/2015
- **MCR:** 9/2012
- **FY 2013 dates:**
  - Q1: 9/2013
  - Q2: 9/2013
  - Q3: 9/2013
  - Q4: 9/2013
- **FY 2014 dates:**
  - Q1: 9/2014
  - Q2: 9/2014
  - Q3: 9/2014
  - Q4: 9/2014
- **FY 2015 dates:**
  - Q1: 9/2015
  - Q2: 9/2015
  - Q3: 9/2015
  - Q4: 9/2015
Discussion

• Did we demonstrate readiness to proceed to a Project CDR?
  – Does the preliminary design appear feasible?
  – What concerns do you have that we need to address as we go to CDR?

• Please provide written input to:

Andy Klesh
Andrew.T.Klesh@jpl.nasa.gov