PI-SAT
Purdue imaging satellite

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Outline of Presentation

- Mission statement
- Concept of operation
- Design requirements
- Orbit selection
- Payload
- ADCS
- Communication
- Command and Data handling
- Power
- Thermal
- Structure
- Summary
**Mission Statement:**

We will make a low cost student-built satellite to observe the Earth’s atmosphere and land masses so that we can post pictures on Purdue’s website for public relations purposes.

**Mission Objective:**

To take pictures of the Earth from orbit and send image data back to ground stations.

**Satellite Description**

<table>
<thead>
<tr>
<th>Number</th>
<th>Part</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cameras</td>
</tr>
<tr>
<td>2</td>
<td>Antenna</td>
</tr>
<tr>
<td>3</td>
<td>Transmitter/Receiver</td>
</tr>
<tr>
<td>4</td>
<td>Batteries</td>
</tr>
<tr>
<td>5</td>
<td>Power Conditioner</td>
</tr>
<tr>
<td>6</td>
<td>Nutation Dampener</td>
</tr>
<tr>
<td>7</td>
<td>Torque Rods</td>
</tr>
<tr>
<td>8</td>
<td>Magnetometer</td>
</tr>
<tr>
<td>9</td>
<td>CDH</td>
</tr>
</tbody>
</table>

Total Mass: 50.5 kg  
Size: 50 x 50 x 50 cm
Orbital Characteristics

Table I: Orbital Characteristics

<table>
<thead>
<tr>
<th>Orbital Type</th>
<th>Sun-Synchronous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude(km)</td>
<td>800</td>
</tr>
<tr>
<td>Inclination</td>
<td>98.7 degrees</td>
</tr>
<tr>
<td>Mean Motion</td>
<td>14.3</td>
</tr>
<tr>
<td>Orbital Period</td>
<td>100 minutes</td>
</tr>
<tr>
<td>Eccentricity</td>
<td>0</td>
</tr>
<tr>
<td>Elevation</td>
<td>64.8 degrees</td>
</tr>
</tbody>
</table>

Orbital Selection

Table II: Descending Pass Keplerian Elements and Times

<table>
<thead>
<tr>
<th></th>
<th>First Pass</th>
<th>Second Pass</th>
<th>Third Pass</th>
</tr>
</thead>
<tbody>
<tr>
<td>UTC</td>
<td>14:28</td>
<td>16:04</td>
<td>17:45</td>
</tr>
<tr>
<td>Longitude</td>
<td>-72.96</td>
<td>-96.495</td>
<td>-123.15</td>
</tr>
<tr>
<td>Latitude</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>RAN(hours)</td>
<td>4.84</td>
<td>6.433</td>
<td>8.21</td>
</tr>
<tr>
<td>Satellite Solar Time</td>
<td>9:36</td>
<td>9:38</td>
<td>9:32</td>
</tr>
</tbody>
</table>
Orbital Selection

Table III: Ascending Times

<table>
<thead>
<tr>
<th>Pass</th>
<th>Ascending Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Pass</td>
<td>21:36</td>
</tr>
<tr>
<td>Second Pass</td>
<td>21:38</td>
</tr>
<tr>
<td>Third Pass</td>
<td>21:32</td>
</tr>
</tbody>
</table>

Table IV: Footprint Crossover and Duration Times

<table>
<thead>
<tr>
<th>Pass</th>
<th>Crossover (UTC)</th>
<th>Duration (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Pass</td>
<td>14:11</td>
<td>11:32</td>
</tr>
<tr>
<td>Second Pass</td>
<td>15:50</td>
<td>11</td>
</tr>
<tr>
<td>Third Pass</td>
<td>17:30</td>
<td>11:32</td>
</tr>
</tbody>
</table>

Launch Vehicle

- Ariane 5 ASAP Program Selected
- Maximum Launch Mass of 120 Kg.
- Maximum Dimensions
  - 0.6 x 0.6 x 0.71 (m)
- Maximum Acceleration
  - 7.5 g longitudinal
  - 6 g lateral
Payload

Objective: Take pictures of the planet with resolution of at least 1km

Hardware: 2 Color CMOS Digital Cameras
- Small Size and Power Requirements
- Picture size of 700 km x 490 km

Note: Not Space Qualified…

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>22 mm (W) x 25 mm (H) x 30 mm (D)</td>
</tr>
<tr>
<td>Weight</td>
<td>11 grams</td>
</tr>
<tr>
<td>Power</td>
<td>0.36 Watts (30mA @ 12VDC)</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>-10°C to 55°C</td>
</tr>
<tr>
<td>Format</td>
<td>NTSC (512 x 492) pixels</td>
</tr>
<tr>
<td>Lens</td>
<td>6.0 mm</td>
</tr>
<tr>
<td>Image Area</td>
<td>499 x 389 px</td>
</tr>
<tr>
<td>Field of View (FOV)</td>
<td>47.3 deg x 33.8 deg</td>
</tr>
<tr>
<td>Resolution</td>
<td>Length: 1.37 km/px, Width: 0.988 km/px</td>
</tr>
<tr>
<td>File Size</td>
<td>734 Kilobytes</td>
</tr>
</tbody>
</table>

ADCS

Attitude Determination and Control

Major Requirements

- Achieve and Maintain Nadir Pointing
  - The camera will be looking down out of the SAT, therefore keep SAT oriented so camera’s view is always down towards the Earth
- Determine Pointing to within 10°
  - Camera FOV is large enough that this level of accuracy still guarantees that the desired target of the picture is within the FOV of the camera
- Maintain the Pointing to within 10°
  - To be sure that we know what the camera is pointing at
- Recover from Failure
  - Must be done if the SAT flips upside down
Solutions to meet requirements

- Gravity Gradient stabilization – a simple way to keep nadir pointing
- Magnetic torque rods (magnetorquer) – achieve pointing and do failure recovery
- Magnetometer – field sensing necessary for magnetorquer and course attitude determination
- Sun Sensors – main source for determination, necessary when torquer is on and magnetometer is useless
- Nutation Damper – minimize pointing error (nutation)

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nadir Pointing</td>
<td>Gravity Gradient Stabilization</td>
</tr>
<tr>
<td>Determination to &lt; 10°</td>
<td>Sun Sensors supplemented with Magnetometer data</td>
</tr>
<tr>
<td>Control to &lt; 10°</td>
<td>Magnetorquer and a passive nutation damper</td>
</tr>
<tr>
<td>Failure Recovery</td>
<td>Magnetorquer capable of countering worst case torques</td>
</tr>
</tbody>
</table>

Attitude Determination Components

The driving considerations for components selection is always mass and power

**Sun Sensors**

2 Model 0.5 Sun Sensors from Optical Energy
- +/- 0.5 degree accuracy over 100 degree FOV – more than needed but this is average for sun sensors and does not have a negative effect
- < 40 grams, < 50 mW

**Magnetometer**

Billingsly Magnetics model TFM100S
- Course attitude determination
- 0.56 W, 200 g

Earth sensors were also considered, but were too heavy and consumed too much power for a level of accuracy that is not required.
ADCS

Attitude Control

Gravity Gradient Stabilization
- Achieved with a Weitzmann Deployable Boom from Surrey
- Cheap and effective, a common approach for nadir-pointing requirements

Magnetic Control – 3 small axially-aligned torqrods from Ithaco Inc.
- 0.54 W, 0.66 kg
- Dipole Moment 1.1 Am² sized to do failure recovery

Nutation Damper – a viscous ring damper
- simple device that needs development and sizing

Considered a yaw wheel which is common for gravity gradient stabilization, but 3rd axis control does not benefit the design and is not required.

Communication

Requirements

• Bi-directional communication
• Send and receive both housekeeping and image data
• Send image size of 800 KB within 10 minutes
• Max bit error rate of 1.0e-5
• Max available power is 10 W
Link budget

Frequency Selection

Frequency of 2.3, 2.4 and 2.32 GHz are chosen for PI-SAT

Advantage:
- Smaller and efficient at higher frequency
- Open for amateur satellite

Disadvantage:
- Not easy to get permission
- Purdue ground station doesn’t cover this frequency
**Antenna Selection**

- **S-band Helix omni directional antenna**
- **Gain:** 4 dbi
- **Power:** 10 W
- **Size:** 11.5 x 1.75 in
- **Weight:** 5.2 oz

**Receiver and Transmitter Selection**

**Transmitter:**
- **Power:** 5V, 680mA
- **Environmental:** -20 to 50 degree
- **Weight:** 500g
- **Frequency:** 2.2-2.45 GHz
- **Dimension:** 160-120-20 mm
- **Data rates:** 9.6Kbps-20Mbps

**Receiver**
- **Power:** 5 to 10 VDC
- **Weight:** 650g
- **Size:** 230 x 110 x 35 mm (L-W-H)
- **Operating temperature:** -20~60 degree
- **Non operating:** -40~85 degree
**Communication**

Deployable antenna

- Antenna rotates 90 degrees
- Possible to make contact if it becomes flipped upside down
- Simple mechanism

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**Command and Data Handling**

**RTSCM**

- 20 MHz Processor
- 8 MB SRAM
- Operating range: -35° to 75° C
- Weight of 1.0 kg
- Power: < 5 Watts
- Radiation Protection
  - Total Dose Tolerance of 300 Krad
  - Upset Level at 10⁹ rad/sec

Made by Maxwell Technologies Microelectronics
MiniModule PCC

- Adapts PCMCIA to Motherboard
- Weighs .102 kg
- 45 mA at 5V ± 5%
- Operating Temperatures
  - 0° to 70° C

Manufactured by Ampro Corp.

Software Tasks

- Tasks software will be required to do
  - Put Satellite in Sleep/Active Modes
  - Initialize Satellite
  - Control Camera
    - Turn On/Off
    - Take Picture
  - Extend Gravity-Gradient Boom
**Power**

- Four body mounted GaAs cell panels.
  - Area of .305 m² each.
  - 36W each; Peak 50 W.
- Li-Ion cells.
- Power system also consists of a battery charge monitor (BCM) and power conditioner.
- A max power of 34 watts to the subsystems will be provided at 28 volts.

**Lithium Ion Cells**

- 8 Li-Ion cells.
- Cost: $50 each
**Power Conditioner**

- Power Conditioner
  - Provide up to 5 output voltages
  - Protection features:
    - over voltage protection
    - over current protection
  - Telemetry and command interface.
  - Radiation hardened for 15 years geostationary mission
  - Very low mass, small size
  - Designed to minimize electromagnetic interference and provide high audio rejection for use with sensitive RF and microwave units.

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**Power Budget**

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Full Power [Watts]</th>
<th>Data Transfer Mode</th>
<th>Station Keeping Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communications</td>
<td>10</td>
<td>10</td>
<td>5 A</td>
</tr>
<tr>
<td>3 Magnetic Torquers [total]</td>
<td>0.54</td>
<td>0.54</td>
<td>0.54 E</td>
</tr>
<tr>
<td>2 Sun Sensors [total]</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1 E</td>
</tr>
<tr>
<td>Magnetometer</td>
<td>0.56</td>
<td>0.56</td>
<td>0.56 E</td>
</tr>
<tr>
<td>Payload</td>
<td>6</td>
<td>0</td>
<td>0 E</td>
</tr>
<tr>
<td>CD&amp;H</td>
<td>10</td>
<td>5</td>
<td>5 A</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>27.2</strong></td>
<td><strong>16.2</strong></td>
<td><strong>11.2</strong></td>
</tr>
<tr>
<td><strong>Margin [25% of Subtotal]</strong></td>
<td><strong>6.8</strong></td>
<td><strong>4.05</strong></td>
<td><strong>2.8</strong></td>
</tr>
<tr>
<td><strong>Total Power needed</strong></td>
<td><strong>34</strong></td>
<td><strong>20.25</strong></td>
<td><strong>14</strong></td>
</tr>
</tbody>
</table>

E=Exact
A=Approximate
Power Distribution At Full Power

- **Communications**: 29.41%
- **2 Sun Sensors [total]**: 0.29%
- **3 Magnetic Torquers [total]**: 1.59%
- **Magnetometer**: 1.65%
- **Payload**: 19.18%
- **Margin [25% of Subtotal]**: 20.00%
- **CD&H**: 29.41%

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**Thermal**

Maximum and Minimum Temperature Requirements (°C)

- **Payload**: -10 to +50
- **CD&H and Comm**: -10 to +20
- **Power**: 0 to +30
- **Sensors**: -30 to +50
- **Structures**: -40 to +50
Thermal

Thermal System:

Using existing satellite data, thermal ranges (PC-SAT)

\[ T_{\text{max}} = 10 \, ^\circ \text{C} \]
\[ T_{\text{min}} = -3 \, ^\circ \text{C} \]

Using 0.5 mil Aluminized Kapton coating on all six surfaces for thermal control.

Total mass: 10.5 grams

Structure

• Total Mass of Spacecraft = 50.4 Kg
  – Mass goal of less than 60 Kg
• Moments of Inertia – Kg-m^2
  – I_x = 13.654
  – I_y = 13.555
  – I_z = 0.765
  – Gravity Boom Extended
**Structure**

**Mass Budget**

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass (kg)</th>
<th>Component</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera</td>
<td>0.011</td>
<td>Power Hub</td>
<td>1.2</td>
</tr>
<tr>
<td>Frame-Grabber</td>
<td>0.1</td>
<td>Computer</td>
<td>2</td>
</tr>
<tr>
<td>Battery 1</td>
<td>0.3</td>
<td>Gravity Boom</td>
<td>2.2</td>
</tr>
<tr>
<td>Battery 2</td>
<td>0.3</td>
<td>Tip mass</td>
<td>1</td>
</tr>
<tr>
<td>Battery 3</td>
<td>0.3</td>
<td>Thermal Blankets</td>
<td>1</td>
</tr>
<tr>
<td>Battery 4</td>
<td>0.3</td>
<td>Solar Panel 1</td>
<td>1</td>
</tr>
<tr>
<td>Battery 5</td>
<td>0.3</td>
<td>Solar Panel 2</td>
<td>1</td>
</tr>
<tr>
<td>Battery 6</td>
<td>0.3</td>
<td>Solar Panel 3</td>
<td>1</td>
</tr>
<tr>
<td>Battery 7</td>
<td>0.3</td>
<td>Solar Panel 4</td>
<td>1</td>
</tr>
<tr>
<td>Battery 8</td>
<td>0.3</td>
<td>Magnetometer</td>
<td>0.2</td>
</tr>
<tr>
<td>Antenna 1</td>
<td>0.3</td>
<td>Magnetorquer</td>
<td>0.66</td>
</tr>
<tr>
<td>Antenna 2</td>
<td>0.3</td>
<td>Sun Sensor 1</td>
<td>0.04</td>
</tr>
<tr>
<td>Antenna 3</td>
<td>0.3</td>
<td>Sun Sensor 2</td>
<td>0.04</td>
</tr>
<tr>
<td>Antenna 4</td>
<td>0.3</td>
<td>Beams</td>
<td>21.3</td>
</tr>
<tr>
<td>Receiver</td>
<td>0.65</td>
<td>Skin</td>
<td>9.57</td>
</tr>
<tr>
<td>Transmitter</td>
<td>1</td>
<td>Adapter</td>
<td>1.89</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
<td><strong>50.461</strong></td>
</tr>
</tbody>
</table>

**Mass by Group**

- Payload: 9.82%
- Power: 16.72%
- Communications: 3.51%
- CD&H: 3.86%
- Gravity Boom: 1.76%
- Thermal: 1.65%
- Attitude: 0.21%
- Structure: 57.47%
- margin: 0.00%
Structure

- Ansys Model
  - Distributed Masses
  - Payload Adapter as Point of Contact
  - Every Component Modeled
- Natural Frequency
  - First Frequency of 91.54 Hz
  - Ariane 5 ASAP requires 90 Hz

Mesh Model
Structure

- Stress at First Natural Frequency

Structure

- Stress at launch load of 7.5g (vertical), 6g (lateral)
  - Max Stress of $2.04 \times 10^6$ Pa
  - Yield Stress of $1.03 \times 10^8$ Pa
Structure

- Material Selection
  - Beams
    - Aluminum 6061
    - 2.5 x 2.5 cm Hollow Square Tubes, thickness of 0.3 cm
    - Steel 1005 AISI
    - 2.5 x 2.5 cm Hollow Square Tubes, thickness of 0.75 cm
  - Stringers
    - Aluminum 6061
    - 2.5 x 2.5 cm L-Angle, thickness of 0.16 cm
  - Sheets
    - Aluminum 6061
    - 0.5 x 0.5 m, thickness of 0.15 cm and 0.30 cm

Areas Needing Further Designing

- Software development
- Analyze radiation effects of hardware more
- Thermal
- Analyze effectiveness of thermal blankets
- Attitude control
  - Develop nutation dampener
- Structure
  - Decrease mass and size
Questions?