TEST READINESS REVIEW (TRR)

Geocentric Heliogyro Operational Solar-sail Technology (GHOST)

DATE

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Emily Proano, Megan Scheele, Taylor Smith, Karynna Tuan
Presentation Sections

• Project Overview
• Schedule
• Project Budget
• Test Readiness
  • Deployment Test
  • Pitching Test
  • Deflection Test
Project Purpose and Specific Objectives

• **Purpose:** Design, build, and test a heliogyro solar sail deployment and pitching mechanism housed in a 6U CubeSat to improve current technology

• **Top Level Objectives and Requirements:**
  - **GHOST_001:** Deploy a heliogyro solar sail in a 1G environment at a controlled rate between 1 and 10 cm/s
  - **GHOST_002:** Pitch solar sail blades in a repeatable periodic motion within error margin of 0.5°
  - **GHOST_003:** House adequate length of solar sail to achieve minimum characteristic acceleration of 0.1 mm/s²
  - **GHOST_004:** Withstand static loads experienced from contact points with the Canesterized Satellite Dispenser (CSD) during launch and static loads experienced during ejection from CSD after launch
  - **GHOST_005:** Deployment and pitching system shall not exceed 10W of power.
3.0 1- G Controlled deployment of solar sails
   3.1 Suspend CubeSat in 1G environment
   3.2 Initiate deployment mechanism
   3.3 Measure Controlled sail deployment using motors

GHOST project responsible for deployment and pitching validation: Steps 3 and 5
3: Controlled Deployment
5: Solar Sail Root Pitch Control
(Major Tests to be Performed)

5.0 1-G Pitch control of blade reel module
   5.1 Establish connection to pitching mechanism
   5.2 Send appropriate pitch command
   5.3 Measure resulting pitch angle
      5.3.1 Measure actual pitch angle and compare to expected pitch angle.
   5.4 Ensure both actuators are capable of generating synchronized –
      collective, ½ P, and 1P cyclic root pitch deflections
Design Solution: Mechanical Overview

### Mass Budget – In Progress

<table>
<thead>
<tr>
<th></th>
<th>Theoretical (kg)</th>
<th>Measured (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRM Outer Structure</td>
<td>0.717</td>
<td>0.670</td>
</tr>
<tr>
<td>CCM Outer Structure</td>
<td>0.999</td>
<td>1.060</td>
</tr>
<tr>
<td>Total</td>
<td>2.433</td>
<td>2.400</td>
</tr>
</tbody>
</table>

### Mass Budget – Total

<table>
<thead>
<tr>
<th></th>
<th>Theoretical (kg)</th>
<th>Measured (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRM Total</td>
<td>1.306</td>
<td>TBD</td>
</tr>
<tr>
<td>CCM Total</td>
<td>1.263</td>
<td>TBD</td>
</tr>
<tr>
<td>Total</td>
<td>3.875*</td>
<td>TBD</td>
</tr>
</tbody>
</table>

*Note: Theoretical mass estimation does not include misc. electrical parts such as wiring, resistors, capacitors, etc.*
Design Solution: Electronics Overview

- **Microcontroller**
  PIC18F programmed and used to control the stepper and servo driver

- **Stepper Driver**
  Used to control the direction and step number of the stepper motor

- **Stepper Motor**
  Used for blade deployment

- **Servo Driver**
  Used to drive the BLDC motor through direction and velocity control

- **RS-232**
  Serial communication to control deployment and pitching

- **RJ-12**
  PicKit Interface for Programming of PIC18

- **BLDC Motor**
  Equipped with HALL and digital feedback
Project Overview

Functional Block Diagram

Serial Communication (RealTerm via RS-232) → Microcontroller (PIC) → Deployment Driver (Stepper) → Deployment Motor (Stepper) → Pitching Driver (Servo Driver) → Pitching Motor (BLDC Motor) → HALL Encoder

Microcontroller (PIC):
- Direction
- Step
- Position Feedback

Deployment Driver (Stepper):
- Direction
- PWM
- Voltage

Pitching Driver (Servo Driver):
- Angular Speed
- Internal Position Feedback

Pitching Motor (BLDC Motor):
- Voltage

Digital Encoder:
- PWM

DAC:
- Voltage

HALL Encoder:
- Angular Speed

Direction
Step
Position Feedback
Presentation Sections

• Project Overview
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  • Pitching Test
  • Deflection Test
GHOST Spring Schedule

Tasks

- Purchase motors/drivers/PIC
- Preliminary code
- Manufacture axles, brackets, and stabilizers
- Purchase raw materials
- Manufacture frame
- Assemble bus
- Integrate system
- Test procedures/set up
- Test code
- Electronics/code interface
- Deployment test
- Pitching test
- Structural Dynamics Tests

Time (date)

1/13 MSR
1/20
1/27
2/03 TRR
2/10
2/17
2/24
3/03
3/10
3/17
3/24
3/31
4/07 SFR
4/14
4/21 PFR
4/28

Key

- Completed
- Still need to do
Current Progress

- Assembled Outer Structure
- Servo Motor
- Pitching Axle Press Fit to Motor Shaft
- Stepper Motor
- Deployment Axle
- Rolled Mylar Blade
- PCB
Presentation Sections

• Project Overview
• Schedule
• Project Budget
• Test Readiness
  • Deployment Test
  • Pitching Test
  • Deflection Test
## Project Budget

<table>
<thead>
<tr>
<th>Part</th>
<th>Cost</th>
<th>Supplier</th>
<th>Arrived?</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Aluminum Sheets – 1/8” thick</td>
<td>$105.84</td>
<td>Metals Depot</td>
<td>Yes</td>
</tr>
<tr>
<td>1 Aluminum Rod – 1/4” diameter</td>
<td>$1.96</td>
<td>Metals Depot</td>
<td>Yes</td>
</tr>
<tr>
<td>1 Aluminum Rod – 7/16” diameter</td>
<td>$23.97</td>
<td>Metals Depot</td>
<td>Yes</td>
</tr>
<tr>
<td>1 roll Kapton Tape – ¾” wide</td>
<td>$25.00</td>
<td>Uniline</td>
<td>Yes</td>
</tr>
<tr>
<td>Miscellaneous Screws, Nuts, Bolts, etc.</td>
<td>$66.37</td>
<td>McMaster-Carr</td>
<td>Yes</td>
</tr>
<tr>
<td>Pic, DACs and Sipex Chip</td>
<td>$30.00</td>
<td>Mouser</td>
<td>Yes</td>
</tr>
</tbody>
</table>

| Total Cost of Purchased Components & Shipping  | $1937.43| Projected Total Cost of Remaining Components | $400.00| Total Estimated Budget Used | $2337.43 |
Presentation Sections

• Project Overview
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  • Deployment Test
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Deployment Test Overview

• Design Requirements Satisfied:
  1. Deploy solar sail in a 1G environment at a controlled rate.
  2. User input changes sail deployment velocity and maintains this rate within 1 cm/s.

• Objectives:
  1. Verify GHOST subsystems perform together within error tolerance of 1 cm/s.
  2. Prove Deployment system responds to user rate input.

• Testing Strategy:
  1. Mount CubeSat vertically at top of plywood scaffolding in Fleming.
  2. Input predetermined deployment rate and direction via Realterm.
  3. Record data and compare to expected performance.
Deployment Test Setup

- Mount to Plywood Scaffolding
- Calibrate camera to 3 meter window
- 3.5 and 5V Power Supply
  - Power On (begins holding torque)
- Remove tip mass locks
- Command deployment at 5 cm/sec
- Measure Deployment Rate
  - Compare footage to expected rate
- Repeated for variable rate testing
  - Compare footage to predetermined deployment profile
# Deployment Verification Tests

<table>
<thead>
<tr>
<th>Test</th>
<th>Design Requirement</th>
<th>Objective</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component Connection</td>
<td>• Stepper motor axle rotates when connected to a waveform generator</td>
<td>• Ensure deployment system electronics work properly before loading code to PIC</td>
<td>• Oscilloscope</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Waveform Generator</td>
</tr>
<tr>
<td>Deployment System Power Check</td>
<td>• Deployment system hardware does not exceed 10W power</td>
<td>• Measure current and voltage drops across electrical components individually to calculate power</td>
<td>• Voltmeter</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Ammeter</td>
</tr>
<tr>
<td>Software Integration</td>
<td>• Verify software is uploaded</td>
<td>• LED lights were designed in the board to light up to verify software</td>
<td>• Computer</td>
</tr>
<tr>
<td></td>
<td>• Verify deployment rate is received by user input</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable Deployment Rate</td>
<td>• Deployment can be stopped given user command</td>
<td>• Measure the pulses given by stepper motor and compare to predicted models</td>
<td>• Voltmeter</td>
</tr>
<tr>
<td></td>
<td>• Deployment rate can be changed at any time given user command</td>
<td></td>
<td>• Oscilloscope</td>
</tr>
</tbody>
</table>
Deployment Test: Electrical

• Measurements
  - Current (Ammeter)
  - Voltage (Multimeter)

• Process
  \[ P = \sum IV = \sum \frac{V^2}{R} \]
  \[ P = I_m V_m + I_d V_d + \frac{V_{mc}^2}{R_{mc}} \]

• Peak Expected Values

<table>
<thead>
<tr>
<th>System</th>
<th>Voltage (V)</th>
<th>Current (A)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microcontroller</td>
<td>5</td>
<td>(R = 150 Ω)</td>
<td>0.16</td>
</tr>
<tr>
<td>Stepper Driver</td>
<td>5</td>
<td>0.004</td>
<td>0.02</td>
</tr>
<tr>
<td>Stepper Motor</td>
<td>3.5</td>
<td>1.5</td>
<td>5.25</td>
</tr>
<tr>
<td>Total</td>
<td>-</td>
<td>-</td>
<td>5.43</td>
</tr>
</tbody>
</table>
Deployment Software

To Test:
- Can reach deployment routine via interrupt
- Can maintain constant deployment rate and deploys in within error margin of 1 cm/s

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>stepAngle</td>
<td>1.8 Degrees</td>
</tr>
<tr>
<td>fullCircle</td>
<td>360 Degrees</td>
</tr>
<tr>
<td>sailThickness</td>
<td>TBD</td>
</tr>
<tr>
<td>deployRate</td>
<td>Variable which can be set via interrupt</td>
</tr>
</tbody>
</table>

Calculate Circumference
\[ C = \pi d \]

Calculate length deployed with step
\[ stepLength = \frac{C \times stepAngle}{fullCircle} \]

Calculate reduction to diameter
\[ d = d - \frac{2 \times sailThickness \times stepAngle}{fullCircle} \]

Calculate the delay until the next step
\[ delayTime = \frac{lengthStep}{2\pi \times deployRate} \]
Presentation Sections

- Project Overview
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  - Pitching Test
  - Deflection Test
Pitching Test Overview

• Design Requirements:
  1. Blade Reel Modules shall pitch in a repeatable, periodic motion and shall be theoretically capable of orbit changing, spin rate change, and attitude maneuvers within a 0.5° error.
  2. CubeSat software receives and responds to pitching maximum angle and period of motion from user.

• Objectives:
  1. Show that electrical, software, and mechanical systems perform together within error tolerance.

• Testing Strategy:
  1. Mount CubeSat vertically at top of plywood scaffolding in Fleming.
  2. Attach angle sensor (ADI516xxxIM4).
  3. Input predetermined pitch and period commands via Realterm.
  4. Record data and compare to expected performance and error tolerance.

Testing Location: ITLL

Extra axle for pitching test

ADI516xxxIM4 (3 axis gyroscope)
Pitching Test Overview: Expected Results

Pitch Angle Response (1P, hP collective) – Error Margin 0.5°, Period of 60 sec

- Begin at 1-P:
  - Period = 60 sec
  - Amp = 15°

- Transition to half-P:
  - Period = 120 sec
  - Amp = 15°

- Transition to Collective
  - Period = 0 sec
  - Amp = 15°
# Pitching Verification Tests

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</tr>
</thead>
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<td>Component Connection</td>
<td>• Servo motor axle rotates when driver receives constant voltage</td>
<td>• Ensure deployment system electronics work properly before loading code to PIC</td>
<td>• Oscilloscope</td>
</tr>
<tr>
<td></td>
<td>• DAC receives PWM signal and outputs constant voltage</td>
<td></td>
<td>• Waveform generator</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Power supply</td>
</tr>
<tr>
<td>Pitching System Power Check</td>
<td>• Deployment system hardware does not exceed 10W power</td>
<td>• Measure current and voltage drops across electrical components individually to calculate power</td>
<td>• Voltmeter</td>
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<td></td>
<td></td>
<td>• Ammeter</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Power supply</td>
</tr>
<tr>
<td>Servo Motor Voltage Calibration</td>
<td>• Single servo must use no more than 5W power</td>
<td>• Motor is designed to have a peak voltage of 5V</td>
<td>• Voltmeter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Need calibration to model system power</td>
<td>• Power supply</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Ammeter</td>
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</tr>
<tr>
<td></td>
<td>• Verify deployment rate is received by user input</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable Pitch Period and Amplitude</td>
<td>• Pitch profiles: collective, 1P, and ½P</td>
<td>• Measure the angles rotated by servo motor and compare to predicted models</td>
<td>• Voltmeter</td>
</tr>
<tr>
<td></td>
<td>• Pitching system capable of deflecting 180°</td>
<td></td>
<td>• Oscilloscope</td>
</tr>
</tbody>
</table>
Electronics Pitching Test

- **Measurements**
  - Current (Ammeter)
  - Voltage (Multimeter)

- **Process**
  \[ P = \sum IV = \sum \frac{V^2}{R} \]
  \[ P = I_m V_m + I_d V_d + I_e V_e + \frac{V_{mc}^2}{R_{mc}} \]

- **Peak Expected Values**

<table>
<thead>
<tr>
<th>System</th>
<th>Voltage (V)</th>
<th>Current (A)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microcontroller</td>
<td>5</td>
<td>(R = 150 Ω)</td>
<td>0.16</td>
</tr>
<tr>
<td>Servo Driver</td>
<td>5</td>
<td>0.025</td>
<td>0.13</td>
</tr>
<tr>
<td>Servo Motor</td>
<td>5</td>
<td>1</td>
<td>5.00</td>
</tr>
<tr>
<td>Encoder</td>
<td>5</td>
<td>0.023</td>
<td>0.11</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>-</td>
<td>-</td>
<td><strong>5.40</strong></td>
</tr>
</tbody>
</table>
**Pitching Software**

- Controller inputs Maximum angle, period of rotation
- Follows $\theta_{next} = (\theta_{desired} + error) \cdot \sin(2\pi t/P)$
- Sends angular velocity:
  $$\omega_{sent} = -2\pi P(\theta_{desired} + error) \cdot \cos\left(\frac{2\pi t}{P}\right)$$
- Time $t$ resets to zero at the start of each period
- Angle and Period may be changed dynamically
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Deflection Test

Analysis assumes CubeSat as three hollow pieces (with center of mass in the center of each respective part) and two composite rods along X-axis.

\[ F = k d \]

where \( F \) is the applied force on the right BRM and \( d \) is the displacement.

The stiffness \( k \) can be determined.

\[ \omega = \sqrt{\frac{k}{m}} \]

where \( \omega \) is the modal frequency and \( m \) is the mass of the system.

Testing Location: Aerospace Shop

Calculated modal frequency is larger than the peak frequency we expect to experience.

\[ k = 1.4 \times 10^8 \text{ N/m} \]

\[ \omega = 767.8 \text{ Hz} \]
## Deflection Verification Tests

<table>
<thead>
<tr>
<th>Test</th>
<th>Design Requirement</th>
<th>Objective</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static Load</td>
<td>• CubeSat walls shall not break in shear stress under loads of 169N</td>
<td>• Ensure that the structure itself will not fail under launch loads</td>
<td>• Weights</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Table</td>
</tr>
<tr>
<td>Axial Compression</td>
<td>• CubeSat walls shall not deflect greater than 1% under 44N force experienced by CSD push</td>
<td>• During the ejection of the CSD container, the CubeSat structure will stay intact</td>
<td>• Dial indicator (measure)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Weights</td>
</tr>
<tr>
<td>CCM Deflection</td>
<td>• Central command module shall not deflect more than 1% during load of 169N experienced under 100 G</td>
<td>• The pitching axels won’t fail under loads on the CCM</td>
<td>• Weights</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Dial indicator</td>
</tr>
<tr>
<td>BRM Deflection</td>
<td>• Blade reel modules shall not deflect more than 1% during load of 169N experienced under 100 G</td>
<td>• The pitching axels won’t fail under loads on the BRM</td>
<td>• Weights</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Dial indicator</td>
</tr>
</tbody>
</table>
Thank you!
Questions?
Deployment Test Considerations

Tip mass is secured with washers and screws to C-brackets for ease of transfer.

Both screws and washers will be removed during testing so blade and tip mass can deploy correctly.

Remove Screws and Washers from Tip Mass for Deployment
Tolerance of Blade Axle Stabilizers

- For solar blade to deploy smoothly and avoid ripping, Mylar blade must not contact front face plates of Blade Reel Module:
  - Due to geometric constraints, this leaves a tolerance of ~3.8° in the horizontal alignment of the blade deployment axle and stabilizers
- Significant to make sure the deployment axle and stabilizer arrangement is not vertically tilted as to impart a significant torque on the spacecraft due to the misalignment of the deployed blades
  - Assuming a restriction of erroneous torque being less than ~3% of the maximum torque, the tolerance of the alignment vertical tilt is ~0.66°
Pitching Test Considerations

Screw and nut hold the BRM to the CCM for ease of transfers, simulated “launch locks”

Top wall of CCM must be unscrewed to remove “launch locks” and replaced

Tool will be inserted into front of BRM to hold nut while screw is taken out

Remove Screws and Nuts from inside CCM for Pitching
## Drawing Tree – Parts List

<table>
<thead>
<tr>
<th>Part Name</th>
<th>Part Number</th>
<th>Distributor</th>
<th>Quantity</th>
<th>Stock</th>
<th>Stock Quantity</th>
<th>Order?</th>
<th>Completed?</th>
<th>Total Cost</th>
<th>Theoretical Mass</th>
<th>Measured Mass</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRM Side Wall</td>
<td>99108A130</td>
<td>McMaster</td>
<td>24</td>
<td>5/8 x 5/8 x 12&quot; Aluminum Key Stock</td>
<td>2</td>
<td>Y</td>
<td>Y</td>
<td>$22.96</td>
<td>0.009</td>
<td>0.010</td>
<td></td>
</tr>
<tr>
<td>BRM Back Wall</td>
<td>R314</td>
<td>Metals Depot</td>
<td>2</td>
<td>1/4 x 24&quot; Aluminum Axle</td>
<td>1</td>
<td>Y</td>
<td>Y</td>
<td>$1.96</td>
<td>0.0136</td>
<td>0.013</td>
<td></td>
</tr>
<tr>
<td>BRM Top and Bottom Wall</td>
<td>R3716</td>
<td>Metals Depot</td>
<td>2</td>
<td>7/16 x 24&quot; Aluminum Axle</td>
<td>1</td>
<td>Y</td>
<td>N</td>
<td>$4.94</td>
<td>0.0059</td>
<td>0.010</td>
<td></td>
</tr>
<tr>
<td>BRM Left Front Wall</td>
<td>91771A09</td>
<td>McMaster</td>
<td>8</td>
<td>4-40 x 1/2&quot;</td>
<td>1</td>
<td>N</td>
<td>N</td>
<td>$10.00</td>
<td>0.00064</td>
<td>0.00064</td>
<td></td>
</tr>
<tr>
<td>BRM Right Front Wall</td>
<td>91771A168</td>
<td>McMaster</td>
<td>8</td>
<td>1-72 x 3/8&quot;</td>
<td>1</td>
<td>N</td>
<td>N</td>
<td>$12.78</td>
<td>0.00026</td>
<td>0.00026</td>
<td></td>
</tr>
<tr>
<td>C-Brackets</td>
<td>N/A</td>
<td>Matt Rhode</td>
<td>4</td>
<td>4 x 3/4 x 3/10&quot; Aluminum Block</td>
<td>1</td>
<td>N</td>
<td>A</td>
<td>$0.00</td>
<td>0.0056</td>
<td>0.0056</td>
<td></td>
</tr>
<tr>
<td>Servo Motor Clamps</td>
<td>N/A</td>
<td>Matt Rhode</td>
<td>4</td>
<td>1 x 1/2 x 1/2&quot; Aluminum Block</td>
<td>1</td>
<td>N</td>
<td>A</td>
<td>$0.00</td>
<td>0.0033</td>
<td>0.0033</td>
<td></td>
</tr>
<tr>
<td>Gear Motor</td>
<td>92703A027</td>
<td>McMaster</td>
<td>72</td>
<td>4-40 x 5/16&quot;</td>
<td>2</td>
<td>Y</td>
<td>Y</td>
<td>$15.20</td>
<td>0.00045</td>
<td>0.00045</td>
<td></td>
</tr>
<tr>
<td>Stepper Motor</td>
<td>SS2421-5011</td>
<td>Pololu</td>
<td>1</td>
<td>N/A</td>
<td>N/A</td>
<td>Y</td>
<td>N/A</td>
<td>$59.95</td>
<td>0.07</td>
<td>0.073</td>
<td></td>
</tr>
<tr>
<td>Encoder</td>
<td>2036U0128K312+CPECO5</td>
<td>Mikrom</td>
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<td>PCB Board</td>
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<td>Servo Motor Driver</td>
<td>ATA6832-DK</td>
<td>Atmel</td>
<td>2</td>
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<td>Need 1</td>
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<td>None</td>
<td>Current only have 1 because of supply shortage with distributor</td>
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<td>Misc. Electronics parts</td>
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<td>JB Saunders</td>
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<tr>
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<tr>
<td>Washer</td>
<td>90107A003</td>
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<td>1/8 ID x 1/4&quot; Od</td>
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<td>$2.64</td>
<td>0.00013</td>
<td>0.00013</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- May want to cut out triangles.
- Needs to be press fit onto stepper motor.
- Encoder and motor ordered together, company interfaced them for us.
- Theoretical mass based off entire blade length.
- Wires, resistors, capacitors, etc…
- Connecting all walls to cubes.
- Connecting stabilizers to walls.
- Connecting tip mass to walls.
- Connecting servo motor clamps to walls.
- Connecting servo motor clamps together.
- Nuts for connecting servo motor clamps to walls and together.
Electronics Testing Overview

- Design Requirement
  - 10 Watt power constraint

- Objective
  - Control pitching and deployment system independently to alleviate power draw

- Testing Strategy
  - Test pitching and deployment system components power independently
  - Calibrate servo motor voltage input
  - Compare measured voltage and current across all subsystems to expected amount
Software Testing Overview

• Design Requirement
  • Asynchronous communication

• Objective
  • Command pitching and deployment systems
  • Be able to change pithing and deployment information
  • Stop functions at any time

• Testing Strategy
  • Test code on computer for expected behavior before integration
  • Run individual functions on hardware to debug
  • Run full system checks
Pitching Capabilities

- Collective Pitch Profile - spacecraft spin-up
  - $M_1$ is net moment vector that demonstrates increasing/decreasing spin
Pitching Capabilities

- Cyclic Pitch Profile - Orbit Raising Maneuver
  - $F_1$ is net force vector that demonstrates in-plane thrust
  - Used for orbit raising/lowering maneuvers
Pitching Capabilities

- hP Pitch Profile – Precesses angular momentum vector
  - $M_2$ is net moment vector that demonstrates movement of gyro rotational axis
  - Used to reorient SC towards sun
Critical Project Elements

- Cut, attach, and roll the aluminized mylar solar sail and maintaining a straight blade
- Integration between the software and the servomotor
- Manufacturing and aligning the deployment axle and stepper motor within alignment of 4°
- Manufacturing and aligning the pitching axles with servo motors within alignment of 1°
Major Changes in Project Schedule

- Software took a week longer than scheduled
  - Integration and test got pushed back a week
- Added an extra week to create the test procedures and set up
- Moved deployment and pitching test to right after the TRR all the way to a week after spring break
  - Have four weeks to complete tests
- Created a stiffness/deflection test
  - Have two weeks to complete test
- Electronics Assembly is done
- Mechanical Assembly is done
### DAC Output Signal

**Table 4. Code Table**

<table>
<thead>
<tr>
<th>DAC CONTENTS</th>
<th>ANALOG OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>B7 B6 B5 B4 B3 B2 B1 B0</td>
<td>+REF × (255/256)</td>
</tr>
<tr>
<td>1 1 1 1 1 1 1 1</td>
<td>+REF × (129/256)</td>
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<tr>
<td>1 0 0 0 0 0 0 1</td>
<td>+REF × (128/256) = +REF/2</td>
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<tr>
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<td>+REF × (127/256)</td>
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<tr>
<td>0 1 1 1 1 1 1 1</td>
<td>+REF × (1/256)</td>
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<tr>
<td>0 0 0 0 0 0 0 1</td>
<td>0V</td>
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<tr>
<td>0 0 0 0 0 0 0 0</td>
<td>0V</td>
</tr>
</tbody>
</table>

**Note:**

1LSB = REF × 2⁻⁶ = REF × (1/256)

**ANALOG OUTPUT = REF × (D/256)** where D = Decimal Value of Digital Input.