Geocentric Heliogyro Operational Solar-sail Technology (GHOST)

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Nicholas Busbey, Mark Dolezal, Casey Myers, Lauren Persons, Emily Proano, Megan Scheele, Taylor Smith, Karynna Tuan
Presentation Sections

• Project Overview
• Schedule
• Manufacturing Elements
  • Mechanical
  • Software
  • Electrical
• Project Budget
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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

• Specific Objectives:
  • Level 1: Deploy a heliogyro solar sail in a 1g environment at a controlled rate
  • Level 1: Pitch solar sail blades in a repeatable periodic motion
  • Level 2: House adequate length of solar sail to achieve minimum characteristic acceleration
  • Level 3: Withstand static loads experienced from contact points with the CSD during launch
  • Level 3: Withstand static loads experienced during ejection from CSD after launch
Critical Project Elements

- Cut, attach, and roll the aluminized mylar solar sail
- Integration between the software and the servomotor
- Manufacturing and aligning the deployment axle and stepper motor
- Manufacturing and aligning the pitching axles with servo motors
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GHOST Spring Schedule

Tasks:
- Electronic integration
- Test procedures
- Preliminary code
- Electronics/code interface
- Deployment test
- Pitching test
- Structural Dynamics Tests
- Test code
- Manufacture remaining parts
- Integrate system
- Assemble bus
- Manufacture frame/CubeSat walls
- Purchase motors/drivers/pic
- Purchase raw materials
- Manufacture frame/CubeSat walls
- Assemble bus
- Manufacture remaining parts
- Test code
- Preliminary code
- Electronic integration

Time (date):
- 1/13
- 1/20
- 1/27
- 2/03
- 2/10
- 2/17
- 2/24
- 3/03
- 3/10
- 3/17
- 3/24
- 3/31
- 4/07
- 4/14
- 4/21
- 4/28

Key:
- Completed
- Still need to do
Major Changes in Project Schedule

• Software taking longer than scheduled
  • Only one week to test code and interface with electronics

• Two weeks added to create test procedures and instruments

• Deployment and pitching test moved to further date to account for TRR
  • Still have three weeks to complete tests

• Shake test was deemed irrelevant without CSD; instead deflection and spring applied tests will be run

• Parts supply/delivery delaying electronics

• Mechanical manufacturing is on schedule
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Basics of CubeSat Design

Blade Modules
- Front View
- Tip Mass
- Launch Tabs
- Brackets to Secure Blade
- Deployment Motor
- Tip Mass

Center Module
- Front View
- Top View
- Pitching Motors and Encoders
- Motor Drivers and Electronics Board
- Launch Locks

Motor

Brackets to Attach Center and Blade Modules

Hub to Attach Walls Together

Deployment Motor

Tip Mass
Initial Stock for CubeSat Walls

1. Purchase 1/8” thick sheet of aluminum (2x2 feet) for CubeSat walls
2. Scribe aluminum into 16 parts
3. Label parts with dimensions
4. Use vertical band saw to cut aluminum sheet along scribed lines
5. Use belt sander to smooth edges
SolidWorks Parts Transferred to CNC Mill

1. SolidWorks extension SolidCAM used for programming CNC Mill
2. Parts are clamped to table, all tools are zeroed in X, Y, and Z
3. CNC program from SolidWorks drills holes and mills edges
BRM Back Walls with SolidCAM Simulation

BRM Back Walls
# Progress of CubeSat Walls

<table>
<thead>
<tr>
<th></th>
<th>Walls to Machine</th>
<th>Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CCM</strong></td>
<td>Side Walls</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Top and Bottom Walls</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Front and Back Walls</td>
<td>No</td>
</tr>
<tr>
<td><strong>BRM</strong></td>
<td>Side Walls</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Top and Bottom Walls</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Back Walls</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Front Walls</td>
<td>No</td>
</tr>
</tbody>
</table>

**CCM Side Walls**

**BRM Side Walls**

**BRM Top and Bottom Walls**
## Remaining Mechanical Work

<table>
<thead>
<tr>
<th>Part</th>
<th>Stock to order</th>
<th>What needs to be done</th>
<th>Machine to use</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCM Top and Bottom Walls</td>
<td>1/8” thick aluminum sheet</td>
<td>Holes drilled, edges milled</td>
<td>CNC mill</td>
</tr>
<tr>
<td>CCM Front and Back Walls</td>
<td>1/8” thick aluminum sheet</td>
<td>Holes drilled, edges milled</td>
<td>CNC mill</td>
</tr>
<tr>
<td>BRM Front Walls</td>
<td>1/8” thick aluminum sheet</td>
<td>Holes drilled, edges milled</td>
<td>CNC mill</td>
</tr>
<tr>
<td>Fastening Corner Cubes</td>
<td>5/8” cube aluminum key stock</td>
<td>Cut cubes, holes drilled and tapped</td>
<td>Band saw, manual mill</td>
</tr>
<tr>
<td>Blade Axle Stabilizers</td>
<td>1/8” thick aluminum sheet</td>
<td>Holes drilled, edges milled</td>
<td>CNC mill</td>
</tr>
<tr>
<td>C-Brackets</td>
<td>Solid aluminum stock</td>
<td>Edges milled, C-shape drilled</td>
<td>Manual mill, lathe</td>
</tr>
<tr>
<td>Tip Mass and Blade Axles</td>
<td>Aluminum axles</td>
<td>Cut length and axle diameter</td>
<td>Band saw, lathe</td>
</tr>
<tr>
<td>Pitching Axe Hub</td>
<td>Solid aluminum stock</td>
<td>Holes drilled and tapped for pitching axle and set screws</td>
<td>Lathe, manual mill</td>
</tr>
<tr>
<td>Servo Motor stabilizers</td>
<td>Solid aluminum stock</td>
<td>Holes drilled and tapped for motor and set screws</td>
<td>Lathe, manual mill</td>
</tr>
</tbody>
</table>

- Roll Mylar blade, attach blade axle to ball bearing and stepper motor
- Attach servo motor to pitching axle and hub, secure servo motor with stabilizers
- Assembly of external CubeSat walls with fasteners, stabilizers, tip mass, and launch locks
Presentation Sections

- Project Overview
- Schedule

**Manufacturing Elements**
- Mechanical
- Software
- Electrical
- Project Budget
Software Capabilities

• Deployment algorithm will follow spool algorithm

\[ L_{\text{step}} = (\theta_{\text{step}} \times D_{\text{roll}} \times \pi) \]

\[ t_{\text{delay}} = \frac{L_{\text{step}}}{2\pi V_{\text{desired}}} \]

• Pitching software will follow blade control algorithm

\[ \text{pitch}_i = -\text{amp}_{\text{coll}} + \text{amp}_{\text{hp}} \sin \left[ \frac{1}{2} \left( \beta_i - \text{phase}_{\text{hp}} - \text{sign}(hP) \frac{\pi}{2} \right) \right] + \text{amp}_{\text{cyc}} \sin(\beta_i - \text{phase}_{\text{cyc}}) \]

- Acknowledgement to Dan Guerrant for his HGVizGui.m

• Interrupt-driven RS-232 communication able to dynamically change variables–\( V_{\text{desired}}, \text{amp}_{\text{coll}}, \text{phase}_{\text{hp}}, \) etc.
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
Deployment Capabilities

- Start - Takes in initial deployment rate and diameter
- Calculates rotation rate each step (circumference changes with each revolution)
  - Commands stepper driver to step
  - Loads timer, starts new step upon timer reset
- Deployment rate may change during deployment via RS-232 command

\[ L_{step} = (\theta_{step} \times D_{roll} \times \pi) \]
\[ t_{delay} = \frac{L_{step}}{2\pi V_{desired}} \]
Software Interrupts

- Framework for Interrupt service routine
  - Takes in interrupt bit
  - Determines instruction via bit masking
- Dynamically change performance of pitching/deployment based on user input

Command to change pitching angle to 57°
10111001
Command deployment rate to 7 cm/s
00100111
Software Progress

• **Finished**
  • Interrupt Layout
  • Pitching
    • Algorithm, ISR
  • Communication
    • Command Format

• **In development**
  • Deployment
    • Integrate with stepper-driver (need PCB)
  • Pitching
    • Algorithm, ISR
    • Integrate with servo-driver (need PCB)
  • Communication
    • Test ISR
    • Integrate with hardware
  • Restart
  • Unit Testing
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PCB Prototype

- RS-232
- 5 V Supply
- I2C Interface
- 3.5 V Supply
- Atmel Driver Interface
- PIC18F
- Stepper Driver
- Encoder Interface
# Parts Status

<table>
<thead>
<tr>
<th>Part</th>
<th>Location</th>
<th>Status</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCB</td>
<td>4pcb.com</td>
<td>Purchased 1/1</td>
<td>In transit</td>
</tr>
<tr>
<td>Stepper Motor</td>
<td>Pololu.com</td>
<td>Obtained 1/1</td>
<td>-</td>
</tr>
<tr>
<td>Stepper Driver</td>
<td>Pololu.com</td>
<td>Obtained 1/1</td>
<td>-</td>
</tr>
<tr>
<td>Servomotor</td>
<td>Micromo</td>
<td>Obtained 1/2</td>
<td>1/2 in transit</td>
</tr>
<tr>
<td>Servomotor Driver</td>
<td>Mouser</td>
<td>Obtained 1/2</td>
<td>Atmel ATA6832-DK out of production: other drivers may have to be used</td>
</tr>
<tr>
<td>Misc Board Components</td>
<td>-</td>
<td>Obtained DACs 2/2</td>
<td>Resistors, capacitors, pin-screw connectors, communication interfaces (RS-232 and I2C,) still need to be purchased</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Obtained Line Driver/Receiver 1/1</td>
<td></td>
</tr>
</tbody>
</table>

Note: A different servo driver may require a different interface with the microcontroller. A new PCB may need to be ordered: the current PCB will suffice for the stepper motor and the servomotor we currently have, so progress can still be made while searching for a second servo driver.
Next Steps

- Test traces on PCB
  - Ensure voltage and current loads are as expected (multimeter)
- Integrate chips (microcontroller, line driver/receiver, DACs) onto PCB
- Integrate software and electronics
  - Test preliminary software with LED and button simulations
- Drive stepper motor with microcontroller
  - Stepper motor/driver configuration has already been run independently via protoboard and waveform generator
- Driver servomotor and verify correct encoder feedback
  - Verify correct velocity and position algorithm
- Dual drive both Servomotors
  - Verify simultaneous pitching capability
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## Budget Table - Structural

<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 – 3/4” wide</td>
<td>$25.00</td>
<td>Unline</td>
<td>Yes</td>
</tr>
<tr>
<td>Miscellaneous Screws, Nuts, Bolts, etc.</td>
<td>$66.37</td>
<td>McMaster-Carr</td>
<td>No</td>
</tr>
</tbody>
</table>
## Budget Table - Electrical

<table>
<thead>
<tr>
<th>Part</th>
<th>Cost</th>
<th>Supplier</th>
<th>Arrived?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brushless DC Motor and Encoder</td>
<td>$744.20</td>
<td>Micromo</td>
<td>1/2</td>
</tr>
<tr>
<td>Sanyo Stepper Motor</td>
<td>$59.95</td>
<td>Polulu</td>
<td>Yes</td>
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<tr>
<td>Stepper Driver</td>
<td>$9.95</td>
<td>Polulu</td>
<td>Yes</td>
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<tr>
<td>PIC</td>
<td>$5.29</td>
<td>Mouser</td>
<td>Yes</td>
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<tr>
<td>2 DAC MAS522CPAs</td>
<td>$12.02</td>
<td>Mouser</td>
<td>Yes</td>
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<tr>
<td>Sipex SP232EEP chip</td>
<td>$1.05</td>
<td>Mouser</td>
<td>Yes</td>
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<tr>
<td>2 Atmel ATA6832</td>
<td>$208.75</td>
<td>Mouser</td>
<td>Yes</td>
</tr>
<tr>
<td>Remaining Electrical Components</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

### Remaining Electrical Components

<table>
<thead>
<tr>
<th>Part</th>
<th>Cost</th>
<th>Supplier</th>
<th>Requires Shipping?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miscellaneous Resistors, Capacitors, Wires</td>
<td>Less than $70</td>
<td>Electronics Lab</td>
<td>No</td>
</tr>
</tbody>
</table>
## Budget Table Totals

<table>
<thead>
<tr>
<th>Total Cost of Purchased Components</th>
<th>Shipping Fees</th>
<th>Projected Total Cost of Remaining Components</th>
<th>Total Estimated Budget Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1742.18</td>
<td>$60.89</td>
<td>$70.00</td>
<td>$1873.07</td>
</tr>
</tbody>
</table>

### Structural Concerns
- All main structural raw materials (walls, axels, etc) have arrived
  - Already being used to create components
- All secondary structural components (screws, brackets, etc) have been ordered.
  - Will arrive within the week

### Electrical Concerns
- Prototype Electrical system will be constructed with one Atmel driver
  - Allows for testing on software, structural and electrical systems
  - Research conducted for alternative drivers (SC2084 from Micromo)
- Entire electrical system will be constructed with two alternate drivers
Questions?