Hephaestus
Critical Design Review

Oregon State University
December 8th, 2016

Huy Nguyen
Cole Morgan
Jonathan Hardman
Sam Lundeen
Subret Aryal
Ian Finn
Helena Bales
Amber Horvath
Michael Humphrey
James Wilson
Michael Polander
Devin Wyckoff
Brett Moffatt
CDR Presentation Outline

• Section 1: Mission Overview
• Section 2: System Overview
• Section 3: Subsystem Design
• Section 4: Prototyping/Analysis
• Section 5: Manufacturing Plan
• Section 6: Testing Plan
• Section 7: User Guide Compliance
• Section 8: Project Management Plan (PMP)
1.0 Mission Overview

Michael Polander
Mission Overview: Mission Statement

The Oregon State University RockSat-X team will demonstrate that an autonomous robotic arm can locate predetermined targets around the payload under microgravity conditions by using precise movements.

The technical actions performed by this demonstration will illustrate a proof of concept for creating assemblies, autonomous repairs, and performing experiments in space.
Mission Overview: Mission Objectives

- Deploy a robotic payload capable of moving with four axes of freedom.
- Deploy a camera with a single axis of freedom.
- Enact a series of pre-scripted movements by the arm including contact with stationary sensors.
- Coordinate camera to track arm movements and record demonstration.
- Store sensor data for when arm is at rest, and when it comes into contact with station sensors.
The idea is that if an autonomous arm can maneuver itself to reach each point, it would be able to do repairs, build assemblies, and perform experiments outside the spacecraft if it was equipped with the correct equipment.

The robot needs to:

• Determine where each point is in a range of target locations
• Perform the necessary motions to reach its target
• Record when it makes contact with a target point based on the force applied

The Canadarm is a somewhat similar idea to this, but it was not autonomous. It aided the Space Shuttle orbiters in working with payloads.

The United States Naval Academy Small Satellites Program is planning to develop a 3U CubeSat called RSAT. The CubeSat will have two remote manipulator arms that can perform experiments and investigations in space.
After the demonstration is performed and the payload returns to Earth, we expect to receive time-stamped pass/fail results with error messages for each sensor showing whether or not the arm made contact with each point.

Additionally, there will be a video recording of the arm while it is outside the craft, further proving the payload met mission success criteria. Two temperature sensors will gather data throughout the demonstration.
Mission Overview: Concept of Operations

1. **Launch**: The payload will stay dormant for launch and the journey to apogee.

2. **Microgravity**: As the rocket approaches Apogee, the arm assembly body will extend out of the rocket and perform its demonstration.
   a. After the arm assembly body is fully extended outwards, the camera will perform sweeping shot of the surrounding space.
   b. The arm will maneuver towards the target to make contact.
   c. Contact will be confirmed when a sensor registers an appropriate amount of force.
   d. Previous steps will be repeated until contact has been made with each target.

*Descent*: The arm assembly body will retract before descent begins and will stay retracted from then on out.
ConOps

Altitude

- **t ≈ 80 Sec**
  - Altitude: 82 km
  - Deployment Activates

- **t ≈ 70 Sec**
  - Altitude: 76 km
  - Skirt Separation

- **Apogee**
  - t ≈ 200 sec
  - Altitude: ≈156 km

- **End of Malemute Burn**
  - t ≈ 28.7 sec
  - Altitude: 17.2 km

- **Terrier Ignition**
  - t = 0 Sec
  - Altitude: 0 km

- **t ≈ -180 Sec**
  - Altitude: 0 km
  - Experiment Power On

- **t ≈ 290 Sec**
  - Altitude: 130 km
  - Forced System Retraction

- **t ≈ 335 Sec**
  - Altitude: 68.9 km
  - Experiment Power Off

- **t ≈ 458.4 sec**
  - Chute Deploys

- **Splash Down**
  - t ≈ 916 sec

Speaker: Michael Polander
# Concept of Operations

<table>
<thead>
<tr>
<th>Event</th>
<th>Time On</th>
<th>Dwell</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSE 1</td>
<td>T-180 sec</td>
<td>520 sec</td>
<td>Minutes before launch. Turn on the Voltage Regulator and AVR microcontroller for the experiment.</td>
</tr>
<tr>
<td>TE-R</td>
<td>T+80 sec</td>
<td>5 sec</td>
<td>Activation line for experiment deployment</td>
</tr>
<tr>
<td>TE-1</td>
<td>T+290 sec</td>
<td>5 sec</td>
<td>Forced system retraction failsafe</td>
</tr>
</tbody>
</table>

Speaker: Michael Polander
Mission Overview: Success Criteria

Minimum Success Criteria:

• The arm assembly body shall deploy and a video sweep is successfully recorded.
• The arm assembly body shall be fully retracted after data collection.

Comprehensive Success Criteria:

• The arm assembly body shall deploy and a video sweep is successfully recorded.
• The arm shall make contact with predetermined targets around the payload.
• The camera shall record all instances of contact between the arm and the targets.
• The arm assembly body shall be fully retracted after data collection.
### Top Level Requirements:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>The full system shall fit on a single RockSat-X deck within the correct weight allocation</td>
<td>Inspection</td>
<td>Visual inspection as well as weighing on a digital scale will verify this requirement</td>
</tr>
<tr>
<td>The system shall survive the force and vibration characteristics prescribed by the RockSat-X program</td>
<td>Analysis and Test</td>
<td>The system will be subjected to these forces and vibrational loads in testing mid February and June during testing week. FEA will also be conducted</td>
</tr>
<tr>
<td>The system will be safe for people and other payloads surrounding it</td>
<td>Analysis and Demonstration</td>
<td>Deployment speed requirements and electrical safety</td>
</tr>
<tr>
<td>The system can operate under extreme temperature conditions</td>
<td>Analysis and Test</td>
<td>The electronic components must stay in operating temperatures during demonstration</td>
</tr>
</tbody>
</table>
2.0 System Overview

Michael Polander, Jonathan Hardman, Huy Nguyen, and Helena Bales
System Overview: Science Design Overview

Instrumentation

- **Camera**: To capture the demonstration on video
- **Sensors**: Track armrest location and contact points.
- **Microcontroller**: Store software and perform command and data handling
• No major changes in scope since PDR
System Overview: Functional Block Diagram

OSU RockSat-X Payload

Thermal Enclosure

Voltage Regulator
- 5V
- 12V
- 3.3V
- TE Voltage Sensor
- Motor Killswitch

Control Unit
- Processing (ATmega64)
- Local Storage (MicroSD)

Camera Storage (MicroSD)

Motor Drivers

Internal Analog Temperature Sensor

Analog Filter

External Switches

External Analog Temperature Sensor

Mechanical Arm
- Stepper Motor
- Stepper Motor
- Stepper Motor
- Stepper Motor
- Camera (GoPro)
- Arm Switches

Wallop Power
- GSE 1
- Timer Event R (TE-RA)
- Timer Event R (TE-RB)
- Timer Event 1 (TE-1)

Wallop Telemetry
- ADC Line 1
- ADC Line 2
- Parallel Lines

Speaker: Jonathan Hardman
System Overview: Functional Block Diagram

Subsystems:

- **Robotics**: Mechanical Arm
- **Structures**: Thermal Enclosure (Electronics Box & Camera) and structures supporting robotic deployment
- **Electronics**: Voltage Regulator, Control Unit, Temperature Sensor
- **Software**: Software Design, Processing (Firmware)
System Overview: Mechanical Design

Full Assembly
Units in inches
System Overview: Mechanical Design

Deployed Full Assembly
Units in inches

Deployment Distance

Speaker: Michael Polander
System Overview: Mechanical Design

Full Assembly Top View
Units in inches
System Overview: Mechanical Design

Full Assembly Side View
Units in inches
System Overview: Mechanical Design

Full Assembly Front View
Units in inches

9.88

5.25

5.00
System Overview: Mechanical Design

Structural Components
Units in inches

Motor Box
Support Arch
Electronics Box
Body Supports
Linear Actuator
Fall Away Supports
Guide Rails
System Overview: Mechanical Design

Structural Components
Top View
Units in inches
System Overview: Mechanical Design

Structural Components
Side View
Units in inches
System Overview: Mechanical Design

Structural Components
Front View
Units in inches
System Overview: Mechanical Design

Robotics Components
Units in inches

Deployment Body
Camera
Shoulder
Upper Arm
Lower Arm
System Overview: Mechanical Design

Robotics Components
Top View
Units in inches
System Overview: Mechanical Design

Robotics Components
Side View
Units in inches
Robotics Components
Front View
Units in inches
System Overview: Electrical Design

Speaker: Huy Nguyen
System Overview: Electrical Design

- **Microcontroller**
  - Atmega64: 8-bit AVR, 16MHz, 53 I/O pins, 64kB flash.

- **Motor drivers**
  - 8.2 - 45 VDC, 1/32 microstepping, current limiter.

- **Stepper Motors**
  - Stepper Motors: 4x Nema8, 1x Pancake, 1x Linear Actuator Nema17

- **Temperature Sensors**
  - Internal Sensor: -70°C to 500°C, 1kOhm.
  - External Sensor: -40°C to 850°C, 1kOhm, 1.5°C precision.

- **External Switches**
  - Touch Points: Tactile switches.
  - Calibration: Electrical contact plates.

- **Camera**
  - GoPro

- **Internal memory card (optional)**
  - 16GB, micro SD.
System Overview: Software Design

Software Modes of Operation

- Science
- Obs.
- Idle
- Off
- Safety

Transitions:
- 3: Science to Obs.
- 4: Science to Off
- 5: Off to Obs.
- 5: Off to Safety
- 1: Obs. to Idle
- 2: Obs. to Safety
- 6: Off to Science
- 7: Safety to Idle
- 8: Safety to Off
- 9: Safety to Science

Speaker: Helena Bales
System Overview: Software Design

Flow diagram detailing discrete code blocks, inputs, and dependencies that will be developed to actualize modes of operation.
System Overview: Description of Partnerships

- OSU AIAA
  - Funding
  - Student Support
- Oregon NASA Space Grant Consortium
  - Funding
- OSU Robotics Faculty
  - Advising on Robotics Design
- OSU School of MIME Faculty
  - Advising on Program and Communication
De-Scopes and Off-Ramps

The area of greatest risk in this project is the robotic arm. If the motors in the arm fail, the arm becomes a liability if it can’t be retracted.

If the risks and development of the arm become too great or strenuous, the arm can be removed from this design and the same parts can be used for a more sophisticated camera mount to do visual sweeps of the rocket exterior.
System Overview: Special Requests

- Extra Timer Line:
  - 1x TE line for signaling a forced retraction of the arm as a safety precaution
- Extra Telemetry:
  - No longer requesting RS232 line as per suggestion
  - Instead using 2x ADC Lines and 4x Parallel Lines
3.0 Subsystem Design

Devin Wyckoff
Subsystem Design:

Subsystems:

3.1: Robotics
   - Mechanical Arm
3.2: Structures
   - Thermal Enclosure
3.3: Electronics
   - Voltage Regulator
   - Motor Drivers/Motors
   - Control Unit
3.4: Software
   - Processing
# Subsystem Design: Detailed Weight Budget

**Weight Budget**

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Total Weight (lbf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload Deck</td>
<td>3.425</td>
</tr>
<tr>
<td>Structures</td>
<td>6.89</td>
</tr>
<tr>
<td>Robotics</td>
<td>5.94</td>
</tr>
<tr>
<td>Electrical</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>17.255</strong></td>
</tr>
<tr>
<td><strong>Over/Under</strong></td>
<td><strong>(2.255)</strong></td>
</tr>
</tbody>
</table>

**Center of Gravity:**
- $X = -0.16$ in
- $Y = 0.28$ in
- $Z = 1.73$ in
### Subsystem Design: Detailed Power Budget

**Speaker:** Devin Wyckoff

#### RockSat-X - Power Budget

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Voltage (V)</th>
<th>Max Current (A)</th>
<th>Start Time (min)</th>
<th>Time On (min)</th>
<th>Watts</th>
<th>Ah</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor</td>
<td>12.0</td>
<td>1.80</td>
<td>1.33</td>
<td>3.5</td>
<td>21.60</td>
<td>0.11</td>
</tr>
<tr>
<td>Motor Driver</td>
<td>5.0</td>
<td>0.08</td>
<td>1.33</td>
<td>3.5</td>
<td>0.40</td>
<td>0.00</td>
</tr>
<tr>
<td>Microcontroller Idle</td>
<td>5.0</td>
<td>0.02</td>
<td>-3</td>
<td>4.33</td>
<td>0.10</td>
<td>0.00</td>
</tr>
<tr>
<td>Microcontroller</td>
<td>5.0</td>
<td>0.48</td>
<td>1.33</td>
<td>3.5</td>
<td>2.40</td>
<td>0.03</td>
</tr>
<tr>
<td>Temperature Sensor</td>
<td>5.0</td>
<td>0.00</td>
<td>-3</td>
<td>9</td>
<td>0.01</td>
<td>0.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Voltage (V)</th>
<th>Max Current (A)</th>
<th>Start Time (min)</th>
<th>Time On (min)</th>
<th>Watts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td></td>
<td>2.38</td>
<td></td>
<td></td>
<td>24.51</td>
</tr>
<tr>
<td>Over/Under</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.36</td>
</tr>
</tbody>
</table>

**# of Flights Margin:** 7.2
3.1 Robotics Design

_Devin Wyckoff_
Subsystem Design: Robotics

Arm: Compact
Arm: Extended
**Subsystem Design: Robotics**

**Arm: Joints**

![Shoulder Joint Image]

**Shoulder Joint:**
3 motors for a total of 3 degrees of freedom.

![Elbow Joint Image]

**Elbow Joint:**
1 motor for a total of 1 degree of freedom.
Camera: Joint

Camera Joint:
1 motor for a total of 1 degree of freedom.
Subsystem Design: Robotics

• Power and data of subsystem
  – Power and data for the robotics subsystem is handled by the Electrical and Software subsystems.
Subsystem Design: Robotics

- Mechanical Interface
  - Arc
  - Rails
  - Fall Away Supports
  - Body Supports
  - Lead Screw
Subsystem Design: Robotics

- Electrical Interface
  - Motors
  - Calibration Sensors
  - Camera
Subsystem Design: Robotics

• Hardware:
  – GoPro Hero Session
  – ⅛” Machine Screws
  – Various Step Motors
  – Contact Sensors
  – Thrust Bearings
Subsystem Design: Robotics

- **Subsystem Weight**
  - Arm: 1.63 lbs
  - Body: 3.78 lbs
  - Camera: 0.55 lbs
  - Overall: 5.96 lbs
Rob.Risk.1: All mission objectives aren’t met IF deployment motor fails.
Rob.Risk.2: Minimum mission objectives aren’t met IF the camera actuation motor fails.
Rob.Risk.3: Maximum mission objectives aren’t met IF 2 or more arm actuation motors fail.
Rob.Risk.4: Maximum mission objectives aren’t met if camera memory is not intact.
Rob.Risk.5: All mission objectives aren’t met IF motors do not survive launch conditions.
Rob.Risk.6: All mission objectives aren’t met IF motors do not survive orbit conditions.
Subsystem Design: Robotics

• This subsystem design is still in progress. The final changes needed are as listed.
  – Final motor integration
    • Waiting on final schematics from manufacturer
  – Calibration sensor integration
    • Final sensor selection
  – Weight Reduction
    • Overall payload weight is slightly high
  – Manufacturing
    • Adjustments for manufacturing simplicity
3.2 Structures Design

Ian Finn, Subret Aryal, and Sam Lundeen
STR.RSK.1: Mission objectives are not met IF structures don’t withstand launch and reentry forces.
STR.RSK.2: Mission objectives are not met IF structures don’t withstand launch vibrations.
STR.RSK.3: Mission objectives are not met IF suitable insulation is not used.
STR.RSK.4: Mission objectives are not met IF water is allowed to damage data collected during the mission.
STR.ABS.RSK.1: Mission objectives aren’t met IF the arch support permanently deforms into arm
STR.ABS.RSK.2: Mission objectives aren’t met IF base support deforms into linear bearing path
Payload Support: Arm Support

- Arch Support
- Base Support
Payload Support: Arm Support

Currently:
• Catches arm in a secure place
• Material: Aluminum 6061
• Fasteners:
  – 18-8 Stainless Steel Hex Drive Flat Head Screw
    • 1/4"-20 Thread Size, 3/4" Long
    • 1/4"-20 Thread Size, 1" Long
  – 18-8 Stainless Steel Hex Drive Round Head Screw
    • 1/4"-20 Thread Size, 1-1/4" Long
    • 10-24 Thread Size, 3/4" Long
• Weight: 4.01 lbs

Next Steps:
• Weight reduction
• Prototype
• Manufacture
STR.DS.RSK.1: Mission objectives aren’t met IF motor is unable to pull robotic arm to original position
STR.DS.RSK.2: Mission objectives aren’t met IF guide rail is obstructed
Payload Support: Deployment System

- Drive Shaft
- Motor
- Motor Case
- Guide Rail
- Guide Rail Support
- Linear Bearings
- Support Hinges
Payload Support: Deployment System

Currently:
- **Material:**
  - Milled Aluminum 6061
  - 316 SS Guide Rails
- **Fasteners:**
  - 18-8 Stainless Steel Socket Head Screw
    - 1/4"-20 Thread Size, 5/8" Long
- **Weight:** 1.74 lbs

Next Steps:
- Prototype
- Manufacture
STR.EB.RSK.1: Mission objectives aren’t met IF data from the electronics box is not recovered
STR.EB.RSK.2: Mission objectives aren’t met IF water penetrates the electronics box
Payload Support: Electronics Box

- Electronics Box Lid
- Electronics Box Body
Payload Support: Electronics Box

Currently:

• Provides needed temperature, water, and stress resistance
• Material:
  – Aluminum 6061
  – Space Rated Silicone Sealant
• Fasteners:
  – 18-8 Stainless Steel Hex Drive Flat Head Screw
    • 10-24 Thread Size, 1" Long
• Weight: 1.0 lbs

Next Steps:

• Finalize internal box design to conform with electronics
• Prototype
• Manufacture
Payload Support: Thermal Management

STR.TM.RSK.1: Mission objectives aren’t met IF camera fails due to falling below minimum operating temperature
STR.TM.RSK.2: Mission objectives aren’t met IF circuitry fails due to falling below minimum operating temperature
STR.TM.RSK.3: Mission objectives aren’t met IF data storage fails due to rising above maximum operating temperature
Payload Support: Thermal Management

- 3 sq ft of emergency Mylar thermal sheets
  - Weight: 0.02 lb
  - Material: 12 micron silvered polyester film (true Mylar)

- 2 ft of Kapton space tape
  - Weight: 0.01 lb
  - Material: Kapton HN film with silicone adhesive

- Final thermal solution
3.3 Electronics Design

Cole Morgan, Huy Nguyen, and Jonathan Hardman
Subsystem Design: Voltage Regulator

• 3-Channel Switching Buck Converter: LT3514
  – High power efficiency
  – Low heat generation
  – Programmable Frequency
• Under Voltage Lockout Pin
  – Insures input voltage is above 1.44V
• Soft Start Pin
  – Ramps up each channel output
  – Prevents start up current spike
  – Can shut down each channel individually
• Programmable Switching Frequency
  – Allows control over the switching frequency
  – Affects power efficiency
Subsystem Design: Voltage Regulator

- **3 Channel Output**
  - 3.3V, 12V, 5V rails
  - 2, 1A channels and 1, 2A channel
- **Voltage Feedback Pin**
  - Manages switching frequency from output voltage
- **Overcurrent protection**
  - Prevents switching when above channel limit
- **This is the Final Design**
Subsystem Design: Mechanical Arm (Electronic)

• Motor Drivers DVR8825
  – 5VDC: supply logic high to select stepping mode.
  – 12VDC: supply power to drive motor
  – Signal from microcontroller:
    • Step: Control motor rotation angle
    • Dir: Control motor rotation direction
    • Enable: Turning the driver On/Off
  – Current Limiter: able to limit Motor’s power consumption

• This is FINAL design
Subsystem Design: Mechanical Arm (Electronic)

• Motor
  – NEMA8, Pancake, NEMA17 linear actuator.
  – 12VDC.
  – 600mA, Can be limited to 350mA or lower using Motor Driver.
  – Supplier: LIN Engineer
  – Average Power consumption: 0.11 Ah

• Camera/Camera Storage
  – GoPro Hero Session 4
    • Integrated Lithium battery.
    • Power button wire out to control on/off using AVR.
  – Micro SD
    • 16GB.
    • Using extension to safely protect inside electrical box

• This is the Final design
Subsystem Design: Control Unit

• Switches: Touch Points and Calibration
  – Touch Point: Tactile Switches
    • Pulls µC pin voltage to ground on press.
  – Calibration: Electrical Contact Plates
    • Closes the circuit when arm is folded raising µC pin voltage.

• Sensors: Internal/External Temperature
  – Internal: Honeywell Platinum Temperature Sensor
    • Input voltage: 5VDC
    • Resistance: 1kOhm
    • Temperature range: -70 to 500°C
  – External: Amphenol High Temperature Sensor
    • Input voltage: 5VDC
    • Resistance: 1kOhm
    • Temperature range: -40 to 500°C

• Analog Filter:
  – Capacitor filter to reduces noise in the temperature sensor output.

• This design is Final
Subsystem Design: Control Unit

- **Microcontroller: Atmega64**
  - 8-bit AVR instruction set, 16MHz, 53 I/O pins, 64kB flash.
  - 2x 8-bit timers, 2x 16-bit timers, 8x external interrupts, 8x ADC channels (10-bit res), 1x SPI

- **Data Connections**
  - **Motor Driver**: 6x PWM signal for stepping, 12x digital signal for direction and enable
  - **Switches**: 6x digital interrupts, 4x for arm calibration, 2x for ext. test points
  - **Sensors**: 1x digital signal for power, 2x ADC input from analog filter.
  - **Local Storage**: 1x SPI interface for serial connection with onboard microSD card.
  - **Telemetry**: 1x digital signal for the RS-X Parallel Line

- **Power Usage**
  - 5V, 20mA idle, 40 mA max for each I/O pin
  - 480mA max for all systems running, 0.03Ah

- **This design is not Final**
  - Local storage may be omitted from
Elct.Risk.1: All mission objectives aren’t met IF microcontroller fails.
Elct.Risk.2: All mission objectives aren’t met IF a suitable motor driver could fail when used at a high current for an extended time.
Elct.Risk.3: All mission objectives aren’t met IF power unit not function properly prior to apogee.
Elct.Risk.4: Partial mission objectives aren’t met IF the camera storage can’t be recovered or is damaged.
3.4 Software Design

*Helena Bales*
Subsystem Design: Software SubSystem

- **Software Overview**

  The software shall run on the ATmega64 controller.
  It is responsible for:
  - Turning on the camera
  - Deploying the payload
  - Moving arm to each test point
  - Retracting payload
  - Turning off camera
  - Turning off OBC
  - Reporting telemetry
  - Processing data and generating visualizations
Subsystem Design: Software SubSystem

- Software Modes of Operation

1. Rocket reaches apogee, payload is deployed, and camera is turned on.
2. Failure to turn on camera or deploy payload, fallback to idle.
3. The arm is deployed.
4. Arm becomes stuck and is retracted. Fallback to Observation mode.
5. Experiment ends.
6. Arm retracts, payload retracts, camera turns off, and OBC turns off.
8. Payload is retracted correctly or is retracted with the arm open or is expelled.
9. First attempt to retract the arm and payload correctly. Upon failure, attempt to retract the payload with the arm open. Upon failure, attempt to expel the payload.
Subsystem Design: Software SubSystem

Tracking Arm Location

Requirement: The position of the arm shall be accurately tracked.

Description: The location of the tip of the arm shall be tracked. It shall be denoted point $p$ and will be stored in 3D polar coordinates. In order to keep the position accurate over time, we shall calibrate the position by returning to the retracted state, triggering a sensor and resetting $p$ to zero. The points shall be stored in 3D polar form with an angle ($\theta$) from the normal, a radius ($r$) from the base of the arm, and a height ($h$) above the base plate.
Arm Movement

**Requirement:** The software shall control the movement of the arm body assembly. The position of the tip of the arm shall be tracked in 3D polar coordinate form.

**Description:** The movement of the arm shall be controlled by the software. The software shall first rotate the arm to the desired $\theta$ value. Then the arm’s actuator motors will move until the tip of the arm (point $p$) is at the target location, calculated using the current position and motion of the motors.

**Motion is limited:**
- Height (h) shall not exceed $\frac{1}{2}$ can in order to insure no damage is caused to neighboring experiments.
- Rotations (theta) shall not exceed 360 degrees in order to prevent damage to the wiring in the arm.
- Velocity of the arm at point $p$ (the tip of the arm) shall be limited to prevent damage to the arm, the rocket, and the payload in case of a collision.
- The torque applied by the motors shall be limited in order to prevent damage to the motors, the arm, and the rocket in case the arm becomes stuck.
Emergency Payload Retraction

Requirement: The software shall force retract the arm upon system failure. System failure in this case is defined as the arm stalling in a state where it is unable to compact.

Description: If an error occurs in the shutdown sequence, the software shall enter Safety mode. In Safety mode, the payload was either shut down correctly, retracted fully into the can with the arm open. The software shall remain in Safety mode until the payload is retracted.
Subsystem Design: Software SubSystem

Target Success Sensors

**Requirement:** The software shall know whether or not the arm succeeded in touching the targets. The sensors shall report back whether or not contact was made.

**Description:** The payload shall be equipped with pre-placed sensors. The coordinates for the sensors shall be stored within the system and used as inputs for the function controlling the arms’ movements, with the target position being where the tip of the arm should be located. The arm shall exert force to touch the sensors.
Subsystem Design: Software SubSystem

Telemetry

Requirement: The telemetry component shall report via telemetry lines all sensor data and test results.

Description: The software shall report a pass/fail result for each test completed. The telemetry output shall be encoded as a binary string, transmitted at a rate of no more than 5,000 Hz. If necessary, the output shall include a timestamp of when the test was completed. Upon encountering any errors, the system shall transmit a unique error code referring to what system failed.
Video Handling

Requirement: The software shall be responsible for controlling the camera.

Description: The camera shall be a GoPro Hero. The SD card shall be located in a pressurized water and heat proof enclosure. The software shall enable power to the camera when the rocket reaches apogee. The software shall disable power to the camera when the experiment completes, or when the rocket begins its descent.
EPS.RSK.1: All mission objectives aren’t met IF the camera fails to power on.

EPS.RSK.2: All mission objectives aren’t met IF the camera fails to begin recording when powered on.

EPS.RSK.3: All mission objectives aren’t met IF the camera is not successfully saved and the SD card does not survive re-entry.

EPS.RSK.4: Maximum success objectives aren’t met IF the arm collides with itself, another payload, or any part of the rocket.
4.0 Prototyping/Analysis
Results/Plans

Devin Wyckoff, Subret Aryal, and Sam Lundeen
Prototyping Plan: 3D Payload

- **Robotics**: Create 3D printed version of the arm.
- **Structures**: If possible fully 3D print the entire payload.
- **Electronics**: Protoboard version of the final PCB to run 3D printed payload.
- **Software**: Test pathing and operations on 3D printed payload.

The purpose of the 3D printed payload is to test the operation of the arm and confirm path planning. This allows us to make adjustments to payload if unforeseen problems arise in testing, before machining starts.
Analysis Results/Plans: Finite Element Analysis

- Arc FEA
- Minimum Factor Of Safety: 8.0
- Structure will survive the G-loading
Analysis Results/Plans: Finite Element Analysis

- Base Support FEA
- Minimum Factor Of Safety: 17.0
- Structure will survive the G-loading
Analysis Results/Plans: Finite Element Analysis

- Motor Case
- Minimum Factor Of Safety: 8.0
- Structure will survive the G-loading
Analysis Results/Plans: Thermal Analysis

• Analyzed change in average camera temperature during demonstration
• Under certain assumptions, the Mylar wrap allowed the camera to stay above the minimum operating temperature

• *These results confirm the Mylar wrap will sufficiently insulate the camera and electronics box.*
5.0 Manufacturing Plan

* Brett Moffatt, Cole Morgan, 
* and Helena Bales
# Mechanical Elements

## Robotics

<table>
<thead>
<tr>
<th>Item Number</th>
<th>Quantity</th>
<th>Description</th>
<th>Material</th>
<th>Manufacturing</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>001-001</td>
<td>2</td>
<td>(NEMA 08) Size 8 1.8 Degree Std Motor w/ up to 3 oz-in holding torque</td>
<td>N/A</td>
<td>Olympus Controls</td>
<td>208-13-01</td>
</tr>
<tr>
<td>001-002</td>
<td>1</td>
<td>(Pancake) SIZE 17 - 0.9 Degree - SMOOTH STEP XTREME ACCURACY</td>
<td>N/A</td>
<td>Olympus Controls</td>
<td>3709V-06</td>
</tr>
<tr>
<td>001-003</td>
<td>1</td>
<td>NEMA 17 Linear Actuator</td>
<td>N/A</td>
<td>Olympus Controls</td>
<td>LE-G4518S-03-ROM</td>
</tr>
<tr>
<td>002-001</td>
<td>1</td>
<td>HERO Session</td>
<td>N/A</td>
<td>GoPro</td>
<td>CHDH-S-102</td>
</tr>
<tr>
<td>002-002</td>
<td>1</td>
<td>Camera Case</td>
<td>AL 6061-T6</td>
<td>In-House (CNC)</td>
<td>002-002</td>
</tr>
<tr>
<td>003-001</td>
<td>1</td>
<td>Arm Linkage - 1</td>
<td>AL 6061-T6</td>
<td>In-House (CNC)</td>
<td>003-001</td>
</tr>
<tr>
<td>003-002</td>
<td>1</td>
<td>Arm Linkage - 2</td>
<td>AL 6061-T6</td>
<td>In-House (CNC)</td>
<td>003-002</td>
</tr>
<tr>
<td>003-003</td>
<td>1</td>
<td>Base - Top</td>
<td>AL 6061-T6</td>
<td>In-House (CNC)</td>
<td>003-003</td>
</tr>
<tr>
<td>003-004</td>
<td>1</td>
<td>Base - Body</td>
<td>AL 6061-T6</td>
<td>In-House (CNC)</td>
<td>003-004</td>
</tr>
<tr>
<td>003-005</td>
<td>4</td>
<td>Thrust Bearings</td>
<td>N/A</td>
<td>McMaster-Carr</td>
<td>5429T7</td>
</tr>
</tbody>
</table>

## Structures

<table>
<thead>
<tr>
<th>Item Number</th>
<th>Quantity</th>
<th>Description</th>
<th>Material</th>
<th>Manufacturing</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>004-001</td>
<td>2</td>
<td>Guide Rails</td>
<td>Steel</td>
<td>McMaster-Carr</td>
<td>2190A22</td>
</tr>
<tr>
<td>004-002</td>
<td>1</td>
<td>Guide Rails Support-1</td>
<td>AL 6061-T6</td>
<td>In-House (CNC)</td>
<td>004-002</td>
</tr>
<tr>
<td>004-003</td>
<td>1</td>
<td>Guide Rails Support-2</td>
<td>AL 6061-T6</td>
<td>In-House (CNC)</td>
<td>004-003</td>
</tr>
<tr>
<td>004-004</td>
<td>1</td>
<td>Guide Rails Support-3</td>
<td>AL 6061-T6</td>
<td>In-House (CNC)</td>
<td>004-004</td>
</tr>
<tr>
<td>004-005</td>
<td>2</td>
<td>Fall Away Supports</td>
<td>N/A</td>
<td>McMaster-Carr</td>
<td>2190A22</td>
</tr>
<tr>
<td>004-006</td>
<td>1</td>
<td>Launch Support- Main Body</td>
<td>AL 6061-T6</td>
<td>In-House (CNC)</td>
<td>004-006</td>
</tr>
<tr>
<td>005-001</td>
<td>1</td>
<td>Arc Support - 1</td>
<td>AL 6061-T6</td>
<td>In-House (CNC)</td>
<td>005-001</td>
</tr>
<tr>
<td>005-002</td>
<td>2</td>
<td>Arc Support - 2</td>
<td>AL 6061-T6</td>
<td>In-House (CNC)</td>
<td>005-002</td>
</tr>
<tr>
<td>005-003</td>
<td>1</td>
<td>Arc Support - 3</td>
<td>AL 6061-T6</td>
<td>In-House (CNC)</td>
<td>005-003</td>
</tr>
<tr>
<td>005-004</td>
<td>1</td>
<td>Electronics Box</td>
<td>AL 6061-T6</td>
<td>In-House (CNC)</td>
<td>005-004</td>
</tr>
<tr>
<td>005-005</td>
<td>2</td>
<td>Brackets</td>
<td>N/A</td>
<td>McMaster-Carr</td>
<td>1556A24</td>
</tr>
<tr>
<td>006-001</td>
<td>1</td>
<td>Motor Case</td>
<td>AL 6061-T6</td>
<td>In-House (CNC)</td>
<td>006-001</td>
</tr>
<tr>
<td>007-001</td>
<td>10</td>
<td>Thermal Blanket</td>
<td>Mylar</td>
<td>Primacare</td>
<td>007-001</td>
</tr>
<tr>
<td>007-002</td>
<td>1</td>
<td>Kapton Space Tape</td>
<td>N/A</td>
<td>Kapton</td>
<td>KPT-5/8</td>
</tr>
<tr>
<td>007-003</td>
<td>20</td>
<td>Flathead Screw-1/4-20, 1/2in</td>
<td>SS</td>
<td>McMaster-Carr</td>
<td>90471A410</td>
</tr>
<tr>
<td>007-004</td>
<td>30</td>
<td>Flathead Screw- 8-32, 1/2in</td>
<td>SS</td>
<td>McMaster-Carr</td>
<td>95145A194</td>
</tr>
<tr>
<td>007-005</td>
<td>12</td>
<td>Sockethead - 1/4-20, 1/2in</td>
<td>SS</td>
<td>McMaster-Carr</td>
<td>92488A216</td>
</tr>
</tbody>
</table>
Manufacturing Schedule: Mechanical

Speaker: Brett Moffatt
Electrical Elements

• To be soldered
  Voltage Regulator
  Control Unit
  Motor Drivers Unit

• 3 Revisions

• To be procured
  Discrete Parts
  Regulator IC
  Temperature Sensors
  Motor Driver IC
  Custom PCB
Manufacturing Schedule: Electronics

Speaker: Brett Moffatt
Software Elements

Discrete blocks to be completed and dependencies visualized

- Are there still sensors for the arm to visit?
  - Yes: Load coordinates for the arm to move to
  - No: Retract the Arm

  - Unable to compact arm?
    - Yes: Kill Power to arm and Force Retract
    - No: Move the Arm

- Drivers to interface with Stepper Motors
  - Send telemetry data
    - Visualize telemetry data
Manufacturing Schedule: Software

Speaker: Brett Moffatt
6.0 Testing Plan

Sam Lundeen, Devin Wyckoff, Huy Nguyen, and Helena Bales
Testing Plan: Compliance Tests

- Load capacity
- Weight & size
- Center of gravity
- Waterproof depth
- Operating temperature range
- Vibration capacity
- Arm deployment speed
- Motor precision
- Voltage & Power Draw
Testing Plan: Load Capacity

• 25 G in the X & Y axes, 50 G in the thrust axis
• Tested in SolidWorks through FEA
Testing Plan: Weight & Size

• Weigh the payload on a digital scale
• Measure height and width with a tape measure
• February 28th
Testing Plan: Center of Gravity

- Required to be within 1 inch square thrust axis
- Analyzed in SolidWorks
- Verified by balancing payload on square block.
- February 28th
Testing Plan: Waterproof Depth

- Payload electronics are susceptible to water damage
- Submerge electronics box 1 yard down in Dixon pool for 3 minutes
- February 29th
Testing Plan: Operating Temperature Range

- High and low temperature extremes
- Operations are tested at -30 °F for full deployment and demonstration cycle.
- Data storage is tested after being exposed to 500 °F for 1 minute
- March 6th
Testing Plan: Vibration Capacity

- Shaker table at Oregon State University
- **Sine vibration test**: 10-2000 Hz in all axes at 7 G with a rate of 4 octaves per minute.
- **Random vibration test**: 20-2000 Hz in the thrust axis at 10 G_{RMS}.
- **Random vibration test**: 20-2000 Hz in the X and Y axes at 7.6 G_{RMS}.
- Tests can start March 8th.
Testing Plan: Arm Deployment Speed

- The speed of the arm should not be harmful
- Time the full deployment of the arm
- Divide the distance traveled by the end of the arm by the time to get the speed.
- March 10th
Testing Plan: Motor Precision

• The motors must maintain precision through multiple cycles
• Record the difference in angles after 5 full rotations of each motor
• March 10th
Testing Plan: Voltage and Power Draw

- Record voltage and current across electrical components with ammeter
- Calculate power usage during demonstration
- March 10th
Testing Plan: Electrical Testing

- Voltage Regulator
  Nominal output voltage with min voltage input
  Nominal output voltage with max voltage input
  Max output current with nominal output voltage for 30 seconds
- Heat measurements
- January 19th
Testing Plan: Electrical Testing

• Motors/Motor Drivers
  Test different step input frequency to driver
  Test direction input to driver (CW and CWW)
  Test motor functionality
    Using different frequency for vary speed
    Test at higher/lower than 12V voltage supply
• Test schedule: January 19th
Testing Plan: Electrical Testing

• Microcontroller
  Verify proper behavior of µC features
  Digital Signals - Logic high and low Voltage (>2.2V, <0V)
  External Interrupts - Interrupts detection, latency
  ADC accuracy - Voltage precision/sensitivity testing

• Temperature
  Verify sensor parameters
  Temperature range
  Voltage accuracy at varying ranges

• External Switches/Calibration
  Switch bounce testing
  Debounce tuning

• Test schedule: January 19th
Testing Plan: Video handling component

- Software for enabling and disabling power to the camera.
- Ensure video footage was written to data storage without corruption.
- February 27th
Testing Plan: Motor control

- Software for accurate control of the motors.
- Ensure that the motors can be commanded from their start position to another position and return back to the start position within a reasonable error.
- Dependent upon electrical component being completed
- March 3rd
7.0 User Guide Compliance

Michael Polander and Cole Morgan
## User Guide Compliance: Summary

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Status/Reason (if needed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center of gravity in 1&quot; plane of plate?</td>
<td>YES</td>
</tr>
<tr>
<td>Weight 30.0+/- 1.0 (15.0 +/- 0.5) lbs?</td>
<td>NO, 17.255 lb Plan to Reduce</td>
</tr>
<tr>
<td>Max Height &lt; 10.75&quot; (5.13&quot;)</td>
<td>YES, 5.0&quot; from top of deck plate</td>
</tr>
<tr>
<td>Bottom of deck has flush mount hardware?</td>
<td>YES</td>
</tr>
<tr>
<td>Within Keep-Out Zone</td>
<td>YES</td>
</tr>
<tr>
<td>Using &lt; 10 A/D Lines</td>
<td>YES, 2 ADC Lines</td>
</tr>
<tr>
<td>Using/Understand Parallel Line</td>
<td>YES, 4 Parallel Lines</td>
</tr>
<tr>
<td>Using/Understand Asynchronous Line</td>
<td>No Asynchronous Lines Used</td>
</tr>
<tr>
<td>Using X GSE Line(s)</td>
<td>YES, GSE 1</td>
</tr>
<tr>
<td>Using X Non-Redundant PWR Lines (TE-1, TE-2, TE-3)</td>
<td>YES, TE-1</td>
</tr>
<tr>
<td>Using X Redundant Power Lines (TE-R)</td>
<td>YES, TE-RA and TE-RB</td>
</tr>
<tr>
<td>Using &lt; 1 Ah (.5Ah for Half Can)</td>
<td>YES</td>
</tr>
<tr>
<td>Using &lt;= 28 V</td>
<td>YES</td>
</tr>
<tr>
<td>Using RF (If yes, list frequency and TX Power)</td>
<td>No</td>
</tr>
<tr>
<td>Using deployable?</td>
<td>YES, speed will be under 1”/s</td>
</tr>
<tr>
<td>Whole team consists of US Persons</td>
<td>YES</td>
</tr>
<tr>
<td>Using ITAR and/or Export Controlled hardware</td>
<td>YES</td>
</tr>
</tbody>
</table>
## Power Connector--Customer Side

<table>
<thead>
<tr>
<th>Pin</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GSE1 Voltage regulator</td>
</tr>
<tr>
<td>2</td>
<td>TE-RA Deployment and program activation</td>
</tr>
<tr>
<td>3</td>
<td>TE-RB Deployment and program activation</td>
</tr>
<tr>
<td>4</td>
<td>TE-1 Deployment retraction fail/safe</td>
</tr>
<tr>
<td>5</td>
<td>GND Voltage Regulator and Microcontroller</td>
</tr>
<tr>
<td>6</td>
<td>GND Half of Motor Drivers</td>
</tr>
<tr>
<td>7</td>
<td>GND Half of Motor Drivers</td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Pin</td>
<td>Function</td>
</tr>
<tr>
<td>-----</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>1</td>
<td>Internal Temperature Sensor</td>
</tr>
<tr>
<td>2</td>
<td>External Temperature Sensor</td>
</tr>
<tr>
<td>3</td>
<td>N/C</td>
</tr>
<tr>
<td>4</td>
<td>N/C</td>
</tr>
<tr>
<td>5</td>
<td>N/C</td>
</tr>
<tr>
<td>6</td>
<td>N/C</td>
</tr>
<tr>
<td>7</td>
<td>N/C</td>
</tr>
<tr>
<td>8</td>
<td>N/C</td>
</tr>
<tr>
<td>9</td>
<td>N/C</td>
</tr>
<tr>
<td>10</td>
<td>N/C</td>
</tr>
<tr>
<td>11</td>
<td>N/C</td>
</tr>
<tr>
<td>12</td>
<td>N/C</td>
</tr>
<tr>
<td>13</td>
<td>N/C</td>
</tr>
<tr>
<td>14</td>
<td>N/C</td>
</tr>
<tr>
<td>15</td>
<td>N/C</td>
</tr>
<tr>
<td>16</td>
<td>N/C</td>
</tr>
<tr>
<td>17</td>
<td>N/C</td>
</tr>
<tr>
<td>18</td>
<td>N/C</td>
</tr>
<tr>
<td>19</td>
<td>N/C</td>
</tr>
</tbody>
</table>
8.0 Project Management Plan (PMP)

Michael Polander
PMP: Semester Schedule

Speaker: Michael Polander
# PMP: Latest Contact Matrix

## Oregon State University Team

<table>
<thead>
<tr>
<th>Role</th>
<th>Name</th>
<th>Day Phone</th>
<th>Cell Phone</th>
<th>Receive Texts?</th>
<th>Email</th>
<th>Citizenship</th>
<th>Add to mailing list?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Manager</td>
<td>Michael Polander</td>
<td>5036894119</td>
<td>5036894119</td>
<td>Yes</td>
<td><a href="mailto:polandem@oregonstate.edu">polandem@oregonstate.edu</a></td>
<td>U.S.</td>
<td>Yes</td>
</tr>
<tr>
<td>ME Team Member</td>
<td>Devin Wyckoff</td>
<td>5036216228</td>
<td>5036216228</td>
<td>Yes</td>
<td><a href="mailto:wyckoffd@oregonstate.edu">wyckoffd@oregonstate.edu</a></td>
<td>U.S.</td>
<td>Yes</td>
</tr>
<tr>
<td>ME Team Member</td>
<td>Brett Moffatt</td>
<td>5415219505</td>
<td>5415219505</td>
<td>Yes</td>
<td><a href="mailto:moffatbr@oregonstate.edu">moffatbr@oregonstate.edu</a></td>
<td>U.S.</td>
<td>Yes</td>
</tr>
<tr>
<td>ME Team Member</td>
<td>Sam Lundeen</td>
<td>5034375079</td>
<td>5034375079</td>
<td>Yes</td>
<td><a href="mailto:lundeens@oregonstate.edu">lundeens@oregonstate.edu</a></td>
<td>U.S.</td>
<td>Yes</td>
</tr>
<tr>
<td>ME Team Member</td>
<td>Subret Aryal</td>
<td>5039290371</td>
<td>5039290371</td>
<td>Yes</td>
<td><a href="mailto:aryals@oregonstate.edu">aryals@oregonstate.edu</a></td>
<td>U.S.</td>
<td>Yes</td>
</tr>
<tr>
<td>ME Team Member</td>
<td>Jan Finn</td>
<td>5412311132</td>
<td>5412311132</td>
<td>Yes</td>
<td><a href="mailto:finni@oregonstate.edu">finni@oregonstate.edu</a></td>
<td>U.S.</td>
<td>Yes</td>
</tr>
<tr>
<td>CS Team Member</td>
<td>Helena Bales</td>
<td>5034592253</td>
<td>5034592253</td>
<td>Yes</td>
<td><a href="mailto:balesh@oregonstate.edu">balesh@oregonstate.edu</a></td>
<td>U.S.</td>
<td>Yes</td>
</tr>
<tr>
<td>CS Team Member</td>
<td>Amber Horvath</td>
<td>5038845025</td>
<td>5038845025</td>
<td>Yes</td>
<td><a href="mailto:horvatha@oregonstate.edu">horvatha@oregonstate.edu</a></td>
<td>U.S.</td>
<td>Yes</td>
</tr>
<tr>
<td>CS Team Member</td>
<td>Michael Humphrey</td>
<td>5412234594</td>
<td>5412234594</td>
<td>Yes</td>
<td><a href="mailto:humphrmi@oregonstate.edu">humphrmi@oregonstate.edu</a></td>
<td>U.S.</td>
<td>Yes</td>
</tr>
<tr>
<td>ECE Team Member</td>
<td>Huy Nguyen</td>
<td>5038888372</td>
<td>5038888372</td>
<td>Yes</td>
<td><a href="mailto:nguyenh5@oregonstate.edu">nguyenh5@oregonstate.edu</a></td>
<td>Green Card</td>
<td>Yes</td>
</tr>
<tr>
<td>ECE Team Member</td>
<td>Jonathan Hardman</td>
<td>5038288739</td>
<td>5038288739</td>
<td>Yes</td>
<td><a href="mailto:jonhan4@gmail.com">jonhan4@gmail.com</a></td>
<td>U.S.</td>
<td>Yes</td>
</tr>
<tr>
<td>ECE Team Member</td>
<td>Cole Morgan</td>
<td>5035455723</td>
<td>5035455723</td>
<td>Yes</td>
<td><a href="mailto:Morgacol@oregonstate.edu">Morgacol@oregonstate.edu</a></td>
<td>U.S.</td>
<td>Yes</td>
</tr>
</tbody>
</table>
## PMP: Budget

<table>
<thead>
<tr>
<th>Sections</th>
<th>Sub-sections</th>
<th>SubTotals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robotics</td>
<td>Motors</td>
<td>$5,050.00</td>
</tr>
<tr>
<td></td>
<td>Materials</td>
<td>$100.00</td>
</tr>
<tr>
<td></td>
<td>Others</td>
<td>$1,199.94</td>
</tr>
<tr>
<td></td>
<td><strong>Purchased</strong></td>
<td>$1,300.00</td>
</tr>
<tr>
<td></td>
<td><strong>Materials</strong></td>
<td>$800.00</td>
</tr>
<tr>
<td></td>
<td><strong>Electronics</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PCB</td>
<td>$250.00</td>
</tr>
<tr>
<td></td>
<td>Manufacturing</td>
<td>$250.00</td>
</tr>
<tr>
<td></td>
<td>Components</td>
<td>$373.05</td>
</tr>
<tr>
<td></td>
<td>Connectors</td>
<td>$180.00</td>
</tr>
<tr>
<td></td>
<td>Microcontrols</td>
<td>$55.00</td>
</tr>
<tr>
<td></td>
<td>Sensor</td>
<td>$301.00</td>
</tr>
<tr>
<td><strong>Project Total</strong></td>
<td></td>
<td><strong>$9,858.99</strong></td>
</tr>
<tr>
<td>Travel/Hotel/Food</td>
<td></td>
<td>$15,000.00</td>
</tr>
<tr>
<td>Deposit</td>
<td></td>
<td>$14,000.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>$38,858.99</strong></td>
</tr>
</tbody>
</table>

**Speaker:** Michael Polander
PMP: Worries and Mitigations

• Motor Failure
  – Purchased upgraded motor windings
• Failure to Retract Payload
  – Positioned arm to come in at multiple angles
This mission provides an opportunity for proving the viability of flying a small arm to perform delicate on-orbit autonomous actions. This process could be extended to building structures or making repairs in a space environment. This project would additionally provide precedence for our university in pursuing more complex space missions.

- **Next steps for STR (Subsystem Testing Review)**
  - Finalize Vendor Details
  - Print Prototype Assembly
  - Manufacture and Purchase Assembly Parts

- **Questions:**
  - What is the flexibility in power budget if we need more than we estimate?