Spacial HEO Autonomous Detector & Evaluator

Test Readiness Review

Team
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Sponsor
The Aerospace Corporation

Advisor
Dr. Zachary Sunberg
Project Overview
Project Goal

- Increasing amount of Earth-orbiting objects
- Large SSA systems now have an overwhelming number of tracks
- Need inexpensive tracking solution to relieve large systems

SHADE Mission Statement
To provide an easily accessible, multi-night orbit tracker, specializing in the evaluation of highly elliptical orbits. SHADE will be a low-cost capable tracking system, able to withstand adverse weather conditions.
Critical Project Elements

- Power System
- Modularity
- Software

- Weather Detection
- Passive Protection
- Active Protection
Physical Block Diagram
### System

<table>
<thead>
<tr>
<th>System</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power (Level 3/3)</td>
<td>• Five nights of continuous operation in SOC</td>
</tr>
<tr>
<td></td>
<td>• Enters safe mode if power is lost</td>
</tr>
<tr>
<td>Modularity (Level 3/3)</td>
<td>• Each module weighs less than 35 lbs</td>
</tr>
<tr>
<td></td>
<td>• Minimal on-site system assembly</td>
</tr>
<tr>
<td>Environmental Protection (Level 3/3)</td>
<td>• Active protection triggered by sensors/remote override</td>
</tr>
<tr>
<td></td>
<td>• Protects hardware from light rain/snow/wind</td>
</tr>
<tr>
<td></td>
<td>• Updates system status to ground station</td>
</tr>
<tr>
<td>Scheduling (Level 2/3)</td>
<td>• Generates schedule based on imaging time, visibility, and FOV</td>
</tr>
<tr>
<td></td>
<td>• Adapt schedule for missed observations or human override</td>
</tr>
<tr>
<td></td>
<td>• Schedule up to 6 observations per hour</td>
</tr>
<tr>
<td>Tracking (Level 2/3)</td>
<td>• Track HEOs near apogee (GEO), and perigee (LEO)</td>
</tr>
<tr>
<td>Image Processing (Level 2/3)</td>
<td>• Accurately extract endpoints of varying streaks</td>
</tr>
<tr>
<td></td>
<td>• Identifies when an object is missed and notifies scheduler</td>
</tr>
<tr>
<td>Orbital Determination (Level 3/3)</td>
<td>• Complete accurate orbit determination using Batch filter</td>
</tr>
<tr>
<td></td>
<td>• Predict possible orbits for missing objects</td>
</tr>
</tbody>
</table>

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### Success for SHADE

**Project Overview**

- **Timeline**
- **Schedule**
- **Test Readiness**
- **Budget**

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**Budget**

- **Project Overview**
- **Timeline**
- **Schedule**
- **Test Readiness**
- **Budget**
Schedule
Full Spring Semester Schedule
Power System

**Timeline**

- **Feb '21**
  - Frame & Stand Manufacturing
  - Stand Setup Test
  - Heat Sink Assembly
  - Solar Cell Assembly
  - Segment Connection Tests
  - Panel/Battery Integration
  - Solar Charging Test
  - Solar Panel Thermal Test
  - LiFePO4 Battery Duration Test
  - Battery/Software Development
  - Low-Power Shutdown Test
  - Power/SHADE System Integration

- **Mar '21**
  - Solar Charging Test
  - Solar Panel Thermal Test

**Test Readiness**

- LiFePO4 Battery Duration Test 2/5

---Test described in detail---

**Budget**
Active Protection

Shell Manufacturing
Rail & Lid Installation
Thermal Test (Shell)
Camera/Mount Install Test
Structural Test
Motor Integration
Limit Switch Installation
Lid Actuation Test
Polycase Installation
Wiring & Power Distribution
Processor Integration
Active Protection System Test

Test described in detail
Full System V&V

SHADE System Final Tests

30 Min Deployment Test
One Night Deployment
Five Night Deployment
SHADE Full System V&V

--Test described in detail
Test Readiness
Planned Verification & Functional Tests

Full System Tests
- 30-Minute Transport & Assembly Test
- Single Night Deployment Test
- Multi-Night Deployment Test

Power Tests
- Battery Duration Test
- Solar Charging Test
- Thermal Solar Cell Test

Active Protection Tests
- Thermal Test
- Structural Test
- Lid Actuation Test

Weather Detection Tests
- Sensor Safe Mode Shutdown
- Low-Power Shutdown Test

Software Tests
- Orbit Propagation and Scheduling Test
- Week-Long Dynamic Scheduling Test
- Image Processing Test
- Timed Software Setup Test
Full System Tests
30-Minute Transport & Assembly Test

Purpose: Show that SHADE can be transported and deployed by a single operator in 30 minutes.

Requirement Satisfied: FR 7

Facilities: Protected outdoor space

Equipment: Full System, stopwatch, 2 team members

Testing Procedure:

1. Measure 100 ft from vehicle to field
2. Start timer and begin module transport
3. Begin module assembly
4. Conduct power-up sequence of the SHADE system
5. Equalize weather detection sensors
6. After sensor equilibrium, stop timer
7. Power-off and disassemble system modules for transport back to vehicle

FR 7: SHADE shall be deployed and recovered in 30 minutes by one operator.
Expected Results:
- A single operator is capable of assembling and deploying SHADE in 30 minutes.
- The initial Time Budget will be altered.

Risk Mitigation:
- Failure to transport, assemble & deploy the SHADE system in 30-minutes.
- Directly related to FR 7

Model Validated:

Test Readiness System Power Modularity Software
Single Night Deployment Test

**Purpose:** Verify that the system is functioning properly for a single night, prior to a multi-night deployment attempt.

**Requirements Satisfied:** FR 1, 3, 4, 5, 6

**Facilities:** Protected outdoor space

**Equipment:** Full System

**Testing Procedure:**
1. At dusk, SHADE will be deployed in a location with a clear view of the sky.
2. 12 hours later, the operator will return to the deployment site and disassemble SHADE.

*Procedure follows CONOPs, except for 30-minute deployment restriction.*

**Expected Results:**
- Scheduler determines accurate viewing windows
- Image processing system determines accurate streak endpoints
- Accurate updated TLE list
- Weather detection adequately protects the system
- Battery can endure a full night’s deployment
- **Note: this assessment does not test the functionality of the solar panels.**
Risk Mitigation:
- Single Night Deployment failure caused by components other than the solar panels

Models Validated:
- Battery can endure a full night’s deployment
- Orbit propagation and determination
## Multi-Night Deployment Test

### Purpose:
Following a single night deployment attempt, a multi-night deployment test will verify the functionality of solar panels and ability to schedule multiple night observation windows.

### Requirements Satisfied:
FR 1-8

### Facilities:
Protected outdoor space

### Equipment:
Full System

### Testing Procedure:
1. At dusk, SHADE will be assembled in a location with a clear view of the sky.
2. An operator will deploy the system and depart.
3. 36 hours later, the operator will return to the deployment site and disassemble SHADE.

### Expected Results:
- Single night deployment results achieved
- Weather detection adequately protects the system
- Solar panels are able to charge battery for the following night
Multi-Night Deployment Test (cont.)

Risk Mitigation:
- Multi-Night Deployment failure caused by components such as the solar panels

Models Validated:
- Solar Panels can charge the battery for full night of deployment
- Weather Detection Safe Mode trigger logic
Power Tests
Purpose: Testing the expected duration of the battery when subjected to full current draw

Requirements Satisfied: FR 8

Equipment: Cycle tester, VictronConnect

Facilities: Senior project space

Testing Procedure:

- Battery shall start with a full charge
- Cycle tester draws 5 A over an 11-hour period, ultimately drawing 55 Ah
- Monitoring the voltage of the battery over the course of the test allows analysis of the discharge curve
- Similarly, monitoring the rate of change of the capacity will characterise the transient performance of the battery over the course of an observation window
Battery Duration Test (cont.)

Expected Results:

- ≥ 30% of the battery capacity should remain following the test
- Variation of the voltage should match the discharge curve provided

Risk Mitigation:

- Empirical knowledge of the discharge curve allows for better mission planning and scheduling
- Increased confidence that the battery will last a full 12 hour observation period (DR 2.2)

Models Validated:

- Battery discharge model
Solar Charging Test

Purpose: To assess that the solar panels have been manufactured correctly and are functioning properly.

Requirements Satisfied: FR 2, 4, 7, 8

Equipment: Multimeter, VictronConnect

Facilities: Outside

Testing Procedure:
- The battery before deployment will be at a battery capacity 80%.
- The solar panels shall be deployed on a clear, sunny day between 1130 to 1530.
- Utilize Multimeter and VictronConnect to record power generation and battery voltage throughout deployment.
Solar Charging Test (cont.)

Expected Results:
- Power generation and open-circuit voltage would closely match between the theoretical model and the test data
- Solar Cells will not short

Risk Mitigation:
- Continual power source
- Able to perform on days without clouds (Risk ID SOC)
- Solar cells do not contact the backplate (short out)

Models Validated:
- Solar charging model
**Testing Procedure:**

1. Record open circuit voltage of the test pieces prior to the test
2. Record ambient temperature and solar cell temperature at 30 min intervals
   a. Use IR camera to capture heat sink temperatures, solar cell face temperatures
3. Record open circuit voltage at the end of the test
4. Build SolidWorks model using testing day’s data to compare to the empirical data
**Expected Results:**
- Solar segments with Heatsinks are observed to be at a lower temperature compared to those without heat sinks
- IR camera temperature contours match similarly with SolidWorks model

**Risk Mitigation:**
- Failure to fully recharge battery after a full night’s deployment
  - Solar charging dependent on solar cell temperature

**Models Validated:**
- SolidWorks Thermal Model
Active Protection Tests
Lid Actuation Test

Purpose: To verify the operation of the roof motor and gear system of the active protection box.

Requirements Satisfied: FR 3

Equipment: Active protection box, UDOO, Motor controller & roof motor

Risks Mitigated: Timely roof actuation protects against quickly developing precipitation (Risk ID RCR)

Testing Procedure:
- Observe whether or not lid glides smoothly on slides
- Observe whether or not the lid is able to open and close completely
- Verify that the lid can open/close in 10 seconds. (success criteria imposed by WRAITH)

Motor Specification Model:
\[ \Sigma F_x = m_a \]
\[ F_{Friction} = N \mu_{static} \]
\[ F_{Friction} = N \mu \]
\[ a = \alpha R \]
\[ T = I \alpha \]
\[ T_{required} = 146 \text{ [oz in]} \]

Gear Rate Model:
- 24 Teeth/Revolution
- 5 Teeth/Inch
- 24 Inches of Travel
- 10 Second Close: 30 [RPM]

Test Readiness | System | Power | Modularity | Software
--- | --- | --- | --- | ---
Expected Results:
- The lid will open/close in 10 s
- The lid will open/close completely

Initial Testing (WRAITH)
- 125 [oz in] motor actuated roof at 1 [in/sec] reliably
Testing Procedure:

1. Set up assembled active protection enclosure in sunny area with open roof.
2. Wait 1 hour.
3. Close the roof and record temperature, solar, and pressure parameters.
4. After 3 hours, repeat Step 3 and clean up.
5. Input initial temperature, pressure, and solar flux conditions into thermal model.

Purpose: To verify that the internal temperature of the active protection enclosure does not exceed or fall below the material and component temperature limits.

Requirements Satisfied: FR 3

Equipment: 2 ambient thermometers, 1 wall temperature sensor, 1 barometric sensor, 1 pyrheliometer, empty active protection enclosure.

Facilities: Sunny outdoor location.
Expected Results:
- The thermal model will provide similar wall and internal temperature results to the experimental thermal test after 3 hours.
- The thermal model will be validated and may then be used to predict other environments.

Risk Mitigation:
- Extreme (high/low) temperatures prohibiting component functionality (Risk ID DIH)

Models Validated:
- Solidworks active protection enclosure thermal model.
Weather Detection Test
Safe Mode Trigger Test

Purpose: To ensure each weather shutdown case triggers the appropriate signals, accurately telling the system to enter or exit safe mode.

Requirements Satisfied: FR 3

Equipment: Weather Detection Box, Battery, Computer

Expected Results: Sensor trigger response matches human observation

Risk Mitigation: Verifying proper trigger response (Risk IDs WDC & WFT)
Software Tests
Image Processing Test

**Purpose:** To assess the functionality of SHADE’s streak detection algorithms.

**Requirements Satisfied:** FR 5

**Equipment:** Computer

**Facilities:** N/A

**Testing Procedure:**

1. Create images with synthetic streaks and known RA-Dec coordinates of those streaks.
2. Upload images with synthetic streaks to the computer.
3. Run the image processing function to determine RA-Dec coordinates, recording the time taken.

*FR 5: SHADE shall image objects with apparent magnitude of less than 10.*
Expected Results:
- RA-Dec coordinates will coincide with known values from synthetic streaks.

Risk Mitigation:
- Image processor improperly identifying streaks
- Image processor identifying the wrong streak if there are multiple streaks. (Risk ID SLS)

Models Validated:
- Hough Transform for Image Processing
Scheduler Test

Purpose: To assess the functionality of SHADE’s scheduler process, including orbit propagation, and target prioritization.

Requirements Satisfied: FR 1

Equipment: Computer

Facilities: N/A

Testing Procedure:

- Define multiple TLEs, a location, and a time to test.
- Call the scheduler with the defined TLEs, location, and time.
- Record passes output by the scheduler.
- Run scheduler again for multiple night deployment

FR 1: SHADE shall schedule predicted locations and locations and visibility windows for objects in LEO, MEO, GEO and HEO orbits.
Scheduler Test (cont.)

Expected Results:

● Scheduler outputs a schedule for one night.

● Viewing opportunities align with SGP4 propagation.

● If this is not the first night, scheduler de-prioritizes objects that have already been imaged.

Risk Mitigation:

● Verifying ability to prioritise objects with less stable orbits. (Risk ID TOI)
## Updated Budget

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Estimated Cost</th>
<th>Budget</th>
<th>Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Protection</td>
<td>$434.90</td>
<td>$590.00</td>
<td>16%</td>
</tr>
<tr>
<td>Power</td>
<td>$2,023.70</td>
<td>$2,310.00</td>
<td>11%</td>
</tr>
<tr>
<td>Software</td>
<td>$313.98</td>
<td>$350.00</td>
<td>10%</td>
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<tr>
<td>Legacy</td>
<td>$94.00</td>
<td>$300.00</td>
<td>75%</td>
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<tr>
<td>Deposit</td>
<td>$200.00</td>
<td>$200.00</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$3,093.07</strong></td>
<td><strong>$3,750.00</strong></td>
<td><strong>17%</strong></td>
</tr>
</tbody>
</table>

### Timeline

- **Project Overview**
- **Schedule**
- **Test Readiness**
- **Budget**
Updated Budget

<table>
<thead>
<tr>
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<th>Budget</th>
</tr>
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<tbody>
<tr>
<td>Active Protection</td>
<td>$590.00</td>
</tr>
<tr>
<td>Power</td>
<td>$2,310.00</td>
</tr>
<tr>
<td>Software</td>
<td>$350.00</td>
</tr>
<tr>
<td>WRAITH Recovery</td>
<td>$300.00</td>
</tr>
<tr>
<td>Deposit</td>
<td>$200.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$3,750.00</strong></td>
</tr>
</tbody>
</table>

SHADE Budget Allocation

- Active Protection System: 16%
- Power: 62%
- Software: 9%
- WRAITH Recovery: 8%
- Deposit: 5%
<table>
<thead>
<tr>
<th>Item</th>
<th>Subsystem</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery</td>
<td>Power</td>
<td>Received</td>
</tr>
<tr>
<td>Battery Charger</td>
<td>Power</td>
<td>Received</td>
</tr>
<tr>
<td>Aluminum backplate sheets</td>
<td>Power</td>
<td>Received</td>
</tr>
<tr>
<td>Aluminum tubing for frame</td>
<td>Power</td>
<td>Received</td>
</tr>
<tr>
<td>Thermal Epoxy 1</td>
<td>Power</td>
<td>Received</td>
</tr>
<tr>
<td>Thermal Epoxy 2</td>
<td>Power</td>
<td>Received</td>
</tr>
<tr>
<td>Heat Sink</td>
<td>Power</td>
<td>Received</td>
</tr>
<tr>
<td>Charge Controller</td>
<td>Power</td>
<td>Received</td>
</tr>
<tr>
<td>Friction Hinge</td>
<td>Power</td>
<td>Received</td>
</tr>
<tr>
<td>Isolation Switch</td>
<td>Power</td>
<td>Pending</td>
</tr>
<tr>
<td>Thermal Reflective Paint</td>
<td>Active Protection</td>
<td>Received</td>
</tr>
<tr>
<td>Anaerobic Gasket</td>
<td>Active Protection</td>
<td>Received</td>
</tr>
<tr>
<td>Silicon Seal Strip</td>
<td>Active Protection</td>
<td>Received</td>
</tr>
<tr>
<td>Custom Corner Guards</td>
<td>Active Protection</td>
<td>Received</td>
</tr>
<tr>
<td>Corner Guards</td>
<td>Active Protection</td>
<td>Received</td>
</tr>
<tr>
<td>Polycarbonate Sheets</td>
<td>Active Protection</td>
<td>Received</td>
</tr>
<tr>
<td>Leveling Feet</td>
<td>Active Protection</td>
<td>Received</td>
</tr>
<tr>
<td>Box Handles</td>
<td>Active Protection</td>
<td>Pending</td>
</tr>
<tr>
<td>UDOO Processor</td>
<td>Software</td>
<td>Received</td>
</tr>
<tr>
<td>Particle Weatherboard</td>
<td>Software</td>
<td>Received</td>
</tr>
</tbody>
</table>
Budget: $3,750.00

Total Spent: $3,255.31

Purchased 95% of budgeted items, using 65% of funds
Questions?
Additional Slides
**Project History**

**2018/19**

**Ground-Based Hardware for Orbital Space Testing**

Foundation systems for autonomous imaging of circular LEO and MEO objects

Validated with ISS tracking tests

**2019/20**

**Weather Resistant Autonomous Imaging for Tracking HEOs**

Added HEO tracking capabilities & weather protection

Systems operate autonomously for 12 hours

Project cut short in March 2020 due to COVID-19 pandemic
## Levels of Success

<table>
<thead>
<tr>
<th>Category</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scheduling</strong></td>
<td>● Accept NORAD Satellite IDs</td>
<td>● Prioritize scheduling by image capture probability or human override</td>
<td>● Search for missing objects and send alert</td>
</tr>
<tr>
<td>[WRAITH]</td>
<td>● Sort based on time, visibility, field of view</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>● 6 objects per hour</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Image Processing</strong></td>
<td>● Extract endpoints of streaks</td>
<td>● Identifies when a target object is missed</td>
<td>● Camera maneuvers to find missing object</td>
</tr>
<tr>
<td>[WRAITH]</td>
<td>● Signal to noise ratio of 30 or less</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Orbital Determination</strong></td>
<td>● Accurate orbit determination using Batch filter</td>
<td>● Level 1</td>
<td>● Predict possible orbits for missing objects</td>
</tr>
<tr>
<td>[WRAITH]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pointing</strong></td>
<td>● Track HEO orbits near apogee (GEO)</td>
<td>● Track HEO orbits near perigee (LEO)</td>
<td>● Search for missing objects using possible locations</td>
</tr>
<tr>
<td>[WRAITH]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Category</td>
<td>Level 1</td>
<td>Level 2</td>
<td>Level 3</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Environmental Control</td>
<td>● Initiate protection from on-board sensors.</td>
<td>● Level 1</td>
<td>● Initiate protection in accordance with remote override.</td>
</tr>
<tr>
<td>[WRAITH]</td>
<td>● Protection from light rain/wind.</td>
<td></td>
<td>● Update weather &amp; system status to ground station</td>
</tr>
<tr>
<td>Modularity</td>
<td>● Module weight under 50 lbs</td>
<td>● Level 1</td>
<td>● Module weight under 35 lbs</td>
</tr>
<tr>
<td></td>
<td>● On-site system assembly is required</td>
<td></td>
<td>● Minimal required on-site system assembly</td>
</tr>
<tr>
<td>Power Efficiency</td>
<td>● Operates autonomously for two nights</td>
<td>● Operates autonomously for three nights</td>
<td>● Operates autonomously for five nights</td>
</tr>
</tbody>
</table>
Satisfaction of Functional Requirements
<table>
<thead>
<tr>
<th>Functional Requirement</th>
<th>Relevant Tests</th>
<th>Additional Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FR 1:</strong> SHADE shall schedule predicted locations and visibility windows for objects in LEO, MEO, GEO, and HEO orbits.</td>
<td><em>Single Night Deployment, Multi-Night Deployment, Orbit Propagation, Week-Long Scheduling</em></td>
<td>Accurately predicts locations and visibility windows for 90% of the requested objects in the Single and Multi-Night Deployment assessments</td>
</tr>
<tr>
<td><strong>FR 2:</strong> SHADE shall function autonomously in standard operating conditions with no human intervention for at least two nights.</td>
<td><em>Multi-Night Deployment, Week-Long Dynamic Scheduling</em></td>
<td>Completes 80% of its requested tracking</td>
</tr>
<tr>
<td><strong>FR 3:</strong> SHADE shall autonomously enter and exit a safe mode to protect itself from adverse weather.</td>
<td><em>Single Night Deployment, Multi-Night Deployment, Lid Actuation, Weather Detection Tests</em></td>
<td>-</td>
</tr>
<tr>
<td><strong>FR 4:</strong> SHADE shall autonomously point to and track objects in LEO, MEO, GEO, and HEO</td>
<td><em>Single Night Deployment, Multi-Night Deployment, Week-Long Dynamic Scheduling, Image Processing, Orbit Propagation</em></td>
<td>Accurately points to and tracks 80% of the requested objects in both the Single and Multi-Night Deployment assessments</td>
</tr>
<tr>
<td>Functional Requirement</td>
<td>Relevant Tests</td>
<td>Additional Satisfaction</td>
</tr>
<tr>
<td>------------------------</td>
<td>----------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td><strong>FR 5:</strong> SHADE shall image objects with apparent magnitude of less than 10.</td>
<td><em>Image Processing</em></td>
<td>-</td>
</tr>
<tr>
<td><strong>FR 6:</strong> SHADE shall create and save an orbit estimate for each object imaged within five minutes of the end of the associated visibility window.</td>
<td><em>Single Night Deployment, Multi-Night Deployment, Image Processing</em></td>
<td>Accurately creates and saves the orbit estimate for 90% of the objects within 5 minutes of the end of the associated visibility window in the Single and Multi-Night Deployment assessments</td>
</tr>
<tr>
<td><strong>FR 7:</strong> SHADE shall be deployed and recovered in 30 minutes by one operator.</td>
<td><em>30-Minute Transport &amp; Assembly</em></td>
<td>-</td>
</tr>
<tr>
<td><strong>FR 8:</strong> SHADE shall be capable of making observations on multiple nights during a single deployment.</td>
<td><em>Multi-Night Deployment</em></td>
<td>-</td>
</tr>
</tbody>
</table>
Spring Schedule - MSR to TRR
New Imaging System (Streak Detection)

Old System: Matched Filter
(Find where template matches image)
- Requires a “blank” image
- Can only detect single point
- Prone to false positives

New System: Hough Transform
(Detect features, i.e. lines, in image)
- Only one image required
- Can detect both endpoints
- Independent of orbit estimate
<table>
<thead>
<tr>
<th>Risk</th>
<th>Risk ID</th>
<th>Likelihood</th>
<th>Recoverability</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starlink Streak</td>
<td>SLS</td>
<td>5</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>Diurnal Heating</td>
<td>DIH</td>
<td>5</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>Target Orbit Instability</td>
<td>TOI</td>
<td>4</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Suboptimal Charge</td>
<td>SOC</td>
<td>5</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>Power Budget Accuracy</td>
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### Risks - Management

#### Management Risks - Pre Mitigation

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## Risks - External

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Preliminary Battery Discharge Rates

SHADE Warm Battery Discharge Test

\[ T = -10 \, ^\circ C \]

SHADE Cold Battery Discharge Test

\[ T = 21 \, ^\circ C \]