ODINSun
(Observing Dust Impacts Near the Sun)

Critical Design Review
CU Boulder
December 5th, 2013

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Mike Lotto
Chris Nie
## Agenda/Overview

<table>
<thead>
<tr>
<th>Topic</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Introduction</td>
<td>Kirstyn Johnson</td>
</tr>
<tr>
<td>Baseline Design</td>
<td>Ian Franklin</td>
</tr>
<tr>
<td>DIM Front End Electronics Design</td>
<td>Ian Franklin</td>
</tr>
<tr>
<td>Test Support Equipment Design</td>
<td>Lenny Komow</td>
</tr>
<tr>
<td>Thermal Environment Analysis</td>
<td>Kier Fortier</td>
</tr>
<tr>
<td>Mechanical Design</td>
<td>Chris Nie</td>
</tr>
<tr>
<td>Testing</td>
<td>Chris Nie</td>
</tr>
<tr>
<td>Project Logistics</td>
<td>Kirstyn Johnson</td>
</tr>
</tbody>
</table>
PROJECT INTRODUCTION
## Problem Statement

Design a protoflight dust impact monitor to characterize the dust environment within 0.041 to 0.25 AU from the surface of the Sun.

<table>
<thead>
<tr>
<th>0.FR.1</th>
<th>The DIM shall use impact ionization to measure micrometer and nanometer-sized dust particles charged from $1.6 \times 10^{-14}$ to $1.6 \times 10^{-7}$ Coulombs and output corresponding voltage signatures.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.FR.2</td>
<td>The DIM shall be designed to survive within environments expected along the orbital trajectory of SPP and operate within 0.25 AU of the Sun.</td>
</tr>
<tr>
<td>0.FR.3</td>
<td>The DIM shall be a protoflight instrument designed to the integration standards of Solar Probe Plus established by the ODINSun Interface Control Document.</td>
</tr>
</tbody>
</table>

*Protoflight: hardware that is designed to flight standards, but may not incorporate all the necessary materials or testing required to be flight-certified (also commonly referred to as flight-weight).*
Project Background

Benefits of Impact Monitor

- Provide first in-situ dust measurements within 0.25 AU of the Sun
- Quantify potential damage due to MMOD strikes during Solar Probe Plus mission
- Frequency of impacts expected for spacecraft structures
- Mitigate effects of dust impacts on spacecraft electric field antennae signals

Flight Heritage

- Munich Dust Counter on Muses-A
  - Has a similar design and utilizes dust impact detection
- HEOS 2
  - Dust impact monitor that went to 0.3 AU of the Sun

*MMOD: Micrometeoroid orbital debris*
Solar Probe Plus Mission

- NASA mission to characterize the solar environment within 0.25 AU of the Sun
- Environmental conditions
  - Temperature extremes of -170°C and +60°C
  - Expected Dust Environment
    - Expected Speed = 200 km/s
    - Smaller Particle Impacts Hourly
    - Larger Particle Impacts Daily
    - 100g occur at $8.3 \times 10^{-19} \text{ (m}^2\text{s)}^{-1}$
Concept of Operations

Impact Ionization Dust Detection Technique:

- **V** out
- Front-end Electronics Board
- EMI Protection Grid
- Signal GND
- Impact Plates (biased by +28 V)

**Note:** Dust size not to scale of instrument
Impact Ionization Dust Detection Technique:

- = Charged Particle

Impact Plates (biased by +28 V)

- Note: dust size not to scale of instrument
Concept of Operations

Impact Ionization Dust Detection Technique:

○ = Charged Particle

Impact Plates (biased by +28 V)

Front-end Electronics Board

Signal GND

EMI Protection Grid

Note: dust size not to scale of instrument

Impact Ionization Dust Detection Technique:

= Charged Particle

Impact Plates (biased by +28 V)

Front-end Electronics Board

Signal GND

EMI Protection Grid

Note: dust size not to scale of instrument

Relate $V_{\text{peak}}$ to experimental particle charge

Compare experimental particle charge to true values from testing facilities

$V_{\text{out}}$

$V_{\text{peak}}$

$t$

$V$

Overview

Baseline

Impact Plate

TSE

Thermal

Mechanical

Testing

Logistics and Summary

9
DESIGN OVERVIEW
Final Design Summary

Structural/Thermal
- Mass: 213.8 grams
- Volume: 2.5” x 5” x 13.1”
- Materials Used: aluminum, PEEK

Front End Electronics/Impact Plates
- Gold-plated copper pads as impact plates
- Cover 1.6x10^{-14} to 1.6x10^{-7} C with two plates
- Power Consumption = 33 mW

Test Support Equipment (not shown)
- Includes conditioning circuit and analyzed through Python code
- Noise mitigation through software filtering and signal averaging
Functional Block Diagram

Key:
- Physical Contact: →
- Analog Signal: →
- Digital Signal: →

1. **Incoming Dust Particles**
   - **Dust Impact Monitor**
     - Analog voltage signal from impact
     - Impact Plate
     - Convert Charge to Voltage
     - Invert and Amplify Signal

2. **Test Support Equipment**
   - Digitized voltage signature of impact
   - Condition Signal
     - A/D Conversion
     - Average Voltage Trigger
     - Relate Voltage Signal to Charge, Q
     - Velocity Estimate from Dust Models
     - \( Q = \frac{1}{2} m \beta v^2 \)
     - Mass of Dust Particle

3. **Key**
   - +28V Power Supply
   - ±6V Low Noise Power Supply
   - GSE Power Supply

4. **Thermal energy interaction with environment**
## Critical Project Elements

<table>
<thead>
<tr>
<th>Critical Element</th>
<th>Subsystem</th>
<th>Driving Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detect particles over full charge range</td>
<td>Impact Plate and Front End Electronics</td>
<td>The DIM shall measure dust particles charged from $1.6\times10^{-14}$ to $1.6\times10^{-7}$ C</td>
</tr>
<tr>
<td>Identify dust impacts</td>
<td>Test Support Equipment</td>
<td>TSE shall capture and interpret voltage outputs from the DIM to quantify particle mass</td>
</tr>
<tr>
<td>Survive thermal environment</td>
<td>Thermal</td>
<td>The DIM shall be capable of surviving in an external temperature environment of $-170$⁰C to $+60$⁰C</td>
</tr>
<tr>
<td>Mass budget</td>
<td>Mechanical/Structural</td>
<td>The mass of the DIM shall not exceed 150 grams. This does not include wire harnesses</td>
</tr>
</tbody>
</table>
DIM FRONT END
ELECTRONICS DESIGN
Driving Requirements

0.FR.1:
The DIM shall use impact ionization to measure micrometer and nanometer-sized dust particles charged from $1.6 \times 10^{-14}$ to $1.6 \times 10^{-7}$ Coulombs and output corresponding voltage signatures.

<table>
<thead>
<tr>
<th>1.DR.1</th>
<th>The DIM shall detect dust impacts upon two distinctly separate impact surfaces.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.DR.2</td>
<td>The DIM electronics shall output analog voltage signatures of corresponding dust particle impacts within a range of 0 – 3.1V.</td>
</tr>
<tr>
<td>1.DR.2.1</td>
<td>The RC circuit shall have a time constant of 1ms</td>
</tr>
<tr>
<td>3.DR.1.1</td>
<td>The DIM shall output data through four single-ended channels.</td>
</tr>
<tr>
<td>3.DR.1.2</td>
<td>The DIM shall use no more than 100mW of power during operations.</td>
</tr>
</tbody>
</table>
Board above contains components for 4 complete circuits (one per impact plate).
Charge Amplifier Design

1.DR.2.1  The RC circuit shall have a time constant of 1ms

Modeling the charge amplifier:

\[ V_{out, peak} = \frac{Q_{in}}{C} \]

Time Constant = \[ RC \]

\[ V_{out}(t) = \frac{Q_{in}}{C} e^{\frac{-t}{RC}} \]

Resistance = \[ R \]

Capacitance = \[ C \]

<table>
<thead>
<tr>
<th>Circuit</th>
<th>Charge Range</th>
<th>Capacitance</th>
<th>Time Constant</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>[ 1.6 \times 10^{-14} \text{ – } 4.96 \times 10^{-11} \text{ C} ]</td>
<td>16 pF</td>
<td>1 ms</td>
<td>68 MΩ</td>
</tr>
<tr>
<td>2</td>
<td>[ 4.96 \times 10^{-11} \text{ – } 1.54 \times 10^{-7} \text{ C} ]</td>
<td>52 nF</td>
<td>1 ms</td>
<td>20 kΩ</td>
</tr>
</tbody>
</table>

Key Design Drivers for Component Selection:

- Output voltage range for each plate: \[ 1 \text{mV} \text{ – } 3.1 \text{V} \]
- Op Amp input bias current must be small (\[ V_{shift} = I_b \times R_f \])
Charge Amplifier Output Voltage

- Charge amplifier acts as an integrator to measure charge from current.
- Upon impact, capacitor charges and then begins to discharge according to RC time constant.

\[ Q_{in} = I \, dt \quad Q = CV_0 \quad V_{\text{discharge}} = V_0 \left( e^{\frac{t}{RC}} \right) \]

- \( V_0 = \) voltage of fully charged capacitor
- \( Q = \) charge (C)
- \( C = \) capacitance (F)
- \( R = \) resistance (Ω)

\[ Q = CV_0 \]

\( V_0 \) is equal to peak voltage of spike.

Charge Deposited on Plate

Output Voltage vs. Time During Dust Impact

Overview
Baseline
Impact Plate
TSE
Thermal
Mechanical
Testing
Logistics and Summary
Prototype Testing

- Waveform generator: Square wave with 200mV_{pp}
- Produces voltage spike with peak voltage equal to ΔV, resulting in a 200mV peak
- Measured voltage spike is shown below:
  - Peak Voltage: 175mV
  - Time Constant: 1.01ms
3.DR.12 The DIM shall use no more than 100mW of power during operations.

For op amp **LT1014**:  
Supply voltage: \( V_S = 12 \text{ V} \)  
Supply current: \( I_S = 0.35 \text{ mA} \)

Total Power Consumed =  
\[ 0.35 \text{ mA} \times 12 \text{ V} \times 8 \text{ amplifiers} = 33.6 \text{ mW} \]

33.6mW < 100mW requirement

*Note: will use an appropriately sized resistor to dissipate remainder of 100 mW as heat source*
Summary and Future Work

Summary
• Charge amplifier capable of producing expected output signal for a simulated input

Future Work
• Decide between through hole and surface mount board design
• Order PCB and begin testing
• Continue thermal characterization of electrical components
TEST SUPPORT EQUIPMENT
Driving Requirements

0.FR.1:
The DIM shall use impact ionization to measure micrometer and nanometer-sized dust particles charged from $1.6 \times 10^{-14}$ to $1.6 \times 10^{-7}$ Coulombs and output corresponding voltage signatures.

1.DR.3
| Test Support Equipment (TSE) shall capture and interpret voltage outputs from the DIM to quantify particle mass. |

- System is designed to imitate SPP functionality
- TSE provides power to DIM via voltage regulated 9V batteries
The DAF outputs timing of impacts and is used to confirm timing of impacts.

Temperature is measured during thermal tests instead of DAF output.

- Anti-aliasing filter mitigates any high frequency noise.
- Level shifter moves signal into desired voltage range.
- DAQ converts analog signal to digital.
- Impact detection software identifies impacts from signal.
Signal Conditioning

- 60 kHz 2-pole filter mimics the anti-aliasing filter on SPP
- Level shifter shifts signal into the range of 0.08 V to 3.2 V
- Preprocessing circuit is assembled on a perfboard four times (one per impact plate)

![Anti-aliasing filter circuit](image1)

![Level shifter circuit](image2)
Data Acquisition System

Commercial DAQ
- Use NI USB-6351 DAQ: 5 channels at 150 kHz each
  - Four channels measure DIM
  - One channel receives either DAF output or temperature data

Software
- Use Python version 2.7 with libraries:
  - NI-DAQmx with Python Ctypes library (DAQ drivers)
  - wxPython (GUI)
  - Scipy (math, signal processing, plotting)
• Modified version of the Lunar Dust Experiment algorithm used previously by LASP
• The algorithm is currently being flown on a mission called LADEE
Noise Characterization: Frequency Analysis

- Lab noise will be characterized prior to each test, analyzed with a Fourier transform.
- A digital filter will be applied to the signal in software prior to impact detection algorithm.
- Filter characteristics will be modified at runtime during testing based on measured noise.
SPP ADC Noise

• SPP ADC shows a standard deviation of 3.35 counts due to noise

• Averaging signal over 8 samples results in a standard deviation of 1.46 counts due to noise

• Averaging will not prevent signal recognition; signal will rise for over 1 ms
Summary and Future Work

Summary

• TSE provides power to DIM and interprets voltage outputs from DIM
• TSE will locate dust impacts by mitigating noise through filtering and signal averaging, then measuring settling time

Future Work

• Determine the effects of time averaging on pulses from the DIM
• Implement algorithms and build circuit
THERMAL ENVIRONMENT ANALYSIS
2.DR.1 The DIM shall be capable of surviving in an external temperature environment of -170°C to +60°C.

Modeling Assumptions:
- Steady state 1D heat transfer
- Boom and SPP isothermal during steady state
- DIM is small compared to SPP
- Opaque surfaces
Thermal Circuit

Thermal Circuit Diagram:

- **Telec**
- **T_{SPP,i}**
- **T_{harness}**
- **T_{int}**
- **T_{ext}**
- **T_{back}**
- **T_{IP}**
- **T_{SPP,e}**
- **T_{Boom}**

Equation: **T_{DS} = 2.7K**

**Wire & Harnessing**

1. Conduction through wire insulation and radiation from wire insulation to deep space
2. Radiation between electronics and housing interior
3. Conduction through electronics housing
4. Conduction through PCB thickness and radiation to rear housing interior
5. Conduction through electrical connections in PCB
6. In-plane conduction through PCB material
7. Radiation from impact plates to deep space
8. Radiation from electronics housing to deep space
9. Radiation between electronics housing and SPP exterior with view factor
10. Conduction through wires between electronics and SPP interior
11. Radiation between impact plates and SPP exterior with view factor
12. Conduction through structural mounting to SPP boom

**Electronics & Housing**

**Impact Plates & Structure**
Thermal Circuit

Overview
Baseline
Impact Plate
TSE
Thermal
Mechanical
Testing
Logistics and Summary

Thermal Circuit Diagram:

- **T_{elec}**: Electrical Temperature
- **T_{SPP,i}**: Temperature of SPP Interior
- **T_{harness}**: Harness Temperature
- **T_{int}**: Internal Temperature
- **T_{ext}**: External Temperature
- **T_{SPP,e}**: Temperature of SPP Exterior
- **T_{IP}**: Temperature of Impact Plate
- **T_{Boom}**: Temperature of Boom

**T_{DS} = 2.7K**

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Thermal Circuit

Overview
Baseline
Impact Plate
TSE
Thermal
Mechanical
Testing
Logistics and Summary

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\[ T_{DS} = 2.7K \]

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Overview
Baseline
Impact Plate
TSE
Thermal
Mechanical
Testing
Logistics and Summary
Thermal Circuit

\[ T_{\text{elec}} \]

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Overview  
Baseline  
Impact Plate  
TSE  
Thermal  
Mechanical  
Testing  
Logistics and Summary
Operation and Survival

Slew period outside 0.76 AU

- Power off
- Up to 72 hr
- Slew angle up to 45°
- 150°C survival limit

Science period inside 0.25 AU

- Power on for 226 hr
- Zero solar flux
- -40°C operational limit

Transit periods

- Power off, zero solar flux
- -170°C steady state
Baseline Materials
- Untreated aluminum
- Gold impact plate

Thermal Circuit – Science

Science Mode Lower Limit (Op Amp Operational) = -40°C
Preliminary Electronics Temperature = -37°C (7.5% Margin)
Thermal Circuit – Slew

Slew Mode Upper Limit (Op Amp Survival) = 150°C
Preliminary Electronics Temperature = 137°C (8.6% Margin)
Time to Steady State

Order of magnitude transient time between steady states calculated using lumped methods

\[ Q_{in} = \frac{mC_p \Delta T}{\Delta t} \]
\[ \Delta t = \frac{mC_p \Delta T}{Q_{in}} \]

\[ \Delta t_{sci} \approx 10 \text{ hr} \]
4.5% of 226 hr
science mode

\[ \Delta t_{slew} \approx 1 \text{ hr} \]
1.5% of 72 hr
slews

DIM will reach steady state in both science and slew
Thermal Design Summary

Science Temperature
-28°C, 30% Margin (+22.5%)

Slew Temperature
130°C, 13% Margin (+4.4%)

Requirements for DIM Structure

<table>
<thead>
<tr>
<th>Impact Plate</th>
<th>Housing Exterior</th>
<th>Housing Interior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polished Gold</td>
<td>Clear Anodized Aluminum</td>
<td>Polished Aluminum</td>
</tr>
<tr>
<td>$\alpha = 0.12$</td>
<td>$\varepsilon = 0.03$</td>
<td>$\alpha = 0.14$</td>
</tr>
<tr>
<td>$\varepsilon = 0.03$</td>
<td>$\varepsilon = 0.06$</td>
<td>$\varepsilon = 0.84$</td>
</tr>
</tbody>
</table>
MECHANICAL DESIGN
### Driving Requirements

<table>
<thead>
<tr>
<th>2.DR.1</th>
<th>The DIM shall be capable of surviving in an external temperature environment of -170 °C to +60 °C.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.DR.2</td>
<td>The DIM shall be capable of mechanically interfacing with SPP.</td>
</tr>
<tr>
<td>3.DR.2.3</td>
<td>The mass of the DIM shall not exceed 150 grams. This does not include wire harnesses.</td>
</tr>
<tr>
<td>3.DR.2.5</td>
<td>No materials in the DIM shall include ferrites (iron, nickel, manganese, etc.), including impurities or coatings.</td>
</tr>
<tr>
<td>3.DR.2.6</td>
<td>The DIM shall meeting the following outgassing standards:</td>
</tr>
<tr>
<td></td>
<td>TML (Total Mass Loss) &lt; 1.0%</td>
</tr>
<tr>
<td></td>
<td>CVCM (Collected Volatile Condensable Materials) &lt; 0.1%</td>
</tr>
</tbody>
</table>
Integrated Dust Impact Monitor Design

Oblique View

13.1”

2.5”

Impact Plates (x 4)

Spacecraft Boom

Electronics Housing (x2)

0.24”

Mount (x4)

1”

1.619”

2.5”

Side View
# Instrument Mass Budget

<table>
<thead>
<tr>
<th>Detail</th>
<th>Material</th>
<th>Mass per individual component [g]</th>
<th>Quantity</th>
<th>Total Mass of Components [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electronics Board</strong></td>
<td>PCB, impact plates, connector</td>
<td>FR-4, gold, aluminum</td>
<td>59.5</td>
<td>1</td>
</tr>
<tr>
<td><strong>Housing</strong></td>
<td>--</td>
<td>Aluminum</td>
<td>104.0</td>
<td>1</td>
</tr>
<tr>
<td><strong>Grid</strong></td>
<td>0.001&quot; thick, 80% Open Area</td>
<td>Aluminum</td>
<td>0.9</td>
<td>2</td>
</tr>
<tr>
<td><strong>Spacers</strong></td>
<td>0.1&quot; Thickness</td>
<td>G10 glass-reinforced epoxy</td>
<td>4.8</td>
<td>4</td>
</tr>
<tr>
<td><strong>Mount</strong></td>
<td>--</td>
<td>PEEK (Polyether ether ketone)</td>
<td>5.4</td>
<td>2</td>
</tr>
<tr>
<td><strong>Fasteners</strong></td>
<td>--</td>
<td>Brass</td>
<td>~0.39</td>
<td>20</td>
</tr>
</tbody>
</table>

**Total Instrument Mass = 213.8 grams**

<table>
<thead>
<tr>
<th>Margin Relative to Levels of Success [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 3 (150 grams)</strong>: -63.8</td>
</tr>
<tr>
<td><strong>Level 2 (250 grams)</strong>: 36.2</td>
</tr>
<tr>
<td><strong>Level 1 (500 grams)</strong>: 286.2</td>
</tr>
</tbody>
</table>
Impact Plate Design

- **Thickness**: 50 μin
- **Surface Finish**: √32 μin
- **Surface Material**: Gold-plated copper
- **Quantity**: 4 plates
- **Area**: 50 cm² (equal)
Grid Design

- Attenuation of Radiation: 218dB
  - 1mm diameter holes
  - rejects waves larger than infrared
- Thickness: 0.001”
- >80% Open Area
- Grid Vendor: Thin Metal Parts

Example of Thin Metal Parts Grid
Attachment Mechanism Design

Collar Mounts

- **Inner Diameter**: 1.169"
- **Inner Diameter**: 2.5"
- **Thickness**: 0.24"
- **Material**: PEEK
- **Quantity**: 2 collar mounts

Force Concentration
Thermal Expansions: Boom and Collar Mount

\[ \frac{\Delta D}{D} = \alpha_L \Delta T \]

\( D = \) Diameter
\( \alpha_L = \) Coefficient of Thermal expansion (CTE)
\( \Delta T = \) Change in temperature relative to 68 \(^\circ\)F

<table>
<thead>
<tr>
<th>Material</th>
<th>CTE (in/in-(^\circ)F)</th>
<th>( \Delta D ) (in) with ( \Delta T = -459.67 ) (^\circ)F</th>
<th>( \Delta D ) (in) with ( \Delta T = 140.00 ) (^\circ)F</th>
</tr>
</thead>
<tbody>
<tr>
<td>M55J Carbon Fiber</td>
<td>(-1.98 \times 10^{-6})</td>
<td>(3.384 \times 10^{-4})</td>
<td>(-7.124 \times 10^{-5})</td>
</tr>
<tr>
<td>PEEK</td>
<td>(8.46 \times 10^{-4})</td>
<td>(-0.046)</td>
<td>0.010</td>
</tr>
</tbody>
</table>

**Conclusion:**
Expansion and contraction of boom and DIM collar mount do not exceed structural tolerances.
Summary and Future Work

Summary:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.DR.1  Temperature range of -170 °C to +60 °C</td>
<td>Thermal compatibility of materials pose low risk</td>
</tr>
<tr>
<td>3.DR.2  Interfacing with cylindrical structure</td>
<td>Thermal, electrical isolation and mechanical stability</td>
</tr>
<tr>
<td>3.DR.2.3 Maximum mass of <strong>250 grams</strong></td>
<td>Mass of design is &lt;214 g</td>
</tr>
</tbody>
</table>

Future Work:

- Impact plate sizing
- Drawing Set
- Assembly procedure
- Long-lead items order
- Clamp design optimization
TESTING
Laser Pulse Testing

- **Purpose:** verify capability for peak voltage recognition via ablated electrons
  - Pretest to operational testing in DAF
- **Location:** LASP
- **Tentative Test Date:** March 3, 2014
- **Procedure**
  - 2-3 day set up time to pump down vacuum chamber
  - Fire 8 ns-long laser pulse at impact plates
Dust Accelerator Facility Testing

- **Purpose:** validate impact detection and measured charge of accelerated particles
- **Location:** LASP
- **Tentative Test Date:** March 18, 2014
- **Procedure**
  - Dust particles accelerated towards vacuum chamber
  - Collect information continuously
  - Will obtain mass/velocity info from DAF, correlate with DIM collected data
DIM Functional Thermal Test

• **Purpose:** validate survivability of DIM through expected SPP orbit and operation

• **Location:** LASP

• **Tentative Test Date:** April 7, 2014

• **General Procedure**
  – 8 thermal cycles between -170°C and +60°C
  – Soak at temperature extremes, complete operational test with laser pulse

Thermal Hut

Overview

Baseline

Impact Plate

TSE

Thermal

Mechanical

Testing

Logistics and Summary

56
## Pre-testing Risk Matrix

<table>
<thead>
<tr>
<th>Probability</th>
<th>Consequence:</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Likely</td>
<td>Thermal Impact on Instrument Functionality</td>
<td>Very Likely</td>
</tr>
<tr>
<td>Likely</td>
<td>Low SNR</td>
<td>Unlikely</td>
</tr>
<tr>
<td>Possible</td>
<td>Electrical Component Damage due to Thermal Environment</td>
<td>Unlikely</td>
</tr>
<tr>
<td>Unlikely</td>
<td></td>
<td>Unlikely</td>
</tr>
<tr>
<td>Very Unlikely</td>
<td></td>
<td>Unlikely</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Severity</th>
<th>Acceptable</th>
<th>Tolerable</th>
<th>Intolerable</th>
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<tbody>
<tr>
<td>Negligible</td>
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<tr>
<td>Minor</td>
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<tr>
<td>Significant</td>
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<td></td>
<td></td>
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<tr>
<td>Severe</td>
<td></td>
<td></td>
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</tbody>
</table>
Risk Matrix: Test Mitigations

• Thermal Impact on Instrument Functionality
  – Determine sensitivity of electronics over entire temperature range

• Low SNR
  – Characterize noise prior to testing
  – Apply appropriate filters prior to running dust detection algorithm

• Electrical Component Damage
  – Test how electronics respond after being soaked in LN$_2$ for 5 minutes
  – Determine what the lowest temperature is before they are damaged
Post-testing Risk Matrix

<table>
<thead>
<tr>
<th>Probability</th>
<th>Very Likely</th>
<th>Likely</th>
<th>Possible</th>
<th>Unlikely</th>
<th>Very Unlikely</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Severity</strong></td>
<td>Instrument Functionality Affected by Thermal Environment</td>
<td>Low SNR</td>
<td>Electrical Component Damage due to Thermal Environment</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Consequence:</strong></td>
<td>Acceptable</td>
<td>Tolerable</td>
<td>Intolerable</td>
<td></td>
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</tbody>
</table>

Overview
Baseline
Impact Plate
TSE
Thermal
Mechanical
Testing
Logistics and Summary
PROJECT LOGISTICS
<table>
<thead>
<tr>
<th>Position</th>
<th>Individual</th>
</tr>
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<tbody>
<tr>
<td>Project Manager</td>
<td>Kirstyn Johnson</td>
</tr>
<tr>
<td>Subsystem Lead</td>
<td>Mike Lotto</td>
</tr>
<tr>
<td>Mechanical Design Lead</td>
<td>Chris Nie</td>
</tr>
<tr>
<td>Manufacturing Lead</td>
<td>Paul Guerrie</td>
</tr>
<tr>
<td>Thermal Lead</td>
<td>Kier Fortier</td>
</tr>
<tr>
<td>Electrical Lead</td>
<td>Ian Franklin</td>
</tr>
<tr>
<td>Test Support Equipment (TSE) Lead</td>
<td>Lenny Komow</td>
</tr>
<tr>
<td>Financial Lead</td>
<td>Lauren Hurst</td>
</tr>
<tr>
<td>Safety Lead</td>
<td>Sarah Kemp</td>
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</table>
Work Breakdown Structure: Spring Deliverables

**ODINSun**
- Spring Final Report
- Expected DIM Modifications for Flight Documentation

**Dust Impact Monitor**
- Final Revision of Functional Board
- DAF Test Plan
- DAF Test Results
- Laser Pulse Test Plan
- Laser Pulse Test Results
- System Level Thermal Test Plan of DIM
- Thermal Operational Test Results
- Front End Electronics Temperature Sensitivity Report
- Dust Impact Monitor Final Assembly (Insulation, collar mounts, electronics board, electronics housing, grids)
- DIM Integration Procedure
- DIM to SPP Interfaces Document
- Code to Calculate Particle Charge
- Code to Calculate Particle Mass
- Operating TSE Documentation
- DIM to SPP Interfaces Document
- Code to Monitor DIM Internal Temperature

**Test Support Equipment**
- Code to Calculate Particle Charge
- Code to Calculate Particle Mass
- Operating TSE Documentation
- DIM to SPP Interfaces Document
- Code to Monitor DIM Internal Temperature
- Code to Calculate Particle Charge
- Code to Calculate Particle Mass
- Operating TSE Documentation
- DIM to SPP Interfaces Document
- Code to Monitor DIM Internal Temperature

**Front End Electronics**
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**Mechanical**
- Dust Impact Monitor Final Assembly (Insulation, collar mounts, electronics board, electronics housing, grids)
- DIM Integration Procedure
- DIM to SPP Interfaces Document

**Software**
- Code to Calculate Particle Charge
- Code to Calculate Particle Mass
- Operating TSE Documentation
- DIM to SPP Interfaces Document
- Establishing Trigger Threshold Procedure and Results
- Code to Monitor DIM Internal Temperature

**Electrical**
- Code to Calculate Particle Charge
- Code to Calculate Particle Mass
- Operating TSE Documentation
- DIM to SPP Interfaces Document
- Establishing Trigger Threshold Procedure and Results
- Code to Monitor DIM Internal Temperature
- Code to Calculate Particle Charge
- Code to Calculate Particle Mass
- Operating TSE Documentation
- DIM to SPP Interfaces Document
- Establishing Trigger Threshold Procedure and Results
- Code to Monitor DIM Internal Temperature
- Code to Monitor DIM Internal Temperature

**Structural**
- Laser Pulse Testing Mounts
- DAF Testing Mounts
- Thermal vacuum chamber mounting plates
- TSE Housing

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- System Level Thermal Test Plan of DIM
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**Structural**
- Laser Pulse Testing Mounts
- DAF Testing Mounts
- Thermal vacuum chamber mounting plates
- TSE Housing
Post-CDR Schedule

<table>
<thead>
<tr>
<th>Name</th>
<th>Begin date</th>
<th>End date</th>
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<tbody>
<tr>
<td>First Order of Primary Hardware</td>
<td>12/16/13</td>
<td>1/10/14</td>
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<tr>
<td>Manufacturing Status Review</td>
<td>2/3/14</td>
<td>2/4/14</td>
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<tr>
<td>Test Readiness Review</td>
<td>2/28/14</td>
<td>3/1/14</td>
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<tr>
<td>3 Revisions of Front End Electronics</td>
<td>12/23/13</td>
<td>2/26/14</td>
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<tr>
<td>Development of LabVIEW Thermal Cycling Program</td>
<td>3/3/14</td>
<td>3/22/14</td>
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<tr>
<td>Manufacture DIM Housing</td>
<td>1/10/14</td>
<td>1/30/14</td>
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<tr>
<td>Manufacture collar mounts</td>
<td>1/30/14</td>
<td>2/8/14</td>
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<tr>
<td>Entire System Fit Check</td>
<td>2/10/14</td>
<td>2/14/14</td>
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<tr>
<td>Ship hardware out for anodization</td>
<td>2/14/14</td>
<td>2/21/14</td>
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<tr>
<td>Vacuum Bakeout of Structure</td>
<td>2/21/14</td>
<td>2/27/14</td>
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<tr>
<td>Hardware/Electrical Integration</td>
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<tr>
<td>Manufacture Test Mounts</td>
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<td>2/28/14</td>
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<tr>
<td>Dust Impact Detection Code</td>
<td>1/3/14</td>
<td>2/6/14</td>
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<tr>
<td>Build/Test TSE Signal Conditioning Board</td>
<td>1/6/14</td>
<td>1/31/14</td>
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<tr>
<td>Laser Pulse Test</td>
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<tr>
<td>DAF Test</td>
<td>3/17/14</td>
<td>3/22/14</td>
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<td>DIM Functional Thermal Test @ LASP</td>
<td>3/31/14</td>
<td>4/5/14</td>
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<td>Senior Design Symposium</td>
<td>4/14/14</td>
<td>4/15/14</td>
</tr>
<tr>
<td>Spring Final Review</td>
<td>4/21/14</td>
<td>4/22/14</td>
</tr>
</tbody>
</table>

= Thermal  = Structures  = Testing  = TSE  = Front End Electronics
Budget Breakdown

General Supplies
- Clean room supplies
- Testing supplies

Electrical (DIM)
- Components
- PCB iterations
- $800 coated PCB

Structural (DIM)
- Structural materials
- Fasteners/connectors
- Surface Coatings
- $2000 grid

Electrical and Software (TSE)
- Components
- Batteries
- $1500 DAQ

Test Equipment
- Mount materials for DAF, T-Vac

<table>
<thead>
<tr>
<th>Funding Source</th>
<th>Amount</th>
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<tbody>
<tr>
<td>CU Aerospace Department</td>
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<tr>
<td>UROP</td>
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<td>Engineering Excellence Fund</td>
<td>$1500</td>
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Total: $8000
Project Summary and Future Work

Summary
• Can measure charge range of $1.6 \times 10^{-14}$ to $1.6 \times 10^{-7}$ C
• Will be able to validate charge range through DAF testing
• Can maintain electronics in temperature range of -40°C to 150°C

Future Work
• Purchase long lead items
• Future thermal characterization of front end electronics
• Determine impact plate area relative sizing
• Begin developing test plans
Acknowledgements

Thanks to:

Dr. Zoltan Sternovsky
Dr. David Malaspina
Bret Lamprecht
Magnus Karlsson
Mark Kien

Dr. Jim Nabity
Trudy Schwartz
Matt Rhode
Dr. Scott Palo
Dr. Dale Lawrence &
PAB
References


Questions?
BACKUP SLIDES
IMPACT PLATE BACKUP SLIDES
PCB Design

- 13” x 2.4”
  - Better for thermal to be longer rather than taller
- Impact Plate total area per side: 100 cm²
  - Areas of impact plates are easily altered based on dust number density
- 4 layer board
  - Minimize electronics mounting area
  - Revisions can be ordered for $66
- Current design uses through hole
  - Thermal testing could allow for surface mount which would lead to a smaller board.
  - Smaller is lighter and consumes less power
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Altium Design
Simulated voltage spike from $1.6 \times 10^{-14}$ C impact on plate ~ 1 mV peak

Simulated voltage spike from $1.54 \times 10^{-7}$ C impact on plate ~ 3.1 V peak
Prototype Circuit
Op-Amp: LT1014

- Quad Precision op amp
- Low noise
- Low input bias current
- Low power consumption
- Rad-hard option available: RH1014M

Specs:
- Max supply voltage = $\pm 22V$
- Operating temp. range = -40 to 85 °C
- Survival temp. range = -65 to 150 °C
- Input Bias Current: $I_b = 15 \text{ nA}$
- Supply Current: $I_s = 0.35 \text{ mA (per amplifier)}$
- Input Voltage Noise: $e_n = 0.55 \text{ μV}_{p-p}$

Packages Available:
- 14-Pin DIP (Through Hole)
- 14-Pin SOIC (Surface Mount)
Grounding

Structure

Mesh

Electronics Board

SPP Signal Ground

Signal Ground

Signal Ground (Current Return)
Mesh Attenuation Calculation

- $a_s =$ mesh size (diameter of hole) [m]
- $r_w =$ radius of mesh (1/2 mesh thickness) [m]
- $\sigma =$ conductivity of metal [S/m]
- $SE =$ attenuation [dB]

\[ Z_o = \sqrt{\sigma / \epsilon_o} \]
\[ R_s = \frac{a_s}{r_w^2} \]

\[ SE_o(q) = 10 \log_{10} \left[ \frac{1}{2} \left( \frac{(2R_s / Z_o) \cos(q)}{(2R_s / Z_o) \cos(q) + 1} \right)^2 + \frac{1}{2} \left( \frac{(2R_s / Z_o)}{(2R_s / Z_o) + \cos(q)} \right)^2 \right] \]

Example:
- For 0.001mm thick aluminum mesh with 1mm diameter holes:
  - $SE_o =$ 218 dB of attenuation
TEST SUPPORT EQUIPMENT
BACKUP
Impact Discrimination Criteria:
- Area under signal
- Settling time
- Rise time

Detection Theory
- Trigger and impact detection algorithm must account for false signals
- Use during testing to determine trigger levels
THERMAL BACKUP
Based off of Op Amp specifications:
- During **science**, achieve an electronics temperature **greater than -40°C**
- During **slew**, achieve an electronics temperature **less than 150°C**

Start by selecting sample values, based off of PDR results and initial research:

**Impact Plates and Structure:**
- Gold Plate: $\epsilon = 0.03$, $\alpha = 0.2$
- Collar Mount: $k = 0.3$ W/mK
- PCB: $k = 0.3$, $0.9$, $\epsilon = 0.91$
- Traces and wires: $k = 401$ W/mK

**Electronics Housing:**
- Aluminum Housing: $k = 205$ W/mK
- Interior coating: $\epsilon = 0.15$
- Exterior coating: $\epsilon = 0.5$, $\alpha = 0.3$

**Other System Components:**
- Visible SPP Surfaces: $\epsilon = 0.84$, $\alpha = 0.14$
- Wire harness: $k = 0.25$ W/mK, $\epsilon = 0.03$, $\alpha = 0.19$
**Science Mode:**
- $T_{SPP,\text{ext}} = 0^\circ\text{C}$
- $T_{SPP,\text{int}} = 60^\circ\text{C}$
- $T_{\text{boom}} = -170^\circ\text{C}$
- $Q_{\text{dis}} = 100$ mW

**Example Material Properties:**
- Plates (Gold): $\varepsilon = 0.03$
- Housing (Al): $k = 205$ W/mK
- Interior coating: $\varepsilon = 0.15$
- Exterior coating: $\varepsilon = 0.5$
- Collar: $k = 0.3$ W/mK

**Steady State Electronics Temperature** = $-37^\circ\text{C}$
BACKUP: Thermal Circuit
– Slew

Slew Mode:
• $T_{\text{SPP,ext}} = 50^\circ\text{C}$
• $T_{\text{SPP,int}} = 60^\circ\text{C}$
• $T_{\text{boom}} = 60^\circ\text{C}$
• $Q_{\text{dis}} = 0\text{mW}$
• $G_{\text{solar}} = 2833\text{ W}$

Example Material Properties:
• Housing Exterior: $\alpha = 0.3$
• Plate (Gold): $\alpha = 0.2$

Steady State Electronics Temperature = 115°C
## BACKUP: Thermal Modeling Results

<table>
<thead>
<tr>
<th></th>
<th>Gold Impact Plate</th>
<th>Silver Impact Plate</th>
<th>Copper Impact Plate</th>
</tr>
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<tbody>
<tr>
<td>$\varepsilon_{\text{impactplate}}$</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>$\alpha_{\text{impactplate}}$</td>
<td>0.12</td>
<td>0.09</td>
<td>0.3</td>
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### Design Space

<table>
<thead>
<tr>
<th></th>
<th>Gold Impact Plate</th>
<th>Silver Impact Plate</th>
<th>Copper Impact Plate</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\varepsilon_{\text{interior}}$</td>
<td>0.05-0.12</td>
<td>0.12-0.18</td>
<td>0.12-0.18</td>
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<tr>
<td>$\varepsilon_{\text{exterior}}$</td>
<td>0.5-0.9</td>
<td>0.3-0.5</td>
<td>0.3-0.7</td>
</tr>
<tr>
<td>$\alpha_{\text{exterior}}$</td>
<td>&lt;0.3</td>
<td>&lt;0.3</td>
<td>&lt;0.3</td>
</tr>
</tbody>
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### Selected Material Properties:

- **Impact Plate**: Gold
- **Housing**: Aluminum, polished on interior and clear anodized on exterior

<table>
<thead>
<tr>
<th></th>
<th>Science Temp</th>
<th>Slew Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-28°C, 30% margin</td>
<td>130°C, 12.7% margin</td>
</tr>
</tbody>
</table>
BACKUP: Equations

\[ q_1 = \frac{k_{\text{har}}A_{\text{wire}}SA_{\text{har}}}{t_{\text{har}}}(T_{\text{ec}} - T_{\text{har}}) \]

\[ q_1 = \varepsilon_{\text{har}}\sigma A_{\text{wire}}SA(T_{\text{har}}^4 - T_{\text{DS}}^4) - G\cos(\theta)A_{\text{wire}}SA\varepsilon_{\text{har}} \]

\[ q_2 = \frac{\sigma(T_{\text{ec}}^4 - T_{\text{int}}^4)}{1 - \varepsilon_{\text{ec}}/A_{\text{ec}} + 1/F_{\text{12}}A_{\text{ec}} + 1 - \varepsilon_{\text{int}}/A_{\text{int}}} \]

\[ q_3 = \frac{k_{\text{housing}}A_{\text{housing}}}{t_{\text{housing}}}(T_{\text{int}} - T_{\text{ext}}) \]

\[ q_4 = \frac{k_{\text{PCB}}A_{\text{ec}}}{t_{\text{PCB}}}(T_{\text{ec}} - T_{\text{back}}) \]

\[ q_4 = \frac{\sigma(T_{\text{back}}^4 - T_{\text{int}}^4)}{1 - \varepsilon_{\text{back}}/A_{\text{ec}} + 1/F_{\text{12}}A_{\text{ec}} + 1 - \varepsilon_{\text{int}}/A_{\text{int}}} \]

\[ q_5 = \frac{k_{\text{cnx}}A_{\text{cnx}}}{L_{\text{cnx}}}(T_{\text{ec}} - T_{\text{IP}}) \]

\[ q_6 = \frac{k_{\text{PCB}}A_{\text{PCB}}}{L_{\text{PCB}}}(T_{\text{ec}} - T_{\text{IP}}) \]

\[ q_7 = \varepsilon_{\text{IP}}\sigma A_{\text{IP}}(T_{\text{IP}}^4 - T_{\text{DS}}^4) - G\cos(\theta)A_{\text{IP}}/2\alpha_{\text{IP}} \]

\[ q_8 = \varepsilon_{\text{ext}}\sigma A_{\text{housing}}(T_{\text{ext}}^4 - T_{\text{DS}}^4) - G\cos(\theta)A_{\text{housing}}/2\alpha_{\text{ext}} \]

\[ q_9 = \frac{\sigma(T_{\text{ext}}^4 - T_{\text{SPP}}^4)}{1 - \varepsilon_{\text{ext}}A_{\text{housing}} + 1/F_{\text{12}}A_{\text{housing}} + 1 - \varepsilon_{\text{SPP}}A_{\text{SPP}}} \]

\[ q_{10} = \frac{k_{\text{wire}}A_{\text{wire}}XS}{L_{\text{wire}}}(T_{\text{ec}} - T_{\text{SPP},i}) \]

\[ q_{11} = \frac{\sigma(T_{\text{IP}}^4 - T_{\text{SPP}}^4)}{1 - \varepsilon_{\text{IP}}A_{\text{IP}} + 1/F_{\text{12}}A_{\text{IP}} + 1 - \varepsilon_{\text{SPP}}A_{\text{SPP}}} \]

\[ q_{12} = \frac{k_{\text{mount}}A_{\text{mount}}}{L_{\text{mount}}}(T_{\text{IP}} - T_{\text{Boom}}) \]

\[ q_{\text{tot}} = q_1 + q_2 + q_4 + q_5 + q_6 + q_{10} \]

\[ q_4 + q_2 = q_3 \]

\[ q_8 + q_9 = q_3 \]

\[ q_5 + q_6 = q_7 + q_{11} + q_{12} \]
Order of magnitude transient time between steady states calculated using lumped methods 

\[ \dot{Q} = \frac{mC_p \Delta T}{\Delta t} \]

Backup: Time to Steady State

Transient time ~10hr (4.5% of science time)

Transient time ~1hr (1.5% of slew time)
BACKUP: Degradation Sensitivity

Absorptivity Sensitivity - Slew

Emissivity Sensitivity - Slew

Emissivity Sensitivity - Science
BACKUP: Power vs. Temperature

Heater Input Analysis

- Power In (mW)
- Temperature (degC)

- Electronics Temp.
- Min. Operational Temp.
## Thermal Requirements

### Requirements for DIM Structure

<table>
<thead>
<tr>
<th>Impact Plate</th>
<th>Housing Exterior</th>
<th>Housing Interior</th>
</tr>
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<tbody>
<tr>
<td>Polished Gold</td>
<td>Clear Anodized Aluminum</td>
<td>Polished Aluminum</td>
</tr>
<tr>
<td>( \alpha = 0.12 )</td>
<td>( \varepsilon = 0.06 )</td>
<td>( \alpha = 0.14 )</td>
</tr>
<tr>
<td>( \varepsilon = 0.03 )</td>
<td></td>
<td>( \varepsilon = 0.84 )</td>
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<table>
<thead>
<tr>
<th></th>
<th>Science Temp</th>
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<tbody>
<tr>
<td></td>
<td>-28°C, 30% margin</td>
<td>130°C, 13% margin</td>
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MECHANICAL BACKUP
SLIDES
## Materials Trade Study

<table>
<thead>
<tr>
<th></th>
<th>Mass</th>
<th>Cost</th>
<th>Thermal</th>
<th>Machinability</th>
<th>Total</th>
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<tbody>
<tr>
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<td>5</td>
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<td>Magnesium</td>
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<td>5</td>
<td>3</td>
<td>2</td>
<td>2.7</td>
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</table>

- Magnesium and Aluminum are the most feasible options for this project
- Aluminum weighs slightly more than magnesium but costs the least and is easy to machine
- Magnesium weighs the least and is also simple to work with but is more expensive
- Titanium and Zinc did not meet the mass and cost budget of this project
Thermal Expansion of Brass Fasteners and Aluminum Receptacles

\[
\frac{\Delta D}{D} = \alpha_L \Delta T
\]

- \(D\) = Diameter of Fastener or receptacle
- \(\alpha_L\) = Coefficient of Thermal expansion (CTE)
- \(\Delta T\) = Change in temperature relative to 68 °F

**Conclusion:** Tolerance between brass fasteners and aluminum receptacles must be ≥ TBD inches
Thermal Expansion of Housing
Normal to Impact Plates

L = Width of G10 Frame or Aluminum Housing
\( \alpha_L \) = Coefficient of Thermal expansion (CTE)
\( \Delta T \) = Change in temperature relative to 68 °F

<table>
<thead>
<tr>
<th>Component</th>
<th>CTE (in/in °F)</th>
<th>( \Delta L ) (in) with ( \Delta T = -459.67 ) °F</th>
<th>( \Delta L ) (in) with ( \Delta T = 140.00 ) °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>G10 (sum of both sides)</td>
<td>0.5 x 10^{-5}</td>
<td>-3.447 x 10^{-4}</td>
<td>7.258 x 10^{-5}</td>
</tr>
<tr>
<td>Aluminum Housing</td>
<td>12.3 x 10^{-6}</td>
<td>-0.00342</td>
<td>7.205 x 10^{-4}</td>
</tr>
</tbody>
</table>

**Maximum Expansion:** 0.000793 inches

**Maximum Contraction:** -0.00376 inches
Thermal Expansion of FR4 and Housing in WIDTH-axis

Where:

\[
\frac{\Delta L}{L} = \alpha_L \Delta T
\]

- \(L\) = Width of FR4 or Aluminum Housing
- \(\alpha_L\) = Coefficient of Thermal expansion (CTE)
- \(\Delta T\) = Change in temperature relative to 68 °F

<table>
<thead>
<tr>
<th>Component</th>
<th>CTE (in/in-°F)</th>
<th>(\Delta L) (in) with (\Delta T = -459.67) °F</th>
<th>(\Delta L) (in) with (\Delta T = 140.00) °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR4 (Half of Total Width)</td>
<td>6.11 x 10^{-6}</td>
<td>-0.00502</td>
<td>0.00106</td>
</tr>
<tr>
<td>Aluminum Housing</td>
<td>12.3 x 10^{-6}</td>
<td>-3.391 x 10^{-4}</td>
<td>7.140 x 10^{-5}</td>
</tr>
</tbody>
</table>

**Conclusion**: TBD
Thermal Expansion of FR4 and Housing in LONG-axis

\[ \frac{\Delta L}{L} = \alpha_L \Delta T \]

Where:
- \( L \) = Width of FR4 or Aluminum Housing
- \( \alpha_L \) = Coefficient of Thermal expansion (CTE)
- \( \Delta T \) = Change in temperature relative to 68 °F

<table>
<thead>
<tr>
<th>Component</th>
<th>CTE (in/in-°F)</th>
<th>( \Delta L ) (in) with ( \Delta T = -459.67 ) °F</th>
<th>( \Delta L ) (in) with ( \Delta T = 140.00 ) °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR4 (Half of Total Length)</td>
<td>( 6.11 \times 10^{-6} )</td>
<td>-0.0272</td>
<td>0.00572</td>
</tr>
<tr>
<td>Aluminum Housing</td>
<td>( 12.3 \times 10^{-6} )</td>
<td>-3.391 \times 10^{-4}</td>
<td>7.140 \times 10^{-5}</td>
</tr>
</tbody>
</table>

**Conclusion:** TBD
Conclusion:
Expansion and contraction of fasteners and housing do not exceed structural tolerances.

<table>
<thead>
<tr>
<th>Material</th>
<th>CTE (in/in(^\circ)F)</th>
<th>(\Delta D) (in) with (\Delta T = -459.67\ \circ F)</th>
<th>(\Delta D) (in) with (\Delta T = 140.00\ \circ F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fastener</td>
<td>(15 \times 10^{-6})</td>
<td>(-5.38 \times 10^{-4})</td>
<td>(1.13 \times 10^{-4})</td>
</tr>
<tr>
<td>Housing</td>
<td>(23.6 \times 10^{-6})</td>
<td>(-8.45 \times 10^{-4})</td>
<td>(1.78 \times 10^{-4})</td>
</tr>
</tbody>
</table>
Grounding
PROJECT SUMMARY
BACKUP SLIDES
## Purchasing Post-CDR

<table>
<thead>
<tr>
<th>Item</th>
<th>Subsystem</th>
<th>Lead Time</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connectors</td>
<td>Front End Electronics</td>
<td>4 weeks</td>
<td></td>
</tr>
<tr>
<td>Front End Electronics PCB</td>
<td>Front End Electronics</td>
<td>1 week</td>
<td></td>
</tr>
<tr>
<td>Electrical Components</td>
<td>Front End Electronics, Test Support Equipment</td>
<td>2 weeks</td>
<td></td>
</tr>
<tr>
<td>Mesh Grid</td>
<td>Structural</td>
<td>2 weeks</td>
<td>$2000</td>
</tr>
<tr>
<td>NI USB-6351</td>
<td>Test Support Equipment</td>
<td>2 weeks</td>
<td></td>
</tr>
</tbody>
</table>

These are items that have significant lead time and need to be purchased soon after receiving spending approval.
## Current Purchasing Status

<table>
<thead>
<tr>
<th>Item</th>
<th>Use</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid Nitrogen Tank</td>
<td>Electrical Component Survival Thermal Test</td>
<td>$104.94</td>
</tr>
<tr>
<td>General PCB</td>
<td>Electrical Component Survival Thermal Test</td>
<td>$43.00</td>
</tr>
<tr>
<td>Electrical Components</td>
<td>Breadboard of front end electronics</td>
<td>$62.61</td>
</tr>
<tr>
<td>Dunk Containers</td>
<td>Electrical Component Survival Thermal Test</td>
<td>$10.78</td>
</tr>
</tbody>
</table>

**Total Spent**  
221.33

**Fraction of Money Spent**  
27.7%
## Budget – General Summary

### Budget Summary

<table>
<thead>
<tr>
<th>Funding Sources</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Supplies</td>
<td>$1,277.78</td>
</tr>
<tr>
<td>Electrical (DIM)</td>
<td>$1,145.04</td>
</tr>
<tr>
<td>Structural (DIM)</td>
<td>$3,283.00</td>
</tr>
<tr>
<td>Electrical and Software (TSE)</td>
<td>$1,561.66</td>
</tr>
<tr>
<td>Hardware (TSE)</td>
<td>$290.65</td>
</tr>
<tr>
<td><strong>Margin</strong></td>
<td><strong>$441.87</strong></td>
</tr>
</tbody>
</table>

### Total Expected Expenses

| Total Expected Expenses | $7,558.13 |

### Margin Allocation

<table>
<thead>
<tr>
<th>Category</th>
<th>Percent Allocation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Supplies</td>
<td>0.30</td>
<td>$132.56</td>
</tr>
<tr>
<td>Electrical (DIM)</td>
<td>0.20</td>
<td>$88.37</td>
</tr>
<tr>
<td>Structural (DIM)</td>
<td>0.10</td>
<td>$44.19</td>
</tr>
<tr>
<td>Electrical and Software (TSE)</td>
<td>0.20</td>
<td>$88.37</td>
</tr>
<tr>
<td>Hardware (TSE)</td>
<td>0.20</td>
<td>$88.37</td>
</tr>
<tr>
<td><strong>Total Margin</strong></td>
<td><strong>1.00</strong></td>
<td><strong>$441.87</strong></td>
</tr>
</tbody>
</table>
# Budget – General Supplies

<table>
<thead>
<tr>
<th>Description</th>
<th>Vendor</th>
<th>Lead Time</th>
<th>Individual Cost</th>
<th>Quantity</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>160L Dewar of LN2</td>
<td>CU</td>
<td>n/a</td>
<td>$104.94</td>
<td>1</td>
<td>$105.00</td>
</tr>
<tr>
<td>160L Dewar of LN2</td>
<td>CU</td>
<td>n/a</td>
<td>$104.94</td>
<td>2</td>
<td>$210.00</td>
</tr>
<tr>
<td>Clean Room Gloves</td>
<td>CU - Chem Stores</td>
<td>n/a</td>
<td>$7.62</td>
<td>3</td>
<td>$22.86</td>
</tr>
<tr>
<td>Foil</td>
<td>CU - Chem Stores</td>
<td>n/a</td>
<td>$2.98</td>
<td>2</td>
<td>$5.96</td>
</tr>
<tr>
<td>Alcohol Wipes</td>
<td>CVS Pharmacy</td>
<td>n/a</td>
<td>$2.37</td>
<td>2</td>
<td>$4.74</td>
</tr>
<tr>
<td>Semester Final Report Printing</td>
<td>Staples</td>
<td>n/a</td>
<td>$100.00</td>
<td>2</td>
<td>$200.00</td>
</tr>
<tr>
<td>Cryo Apron</td>
<td>Amazon</td>
<td>1 week</td>
<td>$109.22</td>
<td>1</td>
<td>$109.22</td>
</tr>
<tr>
<td>Cryo Gloves</td>
<td>Amazon</td>
<td>1 week</td>
<td>$108.02</td>
<td>1</td>
<td>$108.02</td>
</tr>
<tr>
<td>Thermal vacuum chamber time</td>
<td></td>
<td></td>
<td>$500.00</td>
<td>1</td>
<td>$500.00</td>
</tr>
<tr>
<td>Paint cans for thermal dunk testing</td>
<td>McGuckin's</td>
<td>n/a</td>
<td>$5.99</td>
<td>2</td>
<td>$11.98</td>
</tr>
</tbody>
</table>

**GENERAL SUPPLIES TOTAL:** $1,277.78
<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Vendor</th>
<th>Lead Time</th>
<th>Individual Cost</th>
<th>Quantity</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTC6257CMS#PBF</td>
<td>Op Amp</td>
<td>DigiKey</td>
<td>n/a</td>
<td>$5.30</td>
<td>3</td>
<td>$15.90</td>
</tr>
<tr>
<td>LT1056CN8#PBF (Through Hole)</td>
<td>Op Amp</td>
<td>DigiKey</td>
<td>n/a</td>
<td>$3.82</td>
<td>3</td>
<td>$11.46</td>
</tr>
<tr>
<td>LT1056S8#PBF (Surface Mount)</td>
<td>Op Amp</td>
<td>DigiKey</td>
<td>n/a</td>
<td>$4.72</td>
<td>3</td>
<td>$14.16</td>
</tr>
<tr>
<td>VRG8000005605JAC00</td>
<td>62.5 MegaOhm Resistor (actual value 56 meg)</td>
<td>DigiKey</td>
<td>n/a</td>
<td>$1.26</td>
<td>3</td>
<td>$3.78</td>
</tr>
<tr>
<td>ERG-1SJ203</td>
<td>20 kOhm Resistor</td>
<td>DigiKey</td>
<td>n/a</td>
<td>$0.34</td>
<td>3</td>
<td>$1.02</td>
</tr>
<tr>
<td>FMP100JR-52-100K</td>
<td>100 kOhm Resistor (through hole?)</td>
<td>DigiKey</td>
<td>n/a</td>
<td>$0.14</td>
<td>10</td>
<td>$1.35</td>
</tr>
<tr>
<td>C317C160J5G5TA</td>
<td>16 pF Capacitor</td>
<td>DigiKey</td>
<td>n/a</td>
<td>$0.68</td>
<td>5</td>
<td>$3.40</td>
</tr>
<tr>
<td>BPC241645103</td>
<td>52nF Capacitor (actually 51 nF)</td>
<td>DigiKey</td>
<td>n/a</td>
<td>$1.10</td>
<td>5</td>
<td>$5.50</td>
</tr>
<tr>
<td>FK28X7R1C105K</td>
<td>1 uF Decoupling Capacitor</td>
<td>DigiKey</td>
<td>n/a</td>
<td>$0.22</td>
<td>10</td>
<td>$2.22</td>
</tr>
<tr>
<td>SHIPPONG</td>
<td>SHIPPONG</td>
<td>DigiKey</td>
<td>n/a</td>
<td>$0.24</td>
<td>10</td>
<td>$2.24</td>
</tr>
<tr>
<td>practice PCB</td>
<td>Advanced Circuits</td>
<td></td>
<td></td>
<td>$33.00</td>
<td>1</td>
<td>$33.00</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>$105.61</strong></td>
</tr>
</tbody>
</table>
## Budget – DIM Electrical (Post-CDR)

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Vendor</th>
<th>Lead Time</th>
<th>Individual Cost</th>
<th>Quantity</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTC6257CM</td>
<td>Op Amp</td>
<td>DigiKey</td>
<td></td>
<td>$5.30</td>
<td>3</td>
<td>$15.90</td>
</tr>
<tr>
<td>S#PBF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VR68000005</td>
<td>62.5 MegaOhm</td>
<td>DigiKey</td>
<td></td>
<td>$1.26</td>
<td>7</td>
<td>$8.82</td>
</tr>
<tr>
<td>605JAC00</td>
<td>Resistor (actual value 56 meg)</td>
<td>DigiKey</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FMP100JR-52-100K</td>
<td>100 kOhm Resistor</td>
<td>DigiKey</td>
<td></td>
<td>$0.10-$0.14</td>
<td>15</td>
<td>$2.10</td>
</tr>
<tr>
<td>ERG-1SJ203</td>
<td>20 kOhm Resistor</td>
<td>DigiKey</td>
<td></td>
<td>$0.34</td>
<td>7</td>
<td>$2.38</td>
</tr>
<tr>
<td>C317C160J5</td>
<td>16 pF cap</td>
<td>DigiKey</td>
<td></td>
<td>$0.68</td>
<td>5</td>
<td>$3.40</td>
</tr>
<tr>
<td>G5TA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BFC241645103</td>
<td>52nF Capacitor (actually 51 nF)</td>
<td>DigiKey</td>
<td></td>
<td>$1.10</td>
<td>5</td>
<td>$5.50</td>
</tr>
<tr>
<td>FK28X7R1C105K</td>
<td>1 uF Decoupling Capacitor</td>
<td>DigiKey</td>
<td></td>
<td>$0.22</td>
<td>15</td>
<td>$3.33</td>
</tr>
<tr>
<td>PCB Revs</td>
<td>PCB Revs</td>
<td>Advanced Circuits</td>
<td></td>
<td>$66.00</td>
<td>3</td>
<td>$198.00</td>
</tr>
<tr>
<td>Final PCB with desired plate coating</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$1,039.43</td>
</tr>
</tbody>
</table>
## Budget – DIM Structural (Post-CDR)

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Vendor</th>
<th>Lead Time</th>
<th>Individual Cost</th>
<th>Quantity</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesh Grid</td>
<td>large sheet of mesh grid</td>
<td>Thin Metal Parts</td>
<td></td>
<td>$2,000</td>
<td>1</td>
<td>$2,000</td>
</tr>
<tr>
<td>18&quot;x18&quot;x0.5&quot; Al 6061 Sheet</td>
<td></td>
<td>Online Metals</td>
<td></td>
<td>$140</td>
<td>1</td>
<td>$140</td>
</tr>
<tr>
<td>2-56Mg/al fasteners</td>
<td>Fasteners</td>
<td>not found yet</td>
<td></td>
<td>$2.50</td>
<td>50</td>
<td>$125.00</td>
</tr>
<tr>
<td>Micro-d 9 pin connectors</td>
<td></td>
<td></td>
<td></td>
<td>$52-$80</td>
<td>4</td>
<td>$320.00</td>
</tr>
<tr>
<td>Mechanical Coatings</td>
<td></td>
<td>The Metal Finishing Company</td>
<td></td>
<td>$100.00</td>
<td>3</td>
<td>$300.00</td>
</tr>
<tr>
<td>Anodization</td>
<td></td>
<td>S&amp;S Anodizing</td>
<td></td>
<td>$100.00</td>
<td>3</td>
<td>$300.00</td>
</tr>
<tr>
<td>Machining Tools, End Mills</td>
<td></td>
<td>McMaster-Carr</td>
<td></td>
<td>$12.00</td>
<td>4</td>
<td>$48.00</td>
</tr>
<tr>
<td>G10 Stock (if we are machining ourselves or are sending out to be machined)</td>
<td></td>
<td></td>
<td></td>
<td>$50.00</td>
<td>1</td>
<td>$50.00</td>
</tr>
<tr>
<td>G10 Machining Cost (may not need this if we are machining ourselves) · thermal and electrical isolator, various parts and sizes</td>
<td></td>
<td>not found yet</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**DIM STRUCTURAL TOTAL:** $3,283.00
# Budget – TSE

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Vendor</th>
<th>Lead Time</th>
<th>Individual Cost</th>
<th>Quantity</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTC1562IG-2#PBF</td>
<td>Anti-Aliasing Filter</td>
<td>DigiKey</td>
<td></td>
<td>$17.69</td>
<td>2</td>
<td>$35.38</td>
</tr>
<tr>
<td>NI USB 6351</td>
<td>DAQ</td>
<td>National Instruments</td>
<td></td>
<td>$1,437.60</td>
<td>1</td>
<td>$1,437.60</td>
</tr>
<tr>
<td>Duracell 9V Batteries</td>
<td>Batteries (low noise power supply) [many different vendors]</td>
<td>n/a</td>
<td></td>
<td>$11.99</td>
<td>4</td>
<td>$47.96</td>
</tr>
<tr>
<td></td>
<td>Linear Voltage Regulator for +6V source</td>
<td>Digikey</td>
<td></td>
<td>$1.00</td>
<td>1</td>
<td>$1.00</td>
</tr>
<tr>
<td></td>
<td>Linear Voltage Regulator for -6V source</td>
<td>Digikey</td>
<td></td>
<td>$1.00</td>
<td>1</td>
<td>$1.00</td>
</tr>
<tr>
<td></td>
<td>Linear Voltage Regulator for 28V source</td>
<td>Digikey</td>
<td></td>
<td>$5.00</td>
<td>1</td>
<td>$5.00</td>
</tr>
<tr>
<td>VD1042-ND</td>
<td>6.5 inch by 4.5 inch Perfboard</td>
<td>Digikey</td>
<td></td>
<td>$8.10</td>
<td>1</td>
<td>$8.10</td>
</tr>
<tr>
<td>LT1056CN8#PBF (Through Hole)</td>
<td>LT 1056 Through Hole Op Amp</td>
<td>DigiKey</td>
<td></td>
<td>$3.82</td>
<td>6</td>
<td>$22.92</td>
</tr>
<tr>
<td>FMP100JR-52-100K</td>
<td>100kOhm Resistor Through Hole</td>
<td>DigiKey</td>
<td></td>
<td>$0.14</td>
<td>20</td>
<td>$2.70</td>
</tr>
</tbody>
</table>

**TSE ELECTRICAL & SOFTWARE TOTAL:** $1,561.66
## Budget – TSE Hardware

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Vendor</th>
<th>Lead Time</th>
<th>Individual Cost</th>
<th>Quantity</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&quot;x12&quot;x24&quot;</td>
<td>Aluminium-6061 Tvac adapter plate</td>
<td>Online Metals</td>
<td>n/a</td>
<td>$223.18</td>
<td>1</td>
<td>$223.18</td>
</tr>
<tr>
<td>.063&quot;x12&quot;x48&quot;</td>
<td>Aluminium-6061 Thermal hut sheet metal</td>
<td>Online Metals</td>
<td>n/a</td>
<td>$23.94</td>
<td>1</td>
<td>$23.94</td>
</tr>
<tr>
<td></td>
<td>Fasteners Stainless 8-32, 1/2&quot;, package of 25</td>
<td>McMaster-Carr</td>
<td>n/a</td>
<td>$9.94</td>
<td>1</td>
<td>$9.94</td>
</tr>
<tr>
<td></td>
<td>Washers #8 Stainless 18-8 general purpose</td>
<td>McMaster-Carr</td>
<td>n/a</td>
<td>$2.00</td>
<td>1</td>
<td>$2.00</td>
</tr>
<tr>
<td>80/20</td>
<td>for DAF adaption, 1&quot; extrusion, 10 ft.</td>
<td>McMaster-Carr</td>
<td>n/a</td>
<td>$31.59</td>
<td>1</td>
<td>$31.59</td>
</tr>
</tbody>
</table>

**GENERAL SUPPLIES TOTAL:** $290.65
## Flight Risk Matrix

<table>
<thead>
<tr>
<th>Probability</th>
<th>Consequence:</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Likely</td>
<td>Very Likely</td>
<td>Negligible</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>Likely</td>
<td></td>
<td>Significant</td>
</tr>
<tr>
<td>Possible</td>
<td></td>
<td>Severe</td>
</tr>
<tr>
<td>Unlikely</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very Unlikely</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low SNR</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electrical Component Damage due to Thermal Environment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Large particle MMOD strikes DIM movement along boom</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Impact Plate Degradation</td>
<td></td>
</tr>
</tbody>
</table>

**Consequence:**
- Acceptable
- Tolerable
- Intolerable

**Severity:**
- Negligible
- Minor
- Moderate
- Significant
- Severe