Boulder Unmanned Sensor for Transport Events and Repositioner

Test Readiness Review

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Customer: Dr. Xu Wang, Dr. Zoltan Sternovsky
Advisor: Dr. Torin Clark
Overview
Dr. Wang’s research at LASP suggests that charged particles could be lifted by Coulomb force

- **Dust transport events**: micron-sized dust particles are charged by various sources in space and ejected from the surface of low-mass bodies

- Current instrument is too large for a space application in low-gravity

- **Data could be collected with a smaller instrument in a CubeSat form factor, for a potential mission to an asteroid**
Project Statement

- Dust BUSTER will miniaturize, manufacture, and test a Technology Readiness Level (TRL) 4 dust instrument to characterize dust transport events similar to those that occur on asteroids.

- To aid the instrument, the team will also design and test an Autonomous Repositioning System (ARS) to tilt a 6U CubeSat to a specified angle for dust collection.
Overall Mission ConOps

1. CubeSat launched from mother spacecraft.
2. CubeSat lands on a specified side on a small body.
3. CubeSat determines where the Sun is.
4. CubeSat tilts based on sun location: the instrument should not face the sun.
5. ARS determines which cover should be opened. The cover is opened upon a ground command so voltage data collection can begin. The cover on the opposite side should block solar wind.
6. Instrument collects dust particles. The software filters data and only stores dust particle data.
7. CubeSat sends raw particle data to the ground (Earth).
8. Data is analyzed: Charge, velocity, and mass of the particles are extracted from the data.
## Levels of Success

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<th>Level 2</th>
<th>Level 3</th>
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<td><strong>Instrument</strong></td>
<td>- 2U TRL 4 dust instrument</td>
<td>- Wire electrodes remain intact upon 10 m/s impact</td>
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<td></td>
<td>- Operates in vacuum chamber</td>
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<td>- Interfaces mechanically with CubeSat</td>
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<tr>
<td><strong>CubeSat/ ARS</strong></td>
<td>- Construct 6U CubeSat model</td>
<td>- Open loop autonomous tilt with 5° accuracy</td>
<td>- Closed loop tilt with 1° accuracy</td>
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<td></td>
<td>- Tilt CubeSat model up to 45 degrees on a flat surface</td>
<td>- Operates on sandy surface</td>
<td>- Instrument cover opens once under operator command</td>
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<td>- Determine which side of the CubeSat has the least sun</td>
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<tr>
<td><strong>Software</strong></td>
<td>- Detect dust via external trigger</td>
<td>- Self-triggering dust detection algorithm</td>
<td>- Determine uncertainty in mass, velocity, and charge</td>
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<td></td>
<td>- Send dust data over serial</td>
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<tr>
<td></td>
<td>- Post processing algorithm extracts mass, velocity, charge</td>
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Autonomous Repositioning System

FBD

CubeSat Model & Autonomous Repositioning System

Legend

- Power
- Digital Signal
- Analog Signal
- Physical

Component to design & build
Component to buy
Component provided

Operator Command: Door Cover Actuation

External PC
External Power Supply
Design Recap

- Dust Instrument
- Door Mechanism
- Tilting Mechanism
Design Recap - CS Model & Photodiodes

- Dust Instrument
- Door Mechanism
- Photodiode housings
- Instrument Door
- Tilting Mechanism

Dimensions:
- 36.6 cm
- 23.9 cm
- 11.6 cm
Design Recap - Photodiodes

- Photodiodes
- Door Mechanism
- Dust Instrument
- Tilting Mechanism
- Instrument Door
- Photodiode Board
- Photodiode Structure
- Aperture
- 1.35 cm
- 2.73 cm
- 0.13 cm
Design Recap - Door Mechanism

- Dust Instrument
- Door Mechanism
- Tilting Mechanism
- Rack & Pinion Systems
- Doors
- Closed Configuration
Design Recap - Tilting Mechanism

- Door Mechanism
- Dust Instrument
- Tilting Mechanism
- Lead Screw Motor
- Scissor Lift System
- Tilting Mechanism Extended
Design Recap - Dust Instrument

Dust Instrument

Door Mechanism

Tilting Mechanism

Wire Electrode Arrays

10.0 cm

CSA board

DFR

DFE

DTS

10.0 cm

20.0 cm
## Critical Project Elements

<table>
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<th>Critical Project Element</th>
<th>Relation to Testing</th>
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<td>Sun determination</td>
<td>Full sky accuracy, closed-loop autonomous tilt</td>
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<td>Tilting mechanism</td>
<td>Tilt actuation accuracy, closed-loop autonomous tilt</td>
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<td>Surviving Impact</td>
<td>Instrument Dust Trajectory Sensor (DTS) and wire electrode impact testing</td>
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<td>Real-time event detection</td>
<td>Analog electronics, DTS, electron shield, trigger algorithm, dust detection</td>
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Scheduling
ARS Test Schedule

### Completed
- Power checks
- Filter test
- Fit checks
- Photodiode PCB
- Motor driver test
- Cover calibration
- TRR
- Vector calibration
- Accelerometer test
- Teensy test
- Open loop tilt test
- Last Machining Day
- Sun sensing test
- Closed loop test
- Full ARS Test

### Left
- Components
- Calibration
- Full System

1 week behind schedule due to machining
Instrument Test Schedule

Completed

Left

Software is taking longer than expected

Critical Path

Vacuum Testing
Instrument Test Readiness
Analog Electronics: Charge Sensitive Amplifier

Verify our implementation of customer’s design for a charge sensitive amplifier, Req 5.1, 5.11, 5.12

Purpose: Measure each CSA’s amplification of a simulated dust event.

Facility: Electronics Lab
- Power supply (±5V & ±15V)
- Waveform generator
- Oscilloscope & probe
- ESD mat/straps
- Assembled CSA PCB

Measurement: voltage of the amplified signal (expected test gain = 100)
Analog Electronics: Charge Sensitive Amplifier

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- Assembled CSA PCB

Measurement: voltage of the amplified signal (expected test gain = 100)

![Graph showing amplification](image)

- **CSA #3 Output to 1 ms, 20 mV pulse (60 Hz noise removed)**
  - **2.07 V**
  - **20 mV**
Impact Testing

Verify that Wire Electrodes can withstand 10 m/s impact (Req 2.5.1)

Purpose: Drop a DTS at successively larger impact velocities to characterize failure (when wire electrode becomes free to move)

Facility: Idea Forge
- Lansmont 15D Shock Test Machine
- One DTS unit
- Accelerometer

Procedure:
- Mount DTS to drop test table
- Raise table up to desired height and drop
- Visually inspect wire electrodes for broken or freely moving wires
- Drop again at new height
Impact Testing

Verify that Wire Electrodes can withstand 10 m/s impact (Req 2.5.1)

Testing Set-up:
- Preliminary drops without DTS to determine drop height vs velocity relationship
- Wire electrodes installed as rigid bar (no slack) with no requirement for tension
- Analyzing for failure (wires free to move) at 3 locations after each test

Limitations:
- Only 1 DTS to test
- Material deformations are difficult to analyze
## Intro to facilities and data

<table>
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<tr>
<th>Location</th>
<th>IMPACT Lab (CU East Campus)</th>
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</table>
| **Equipment (Customer Provided)** | **Vacuum chamber (w/ pump)**  
 | | **Vacuum wall cable interfaces**  
 | | **Dust dropper**  
 | | **Free electron emitter**  
 | | **Power supplies (±5V, +3.4V, ±15V, ±5kV)**  
 | | **Data acquisition**  
 | | | ○ **8-channel voltage DAQ**  
 | | | ○ **Lab computer & software**  
 | | **Translation table**  
 |
| **Data Out** | **Analog voltages**  
 | | | ○ **DTS Stand-alone**  
 | | | ○ **Electron Shield**  
 | | **Voltage data file to calculate charge, mass, and velocity**  
 | | | ○ **MCU/Trigger Software**  
 | | | ○ **Full Instrument Test**  

- Dust Dropper
- Feed through ports
- Pump
- Translation Table Motor
DTS Stand-alone

Verify wire electrode and CSA correctly respond to dust event

Purpose: Confirm the wire electrode connections and CSA conversion from charge to voltage, and signal amplification

Facility: IMPACT no vacuum

Measure: Live analog voltage output from CSA board (8 wires at a time)

Success: Signal roughly matches expected shape and voltage magnitude (~2 V)

Sample Shape:

![Voltage Waveform](image)
MCU/Trigger software

Verify trigger threshold and MCU data processing

Purpose: Test the ability of the trigger to correctly identify dust events and MCU’s ability to process and send data over serial

Facility: IMPACT no vacuum
Output: CSA digital voltage over serial
Electron Shield

Purpose: Verify magnetic shield blocks electrons up to 100 eV of energy which would cause noise on the wire electrodes

Facility: IMPACT vacuum (for free electrons)

Procedure:
- Replace dust dropper with electron emitter
- Apply set voltage to emit electrons up to 100 eV of energy
- Measure response from CSA over test duration (1 min)

Measure: Digital Voltage
Success: Null Voltage (random noise)
Full Instrument Test

Verify that instrument detects dust particles that enter the instrument.
Req 2, 5, 6

**Purpose:** Detect a dust event and extract the charge, mass, and velocity of the particle.

**Facility:** IMPACT vacuum

**Measure:** Output digital voltage in a data file to post-processing software, calculate charge, mass and velocity distribution in 6 positions (~90 events total)

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Expected Range</th>
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<tr>
<td>Charge (Q)</td>
<td>1 - 160 fC</td>
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<tr>
<td>Mass (m)</td>
<td>50-150 µg</td>
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<tr>
<td>Velocity (v)</td>
<td>1 - 2 m/s</td>
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± 5.5V
± 15V
± 5kV
+ 3.4V
Characterization of Sun-sensing

Verify the system can find the sun to within 1° over the full sky. Requirements 3.21 and 3.22

Purpose: Characterize the accuracy of the photodiodes, covers, and algorithm across the sky.

Facility: Bobby’s Lab with overhead lights off

Measurements:

- Measured light source position
  - 5ft distance to source, know position to 0.5” for 0.5°
- CubeSat calculated sun vector
  - Based on photodiode measurements

Full sky characterization:

- 32 locations that use all photodiode combinations
Open Loop Tilt Testing

Verify the tilting mechanism can tilt the instrument up to $45^\circ$ in $1^\circ$ increments (+/- $0.5^\circ$ accuracy) - Requirements 4.12, 4.121

**Purpose:** Measure the tilt angle of the Cubesat relative to level ground in $1^\circ$ increments

**Facility:** Senior Project Depot

**Measurements:** Tilting angle of the CubeSat using accelerometer

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### Diagram

- **Ceiling Beam**
- **Pulley**
- **Counterweight**
- **Hole for Photodiode**
- **CubeSat**
- **Cable**
- **Eye bolt**
- **Washers**
- **Photodiode cover hole**
- **Nuts**

---

**+5 V power supply**

---

**Tilt angle**

---

**Legs Deployed**
Tilt Testing

Verify the tilting mechanism can tilt the instrument up to 45° in 1° increments (+/- 0.5° accuracy) - Requirements 4.12, 4.121

Angle measurements from test will be compared to our tilting model

- If within the allowable error, requirement is satisfied
- Accelerometer has an ¼ degree resolution with ¼ degree accuracy
Tilt Testing

Verify the tilting mechanism can tilt the instrument up to 45° in 1° increments (+/- 0.5° accuracy) - Requirements 4.12,4.121

Angle measurements from test will be compared to our tilting model

- If within the allowable error, requirement is satisfied
- Accelerometer has an ¼ degree resolution with ¼ degree accuracy
- Expected Values from Accelerometer
Integrated Tilting and Sun-sensing

Verify integration of tilting mechanism, door, and sun sensing for 1° accuracy and closed-loop tilting - Requirements 3 and 4

**Purpose:** Measure the tilt angle of the Cubesat as it responds to light locations

**Facility:** Senior Project Depot

**Measurements:**
- Tilting angle of the cubesat using accelerometer - compare to calculated ideal tilt based on actual light source position
Integrated Tilting and Sun-sensing

Verify integration of tilting mechanism, door, and sun sensing for 1° accuracy and closed-loop tilting - Requirements 3 and 4

Purpose: Measure the tilt angle of the Cubesat as it responds to light locations

Facility: Senior Project Depot

Measurements:

- Tilting angle of the cubesat using accelerometer - compare to calculated ideal tilt based on actual light source position
Budget
Cost Plan

- Total Cost: $2337.84 / $570.00
- Instrument Electronics: $865.47 / $200.00 / $266.37
- ARS Mechanisms: $423.56 / $50.00 / $118.39
- ARS Sun Sensing: $398.97 / $50.00 / $112.24
- Structures: $452.90 / $100.00 / $138.23
- Cleaning: $0.00 / $70.00 / $17.5
- Shipping: $197.54 / $100 / $25

Purchases to Date

Planned Purchases

Margin

Remaining Budget
Thank you!

Feedback?
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<td>Dust Cover</td>
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**Levels of Success**
- FBD ARS
- FBD Instrument

**Budget**
- Updated Cost Plan
- Backup slides
- Photodiode cover
- Photodiode cover
- Photodiode vector
- Locations
- Accelerometer
- Vacuum chamber
- Tilt testing
- Door testing
- Photodiode boards
- Instrument test
- Teensy
- Impact testing
- Impact testing
Photodiode Cover Calibration
Verify the photodiodes can measure the sun angle to within 0.5° over the 60° field of view. Requirements 3.21 and 3.22

Purpose: Provide a calibration for the photodiode output to sun angle
Facility: Bobby’s Lab
- Cubesat
- QB50 Turntable
- Light Source (bike light)
- 5V Power Supply

Measurements: Output voltage to oscilloscope

Procedure:
- Set up turntable and photodiode
- Turn 1° increments, measure voltage
Photodiode Cover Calibration

Verify the photodiodes can measure the sun angle to within 0.5° over the 60° field of view. Requirements 3.21 and 3.22

- Current comparison of model and true voltage as measured with the oscilloscope
  - Actual measurements will be done with microcontroller
- Random noise of ~0.1 V is higher than anticipated during design
- Mitigating with an active filter to remove noise
- All points will fall inside the allowable limits
Photodiode Vector Calibration

Verify the pointing of each individual photodiode. Requirements 3.21 and 3.22

Purpose: Provide a calibration for the pointing of each photodiode on the CubeSat

Facility: Bobby’s Lab
- Cubesat
- QB50 Turntable
  - 1 increments, 0.25” to within 0.005”
- Light Source (bike light)
- 5V Power Supply

Measurements: Output voltage to microcontroller, resulting sun angles
Sun Sensing Characterization

Locations
Accelerometer Testing

Verify that accelerometer can resolve less than 0.5 degree tilt angle

- Characterization of noise levels of digital output
- Machine Shop
  - ADXL345 Triple Axis Accelerometer
  - CNC
  - Accelerometer mount
- Procedure (this can also be a diagram)
  - Calibrate accelerometer
  - Take data at level (0 deg tilt) (10 s)
  - Move CNC known amount
  - Take data at tilt (10s)
  - Compare measure to computed
  - Repeat
Vacuum Chamber Preparations

- Cleaning
  - Alcohol/flux remover cleaning for PCBs
  - Acetone and ethanol cleaning in ultrasonic bath for machined components
  - Cleaned instrument stored in ESD bag for transport

- Proper Material Selection
  - Low outgassing materials: aluminum, PEEK, Delrin
  - Vented Bolts
Tilt Testing

Procedure

- Suspend pulley from roof support
- Attach Rope to Pulley
- Attach one end of rope to cubesat fixtures
- Attach other end to counterweight
- Begin Tilting
- Measure Tilting
- Repeat last 2 steps
Door Testing

Purpose: Ensure the Door Opens Correctly
Facility: Senior Project Depot
Measurements:
  ▪ Does the door protect this instrument
Procedure:
  ▪ Attach door to power supply and Teensy
  ▪ Activate door mechanism at level and tilting platform
Photodiodes Boards

Verify functionality of PCB and overall design

- Voltage relative to intensity of light
- Electronics lab
  - Power supply (5V)
  - Oscilloscope/multimeter

- Procedure
  - Connect PCB to power supply and measuring device
  - Turn on and check readout in ambient light
  - In a dark room, position light source 5ft away and check readout at different angles
Instrument Test

Test will must be done 90 times:

- 6 different translation table positions
- 3 different sized dust particles
- 5 recorded events for each particle size in each position

= 90 total events

These numbers are customer specified.
Teensy Shield Test (backup)

Verify functionality of PCB and filter design

- Fit check, verify all components are powered correctly and outputting information
- Electronics lab
  - Power supply (5V)
  - Oscilloscope
  - Multimeter
- Procedure
  - Fit check all COTS boards (do not solder on yet)
  - Connect to power supply and check proper power distribution
  - Connect photodiode and check output after filter
  - Solder on COTS boards one at a time and check functionality of each
Impact Testing Models

- Rigid Bar Statics Model
  - Wire’s fail at 4 N impact force
  - Unable to correlate impact velocity to impact force without impact time

- Solidworks Model
  - Proper Material Selection
  - 10 m/s impact results show stresses not exceeding failure stress
Impact Testing Model

Assumptions
- Entire DTS is bonded
- Landing on rigid surface
- Perfectly inelastic collision

Stainless steel 304 wire electrodes
- Ultimate Tensile Strength: 505 MPa

Solder Stoppers
- Length (~ 2.2 mm) designed to shear at 520 MPa normal stress
- Wire will fracture before solder joint shears off