Orbital Debris Redirection and Thermal Re-entry: D.O.T.T.S.(Debris Orbital Tumbler and Thermal Sensor)

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Abstract

Mission Statement: As participants in a global effort to prevent harmful repercussions associated with increasing space debris, our project mission is to design, implement and fly a sounding rocket payload that will collect the foundational data needed to develop passive, cost-effective methodology for de-orbiting small, fragmented space debris, using a platform of electrostatic repulsion and incorporating material properties of 3D printed components.

Objective: We have designed a sounding rocket payload which contains two experiments: 1. Implementation and use of a static electric field to meaningfully impact the trajectory of simulated space fragments.

How it works: The primary experiment uses a worm-drive mounted motorized rabbit fur covered apparatus to impart static charge on a polycarbonate plate. A linear sequence of timer events, will power a launcher to propel four small (6mm, 0.26 g) aluminum balls across the charged sheet.

A camera augmented with image processing code will record changes to particle trajectory with video over-plotting onto a grid system. Limited data will be sent back via telemetry to confirm functionality and image capture. This will provide a proof of concept for a space clean up method where electrostatic induction reduces the orbital velocity of space debris, resulting in a decaying orbit, where debris burns up in the atmosphere before reaching Earth..

Benefits: Space debris will continue to pose significant problems or failures to current and future space missions. Mitigation is imperative to ensure successful missions and to protect vital orbiting satellites.

Introduction

The aggregate of space debris orbiting the earth has grown exponentially over the past two decades; an alarming trend with potentially catastrophic impacts on global aerospace activity. In 1978, Donald J Kessler, a scientist at NASA, predicted that the finite area in LEO available to satellites coupled with the growing number of satellites would lead to an inevitable, self-sustaining cascade of collisions, which has far-reaching negative impacts on space exploration [1,2].

According to Holger Krag, head of the European Space Agency, Space Debris Office, only approximately 60 percent of missions follow the International guidelines for the removal of space debris from low-Earth orbit (LEO) within 25 years of mission completion [1].

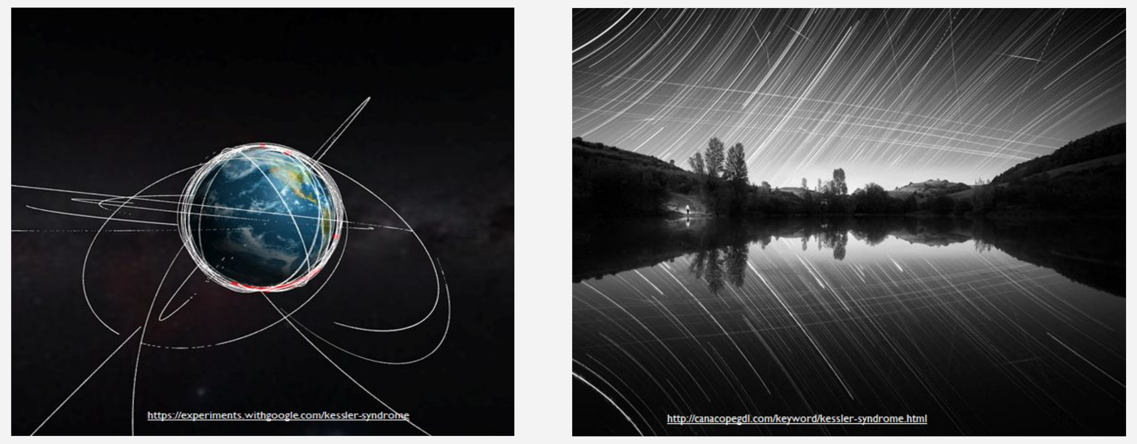


Figure 1. Artistic representations of the Kessler Effect.

The current debris load will require the removal of more than 100 objects from LEO at a minimum rate of five per year to "stop the proliferation of fragments resulting from in-orbit collisions and explosions," says Satomi Kawamoto, of the Japan Aerospace Exploration Agency (JAXA) [1].

Currently, the U.S. Space Surveillance Network tracks 1,200 intact, operational satellites and 18,000 objects larger than 4 inches (10 centimeters), but estimates about 750,000 "flying bullets" (~1 centimeter) and around 150 million fragments (~1 millimeter) are orbiting earth, which could seriously damage operational satellites [3].

As participants in a global effort to prevent these consequences, our project mission is to design, implement and fly a sounding rocket payload that collects the foundational data needed to develop passive, cost-effective methodology for de-orbiting small, fragmented space debris, using a platform of electrostatic repulsion

Materials

- ★ Raspberry Pi Zeros (2)
- ★ Arduino Pro Mini
- ★ Teensey
- ★ NoIR PI Cameras (2)
- ★ Small Servos (4)
- ★ Medium Servo
- ★ DC Motor
- ★ Temperature Probes (5)
- ★ PETG print filament
- ★ Polycarbonate sheet (4.75" X 5")
- ★ Rabbit Fur
- ★ Solid state relay (2)
- ★ LiPo Battery
- ★ Power converter
- ★ Customized PCB
- ★ 22 gauge wire
- ★ Aluminum beads (.25g, 5mm)
- ★ PVC
- ★ LED strip
- ★ Aluminum Base Dividers
- ★ Multimeter (Testing)
- ★ Vacuum Chamber (Testing)

Methodology

For this project, our team designed a sounding rocket payload (Figure 2) which contains two experiments. This poster features our primary experiment, which focuses on creating a static electric field to cause change in the trajectory of a simulated space debris fragments. The functional and innovative design of the payload was the result of our mechanical, electrical and software teams working in concert.

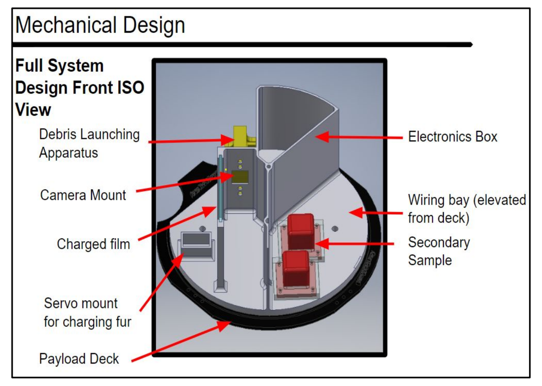


Figure 2. Mechanical payload design

Overview: The sequence begins when the rocket reaches apogee at 90,000ft, and is despun, producing microgravity conditions. Our control system signals the charging apparatus to apply a charge to the polycarbonate plate, and the debris launcher ejects four aluminum balls in series into the trajectory chamber. As the aluminum balls pass by the charged plate, two cameras measure any shift in the debris path caused by the generated static electric field. All four trajectories will be measured, including a control with no plate charge. All data will be sent via telemetry and stored in onboard SD cards.

Static Electric Generator & Charge Plate: A 1.5V motor spins a cylinder wrapped in rabbit fur against the polycarbonate plate, applying a negative charge via friction. This armature moves toward the plate when charging it and moves away when the debris is launched and the plate allowed to discharge.

Software and Electrical Systems:
The primary electrical considerations for the experiment were pin availability and power budget. Five servos run in sequence with a motor, while two cameras record and process video. Photo recognition software allows us to use a simplified matrix to track changes in the debris trajectories. The chain activates through timer events from the Wallops power lines. Telemetry will verify activation and send back rudimentary data. A functional block diagram was created to illustrate the electrical design and facilitate system integration. (Figure 3). Space was optimized by incorporating IC components directly into our custom PCB. (Figure 4).

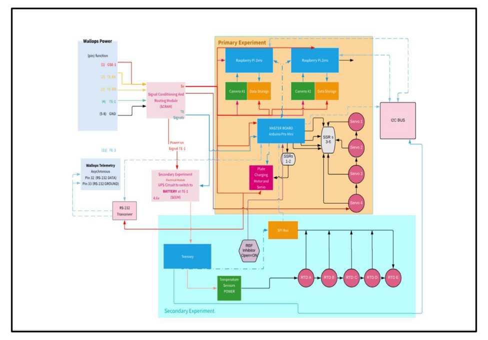


Figure 3: Electrical functional block diagram

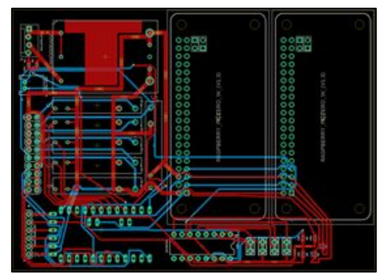


Figure 4. Autodesk Eagle schematics for primary PCBs.

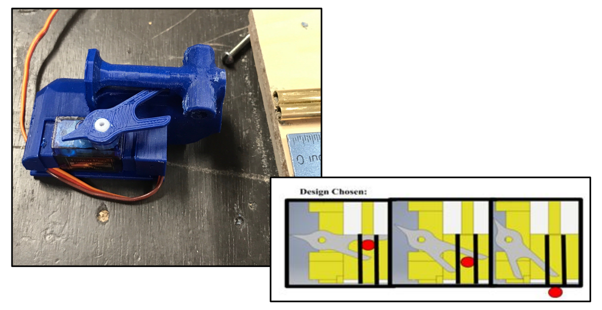


Figure 5. Mechanical launcher spoke design.

The Launcher: In the figure above, our testing launch tube is displayed. After several iterations of design, a simple spoke mechanism was found to be the most effective and energetically inexpensive way to hold the debris in place until testing, and to launch the debris with a controlled speed by adjusting the servo delay (Figure 5).

Results

NASA Wallops Flight Facility requires any projectile shot from the sounding rocket to have a velocity of less than 1 inch/sec. To achieve this goal a spoke was mounted to a servo which was programmed with a simple Arduino "delayed step" servo code. We then measured velocity to determine the appropriate delay.

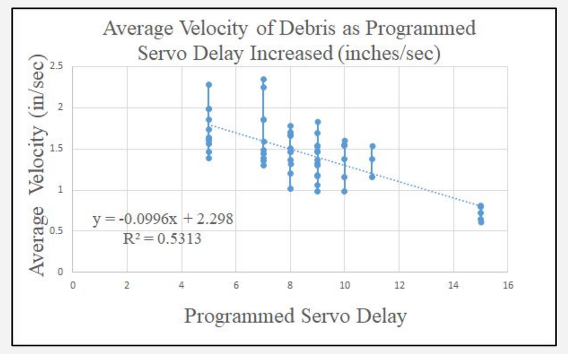


Figure 6. Mechanical servo code delays increased vs velocity of debris recorded.

Debris Launcher Velocity
Measurements were taken initially with slow motion video, and a meter stick along a track. Delays in the return of the servo arm were increased systematically and the data was graphed. Figure 6 shows a strong correlation between increased servo step delay and decreased debris velocity.

Servo Code Delays and Testing Calibrations
To increase trial speed and accuracy, a photogate was constructed and calibrated for the ideal sensitivity programmed from the Arduino. We designed a launcher chamber with apertures for LEDs and corresponding photoresistors. (Figure 9) The Arduino code was written to take time measurements between the first and second sensor activation. Thirty trials at each of the sensitivity settings were conducted and graphed.

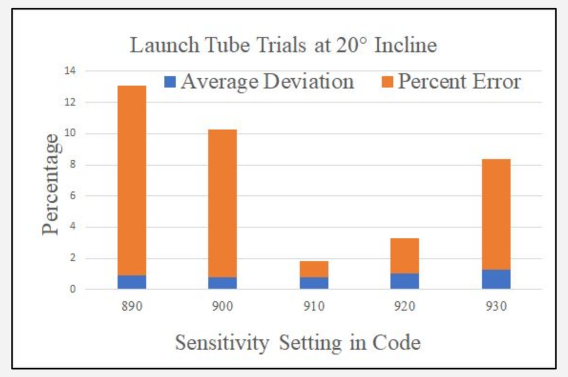


Figure 7. Average deviation and percent error within trial sets vs sensitivity settings.

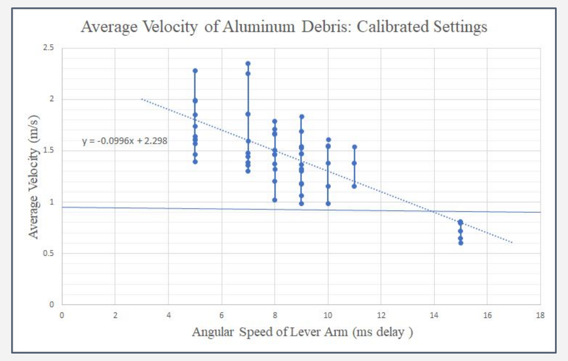
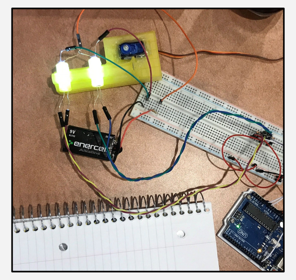


Figure 8 (above). Average velocity of aluminum debris using calibrated photogate settings.

Figure 9 (right). Photogate launch apparatus using LEDs and photo resistors.



In addition we calculated percent error from the projectile and compared the results (Figure 8). We selected the settings with the smallest average deviation and the smallest percent error, moving forward with the optimized results.

Photogate Trials and Optimized Sensitivity Settings
After determining the best settings to conduct our velocity trials, we tested the servo delay settings against velocity. After graphing the results, we chose the delay setting of 15ms, which gave us 100% of values well below the prescribed limit set by NASA.

Charged Plate Debris Attraction and Optimal Charger Positioning
When integrating the charging plate, charging apparatus, and debris samples, we first verified that the debris was attracted to the charged plate (Figure 10). Using a digital voltmeter, we tested the voltage on the plate with the charging apparatus at different locations to determine the the ideal positioning. We found the position farthest from the charging plate showed the highest voltage readings, and caused the highest attraction for the aluminum debris (Figure 11).

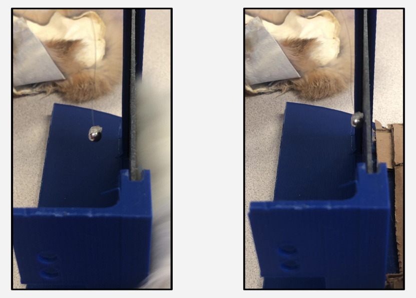


Figure 10. Debris attraction to plate before (left picture) and after (right [picture) charging apparatus applied.

Figure 11. Measured volts at various positions from the charged plate to determine optimal distance.

Conclusion

Key solutions to the space debris problem include the characterization of stable and unstable orbital regions where debris could be moved for either safe containment or induced orbital decay [5]. Technologies, such as electrostatic charge repulsion, can redirect debris without making contact, providing distinct advantages like increased operational distances and reduced risk of collision [6]. The mission of our primary experiment will demonstrate that a passive electrostatic charge can be used to influence the trajectory of small debris.

Recommendations

The concept of using static electric charge as a mechanism to de-orbit space debris offers exciting new prospects for Kessler Syndrome solutions. The implications are not fully understood or explored, but teams like ours are laying the groundwork for future studies. Already, our team is continuing the research done by the 2017-2018 Colorado Community College RockSAT-X Team: O.S.C.A.R. We have learned that the inductive properties of materials do not always perform as expected in low pressure environments, presenting us with several material challenges that were resolved with research and creative engineering strategies. Optimally, we would like to encourage future teams to test a broader variety of charged materials in vacuum conditions in order to better understand their electron behavior at low pressure, prior to design finalization.

Acknowledgments

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