Engineering Memorandum

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Title: Particulate Environment

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References:

[1]Cour-Palais, B. J., Crews, J. L., "Hypervelocity Impact and Upper-Stage Breakups," NASA Johnson Space Center, Houston, Texas., Rept, 1989.

Revision History:

Version	Date	Comments
1	3/9/22	Document creation
2	3/11/22	Reformatted paragraphs into bullet points

1.0 Table of Contents

2.0 Background

- **The rate of new spacecraft launched into Earth orbit continues to increase exponentially in recent years**
  - Degradation from the space environment and collisions with other objects means these objects are producing more and more orbital debris
  - Collisions with orbital debris will become ever more common in the coming years
- **We investigate the effects of high-velocity impacts on discarded spacecraft parts by simulating a collision with a non-empty fuel tank on orbit using methods similar to NASA's pressurized can experiments[1]**
  - Specifically, we study the debris field generated by such a collision with a ground test of an aluminum energy drink can filled with volatile gases

3.0 Objectives

- Objective 1: Characterize the formation and cataloging of space debris
- Objective 2: Simulate the explosion of an upper-stage rocket using a pressurized aluminum can
- Objective 3: Collect and analyze the debris generated by the pressurized aluminum can explosion

4.0 Summary

- **There were several difficulties with the pressurization of the can, hindering our ability to conduct the experiment**
  - We still found the explosion to be a reasonable simulation of that experienced by a real fuel tank
- **We found that the explosion tends to generate:**
  - A single piece of debris with at least half of the original mass and a very large surface area
  - A large number of much smaller pieces of debris
- **Further, we determined that there is a linear correlation between debris area and mass**
  - This leads to the generation of many small pieces of orbital debris as the more massive pieces are returned to Earth quickly due to the effects of drag

5.0 Nomenclature/Definitions

- A - cross-sectional area
- a_d - acceleration due to drag
- C_d - drag coefficient
- $\hat{i}$ - unit vector in the ram (velocity) direction
- L_c - characteristic body length
- m - mass
- V - velocity
- X, Y, Z - dimensions in order of magnitude
- ρ - atmospheric density

6.0 Methodology

- **Test vessel assembly:**
  - Remove energy drink liquid
  - Drill 1 large & 4 small holes in cap
  - Cut out Presta valve from inner tube
  - Cut 4 holes in rubber around valve
  - Insert valve and rubber into cap
  - Solder wires to igniter
  - Insert wires through rubber around valve and holes in cap; press tightly
  - Seal with generous amount of epoxy
  - Mark exterior with identifiable pattern
  - Apply a small bead of solder and heat shrink to the wires to prevent leaks through the wire casing

6.0 Methodology

- **Test vessel dimensions:**
  - Length:
    - 7.6" without cap
    - 8.4" including cap
  - Diameter: 2.814"
  - Volume: 47.3 - 52.2 in^3
  - Initial mass: 58.592 g

6.0 Methodology

- **Coordinate system**
  - Cartesian grid setup
  - 1 foot x 1 foot squares
  - Range from A1 to W18
  - Some grid spaces incomplete due to obstruction from objects and insufficient time to finish

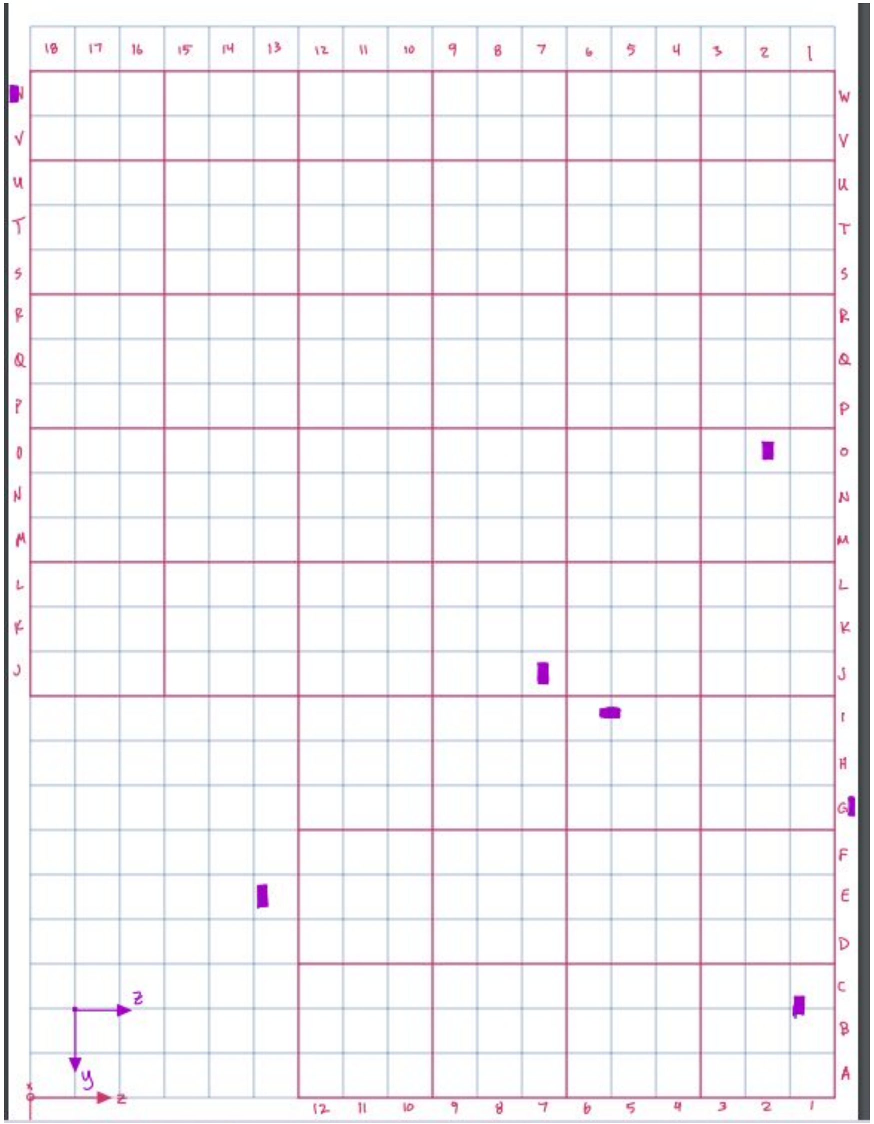
7.0 Assumptions / Limitations

- **Assumptions**
  - Aluminum can has similar proportions to a rocket body
  - All pieces of debris remained in the test area
  - Debris was perfectly reflected by the test area perimeter
- **Limitations**
  - Precision of the scale
  - Consideration of 3-D debris as a flat plate
  - Interference from objects within the test area
  - Accuracy of the grid layout

8.0 Results

- **Results**

  - The figure to the right shows the grid system we used to track and catalogue our pieces of debris
  - The purple rectangles represents where the pieces of debris landed



8.1 Characteristic Body Length & Cross Sectional Area

- Lc was calculated using Eqn 1 and A was calculated using Eqn 2

$$Lc = \tfrac{1}{3}(x + Y + Z) \qquad (1)$$

$$A = \tfrac{1}{2}(Lc^2 + 2Lc*Z) \qquad (2)$$

Piece	Mass (g)	Lc (in)	A (in^2)
1	1.8	2.171	2.3848
2	5.333	1.471	1.1010
3	34.5	3.1377	4.9633
4	11.5	1.6377	1.3623
5	0.598	1.2543	0.8029
6	0.021	0.271	0.0403
7	0.56	1.3043	0.8676
8	0.99	1.6377	1.3623

8.2 Acceleration due to Drag & Discussion on Mass

- The equation for acceleration due to drag is given in Eqn 3

$$a_d = -\tfrac{1}{2}(C_d*A/m)\rho V^2 \qquad (3)$$

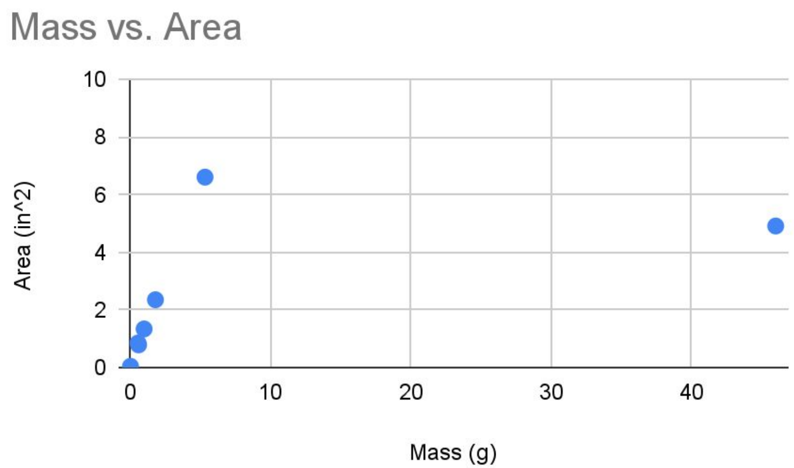
- Based on this equation the cross sectional area has a direct relationship to drag
  - The greater the cross sectional area is, the greater the drag

- The initial mass of the can was 58.982 g. The total mass accounted for in the collected material was 55.302 g
  - 93.76% of mass is accounted for in the collected material

- The largest piece of debris was 34.5 g. This one piece accounts for 58.49% of the mass

8.3 Cross Sectional Area and Mass

- The cans are all made of the same material, so there should be a clear correlation between mass and area
  - More area means more material which translates to more mass
- As shown from the chart, minus the erroneous outlier, there is a linear correlation between mass and cross sectional area
  - For debris lifetime, the more massive the debris typically the more cross sectional area there is
- A larger area leads to more drag being imparted onto it, meaning the piece of debris will deorbit more rapidly



8.4 Pressurizing the Can

- We do not know the pressure of the inner can in earlier tests
  - Fair to assume it is at or slightly above atmospheric pressure
- The ignition of a hydrogen-oxygen mixture produces water
- Water is far denser than the gas, so the overall pressure of the remaining gas is far lower than atmospheric for the same volume
  - This causes a compression of the can until the volume of the can allows for atmospheric pressure within the can
- This did not happen in tests that were pressurized significantly above atmospheric pressure
  - Despite the same drop in pressure occurring, the final pressure should still be above atmospheric
  - The violent ignition causes enough energy to rupture the can, the pressure difference propagates the initial eruption to explode the can

8.4 Pressurizing the Can

- When filling the cans with hydrogen, it is not a very safe assumption that simply venting and refilling the cans with hydrogen would mean that it is purely hydrogen
  - Hydrogen is significantly less dense than air, and knowing that prior to filling the can with hydrogen it was internally comprised of air, meaning that hydrogen would sit on top of the air
- The relief valve is positioned at the top of the can, venting the can would also mean venting the hydrogen first, along with the air.
  - This is not an efficient method of ensuring that pure hydrogen is present in the chamber
- A much better method would be to utilize a tube and a balloon:
  - Fill the balloon with pure hydrogen until it has a volume greater than that of the can
  - Affix the balloon to the tube and the other end of the tube to the one-way valve on the can
  - Ensure no leaks are present, then turn the system upside down so the balloon filled with helium is toward the ground
  - Since hydrogen is lighter than air, the hydrogen takes the place of the air in the can and completely fills it with pure hydrogen
  - Finally, to increase pressure further simply add hydrogen directly to the can as the contents of the can are already pure hydrogen

8.5 Improvements to Lab

- **Environmental Effects**
  - One environmental effect on this experiment was wind
    - The can resisted staying upright because the weather was extremely windy
    - The can had to be refilled each time it was tipped over
    - The wind may have pushed pieces of debris and affected the way it traveled
    - We also had to rush to mark where the debris landed before they shifted due to the wind
- **Improvements**
  - Implement this experiment in an enclosed space so environmental effects would be minimized
  - Use more insulated wires so that air does not escape through the gap between the copper wire and its insulation
  - Use of a metal cube with adhesive on the interior surfaces could be a possible method of capturing the debris in 3-D, while being able to withstand the blast, unlike the Styrofoam cube

9.0 Conclusion

- The primary learning outcome came from cataloging various particles of debris created from the explosion of a canister which simulated a rocket body in space
  - We analyzed the pieces of debris for size, mass, and distance traveled which has parallels to real explosions of rocket bodies or dead satellites in space
  - We learned about the differences in space debris size, how these particles are generated, and their similarities to real space debris
- As a secondary learning outcome, we learned that ensuring each part used in an experiment or project meets the criteria required by the project is critical
  - There were catastrophic leaks through the wiring system which lead to a malfunction of the can detonation and a failure of experimentation for our group
  - The wires were unsuspected to have a leak as we assumed that they were sealed from the factory
  - However, in the end it was a very small gap between the copper wire and its insulation which allowed excessive venting of the can's internal gasses to the atmosphere
- It is of the utmost importance that each piece installed on a system is screened to the specifications demanded by the experiment to ensure its success
- Despite this, with the help of other groups, it is fair to say that we did meet our objectives and together had a successful experiment