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Proof of Concept Planetary Lander Test Article

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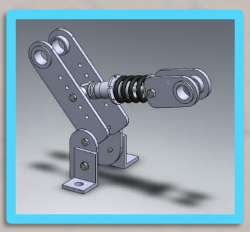
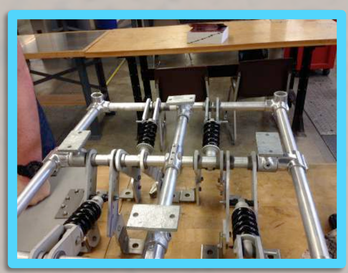
Design Requirements

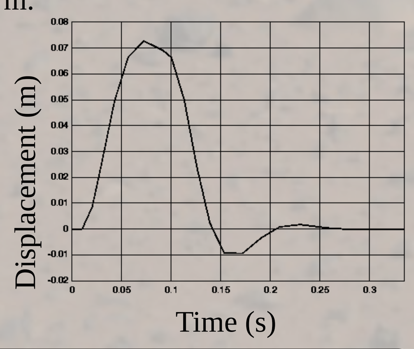
Desired weight < 50 kg
Desired volume < 1 m^3
Desired drop height < 4th story building
Goal energy absorption 5,141.6 J

Suspension Design

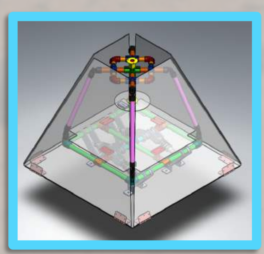
The purpose of the internal damper was to absorb residual energy that the crushable material did not absorb. Our design utilized four DNM-22 bicycle shocks so that the suspension system could symmetrically absorb energy in the vertical direction. The suspension featured a primary lever arm that amplified the impact, making the force experienced by each shock 7,667 N. The simulated suspension system reacted to the impact and settled within 0.4 seconds. The maximum travel the suspension could handle was 0.1842 m and the maximum simulation displacement was 0.066 m.





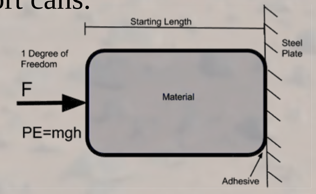


CAD Model



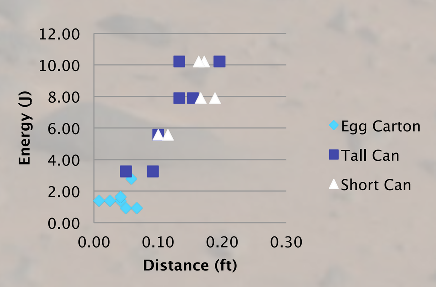
Material Testing

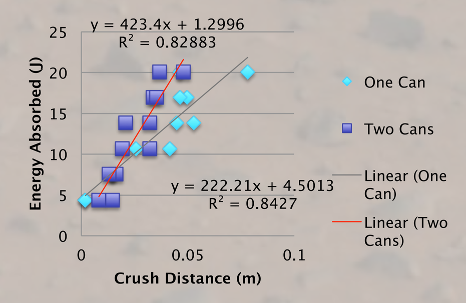
The purpose of the crushable material was to absorb the initial impact forces. We tested different materials to see which could absorb the most energy: egg cartons, tall cans, or short cans.



The crushable materials were tested using a pendulum with a mass of 4.2kg, which was raised to various heights and released in order to crush the material. The energy dissipation distance and energy absorbed were measured.

Both the tall and short cans absorbed about the same amount of energy, which was more energy than the egg cartons. The short cans were easier to acquire than the tall cans, which was why they were used as the crushable material on the planetary landing capsule base.





Cylindrical Shell Buckling Model

During material testing, we found that the cans failed due to cylindrical shell buckling. We assumed perfect plastic deformation, which allowed us to assume a constant impact force. Using this impact force we were able to calculate the energy absorption, time of buckling, and expected acceleration.

Equations

$$D = \frac{Et^3}{12(1-\mu^2)}$$
$$Z = \frac{l^2}{rt}\sqrt{1-\mu^2}$$
$$k_x = \frac{4\sqrt{3}}{\pi^2}\gamma Z$$
$$N_x = k_x \frac{\pi^2 D}{l^2}$$
$$\gamma = 1 - 0.901(1 - e^{-\phi})$$
$$\phi = \frac{1}{16}\sqrt{\frac{r}{t}} \quad for \left(\frac{r}{t} < 1500\right)$$

D is wall flexural stiffness per unit width
Z is the curvature parameter for an isentropic cylinder
kx is the buckling coefficient of a cylinder subject to axial loading
Nx is axial load per unit circumference
γ is the correction factor
ϕ is a function of radius *r* and thickness *t*

Mission Statement

To design, build, and test a landing capsule test article that incorporates external crushable impact dampening in tandem with an internal suspension.

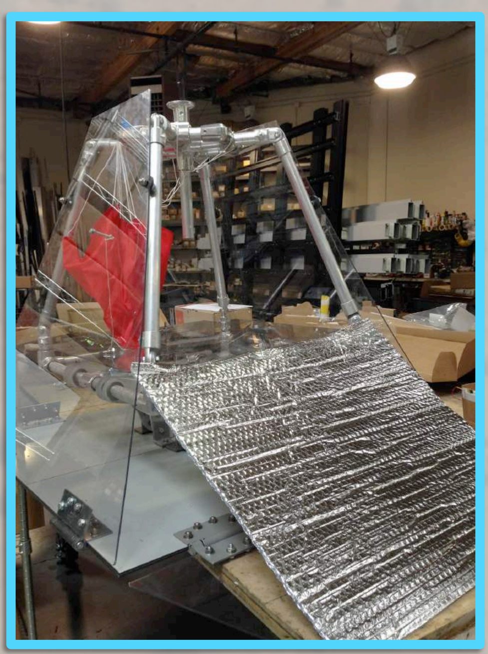
Problem Statement

Our objective was to create a more compact and lightweight, passive landing device. Our team designed and built a planetary landing capsule proof of concept test article that safely delivered a functioning payload to Earth. Afterwards, our modular design could be scaled up or down for different applications.

Solution

This proof of concept planetary lander safely delivered a radio controlled car to the Earth's surface. This lander was designed to be used as the last stage of landing in the existing entry, descent, and landing procedures used in previous Mars missions. The design improved upon past missions to Mars by reducing risk of failure during landing by utilizing a passive system with no electronics or control systems while also increasing landing site accuracy. These goals were accomplished by incorporating external crushable materials and internal damping systems. Five drop tests of our final design were completed. The test results can be used for scaling the components of the modular design to suit different planet conditions.

The force required to buckle one can under gradual load is 1582 N. Using the correction factor for impact, the actual buckling force experienced by one can is 791 N. By multiplying the buckling force by the distance crushed, the energy absorbed by one can is 97 J. The energy absorbed by the planetary landing test article divided by the energy absorbed by one can yields 53 cans needed on the crushable base to absorb 10% of Spirit impact energy.



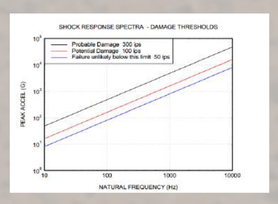
Testing Procedure

The completed design is shown in the picture below. The accelerometer used was a YEI-Technologies 3-Space Bluetooth Sensor. The settings used for these tests provided a sampling rate of 600 Hz, and the raw acceleration was recorded.

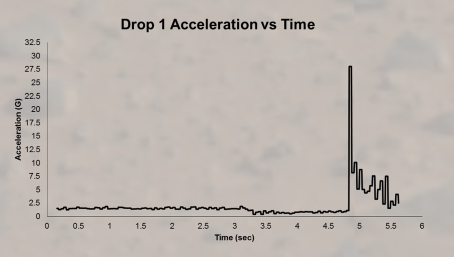
The quick release mechanism was a rope that was looped through the capsule and tied to the boom lift. The knots on the boom lift were quick release knots that could be undone by one pull. After the capsule was secured, and the accelerometer was functioning, the capsule was raised to the desired test height and dropped while recording the acceleration. The testing procedure was repeated for three heights including 3 m, 6 m, and 12 m.

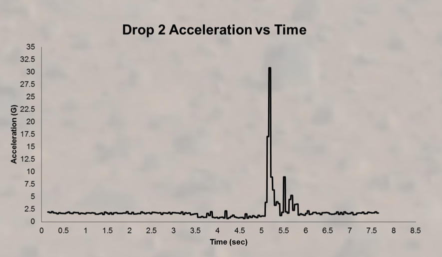
Results

The results from the testing found that the peak acceleration experienced by the payload was 28.04 G and 30.87 G, respectively. The acceleration versus time plots can be seen below. The acceleration data was recorded with a YEI Technologies 3-Space Bluetooth sensor.



A paper by a NASA engineer, Tom Irvine, discusses a method for predicting the damage threshold for electronics. Seen on the right, a shock response spectra takes into account the expected acceleration and natural frequency of the electronic chip in order to predict whether or not damage may occur. For the purposes of this project, a typical sized silicon chip was used for this analysis, and it was found that the required acceleration for damage was 2,000 G, well below the measured accelerations of 28.04 G and 30.87 G.



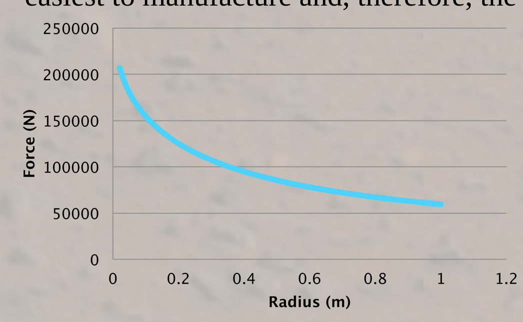


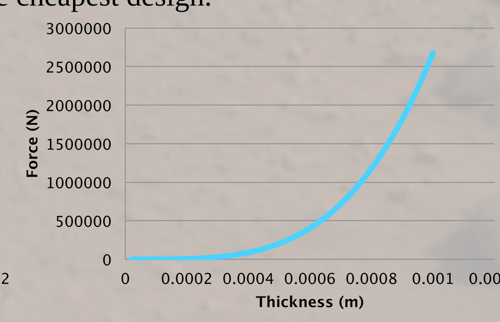
Scale Up Suggestion

We scaled up our design so that it could absorb 100% of the Spirit lander impact energy by assuming that the crushable materials were evenly spaced cylinders that failed due to buckling. By making this assumption we could calculate the energy absorbed by multiplying the buckling force by the crush distance. By changing the cylinder geometry or material we could control the threshold force, which is the force required to begin buckling the thin walled cylinder. We designed several solutions for a scaled up design that absorbs the same amount of energy as the Spirit lander while maintaining the same size lander.

The shape of the Spirit landing capsule was a tetrahedron made up of equilateral triangles with side lengths of 3.45 m. This meant that the bottom area available on the Spirit lander to implement our crushable material design was 5.15 m². The calculated thickness of the deflated airbag actuator assembly on the Spirit lander was 0.1377 m. We set the height of the cylinders for our crushable material to be the same as the Spirit lander assembly height to maintain the same size of the landing capsule.

Aluminum cylinders of different geometries were used for all five of our solutions for a scaled up design, which is shown in the table below. The solutions used the cylindrical buckling equations. All of our solutions absorbed slightly more than the impact force the Spirit lander was subjected to. The crushable base for the solutions is made from a grid of cylinders touching in four places. As the radius of the cylinders increased, fewer cylinders were able to fit on the 5.15 m² base of the lander. As the radius of the cylinders increased, the thickness of the cylinders also increased in order for the same amount of energy to be absorbed. The solution that was best for implementing on the Spirit sized lander is the 5th iteration because it used the least amount of volume of material and was the easiest to manufacture and, therefore, the cheapest design.





Parameters	1nd	2rd	3th	4th	5th
Total Energy Absorbed (J)	5.14E4	5.19E4	5.15E4	5.17E4	5.17E4
Radius (m)	8.00E−3	1.00E−2	2.00E−2	4.00E−2	6.00E−2
Thickness (m)	1.78E−3	1.8E−3	1.84E−3	1.91E−3	1.96E−3
# Cylinders	2.00E4	1.25E4	3.20E3	8.00E2	3.50E2
Volume of Material	2.18E−1	1.77E−1	9.71E−2	5.16E−2	3.50E−2
Area (m^2)	5.12	5.00	5.12	5.12	5.04

Conclusion

We successfully designed, built and tested our planetary landing capsule. The remote-controlled vehicle payload we used survived all five of our drop tests. To scale up our design for a Spirit sized mission, the crushable material would need to use 350 cylinders with the dimensions of 0.06 m radius, 0.00196 m thickness, and 0.1377 m height. An array of cylinders with these dimensions would fit on the bottom of the Spirit landing capsule and would be able to absorb 51,736.6 J, more than the impact energy experienced by Spirit during its arrival to Mars.