Testing a 3D Printed Nano-Satellite for Spaceflight

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This project is focused on determining if 3D printed CubeSats can withstand space launch. CubeSats are nanosatellites that are 10x10x10 cm in dimension and are becoming increasingly popular in research missions due to their size and cost effectiveness. The goal of this project is to test an ABS-based 3D printed CubeSat using the standards set for space launch by NASA and NIA. In order to determine the CubeSat's ability to withstand space flight, a drop test and a vacuum test were applied to the CubeSat. Non destructive testing is done to the CubeSat to determine the integrity of the CubeSat post-testing. Preliminary results suggest 3D printed CubeSats may not be able to withstand spaceflight.

Introduction

CubeSats are modular nano-satellites comprised of blocks that measure 10 x 10 x 10 cm; they are becoming increasingly popular in research missions due to their size and cost efficiency. They were developed for space science and exploration in 1999 by California Polytechnic State University and Stanford University. Their simple and small infrastructure made CubeSats low cost without sacrificing significant utility. Despite the constraints, they have become vary popular in private and public missions.

The standard size for a CubeSat is 10 x 10 x 10 cm, which makes up “one unit” (1U) of a CubeSat, and their sizes increment in units. Since the first CubeSats launched in the early 2000s, almost 200 have been launched as of 2013.

CubeSats are usually launched from a special pod (called a P-POD) from a rocket or from the international space station. They must withstand the forces acting upon them at launch and are held to the standards set in place by GSFC-STD-7000A for random vibration testing.

While the normal cost for a CubeSat itself is $10,000, without taking launch into consideration, what if there was a better way to design CubeSats? I propose to 3D print a CubeSat and determine if it could survive launch and space. This would be important for determining what kinds of things could become 3D printed in new missions, and what could not be 3D printed. If entire or even just parts of CubeSats could be 3D printed, they could reach a new audience, become even cheaper to deploy, and save time in planning missions.

Theory

The results of this experiment will be compared to the launch qualifications and requirements set in the "CubeSat Design Specification" document made by California Polytechnic State University. Almost all of the requirements defer back to the NASA document GSFC-STD-7000, which discusses necessary launch minimums, and acceptable results for pre-launch tests. The CubeSats in the California Polytechnic State document were made of various metals and were welded together, and some values were taken from previous satellite launches. Despite the 3D material being plastic filament, these will be the standards the testing will be held up to for this experiment.

Drop Test calculations were made to compare to a reported 4G's of force (from contact at NIA) needed to test for launch. The calculations were impact velocity (v), Kinetic energy (KE = $\frac{1}{2} mv^{2)}$, and using the work-energy principle to determine the average force on the CubeSat after it hits the ground. The variables used were 1.33 for mass, height was calculated for 0.5m to 0.1 m, with a bounce height assumed to be 0.1m to 0.08m. For a mass of 1.33, the force in G's was converted to Newtons (F=G*g*m) and found to me around 53 Newtons.

The vacuum test will be compared to requirements of the GSFC-STF-7000 (3) as closely as possible within the constraints of the project. This requires a thermal vacuum test of 1.33x10^-6 Torr for at least four hours, at the extremes of 200 degrees celsius to -100 degrees celsius.

If CubeSats could be 3D printed, their costs would be even further reduced, resulting in more widespread use of CubeSats. Potentially they could be 3D Printed on rockets headed to distant planets, which would allow for multiple CubeSats gathering different types of data at different times on one planet. They could be printed on the International Space Station, and then placed into atmosphere, speeding up the mission planning time.

Methods

The MakerBot 2X Replicator Experimental 3D Printer was used for this project. 3D Printing is a process of creating physics objects from a printable material by melting the material and slowly depositing it onto a plate that slowly lowers as a new layer of material is deposited. The MakerBot 2X Replicator uses ABS plastic filament and generates the layers for models in MakerBot Desktop.

The model used is an open source CubeSat model from Pumpkin, Inc (6). The model was split into two sections using netFabb software before printing, and then glued back together using ABS glue. Splitting the model into two sections and then gluing mimicked the standard process of welding two sections of a metal CubeSat together. The ABS glue was made using pure acetone and scrap ABS plastic parts, which were then melted into the acetone in a jar. The mixture was then applied only the top part of the bottom sections (Figure 1 a), the bottom part of the top (Figure 1b) and then placed together. The acetone then evaporates, leaving behind the solidified plastic.

The printers settings, before printing, were set on High settings (.1 mm), 20% infill, platform temperature of 125*, no raft or supports for either section. With these settings, printing continuously resulted in a print time of 6 hours for the bottom part, and 2 hours for the top part.

The ABS Glue was made with 100% acetone and scrap ABS plastic. Once the ABS plastic was melted in the acetone, it was applied to each part of the CubeSat, then placed together to fuse. The acetone then evaporated, leaving behind only ABS Plastic, essentially mimicking the procedure for welding a metal CubeSat.

The Wii Remote used was connected via BlueTooth to a computer, and the accelerometer data was gathered using WiiMote Physics. WiiMote Physics read off the total acceleration from the wii remote, which had a range of +/- 4Gs, and an uncertainty of about 2% (1). The Wii Remote was secured onto the printed CubeSat, which was then subjected to the drop test.

The drop test was constructed specifically for a CubeSat. It was based on several principles for drop tests, which are usually guided, have a heavy, flat and metal landing pad. This CubeSat drop test was constructed out of a concrete block base, a steel bench block for the landing pad, and wooden posts for guiding the CubeSat down. The posts were skewed out slightly so that the CubeSat would fall down without touching the posts, which would create a lot of friction, but could still be used as guides. The wooden posts also doubled as markers for the proper dropping height. The CubeSat was drop from a marked height and landed firmly on the steel block.

The vacuum test was constructed with Dr. Raouf Selim, which used one of his vacuum pumps, a pressure gauge, and a vacuum chamber, consisting of a bell jar and vacuum plate. The CubeSat was placed in the vacuum chamber, and a vacuum of 100 milliTorr was achieved. After the vacuum test was completed, a dye penetrant test was done on the CubeSat.

The dye penetrant test was done using Tide Laundry Detergent and a blacklight. The CubeSat was dipped into the Tide Detergent, which was left to soak for an hour, then the Tide was scrapped off the surface. The CubeSat was then placed under a blacklight, which the phosphors in the Tide Detergent would react to, lighting up cracks or break in the CubeSat.

Data

A total of about 5 full procedures were completed. There were multiple Drop Tests in the process of determining if the Drop Test was working properly, however only 5 CubeSats went through the full procedure of printing, dropping, vacuuming and finishing in a dye penetrant test. Two of these tests had a reversal of the normal procedure, where they were placed into a preliminary vacuum test before being drop tested.

The data was gathered from the Drop Test using a Wiimote Physics, a program discussed in the Methods section. Wiimote Physics measures the acceleration data from the internal 3 axis accelerometer in the wii remote, displays the data in Gs and seconds, and creates a plot of the data (Figure 1), and saves the data to a .csv file (Figure 2). A Drop Test was considered passed if it reached 4Gs and no cracks appeared on the CubeSat or sections of CubeSat came off. The Drop Test was considered partially passed if only a few cracks appeared, and the CubeSat failed the Drop Test if any parts came off. Two of the Five CubeSats passed, one partially passed and the two outliers failed the drop test.

The vacuum data was saved in an Excel file. The results of each run were the same - the CubeSat did not crack or expand from the vacuum. However during the outgassing, the CubeSat began to dry out. This resulted in a brittle CubeSat that broke easily and failed the Drop Tests. Figure 2 gives the five Vacuum Tests that were completed.

The dye penetrant was fully inconclusive. Once the procedure was done, it did not reveal any new cracks or breakages that were not already easily seen with the naked eye. None of these tests could be said to fail or pass, as it did not show any new information. Figure 4 shows one of the inconclusive tests.

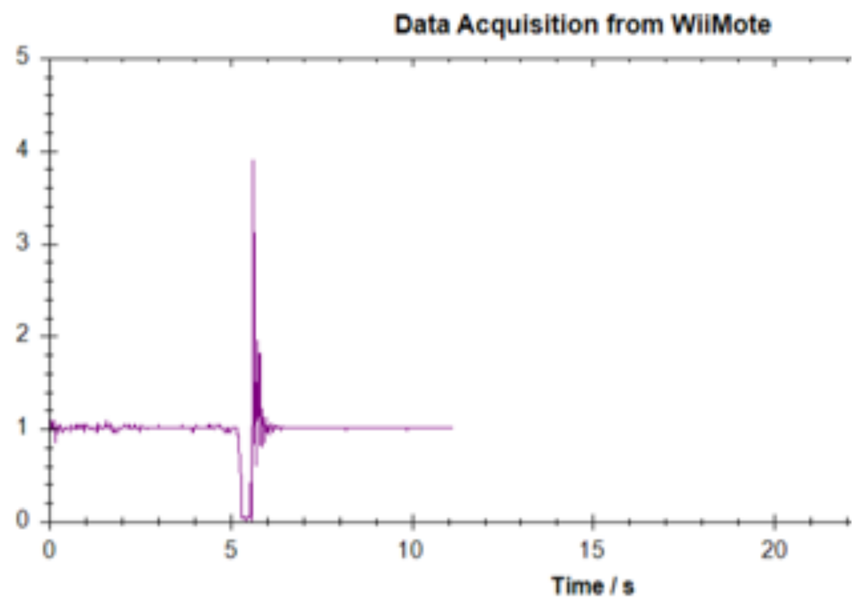

Figure 1

Figure 1 is a plot of Gs versus Time taken while the CubeSat was dropped and reached 4 Gs. The CubeSat was held steady for 5 seconds, then released into free fall. Notice that the Gs drop from 1 G pre-release, to 0 Gs after 5 seconds, and then spikes up to 4 full Gs. This shows that 4Gs were applied onto the CubeSat when it landed.

Figure 2

Time (s)	Force(G)
5.536617	0.05549135
5.543151	0.2780533
5.543449	0.2780533
5.557803	0.3320833
5.56495	0.4189477
5.57999	0.1634538
5.585933	0.08944272
5.599213	0
5.606802	0.2075555
5.619206	1.861127
5.629179	2.345072
5.63895	3.809518
5.643732	3.898948
5.660378	2.35766
5.669257	2.02502
5.68049	2.171926
5.687111	0.8963357
5.700735	0.7633576
5.707116	1.494584

Figure 2 is an example of the .csv file that results from a Drop Test. The drop begins at 5.536617 as the Gs drop, and the hit happens at 5.5606802 with a value of 3.809 Gs.

Figure 3

Test	Pressure	Time (hours)
1	100 milliTorr	7
2	100 milliTorr	8
3	100 milliTorr	8
4	100 milliTorr	4
5	100 milliTorr	5
4-b	100 milliTorr	9
5-b	100 milliTorr	7

Figure 3 shows the vacuum test that were done on the Five CubeSats. Test 4 and Test 5 were the two outliers initial vacuum tests pre-Drop Test. Test 4-b and Test 5-b were the vacuum tests on the outliers after the Drop Tests.

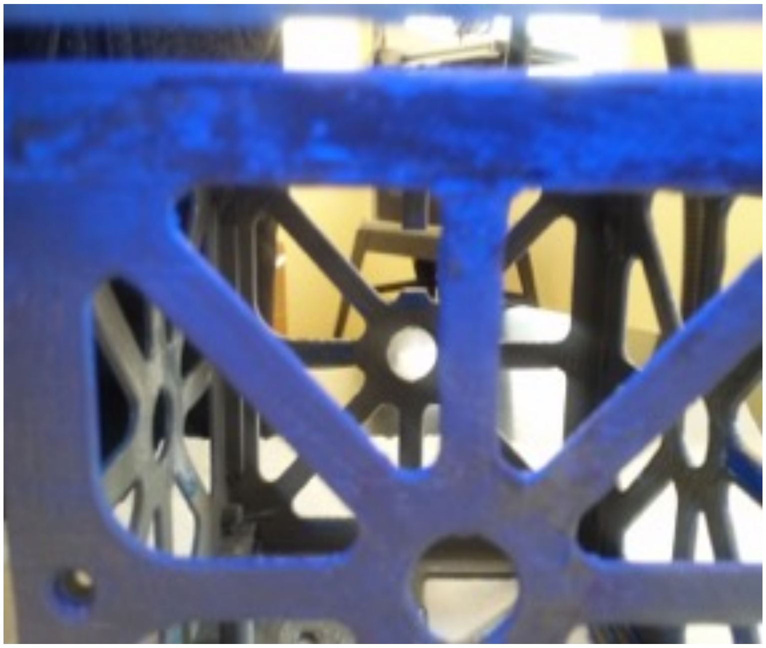

Figure 4

Figure 4 shows a dye penetrant test that was inconclusive. In the foreground, under the blacklight, no new cracks were revealed - all the areas that light up were also visibly cracked without the dye penetrant. The in background shows a breakage in the CubeSat that resulted from a failed Drop Test.

Discussion and Conclusions

The .csv file was used to create a superimposed epoch plot (Figure 5) of multiple runs. This graphs shows many runs all on the same graph, with all the drops being timed started at now the 2 second mark. Each run spikes at approximately 4Gs, which indicates that the drop test was properly attaining 4Gs during each run.

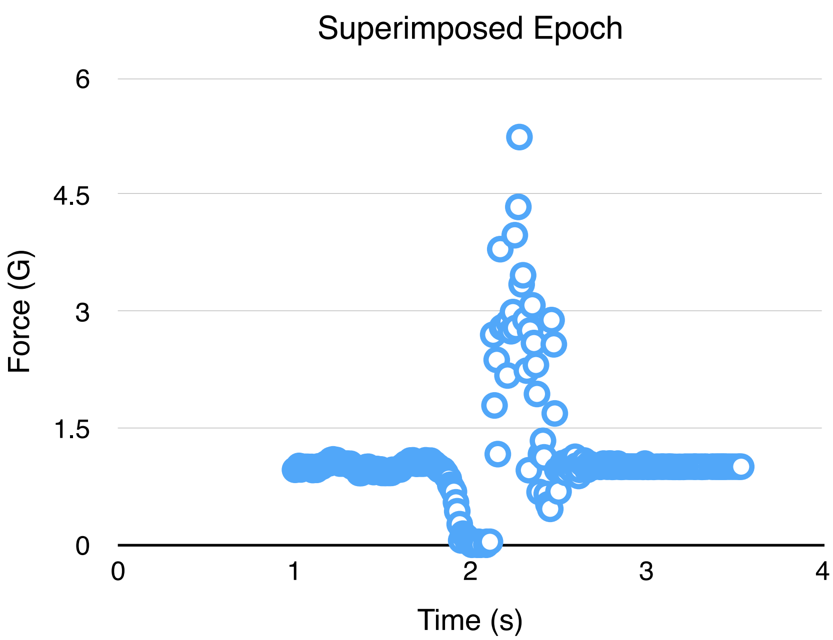

Figure 5

While the CubeSats could pass a Drop Test if they were printed and then dropped, the outliers failed the Drop Tests after being placed in a vacuum. Before CubeSats are launched, they are usually placed in a vacuum, and thus based on these results, 3D Printed CubeSat would not survive launch.

That being said, other than becoming brittle, the CubeSats passed the vacuum tests. This could mean that if a CubeSat were to be printed in space and simply distributed in space, they would survive and could gather data. The international space station could print the CubeSats, or rockets traveling to other planets could print them, add the instrumentation and they would be able to gather data when they arrived at their destination. They would then burn up if they entered Earth's or the planet's atmosphere, reducing satellite crowding.

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