A Simple System for Deploying Science Instruments from a CubeSat

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Abstract

The CubeSat community has been a research platform for the simplification and miniaturization of scientific instrumentation. Although the instrumentation has been developing rapidly within the last few years, the means of deploying said instruments have been lacking. Presented is a means of deploying a scientific instrument based on the use of scissor-boom technology, which has governed the deployment of large instruments on large spacecraft for decades. This technology has been miniaturized specifically for use on small satellites, especially CubeSats.

Introduction

As technology has advanced, so have the abilities and needs of space. To fill this need, the CubeSat has been developed. This has allowed universities and industry to have the ability to put up low-cost solutions to accomplish million-dollar science. One of the greatest aspects and abilities that these miniaturized satellites have is the ability for low-cost access to space.

One of the largest challenges that the CubeSat community has faced is the size constraint. Massive effort has gone into the development and integration of large satellite subsystems that have been adapted for CubeSat sizes. The goal for any CubeSat technology is to be low cost, low power consumers, and low volume occupiers. Developers have had to weigh these three options, choosing the best fit for their application. The smaller on every front, the better application and implementation capabilities exist.

The CubeSat community has been evolving rapidly within the last few years as industry and educational institutions have become more and more involved. Science instruments and the technology surrounding them have begun to evolve into a CubeSat-size standardization. These size constraints require every piece of the satellite system to be no larger than 10cm wide, 10cm deep, and any multiple of what is known as a “U”. “1U” refers to a satellite that is 10cm tall. The largest these satellites can be and still have ease of access to space is “3U”s, or 30cm tall.

One of the most typical uses of a CubeSat is to pack a science instrument into a jack-in-the-box style satellite, requiring extensive deployment of said instruments in order to accomplish what the mission has been set out for. As much as technology has developed, the ability to deploy instruments from a CubeSat, and the deployment mechanisms involved have been lacking in development, requiring each mission to come up with a customized design and application that works for their mission.

This paper proposes a scissor-type deployment structure to simplify this need. This design allows for the flexibility needed in order to accomplish the deployment needs on a CubeSat.

Approach

Following suite to the evolution of CubeSat technology, a scissor-structure based on technology that is decades old has been developed in order to deploy a DC Probe from a National Science Foundation CubeSat mission known as DICE. The need for DICE was to have miniaturized DC Probes placed as far away from the Electrical Power Subsystem located at the bottom of the spacecraft because of magnetic contamination issues faced during readings. A second science reason was to attempt to get the Probes as far away from the wake of the spacecraft antennas as possible, thereby allowing for clean and consistent measurements.

The approach uses a rapid-prototyped cross-beam frame to deploy single sensors, or even a panel of sensors, away from a CubeSat in order to accomplish the science objectives defined for a specific mission. Analysis was done in choosing the specific material that would be used for this device. Plastics, metals, and fiberglass composites were considered for this mechanism. It was decided to use plastic material on the mechanism's structure. The reason behind choosing to use plastic material is the ease of rapid-prototyping and to keep the weight of this device as small as possible, thereby allowing for more weight to be allocated to the main satellite's operational subsystems and structures. If this design used more than 30 grams of the allocated satellite weight then it becomes more of a payload than an actual mechanism.

Design

Again, the design of this system has been around for decades and is one that many NASA missions have used in order to accomplish deployments for satellites. As with all CubeSat hardware, time was spent to miniaturize and simplify this approach to allow for ease of use. One key requirement for this mechanism was that it remained completely non-magnetic in material and fastener choices. This requirement led to the use of torsion springs on the lower frame instead of using a micro-DC motor. This requirement also influenced the choice of a non-magnetic space rated plastic over most metal materials.

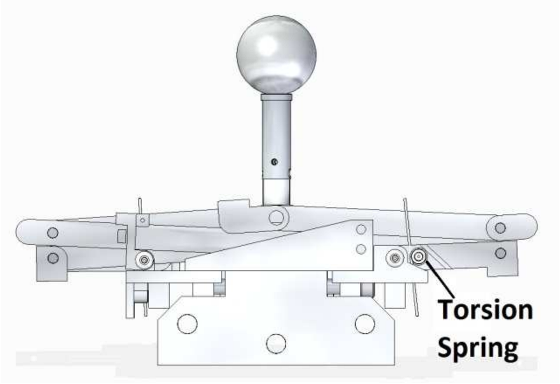

Figure 1

The torsion springs rest on the bottom bars of the frame, as shown in Figure 1 above, and when the mechanism is released using any number of release mechanisms readily available, the springs force the structure to deploy upwards, as shown in Figure 2 below.

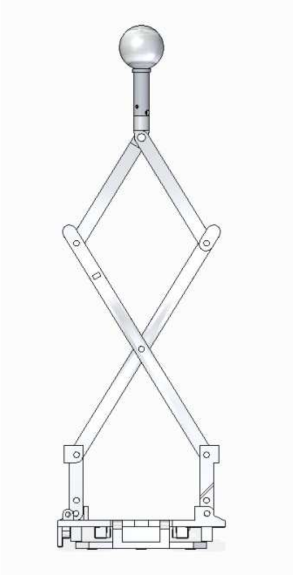

Figure 2

The current design uses Shape Memory Alloy (SMA) to pull back on a lever that is used to hold down the structure by means of a ledge printed on the main bar of the structure. This SMA requires 5.5 Volts and 1.0 Amp for a deployment time of less than 2.0 seconds, easily meeting the power requirements for even a 1U CubeSat.

Shape Memory Alloy works as basically a contractor. When current passes through the wire, the alloy is heated up to a certain temperature, which changes for different alloys of wire. This temperature is a phase-change temperature which allows for the alloy to change shape accordingly. For the SMA wire application, the heating of the wire causes it to contract by about 4.0% of its original length. Using this contraction length, as well as simple mechanical advantages allows users to be able to extract a much higher rate of contraction than off of the wire alone. The SMA that was used for testing is from a company called Dynalloy. They have provided SMA wire to space applications and missions for years. Some of their wire is actually currently on the Mars Rover and was used for releasing one of the covers for its instruments.

To ensure that the probe would remain perpendicular to the spacecraft after deployment, two shelves were designed into the top rails of the assembly. These shelves act as a cupping lock as the mechanism deploys, allowing for the top tube, as well as the sphere, to be as straight relative to the spacecraft as possible.

For volume concerns, this deployment system was developed to occupy less than a 3.25” x 1.00” x .65” volume. This volume occupation while stowed allows for the ability to deploy over 5.0” away from the spacecraft.

One key goal with this design was to have the ability to simply modify the height of the design depending on what the end driving science requirements were. The design allows for extra main-support pieces to be added, while only adding a height of 0.17” to the 1.0” dimension. For this additional 0.17” in height, another 2.5” is added to the height of the structure, thereby increasing the distance of the actual deployment away from the CubeSat structure.

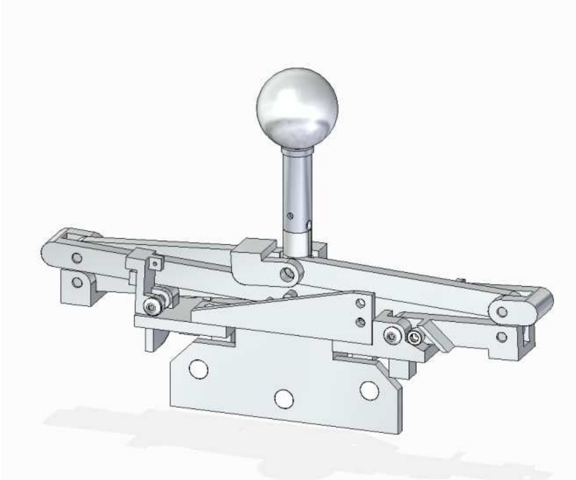

Figure 3

For the DICE mission, this structure deployed the attached DC probe shown in Figure 3. This figure also shows the release mechanism in its stowed state, occupying a small volume of space. Since this requires a guard beneath the probe, the entire structure needed to fold flat against the spacecraft to minimize the space occupation. This flattened state is shown in Figure 4.

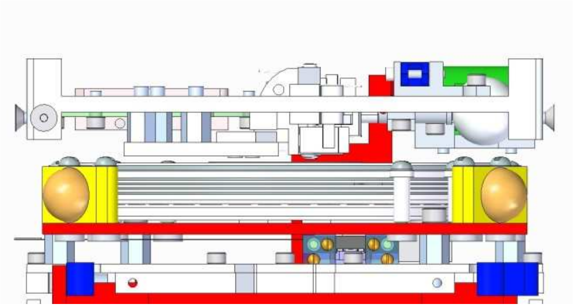

Figure 4

Because of this, a second motion was required in order to position the structure in the correct position. To fulfill this requirement, there is a main support structure that is attached to the spacecraft structure as shown. On this support structure is a place for a single #2-56 fastener to be placed and used as a rotating shaft. On this shaft is placed two additional torsion springs, giving a higher tension load against the structure and thereby ensuring that once deployment has occurred, there will be as little motion in the assembly as possible. This second deployment is shown in the following figure.

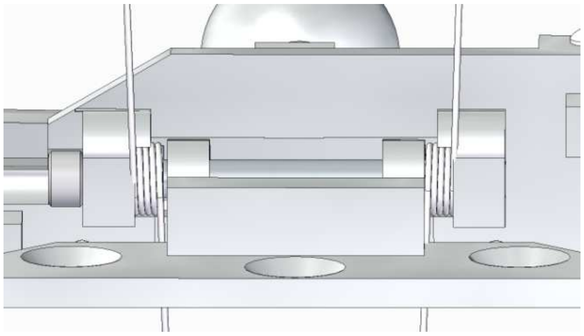

Figure 5

Another key requirement for the DICE mission was that this DC Probe deployment mechanism needed to not impede the view of the GPS patch antenna located on the top of the spacecraft. The DICE mission was a spinning satellite platform, as many impeding variables were removed in order to let the antenna get as much of an unimpeded view as possible, allowing for faster and better acquisition of the GPS signals. Shown in Figure 6 is the location of the deployment mechanism relative to the rest of the satellite's top structure. The second shows the same location, but on the bottom of the satellite's structure. The locations are mirror images of each other, allowing for the forces experienced during deployment to cancel one another out.

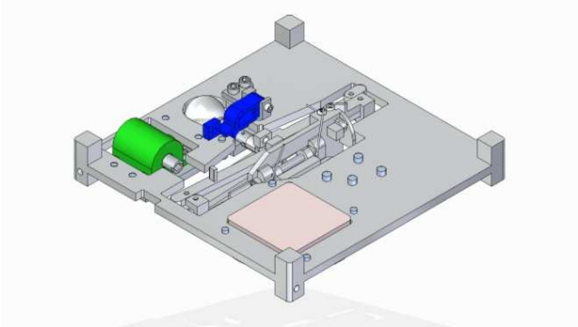

Figure 6

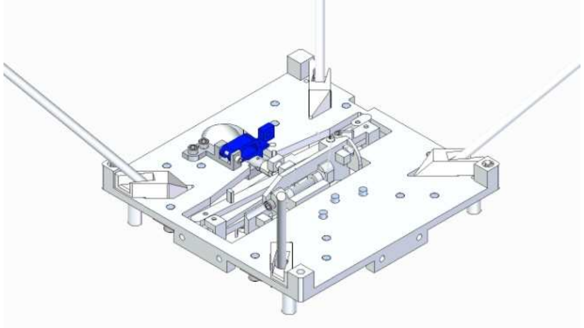

Figure 7

After both sections of the deployment structure have deployed, a simple spring-and-pin system was developed to lock the structure in that position. For the initial lock, a spring pushes a pin into the main rotating piece that the structure is fastened to. For the second lock after the main deployment, two additional springs push two more pins into the bottom of the torsion pieces at the bottom of the structure.

This was done to help ensure that the motion of the assembly would be kept to a minimum. These spring systems are shown in the following two figures.

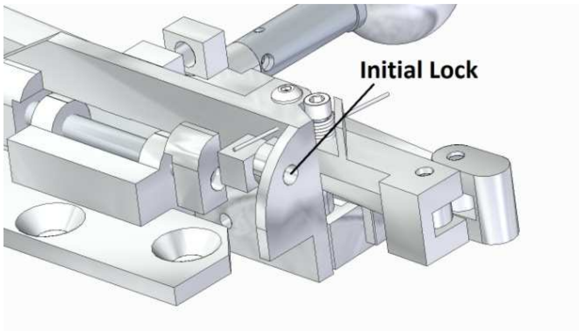

Figure 8

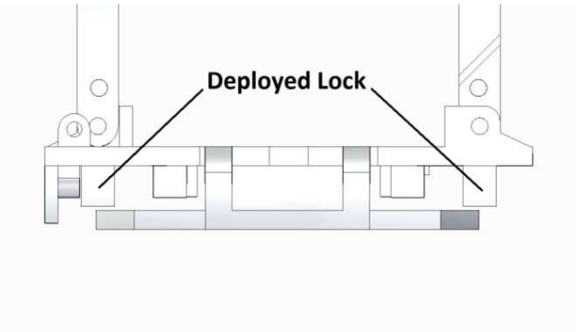

Figure 9

To help ensure that there is enough force acting on the structure to deploy the system, the four torsion springs that are used on this design are designed to be used 90 degrees further than what this structure uses them as. This allows for a constant load to be put on the mechanism, with little to no slack in the springs. This prevents the springs from collapsing against themselves because of any weight that is placed upon them. It also gives some margin of force to ensure that the springs will be able to handle their loads.

Modeling and Testing

This deployment mechanism was designed using Siemens Solid Edge package. This model was then implemented into two motion modeling software packages in order to test the dynamics of what occurs while this mechanism deploys. These packages allowed the ability to modify small changes on the mechanism, including spring force, number and location of springs, and mass of the mechanism itself. Because of the freedom to change these variables, a design was finished that met the size and power goals that were laid out before this design was begun.

The software packages used were MSC Software’s ADAMS modeling package, and MSC Software’s Dynamic Designer Motion Professional. The deployment mechanism is shown in both modeling packages in the following two figures. Figure 10 shows the model in the ADAMS software package. Figure 11 shows the model in the Dynamic Designer software package. These packages are similar in nature, each allowing for the models to have exact calculations and measurements, but still allowing for the easy manipulation and changes of the interaction of parts on the mechanism. These packages both work with the Solid Edge models and allowed for the movement of information back and forth between dynamic analysis and the actual model.

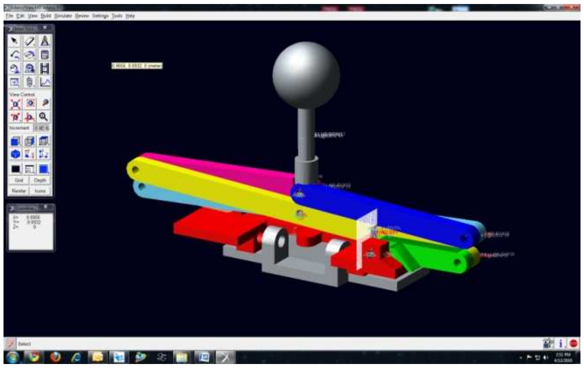

Figure 10

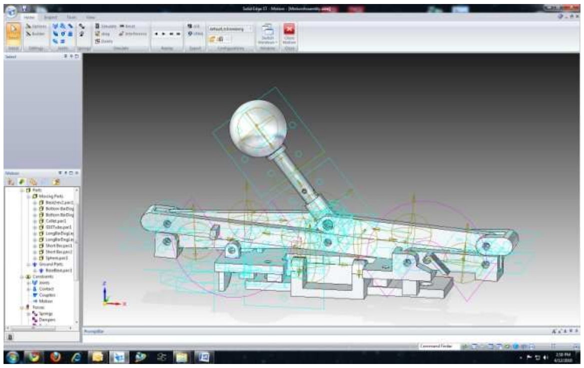

Figure 11

In order to study the dynamics, these software packages allowed for the ability to study the motion of each individual piece, as well as the forces experienced for each piece and whether or not the current design would be able to handle such forces. This allowed for an in-depth study of the needs of the mechanism in a microgravity environment, with the ability to compare side-by-side the effects that different changes had on the overall operation of the design. Doing so eliminated the need for hundreds of prototypes and hours of testing.

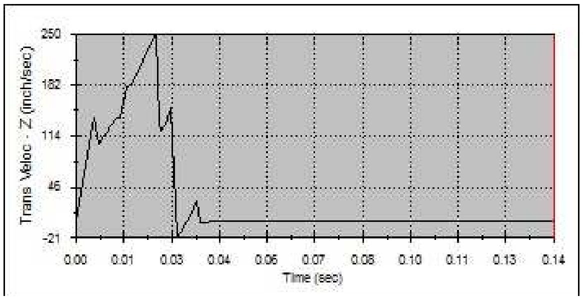

Figure 12

Figure 12 above shows the z-axis motion of the assembly using the DD package. This model was taken using a frictionless surface contact between the moving parts for simplicity. Models with friction have been done, and they are shown in Figure 13

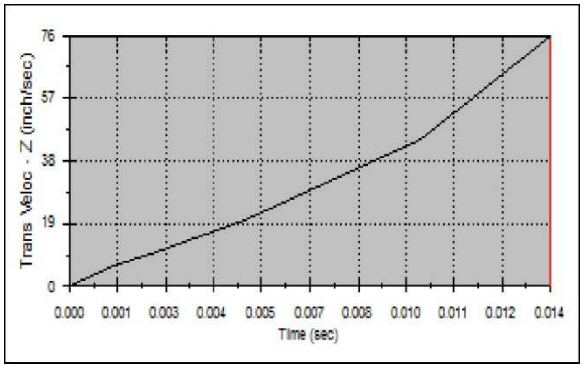

Figure 13

Both analysis software packages showed that the current design would be able to handle the loads that it would experience during flight. It also showed that the interaction between the different elements in the design would not immensely impact the performance of the analyzed design.

A unique trend that appeared during modeling was that the speed at which the mechanism deployed varied drastically with time. Instead of being a constant value, it depended on where the mechanism was in its deployment stage. However, the speeds shown in the charts follow the fact that as the mechanism begins to move, more motion is thrown into the translational z-axis motion, rather than elsewhere. With the concentrated motion in that direction, the speed at which the sphere moved increased over time.

Through design and analysis throughout the design process of fasteners and hardware, the mechanism has been confirmed as a non-magnetic mechanism. This fulfills the main requirement for DICE being a non-magnetic mission.

After analysis was accomplished using these software packages, actual mechanisms were printed up using a 3D rapid-prototyping printer located at the Utah State University campus. These cheap and simple full-scale models have allowed for the design to be verified and tested before money will be spent on purchasing a highquality rapid-prototyped mechanism. Shown in the following figures is a prototype that has been printed and used to test the concept and deployment effects.

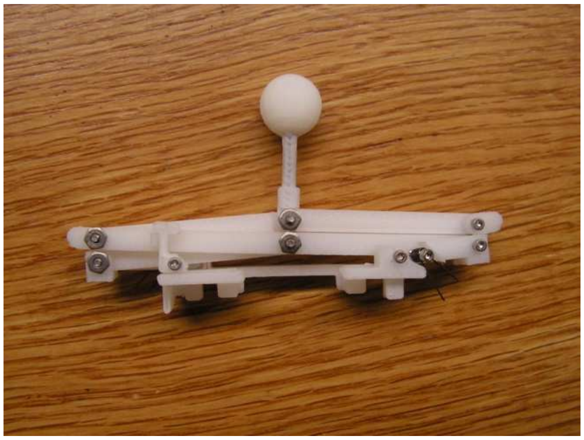

Figure 14

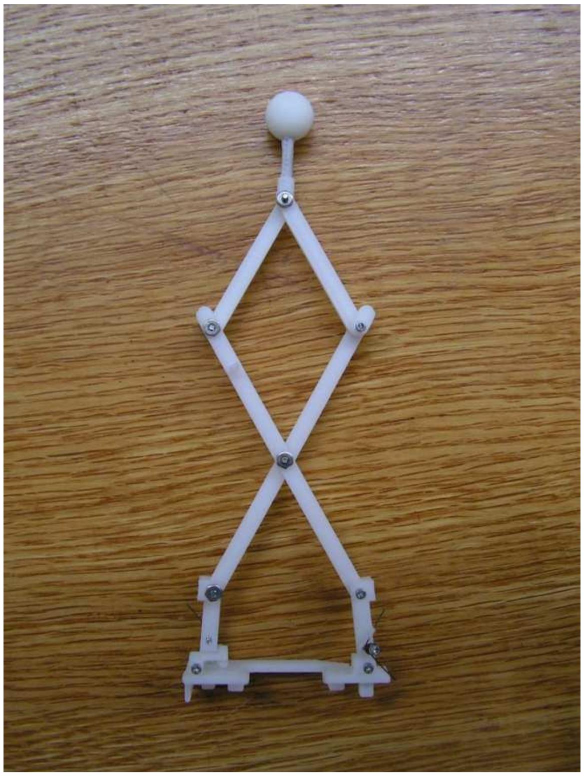

Figure 15

Application

As stated previously, this mechanism will fly on the NSF DICE mission as its maiden flight. It will deploy the DC Probes from the spacecraft to a height of more than 5.50” away from the spacecraft. This design has fulfilled the science objectives and requirements written by the DICE science team. The ability to modify the height as needed allows for a simplistic device that will serve as an immense scientific benefit.

One small modification that is involved in the DICE mission is that there is a second science instrument that will be deployed from the same mechanism. A science-grade magnetometer has been setup to run on the frame of the deployment structure. This magnetometer’s resolution is so immensely small that any disturbances of any kind can have an effect on its readings. In order to isolate the magnetometer as much as possible, it needs to be placed at a known distance away from the EPS system of the spacecraft, which contains the most impactful contamination problems.

In order to accomplish the needs of the magnetometer, the design for the mechanism will change slightly. Instead of only having two torsion springs located on the bottom of the mechanism, two additional torsion springs will be added to the first leg of the frame to allow for the extra force that is required to lift the magnetometer.

To release this mechanism from its stowed state against the top and bottom of the spacecraft on DICE, a TiNi Frangibolt actuator will be used to release a spring loaded system to deploy all of the mission’s deployables at the same time, allowing for a simple and complete deployment. This release mechanism is shown in Figure 16. The blue colored pieces show the deployables, where as the red pieces show the deployment mechanism.

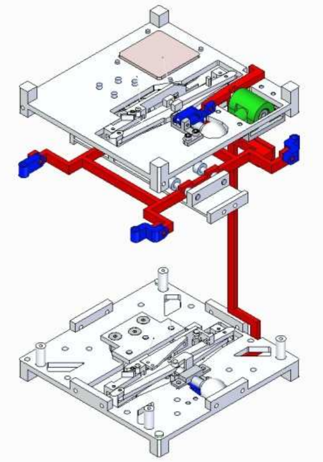

Figure 16

For a deployment of a complete panel of sensors, or a sensor other than a DC Probe, the need to have the mechanism stowed against the top and bottom of a spacecraft would be obsolete. This would allow for a single-release mechanism using the SMA wire that was discussed earlier in this paper. The added primary release and movement of the SMA actuator to a secondary release changes the simplicity of the actuator and requires a slightly higher power draw from the spacecraft system.

For comparison of size and spacing, the following figures show the mechanism both stowed and deployed on the DICE mission.

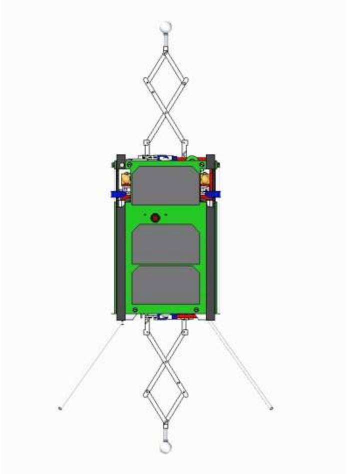

Figure 17

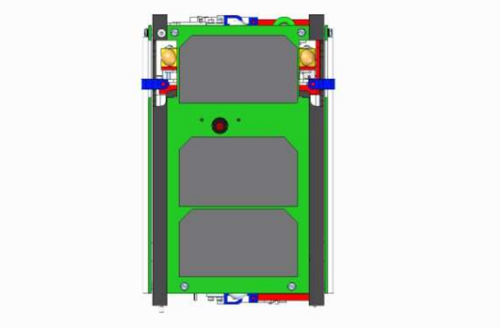

Figure 18

Conclusions

This design, which was developed for the DICE mission, has provided a simple means of getting space instruments away from the actual spacecraft body. This deployment mechanism will allow for the further development of jack-in-the-box style deployments that will vastly increase the capabilities and attractive assets that pull industry and educational developers into the community. This design gives a simple yet effective means of deploying science instruments away from the CubeSat bus, allowing for the simplification of packaging and deployment that the community has been lacking in development until recently.

The future for the community seems to be moving towards a total-Earth observation that will require complex systems to monitor all aspects of the world that we live on. There are some simple restrictions that have been hindering the massive development of some highly effective scientific instruments that exist for small satellites in general, but have yet to be further developed to fly on a CubeSat bus. With this deployment mechanism, the future of deployables from a CubeSat will grow with the ability to stow highly scientific instruments into a satellite that can rest in the palm of a hand.