

ALL-STAR Microgravity Structural Deployment and Attitude Control Test

Reduced Gravity Student Flight Opportunities Program Engineering Proposal



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Acronym List

ACS: Attitude Control System

ALL-STAR: Agile Low-cost Laboratory for Space Technology Acceleration and Research

CalPoly: California Polytechnic State University

P-POD: Poly Picosatellite Orbital Deployer

RGSFOP: Reduced Gravity Student Flight Opportunities Program

3U: 3 Unit CubeSat, 10 cm x 10 cm x 34 cm cube

I. Technical

1. Abstract

ALL-STAR is a low-cost 3U CubeSat bus capable of supporting the 1 year on-orbit operation of a variety of space-based research payloads that can be configured and ready for flight in 6 months through a simplified payload hardware and software interface. CubeSats are a standard size and shape of picosatellites that measure 10 cm by 10 cm by 10 cm for every 1U. These satellites are then launched on any rocket as a secondary payload in the Poly Picosatellite Orbital Deployer (P-POD) ^[1]. Once in space, after being ejected from the P-POD, the ALL-STAR satellite will deploy an external shell and solar panel wings to increase the surface area available for solar panels. The deployment mechanism is being designed and manufactured by students on the ALL-STAR team and has never been tested in a microgravity environment. In addition to needing to test the deployment system, the ALL-STAR students are also designing and manufacturing a micro Attitude Determination and Control System (ACS). This system includes reaction wheels to control attitude. These wheels can only be tested in one degree of freedom at a time on the ground. By flying with the Reduced Gravity Student Flight Opportunities Program, the ALL-STAR team can verify a portion of their requirements for operating in the space environment and increase their Technology Readiness Level. This document outlines the benefits of this test as well as an outline of procedures for the tests.

2. Test Objectives

The ALL-STAR project consists of both graduate and undergraduate students working to design a 3U CubeSat bus capable of supporting the 1 year on-orbit operation of a variety of space-based research payloads that can be configured and ready for flight in 6 months. This project is mentored by engineers from Lockheed Martin who have an interest in using the ALL-STAR bus for small standalone payloads and technology demonstrations. This bus, however, can be used by any company or university as a platform for small experiments in space. In order to increase the Technology Readiness Level of the satellite and to instill confidence in potential users, two systems need to be validated in a microgravity environment.

The first system to be tested is the structural deployment mechanism. Both the body of the satellite and the solar panel wings will be deployed after launch to expand the total available surface area of the satellite. Figure 1 shows the satellite in its fully deployed state where the top half consists of the shell and wings while the supporting electronics and payload are in the bottom half. This deployment system is being designed and manufactured by students at the university and has never been tested before in microgravity. If the deployment mechanism fails on orbit, it would mean mission failure for the satellite. Only a small spring force is required for the deployments, meaning the system may act differently in microgravity than it does in 1G. One concern is that the drawer (payload section) may torque inside the shell as it is deployed, potentially catching on an edge preventing a smooth deployment. Along the same lines, a test in zero gravity will verify that there will be no unexpected factors hindering the deployment in

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space. In addition, the deployments will take place while the satellite is tumbling just after deployment. While this tumbling is not expected to be violent, the ALL-STAR team needs to verify the ability to deploy while rotating. If the test is successful then all four solar panel wings will be fully extended and the drawer will deploy until a spring plunger stops its motion. When the structure deploys, the rotation will slow as momentum is conserved. Ground test prior to the microgravity flight will provide the basic knowledge that the system is working; however it does not validate this new method of deployment in a space environment.



Figure 1: Fully Deployed ALL-STAR Bus

The second system to be tested in microgravity is a student designed and built attitude control system. The attitude of the satellite is controlled using three reaction wheels. Although torque wheels are a typical method of attitude control, they are rarely designed so small, or by students. On the ground, the team can verify the attitude control for each axis, one at a time, by using an air bearing table or by hanging it from a long string. It is not feasible to test all three axes at once in a 1G environment. The microgravity flight would provide the ability to test the entire system's capabilities at once, proving that the students' calculations and algorithms work as predicted for 3-axis control. If the test is successful, then the students should be able to control the attitude of the satellite to within 1 degree of the desired location. This test also has the potential to allow the ALL-STAR team the chance to characterize the jitter caused by the spinning wheels. This information would be useful to payloads interested in taking images or other high precision instruments that would be affected by tiny vibrations in the satellite.

Both of these systems are being designed entirely by students and have never been tested in microgravity environments. It is for this reason that ALL-STAR would like to fly with the Reduced Gravity Student Flight Opportunities Program. While the mechanisms mentioned are based off of the designs of large satellites, they are rarely implemented in satellites this small. This test would help verify the functionality of the deployment system and attitude control

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system in microgravity as well as help characterize the behavior of the satellite when those systems are actuated.

3. Test Description

i. Deployment System

There are two aspects to the deployment system that need to be verified, the actuation of the deployment and the spring force that extends the structure. There are four locations where the deployment is actuated, one on each end of the satellite which deploys the drawer and the ends of the solar panels, and another two are in the center of the solar panels one two of the sides, keeping the panels from vibrating during launch. The deployments at the ends are the main actuation and are done using a non-explosive actuator called Frangibolt, produced by TiNi Aerospace, Inc^[2]. Frangibolts work by heating a cylindrical piece of shape memory alloy until it elongates, fracturing a preloaded bolt, and the two parts of the bolts are retained by the main structure and the solar array. When the bolt breaks the two components are free to separate. The release mechanism restraining the solar panels in the center is a non-load bearing bolt attached with solder to the structure. When the solder melts, the bolt is released and the panels are free to spring open – this system is commonly termed a fusible link. To melt the solder a signal is sent to a heater which only has to reach a few hundred degrees before the bolt is released. This actuation takes time to reset and the custom bolts for the Frangibolts are extremely expensive, so it can only be tested a few times per flight. This test takes place during the first cycle of zero gravity on the flight. The goal is to verify that this actuation in combination with the deployment works in a zero gravity environment. All other deployment actuations will be done by hand.

The other aspect to the deployments is the springs that force the structure to fully deploy. The solar panels are deployed with torsion springs in the hinges while the drawer is attached to constant force springs. In the stored configuration, the constant force springs will be stretched out and wanting to roll back up, like a tape measure. This will pull the shell off of the drawer until it is stopped by a spring plunger. This spring is only present in two of the corners meaning the satellite runs the risk of torquing the inside drawer to prevent smooth deployment. This may not be evident on the ground and may only affect the satellite more in microgravity. The hope is that there is little to no difference between microgravity and tests on the ground. The solar panel wings are stopped by a flattened ‘nail head’ in each hinge. To test this deployment repeatedly, ALL-STAR team members will reset the satellite to its stowed configuration and use a type of pin or clip to hold it in place. When the microgravity cycle starts they will release the pin or clip by hand, initiating the deployment. They will observe any violent or unexpected reactions that happen during deployment and record those as areas of concern. Onboard accelerometers and gyroscopes will measure the rotation rate and movements for quantitative analysis of the dynamics of the system as it deploys. It is important to note that nothing deploys off of the satellite during this test and that during these tests, it is

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possible to tether a corner of the satellite to the aircraft; however, a tether is not preferred, as it may affect the dynamics of the system.

ii. Attitude Control System

In the cycle following a deployment, while the satellite is in its flight configuration, the ACS reaction wheels will be tested. There are two ways the wheels performance can be tested. The first method would be a slew test in which the satellite will change the attitude by a predetermined angle. This angle would be small enough to allow the satellite to finish the slew before the end of the cycle. The second method would command the satellite to maintain the current attitude against any disturbance. The flyers would then perturb the satellite and show that it returns to its initial state. The onboard gyroscope will measure rotation rate, while the accelerometers record jitter from vibrations in the motors. The goal is to verify the control algorithm created by students, in all three axes. This goal means any attachment to aircraft would change the dynamics, skewing the results of the test. During this test, students will also be looking for flexing in the joints connection solar panels or in the solar panel wings themselves. After this test is complete the deployment system is reset and tested again as described above.

4. References

- [1] "Developers." *CubeSat in the News*. CalPoly. Web. 23 Oct. 2010.
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<<http://www.tiniaerospace.com/fbt/frangibolt.html>>.
- [3] "Gest Alta - Bicycle Wheel." *Gest Alta - Alta Health Products*. Web. 25 Oct. 2010.
<[http://gestalta.net/index.php?key=bicycle wheel](http://gestalta.net/index.php?key=bicycle%20wheel)>.
- [4] "COSGC Outreach". *Colorado Space Grant Consortium*. Web. 24 Oct. 2010.
http://spacegrant.colorado.edu/COSGC_Projects/outreach/

II. Safety Evaluation

1. Flight Manifest

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Jessica Brown	Alt Flyer	Senior	Aerospace Engr	jessica.l.brown@colorado.edu

None of the flyers have any previous flight or ground crew experience with the RGSFOP

2. Experiment Description

The ALL-STAR microgravity experiment will be verifying the deployment mechanism used to extend the body of the ALL-STAR satellite and the solar panel wings. This deployment is designed to increase the surface area available for solar panels. The deployment mechanism is being designed and manufactured by students on the ALL-STAR team and has never been tested in a microgravity environment. The deployment can be actuated two different ways, one by removing a clip or pin restraining everything or by using Frangibolts to separate the two sections. Springs in the solar panel hinges and along the body of the satellite will force the different components to extend before being stopped with a spring plunger or flattened 'nail head'. In addition to needing to test the deployment system, the ALL-STAR students are also designing and manufacturing a micro Attitude Determination and Control System (ACS). This system includes reaction wheels which can only be tested in one dimension at a time on the ground. A signal will be sent to the wheels telling it to rotate at a certain rate allowing students to verify the system in all three dimensions at once. This will most likely be a free floating experiment, however the team could potentially create a cage for the test if need be.

3. Equipment Description

During the testing of the deployment mechanisms the ALL-STAR satellite will be allowed to be free floating so that the dynamics of the deployments in a zero gravity environment can be properly characterized. This part of the test will be testing the deployment of the external solar array structure from the main electronic stack structure and the deployment of the solar panel wings from the solar array structure. The power required for these deployments will be provided by the internal power system and its batteries. Testing will not require any external power sources or connections.

The ACS subsystem for this test will consist of three reaction wheels oriented orthogonally and mounted to the structure using printed circuit board (PCB). Additionally, the control electronics will be attached to the satellite using an additional PCB. The ACS system will also require an

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internal power system although this could be the same set of batteries used to actuate the deployment.

4. Structural Design

i. The Main Structure and Interface to the Aircraft

The external structure of the ALL-STAR satellite will be constructed of hard anodized AL-6061-T651 and has been designed to survive NASA GEVS launch profile. The satellite will be stored in a cage that will be most likely constructed out of Rexroth so that the satellite can be properly restrained during takeoff and landing as well as when the satellite is not currently being tested. The design of this restraint structure and how it will be interfaced to the aircraft will be included in formal TEDE submitted after the proposal has been accepted.

ii. The Structures and Sub-Structures

The ALL-STAR structural design encompasses the structural components responsible for the mechanical stability of the spacecraft in addition to the mechanisms that produce all deployments. During the microgravity flight the deployments that will be tested include the deployment of the solar panel shell and of the solar wings.

The ALL-STAR structure is made of sub-structures – the exterior Exo-structure and internal Payload Extension Zone ‘PEZ’. The Exo-structure contains the deployable and fixed solar panels - it thus far has been referred to the solar panel shell that will be shed during deployment. The secondary structure – the Payload Extension Zone ‘PEZ’ houses the bus electronics and payload subsystems. The PEZ structure is fitted within the Exo-structure, which slides within the z-axis along the length of the system. The sliding surfaces are Teflon-anodized aluminum. Figure 2 shows the PEZ and Exo-structures in their stowed and deployed states.

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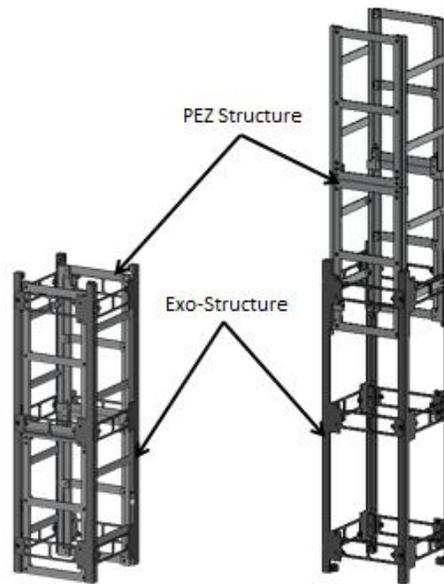


Figure 2 - PEZ and Exo Structures

Each structure is composed of perpendicular panels that are fastened with hex-bolts – 4-40 and 2-56 for the Exo and PEZ respectively. It is important to note that the PEZ structure is composed of the Bus and Payload sub-structures that are assembled individually and then integrated at the center – also using 2-56 hex bolts. Figure 3 depicts this assembly.

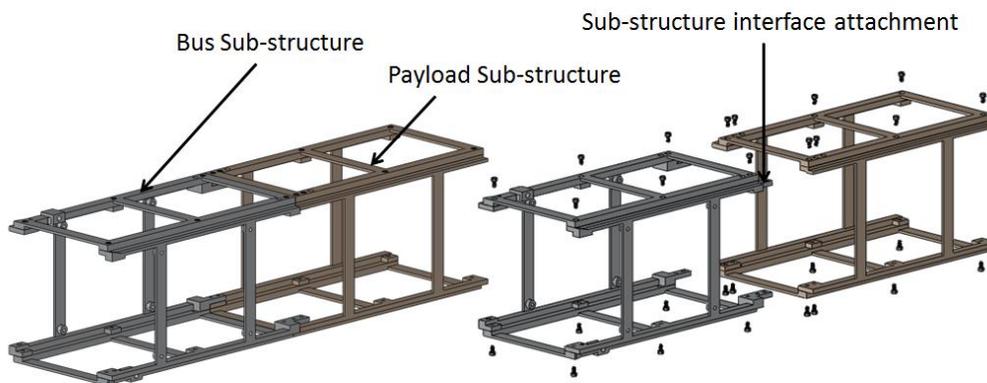


Figure 3 - PEZ Sub-structures

iii. Mechanisms

The mechanisms used for deployments fall into two categories – PEZ deployment and Solar Panel deployment. These two systems are outlined in the diagram below and are later detailed.

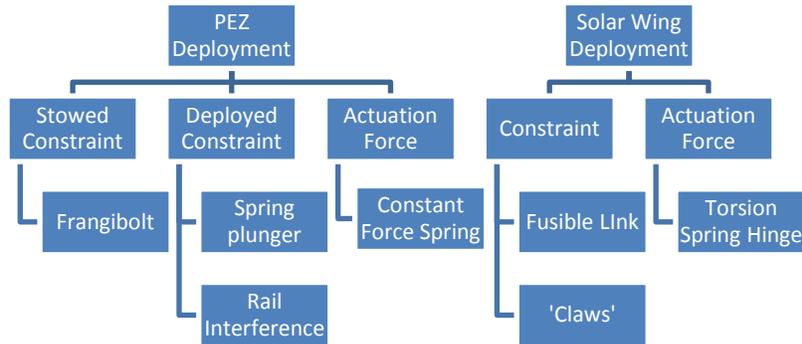


Figure 4 - Deployment Systems

iv. PEZ Deployment

The PEZ deployment force is provided by a constant force spring, which provides a constant force independent of extension length. The spring is mounted such that the motion of the spring re-coiling itself will deploy the Exo-Structure. The motion of the system is retarded by a rail-interference and pin-setting system that is best pictured: Figure 5.

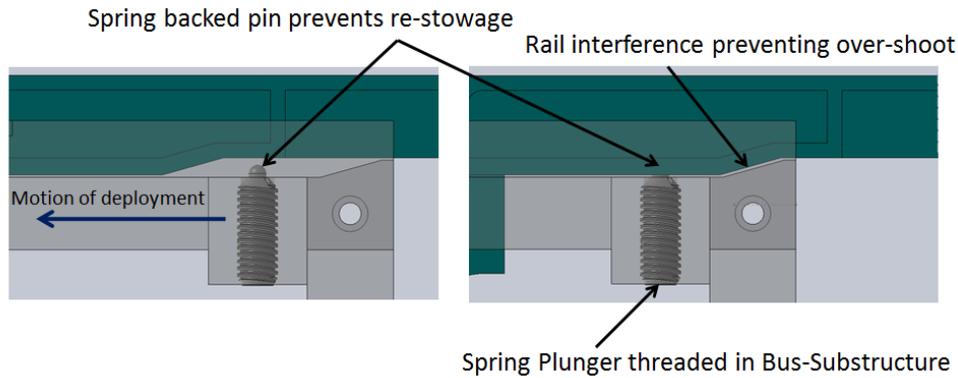


Figure 5 - PEZ Deployed Constraints

The stowed state is maintained by a Frangibolt assembly. The Frangibolt is composed of a shape memory Ti-Ni alloy (SMA) encompassed by an insulated heating element. Once a voltage is applied and the actuator is heated the SMA expands supplying adequate tension to break a pre-notched TiAl6 bolt. This actuation is pictured in Figure 6 below.

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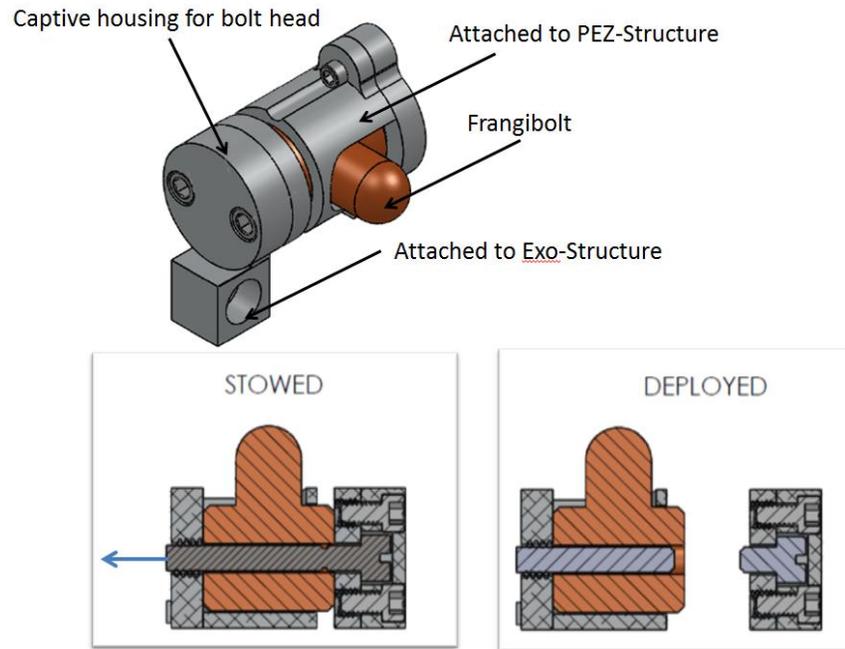


Figure 6 - Frangibolt Deployment

The Frangibolt assembly has two isolated sections that once the bolt is broken, are able to separate from each other and allow the deployment to commence.

v. Solar Panel Deployment

The solar panels are held in their stowed state by claws on either end of the assembly that are affixed to a bracket on the outermost solar panel wing. One set of claws closes to the bottom (bus side) of the structure is attached to the Exo-Structure and is able to rotate by an integrated torsion spring. This claw is held in the 'un-rotated' state as pictured in Figure 7 by the PEZ-Structure. On the converse side of the assembly the claws are non-rotating fixed components that are attached to the PEZ-Structure. The motion of the PEZ deployment will slide these claws out of the bracket thus allowing for solar panel deployment.

To mitigate for vibrational concerns of the assembly, a fusible link has been incorporated into the center of the solar panels. This mechanism is comprised of copper 'bolt and cup' parts that are mechanically fixed with a Bismuth solder alloy that melts at 203F. On the converse side of the bracket (labeled in Figure 8) a Kapton tape heater is affixed. While in the stowed state this system is fixed – and after PEZ deployment, which consequently releases the solar panels from the claws, the Kapton tape heater will be supplied with power subsequently melting the solder and releasing the solar panel wings.

The force required to rotate the solar panels from their stowed to deployed state is provided by a torsion spring integrated into the three hinges on each axis of rotation, see Figure 9.

In order to stop the rotation of the solar panels at the correct angle – 135 and 180 for the first and second wing panels respectively, a hard stop mechanism will be incorporated. The mechanism theorized for the 135 degree panel application is pictured in Figure 9.

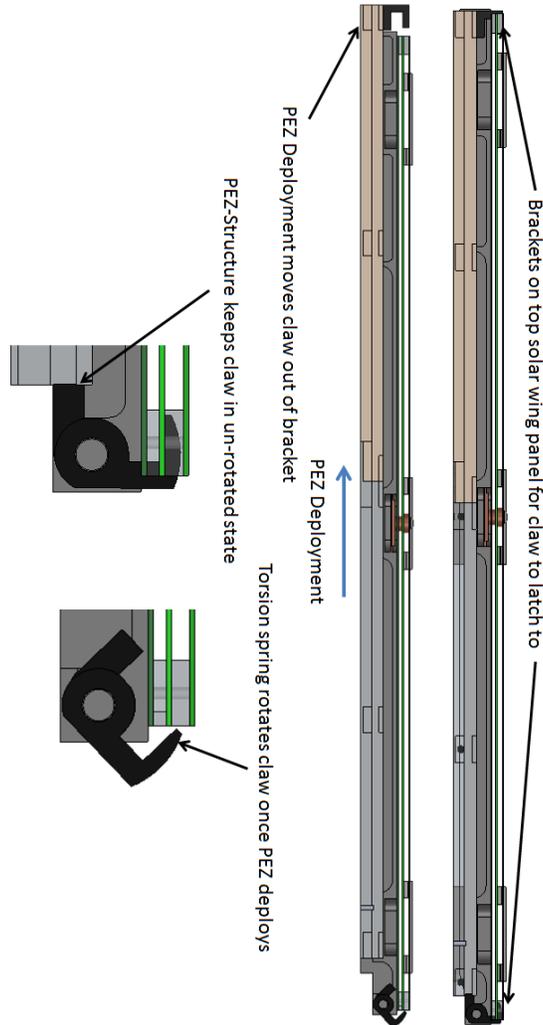


Figure 7 - Claw Deployment

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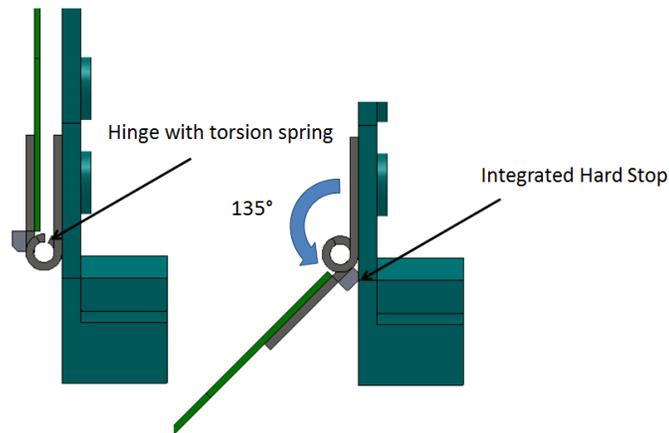


Figure 8 - Hinge and deployed constraint

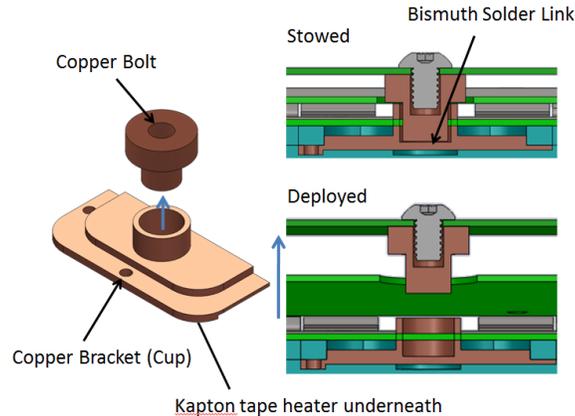


Figure 9 - Fusible Link

vi. ACS Reaction Wheels

The reaction wheels will be manufactured out of Aluminum, similar to the rest of the satellite structure. Each motor will be threaded into an aluminum plate that will be attached to a motor mount PCB. The reaction wheel will be press fit onto the motor shaft. Three motor mount PCBs will be arranged orthogonally to create three sides of a cube while the motor control PCB will make the fourth side of the cube. The two empty sides of the cube are reserved for satellite components not being tested during this flight. The four ACS PCBs will be attached to the structure using special attachment clips designed to interface with the ALL-STAR structure. In addition to the ACS subsystem itself, the ALL-STAR test article will also require a set of ballast to simulate the mass properties of the fully functional satellite. Figure 10 shows this construction, integrated with the bus structure.

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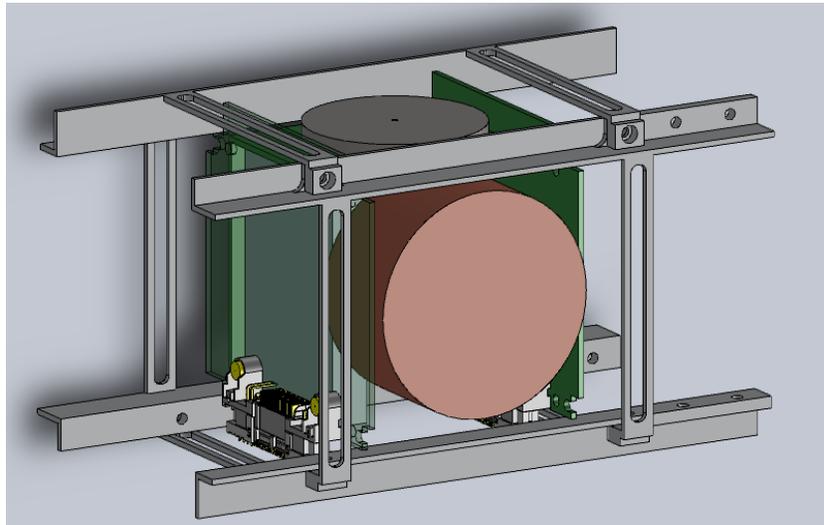


Figure 10: ACS Box

5. Electrical System

The electrical system required during the flight testing will be self-contained within the ALL-STAR satellite. The internal electronics will provide commands to the deployment mechanisms and the ACS components. The power required for the testing will also be provided by the internal electronics and will never exceed 5 watts. For ground operations a commanding computer will be used to make sure that the satellite is programed for the different tests. A bench top power supply will also be required to charge the internal batteries between flights and for testing.

The electronics for the ACS test system will consist of the same motors, motor control electronics, gyroscopes and microcontroller as the final ALL-STAR satellite. In addition to these components, the test ACS system will have a 3-axis accelerometer to stop the test when a prolonged period of acceleration is detected to prevent damage to the motors when the system is no longer in a zero gravity environment. Additionally, the commanding of the ACS system will be simplified to a few switches to elect the test mode, initiate the test and to toggle data collection.

6. Pressure/Vacuum System

No pressure/vacuum systems incorporated in this experiment and no fluid/gas is to be used.

7. Laser System

No Laser System is incorporated in this experiment.

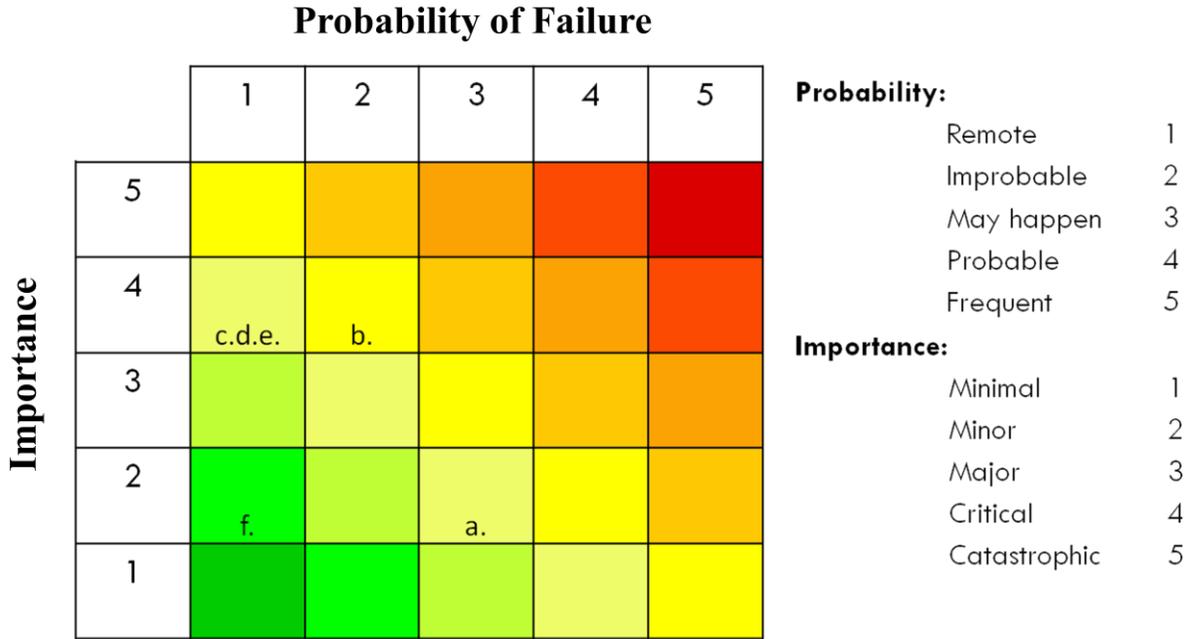
8. Crew Assistance Requirements

This experiment should not require any special duties to be carried out by the Flight Crew.

9. Institutional Review Board

No human test subjects, animal test subjects, or biological substances are incorporated in this experiment.

10. Hazard Analysis



- a. Satellite goes out of control and runs into someone
 - **Consequence:** Because this experiment is free-floating, the satellite has the potential to drift astray and run into someone or something during free float. Since the external panels and shell are being deployed and rely on rails and square edges, it would be difficult to add padding for protection. However the satellite is only allowed to weigh 4 kg at its maximum.
 - **Cause:** If the satellite is not tethered to the aircraft or closely monitored, it runs the risk of floating in any direction and potentially running into someone.
 - **Mitigation:** If the only thing being tested during a free float cycle is a deployment, then the satellite can be tethered to the aircraft. Otherwise it will be closely monitored and surrounded by the ALL-STAR flyers. If required an additional structure could potentially be created around the satellite that would have padding or a cage that would contain the satellite. This solution however, would affect the dynamics of the system and would have to be accounted for when characterizing the behavior.
- b. Breaks during deployment
 - **Consequence:** If the satellite breaks during deployment, it could potentially send small pieces such as springs or bolts floating around the cabin or larger

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pieces such as a broken off solar panel. This would pose a potential threat to personal safety as well as endanger other experiments. Most importantly these pieces would be hard to retrieve and could endanger future missions.

- Cause: This could be caused by weak or faulty connections, or a spring force too strong for the deployment.
 - Mitigation: Thorough and repeated testing on the ground should show that the springs are properly sized and that everything is well constructed. By having a written procedure for integrating the structure, it is even less likely that something will break. However if this does occur, we will have a list of all components and can make sure each piece is accounted for.
- c. Deployment actuation doesn't capture broken bolt
- Consequence: The piece of bolt that is broken off would be shot off in some direction potentially causing damage. This is a very similar hazard to something breaking during actuation.
 - Cause: The cause would be a failure in the capture mechanism. If the box designed to capture the broken bolt comes loose, then the bolt could be free to float around the cabin.
 - Mitigation: Extensive ground tests should lower the risk of this happening and guarantee that everything will remain contained. If this does somehow occur, only half of a bolt needs to be accounted for before the next flight.
- d. Breaks during wheel actuation
- Consequence: If the satellite breaks while testing the attitude control system, it could potentially send small pieces such as the wheels or bolts floating around the cabin. This would pose a potential threat to personal safety as well as endanger other experiments. Most importantly these pieces would be hard to retrieve and could endanger future missions.
 - Cause: If the satellite started to spin out of control and could not handle the forces caused by violent tumbling, or if the jitter caused by the vibration of the motors is too great, then bolts and other pieces could potentially break off.
 - Mitigation: Once again, ground tests should increase the level of confidence in the design. Procedures for proper integration and a physical limit on the maximum wheel speed would prevent anything from happening. Most importantly though the wheels will be inside the satellite structure ensuring that if they were to break or fly off in while spinning, they would remain contained within the structure.
- e. Solder from panel deployment is not contained
- Consequence: If the solder from the center panel deployment is not contained, it could send small solder balls floating around the cabin. This would pose a potential threat to personal safety as well as endanger other experiments.

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Most importantly these pieces would be hard to retrieve and could endanger future missions.

- Cause: Since gravity will not be forcing melted solder downwards, the ALL-STAR deployment mechanism relies on the viscosity of solder to remain attached to the copper coated structure. There is always the chance that solder could “glob off” and solidify while not attached to the structure.
 - Mitigation: Putting a housing around the solder deployment mechanism would guarantee none of it “globs off” and floats around the cabin.
- f. Heater for panel deployment overheats or burns someone
- Consequence: If the heater for the panel deployment overheats, it could potentially burn someone or damage the experiment, however it is unlikely to cause harm to anyone or damage other projects unless coupled with another problem such as the first risk listed.
 - Cause: This could be caused by improper control from the electrical components.
 - Mitigation: Insulating the heater from other conductive materials will help prevent anyone from getting burned and testing on the ground will insure the heater is operating as expected. Temperature sensors can be added to monitor the heater.

11. Tool Requirements

The tools that will be needed for the test have not yet been finalized. A final list should go out with the Test Equipment Data Package, submitted after the proposal has been accepted. However, some basic tools, such as Allen wrenches, open-end wrenches or adjustable wrenches, screw drivers, and possibly a portable soldering iron will be needed. The experiment in whole should not require many tools once in the aircraft. The ALL-STAR ground crew will have more equipment for resetting the deployment actuation between flights.

12. Ground Support Requirements

This project should not require any additional ground support from the RGSFOP

13. Hazardous Materials

No hazardous materials are incorporated in this experiment.

14. Procedures

i. Ground Operations

The ground operations will consist of setting the satellite up for deployment actuation and ensuring that all of the electronics are working. Most ground based tests should be completed prior to flight week, however between flights, it may be necessary to rerun some of these tests.

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ii. Pre-Flight

Very little set-up will be required prior to flight. The first test will be a deployment test only, and therefore can be tethered to the aircraft. This will be set-up during pre-flight while pictures are being taken of the system. Everything else should already be set to go.

iii. In-Flight

During the first microgravity cycle, the deployment system will be tested by sending a signal to the actuation, which will release the solar panel wings then the external shell will be deployed. This will be videotaped and photographed extensively. During the 2G ascent, the system will be untethered from the aircraft in preparation for an attitude control test. With the structure and wings deployed, the satellite will be instructed to rotate to a specific location at a specific rate. On board sensors will be taking data and video and pictures will record visually what occurs. During the next 2G climb, the satellite will be reset back into its stowed configuration, though the actuation system cannot be reset on flight. Once back in zero gravity, the satellite will be released and the structure and drawer should deploy smoothly. In the next zero gravity cycle, the attitude control system will run its test again. This repeats until the end of the flight.

iv. Post Flight

Before the next flight, the videos and pictures will be looked at to identify any problems seen on the first round. The sensor data from the satellite will be analyzed to ensure all values were within their expected range, specifically, data from the gyroscope and accelerometers. If there are any unexpected anomalies, the ground crew will attempt to solve and retest those specific issues. If not, then they will reset the deployment actuation system and proceed with tests similar to the first flight.

III. Outreach Plan

The ALL-STAR team operates out of The Colorado Space Grant Consortium which has a very strong K-12 Outreach program. ALL-STAR students are working with this Outreach office to set up a special volunteer activity to be run entirely by students working on the microgravity flight opportunity. The goal of the outreach would be to inspire younger students, specifically 7th-12th grade, to pursue a career in math and science. During this outreach, they will hear a short speech about the microgravity program and the ALL-STAR payload, then they will be shown a video showing the progress of the team from preparation and testing through flight day videos. Students will then give a short lecture on conservation of momentum and how that is used to control a satellite's attitude. Examples will be given of satellites that use reaction wheels or control moment gyros for pointing, then the high school or middle school students will break into small groups for the activity. Each student will get the chance to sit or stand on a rotating platform while holding a spinning bicycle wheel, similar to what is being demonstrated in Figure 11. When they turn the wheel sideways they should rotate, demonstrating how Control Moment Gyros work.



Figure 11: Bicycle wheel demonstration^[3]

This outreach can be performed at Space Grant or at any school interested in hosting an outreach. There are no current plans to make this a reoccurring outreach; however this would be an easily reproducible activity if someone wishes to continue supporting it. No schools have signed up for the outreach at this time, but the Outreach program at the Colorado Space Grant Consortium hosts Upward Bound every summer and has offered to let the ALL-STAR students work with the students for one of their activities^[4].

To further promote our project and the NASA Microgravity program, the ALL-STAR team will be establishing a website in the near future. The website will contain information about the progress of the project, pictures from the development, and results from the flight when it is complete. The website will also advertise the Outreach Opportunity and give a general overview of the microgravity experiment.

October 27, 2010

IV. Administrative

1. Budget

Item	Unit Cost	Qty	Total Cost
Travel			
Plane tickets	\$ 250.00	6	\$ 1,500.00
Hotel	\$ 150.00	36	\$ 5,400.00
Rental Car	\$ 75.00	9	\$ 675.00
Food	\$ 45.00	54	\$ 2,430.00
Total			\$ 10,005.00
Structures Hardware			
Raw Materials	\$ 410.00	1	\$ 410.00
Fasteners	\$ 200.00	1	\$ 200.00
Tooling	\$ 130.00	1	\$ 130.00
Post Processing	\$ 200.00	1	\$ 200.00
Mechanisms	\$ 1,300.00	1	\$ 1,300.00
Total			\$ 2,240.00
Attitude Control System Hardware			
Raw Materials	\$ 20.00	3	\$ 60.00
Fasteners	\$ 200.00	1	\$ 200.00
Motors	\$ 167.00	4	\$ 668.00
Control Electronics	\$ 900.00	1	\$ 900.00
Sensors	\$ 480.00	1	\$ 480.00
Total			\$ 2,308.00
Total Cost			\$ 14,553.00

Funding Source	Amount of Funding
Colorado Space Grant Consortium	\$5,000
Industry Partnership	\$10,000
Total	\$15,000