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# Suitability of Nickel Chromium Wire Cutters as Deployable Release Mechanisms on CubeSats in Low Earth Orbit

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# Suitability of Nickel Chromium Wire Cutters as Deployable Release Mechanisms on CubeSats in Low Earth Orbit

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**Abstract**. This paper investigates the suitability of a nickel chromium wire cutter (NCWC) for use on the GASPACS (Get Away Special Passive Attitude Control Satellite) Mission. It is intended that when activated the NCWC will cut through a restraining wire and thereby release the stored energy of the deployable AeroBoom. Flight worthiness is based on favorable performance during functional testing to address known issues with the NCWC, such as wire burn through and cutting issues. In-depth testing discussed in this paper includes: Manufacturability of the NCWC, including analysis of possible acceptable performance errors induced from inefficiencies in the assembly process, functional testing of a prototype NCWC under flight conditions, and analyzing the safety margin between the flight running conditions and the point of failure (destructive testing). The results from these tests support the conclusion that the current design of the NCWC will successfully support the GASPACS mission in deploying its AeroBoom Experiment.

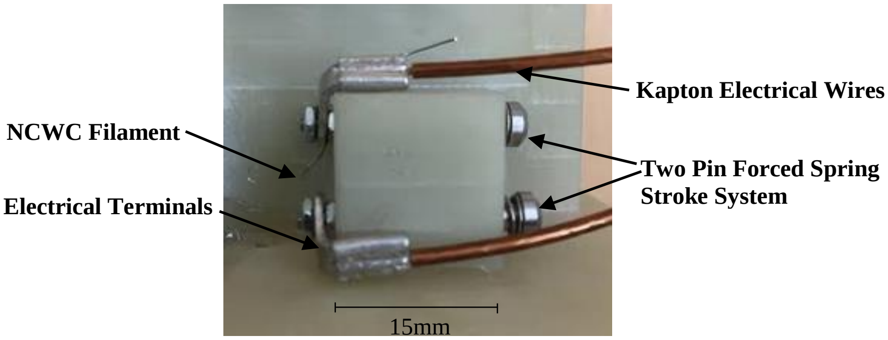

Figure 1: NiChrome Wire Cutter (NCWC) assembly in projected flight configuration and integrated with GASPACS support structure

# INTRODUCTION

Beginning in 2012, the Utah State University Get Away Special Team began developing a CubeSat as a technical demonstration of inflatable technology in space called the AeroBoom. The AeroBoom is a self-contained inflatable boom with a flexible fiberglass layer, impregnated with a UV curing epoxy. After the AeroBoom is deployed it will be exposed to sunlight and cure, solidifying the deployed shape of the boom. The self-inflating boom is a response to NASA's Critical Technology Development for Human Spaceflight Directorate.

Launched through the NASA ELaNa[1] (Educational Launch of Nanosatellites) mission directorate, the small 1U (10cm x10cm x10cm) CubeSat will be fitted to a NanoRacks[2] PPod (canister for storing and deploying multiple CubeSats) and then attached to the exterior of the International Space Station. Following a command from NASA mission control, the PPod door will be opened and the CubeSat cargo pushed out into low Earth orbit.

Based off of the designers of the PPod's (cal-poly) own predictions, any given CubeSat will likely have a tumble rate of 2-5°/sec deploying from the PPod. However observations of CubeSats deploying and testimonies from other CubeSat missions suggest a much higher deployment tumble rate of approximately 20-30°/sec[1]. These tumble rates often limit the amount of science that can be achieved because of the lack of pointing control or the aligning of the satellite with a given axis. Active attitude control measures such as magnetorqers or reaction wheels require relatively large amounts of power which can only effectively be delivered by larger platforms thus requiring larger production and launch costs. Passive attitude control measures, such as permanent magnets and gravity gradient stabilization, are not effective at a large range of orbits including the highly used 325km x 51.6 inclination. Aerodrag stabilization created by the deployment and curing of the AeroBoom on the GASPACS satellite would cause a completely passive 2 Axis stabilization about the velocity vector of the CubeSats orbital path.

After PPod deployment GASPACS will spend the next 30 minutes in a safety sleep mode, after which its antenna will be deployed and communications with the USU ground station will be started. A few days later the GASPACS satellite will deploy its AeroBoom. The actuation AeroBoom system is very simple, the gas stored within the inner layer of the AeroBoom causes the boom to swell and expand into its full elongated shape when in a vacuum. The whole system works off the difference in pressure between the stored gas in the boom and the vacuum of space.  As such, deployment of the AeroBoom requires only that it is released to the vacuum of space. Therefore a release mechanism was designed around the need to be able to restrain the pressure of the AeroBoom during launch and PPod deployment while still reliably deploying the boom at the necessary time and fitting it into the cramped spaces of the 1U CubeSat.

Primary options for deployment devices used in current satellites are: Mechanical motors/actuators, explosive bolts, frangi bolts, and nickel chromium cut wires. It was determined that the motors and actuating devices would be beyond the budget for GASPACS and require significant volume capacity. Explosive bolts are prohibited by the NASA CubeSat guidelines. A significant analysis was conducted regarding the use of frangi bolts from Tini Aerospace; however, the system limited the amount of room in the AeroBoom storage bay as it would be required to be mounted in the middle of the storage bay. Nichrome wire cutters offered the best optimization of volume and capability. As no nichrome wire cutters are available commercially the entire system had to be developed and tested by the USU Get Away Special Team. This indicated a final but important design requirement. The NCWC needed to have a very simple design that could be easily and consistently built by students.

## DESIGN

The NCWC adapted for use on the GASPACS mission is a two-pin forced spring stroke mechanism with an 11mm nickel chromium heating element. The two pin forced spring stroke design consists of two pins or sleeved screws, which are embedded in to a block of G10, being forced in to the open position by springs surrounding each pin. An 11mm piece of nickel chromium wire (30AWG) is connected between each pin in addition to power terminals. In flight configuration the NCWC will be forced into a compressed position by the restraint wire. Because the NCWC is compressed against the force of the springs it applies a constant force against the restraint wire. This constant force provided by the springs not only provides a vibrational damping effect during launch, but it also ensures a consistent cut of the restraint wire through a dynamic range of temperatures. When a specialized constant current circuit is activated, the nichrome wire will receive approximately 2.3 amps of current which will heat the element up to 260C melting the restraint wire. As the wire begins to melt the springs force the nichrome wire to slice directly through the restraint wire while at the same time moving the nickel chromium wire out of the way preventing re melting of catching of the remainder of the restraint wire. A second NCWC is on board as a backup to the primary in case the primary is damaged during launch or during operation. The full system contains only 28 parts and can be assembled in less than half of an hour. Allowing it to be simply and quickly built by undergraduate students with limited technical skills.

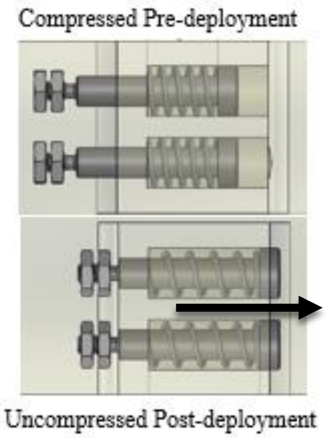

**Figure 2.** Front View of the NiChrome Wire Cutter assembly showing the compressed and uncompressed states of the forced stroke system

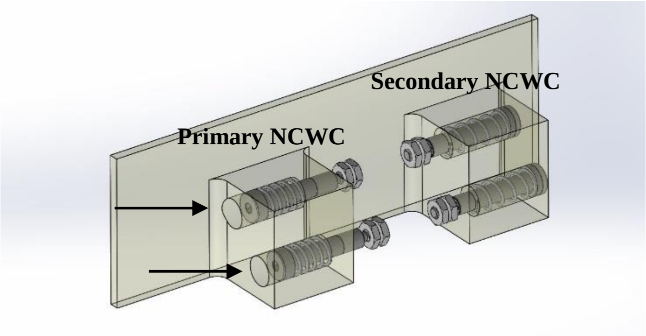

**Figure 3**. ISO View of the NiChrome Wire Cutter assembly showing the compressed and uncompressed states of the forced stroke system (note the offset of the pins)

## Circuit

A special circuit design is necessary for consistent activation of the NCWC. Given too little power the cutter may not heat properly and fail to cut the release wire. Given too much power the nichrome may burn out or simply cut too quickly through the release wires allowing the melted fibers to re-fuse together. The circuit chosen for the GASPACS mission is based on a LED constant current driver. This allows one of the latch up switches on the GOM space

NanoPower to activate the NCWC and control its power output from the batteries. The circuit was chosen for its simplicity and ease of configuration based on the cutter. For instance the output of the driver can be modified by changing the in line resistor values. This allows the system to be adapted to any change in resistance of the NCWC. Most importantly the system is able to deliver a constant 2.3Amps of current to the NCWC allowing the

## Free Length

Free length is the length of the nickel chromium wire free to warm up when exposed to an electrical circuit. Research done by the NRL (Naval Research Laboratory[4]) identified the optimal free length to be between 10- 30 mm long. The specific free length for any given design of NCWC is dependent on: 1. Operating current, 2. Desired operating temperature, 3. Desired safety margin, 4. Physical constraints, and 5. Wire type. Understanding these variables, a free length of 11mm was selected for the GASPACS mission. At that length the identified resistance would be 0.7ohms

## Release Wire

The release wire is attached to the lid and ensures the lid, or storage bay cover, remains in place during the violence of the launch and increase in physical force from the inflated AeroBoom before deployment. The release wire is made from three intersecting loops, the main loop and two supporting loops, each of which can be individually tightened and adjusted to prevent dislocation of the bay cover. Catastrophic failure of the release wire may lead to the premature deployment of the AeroBoom. A slight failure of the release wire could allow the bay cover to dislodge and expose the AeroBoom to UV light, solidifying it in its compressed and stowed state. There are many materials available for use as the release wire. These include

Vectran, Kevlar, and various polymers. The chosen release material for the GASPACS mission is Dyneema. Dyneema has a melting point of 150°C[5], which is significantly cooler than that of the other considered materials. Additionally the strength of the Dyneema is comparable to the other materials. The lower melting point of the Dyneema release wire poses a significant advantage to the NCWC because it allows the filament to significantly surpass the melting point of the Dyneema release wire, but maintain a temperature well under the failure point of the nickel chromium wire, at approximately 982°C[6].

## TESTING

Design Reliability**:** For the NCWC system to be accepted and considered a reliable and fully functional system, its manufacturing process must be repeatable. A block of testing was completed in order to identify the variations possible with in the design and the amount of manufacturing error probable in the final product.

Test Set Up: Three 11mm and three 9mm nickel chromium filaments were assembled. First each filament's resistance was measured in order to determine the variation caused by the production process. Each filament was then connected to a power source independently and put through a test regime that consisted of turning on the power source and tuning it off every 150 seconds for 1500 seconds. The test was repeated until each of the filaments had been tested. The data was processed and the data sets from the 9mm and 11mm were compared.

| 9mm | Average Resistance Ω | Dev |
|---|---|---|
| Filament 1 | 0.93 | 0.15 |
| Filament 2 | 0.90 | 0.00 |
| Filament 3 | 0.93 | 0.06 |
| Results | 0.92 | 0.07 |

**Table 1.** 9mm Free Length Resistance Results

| 11 mm | Average Resistance Ω | Dev |
|---|---|---|
| Filament 1 | 1.10 | 0.17 |
| Filament 2 | 1.00 | 0.00 |
| Filament 3 | 1.07 | 0.06 |
| Results | 1.06 | 0.08 |

**Table 2**. 11mm Free Length Resistance Results

Phase 1 Results: Tables 1 and 2 show the average measured resistance for each filament set. The values shown were averaged from 5 measurements of the resistance. The average value for each filament and its deviation was found and then the similar filament results were averaged. A comparison of Table 1 and Table 2 was then conducted. The major difference between the two sets of filaments was change in length by 2 mm. According to the measured results, the 2mm difference yielded a resistance difference of 0.14Ω resulting in 0.07Ω/mm of filament free length.

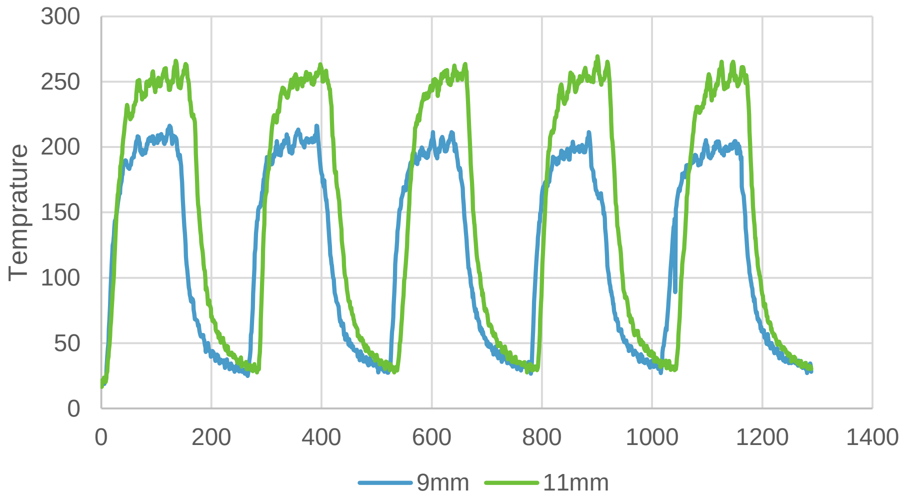

Figure 4: Graph displaying the NCWC temperature over time during repeated cycles of heating and cooling

Phase 2 Results: Figure 1 displays the results from the testing regime of the design reliability test. The figure is a graph which displays two different but similar lines. The lines represent the temperature as a function of time of the different free lengths tested in phase 1. Each line comprises the average temperature fluctuation of each the three filament sets in tables 1 and 2. As time increases each filament was activated for 150 seconds and then allowed to cool for the same amount of time. The measured average peak temperature for each on/off period for the 9mm filament was 205.6°C. The measured average peak temperature for each on/off period for the 11mm filament was 260.3°C. The difference in the two temperatures was found to be 54.7°C. This would indicate that per mm of free length the nichrome wire the temperature increases 27.37°C. Offset in the graphs is caused by instrument timing errors; however, these effects are inconsequential.

Functional Testing: Addressing one of the largest concerns of the NCWC system is its ability to operate with in the space environment. For the GASPACS mission this would include vacuum pressures below 1.0x10^-4 torr, and thermal fluctuations from -60°C to 60°C. Ideally the NCWC would be able to engage and sever the release wire without causing damage to itself or to its surrounding support structure.

Phase 1 Testing: A prototype NCWC was evaluated in an equivalent environment that it would operate in LEO.  Holding at room temperature, the NCWC was activated for longer and longer time periods, starting with 10s, and continuing on to 20s, 30s, 40s, 50s, and 60s. In doing so the heating profile of the device can be determined; that is to say, the rate at which the temperature nichrome wire reaches its maximum, the rate at which its temperature decreases back to room temperature, and the total power used can be observed. Because the total triggering time will be less than 60 seconds on mission, incrementing the activation time from 10 to 60 seconds allows understanding of a number of different possible heating profiles and its effects on the AeroBoom system.

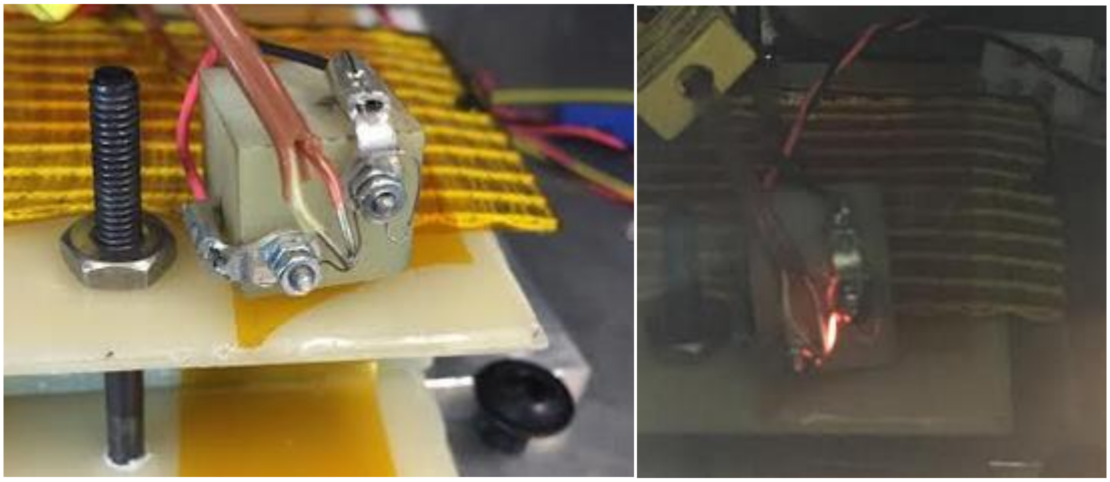

Figure 5: NCWC set up during functional testing. Left side, close up of NCWC block.  Right side, activated NCWC under vacuum.

Test set up: The NCWC prototype block was mounted on an AeroBoom test structure and placed in a Utah State University department of engineering .75 cubic meter vacuum chamber. A type K thermocouple was mounted so that the tip was in contact with the nichrome wire cutter filament. Two other type K thermocouples were placed within the test structure monitoring the actual AeroBoom in its folded state, and one other type K thermocouple was placed on the lid of the test structure. (These extra thermocouples are intended for other non NCWC related testing; however, the data from these sensors is discussed as it shows the effect that the NCWC has on the entire system.

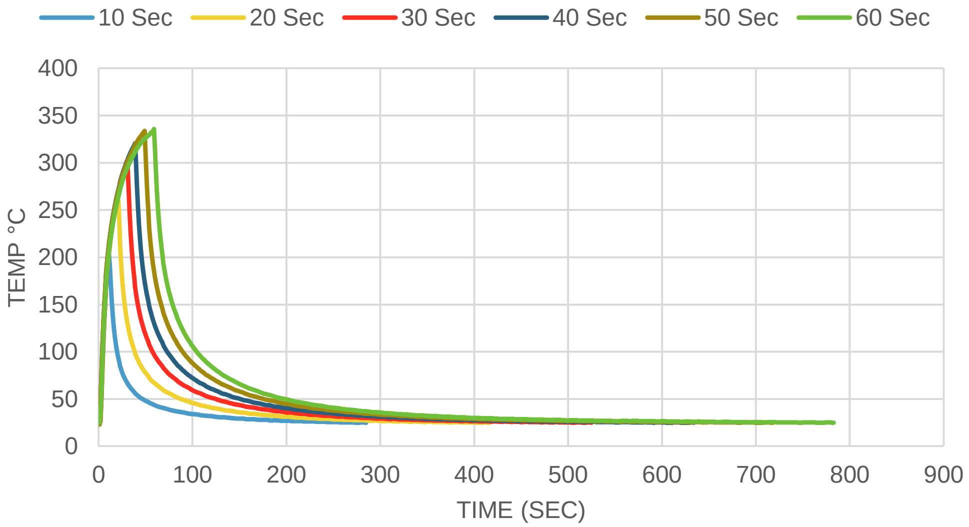

**Figure 6**. Graph of Temperature of the NCWC Over Time Comparing Heating Duration Times

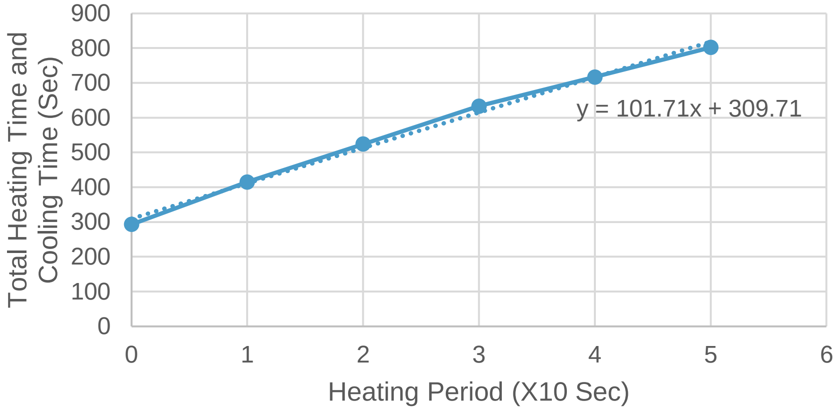

**Figure 7**. Graph showing the increase in total heating/cooling time as a result of total heating time as shown in Figure 6

Phase 1 Results: As depicted in figures 5 and 6 the NCWC while under a vacuum of 4.0x10^-2 torr, was triggered for increasingly longer periods of time ranging from 10 to 60 seconds in increments of 10. In each case it was observed that maximum temperature increased as well as the total cool down time. Plotted in figure 7, a linear relationship was observed that for every 10 second increase in heating time there is an increase in the total required running time by 101.71seconds. As the increase in heating time is 10 seconds this would indicate that the increase in cooling period is equivalent to 91.71seconds. The maximum temperature range found during the test ranged from 204.5°C during the 10 second activation event to 333.6°C during the 60 second event in a nonlinear fashion. The average time to reach 150°C (the melting point of Dyneema) was 5.5 seconds.

Phase 2 Testing: In an attempt to identify the limitations of the NCWC system long duration testing was conducted. The NCWC was activated and left in its activated state for over 15minutes. This long duration test demonstrates at the extreme limit the absolute maximum thermal load that will be placed on the wire filament and its surroundings. The length of the test shows the absolute durability of the system in its flight configuration.

Test Set Up: The same NCWC prototype block set up in phase 1 function testing was used, and under the same tests conditions.

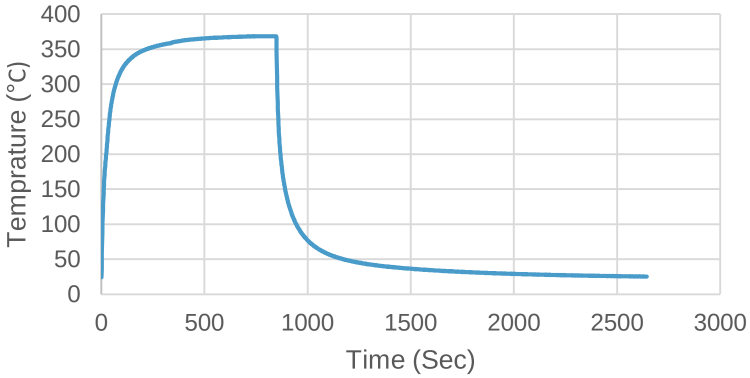

**Figure 8.** Graph depicting the long term performance of the NCWC in actual flight conditions.

Results of Phase 2: Activated for 15 minutes (900seconds), the NCWC in-flight conditions heated to a maximum temperature of 366.5°C. However, the cutter reached a temperature of 330°C in 140 seconds, the maximum expected operating temperature as described in phase one. This means that over a period of 760 seconds (the bulk of the activated period) the nichrome wire only increased in temperature 36.5°C. The cooling of the NCWC was similar to those seen in other tests. There was a rapid drop to a temperature less than 100°C, and then a long slow decay to room temperature. The rate of decay is inconsistent with the model found in phase one showing that phase one results are only applicable to short duration activation events such as those observed during the GASPACS mission 0-60 seconds. The longer cool down period is likely a direct result of thermal energy transfer to structural support mass around the NCWC.

Forced Critical Failure Testing: During all phases of testing, a critical failure of the nickel chromium filament was never observed. In an attempt to identify and understand the approximate point of failure of the system, testing was conducted. Testing focused on demonstrating the margin of safety by inducing a critical failure of the filament and comparing those results against the prescribed operating conditions of the NCWC on orbit.

Test Set Up: 15 11mm filaments were connected independently to a power supply. Slowly the amperage was increased starting at 2.3 amps (the specified operating current for the GASPACS design) until the filament wire failed.

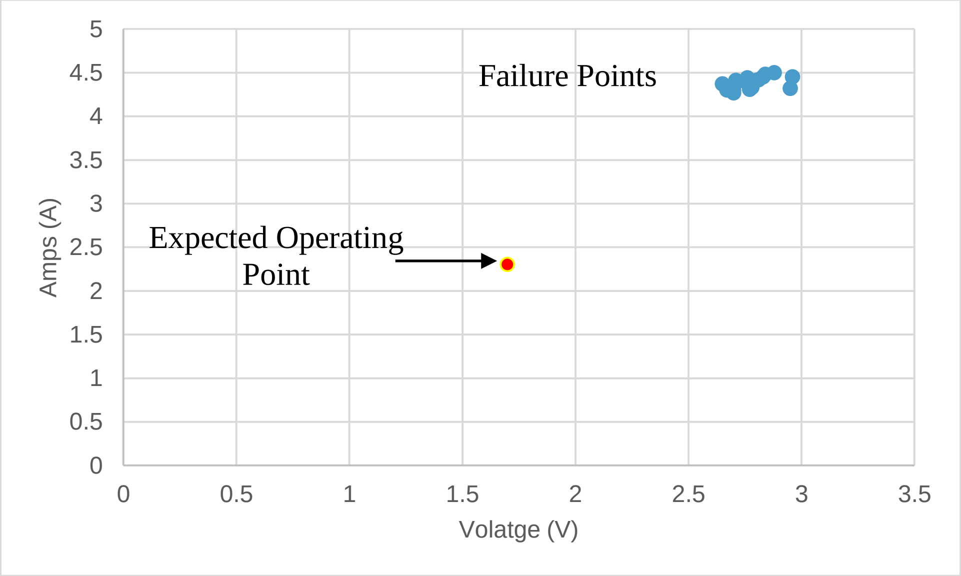

**Figure 9**. Depiction of failure points of an 11mm nickel chromium filament and its actual operating point in terms of power.

Forced Critical Failure Results: As each nickel chromium filament was exposed to more and more power, each one glowed brighter and brighter until the filament could not withstand the energy flow and catastrophically failed. The graph shown in figure 6 describes the power at which the filaments failed in terms of Amps and Volts. Based on the data, the failure point of the 30AWG nickel chromium wire used in the GASPACS design is approximately 12.21±1.6 watts.

## CONCLUSIONS

The final results of testing positively show the suitability of the NCWC design for use on the GASPACS mission. As identified in the functional testing, the average time to 150°C or the minimum melting point temperature of the Dyneema restraint wire is 5.5 seconds. This is a very positive result as it shows a slow enough heating rate to prevent the restraint wire from re-fusing after being cut.  For safety and for a buffer against the external temperature changes the minimum triggering time will be 11 seconds. This insures a 2x safety factor over the average restraint wire melting time. Applying the model found in figure7, the predicted max temperature would be 212.9°C which is consistent with other findings in the phase 1 of the function testing. At that temperature there is a 4.6x safety factor over the failure temperature while reaching 1.4x the minimum melting point temperature. This indicates that not only will the NCWC significantly surpass the minimum requirements for cutting the wire, but it will maintain a safe operating level. Additionally based on results from functional testing, it is expected that the cutter will operate at 4.6W, again showing a healthy safety margin of 2.7x while the failure point of 12.21W was identified in the critical failure testing.

These results represent a minimum use situation for which the lowest safe temperature is achieved. Further analysis of the results also show a maximum efficiency temperature. According to the results in figure 3 and 4, at approximately 50 seconds the rate of temperature increase becomes less significant resulting in a loss of efficiency. Therefore, based on testing results, 50 seconds is the longest efficient activation time possible. In accordance with figure 3, the expected temperature of the filament will reach 336°C, which is 2.24x the minimum cut temperature, but still maintains a 2.9x safety factor below the critical failure temperature.

Using the 11 second activation as the lower limit and the 50 second activation as the upper limit an expected performance model has been found. Because both the lower and upper limit have exceptional safety margins, the design is acceptable for use on the GASPACS mission. Assembling the entire system into its flight configuration including its specialized circuitry and AeroBoom, and conducting all up tests is the next step for final validation of the NCWC system and the performance limits described in this paper. Further understanding is needed for powering the system from batteries and in cold and hot conditions while under vacuum. Furthermore a fully loaded AeroBoom vibrational analysis needs to be conducted to understand the damping effect of the spring actuation system. Improvements in materials and manufacturing techniques will improve its ability to integrate with the GASPACS AeroBoom. In late may the NCWC system along with a prototype of the AeroBoom system will be tested in a near space environment on a high altitude balloon flight.

## *The Appendix*

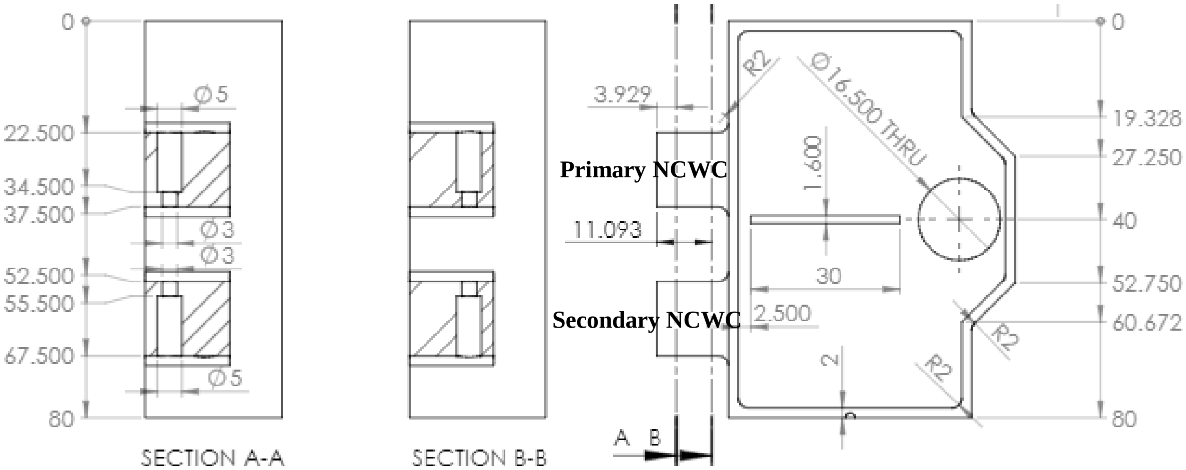

**Figure 10**. Diagram of the G10 fiberglass AeroBoom storage bay used on GASPACS including the structural support for the two NCWC devices.

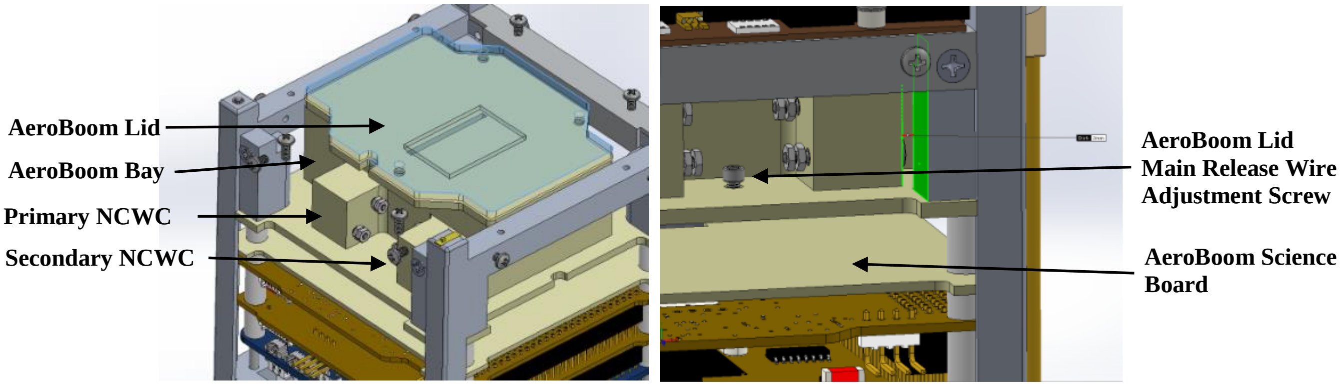

**Figure 11**. Solid Works models of the AeroBoom storage bay and cover, NCWC/support structure integrated with the rest of the GASPACS CubeSat to give size and location perspective.

| **NCWC Cost Analysis** | | | | | |
|---|---|---|---|---|---|
| **Item** | **Manufacturer** | **Order Amount** | **Cost** | **Amount Per AeroBoom** | **Cost Per AeroBoom** |
| Short vented screw | 93235A077 McMaster Carr | 5 | $5.76 | (x1) | $1.15 |
| Long vented screws | 93235A081 McMaster Carr | 5 | $14.07 | (x2) | $5.63 |
| Small hex nut for vented screws | 91841A003 McMaster Carr | 100 | $14.07 | (x6) | $0.84 |
| Shoulder screws for nichrome | 90278A440 McMaster Carr | 1 | $6.43 | (x4) | $25.72 |
| Thin hex nut for nichrome | 90695A025 McMaster Carr | 100 | $3.64 | (x8) | $0.29 |
| High Temperature Nickel Chromium Wire | 8880K79 McMaster Carr | 175' | $12.83 | 7" | $0.04 |
| Wire Terminals | 8429T11 McMaster Carr | 10 | $6.25 | (x4) | $2.50 |
| Kapton Wire 26 AWG | 112366 Accu Glass Products | 30' | $37.00 | 14" | $1.44 |
| 302 Stainless Steel Compression Spring | 9002T15 McMaster Carr | 6 | $6.62 | 4 | $3.31 |

**Table3.** Materials List for NCWC used on GASPACS Mission (Note the G10, and Dyneema is not Included)

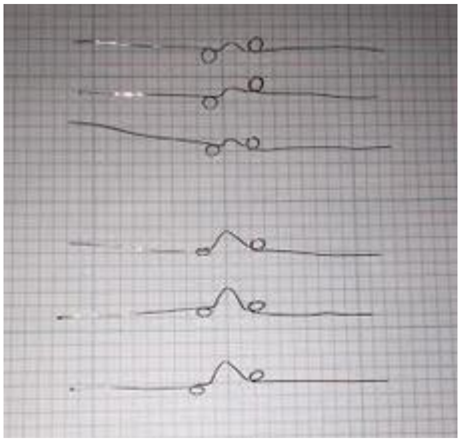

**Figure 12**. 9mm and 11mm 30 AWG nickel chromium filaments used during Design Reliability testing.

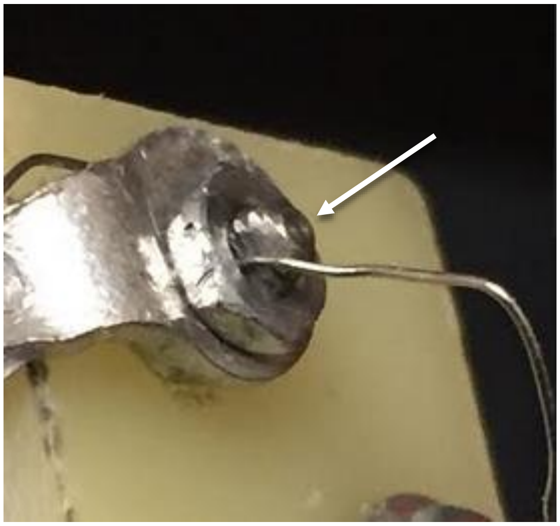

**Figure 13.** Close up of NCWC filament terminal (Note pin threads are faced in order to prevent slipping of the filament wire, it is at this interface that additional testing with thermal adhesives should be conducted)

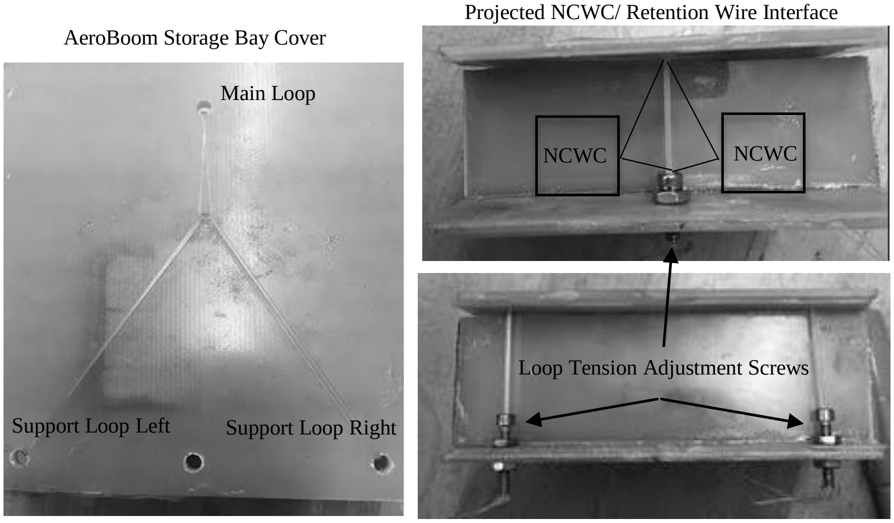

**Figure 9**.  Images of the release wire system used on GASPACS mission to restrain the force of the AeroBoom from escaping and prematurely deploying, together with the NCWC this represents the ful1 deployment mechanism. The above images are of an AeroBoom structural mock up used for understanding fit and spacing within the CubeSat and as such does not have NCWC installed. In the upper right hand corner is a representation of how the retention wire would be integrated with the NCWC. (Note the screws used to adjust tension of the release wire)

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