

SOLAR STRUCTURES PROGRAM

Craig J. Kief

**COSMIAC at UNM
2350 Alamo Avenue SE, Ste 300
Albuquerque, NM 87106**

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Final Report

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**AIR FORCE RESEARCH LABORATORY
Space Vehicles Directorate
3550 Aberdeen Ave SE
AIR FORCE MATERIEL COMMAND
KIRTLAND AIR FORCE BASE, NM 87117-5776**

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//SIGNED//
JESSE MEE
Program Manager

//SIGNED//
JAMES LYKE
Tech Advisor, Space Electronics Protection Branch

//SIGNED//
JOHN BEAUCHEMIN
Chief Engineer, Spacecraft Technology Division
Space Vehicles Directorate

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14. ABSTRACT The purpose of this research project was to explore the various aspects of solar power with a particular focus on nanosatellites. The team at the University of New Mexico's COSMIAC Center utilized a solar array, electrical power system and battery unit to do research on the various aspects required to be able to create a reliable power system for nanosatellites. The solar array was a six wing deployable array from the MMA Corporation. The electrical power system was from the Clyde Space Corporation and the batteries were from the GomSpace Corporation.					
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1. Summary

This report describes work proposed by the University of New Mexico (UNM) to develop a series of solar powered balloon and glider systems to allow for testing of electronics in high altitude and extreme temperature environments.

2. Introduction

The current trend in nanosatellites is the use of a standard called the CubeSat [1]. The CubeSat form factor is described with the use of “U” for units. A 1U is 10cm x 10cm x 10cm. A 6U is 10cm x 20cm x 30cm. UNM completed the design, build and launch of a 1U CubeSat called Trailblazer [2] (see Figure 1) that was launched in November of 2013 upon an Operationally Responsive Space (ORS) mission [3]. In addition, Configurable Space Microsystems Innovations and Applications Center (COSMIAC) is working to complete a 6U spacecraft called Scintillation Observations and Response of The Ionosphere to Electrodynamics (SORTIE) for launch in late 2015. A model of this spacecraft is shown in Figure 2. These small spacecraft concepts provide a low-cost solution for testing electronics in flight. However, before choosing one over the other, it is important to have power systems that are reliable, affordable and in the right form factor. Currently, the bulk of available CubeSat power systems are supplied non-U.S. The main focus of this work was related to developing and testing power systems with a future capability for nanosatellite use in extreme temperature environments.



Figure 1 Trailblazer Satellite

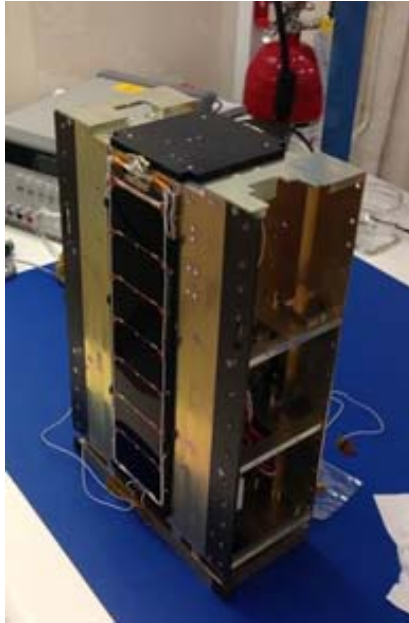


Figure 2 UNM's ORS Squared Satellite (SORTIE satellite similar in design)

The team said that they would use the provided funds to complete three major goals:

1. Perform an analysis of the various solar panel systems for flight. The team proposed to create a series of tests to be applied to the selected available solar panels. The various solar articles will be tested for their ability to perform for terrestrial as well as space missions. Simple tests that are repeatable will be created and they will be applied to a variety of different solar panel systems. A basic framework will have to be developed by which the panels can be compared.
2. Develop a control system for the flight articles. This control system will not only have to interface to a solar electronics system but also control a flight type article. The plan that is envisioned is to utilize the existing series of glider platforms available at COSMIAC as a baseline for the system. What will be necessary is to modify the existing power and control systems to accommodate the new solar power supply systems.
3. Perform flights of the prototype system. It will be important to obtain flight information about the developed system. Although modeling will give a significant amount of detail, only by flying the prototype will it be possible to obtain real data in a high altitude environment. The team routinely performs flights of the balloon program with students.

3. Methods, Assumptions, and Procedures

The plan involved obtaining parts, creating designs and then testing them in connection with a variety of different CubeSat form factors with differing motherboard combinations.

Progress has been made on these goals and the details are provided below.

Goal 1: Several different solar array systems were acquired, tested and analyzed. Once the team was working on this project, an opportunity arose to involve actual flight hardware from a different satellite mission. These opportunities were exploited to take full advantage of available systems and provide the best return on investment for Air Force Research Laboratory (AFRL).

All satellite power systems consist of three parts: Electrical Power System (EPS), batteries, and solar arrays. Currently, the majority of the small satellite parts that fit into these three categories are made by foreign companies such as the Clyde Space Corporation [4] and the GomSpace Corporation [6, 7]. This creates a large problem for American nanosatellite developers due to export issues with dealing with foreign nationals. The team of students and researchers at COSMIAC had to design and integrate all three available systems (EPS, batteries and solar arrays) for testing by utilizing often broken or defective systems from other projects as models or starting points. This provided the team with the opportunity to learn more about these systems as well as providing a challenge for students from a research and engineering perspective.

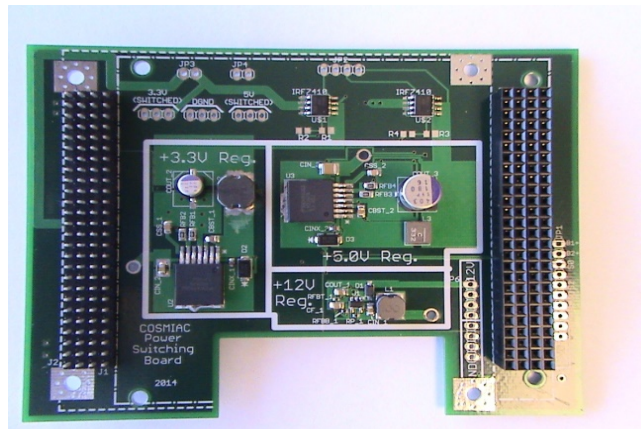


Figure 3 Voltage Regulator Board

- i. EPS – The team started with a Clyde Space power system for CubeSats [4]. This EPS (similar to other nanosatellite EPS) has two parts: solar array to battery charge, and the regulation output section. The solar array to battery section is responsible for taking in energy from the sun through the solar panels and then charging (but not overcharging) the batteries. It also provides output power to supply the regulation section. The Clyde Space EPS the team was provided with had the regulation output section broken. The system will charge

batteries but will not provide the advertised regulated output voltages. No documentation is provided by the vendor for troubleshooting and no funds were available to have the vendor repair the item. This provided researchers the ability to be able to construct a voltage regulation output section on a very limited budget. Half of the EPS was already provided. The team worked to first understand the solar array to battery charge section. This was critical to the team's research since UNM students needed to be able to provide enough voltage (at a high enough current level) to charge the batteries. This section of the EPS worked as specified in the Clyde Space manuals and documentation [4]. The next part was to create a regulated output section. The team wanted to be able to see if they could utilize a deployable solar array assembly to provide a steady output at three different voltages: 3.3VDC, 5.0VDC and 12.0VDC (volts direct current). These three specific output voltage levels are the most common voltage requirements asked for by CubeSat module developers. The Texas Instruments Corporation has now provided a power design tool on their website [5]. This tool allowed the team to design the three power sections and then to be able to import the design into the Eagle printed circuit board design tools being used to design the printed circuit boards. The tool also generated a bill of materials so it was possible to order all of the bits and pieces from common parts distributors. Spice simulations were utilized to ensure overcurrent and undercurrent situations were addressed properly. The final board is shown in Figure 3 and is compatible with the PC-104 standard (most common connector format for CubeSats) and provides high quality output voltage at the required voltage levels. Future activities revolve around having students create the other half of the EPS.

- ii. Batteries – The team sought development of a means to collect and store the solar energy in a system that would most closely emulate a flight battery array but on a much reduced budget. The team purchased Lithium battery cells similar to the ones shown in Figure 4. These are 2800 milliamp hour battery cells that are commonly available through the Internet [8]. The ones purchased by the team were 3.7 volt, type 18650 batteries from the Sanyo Corporation. These batteries have a charge temperature from 0 to 40 degrees Celsius and a discharge temperature from -20 to 60 degrees Celsius.



Figure 4 Lithium Ion Battery

The team used these cells and combined them into packs for environmental testing. Each pack had six cells as shown in Figure 5. The battery pack then had a circuit board designed for interfacing. Finally, the battery pack was conformably coated for

flight checking. The students had to do research related to charging systems and interconnection of batteries in series. Each cell is 2800 milliamp hour at 3.7 volts (rated). The team combined them so as to provide a steady high current output and charging potential at 8 volts. The team was able to conformal coat the battery pack and then run it through the rigors of space qualification testing. The testing was performed at the Operationally Responsive Space test facility at Kirtland Air Force Base during the week of July 23rd, 2014. The testing consisted of two distinct phases. The first was vibrational testing. This testing was performed to the National Aeronautics and Space Administration's General Environmental Verification Standard (GEVS) levels for payloads of less than 50 kilograms. Vibrational testing occurs in three axis and is performed by first performing a simple sine sweep. After the sine sweep, the actual GEVS levels are performed and then the simple sine sweep is performed again. If no differences are identified between the two simple sine sweeps, then the test is considered successful. After vibrational testing is complete, the next test is thermal vacuum testing. This testing is accomplished by first taking the item to a pressure of 10^{-6} Torr (a unit of pressure) at 60 degrees Celsius. The unit is left under these conditions for six hours. This process is known as "outgassing" as it removes all moisture from the system. After this is complete, the system is subjected to a complete series of functional tests. Upon completion of these two tests, the item is certified as space qualified.

The team interfaced this battery pack to the EPS to ensure it would interface properly and also allow for charging and discharging at the required levels and rates. Thermal analysis was accomplished and the battery packs never experienced a temperature change of more than 5%.



Figure 5 Battery Pack Development

- iii. Solar arrays – The team was able to purchase small commercial cells for initial testing but the team was also able to have access to a flight solar array system (see Figure 6) from the MMA Corporation at no cost. This provided the students with an excellent opportunity to be able to see not only solar cells but also complete solar systems. As can be seen in Figure 6, the arrays have quite

a large and complex wiring platform so this provided researchers with the ability to explain the interfacing to students during connection and testing.

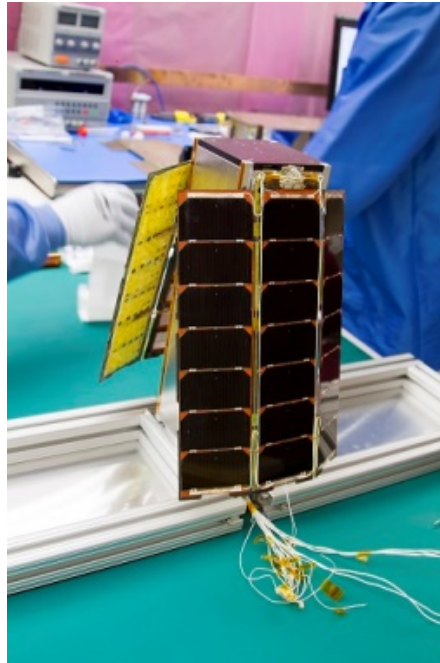


Figure 6 Solar Array

The cells allowed the students the ability to see how individual solar cells charge and distribute solar energy. They were also able to see how effects of external sun conditions affected the charging cycles. The MMA solar array we acquired is called the High Watts per Kilogram (HaWK) system [9] and is shown in Figure 7. This was a great benefit as it allowed the team to be able to see the advantages and disadvantages of real flight hardware. This solar array has six outputs to an EPS and we were able to connect all six and then do testing. Creation and assembly of cabling systems were accomplished. Each of the HaWK outputs was aligned to the six individual solar panel inputs to the EPS as shown in Figure 7.

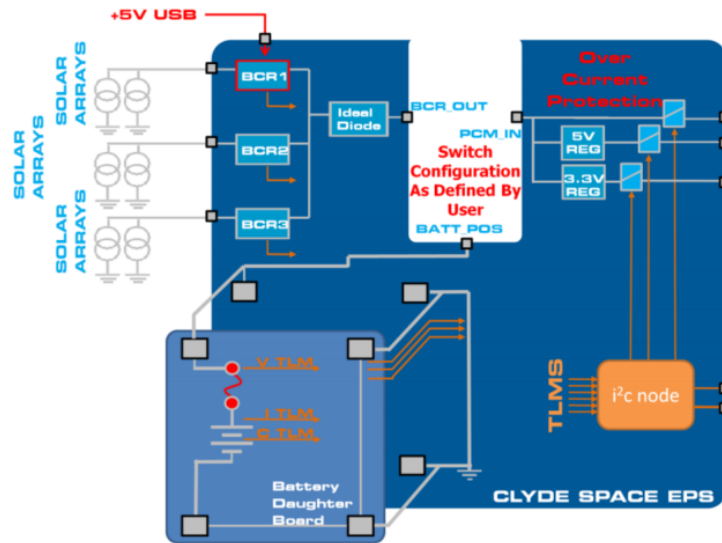


Figure 7 CLYDE Corporation Power System

The team originally planned to create a solar generation system in the COSMIAC cleanroom for testing but we quickly determined that it was impossible to generate enough solar irradiance for proper charging. Purchasing solar panels and bulbs were just not sufficient enough to be able to drive the amount of solar energy required by the EPS to function properly. The HaWK solar arrays consist of panels. Each panel produces a certain amount of power when in sunlight (testing shown in Figure 8). Unless a certain current threshold is achieved (6 volts for 1.2 amps), the EPS will not begin to see it as a valid input and will not use it to charge the batteries. When this occurs, the EPS continues to drain energy from the batteries and does not charge as required to emulate being in sunlight. This was an excellent learning experience for the students as they were able to check all these readings with test equipment and then compare the theory of what they are learning in class with practical experiences.

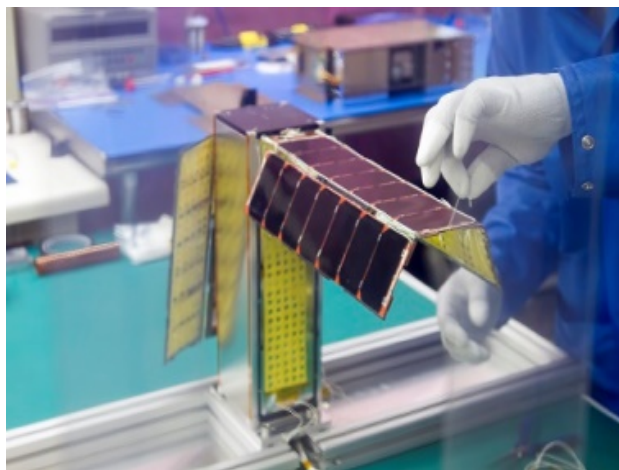


Figure 8 Battery Charging Through Array

Goal 2: The control systems were designed and interfaced into the flight systems that currently exist at COSMIAC. The satellite design team at COSMIAC recently created a spacecraft command and data handling unit that is based on the popular Beagle Bone Black motherboard. This motherboard operates on a state-of-the-art Texas Instrument's processor. The control system was written in the object oriented programming language called C. The code takes as inputs the control signals from the EPS and then provides outputs for charge levels, charging rates, temperature and voltages. This system interfaces were completely tested and all circuits performed as designed.

Goal 3: The team spent the entire summer designing, integrating and testing solar power systems. The team created a test facility in the COSMIAC cleanroom and other capabilities on our roof. The team was able install a solar power collection and monitoring system (see Figure 9) on the roof that provided the team with constant data on how much power was being generated and then supplied to the solar arrays. The team originally intended to do a flight test on balloons but this was later deemed unacceptable due to the large costs associated with the flight hardware and the risk of damage. To achieve flight certification, the team did perform environmental testing at AFRL. This included thermal baking as well as vibrational testing. The hardware showed no signs of degradation or failure as a result of the space environmental testing.

The final goal was to fly the developed solar power system as part of the ORS Squared spacecraft. As is usually the case with satellites, delays in launch proved too much and prohibited the actual flight of the hardware on UNM's second satellite (ORS Squared). Current plans are to fly this article on UNM's SORTIE mission that is currently under development.

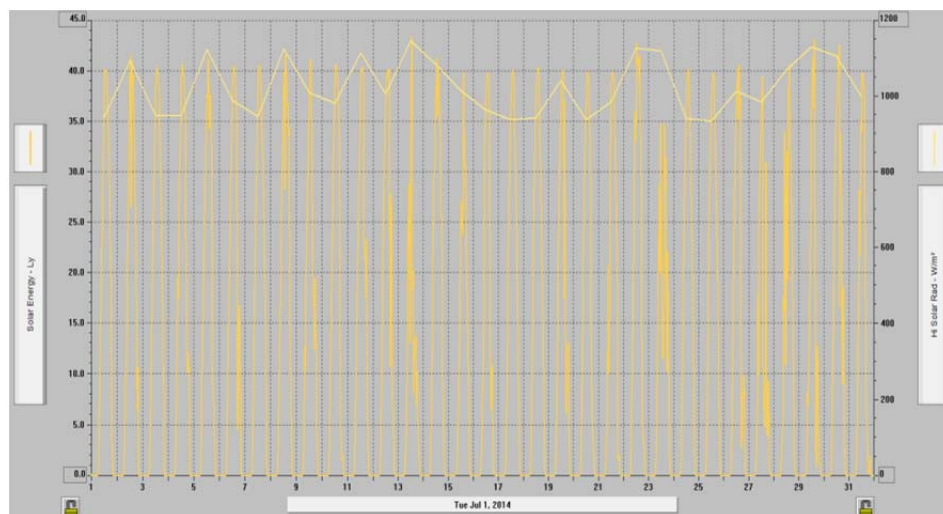


Figure 9 Solar Readings on Weather Station

4. Results and Discussion

The team completed all work on time. Future work could involve the creation of a battery charge regulation section as well as publication of results at small satellite conferences. The team was able to create a complete power system by utilizing various pieces of commercial off the shelf equipment and equipment that was designed to perform specific functions. The off the shelf equipment consisted of the solar arrays, batteries and the battery charge regulation section. The voltage regulation section was created. All systems were tested individually and then when they were combined, they were tested as a system. Voltage and Currents were all within specifications as defined by the CubeSat motherboard and associated equipment. The entire system was then tested to launch standards and performed without failure. The system is acceptable for Low Earth Orbit (LEO) utilization.

5. Conclusions

The team expanded on the initial scope of work to not only investigate solar arrays but to also consider entire solar power systems for space applications. The team at UNM/COSMIAC is now working with these power systems to help to develop future applications and missions where they would be utilized and are creating proposals to support future development.

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List of Symbols, Abbreviations, and Acronyms

AFRL	Air Force Research Laboratory
COSMIAC	Configurable Space Microsystems Innovations and Applications Center
EPS	Electrical Power System
GEVS	General Environmental Verification Standard
HaWK	High Watts per Kilogram
LEO	Low Earth Orbit
ORS	Operationally Responsive Space
SORTIE	Scintillation Observations and Response of The Ionosphere to Electrodynamics
UNM	University of New Mexico
VDC	Volts Direct Current

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