SOCIETY OF PHYSICS STUDENTS

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SPS Chapter Research Award Proposal

Project Proposal Title	MMOD Hardware Testing and Communications for the Rhodes College CubeSat Program
Name of School	Rhodes College
SPS Chapter Number	5940
Total Amount Requested	$1992.76

Abstract

Rhodes College has undertaken a CubeSat project that will span approximately three years. This project will have students planning a CubeSat mission, designing and building the 10x10x10 cm^3 CubeSat, and working with launch providers to launch the satellite into Earth orbit. Students will also build a ground station on campus to communicate with the satellite. An integral part of this ambitious plan is thoroughly testing various payload concepts before deciding which will be integrated into the spacecraft. One primary payload concept is the use of acoustic/stress sensors to measure micrometeor and orbital debris (MMOD) impacts on the CubeSat body. An SPS Chapter Research Award would allow the Rhodes College chapter to investigate different types and areas of sensors, their sensitivies to simulated MMOD impacts, and ultimately help the team choose the configuration most appropriate for the Rhodes CubeSat mission. The award would also allow for the purchase of a suitable transceiver to enable communicaiton with the Rhodes CubeSat once it is in orbit.

Proposal Statement

Overview of Proposed Project

Rhodes College has decided to go to space! The college has acquired adequate support, both financial and administrative, for a CubeSat mission. The financial support for the Rhodes CubeSat project comes from a generous alum (a recipient of the Sigma Pi Sigma Service Award) and covers the actual flight module, launch, and staff salary. It does not cover essential parts of the overall project, and that is the reason for our application for the SPS Chapter Research Award.

The overarching goal of the Rhodes CubeSat project is to have Rhodes students experience all aspects of research at the large scale. They will participate in a long-term, in-depth space science project that will have them actively engaging in concept design, experimental design, data acquisition, data analysis, regulatory procedure, and budgetary oversight. As a small liberal arts college in Memphis, Tennessee, some big questions are: "Can a small liberal arts college without an engineering school be successful with a CubeSat mission?" and "Can a research team consisting of only undergraduate students and their mentors produce a research-oriented, space-functioning device that will produce useful data?" This is a large undertaking for the college, and one which involves many smaller projects that contribute to the CubeSat mission as a whole. The projects we propose for this SPS Chapter Research Award are these types of smaller projects. They are related to the testing and finalization of payload concepts for the Cubesat mission and the communication with our orbiting CubeSat.

The Rhodes CubeSat team has spent the fall 2019 semester narrowing down ideas for our CubeSat mission and learning about ground communications with satellites. One current high-ranking payload concept is to employ piezoelectric film on the satellite to detect and record micrometeor and orbital debris (MMOD) collisions in order to quantify space pollution. It has also become obvious that we will need to build a ground station consisting of a radio transceiver with appropriate antennas, other hardware, and software with which to communicate with our CubeSat. This proposal requests funding for each of these essential aspects of the larger Rhodes CubeSat program.

As an outstanding chapter for 19 years and counting, the proposed projects will allow our SPS chapter to continue demonstrating SPS' mission through the CubeSat Program by promoting interdisciplinary skills and community engagement through undergraduates and science.

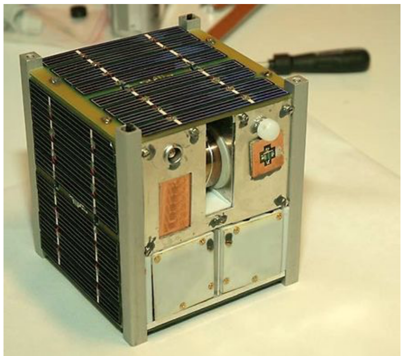

Fig 1: nCube, a Norwegian CubeSat. A Cubesat is standardized by 10cmx10cmx11.35cm volume and can weigh at maximum 1.33 kg

Fig. 2 An example of a small PVDF, or piezoelectric, sensor. These work by deformations to the film, which creates a voltage.

Background for Proposed Project

A CubeSat is a standardized nanosatellite originally designed by Dr. Jordi Puid-Suari of California Polytechnic State University and Bob Twigs of Stanford University in 1999 [Chin]. Their main goal was to create a satellite accessible to educational institutions of all kinds, making space more of a tangible reality for students and researchers alike. A CubeSat is standardized at a fixed volume and maximum weight requirement (refer to figure 1), with each 'cube' constituting a "Unit". CubeSats have been instrumental in giving open access to space to graduate space science program, undergraduates, and even high school students. CubeSats have quantified many aspects of space, Earth's atmosphere, and studied properties pertaining to the surface of Earth.

Rhodes College plans to utilize this opportunity for space science research by CubeSat to investigate micrometeorites and orbital debris (MMOD). Orbital debris ranges from bits of paint in orbit all the way to whole satellites, while micrometeorites can be particles of dust and small rocks natural to the space environment. MMOD, according to NASA, moves at approximately 5 miles per second, with the average impact speed being close to 6.2 miles per second [Stack Exchange]. These data imply that orbital debris has the capability to inflict rather large damage on anything it comes into contact with. This fact was kept in mind in the design of the ESA's Cupola module, currently mounted on the ISS. Its windows are made of a fused silica and borosilicate bulletproof glass [Cupola]. Astronauts as well are fitted with suits made out of a material similar to bulletproof vests for MMOD protection outside the spacecraft. The quantification and study of how space debris has increased over time is extremely pertinent to current space science research. Since humankind's first entry into Earth's orbit with Sputnik, we have continually introduced man-made material into space (debris). As climate change and human Earth pollution weighs more and more heavily on our minds each day, we must also take care to study pollution in Earth's immediate surroundings.

NASA has kept tabs on orbital debris smaller than 1 mm by counting the dents and holes on space shuttles after reentry and correlating that with how far the shuttle traveled in a given mission [May]. CubeSats do not survive reentry, so we will quantify MMOD collisions with our CubeSat while it is in orbit and transmit that data back to our ground station. A piezoelectric film sensor is thus the fundamental component of our payload (figure 2). A piezoelectric material generates a voltage when the film undergoes a mechanical stress. They do not require external power; the signal is generated intrinsically. We have already purchased an inexpensive sensor much like in figure 2; a polyvinylidene fluoride (PVDF) film. When attached to a CubeSat frame we were able to observe a signal. Even very small taps on the frame gave detectable signals, which is an indicator of the high sensitivity of these films. The next step in the process will be to test various piezoelectric PVDF sensors for sensitivity and determine the most effective way to translate this voltage into measurements of MMOD.

We have delved a little deeper into the theory of this payload concept. If we anticipate a measurable MMOD collision once every ten days, it amounts to 37 per year. Given the surface area of the CubeSat frame, this introduces a particle flux of 3700 impacts/$y \cdot m^2$. Following figure 3, the relationship between flux and particle diameter, this corresponds to us measuring impacts from particles with a diameter size of5 microns. This particle size can be used to determine mass (using volume and density), and thus kinetic energy. A 5 micron micrometeoroid with a density of 3 g/cm^3 (assuming a density of sand) has a mass of 12 $x10^{-15}$ kg, and thus approximately 500 nanoJoules of kinetic energy, assuming it was moving with an average speed of 8700 m/s (5.5 mi/s). To put things into perspective, this is equivalent to the kinetic energy of a BB pellet dropped from a height of 1mm. That being said, a very sensitive acoustic sensor is necessary.

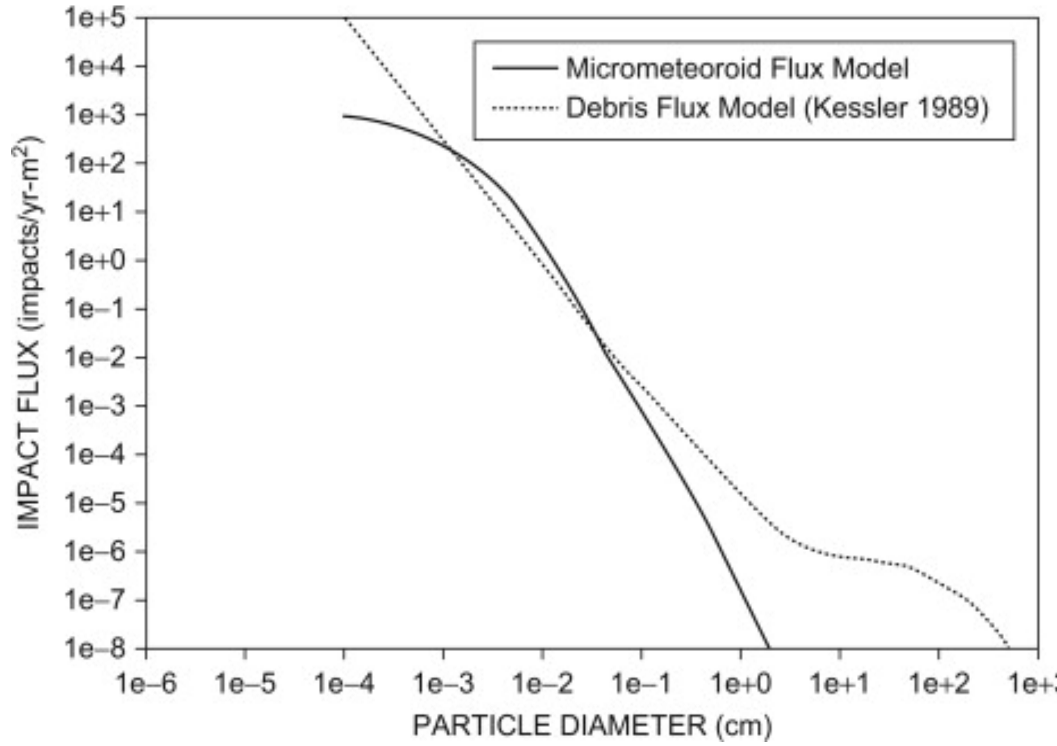

Fig 3: Micrometeoroid Flux Model, showing the relationship between impact flux and particle size. [Dever]

A ground station is essential for communication with our CubeSat. The ground station will be responsible for receiving downloads of CubeSat data and for uploading commands to the satellite. The basic requirements of a ground station are a transceiver (to send and receive radio signals), appropriate antennae, a low noise amplifier (LNA), a rotator, and an Amateur Radio Technician's License.

The Rhodes CubeSat communication team has already begun preparations for the ground station as follows:

- Dr. Ann Viano, Mr. Joe McPherson, and Mark Ellenberger have obtained their amateur radio licenses.
- Software for ground-track projection, rotator control, and doppler shift adjustments has been purchased and installed.
- a YAGI antenna has been constructed, and parts to build automated rotors have been 3D printed.

Description of Proposed Research - Methods, Design, and Procedures

- Methods
  - In order to test the feasibility and sensitivity of piezoelectric film sensors, we plan to conduct trials of different types and sizes of sensors in order to determine the relationship between momentum and/or kinetic energy of a simulated MMOD and the output voltage of the sensors. Once the output of the various sensors has been characterized, we can predict what type of sensor and sensor area is needed to effectively measure MMOD impacts with our orbiting CubeSat. We can then deduce characteristics we expect to see from our measured MMOD data.
  - The transceiver specified in this proposal will allow us to complete our ground station and begin tracking satellites and testing our communication abilities.
- Design
  - Through the development process this semester and the narrowing of payload ideas, we have already purchased a small, inexpensive sensor much like the one in figure 2, and have attached it to a sample CubeSat frame and an oscilloscope. From this, we were able to manually stress any part of the frame and measure the response. More thorough testing will involve making a test frame from which we can drop objects of known mass onto the various sensors. We will correlate the energy and momentum of the dropped mass with the measured response. Results will help us clarify the sensitivity needed to detect MMOD in orbit, and the configuration needed on our spacecraft frame to acquire adequate data during the mission.
  - Three different types of sensors will be evaluated. The types vary in sensitivity and size. The DT series films produce 10mV per microstrain. The LT series is a laminated film that supposedly produces a higher voltage output. These sensors are available in sizes ranging from 0.6 inch x 1.6inch all the way up to 8 x 11 inch sheets.
  - Our ground station design comes from AMSAT (Radio Amateur Satellite Corporation) and the requested transceiver is an integral part of this design [AMSAT].
- Procedure

  <u>MMOD detection</u>
  - Small beads of varying masses will be dropped onto the sensors from varying heights. The sensor output voltage will be recorded for each "impact".
  - Bead kinetic energy and momentum at impact will be calculated for each bead and drop height using basic kinematic equations and recorded.
  - The sensor type will be characterized by correlations between kinetic energy and sensor response, and momentum and sensor response.
  - Sensor area will be investigated by recording the sensor signal as a function of the impact location.

  <u>Transceiver integration into ground station</u>
  - Communications with currently orbiting satellites, including the International Space Station, will be attempted to test the power, tracking ability, and performance of our ground station. The three members of our Rhodes CubeSat communications team who have obtained their amateur radio license have the knowledge and authority to conduct these tests.

Plan for Carrying Out Proposed Project

The plan for the proposed project spans approximately one semester. The varying sensor types and areas are currently available to ship and can be purchased as soon as the award is received.

This proposed project will involve a number of SPS members, with oversight by physics department staff and faculty. Lead students for the MMOD feasibility tests and communications team are as follows:

- Mark Ellenberger, a sophomore SPS member. Mark has been at the forefront of the CubeSat project since its inception and has obtained his amateur radio license. He has completed one summer and a semester of nanosatellite research, gathering knowledge and skills needed to construct a CubeSat. He attended the Small Satellite Conference in August and is a lead CubeSat team member.
- Giuliana Hofheins, a sophomore SPS member. Giuliana is the On-Campus Programmer for Rhodes' SPS Chapter and has organized campus wide events like Pumpkin Drop. These organizational skills and her interest in aerospace science garnered her a position on the CubeSat team. She has been involved in the development of the MMOD detection payload theory so far.
- Other SPS members who will be involved in the proposed project are Nolan Brown '23, Mackenzie Gibbs '22, Finn Giddings '22, Lloyd Templeton '23, Olivia Kaufmann '23, Dung Hoang '23, Yuxin Shi '21, and Benjamin Wilson '22. As the 2020 calendar year gets underway and the Rhodes CubeSat program is officially announced to the college and Memphis community we expect more students to join the Rhodes CubeSat team.
- Joe McPherson, Physics Technical Associate and the CubeSat Project Manager. Joe has obtained his amateur radio license to be a mentor for the Rhodes CubeSat Communications team.
- Dr. Ann Viano, Sigma Pi Sigma chapter advisor and physics faculty member. Ann has obtained her amateur radio license to be a mentor for the Rhodes CubeSat Communications team.
- Dr. Brent Hoffmeister, SPS chapter advisor and physics faculty member.

The activities of the proposed project will be conducted at Rhodes College. The physics department has a space dedicated to student projects which has laboratory furniture, computers, electrical supplies and all other necessary resources for the proposed project. The CubeSat communications room will be located on the top floor of the building, to facilitate easy connection to the communications antennae which will be located on the roof of the physics building.

Project Timeline

The timeline for the proposed project is approximately one semester, as stated above. We anticipate one week to order and receive the budgted items. One-three weeks will be spent desinging and constructing an appropriate apparatus to drop the masses from a known height. Four weeks will be spent performing multiple trials for the various masses and sensors. The remaining four to five weeks will be spent analyzing the data and interpretting the results. By the end of the semster we will have made a decision as to the type and configureation of sensor needed for our CubeSat.

The entire CubeSat project has a much longer timeline. It is scheduled for about three years, and a sample CubeSat project timeline is shown below (Fig 3). The MMOD hardware testing portion constitues the timeline for the project outlined in this proposal.

Fig. 4 Timeline of Ground Station Development/MMOD Testing

	January '20	February	March	April	May	June	July	August	September	October	November	December
Ground Station	School Year	---------	---------	-------	Summer Work	------	-----	--------	School Year	---------	-------------	-------------
Software Development												
Hardware Development												
Software Testing												
Hardware Testing												
Communication Process												
	January '20	February	March	April	May	June	July	August	September	October	November	December
MMOD Testing	School Year	---------	---------	-------	Summer Work	------	-----	--------	School Year	---------	-------------	-------------
Software Development												
Software Testing												
Hardware Testing												
Integration onto Test Vehicle												

Budget Justification

- Item 1 - The ICOM IC9700 is the radio transceiver we will use to communicate with our CubeSat. We have much of the infrastructure besides a transceiver operational, and while we design and assemble our spacecraft, this transceiver will enable us to educate ourselves on radio communication via correspondence with other spacecraft.
    - Cost: $1350.00

- Item 2-4 – These piezoelectric vibration sensors are our planned payload. These thin polymer films generate voltage when deformed, and the amount of voltage produced is proportional to the momentum of the impactor. We plan to familiarize ourselves with these proportionalities and practice interpreting and relaying data produced by these sensors. On the spacecraft, we will use these to characterize micrometeoroid and orbital debris (MMOD) environment.
    - Piezo film sheet 8x11 inch Silver Ink (28 micron thickness) Cost: $128.00
    - Laminated piezo film vibration sensor with tabs (205 micron, thickness LDT series) Cost: 5x $4.25
    - Silver ink vibration sensor with wire leads (64-micron, DT Series) Cost: $14.77

- Item 5 – This Tektronix oscilloscope is the tool we'll use to interpret waveform outputs from our sensors.
    - Cost: $470.00

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