The Naval Postgraduate School SCAT++ CubeSat Program

Christopher Ortiona, Robert D. Jenkins, Christopher S. Malone, Lawrence T. Dorn, Matthew P. Schroer, Alexander Schulenburg, Paul M. Oppenheimer, William M. Crane, Daniel Sakoda, Marcello Romano, Rudolf Panholzer, and James H. Newman

Space Systems Academic Group, Naval Postgraduate School
1 University Circle, Monterey, CA 93943; 831-656-2487
jhnewman@nps.edu

ABSTRACT

The Naval Postgraduate School (NPS) Small Satellite program provides graduate students with hands-on experience designing, building, and operating satellites. NPS’s first satellite, Petite Amateur Navy Satellite (PANSAT) was deployed through the NASA Hitchhiker program on board STS-95 on October 29, 1998 and operated for several years. As a follow-on project to PANSAT, NPS plans to launch the Spacecraft Architecture and Technology Demonstration Satellite 1 (NPSAT1) sometime in the future. Currently the NPS Small Satellite program is evolving to include CubeSats to further enhance the educational and research opportunities at NPS. As ongoing university, government, and commercial satellite programs are showing, the CubeSat standard is proving to be a unique platform for focused research objectives and engineering design innovation. The first CubeSat to be developed at NPS is called the NPS Solar Cell Array Tester (NPS-SCAT). The overall goal of the project is to gain experience in all phases of CubeSat construction, deployment, and operations by implementing just one of NPSAT1’s many experiments: a solar cell tester. The program is creating a baseline subsystem design for future NPS CubeSats, allowing the NPS Small Satellite program to efficiently use a standard satellite bus for focused research objectives of national interest.

NPS CUBESAT PROGRAM

NPS presented the experimental NPS Solar Cell Array Tester (NPS-SCAT) CubeSat program to the Department of Defense (DoD) Space Experiments Review Board (SERB) in October 2008 and was ranked for space flight along with other DoD experiments, including four NPS space experiments. Complementing the CubeSat program at NPS is the development of the NPS CubeSat Launcher (NPSCuL) to build an ESPA-compatible capability of carrying eight California Polytechnic Institute (Cal Poly) Poly Picosatellite Orbital Deployers (P-PODs).

While the mission objective of NPS-SCAT is to test solar cells in the space environment, the educational objective is to develop and demonstrate NPS capability to use the CubeSat form factor as a means of hands-on education, enabling technology testing and other experiments. The reduced complexity of the structure, power, and communication subsystems provided by the CubeSat form factor allows for an effective, responsive, and relatively inexpensive approach to space missions. SCAT provides a platform for validating solar cell performance through exposure to the space environment over the life of the satellite. As the university’s baseline CubeSat program, SCAT utilizes commercial-off-the-shelf (COTS) components wherever possible. Each primary subsystem has been selected to be CubeSat “compatible:” the structure and processor board from the Pumpkin CubeSat Kit (CSK), the Microhard 2400 Transceiver, and the ClydeSpace 1U Electrical Power System.

Evolution of the NPS-SCAT++ Concept

The Space Test Program (STP) conducts space test missions for the purpose of accelerating DoD space technology by arranging flights of opportunity (“piggyback” or secondary) on domestic and foreign spacecraft. The SERB, managed by STP, is tasked with maintaining the DoD experiment priority list, which ranks proposed space flight experiments, and provides general indication of the priority and likelihood for flight. As a ranked experiment, SCAT becomes eligible for a space flight of opportunity. Through this process, NPS was offered the possibility of deploying SCAT using the Space Shuttle Payload Launcher (SSPL) 5510, with a payload volume of five inches by five inches by ten inches. NPS was also encouraged to consider including parts of other NPS SERB-ranked experiments and fly them as risk mitigation. A launch aboard NASA’s Space Shuttle, though a great opportunity, entails its own challenges.
Motivated by the possible launch opportunity, but still desiring to build a CubeSat, NPS has developed a satellite structure called NPS-SCAT++, utilizing the full SSPL volume. SCAT++ will house the SCAT CubeSat during launch and release it after its own deployment. In addition to being a solar cell array tester, duplicating the same components and boards as SCAT, SCAT++ has room for other, small SERB-approved experiments. However, because of the uncertainty of whether the SSPL will be available, SCAT++ is also being designed as a 2U CubeSat. The systems and subsystem architectures are the same to the maximum extent possible between the different form factors.

**NPS-SCAT++ Mission**

The mission of the SCAT++ project is to leverage existing and previously developed SCAT CubeSat systems and subsystems, providing a multifunctional nano-satellite capable of conducting experimental objectives in a low earth orbit (LEO). Its mission objectives include:

- Demonstrating CubeSat viability as part of a hands-on educational program and as a technology test bed using a relatively inexpensive system to measure solar cell performance on orbit;
- Integrating a satellite bus that maximizes the use of COTS;
- Containing and protecting the SCAT CubeSat during launch;
- Ejecting the SCAT CubeSat upon command after deployment from the SSPL-5510;
- Conducting solar cell test experiments;
- Utilizing any extra payload volume, providing risk mitigation opportunities for other SERB-approved experiments, including components of an attitude control and determination system (ACDS) suite, possibly comprising an NPS-developed miniature control moment gyroscope (CMGs) and COTS inertial measurement unit (IMU), an NPS innovative release mechanism, and a Cal Poly-designed beacon transceiver with antenna.

The SSPL-5510 can deploy payloads with a volume of 127mm by 127mm by 254mm (5” by 5” by 10”) and a maximum mass of 7kg (15.6lb). The SSPL is reusable and is contained in the payload bay of the Orbiter. To initiate the launch of the satellite, the Orbiter crew will use a switch located inside the cabin of the Space Shuttle. The non-explosive actuator releases the latch rod that holds the spring-loaded SSPL door. Once the door is released, a pusher plate ejects the nano-satellite into its designated orbit. Built as a containment mechanism during launch, the SSPL applies a force of 900lbs on the nano-satellite’s primary structure to preclude the possibility of any movement. These loads from the SSPL do not include the forces of the launch environment. Once the door of the SSPL is opened, the pusher plate can eject a 7kg nano-satellite at a velocity of about 2 meters per second.

**SYSTEMS ENGINEERING / CONFIGURATION**

**Critical Requirements:**

The primary SCAT++ design requirement is to contain, safeguard, and then deploy the SCAT CubeSat. Secondary design mission system requirements include the capabilities to sustain and operate subsequent experimental payloads including the collection and transmission of current versus voltage (I-V) curve data from designated experimental solar cells; commanding, monitoring, and transmitting of spacecraft attitude control data; and characterization of the CMG suite. The SCAT++ design constraints as an SSPL payload, are listed as Table 1.

<table>
<thead>
<tr>
<th>Table 1: Design Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design Life:</strong></td>
</tr>
<tr>
<td><strong>Altitude:</strong></td>
</tr>
<tr>
<td><strong>Inclination:</strong></td>
</tr>
<tr>
<td><strong>Launch Vehicle:</strong></td>
</tr>
<tr>
<td><strong>Survivability:</strong></td>
</tr>
<tr>
<td><strong>Primary Telemetry, Tracking &amp; Control:</strong></td>
</tr>
<tr>
<td><strong>Secondary TT&amp;C:</strong></td>
</tr>
<tr>
<td><strong>Regulations:</strong></td>
</tr>
<tr>
<td><strong>Schedule:</strong></td>
</tr>
<tr>
<td><strong>Components:</strong></td>
</tr>
<tr>
<td><strong>Volume/Mass:</strong></td>
</tr>
<tr>
<td><strong>Power:</strong></td>
</tr>
</tbody>
</table>

A federated bus architecture for the overall satellite system was chosen which would use a common data bus with multiple processors/microcontrollers sharing the bus. This design encourages the use of standard protocols and communication schemes for all subsystems. A simplified functional block diagram illustrates the SCAT++ architecture in Figure 1.
The SCAT++ nano-satellite derives its main system and subsystem architectures from the original SCAT CubeSat design. It is currently utilizing a Pumpkin Cube Sat Kit with an FM430 flight module, a Clyde Space 1U Electrical Power System, Spectrolab Improved Triple Junction (ITJ) solar cells, and a Microhard MHX-2400 transceiver. The SCAT++ primary payload is the SCAT CubeSat. In addition to the solar measurement system, SCAT++ is expected to contain miniature control moment gyroscopes (CMG), an innovative release mechanism, and a beacon transceiver with antenna.

Multiple design iterations verifying available volume versus subsystem requirements and payload space were conducted, resulting in the current configuration as shown in Figure 2. It should be noted that the entire configuration will fit within the volume of a normal 2U CubeSat “stack,” with the exception of the additional solar panels and location of the SMS payload. This was done to validate interoperability for a CubeSat form factor structure.

The overall mass for current SCAT++ configuration is approximately 4.5kg. This is approximately 64% of the possible 7kg allowed for a SSPL-5510 payload. This leads to a 2.5kg margin for the total mass of the structure. Given the 2 meter per second ejection velocity for a 7kg payload, the ejection velocity of a 4.5kg SCAT++ will be about 3 meters per second from the SSPL-5510. The mass of each of the primary structural elements (walls) is about 1.3kg; this is 28% of the total mass of SCAT++. Although a common mass ratio of the primary structure for any given satellite would be 10-20% of the dry mass of a satellite, the primary structure of SCAT++ exceeds this because it must be designed to be exceptionally strong to withstand the high loads experienced in the SSPL launch environment. The SCAT CubeSat follows the CubeSat design specification for mass and is expected to meet the 1kg requirement.

NPS SCAT++ SUBSYSTEMS

Structure: NPS-SCAT++ Structural Design and Engineering

During the structural design process, multiple factors contributed to the final approved design. The largest contributing factor was that SCAT++ will be deployed from the SSPL-5510 and will subsequently deploy the SCAT CubeSat contained within. The initial conceptual design involved the construction of a sleeve that would fit within the SSPL-5510 volume. This sleeve would adapt the SCAT CubeSat form factor (10cm by 10cm by 10cm) to the SSPL-5510 volume (5in by 5in by 2.4in). This was abandoned when it was realized that the SSPL does not provide positive contact with the satellite except at the edges of the sleeve, leaving anything inside the sleeve free to move.

After several iterations of structural designs, instead of only having a sleeve in the SSPL-5510, the adapter itself became a nano-satellite. The nano-satellite, designated SCAT++, will fit into the SSPL-5510 and the SCAT CubeSat will then be housed in SCAT++.

The decision to deploy SCAT led to requiring a release mechanism. The design consists of a robust load bearing primary skeleton structure with redundant assembly divisions to mitigate stresses. A depiction of the stress contours is shown in Figure 3 for the static clamping load of the stowed SCAT++.
**EPS: SCAT Electrical Power System Design, Test, and Integration**

Wertz states that the purpose of the Electrical Power Subsystem (EPS) is to store, distribute, and control spacecraft power. The SCAT power system was selected with the goal of using COTS. Use of COTS hardware should allow for rapid integration of CubeSat designs while maximizing educational opportunities for NPS students. After a review of available products, the Clyde Space EPS was selected. The Clyde Space EPS is a self-contained, independent, and self-regulating power unit. The power supply can provide up to 6 watts and 3.3 watts of continuous power at 5 volts and 3.3 volts, respectively. The Clyde Space EPS 1.25 amp-hour battery was also selected for use within the satellite. Two lithium polymer battery cells are wired in series to provide about 10 watt-hours of energy at about 8 volts. The solar cells selected for use are SpectroLab Improved Triple Junction (ITJ) solar cells. About eight cells will be used for SCAT and fourteen cells will be used for SCAT++. Initial calculations indicate that SCAT++ will produce approximately a minimum of 4 watts of power when illuminated. The SCAT++ fail-safe programming will secure loads to prevent a complete discharge of the system when available power is insufficient to support system loads.

Below are simulated power profiles for the initial launch and power generation of SCAT++. The simulation assumes SCAT++ begins at half power capacity. Simulations show the nano-satellite will become fully charged within the first 250 minutes of activation. The loads include a 1 watt beacon with a 20% duty cycle throughout the orbit. The 6.5 watt load represents the period in the orbit with a communications window, transmitting to the ground station located at NPS in Monterey, California. The simulations clearly show that with the power generation and the expected loads, the SCAT++ battery should not drop below 95% state of charge.

**COMMS: SCAT Communications System Design, Test, and Integration.**

Telemetry, tracking, and command (TT&C) systems on traditional small satellites have advanced significantly in capacity, throughput, and complexity over the last several decades. The CubeSat community is in need of similar advancements. The SCAT program seeks to provide a TT&C foundation on which to base the future of CubeSats at NPS. The satellite will have two TT&C systems that provide full telemetry for experiments through a primary communications channel and secondary telemetry through an amateur band beacon.

Wertz also states that the ultimate purpose of a satellite communication subsystem is to allow the satellite to function by carrying tracking, telemetry, and command data (TT&C) or mission data between its elements. The complexity of the system is driven by the amount of TT&C that the satellite and the ground station require.

One of the goals of SCAT is to develop a baseline subsystem configuration for future NPS CubeSats and to
leverage COTS technology during that process. With that philosophy in mind, the program chose COTS components marketed by Pumpkin Inc. as fully interoperable with the CubeSat Kit, including the MHX 2400 Series Radio. The radio also has flight heritage, having been successfully used with GeneSat1 from NASA and MAST from Tethers Unlimited Inc. Following the success of GeneSat, two students who worked on the subsystem with NASA published a paper at the 2007 Small Satellite Conference. The paper outlined some of the key performance parameters of the system, namely power and sensitivity as seen in Table 2.6

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band</td>
<td>2.4GHz ISM</td>
</tr>
<tr>
<td>Transmission Method</td>
<td>Freq. Hopping Spread Spectrum</td>
</tr>
<tr>
<td>Serial Data Rate</td>
<td>up to 115 kbps</td>
</tr>
<tr>
<td>RF Output Power</td>
<td>up to 1W, selectable</td>
</tr>
<tr>
<td>Power Consumption (Rx/Tx)</td>
<td>1.15W / 4.38 W</td>
</tr>
<tr>
<td>Sensitivity (@25°C)</td>
<td>-105 dBm</td>
</tr>
<tr>
<td>Max. Throughput</td>
<td>83kbps (no delay)</td>
</tr>
<tr>
<td>Weight</td>
<td>75 grams</td>
</tr>
<tr>
<td>Size</td>
<td>90 mm x 55 mm x 25 mm</td>
</tr>
</tbody>
</table>

Given the specifications in the paper, the MHX 2400 should provide satisfactory sensitivity, throughput, and power draw to allow a satellite to receive commands and transmit data over its lifetime. Note that the MHX 2420 was originally sold as CSK compatible, but it turns out that its peak current draw can exceed two amps, making it incompatible with the Clyde Space EPS. NPS was fortunate to procure the older MHX 2400, requiring about an amp peak current draw.

The SCAT++ baseline is defined by the sufficient reception of experiment and system housekeeping data to accurately characterize the subsystem performance. The data will be generated by the SMS, the ACDS suite, the Clyde-Space 1U CubeSat EPS, temperature sensors placed throughout the spacecraft, and the FM430 flight module. Two versions of telemetry have been identified: primary telemetry and secondary telemetry. Primary telemetry will include all measurements by the experimental payloads and comprehensive system health and will utilize the higher data rates of the MHX 2400. Secondary telemetry will include an abbreviated weekly measurement by the solar cell measurement system and instantaneous system health measurements broadcast via the beacon.

A patch antenna manufactured by Spectrum Controls Incorporated has been selected to broadcast the primary telemetry from the MHX 2400. The utility and need for a beacon to broadcast secondary telemetry became more apparent as the program progressed through the early part of 2009. Through the last several years more CubeSat programs began incorporating a beacon as a risk mitigation to a primary radio. The SCAT beacon radio will be built by the California Polytechnic University (Cal Poly) CubeSat program. The beacon will allow SCAT to transmit telemetry on the AM Band using a Cal Poly beacon transceiver. The beacon will be built around the ADF7021 High Performance Narrowband ISM Transceiver IC. Though the transceiver is a COTS item, the complete beacon system is custom built allowing coordination with Cal Poly on modifications that will improve the integration of the beacon into the CubeSat. Some of the interfaces that NPS and Cal Poly have agreed upon are footprint and configuration, power output, data rate, and interface with the FM430.

The data rate of the beacon may be significantly less than that of the primary radio which also allows it to provide more energy per bit for the transmission than a radio with the same power and a higher data rate. The beacon is a simpler and better understood design than that of the MHX 2400 and is also more efficient in radiating an equivalent output power.

The SCAT++ baseline is defined by the sufficient reception of experiment and system housekeeping data to accurately characterize the subsystem performance. The data will be generated by the SMS, the ACDS suite, the Clyde-Space 1U CubeSat EPS, temperature sensors placed throughout the spacecraft, and the FM430 flight module. Two versions of telemetry have been identified: primary telemetry and secondary telemetry. Primary telemetry will include all measurements by the experimental payloads and comprehensive system health and will utilize the higher data rates of the MHX 2400. Secondary telemetry will include an abbreviated weekly measurement by the solar cell measurement system and instantaneous system health measurements broadcast via the beacon.

A patch antenna manufactured by Spectrum Controls Incorporated has been selected to broadcast the primary telemetry from the MHX 2400. The utility and need for a beacon to broadcast secondary telemetry became more apparent as the program progressed through the early part of 2009. Through the last several years more CubeSat programs began incorporating a beacon as a risk mitigation to a primary radio. The SCAT beacon radio will be built by the California Polytechnic University (Cal Poly) CubeSat program. The beacon will allow SCAT to transmit telemetry on the AM Band using a Cal Poly beacon transceiver. The beacon will be built around the ADF7021 High Performance Narrowband ISM Transceiver IC. Though the transceiver is a COTS item, the complete beacon system is custom built allowing coordination with Cal Poly on modifications that will improve the integration of the beacon into the CubeSat. Some of the interfaces that NPS and Cal Poly have agreed upon are footprint and configuration, power output, data rate, and interface with the FM430.

The data rate of the beacon may be significantly less than that of the primary radio which also allows it to provide more energy per bit for the transmission than a radio with the same power and a higher data rate. The beacon is a simpler and better understood design than that of the MHX 2400 and is also more efficient in radiating an equivalent output power.

A half-wave (two quarter-wavelength) dipole antenna was developed for the beacon communications subsystem. The half-wave dipole has been used extensively in the CubeSat community and is commonly used in the amateur community as well. The design and integration of the dipole is well documented and will be integrated into SCAT using a design similar to the Cal Poly CP series of satellites.

C&DH: NPS SCAT Software Description

The FM430 flight module is the spacecraft processor, based on TI’s MSP430 series of ultra low power microcontrollers. All commands and telemetry generated within the satellite will be sent to the FM430 for processing as necessary. As telemetry is processed, the FM430 will route data to the correct communications subsystem for transmission to the ground.

The software being developed for the SCAT program is written in ANSI C and makes use of Salvo, an event-driven cooperative multitasking real-time operating system (RTOS). A Texas Instruments MSP430F1612 microcontroller directs operations between the system components: the solar panels, experimental payloads, temperature sensors, and EPS. The written code sends and receives commands from the sun sensor using the serial peripheral interface (SPI) protocol.
Communications with the EPS and temperature sensors is accomplished through the inter-integrated circuit (I2C) protocol.

The overall form of the concept of operations relating to the primary payload lends itself to four non-mutually exclusive modes: Sun, Eclipse, Transmission and Beacon modes. SCAT will orbit the earth approximately every 90 minutes with about 60 minutes spent in the sun and the remainder in eclipse. When in the sun, the satellite will be taking its most important telemetry, high-precision I-V curves on the experimental solar cells, about every 15 minutes, along with the sun angle and cell temperatures. System health telemetry will also be measured and recorded. This set of data includes any error events in the code, watchdog timer resets, multiple separate temperature readings from several components and also battery cell voltages. Once per week, abbreviated I-V curves will be taken in Sun mode and this data will be transmitted in Beacon mode. Provided there is sufficient power, the beacon transceiver will transmit data approximately every couple of minutes, regardless of being in the sun or not, on the amateur band using the AX.25 protocol. The beacon telemetry packets can be received by amateur radio operators and sent to NPS, effectively increasing the amount of data received from the satellite. The highest priority mode, which will interrupt normal operations, is Transmission Mode. The NPS ground station in Monterey will command the SCAT satellites to transmit their full telemetry via the primary MHX-2400 transceivers.

EXPERIMENTAL PAYLOADS

CubeSats, like any other satellite program, are generally designed using a systematic design process. The overall goal of the NPS Small Satellite Laboratory is to gain experience in all phases of CubeSat construction, deployment, and operations. This nano-satellite program intends to integrate a baseline subsystem design for future NPS CubeSats. This will allow the NPS Small Satellite program to efficiently use CubeSats for focused research objectives of national interest. In particular, the SCAT program contains experimental payloads each with a particular niche for potential advancement of future CubeSat designs:

- Mechanisms: Deploy SCAT CubeSat through NPS custom made innovative release latch;
- EPS: Collect and downlink I-V curve on designated solar cells utilizing an NPS custom made solar measurement system;
- ACDS: Command, monitor, and downlink attitude control data and attitude information.

- Satellite Communications: Transmit command, data, and telemetry through a CubeSat Class beacon transceiver and beacon antenna.

NPS-SCAT Payload

The primary experimental payload of the SCAT satellites is a Solar Cell Measurement System (SMS). The system consists of four different experimental solar cells, temperature sensors, sun sensor, and circuitry. The SMS was picked as the payload of the NPS’ first CubeSat because the concept of the experiment was already well developed for NPSAT1. The hardware simply needed to be customized for the CubeSat form factor. The first prototype of SCAT was developed in 2008. The experimental solar cells and sensors will be on one face of the satellite. Next to each of the experimental solar cells is a temperature sensor. The center of the panel contains the sun sensor’s aperture. The circuitry will measure each experimental solar cell current as a function of voltage, periodically during an orbit.

![Figure 6: Baseline SMS Circuit](image)

As shown in Figure 6, the SMS uses a voltage set by a digital-to-analog converter in the onboard microcontroller to vary the solar cell current, producing the solar cell voltage as an output. The SMS is capable of gathering two I-V curves simultaneously, giving it the ability to test two individual solar cells at one time. Latching relays, also controlled by the microcontroller, located on the SMS printed circuit board, switch the remaining two experimental solar cells to be tested by the SMS circuits. Figure 7 shows the first iteration of the custom printed circuit board for the SMS payload.

The experiment solar cells on SCAT were chosen based on their characteristics and function. For the control cell, a modified Spectrolab Improved Triple Junction (ITJ) solar cell was selected due to the fact that others of this type are also being used as power cells on the remainder of the satellite. It is modified only in the manner to allow it to fit on the experimental solar cell panel. A Spectrolab Ultra Triple Junction (UTJ) Triangular Advanced Solar Cell (TASC) without cover-glass was picked because other CubeSats are known to use this type of solar cell and the lifetime in low earth
orbit is not decisively known. Another experimental solar cell is a silicon single junction solar cell. The final experimental solar cell is a terrestrial polycrystalline silicon solar cell.

Figure 7: SMS Version 1 in the SCAT Prototype
The major factors affecting the performance of solar cells are temperature and light incidence angle. The thermal environment will vary considerably during each low earth orbit. There is a requirement to determine the temperature of each solar cell because a change in temperature significantly affects the open-circuit voltage. For each of the solar cells, a digital sensor will provide the temperature to help assess the I-V curve data. The MAX6633 temperature sensor provides a 12-bit plus sign temperature value, accurate to about 1°C. It is interrogated by the onboard microcontroller via an I2C bus. The other critical parameter for classifying the I-V curve data is the sun angle. The sun angle is the angle between the incident light ray and the normal to the surface and will cause decreased solar cell current output as the angle increases. This angle is determined by the onboard sun sensor manufactured by Sinclair Interplanetary, which has ±0.1° accuracy over a ±70° field of view and is connected to the microcontroller via an SPI bus. With the knowledge of the sun angle and temperature, the I-V curve data points can be matched up to a database of known current and voltage values at given angles and temperatures. Measurements will continue throughout the lifetime of SCAT++, which is estimated to be about a year or so. Over time, the data will be analyzed and the degradation of the solar cells can be quantitatively determined. Figure 8 shows results of preliminary ground based testing of the SMS payload where the SMS recorded and transmitted I-V curves and temperature data from an experimental solar cell panel. The maximum power produced by the solar cell panel is at the knee in the curve, where the solar cell current rapidly drops off as the voltage is increased. The temperature variation corresponds with a predetermined shading profile executed during testing.

Figure 8: SMS Version 1 I-V Curve and Temperature Data

NPS Miniature CMG ACDS Payload
CubeSats are increasingly providing more advanced capability and many creative applications have been proposed from remote sensing to on-orbit assembly. They have recently drawn the high profile attention of the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), and the US Department of Defense (DoD) because of the new application areas and increasing capability. Some of the new concepts require a robust, agile (≥ 3 degrees per second slew capability) spacecraft to perform the mission. A few attitude control subsystems are commercially available with flight heritage from magneto-torquers to reaction wheels. These available systems cannot yet provide agility for multi-unit CubeSats. The NPS design (patent pending) proposes an attitude control system based on CMGs meeting the agility and pointing accuracy requirements for a more advanced class of CubeSats without increasing the power requirements. This system will be tested on the SCAT++ mission with several goals for the experiment. The primary objective is to provide on-orbit heritage for a complex mechanism that is historically prone to lubricant and bearing degradation. Additional goals are to demonstrate the torque capability and accuracy of the system. This will be achieved by having three-axis control using an experimental inertial measurements unit (IMU) and the sun sensor used for the SMS. The total system including all of the motor drive electronics and processors occupy a volume less than 1U.
**NPS Single Motion Actuated Coupling (SMAC) Payload**

The objective for the latch mechanism is to provide a very small, yet relatively strong and reliable, non-explosive coupling mechanism for nano-satellite and CubeSat applications. It will be constructed with very few moving parts and actuated by a simple single-motion operation. This device can be used for deployables such as doors, solar panels, antennas, etc. This (patent pending) concept minimizes the possibility of actuation failure by eliminating the use of motors, clasps, or latches. The design criteria considered were primarily based on size and capability. Mating sections of a spacecraft can be separated ‘on command’ by a mechanism that is reliable yet secure under the extreme forces experienced during satellite launch. The volume available for the mechanism in nano-satellite applications is on the order of 1 cm³. An aggressive test program has been initiated to verify its current design.

**CONCLUSION**

The NPS-SCAT++ design was conceived leveraging the existing NPS-SCAT CubeSat program, its previously developed system and subsystem architectures, and the launch prospect through the STP.. As a deployable custom adapter, the SCAT++ nano-satellite is designed to hold the SCAT CubeSat during launch and eject it upon command after its own deployment from the SSPL-5510.

After the deployment from the SSPL-5510, SCAT++ would initialize, and through a non-explosive, innovative release mechanism, SMAC, release a door allowing the CubeSat to be ejected. Utilizing SCAT hardware, SCAT++ will be used for another solar cell tester experiment and the excess payload volume will be used as risk mitigation opportunities for other NPS, SERB-approved experiments.

The expected benefit of building a CubeSat is that the development and launch can be finished much more quickly than building a custom-made small satellite. Moreover, the purpose of the SCAT project is educational as well as providing research within the arena of DoD interests. Utilizing primarily COTS components allows the students working on this project to focus more on the integration of the subsystems and payloads while also experiencing the full lifecycle of a satellite, from initial concept to launch and on-orbit operations. By starting off with a simple payload, the Small Satellite Laboratory at the Naval Postgraduate School expects to build a base of knowledge, then apply this standardized development towards more advanced concepts within the CubeSat form factor for research within the DoD and educational communities.

**References**


