RocketSat VI: Meteoritic Smoke Particles

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Abstract
The upper atmosphere contains several tons of meteoritic smoke particles that are deposited from meteoroids burning up upon entry each day. These particles collect and eventually sink downwards to lower altitudes, but remain in the mesosphere for several months. The collection of the particles affects the metal budget in the mesosphere, and they may also provide a solid surface to form the nuclei of the ice crystals that compose noctilucent clouds. There are many models that predict the distribution of these particles in the atmosphere around the world; however there are few in-situ measurements to fully support these predictions. The mission of RocketSat VI (RSVI) is to measure the particle levels in the atmosphere from 75km to 95 km above the launch site in Virginia. Measurements have not been carried out at this particular launch latitude before. RSVI is using a system of particle detectors that has previous flight heritage from a similar mission. This system will detect the amount of large aerosol particles and the charge of the particles in the atmosphere during ascent. The analysis used to determine the numerical density of the particles detected is based on the output from the detector and also requires knowledge of the angle of attack of the flow. This means the system must measure attitude of the payload during flight and the velocity of the rocket. The payload system will require detectors, gyroscopes, power and data storage, and a structure to support the payload during flight. The team hopes to find conclusive data as to whether or not there is a significant amount of large aerosol particles in the atmosphere above Virginia, and to release the results so that they may be used to further validate models predicting the shift of these particles. These results could support or refute the theories that have been developed based off of the distribution of these particles, and lead to a better understanding of the effect these aerosols have on the atmosphere and their relation to mesospheric phenomena.

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1. Background

1.1 Meteoritic Smoke Particles

Meteors enter the atmosphere and burn up every day, leaving behind several tons of small smoke particles in the upper mesosphere and lower thermosphere [1]. These particles add significantly to the layers of metals already found in the atmosphere, which consists of mostly sodium and iron, but also contains potassium and magnesium. It is unclear what type of metal is left behind from meteoroids, but scientists suspect that they are typically positively charged sodium ions. These ions form larger aerosol particles (diameter > 1 nanometer) when ice collects around the sodium ion. This also causes the particle to descend slightly, so that the particles are concentrated through a range of the atmosphere, approximately 75 km to 95 km.

The meteoritic smoke particles have numerous effects on the upper atmosphere. As previously mentioned, these particles increase the overall metal budget, or amount of metal, in the mesosphere. The concentrations of metals can affect radar waves in the mesosphere [4]. The metal budget is also important to atmospheric scientists because it affect tidal and gravity activities that dictate global circulation [2]. The increasing amount of large particles in the mesosphere also increases the number of solid surfaces on which reactions can occur. Scientists are still investigating the major effects of these particles on the atmosphere.

Another important implication is that the sodium ions in the mesosphere are believed to be the positively charged core for ice particles that form in the altitude range from 75 to 95 km in the atmosphere. These ice particles are the result of sub freezing temperatures and an increase in water vapor. As the sodium ions descend in the atmosphere the ice particles continue to gain new layers of ice and the particle grows substantially by the time it reaches 75 km above the surface. The ice particles can reach up to 50 nm in size. The formation of these particles is linked to the increase in global warming effects on the planet. The increased amount of methane causes an increase in the water vapor in the atmosphere, and the increased carbon dioxide causes a reduction of upper atmospheric temperatures. This combination results in a much higher formation rate of these ice particles. However, the ice particles do not form over all locations on Earth. The particles have been measured to be more present in the more polar latitudes of the Earth [1].

1.2 Detector Design

A modified electrometer called the Colorado Dust Detector will be used to detect these large aerosol particles. This electrometer is also called as a graphite patch detector, due to the large section of graphite located in the middle of the white plastic, as seen in Fig. 1.

![Gratite patch detector with aluminum casing](image)

This detector works very similarly to a regular electrometer. When a particle comes into contact with the graphite, the charge is deposited onto the graphite in the form of a current. The current signal is then transferred through the back of the graphite with a wire and is transmitted through a cable to electronics that convert and store the signal. For this type of detector, a higher current corresponds to a greater number of particles impacting the detector. This detector also requires direct exposure to the atmosphere, which means for rocket flights it must be mounted to the skin of the rocket [1].

The detector is designed specifically for larger aerosol particles. To avoid detection of small ions and particles with less mass, there are four magnets in the white plastic around the graphite. These magnets help repel charged particles with a radius less than 1 nm because small particles have less momentum than larger particles due to the smaller mass. Also, smaller particles such as stray ions are not as insulated as meteoritic smoke particles, which have a shell of ice formed around the nucleus of charge [3]. The distance that the charged particles are deflected by is defined by the Larmor radius [1], or gyroradius, equation:

\[ r_g = \frac{m*V_{perp}}{|q|*B} \] (1)

where \( r_g \) is the radius of the particle, \( m \) is the mass of the particle, \( V_{perp} \) is the velocity perpendicular to magnetic field, \( q \) is the charge of the particle, and \( B \) is the magnetic field.

This equation defines the radius of the particles that will be deflected, and is based on the strength of the magnetic field produced by the magnets. The magnetic field is not 100% effective, though, due to the fact that as particles collide in the air, small ions can be deflected with enough speed to penetrate the magnetic field and hit the patch. Also, the formation of the boundary layer around the detector can affect how many particles
impact the detector. This issue is accounted for in the data analysis, discussed in the Analysis section.

The flight configuration being used for RocketSat VI has been used for a previous experiment on the MAGIC Sounding Rocket Mission. The detectors were donated to the team by Professor Zoltan Sternovsky of CU Boulder. The detectors were effective for this mission, and the results of the MAGIC mission are discussed in Expected Results.

2. Analysis

2.1 Boundary Layer Effects on Particle Detection

Due to the supersonic speed of the rocket, there was concern about the data collected being affected by the boundary layer formed on the detectors. This layer would reduce the efficiency of the detectors, therefore providing inaccurate results. A Direct Simulation Monte Carlo (DSMC) code was used to simulate the airflow around the detectors with inputs specifying the altitude and flight conditions. The simulation showed that particles with a diameter greater than 5 nm were not affected by the boundary layers formed on the detectors [1]. To account for the particles with a diameter greater than 1 nm (particles of interest) but less than 5 nm, a relatively small voltage bias of 2V is added into the data collection from the detectors. This voltage bias is important to account for aerosol particles affected by the boundary layer, as well as small ions that may not be deflected by the detectors due to particle collisions.

2.2 Attitude Determination

The attitude of the rocket plays an important role in determining the numerical density of the particles at each altitude. While the boosters on the rocket are firing, there is no particle detection. This is because all of the airflow is parallel to the detectors. The rocket is being forced in one direction from the engines, which doesn’t allow any flow perpendicular to the detectors, allowing for particle detection. After burnout, the rocket is on a parabolic trajectory. At this point, it is no longer being forced in the direction of the nose cone. The rocket has velocity in the x and y directions, and it is the velocity in the x direction that is critical for the detectors. The longitudinal velocity, no longer forced in any direction, allows air to flow perpendicular to the detector. As the rocket spins, each detector will be exposed to this airflow. However, since the airflow on the detector is constantly changing, the attitude of the rocket needs to be measured at all times during data collection to determine how much airflow is hitting the detector, or the effective area of the detector [3].

The system devised for measuring attitude is using two MEMS analog gyroscopes to measure pitch, yaw, and roll. These components output the angular rate of the rocket, meaning that they are relative sensors as opposed to absolute. Accelerometers, measuring all three axes, will also be used to measure the attitude of the rocket. The gyroscope and accelerometer output will be integrated to determine the absolute attitude and velocity of the payload. An attitude algorithm will be used in analysis that will use quaternion models to determine the attitude of the rocket.

2.3 Determining the Numerical Density and Charge

The numerical density of the particles as a function of altitude can be computed using the following equation:

\[ n = \frac{I}{S_{eff} \cdot u \cdot q} \]  

where \( n \) is the numerical density, \( I \) is the charge measured on the detector, \( S_{eff} \) is the effective area of the detector, \( u \) is the velocity of the payload, and \( q \) represents one elementary charge [1]. The numerical density is typically calculated for one full revolution, because for half of a revolution the detector face is not exposed to the flow. Professor Sternovsky will be assisting with the data analysis to ensure all flight effects are properly accounted for.

2.3 Error Analysis

Some of the detectors being used during flight will output shifted data when used over a long period of time. In particular, the MEMS gyroscopes are known for having very high drift rates, especially on board sounding rockets. Some time will be spent to ensure that the data obtained during flight is not skewed by error from the detectors.

The amount of error outputted from the gyroscopes will be measured by a spin test. This test will spin the payload, with the gyroscopes integrated, along the z-axis for a length similar to the length of flight. During the whole test the gyroscopes will be experiencing the same angular rate. After the testing, the data stored from the gyroscopes will be analyzed to see how much they drifted from the known angular rate of the spin table.

This error analysis will later be implemented into the attitude determination code. The error will be utilized as a filter, to eliminate some of the error from the flight data.
3. Design

3.1 Overall System Description

The RocketSat VI system will be utilizing two graphite patch detectors and the electronics boards designed by the RocketSat VI Electrical team. The detectors will be mounted flush with the skin of the rocket for direct exposure to the atmosphere. The detectors will be connected to the electronics using RF cables. All electronics components will be secured in an aluminum canister provided by Wallops Flight Facility (WFF). The system will be recording data for the full battery life (no sequence is used to power down). This is because power down is not required for this mission. Data is stored on board will be read from the electronics memory after the payload is retrieved.

3.2 Electrical System

The electronics system must be capable of handling multiple data sets during flight for data analysis and control the payload. The system must be able to determine the attitude and velocity of the rocket during at least the ascent of the flight. The electronics will use gyroscopes to measure the pitch, yaw, and roll, and accelerometers to determine x, y, and z axis accelerations. The objective is to achieve six degrees of freedom attitude determination. It will also retrieve and store signals from the detectors to a nonvolatile memory for future analysis. As mentioned, a similar flight configuration has been used before, and Current to Voltage Amplifiers (CVAs, also known as Transimpedance amplifiers) will be used to convert the current output from the detector to a voltage signal. All signals must be stored into a flash memory so that they can be retrieved upon recovery of the payload. Additionally, the detectors must be sampled at a rate of 1 kHz to achieve the precision required for attitude determination. Additionally, pressure and temperature will be measured to monitor the flight environment. The system is divided into a total of five electronics boards: the AVR board, the SCIENCE board, the Mesospheric Particle Observation (MEPO) board, and two CVAs. The AVR, MEPO, and SCIENCE board each have a separate battery, for system redundancy. If a battery connection fails for one board, it can still draw power from the other boards. A single 9V battery would be sufficient to power all three boards for the entire 15 minute flight.

The AVR board will be recording pressure, temperature, and accelerometer data. The AVR is a general board that has been used on previous RocketSat flights and is used in the RockOn Workshop. It has flight heritage, but modifications were required for this year’s mission. The accelerometers were replaced with versions that could detect a wider range of accelerations. This is due to the fact that the previous RocketSat flight experienced a shock that exceeded the range of the accelerometers and potentially knocked out the power on the board. It was difficult to determine the magnitude of the shock and therefore prove it was the cause of the power interrupt. The z-accelerometer is mounted separately from the AVR board and is connected using discrete wires. The board also had to be modified to be compatible with a command line that would power the payload on before launch. The command line is designed to meet the Wallops requirement. Wallops must be able to turn the payload on and off using a single command line for payloads wanting early activation in order to provide a safe environment for possible launch delays and removing the rocket from the launch pad. Typically the payload is triggered on by both the removal of the Remove Before Flight (RBF) pin and the g-switch (closed upon launch), however the gyroscopes being used for attitude data need to collect initial conditions of the rocket. The g-switch system has a delay to where the payload does not begin collecting data for more than 2 seconds after launch, by which time the rocket has already left the rail and could have changed attitude. The command line required an additional design and section on the AVR board. An initial revision of the board is shown in Fig. 2.

Figure 2: Initial revision of the AVR board. The microcontroller is in the upper left corner of the board, and DB9 connectors for power and board to board connections are the two connectors on the lower edge of the board.

The board uses 3.3V and 5V regulators to control power from a 9V battery, which is then used to power all of the components. An Atmega 32 microcontroller is used as the host to control the components on each board and most importantly sampling and handling data. The microcontroller is implemented using C basic as the core architect and Python to present a user friendly GUI to retrieve data, analyze latch status, and change timer settings. The software is developed in AVR studio provided by Atmel.
The CVAs were provided from our faculty mentor, Zoltan Sternovsky. The CVA will take the current signal from the detector and amplify it, because it is so small, in the region of nano-amps. The CVA will then convert the amplified signal to a voltage signal, which is the output of the board. Each board has an output centered on 2.5V, and ranges from 0V to 5V. As previously discussed, one CVA has a voltage bias of 2V for analysis purposes. The schematics of each type of CVA were provided by Scott Knappmiller, and each circuit schematic (bias and no bias) will have to be analyzed to back out the original current signal for data analysis. The CVAs and their corresponding schematics are shown in Fig. 3.

Figure 3: The CVAs being used for flight and their corresponding schematics, provided by Z. Sternovsky and S. Knappmiller

The MEPO board will be receiving the analog voltage signals from the CVAs, converts the analog signal to digital and then stores it onto a 64Mbit flash memory. This board is also controlled with a microprocessor. The board uses an external analog to digital converter to match the resolution of the current to voltage amplifier, and increase the sample rate to 1kHz to meet the sampling requirements for the detectors. The external analog to digital converter communicates to the host microcontroller through a serial to peripheral interface (SPI). The PCB of the MEPO is shown in Fig. 4.

Figure 4: MEPO board with hardware latch installed and tested

The SCIENCE board will be flying the gyroscopes. Each gyroscope has been mounted on a smaller breakout board, and each gyroscope board is mounted on two 1x5 headers to interface with the SCIENCE board. The PCB for the SCIENCE board is shown in Fig. 5. This is the newest revision of the board and has not been populated at this time.

Figure 5: MEPO board before population

Similar to the AVR and MEPO, the SCIENCE board also uses the same microcontroller and flash memory. The gyroscopes will be sampled at a rate of 300 Hz, which is enough to account for the minimum sample rate to avoid aliasing. The LPY5150 and LPR5150 gyroscopes are both dual axis and MEMs technology. The maximum spin rate for the gyroscopes before saturation is 6000 degrees per second. The maximum expected spin rate experience during the rocket flight is 6Hz from previous flight data. 6Hz correspond to a spin rate of 2160 degrees per second which is well within the range and capability of the LPY5150 and LPR5150. This board also has a hardware latch to activate early, due to the fact that the initial
conditions of the rocket are critical for analysis purposes.

3.3 Structural System

The structure design for RocketSat VI is dictated by the constraints imposed by the flight provider, Wallops Flight Facility. The structure will be enclosed in an aluminum canister, secured to an internal structure within the rocket. Multiple universities utilize the canister system, and this year RocketSat VI will be sharing the canister with another university. The result is that the payload must weigh 6.55 pounds and have a height no greater than 6 inches, half the height of the canister. The design consists of two Makrolon plates, which is the same material that has been used on previous flights. The structure houses five electronics boards and four batteries. The Makrolon plates have a diameter of 8”, which leaves space between the edge of the plates and the inner diameter of the canister, which is 9.5”. The stack will be connected to the lid of the canister and extend downwards to a height of 5”, where the stack will be connected to the other university’s stack. A model of the layout of the stack is shown in Fig. 6.

![Figure 6: A SolidWorks drawing of our half of the canister payload](image)

Each Makrolon plate is separated by 2” stainless steel standoffs to allow for enough clearance for the electronics boards. The plates are complete circles without additional holes for wireways because the plates have extra clearance from the edge of the plates to the canister.

The top plate on the stack will hold four lithium 9V batteries, the SCIENCE board, and the z accelerometer. The batteries will be secured individually by brass brackets, and secured with hot glue before flight. Three of the batteries will be connected to boards; the fourth is to balance out the others to keep the center of gravity in the middle of the stack. The SCIENCE board is mounted so that it is centered on the plate. This is so that the gyroscopes can provide data from the center of the rocket, otherwise conversions would be needed to translate the location, reducing the accuracy of the results. The plate layout is shown in Fig. 7. This board is mounted above the z-accelerometer, which is connected to the AVR board on the plate below.

![Figure 7: Top plate in stack with batteries, z-accelerometer, and SCIENCE board](image)

The lower plate contains the AVR, MEPO, and CVA boards. The MEPO board is mounted in the center of the plate, elevated slightly off the surface with nylon spacers. The AVR board is mounted directly above the MEPO board, again centered on the plate. The CVAs are mounted on opposite sides of the plate, and are connected to the MEPO board with wire connections secured by staking with hot glue, shown in Fig. 8.

![Figure 8: Second plate in stack with the AVR board mounted above the MEPO board, and two CVAs on either side of the MEPO](image)

The detectors will be mounted flush with the skin of the rocket. This required a special interface so that the detectors would be compatible with the Wallops rocket ports, and also one that would ensure the rocket was still watertight, as the payload section will land in the ocean. The mounting flange for the detector was designed by WFF, and the RocketSat Structures team was in charge of machining it to the specified tolerance from Wallops, 1/1000”. Both flanges have been completed, and a fit check was performed to ensure the detector fit in the flange. The result is shown in Fig. 9.
RocketSat VI hopes to collect data with a trend similar to that measured by the MAGIC experiment from the flight in June. We are also expecting that the numerical density of the particles will be much lower than those measured at higher latitudes, based on the models developed for the particle distribution globally. These models predict the particles are concentrated near the poles, but this has not been fully verified. The payload is scheduled to launch June 24, 2010. The teams are currently working on subsystems testing to prepare for systems testing and integration.

5. References


6. Appendix
6.1 Appendix A

Figure 11: AVR Board Schematic
Figure 12: MEPO Board Schematic. The Schematic is organized in blocks, so the full schematics for the latch, ADC, AVR, and power are in separate schematics not shown here.

Figure 13: SCIENCE Board Schematic. The Schematic is organized in blocks, so the full schematics for the gyroscopes and latch are in separate schematics not shown here.