SpinSat Mission Ground Truth Characterization

Andrew Nicholas, Ted Finne, Ivan Galysh, Anthony Mai, Jim Yen
Naval Research Laboratory, Washington, DC
Wayne Sawka, Jeff Ransdell, Shae Williams
Digital Solid State Propulsion, Reno, NV
Heather Cowardin
Jacobs Technology Inc.
Aroh Barjatya, Forrest Gasdia
Embry-Riddle Aeronautical University

ABSTRACT

The SpinSat flight is a small satellite mission proposed by the Naval Research Laboratory and Digital Solid State Propulsion (DSSP) LLC to demonstrate and characterize the on-orbit performance of electrically controlled solid propellant technology in space. Launch is expected in summer of 2014. This is an enabling technology for the small satellite community that will allow small satellites to perform maneuvers. The mission consists of a spherical spacecraft fitted with Electrically Controlled Solid Propellant thrusters and retro-reflectors for satellite laser ranging (SLR). The spacecraft will be deployed from the International Space Station. This paper presents a mission overview, ground truth characterization and unique SSA observation opportunities of the mission.

1. MISSION CONCEPT

The Naval Research Laboratory is in a work for outside parties agreement with Digital Solid State Propulsion (DSSP) LLC, to perform a spaceflight demonstration of an advanced rocket/projectile thruster technology that employs a special new class of energetic but non-pyrotechnic materials known as Electrically-Controlled Solid Propellants (ESPs). NRL is designing the spacecraft, and DSSP is designing the electrically controlled solid propulsion system. The spacecraft, known as SpinSat[1], is based on the Atmospheric Neutral Density Experiment (ANDE) design[2], and will provide a test platform to demonstrate and characterize the on-orbit performance of the thruster technology.

There are four primary goals of the SpinSat mission. The first goal is to characterize the performance of the ESP thrusters on orbit. The second goal of the mission is to provide a calibrated drag experiment at higher solar activity than the ANDERR and ANDE2 missions to provide a monitor of total neutral atmospheric density.
The SpinSat spacecraft is a 22”-diameter aluminum sphere, Fig. 1, with the ESP thrusters physically arranged on the exterior of the satellite to provide two basic maneuvers as spin-up (de-spin) maneuver and a normal thrust maneuver**.** For the spin-up maneuver, pairs of thrusters will be co-aligned 180 degrees apart, will provide a tangential component force on the exterior; for de-spin, a 2nd pair of thrusters will provide the opposite force. For the normal thrust maneuver, thrusters will be oriented perpendicular to the exterior of the satellite to provide force in the normal direction. Another set of thrusters placed at the opposite pole will provide normal force in the opposite direction. The third goal of the experiment is to provide a test object for space object characterization. SpinSat provides a unique object for this purpose, as the design of the spacecraft and exterior finish for thermal conditioning, and thruster testing operations provide an excellent test object for ground (and space) based surveillance systems.

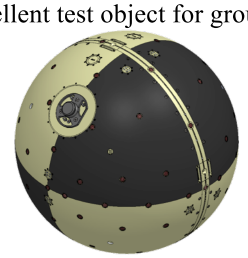

Fig. 1. SpinSat spherical spacecraft.

The spacecraft itself acts as the primary sensor for the final experiment goal; with a well-determined and characterized ballistic coefficient the routine collection of radar tracking and satellite laser ranging data will provide a high-resolution atmospheric drag data set used to derive thermospheric density.

SpinSat has manifested by the DoD Space Test Program (STP) for launch via the SpaceX Falcon 9 CRS4 mission on 12 Sept 2014 and is to be deployed from the International Space Station (ISS) on 29 Sept. 2014.

2. Ground Characterization

2.1 Spectrometer Ground Truth

SpinSat spectral measurements were acquired on June 19th prior to launch (scheduled for 12 September) at the Lockheed Martin Building (CMC subcontract) located in Houston, Texas. The spacecraft was stowed in the packaging box during all measurements and all instrumentation and personnel followed pre-flight protocol for handling, including electrical grounding and no contact with the spacecraft during optical measurements. The primary goal for obtaining pre-flight spectral measurements was to characterize the main surface materials on the spacecraft, as they have the highest probability of detection from optical ground-sensors based on surface composition. The two materials investigated were Aluminum 6061-T6, the black was IAW MIL-A-8625F, Type II Class 2 and the gold was chemical conversion coat IAW MIL-C-5541, Class 3 "Gold Irridite." Figure 2 shows the two main materials of the SpinSat spacecraft that were used for pre-flight spectral measurements.

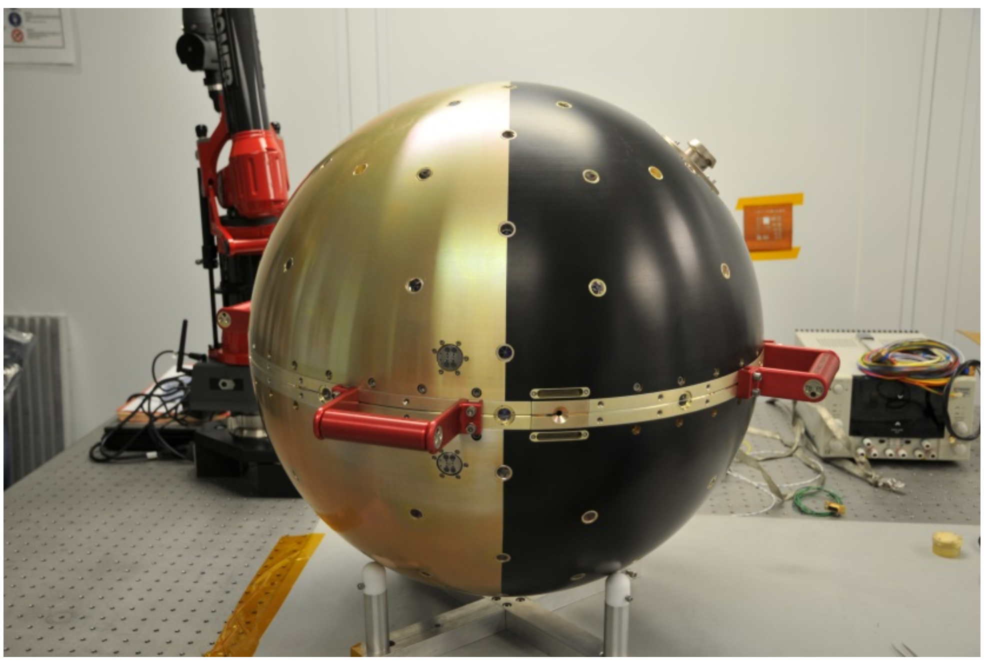

Figure 2. SpinSat

The instrumentation used to acquire spectral measurements consisted of an Analytical Spectral Device (ASD) field spectrometer with a range from 300-2500 nm and a resolving power of approximately 200 (corresponding to a bandwidth of 10 nm at 2000 nm) with 717 channels. Measurements were acquired by placing the target under the quartz lamp illuminator and orienting the spectrometer's fiber feed (mounted in a pistol grip) approximately perpendicular to the target surface. Due to the constrained area to work with, the fiber optic detector was held by hand to allow for the maximum reflectance without saturation for spectral characterization. Figure 3 shows an example of how the measurements were set-up.

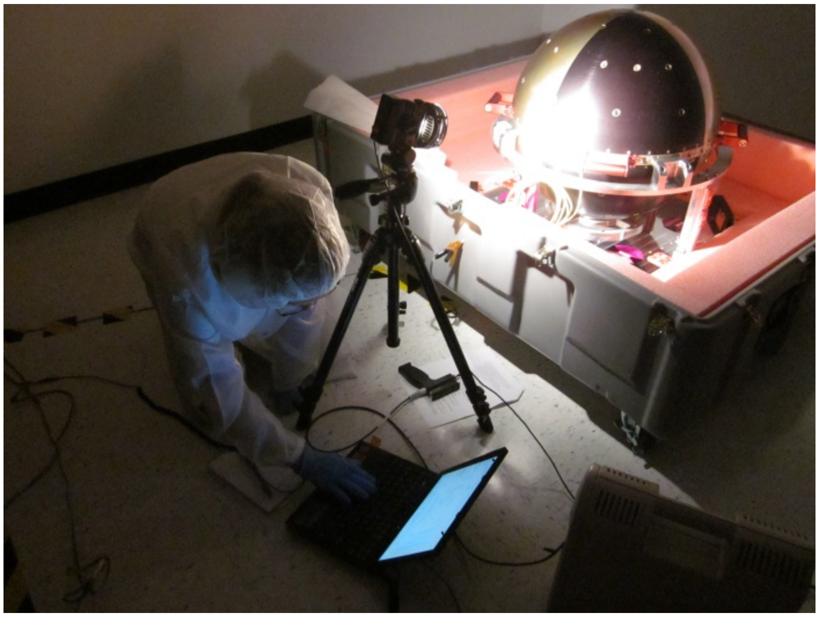

Figure 3. Spectral measurements instrumentation set-up

Standard procedure requires a minimum of three spectral measurements to be acquired for each material investigated. The mean is then computed and any outliers (bad measurements) are discarded. **Error! Reference source not found.** shows the mean measurements for the gold and black Aluminum surface materials, both scaled between 0 and 1, where 1 indicates 100% absolute reflectance as a function of wavelength in nanometers. The IAW MIL-A-8625F, Type II Class 2 is plotted in red and referenced as "Black" and the chemical conversion coat IAW MIL-C-5541, Class 3 Gold irridite is referenced as "Gold." The aluminum feature is present in both materials near 820 nm, more pronounced in the Gold material. The small features in the Gold between 600-800 nm are due to the coating used on the spacecraft. For the gold irridite material, the bandgap centered at 400 nm is indicative of the gold color. The black aluminum is featureless in the visible spectrum, 350 nm to ~630 nm, due to low reflectance and light being absorbed in this region.

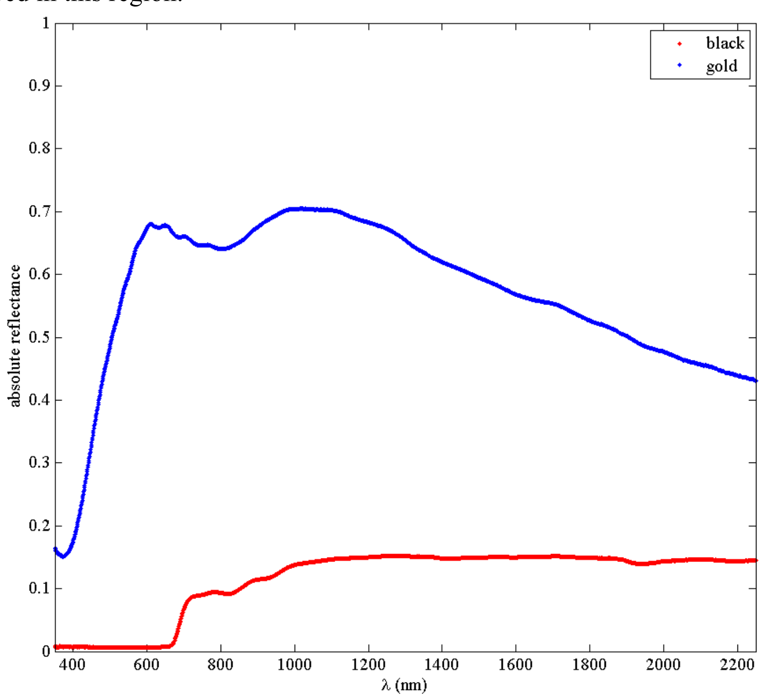

Figure 4. Mean spectral measurements for SpinSat surface, absolute reflectance versus wavelength (nm).

2.2 CCD Ground Truth

Embry-Riddle Aeronautical University (ERAU) is developing an optical tracking and spectral characterization system for small-satellite and CubeSat operational missions. The system, hereafter referred to as OSCOM, will primarily make use of the existing 0.5 meter telescope and a new 1 meter telescope at ERAU. In April 2014, optical ground truth data were collected on NRL SpinSat, which consists of images in four astrophotometric bands covering from 400 to 950 nm. These allow for direct comparison with on orbit observations that will be conducted in those same four bands using a 16 frame per second cooled CCD camera and the ERAU telescopes. The system relies on an optical feedback method to keep the satellite centered in the telescope's field of view as it tracks through the sky. By analyzing the satellite's lightcurve over the pass duration using techniques similar to those applied by astronomers to observations of near Earth asteroids, it is possible to determine the spin rate of the satellite. The observations of the SpinSat mission are meant primarily as a proof of concept to the OSCOM system overall and to see how it may be applied to CubeSats and other small-satellites that were not designed with optical observation in mind. For example, the lightcurve of a satellite with more complex geometry might reveal the presence of uniquely bright features or changes in the satellite's overall size, shape, or albedo overtime. Additionally, by recording data in several optical bands, a low-resolution spectrum can be obtained that may allow identification of any features which imprint color information on the reflected solar spectrum. The ability to obtain ground-based optical observations of CubeSats is particularly enticing because of the high failure rate associated with these satellites. Of these failures, nearly half are "no-contact" failures, so it is unknown whether the failure was electrical, mechanical, or something else altogether. Optical tracking measurements provide small-satellite operators the ability to obtain information directly, regardless of the satellite condition, so that anomaly resolution and independent confirmation of events may take place. In essence, these measurements are crucial in order to get a full picture of CubeSat performance alongside their standard telemetry data.

A researcher form ERAU travelled to NRL to acquire ground truth images of the SpinSat spacecraft. The spacecraft was setup on an optical bench, sitting on a pedestal mount in a darkened clean room. The original data was taken with a pinhole "lens" with slightly soft focus to smooth the data. A standard CCD (KAI-2020M) was used for recording the data. Its quantum efficiency curve has not been removed from this data. The light source was a 1000 watt quartz halogen bulb with a peak intensity around 800 nm set up with a roughly parabolic reflector to approximate parallel rays. The images were dark subtracted and hot pixels removed. Sample V and I band images are presented in Figure 5 for the black anodized and gold irridite surfaces. The flux intensity is a sum of the absolute sample values over the area of the satellite in each image, including glint. These flux values are plotted in Figure 6 and were scaled by the mean intensity of a standard object that was in every geometry. This corrects for alignment inconsistencies in the equipment setup. Measurements were obtained at multiple phase angles (the angle formed between the light source, the spacecraft and the detector), however due to physical constraints within the cleanroom, only measurements at phase angles of 70 deg and 90 deg were possible.

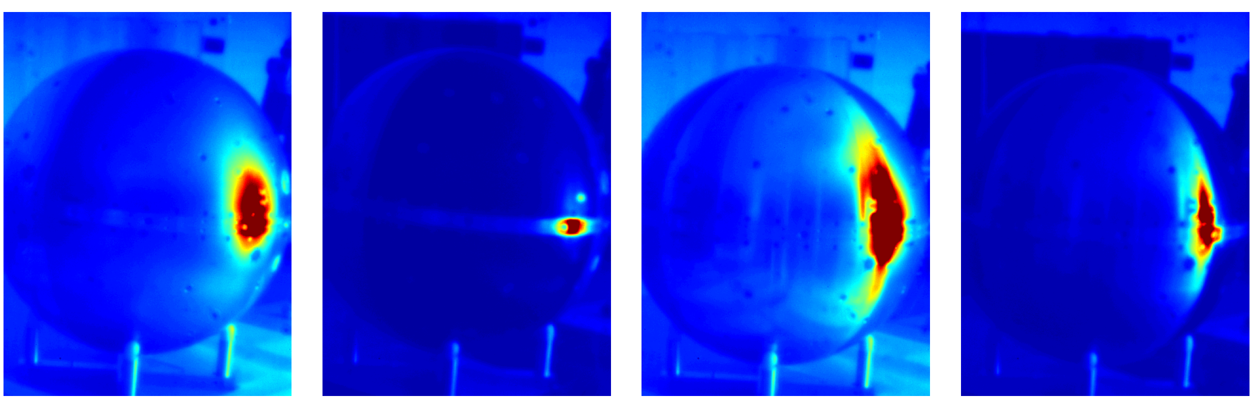

Figure 5: SpinSat quadrant images from left to right: black anodized in I band, black anodized in V band, gold irridite in I band, gold irridite in V band. All images are presented on the same scale.

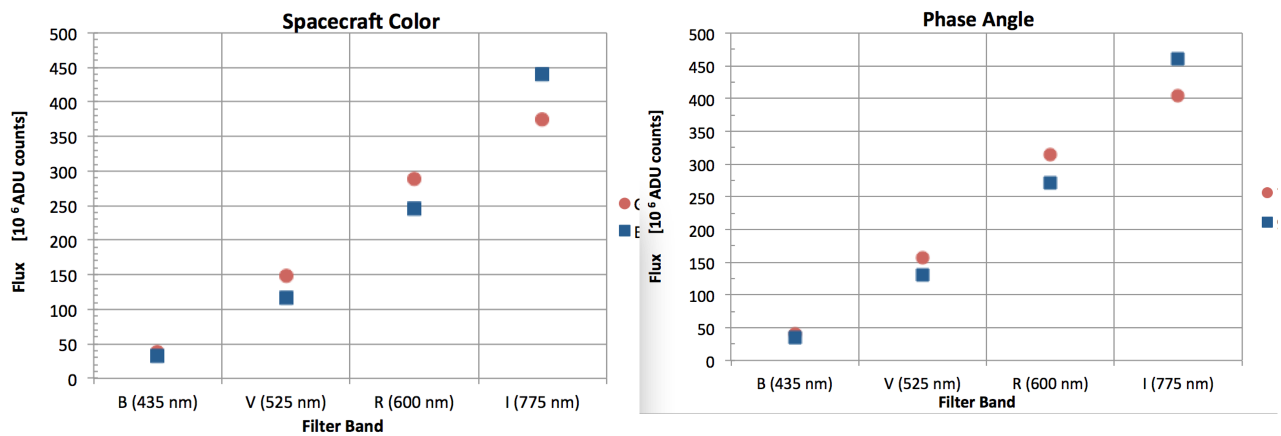

Figure 6. (Left) Intensity data for each band looking at the gold irridite and black anodized portion of the spacecraft. (Right) Intensity data in each band at two slightly different phase angles.

3. MISSION OPERATIONS

3.1 Launch and Deployment

The launch and deployment of SpinSat into its 400km 51.6° inclination circular orbit is provided by the DoD Space Test Program. SpinSat will be launched to the ISS as part of the soft-stow cargo allotment on the SpaceX Dragon spacecraft launched by the SpaceX Falcon 9 two stage to orbit launch vehicle during the SPX-4 resupply mission to the ISS. The satellite will be transferred into the ISS. The ISS crew will remove SpinSat from the launch configuration. The safe plug will be removed and a test plug installed to verify that Spinsat is functioning properly and in a safe condition prior to installing it onto the Cyclops orbital insertion apparatus. Cyclops was developed by NASA Johnson Space Center's Engineering Directorate in collaboration with the DoD Space Test Program. Once installed on Cyclops, the crew will verify that all safety inhibits are functioning properly, remove the test plug, and install the arm plug. The Cyclops will then be placed in the Japanese airlock and the airlock cycled. The ISS team will robotically remove Cyclops/SpinSat and position it in the deploy orientation. Cyclops will then deploy SpinSat with a Δv of 0.5 m/s and be restowed into the Japanese airlock.

3.2 On-Orbit Operations

Once deployed SpinSat will power up in a few minutes, final value pending concurrence from NASA Phase III Payload Safety Review after the plunger inhibit switches disengage from the Cyclops pusher plate. The spacecraft will go through early orbit checkout to verify command and control capabilities, reference instrumentation functionality, and thruster control module performance verification. The characterization of the ESD thruster technology will be performed by firing the ESD thrusters in pairs and measuring the changes to the spin rate via on-board rate instrumentation. Ground campaigns by the international laser ranging network will also provide a high resolution means to determine the spin rate of SpinSat from the ground. Small Δv firings normal to the surface of SpinSat will be characterized by on-board accelerometers. The lifetime of the satellite is expected to be >6 months and characterization should be complete within the first three months.

4. SUMMARY

The SpinSat spacecraft has been delivered and packed into its launch configuration for the CRS-4 mission. Fortunately, the SpinSat development schedule timeline allowed for multiple parties to make optical ground truth characterization measurements of the surface of the spacecraft. The collection of this ground truth data will provide an exquisite baseline for comparisons of observations acquired with the AEOS and OSCOM systems on Haleakala, HI and Daytona Beach, FL respectively. The SpinSat team is excited for the upcoming launch/deployment of the spacecraft from the International Space Station.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

1. Nicholas A.C., Thonnard S.E., Galysh I., Kalmanson P., Bruninga B., Kelly H., Ritterhouse S., Englehardt J., Doherty K., McGuire J., Niemi D., Heidt H., Hallada M., Dayton D., Ulibarri L., Hill R., Gaddis M., Cockreham B., "SpinSat Mission Overview", Proceedings of the AMOS Technical Conference, Maui, HI., Sept. 2013.

2. Nicholas A.C., Finne T., Galysh I., Mai A., Yen J., Sawka W., Ransdell S., Englehardt J., Doherty K., McGuire J., Niemi D., Heidt H., Hallada M., Dayton D., Ulibarri L., Hill R., Gaddis M., Cockreham B., "An Overview Of The ANDE Risk Reduction Flight", Proceedings of the AMOS Technical Conference, Maui, HI., Sept. 2002.