

MSU Solar Physics NSF REU

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By

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July 8, 2016

Introduction

The Montana State University (MSU) Solar Physics Department conducts cutting edge research studying the sun. Research involves analysis from many existing satellites such as Yohkoh, SOHO, TRACE, RHESSI, Hinode, SDO, and IRIS. To supplement this research, the physics department at MSU has created a Space Science and Engineering Laboratory (SSEL). Dr. Dave Klumpar, director and research professor, heads this lab. The lab combines students of many disciplines, including Physics, Electrical Engineering, Computer Science, and Mechanical Engineering. Together these students, along with their mentors, are able to propose, design, build, and test satellites that are sent to space year after year. Once these satellites are in space, the SSEL uses its Space Operations Center (SOC) to communicate and recover scientific data.

I am involved in this program through the National Science Foundation's (NSF) Research Experiences for Undergrads (REU) program. This program aims to help undergraduate students gain research experience who are preparing for graduate school. My expertise is the mechanical engineering (ME) aspect of satellite projects, specifically the Guidance, Navigation, and Control (GNC) subsystems. GNC Engineers work on two aspects of satellite projects, Attitude Determination and Control Systems (ADACS) and Trajectory Planning and Propagation Calculations. ADACS systems help in determining and controlling a spacecraft's orientation in 3D space. Trajectory planning consists of planning a spacecraft's orbit, and propagation consists of predicting a spacecraft's future orbit based off of its' current orbit.

IT-SPINS

I've worked GNC on three different missions already, the first of which is the Ionospheric-Thermospheric Scanning Photometer for Ion-Neutral Studies (IT-SPINS). Its mission is to provide the first 2D tomographic imaging from a 3U research Cube Sat. It is also

MSU's first Cube Sat with an active ADACS system. It will carry Stanford Research Institute International's CTIP measuring device, and is planned to launch on October 17, 2017 on NASA Educational Launch of Nanosatellites (ELaNa) mission #18. Its orbit is circular, with a 650 km altitude and a 92° inclination. The plan is to spin the spacecraft at 2 rpm around the antenna axis, as seen in *Figure 1: IT-SPINS*.

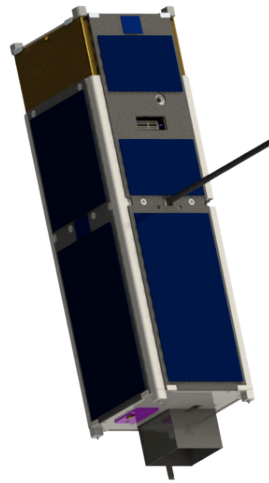


Figure 1: IT-SPINS

As seen in *Figure 2: IT-SPINS Internals*, the ADACS system is on top (in grey) with CTIP on the opposite side (in yellow) and the electronics stack in the middle (in blue).

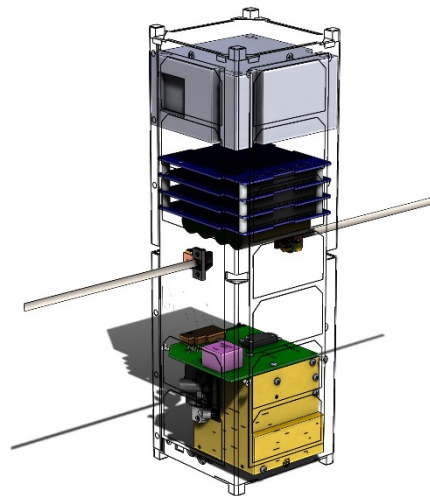


Figure 2: IT-SPINS Internals

The ADACS system chosen for IT-SPINS is the MAI-400 built by Maryland Aerospace Inc. While one can purchase a MAI-400 directly from Maryland Aerospace, the SSEL team will be working with them to design a custom ADACS that fits IT-SPINS exact requirements. The commercial off the shelf (COTS) MAI-400 consists of 3 reaction wheels, a 3 axis magnetometer, 2 infrared Earth horizon sensors (IR EHS), 3 electromagnets, and an ADACS computer. Our custom ADACS will have the 2 IR EHS oriented in an abnormal pattern, a custom ACS mode to accomplish IT-SPINS' 2 rpm, and will be custom fit to work in the IT-SPINS chassis. *Figure 3: MAI-400* shows what the COTS ADACS system looks like.

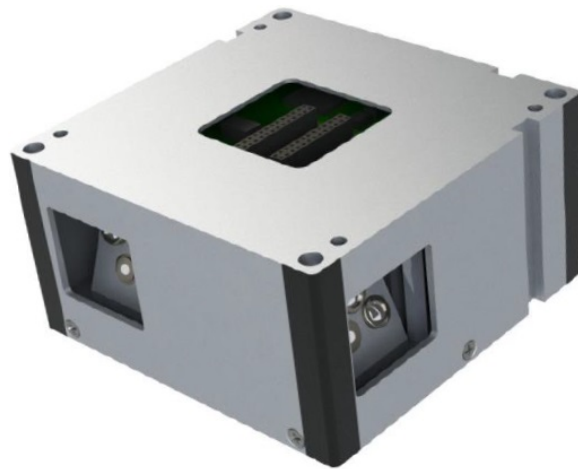


Figure 3: MAI-400

This system has not been built yet, however, the SSEL has a MAI test ADACS board along with a test harness that allows the board to be plugged directly into the computer. This is useful to flash new firmware onto the flight computer, and to run simulations. In *Figure 4: Test Board & ADACS Board*, the test board is on top, with the ADACS board on the bottom.

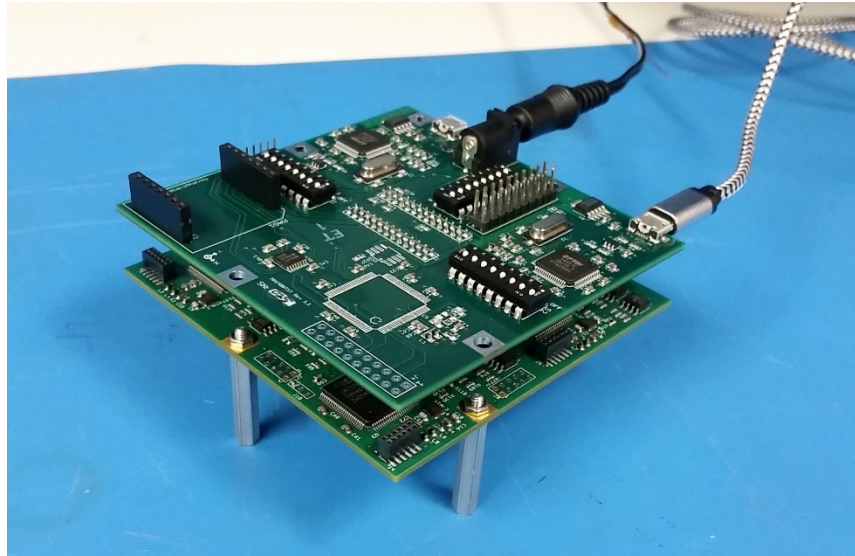


Figure 4: Test Board & ADACS Board

These are very expensive proprietary boards, so all electrostatic discharge (ESD) precautions must be taken when dealing with them. These include wearing ESD preventative lab coats and grounding bracelets that ground you to the table. To simulate day-to-day operations, the test and ADACS board are connected to the computer. Then, as seen in *Figure 5: Dynamic Simulator*, a dynamic simulator is run on the computer that simulates input data the board would see in space.

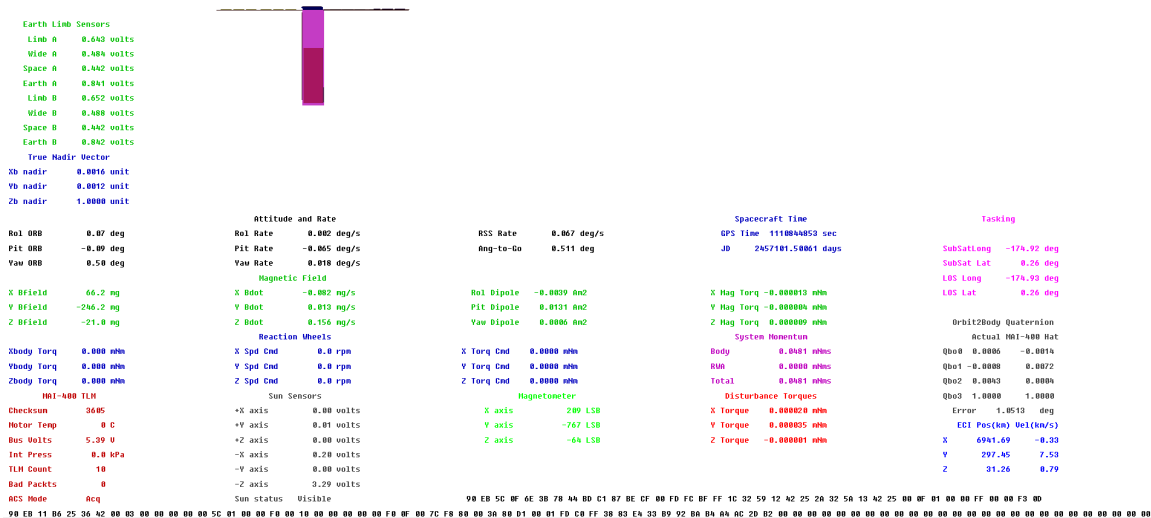


Figure 5: Dynamic Simulator

This information is then run back into the computer through a ground station program, as seen in *Figure 6: Ground Station*, to simulate what a satellite operator would see from the ground. Many tests were done simulating and testing multiple initial conditions and situations the spacecraft could be put in, such as initial de-spin and normal operations.

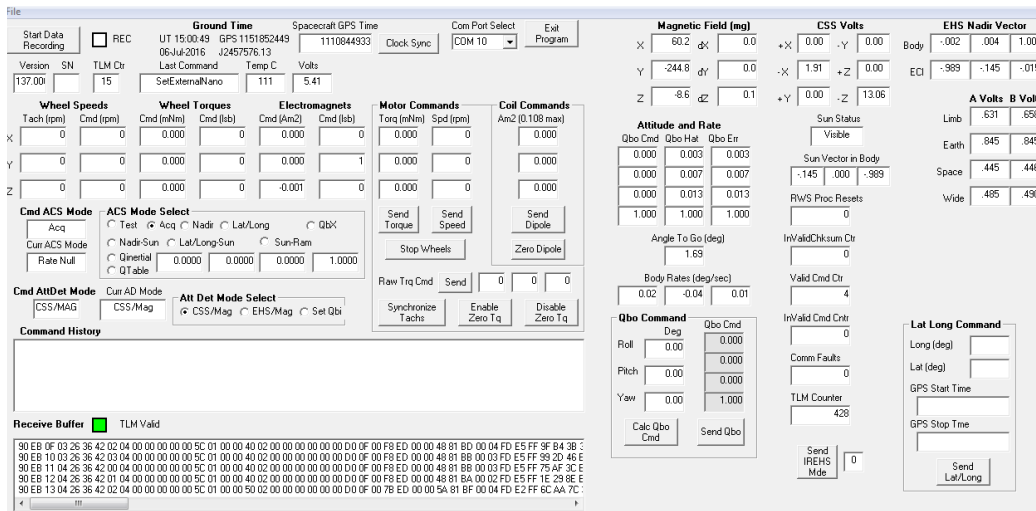


Figure 6: Ground Station

The ground station shows what the actual command telemetry hexadecimal code will look like on the MAI-400, so another task was to input every possible command on the ground station and record the hexadecimal command line that it output. This data was then given to the software engineering team at the SSEL to integrate with the IT-SPINS Space Flight Computer (SFC). When I first arrived at MSU, all simulations being run on the trajectory were simple 2-body problem, with an inclination of 92° , 650 km altitude, and 270° Right Ascension of the Ascending Node (RAAN). When I inquired about the ELaNa launch, I discovered the RAAN was not actually given to us. NASA actually specified the Mean Local Time of Ascending Node (MLTAN). The MLTAN is a sun-based coordinate system, however the RAAN is an Ares based, or Earth Centered Earth Fixed (ECEF) based coordinate system. The first steps I took to improve the trajectory calculations and propagations consisted of converting a few MLTAN's in the given range to RAAN as seen in *Table 1: MLTAN to RAAN*.

MLTAN (hours)	RAAN
1630	273°
1745	292°
1900	311°

Table 1: MLTAN to RAAN

As seen above, none of the given RAAN values are within the 270° previously used to propagate the orbit. The second improvement I added to the trajectory propagation was adding a much more complex propagation model. This model included aerodynamic drag, non-sphericity of the Earth, gravity gradient torque, solar radiation pressure, and the pull of the masses of the Sun and the Moon on the spacecraft. All of this combined to create a very complex and much more accurate propagation model. Interestingly enough, this model predicts no eclipses for the first month, with the first eclipse lasting 5 minutes on the 10th of November 2017. Another necessary calculation that I did was the sun vector calculations. These calculations consisted of determining the angle of each of the six sides of IT-SPINS with the Sun at any given time. These angles, combined with the max power output of the solar panels on each side, can be used to calculate the power budget of the satellite. A good way to visualize the orbit's orientation related to the sun is the β angle. The β angle is the angle between a vector normal to the orbital plane, and the satellite's sun vector. The β angle can be calculated by taking the cross product of the position and velocity vectors of the satellite with respect to (WRT) the Earth, and the dot product of the Sun vector of the satellite and that perpendicular vector. Running this calculation through a MATLAB script gives *Figure 7: Sun Angle vs. Time*.

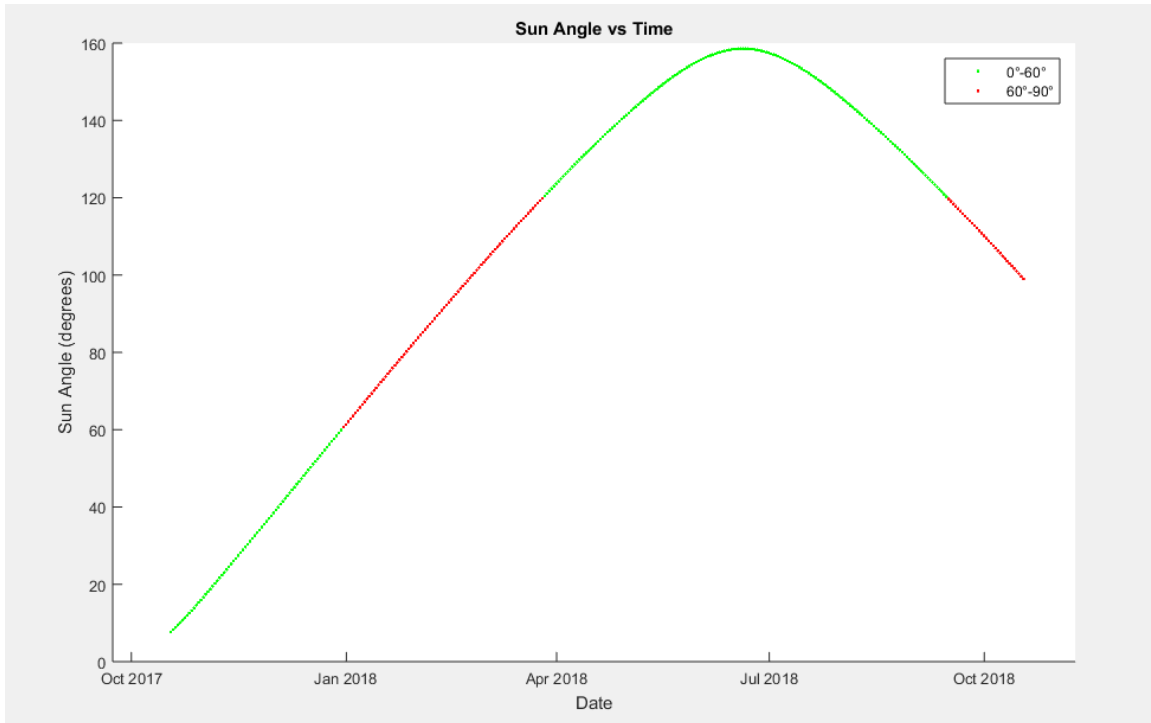


Figure 7: Sun Angle vs. Time

The sections of this figure in green are when the satellite gets the most sunlight, versus the sections in red when it gets the least sunlight.

Mission Concept 1

Another satellite mission I worked on is called Mission Concept 1. It's a 6U Cube Sat with a mission to detect optical signatures of atmospheric gravity waves (AGW), traveling atmospheric disturbances (TAD), and traveling ionospheric disturbances (TID) against the limb far ultraviolet (FUV) background. It is planned to launch in Early 2018 and has a non-circular orbit. To complete its scientific mission, its perigee must be between 400-600 km altitude and its apogee must be between 500-600 km altitude and must have an inclination greater than 65° . It will have two attitude modes during its mission, one spinning very similar to IT-SPINS at 2 rpm, and another one that involves simple nadir pointing. This mission is currently in the concept/proposal phase. To properly prepare a preliminary power budget for Mission Concept 1,

I ran simulations of possible orbits within its scientific orbital parameters. From this I could determine the best and worst case scenarios, as seen in *Table 2: Mission Concept 1 Orbital Analysis*.

<u>Orbital Element</u>	<u>Effect on Sunlight</u>	<u>Worst Case</u>	<u>Best Case</u>	<u>Correlation</u>
RAAN	Medium	225°	90°	Sinusoidal
Inclination	Large	50°	70°	Linear (higher is better)
AOP	Small	180°	315°	Sinusoidal
Perigee	Large	400 km	600 km	Linear (higher is better)
Apogee	Large	500 km	600 km	Linear (higher is better)

Mission Concept 1 Orbital Analysis

Mission Concept 2

Another satellite mission I worked on is called Mission Concept 2. It's a 6U Cube Sat with a mission to take in-situ measurements of the O⁺ and H⁺ temperatures and the electron temperature in the same volume. It is planned to launch in Summer 2019 and has a non-circular orbit. To complete its scientific mission, its perigee must be between 400-500 km altitude and its apogee must be greater than 800 km altitude. It must have an inclination greater than 50°. It will have 1 attitude mode during its mission, ram-pointing, which means it will be facing its sensors in the velocity direction. This mission is currently in the concept/proposal phase. To properly prepare a preliminary power budget for Mission Concept 2, I ran simulations of possible orbits within its scientific orbital parameters. From this I could determine the best and worst case scenarios, as seen in *Table 3: Mission Concept 2 Orbital Analysis*.

<u>Orbital Element</u>	<u>Effect on Sunlight</u>	<u>Worst Case</u>	<u>Best Case</u>	<u>Correlation</u>
RAAN	Medium	135°	0°	Sinusoidal
Inclination	Large	50°	70°	Linear (higher is better)
AOP	Small	180°	90°	Sinusoidal
Perigee	Large	400 km	550 km	Linear (higher is better)
Apogee	Large	700 km	900 km	Linear (higher is better)

Mission Concept 2 Orbital Analysis

Future Work

For the rest of my time here at MSU, I will be studying and working on the day-to-day operations of the IT-SPINS MAI-400. Also, Mission Concept 1 and 2 will both need much more in depth analysis of their power budgets, similar to what was done with IT-SPINS.