SIMULATION STUDIES AND ANALYSIS IN THE DESIGN AND DEVELOPMENT OF A MINIATURE SATELLITE

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This article shares some of the analysis and simulation tools for a miniature satellite (CubeSat) developed entirely by Norwich University and Vermont Tech. students and accompanied by The National Aeronautics and Space Administration (NASA) in the year of 2012. The project is classified as "low cost project" compared to other space projects by NASA, and the research could lead for the initial space program in the Kyrgyz Republic and universities for its flexibility and innovation.

CubeSats are a class of research spacecraft called nanosatellites. The cube-shaped satellites are approximately 10x10x10 cm, 1kg (1U). Moreover, larger models 1.5U, 2U or 3U are also used for more complex projects. Compared to traditional multi-million-dollar satellite missions, CubeSat projects have the potential to use new innovations in useful missions in science and industry at considerably lower costs. CubeSat payloads and experiments are often new and unique, and project timelines are typically 9-24 months from inception to launch. CubeSat missions still require advanced planning and work hours for successful missions. CubeSat uses many of-the-shelf commercial and freely available tools and components in the construction.

The main objectives for the 2012 mission were, first, to integrate camera with the onboard processor, where the camera system received a command from Earth to take a picture of the Moon at the specific time. The picture then was downloaded to Earth. Secondly, to develop computer simulations of the 2012 mission to assist in making design decisions for the satellite. Finally, and most importantly, use the simulations to model mission elements such as temperature variation, rotation rates, satellite orientation, and Moon viewing opportunities.

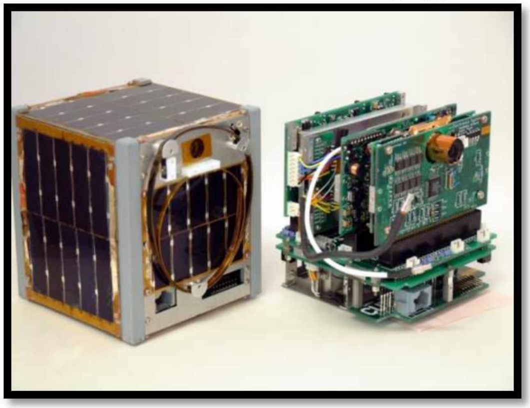

Fig.1 1U CubeSat

Software provided for the research and development aided for successful and detailed mission planning and simulations. For the future-potential Kyrgyz Space Program the software can be purchased to avoid an expensive and long personal software development. One of the powerful software used for the mission was STK and STK/SEET.

STK or Satellite Tool Kit is a general-purpose modeling and analysis application for any type of space, defense or intelligence system. It derives its power from AGI's patented spatial mechanics engine and integrated visualization. In its base form, STK addresses a majority of the requirements for concept development and preliminary system or mission designs.[i]

- Intuitive user interfaces for creation of detailed models and simulations
- Tens of thousands of data output parameters
- Fully customizable report and graph styles with hundreds of standard reports and graphs included[ii]

STK/SEET is software for whether trade studies, mission planning, or satellite design, or just contemplating the long-term impacts of the space environment on a spacecraft are done, which provides the expert analysis tools needed. STK/SEET models the near-Earth space environment and its expected impacts on any space vehicle.

STK/SEET provides:

- The radiation dose information needed to model any equipment's performance degradation and its expected lifetime
- Abilities to mitigate the Risk of Single Event Upsets and latch-up to a mission by estimating expected SAA entrance and exit times and knowing when to turn off or reboot LEO spacecraft's sensitive electronics
- Abilities to mitigate the risk of damaging impacts due to small particles and debris
- Information a likely range of mean vehicle temperatures for a spacecraft and plan for those that impact its performance
- Abilities to compute the local magnetic field at a satellite providing information about its attitude along the specific satellite path

Another software used during the project, and, which might be used for Kyrgyz Space Program is The CubeSat Toolbox. The CubeSat Toolbox is MATLAB based software provides tools needed to design CubeSats. The tool is provided by Princeton Satellite Systems and has a reasonable price. The software provides the following applications:

- Trade studies
- Visualization
- Control system design
- Communications Link Analysis
- Power and Thermal Analysis
- Orbit modeling and simulations
- Generate orbits from Two-Line Elements sets
- Generate attitude profiles with sequences of primary and secondary alignments
- Relative orbit simulations and coordinate transformations
- Compute observation time windows of ground targets
- Compute line of sight of GPS satellites
- Animate the orbits of multiple satellites with sensor cones

The software is specific to CubeSats. Although the Toolbox is not as powerful as STK, it contains more in depth analysis such as thermal and magnetic analysis.

The last software used for the project is SNAP. The Smart Nano-satellite Attitude Propagator (SNAP) is a 6-DOF satellite attitude propagator implemented in MATLAB and Simulink used to analyze the environmental torques affecting a satellite and to design and analyze passive attitude stabilization techniques, such as Passive Magnetic Stabilization and Gravity Gradient Stabilziation. Abilities:

- A simple-body gravitational model for orbit propagation
- Gravity gradient torque
- Magnetic torque due to permanent magnets
- Magnetic Hysteresis torque and damping

SNAP can be used to simulate the attitude and pointing dynamics in orbit for passive satellites. This is suitable for light-weight satellites (CubeSats, Nano-satellites, etc.) whose attitude stability is largely affected by external environmental torques that are normally ignored in larger spacecraft design. SNAP was initially designed to simulate magnetic field tracking stabilization using permanent-magnets and hysteresis material for damping. It can also be used to simulate earth-pointing stabilization using a gravity gradient bias.

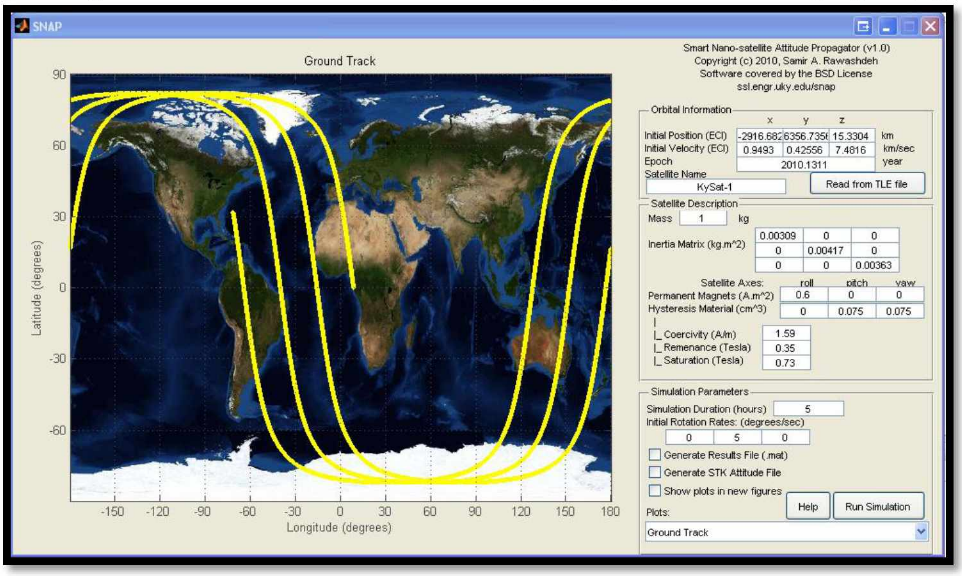

Fig.2 SNAP parameter window

RESULTS

For the 2012 mission, the satellite was have to align with the Earth's magnetic field and spin slow enough to allow the camera onboard to take pictures; therefore, the CubeSat's attitude was controlled with a passive magnetic system. The passive magnetic attitude stabilization system is the most common attitude stabilization system implemented on board of small satel

lites, which is cheap and does not require software development and energy consumption. The system is based on permanent magnets, which provide a restoring torque to align an oriented axis of the satellite with the Earth's magnetic field direction, and a set of magnetic hysteresis rods (dissipation system) to slow an initial spin of the CubeSat. The system was carefully designed in SNAP. The results show that it takes about 60 minutes for the 2012 mission CubeSat to damp the initial spin to near zero degrees per second (Fig.3).

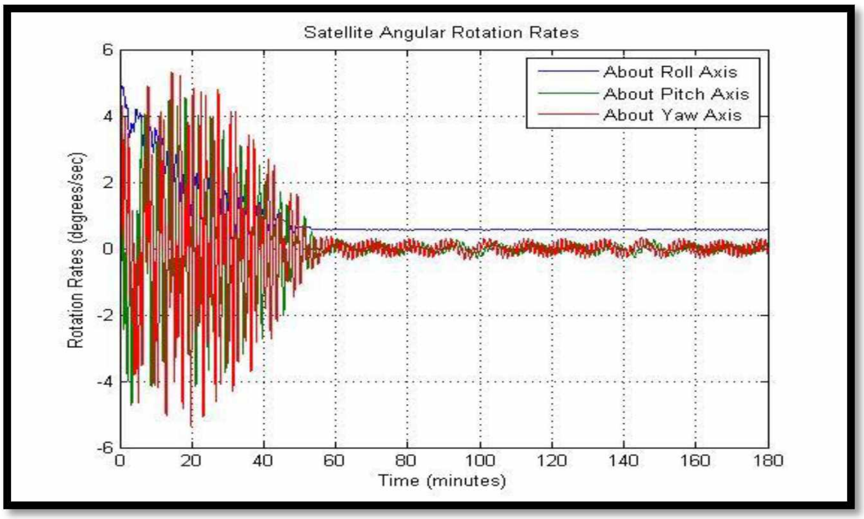

Fig.3 CubeSat angular rotation rates for 2012 mission

The Thermal Analysis was done by using both STK/SEEt and the CubeSat Toolbox. For both tools few parameters had to be defined such as: material absorptivity and emissivity, altitude, volume, and date of launch. The results showed reasonable temperature variations for satellite's stable performance (Fig.4).

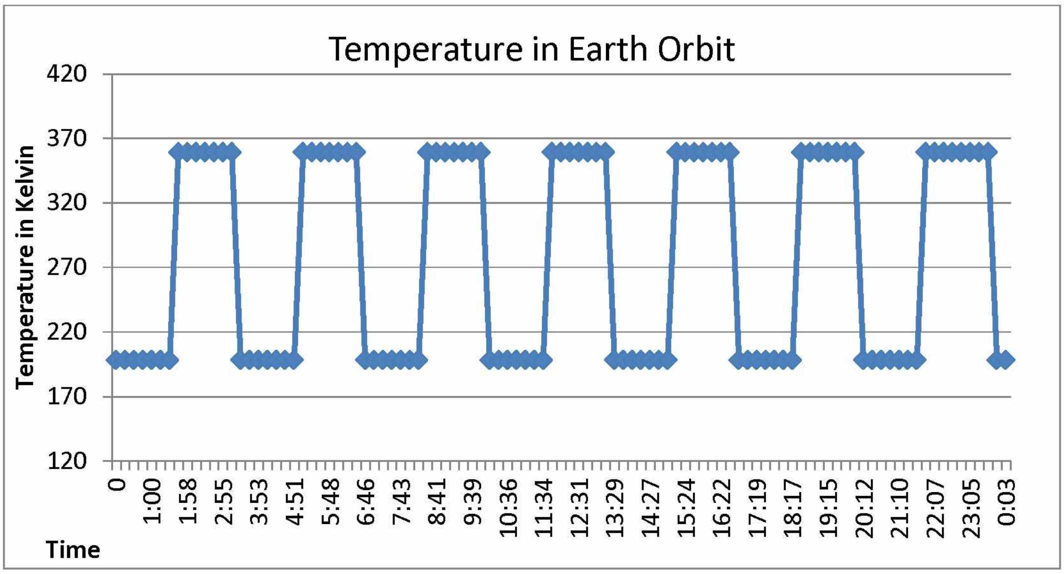

Fig.4 Internal temperature of CubeSat in Earth Orbit for 2012 mission

The mission planning was successfully performed and animated in STK. The CubeSat was launched in June, 2012. The duration of the mission was 15 months, during which reasonable pictures of Moon were downloaded to Earth. The whole project cost less than $100,000, and was performed entirely by students. As it known from the history, space research leads for breakthrough in technology and innovation. Thus, programs such as CubeSat might be the beginning for Kyrgyzstan's own space program. With tools and software available the program can be launched in short amount of time.