SSC09-XII-5

TJ^{3}Sat – The First Satellite Developed and Operated by High School Students

Carlos G. Niederstrasser
Orbital Sciences Corporation
21839 Atlantic Blvd Dulles, VA 20166, USA; +1 (703) 406-5504
Niederstrasser.Carlos@orbital.com

Alishan Hassan, Jake Hermle, Adam Kemp, Alexander McGlothlin, Devan Samant, Joel Stein
Thomas Jefferson High School for Science and Technology
6560 Braddock Rd. Alexandria, VA 22312, USA; +1 (301) 693-1914
adam.kemp@fcps.edu, tjcubesat@gmail.com

ABSTRACT

In 2006 Thomas Jefferson High School for Science and Technology (TJHSST) and Orbital Sciences Corporation (Orbital) announced a new initiative to have students from TJHSST design and build the first ever high school satellite. Leveraging the large body of prior work done in the CubeSat community, and under the mentorship of Orbital engineers, TJHSST students are in the advanced prototyping phase of their CubeSat dubbed TJ^{3}Sat. The TJ^{3}Sat payload includes a digital voice synthesizer that is accessible by the general amateur radio community. The TJ^{3}Sat project was conceived from the idea that some things simply cannot be taught by a teacher standing in front of a class. Instead students must be engaged not just through textbooks and lectures, but by actively designing, building, and operating real-world projects. Over the past three TJHSST students have learned the intricacies of requirements development, subsystem design, space-qualified soldering techniques and many other elements unique to the aerospace field. Through the TJ^{3}Sat program we will expose a new generation of scientists and engineers to the benefits and excitement of space missions at an age when they are making their first, crucial career decisions.

INTRODUCTION

Since the mid 1990's the number of university-built student satellites has been steadily growing. With the advent of the CubeSat platform and Nanosat competitions, the number of universities involved in the design and construction of small satellites has increased significantly. During this time several initiatives, most notably KatySat, have been started to involve K-12 students on several satellite programs. However, up until now, no primary or secondary school has actually led the design and development of a new satellite.

Conception of Project Excelsior

It was five years ago when, while interning at Orbital Sciences Corporation (Orbital), Jason Ethier made such an observation and asked, "So why not?" "I read that a bunch of colleges were doing it [building satellites] this last decade with CubeSats. Prior to that they were building things from the ground up on several million dollar budgets, but with the introduction of CubeSat, the price went below 1 million. With everything so much cheaper, I thought it was a lot [more] accessible to high school students."

The initial reaction from his mentors and bosses when Jason proposed *Project Excelsior* and the idea of a high school satellite was one of surprise followed by dismissal. Even a science and engineering magnet school such as Thomas Jefferson High School for Science and Technology (TJHSST) usually does not have the prerequisite knowledge to support a satellite program of any kind. After the initial dismissal, however, a more detailed evaluation of the idea led some to believe that such a program could be established.

The Birth of TJ^{3}SAT

Fresh from his internship at Orbital, Jason began to present some of his ideas to the administration at TJHSST, and noted that it could become the first high school to produce a small-sized satellite. That spring Jason founded *Excelsior Aerospace Club*, which taught basics for aerospace design and participated in the CanSat program.

As the school's administration warmed up to this innovative concept, a new Systems Engineering course and curriculum were developed. In the fall of 2006 the Systems Engineering class met for the first time under the direction of Mr. Adam Kemp. The group consisted of fourteen students ranging from sophomores to seniors, all with varying backgrounds that could contribute something different to the group.

Figures 1 and 2: From the onset, the assistance of mentors and members of industry has been integral to the student's learning as a part of the development of TJ^{3}Sat.

The course began by establishing the research backbone required to determine and justify the satellite's mission. The first semester consisted purely of educational research into both Systems Engineering and into the world of amateur satellite design and construction. Daily class consisted of lectures pertaining to satellites and orbital theory, as well as basic electronics, construction techniques and the engineering design process. Approximately once a month speakers from different areas of expertise gave presentations to the class as well as offer guidance in response to student's questions. Industry mentors interacting with some of the TJ students are shown in **Figures 1 and 2**.

On December 6, 2006, the TJ^{3}Sat program was officially kicked off when Orbital announced its partnership with TJHSST for the first-ever high school satellite, and Orbital's CEO, David W. Thompson presented the class with the kit that would serve as the core of their flight vehicle. In the partnership agreement, Orbital offered to provide the resources needed for the flight hardware, testing facilities for the finished spacecraft, and engineering mentorship by its employees. During this kickoff meeting, Virginia Congressman Tom Davis spoke eloquently on the need for tomorrow's engineers to be trained on the latest technologies and the importance of projects such as TJ^{3}Sat to our nation's future—a view which has since been reiterated by Secretary of Education Arne Duncan while delivering keynote remarks at the TJHSST Star Symposium.

PROJECT TEAM

The TJ^{3}Sat team hierarchy is modeled after development teams in industry, as shown in **Figure 3**. It is headed by a director, similar to an executive in industry, who has the final say in all project decisions and who makes sure that the project is progressing. The director and primary advisor to the team is the systems engineering teacher, Mr. Adam Kemp.

Underneath the advisor is the systems engineer. The systems engineer produces the majority of the paper work and documentation for the project. He drafts and revises the majority of the documents for TJ^{3}Sat, especially if they deal with system-wide issues and concerns. He also is the main vehicle through which mentors and the public learn about and help the project. Each week he is in touch with several mentors and outside people to both generate publicity for the project and help the various subsystems resolve their issues. Project management is part of another one of his responsibilities. The systems engineer is responsible for making sure the subsystems and their members are on task and adhering to the technical requirements set forth by the team during the 2007-2008 school year. He also solves inter-subsystem issues and works to make sure that data and information is transmitted effectively throughout the subsystems so that the subsystems do not interfere with each other.

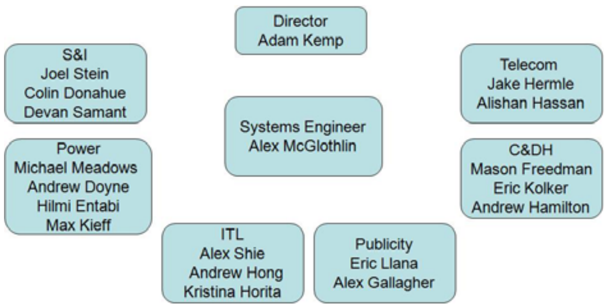

Figure 3: The TJ^{3}Sat team is modeled after one in industry.

After the systems engineer come subsystem leaders. These students have taken either two or three years of systems engineering, the class through which the satellite is developed; they are the experts in the workings of their individual subsystems. They know all the work that has been accomplished in previous years and are responsible for furthering the development of their subsystem, catching up new team members, making sure the advisor and the systems engineer know what they are doing and making sure the advisor and systems engineer are aware of subsystem issues. To help them are the members of their subsystem. These are all first year students who selected their subsystem based on personal interest. The members and leaders of each subsystem are responsible for the development of the hardware, software, and testing of the satellite. Their work is integral to mission success in that most of the mission failures that have been identified happen at the subsystem level.

The team works on the project primarily during the Systems Engineering class. The class is focused on teaching systems engineering and other engineering disciplines solely through the development of the satellite. Mentors and industry representatives frequently come in to the class to aid the students and give them help with figuring out how to best be engineers in their respective subsystems and the correct procedures for translating ideas to hardware and software for the satellite. Last year was the final year of the class with work that investigated systems engineering and product development. These topics are now solely learned through the collaboration of students with other students and mentors. It provides for a realistic industry experience that mimics the reliance of workers on co-workers to develop and test new ideas that have no documentation to grow off of.

MISSION DESCRIPTION

TJ^{3}Sat is primarily concerned with creating resources from which the aerospace industry and specifically the satellite industry can be promoted within K-12 institutions. The cost-friendliness of the CubeSat platform allows this to be possible. The satellite's team has documented all their work and progress throughout the development process in order to do this. When the satellite is launched a website will be published that will offer the public a variety of things. First, it will offer the designs of all the original hardware and software that was developed by the TJ^{3}Sat team. This will be done to aid in future satellite projects in K-12 institutions by helping them to develop their own hardware, through (hopefully) proven designs. The initial version of the website is shown in **Figure 4**.

Second, this will offer the ability for the public to interact with TJ^{3}Sat's primary payload, a TextSpeak module. This module is a voice digitizer; it takes written code and coverts it to audible speech. The Stensat Radio will then broadcast the speech over TJ^{3}Sat's Amateur Radio frequency so that the submitter of the message can listen to it. Through this feature of

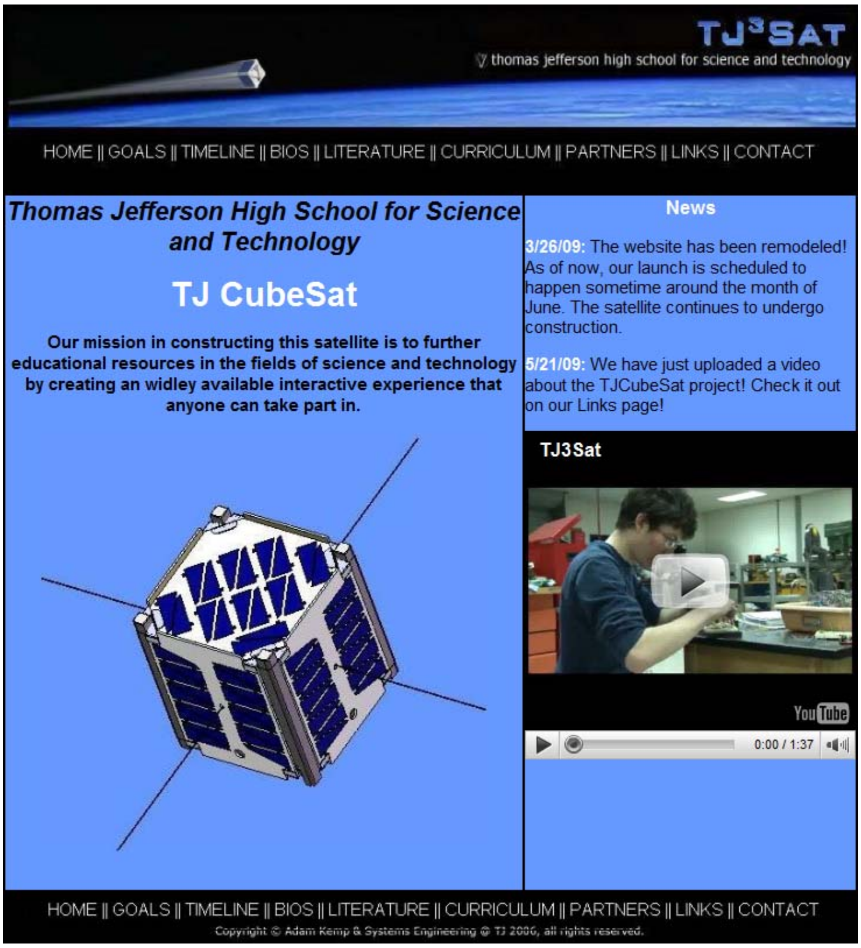

Figure 4: The current TJ^{3}Sat website contains information about the project, links to past presentations and our class video in YouTube. Contact information of the director and systems engineer of the project are also provided.

the website students all over the world will be able to take a part in TJ^{3}Sat's mission. An elementary school can send messages up to celebrate special holidays, high schools can have the satellite cheer on their sports teams, and individuals can send messages across the world to friends and family. Furthermore, the data from the sensors located on the satellite will be published. Math classes will be able to simulate various aspects of the satellite's life through this data. A number of telemetry sensors will work together to provide temperature, current, and voltage data for various hardware components on the satellite. From this information one can see the power draw over an orbit, the temperature fluctuations over an orbit, the tumble of the satellite (TJ^{3}Sat has no attitude control system) and the degradation of the components of the integrated system.

Lastly, the website will serve as a catalyst by which the public can be informed of TJ^{3}Sat's story and can ask questions of the team members involved in the project. The website will allow others to learn from this project's mistakes and successes to make their respective projects less likely to fail. It will make members of the project open to extend aid to fellow institutions in the hope that the aerospace industry will be expanded at the student level.

SUBSYSTEMS

The project is broken up into six subsystems: Power, Telecom, Communication and Data Handling, Sensors and Instrumentation, Publicity, and Integration, Testing, and Launch. Each of these subsystems concerns itself with a different part of the system that is responsible for mission success.

The *Power* subsystem is responsible for the selection and development of the electronic power system, which was completed this year. Working with Stensat LLC., a system was designed that was tailored to the specific requirements of TJ^{3}Sat. In addition, the group has prototyped the solar panels and power distribution unit for this system. The physical layout of the solar panels is shown in **Figure 5**. The group is also responsible for making sure the electronic parts used in the manufacture of the different system components are in sufficient supply to build both prototype components replacements for them. In addition, they are charged with documenting information on all the electronic parts put into the satellite.

Telecom is concerned with the satellite's radio and link budget. The group designed its own antenna board and selected the Stensat Radio for implementation in the system. Furthermore, it has developed a link budget and prototyped the parts necessary to test the ground software written in the lab and see if it can successfully transmit and receive data and control the satellite. Initial tests of the software have been successful.

Communication and Data Handling along with *Sensors*

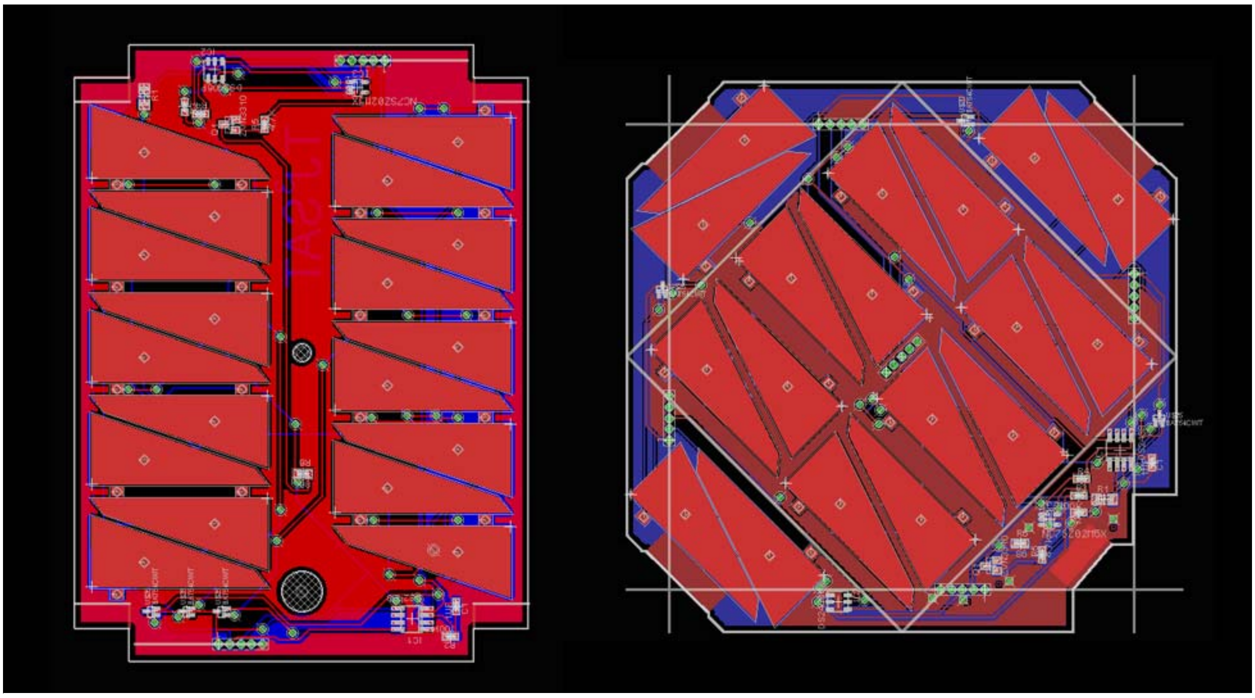

Figure 5: Preliminary designs for the layout of TJ^{3}Sat's solar panels, created by Jefferson students using EAGLE software.

and Instrumentation are responsible for creating the software and data budgets for the project. All onboard telemetry gathering is done via Maxim's DS2438, DS2406, and DS2480 1-Wire interface sensor chips. The software that controls the satellite is written for the Texas Instruments MSP430 central processing unit. These teams will make all their research and work public information through the website.

Website maintenance, project videos, and information aggregation are the responsible for the *Publicity subsystem*. This year they produced a video of the class made that was sent to major news outlets and is available on YouTube. They also edited and maintained the website and collected information so that articles can be written about TJ^{3}Sat.

Former subsystems *Thermal* and *Structures* were merges this school year to create *Integration, Testing, and Launch* (ITL). ITL took over the thermal simulation and structural simulation responsibilities of thermal and structures and were responsible for carrying out preliminary system and subsystem tests. They created system prototypes and modeled the satellite in both CAD and SolidWorks. Furthermore, they will be responsible for bringing all the information together from the testing that will occur this summer and providing what is not proprietary to the public through the website.

OPERATIONS

The operation of the satellite will be conducted solely through Mr. Kemp and the students on the project. There is a ground station located at Thomas Jefferson High School and equipment has been created so that they can fully operate their CubeSat from one of the school's labs. Students will take in and analyze the data from the satellite and maintain the system's health. There is also a benchtop model in the lab to troubleshoot on. A number of students have Amateur Radio licenses so that they can transmit and receive information and commands from the satellite.

LESSONS LEARNED

The purpose behind the TJ^{3}Sat project and the Systems Engineering class at Thomas Jefferson High School is ultimately educational, but the students learn through experience rather than through the typical learning practices of core classes. Some things simply cannot be taught by a teacher standing at the front of a classroom; the Systems Engineering class is characteristic of that. The students went through the engineering design process – presenting a requirements review, and developing both preliminary and critical design review presentations just as professionals would. They received feedback from mentors, made modifications to the designs, and presented their revised design again for review. The students can only be taught this process by going through it themselves. **Figure 6** shows two students testing the prototype solar panels developed for the project.

Systems engineering, in general, is an experience. Although the TJ^{3}Sat project itself has had only one or two systems engineers at a time, the students learned how systems work as a whole, and learned to balance the satellite's subsystems and make compromises – this came up when we were making our power and mass budgets in the early design phase – one subsystem cannot horde all of the power from the batteries, nor can a subsystem have unnecessarily massive parts that leave little mass in the budget for more important components.

Though experience has been an important factor when it comes to learning in the class, mistakes have often been the most powerful and effective teaching tool. Whether it is a completely inaccurate link budget, a solar panel ruined by electrostatic discharge, or a simple miscommunication of units of measurement, these mistakes have been valuable to the students' learning during the TJ^{3}Sat project. The various situations that the students encountered required them to practice their problem solving abilities, essential skills for any systems engineer.

Other lessons that we have learned have been more specific to our own project, and would be important should there be a second or third TJ^{3}Sat. One of the greatest obstacles for TJ^{3}Sat has been the constant cycle of students working on it; only one student on the team during the original 2006-2007 school year worked on it

Figure 6: Students learn many things in the midst of the development process, such as proper soldering techniques, the necessity of taking ESD precautions, and which methods do and do not work in manufacturing TJ^{3}Sat's components.

during the current school year, and only three students who started work during the 2007-2008 school year will be working on it during the 2009-2010 school year. Transition is difficult when students are constantly graduating out of the project, however, as of now, the old team members have been able to get the new members up to speed at the beginning of the year and progress has not been severely limited.

The TJ^3Sat project has been a journey, and while students have run into various challenges with the project, there has been no learning experience like it – a "learn by doing" class like this has proven its worth over time and has taught students new skills and concepts that could not have been taught by a teacher.

CONCLUSION

Before this year, there were few flight-ready pieces of hardware for the project. This year, each sub-system has finalized its hardware designs and has the hardware in the lab or has sent it out to be prototyped. Students have recently prototyped the antenna board, payload board, battery and electronic power system board, and both solar panel layouts. The boards have been shown to be successfully implemented by demonstrating operation of the payload during one of the design reviews. The satellite has been almost completely integrated and is ready to go into testing.

The sensors monitor different measurements for modeling data on Earth but also for making sure the CubeSat is working properly. The Sensors sub-system needs to determine the credible operating ranges for these sensors. One type of sensor is designed to turn on a transistor which heats up a resistor to burn a string of nylon that prevents the antenna from deploying until the satellite is in orbit. This design needs to be tested to see if it will work with the specified nylon. During this test

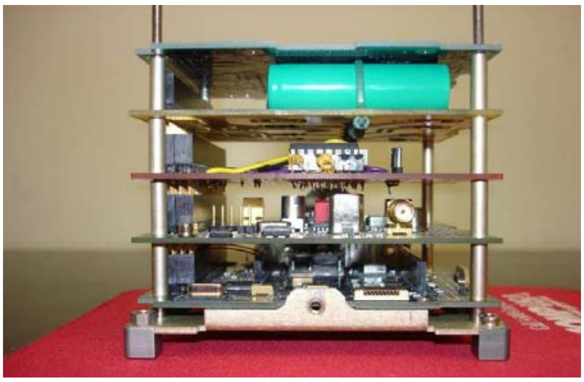

Figure 7: The satellite has almost been fully integrated on the desktop chassis model in the lab and the final designs are being manufactured so that will go into the testing model currently being developed.

the amount of power required to deploy the antennas will be noted in order to finalize the requirements of the satellite during its deployment phase. One type of sensor will be encased in thermally conductive epoxy to monitor the temperature fluctuations of the batteries during orbit. This has yet to be tested for effectiveness or stability in space. In terms of concept of operations, the group has yet to determine the frequencies of sensing.

Closely coupled with Sensors is the CDH subsystem. The subsystem needs to test if the processor can handle bad data from the sensors, the fastest speed of sensing, and how the lag time from the processor affects the timestamp. Code needs to be added to account for error situations such as a data buffer becoming overrun. To simulate orbiting, the student should run the program and leave it untouched for a week. The website described in our mission statement needs to be up and running with the integrated transmission to the TextSpeak.

The TJHSST ground station is in order but the students who would be monitoring the satellite need practice before the launch. They should track existing targets, predict passes, and listen to local HAM voice communications.

The Power sub-system has yet to construct all the solar panels but each consecutive one should get easier. They also need to test the correlations between temperature and power output for the panels.

ITL or Integration, Testing, and Launch now have a large load of work to do especially now that TJ received a vacuum chamber and vibration table. Both devices will be used to test the integrity of the CubeSat. Many informal tests are done at TJHSST but the formal ones will be performed at Orbital Sciences Corporation. Their facilities are more up to date and the tests are required for verification. Currently students do not meticulously detail test of subsystem components. This may make it difficult for other CubeSat developers to follow the work and may lead to incorrect verifications. Students will have to summarize all testing in a common folder, with dates, procedures, results, deviations, and other notes.

New to the TJHSST CubeSat is the publicity sub-system. Their progress will soon have everyone at TJ know about TJ^3Sat's mission. Additionally, the expanding informative website should provide a handy overview for prospective media willing to broadcast the project.

Most of the class has graduated and only six others will be left with experience. Testing will have to be done in summer to utilize the college freshmen and to hit the ground running in fall of 2009. Hopefully all this will help students gain a greater understanding of engineering but also increased interest in the fields.

Soon we will see the conclusion of the first ever four - year project by high school students to launch a picosatellite: TJ^3Sat

ACKNOWLEDGMENTS

This project would not be possible without the involvement of numerous individuals and organizations. First and foremost, special thanks to Jason Ethier, TJHSST alumnus and Orbital intern, who had a vision and the motivation to make it a reality.

Additional thanks are owed to the leadership of THJSST, including Adam Kemp and Dr. Wu (*we do not know his first name*) and executive support from Orbital, including Dave W. Thompson, Antonio Elias, and Ray Crough. Providing their insight to the students has been an extensive team of mentors including Bob Bruninga (Naval Academy), Hannah Goldberg (JPL), Kevin Doherty and Ivan Galysh (Stensat LLC), John Brunschwyler (Orbital) and over 15 other Orbital employees.

Orbital, AmSat, and the FAA donated a variety of equipment and flight hardware.

Special Thanks to Adam Kemp, Alexander McGlothlin, and Jeffery McGlothlin for providing the pictures used in this paper.

REFERENCES

1. Niederstrasser, Carlos, Adam Kemp, Joy Lee, Ashley Lewis, Nishad Samant, and Joel Stein. "TJ^3Sat – Unique Challenges of Building a Small Satellite within a High School Environment." *Proceedings of the 22nd Annual AIAA/USU Conference on Small Satellites.* 2008.