

## **TJ<sup>3</sup>Sat – Unique Challenges of Building a Small Satellite within a High School Environment**

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### **ABSTRACT**

In 2006 Thomas Jefferson High School for Science and Technology (TJHSST) and Orbital Sciences Corporation 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 Sciences engineers, TJHSST students are in the design phase of their new CubeSat dubbed TJ<sup>3</sup>Sat. The TJ<sup>3</sup>Sat payload consists of a digital voice synthesizer that will be accessible to the general amateur radio community. The launch of TJ<sup>3</sup>Sat is currently scheduled for mid 2009. Unlike most other student satellite programs, the TJ<sup>3</sup>Sat project has unique challenges by virtue of being a high school satellite. These challenges include organizational obstacles, resource constraints, and the absence of similar programs to draw experiences from. A high school usually does not have the required knowledge base to support a satellite program of any kind. To overcome these obstacles, the TJ<sup>3</sup>Sat program established a unique collaboration an industry partner to provide resources and real-world mentors.

### **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.

#### ***A New Partnership is Born***

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 design phase of their new CubeSat dubbed TJ<sup>3</sup>Sat. The launch of TJ<sup>3</sup>Sat is currently scheduled for 2009.

The primary TJ<sup>3</sup>Sat payload is a digital voice synthesizer that will be accessible to the general

amateur radio community. However, as with all educational spacecraft, the primary mission of TJ<sup>3</sup>Sat is to provide students with hands-on experience in satellite design, systems engineering, and project management. Unlike most other student satellite programs, however, the TJ<sup>3</sup>Sat project has unique challenges by virtue of being a high school satellite. These challenges include organizational obstacles, resource constraints, and the absence of similar programs to draw experiences from.

#### ***From Dismissal to Cooperation – Evolution of an Idea***

The long list of challenges surfaced when the concept of a high school satellite was first proposed. Jason Ethier, a TJHSST student working as an intern at Orbital raised the idea of a student satellite during the course of his summer internship. The initial reaction from his mentors and bosses was one surprise followed by dismissal. A high school usually does not have the required knowledge base to support a satellite program of any kind. Faculty members, for instance, are typically well versed in physics, mathematics, and computer science, but lack a working knowledge of space systems and have little or no spacecraft engineering expertise. Similarly, although many of the students are extremely talented, they have not had formal engineering training typically found in a

college's first year curriculum, let alone more advanced undergraduate or graduate topics.

After the initial dismissal, however, a more detailed evaluation of the idea led some to believe that such a program could be established. The key to success laid in establishing a system that would help alleviate some of the primary deficiencies that a high school was captive to.

***The Key to Success is Teaching and Mentoring***

To achieve its goals, it was necessary that the TJ<sup>3</sup>Sat program be set up as collaboration between the high school and an industry partner, in this case Orbital. Orbital would provide the resources needed for the flight hardware, testing facilities for the finished spacecraft, and engineering mentorship by its employees. However, it was imperative that the design and manufacturing of the satellite remain the domain of the high school; this was not to be an industry program with some "help" from the students.

In the collaboration that was set up, the students are responsible for all aspects of the design, building and operations of the satellite. Orbital, in turn, provides access to real-world mentors. The mentors train students in all aspects of systems engineering, including requirements generation and verification, interface control, spacecraft subsystems, orbital dynamics, and other challenges of the space environment. In a way, the mentors are simply an extension of the high school faculty. Just like a teacher, a mentor will not do a student's homework assignment, but instead will give the student tools and guidance on how to complete the assignment.

**BACKGROUND ON TJHSST SYSTEMS ENGINEERING PROGRAM**

***From Theory to Application***

Fresh from his internship at Orbital, but before any partnership had been established between the school and the company, Jason began to present some of his ideas to the school's administration and noted that it could become the first high school to produce a small sized satellite. At the same time, the school's Excelsior Aerospace club became the basis for educating students in space-based topics that Jason had covered while interning for Orbital.

As the school's administration warmed up to this innovative concept a new Systems Engineering course and curriculum was 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 14 students ranging from sophomores to seniors, all

with varying backgrounds that could contribute something different to the group.

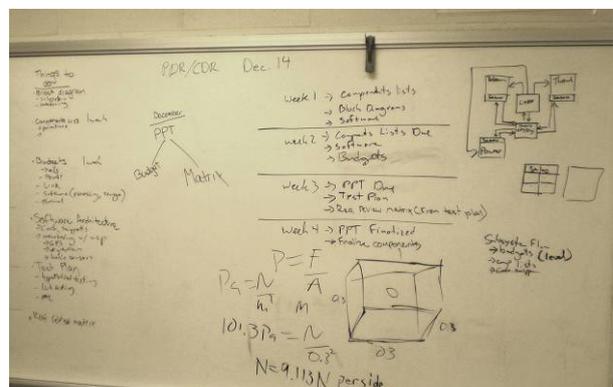
The Systems Engineering course is designed to bring High School students into an engineering environment where they learn to collaborate as a team around a common large-scale goal. Working with industry and professionals, the students in Systems Engineering are given first-hand experience with equipment and environments typically not seen in high schools. Over a three year timeframe the course will work to produce a small sized satellite.

The TJ<sup>3</sup>Sat program was officially kicked off at the end of the first semester when Orbital's CEO, David Thompson presented the class with the kit that would serve as the core of their flight vehicle. 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<sup>3</sup>Sat to our nation's future.

***Creating a New Curriculum***

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. From this research the students began to formulate what they would present during their System Concept Review as mission objectives and goals. 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 give presentations to the class as well as offer guidance in response to student's questions. These speakers consisted of volunteers from organizations such as Orbital, AmSat, the Naval



**Figure 1: PDRs and CDRs, Budgets and Test Plans – this is not your standard high school course.**

Academy, FAA, and Raytheon. The presentations have proven to be very important to the student's understanding of their subsystems and the project as a whole. They have also proven to be beneficial in establishing resources for future questions and assistance.

In addition to investigative research, the students worked to determine the potential mission concepts for our satellite. The students then presented these concepts to the class to be voted upon based on feasibility and interest in the topic. The final selection of the spacecraft's mission was made after the Mission Concept review held at the end of the first semester.

With a mission selected, students began the process of developing mission, system, and subsystem requirements to capture the scope of their project. At the same time they contacted equipment manufacturers, investigate costs, choose components, and further research the feasibility of their proposed mission objectives. From this research the students began to construct technical budgets in order to set guidelines for resources used by each subsystem. These budgets are a critical component in the design of a project such as this. These budgets included power, cost, mass, data handling, and telecom.

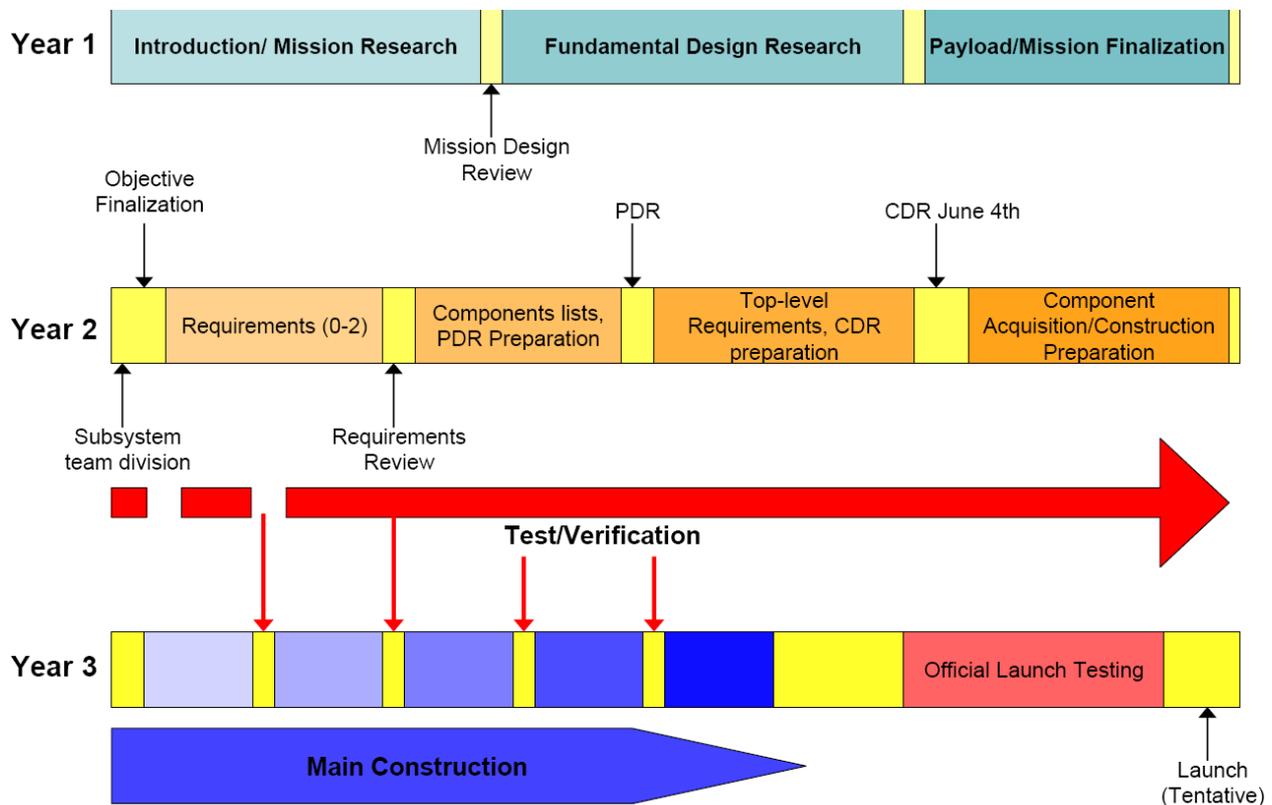
Students also worked on setting up their ground station.

The development of a ground station capable of achieving communication with orbiting satellites is mandatory for the success of the class and allows for teaching topics that directly influence the design of the satellite. In order to acquire the necessary equipment the students were delegated into teams to pursue potential sources for donation. The students were successful in receiving donations from corporations and produced approximately 90% of the ground station, including complete antenna array, control hardware, cabling, and five computer workstations capable of running our satellite simulation software and 3D CAD, and countless hours of donated time.

**Reviews, Reviews, Reviews**

No aerospace project would be complete without a long string of design reviews, and TJ<sup>3</sup>Sat is no exception. Reviews offer a unique setting to the students and allow them to obtain independent feedback on the work they have accomplished. Reviewers include fellow students, teachers from various disciplines including science, technology and humanities, and professional engineers from organizations such as JPL or Orbital. For one review an Executive Vice-President was even spied in the room.

AT the end of the first semester, students held their first



**Figure 2: The process followed in developing TJ<sup>3</sup>Sat is not unlike the one used by NASA and industry.**



**Figure 3: Students present their design to an audience that includes their peers, teachers, and professional engineers.**

Mission Concept Review. This review consisted of an hour and a half long formal presentation conducted by the students to present the current status of our project. During this time the students presented their proposed mission concepts and discussed the benefits and potential problems with each. This presentation proved invaluable and allowed the students to evaluate the design for feasibility and outlined potential flaws in the mission concept.

Having outside opinions critique a project helped to shed light on issues that would have normally gone unnoticed, while opening the door for potential new ideas. The preliminary design review that commenced in the first semester acted as a building block for the work that needed to be conducted during the remainder of the year. The students had the opportunity to have their research scrutinized and in many cases, were given new research areas to investigate.

This was the student's first exposure to outside reviewers. Throughout the next three semesters students held a System Requirements Review, a second Mission Concept Review, a Preliminary Design Review, and a Critical Design Review. At first, many students found the reviews overwhelming. As any engineer in the industry will attest to, design reviews can be brutal with darts flying from all directions and poking holes at every aspect of the design. Yet with each review, students realized that the only reason criticism and suggestions were abundant was because they had a strong design that could be evaluated critically.

## TJ<sup>3</sup>SAT MISSION

### *Mission Goals and Objectives*

The mission of the TJ<sup>3</sup>Sat is: To develop primary educational resources in the fields of science and

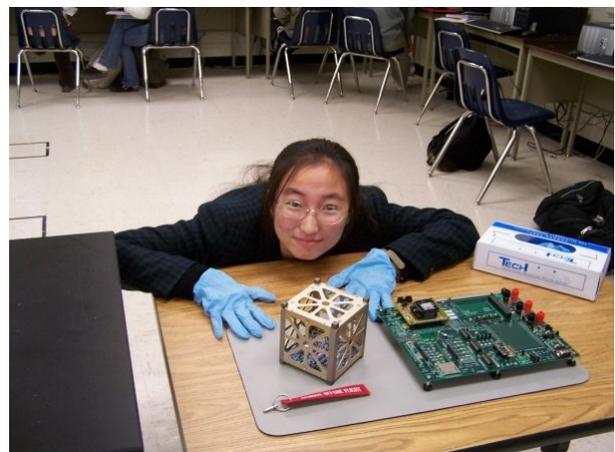
technology through the design, construction, and flight of a picosatellite. These goals are structured around the class's primary objective of not just proving that a high school can successfully fly a cubesat, but to provide a source of educational outreach. Part of this mission is to remove the misconceptions of "rocket science" that deter many from pursuing such an interest. The TJ<sup>3</sup>Sat team wants to prove "even high school students" are capable of launching a successful satellite provided material needs are fulfilled.

From these goals the primary and secondary objectives have been formed. TJ<sup>3</sup>Sat's primary mission objective is to provide access to resources for research in space education and focuses on Thomas Jefferson High School's mission of being an outreach school. The secondary mission objectives state that TJ<sup>3</sup>Sat will collect data on satellite systems, produce an operational satellite to substantiate the educational resources, provide educational resources to third parties and will use a voice synthesizer to broaden the scope of the global resources. These secondary mission objectives tie directly into the scope of the primary objective and are detailed in the satellites concept of operations.

### *The CubeSat platform*

The first step in implementing the TJ<sup>3</sup>Sat mission was the selection of a platform for the spacecraft. It was apparent to everyone involved that the easiest route was to follow the CubeSat standard introduced by Stanford University and CalPoly. A small package such as a CubeSat provided a manageable scope for the project, while still requiring all relevant subsystems and having the possibility of true spaceflight.

Because the course is designed to stress systems engineering and mission development, it was important that the students not be caught in the details of



**Figure 4: The CubeSat Kit™ allows students to focus on mission design and systems engineering rather than electronics development.**

component design. Because of this, it was recommended that TJ<sup>3</sup>Sat use as many off-the-shelf components as possible. By using off-the-shelf components students do not need to worry about the subtleties of radio design, processor board layout, or structural analysis. Although students are encouraged to further study any of these areas, if they are interested, the overall project is not held back by low-level design work.

At the core of TJ<sup>3</sup>Sat is the CubeSat Kit™ which provides the primary structure and command and data handling system. Completing the main subsystems of the spacecraft bus are a transceiver and power subsystem developed by Stensat LLC. Because of its simplicity, TJ<sup>3</sup>Sat does not require any form of attitude determination and control.

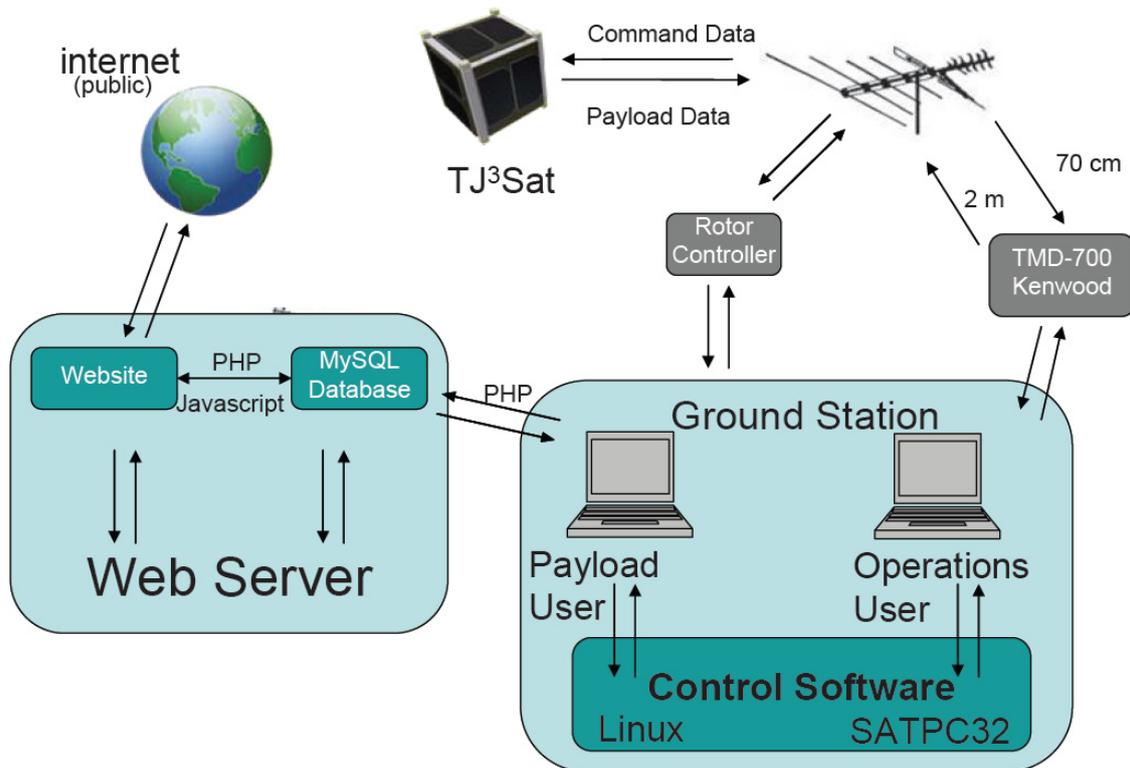
**Payload Selection**

During the initial stages of the project, the students worked to determine the potential mission concepts for the satellite. The students then presented these concepts at the first Mission Concept Review, and the class voted based on feasibility and interest in the topic. One of the mission concepts that was rejected early on was the use of a low resolution camera to take pictures of the Earth and determine the satellite’s position. Although this concept is not original, investigative research into the

satellite’s potential capability and the scope of the TJHSST course led the students to decide that a camera was infeasible. From this investigation, the students discovered that they could use telemetry data and computer modeling to simulate the satellite’s position and tumble through space without the use of a camera, a concept that might not have been formulated without the proposed camera payload.

With the camera (and several other potential payloads) ruled out, the student’s settled on a voice synthesizer able to transmit digitalized messages over amateur radio. This payload nicely fit into TJ<sup>3</sup>Sat’s stated mission objectives of education and outreach.

The hardware selected is a TTL-03 voice synthesizer that has previously been flown on the Navy’s ANDE and RAFT satellites. The payload accepts an ASCII string of text, converts it to speech, and broadcasts a synthesized voice via the downlink radio. The broadcast continues for a set amount of time, and then the next string in the queue is transmitted. Although command and control of the satellite is possible only from TJHSST ground station (or other authorized amateur ground stations), the payload itself can be commanded using a web-based front-end accessible through the Internet. This feature will serve as the primary method of providing outreach to other schools.



**Figure 5: The TJ<sup>3</sup>Sat Concept of Operations allows remote operators to command the voice synthesizer payload over the internet. The transmitted voice recording can be picked up using a handheld amateur radio.**

TJ<sup>3</sup>Sat's secondary payload consists of a sensor package used to monitor the health and environment the satellite has encountered. It consists of an array of ten DS18B20 One-Wire temperature sensors and six DS2438 smart battery monitors for voltage and current sensing. This data will be packetized and broadcasted at a set duration.

## **UNIQUE CHALLENGES FOR HIGH SCHOOL STUDENTS**

### ***“What is Systems Engineering?”***

The challenges faced by the students start with the very title of the class they have signed up to take. “Systems Engineering” as the class is called did not give a student, unversed in engineering terminology, much of an understanding of the class itself. All the students knew going in was that the class was aimed at building a satellite.

Initially, the class appeared to be disjointed and ineffective. By its nature Systems Engineering is broad in scope, and the class curriculum reflected this. However, through the first assignment of a 3-page paper on “What is Systems Engineering?” as well as the frequent presentations and guest speakers, the students were able to grasp a better feeling for what the class offered.

However, it was until much later in the year that the class started working as a whole. This, unfortunately, was evidenced by the results of the Mission Design Review in early December. As the year went on, the students began to learn more and specialize further into individual niches.

Then slowly the pendulum swung back as the students slowly began to realize that good systems engineers are both specialists and generalists. For instance, to conduct a thermal analysis an engineer learns how the different subsystems have to work together to complete even a simple step in the long process. To calculate the thermal requirements of the materials selected, one had to take electrical components within the CubeSat into consideration because they might significantly affect the thermal design

### ***Constraints of the High School Environment***

Many of the problems the students have faced can be attributed to being in a school environment. The biggest challenge encountered throughout the project is a lack of communication. The second year the students working on the TJ<sup>3</sup>Sat are split between two classes that meet different periods of the day. The concept was to divide up the roster into the “veterans” from the first year and the “newbies” of the second year. In practice, the lack of communication between classes and

difficulty in scheduling presentations led to much confusion and problems in getting everyone together.

Being put into classes also means that there are specific time slots allotted for working on the project during school. However, as much as the students would like to work outside of school, the demanding nature of high school, especially at TJHSST, means that they must constantly be making trade-offs and deciding which subjects they have time to focus on outside of school. Unfortunately, due to this nation's emphasis on testing, most of the time TJ<sup>3</sup>Sat must sit in the back row, while the AP courses take center stage.

### ***Changing of the Guard***

The start of a new school year led to many other different changes in the overall structure and organization of the project. For one, the previous year's seniors had left. No longer were students able to look to the founding members for guidance and direction. With the graduation of the seniors came the emergence of new, eager juniors and sophomores. At first, the lack of continuity affected the program as new students were unsure of the reasoning behind past decisions. Despite this, work was still able to get done. So much work, in fact, that those veteran members who had been with the program since the start looked at the first year as an inefficient use of manpower.

For the third year additional changes are in store. All the students are required to maintain a detailed journal or engineering notebook. So even when a student leaves, their work is well documented for the person who takes over that role. The departure problem, however, is not limited to graduating seniors. For a variety of reasons, sophomores and juniors are not always able to come back. When faced with this problem, some students realized that there are ways to be creative. They do not necessarily have to be enrolled in the class to participate in the project. Hence, this coming fall, they plan on continuing their work on the satellite. This is a project about which many are very enthusiastic and passionate. Some ideas for continuous involvement include writing descriptive articles for the website during the summer.

### ***Presentation Skills***

The design reviews the students presented were the first experience for many in presenting before professional engineers. While scary at first, the underlying concept was that the reviewers were only there to help the team and any hard feelings were just side-effects of the production process. Students very quickly realized that this class was not just about building a nifty toy. To be successful, they not only have to hone their

technological proficiency, but they also had to improve their research and presentation skills.

## COLLABORATION WITH INDUSTRY

### *Corporate Challenges*

The challenges in this joint endeavor have not been limited to the students. Orbital, too, has faced numerous new situations in which the company and its employees had to adapt. Orbital's previous involvement with educational institutions has been with colleges and universities. Furthermore, this involvement usually took the form of paid research grants or recruiting activities. Specifically, previous partnerships involved a direct and tangible benefit to Orbital. This is not the case for the TJ<sup>3</sup>Sat project, where the most direct benefit is to the students.

To properly fund the project at TJHSST decisions had to be made about the mechanism for allocating a budget. Would the budget be managed by the head corporate office, by the operating group where the intern had been employed, or by the public relations group? Because Orbital is a government contractor, strict rules had to be followed in accounting for any money spend. Questions arose whether this would be an allowable expense under government rules. Did it qualify as outreach or was it primarily for employee morale building? None of these questions were insurmountable, and multiple solutions, including the one executed were valid. The challenge was not in resolving these issues, but rather in realizing that number of details that had to be taken care of.

Even ITAR regulations proved to be an issue. Because mentors are providing hands-on experience in spacecraft design, their work can be categorized as a "technical service" under ITAR. If any of the students happened to be a foreign national the regulations would require a Technical Assistance Agreement (TAA). When the subject was broached with the Department of State, the system broke – how could one issue a TAA to a minor who has no signature authority. Fortunately, the class has not had any foreign nationals so the problem has been avoided — for now.

### *Employees Volunteer as Mentors*

When they heard about the project, and Orbital's sponsorship, employees were eager to jump in as mentors. An initial roster of over fifty mentors showed the level of interest and excitement encountered. For many employees this is an opportunity to share their knowledge in a field that they love. For others it is a way to give back to the community. And for more than one, the TJ<sup>3</sup>Sat project allows them to be involved in a

project that may get to space before their real-life project ever does!

However, much like the students, mentors soon realized that their schedule did not allow as much mentoring time as they would have liked. Travel time between corporate headquarters and TJHSST is at least forty minutes, and up to ninety minutes in the famous D.C. rush hour traffic. Combine long working hours with students needing to catch the school bus home in mid-afternoon, and finding common time to meet becomes close to impossible. Mentors wanted to provide the help, students were anxious for guidance, yet the logistics involved presented a major stumbling block. Mentors had to carve out time during the middle of the day to drive to the high school, thereby ensuring that class would be in session and traffic would be at a minimum.

Logistics, however, was not the only challenge facing the mentors. Each mentor clearly is an expert in their field, whether it is thermal design, software engineering, or systems engineering. However, as they quickly found out, being an expert does not make one a good teacher. The students are very fast learners and able to pick up complex topics. However, because they lack a formal training in engineering, explanations must start with the fundamentals. Even then, for an engineer it is far too easy to fall back into technical jargon, and assume that a concept is so simple or obvious that it doesn't need explanation. The best mentors are able to understand the background of the students and tailor their presentations and advice accordingly.



**Figure 6: With the assistance of mentors, students learn electronics skills such as soldering and the use of power supplies and oscilloscopes.**

## CONCLUSIONS

### *Bringing it All Together*

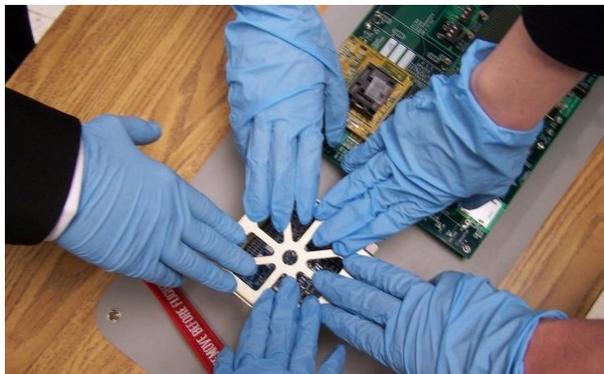
Through the two years, the students working on the TJ<sup>3</sup>Sat program have had the opportunity to learn a variety of often unrelated skills whose only common attribute is their applicability to a whole project. In high school it is too often the case that the subject matters studied are disjointed, segregated in the daily schedule with no real linkage between them. But systems engineers are generalists; by their very nature they thrive to bring the disparate together.

The young junior in charge of the payload learned not just to research the characteristics of the component being purchased, but also how to program the flight computer, solder components onto a proto-board and present her work to a group of her fellow students and engineers for their review and approval. When the ground station manager began the process of filling out the frequency application for the spacecraft, she expected the process would be isolated and straight forward – after all, it was *only* a frequency request. However, she soon discovered that coordination is a key part of engineering, regardless of the job.

### *Lessons learned*

Through the past two years, it has been enlightening to watch the students in the class learn many of the lessons that industry takes for granted yet often ignores. They have had an opportunity to experience what a career in engineering might be like, especially since throughout the project they have had to follow specific requirements and meet a variety of deadlines.

After a year working in the program, each of the young engineers realizes that much of the work that they are doing involves solving the same problems that



**Figure 7: Building a satellite is a great catalyst to instill students with a sense of discipline, teamwork, and accomplishment.**

professional engineers may face. They are developing a project for which there is no set answer. There is the freedom to choose a design, but it carries the responsibility to execute in a thorough manner. For all of them this has been a unique experience – they have been given the opportunity to develop a satellite and one day, see it functioning in space.

When asked to compile a list of some of the most important lessons they have learned, the students came up with a set that many engineers in industry would do well to remember in their professional lives:

- How to acquire relevant information to accomplish a complex objective
- Find out what needs to be learned, learn it, and know *why* one is learning it. Self-initiated learning doesn't receive enough credit.
- Good communication skills are critical
- Independent thinking must be valued.
- Technical jargon is often a hindrance
- The Internet is like a dog: your best friend but doesn't always do what you say
- Progress comes in spurts – periods of incredible accomplishment with bouts of extreme laziness, partially evidenced in somewhat rushed design reviews.

Most importantly, as one of the students stated, “This program has provided me with many great opportunities, meeting inspirational people and talking with intelligent, experienced professionals”

### *Looking Forward*

To many of the graduating seniors the last two years, their involvement has been bittersweet. They are proud to have been part of a unique endeavor never attempted before — the construction and launch of a high-school designed spacecraft. However, their time to graduate arrived before completion of the project. For the rest of the students, the next year holds exciting promise.

With the launch of TJ<sup>3</sup>Sat in 2009, the small satellite community will achieve a significant milestone on multiple fronts. The CubeSat platform will once again demonstrate the flexibility and adaptability of small satellites. A group of aerospace professionals will gain a profound sense of accomplishment and contribution to their community. Most importantly, a new generation of scientists and engineers will be exposed to the benefits and excitement of space missions at an age when they are making their first, crucial career decisions.

### *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 Joshua Strong, Jim Darvis and Gary Bottorff and executive support from Orbital, including David Thompson, Antonio Elias, and Ray Crough. Providing their insight to the students has been an extensive team of mentors including Arthur Feller (former FAA), Bob Bruninga (Naval Academy), Hannah Goldberg (JPL), Kevin Doherty and Ivan Galysh (Stensat LLC), John Brunschwyler (Orbital) and over 15 other Orbital employees.

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