AC 2009-1847: PASSAT: A CUBESAT STUDENT DESIGN PROJECT FOR ACTIVE CONTROL-SYSTEM DEVELOPMENT AND VERIFICATION

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PASSat: ACTIVE CONTROL SYSTEM DEVELOPMENT AND VERIFICATION

Abstract:

The CubeSat program at Saint Louis University's Parks College is a highly educational and valuable program for engineering students. Students gain a large spectrum of knowledge; both theory and real world based, and obtain valuable hands-on design experience. PASSat is a 10 x 10 x 10 cm picosatellite weighing approximately one kilogram and is completely designed and built by multi-disciplinary undergraduate students. PASSat (Parks Actively Stabilized Satellite) has provided the students with knowledge and experience in the fields of spacecraft structures, attitude control and determination, project management, teamwork, communication, and design process. This paper will describe the current pico satellite design PASSat; describing the satellite, its mission, systems engineering, vehicle design and overall organization and management. The paper will also discuss the student educational benefits.

Introduction

Saint Louis University's Aerospace Engineering department initiated the pico and nano satellite program in 2005. The purpose of the program is two is to provide highly skilled, hands-on experienced student workforce for the aerospace industry and to offer a low-cost, quick-to-launch satellite platform and subsystems to execute scientific and technology demonstration missions.

As the "Apollo Generation" reaches retirement, these workforce problems will increase significantly. While the need for trained workforce is growing, there has been a steady decline in students' opportunity to obtain meaningful hands-on experience with spaceflight hardware [1 - 3]. Industry, by large and most experienced space systems engineering faculty will attest to the following observations:

1. At present, there are insufficient methods for students to acquire hands-on experience in the scientific and technical disciplines necessary for space commerce and exploration.
2. Students have a hard time identifying relevant space systems hardware requirements while designing a real mission.
3. The National Research Council (NRC) committee believes that training students to design and build satellite and satellite instruments, gain hands-on experience with the unique demands of satellite and satellite systems environments and operations, and acquire early knowledge of systems engineering techniques is an extremely important investment to make[4, 5].

Founded by California Polytechnic State University and Stanford University, the CubeSat project was started as a means to give universities a chance to participate in the design, production, and operation of satellite systems. Starting in 1999, the two schools developed the CubeSat standard of a 10cm on edge cube weighing no more than 1 kg. Since then over 40 universities, high schools, and firms have developed or are developing satellites for the CubeSat project.

The CubeSat program brings students from multiple disciplines together with the common goal of designing and building a satellite. If not for CubeSat it would much mored difficult for students to get involved in a space project that results in the build of an actual spacecraft, for the program provides a fairly inexpensive method to enter space. Because of its ability to put space in the reach of students across the world, CubeSat is a highly valuable and educational program.

CUBESAT Mission Designs at Parks College

Saint Louis University's Aerospace Engineering department initiated the pico and nano satellite program in 2005. A number of students from various engineering and science disciplines have participated in the program. Section below provides a brief description of past student CubeSat design missions.

BillikenSat I

The 2005-2006 school year was the first year that seniors at Parks College decided to participate in the CubeSat program. The project had received great interest of the students, having 9 seniors and an additional 11 other students, and was composed of aerospace, mechanical, electrical and computer engineering students. Led by Abe Grindle, the team completed the design phase of their satellite, a huge accomplishment given that Parks had very little background in space and that it was done in only two semesters. However, they were unable to start the build process because of their time constraint.

BillikenSat II

During the 2006-2007 school year the CubeSat maintained a strong presence at Parks with 10 seniors and 10 other students and was able to expand the scope of the team to include a chemistry graduate student as well. Lead by Darren Pais the team was able to bring a very significant payload on board, a bio fuel cell. If successful in their goal, BillikenSat II would test the first bio fuel cell in space. The team progressed further than the previous years team, completing the design and most of the production of the satellite. Only a few electrical boards needed to be built and then satellite would have been ready for testing.

SLUCube

Interest for the CubeSat program started to wane during the 2007-2008 school year and the group only consisted of six seniors and two other students. The goal for the year was to design a new bus for the satellite that would be more versatile while still being able to use the previous year's payload. In addition to updating the previous year's structure a software-defined radio was developed

Objectives of PASSat Mission

The PASSat project is to build a picosatellite, strictly adhering to the specifications of the California Polytechnic Institute's CubeSat program(reference to CubeSat Design Specifications document). It will have a mass of not more than one kilogram and have dimensions of ten centimeters by ten centimeters by ten centimeters. The technical and educational objectives of PASSat are discussed below:
The **technical mission** of PASSat is two fold: (1) in-space technical demonstration of an effective and efficient attitude determination and control system using in-house designed and built magnetic torquer coil and attitude determination schemes, (2) to improve the structure design from previous years to increase the volume, while maintaining strength and stiffness to survive launch loads.
The **educational mission** provides practical hands-on education to students on satellite design in a multi-disciplinary environment. The students are involved in the planning, development, construction, test and operation of the picosatellites in orbit and gain valuable experience for their later profession.

Mission Profile

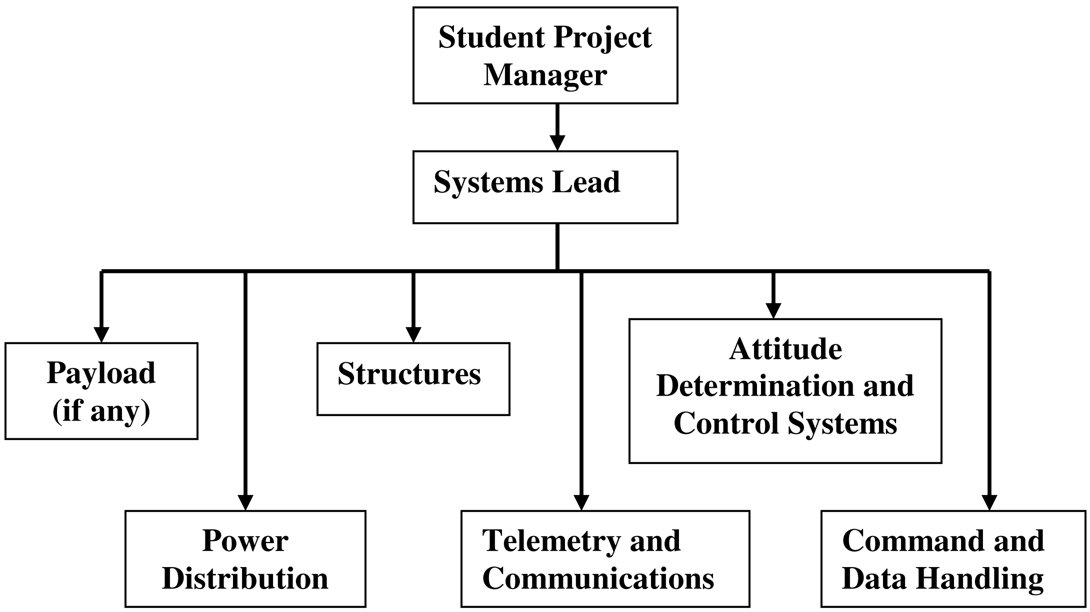
1. Launch PASSat on Dnepr launch vehicle to a 500 km sun-synchronous circular orbit with an inclination of 97.43 degrees and a right ascension of the ascending node (RAAN) of 115.67 degrees.
2. Once PASSat is free from the launch vehicle it will stabilize itself using its primary attitude control devices (three torque coils) and relay the confirmation of stabilization back to a ground station once it has achieved it.
3. After initial stabilization, PASSat will maintain an align attitude using only the primary attitude control device for a period of time. Meanwhile the satellite will relay data about its attitude to ground stations.
4. After the time period has elapsed the primary attitude control device will be switched to its secondary attitude control devices (three momentum wheels) for a set period of time. Meanwhile the satellite will relay data about its attitude to ground stations.
5. The satellite then makes one final switch back to the primary attitude control devices for the remaining time in orbit.

Systems Engineering

Project Organization and Management

The PASSat project is a complex endeavor that requires input from many disciplines. Therefore it is important to make certain that the project is managed efficiently so that it stays on track and can be successful. To achieve success, a student project manager was selected who managed different teams. Furthermore, each team is lead by a team leader from that discipline. PASSat employs a team structure consisting of a student program manager, systems team and subsystems teams each wit a respective lead as shown in Figure 1 below. PASSat team maintains a diverse students coming from various academic standing to ensure the retention and transition of knowledge from upperclass undergraduate students to their lower classmen.

The Preliminary Design phase began in September 2008 with a Preliminary Design Review (PDR) completed in December 2008. The Detailed Design phase began shortly after the conclusion of the Preliminary Design phase and concluded in February 2009 with a Critical Design Review (CDR). The Flight Unit (FU) Production phase has already began in February 2009, with a final Test Readiness Review (TRR) in April 2009. The FU Qualification phase shall commence after the FU Production phase in April 2009 and conclude in May 2009. The final Launch & Operations phase will begin after the FU Qualification phase and end with a prospective launch window in the fall of 2009.



System Integration

With several interdisciplinary teams working on different aspects of PASSat, integrating the system is essential in realizing the project's technical goals. Systems integration involves coordination in weight management, module layout diagrams, launch sequence, assembly procedure, and subsystem interfaces, managing project-wide technical tasks that do not fall into a specific team's area, including epoxy, connector, and material research, construction of wiring harnesses, and CAD modeling of the CubeSat housing.

Test and Verification

Testing will be performed to meet all launch provider requirements as well as any additional testing requirements deemed necessary to ensure the safety of the CubeSats and the P-POD. All flight hardware will undergo qualification and acceptance testing. Specifically, some of the tests conducted to verify the design are (i) random vibration testing, (ii) thermal vacuum bake-out test and (iii) additional testing for qualification and acceptance.

The designed control system will go through a series of test that will initially be very basic and built up to more complex. First, a static test will ensure that there is no shorts and determine the power used by the control device. The second test will be a practical test to see if the control device can actually create a torque that will be sufficient enough to change the orientation of the satellite. The third test will be to implement software with the control device to determine that a) the software loads properly and b) that the software can control the device enough to orient it in a desired position.

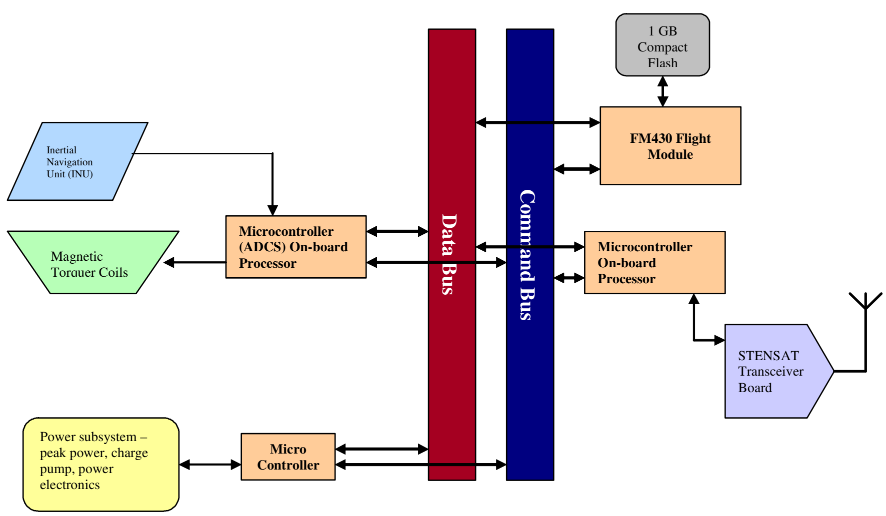
Scheduling and Budget

As with any project the time and money available has serious effects on the effectiveness of the product. To make certain that time is managed wisely a Gantt chart was created to plan out phases of design, build, and testing. By keeping the chart in mind and making revisions where necessary, it is possible to finish the project by the deadline.

Budget is a huge driving factor in the PASSat project because we are a university student project, meaning there is a very small amount of funds available. Therefore, many components are made in house instead of bought, saving money on labor and research. If a product component cannot be made, then a commercial off-the-shelf product is then bought, saving the extra cost of custom made commercial parts.

This systems engineering process has been extremely educational for both students and faculty.

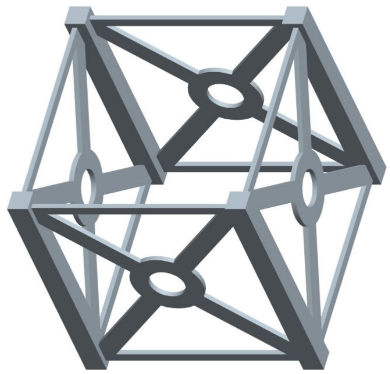
Engineering Aspects of PASSat



Structure

The Structure subsystem is responsible for the design of inner and outer structure of PASSat and design of the thermal control system. The subsystem also ensures that dimensional and mass criteria specified in the CubeSat Design Specifications are met by all sub-systems.

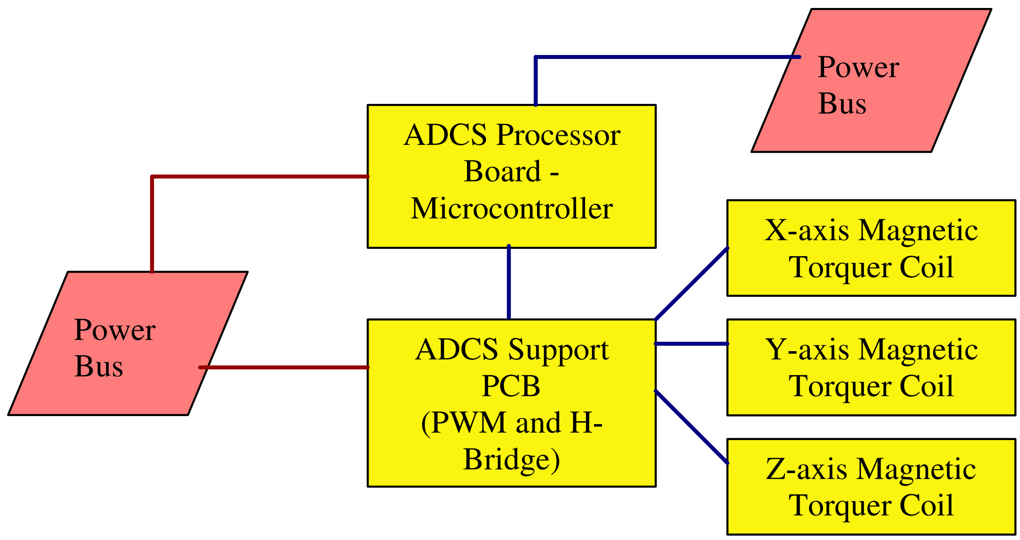
The Structures subsystem design consists of three types of parts: rails, beams, and panels, all of which are made of T-6061 Aluminum (figure). Modal, harmonic, and transient finite element analyses are performed to determine the CubeSat's natural frequencies, and whether the satellite and its components can safely survive the launch environment. Modal and transient experiments in three principal axes of the CubeSat are performed to simulate the launch environment, and the results compared with the finite element analysis computer simulations.



Attitude Determination and Control System (ADCS)

The ADCS subsystem will consist of active attitude control system using in-house built magnetic torquer coils. The technical mission of PASSat is to demonstrate and verify the design in space. The goal of the active attitude control system is to have a capability of 3-axis attitude determination and control to less than 3% error. Software algorithms will be written that will take attitude inputs from sensors and then utilizing magnetic torquer coils to keep the spacecraft in proper orientation.

Three axis attitude determination and control of the satellite is done by using a suite of sensors and actuators. Attitude determination accuracy of within $\pm 10^0$ is achieved using Nano IMU from Atair Aerospace. The NANO IMU is a combination of triaxial angular rate gyro, triaxial accelerometers and triaxial magnetometer and a GPS. It operates with complete 360-degree coverage on three axes, and outputs real-time calculations of its orientation in static operational settings. Three axes control is achieved by using a momentum bias system with three orthogonal magnetic torquer coils. The figure below shows the attitude determination and control system components.



Power Distribution System

PASSat has ten solar cells spread over its surfaces to generate power. In eclipse, power is drawn from a rechargeable 3.6 Ah lithium ion battery. The distribution of electrical power is accomplished by using the unregulated voltage bus and stepping up or stepping down the voltage to the appropriate levels by way of DC/DC converters. There are three different regulated voltage busses on board PASSat: 3.3V, 5V, and 9V. These regulated voltage busses distribute voltage at the appropriate magnitude to the various auxiliary subsystems.

Command and Data Handling

The command and data handling for PASSat is composed of an On-Board Computer (OBC) that will be based on PC-104 standard, the FM-430 Flight Module. It is an ultralow-power RISC microcontroller with 50-60 KB Flash memory, 2-10 KB RAM, 48 I/O pins, 2 USART, 2 SPI, 1 I2C, 12-bit ADC, 12-bit DAC, 3 DMA, multiple timers, on-board temperature sensor, and multiple clock sources. The board is designed with stackable pins for multiple processor capability. It supports a wide range of transceivers for telemetry and communications. It has an SD card socket for mass storage of up to 2 gigabytes of data.

Telemetry and Communications

Telemetry and Communications from SLUCUBE will be handled by a dedicated transceiver. StenSat UHF/VHF transceiver, a commercial off-the-shelf transceiver board will be used as primary device for communications from PASSat to satellite ground station. It is a fully integrated communications transceiver that uses the AX.25 packet data standard. Radio communications will take place over amateur radio channels within the VHF (uplink) and UHF (downlink) frequency bands using narrow-band frequency modulation (FM). This board is a combination of the UHF transmitter and VHF receiver, operating in half-duplex mode. The board contains hardware terminal node controllers

(TNC's) for decoding AX.25 amateur packet protocol for uplink and downlink. The figures below show the FM430 flight module and the STENSAT transceiver board.

Educational Value of the PASSat Project:

The PASSat project has provided all the students involved with numerous educational benefits in multiple areas. Overall, the knowledge gained from such a large and in-depth project can be divided into two areas: technical and project management. The gained understanding and the lessons learned in both areas as well as how the two fit together cannot be taken for granted.

From its start, the students involved in the project have controlled it. Groups of students in each subsystem teams have the responsibility for one single subsystem of the satellite. This approach has not only given the students a profound insight into the overall spacecraft mission design elements and specific subsystem that the has been working on, but due to the highly integrated architecture of a picosatellite, it has also been necessary for each student to have a good overview of the subsystems that they are not directly involved in order to be successful. To be a part of a project like this is very motivating and the problems to be solved on a picosatellite are very technically challenging. The project has therefore provided the student with a very beneficial educational opportunity that has both focused on a single technical design while also teaching the student to coordinate work within a group and coordinate work between groups working on different parts of the satellite. The project has also received a lot of attention from under classmen and younger (prospective) students at the university.

It is safe to say that without any type of project management, the technical details cannot be organized into an end product. At the same time the end result of a project that does not have meaningful technical basis is a useless product. It is the achieved balance of these two areas that makes for a successful engineering project.

From a project management standpoint, PASSat project has allowed the student teams to experience every phase of the project beginning with the outlining of mission to final design of the spacecraft. This is unique in that a relatively small group of people was working directly in all phases. The exposure to the multiple aspects of project management will prove to be beneficial in any future experiences within the engineering industry. Another area of this project that proved to be a great learning experience for students was in budgeting and scheduling. Although creating a schedule is important, it is far more important that once a schedule is made, the tasks on it are completed on time. Thus, it was learned that it becomes imperative to make a plan that is realistic and coincides with project goals. Finally, one of the most important concepts learned in the project management area was in the area of personnel management. In order to be efficient and effective it was important to identify ones strengths and weaknesses, make those known to the group, and choose tasks accordingly. As some people have a greater knowledge in one technical area than another it is important to recognize and apply that strength to maximize the student potential.

The PASSat project also required that those involved become much more proficient in certain technical areas. Within the aerospace group, numerous other disciplines were consulted as the knowledge required extended well beyond any undergraduate aerospace engineering curriculum. Concepts from not only aerospace but electrical, materials, mechanical and software engineering as well as computer science were employed which required a significant amount of research and study.

Overall, the PASSat project has provided a great introduction into the concepts of project management as well as promoted advanced study in different aspects of aerospace engineering. The relatively small team size has allowed for a wide range of study among all team members. Also, the fundamentals in the management of a large project such as this one will provide a great base that can be built on in an industry environment. The exposure to the wide range of topics in this project will also help guide students in figuring out what their interests are and helping to guide them as they become closer to moving on past the undergraduate level.

Developing Engineering Competencies

The most challenging aspect of this project was in designing a pico satellite in a university setting, with students from multi-disciplinary engineering programs. Design progress and evolvement from last four years has enabled our students to be more creative and efficient in decision making and designing complex systems that has enabled them to be increasingly competitive in the global market.

Multi-disciplinary Teamwork

Students must learn to work effectively with people that do not necessarily think or talk like themselves. They must learn to understand and value the skills that each team member provides, and then employ these various skills in an optimal way to realize the final design goal. The challenges of working within a multidisciplinary team environment include team problem-solving, project management, and team communication.

Team Communications

Communications among various subsystem team members is a crucial facet in successful completion of a complex project. Students must be able to share ideas within the team, as well as clearly articulate, justify, and defend ideas with the team, external customers, and reviewers.To achieve this, the team members hold regular weekly meetings with team leaders as participants and any critical decisions were communicated by the team leaders to the others. This protocol allowed an efficient and productive discussion about the design of the overall satellite, as well as to communicate important design considerations in each subsystem, which would undoubtedly affect other subsystems.

Additionally communication is essential to ensuring that the project will be continued on in future years and hopefully be completed. To make certain this happens, the team must seek out underclassmen to include them in the design and decision making processes. Therefore, when the upperclassmen leave school there will be other students with a vested interest in the project, increasing the probability of project completion. So far, teams have not been succesful in this endeavor, causing a new project to be started each year.

Multi-disciplinary Engineering and Realistic Design Constraints

Students must incorporate engineering standards and design constraints that impact engineering solutions across all disciplines. Thus, students gain an appreciation for how/why other subsystem members may be constrained in their design solutions.

Design Evaluation

During the two semesters of the senior capstone design process, two major reviews are performed, one each semester. The Preliminary Design Review is conducted in the first semester and a final review is conducted in the second semester. An important component of this review process is the inclusion of external industry representatives during the design reviews. Their feedback is formally solicited during the reviews as well as during debriefing sessions after each review. Thus, this group is an invaluable resource to ensure that the program continues to evolve every year and meet the needs of industry. This external feedback is more objective than student ratings and helps in meeting ABET requirements.

A poster competition is conducted in May at the completion of the academic year. All student teams must complete their project for review and evaluation prior to the poster competition. The poster competition includes judges from select faculty and local industry executives not directly involved with any of the projects under consideration. The posters are then on display in the department.

Conclusion

The CubeSat program has allowed and encouraged development of pico-satellite systems with much success. It has encouraged cross-disciplinary learning and team building that is much needed in any work environment. Having a small satellite designed and developed by students has a high educational value, since they have to go through all steps, including selection of components, final implementation and testing. The implementation of CubeSat project has achieved two major results: Primarily a large group of students will leave the university with a great deal of “hands-on experience” within satellite design and experience with working with a large project that requires cooperation between everybody involved. Secondly, students are exposed to research in the areas of spacecraft design and analysis that will help and motivate them to pursue graduate programs, thus contributing to the future workforce development. Finally, the project has provided enough feedback as a sound starting point for the next picosatellite project at Saint Louis University, where the students utilize all the experience gained from the PASSat project.

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