SPARTNIK: Student Developed Micro Satellite, Benefits Education and Industry

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Abstract

This paper describes a micro-satellite design and construction project. SPARTNIK, the capstone design project of the Aerospace Engineering undergraduate program was conceived with the industry ideal of "faster, cheaper, and better." With minimal funds and resources, SPARTNIK's main goal is to educate students for the real world, through the design and manufacturing of a working micro-satellite. A multi-disciplinary team of Aerospace, Mechanical, and Electrical Engineering undergraduate students was formed to confront this challenge. This project will help prepare engineering students to contribute to the emerging field of micro-satellite development.

Classified as a secondary payload, SPARTNIK will conform to the size and weight limits for a wide range of launch vehicles. This design constraint maximizes the possibility of obtaining a donated launch. Baseline structural configuration of the micro-satellite will be 43 cm in diameter, 28 cm high, and 30 kg mass, to meet this constraint. The spacecraft will use the Earth's magnetic field for its primary attitude control. The available power from the solar array is limited to a few watts, since the only available area for solar arrays is on the surface of the spacecraft. SPARTNIK will carry a digital color camera, a Global Positioning System (GPS) and a micro-meteorite impact detector as its experimental payloads.

SPARTNIK will communicate through FCC licensed amateur radio frequency bands. This will not only enable the San Jose State ground station personnel to access the satellite but also other amateur radio operators.

These types of projects have the ability to bring universities and industries closer together. By pursuing this type of project in collaboration with industry, universities would be able to serve as a test-bed where industry can develop and test new technology quickly and inexpensively. The benefit to industry would be the enhancement of their technology, as well as the education of the students that will be coming into the work force.

An overview of the satellite is described in the paper, focusing on technical design challenges of each of the subsystems, also showing how the design team resolved these issues with research and industry mentors. The paper also addresses the educational challenges and benefits of hardware design and manufacturing as well as the benefits to the micro-satellite industry. It discusses the value of careful preliminary research and of experienced industry volunteers to a student micro-satellite project.

Concept

The focus of this project was to prepare engineering students for careers in the aerospace industry, with practical experience. This was done by an interdisciplinary team that went through the steps of building a real micro satellite, which consists of the following;

- Forming a conceptual design
- Determining satellite system constraints and requirements
- Researching design trade-offs
- Satellite manufacturing and testing for verification of operational readiness
- Working with the launch vehicle company prior to and during launch
- Mission operations and maintenance.

The students have been accepting these tasks with the industry ideal of "faster, cheaper, and better" in mind. This ideal has been incorporated in the design of each subsystem, making the full satellite inexpensive (under $50,000), as well as easy to manufacture, and reliable.

For undergraduate students to accomplish this project, mentorship from local aerospace companies was obtained. The close interactions of the students and mentors benefited the education and practical experience of the students as well as made the project more successful. These interactions between the university and industry show how a successful working relationship benefits both groups. The industry can use the university team to design and manufacture a test-bed for new satellite technology and space-based experiments, quickly and inexpensively. At the same time students are educated and prepared for the aerospace industry. Thus, the university can become a center for micro satellite development, providing a low cost service to the aerospace industry and research companies.

Design

Following is a detailed description of the design of SPARTNIK. The focus of the discussion is on the technical challenges of each subsystem. In addition, the industry benefits of this type of project are discussed.

Launch Vehicle

There are many different launch vehicles that can launch a micro satellite into low Earth orbit. The normal price of obtaining a launch is about 1 million dollars, and the project needs to keep the cost of the satellite well below $50,000. Therefore, the project will need to look for a discounted or donated launch as a secondary payload.

One opportunity is that some launch vehicles would have to add ballast to the launch vehicle if the primary payload weights less than first specified, because of propulsion and dynamic constraints. The micro-satellite could take the place of this ballast inexpensively. This will give the university the launch it needs as well as meeting the launch vehicles requirement for extra weight. Some launch vehicles, such as the Space Shuttle, have discounted secondary payload programs in operation, for universities. The cost for a university payload aboard the STS is approximately $10,000. This is a good example of how a university can provide low cost resources to research companies, by giving companies access to low-cost launch opportunities through university run projects.

The possible launch vehicles were researched for use were;

- The Space Shuttle Hitchhiker
- Delta
- Pegasus
- Lockheed Launch Vehicle
- Ariane

First the respective secondary payload fairing size and weight constraints were determined. The goal was to design the spacecraft so that it would meet all of the constraints of each launch vehicle thus increasing the possibilities of obtaining a discounted or donated launch. From the original list of possible launch vehicles, Delta was the only one for which SPARTNIK could not be designed for. Deltas secondary payload fairing does not have the required height for the spacecraft.

Orbit

Since the launch vehicle is not defined at the beginning of the project and the orbit is defined by the launch vehicle and its launch site, the design had to be done for multiple possible orbits. Once the satellite is released from the launch vehicle it will not be able to do any orbit transfers or station-keeping Δvs because the micro satellite will not have a propulsion system. The possible range for SPARTNIK was determined to be 300 to 1000 km altitude with an inclination greater than 30°. The altitude was determined by the definition of a LEO and the nominal orbits of the launch vehicles. The inclination parameter is strictly due to the visibility of the satellite, based on a 300 km altitude orbit, and the location of the SJSU ground station, which is 37.5° longitude. If the satellite has an inclination less than 30° it will never be visible to the ground station. From these parameters the design team selected 12 candidate orbits: The candidate orbits are; 300, 500 and 700 km altitude and 30, 45, 60 and 90° inclination. Eccentricity of all orbits was assumed to be equal to 0°, since most launch vehicles go into a circular LEO. These candidate orbits gave the subsystems an indication how the spacecraft would perform over the orbit range.

Orbit life is also of concern , because this parameter determines how long the spacecraft will be operational. SPARTNIK is designed to be operational for a minimum of two years, thus the orbit needs to meet this constraint. Orbit life is determined by how high the orbit is. The life is proportional to the altitude, e.i. the higher the satellite is, the longer it will be there since at low altitudes the spacecraft will be flying through the upper portions of Earth's atmosphere. The spacecraft would then experience aerodynamic drag, proportional to its ballistic drag coefficient, thus slowing the spacecraft and lowering its orbit altitude. The altitudes at which this happens fluctuate on the ten year cycle of solar radio flux activity. At the peak of this activity the atmosphere has a density of 10^{-12} kg/m^3 at 600 km and at the solar radio flux minimum a density of 10^{-14} kg/m^3. This difference can greatly affect the orbit life. At an altitude of 600km and a peak solar activity, a satellite with a ballistic coefficient of 200 kg/m^2 has an orbit life of approximately 55 years.[1] This is a good approximation of what SPARTNIK will do in these conditions because the ballistic coefficient corresponds to a similar satellite, Explorer 11[2]. So, an orbit altitude above 350 km would meet the operational life requirement, during peak solar radio flux.

Structure

The goals of the structural design of SPARTNIK are of modularity and ease of assembly, yet durable to the launch load environment. The configuration is an octagon "tuna can" with two internal trays. The satellite stands 31 cm high with the antennas in the stowed position, and 43 cm diameter (Fig. 1). and 30 kg in mass.

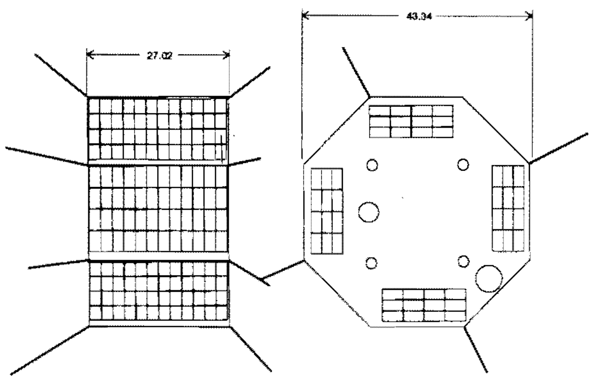

Figure 1 - SPARTNIK dimensions

This configuration will meet all the launch vehicle secondary payload volume constraints except that of the Delta, due to the low height constraint. Table 1 lists the allowable secondary payload fairing dimensions for the possible launch vehicles.

Dimension	STS	LLV	Delta	Pegasus	Ariane
Length (cm)	48	50	>77	45.7	45
Width (cm)	48	50	77	45.7	45
Height (cm)	52	50	25.5	38.1	45

Table 1 - Maximum Allowable Volume Specifications[3]

The satellite's dimensions will help give the satellite favorable moments of inertia for the required spin stabilization. The satellite be spun around the z-axis, so I_{zz} must be much greater than I_{xx} and I_{yy}. The height of the satellite needs to be less than that of the width for this to be true. Which the design has achieved. The preliminary calculated moments and products of inertia are as follows;

$$I_{zz} = .0989 \text{ kg*m}^2$$
$$I_{xx} = .0778 \text{ kg*m}^2$$
$$I_{yy} = .0749 \text{ kg*m}^2$$
$$I_{xy} = .0152 \times 10^{-9} \text{ kg*m}^2$$
$$I_{xz} = .0523 \times 10^{-10} \text{ kg*m}^2$$
$$I_{yz} = .0118 \times 10^{-9} \text{ kg*m}^2$$

The internal trays are equally spaced with 7.49 cm distance between them. The inside surface of the -z panel will be used as the third tray. Each tray will be supported by four cylindrical spacers, except the third tray which will be supported by the aluminum battery boxes. The trays will be divided between each subsystem, tray number 3 will house the payloads, tray number 2 will house the power system components, and the -z panel will have the computer, communication system and the GPS circuit boards.

The outside panels and trays are made of 1.27 cm thick aluminum honeycomb, comprised of 6061-T6 Al. The 8 side panels and the +z panel were assembled into one piece that is called the shell. The -z panel and the two trays can be assembled and stacked on top of each other, with all internal wire connections completed. The shell is then slipped over the internal trays and bolted to the -z panel at each of the eight vertices. Once the satellite is bolted together, four threaded steel rods will be inserted through the structure and bolted on the +/- z panels to help keep the structure together. Figure 2 shows this in an exploded view.

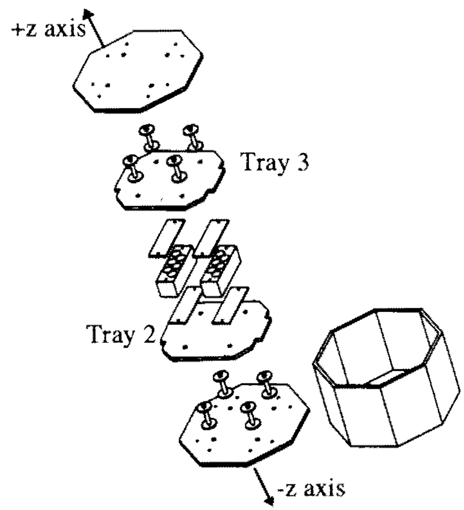

Figure 2 - SPARTNIK Exploded view

Along with meeting the above requirements the structure must be designed to withstand the launch environment. This environment can be difficult to design to when the mass and volume constraints are extremely strict. There are various contributors to the launch loads: the smaller, but sustained loads are from the thrust of the vehicle and wind buffeting during launch. These loads can range from 2-12 Gs and are not always predictable. The stronger loading comes from shock and acoustic vibration and quasi-static loads. Shock loads can not be designed for, rather the satellite was designed to not have natural frequencies equal to the frequencies at which these shock loads occur. Table 2 shows peak shock loads and their related frequencies for several of the possible launch vehicles.

Launcher	Frequency(Hz)	Peak Shock Loads (g)
STS	31	50
LLV3	1500	15
Pegasus	1000 and above	200
Ariane I	1500 and above	2000

Table 2 - Launch Vehicle Shock Loads[4]

Acoustical loading is also a major factor in launch survivability. Acoustic loads also vary with frequency, so by knowing the natural modes of the satellite the acoustic loads that were of concern were located and designed for.

A computer code called Mechanica, by Rasna Corp., was used to get an estimate of the satellites natural frequencies and structural response to these loads. the modes of the satellites fell between 43Hz and 60Hz. The maximum Von Mises stresses were approximately 6.2375E+5 Pa. and the maximum displacement was 2.04762E-4 m. These results will be checked with a shake table test of the satellite coupled with the payload adapter.

Payload Adapter

The payload adapter (PLA) is an interface between the satellite and the launch vehicle, as well as a release mechanism for the satellite. During launch the PLA must be a rigid body so that all the loads are transferred to the satellite without any damping or amplification. The design of the PLA also needed to be versatile so that it may be attached to any launch vehicle. This was accomplished by making a solid circular base plate with the capability of the mounting holes being drilled in, once the launch vehicle is determined.

The design needed to have a release mechanism that would release satellite with minimal stress and be able to use the 28V DC signal that most launch vehicles provide[5]. A G&H Technologies release bolt was used to fulfill these requirements. The bolt is a separation nut mechanism, where the 28 V DC signal activates a mechanism to pull a nut in half. The satellite will launch if only one half of the nut separates from the bolt. Once released, a spring will push the satellite away from the launch vehicle. Most of the PLA will remain with the launch vehicle except for the satellite attachment plate and the bolt. The satellite plate will stay on the -z panel and act as a thermal reflector to help keep the satellite in its required temperature range. Figure 3 shows the different parts of the PLA.

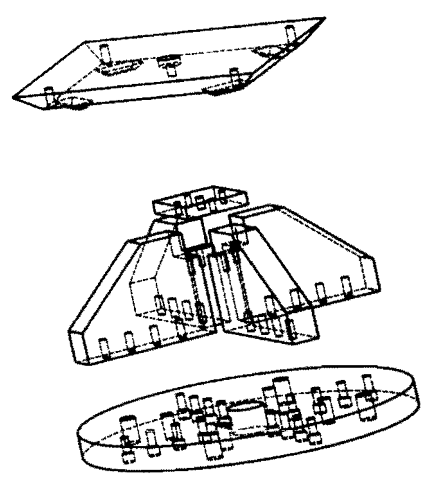

Figure 3 - PLA Exploded View

Figure 4 shows the satellite and the payload adapter, in an exploded view. It gives the orientation of the satellite to the rest of the payload adapter.

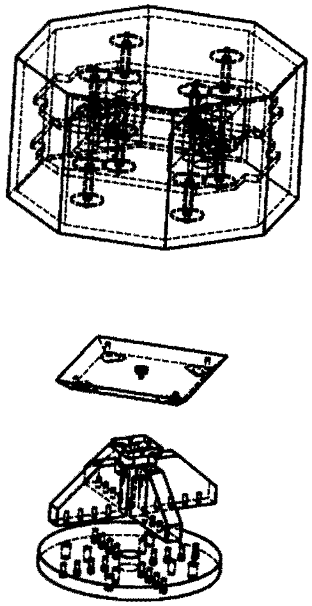

Figure 4 - Satellite and PLA Exploded View

It was necessary to ensure that the satellite and payload adapter fit into the allowable secondary payload fairing for all possible launch vehicles. The payload adapter is approximately 17 cm high by 29.4 cm diameter. This brings the over all height of the assembly to 37 cm and 43.43 diameter.

Attitude Determination and Control

The all passive attitude determination and control system, uses spin stabilization and a controlled tumble to maintain an acceptable orientation. The spin is induced by solar radiation pressure hitting the communications antennas which are coated with a highly reflective tape on one side and black anodized on the other. Figure 5 shows the satellite from an edge on view. The angled lines are the communications antennas, with the black anodized side on the right and the highly reflective on the left. If the sun vector was perpendicular to the page, the differential between the absorptive and the anodized sides will cause the satellite spin to the left.

To prevent the spacecraft from indefinitely spinning up, four soft iron rods were mounted perpendicular to the spacecraft's z-axis. As the iron rods, or hysteresis rods, rotate in the Earth's magnetic field, a current will be generated along the rods. At each half turn of the rods the current flow will reverse and the poles will switch. This flipping of the poles and reversal of the current in the rods will create heat within the iron rods. The heat is the conversion of spin energy of the satellite, thus as heat is radiated into space, the spin energy is also dissipated.

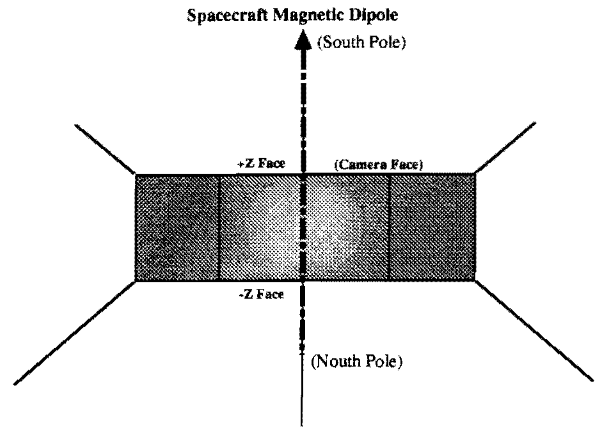

Figure 5 - Solar Pressure paddles

As the satellite increases in spin rate, more heat will be generated in the rods, thus making the hysteresis rods dissipate the energy more quickly.

This control system is useful to keep the spacecraft pointed in one direction. But, since the spacecraft could be in an unwanted attitude when released into orbit and there is no propulsion system to re-orient the satellite, it was necessary to find a way to ensure proper pointing, which is necessary for the camera lens that is mounted on the +z-face. This was done by inducing a controlled tumble of the spacecraft's z-axis. Bar magnets were placed inside the honeycomb shell, with the poles parallel with the satellites' z-axis. These magnets will interact with the Earth's magnetic field and align the z-axis of the spacecraft with the local magnetic field lines. This is a controlled tumble because we can approximate the angle between the spacecraft z-axis and the Earth's inertial frame. Figure 6 shows the approximate attitude of the spacecraft for a quarter of an orbit.

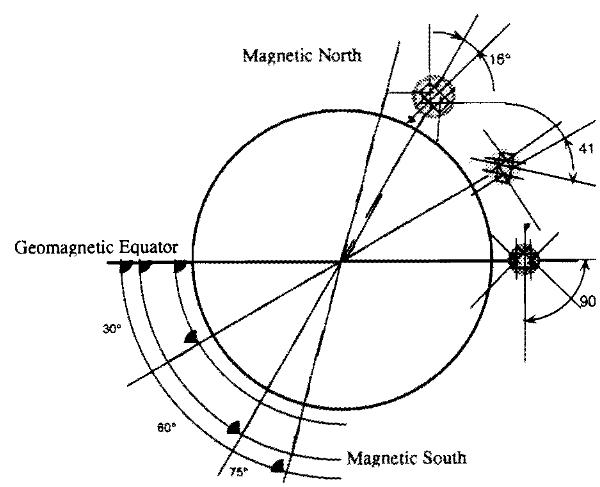

Figure 6 - SPARTNIK Orientation for a Quarter Orbit

With the controlled tumble will ensure that the camera lens will be pointing toward the Earth in the northern hemisphere only. The magnets will align the satellite so that the camera is pointing to space in the southern hemisphere.

To control nutations about the z-axis of the spacecraft, a nutation damper hoop was mounted parallel to the xy-plane of the spacecraft. The nutation damper is filled to 40% capacity with a viscous fluid. As the hoop rotates the fluid will lag behind, acting as a spin damper until it reaches equilibrium with the satellite. If the spacecraft starts to nutate in small angles, waves will be formed on the surface of the fluid. The waves will propagate around the hoop and damp the small nutations. If the satellite experiences large nutations, the viscous fluid will act as a slug to damp out the unwanted nutations.

In order to determine the orientation of the spacecraft, current measurements will be taken from the solar strings. The angle between the solar vector and the solar string is directly proportional to the current going through the string. The on-board CPU will compute the orientation of the spacecraft, from the current readings, relative to the local inertial coordinate system of the satellite. This will give the spacecraft's attitude at any time on the orbit. And will provide a means to predict the attitude at any future time, and allows the planning of when a picture can be taken of the surface of the Earth, as well as the moon.

To aid the current sensor calculations to determine when the camera lens is pointing nadir, two 1μ infrared sensors are mounted on either side of the lens. When both IR detectors are registering a reading the surface of the Earth is in view.

The attitude determination and control system is a good example of how university projects can benefit the aerospace industry. The hysteresis rods are an experimental system. Many past projects have used them successfully, but there were no mathematical formulas to use to design the size or number of rods to use for the satellite configurations. University projects can be used, by industry, to design and manufacture several micro-satellites to research how hysteresis rods behave in space. This could be done though a multiple satellite project, with each satellite being basically the same, except for each one well carry a different configuration of hysteresis rods. While on orbit, each satellite will have a different spin rate, by having several of the same satellite in the same orbit, a comparison can be made from the telemetry data and from that a means to derive equations to calculate the spin damping force of the hysteresis rods. A project such as this would produce invaluable results for the aerospace industry, quickly and inexpensively, and at the same time enhancing the education of graduating students.

Power

Industry and university partnerships for research can be seen in the design of the SPARTNIK power system. The system is a battery dominated configuration, where the batteries determine the bus voltage. The batteries are Sanyo rechargeable commercial grade Nickel Cadmium, that were tested and matched by Eagle Picher using a new procedure that they are developing for micro satellite batteries. Eagle Picher donated these batteries to be used on SPARTNIK, so that they may evaluate the performance of their testing procedures. Towards this end, telemetry will be recorded on the health and performance of the batteries while on orbit.

A dual battery pack design was used to minimize the depth of discharge to approximately 5%, thus increasing the number of possible cycles and operational life of the batteries. The power budget for the on-board systems in summarized in Table 3. The satellite will have various operational modes where different systems will be operating. The power system is capable of handling all the systems at once.

Systems	Load Requirement (W)
CPU	1
GPS	1.85
Camera	.5
MMI	.1
Receiver	1
Transponder	5 (max.)
Total	9.45

Table 3 - System Power Requirements

The transponder is a transient load with a maximum of 5W to accommodate for interference and anomalous signals from the satellite by boosting its power.

The nominal bus voltage will be 7.2 V from the battery packs, where each payload will have a Maxim step down DC-DC converter to bring the bus voltage to the systems' required voltage. The peak voltage of the batteries is 9.0 V DC, in order for the solar arrays to recharge the batteries to full capacity the array voltage needs to be higher than that of the batteries. The solar array uses 16% efficient Gallium Arsenide, 2x4 cm, cells that were donated by Applied Solar Energy Corp. The solar array will provide a nominal voltage of 9.76 V and approximately 13 Watts, at end-of-life (3 years). This is acceptable for the recharging of the NiCd batteries, and supplying the required system load.

The students had challenges determining how the power system should have been configured to maximize the life yet maintain a reliable system. A major concern was with recharging the batteries with the solar arrays. The design team found that recharging the batteries at too fast of a rate would increase the number of cycles on the batteries, thus lowering the life expectancy. To ensure that the batteries recharged at the proper rate and at a rate slow enough to maximize life, without having the system continually being in a state of charge, the solar arrays were split into two systems. The two solar arrays could be switched between the two battery packs. The system could use both arrays to recharge the batteries, or split the arrays between the two packs, or remove one or all arrays from the system until needed. This design was accomplished with the close interactions between the student team and local Lockheed Martin engineers who volunteered their time and knowledge. This close interaction with the industry mentors increased the experience and the knowledge of the students, better preparing them for the work force.

Experimental Payloads

The ability to carry one or more small experimental payloads is a prime benefit to industry as a test-bed facility. Since the micro-satellite is produced by students, a company could test and develop new products for space use in a cost effective manner. In turn, the students use their engineering skills to integrate the product into the satellite. Once launched, the test data is included as part of the normal telemetry downlink. The data can then be given to the company for review. The SPARTNIK satellite carries three student chosen experimental payloads to prove the value of such a test-bed.

The first experimental payload is the prototype digital color camera donated by Logitech Inc. It has two megabytes of Flash RAM for image storage and uses a charge coupled device (CCD) developed by Eastman Kodak. The camera was originally intended for home computing uses but is being modified for space use. Modifications include the removal of the flash and the coating of the electronics board.

The lens assembly is mounted on the top face of the satellite and will be nadir pointing at the North Pole due to the nature of the attitude determination and control design. The electronics will be mounted directly under the lens assembly.

One concern for the camera is the effects of infrared radiation on the Flash RAM. It is unknown if repeated exposure to high radiation levels would adversely affect the quality of the digital images.

The second payload is the Global Positioning System (GPS) board donated by Trimble Navigation. The GPS board will serve two functions. Its primary use is comparing the orbital elements provided by NORAD tracking to the GPS board itself. This will eventually lead to autonomous tracking of the satellite by the San Jose State University ground station since six orbital elements will be provided during a telemetry downlink. The GPS board will also be used in conjunction with the camera to easily identify the area in the camera's field of view.

The GPS board outputs its latitude, longitude, and altitude as well as its velocity components with respect to a three axis coordinate system. Due to the nature of GPS as a source of guidance the United States Department of Defense imposes a hardware altitude and velocity restriction on consumer GPS equipment. As a part of the modification for space use, the SPARTNIK team reached an agreement with Trimble Navigation to remove the COCOM limitations.

The board itself is integrated into the onboard computer system since it was designed in a computer plug-in style.

Both the camera and the GPS board are examples of the "off the shelf" parts modified for space use.

The third payload is the micro-meteorite impact (MMI) detector, similar to one used on the Webersat satellite. An impact on the piezio-electric sensor causes a hardware interrupt to generate on the onboard computer. The computer will maintain a count of the number of impacts for a given duration of time.

Since the Earth is an oblate spheroid, one can reason that micro-meteorites are not evenly distributed due the difference in gravitational attraction. Since Webersat is in a particular orbit and SPARTNIK may be launched into a different orbit, the number of impacts may vary. The data collected from the MMI experiment can then be compared with the data from Webersat.

Should future micro-satellites carry this experiment, their data could be added to determine the distribution or density of micro-meteorites around the Earth. Such data benefits the various space agencies and aerospace companies in terms of adequate shielding for their spacecraft.

Two piezio-electric sensors are mounted inside and outside on the top face of the satellite. Two sensors are necessary since thermal expansion may give out a false impact reading. Both sensors are connected directly to the onboard computer.

Computer Hardware/Software

The design of the on-board computer went through a trade-off comparison between buying a pre-made CPU and operating system or building one. To maintain low cost, it was decided to build a computer and program the operating system in house. The custom built design allows for future expandability for other satellite needs and a redundancy within the CPU that the pre-made board would not have.

The on-board computer is based on Intel 386 technology which was tested to be reliable in high radiation environments[6]. The main CPU will have two EPROM chips that will hold the boot-up code in each. In the event that one chip fails the other will be able to take over. The is also a redundant design in the analog to digital converter, where there are two A/D chips and all sensors are routed through both of them, allowing a total of 64 redundant sensors.

The computer code is being written in C, which will become public domain once completed and tested. The code will control the CPU through hardware and software interrupts, therefore the necessity for an operating system has been removed, making the computer easier to program, control, and de-bug.

Once the computer completes the boot-up sequence, the operational program will be transferred to memory in static RAM. There will be a total of 8 Megabytes of static RAM available to store code and telemetry data. To conserve power, the static RAM will be accessible in 4 MB blocks, one block active at a time. Having the operational code stored in static RAM, mission control will have the ability to upload new code at anytime.

The endeavor to build and program a custom computer has been very difficult due to that most of the aerospace engineers did not have a good background in C programming or integrated circuit design. Electrical engineering students where brought onto the team help out in this capacity, and mentorship from local programmers educated the student programmers to handle the task. This shows the value of such a project, with improving the education and practical knowledge of the students, increasing their value in industry.

Thermal Control System

The majority of the past micro-satellites and amateur satellites have regarded thermal control as an unimportant topic. Because of the lack of data in this area and a difference of opinion between micro-satellite builders and industry consultants, the SPARTNIK team elected to performed extensive computer analysis for thermal conditions for all possible orbits.

Individual component temperature ranges and maximizing satellite life have been taken into account and an orbit simulation process has been undertaken for different thermal control configurations and different orbit inclinations.

From manufacturers specifications, the battery packs became the driving factor for the thermal design since they had the narrowest operational range. The SPARTNIK thermal target range is -5°C to 10°C for optimal efficiency although they will operate between -5°C to 25°C[7].

Due to the power constraint, all thermal control must be passive. This is accomplished by using conduction paths, thermal insulators, aluminum FOSR (Flexible Optical Solar Reflector) and radiators. Of the different types of thermal control, aluminum FOSR, a reflective tape, is the component that depends on orbit simulation to determine the amount needed for thermal control.

Since the satellite's orbit will not be known until the time of launch the exact amount of FOSR is still unknown. Initial design was done with the candidate orbits and a graph was generated to help determine the percent FOSR needed for each obit. Figure shows one of these graphs. Once a launch donation is obtained, a final orbit calculation will be done to finalize the percentage FOSR required.

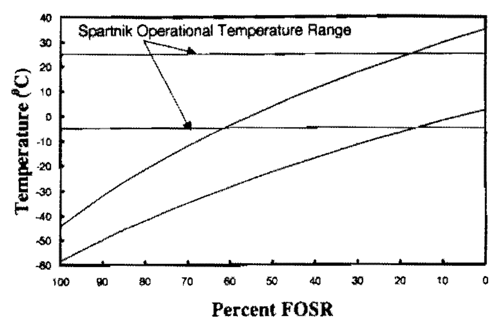

Figure 7 - Percent FOSR vs. Temperature Range

To complement the thermal analysis, the SPARTNIK satellite has several thermal temperature sensors. These sensors are used to monitor the ambient internal temperature and the temperature of several electronic components. Should a sensor register an undesirable reading, the onboard computer will turn on or off various electronic components to try and rebalance the temperature.

Communication System

The communication system serves as the data link between the satellite and any ground station. The onboard electronics are both low power and frequency versatile. Telemetry data will be encoded into a packet protocol. The system features nonstandard data throughputs of either 9600 baud or 57.6 kilo-baud.

Additionally, extensive electromagnetic (EM) field modeling is being performed to determine the satellites far field characteristics as well as to optimize the design of the antenna system.

The onboard electronics operate on the principle of state-of-the-art direct synthesis. The components are donations from Philips Semiconductor and are normally used in cellular telephones. Since the system has the ability to be reprogrammed to a different frequency, the satellite can avoid interfering with another satellite. However, any frequency change will adhere to the recognized amateur bands of 144 MHz. for uplink and 435 MHz. for downlink.

Physically the communications electronics is a standard two layer circuit board measuring approximately 15.2 cm. in length by 10.2 cm. in width, the size of a household pocket calculator. It sits on the bottom deck of the satellite and is connected to the four uplink and four downlink antennas. The uplink antennas are located on the top face of the satellite with one antenna on every other vertex of the octagon shape. The downlink antennas are placed on same vertices but on the bottom face of the satellite. Both sets of antennas are made of a spring steel material similar to that found in a roll up tape measure.

To simplify the licensing of the satellite by the FCC the amateur radio bands will be used. This allows not only the university but also any amateur radio operator access to the satellite. Unlike most amateur satellites which have a standard data throughput of 1200 baud, SPARTNIK will employ high speed data transmission rates to ensure all data is received by the ground station in a single pass of the satellite.

Currently under development is the packet protocol structure. This structure will help ensure error free data is received by the ground station as well as separate the various data into manageable groupings. A sample structure could be all temperature sensors in the first packet while attitude determination sensors in the second packet. When completed the packet structure will become public domain since it is a nonstandard format.

New to the field of micro-satellites is electromagnetic field modeling. Since most micro-satellites are in low earth orbit, a one watt[8] transmitter power is sufficient to transmit a usable signal assuming an isotropic antenna as the worse case. By definition an isotropic antenna radiates in every direction with a gain of 0 dB. Any antenna will have some gain in some direction which is an improvement over the isotropic assumption.

The goal of electromagnetic field modeling is to predict the actual antenna performance in free space accurately. To predict antenna performance, far field antenna ranges must be determined. Far field antenna ranges or radiation patterns are the radiated fields a long distance away from the antenna sufficient to be considered a plane wave.

There are two methods used in electromagnetic field modeling. The first method for electromagnetic field modeling uses an analytical technique. This would involve using a mathematical model of the satellite structure and then deriving and solving electric field integral equations. The SPARTNIK satellite structure is too complex to solve for a closed form integral solution. The second approach to electromagnetic field modeling is numerical analysis. Numerical analysis entails modeling the satellite structure into many elements in which closed form analytic solutions are known. By applying the method of superposition, a process of taking the vector sums of a linear system, the far field radiation pattern can be determined.

Once the numerical values of the gain pattern is determined, a three dimensional graphical model can be constructed showing the peeks and nulls in the field. The antenna system design can then be optimized by the minimization of the nulls, the areas that fall below the isotropic level.

The overall gain figure can then be inserted into a link analysis to determine the gain margin of the communications link.

Educational Challenges

The scope of a project the size of SPARTNIK can be challenging to the students at the undergraduate level. Due to the competitive environment that is sometimes found in other classes, students often initially resist working in a team environment.

For a micro-satellite project to succeed, several educational disciplines must be involved.. Traditionally, aerospace engineering was primarily concerned with the orbital mechanics, structures, dynamics and propulsion of a satellite, but when an actual satellite is manufactured, the expertise of electrical and mechanical engineers are needed. Also the programming expertise of the computer engineer is necessary to develop application specific computer code.

The addition of several disciplines contributing different ideas to a project is an organizational challenge. The key to solving most of the challenges encountered is communication with understanding. Each individual must learn to keep the entire project scope in mind in order for it to succeed as a whole. Once this solution is realized, the student can mature into an effective communicator as well as an efficient team contributor.

The underlying benefit of all the educational challenges is the preparation for industry that the project provides. Any project suffers setbacks and conflicts, but the practical experience gained from a project the size of SPARTNIK prepares engineers for the demands of industry. The experienced entry level engineers who are innovators also benefit the aerospace industry.

A long-term goal of the SPARTNIK micro-satellite project is to introduce the actual design and manufacturing of a satellite into curriculum at San Jose State University. Such a class would produce one micro-satellite every academic year. This allows the students involved to see the design process from conception to completion.

Conclusion

Although project SPARTNIK has been a challenge for many of the undergraduate students, it showed them how to act, perform and produce a working product in a real world environment. The undergraduate students that have participated have come out of college with practical knowledge that will be valuable to them and to the companies that hire them.

Not only did the students and the university benefit from this project, but many industry companies will gain vital information about the new field of micro satellite design and operations. Eagle Picher will benefit from the telemetry data that will be collected on the performance of their batteries at a low-cost. If Eagle Picher went to another company to launch and test the batteries it would of been expensive compared to what they paid for the batteries and testing. Future projects researching hysteresis rods will also benefit the aerospace industry at a low-cost, if universities were employed to do the work.

Future relationships between universities and industry will give access for both parties a means for performing highly beneficial research at low-cost, that could not have been done before with the industry's tight budget. Universities can become centers for micro satellite development and operations, supported by local industry, and opening a technological transfer between the two institutions.

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