DESIGNING A SMALL SATELLITE - STARSAT

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ABSTRACT

STARSAT, the Standardized Teaching and Research Satellite, is a small, low-cost satellite being designed and built at the USAF Academy. The basic function of STARSAT is to expand upon NASA's Get-Away-Special concept by allowing similar type payloads to be flown in low earth orbit for extended periods of time. As a standardized spacecraft bus, STARSAT will be able to support a variety of such research payloads. While research is a major goal, STARSAT is also an outstanding tool to aid in teaching undergraduate engineering students. This paper describes the technical specifications for the spacecraft, ground support, launch support and payload services. Finally, the overall management plan is discussed.

BACKGROUND

The mission of the United States Air Force Academy is to provide instruction and experience to all cadets so that they graduate with the knowledge and character essential to leadership and the motivation to become career officers in the U.S. Air Force. Academics plays a key role in this process. Designing an actual spacecraft brings together several engineering disciplines and requires the students to think about and use more than one academic subject at a time. As the design progresses, the students are forced to make some tough trade-offs between capabilities and various design implementations of the subsystems. These tough interdisciplinary choices provide the real life experiences that are so vital to learning the system engineering process and preparing for a career in the increasingly technical Air Force.

Designing and building spacecraft is actually not new at the Air Force Academy. In the late seventies cadets began designing and building experiments for NASA's Get-Away-Special (GAS) program. Two GAS canisters have been flown on the Space Shuttle and another is being readied. Also, cadets have designed and built an ultraviolet sensor which will be flown on the sensor suite of the Delta 183 mission. STARSAT will be designed and built as a continuation of these experiences.

INTRODUCTION

Payloads come in all shapes, sizes, and price ranges. As a spacecraft, STARSAT will not be able to support all payloads. However, there is an identifiable need for a spacecraft of this size to support a variety of small payloads. GAS canister types of experiments that need longer durations in orbit and Air Force Space Test Program types of experiments are the most obvious examples. Payload needs also determine orbit requirements. STARSAT will be designed to be compatible with three launch mechanisms to allow maximum orbit flexibility. The overall size constraints are dictated by the Shuttle Extended GAS canister concept, even though the current status of this concept is uncertain. Other launch options include the Scout and Pegasus.

Standardization will be the key design consideration. The goals are to keep costs low, make the system reliable and ease the fabrication process. By using off-the-shelf components, development cost can be minimized and interfaces with payloads and launch vehicles can be standardized. Proven hardware will also contribute to higher reliability. During the fabrication and testing process, standard components will speed replacement of defective or broken components.

TECHNICAL SPECIFICATIONS

Overall System Specifications

The STARSAT project must meet three main system requirements dealing with overall design concept, reliability, and expected on orbit life. Standardization is the key design concept. A standardized design can be reused, thus reducing costs. Further, a standardized set of payload support services and interfaces eases the payload design. Finally, standardization involves the use of modularity and line replaceable units. Modularity adds flexibility to the spacecraft bus by allowing it to expand to meet the needs of a particular payload. For example, if a payload requires more peak power, another set of batteries could be added. The concept of line replaceable units allows for easy replacement and maintenance during the testing and burn-in phases.

Reliability must continue to be a key factor in the design of all spacecraft. Even small, low-cost spacecraft must have a high probability of success due to the limited availability of launch opportunities. STARSAT will be designed with a goal of 90% probability of completing the primary mission. This reliability will be obtained by designing subsystems with redundancy, using highly reliable parts, and a combination of both. Cost will be a major factor in determining the approach to reliability and also the acceptable level of reliability.

On orbit lifetime is a function of several factors, such as payload requirements and orbital altitude. STARSAT will be designed to support orbital operations for a period of at least one year, regardless of other considerations.

STARSAT consists of four segments: Space Segment, Mission Control Segment, Launch Support Segment and Payload Segment. The Space Segment is the spacecraft bus and will be the core of the system. Normally the payload would be considered as part of the Space Segment; however, with the ability to carry more than one type of payload, the spacecraft bus will be considered one segment and the payload another segment. All other segments will interface directly with the Space Segment.

Space Segment

Design specifications for spacecraft have a natural tendency to be very interrelated, but can be broken down into several subsystems. The Space Segment for STARSAT is divided into five major subsystems: Attitude Control Subsystem (ACS), Electrical Power and Distribution Subsystem (EPDS), Telemetry, Tracking, and Commanding (TT&C) subsystem, Thermal Protection Subsystem (TPS) and Structure and Mechanisms Subsystem (SMS). The specifications of each subsystem are presented to the engineering students and they are expected to refine these requirements, propose a block diagram approach to meet these specifications and finally design the hardware. Parts of subsystems or models may be built, but major fabrication and test will occur in subsequent semesters. The constraining design consideration is the size and weight allowed by the extended GAS canister concept. Although this concept is not finalized, the expected size allowed is a 35 inch (88.9 cm) long by 19 inch (48.26 cm) diameter spacecraft. Total satellite vehicle weight including the spacecraft bus and the payload will be 250 pounds (114 Kg). A weight budget is included in Table 1.

Table 1

WEIGHT BUDGET

Subsystem	Weight (lbs)	Weight (Kg)
ACS	25	11.6
EPDS	60	27.3
TT&C	60	27.3
TPS	5	2.4
SMS	50	22.7
PAYLOAD	50	22.7
Total	250	114.0

Attitude control for STARSAT will be designed with two primary considerations in mind, simplicity and flexibility. The simplest approach is if the payload did not need attitude control. An unstabilized spacecraft might be fine for several payloads, although most will need some sort of stabilized attitude. The design range for attitude control is 1 to 10 degrees. STARSAT will have two design options, depending on payload needs. The first option, which will support the less stringent requirements is a gravity gradient approach supplemented with magnetic torquers or a momentum wheel. The second and more accurate means will be a three axis stabilized reaction control wheel system. As is usual, the more stringent requirements will increase complexity and cost. However, an accurate three axis approach does provide the most flexibility. These systems were chosen to eliminate the need for expendables on-board the spacecraft. Horizon and sun sensors will be used to determine attitude because of their simplicity and low weight.

The Electrical Power and Distribution Subsystem (EPDS) must provide enough power to meet the needs of the payload and also the housekeeping duties of the spacecraft bus. Based on the size of the bus and existing solar cell and NiCd battery technology, the system is expected to provide about 60 watts of peak power and 20 watts of average power. Fifteen watts should be available to payload uses and 5 watts for housekeeping functions. Industry standards for aerospace vehicles dictates the 28 volts regulated bus voltage, with +15 v and +5 v also being available. Chargers, converters, isolators, regulators and sensors will be off-the-shelf components. The EPDS will have a protection system to detect and correct out-of-limit conditions for voltage, power and temperature. In the future, additional power may be provided by improvements in technology, steerable solar panels or by a sheath of solar panels that slide down from the main body of the spacecraft.

The Telemetry, Tracking and Command (TT&C) subsystem will interface directly with the ground based Mission Control Segment (MCS). The telemetry system will be microprocessor based to allow flexibility. Data must be able to be recorded, preferably by solid state means. Telemetry data will be able to be read out both in real time and in a playback mode simultaneously. The system will be capable of handling at least 128 analog, digital, and discrete data parameters. The exact allocation of these individual parameters must be changeable between spacecraft state of health data and payload data. The microprocessor based system will also allow for both subcommutation and supercommutation of data, thus increasing the amount of data parameters available or the frequency of their reporting. Synchronization words, time tags and bit checking techniques will also be used. The telemetry system will allow for encryption, although this feature is not planned. Tracking data will be obtained from three means. First, the North American Aerospace Defense Command, NORAD, provides tracking data on most all orbiting space objects. Second, STARSAT will be capable of using the Air Force Satellite Control Network, an S-band system which uses a pseudo random noise ranging code to obtain accurate range and range rate data. Third, the USAF Academy is obtaining an optical satellite tracking system which will also be able to provide tracking data for satellites in orbits greater than 39 degrees inclination. The command system will also be microprocessor based. It will use three types of commands, real time commands, stored program commands and data update commands. Real time commands (RTCs) can be sent to the command system and will be executed immediately upon receipt and verification of execution will be relayed back to the ground. An RTC could be used to instruct the command system to playback recorded data once a solid link has been established. Stored program commands (SPCs) are stored in the command system's memory to be executed at a designated time. The command system memory will be capable of storing at least 1000 SPCs. As with RTCs, the command system will verify execution of each SPC, but the information will be stored in the playback portion of telemetry. Data update commands (DUCs) are data to be stored on-board the spacecraft and can be used for such things as updating the out-of-limit parameters and payload pointing information. The command system will also allow for encryption, if required. The TT&C subsystem will have the most redundancy of all subsystems. It will have diagnostic tools available such as memory readout, command verification, and telemetry health and status information. Further, the TT&C subsystem will have the capability to detect out-of-limit conditions and take corrective action by reading from memory a set of SPCs.

Temperature constraints are critical for successful operation of any spacecraft. These constraints are different for each subsystem and even each component. The Thermal Protection Subsystem (TPS) must accommodate each requirement. As a further complication, temperature depends upon a number of factors including orbit, electrical component heat generation, and internal subsystem arrangement. Analysis will be required throughout the design process to assure that the limits of each subsystem are satisfied. Batteries and electronics are expected to have the most stringent allowable temperature ranges. Passive means, including thermal blankets, coatings and louvers are the primary heat rejection approaches. Heaters will be used if the position of various components cannot be matched to the correct temperature region within the spacecraft. For example, the batteries may be located near the heat generating electronic component sections. The overriding design goals of the TPS are simplicity and light weight. Thorough testing will be used to verify analysis.

While the size and shape of the structure is governed by the size of the extended GAS canister, the launch environment will be driven by the Scout and Pegasus launch vehicles. The Structure and Mechanisms Subsystem (SMS) will be designed and tested with these launch environments in mind. Modularity and easy access to the inside of the spacecraft will be major design considerations. To keep the weight low aluminum will be the main structural material, although composites will be considered. The STARSAT design will try to minimize the number of mechanisms to keep things simple. However, GAS canister ejection mechanisms, Scout and Pegasus interface mechanisms, yo-yo de-spin mechanisms, gravity gradient stabilization booms and antennas will all be required. Testing is, here again, a major consideration to assure successful operation.

Mission Control Segment

The MCS consists of both hardware and software required to support mission operations. The STARSAT TT&C subsystem will be compatible with the Air Force Satellite Control Network. This system, centered at the Consolidated Space Test Center in Sunnyvale, California, operates a network of seven remote tracking stations located around the world. The network operates in S-band and UHF and provides complete telemetry, tracking and command capabilities. The USAF Academy will also have a dedicated ground station. Called the Dedicated USAFA Ground Operations (UHF) Terminal (DUGOUT), the system will operate telemetry and command operations on a UHF channel. The heart of DUGOUT will be a PC based system with connections to printers and the antenna. Link margins and data rates have not yet been established. Tracking will be obtained from NORAD or the optical tracking system at the Academy. The DUGOUT software will have the standard capabilities of telemetry and tracking data reduction, look angle prediction, command message generation, and spacecraft models.

Launch Support Segment

STARSAT is being designed to be launched by any of three means, Shuttle extended GAS canister, Scout, or Pegasus. While each presents a different set of launch interfaces, this design complexity is offset by the flexibility and number of launch opportunities afforded STARSAT. As mentioned earlier, the Shuttle extended GAS canister sets the limits on size and weight, while the Scout and Pegasus present the more rigorous launch environments.

Payload Segment

The Payload Segment will vary with each payload, but the support services provided by the spacecraft will be standardized. Fifty pounds (22.7 Kg) of payload will be supported and up to one third of the total STARSAT volume will be available. The arrangement of the space will be slightly variable due to the modular design of the spacecraft. Up to 15 watts continuous power will be available for payload use. The exact attitude pointing requirements will vary, but the design range is 1 to 10 degrees. At least 64 data parameters on the telemetry wavetrain can be used by the payload. Thermal requirements will be handled on a case by case basis. Even before the integration and test phase, a comprehensive test program will be worked out with the payload developers.

MANAGEMENT PLAN

Organizational Structure

STARSAT begins with an interdisciplinary engineering design course. Students are provided the specifications and some general background in spacecraft subsystems and small satellites. They are expected to develop a block diagram level of design for a preliminary design review. Upon acceptance by the program manager, the students refine their design from the block diagram level to the component level of design for a critical design review. Subsequent semesters will continue refinement of the design and begin construction and test. Throughout the entire process various reviews and analyses will keep the design on track. Support will come from the contributions of instructors and students from various departments at the USAF Academy. Although research time for instructors at the USAF Academy is limited, it is critical. The goals of both research and teaching will be achieved. The real challenge will be to keep consistency from semester to semester and from year to year. A great deal of time and effort could be wasted without a continuous ongoing program control mechanism.

Program Control

The current STARSAT schedule contains three one-year partitions. The first year is devoted to design and analysis. The second year will be devoted primarily to construction of the spacecraft and integration of the first payload. Testing will take up most of the third year. Current budget estimates call for a total cost of about $300,000. Most of the budget expenses are for subsystem components and travel. Funding has not yet been approved. Virtually all of the labor will be provided as part of class related activities, instructors' research or donations. Accurate and complete documentation and configuration control will be a key management tool to keep the program running as smoothly as possible. A hierarchy of documents will be written and maintained. The top level documents will describe the overall system requirements, followed by segment, subsystem and component requirements. The continuing refinement of the actual design will be contained in this documentation hierarchy. All changes to these documents will be configuration controlled and approved by the program manager.

CONCLUSIONS

STARSAT provides to students the real life problems of getting a small, low-cost satellite into orbit. It also provides an inexpensive standardized spacecraft bus to support various payload needs. Meeting the objectives of both teaching and research is not without challenges. Technical challenges come not from pushing technology, but from the complexity presented to undergraduates. Management challenges result from the need for continuity from year to year, the limited time available for research by instructors and the need to keep costs low. However, it can be done!