Dartmouth Nanosatellites as Orbital Research Platforms

by Amish Parashar '03

INTRODUCTION

Satellite projects have historically been large and expensive operations. As a result, reducing cost and size of satellites have become key issues in engineering science. The space industry, however, has moved towards larger, more elaborate spacecraft, because this may reduce launch costs and increase the longevity of space investments. The European Space Agency, in increasing the size of the Arian rockets, met the demand for a launch vehicle capable of placing large satellites (over 1000 kg) into high altitude orbits. Engineers at Stanford, California State Polytechnic University San Louis Obispo, and Dartmouth have seen this trend and reacted against it. In the future, small satellites will handle a variety of tasks, while larger space vehicles will be reserved for specialized functions in which small satellites may not be adequate (i.e. high orbit applications and geo-synchronous orbits).

A modular approach to the creation of a versatile orbiting platform may revolutionize in space technology. A standardized modular bus will be able to accommodate a variety of payloads thus increasing possible applications and reducing cost. A modular approach to the construction of a small satellite may provide a standard for future space-based research, educational, and communication platforms.

The DARTSAT program was initialized to provide the footing for space-based research at Dartmouth College. DARTSAT's plan for satellite launch has two phases: Generation I is primarily a proof of concept, and Generation II will encompass all of the features that would make it a viable commercial option. The following pages outline the DARTSAT project and its implications.

MECHANICAL DESIGN

DARTSAT has dimensions of ten cubic centimeters and a mass of one kilogram. The modular design of the satellite allows the "snap-in" of interchangeable, independently engineered payloads. This design will be a standard for future space flight orbital operations. There are a number of factors that need to be considered when constructing a small satellite:

Structural Integrity: The satellite space frame must be able to withstand the rigors of launch and orbit.

Mass: The mass of the structure must be minimized in order to allow for greater payload mass.

Thermal and radio frequency interference (RFI): Thermal and radio frequency interference factors must be accounted for. The drastic thermal oscillation that will occur each orbital cycle is amplified by a low thermal mass. Reduction of thermal mass must be carefully balanced with reducing the overall mass of the structure. Some electronic components used onboard are susceptible to RFI as well as radiation. Special measures must be taken to ensure their functionality.

Integration: Compatibility of satellite sub-divisions is important. The final stage of mechanical design should be integration of all the satellite sub-divisions.

In an effort to standardize some of the efforts in the satellite community, a group at California State Polytechnic University San Louis Obispo has developed a rocket-to-satellite interface. In order to make use of this resource the pre-deployment dimensions cannot exceed ten centimeters on each side. A total of eight seven-millimeter standoffs are to be attached to the top and bottom faces of the cube, one per corner of each of the two faces. These standoffs will be oriented so as to provide adequate separation between adjacent satellites in the launcher. The mass of the satellite, in launch ready mode, cannot exceed one kilogram.[1]

The interior volume of the satellite will be divided into two areas. Area one will contain the system boards, and area two will be allocated for payload space. The first board will house system bus components, which includes the processor, power system, and associated circuitry. A second board will accommodate the transmitter and receiver. A third board will house data collection and data packaging. Area two will house the payload.

Expandability and versatility are fundamental design considerations in the development of this first generation satellite.

ORBITAL CHARACTERISTICS

Upon ejection from the launching apparatus, the satellite will orbit in an unstable and unpredictable manner. Many of the exact launch characteristics are unknown (small satellites are carried by rockets carrying larger primary payloads. These rockets pay the bulk of the launch costs, thereby setting launch specifications). In order to add stability to the orbiter, one of two options may be implemented: active stabilization and passive control. Active stabilization, the use of thrusters to achieve desired satellite orientation, is costly in terms of space and power consumption. However, the cost in power and space is too great. Passive control, on the other hand, is more efficient. A permanent magnet or ferrous rods housed onboard the satellite can act as a stabilization device by aligning the satellite with the earth’s magnetic field lines. This stabilization is enough to allow optimal positioning of deployed antennas and the heat dissipation face.

The satellite will reside in a low-earth orbit (LEO), between 300 and 1500 kilometers in elevation, in high inclination (a polar north to south to north) as determined by the launch parameters. When combined with the trace atmospheric drag forces present at the given elevation of the flight path, the satellite is expected to undergo atmospheric degradation between one and two years from launch due the high velocity associated with re-entry. Active thrusting capability may be a potential solution to this seemingly early demise. Because of the low cost of producing such a satellite, a short lifetime is acceptable.

POWER

Power is supplied by batteries that are charged via a photovoltaic array. In order to accept the most diverse set of payloads, the dimensions and placement of the battery must accommodate other aspects of satellite design.

Five of the six faces of the orbiter will be covered by solar cells. Gallium-Arsenide cells are the most efficient photovoltaic option. These cells have a peak efficiency in the 20% to 25% range. Silicon cells, with less than 20% efficiency, possess unique structural benefits. An amorphous silicon (a-Si) cell is thin, ultra light, and extremely resilient to external stresses. These cells allow for a balance between efficiency and desirable mechanical properties. The sixth face of the satellite will serve as a thermal dissipation face. Through passive control, this face will be aligned so as to rarely be oriented towards the the Sun. This design allows for greater thermal stability of the satellite as a whole.

Nickel-cadmium batteries, although less efficient than Ni metal-hydride and Li ion, are able to handle the power cycles the satellite may undergo. The satellite will be in radio view for a fifteen-minute window during each pass. During this time, the transmitter will transmit at 0.5 Watts RF. A total of 90 minutes of high power draw (in the form of transmission) is expected each day. The transmitter is deactivated once out of range. A gradual degradation of satellite functions was created to decrease chances of failure. Satellite func-

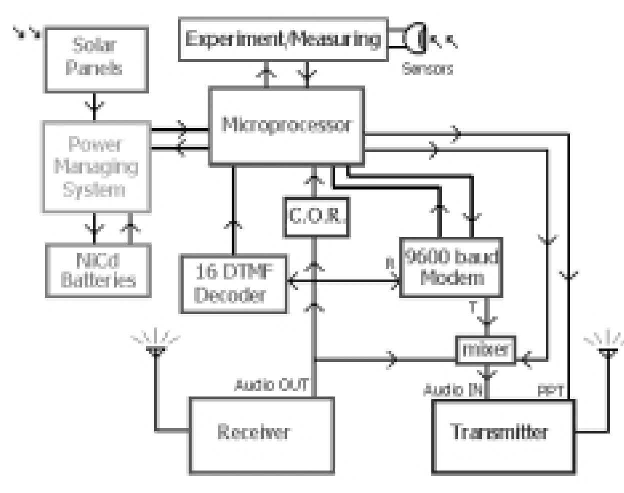

Figure 1: Satellite Subcomponents.
This figure illustrates the relative positioning of satellite subcomponents. Each subcomponent can be modified independent of one another.

1 This is a standard governed by the California Polytechnic State University Pico Orbital Deployer program.

tions will be progressively deactivated based on power consumption. For example, the receiver, then the microprocessor control unit, followed by the experiment, and finally the transmitter will be placed offline as power levels fall beneath threshold values.

MICROPROCESSOR CONTROL

The microprocessor control unit (MCU) will oversee core satellite functions. It will monitor power status, collect and store data, prepare the data for transmission, and send out a periodic identification signal in future generations. The first iteration MCU will be simplified so as to reduce potential sources of error. A specific goal of the initial MCU design is ease of expandability (e.g. memory). Space rated parts were used to assemble the MCU and all other electronics, in order to withstand the high amount of radiation in space.

The Generation II MCU will be based on a stable microcontroller. Low power versions will be used in order to comply with the power budget of the satellite. This chip will be used in conjunction with 20 kilobytes of Flash RAM. The RAM will be the primary memory bank, housing the basic onboard programs. The microprocessor will be controlled in two ways. Touch-tone codes will serve as primary control of the MCU. The dial tone mixed frequency (DTMF) standard was selected because there are a large number of base stations that will be able to communicate with the satellite. Each DTMF tone received by the satellite will be converted to a corresponding four-bit number. The MCU will use this number to alter its operating functions or implement a series of routines.

DARTSAT Generation I, will use discrete logic circuitry to provide simple control of the most basic satellite functions. The simplistic nature of Generation I increases system reliability.

The MCU is designed to handle the collection and storage of data. The first iteration of DARTSAT will collect information regarding its LEO. Sensors aboard the satellite will capture and send analog data to the radios, where it will be transmitted to Earth. Generation I employs recognition of a series of tones to downlink real-time sensor data. Valuable information regarding sun exposure, thermodynamic characteristics of the spacecraft, and solar cell performance will be obtained as a result of the sensor data stream. The receiving base station will collect and analyze this data.

The satellite must also be able to perform a set of other functions. Federal Communication Commission rules state that the satellite must send out an identification signal (a beacon) at given intervals when the satellite is operational. In order to limit the use of memory and simplify circuitry, a Morse code message will be transmitted in lieu of voice identification. The timer portion of the MCU will govern the transmission of the beacon signal. Adaptability and expandability are key design goals of the first iteration MCU. The proposed design should allow efficient, reliable, and consistent operation of basic satellite tasks. This should serve as a platform upon which more complex MCUs may be based.

Example applications include aurora borealis and plasma ion density measurement, acting as a test bed for zero gravity micromachines and space-borne networks.

COMMUNICATIONS

Satellite communications must strictly adhere to FCC and international regulations and must be universally accessible using an established standard of communications in order to be commercially viable in the future. Finally, the communications method adopted must be able to sufficiently penetrate the Earth's atmosphere under a variety of weather, solar, and atmospheric conditions.

In order to reduce unwanted harmonic desensitization of the receiver, a cross band repeater operation was chosen for the satellite. Harmonic desensitization primarily occurs above the frequency of transmission. Consequently, the range of possible transmitter frequencies was set above that of the onboard receiver. UHF and VHF band signals possess the ability to permeate the ionosphere under a wide variety of conditions. Shortwave frequencies, however, bounce within the ionosphere and are dependent on solar and atmospheric conditions.

Aside from voice communication modes, the satellite must be able to send as well as receive data. Reception will be in the form of DTMF codes sent up to DARTSAT from ground stations. Transmission of onboard data will be fundamentally different. In Generation II, the packet radio

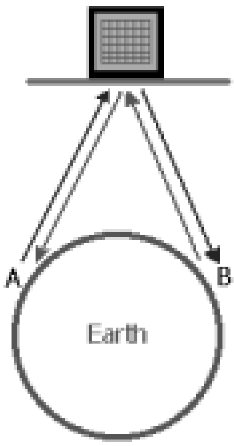

Figure 3. Radio "repeater" functionality of DARTSAT.

standard will be used, because of its widespread use in amateur radio and at ground stations worldwide. The packet system ensures accurate transfer of information. Data streams are broken up into small segments known as packets that are transmitted to the receiving station. The packet system requires checks on the data transmission. At regular intervals a check set is sent to the packet circuitry in order to confirm that a variable amount of the data stream has been received. If for some reason a portion of the data is not received, it is re-sent until a reception receipt is transmitted. This method ensures that communication is complete and accurate. Data speeds will most likely occur at 1200 bps. Due to atmospheric, Doppler, and other phenomena, it is unlikely that higher baud rates will ensure accurate data exchange.

Communication quality is largely dependent on antenna design and implementation. One axis of the satellite will be fixed through passive magnetic stabilization, as design that will also stabilize the antenna. A second consideration is the number and complexity of deployables, which exponentially increase the probability for error. A set of dipole antennas will be used in order to provide the most omni-directional signal possible thus reducing the problems caused by the lack of stability in satellite motion. Omni-directional antennas provide a distinct propagation pattern that is suitable for space to earth communications. Two one-quarter-wavelength rods will serve as the receiving antenna. Another pair of one-quarter wavelength rods will function as the transmitting antenna. This is superior in many respects to the commonly used quarter wavelength antenna design. Such a design calls for a quarter wavelength driven element and four additional quarter wavelength rods to serve as a psuedo ground plane. This design is inferior to the dipole design with respect to the two criterion – omni directionality and a few, simple deployables.

The ground station will be located at the Thayer School of Engineering. Satellite transmissions will occur at relatively low power, about 0.5 W RF. Two high gain antennas connected to a VHF/UHF radio will serve as the backbone of ground communications. A computer, through a three-axis rotator, will control the antennas as well as compensate for Doppler shift through radio control.

By using many standards adopted by amateur radio operators worldwide, DARTSAT and future nanosatellites should provide a valuable communications link while presenting unique scientific research opportunities. Nanosatellites may, in the near future, possess the ability to communicate to not only the ground, but also each other. Communication networks in space using protocols such as internet protocols, may be the next step in the development of small satellite projects in space. Large area coverage can be achieved using many small spacecraft.

EXPERIMENTATION

Strict specifications concerning power, external space, interior volume, and available memory will be presented to the scientific community. The hope is for researchers to approach the satellite team with drop-in modules. Seamless integration of an experimental module is a goal of DARTSAT. Example applications include aurora borealis and plasma ion density measurement, acting as a test bed for zero gravity micromachines and space-borne networks. Future models may house GPS reception equipment in order to provide time and location stamps for each collected data set.

TESTING

Testing will start at the satellite sub-system level. After each section of the satellite functions correctly, the entire unit will undergo testing. It must be ensured that the satellite will function properly, but also not endanger the launch vehicle, other satellites aboard it, and other orbiting craft. Thermal vacuum testing will subject the satellite to temperatures of -40° C to 65° C. Vibration testing will ensure that the satellite can withstand the 15G's of force and associated vibrations that may be encountered during launch. Electromagnetic testing will check that radio systems and other circuitry do not interfere with other orbiters. Finally, integration with the launch apparatus will be tested. Most testing will take place at Saunders Labs in Nashua, New Hampshire.

CONCLUSION

Due to modularity of design and the ability to "snap-in" interchangeable payloads, the Dartmouth College nanosatellite, DARTSAT, will have a limitless future. Since the project's conception, many proposals concerning the use of such an orbital platform have emerged.

It is believed that the satellite will prove to be a cost effective, mass-produced space vehicle. Its small size and versatility may prove it to be a valuable research tool for the scientific community. Applications in space borne sensing, orbital data acquisition, and microgravity testing may be ideal for this satellite – a low cost test bed for researchers in many fields is obviously advantageous. Many such satellites could fly in formation. Known as a constellation, this may be a viable solution in an era of global handheld communications. A small handheld transceiver on the ground may be able to provide communications on a global level. ❖

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