VCL: The Vegetation Canopy Lidar Mission

Jonathan Cooper
Orbital Sciences Corporation
1521 Westbranch Drive
McLean, VA 22102
703.883.1456
jcooper@email.cta-space.com

Abstract. The Vegetation Canopy Lidar (VCL) mission will be the first mission under the aegis of NASA's Earth System Science Pathfinder (ESSP). The mission will pioneer the execution of important science, in a short time period, with modest investment from the sponsoring organization. The mission team is a unique blend. The Principal Investigator, the science team, and ground operations is comprised of staff and students at the University of Maryland. The program management, and ground station development is performed by Omitron Incorporated. The satellite bus is designed, and developed, by Orbital Sciences Corporation. The mission funding, and science instrument integration, is provided by NASA Goddard Space Flight Center.

The purpose of the mission is to fill the gaps in our global understanding of Earth's vegetation land cover. VCL will characterize the three dimensional structure of land cover for ecosystem/climate modeling, monitoring, and prediction. Important land cover parameters are poorly represented by currently available data, and the VCL mission will address the need for global quantitative data.

During the design phase, VCL has encountered increases in the power requirements requested by the payload. The subsequent lesson learned was that the consequences affect nearly every spacecraft subsystem.

Introduction

The VCL mission is currently in Phase B design, and spacecraft fabrication will begin in early 1998. During the VCL mission design the spacecraft energy balance quickly became the driving factor in nearly all of the spacecraft subsystems. A description of the VCL mission, and the lessons learned, follows.

Science Description

The objective of the mission is to map the biomass of the earth. The height of the vegetation layer, as well as the density profile of the layer, will be measured. The data can be used for analyses of Earth climate, croplands, deforestation, and the terrestrial carbon cycle. The size and distribution of the Earth's biomass is not well understood. Complex environmental computer models currently use rather poor estimates of these factors. The VCL mission will produce data sets that will accurately characterize the Earth's biomass. In addition, a byproduct of the science will be comprehensive global topographical data sets.

The instrument on board VCL is a Multi-Beam Laser Altimeter (MBLA). The MBLA has five lasers, each of which fires 7 nanosecond pulses at a rate of 290 Hz. A parabolic telescope receives the return signals. The cross section of the return signal reveals vegetation canopy heights and densities.

Laser spots on the Earth's surface will be 25m in diameter, with 25m spacing. Pointing control requirements are 0.1° (1σ) for each axis. Pointing knowledge requirements are 10 arc seconds (3σ) for pitch and roll, and 200 arc seconds (3σ) for yaw. The challenging attitude determination and control requirements are largely met with a low cost, high performance Lockheed Martin star tracker, and a Litton hemispherical resonator gyro (HRG).

The instrument duty cycle is roughly 30 percent. Over land the MBLA is operational, and over water it is in standby.

Orbit

VCL will be launched by a Pegasus XL into a circular 400km orbit with an inclination of 65°, for a two year mission. The instrument will be nadir pointing for the entire mission. Three axis, zero momentum biased attitude control will be maintained with reaction wheels and magnetic torque rod momentum dumping. The orbit will be raised approximately once per month to extend mission life.

Physical Description

The VCL spacecraft is composed of two octagonal cylinders of different diameters. The instrument is slightly wider than the spacecraft bus, but roughly the same height. One end of the instrument cylinder has a parabolic telescope that always points to Earth (nadir). Five laser assemblies are mounted on the periphery of the cylinder, all of which are clustered to one side. The other end of the instrument cylinder is mated to the spacecraft bus.

The spacecraft bus is of slightly smaller diameter so that the solar panels may be stored close to the body prior to deployment. The other end of the spacecraft bus has the separation subsystem, orbit adjustment thrusters, and GPS antennas. The two solar panel arrays are connected on each side of the spacecraft bus about ten inches from the instrument on the Y axis. The solar arrays each have two degrees of freedom, and describe a cone shaped arc during the course of an orbit.

The primary instrument structure is a five inch thick composite optical bench. The parabolic telescope is mounted on the nadir side of the deck and the gyro, star tracker, and computer/power assembly is mounted on the zenith side. Five lasers are mounted, one per face, on the periphery of the octagonal bench. Each laser will dissipate 100W of power when it is firing at maximum rate, so large radiators are connected to each one. The radiators extend below the spacecraft bus / instrument interface, and well above the edge of the parabolic telescope. In addition to rejecting heat from the lasers the radiators also shade the telescope from sun impingement.

The spacecraft bus structure is connected to the instrument optical deck via a special interface designed to prevent thermal expansion/contraction of the bus from transmitting unacceptable stresses to the optical bench.

The VCL bus structure is based on the Orbital (formerly CTA/SS) Leo Star design which has heritage from the current TSX-5 mission and its predecessors. The structure is comprised of three main sections; separation system, propulsion module, and core module.

The propulsion module includes a hydrazine tank supported by an aluminum truss which is enclosed in a 38 inch diameter aluminum cylinder approximately 25 inches in height. A NiH2 battery, X & Y reaction wheels, and some electronics are also mounted in this section. The aluminum cylinder is reinforced with vertical stringers or longerons, and shear panels. The underside of the propulsion deck also holds the launch vehicle separation subsystem.

The core module is mounted to the top of the propulsion module. It is an eight sided aluminum structure composed of an aluminum honeycomb plate to which the bus electronics are mounted. The same side panel and stringer structure is used for the core. The module is approximately 12 inches in height.

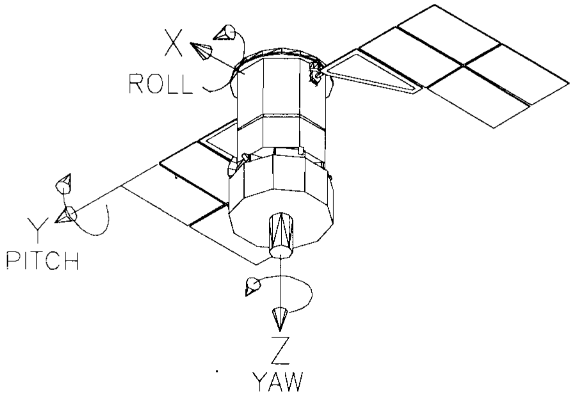

Figure 1. VCL Spacecraft Axes

Lessons Learned - Power

VCL has experienced an increase in requested power from the instrument, and it impacts the spacecraft bus design in many ways. What follows are some of the lessons learned during the accommodation of the increased power into the spacecraft bus design. Most spacecraft are custom built. For this reason the information presented below is not quantitative. Rather, the problems and trade-offs are expressed subjectively so that the details specific to this mission do not hinder the discussion of general considerations that may apply to a broad spectrum of spacecraft.

Mass

Increased power requirements lead directly to the addition of mass to the spacecraft in an incremental fashion. The cumulative effect can be dramatic. Increased solar panel area is obviously necessary to maintain energy balance. The increase in mass is roughly linear with the desired increase in capability. The increase in laser power requirements dictate either the addition of heat pipes within the laser radiators, or larger radiators, and perhaps both. The increase in solar array size also impacts the drag of the spacecraft, and more fuel is therefore necessary to maintain altitude. A consequence of carrying additional fuel can be the necessity of carrying a larger tank, and thus additional structural mass.

Volume

The increases in power demand come largely from the MBLA lasers, so the size of the laser radiators expands accordingly. The launch vehicle shroud limits the expansion of the radiators towards nadir. The finite shroud dimensions limit the overall diameter of the instrument, and thus the width of each side of the octagonal structure. For this reason the radiators cannot expand in width. The only available area for expansion is in the zenith direction, towards the spacecraft bus. The radiators thus take volume that would otherwise be used for the bus. Since the radiators are on the periphery of the spacecraft, they take up valuable space that would otherwise be used to store the solar panel assembly prior to deployment. The solar array size is already experiencing growth, so radiator size is important. The increase in power demand coupled with less available solar array storage volume drives the design toward the use of more efficient solar cells. Another volume consideration is the size of the battery necessary to compensate for the increased depth of discharge that the increased instrument power demand entails.

Fuel

As the size of the solar array expands, the cross section of the spacecraft normal to the velocity vector also expands. The expanded cross section produces a larger drag. Additional fuel, and a correspondingly larger fuel tank, are therefore necessary to maintain altitude.

Attitude Determination and Control Subsystem (ADACS)

Additional drag on the spacecraft increases the aerotorques to which the spacecraft is subjected. The size of the actuators must be reevaluated to assure adequate capability. In addition to drag, the spacecraft moment of inertia may also increase when the extra solar array area is added. The effect is exaggerated if the additional area is added on the part of the array that is farthest from the spacecraft center of gravity. The VCL program must reevaluate the size of the momentum wheels, as well as the torque rods which dump stored momentum.

Thermal

In addition to the increased laser radiator size the increased solar array size has some impact on the thermal conditions. The solar arrays, which have two degrees of freedom, move in cone shaped paths to track the sun. The entire cone is traveled during each orbit. The radiators try to reject heat to space so when the solar array sweeps past the radiator efficiency is affected. The increased solar array size will make the problem worse to a degree largely dependent on the solar array configuration.

Gimbal

The two axis gimbal used to move the arrays must be reevaluated in light of the increased power flowing through the slip rings. The joint that rotates the arrays on the Y axis is a 360° joint that continues into the next rotation without rewinding. To transmit the power from the panels to the bus the current must flow through slip rings within the gimbal. Sizing the rings is a laborious task and must be reevaluated each time the array power increases.

Cost

All of the effects mentioned above have a very real monetary cost. Increased solar array size, more efficient solar cell technology, a larger fuel tank, the introduction of heat pipes into the radiator design, increased ADACS actuator sizes, and larger solar array gimbals, all have a direct tangible cost.

Lessons Learned - Redundancy

Designing small spacecraft architectures requires a constant trade between redundancy and cost. Cost may be understood as the cost of mass, volume, and power, as well as money.

VCL requires fairly sophisticated instrument boresight pointing knowledge, so a star tracker and a good gyro are essential. Taken together they represent nearly ten percent of the budget for the spacecraft bus. Although they are critical subsystems, they are obvious candidates for acceptable single point failure.

Reaction wheels are mechanisms, which makes them more likely to fail or experience degraded performance over time. VCL requires three axis stabilization, and the ability to maneuver for delta V events. Totally redundant reaction wheel subsystems are rare on small spacecraft due to the additional weight and volume. A compromise can be made with the addition of a fourth reaction wheel with its axis skewed 45° from each of the spacecraft axes. If one of the primary wheels fails, the fourth wheel can compensate for it in concert with the two remaining wheels, albeit with less overall capability. An additional benefit to the off axis wheel is that it can be used to bias the other three wheels to a non zero speed, maintain zero momentum bias, and avoid wheel dead band problems that commonly occur at low wheel speeds. Although the VCL program is experiencing the ubiquitous spacecraft mass problem, the addition of a fourth wheel is still attractive.

The MBLA instrument duty cycle requires that it is operational whenever the satellite passes over land, and that it is in standby over water. The Earth's surface is 70% water, so the difference between instrument orbit average power and peak power is large. If long land passes coincide with the portion of the orbit that passes through the Earth's umbra, the battery must be able to withstand a rather deep depth of discharge. Orbit simulations indicate that there are times when this case may be experienced for consecutive orbits, thus aggravating the problem. The development of single pressure vessel NiH2 batteries provides a very cost effective solution for capacity vs. mass and volume.

VCL will use a solid state recorder to store up to 32G bits of instrument data. These units are typically not redundant on the unit level, but provide internal redundancy by board level duplication of critical circuits, and the ability to dynamically remove nonfunctional sections of memory from use.

Conclusions

The VCL mission illustrates many of the design dilemmas that are commonly encountered in a small spacecraft program. New payloads frequently experience expanding electric power requirements as the detailed design is completed. Spacecraft bus designers need to be cautious of the manifold ramifications of a seemingly straightforward change in those requirements.

The campaign to accommodate the requested increase in power from the MBLA instrument is currently underway. The increased power demand is largely due to the lasers, so the new laser design is emphasizing efficiency. It is anticipated that this will only be partially successful, and the bulk of the power relief will be compensated for elsewhere on the spacecraft. The options under consideration include sacrificing redundancy, and the use of better, more efficient, technology.

Mass and volume relief can be found by use of high efficiency solar cells, use of one rather than two single pressure vessel NiH2 batteries, reduction in the number of reaction wheels from four to three, and the use of new composite technology for the laser radiators.

Ultimately, if enough relief cannot reasonably be found, the instrument will sacrifice operational time in the form of mission life, duty cycle, or data quality. A compromise between the science and the engineering will eventually be made to enable a practical mission to come to fruition.