SSC03-IX-4

The Montana Nanosatellite for Science, Engineering, and Technology for the AFRL/NASA University Nanosat Program

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Abstract. Montana State University's interdisciplinary Space Science and Engineering Laboratory (SSEL) has been selected under the AFRL/NASA University Nanosat Program to design, build, and test an earth orbiting satellite. The Montana Nanosatellite will carry a scientific payload to characterize variations in the energetic charged particle fluxes in the Earth's Geospace environment using newly developed sensors. Recent solid-state sensor developments have opened a new window of access for these low mass low-power detector systems at lower particle energies than previously achievable. Several new technologies are planned for incorporation into the design of the satellite. Among these are the first in orbit application of an elastic memory composite (EMC) mechanism under development by CTD, Inc of Lafayette, CO. An EMC hinge will be used to deploy a solar array wing using thermal energization and without mechanical moving parts. Another technology development includes miniature solid-state magnetoresistive magnetometer devices that will be employed as part of an active magnetic three-axis attitude control system. The satellite will continue ongoing efforts to adopt, for space flight, state-of-the-art, mass produced integrated circuit components and subsystems developed for consumer applications. One specific application of COTS integrated circuits includes the design of a regulated 5 v spacecraft power system using regulators, single-chip DC-DC converters, and control chips developed for cell phones and hand-held computing devices. A standardized Department of Defense deployer system designed for launch from the Space Shuttle Payload Bay allows deployment of up to 25 kg of satellite mass contained within a cylindrical volume of 18.7" diameter and 18.7" height. The project is one of fourteen university projects selected for a two-year design and development cycle culminating in competitive selection for spaceflight in February, 2005. The project puts heavy emphasis on student involvement in all phases of the management and design of the hardware. Partnerships with industrial concerns and government laboratories are actively encouraged. This paper describes the both the technical implementation and design as well as the not inconsiderable task of team organization and management in a fluid environment.

Introduction

As a result of a Broad Agency Announcement in November, 2002, Montana State University is one of thirteen U. S. universities selected to each perform design, fabrication and functional testing of a nanosat. The University NanoSat Program is administered through the Air Force Office of Scientific Research (AFOSR), for and in conjunction with the Air Force Research Laboratory (AFRL) Space Vehicles Directorate (AFRL/VS), NASA Goddard Space Flight Center (GSFC) and the American Institute of Aeronautics and Astronautics (AIAA). The AIAA will sponsor a program competition to select a one (or more) of the nanosat designs from the participating universities for space launch and operation on orbit. The program goals "promote the education of future spacecraft systems engineers, at the university level, motivate/sustain related research on targeted technologies by focusing on the development of small satellites (nanosats) or flight experiments, and inspire the interest of students, below the university level, for careers in space" [Program Announcement, AFOSR BAA 2003-2, Nov. 2002]. Secondary program objectives are "to foster research in enabling technologies for nanosats and the design of experiments that can be performed by nanosats in orbit".

This paper describes the Montana State University's (MSU) participation in the University NanoSat Program under the Maia mission. The Space Science and Engineering Laboratory (SSEL) at MSU was established in November, 2000 to enable the involvement of university students in the design and development of space flight hardware. Among the several projects within the SSEL is Montana's first Earth orbiting satellite the Montana EaRth Orbiting Pico Explorer (MEROPE)[1]. MEROPE is a CubeSat-class satellite (a 1-kg satellite contained within a 10 cm cube) sponsored primarily by the Montana Space Grant Consortium. The scope of the Maia satellite represents a significant follow-on development to MEROPE, representing an order of magnitude increase in mass and approximately a factor of forty increase in volume. With these increases comes an increase in functionality, Maia has 3-axis active magnetic attitude control while MEROPE has 1-axis passive magnetic control. Deployables are another advancement as Maia will have deployable antennas as well as a deployable solar panel. In every way Maia is a step forward in the progression of technology and difficulty and performance from SSEL's previous missions. SSEL is taking lessons learned on MEROPE and other projects and applying that knowledge to the Maia satellite as a stepping-stone for future missions.

The name Maia follows the theme of MEROPE (MSU's first satellite) as being one of the stars in the Pleiades star cluster. Additionally the *Maiasaurus* is the name of dinosaur that roamed the prehistoric plains of what is now Montana, discovered and named by MSU paleontologist, Jack Horner.

Mission Objectives

Nanosatellites as viable science platforms

The Montana State University's Maia University Nanosatellite will characterize magnetospheric energetic charged particle variations near Earth using new state-of-the-art solid-state particle detectors. It will demonstrate operation of a novel on-orbit deployment system and the use of newly developed miniature hybrid magnetoresistive magnetometers for attitude control. Maia is mandated to be a test-bed for technologies, a science support platform, and includes the unstated goal of being an educational experience for all involved. Maia is a spinning nanosatellite of about 10 kg in the shape of a short (~10 in), wide (~18 in) hexagon as shown in figure 1.

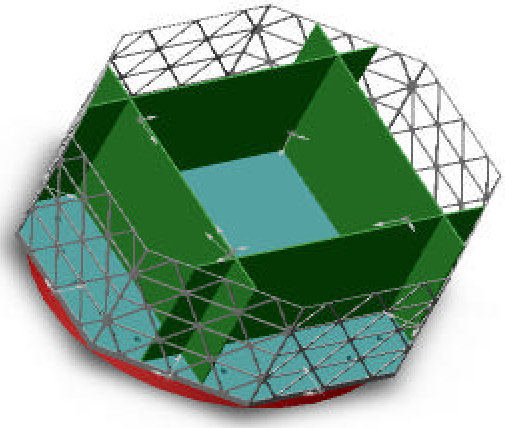

Figure 1 Proposed satellite design, focus is to have a load bearing central core and a non-load bearing skin.

Engineering Objectives

New and continued flight heritage

Everything on a university nanosatellite is an engineering challenge and has the objective of successful functionality on orbit. Maia's major engineering objective is the demonstration of a deployable solar panel using a novel CTD manufactured TEMBO™, elastic memory composite deployment hinge system. Another important engineering goal is further establishing that moderate attitude control is possible in a nanosatellite. This system uses a new breed of miniature 3-axis magnetoresistive magnetometers to measure the attitude changes and magnetotorquers to align the spin axis of the satellite in the desired orientation. Further use of both Commercial-Off-the-Shelf (COTS) and Consumer-Off-the-Shelf parts will be demonstrated, as it is our belief that these components are a largely untapped resource for nanosatellite use. The components, such as those found in PDAs, cell phones, and laptop computers are light, efficient and well suited for development into nanosatellite systems.

TEMBO™, elastic memory composite deployment hinge solar panel

Creating a slow controlled release simply

Maia contains a solar panel deployable with its CTD manufactured TEMBO™, elastic memory composite deployment hinge system. This hinge system combines the structural properties of traditional carbon fiber composites while also having shape memory characteristics[2]. The TEMBO™ looks much like a section of a wide carbon fiber tape measure that, once heated, becomes flexible and can be bent to a new position. When cooled in the new position the TEMBO™ hardens and remains in that stowed configuration. Then when the TEMBO™ is heated again above its glass transition temperature it returns to its original straight configuration. This system makes deployment much simpler as there is no longer any need for complicated space rated hinge designs, reducing or eliminating the problems with thermal expansion, cold welding, and damping that are inherent to rigid hinge systems. The TEMBO™ is proven to provide a slow controlled release, taking about 2 minutes to full deployment, with no shock to the deployed system. Montana State University is working closely with CTD to develop a method to incorporate the TEMBO™ into a system that will be mission safe and mission successful.

The TEMBO™ is not meant to be load bearing in its stowed (bent) position, so the system must be designed to stow the deployable such that the TEMBO™ only feels its own launch loads and not the loads of the wing. Figure 2 shows the TEMBO™ deployment hinges attached to a proposed solar panel. The solar panel use is as follows: the TEMBO™ hinges are heated above their glass transition temperature, after which the panel can be folded back to a stowed position where the panel is then rigidly constrained to the satellite using standard pre-loading and "cup and cone" restraints. Then on orbit deployment occurs by releasing the pre-load allowing the deployable to separate slightly from its stowed position. The TEMBO™ hinges are then heated and the deployable makes its slow transition to deployed position[3]. It is our intention to use this deployed solar panel as a proof of concept more than a mission critical power generation feature.

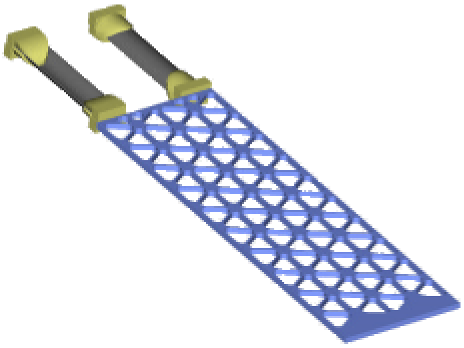

Figure 2 Preliminary design of the TEMBO™ elastic memory composite deployment hinges attached to a rectangular deployable.

Attitude Control

Moderate spin axis control in a nanosatellite

Maia's science experiment needs information about its relation to the magnetic field. Knowledge of satellite orientation also makes more directional, higher gain, and higher rate communications systems possible on the nanosatellite. To accomplish this goal Maia has 3-axis magnetotorquers used to orient the satellite spin axis in the appropriate orientation. It is our intention to use this system as an autonomous entity that has several modes of operation, some of which are de-tumble, spin parallel, and spin perpendicular. The de-tumble mode is a self-explanatory mode used after nanosatellite ejection into orbit. The spin parallel and spin perpendicular modes refer to the orientation of the satellite spin axis and the local magnetic field. Much of this system will be in-house, including the control algorithms, power supplies, and magnetometer sensing system. The magnetometers themselves are a supplied part. The source of the magnetotorquers is yet to be determined.

Commercial-Off-the-Shelf (COTS) and Consumer-Off-the-Shelf

Similar ideas, different scales

The differences between Commercial and Consumer are really a question of operation size and budget. To be a Commercial-Off-the-Shelf part it only needs to be "mass manufactured" and available for purchase as opposed to custom-built; there is no mention of price and/or mainstream availability of the parts. To be a Consumer-Off-the-Shelf part is really the same thing with the difference being that the part is truly mass-produced and there is mainstream availability of the parts. This difference becomes apparent when a university project sets out to budget for a mission and clearly sees two sets of COTS parts: those with vast flight heritage and large price tags and those with less heritage and a much lower price tag. This is one of the major driving forces behind university decisions in mission specifics, subsystem implementation, and system inclusion. It is our firm belief that these Consumer-Off-the-Shelf parts are viable, safe, useful options for space flight. Yet, they present their own challenges in that as these components become smaller and draw more power they also get hotter, without convection acting as a cooling mechanism, something must be done to keep components operating within their acceptable temperature ranges. This problem has several solutions, from clever board design to dissipate heat dumped by the component electrical contacts to possible heat conductive coatings over boards to help to disperse the heat.

Science Objectives

Ionospheric Measurements and Effects

The principal scientific purpose of the Maia mission is to characterize variations in the energetic charged particle environment in the topside ionosphere by measuring precipitating electrons (with energies > 1 keV) and ions (with energies > 50 keV) using state of the art sensors developed in recent years. A secondary purpose of our radiation instrument measurements will be to characterize the ionizing radiation environment to which our engineering and technology demonstration components are subjected.

Ionization produced in the ionosphere by precipitating energetic particles contributes the largest single unpredictable component of ionospheric density. While the solar UV and EUV induced component varies predictably, variations in the location and intensity of precipitating charged particle fluxes, driven by violent solar eruptions, are more difficult to model or predict. There is a need for operational monitoring of this energy flux into the ionosphere with simple, reliable detectors that can be strategically and globally located in near-earth space. Our science goal is to demonstrate that nanosatellites provide an inexpensive, easily deployable platform for such monitoring.

The science mission is not entirely novel or unique, as energetic charged particle detectors have been aboard many previous earth-orbiting scientific satellites, but instead focuses on the development and testing of solid-state silicon (Si) detectors in a new lower energy domain that has no prior space usage. While many Si detector telescopes have flown in space, most have cutoff detection energies around 30 keV for electrons and several MeV for protons. New technologies have come about in recent years that show promise for dropping the electron cutoff down to the range of a few keV. This new generation of detectors is important to the field of magnetospheric physics in that Si detector telescopes are reliable, low power, low voltage systems that can be packaged in a small volume. Electrostatic analyzers are most commonly used for electron detection below 30 keV. For operational monitoring the solid-state telescope might prove to be easier to manufacture and easier to implement than other low-energy detectors and could become widely used if they can be shown to detect electrons down to a few keV. As we move to constellations of satellites to characterize Geospace, there will be increasing demand for simpler sensor systems provided they have proven successful and functional. Maia will provide flight heritage to this new generation of detectors while showing that nanosatellites are viable platforms to test new technologies and to push the state-of-the-art in size, function, reliability, and cost.

Mission Requirements

What does it mean to succeed?

For Maia to be considered a success we have set out a list of success requirements for each objective associated with the mission. These requirements mandate the workings and design of the satellite. Table 1 has the highlights of the mission requirements. In general, Maia is a mission meant to be a proving ground for not only the nanosatellite but the Space Science and Engineering Laboratory (SSEL) at Montana State University as well.

Table 1 Selected mission objectives and associated requirements.

Objective	***Minimum Requirement***	***Full Requirement***
Mission lifetime	3 months	1 year
Solar wing deployment	Partial deployment	Full deployment
Science	One geomagnetic storm's data	Continuous coverage
Communications	Demonstrate 2-way communications	Clean link at 9600 baud
Attitude control	De-tumble control	Moderate spin-axis control

Educational Side of the Mission

Why should universities be building satellites?

Along the way to the completion of a successful mission for the Maia satellite is the goal of providing an experience for students that will give them a launch pad into the aerospace industry as well as valuable experience in a team project. The educational value cannot be overstated as Maia gives students a chance to see what is involved in the design and implementation of a project that will leave the Earth in order to collect data from both science and engineering missions. Maia has a continuous workforce of about 15 students and one faculty adviser, and has encompassed as many as 30 students at one time. Of those students only a few are graduate students, all of which are in non-aerospace programs, often at the expense of their thesis work. The Maia student pool comes from all aspects of the Montana State University campus. No student is unable to contribute and no student is turned away based on previous experience. Students from technical fields get funneled in to their respective subsystems and those from non-technical fields may require extensive training, but have made great contributions to the missions, systems, and educational environment. The question of why universities should be building satellites has an easy answer: when universities are building satellites the knowledge flows down from the industry professionals to the university faculty, students, and communities. Industries that want productive, capable employees look to universities that are producing students with experience in their field. Aerospace is no exception and as the number of universities with the capabilities to build satellite missions increases, so will the quality of the "professional" missions.

Conclusions

Build something and build it well

The Maia mission is neither amazing nor hugely complex, but was chosen to be valid, interesting, and possible to complete given our time frame, expertise, and budget. We believe that it takes time to build up aerospace heritage and that interesting, tractable missions are the way to progress. Maia is however a believable worthwhile, possible mission. Maia will meet of its requirements as well as the programmatic goals of the University Nanosat Program. The technology demonstrations involved in the mission will open the door for new technologies that will help shape the future of the satellite industry. The students that it trains will be the future satellite industry, and the Space Science and Engineering Lab will continue to move forward to bigger and better things.

This work supported through a grant from the Air Force Office of Scientific Research. The NASA Montana Space Grant Consortium is providing additional support.

Brian Larsen - Earned his B.S. in Physics and Mathematics in 2000 from Linfield College and his M.S. from Montana State University (2002). He is currently a Ph.D student in physics at Montana State University. Brian is the Maia project manager and is the one holding this whole thing together. He is trying (successfully?) to balance his duties to the mission his need to ski, climb, and bike.

Dr. David Klumpar - David Klumpar is a research professor and director of the SSEL lab here at Montana State. He received his B.A. in physics and mathematics at University of Iowa. He received his M.S. in physics from the University of Iowa in 1968. In 1972 he received his Ph.D in physics from the University of New Hampshire.

Mike Obland - Earned his B.A. in Physics and Mathematics in 2000 from the University of Montana. Currently he is a Ph.D student in physics at Montana State University. He is the MEROPE Project Manager. He is a consulting member of the Maia team. In his few moments of spare time, he enjoys outdoor activities including exercising, camping, and fishing.

Dr. William Hiscock - Bill Hiscock is a Professor of Physics at Montana State University and is also Director of the Montana Space Grant Consortium and the Montana NASA EPSCoR Program. He received his B.S. in physics from the California Institute of Technology in 1973. He received his M.S. (1975) and Ph.D. (1979) in physics from the University of Maryland. He enjoys hiking, biking, and flying.

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