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13. ABSTRACT (Maximum 200 Words) Montana State University students, faculty mentors, and collaborators, designed a microsatellite under the AFOSR/AFRL/GSFC/AIAA University Nanosatellite Program III. Major motivation for the project was to promote the educational development of students as engineers and scientists in space hardware and space systems engineering. Approximately 85 students participated in the project. The satellite will accomplish substantive scientific, engineering, and technological objectives including the first orbital test of several new technologies including new solid state charged particle sensors for science; a solar panel deployed via an Elastic Memory Composite deployment hinge developed under separate AFRL support to CTD, Inc of Lafayette, CO; the use of hybrid magnetoresistive magnetometer devices within an active magnetic three-axis attitude control system; and further application of consumer and COTS devices in the space environment. During the grant period the Maia satellite moved through initial design, design freeze, engineering design, prototyping, subsystem testing, and well into hardware fabrication. Strict adherence to proper design methodologies was enforced; internal and external design reviews took place; and a configuration management system was implemented ensuring adequate documentation of the design, and tracking of changes following subsystem design freeze. This final report updates progress subsequent to the two prior progress reports incorporated as appendices.				
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**The Montana Nanosatellite for Science, Engineering, and Technology
Solicitation Title: University Nanosat Program**

FINAL REPORT

Award Number: F49620-03-1-0195

April 20, 2006

This final report includes, in Appendix 1 and Appendix 2, two prior progress reports covering, respectively, the period from April 1, 2003 – August 31, 2003 submitted on September 29, 2003 and the period from September 1, 2003 – August 31, 2004 submitted on November 30, 2004. The period of performance for the entire grant covers the period from April 1, 2003 to March 31, 2005. The following section describes grant activities from September 1, 2004 through the end of the grant period on March 31, 2005. This entire package constitutes the Final Project Report.

Summary

Montana State University students, faculty mentors, and our collaborators, designed a microsatellite under the AFOSR/AFRL/GSFC/AIAA University Nanosatellite Program III. A major motivation for the project was to promote the educational development of students as engineers and scientists in space hardware and space systems engineering. Approximately 85 undergraduate and graduate students participated in the project. Additionally, the satellite will accomplish substantive scientific, engineering, and technological objectives including the first orbital test of several new technologies. New technologies incorporated in the satellite include 1) new solid state charged particle sensors for science; 2) a solar panel deployed via an Elastic Memory Composite deployment hinge developed under separate AFRL support to CTD, Inc of Lafayette, CO; 3) the use of hybrid magnetoresistive magnetometer devices within an active magnetic three-axis attitude control system; and 4) further application of consumer and COTS devices in the space environment. During the reporting period the Maia satellite moved through initial design, design freeze, engineering design, prototyping, subsystem testing, and well into hardware fabrication. Subsequent to the January, 2005 program "Flight Competition Review", the satellite was not selected by AFRL for flight development under the University Nanosatellite Program III. Processes and procedures adopted by the Montana State University design team included strict adherence to proper design methodologies; regular internal and external design reviews; and adoption of a configuration management system ensuring adequate documentation of the design, and tracking of changes following subsystem design freeze. This portion of the final report updates progress subsequent to September 1, 2004 and summarizes the final status at the end of the grant. Two prior progress reports that are incorporated herein as appendices 1 and 2 detailed activities from the beginning of the grant through August 31, 2004

Status of the Effort and Accomplishments

Flight review January 9, 2005

The Maia development team prepared and participated in the AFOSR/AFRL/GSFC/AIAA flight competition review held in Reno, NV on January 9, 2005 for the University Nanosat program. A total of six students and one faculty advisor made the trip to Reno to present the Maia satellite mission to the review panel. The Maia presentation focused on our successes and flyability as well as our well thought out, well documented mission. Maia was not chosen for continuation in that venue; however we are continuing the development of Maia on internal resources.

Continued fabrication

In the interval between September 1, 2004 and March 31, 2005 the Maia student team continued fabrication of hardware both to get ready for the January, 2005 flight review and for use in the eventual completion of the satellite. At the time of the Flight Competition Review (FCR) a complete flight prototype spacecraft structure had been built and integrated together and selected subsystems had been developed. The Nickel-Cadmium battery package had been entirely assembled in full compliance with Nanosat program safety requirements. The storage and deployment system for the communications antennas had been designed, built and tested. Power conditioning boards including DC-DC converters and the power regulation system had been designed, and prototype boards had been built and tested. At the time of the FCR, further work remained on the attitude determination and control electronics, although considerable progress had been made on the software control logic. RF transceivers had been built and were undergoing testing although some issues remained. The microprocessor and command and data handling system had experienced significant design and development, and prototype testing was in process.

The structural design was developed entirely by students at Montana State University using a design of their own invention. The spacecraft structure is designed to accommodate a reasonable amount of adaptability to other mission that might require a larger (or a smaller) spacecraft. This modular flexibility easily allows for the height of the spacecraft to grow or shrink to meet particular mission requirements by the use of a modular stacking central electronics bay that houses batteries, and both payload and spacecraft electronic subsystems. In the weeks leading up to the flight review our team produced detailed engineering bid packages, and worked with suppliers (machine shops) to procure all elements of the spacecraft skeletal structure. In the process, contracts were awarded to machine shops in 4 different states. Our engineering students interacted with our vendors, and successfully took delivery of the certified flight hardware components. To date the flight quality structural bus is complete and prototype systems exist for the attitude determination and control (ADCS), command and data handling (CDH), power, and communications systems. These systems continue to move forward toward a completed overall system. The systems are currently moving toward prototype system integration in a "flatsat" configuration.

The Maia satellite is shown in Figure 1 during an integration test with the Planetary Systems LightBand deployer system. The satellite integrated seamlessly to the Lightband during this test. No issues were uncovered.

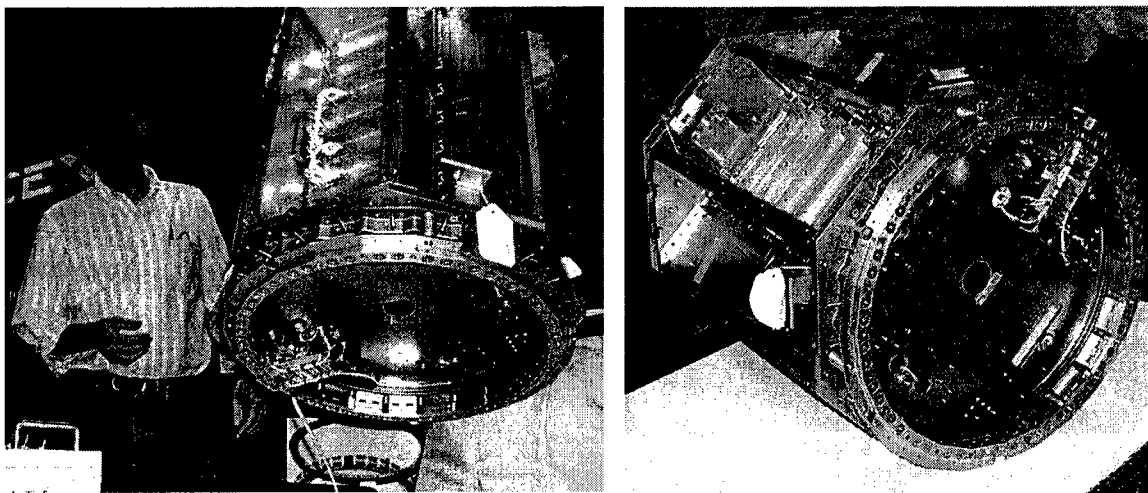


Figure 1 Maia Satellite integration and deployment test with Planetary Systems Inc.'s Lightband. Planetary Systems Inc President Walter Holemans observing.

Program's lasting impact on the aerospace industry

The undergraduate students on the Maia team have begun to graduate and move into aerospace jobs. We consider this to be a major strength of our program, particularly given that Montana institutions are not often thought of as suppliers of aerospace talent. Program students have left Montana State University for jobs with NavSea, Orbital Sciences, Boeing, Tethers Unlimited, MicroSat Systems, and others have chosen graduate school. Figure 2 shows a slide from the flight review showing the bulk of the Maia team and where many have moved on to after graduation. These students have proven to be capable and valuable employees at their respective companies.



Student Involvement

Partial list of students (Aerospace Employer)

- | | |
|--|---|
| • Brian Larsen – Physics – Grad student – PM | • Ame Mashburn – SOC – Undergrad |
| • TJ Sayer – ME – Graduated (MicroSat) | • Ross Carlson – EE – Undergrad |
| • Tim Orr – MET – Undergrad | • Calvin Coopmans – ECE – Graduated |
| • Sean Kim – EE – Graduated | • Chris Davenport – EE – Undergrad |
| • Keith Mashburn – Physics – Undergrad | • John Friedrich – ME – Undergrad |
| • Joey Moholt – CS – Undergrad | • Aaron Hanson – EE – Undergrad |
| • Heath Eldeen – CS – Undergrad | • Steve Jepsen – CE – Grad student |
| • Levi Junkert – CS – Undergrad | • Eric Kuntzelman – Physics – Undergrad |
| • Aaron Hall – CS – Grad student | • Loren Lee – EE – Undergrad |
| • Chris Stephani – ECE – Undergrad | • Rubin Meuchel – MET – Undergrad |
| • Ian Barnes – ME – Graduated (Tethers Unlim.) | • Ryan VanVoast – EE – Undergrad |
| • Jesse Parker – ME – Graduated (Grad School) | • Cody Pinion – ME – Graduated (NavSea) |
| • Tyler Brosten – ME – Graduated (Grad School) | • Dax Lavandoske – Physics – Graduated |
| • Alex Woidtke – ME – Undergrad | • Michael Schmidt – EE – Undergrad |
| • LeRoy Verwolf – CS – Undergrad | • Kyle Amstadter – ME – Graduated |
| • Shane Driscoll – ME – Undergrad | • Jay Evers – MET – Undergrad |
| • Jack Allison – EE – Undergrad | • Mike Stebbins – ME – Graduated (Boeing) |
| • Chad Bohannon – CS – Undergrad | • Charlie Keith – EE – Undergrad |
| • Sam Gardner – CS – Grad student | • Drew Eldeen – ECE – Undergrad |
| • Janet Glenn – ME – Undergrad | • Shannon Burtch – MET – Graduated |

Women and minorities

There have been about 60 students involved in the program in the past two years, several of which have moved into aerospace careers. Few to none would have gone into aerospace without this program.

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Figure 2 Selected slide from the Maia flight review presentation showing the Maia team and the place of employment of those who have left. Note Sean Kirn has since moved to Orbital Sciences Corporation.

Program's lasting impact on Montana State University

The University Nanosat program's lasting impact on Montana State University has been to develop a more professional setting sensitive to review and quality assurance issues. Future and new mission such as Electra (<http://www.ssel.montana.edu/electra>) have benefited from the structure taught by the University Nanosat program. These lessons will be long lasting and yield major improvements in the quality of the education and workmanship from Montana State University as compared to before our participation in the program.

Participants and Collaborators

Composite Technology Development, Inc (CTD) provided the technology test element that enables controlled deployment of the solar wing. CTD, located in Lafayette, Colorado, invented the Elastic Memory Composite hinge

named TEMBO®. This hinge is the basis of Maia's material/mechanism experiment to demonstrate the applicability of this technology to in-orbit deployables. CTD scientists and engineers have determined how to make shape memory polymers based on thermoset resin chemistry and how to reinforce these shape memory polymers with fibers to provide a dramatic increase in stiffness and strength while accommodating much higher strain. Spacecraft designers can use the EMC material in hinges or in other devices as a lightweight means of unfolding solar arrays and antennas in space without motors or springs. CTD is working aggressively to qualify the TEMBO® hinges and EMC material for spaceflight applications. The CTD team is led by polymer chemist and CTD President, Dr. Naseem A. Munshi, and chief engineer, Dr. Mark S. Lake, while the TEMBO® construction is led by Will Francis. The opportunity to include EMC hinges on the MSU nanosatellite to enable controlled deployment of a solar panel may provide a significant breakthrough for the EMC technology by providing the inaugural spaceflight.

CTD is a unique company that merges the development of innovative materials with the incisive engineering methods to provide customized solutions to its customers. Michael Tupper, Vice President, has provided MSU with TEMBO® hinges and hardware for the Maia mission. In addition, CTD is provided engineering expertise to integrate the TEMBO® hinges into MSU's nanosatellite.

Montana Tech in Butte, MT, a component of our sister institution, the University of Montana, and its Rocky Mountain Agile Virtual Enterprise Technical Development Center (RAVE TDC) provide another interesting educational aspect of the mission. RAVE TDC students have manufactured the battery box for Maia. RAVE TDC is a facility to train technology and engineering students in next-generation manufacturing practices using high-performance facilities by building actual parts under the supervision of Director Dr. Richard Donovan. This collaboration allows students at multiple institutions within the state of Montana to both design and build the Maia satellite as well as learn skills to be taken into the aerospace industry after graduation.

The Montana State University's Space Science and Engineering Laboratory (SSEL), directed by Dr Klumpar, is an interdisciplinary laboratory headquartered in the Physics Department at Montana State University, with close ties to the Electrical and Computer Engineering (ECE) and Mechanical and Industrial Engineering (M&IE) Departments at MSU. Ongoing projects with SSEL include The Multi Order Slitless EUV Spectrograph, a NASA supported sounding rocket that launched from White Sands in February 2006 to measure solar emissions in the He-304 line. Our very active (more than 30 flights in four years) high altitude balloon project provides rapid turn-around flight experiences for beginning engineering and science students. SSEL has experience in leading student teams in the development for flight of miniature satellites. The Montana EaRth Orbiting Pico-Explorer (MEROPE), a 1 kg satellite, has been under development for spaceflight in the SSEL for 36-months. This project receives primary support from the MSGC. The Maia satellite under development from this program has increased the knowledge of the lab greatly in a structured and mentored program.

The Maia nanosatellite followed naturally from the MEROPE program in many ways. It built upon the experiences gained from the past program and extended our management protocols while presenting a significantly greater engineering challenge. Student involvement in all aspects of the program, including project management, tracking and reporting as well as engineering, design, fabrication, and test have been a key element of our program and were greatly enhanced in the Maia project. Development challenges were faced and met with MEROPE. A brief comparison is included in Table 3. Those that were successful have been reapplied to Maia and lessons learned from Maia are being incorporated in our newest projects. For example, the satellite structure minimized design effort and machining set-up effort by utilizing a single common sidewall that was used for all four-side panels. One design and one machine set-up allows a CNC mill to build them almost automatically. Lessons learned from components that did not work so well will motivate us to look for improved solutions. As an example, early in the MEROPE design process we settled on a FIFO memory chip to store on-orbit data. This device has been replaced in the Maia design with RAM which allows significantly more flexibility. Maia construction, integration, and testing is providing new engineering challenges, which are being met with the same determination and insight as those in the design phase but with more experience.

	MEROPE (past project)	Maia (this project)	Capability Extension/Enhancement or challenge
Project management			
	Student led	Student led	
Major Reviews	PDR, CDR held internally	PDR, CDR, external participants	Formalize review process, involve external experts
Reporting	Internal	Internal and external	Formalize review process
Team meetings	Weekly	Weekly	Document meetings
Documentation	Subsystem Notebooks and web	Formalized documentation system	Formalized reporting procedures
Engineering			
Power system		5 v bus, commercial	
Attitude Control	Passive magnetic	Active magnetic	Develop capability to control spin axis, spin rate
Magnetometer	None	3-axis	For attitude knowledge and control
Science			
Sensor System	Geiger counter	Solid State Silicon device	Particle discrimination and energy discrimination
Technology Demonstrations			
Batteries	Li-Ion and NiMH	NiCad	Use the safe stable technology
Deployables	None	Solar wing deployed by Elastic Memory Composite Hinge	Adds engineering complexity and power
Sensors	None	Reduced energy threshold radiation sensors	Complicated design and implementation
GNC Sensors	None	Miniature low power magnetoresistive three axis magnetometer	To qualify for space flight newly developed sensor, and provide software control challenges

Table 3. Relationship of University Nanosatellite project (Maia) to previous program (MEROPE).

Student Involvement

A primary goal of the Space Science and Engineering Laboratory is to educate students with the technical knowledge necessary to succeed in an aerospace career by immersing them in hands-on satellite projects. To this end, students fill all subsystem leadership roles while faculty at Montana State University act only as mentors. Designs and trade-off decisions are made by students on the project, giving them an intimate view of satellite construction from conception, to launch, to on-orbit operations.

Students new to the lab or to satellite construction in general are taken in as volunteers and assigned to tasks that help them to understand one aspect of the satellite more thoroughly. Some assignments that have been performed or are planned include: supporting balloon launches for science experiments and subsystem testing, researching

possible new detectors for future missions, building sun sensors, familiarization with solar panels, and designing and modeling new structure shapes and sizes. Once the student is technically ready, they are moved to a position within a satellite subsystem according to their abilities and interests.

This system of training new students offers several advantages. First of all, the students perform much better with satellite construction after they have a deeper understanding of the limitations and design theories involved therein. Second, they can contribute to the success of the lab and future missions with the completion of the training task to which they are assigned, contributing to their feeling of "ownership" in the project, and in turn increasing student retention. This procedure has been extremely successful for the two years of the Maia program as indicated by the fact that over 85 students, coming from all different majors and interests, have worked in the lab. During summer 2004 (and again during summer 2005) a crew of ~20 students worked on the satellite as their summer project. Physics, engineering, and math students have contributed to the satellite, and art and business students have found a place on the team as well. Upon graduation students trained in the Space Science and Engineering Laboratory have found employment and internships with prestigious institutions and companies such as NASA, Los Alamos National Laboratory, Tethers Unlimited, MicroSat Systems, Jackson & Tull, and Orbital Sciences Corporation (See Table 3). SSEL will continue to strive to interest and train students of all backgrounds in space science and the aerospace industry.

In addition to our own MSU students, undergraduate at other institutions are becoming involved. During summer 2004, Dan Schwendtner, an undergraduate physics student at Augsburg College in Minneapolis participated in the design of the Maia ADCS system through our Research Experience for Undergraduates (REU) program. Dan developed, designed, and tested a prototype of Maia's sun sensor. As previously mentioned, students from Montana Technical University in Butte, Montana are machining parts for the Maia satellite. Two students from Salish Kootenai College on the Flathead Indian Reservation have been participating in an SSEL space engineering project since June 2004. We make more opportunities available to students beyond MSU through internship programs. Two students participated in SSEL laboratory activities in 2005 and two additional openings are currently available through our Solar, Space, and Astronomy REU program for summer 2006.

Project Management

One major element of any mission is project management. This presents extra difficulties in a university setting where there are distractions not present in a government or industry setting. These distractions include classes, outside internships, and other extracurricular activities. To successfully manage students to achieve an overall unified goal is a challenge, but a rewarding one.

Completing a satellite and meeting a mandated deadline with primarily student labor is a challenge and requires careful planning and project management if it is to be accomplished. With the Maia final design taking form the students are split into subsystem teams according to their interests and abilities. Subsystem teams handle the details of individual subsystems aboard the satellite and in support of it. They include power, payload, structure and attitude control, thermal control, communications, ground support equipment, computer hardware and software, and business and public outreach. Each team manages the intricacies of their system while working closely with other teams and reporting to the Project Manager. An organizational chart of the management structure is shown in Figure 3 below.

Management and Subsystem lead positions are reserved mainly for graduate students and veterans of SSEL projects. Placing graduate students in charge has proven to be vital in maintaining continuity and efficiency in a project of this magnitude. Graduate students have a lighter course load and are at the university specifically to do research projects such as Maia; therefore it is more likely that they will have the time and commitment to see a project through from start to finish on schedule. Finally, to manage the problem of undergraduate student schedules, finals, course loads, vacations, and turnover, several rules have been instituted in the SSEL. All students begin as temporary volunteer workers, and only those who prove they have a lasting interest in the undertaking are hired on for academic credit or stipends. Most students therefore stay with the lab longer, reducing turnover. Also, students who are hired for stipends or credit cannot simply drop out of the program when their schedule becomes busy; they are committed for at least a full semester. An effort is made to hire as many students as possible to work through the summer when they are typically undistracted by classwork and final exams. While working, documentation is

stressed as a critical component to any successful engineering endeavor. Students are required to submit monthly progress reports, keep logs updated and readily available, disseminate information to other team members through a master email list, and attend meetings and design reviews to diversify knowledge throughout the team. It is the goal of these rules to ensure that there is always more than one student intimately knowledgeable on each subsystem, so that in the event that a student leaves the project, they will not take irreplaceable information with them. These rules and organizational methodologies work together to maintain stability and a feasible schedule on a student-operated project.

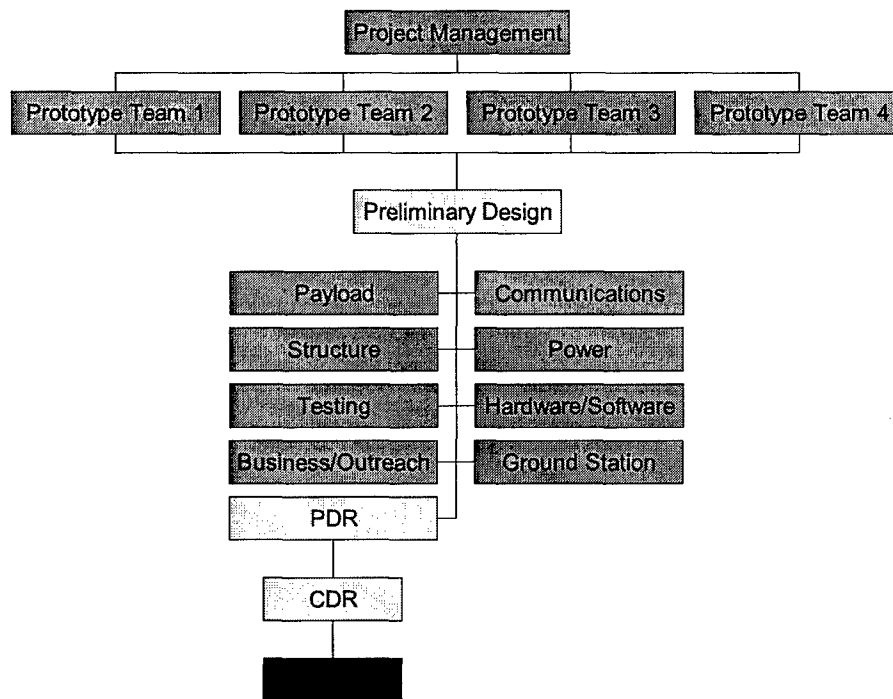


Figure 3 Project management scheme. Prior to Preliminary Design Concept four teams independently developed prototype concepts. Following adoption of a concept at Preliminary Design eight subsystem teams were formed to design, fabricate and test the satellite.

K-16 Outreach

The Space Science and Engineering Laboratory attaches a high degree of importance to educating students and the public about satellites and space science, and to that effect, has instituted a number of public outreach educational programs. Due to this previous experience, much of the infrastructure facilitating a public outreach program for a new satellite mission is already in place. For the MEROPE project, team members disseminated information to students at the K-12 and college levels, university faculty and visitors in a number of ways. Dozens of public lectures have been given since January 2001, primarily to K-12 students. High school physics classes were visited in Montana and Oregon, public talks were given to pre-elementary school children and their parents, and several middle school groups across the state of Montana enjoyed previous MEROPE and Maia presentations.

The outreach does not however end with high school; at the college level, members of the MEROPE and Maia teams have introduced several physics and engineering classes to the opportunities available with the project and have also given introductions to the lab to visiting students from Native American tribal colleges in the state. Lectures about the exciting science and technology aspects of student satellite construction are not only offered by the Space Science and Engineering Laboratory students, but also by the Space Public Outreach Team (SPOT) project operated by the Montana Space Grant Consortium (see <http://www.montana.edu/~wwwmsgc/Text/SPOT.html>). Students involved with this program present a variety of topics concerning space science and exploration free of charge to interested groups in Montana.

The Space Science and Engineering Laboratory's Maia project maintains a student-constructed website containing information about the mission and space science for all levels of browsers (see <http://www.ssel.montana.edu/maia>). Technical information on the construction of the satellite is becoming more available. Explanations of the motivation for the project, and scientific data is available.

As can be seen, the Space Science and Engineering Laboratory places high value on public outreach and will continue to do so with future satellite projects. The precedent that has been set for giving regular public lectures, school visits, and SPOT programs will remain. Students will continue to improve and fill in the web site and a promotional effort will be undertaken allowing students to come up with an original acronym for Maia, receiving a certificate from the web site to signify that they participated in Montana's second satellite.

Space Operations Center

The space operations of Maia are also important; SSEL maintains a ground station for use to the MEROPE mission. Students will perform tracking, telemetry, and on-orbit operations for Maia. It is the goal of Maia to involve the amateur radio (Ham) community as much as possible in the operations, data gathering, and design. This relationship with the amateur radio community greatly increases understanding and knowledge about RF communications and communications systems, as well as development of new and interesting technologies for our students.

Maia's on-orbit operations can then occur primarily from MSU as well as partner institutions around the country or world.

Students will have primary responsibility for assessing the on-orbit performance of the satellite and will publish the results of our experiences in the engineering literature in addition analysis of the scientific data will be carried out by students, and the results published in appropriate peer-reviewed journals.

APPENDICES

APPENDIX 1: First Annual Progress Report submitted September 29, 2003

Pages 11-14

APPENDIX 2: Second Annual Progress Report submitted November 30, 2004

Pages 15-20

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ANNUAL PROGRESS REPORT

Award Number: F49620-03-1-0195

**"The Montana Nanosatellite for Science Engineering and Technology:
The University Nanosat Program"
Montana State University**

**D. M. Klumpar
September 29, 2003**

Objectives

Montana State University students, faculty mentors, and our collaborators, are designing, a microsatellite under the AFOSR/AFRL/GSFC/AIAA University Nanosatellite Program. While a major motivation for the project is to promote the educational development of students as engineers and scientists in space hardware and space systems engineering, the satellite will accomplish substantive scientific, engineering, and technological objectives including the first orbital test of several new technologies.

Our scientific goals are to measure variations in energetic charged particle fluxes in the Earth's Geospace environment using recently developed solid state detectors that allow lower energy thresholds than solid state telescopes have previously achieved in space. Ionospheric ionization produced by energetic particle precipitation, which can vary by orders of magnitude during solar induced storms, has undesired effects on space systems. Characterizing these ionospheric disturbances is the scientific objective.

We will make extensive use of engineering experience gained from our MEROPE picosatellite (a 1 kg CubeSat-class student satellite) to extend engineering challenges for the students in a sensible and measured direction. Among the new technologies are 1) new solid state charged particle sensors; 2) deployment of a solar panel through the first space application of an Elastic Memory Composite deployment hinge developed under separate AFRL support to CTD, Inc of Lafayette, CO; 3) the use of solid state magnetoresistive magnetometer devices as part of an active magnetic three-axis attitude control system; and 4) the further application of consumer and COTS devices in the space environment.

The program is student-based. University students assume all major roles in the program, including project management, tracking and reporting as well as engineering, design, fabrication, test, and on-orbit operations. Students create all designs and make all decisions, with mentoring and guidance from project faculty and industry mentors. This systems engineering experience is of great value to the students involved, going far beyond the usual classroom and lab procedures of the usual engineering curriculum. Ideally, individual students follow the program through the entire design-build-fly-operate cycle, obtaining direct experience in space systems engineering far beyond that offered in traditional curricula.

The program includes an outreach component to make pre-college students aware of career paths in space science and space engineering and to inspire the interest of such students, as well as the general public.

Status of the Effort and Accomplishments

A multidisciplinary group of students was assembled to begin developing the mission concept and initial conceptual designs in mid-February. Three teams of 11 undergraduate students each were formed at this time to develop alternative conceptual designs. These student teams reported the results of their individual concept designs on March 26, 2003 during a formal Concept Design Review. The three concept designs were evaluated with respect to their ability to meet the mission requirements, their maturity, manufacturability, and engineering soundness. This phase of the program gave each student a broad understanding of the challenges and provided an opportunity for each student to demonstrate his capabilities. The strongest elements of each design then became the basis for a team-wide development phase that has continued to the present time in various stages.

On April 14, our student team participated in a System Concept Review in the form of a telecon/power point presentation with representatives of the Nanosat-3 government team. This review gave our students their first opportunity to vet their concept design to an outside team of professionals and represented the kick-off for the detailed preliminary design phase of the project. Beginning in mid-April a concerted design effort was initiated by the student team. The team was divided into subsystem

development subteams that held regular subteam meetings and design work sessions to flesh out the design of their respective systems. To ensure that systems engineering issues were not overlooked, weekly meetings of the entire design group were held throughout the period. This activity culminated in the Preliminary Design Review in Logan Utah on August 15th. Preliminary design of most major elements of the satellite has been completed. At the present time, following PDR, the team will be spending the next several months performing further research and preparing proof of concept models for all subsystems and components. These proof of concept models consist of computer analysis, simulations, and simple prototypes. To date prototyping has begun on the transmitter, receiver, and modem.

Our program is on schedule. The milestone schedule for the project is shown below.

<i>Item</i>	<i>Approx. Beginning Date</i>	<i>Approx Ending Date</i>
Maia design phase begins	15 Feb 2003	1 Oct 2003
Group design phase	15 Feb 2003	15 Mar 2003
Move design to a PDR ready design	15 Mar 2003	1 Aug 2003
Move design to a CDR ready design	1 Aug 2003	1 Jan 2004
Prototyping & Engineering model construction	1 Oct 2003	15 Dec 2003
Engineering model end-to-end functional test	15 Dec 2003	15 Mar 2004
Flight subsystem construction	15 Mar 2004	1 Jun 2004
Flight subsystem integration	1 Jun 2004	1 Sept 2004
Satellite testing (functional, thermal, vacuum, shake)	1 Sept 2004	1 Feb 2005
Maia is ready to fly		1 Feb 2005

Table 1. Design and construction schedule for the Maia mission with a two-year time between design and delivering a ready to fly satellite.

Personnel Supported

Student Involvement

Our research program is characterized by direct hands-on involvement by university students in the design, fabrication and test of space flight hardware. Students take major responsibility for all aspects of the program, working in an interdisciplinary team environment to overcome complex engineering challenges. Over 40 university students have been involved directly in the University Nanosat-3 Program. During each term (spring, summer, and fall) the number of undergraduates actively working in on the Maia student satellite project have numbered between 10 and 15.

Since February 2003, the student team involved in the design of the Maia satellite has numbered as many as 30 students at once. This past summer an active group of about 16 students were preparing for the Preliminary Design Review that was held in Logan Utah on August 15th. Five of the undergraduate students involved in the Maia student satellite project were awarded competitive undergraduate scholarships during summer 2002.

One graduate student, Mr. Brian Larsen is the program manager for the Maia project. He has major involvement in directing the undergraduate team.

The University Nanosat project has spawned Senior Design projects in both Electrical and Computer Engineering (ECE) and the Mechanical Engineering Departments at MSU. During the spring semester, in ECE, Cal Coopmans performed a design project on the use of hybrid magnetoresistive magnetometer sensors to explore a satellite attitude determination system, and four students in ECE (Ross Carlson, Tim Bennett, Spencer Mullen and Lars Rasmussen) designed a magnetotorquer control system. A team of three Mechanical Engineering students (Cody Pinion, Ian Barnes, and Joseph Hughes) did an engineering study as a Senior Design Project to design a deployable solar array wing for use on a microsatellite. This fall semester, mechanical engineering students Ian Barnes and Cody Pinion are continuing the design of the deployment mechanism under ME470, Individual Problems; and the magnetotorquer control system team is doing an ECE Senior Design project to build a demonstration ADCS system. A third group of students, taking ME403 Senior Design, is investigating the design of an antenna storage and release mechanism. In addition to the formal classroom activities described above, several students are receiving academic credit in Undergraduate Research through the Physics Department and several other students are receiving direct part time pay for their work on the Maia project.

Publications

The following papers have been published in conference proceedings.

"The Montana Nanosatellite for Science, Engineering, and Technology for the AFRL/NASA University Nanosat Program", B. Larsen, D. M. Klumpar, M. Obland, and W. Hiscock, Paper number SSC03-IX-4, to be published, Proceeding of the 17th International AIAA/USU Smallsat Conference, August 11-14, 2003, Logan, UT.

Interactions

Through this project several students have been exposed to and participated in professional interactions with industry and government personnel. In March a project team traveled to Boulder and Denver, CO to facilitate planned and future collaborations with space industry professionals in the Denver-Boulder Area. MSU travelers were Res. Prof. David Klumpar, Physics Graduate student, Brian Larsen, and Mechanical Engineering seniors Ian Barnes, Joe Hughes, and Cody Pinion. Special emphasis for this trip was to establish relationships with mechanical engineering experts in structures, thermal analysis, loads analysis, and composite deployables. The group met with technical staff of Composite Technology Development, Inc. Lafayette, CO. CTD is a materials company with special interest in the application of new materials, particularly fiber-reinforced shaped memory polymers, as space deployment devices. We plan to use their "Elastic Memory Composite Hinge" as a potential test device for deploying a solar wing on the Maia satellite. This product, recently trade-named Tembo, may well experience it's first use in space on MSU's Maia satellite, and CTD is very excited to be working with us.

During this trip our team also visited Starsys Research, a company that specializes in the design, development, and manufacture of: solar array drives, antenna pointing systems, motor control electronics, deployable structures and cover systems, satellite separation systems, "Smart" passive thermal control systems, battery bypass switches, and a wide variety of actuators, hinges, latches, and pin pullers. We met with engineers Scott Christiansen (VP of Engineering) and Jeff Harvey (structural engineer with expertise in solar panels) to discuss potential collaboration and the design of latch and release mechanisms for small satellite deployables. Starsys has an active and ongoing collaboration with CTD. The majority of our afternoon at Starsys was spent in a conference area with the above individuals, as well as others. Again our student engineers described their concept designs and, as each concept was discussed and critiqued by the local experts, we gained valuable insight into the issues that will have to be addressed before a robust design is in place. Starsys is willing to provide engineering design consultation with us as our concepts mature into engineering design. Since they are experts in the design and manufacture of space mechanisms, this presents an incredible opportunity to have the guidance of some of the best minds in the business.

During this trip we also visited the Lockheed Martin Astronautics, facility south of Denver, CO. Lockheed Martin Space Systems Company - Astronautics Operations is one of the major operating units of Lockheed Martin Corporation. Space Systems designs, develops, tests and manufactures a variety of advanced technology systems for space and defense. Chief products include space launch systems, ground systems, interplanetary spacecraft, other spacecraft for commercial and government customers, fleet ballistic missiles and missile defense systems.

Another significant interaction with Aerospace industry professionals took place in August when a team of 7 MSU students accompanied Dr. Klumpar to the 17th Annual AIAA/USU Conference on Small Satellites in Logan Utah. This annual meeting is the most significant gathering of Aerospace personnel interested in Small Satellites in the world. Our students participated in extensive discussions with conference attendees. Our group set up and manned a display booth describing our space hardware projects, we attended the technical sessions, and MSU graduate student Brian Larsen presented a formal paper at the conference on our Maia University Nanosat project. Immediately after the conference our team participated in the Preliminary Design review for the UN-3 program in Logan, Utah. The full PDR presentation is incorporated by reference in this progress report, and may be downloaded from our web site at:
http://www.ssel.montana.edu/maia/ppt/msu_pdr.ppt

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13. ABSTRACT (Maximum 200 Words) Montana State University students, faculty mentors, and our collaborators, are designing, a microsatellite under the AFOSR/AFRL/GSFC/AIAA University Nanosatellite Program. A major motivation for the project is to promote the educational development of students as engineers and scientists in space hardware and space systems engineering. Additionally, the satellite will accomplish substantive scientific, engineering, and technological objectives including the first orbital test of several new technologies. Among the new technologies are 1) new solid state charged particle sensors; 2) deployment of a solar panel through the first space application of an Elastic Memory Composite deployment hinge developed under separate AFRL support to CTD, Inc of Lafayette, CO; 3) the use of solid state magnetoresistive magnetometer devices as part of an active magnetic three-axis attitude control system; and 4) the further application of consumer and COTS devices in the space environment. The Maia satellite has progressed through initial design, design freeze, engineering design, prototyping, subsystem testing, and is currently well into hardware fabrication. During this process strict adherence to proper design methodologies has been enforced. Both internal and				
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PROGRESS REPORT

Award Number: F49620-03-1-0195

**"The Montana Nanosatellite for Science Engineering and Technology:
The University Nanosat Program"**

Montana State University

**D. M. Klumpar
November 30, 2004**

Objectives

Montana State University students, faculty mentors, and our collaborators, are designing, a microsatellite under the AFOSR/AFRL/GSFC/AIAA University Nanosatellite Program named Maia. While a major motivation for the project is to promote the educational development of students as engineers and scientists in space hardware and space systems engineering, the satellite will accomplish substantive scientific, engineering, and technological objectives including the first orbital test of several new technologies.

Our scientific goals are to measure variations in energetic charged particle fluxes in the Earth's Geospace environment using recently developed solid state detectors that allow lower energy thresholds than solid state telescopes have previously achieved in space. Ionospheric ionization produced by energetic particle precipitation, which can vary by orders of magnitude during solar induced storms, has undesired effects on space systems, both manned and robotic. Characterizing these ionospheric disturbances, and the highly variable near-earth radiation environment are the scientific objectives.

We have made extensive use of engineering experience gained from our MEROPE picosatellite (a 1 kg CubeSat-class student satellite) to extend engineering challenges for the students in a sensible and measured direction. Among the new technologies employed on Maia are 1) new solid state charged particle sensors; 2) deployment of a solar panel through the first space application of an Elastic Memory Composite deployment hinge developed under separate AFRL support to Composite Technology Development, Inc (CTD) of Lafayette, CO; 3) the use of solid state magnetoresistive magnetometer devices as part of an active magnetic three-axis attitude control system; and 4) the further application of consumer and COTS devices to the space environment.

The program is student-based. University students assume all major roles in the program, including project management, tracking and reporting and configuration management, as well as engineering, design, fabrication, test, and on-orbit operations. Students create all designs and make all decisions, with mentoring and guidance from project faculty and industry mentors. This systems engineering experience, in an interdisciplinary environment is of great value to the students, taking them far beyond the usual classroom and laboratory procedures of the typical engineering curriculum. Ideally, individual students follow the program through the entire design-build-fly-operate cycle, obtaining direct experience in space systems engineering far beyond that offered in traditional curricula.

The program includes an outreach component to make pre-college students aware of career paths in space science and space engineering and to inspire the interest of such students, as well as the general public.

Status of the Effort and Accomplishments

The Maia satellite program began in February 2003 with a multidisciplinary group of students developing the mission concept and initial conceptual designs. Three teams of 11 undergraduate students each were formed at this time to develop alternative conceptual designs. These student teams reported the results of their individual concept designs on March 26, 2003 during a formal Concept Design Review. Following this review the three concepts were used to form the basis for design of the Maia satellite. Since March, 2003 the Maia satellite has progressed through initial design, design freeze, on most subsystems, engineering design, prototyping, subsystem testing, and is now well into hardware fabrication. During this process strict adherence to proper design methodologies has been enforced. Both internal and external design reviews have taken place. A configuration management system has been put into place ensuring adequate documentation of the design, and tracking of changes following subsystem design freeze. This second annual report summarizes the progress on the project during the period 1 September, 2003 to 31 August, 2004.

Detailed technical details are covered in this report by reference. Substantial design details were contained in our Critical Design Review package, delivered to AFRL/NASA in early August, 2004 and presented at the International SmallSat Conference August 8-12, 2004 in Logan, Utah. The entirety of that design review package is available on the web.

Document 1 is a 239 page set of powerpoint slides that describe the satellite system:

<http://www.ssel.montana.edu/maia/ppt/Maia-CDR-Presentation-1.pdf>

The second, 337 page document, contains detailed back-up material representing a complete discussion of the design and its status as of August, 2004.

<http://www.ssel.montana.edu/maia/ppt/maia-cdr-1.pdf>

During the fall semester, September through December, 2003 students continued to refine their subsystem designs, and perform the necessary compromises to ensure compatibility as elements of an overall system. Weekly team meetings ensured that everyone was on the same page.

On October 16-17, 2003 three of our students participated in the Satellite Fabrication Course offered at AFRL Albuquerque. The students brought back considerable insights on dos and don'ts for satellite hardware development including soldering techniques, ESD protection, cabling and harnesses, and general laboratory practice. They have conveyed much of this new-found knowledge other members of the satellite development team. Two of the three remain with the project at the current time.

On January 16, 2004 several students from the Maia student design team participated in the Nanosat-3 program's Subsystem Design Review (SDR) in Herndon, VA. The purpose of the SDR was to review each satellite mission, subsystem by subsystem, to uncover any issues in the current design. At this review we presented our current satellite design and demonstrated operation of a student designed/built antenna deployment system, utilizing memory metal springs for actuation. This prototype made a good showing and was well received among reviewers and other universities. There were approximately 50 successful deployments of this prototype. However, shock testing showed a fundamental flaw in that this prototype system, as designed, was vulnerable to self deployment as a result of physical shock. The same student design team then revised the antenna deployment mechanism to its current and final state, as shown in Figure 1. Subsequent thermal functional tests on the mechanism, between -40C and +150C, and a battery of shake tests have further demonstrated its robustness.

As mentioned above, full team meetings are held each week throughout the year. These meetings provide an opportunity for all students to become fully aware of progress taking place on each subsystem. While individual students typically have primary responsibility within one subsystem, it is critically important that each student has general familiarity with the entire system. At these meetings brief progress reports are given by each student subsystem lead. The particular focus of these communications is current status, identification of issues and their resolution, and impacts on the system or other subsystems. In addition individual subsystem teams, typically consisting of four to eight students, also hold regular (typically weekly) subsystem focus meetings.

In the time between January and the next formal program review, Maia was pushed forward by our student team working toward the final flight design. The primary objective for the period from January through May, 2004 was to achieve design freeze on all

subsystems. To this end, our weekly team meetings, typically of one-hour duration, were expanded to encompass subsystem design reviews that generally lasted two to three hours. Each subsystem, in turn, prepared a detailed briefing covering their design tradeoffs, current status, and the actions required to reach design freeze. Reviewers included the other students on the project, as well as local outside experts. The students mostly achieved their milestone, with about 80% of the subsystems reaching the mid-May design freeze. For those subsystems reaching design freeze, further changes in the design and build are being tracked through our configuration management system.

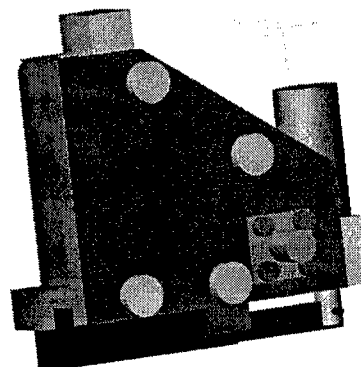


Figure 1. Final Maia antenna assembly ready for shake testing. The door (purple) houses a spring steel antenna that is coiled up inside. As the solenoid in the rear (orange) fires the clasp (red) is actuated which releases the door and allows the antenna to escape. The clasp is designed to be balanced front to rear to alleviate unwanted deployment from shock loading.

Along with the development of the space segment, a concurrent development has led to the establishment of our Satellite Operations Center. This facility consists of a satellite tracking station on campus with computer-controlled fully articulated antennas for receiving data from and uplinking commands to satellites on the 2m and 70 cm bands (amateur and adjacent frequencies). In addition to the antennas the system consists of all the hardware and software necessary to track satellites, uplink and downlink data, acquire and store the data and analyze the results. The ground segment became operational in June 2004.

During the summer, 2004, intense effort was expended to mature the detailed designs. Further analysis was carried out on subsystem behavior. Subsystem prototyping took place on critical systems to establish performance baselines. The system design matured substantially and a complete design package was assembled and submitted in preparation for the Program Critical Design Review in August (referenced on page 2).

During the AIAA/USU Small Satellite Conference (Week of August 9th Logan, UT), the program had its Critical Design Review. Our team presented our design and progress to the reviewers and received many helpful tips and design critiques. We have implemented many of these changes and are pushing much of the satellite into construction. Many of the structural components are out for manufacturing bid, with many more to follow soon. The flight versions of the antenna are constructed. All the other systems are building prototype design tests as well as debugging final designs looking to move into construction.

The final satellite design is a right octagon about 18" across and 18" tall. This octagon is made up of a central stack of dual purpose structural electronic boxes that carry the shear loads within the satellite. Extending from the central stack are wings to both hold the tension and compression within the satellite as well as to increase the surface area of the satellite for body mounted solar arrays as shown in Figure 2.

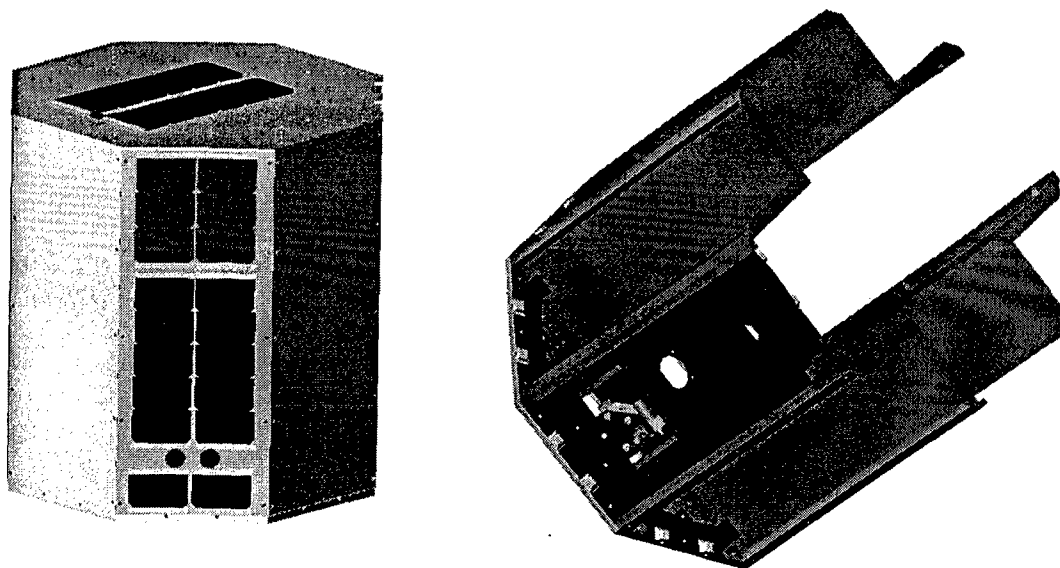


Figure 2. Solid model views of the Maia nanosatellite. The view on the left shows the outside of the satellite and schematically where solar arrays will be located, each side panel will be covered and the panel on top is deployed on orbit. The view on the right shows in the inside of Maia. Seen are the beacon antenna pointing out the bottom of the satellite, the battery box (red), the structural wings (purple), and the baseplate (green/yellow) which serves as the mounting plane for the launch vehicle as well as the main structural platform.

Our program is on schedule to deliver an Engineering Design Unit (EDU) to the review panel at the Flight Competition Review January 9th, 2005 in Reno NV. The milestones from the past year and the upcoming 6 months for the project are shown below.

<i>Item</i>	<i>Approx. Beginning Date</i>	<i>Approx Ending Date</i>
Subsystem design review	16. Jan. 2004	
Incorporate design changes; hold subsystem design reviews	16. Jan. 2004	1. May. 2004
Move design to CDR ready	1. May. 2004	1. Aug. 2004
Complete Ground Station and initiate satellite tracking	1. September. 2003	8. June. 2004
Critical Design Review	9. Aug. 2004	12. Aug. 2004
Finalize designs	12. Aug. 2004	1. Oct. 2004
Construction	12. Sep. 2004	10. Nov. 2004
Integration	10. Nov. 2004	1. Dec. 2004
Testing	1. Dec. 2004	15. Feb. 2004

Table 1 Major phases, milestones and reviews in the past year of Maia development.

Personnel Supported

Student Involvement

Our research program is characterized by direct hands-on involvement by university students in the design, fabrication and test of space flight hardware. Physics, engineering, and math students have contributed to the satellite, and art and business students have found a place on the team as well. Students take major responsibility for all aspects of the program, working in an interdisciplinary team environment to overcome complex engineering challenges. Over 80 university students have been involved directly in the University Nanosat-3 Program. During each term (spring, summer, and fall) the number of undergraduates actively working in on the Maia student satellite project have numbered between 10 and 25. Upon graduation students trained in the Space Science and Engineering Laboratory have found employment and internships with prestigious institutions and companies such as NASA, Los Alamos National Laboratory, Tethers Unlimited, MicroSat, and Jackson & Tull. SSEL will continue to strive to interest and train students of all backgrounds in space science and the aerospace industry.

Over the course of the project, the student team involved in the design of the Maia satellite has numbered as many as 30 students at once. This past summer an active group of about 18 students were preparing for the Critical Design Review that was held in Logan Utah on August 9th. Five students traveled to the design review which afforded them the opportunity to both discuss their work with experts, but also to gain more insight into what this satellite business is really all about.

One graduate student, Mr. Brian Larsen is the program manager for the Maia project. He has major involvement in directing the undergraduate team.

The University Nanosat project has spawned Senior Design projects in both Electrical and Computer Engineering (ECE) and the Mechanical Engineering Departments at MSU. During the Fall semester, in ECE, Aaron Hanson and Chris Davenport performed a design project to develop a low power high efficiency radio beacon. Another group of students investigated the design of an antenna storage and release mechanism as shown in Figure 1. In addition to the formal classroom activities described above, several students are receiving academic credit in Undergraduate Research through the Physics Department and several other students are receiving direct part time pay for their work on the Maia project.

In addition to our own MSU students, undergraduate at other institutions are becoming involved. During summer 2004, Dan Schwendtner, an undergraduate physics student at Augsburg College in Minneapolis participated in the design of the Maia ADCS system. Through our Research Experience for Undergraduates (REU) program. Dan developed, designed, and tested a prototype of Maia's sun sensor. Students from Montana Technical College of the University of Montana in Butte, Montana are machining parts for the Maia satellite. Two students from Salish Kootenai College on the Flathead Indian Reservation have been participating in an SSEL space engineering project since June 2004. We continue to strive to make more opportunities available to students beyond MSU through the University Nanosat program. Two student openings are currently available through our Solar, Space, and Astronomy REU program for summer 2005.

Publications

The following papers have been published in **conference proceedings**.

"The Montana Nanosatellite for Science, Engineering, and Technology for the AFRL/NASA University Nanosat Program", B. Larsen, D. M. Klumpar, M. Obland, and W. Hiscock, Paper number SSC03-IX-4, to be published, Proceeding of the 17th International AIAA/USU Smallsat Conference, August 11-14, 2003, Logan, UT.

Interactions

Through this project several students have been exposed to and participated in professional interactions with industry and government personnel. Most notably has been our continued interaction with Composite Technology Development, Inc. Lafayette, CO. CTD is a materials company with special interest in the application of new materials, particularly fiber-reinforced shaped memory polymers, as space deployment devices. We plan to use their "Elastic Memory Composite Hinge" as a potential test device for deploying a solar wing on the Maia satellite. This product, recently trade-named Tembo, may well experience it's first use in space on MSU's Maia satellite, and CTD is very excited to be working with us.

Students have also been experiencing what it means to finish a part that has been designed, get it out for bid, have the construction done and returned in a timely fashion.

Another significant interaction with Aerospace industry professionals took place in August when a team of 5 MSU students accompanied Dr. Klumpar to the 17th Annual AIAA/USU Conference on Small Satellites in Logan Utah. This annual meeting is the most significant gathering of Aerospace personnel interested in Small Satellites in the world. Our students participated in extensive discussions with conference attendees. Our group set up and manned a display booth describing our space hardware projects, we attended the technical sessions. The display booth was the center of the program Critical Design Review (CDR), where reviewers would come and interact with the students about the technical issues and questions involved in the satellite. The full CDR packet can be found at:

<http://www.ssel.montana.edu/maia/ppt/Maia-CDR-Presentation-1.pdf>

<http://www.ssel.montana.edu/maia/ppt/maia-cdr-1.pdf>