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14. ABSTRACT

The purpose of this final report is to provide a summary of the University Nanosat 4 Program's AggieSati. Nanosat 4 was a joint program among AFOSR, AIAA, NASA GSFC, and AFRL/VS. The objectives of the program were to educate and train the future workforce through a national student satellite design and fabrication competition, and to enable small satellite R&D, payload development, integration, and flight test. Nanosat 4 had two distinct stages. The first part was a design and build phase involving 11 Universities, which lasted two years and culminated in the AIAA Student Satellite Flight Competition in March 2007. The competition winner was to be integrated with the AFRL Internal Cargo Unit (ICU) for flight on the Space Shuttle. The second part consists of construction and test of the flight unit and culminates in launch of the Nanosat. The selected Nanosat from Cornell is expected to be flight-ready by September 2007.

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AggieSat1
FA9550-05-1-0350
Final Report to AFOSR
Spring 2007

Part of the AFOSR / AIAA / NASA GSFC / AFRL/VS University Nanosat 4 Program, the objectives of Texas A&M University System's AggieSat1 were to 1) implement and demonstrate a highly responsive satellite architecture and 2) provide a positive and relevant student experience, and encourage a diverse group of young people to pursue careers in aerospace. This final report details our design and our student program in support of the objectives.

I. Introduction

MULTIPLE interests within the United States, including the Department of Defense (DoD), NASA, Universities, and industry have an interest in using small satellites to perform space experiments, demonstrate new technology, and test operational prototype hardware. In addition, the US Aerospace community is currently experiencing a shortfall in systems engineering experience among its workforce. In an effort to address these two issues, the Air Force Research Laboratory's Space Vehicles Directorate (AFRL/VS), in conjunction with AFOSR, AIAA, NASA GSFC, STP, DARPA and 19 US Universities, has implemented the University Nanosat Program. Begun in 1999, the University Nanosat Program is sponsoring the development and launch of university designed and built nanosatellites. The universities are pursuing creative, low-cost space experiments to research and demonstrate nanosatellite technologies.

The PI for AggieSat1 was the PI for the University Nanosat 1/2 Program's Three Corner Sat (3CS) mission while she was still at Arizona State University (ASU). ASU, the University of Colorado at Boulder, and New Mexico State University collaborated on 3CS. Two of the three 3CS satellites were launched as a constellation on the EELV Heavy Demonstration mission in December 2004. The Multi-Satellite Deployment System (MSDS)/Nanosatellite system was attached to a pedestal that mounted to the side of the heavy demo mass simulator satellite atop of the Delta IV. The MSDS successfully deployed from the demonstration satellite. The individual Nanosatellites were then to be separated via two low-shock separation systems: the Planetary Systems Corporation Lightband, and the Starsys Research Corporation CBOD system, but this was not confirmed because the Delta IV 1st stage cut off too early and satellites were delivered to a much lower than anticipated orbit and were never contacted.. The 3CS science experiments and technology demonstrations consisted of a micropropulsion experiment, low-cost COTS communications, imaging, distributed and automated operations. As well, many lessons learned in implementing a student-satellite program were gained.

3CS attached to DemoSat for launch on Delta IV Heavy Dec 22, 2004

The purpose of this final report is to provide a summary of the University Nanosat 4 Program's AggieSat1. Nanosat 4 was a joint program among AFOSR, AIAA, NASA GSFC, and AFRL/VS. The objectives of the program were to educate and train the future workforce through a national student satellite design and fabrication competition, and to enable small satellite R&D, payload development, integration, and flight test. Nanosat 4 had two distinct stages. The first part was a design and build phase involving 11 Universities, which lasted two years and culminated in the AIAA Student Satellite Flight Competition in March 2007. The competition winner was to be integrated with the AFRL Internal Cargo Unit (ICU) for flight on the Space Shuttle. The second part consists of construction and test of the flight unit and culminates in launch of the Nanosat. The selected Nanosat from Cornell is expected to be flight-ready by September 2007.

II. Scientific and Technical Nanosat Plans and Objectives

The scientific and technical objective of AggieSat1 was as follows and relevant to Air Force missions

- implement and demonstrate a highly responsive satellite architecture

As per the Mission Statement, AggieSat1 was to operationally test technologies for enabling future Responsive Space Missions (RSM). To facilitate these missions a spacecraft must have a manageable control scheme and streamlined interfacing. This is to ensure that dissimilar components can be integrated, tested, and operated with minimal impact. The AggieSat1 team identified the following mission objectives for RSM and developed software and hardware solutions to meet these objectives:

- test streamlined build process that would use pre-manufactured and pre-tested subsystems.
- test technology supporting a streamlined integration and test phase prior to its attachment to the launch vehicle.
- test technology supporting autonomous logging and control of satellite from launch vehicle separation to completion of the mission.

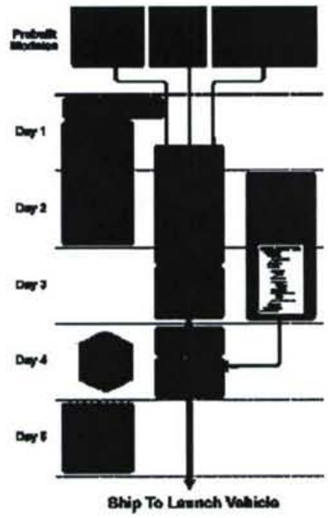
The AggieSat1 team developed the first version of its software package called the Mission Based Intelligent and Control System (M-BICS) to handle high level commands of a rapidly integrated system. It has the following features:

- An abstracted data hierarchy to allow a generalized computing system to handle dissimilar functionality among integrated components/modules.
- Control drivers distributed with dissimilar components/modules to allow rapid assimilation of new devices and functionality to the system.
- Use of the Universal Serial Bus (USB) standard to carry data. This facilitates easier integration and communication between components/modules.

The AggieSat1 team also began development of a test model for a hardware standard that allows ease of physical integration in addition to our control scheme. Its features include:

- Standardized module envelopes for spacecraft subsystems and payloads that define volume, mass, and other tolerances to facilitate successful integration.
- Connector and cabling standards using the DB9 connector interface to simplify wire harness design.
- A model bus class that incorporates standardized hull patterns, reconfigurable layouts, and options for external access for modules.

The techniques the team developed can be expanded and refined in the future to enable truly Responsive Space Missions. This future would see spacecraft standards approved and developed in a manner similar to the computer industry. This would allow various vendors to develop usable modules, subsystems, buses, and command and control systems that could be integrated on fairly short notice and launched. Our ideal integration flow is shown:



III. System Description

This section details the most important features of our design in support of the objectives. This design was entirely student generated from lessons learned on our ASUSat1 (launched in January 2000 on the first Orbital/Suborbital Program Space Launch Vehicle "Minotaur"; Friedman et al. [2002]) and 3CS (launched in December 2004 on the Delta IV Heavy Demo). AggieSat1 was designed to operate within low Earth orbit (LEO) for any inclination. It was hexagonal shaped, with a mass no greater than 30 kg, and fit inside the envelope of a right cylinder with a diameter and a height of 18.7 inches. The top, bottom, and all of the side panels were to be covered with GaAs solar cells mounted on faceplates. The bottom panel was to have a bolt pattern to accommodate the Lightband separation system. All other S/C components were to be mounted inside the primary structure. S/C subsystems included attitude and orbit determination and control (AODC), communications (Comm), command and data handling (C&DH), the electrical and power subsystem (EPS), and structures, mechanisms, thermal, and radiation (SMTR).

C&DH: AggieSat1 used the MIP405 Power PC computer board for onboard command and data handling. The MIP405 is manufactured by MPL in Switzerland and has been selected to fly onboard ISS experiments in the LEO environment.

Operating System: LINUX w/ USB support.
Primary Control Software: M-BICS Large
Backup Software M-BICS Small
Operating Power: 3.5 W
Disk Space: 2 Gigabytes

M-BICS runs in a Linux environment onboard the MIP405. M-BICS loads and stores all its supporting software and drivers on the computer in a flash module. A client software applet allows user access into M-BICS, either through Ethernet on the ground for integration and test, or via the COMM system and USB lines on orbit.

M-BICS and the RSM system developed by the AggieSat1 team were to go through a staged test program on orbit that started with minimum success and built up to the nominal objectives. Minimally AggieSat1 was to prove M-BICS ability to boot up, load the drivers for all the extended modules, and survive for 24 hours thereafter in an idle state on orbit. In this idle state M-BICS was to be responsible for monitoring temperature and power and acting to make sure that these stay within defined parameters. A mission rule book and rule logic were to be implemented in M-BICS to govern this period of operations. Nominally, and after the ground team was satisfied with the 24 hour test period, M-BICS was to be given payload tasking and asked to complete items within allotted windows. M-BICS was to have the authority to decide when to run these payload tasks. M-BICS was to be evaluated on its ability to successfully manage power resources and communications windows to complete the assigned tasks.

EPS: The AggieSat1 Electrical Power Subsystem was designed to work in conjunction with the CDH system to provide data and power to the spacecraft. M-BICS data, sent from CDH, was to be routed through a USB hub in the EPS system, added with power lines, and routed to the various subsystems in the spacecraft. A 12 Cell Ni-Cad battery box was to supply stored power to the system and this was to be replenished by 144 solar cells mounted on the surface of the spacecraft.

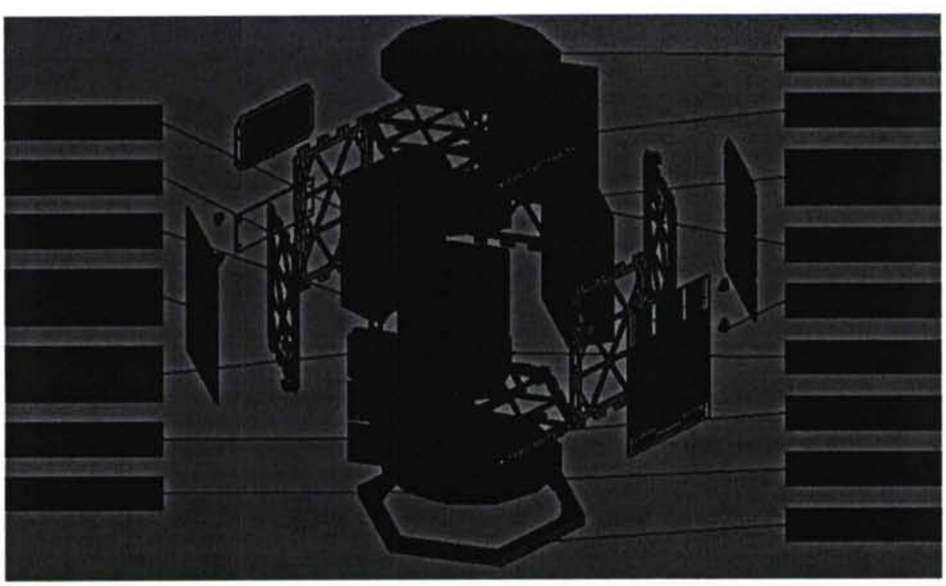
COMM: The AggieSat1 communications subsystem was based on the Kenwood TH-D7A handheld amateur radio and was similar to what was flown on 3CS. Two radios were to be flown, with one always being the receiver and the other the transmitter. An onboard Terminal Node Controller (TNC) was featured in these radios to allow packet data transmission.

Downlink: 2 Meter Band, Near Amateur
Uplink: 70 Cm Band, Near Amateur
Baud Rate: 1200 Bps
Transmit Power Draw: 6 Watts
Idle (Receive) Power: 1.32 Watts

Communications from the ground were to be accomplished by a PC running a Windows environment with the M-BICS interface client. This was to be run in through a standard Terminal Node Controller Modem and in conjunction with an orbit propagator and Doppler tuning equipment.

SMTR: The structures, mechanisms, thermal, and radiation subsystem consisted of the basic S/C structure, deployable mechanisms (antennas), mountings, and thermal and radiation control for AggieSat1. The primary load bearing structure was an aluminum 6061-T6 isogrid frame as shown below. Internal components were to be mounted to the isogrid structure on any of the available surfaces. Side panels were designed to be removable for maximum flexibility in handling and testing. Solar cells were to be mounted on facesheets attached to the top, bottom, and side surfaces of the structure. All fasteners and structural materials were to be selected from the approved safety list. Analysis was conducted to verify the response of the structure to the static and dynamic envelopes of the Shuttle. This design was predicted to meet all safety requirements for the Shuttle and was predicted to survive launch and deployment. COSMOS Works simulation showed a Lowest Factor of Safety (FOS) of 4.1 in the X axis direction under 20g load. (2 FO is the requirement). The spacecraft first mode frequency was predicted to be 156 Hz (100Hz is the requirement). Survivability and a valid FOS under a 30g shock load have been proven.

Thermal control was delegated to be the responsibility of the individual pre-made modules and analyzed by SINDA/G simulations. It is always ideal if thermal control can be successfully accomplished by passive means – black paints, MLI (multi-layer insulation), and so forth.



Demonstration experiments: To demonstrate the utility of our RSM architecture, three experiments were to be flown in module boxes –

- Bio-Fuel Cell (BFC)
- Shape Memory Alloy (SMA)
- Free Molecule Micro-Resistojet (FMMR)

Bio-Fuel Cell (BFC): With the strong National interest in bio/nano systems for space applications especially by NASA, AggieSat1 involved the development of a new capability: a low-cost, generic yet flexible, nanosatellite testbed for rapid evaluation of and to learn about the response of such systems to the space environment. The current facility for bio research is the International Space Station, however the costs can be in the 10s of millions of dollars and the lead time can be years. Ground testing does not feature the complete space environment including the combined effects of radiation, micro-g, thermal cycling, and violent launch, deployment, and on-orbit events. It is necessary to learn about these systems on orbit. Additional challenges for the AggieSat1 team included cleanliness, long shelf storage prior to launch, and determining clever and meaningful measurements to make to characterize our experiments and transmit to Earth.

This mission was to demonstrate the utility of our bio-sat by the following experiment: space verification of a bio fuel cell, or BFC. The basic idea was to use a biological method to generate electricity from glucose & oxygen via bacteria. Radiodurans, a radiation resistant bacteria, which can survive under continuous high dose radiation, oxidize glucose and transfer electrons to a platinum electrode. Another type of bacteria, ferrooxidan, obtains electrons from Fe^{2+} and a cathode platinum electrode. Protons moving through a nafion membrane (proton permeable membrane) are essential for continuous power generation.

The mission profile was to be the following:

- BFC module comprised of 8 individual cells
  - Packaged in 4 sets, 2 cells per set
- Each set of cells linked to 1 kΩ test load
  - Measure voltage across load, use collected data to create "state-of-health" fingerprint
  - Data taken at 5 Hz
- Control/measure temperature during experiment
  - 4 temperature sensors measure temperature
  - Data taken at 1 Hz
- BFC tested over wide range of radiation environments on ground
  - Expected total radiation dose based on orbit determined
- Experiment run over the course of the entire mission
  - 1 set of cells run every "x" number of days (based on orbit lifetime)
  - Data for all sets of cells compared to determine if any degradation to performance over lifetime of experiment

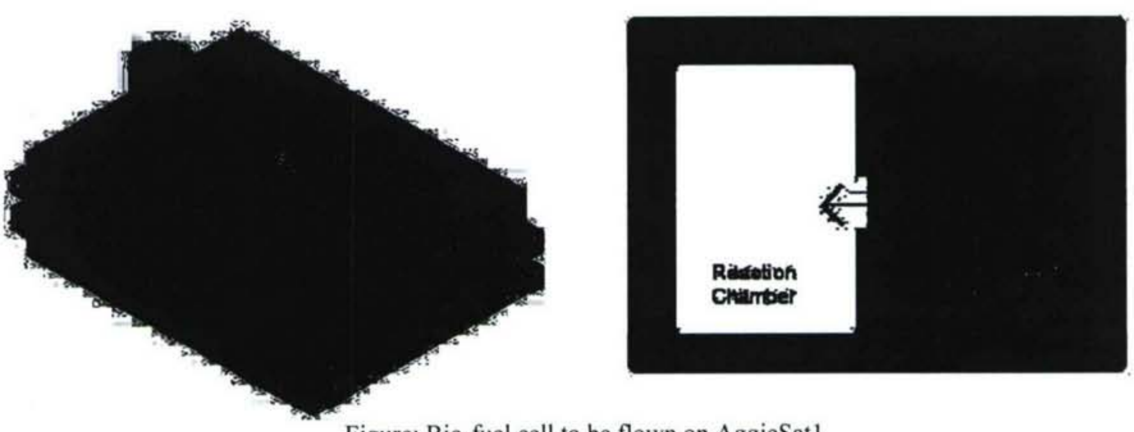


Figure: Bio-fuel cell to be flown on AggieSat1

Shape Memory Alloy (SMA): The next revolution in air travel and space exploration depends on our ability to dramatically reduce mass, size and power consumption of aerospace vehicles while increasing reliability. The key is integrating intelligence and multifunctionality into the varied components of aerospace systems and vehicles.

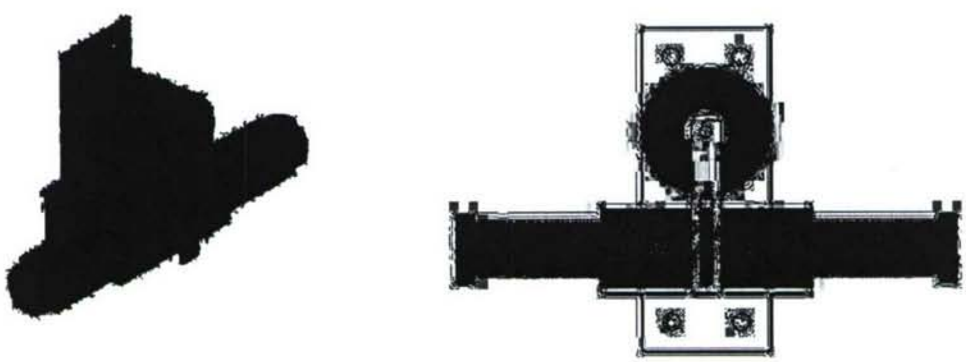
The Texas Institute for Intelligent Materials and Structures (TiiMS) was established in 2002 as one of the seven 5+-year NASA URETI (University Research, Engineering and Technology Institutes) programs and is a collaboration among Texas A&M University (lead), Prairie View A&M University, Rice University, Texas Southern University, the University of Houston, the University of Texas at Arlington, and NASA LaRC. The main focus of TiiMS is to develop and advance the nano and biotechnologies that enable our vision of adaptive, intelligent, shape-controllable micro and macro structures, for advanced aircraft and space systems. Revolutionary materials, structures and subsystems are sought to embody sensing, adaptability, self-monitoring, fault-tolerance, self-healing and autonomy to provide the functionality and intelligence for the needs of NASA aerospace missions.

Shape Memory Alloys (SMA) have the advantage of being the highest energy density actuators (actuation energy per unit mass) from the existing active or smart materials and they are suitable for high force/high stroke and low frequency applications. Due to their high energy density they are very attractive for space systems as actuation devices. Several SMA devices have already been designed and used in space for satellites, while their miniaturization is currently the key challenge. Companies such as StarSys have developed SMA devices and in collaboration with National Labs and Universities have tried to design new SMA systems for nano-satellites. Texas A&M University, and in particular TiiMS and STC have been involved with such design efforts, especially through a collaboration with APL. In discussing possibilities for implementing an SMA driven actuator on the proposed nanosatellite AggieSat1, trade studies now suggest pointing an instrument such as a camera. This would be of great benefit to space exploration in that gimbal mechanisms could be replaced by systems with much fewer moving parts.

For AggieSat1, the following was to be the mission:

- The SMA mechanism was to move a piston to five different positions.
    - Points determined during model testing on ground.
    - Verification: Linear position of sufficient accuracy for 1° pointing accuracy. (Roughly .3 mm linear accuracy required)
    - Additional goal: Cycle testing, 25 and 50 cycles.

The main challenge was determined to be temperature management on orbit, and this was to be monitored.



SMA device to be flown on AggieSat1

Free Molecule Micro-Resistojet (FMMR): AggieSat1 teamed with Dr. Andrew Ketsdever and his colleagues at AFRL Edwards Air Force Base and the University of Southern California (USC) toward the integration and demonstration of a Micro-Electro-Mechanical Systems (MEMS) micropropulsion system, the Free Molecule Micro-Resistojet (FMMR). Details are available from Dr. Ketsdever and his student Riki Lee (2004).

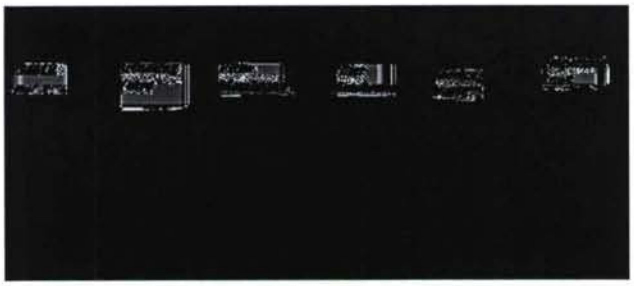
The majority of proposed nanosatellite missions require means by which constellations are formed, altitude is changed, attitude is changed, and orbits are maintained. Therefore, micropropulsion can be mission enabling for nanospacecraft missions. MEMS technology offers several advantages for micropropulsion systems. First, a large degree of miniaturization is possible with current MEMS fabrication techniques which can begin to accurately fabricate feature sizes on the order of a few microns. A high degree of miniaturization allows for the possibility of high thrust to mass ratios for propulsion systems. Second, a large degree of integration is possible between the thruster and its components such as valves, regulators, and the propellant feed system. Finally, MEMS fabrication requires the use of silicon or silicon derivatives such as silicon carbide or silicon nitride. These materials typically possess very high yield strengths important for pressurized systems such as propulsion components.

The FMMR was a MEMS fabricated electrothermal propulsion system designed by AFRL Edwards and USC for on-orbit maneuvers of nanospacecraft. Electrothermal propulsion defines a class of thrusters that heat propellant molecules electrically. In the case of resistojets, the propellant flow is heated by passing it over an electrically heated solid surface In high pressure operation, a fraction of the propellant molecules are heated by direct impact with the high temperature surface while the remaining flow is heated by intermolecular collisions. However in the FMMR, which operates at very low stagnation pressures, the molecules are heated only by direct interaction with a surface held at elevated temperature since intermolecular collisions are negligible. (Low-pressure operation also reduces MEMS valve leakage and reduces propellant storage tank mass.) For AggieSat1, the propellant was to be water vapor and the system was to be verified by planned and predictable attitude changes. In particular, a spin or de-spin was to be imparted to ASUSat3, and the produced thrust measured by change of angular rate of ASUSat3 about its spin axis. About 1 mN of thrust was expected.

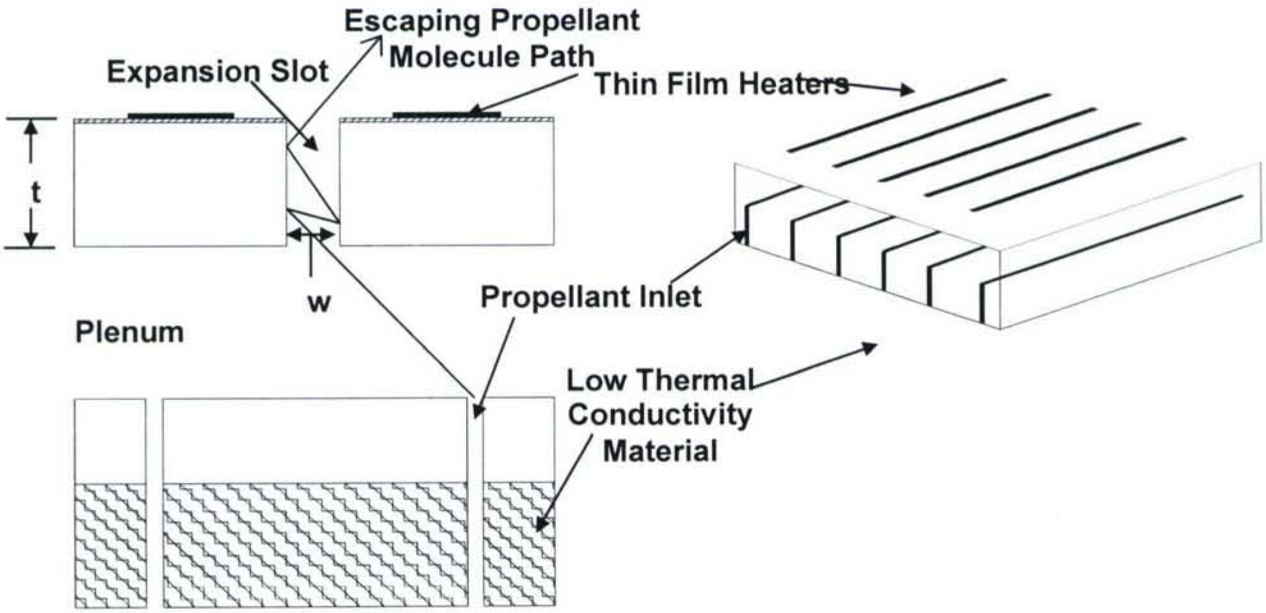
As shown conceptually below, the propellant gas (water vapor for AggieSat1) was to enter the FMMR stagnation chamber through propellant inlets that are connected to the propellant tank through a MEMS valve and filter assembly. The device was to operate at unusually low pressures giving the propellant gas molecules a mean free path on the order of the expansion slot width. Energy was to be imparted to the propellant gas through collisions with the expansion slot walls maintained at an elevated temperature prior to exiting the device. The FMMR operation and performance was to rely on the transfer of energy into the propellant gas through molecular collisions with the heated expansion slot surfaces. For electrothermal devices, the thrust varies linearly with the operating temperature while the specific impulse goes with $T^{1/2}$. Therefore there is a limited benefit to increasing the operational temperature of a resistojet with a practical limitation caused by material properties.

The FMMR used a heated slot configuration, which was chosen for its design simplicity (low-cost testing and elimination of single-point failures) and minimal fabrication cost. These design benefits came at the cost of increased power consumption to heat a rather large surface area compared to optimized designs. The FMMR thrust chip was fabricated from a 500 μm thick silicon chip with a silicon oxide layer that acted as an electrical insulator between the silicon substrate and a vapor deposited thin film heater. For flight operation of the FMMR, parametric studies indicated that an operating temperature of 600 K for the heater chip was optimum. This tended to maximize the use of power for a given specific impulse (approximately 70 sec).

The FMMR heater chip (i.e. not a fully operational thruster) flew on 3CS in late 2004. The heater chip is the most vital component of the FMMR micropropulsion system's success. 3CS satellite Ralphie had two FMMR chips mounted on a machined Teflon plenum. The plenum was mounted on the outside of a bottom bulkhead with 2 bolts. The chip measured approximately 13 mm x 42 mm and was primarily made of a silicon nitride coated silicon wafer. One primary difference between the 2 chips is that one had its backside (exposed to space) completely coated with gold, and the other exposed the silicon nitride layer. Different chip surfaces were being used to characterize them under differing surface temperatures. Even though the chips were to be given the same amount of power, the difference in emissivity would cause the surface temperatures to be different. Each chip weighed about 0.5 grams. The chips were to be tested by measuring temperature and current. These data sets would have allowed the MEMS chips to be characterized for future use in a FMMR unit. See Wong et al. (2000, 2003).



FMMR microthruster system (Ketsdever and Lee 2004)



FMMR concept (Ketsdever and Lee 2004)

IV. Program

TAMUS undergraduate and graduate students were responsible for all aspects of the satellite program, including: concept, design, fabrication, integration, testing, launch support, flight operations, AND program management. Student leaders and team members will be identified for SMTR (Structures, Mechanisms, Thermal, and Radiation), AODC (Attitude and Orbit Determination and Control), EPS (Electrical Power System), COMM (Communications), PAY payload interface with UCLA and TAMU, PM (Program Management), SE (Systems Engineering), Shuttle Safety, I&T (Integration and Test), GSE (Ground Support Equipment), QA (Quality Assurance), and CM (Configuration Management). Students from 18 different majors (20 from the 6 disciplines of Business) were active on the team. Over 100 students participated.

The kickoff meeting with the Air Force was held on March 16, 2005, the System Concept Review was on May 6, 2005, SHOT I (Student Hands-On Training via a high altitude balloon) was held on June 8-11, 2005, and the Preliminary Design Review was held on August 11-12, 2005. A Delta PDR was held on October 11, 2005 with the Air Force. The team successfully passed Critical Design Review on April 12, 2006 in a 7am – 5 pm meeting with the Air Force. Eight TAMUS students participated in the AFRL-/Colorado Space Grant Consortium-sponsored

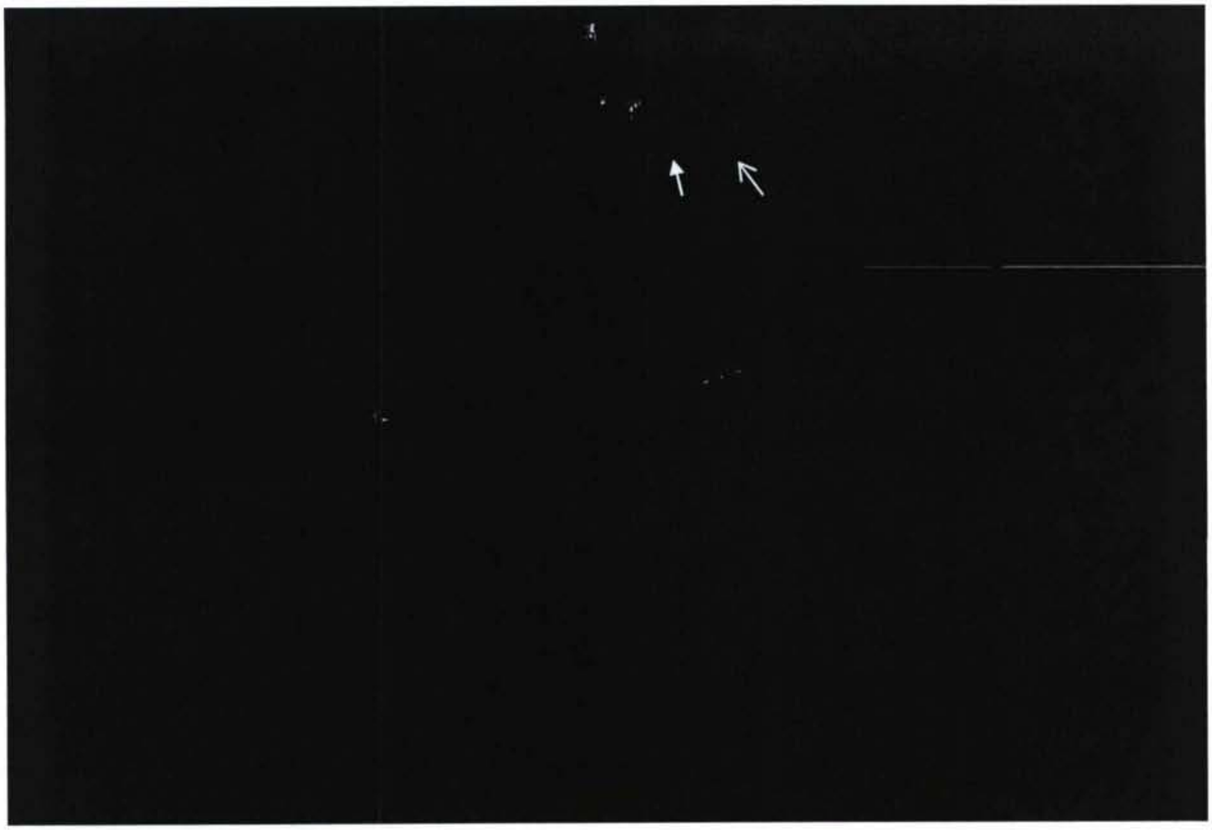
SHOT I workshop. The students learned valuable design and fabrication skills and devised a simple experiment. The experiment was launched by high-altitude balloon to 100,000 feet and then recovered. The device survived the launch, and the TAMUS team won best design. SHOT II (Student Hands-On Training via a high altitude balloon) was held in June 2006, and the PQR (Prototype Qualification Review) was held August 14-17, 2006, at the AIAA/USU Small Sat Conference in Logan, UT. Fifteen students presented to the Air Force, industry, and NASA on their progress. The team delivered prototype systems to the Air Force 26-27 March 2007 at the Flight Competition review. Even though Cornell was selected to be the team that flies, many lessons learned are feeding forward to our next Nanosat mission - a successful proposal was submitted to the Air Force for the AggieSat team to begin AggieSat3 with the University Nanosat 5 Program, and the System Concept Review is 20 April 2007.

When first introduced, the concept of AggieSat Lab and building a real satellite AggieSat1 were brand new to students at Texas A&M and the past two years has been a time of growth and learning. AggieSat Lab has now given students a frame of reference and feel for satellite programs, and developed a core of experienced students prepared to lead future student teams. Students have gained initial prototype experience and confidence critical for building future systems. Moreover, the Lab has developed a baseline strategy and concept for reusable, expandable, and responsive command and data handling in future satellites that is attractive for building on previous missions as well as implementing the research of other faculty and our partners.

In an effort to develop human resources, AggieSat Lab is implementing a multidisciplinary Junior Engineer / Senior Engineer Certificate Program. The direct goals and incentives are to promote creativity and increase productivity within an academic environment. With industry input into the requirements, the emphasis is on exposing students to all underlying aspects of spacecraft engineering, systems engineering, communication, management, and leadership

Texas A&M students participate in a Team AggieSat Integrated Concurrent Engineering session

Participation in these programs will also teach students the concept of Integrated Concurrent Engineering (ICE), which is used by NASA and several other engineering companies. Based on practices currently implemented by Team-X at the Project Design Center at the Jet Propulsion Laboratory, Team AggieSat incorporates a real-time collaborative process in which a multidisciplinary team of students approaches each design or analysis problem through the use of network-linked analysis tools. Databases built into the tool capture design iterations and trade space research providing a central location for updating and capturing the corporate knowledge of the lab. In addition, the analysis tool facilitates the mentoring of less experienced students by emphasizing the need for system-level cognizance by all participants and by providing a forum for multidisciplinary discussions. This process stresses the importance of communications and knowledge of the system or subsystem for which you are assigned. During the time spent within these programs, students will participate in multiple design sessions in which a set of requirements will be delivered to them from which they will have to make sound engineering judgments based on experience and data provided from the corporate knowledge of the program. Students will have the opportunity to assume multiple roles for the design iteration experience. This will give them a chance to learn engineering skills as well as gain experience in the business segment (cost justification, personnel management, program management, and so forth).



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HELEN LOUISE REED

Professor and Head
Aerospace Engineering
Texas A&M University
helen.reed@tamu.edu

Education:

Ph.D.	Engineering Mechanics	Virginia Polytechnic Institute	Dec. 1981
M.S.	Engineering Mechanics	Virginia Polytechnic Institute	June 1980
A.B.	Mathematics	Goucher College	May 1977

Career Experience:

Dec. 2004-present	Texas A&M, Professor and Head, Aerospace Engineering
Aug. 1985-present	Arizona State University (ASU)
Jan. 2005-present	Emeritus Professor, Mechanical and Aerospace (MAE)
July 2003-Aug. 2004	Vice Chair for Graduate Programs, MAE
July 1992-Dec. 2004	Professor, MAE
Dec. 1994-Dec. 2004	Associate Director, ASU / NASA Space Grant Program
Aug. 1993-Aug. 1996	Director, Aerospace Research Center
Aug. 1985-June 1992	Associate Professor, MAE
Sept. 1991-June 1992	Associate Professor, Tohoku Univ., Sendai, Japan
Sept. 1982-Aug. 1985	Assistant Professor, Mechanical Engineering, Stanford
June 1977-Dec. 1981	Aerospace Technologist, NASA/Langley Research Center

Research:

Hypersonic/supersonic flow; nanosatellite design; autonomous rendezvous & docking; responsive hardware and software architectures; unmanned aerial systems (UAVs/MAVs). Recent work:

- ASUSat1: 6-kg student nanosatellite; ***launch*** Jan. 26, 2000 on 1st Air Force OSP SLV.
- Three Corner Sat: Part of Air Force's University Nanosat I/II Program and joint among ASU (lead), CU Boulder, NMSU; ***launch*** Dec 22, 2004 on Delta IV Heavy demo.
- ASUSat3: Part of the Air Force's University Nanosat III Program. Ended Jan. 2005.
- AggieSat1: Part of the Air Force's University Nanosat IV Program. Ended Mar 2007.
- MIMIC: Nationwide students design satellite to measure magnetic field at Mars. Science from Mars Exploration Program Assessment Group. Piggy-back: 2011 NASA Mission. Ended.
- SubSEM/SEM: In June 2000, 5 students ***launched*** Orion sounding-rocket mission out of NASA Wallops. In August 2001, STS 105 ***launched*** ASU's STARS for local K-12 students.
- AZeroG: 4 teams of undergrads have flown microgravity experiments on the KC-135.
- ASU CanSat: Students build soda-can-sized "spacecraft" to launch by amateur rocket.
- ASU BalloonSat: Student experiments on high-altitude balloons. Spin-off for Arizona K-12 inservice teachers and their students. Video on NASA Channel Dec. 29, 2003.
- Moon Devils: 11 years in Moon Buggy Race at NASA Marshall. In 1999, NASA video with ASU as focus for NASA Channel and Visitor Centers. Several Best Design awards.
- Design of laminar-flow wings for DARPA Quiet Supersonic Platform program. With Lockheed Martin, Northrop Grumman, NASA-Dryden, NASA-Langley.
- Stability of hypersonic boundary layers on reentry vehicles, with Sandia and AFOSR.

PRINCIPAL PUBLICATIONS (SELECTED RECENT AND RELEVANT):

- "The University Microsatellite as Micropropulsion Testbed," Wong, Reed, Ketsdever, *Micropropulsion for Small Spacecraft, AIAA Progress in Astro & Aero* 187, 25-44, 2000.
- "ASUSat1: Low-Cost Student Nanosatellite," Friedman, Underhill, Ferring, Lenz, Rademacher, Reed, *AIAA Journal Spacecraft Rockets* 39, 5, 740-748, Sept.-Oct. 2002.
- "ASUSat Lab: Student Projects in Aerospace", Reed, *Invited, AIAA 01-0583,* Jan. 2001.
- "Numerical Modeling of Free Molecule Micro-Resistojet Prototype and Next Generation Designs Evaluation," Wong, Ketsdever, Reed, *Invited, AIAA Paper 03-3581*, Jun. 2003.

- "ASUSat Program: Lessons Learned of University Satellite Program and Its Contributions to Aerospace Community," Allison, Egan (Students), Reed (Faculty), 1st in Team Division, Western Regional, AIAA Student Competition, Apr. 2003, Seattle.

AWARDS:

AIAA /ASEE J. Leland "Lee" Atwood Award, bestowed annually upon an aerospace engineering educator in recognition of outstanding contributions to the profession, 2007
Fellow, American Physical Society, Sept. 2003
Fellow, American Society of Mechanical Engineers, Jul. 1997
Excellence in Service Award, ASU Alumni, Founders' Day, Mar. 12, 2003
Distinguished Mentor of Women Award, Faculty Women's Association, ASU, Apr. 17, 1996
Outstanding Graduate Faculty Mentor, Graduate College, ASU, 1994-95
Teaching Excellence Award in Undergraduate Category, Engineering, ASU, 1993-94
Professor of the Year, Pi Tau Sigma, ASU, 1988-1989
AIAA Excellence in Teaching Award, ASU, Fall 1988
Faculty Awards for Women in Science and Engineering, National Science Foundation, 1991
Presidential Young Investigator Award, National Science Foundation, 1984
Outstanding Achievement Award from NASA/Langley Research Center, 1978
Torrey Award for Excellence in Mathematics, Goucher College, 1977
Outstanding Summer Employee Award from NASA/Langley Research Center, 1976

RELEVANT ACCOMPLISHMENTS:

- Three Corner Sat "Petey" on display at Air & Space Museum, March 2006.
- Associate Director for Research-leads student-satellite group for NASA URETI "Institute for Cell Mimetic Space Exploration". UCLA (lead), Caltech, JPL, NASA-Ames.
- Three Corner Sat team invited to display at AFOSR 50th Anniversary, Wash. D.C., Apr. 25, 2002, and DoD STP exhibit at NASA-Johnson Public Open House, Aug. 25, 2001.
- ASUSat1 designated AO-37 (ASUSat OSCAR–37) by AMSAT-NA, 2000
- ASUSat team invited to Washington D.C. for three-day "ASU Space Student Satellite Workshop" by Rear Admiral Paul Gaffney, Chief of Naval Research, May 1999

Service:

Served on various NASA Headquarters Aeronautics Advisory Committees, Subcommittees, Task Forces; NASA Federal Laboratory Review Task Force of NASA Advisory Council; and NATO/AGARD Fluid Dynamics Panel. Presently

- Chair of the Aerospace Department Chairs' Association
- Texas A&M Institutional Representative for USRA