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Part of the AFOSR / AFRL/VS University Nanosat 5 Program, the objectives of Texas A&M University System's AggieSat3 were to 1) demonstrate tracking technologies, 2) demonstrate a new multi-place single ejection deployment system for picosatellites, 3) demonstrate a Global Positioning System (GPS) system, and 4) 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 student program in support of the objectives.

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# University Nanosat Program: AggieSat3
# ICN# FA955007-1-0184
# Final Report to AFOSR
# June 2009

**Part of the AFOSR / AFRL/VS University Nanosat 5 Program, the objectives of Texas A&M University System's AggieSat3 were to 1) demonstrate tracking technologies, 2) demonstrate a new multi-place single ejection deployment system for picosatellites, 3) demonstrate a Global Positioning System (GPS) system, and 4) 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 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 numerous 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 AggieSat3 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 the 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 5 Program's AggieSat3. 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 5 had two distinct stages. The first part was a design and build phase involving approximately 11 Universities, which lasted two years and culminated in the Student Satellite Flight Competition in January 2009. The second part then consisted of construction and test of the competition winner's flight unit and will culminate in launch of the Nanosat. The selected Nanosat is expected to be flight-ready by September 2009. AggieSat3 was not selected as the competition winner.

## II. Scientific and Technical Nanosat Plans and Objectives

The scientific and technical objectives of AggieSat3 were as follows and relevant to Air Force missions

- Implement close-proximity tracking technologies
- Implement a multi-place single ejection deployment system for pico satellites
- Implement a GPS system
- Implement second-generation responsive space mission software and hardware

As per the Mission Statement, the AggieSat3 mission aimed to investigate close proximity navigation utilizing a stereo vision system in an advancement toward autonomous rendezvous and docking missions. The AggieSat3 team identified the following mission objectives and was developing software and hardware solutions to meet these objectives:

- Primary Objective
  - Obtain verifiable data in space environment to characterize stereo based relative navigation system
- Secondary Objective
  - Characterize miniaturized GPS receiver and obtain differential tracking solutions between AggieSat3 and known target

## III. Objectives

### 3.1 Implement close-proximity tracking technologies

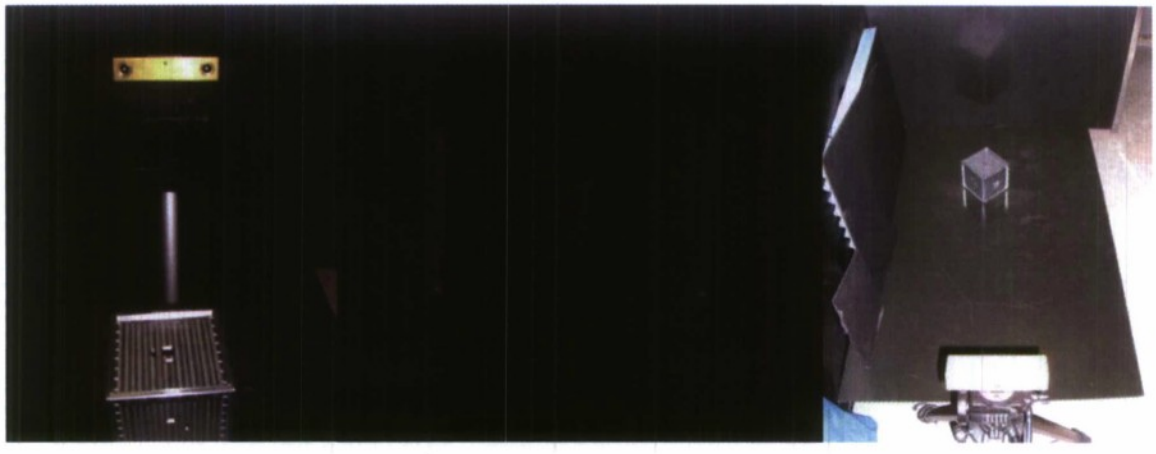
Maintaining space situational awareness remains a high priority for both the Air Force and NASA, but requires further development and in-orbit demonstration of the necessary tools. Close-proximity operations are one aspect that provides the opportunity to inspect, monitor, and dock with another spacecraft. However, to support the needs of such operations, tracking sensors must enable accurate relative navigation solutions. Several new technologies offer robust performance, but lack space-flight heritage. Our team included as part of the AggieSat3 mission proposal, a potential implementation of several of these technologies.

Video Guidance Systems are one class of current technology most widely in use; however, these systems generate real time navigation solutions at the expense of computationally intensive algorithms. In addition, individual system constraints stemming from camera pixel resolution and supporting optics directly affect overall performance. Sensitivity to on-orbit light conditions further contributes to shortcomings of these implementations. Such limitations coupled with the constrained resources inherent to nanosatellite platforms render these systems impractical for small-scale missions.

Our team proposed to incorporate into AggieSat3 a new Stereo Vision Video Guidance System (SVVGS), which required several modifications to the BumbleBee 2®, a commercially available product for stereo machine vision developed by Point Grey Research. The current binocular BumbleBee2® system incorporates two 1/3" progressive scan CCD sensors and transmits both images via an IEEE-1394 interface to provide approximately 7cm accuracies out to a distance of 5m. However, this system includes several computationally expensive algorithms, which require at least a Pentium 4 processor to produce an 18 Hz solution. Our collaborative development with Dr. John L. Junkins here at TAMUS included the addition of a structured light source for projecting known features onto the target, to facilitate a more rapid solution convergence by focusing the search algorithms to a window bounded by the identification of these features. Coupling some aspects of the current navigation software with these "smart" algorithms could result in significant savings in the computational cost, increase the accuracies of system estimations, and protect against failure to identify target features.

The mission objectives of AggieSat3 aimed to characterize the performance of the stereo vision system for relative navigation tasks by deploying picosatellites as targets. Each picosatellite also included a GPS system for baseline range measurements to serve as a quantitative comparison for these new systems. First we planned to characterize system performance on the ground in a comprehensive test matrix of representative simulated space environments. Next we planned to select representative conditions for flight experiments (lighting conditions and so forth) that validate ground assumptions. Then we planned to analyze data returned from the space environment to determine the feasibility of generating future six-degree-of-freedom navigation solutions. We planned to compare results with our physical ground test and verify system performance against models to characterize the system. Our mission experiments were relevant to UN5-0001 Appendix B goals 5,6,9,14

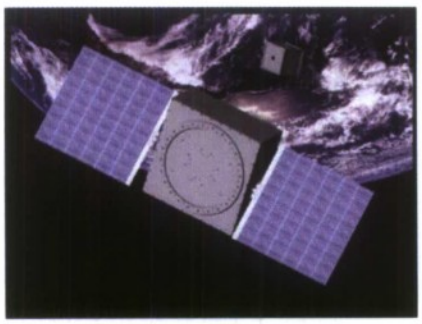
This figure shows a lab demonstration of the stereo vision system imaging an engineering development unit of one of our picosatellite targets.

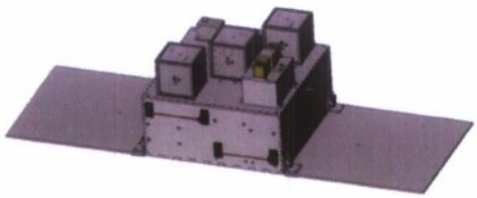


### 3.2 Implement a multi-place single ejection deployment system for picosatellites

Pico-satellite deployment systems currently in use today employ designs intended for the Shuttle Bay release or piggybacking on other large primary payloads. Our team proposed to design, test, and implement a self-contained, single deployment system for picosatellites as part of the AggieSat3 mission. This system would allow for the deployment of supplementary satellites from a nanosatellite host vehicle, providing a variety of new capabilities to this and any larger spacecraft class. AggieSat3 was to deploy up to three picosatellites, each equipped with a GPS unit to allow for differential GPS solutions, thus aiding in the characterization of the aforementioned tracking sensor technologies. Future implementation of such a deployment system would provide the capability for diverse operations depending on the configuration of the individual picosatellite. These operations potentially include self inspection, relative navigation, distributed sensor systems, relayed communications, and precise relative station keeping.

The figure on the left shows our plan for AggieSat3 to sequentially release 5-inch cube picosatellite targets to validate our stereo navigation system. The figure on the right shows the three targets stowed on the payload deck of our satellite bus.





### 3.3 Implement a GPS system

AggieSat Lab is currently collaborating with Johnson Space Center, AFMD on the initial flight tests of an upgraded and miniaturized GPS receiver with heritage from AERcam. The unit is scheduled for flight on AggieSat2, a five inch cube satellite, for testing and characterization purposes, and the first step in a longer-term campaign to ultimately demonstrate Autonomous Rendezvous and Docking (ARD) technologies. Earlier this Spring 2009, AggieSat Lab delivered AggieSat2 to NASA for launch on the Space Shuttle STS 127 Endeavour. We are integrated into the Department of Defense Space Test Program Space Shuttle Payload Launcher (SSPL), and attached to the starboard side wall of the orbiter payload bay #3, with launch currently rescheduled for 11 July 2009. This is the mission called DRAGONSat (Dual RF Astrodynamic GPS Orbital Navigator Satellite) on the manifest. Mr. David Kanipe, Chief of the AFMD, has expressed interest in the opportunity for the AFMD to obtain flight experience on its in-house GPS receiver design. This receiver is designed solely for use in space and will potentially be used in the Orion vehicle as part of the National Exploration Vision. AFMD agreed to supply and support the implementation of additional units for the AggieSat3 mission.

a) b) c) d)

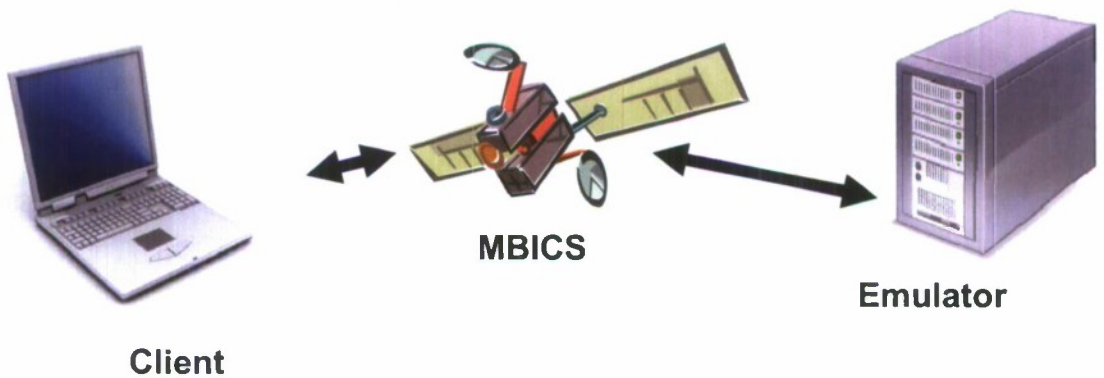
a) Successful AggieSat2 EDU fit check into SSPL at MEI / Oceaneering in Oct 2008
b) Student-built "SSPL"-like test apparatus to demonstrate deployment in 2-D plane in Lab
c) AggieSat2 flight unit just prior to shipping to NASA JSC on 20 February 2009
d) AggieSat2/DRAGONSat mechanically installed in STS 127 Endeavour on starboard side in Payload Bay #3

### 3.4 Implement second-generation responsive space mission software and hardware

Although neither was or will be launched, development of our previous AggieSat1 (during University Nanosat IV) and AggieSat3 platforms and missions have provided the AggieSat Lab with working concepts for Responsive Space Mission software and hardware. The AggieSat1 approach included such practices as partitioning software logic for an adaptable autonomy and control architecture, modularizing software and hardware for rapid system-level integration and testing, and standardizing components and interfaces for a plug-and-play spacecraft infrastructure. Serving as a path to achieving similar responsiveness in missions of higher complexity, AggieSat1 was to demonstrate a first implementation of these expandable concepts.

The responsive architecture employed on AggieSat1 relied heavily on software that provides a hierarchical view of the satellite built upon entities called Functional Units. These Functional Units are a predefined abstraction of specific functionalities a module may provide for the system and are located in a device driver/hardware combination that implements this abstracted functionality. Traditional device drivers have three disadvantages that run counter to responsive ideals, and these have been addressed in the AggieSat1 software design. First, they must be compiled to run on a specific hardware architecture (e.g. x86 or PowerPC). Second, they usually access the data bus directly to communicate with the hardware. Third, device drivers have specific access functions which the software must know about. To alleviate all of these non-responsive attributes of device drivers, the AggieSat Lab has developed a common RSM Device Driver (RSMDD) library for use by all device drivers. This library includes four functions which the device drivers use to communicate with the control software and with its device. By confining the device drivers to using these functions as the only means of external communication, the device drivers can eliminate the vast majority of platform specific function calls and can readily compile their code for various hardware architectures. The device drivers do not require software for a specific data bus, thus removing much low-level implementation. To take advantage of these benefits, module developers must only include one extra header file and the appropriate compiled object code for their target platform. The AggieSat Lab has developed generic control software that, provided with an arbitrary array of attached modules, is able to perform extensive introspection of its capabilities, configure the system with minimal human intervention, and operate the satellite in an autonomous fashion. This software is aptly named the Mission Based Intelligent Control System (MBICS) because it hierarchically organizes these Functional Units into more meaningful groupings to which it applies various control algorithms to handle the mundane operations of the satellite. This allows the AggieSat Lab ground personnel to concentrate on operating the satellite through high-level commands.

The hierarchical organization employed by the MBICS system is a three-tier system that rests upon the Functional Units available to the system. The lowest level handles necessary overhead associated with operating the Functional Units. This includes Functional Unit list extraction from individual modules, data flow handling between device drivers and hardware, locking mechanisms to individual Functional Units, and XML composition/parsing abilities to communicate in the native tongue (SatXML) of the Functional Units. The second tier utilizes Dynamically Loadable Control Modules (DLCM) that operate on specific types and groupings of Functional Units to provide higher-level capabilities. Because these DLCMs operate solely on Functional Units, they can be reused on other missions utilizing different hardware architectures with no modifications. This allows a single DLCM module to be constantly flight proven, further refined, and incrementally upgraded while being applicable to all systems that have the required Functional Units. The topmost tier is the Global Satellite Model (GSM) which serves as a centralized repository for all data, analyses, and predictions about the combined satellite system. A major benefit of having the GSM is it allows DLCMs to share data between each other without having direct dependencies on which DLCMs are present in the system. All a DLCM knows is that the data is available and is unconcerned about its origins.

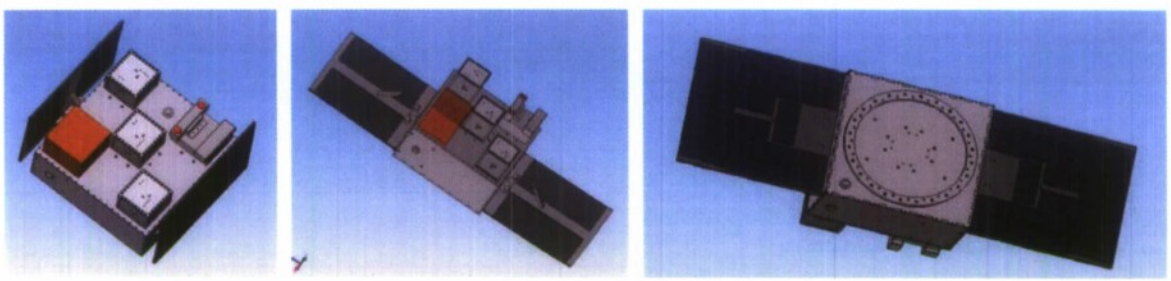



AggieSat Lab Core System

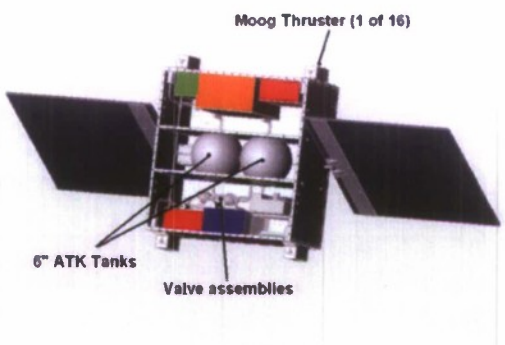
Mission Based Intelligent Control System (MBICS): On-board satellite control system and libraries
Client: Provides a common user interface across all missions
Emulator: A common testbed enabling faster module development and system verification

The goals for our responsive hardware system include 1) providing a capable and expandable student satellite platform for the AggieSat Lab to support NanoSat missions, the NASA JSC Autonomous Rendezvous and Docking campaign, and missions of opportunity, and 2) minimizing recurring satellite development overhead. Our implementation goals include 1) providing external reconfigurable payload carrier space for student payloads (up to 25 kg), 2) providing upgradeable support systems internally for future mission requirements, and 3) providing system space and capability for future advanced attitude determination and control and propulsion systems.

For the reconfigurable bus, after a 6-week concept study in our new Integrated Concurrent Engineering Lab, called Team AggieSat, the following configuration was developed for AggieSat3. The reconfigurable bus features an internally supported, reconfigurable space for subsystems; and an upper payload deck for reconfigurable missions. The support bus is 0.47 $m^2$ with twin 0.22 $m^2$ solar arrays. The 45 kg support bus has a 28 V power system, with 120 W generated, and 75 W available for subsystems and payloads. It is upgradeable to ≥75 kg total S/C mass (25 kg payload) for future missions. There is pointing capability, and the system is upgradeable to cold gas and similar propulsion systems for future low ΔV translational missions including our ARD demonstration with NASA Johnson Space Center.



First generation ARD Platform ("Pointing" Variant)
3 axis stabilization, 28 V baseline power system, AR&D bus structure, fixed solar arrays




Proposed concept for propulsion capable variant for (ARD Campaign)
Cold gas propulsion, evolved ADC system, articulated solar arrays

All modules developed for the AggieSat3 spacecraft also adhere to a set of standard interfaces to achieve a plug-and-play environment. Electrical specifications restrict all module power and data lines to conform to identical voltages and USB connections. Standard pin out configurations and DB-9 connectors generate uniform cabling. Generic microcontroller units common to all modules coupled with interface specifications allow the spacecraft to monitor and operate any device once its driver is uploaded. Contrary to traditional spacecraft design, these practices conform subsystems and payloads to a standard bus, thus facilitating rapid system-level integration and testing. Furthermore, this design philosophy propagates to increased mission flexibility after the development of numerous modules.

The future goal of AggieSat Lab is to expand MBICS and this RSM methodology by implementing new capabilities such as DLCMs to control multiple modules simultaneously as well as the attitude of the system. New modules include tracking sensors, attitude control, and a generic picosatellite deployment system all developed to a second generation of RSM specifications. In addition, the Lab desires to expand its capabilities by introducing a new bus class of increased size and performance; however, the MBICS software architecture will allow this new system to be fully backwards compatible with previously developed spacecraft modules and relevant software. It is the goal of the AggieSat Lab to further research and promote development in these RSM concepts, providing to other universities our RSM Interface Control Document (ICD). This document defines the interfaces required to make a module compatible with the RSM architecture and MBICS.

## IV. System Description

In the Appendix, we have included the slides from our Critical Design Review held on 27 February 2008 and our Prototype Qualification Review held on 11 August 2008 with the Air Force. These slides detail 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]), Three Corner Sat (University Nanosat I/II Program and launched 22 December 2004 on the Delta IV Heavy Demo), ASUSat3 (University Nanosat III Program), AggieSat1 (University Nanosat IV Program), and AggieSat2/ LONESTAR (Johnson Space Center Program – ARD, to be launched on STS 127 NET 11 July 2009).

## V. Program

### 5.1 Integration and Test (I&T)

For the spacecraft AggieSat3 itself, it was planned that all I&T would take place at TAMUS. AggieSat Lab has the goal of establishing a one stop, integration and test facility. This facility will house vibration system, thermal vacuum system, clean room, thermal cycling chambers, and other necessary test equipment for satellite integration and test. A complete Quality Assurance and Configuration Management program exists within the AggieSat Lab for hardware tracking and control, and documentation control ensuring proper flight hardware and integration controls.

Configuration Management (CM) & Safety are an integral part of one another and in order to successfully pass our Reviews a detailed CM plan is in place and used within the AggieSat Lab. Using guidance from AFRL and current staff on required measures as learned from multiple satellite programs, the following list shows the major requirements for CM:

- Peer/Professional Reviews of all designs
- Training and hours tracking of all tasks and personnel
- Minimum two person verification for all design, assembly, integration and testing
- Quality Assurance checks throughout the design, assembly, integration and testing
- Purchasing records for all materials and parts
- Certificates of Compliance for all components and materials purchased
- Shipping and receiving logs for all parts and materials
- Hardware tracking logs
- Restricted access to flight hardware and materials
- Restricted access to electronic files related to design
- Assembly and Test Logs for all components

Successful CM means increased confidence in the safety of our system and in mission success. In order to pass each review, the satellite will have to meet certain requirements (depending on the particular launch vehicle) to include:

- Sine Burst: Test Load requirement in each axis
- Random Vibration: minimum 1$^{st}$ fundamental frequency
- Total satellite mass and volume
- Pressurization/depressurization analysis
- Materials with high resistance to stress corrosion cracking (SCC)
- Maximum collectable volatile condensable material content
- Total mass loss


### 5.2 Management and Schedule

#### 5.2.1 Management Approach

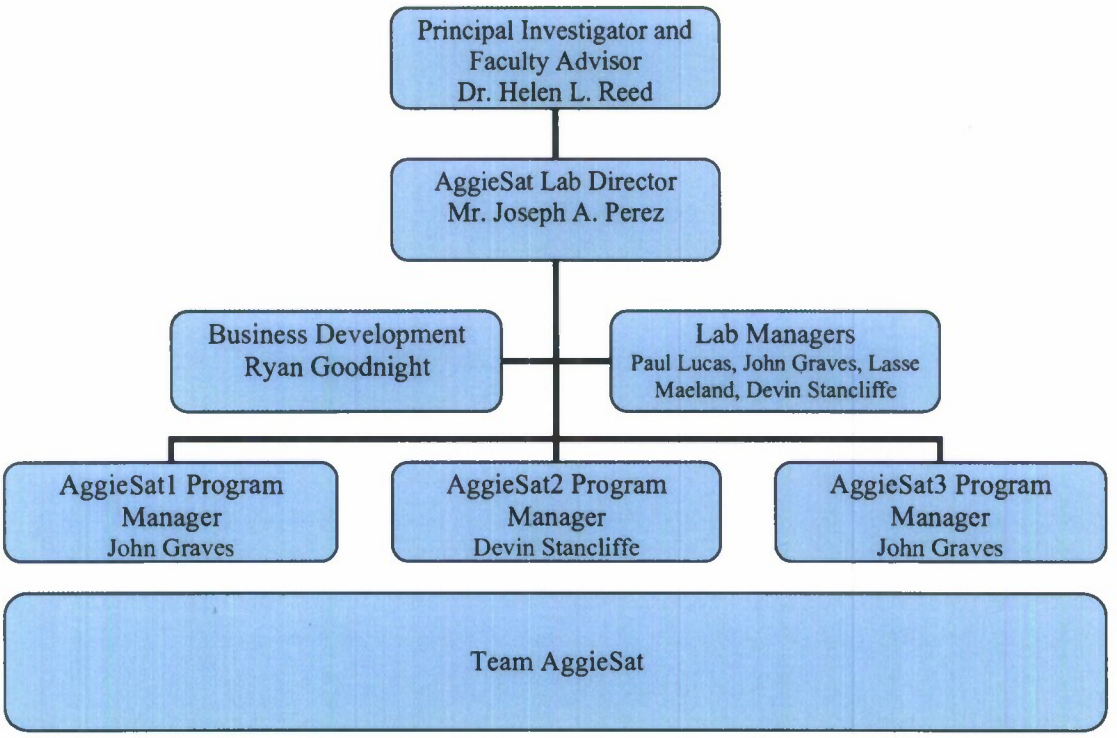
AggieSat3 was modeled as much as possible after industry and completely student managed. The project was conducted from a systems point of view keeping requirements and constraints in mind; the students contributed to a multidisciplinary team (18 different majors have participated). The project was required to be accepted by AFRL and actually work to perform valuable research or science, giving students invaluable hands-on teaching in design. With a provided launch, students had to meet real constraints on requirements, testing, safety, deadlines, documentation, and reviews.

The project was overseen on several different levels. The Universities and other supporting organizations reported to TAMUS, which in turn reported to AFRL, which in turn reported to the Space Test Program (STP) for integration and launch issues. At the University level, faculty leaders provided guidance and support for the project. Dr. Reed and Mr. Joseph Perez were the principal interfaces with students and with AFRL; they were the final arbiters on all payload-design issues; and were responsible to AFRL.

The program itself was entirely student staffed and run. A majority of the students were undergraduates and they were responsible for everything from initial concept and design to final integration and delivery to AFRL. Some participated as volunteers, some were paid interns, some received class credit. Students served in the following capacities. AggieSat3 had a Program Manager, Systems Engineer, Subsystem Leaders (payload, structures and materials, attitude and orbit determination and control, electrical power subsystem, command and data handling, communications, ...), and identifiable team members. The Program Manager reported to the AggieSat Lab Director (Mr. Perez) and the faculty advisor (Dr. Reed, PI). The Systems Engineer and Subsystem Leaders reported to the Program Manager, and team members reported to their respective Subsystem Leaders.

#### 5.2.2 Meetings and Communication

The University Nanosat Program provided unique opportunities and challenges for students to learn how to communicate and work with other students and professionals over long distances. Clear management, documentation, and communications were necessary for success. Students were encouraged to participate on any subsystem, allowing them to work outside of majors and to broaden areas of expertise and experience. A weekly mandatory meeting (unless there is a class conflict) among all participants was held to discuss project development. The Program Manager and Systems Engineer met once a week with subsystem leads to go over progress and lay out milestones. Subsystem leads held weekly meetings with their team members to discuss what needs to be done, train students, and teach concepts related to their subsystem. Beyond these, email and a password-protected document listserv facilitated communication. Face-to-face meetings were held whenever possible and were mandatory for more detailed operations such as design reviews and integration and testing.




Team Organization

### 5.2.3 Schedule

The AggieSat Lab developed and adhered to a schedule according to the released user guide.

## 5.3 Relevant Experience by the Principal Investigator and Major Associates

AggieSat3 represented a close collaboration among Texas A&M University System (TAMUS; lead) and NASA Johnson Space Center.

**Department of Aerospace Engineering**
**at Texas A&M University System**

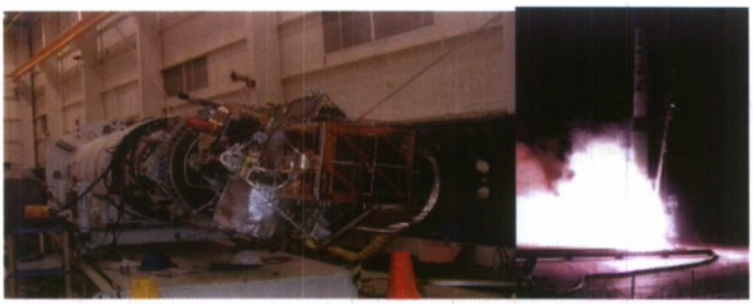
The organizational home to AggieSat3 was the Department of Aerospace Engineering at TAMUS where the PI, Dr. Helen Reed, served as the Department Head from December 2004 through November 2008. Aerospace Engineering was designated a "signature program" by the Look College of Engineering with significant investment to grow the number of faculty by 50% over five years and achieve top-ten status. The Department holds a strong commitment to education and opportunities for its students.

Dr. Reed brings 16 years of significant experience in space flight, nanosatellite design, and student education from Texas A&M University System and Arizona State University, the latter institution at which she provided educational, research, and service experiences for over 700 students through the provision of various real aerospace projects including two major satellite programs launched with the Air Force:

- ASUSat1
  - 6-kg nanosatellite designed and built by students for spectral imaging, global positioning system (GPS), 3-axis passive stabilization, ±10 degree attitude determination at low cost ($1000 per

satellite), autonomous operations, communications; ASUSat1 launched January 26, 2000 at 19:03 PST on the 1st Air Force OSP Space Launch Vehicle Minotaur from Vandenberg AFB. ASUSat1 was designated AO-37 (ASUSat OSCAR–37) by AMSAT-NA

- ASUSat team invited to Washington D.C. for all-expenses-paid 3-day "ASU Space Student Satellite Workshop" by Rear Admiral Paul Gaffney, Chief of Naval Research, May 1999



ASUSat1 attached to JAWSAT for launch on Minotaur Jan 26, 2000

- Three Corner Sat (3CSat or 3CS)
  - Part of AFOSR/DARPA/AFRL/NASA GSFC/Air Force Space and Missile Command's Space Test Program (STP) University Nanosat I/II Program and joint effort among ASU (lead), University of Colorado at Boulder, and New Mexico State University
  - Two of the three 3CS satellites launched as constellation from EELV Heavy Demonstration mission on Dec 22, 2004. Multi-Satellite Deployment System (MSDS)/Nanosatellite system attached to pedestal mounted to side of heavy demo mass simulator satellite atop Delta IV. After deployment from demonstration satellite, individual Nanosatellites successfully separated via two low-shock separation systems: Planetary Systems Corporation Lightband and Starsys Research Corporation CBOD system. Delta IV 1st stage cut off too early and satellites were delivered to much lower than anticipated orbit and were never contacted.
  - 3CS science experiments and technology demonstrations were to consist of MEMS micropropulsion experiment, low-cost COTS communications, imaging, distributed and automated operations. As well, lessons learned in implementing student-satellite program.
  - Team invited to display satellite hardware as part of AFOSR 50th Anniversary, Wash., D.C., April 25, 2002, and DoD STP exhibit at NASA Johnson Space Center Public Open House, Aug. 25, 2001.
  - Undergraduates chosen as Air Force Space Scholars at AFRL Albuquerque
    - Ms. Lauren Egan, Summers 2002 and 2003, now Texas A&M MS/PhD candidate
    - Mr. Erik Henrikson, Summer 2004, now ASU PhD candidate
  - Two of three nanosatellites launched on Delta IV, third delivered to Smithsonian Air & Space Museum in Washington DC, March 13, 2006.

At Texas A&M and established in 2005 with Dr. Helen Reed as its Principal Investigator and Mr. Joseph Perez as its Director, AggieSat Lab is currently providing faculty and students with capabilities to complete small-satellite missions. Besides AggieSat3, the Lab is conducting the following mission:

- LONESTAR/DRAGONSat/AggieSat2/AggieSat4
  - To advance AR&D technologies, NASA Johnson Space Center is fostering collaboration between Texas A&M and the University of Texas at Austin. Each student team is to build a satellite that will ultimately rendezvous and dock autonomously with the other in space. This is an anticipated eight-year campaign with a launch approximately every two years. The first three missions will build in complexity and test individual components and subsystems while the final mission will culminate with the successful docking of two satellites. This project called LONESTAR (Low-earth Orbiting Navigation Experiment for Spacecraft Testing Autonomous Rendezvous) is important to NASA in providing flight data and experience, applicable for the Constellation Program for unmanned cargo vehicles and in space assembly.

- For the 1st launch (LONESTAR Mission 1) on STS 127 NET 11 July 2009, DRAGONSat (Dual RF Astrodynamic GPS Orbital Navigator Satellite) is comprised of two 5" X 5" X 5" satellites (AggieSat2 from Texas A&M and Bevo-1 from UT) to be launched together from the DoD Space Shuttle Payload Launcher attached to the starboard side wall of the orbiter payload bay. When ejected, the two satellites will automatically separate, and begin the experiment to characterize JSC's DRAGON GPS receiver.
- The team is about to begin the next mission which is currently planned for launch NET January 2012 on an expendable launch vehicle. For Texas A&M, this is called AggieSat4. Lessons learned are that due to severe volume constraints this next mission necessitates a larger satellite bus. The continued development and validation of NASA Johnson Space Center's DRAGON and various miniaturized sensors and effectors to enable and ultimately perform an AR&D mission continues to be the focus of this next mission.

The vision of AggieSat Lab is to demonstrate and develop modern technologies by utilizing a micro-/nano-/cube-satellite platform while educating students and enriching the undergraduate experience. 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.

AggieSat Lab has implemented the "Integrated Concurrent Engineering" method (ICE) into all of its design and analysis processes. 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 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.

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

A complete Configuration Management (CM) Plan exists within the AggieSat Lab for providing the framework for document release and document control processes, including software, documents, drawings, reports, and so forth, and defining the roles and responsibilities pertaining to document control, including the review process, signature authority, and so forth. The Document Control Procedure details the procedural implementation of the CM Plan. The Quality Management System assures all AggieSat Lab products meet or exceed customer expectations and uses ANSI/ISO/ASQ Q9001-1994 as a guideline. This system describes various control points for design (input, output, verification, and so forth); product acquisition, inspection, traceability, and storage; and two-person build, with all data recorded in an as-built procedure.

**AggieSat Lab Personnel.** The Principal Investigator was Professor Helen Reed. AggieSat Lab staff members, Joseph Perez and Paul Lucas, were also instrumental to the success of this project. Undergraduate and graduate students within the Lab contributed to the program.

***Dr. Helen L. Reed*** has 16 years of leadership and experience in space flight, satellite design, responsive software and hardware systems, and autonomous rendezvous and docking, and 31 years in hypersonics, boundary-layer transition and flow control, and thermal considerations. She has delivered two major satellites launched with the Air Force (see above). She has also delivered two payloads for a sounding rocket launch out of NASA Wallops in 2000, a NASA Space Shuttle STS-105 experiment, payloads for several high-altitude balloon launches, and four KC-135 microgravity experiments. Now at Texas A&M since December 2004, Dr. Reed established "AggieSat Lab" in March 2005. Dr. Reed was elected Fellow

of the American Institute of Aeronautics and Astronautics (AIAA) in 2008, Fellow of the American Physical Society (APS) in 2003, and Fellow of the American Society of Mechanical Engineers (ASME) in 1997. She was awarded the 2007 J. Leland "Lee" Atwood Award from the ASEE Aerospace Division and AIAA - the award is bestowed annually upon an aerospace engineering educator in recognition of outstanding contributions to the profession. She was inducted into the Academy of Engineering Excellence at Virginia Tech, her alma mater, in May 2008.

***Mr. Joseph A. Perez*** is Director of AggieSat Lab within the Aerospace Engineering Department at Texas A&M. He specializes in the design, fabrication, build and test of space systems and sub-systems, and he has also installed and manages the Quality Assurance Program, Configuration Management System and Operation and test procedures for all process within the AggieSat Lab. He has been a NASA certified instructor for most of the technician skills involved with satellite fabrication and build. Over the past 5 years he has been mentoring and instructing undergraduate and graduate students on the design and build of space systems. For 20+ years prior to joining Texas A&M, he was either active duty military doing research and development or a DOD contractor for the Air Force Research Lab at Kirtland Air Force Base. He was involved with the Air Force University NanoSatellite Program, which challenges higher education institutions to design and build a space mission. He was responsible for electrical integration and flight test qualification of all Air Force Phillips Laboratory Space and Balloon Payloads. He led electrical and mechanical integration and test of the MightySat II.I spacecraft. He was responsible for the telemetry and communications system, power system integration and test, attitude control system testing, flight software test and maintenance, all environmental testing, and launch integration and test procedures to include launch of the satellite. He was responsible for the fabrication, testing, and integration of the DHS (Data Handling System) for the STRV1d spacecraft, fabrication of MAPLE4, TRAM (Transmit/Receive Antenna Module) control board, and integration of all experiments for the ETB (Electronic Test Bed). He assisted in the build of the Micro Control Module for the Mission Research Corporation and Air Force Research Laboratory. He fabricated and tested the MPID (Micro Particle Impact Detection) experiment for MightySat 1. He provided rework and repair of the MightySat 1 bus and structure. He integrated the MAPLE 1 flight experiment and MPID onto the MightySat 1 bus for flight. He assisted in fabrication and test of the MAPLE II flight experiment and spare for flight on STRV1. He performed thermal bake out and vacuum testing of the VISS flight structure, MAPLE II, MightySat 1, FUSE, HSI, and several other flight experiments. He assisted in the preparation of building 277 for use as an integration and testing facility for the Phillips Laboratory, to include Balloon and Sounding Rocket programs. He has worked on multiple satellite programs as the lead for integration and test director for these programs.

***Mr. Paul Lucas*** graduated from Texas A&M University in 2007 with a Bachelor of Science in Computer Science. As a student, he worked with AggieSat Lab in developing the command and data handling subsystems for three different student satellite programs. He now works full-time with the lab designing, prototyping and building embedded hardware and software systems. His research area involves developing a responsive satellite platform that encourages reuse of hardware systems and control algorithms.

**Johnson Space Center**

The Johnson Space Center, AFMD Engineering support team has developed a GPS system that is intended for use on the AERcam Experiment. The Center has set up a collaborative program between Texas A&M University and the University of Texas to perform Autonomous Rendezvous and Docking. This effort will take place over 8 years and consists of 4 missions of increasing complexity. The engineering support staff and management are actively involved with both universities to encourage and challenge the students to come up with a way to perform this complex and very hard task. An integral part of this is the use of the GPS system that has been designed and tested within the space center. AggieSat 3 intended to utilize this technology within the main spacecraft bus as well as within the picosatellites that were to be deployed as part of the tracking technology demonstration.

### 5.4 Educational impact (both undergraduate and graduate) of the project;

Student-satellite projects provide an effective complement to engineering and business education. The projects are managed entirely by undergraduate and graduate students with oversight by a faculty advisor (Dr. Reed and Mr. Perez). Students participate from the initial concept; through the research, design and development; integration and

testing; flight/operation; and data collection and report out. The teams consist of students from varied backgrounds in engineering, science, liberal arts, business, social work, and journalism, and from all levels of experience (90% undergraduate). Students are either paid as interns, receive course credit, or volunteer. The students also participate in a significant number of outreach activities to local schools and community and professional functions and are called upon frequently for recruiting and awareness. The various projects depend on industry and government for mentoring/assessment, financial support, hardware/software donations, and use of fabrication/testing facilities.

Students love space and thrive in a real-world program relevant to national needs in which research is transformed into hardware and then tested. They experience a multidisciplinary work environment representative of aerospace industry where teamwork is a must. In recent years, the community has faced new constraints: lower budgets, shorter design times, etc. The kind of thinking found in student projects such as AggieSat3 may provide solutions for success of future space exploration and make valuable contributions to the aerospace field, by training future scientists and engineers, and by serving as test beds for R&D of new nanosatellite technologies. The limited resources and rigid constraints associated with AggieSat3 require innovative solutions--from the design of new low-cost components to the development of manufacturing techniques to interacting with local industry professionals. Projects such as AggieSat3 address educational needs by involving primarily undergraduates, providing relevance to students' basic classes by helping them see what science, engineering, and business really involve. A feature of these projects such as AggieSat3 that strongly impacts student education is the day-to-day contact/interaction with DoD, NASA, and industry: students learn standard practices, establish long-lasting networks, gain confidence in abilities, develop public-speaking and human-interaction skills, and identify future job opportunities, while training to become tomorrow's highly skilled aerospace workforce.

Student projects have added challenges to face. It is critical to promote and continuously improve team organization. Challenges here include project continuity as students graduate or otherwise leave the team. Information is very easily lost as people leave. To this end, establishing a friendly documentation system (on the computer) is crucial; paperwork is not as fun as design and building and different strategies have to be tried for different students. There is no simple solution. Many times, multiple organizations work together and students have to learn to run programs over long distances, taking into account time zones, cultural differences, and perhaps language. Students often times do not initially have an appreciation for or experience in working with students in other disciplines or other majors. Students also join a team with greatly varying experience levels – usually very little experience; bringing new members up to speed is a challenge. An effective idea is to assign a more experienced student mentor to each new participant. Finally, students have many demands on their time – classes, labs, homework, exams, family,... It is critical to establish a team structure that is flexible, adaptive, and time efficient.

The benefits of these projects far outweigh the challenges, and AggieSat3 was promoted and made available to students in a number of different ways:

- Extracurricular project involving all interested students from varied backgrounds in engineering, science, liberal arts, business, social work, and journalism, and from all levels of experience (freshmen through graduate students). Students either volunteered or received internship support. In all, 18 different majors became involved.
- A Spacecraft Design course was offered as a Technical Elective, with its focus on AggieSat3.
- The PI was responsible for the freshman AERO101 Introduction to Aerospace Engineering course. AggieSat3 was a focal point.
- Graduate students performed research in developing the payloads at TAMUS.
- Undergraduate students at TAMUS served as Student Program Managers and Systems Engineer.
- Graduate Students served as Lab Managers and assisted in oversight of Quality Assurance and Configuration Management.
- Undergraduate students at TAMUS participated in Business areas
- Graduate student served as Business Development Lead.

Our team feels strongly about the educational aspects of the program, and is always willing to share ideas and suggestions as well as learn from others.

### 5.5 Management Aspects

From our experiences and MANY lessons learned over the past sixteen-plus years, our approach to working with students can be expressed by the following points:

- Set high standards and live by them. Promote ethics.
- Encourage students to take initiative and make decisions. Give students as much responsibility as is feasible.
- Encourage students to explore different areas of the project. They should not be confined to work on a problem that directly correlates with their major, they should be able to explore and grow by learning other subsystems.
- Involve as many students as possible in industry-related activities, such as tours, teleconferences, and technical reviews and exchanges, and other aspects of a research program, such as paper writing, reviews, and presentations.
- Spend the extra time teaching a student how to properly do a task. It seems faster as a manager to do it yourself, but if you teach the student properly then he/she can continually perform the task and pass the skill along.
- Create and continuously improve a friendly and useful documentation system that makes it as easy as possible on team members, and document everything. This is a tough one, but critical because of high student turn-over.
- Provide access to state-of-the-art tools.
- Interact frequently, patiently, and respectfully with students. Listen to their opinions. Mentors should include faculty, industry, graduate students, and undergraduate peers. Industry engineers provide a very important facet to mentoring. Students view these individuals as coming from the real world and providing a sense of relevance. The experienced students on the team (both graduate and undergraduate) also make very important contributions to mentoring and take this responsibility very seriously. The closeness in age and similarities in life experiences are major reasons for this success. Student mentoring also addresses the high-student turn-over problem – having younger students in the pipeline shadowing more experienced students is key.
- Involve students in outreach to local kindergarten through twelfth grade schools and community and professional organizations. The students actually embrace this activity as a very important aspect of the program and readily respond to and seek opportunities to inform the public. This contributes to addressing current National concerns about the availability of a sufficient future workforce, by encouraging pre-college students to seek careers in science, engineering, and mathematics.
- Promote diversity. Efforts are made to attract members of underrepresented groups and students who might not otherwise have the opportunity to participate in research. The PI has a history of success in recruiting women and minorities. Once again, this has been recognized as a key element to future workforce needs. An effective way to generate diversity is to encourage minority/women students presently on the team to serve as role models and make personal contacts.

### 5.6 Quality, relevance (to AFRL) of plans for space operations

#### 5.6.1 Mission Overview

**Mission Design.** AggieSat3 had relevance to the Air Force in its objectives to:

- Implement close-proximity tracking technologies
- Implement a multi-place single ejection deployment system for picosatellites
- Implement a GPS system
- Implement second-generation Responsive Space Mission Software and Hardware

AggieSat3 was intended to provided a second-generation platform for testing unconventional design architectures and methodologies in an advancement towards responsive space missions. Its objectives aimed to expand the capabilities of a plug-and-play spacecraft infrastructure by advancing the necessary software and hardware controls to perform several experiments. Furthermore these objectives were to develop the space-worthy hardware and provide the on-orbit characterization of multiple relevant technologies that feed-forward to nanosatellite and larger class spacecraft.

**Spacecraft.** The spacecraft was designed as simple, low-cost, modular, and designed and built to test. A design-to-minimize-Safety-concerns philosophy was used. There were minimal deployables. The payloads were so designed for the simplest experiment possible to verify the device.

**Launch Vehicle/Container Requirements.** The satellite was designed to fly on a variety of conventional launch vehicles at a variety of orbits. We met the appropriate design constraints and Safety requirements.

**Communications Approach.** There were two general classes of communications links in this project:

- o Space-to-ground Links. The AggieSat3 team planned to prepare Form DD1494 to operate in the near-amateur-frequency range. An amateur ground station capable of operation in the near-amateur band was set up at Texas A&M University and tested in support of the AggieSat2 program.
- o Crosslink communications between spacecraft.

**Mission Operations Plan.** Satellite delivery was not to be the end of AggieSat3. The team was to shift its efforts to the Engineering Development Unit (EDU), an identical working replica of AggieSat3. We planned full team meetings to discuss Mission Operations and brainstorm for Failure Modes and Effects Analysis (FMEAs). We planned to use the EDU to continue software testing and train mission operators for post launch operations. We also planned to use the EDU as a training tool for new members coming onto the team and in preparation for any upcoming reviews. Information transfer and training tools like the EDU are essential in the university environment where the person-power turn over rate is high due to a student's limited lifetime. Having working models built to the same standards as the actual AggieSat3 unit would also help with any problems encountered on orbit.

### 5.6.2 Maturity of Mission Elements

**Spacecraft.** Many of the structural elements used for AggieSat3 were based on extensive studies and lessons learned from Three Corner Sat, as well as experience gained from the design and build of AggieSat1 and AggieSat2 satellite programs. Additional experience gained in the area of drawing standards, machining capabilities, solid modeling, safety, configuration management, and quality assurance was implemented in the design of AggieSat3.

**Ground Systems.** The ground station that successfully supported the Three Corner Sat mission and will support the AggieSat2 missions was tasked for AggieSat3. This ground station was moved from ASU and reassembled on the Riverside campus of Texas A&M University this past year. It has been successfully tested in tracking current on-orbit satellites such as AO-51.

This station consists of a 30-foot tower and amateur and other radio gear required for the operation of AggieSat, and is installed on approximately 1515 square feet within an existing outdoor utility space at Riverside Campus, as shown in the 1st 2 figures below. The 1st figure shows the communications hub building (foreground) and surrounding space. The tower is located near the communications hub to minimize cable loss. Electronics (PC workstation or server, three radios, an Ethernet to serial converter box, power supplies, and three controller boxes) are stored on free rack space, or on shelving on wall space in the communications hub building.

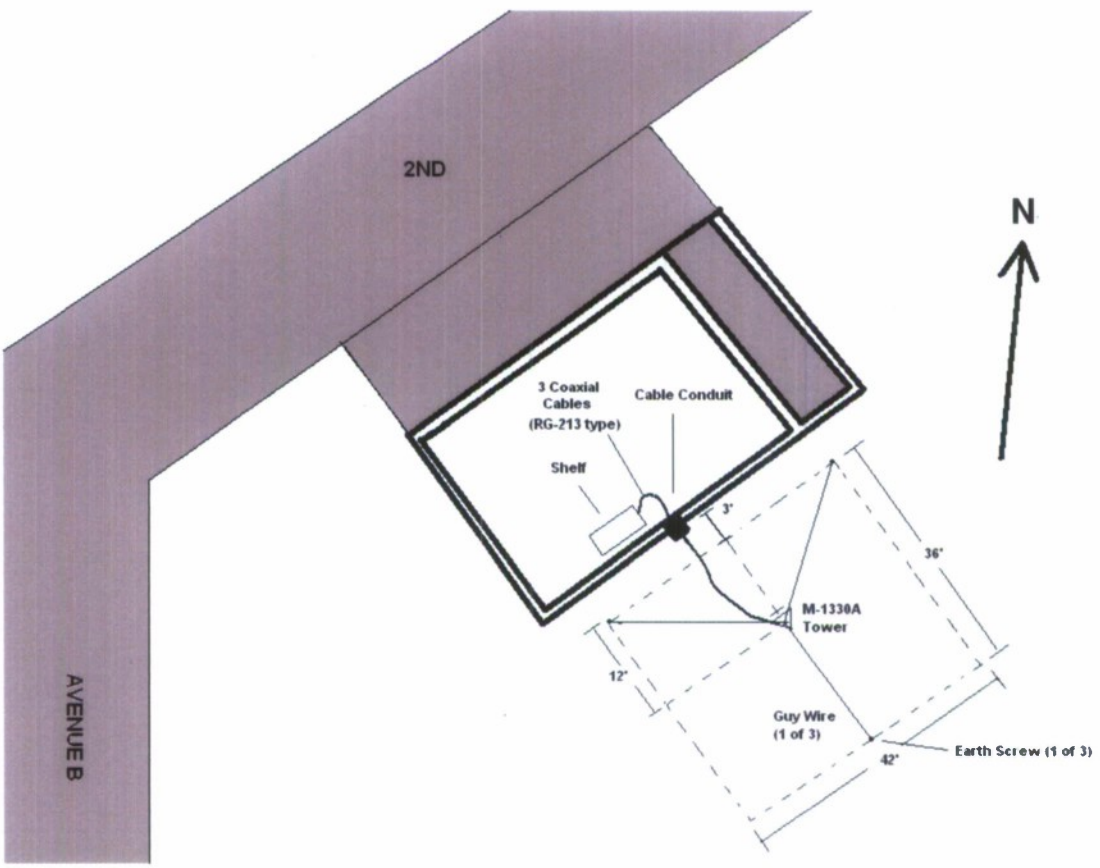
The tower is the M-1330A model from Glen Martin Engineering. These towers are modular and the AggieSat 30' version is constructed from three standard sections for a height of 30'. The tower is supported by a 1.25 cubic yard concrete installation and guy wires. All equipment used at the site can be powered by a standard 120 Volt AC electrical socket and data can be routed back to AggieSat Lab via a standard Ethernet connection. Coaxial cables run from the base of the tower into the communications building through a cable conduit drilled into the building wall.

During normal usage, the equipment on top of the tower can be accessed by an included pulley system called the "Hazer". All antenna hardware is affixed to a shelf that can be raised and lowered, so that if maintenance is required, the shelf is brought to ground level and hardware modified.

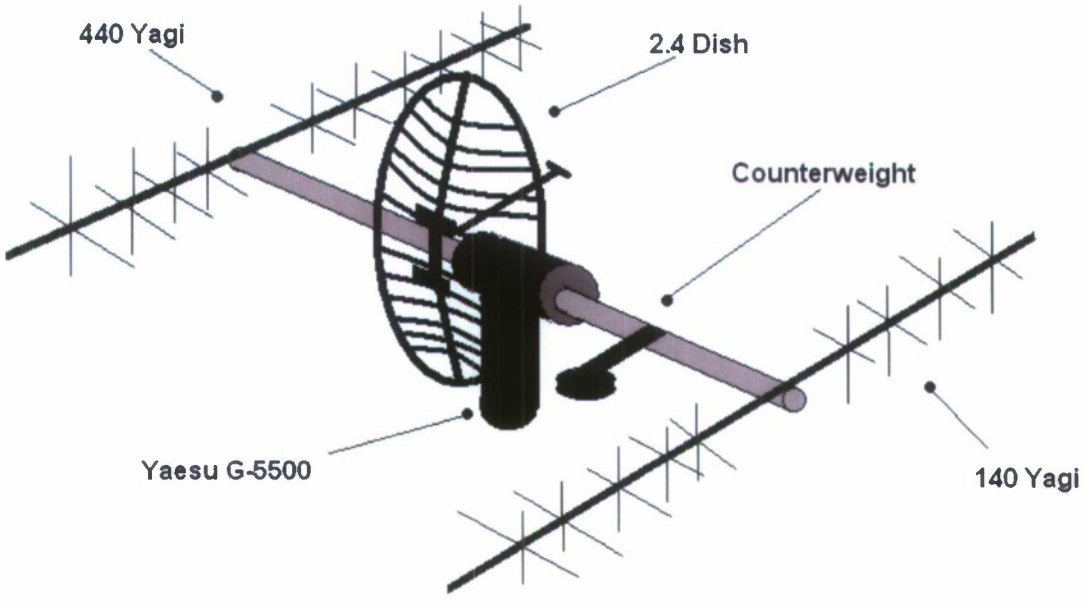
For the boom configuration, the AggieSat ground station utilizes the Yaesu G-5500 rotator for azimuth and elevation control for the antenna systems. The Initial Operating Capability (IOC) arrangement consists of a 440 MHz yagi, a 140 MHz yagi, and a 2.4 GHz dish and counterweight. The 3rd figure below shows the arrangement. There are two separate antenna configurations, one for AggieSat flight operations and the second for post-flight. The first will utilize the 440 yagi and 2.4 GHz dish antenna, while the second will only use the 440 yagi and 140 yagi. Configuration 1 will allow practice with AO-51 and operations with AggieSat. Upon concluding the AggieSat mission, the 2.4 GHz dish will be removed and configuration 2 will allow dual band use of all general amateur radio satellites. Implementing this two configuration arrangement minimizes wind loading concerns.

The initial operating capability of AggieSat Lab's ground site will be on the amateur portions of the VHF and UHF bands and the 2.4 GHz ISM band. AggieSat acquires and maintains FCC approval for all of these bands. The operators are FCC approved amateur operators and a special license has been obtained for the ISM band (call sign WD9XIZ, FCC file number 0263-EX-ST-2008).

Riverside Utility Site (looking south east)




Tower Placement




Rotator/boom configuration

**Mission Design.** ASUSat3 built on extensive studies and lessons learned from the Lab's following missions:

13-pound ASUSat1 ***launched*** on Jan. 26, 2000 at 19:03 PST to 750km X 800km, 100° inclination orbit on first Air Force Orbital/Suborbital Program Space Launch Vehicle "Minotaur". Satellite designed for low-cost Earth imagery, verification of composite-material models, technology demonstration of low-cost student-designed systems, boards, and sensors, and provision of an audio transponder for amateur radio (AMSAT) operators. ASUSat1 was designated AO-37 (ASUSat OSCAR – 37) by AMSAT-NA.

Part of the University Nanosat I/II Program and a joint effort among ASU (lead), CU Boulder, and NMSU; the constellation Three Corner Sat was designed to demonstrate imaging, formation flying, innovative intersatellite communications, innovative command/data handling, and a micro propulsion experiment. Delta IV Heavy Demo ***launch*** on December 22, 2004. Phase 0/1 Safety Review successfully completed June 2001. Phase 2 Safety Review completed Nov. 19-21, 2002. Flight hardware delivered to AFRL on Feb. 18, 2002. Environmental testing completed May 2002.

Aeroscience and Flight Mechanics Division (AFMD) at Johnson Space Center (JSC) sponsoring eight-year / four-mission collaborative program between Texas A&M and University of Texas at Austin to develop autonomous rendezvous and docking (AR&D) technology demonstration. 1st launch (DragonSat/LONESTAR/AggieSat2) is 5"X5"X5" cube ***to be launched*** from SSPL and planned for STS 127 (launch NET 11 July 2009) to implement JSC DRAGON GPS system. NASA Phase 0/I/II Safety Review October 2008 along with fit check into SSPL, Phase III Safety Review 25 Feb 2009, flight unit delivered to NASA 20 Feb 2009.

### 5.6.3 Systems Engineering Approach

**Design Approach.** The AggieSat Lab has implemented the "Integrated Concurrent Engineering" method (ICE) into all of its design and analysis processes. 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).

**Integration and Testing.** The reliability of the structure was tested using simplified models, followed by extensive finite-element modeling. A developmental structure was planned for integration testing, along with static, shock and vibration loading tests. This structure was to be followed by a qualification unit, which was to be assembled identically to flight. The assembled structure was to be tested at 120% of expected shock and vibration levels of the launch environment. Two final structures were to be built: one for flight and one as a backup unit. The structure was to be relatively inexpensive so more structures could be made for general testing and integration purposes.

**Trade Studies.** The main characteristics by which components are judged are size, power, mass, cost, and reliability. The strict resource budget associated with a nanosatellite leads to new and creative ways to do the same tasks that larger satellites do. It also leads to the philosophy of multi functionality; that is, a part has more than one role. For example, a battery pack can also provide structural support. For specific mission needs, where the technology does not yet exist to perform the needed task, it is important to incorporate the ground station as a mission partner, whenever appropriate, to fill this gap.

**Quality Assurance Approach.** Measures are taken to ensure that proper quality is met, timelines are kept, and data are preserved. To ensure quality in design and manufacturing, all students are trained in the use of the software packages and machining techniques. Material selection must pass all outgassing requirements and launch vehicle safety requirements.

Student-run projects need to enforce documentation, yet keep it to a minimum to ensure that students have time to do the engineering work. It is essential to have a documentation system that is reliable yet not cumbersome. Most documentation comes in the form of reports that are compiled and stored electronically. Reports consist of weekly reports of general progress, project reports documenting design details and issues, and final semester reports summarizing progress during the term. The other documentation includes standard review packages. These documents are updated by the individual team members, and reviewed by the systems leaders and external advisors. Documentation, platform, and drawing standards have all been set, allowing for full compatibility among team members. A password-protected document listserv is in place.

**Risk Mitigation and Technology Dependence.** Two mission critical areas are security and redundancy. Any satellite in orbit is susceptible to hackers. It is important that a proper security system is implemented to avoid losing control of the spacecraft. An unauthorized user repeatedly calling the satellite, or calling the satellite and hacking the system, could occur and possibly jeopardize the mission. A system was planned utilizing an encryption scheme that only allows authorized users into the system.

The only systems that were considered for redundancies were the communication system, power-on device, main computer, and deployment signal. These were the main systems that could not endure a single failure without the entire mission being jeopardized. Though there were other systems that were mission critical, many of them could have handled a small failure without being knocked off line, or were just too expensive or heavy to have backups.

HELEN LOUISE REED

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**Education:**

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|---|---|---|---|
| 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 University, Aerospace Engineering |
| Dec. 2004-present | Professor |
| Dec. 2004-Nov. 2008 | Department Head |
| Aug. 1985-present | Arizona State University (ASU) |
| July 1992-Dec. 2004 | Professor, Mechanical & Aerospace Engineering (MAE) |
| Aug. 1985-June 1992 | Associate Professor, MAE |
| July 2003-Aug. 2004 | Vice Chair for Graduate Programs, MAE |
| Dec. 1994-Dec. 2004 | Associate Director, ASU / NASA Space Grant Program |
| Aug. 1993-Aug. 1996 | Director, Aerospace Research Center |
| Sept. 1991-June 1992 | Tohoku University, Sendai, Japan, Associate Professor |
| July 1983-Aug. 1983 | Sandia National Laboratories, Summer University Faculty |
| Sept. 1982-Aug. 1985 | Stanford University, Assistant Professor, Mechanical Engineering |
| June 1977-Dec. 1981 | NASA/Langley Research Center, Aerospace Technologist |

**Research and Teaching Interests:**

Boundary-layer transition and flow control, hypersonic flow, micro-/nano-satellite design, responsive systems – software and hardware architectures, autonomous rendezvous and docking, micro aerial vehicles (MAVs), integrated concurrent engineering and systems design, numerical methods. Recent accomplishments include:

- ASUSat1: 6-kg student nanosatellite; ***launch*** Jan. 26, 2000 on 1st Air Force OSP SLV
- Three Corner Sat (3CS): 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
- LONESTAR/DRAGONSat: 8-year campaign with NASA JSC to launch 4 student missions with end goal of Autonomous Rendezvous and Docking – 1st mission AggieSat2 ***to be launched*** 2009 on STS 127
- ASUSat3: Part of the Air Force's University Nanosat III Program. 2003-2005
- AggieSat1: Part of the Air Force's University Nanosat IV Program. 2005-2007
- AggieSat3: Part of the Air Force's University Nanosat V Program. 2007-2009
- MIMIC: Nationwide students design satellite to measure Mars magnetic field. Science from Mars Exploration Program Assessment Group. Designed to piggy-back on JPL mission. 2002-2005.
- SubSEM/SEM: In June 2000, 5 students did Orion sounding-rocket mission out of NASA Wallops. In August 2001, STS 105 carried ASU's STARS for local K-12 students.
- AZeroG: 4 teams of undergrads have flown microgravity experiments on the KC-135. 2001-2003
- ASU CanSat: Students build soda-can-sized "spacecraft" to launch by amateur rocket. Technical elective class at ASU "Preliminary Mission Analysis and Spacecraft Design"
- ASU BalloonSat: Student experiments on high-altitude balloons. Spin-off for Arizona K-12 in-service teachers and their students. Video on NASA Channel 29 Dec. 2003. 2003-2004
- Aggie BalloonSat: Student experiments on high-altitude balloons. 2005-2006 Boeing Interdisciplinary Senior Design Class at Texas A&M
- Moon Devils: 10 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. 1995-2004
- Lead computational person in several major experimental and flight-test programs to demonstrate Saric-developed discrete-periodic-roughness laminar-flow technology for swept wings.
  - DARPA Quiet Supersonic Platform, F-15B NASA-Dryden, wind-tunnel tests NASA-Langley
  - Air Force HiLDA/Sensorcraft program and O-2 flight tests at Texas A&M

- Collaborate with Lockheed Martin and Northrop Grumman
- Stability and transition of hypersonic chemically reacting boundary layers. Co-PI on new 5-year, $10M "NASA/Air Force National Hypersonics Science Center in Laminar-Turbulent Transition"

**Awards:**

- Fellow, American Institute of Aeronautics and Astronautics, 2008
- Fellow, American Physical Society, 2003
- Fellow, American Society of Mechanical Engineers, 1997
- AIAA /ASEE J. Leland "Lee" Atwood Award, bestowed annually upon an aerospace engineering educator in recognition of outstanding contributions to the profession, 2007
- Academy of Engineering Excellence, Virginia Tech, 2008

- Excellence in Service Award, ASU Alumni, Founders' Day, 2003
- Distinguished Mentor of Women Award, Faculty Women's Association, ASU, 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. 2002-2007
- 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
- 116 Invited Talks, 69 Relevant to Student Projects
- 31 Journal Articles, 33 Invited Papers, 90 Other Pubs (4, 3, 34, Relevant to Student Projects)

**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.
- Served on Science Advisory Board for National Institute of Aerospace, Deputy Co-Chair for National Space Grant Student Satellite Initiative Steering Committee, Chair of Aerospace Department Chairs' Association
- Presently
  - Member, AIAA Academic Affairs Committee, Jan 2007 – present.
  - Texas A&M Institutional Representative for USRA
  - Advisory committee for Aerospace programs at New Mexico State University, University of Washington, and Virginia Tech

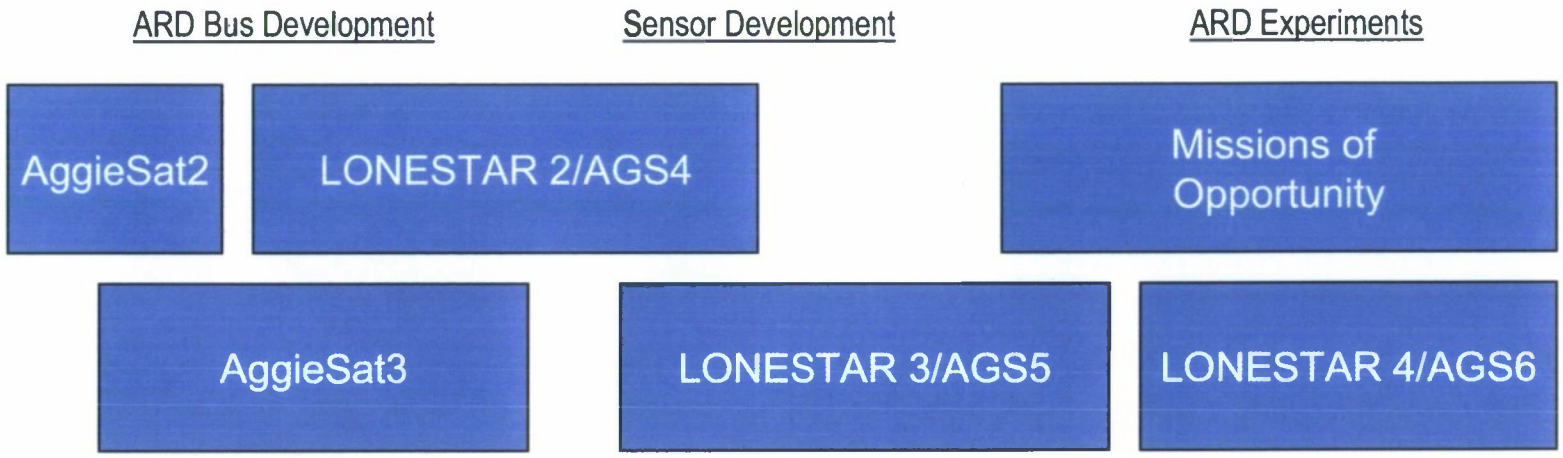

AggieSat3

# Texas A&M University
# University Nanosat 5
# PQR Presentation

# PQR Outline

- AggieSat Lab Strategic Campaign for Autonomous Rendezvous and Docking (ARD)
- AggieSat3 Mission Overview
- AggieSat3 Spacecraft Overview
- Design Status
- Resource Needs
- Program Schedule
- Program Budget
- Current Spacecraft Design and Development work
  - Software
  - Hardware

# AggieSat Lab Strategic Campaign for ARD




- Integrated ARD campaign with Air Force Research Lab (NanoSat Program) and NASA sponsored missions
- Multiphase campaign focusing on lab resource building, infrastructure and common hardware development, sensor development/testing, and ARD experimentation
- Building in house capability for proximity operations testing with Land Air and Space Robotics (LASR) lab

# Mission Statement

The AggieSat3 mission aims to investigate close proximity navigation utilizing a stereo vision system in an advancement toward autonomous rendezvous and docking missions.

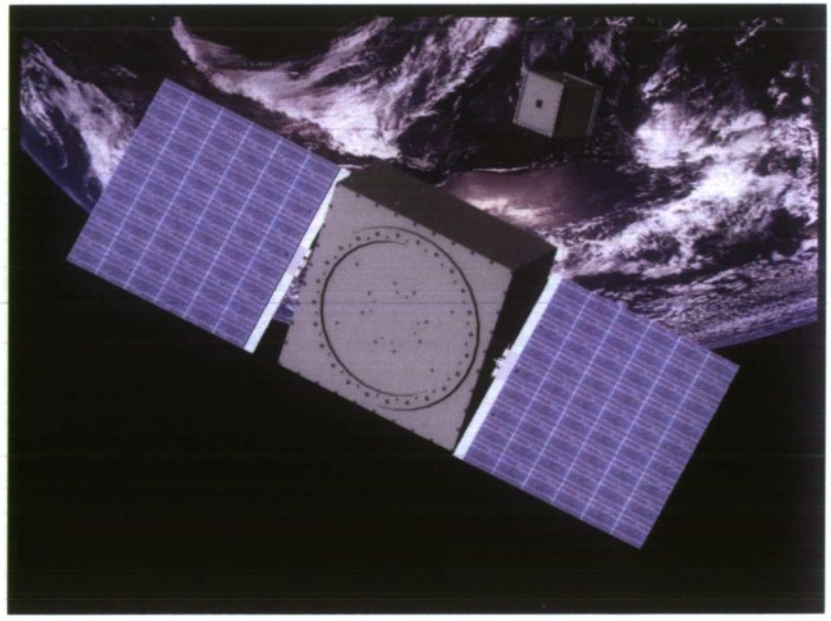
## Mission Objectives

Primary Objective

- Obtain verifiable data in space environment to characterize stereo based relative navigation system

Secondary Objective

- Characterize miniaturized GPS receiver and obtain differential tracking solutions between AggieSat3 and known target

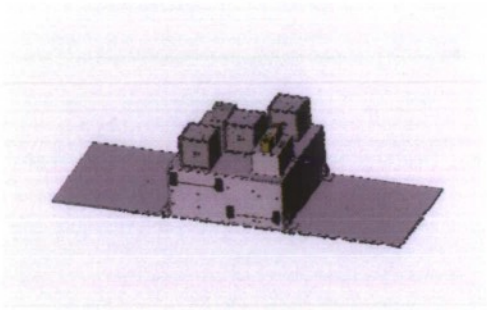


# Overview of the AggieSat ARD Platform

Goals

•To provide a capable and expandable student satellite platform for the AggieSat Lab to support NanoSat missions, the NASA JSC Autonomous Rendezvous and Docking campaign, and missions of opportunity

• To minimize recurring satellite development overhead



First generation ARD Platform (NanoSat5 "Pointing" Variant)

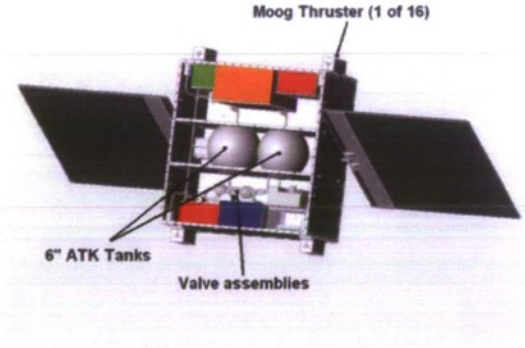
•44.5 kg Spacecraft
•3 Axis Stabilization
•28 V baseline power system, 120 W generated, 75 W available
•ARD bus structure
•Fixed solar arrays

Implementation

•Provide external reconfigurable payload carrier space for student payloads (up to ~55 lb)

•Provide upgradeable support systems internally for future mission requirements

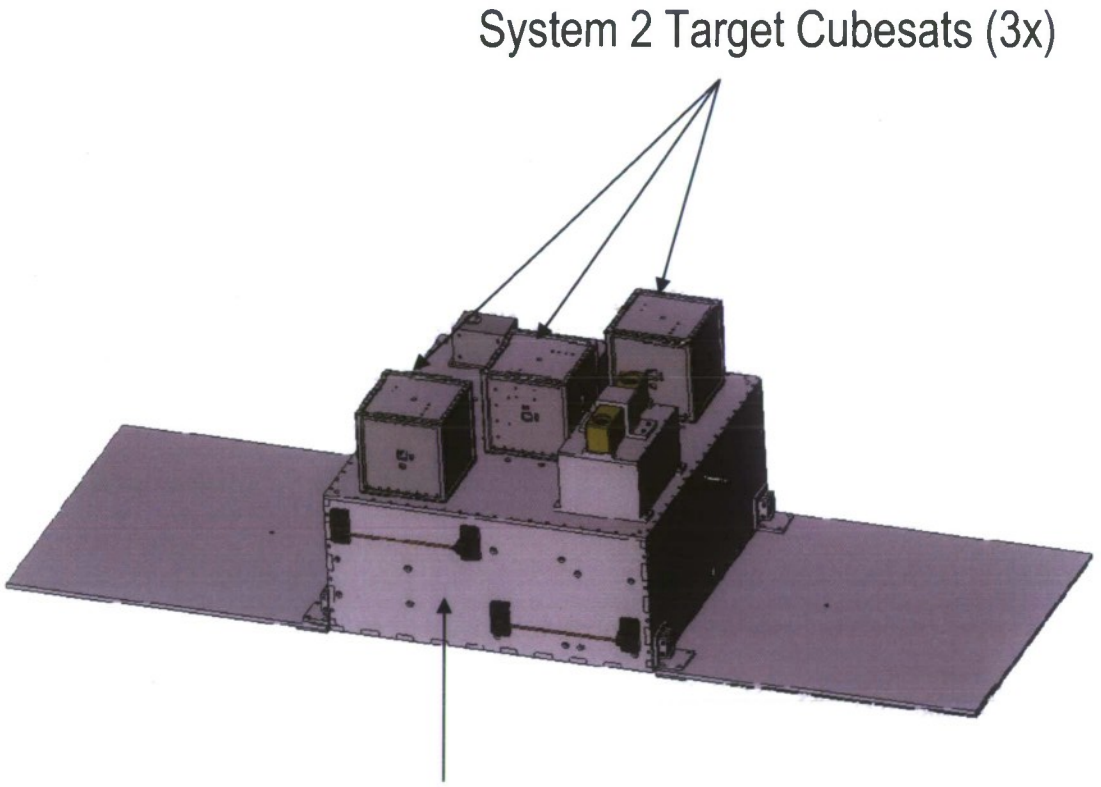
•Provide system space and capability for future advanced ADC and propulsion systems




Proposed concept for propulsion capable variant for (ARD Campaign mission 4)

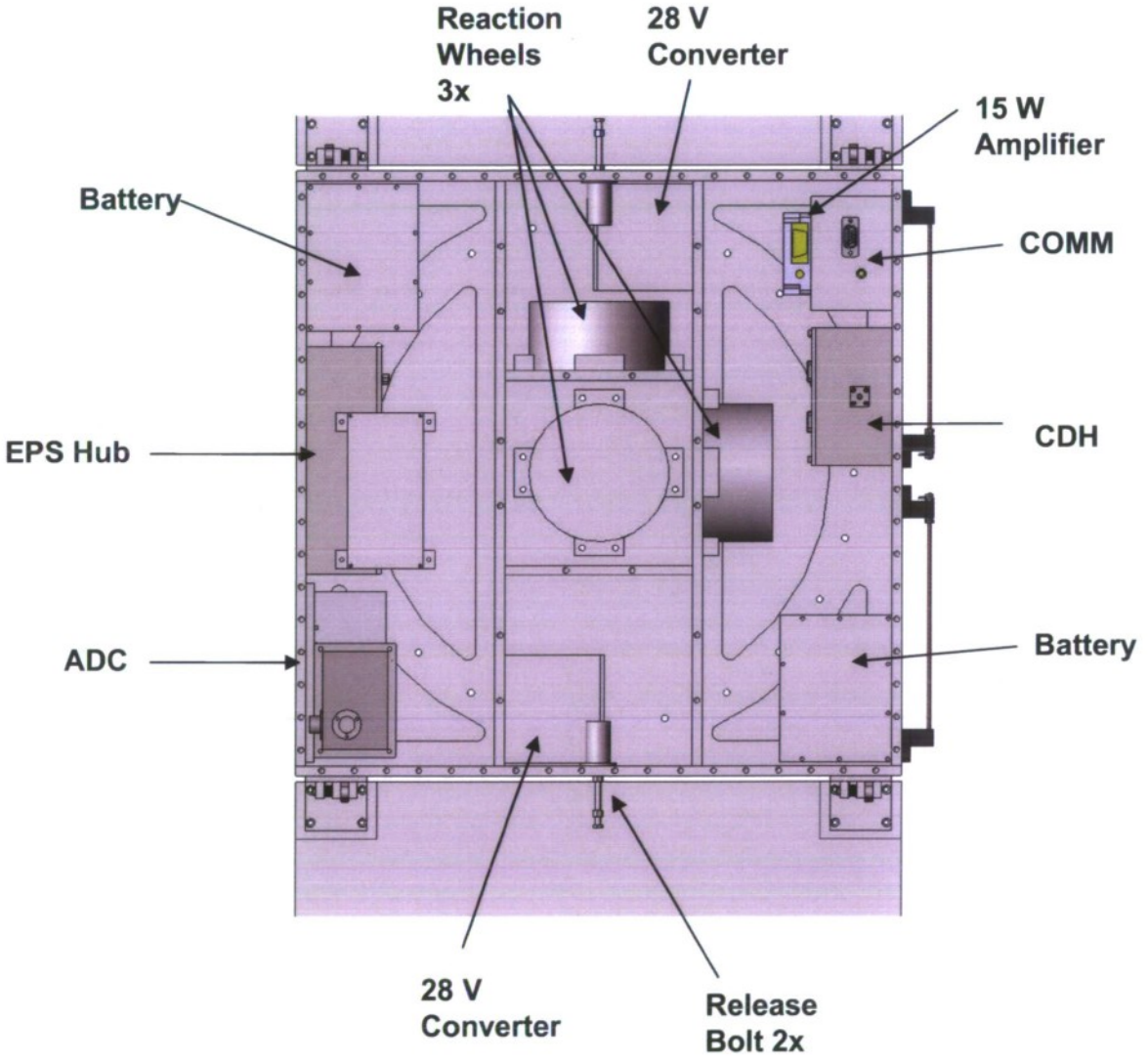
•Cold gas propulsion
•Evolved ADC system
•Articulated solar arrays

# Spacecraft Overview Cont.



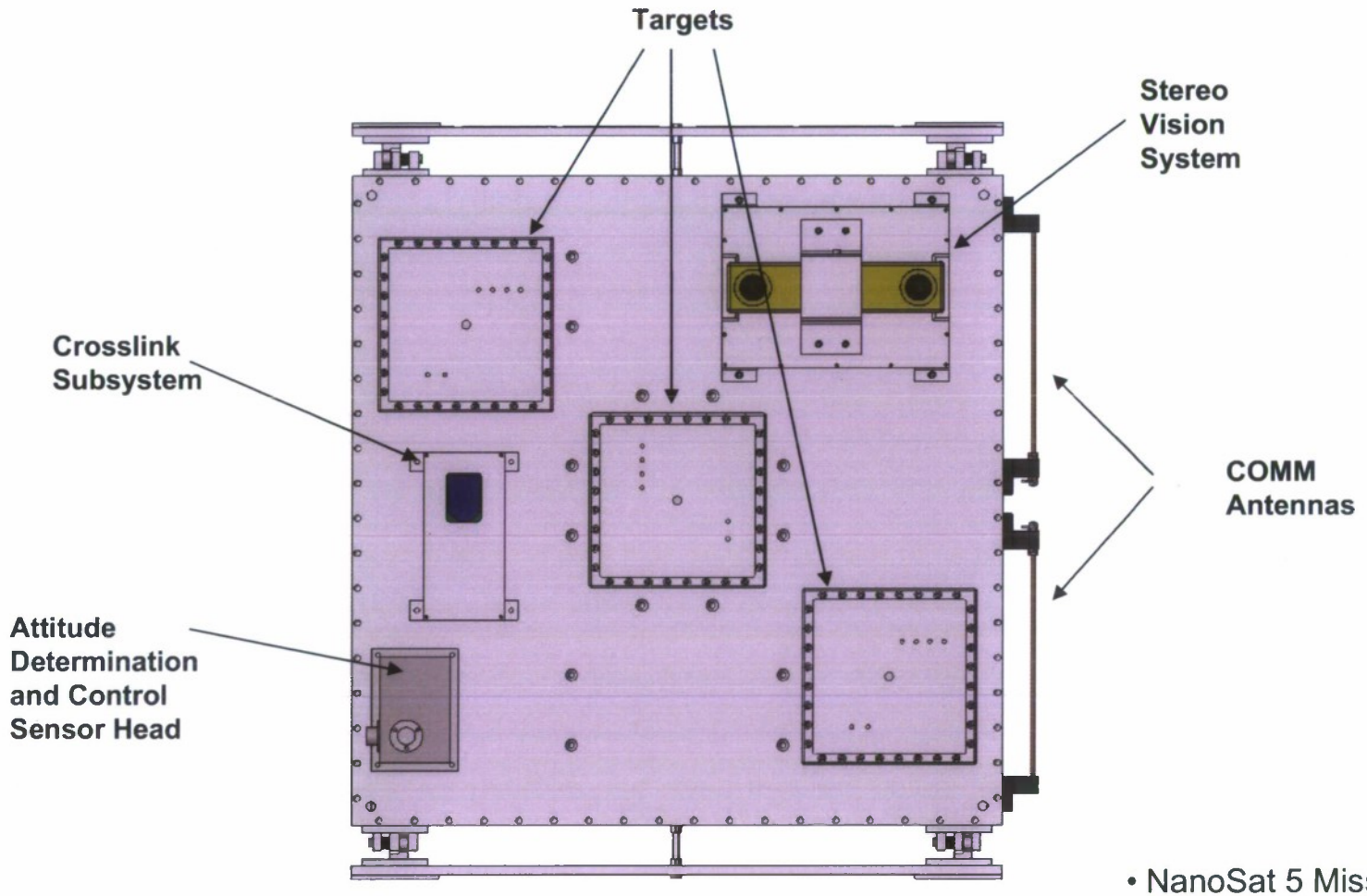

- System 3 Ground Support Equipment

# Spacecraft Overview Cont.




- First implementation of support bus for the ARD Platform

# Spacecraft Overview Cont.




• NanoSat 5 Mission Payload Deck Compliment for ARD Platform

# Mission Timeline

90 Day Nominal Mission

- Initialization Phase (~2 Days)
  - Day 1: Launch, charge/activation
  - Day 2: De-saturation of launch disturbances
- Stereo / GPS Phase (~ 2 Days)
  - Day 3-4: Target deployments (~1 orbit per target deployment, loiter for command and control, and conditions variance)
- Download Phase (Day 5 to End of Life)
  - Download mission data at regular intervals
  - Miscellaneous imaging opportunities, contingency experiment time, …
  - Continue to End of Life

Minimum Success 14 Day Mission (1 Target release, no GPS)

Medium 30 Day Mission (3 Target releases, no GPS, variations thereof)

# Design Status

- Awaiting funding to begin detailed design
  - Lab campaign and architecture defined
  - Basic configuration and systems studied and sized
  - Development Goals
    - Build on Sat2 experience to push in house power systems design
      - 28 V implementation with Lithium Ion power cells with full safety circuitry
    - Expand available modules and functionality to existing Sat2 software architecture
      - Implementation of a "suite" of responsive, reconfigurable modules for future missions
    - Utilize new LASR laboratory at Texas A&M to study and refine ARD goals. This facility will allow the testing of command and control algorithms, sensors, sensing technologies prior to flight test implementation

# Resource Needs

- Estimated $2 million development and implementation cost for 2 Flight Units
  - ADC Subsystem sensors and control actuators are budget drivers
  - Current estimate assumes student worker payroll rates
- Development time estimated at >90,000 man hours
  - Goal is to double student worker count (from 25 to 50) with establishment of funding
  - Interest in striking partnerships with professional engineers from industry

# Program Schedule

Aug '08-Feb '09 – AggieSat2 flight build, qualification and acceptance

Mar '09- Mar '11 – AggieSat3 spacecraft critical design, Engineering Test Unit build and testing, prox-ops testing

Mar '11- Jan '13 –Flight Unit Build, preliminary qualification testing
Jan '13- May '13 – Preparation for acceptance

**Jun '13 – Flight Unit Delivery**

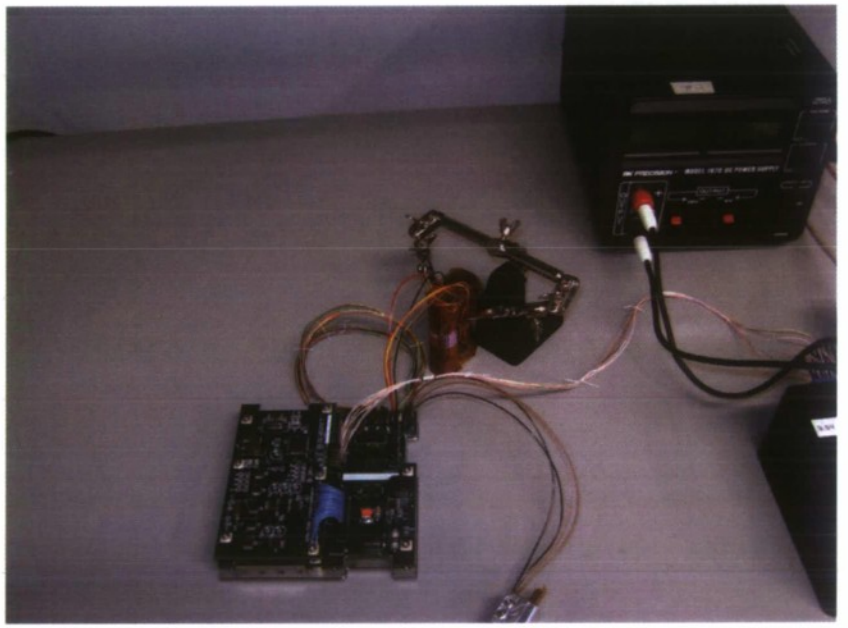
# Software Systems and Processes

- Reusable software libraries and modules for embedded microcontrollers and single board computers
- Continued development of modular ground command and control system (Client)

- Development systems and processes in-place
  - **Subversion** – Source code management
  - **Trac** – Ticket system for tracking issues using Wikipedia style system for organizing project information
  - **Release Process** – Test suite for validating software requirements before a new software version is released

# Hardware Development

- Command and Data Handling (CDH) System
  - Circuit design and fabrication
  - Experience using microcontrollers and single board computers for processing, commanding, and controlling
- Electrical Power System (EPS)
  - Experience with design of solar cell power generation and distribution/regulation systems
  - Experience designing and fabricating charging and safety circuits
  - Li-ion battery safety, use, charging



# Hardware Development (cont'd)

- Communications (COMM) System
  - Experience with serial modems
  - Patch and monopole antenna design, manufacturing, and testing (VSWR, gain)
  - Built in house in cooperation with the EE department

- Assembly, Integration, and Testing
  - Experience with creating and following assembly and test procedures
    - Two person build
  - Experience with wire harnessing and cable routing

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