# CanSat Competition

## Contributing to the Development of NASA's Vision for Robotic Space Exploration

A report prepared for the

**Exploration System Mission Directorate (ESMD) Space Grant Project Student Systems Engineering Paper Competition**

By

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# Executive Summary

CanSat is an international student design-build-launch competition organized by the American Astronautical Society (AAS) and American Institute of Aeronautics and Astronautics (AIAA). The competition is also sponsored by the Naval Research Laboratory (NRL) and the National Aeronautics and Space Administration (NASA). The CanSat competition is designed for college, university and high school students wanting to participate in an applicable space-related competition. The objective of the CanSat competition is to complete space exploration missions by designing a specific system for a small sounding rocket payload which will follow and perform to a specific set of rules and guidelines for each year's competition. The competition encompasses a complete life-cycle of one year which includes all phases of design, integration, testing, judging and competition. The mission guidelines are based from space exploration missions and include bonus requirement options which teams may choose to participate in.

The fundamental goal of the competition is to educate future engineers and scientists. This is accomplished by students applying systems engineering practices to a development project that incorporates an end-to-end life cycle, from requirements analysis, through preliminary design, integration and testing, an actual flight of the CanSat, and concluding with a post-mission debrief. This is done specifically with space related missions to bring a unique aspect of engineering and design to the competition. The competition has been progressing since its creation in 2005. The competition was originally meant to purely convey the engineering and design process to its participants, but through many experiences the competition has also undergone a learning experience with respect to systems engineering process and design.

According to the NASA Exploration System Mission Directorate (ESMD), one of the main goals is to support technologies and foundational research that enables sustained and affordable robotic exploration. The main purpose of this report is to describe how the lessons learned in participating in the CanSat competition, from 2006 to 2008, contribute to the development of NASA's vision for educating future engineers and scientists in the disciplines of systems engineering and robotic space exploration.

### Table 1: Applicable Documents

| Document Title | Description of Document |
|---|---|
| 2008 CanSat Competition Design Guide | Outlines the requirements and missions for the competition |
| Practice Standard for Work Breakdown Structures (Second Edition) | Provides guidance and universal principles for the initial generation, subsequent development, and application of the Work Breakdown Structure . |

## Table of Contents

# 1.0 Introduction

## 1.1 Objective

CanSat is a unique space design competition in that is allows for teams to actually implement their designs through construction and competition. Sponsored by the AIAA and the AAS, the annual CanSat competition features a planetary exploration theme. Teams of up to ten students have the mission of designing and building a CanSat that is launched and deployed from about 760 meters altitude. The CanSat must land and come to rest in its upright position. Appendix A lists the minimal requirements for the CanSat. In order to meet these requirements, the team is responsible for designing, constructing, and testing structures, mechanisms, communications devices, and automated control devices.

The primary mission of the NASA ESMD is to support technologies and foundational research that enables sustained and affordable robotic exploration. This report describes how the CanSat design competition promotes the development of future engineers and contributes to NASA's ideas for robotic space exploration. The CanSat competition goes beyond most space competitions by employing the participants to fabricate and test components and subsystems. Engineering and science students gain the experience of working on a systems engineering project from concept through flight test. This approach to the competition increases the complexity of the project and the demand for greater emphasis on employing good systems engineering practices with effective project management.

## 1.2 Background Information

The CanSat is literally what its name implies; a satellite the size of a soda can. The team's mission is to create a small landing module, which fits in an amateur rocket payload bay, measuring 72 mm in diameter and 280 mm in height (See Appendix A, Figure A-1). The CanSat is launched to an apogee of approximately 760 meters, where it is released from the rocket. A parachute is used to control the decent, and upon landing, mechanisms are activated to place the CanSat in the upright position. Our design has the CanSat coming to rest on its side, then employing spring loaded legs, which will push open the side walls of the CanSat in three locations, forcing it into its upright position. During the entire flight, altitude telemetry will be communicated to the ground station at regular intervals. These requirements; landing in the upright position, descending at a controlled rate, functioning autonomously, and transmitting telemetry, make up the CanSat primary mission.

The primary mission is successfully completed if all minimal CanSat requirements are met. In addition points are next awarded for completing bonus missions. The bonus missions involve useful work that a landing module performing planetary exploration may accomplish. Our design will implement a drill for taking a 5 gram soil sample, a probe for sampling the ground temperature and below ground temperature, and a probe for measuring wind speed and direction. Other considerations include taking a 360° panoramic image and autonomously landing at specific coordinates provided at launch.

## 2.0 Systems Engineering Process

The generalized System Engineering Process Model is depicted in Figure 1 (Defense Systems Acquisition Process). The numbering scheme shown in the diagram follows the flow of the section numbering for this report.

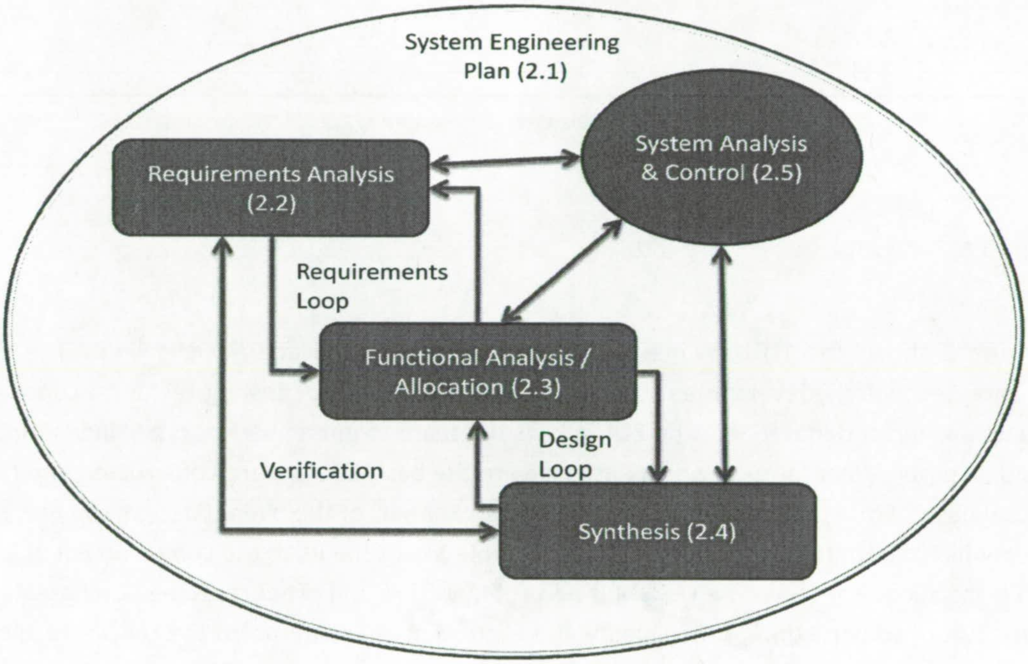


Figure 1: Systems Engineering Process Model

## 2.1 Systems Engineering Process Planning

System engineering planning is the first step in the System Engineering Process. Figure 1 shows planning encompasses the four major steps of the System Engineering Process leading to successful completion and operations of a system. The analysis was used to develop an initial plan of how to best organize and manage people, resources, and materials needed for the project. The analysis used Program Evaluation and Review Technique (PERT) as the network model. Tasks, sequence of tasks, and estimated time required to complete tasks were identified to construct a network diagram based on the PERT model (Refer to Appendix B for equations for estimated time for tasks). The network diagram was used to develop the Critical Path Model (CPM) and identify the following major tasks and milestones: Preliminary Design Review (PDR), Engineering Development Unit (EDU), Long-lead Bill of Materials (LLBOM), Quality Unit (QU), Critical Design Review (CDR), Flight Unit, and the launch date. The milestones are illustrated in the process plan for the construction of the CanSat in Figure 2. The next sub-section of the systems engineering process planning explains each milestone in greater detail.

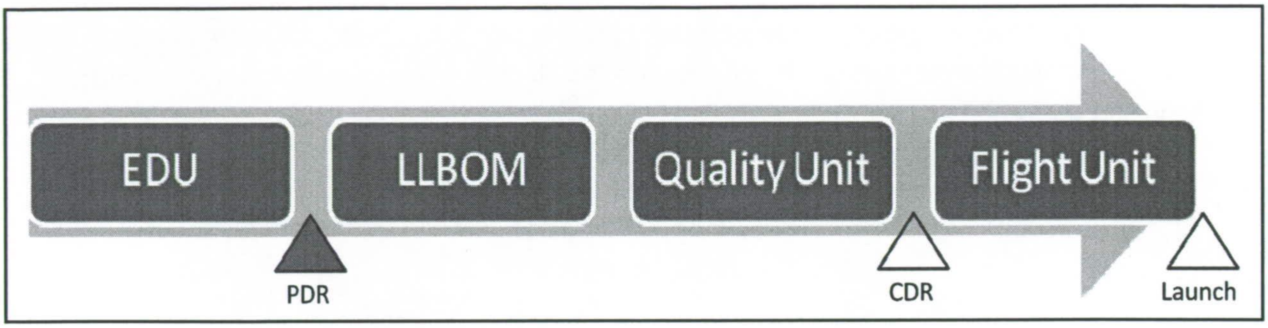


Figure 2: Process Plan for Construction of CanSat

### 2.1.1 Major Products and Results from Process

Figure 2 shows the EDU as one of the predecessors to the actual Fight Unit. The EDU is a separate early technology development that is used as a test-bed for testing technical concepts, sub-system functionality, and materials. The EDU allows the team to get a head start on understanding the system and its parts. To determine which designs were the best, EDU's were constructed and tested on a conceptual basis. From that conceptual testing and an analysis of the overall design, the team made a decision on which design to further pursue. After completion of the EDU, the Long-lead Bill of Materials or LLBOM is the successor task. The LLBOM is a list of materials and products to be purchased ahead of time for the future construction of the Quality and Flight Units. The items on the LLBOM resulted from the design process and ideas developed from the EDU. The items on the bill of materials are long-lead items because the project is operating on an academic calendar and that most of the items are purchased from internet vendors and require shipping. The lead time required for shipping can cause delays in the schedule, and any items not ordered ahead of time may cause the project to not finish on time.

The main purpose of the QU is to construct a system that is of comparable quality to the Flight Unit but used solely for component testing and subsystem development. The QU will determine the reliability, maintainability, and survivability of the design. Another process that is involved in the QU is the writing, performing, and analysis of tests. (Testing of the QU is discussed in further detail in section 5.2). The Flight Unit is the successor to the QU. The Flight Unit involves the final design and construction of the CanSat. It is the unit that will actually be launched. The only tests that will be performed on the Flight Unit are the calibration and diagnostic tests of subsystems as well as a test flight of the entire system.

Deliverables for the competition include the PDR, CDR, Flight Unit, and post mission debrief. Major products that are not deliverables for the competition include the EDU, LLBOM, and QU. The post mission debrief is an oral presentation of the major results and data obtained from the flight and is presented at the conclusion of competition.

### 2.1.2 Resource Allocation

An analysis of the 100% Rule as defined by the Project Management Institute (PMI) in the Second Edition of the *Practice Standard for Work Breakdown Structures* was used to guide the development of the Work Breakdown Structure (WBS). From this analysis, a deliverables-orientated WBS was developed to divide work into project phases as shown in Figure 3. The PDR, CDR, and Launch milestones served as the primary entry and exit criteria for the project phases. The chart shows all major tasks to be accomplished for each milestone.

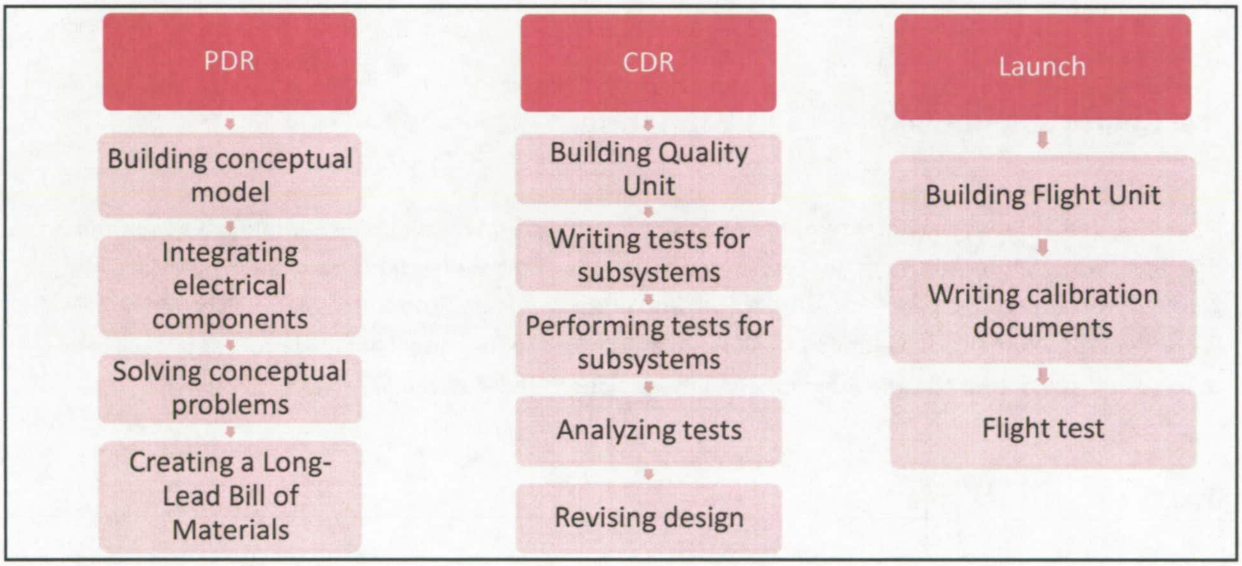


Figure 3: Detailed WBS Elements of each Deliverable

### 2.1.3 Constraints

The CanSat must meet specific constraints as outlined by the CanSat Competition Design Guide document (Refer to Appendix A for all of the minimal CanSat requirements). The constraints are designed to simulate specifications and requirements that real space programs encounter in design and construction of space systems (e.g. size and weight). The CanSat has specific dimensions and weight that directly correlate to the size and power of the launch vehicle. For actual payloads, engineers and scientists also must make sure that their design meets the specifications of the launch vehicle. One of the interesting contributions of CanSat to the future development of economical robotic space exploration is that in terms of payload size and weight, CanSat is much smaller than typical payloads. The reason for this reduction in weight and dimensions is that the CanSat does not travel in space. The CanSat is, however, a conceptual step in the right direction to designing more economical robotic space systems.

### 2.1.4 Verification Planning

Following the completion of the LLBOM, a new position on the team was created to lead the verification of the quality of the construction of the Quality and Flight Units. The position was named Quality Assurance (QA) and functioned in parallel to all of the other resources (mechanical, electrical, recovery, systems). The main purpose of QA was to ensure system quality and reliability. More specifically, QA is responsible for QU and Flight Unit test and verification to include material quality, subsystem functionality, and test procedures.

## 2.2 Requirements Analysis and Validation

Table 2 shows the Requirements Analysis decomposition methodology employed by the team. The first two columns list the major system requirements and specifications provided by CanSat Competition Panel, which include AIAA, NASA, and other sponsors. The third column lists derived functional requirements developed by the team as part of the functional analysis process to facilitate system and subsystem design. Functional Analysis is described in detail in section 2.3 below.

Table 2: Decomposition of System Requirements and Specifications

## Functional Analysis

| **Primary Mission - System Requirements and Specifications** | | **Functional Requirements** *(Derived)* | **Electrical or Mechanical** | **Components and Integration** |
|---|---|---|---|---|
| Weight and Dimensions | • 500 grams<br>• 279.4mm in length<br>• 72.39mm in diameter | Platform Subsystem:<br>• Payload container and structural components<br>• Size, weight, and configuration of payload components, sensors, controllers, power supplies, wiring, etc. | • Mechanical | • Rocket tubing<br>• Fiberglass cloth<br>• G10 fiberglass sheet<br>• Hardware (bolts, screws, nuts, washers, threaded rods, etc.) |
| Payload deployment, operations, and landing | • Descend (Land) within seven minutes of deployment<br>• Descent rate < 4.6 m/s<br>• Release its parachute within 1m of the ground<br>Land in defined upright position or right itself within 10 minutes | Payload Subsystem:<br>•Payload release<br>• Parachute<br>• Parachute release<br>• Landing mechanism<br>•Mechanism to upright | • Mechanical<br>• Mechanical<br>• Mechanical<br>• Electrical<br>• Electrical & Mechanical | • Springs<br>• Servo<br>• Parachute<br>• Servo Controller<br>• Microcontroller |
| Data Communications | • Transmit altitude and location data every 5 sec<br>• All transmitters must:<br>- Be turned off after recovery<br>- Meet FCC regulations | Comm. Subsystem:<br>• GPS and Altimeter (and controller)<br>• RF Transmitter<br>• RF Ground receiver | • Electrical<br>• Electrical | • GPS<br>• Pressure sensor<br>• RF transmitter<br>• RF receiver |
| Cost | • Cost no more than $1000 | • COTS components are needed to stay within budget | | |
| | | Power Subsystem: | • Electrical | • Lithium Polymer Batteries |
| | | Controller Subsystem: | • Electrical & Mechanical | • Microcontroller |
| | | Ground Station Subsystem:<br>For operations monitoring and data acquisition | • Electrical | • Lap top computer<br>• RF Receiver<br>• Ground operations team |

| **Bonus Missions - System Requirements and Specifications** | **Functional Requirements** *(Derived)* | **Electrical or Mechanical** | **Components and Integration** |
|---|---|---|---|
| Perform 360° Panoramic Imaging of surroundings | Imaging Subsystem:<br>• Camera and controller<br>• Image viewer | • Electrical & Mechanical | • Wide angle lenses, lens mounts<br>• Pencam controller |
| Measure wind speed and direction at surface | Wind Measurement Subsystem:<br>• Barometer and controller<br>• Read-out mechanism | • Electrical | • Pressure sensor<br>• Temperature sensor |
| Extract 5 grams of soil | Sample Recovery Subsystem:<br>• Drill and controller<br>• Collection mechanism<br>• Controllers | • Electrical & Mechanical<br>• Electrical | • Dual gear box<br>• Drill bit |
| Measure ground surface temperature | Ground Temperature Measurement Subsystem:<br>•Temperature sensor<br>• Read –out mechanism | • Electrical | • Temperature sensor |
| Measure temperature 25mm below surface | Air Temperature Measurement Subsystem:<br>•Temperature sensor<br>• Read–out mechanism | • Electrical | • Temperature probe |
| Autonomously land at coordinates provided at launch | Autonomous Landing Subsystem:<br>• GPS and data downlink<br>• Guidance control | • Electrical & Mechanical | • GPS<br>• Microcontroller<br>• Servos |

### 2.2.1 Reliability and Survivability

The reliability of the Flight Unit will be dependent on the verification planning described in Section 2.1.4 as well as the test, evaluation, and calibration procedures described in Section 2.2.4. The survivability of the Flight Unit will be dependent on the revisions made to the design due to the analysis of tests conducted in Section 2.2.4.

### 2.2.2 Electromagnetic Compatibility

To ensure a smooth launch and strong communications and telemetry signals, it is imperative to conduct electromagnetic interference (EMI) testing on our QU. The first EMI test of the system will be for normal operation (expected GPS and RF readings) with no artificial interference applied. This will help to illuminate any latent interference problems due to the structure or materials of the CanSat. Next, the QU will be tested for proper operation with the added artificial interference of a metal container surrounding it. This extreme case of signal interruption will help to simulate the type of losses expected while the CanSat is within or near the sounding rocket that will be delivering it to altitude. Finally, EMI testing will attempt to simulate interference due to physical forces on the unit. The GPS receiver will be especially susceptible to physical interference, and so it is vital that we determine its durability. Section 2.2.4 describes procedure for vibration testing the electrical systems of the CanSat.

### 2.2.3 Human Engineering and Safety

CanSat is a design-build-launch competition; thus, a majority of time required on the project is in the machine shop. A safe work environment is the primary concern in the machine shop. Prior to being allowed to use any equipment in the shop, each member of the team completed a training session lead by an experienced technician. In addition to the safety precautions taken in the construction of the CanSat, safety is also a key concern during the competition. The Panhandle of Texas Rocket Society (POT ROCS) will be in charge of creating a safe launch site. POT ROCS is a Tripoli affiliated prefecture #92, with members holding Tripoli or National Association of Rocketry (NAR) certificates from Level 1 to Level 3.

### 2.2.4 Tests, Calibration and Certification Procedures

The tests for the QU will include vibration tests, electromagnetic interference tests, and drop tests. The Flight Unit will include calibration procedures as well as a test flight. The first set of tests to be performed on the QU will be the vibration testing. The vibration testing will be accomplished by introducing a forcing function onto the CanSat via a shaker. One or more points on the CanSat will be controlled to a specified vibration level. Two types of vibration test will be performed: random and a sine wave test. The Sine wave test will be performed to survey the structural response of the CanSat. The random test will be conducted to simulate the environment of a rocket launch. Selected and random electronic devices will be powered on and off during the tests. The purpose of running the vibration tests with the power on and off is to determine the quality of the electrical connections and of the data that is returned while under simulated conditions. Electromagnetic interference (EMI) tests will be performed after the vibration testing. The EMI tests are described in Section 2.2.2. The final test to be performed on the QU will be the drop test. It is the last test to be performed because it is the test with the most potential to cause irreversible destruction to the QU. The purpose of the drop test is to test the recovery subsystem, i.e. the parachute, as well as to the test the survivability of the structure.

The only test to be performed on the Flight Unit will be the actual flight test. Additionally, the calibration procedures for the Flight Unit will be an analysis of the data obtained from the QU as well as the minor adjustments to the payload subsystems that are necessary per the preflight checklist. All tests and calibration procedures will be documented to the system and subsystem level. Calibration procedures will be certified. All calibration tests, data, results, etc. will be documented.

## 2.3 Functional Analysis and Allocation

A functional analysis of a system involves defining the internal and external requirements of a system to function and provide optimal performance. Refer back to Section 2.2 Table 2. Column 3 "Functional Requirements (Derived)" lists and allocates the functions to synthesize (design and build) the CanSat. The system allocation provides an analysis of these requirements and provides the appropriate distribution of the requirements to the corresponding functional division and sub-systems. The functional analysis and allocation is one of the first and most important steps of any design process. The System Analysis and Optimization (Figure 4) represents the overall design process and provides a visual representation of the functional analysis and allocation step in relation to the rest of the design process.

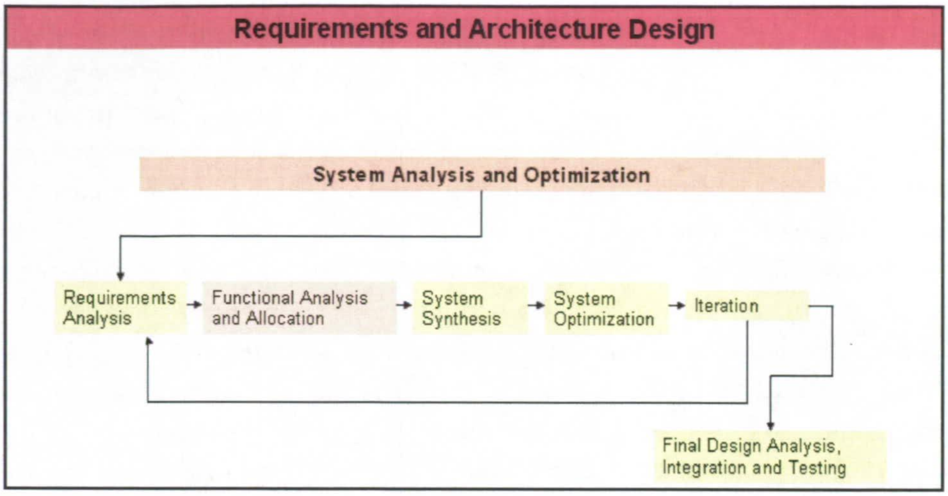


Figure 4: System Analysis and Optimization

Functional analysis and allocation involves the requirements analysis results to be allocated to the proper system and subsequently analyzed to the proper sub-system and mission performance. Each system must first be defined and then decomposed into the appropriate sub-system divisions. Each system and sub-system divisions must also have defined functions and responsibilities which may be co-dependent. The appropriate sub-systems must be properly interfaced based on the defined functions and dependency. This interface can also be defined from system and requirement failure analysis, which may lead to functional analysis iteration to the system definition. Lastly, before forwarding to the system synthesis step, the systems and sub-systems must be properly integrated by design. The proper analysis and implementation of this step may save a large amount of time and effort from the system synthesis and testing phases. Figure 5 provides a visual representation of the general functional analysis and allocation procedure.

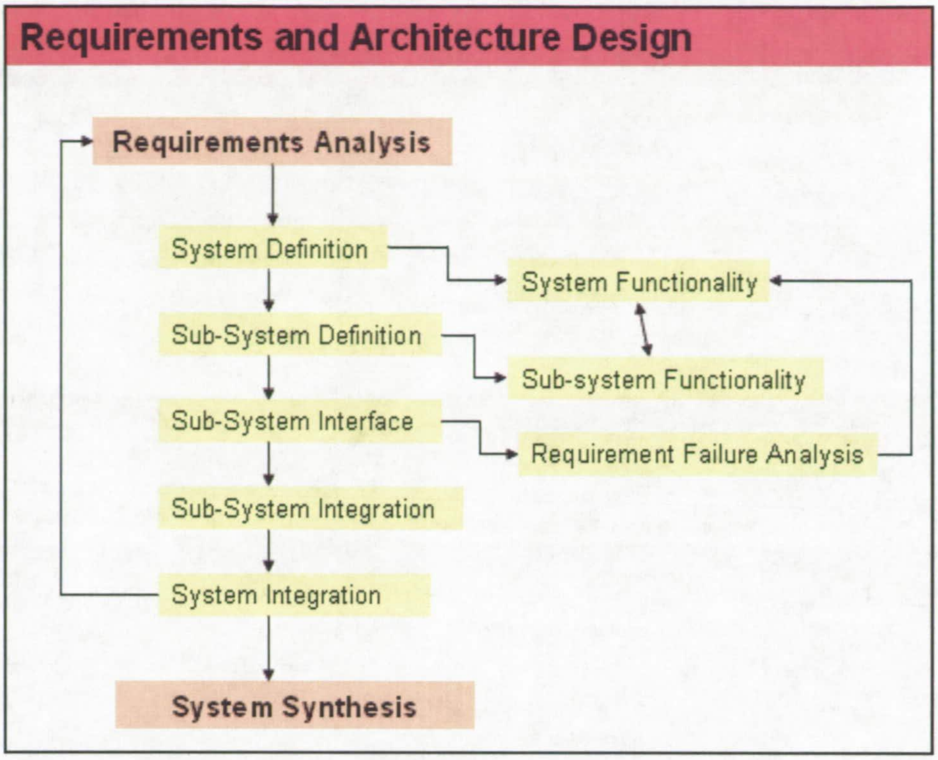
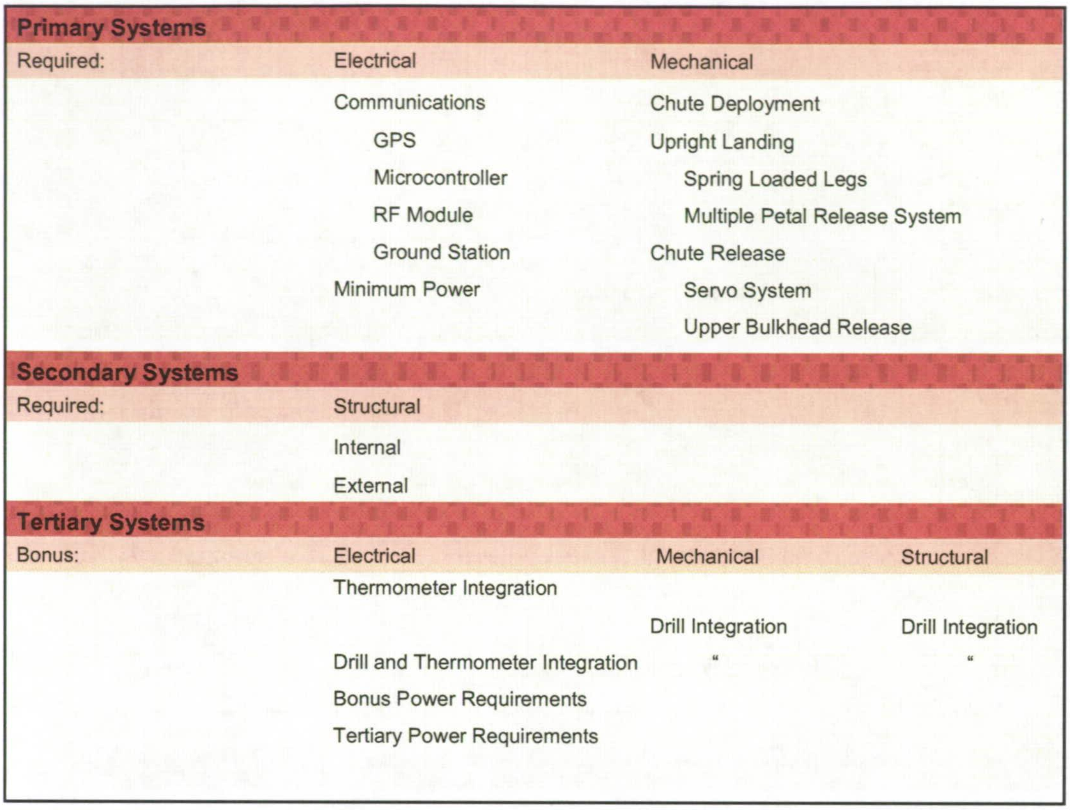


Figure 5: A visual representation of the general functional analysis and allocation procedure.

For the CanSat competition and early design process, the functional analysis and allocation involves specific external requirements, and is derived from overall mission performance, where the appropriate required systems and bonus systems are defined and properly interposed into the functional responsibilities. Table 3 shows the results of our CanSat functional analysis and allocation. The chart identifies the specific systems and subsystems to which to design and fabricate the CanSat to. These results aided the team allocate requirements and responsibility for the various subsystems and functions across the team.

Here, the primary systems involve all systems and sub-systems which directly impact the overall competition and flight requirements with respect to CanSat flight performance. The primary requirements are communication with the satellite, parachute deployment and release, CanSat landing, and power. The systems impacted by these primary requirements make up the primary systems: mechanical and electrical. The secondary system is the structural system, which does not impact the primary requirements, and involves both the internal and external structural integrity. The tertiary systems are determined from the allocated bonus objectives requirements. The combination of surface temperature, soil drilling and depth temperature requirements have all been allocated to impact different, tertiary systems.

Table 3: Illustrating the functional analysis and allocation specific for CanSat



| | | | |
|---|---|---|---|
| **Primary Systems** | | | |
| Required: | Electrical | Mechanical | |
| | Communications | Chute Deployment | |
| | GPS | Upright Landing | |
| | Microcontroller | Spring Loaded Legs | |
| | RF Module | Multiple Petal Release System | |
| | Ground Station | Chute Release | |
| | Minimum Power | Servo System | |
| | | Upper Bulkhead Release | |
| **Secondary Systems** | | | |
| Required: | Structural | | |
| | Internal | | |
| | External | | |
| **Tertiary Systems** | | | |
| Bonus: | Electrical | Mechanical | Structural |
| | Thermometer Integration | | |
| | | Drill Integration | Drill Integration |
| | Drill and Thermometer Integration | " | " |
| | Bonus Power Requirements | | |
| | Tertiary Power Requirements | | |

As the CanSat design and integration continues the functional analysis and allocation may be periodically influenced by future feedback. This can happen through design iteration, failure analysis, testing, or system optimization. It is important to realize that the functional analysis and allocation represented here is based on the preliminary design, integration, and testing.

## 2.4 Synthesis: Factor-Dependent Approaches and Methods

### 2.4.1 Commercial Off-the-Shelf (COTS):

Products that are readymade and available for sale, lease, or license to the general public are defined as Commercial-Off-The Shelf (COTS) items. The primary advantage of COTS items is the significant financial savings in procurement, test, and maintenance. The primary disadvantage is that future changes to the product are not under the design team's control.

COTS items will reduce the overall system development costs and development time because components can be purchased, instead of being developed entirely from concept. Users of COTS must be aware of the potential pit-falls and plan accordingly. For example, by the time of implementation, the design team from the previous year (2006 – 2007 CanSat Team) came in drastically under the budget; and thus had gained leverage only in a financial aspect by using COTS. Reliance on COTS items nevertheless increased dependency on third-party vendors and the time required for component integration. The design schedule for the CanSat Competition in 2006 did not allow sufficient time for integration of components and consequently forced the team to forgo the construction of QUs. The brutal realization of component integration readiness was realized when a material subjected to cyclic loading during testing and integration of the internal structure was used as the actual Flight Unit structure. This inevitably led to the failure of the Flight Unit at competition, and vividly displayed that components designed solely to be used in the conceptual phase cannot be used in the Flight Unit.

Due to our reliance on third party vendors, shipping costs became one of the team's greatest financial burdens. For example, a hundred dollar shipping bill for a camera (only costing ten dollars) for overnight shipping to the competition site, due to lack of testing and integration time, displayed how dependent the team was on online vendors for replacing components. To place that expenditure in perspective, in a complete design that was allotted only two thousand dollars, this shipping bill represented five percent of the entire budget.

Figure 6 displays not only the interaction between the 3rd party vendors and the design team, but also the complete reliance on these vendors for component replacements. Replacing components during the integration phase of the design was an absolute certainty due to the fatigue and sometimes ultimate failure in components during testing. The diagram emphasizes the time lost during shipping. It is also important to note that the design team could not be reimbursed the shipping costs, but simply accumulated them as sunk costs.

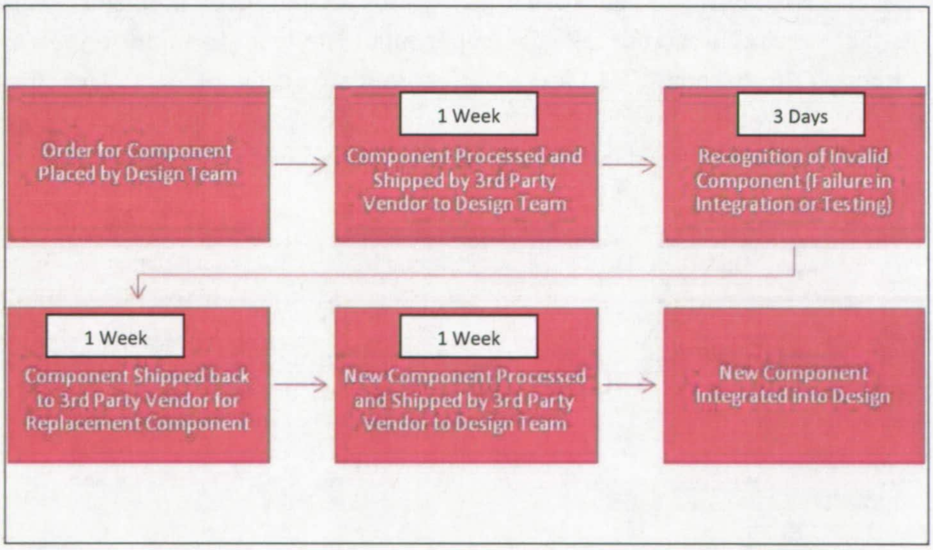


Figure 6: Diagram displaying reliance on 3rd party vendors with focus on time lost during integration

Additional orders for new components had to be placed because each part of the optical system (camera lenses, lens mounts, camera controller) was a separate COTS sub-component. Frequently specific parts and sub-components from the separately purchased items had to be dismantled in order to fabricate the optical system. Consequently, physical and electrical integration was not fully achieved. The time lost waiting for this entire process to be completed overran our expected integration time and thus led to the failure of integrating our optical subsystem correctly at competition. Figures 7 and 8 are two integral parts of the optical system that caused last year's team technical problems and schedule slip.

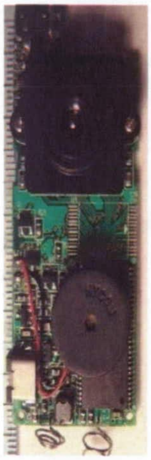


Figure 7: Aiptek Pencam Trio VGA+

Figure 8: Sunex DSL209A Wide Angle Lens

Tables 4 and 5 compare last year's and this year's approaches (respectively) to using COTS and Non-COTS Products. Note how this year's team is mitigating COTS related problems by avoiding those COTS products that require integration of sub-components. The team has transformed more primary components from COTS to non-COTS, accepting more parts expenses and (simple) component fabrication in order to reduce overall integration time. This year's objective is to avoid turning commercial-off-the-shelf components into *custom*-off-the-shelf components; thus avoiding the need for tailored Non-Developmental Items (NDI).

Table 4: COTS vs. Non-COTS for Current Year (2007 – 2008 Competition):

| COTS | Non – COTS |
|---|---|
| **Servos** | Release Mechanism |
| **Microcontroller** | Drilling Tool (Bonus Mission) |
| **Parachute** | Structural Components (Outer Shell) |
| **Cameras** | Software |
| **Batteries** | |
| **Communications** | |

Table 5: COTS vs. Non-COTS for Previous Year (2006 – 2007 Competition):

| COTS | Non - COTS |
|---|---|
| Servos | Release Mechanism |
| Microcontrollers | |
| Structural Components (Outer Shell) | |
| Cameras | |
| Batteries | |
| Arduino (Open – Source) Software | |
| Parachute | |
| Communications | |

### 2.4.2 Open Systems Architecture

The Open System Joint Task Force (OSJTF) defines an open system architecture as "a system that implements sufficient open specifications for interfaces, services, and supporting formats to enable properly engineered components to be utilized across a wide range of systems with minimal changes, to interoperate with other components on local and remote systems, and to interact with users in a style that facilitates portability" (Oberndorf, ph. 3). According to this definition, the majority of the hardware and software of the CanSat design would not facilitate the standards necessary of an open system architecture. Due to the competition's encouragement to develop unique designs and the primary objectives of a "micro-rocket payload", the mechanical subsystems and open-source software development would be difficult to integrate over a wide range. In effect, one subsystem (mechanical or electrical) could not be removed or replaced without affecting the other subsystems. For example, if the micro-servos that perform the mechanical operation of the release mechanism were to be replaced with stepper motors, it would inevitably affect the control algorithms implemented by the microprocessor and created by the open-source software. Again, this is due to the uniqueness of the design and singular purpose of operation. The electrical systems block diagram in Figure 9 shows the interaction of the actuators, sensors, and microcontroller, in which many of the components cannot work independently of each other. The communications systems, however, would facilitate open system architecture due to the Federal Communications Commission (FCC) guidelines that must be followed for operation of the radio modem during competition.

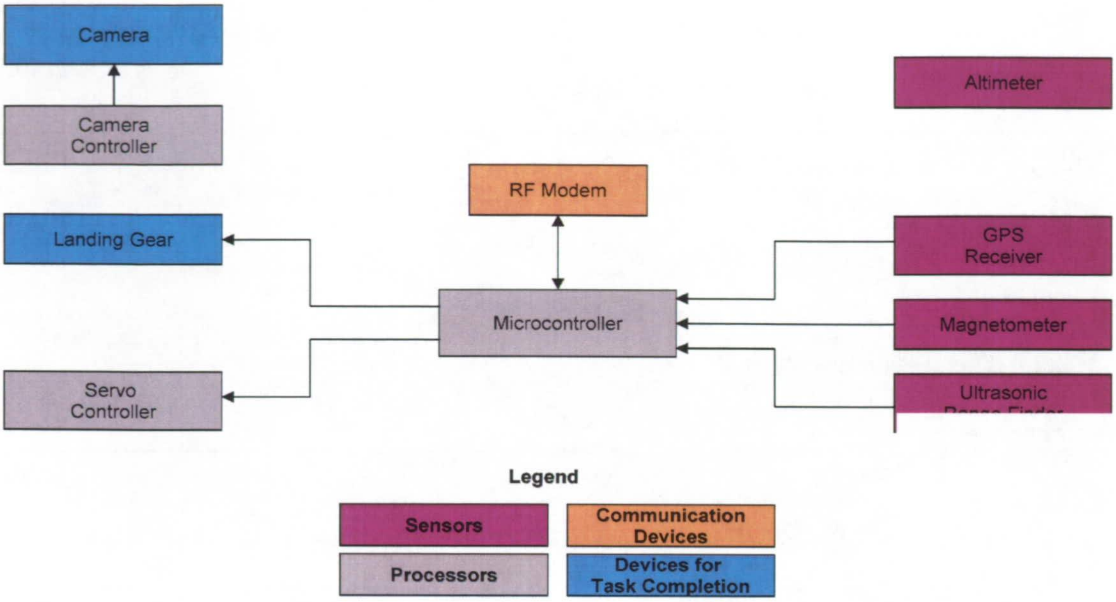


Figure 9: Electrical System Block Diagram: Displaying Dependence that Sensors and Actuators have with the Microcontroller

The competition guideline states, "Teams are allowed to use any radio frequency allowed by the FCC for unlicensed operations. This covers most 900 MHz radios and 2.4 GHz radios. Amateur radio frequencies can be used. If used, at least one team member must be a licensed amateur radio operator. Family Radio Service (FRS) radios cannot be used for transmitting data" (CanSat, pg. 4). From the previous year's experience, this guideline led several design teams to use the same radio modems with great similarities in the ground stations of each team. The MaxStream XTend RF Module (Figure 10), with a transmission rate of 9.6 Kbps was the communications choice for the majority of the teams; and will likely be used by many of the teams again this year, including the Virginia Tech team.

Figure 10: MaxStream XTend RF Module

### 2.4.3 Reuse

A major advantage in participating in this competition for a second year is the ability to discard components that failed during integration and testing last year and to reuse components that have already been designed, tested, and proven to work successfully. The combination parachute release and landing gear mechanism has been completely overhauled from the previous year, because last year's driving component, *Flexinol* Shape Memory Alloy, failed to work appropriately during testing and proved to be unpredictable during integration (Figure 11). This led the design to use a micro servo to drive the release mechanism of this year's design (Figure 12). Last year's team very successfully used servo mechanisms to reliably control a complex ram-air parachute. Thus, it was logical to use micro servos to control other mechanical subsystems.

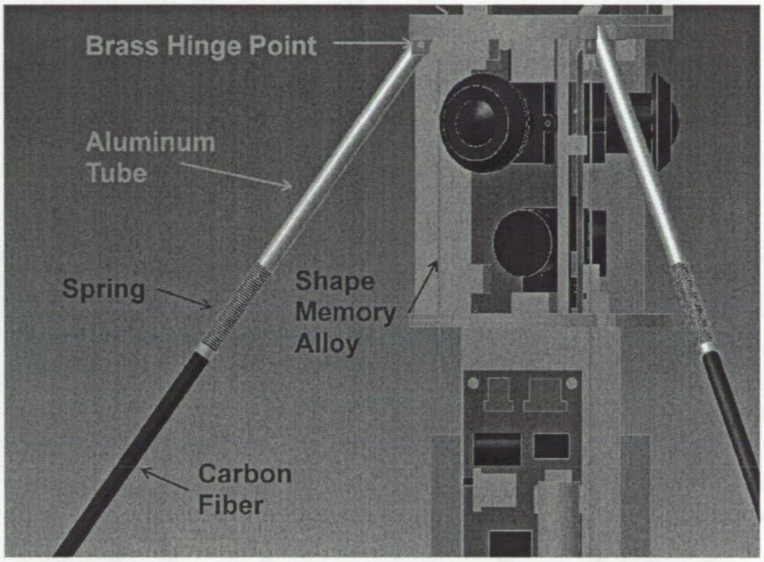


Figure 11: Landing Mechanism from 2006 – 2007 Competition Year that utilized *Flexinol* Shape Memory Allo

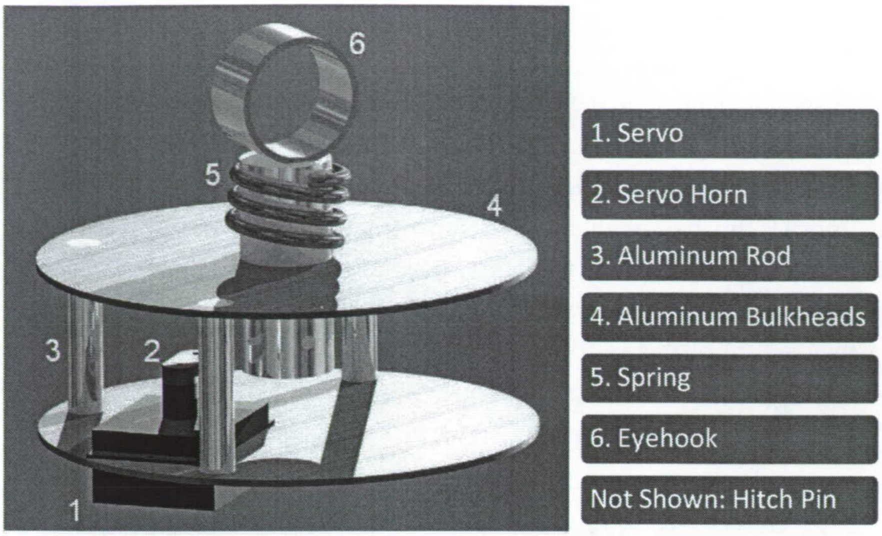


Figure 12: Parachute Release Subsystem for 2007 – 2008 Competition Year that Utilizes Servo Mechanism.

The landing gear is not show here because it is still under fabrication.

## 2.5 Systems Analysis and Control: Approach, Methods, Procedures, & Tools

### 2.5.1 Trade Studies

For this competition year, the trade studies have been focused on developing the mechanical subsystems, specifically the release mechanism and structure used to land in the upright position. Table 6 shows an example of one of the trade studies completed by the mechanical systems team in developing a release mechanism.

Table 6: Mechanical Systems Trade Study.

| **Scissor Design** | | **Umbrella Design** | |
|---|---|---|---|
| **Pro** | **Con** | **Pro** | **Con** |
| **Previous Materials Used** | Top Heavy | Worked – Texas Arlington Team | Less Internal Cross-Sectional Area |
| **Previous Experience** | Less Internal Cross-Sectional Area | Self-Righting | Exposed |
| | | Less Inner Volume | |
| | | Open | |

The result of the majority of the trade studies concluded with a choice between one of the options presented. However, in the table above, the final design of the release mechanism was able to benefit from a combination of both designs, thus taking advantage of the positive attributes of each design while minimizing the negative elements. The trade studies conducted during the preliminary design phase focused on design elements, while trade studies going into the critical design phase of the project will focus primarily on structural strength, weight, power consumption, and volume conservation. These four metrics will determine the components that will be tested in the QUs during the testing and integration phase.

Trade studies that were conducted in the previous year's competition are shown in Table 7 given below. These trade studies of mechanical components, optical layouts, etc. have been advantageous in reducing the research and development phase for this year's design. Figures 13 and 14 show the weather balloon drop tests and the rocket tests. Similar trade studies and tests will be refined and employed this year.

Table 7: Trade Studies from pervious competition year.

| | |
|---|---|
| **Servo Mechanisms:** | Micro, Mini, Pico |
| **Imaging System:** | Multiple Cameras, Rotating Cameras |
| **Testing Methods:** | Rocket Launches, Tethered Weather Balloon Launches, Indoor Drop Tests |

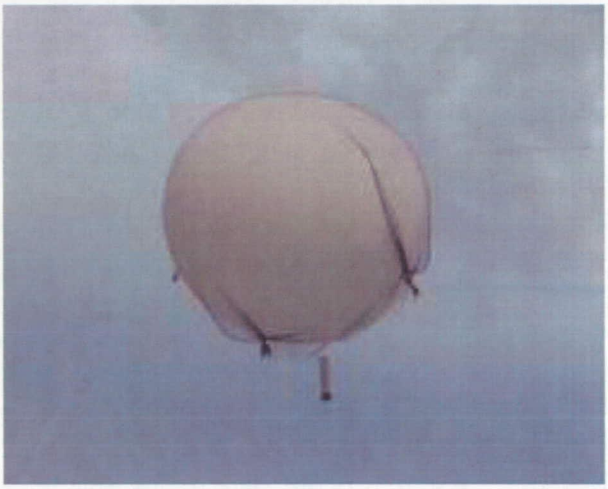


Figure 13: Tethered Weather Balloon utilized in Recovery Systems Drop Tests and Validation of Ram Air Parachute

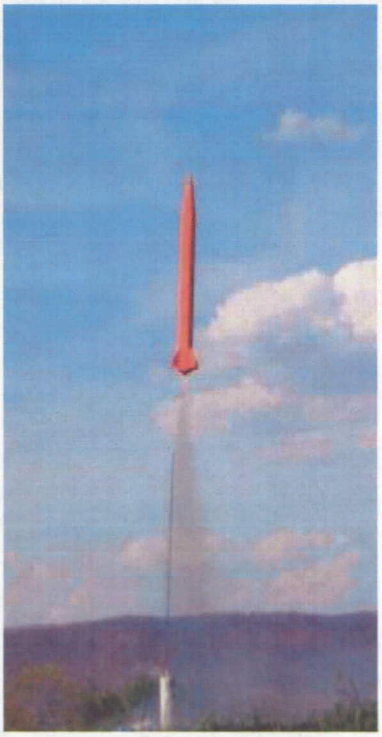


Figure 14: Rocket Tests of Integrated Quality Unit of CanSat – Testing Interaction of Recovery and Electrical Subsystems

### 2.5.2 System Cost-Effectiveness Analysis

The greatest budgeting failure that occurred in last year's competition was the disorganized purchasing of online items and the tolerated shipping costs that accompanied them. Excessive expenditures due to ordering one item at a time from several online vendors, instead of ordering several items in bulk from a few select vendors led to more than ten percent of the budget being spent on shipping costs. In order to avoid this same failure, the design schedule has been devised to have periods of obtaining components instead of the more concurrent approach of ordering, testing, integrating, and then re-ordering that was taken in the previous year.

Using the Cost Effectiveness Ratio determined by the *American College of Physicians*:

Source: ACP

$$CE\ ratio = \frac{cost_{new\ strategy} - cost_{current\ practice}}{effect_{new\ strategy} - effect_{current\ practice}}$$

The two "costs" in question are the actual capital provided by the sponsor and the amount of time available to complete the construction of the design. Both are equally valued because of the constraints placed on both. Using the equation above, creating a LLBOM (long lead bill of materials) is the approach of this competition year to create a cost-effective strategy in obtaining components for the construction of the design.

The Law of Diminishing Returns, defined as "the marginal benefit of a good diminishes as you get more", will be applied to purchasing multiple components of each item as backups for this competition year (Baker, ph. 17). In the previous competition year, components were mostly purchased in singularity and only the cheapest components were purchased in large quantities to be replaced if a catastrophic failure occurred. This ultimately led to the failure of not being able to replace release mechanisms that were subjected to last minute electrical and mechanical integration tests. If the budget permits, final Flight Unit components will be purchased in a quantity of three or more, depending on the expense of each component.

### 2.5.3 Risk Management

As discussed in the cost-effective analysis section of this report, the greatest risk prevention method is to purchase multiple, back-up components for the final Flight Unit, which can be replaced and interchanged easily. This risk prevention method is critical because of the complexity of small, autonomous, robotic systems in which the failure of one component usually leads to the failure of other components.

Another risk prevention method was developed for the electrical and computer subsystems of communications: electing a radio modem/transceiver that could be used on variety of bandwidths, thus not limiting the design with a narrow range to work with on launch day. Multiple ground stations have been added as a requirement to the CanSat competition, thus reducing risk of communications failure if one ground station becomes non-operational during flight. Several teams were unable to locate and recover their payloads in last year's competition. The CanSat will incorporate an audio beacon and will be brightly colored to assist in the recovery of the payload.

### 2.5.4 Configuration Management

"Configuration Management is the key to managing and controlling the highly complex software projects being developed today" (Burrows, ph. 2). A method being used to manage software configuration is a buildup of a library of functions and methods in the open-source software for future CanSat teams. The design team has only one Computer Science major among a group of mostly Aerospace Engineering majors. The team lacks a diversity in knowledge, specifically in the electrical and computer engineering fields. This places a huge dependence on the computer scientist and the adaptability of his programming. By creating a library of functions that can been accessed on the open-source software, the design teams in future years can build off the development of this code even when the computer scientist is no longer available to assist in creation of new code.

### 2.5.5 Interface Management

As defined by the Center for Chemical Process Safety (CCPS), "Interface Management is the systematic control of all communications that support a process operation" (CCPS, pg. 3). The prime method of communicating operations is accomplished through weekly "Team Lead Meetings" and weekly design/construction meetings. Team Lead Meetings occur weekly on Mondays and provide a board meeting atmosphere to communicate subsystem development (i.e. mechanical, electrical, etc.) through subsystem team leads. Teams were set up as follows: mechanical, structural, electrical and computer, and recovery. Each team lead is responsible in communicating their team efforts, concerns, and demands to the "Systems Project Manager" during the Team Lead Meeting thus controlling the hectic nature of a meeting through a representative system. Last year the design team was small enough to avoid a representative system of team leads, but the expansion of the team from seven members to sixteen members has made the representative system of communication unavoidable. This representative system is shown in Figure 15. This process produces a greater level of productivity, conciseness of argument, and direction of design during Team Lead Meetings.

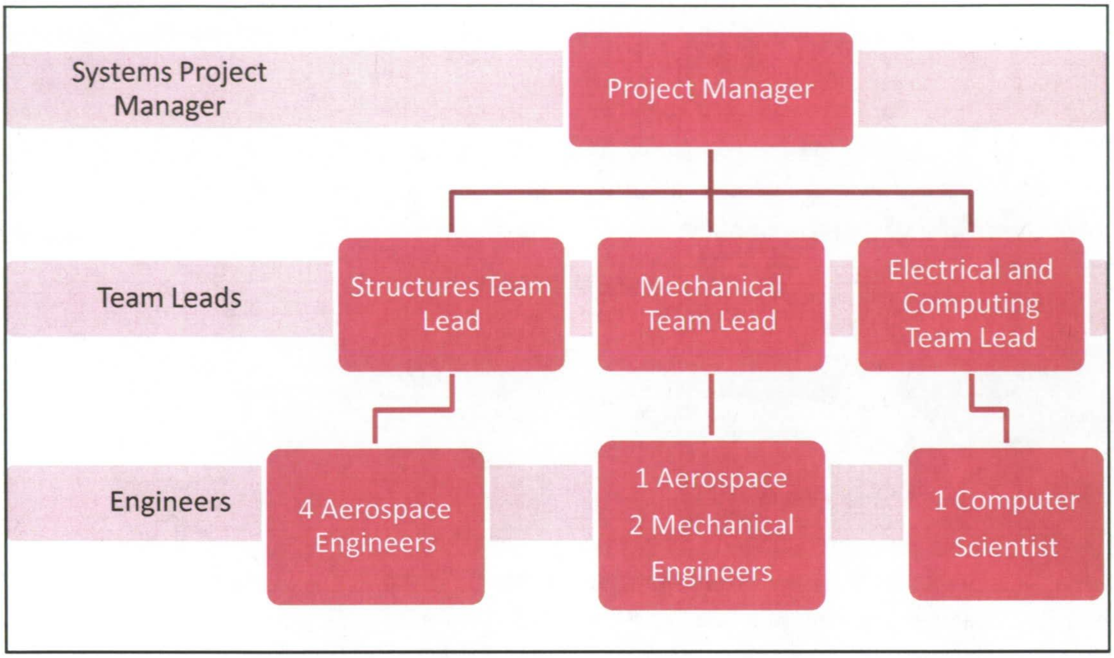


Figure15: Interface Management of Team through Project Manager and Team Leads

Several sources of online communications are utilized throughout the design process in the form of email on a team listserv, instant messaging, and discussion forums with other design teams and the competition panel on a group forum. In the previous year, the online group forum was severely underutilized because design teams wanted to keep design approaches and developments as propriety information. After last year's competition, design teams from other universities became willing to share information to benefit from each other mistakes and accomplishments.

Interface management during the implementation of the CanSat is organized in the form of ground operations on launch day. The term Concept of Operations (Con-Ops) is used to describe how the teams organize themselves during the entire execution of the CanSat operations: before, during, and after flight. The operations are divided between the team leads and communications again flow through a representative system to the systems project manager. Notably, the Virginia Tech CanSat team was the only team to bring handheld radios to communicate more effectively during ground station operations on the launch field and during the recovery process. This method of communication will prove invaluable again for validating recovery of the CanSat visually.

### 2.5.6 Data Management

Data is a very valuable resource. Data collection is a major CanSat competition requirement. Altitude and location data will be transmitted by the payload back to the ground station during flight operations. It is important that accurate data be transmitted and captured throughout the flight for real-time and post mission analysis. There are various points of failure in the data pipeline, but we will apply a few simple safety precautions to protect our data during collection, transmission and storage.

The first risk factor is that the data is inaccurate when it is collected. This factor can only be mitigated by careful test and calibration of the sensors and processor aboard the CanSat. To minimize the chance of inaccurate altitude data, we will use redundant sensors; inaccuracies being produced by one sensor should not propagate to the final product for transmission. Location data will not be made redundant, but the GPS module will be thoroughly tested. Shake testing will be performed to determine the results of the forces the CanSat will undergo during launch and apex. Also, tests will be performed to determine possible sources of EMI. If our targeted module is incapable of providing accurate location data during either of the previous tests, we will purchase a more expensive/accurate module.

Transmission failures can also invalidate data. We will test the communications system under a variety of conditions to minimize the chance of data loss. Additionally, we will rehearse the pre-flight checklist to help ensure that the communications system is set up and working properly immediately prior to launch.

Finally, data can be lost due to inadequate data capture methods. Two laptop computers will be used during competition and each will be configured to receive data and simultaneously store the data to its hard drive and to a USB memory key.

### 2.5.7 SE Master Schedule

Outlined in Figure 16 below is a Gantt chart showing the major design, integration, and testing phases of the CanSat competition. As indicated, both a PDR and CDR are required by the competition guidelines. The team is currently on schedule at the writing of this report on March 2, 2008.

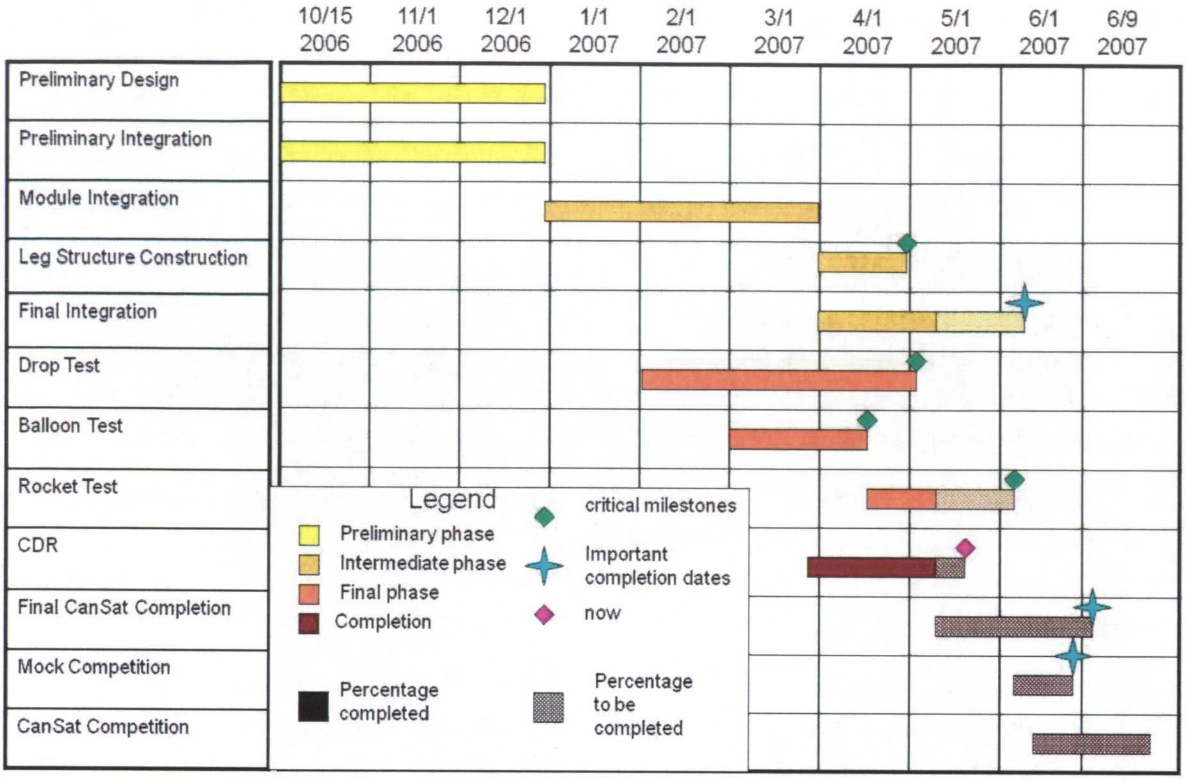


Figure16: SE Master Schedule from 2006 – 2007 Competition Year – Outlining Design Phases and Critical Dates

### 2.5.8 Technical Performance Measurement

The Department of Defense (DOD) defines technical performance measurements as comparing "actual versus planned technical development and design. They also report the degree to which system requirements are met in terms of performance, cost, schedule, and progress in implementing risk handling" (DOD, ph. 1). The competition will be judged and scored on these attributes. System performance is the key metric. They are essentially validating whether or not the design met the required technical objectives and bonus objectives of the competition. The Virginia Space Grant Consortium will also validate if the cost of the project is within budget. Any over budget expenditures will be imposed on the students themselves, with the possible financial assistance of the Department of Aerospace Engineering of Virginia Tech.

A mock competition will be conducted at Kentland Farms, Virginia during the spring semester for the teams to flight test and evaluate their Quality Units prior to June of 2008 competition in Texas.

# 3.0 Transitioning Critical Technologies

## 3.1 Criteria

Due to the complexities of a small autonomous system, many critical technologies are employed in the CanSat. The hardware and software aboard the unit must be capable of handling an absolute minimum of 1 input and 1 output in real time, but in order to provide more accurate and reliable flight data we have set more stringent criteria. Our system will handle at least 3 inputs (GPS receiver, barometric pressure sensor, ultrasonic rangefinder) and 2 outputs (RF base station connection, landing deployment hardware).

Additionally, the team has considered criteria that would be necessary to complete the optional autonomous landing bonus objective. In order to provide feedback to the control systems of the CanSat, the unit would need to be capable of at least one additional output, and be able to withstand the considerable processing load needed to calculate accurate waypoints and headings. Finally, the hardware must be capable of being programmed in a method familiar to the designers and software engineers on our team.

## 3.2 Activities

We took the above criteria into consideration while selecting a hardware and software package for our CanSat. The 2007 competition gave us experience with the Arduino hardware/software package (Arduino), but for completeness we also reviewed competing packages, such as the Basic Stamp system (Parallax).

Both systems have hardware that is capable of meeting the requirements laid out above, but the largest difference between these platforms is the programming language and environment provided. Virginia Tech Computer Science and Computer Engineering programs focus on C and Java language development environments, which the Basic Stamp is incapable of providing. The Arduino package is most easily programmed in C, which several of our members are familiar with.

## 3.3 Risks

There are inherent risks in settling on a hardware and software package, since every step in the integration limits the team's ability to select a replacement system. It is easy to become locked into a specific software package, especially when using COTS systems, because in embedded systems many packages are quite specific about which hardware they will run with.

In order to minimize this lock-in, the Arduino system is programmed in the most widely used language in the world: C. Additionally, because we are using the C standard library that is available on the platform, we have virtual portability to any other platform with C compatibility.

## 4.0 Integration of Systems Engineering Effort

Concurrent engineering practices are being employed by the team in order to minimize design and construction efforts. Some key components of the concurrent engineering structure are as follows:

1. The team is organized into several functional divisions, each one responsible for a different design component.
2. Communication between functional divisions is encouraged through working meetings and brainstorming sessions between groups to enhance the overall compatibility of the design.
3. Multiple designs are tested to ensure viability for construction before selecting a final design.

The functional divisions are responsible for the design, manufacture, and integration of their component of the CanSat. Structure, mechanical, recovery, electronics/computing, and bonus objectives are the current functional divisions. The structures group oversees the design and construction of the CanSat internal and external structure. This work also includes the Always Land Upright (ALU) system, fulfilling one of the primary mission requirements. The mechanical group oversees the internal mechanisms which trigger actions in both the structure of the CanSat, the ALU system, and the interactions between the bonus missions and the structure. The recovery team is responsible for designing and obtaining a parachute and release system which fulfills the primary descent and landing requirements. The electronics and computing section works to provide communication between the sensors aboard the CanSat and to relay that information to the ground. The electronics and computing functional division has responsibilities interfacing with every other group and therefore is highly involved with most design decisions. The final division, the bonus missions group, is a collection of smaller groups operating on specific objectives. These include drilling the surface for a five gram soil sample and measuring ambient temperature upon landing. By compartmentalizing the various design needs, the number of engineers involved with every design decision is kept small in number, thus eliminating overlap in work and increasing the responsibilities of the individuals in the group. The result of such engineering is that all group members are working to capacity to create a coherent design.

The team has a program manager to facilitate the communication between the respective functional divisions. The program manager is a member of all the functional divisions, which is responsible for system/subsystem integration. The program manager is responsible for overall project (and configuration) management to include reallocating resources as needed to provide extra assistance to functional divisions which need help in design or construction of their function, maintaining the schedule, and collecting the necessary paperwork for the team. The entire team is kept abreast of the progress of the design through a weekly team meeting conducted by the program manager. The functional division leaders, however, can also work independently of the program manager to complete design tasks. The team is able to quickly disseminate information and make relevant decisions with full knowledge of the progress of the other functional divisions by using this chain of command.

Finally, the team uses parallel development of various designs to ensure the construction viability before selecting a design. Due to past experience, the use of a single design is ill advised before attempting construction. The small size of the CanSat requires the construction of custom parts at a very small scale, some of which is expensive and time consuming. By creating multiple proof-of-concept models, not only can the idea be verified, but the constructability of the design can be guaranteed before selecting the final design.

# 5.0 Implementation Tasks

The lifecycle of the engineering process is outlined in this section, including construction and competition. The design process requires that all components are designed, built, and tested before they are brought to competition to reduce the probability of failure. A short discussion is included regarding the use of previous design components from earlier models and the maintenance of engineering knowledge for future competitions.

## 5.1 Proof of Concept

The focus of the design was the completion of the primary mission objectives. To achieve a strong and well conceived design, two sub-teams were created under the management of the structural functional division. Both teams developed designs envisioned for the completion of the primary mission objectives, the most critical of which was landing in the upright position. The completion of this objective allows all secondary missions to be completed, since the orientation of the CanSat upon landing has a direct effect on both selected bonus missions. The development of the secondary missions was sidelined until a selection was made for one of the ALU systems. Each team then constructed a rudimentary proof-of-concept model to show the ideas behind the design and to verify that the design could be constructed and by what methods. Several flaws were corrected for both designs, and by group selection, one design was chosen. This design will be taken to quality modeling and testing stages of the design process, and the group responsible for its construction has become the structural functional group.

## 5.2 Construction and Testing

The second stage of the design process will be the construction and testing of the Quality Unit and associated testing of the various subsystems. Primarily, the QU will serve as the final integration test of the various systems, showing that each can be properly constructed and operated at the necessary scale within the necessary budget, weight, and volume constraints. Identification of any overdesign will be done and changes will be made to stay within the parameters required for competition. This process also identifies any challenges with construction or sensitive components which may need to be replaced.

The QU is used to guarantee that the CanSat can withstand competition situations and to determine the operating limits of certain systems, such as the electrical system and the structural system. Such information will permit tweaking the design in key areas. Testing schemes will revolve around ensuring that the CanSat will work to specification in the competition. Each functional division will be responsible for the design and completion of tests of their system, and the administrative officer will oversee tests of the integrated CanSat. Each division will ensure adequate test data collection and analysis is performed. Some tests already designed are as follows:

### 5.2.1 Structural Testing

The structure is the most important system to test in order to ensure the safety of expensive and delicate instruments and sensors onboard. From experience, the structure is pivotal to the completion of the missions, since a structural failure can greatly damage all onboard components. First, testing of the key materials involved with the structure will be done to ensure its ability to withstand conditions exceeding those expected in competition. Using a standard fracture test, the materials can also be tested against crack propagation and fatigue. Small segments of the structure will experience most of the loading, such as parachute attachment points and the landing system. However, rigorous testing of the entire structure is necessary since the actual points of extreme load may not be realized until competition.

Heating of the structural components is also a concern, as the heat experienced in the summer may have an effect. Due to the use of resins and glues, testing will be done in extreme temperatures to make sure any fiberglass components or glued connections will not melt or deform. The heating will be uniform, since no point heat sources are expected to be encountered during operation, save those of the electrical system. The danger of electrical system failure due to extreme temperature will need to be checked in order to validate the design.

### 5.2.2 Mechanical Testing

Mechanical testing concerns the components of the structure responsible for the physical completion of primary and secondary objectives, such as parachute release systems and the drill mechanism. In order to test these components, two steps will be taken. First, the system will be tested without the structural and electrical components to whatever extent possible, to reduce the likelihood of interference from these components. Once the design is validated through these isolated tests, the other necessary components will be integrated and tested individually in order to identify any specific problems. Few problems are expected with the mechanical subsystems due to the relative simplicity of design, but problems may arise with the interfaces between them.

Of primary concern in testing are the connections between the systems. The design hinges on the interrelations between the systems, such as the attachment to the structure and communications with the electrical systems in the case of the mechanical components. The mechanical system has critical failure modes in its connections with these systems since the designs cannot operate without both. For example, if the drill's electrical connections fail, then the drill cannot work. Also, if the drill comes loose from the structure, then the drill will not operate as it was intended. Only once the integration testing is complete can the mechanical systems be tested to ensure they accomplish their missions.

### 5.2.3 Recovery Testing

Testing the recovery system is important to verify that the CanSat does not experience any failures before landing. The recovery system needs to allow the CanSat to safely descend between the allowable descent rates. The two tests which need to be implemented are the examination of forces experienced during parachute deployment and the descent rate of the parachute needs to be verified.

The forces due to deployment can be simulated by either dropping the CanSat and folded parachute from an altitude, or to use the Virginia Tech open jet wind tunnel to test at what speed the parachute cannot withstand the applied forces. Since the connection point will be metal, the most likely points of failure are the connections of the guidelines to the parachute where the forces will be concentrated. By guaranteeing that the parachute can withstand over a 20g shock, the system will be viable for competition. However, by finding the allowable loads, any post-flight analysis of parachute failure can be linked to this data.

To test the descent rate of the parachute, a simulated CanSat mass will be attached to the parachute and the time taken to descend from a known height will be taken. The size of the parachute is designed so that the descent rate will be met with a margin for gusting and thermal uplift. Repeated tests will be conducted to provide adequate amounts of data for later analysis if necessary.

### 5.2.4 Electrical/Computing Testing

The electrical and computer systems are critical due to their connectivity with the other functional divisions. This subsystem is the most critical for mission completion since all mission objectives are controlled by the computing subsystem. Therefore, the rigorous testing of the electrical and computer systems is of the utmost importance.

First, the computer system must operate properly and interface with the ground station before further connections can be made. By preparing operating procedures for the radio modem, the connection with the ground will be guaranteed over the foreseeable future. Also, the internal antenna on the CanSat will need to be tested in the structure to make sure there is no interference with the connection between the CanSat and the ground. Only after these steps are completed will the rest of the system be tested.

Next, the sensors should be tested individually as they are integrated into the computing package. By reducing the amount of unknown connections, troubleshooting will be made easier and more efficient. Any secondary functions, such as servos, should be tested by themselves first, and then via autonomous commands from the microcontroller afterwards. The output devices should be tested after the input devices are tested and working flawlessly.

Another consideration for the electrical system is the testing of the power supplies. Since the CanSat has many independent devices all powered through one or two power sources, the need to provide clean and consistent power is critical to mission success. Primarily, a circuit must be developed which can limit the supplied voltages to protect the sensors and equipment. Then, the batteries must be tested for longevity under flight conditions so that it is known they can provide sufficient power.

### 5.2.5 Quality Unit Test

The integration of the entire QU will be tested then to analyze components which are prone to failure, most specifically the power connections, the electrical components, and the structural connections. By using a shaker table with the assistance of Virginia Tech faculty, the CanSat can be tested at a variety of excited states, ensuring the soldered connections of electrical equipment and the holding power of the structural members. Since the CanSat can be examined during this test procedure, changes to design and construction can be made promptly. After the integrated CanSat system is safely tested on the ground, rocket tests will be used to progressively allow the CanSat to descend from higher and higher altitudes, and attempt to complete bonus objectives in different conditions. The QU will also be tested till just before failure. Prior to failure, the QU can be replaced, giving further experience to the rapid design of parts and repair techniques to be used during competition.

### 5.2.6 Special Test Equipment and Facilities

The Virginia Tech Engineering Department has special test equipment and facilities that the design team may have access to for CanSat test and development. These facilities include a GPS Laboratory with GPS Simulators (Spirent GSS6560) capable of closed loop simulations (see Figure 17), thus being able to test our GPS receiver's accuracy. Also available is the Vibrations and Acoustic Laboratory with shaker tables, thus being able to test the reliability of our release mechanism during the QU phase.

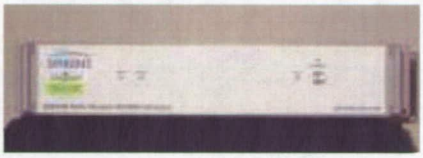


Figure 17: GPS Simulator - Spirent GSS6560

Unique to undergraduate students at Virginia Tech is access to an Experimental Methods Lab that has specialized equipment for developmental testing of the recovery system. Shown below in Figure 18 is a photograph of the Open Jet Wind Tunnel, which will be used to test a 20-G shock on the parachute for the recovery systems of the CanSat.

During the 2006-2007 competition year this 20-G shock was modeled using a dead weight system that could only model the effects of this force on the parachute lines and not the entire structure and parachute envelop. A photograph of this dead-weight test is shown in Figure 19 below.

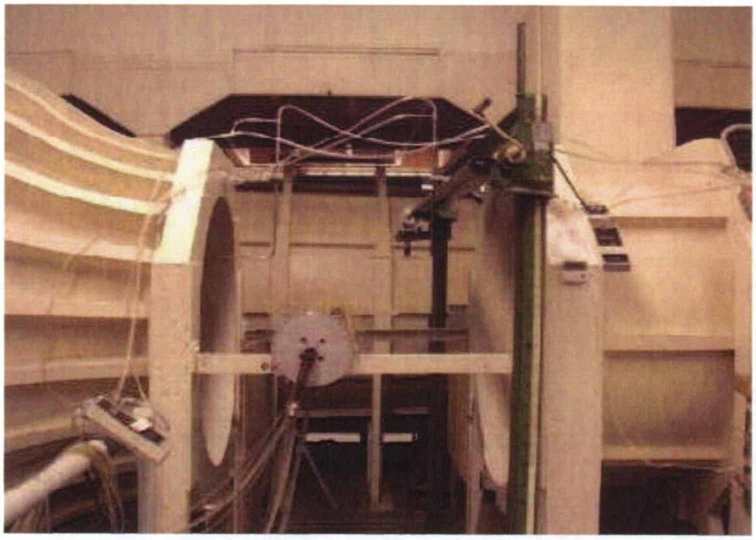


Figure 18: Open Jet Wind Tunnel used for 20-G Shock Test on Recovery System of CanSat

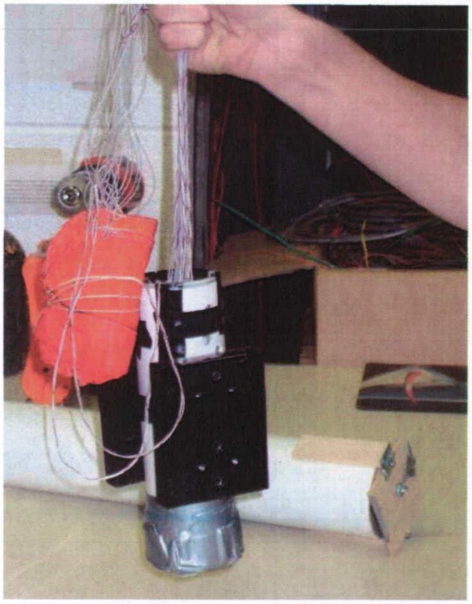


Figure 19: Dead Weight System simulating 20-G Shock on Parachute when Exiting Rocket

## 5.3 Reviews

The competition also provides for two reviews, the Preliminary Design Review (PDR) and the Critical Design Review (CDR). These two reviews allow the judges and the team to understand the current design and to ensure that the proper requirements are being fulfilled. The PDR occurred in February. The team presented its current design, concept of operations, and other ideas currently under development. The judges concurred with our current design and approach to satisfying the requirements for the competition. The judges provided recommendation to improve the overall design, avoid common pitfalls, and how stay on schedule and within costs. The team has already implemented most of their recommendations. The CDR will occur in May, one month before competition. This review will focus on the final design of the CanSat. Specifically, the judges are concerned with the operation of the CanSat, making sure it is non-hazardous, and that students have a good idea of the layout of the competition. Designs are scored against an existing rubric, allowing for a more standardized competition.

## 5.4 Flight

Before competition, the information gained from the testing and integration of the CanSat will be used to produce the Flight Unit. This model of the final system will be the one employed at the competition, with all proven equipment in the polished and presentable form for competition. Replacement parts will be constructed to simplify repair operations during the competition. Since one of the goals for competition is repetition, each functional division will be responsible for creating comprehensive checklists to ensure that all the components of the CanSat are operating in their normal fashion. Cross-checking of work between functional divisions is imperative, based on past competition experience. Once loaded into the rocket, the CanSat functions will be monitored via radio modem; however, the team will have no direct involvement with its operations except for the receiving data during flight.

Following the flight, the team will retrieve the CanSat and analyze the data collected, bonus missions completed, and failure modes if any. This analysis will be presented to the judges at a debriefing the next day. Each functional division will be responsible for briefing on the successes and failure analysis of their own section. The division leaders will then codify these into a single timeline, showing how the failures, if any, affected the performance of the CanSat and deviations from the established norms. The team will document all data and results to assist future CanSat competition teams.

## 6.0 Conclusion

The CanSat project is a complex engineering project which spans many disciplines. Through the knowledge and application of system engineering integration methods and tools, a better solution to this year's missions has been derived. In previous years, the human component of the CanSat project has been sidelined in favor of more advanced physical components. However, by emphasizing the planning of human resources and learning from past mistakes, this year's CanSat team is more focused and prepared to deal with technical challenges associated with system integration.

Further analysis is required concerning the effectiveness of these approaches as they apply before and during competition. Currently, the changes in organization have produced tremendous results, having produced multiple proof-of-concept models for the structural and ALU systems. With the addition of more computer science students, the critical computer and electrical systems also will see greater productivity in the months to come. The team is on track to meet the testing goals, as well as those set for construction and for competition.

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## Appendix A - Minimal CanSat Requirements

1. The CanSat including parachute or any drag devices shall fit inside the payload section.
2. The CanSat and parts of the CanSat shall not exceed the cylindrical envelope of 72.39mm diameter and 279.4 mm in length.
3. No protrusions beyond the envelope defined in item 2 are allowed until the CanSat has deployed from the rocket payload section.
4. The CanSat must be deployed from the payload section.
5. The CanSat shall have a mass of no more than 500 grams including parachute or other recovery device.
6. The CanSat descent time shall not exceed seven minutes.
7. The CanSat descent rate shall not exceed 4.6 meters/second.
8. The CanSat altitude must be transmitted to the ground station at least every 5 seconds.
9. If parachute is used as a main recovery device, it must be released within 1 meter of the ground.
10. The CanSat must land in its defined upright position or upright itself to its defined upright position within ten minutes.
11. All transmitters shall be turned off after recovery.
12. All transmitters must meet FCC regulations.
13. The cost of the CanSat shall be no more than $1000.00 USD.

NOTE: Minimal CanSat Requirements obtained from 2008 CanSat Competition Design Guide

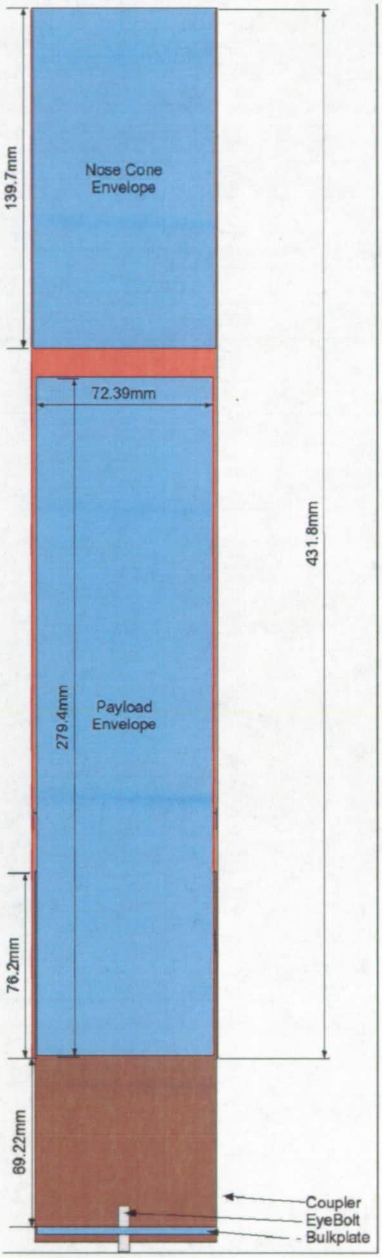

Figure A1: Rocket Payload Specifications

## Appendix B – Equation for Estimated Time for Tasks

Note: The following equation uses a beta probability distribution for time estimate.

$$T_E = \frac{(T_O + 4T_M + T_P)}{6}$$

| Explanation of Variables in Equation for Estimated Time for Tasks | |
|---|---|
| Variable | Explanation of Variable |
| $T_E$ | Estimated time for task |
| $T_O$ | Optimistic time- the shortest time in which the activity can be completed |
| $T_M$ | Most likely time - the completion time having the highest probability |
| $T_P$ | Pessimistic time - the longest time that an activity might require |

## Appendix C – Design Overview Diagram

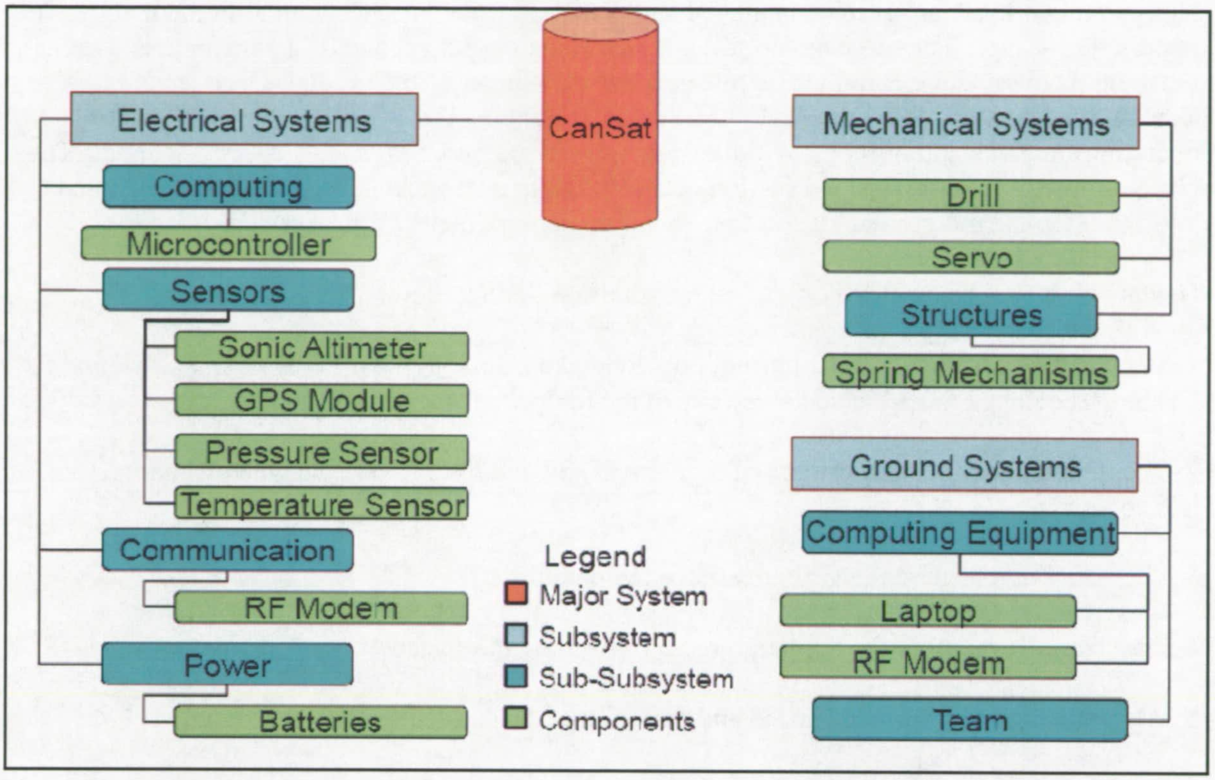

Figure A2: CanSat Design Overview

## Appendix D – Mission

Design and build a CanSat to be launched and deployed from a rocket at an altitude of about 760 meters. The CanSat is to descend no faster than 4.6 meters per second. If a parachute is used as the main recovery device, it must be released within 1 meter of the ground. Once landed, the CanSat must be in its defined upright position or upright itself to its defined upright position. All operations must be autonomous. Altitude data must be transmitted at least every 5 seconds. The CanSat must fit into the payload section of a 76mm diameter rocket. Teams are to design and build the CanSat and ground station to meet all the requirements of the mission.

Bonus points will be awarded only if all the minimal CanSat requirements are met.

1.After landing and being in the upright position, take a 360 degree panoramic image around the CanSat. The image must include some sky in the image.

2.After landing, extract a minimum of 5 grams of soil and hold it to be weighed when the CanSat is recovered.

3.After landing, measure the ground surface temperature.

4.After landing, measure the temperature 25 mm below the surface.

5.After landing, measure wind speed and direction at the surface.

6.Autonomously land at coordinates provided at the launch.

NOTE: Mission obtained from 2008 CanSat Competition Design Guide