CanSat

Design of a Small Autonomous Sounding Rocket Payload

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

By

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March 2, 2009

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), the National Aeronautics and Space Administration (NASA), AGI, Orbital Sciences Corporation, Praxis Incorporated, and SolidWorks. Specifically, the 2009 Virginia Tech CanSat Team is funded by BAE Systems, Incorporated of Manassas, Virginia. The objective of the 2009 CanSat competition is to complete remote sensing missions by designing a small autonomous sounding rocket payload. The payload designed will follow and perform to a specific set of mission requirements for the 2009 competition. The competition encompasses a complete life-cycle of one year which includes all phases of design, integration, testing, reviews, and launch.

Table 1: Applicable Documents

Document Title	Description of Document
2009 CanSat Competition Design Guide [1]	Outlines the requirements and missions for the competition.
Practice Standard for Work Breakdown Structures (Second Edition) [2]	Provides guidance and universal principles for the initial generation, subsequent development, and application of the Work Breakdown Structure.
Oberndorf, T. Software Engineering Institute: Carnegie Mellon. *Open Systems*. from http://www.sei.cmu.edu/opensystems/faq.html [3]	Website that provides information on open systems architecture.

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1 Introduction

1.1 Objective

CanSat is a unique space design competition because it allows teams to actually implement their designs through construction and competition. Sponsored by the AIAA and the AAS, the annual CanSat competition features a remote sensing theme for the 2009 competition year. Teams of up to ten students have the mission of designing and building a CanSat that is launched and deployed from about 900 meters altitude and autonomously navigates to a predefined landing coordinates. In order to meet these requirements, the team is responsible for designing, constructing, and testing structures, mechanisms, communications devices, and automated control devices.

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 (refer to Figure 12 in the Appendix), measuring 72 mm in diameter and 280 mm in height. The CanSat is launched to an apogee of approximately 900 meters, where it is released from the rocket payload section (see Figure 1). A ram-air parachute is used to control the decent, and upon landing, mechanisms are activated to place the CanSat in its upright position. Our design has the CanSat coming to rest on its side, then employing spring loaded arms to rotate the CanSat so its top side and solar panels are facing up. During the entire flight, altitude, GPS, and housekeeping telemetry will be communicated to the ground station at regular intervals. These requirements; descending at a controlled rate, functioning autonomously, and transmitting telemetry, make up the CanSat primary mission.

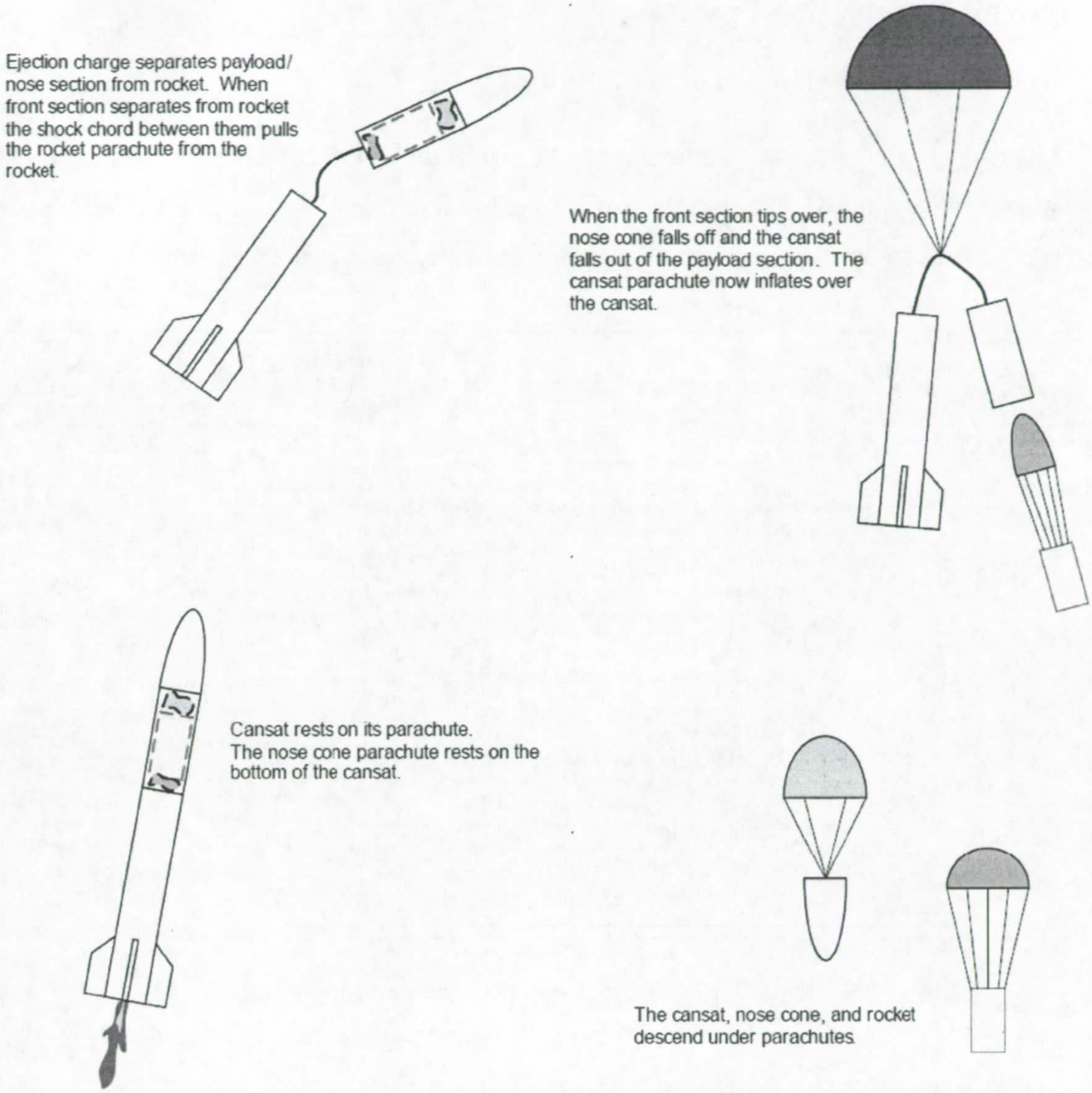


Figure 1. Concept of Operations for CanSat Deployment [1].

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 include autonomous navigation to a predefined set of coordinates downwind of the launch site, additional housekeeping telemetry, landing image, and solar powered system. Our design will implement an autonomous navigation system, five additional telemetry data, and solar panels to power the CanSat's operation after landing.

2 Systems Engineering Process

2.1 Systems Engineering Process Planning

Figure 2 shows the "Systems Engineering 'V' Diagram" for decomposition, definition, integration, and recomposition of a system over its entire lifecycle. Figure 2 is used throughout the design process to develop verification planning for subsystems of the CanSat.

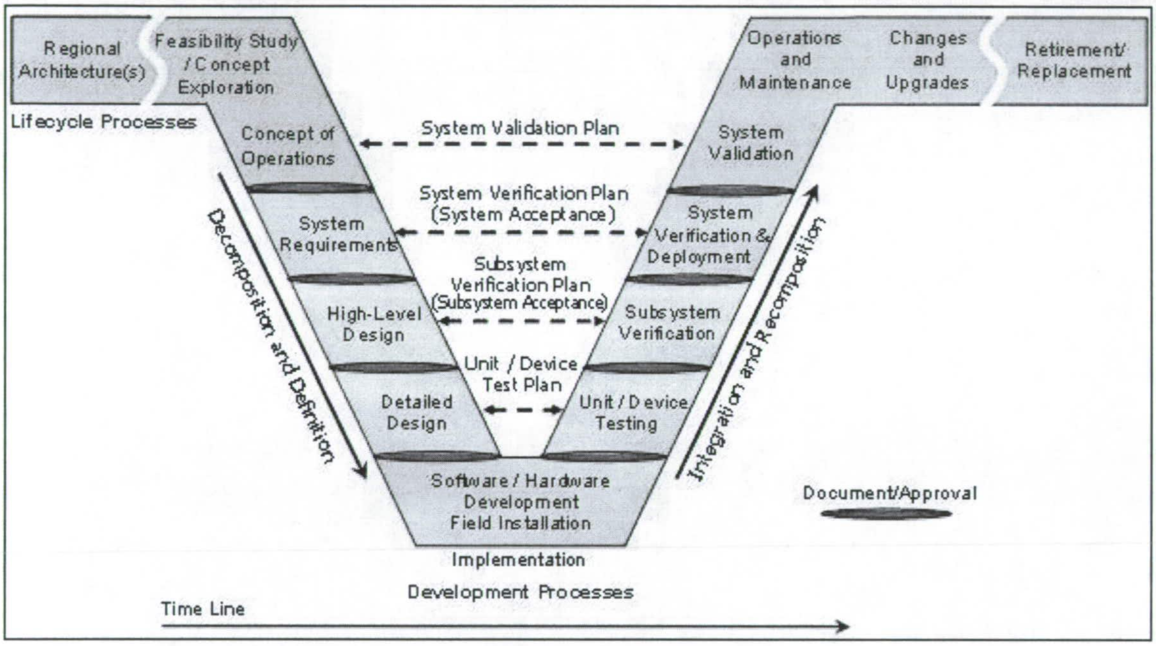


Figure 2. Systems Engineering Decomposition and Integration 'V' [2].

2.1.1 Major Products and Results from Process

The major products and results for the CanSat system are the competition deliverables. Table 2 describes the competition deliverables.

Table 2. CanSat Deliverables for 2009 Competition.

Deliverable	Description	Deadline
Master Schedule	Gantt chart to be used to track all progress toward completion of CanSat development.	January 16, 2009
Preliminary Design Review (PDR)	A multi-disciplined technical review (teleconference) to ensure that the system under review can proceed into detailed design and can meet stated requirements.	February 13, 2009

ESMD Space Grant Systems Engineering Paper	A technical paper prepared for NASA that focuses on the systems engineering lessons learned by participating in the 2009 CanSat competition.	March 2, 2009
Hardware Review	Review (teleconference or email) of the hardware selection and procurement to ensure successful completion of the CanSat.	March 13, 2009
Critical Design Review (CDR)	A multi-disciplined technical review (teleconference) to ensure that the system under review can proceed into fabrication, integration, and testing.	April 10, 2009
CanSat (Quality Unit)	Completed quality unit for system requirements verification.	May 1, 2009
CanSat (Flight Unit)	Completed flight unit to be delivered for competition.	May 13, 2009
Flight	Sounding rocket launch of CanSat in Amarillo, Texas.	June 13, 2009
Post Flight Review	Assessment of flight operations and remote sensing data collected during mission.	June 14, 2009

2.1.2 System Constraints

The CanSat must meet constraints set by the CanSat Competition as outlined in the CanSat Competition Design Guide [1] and chosen by the team (refer to Figure 12 in the Appendix for the Launch Vehicle Layout). The constraints set by the CanSat Competition Guide are much like the constraints that would be given to a design team by a customer, and are non-negotiable. These constraints are driven by real world conditions, such as payload volume on the launch vehicle, power of the launch vehicle, and existing communications infrastructure. Constraints chosen by the team are driven by bonus mission objectives outlined by the CanSat Competition Design Guide and dictate detailed design choices much more than the baseline design. The CanSat mission is admittedly simpler than many NASA missions, primarily because it does not travel in space, but the lessons learned from its design are directly applicable. The space industry is increasing interested in micro-craft that perform one function at little cost (cost being fuel, power, size, money) to the mission. The CanSat mission is a useful abstraction of the same problem at much lower risk.

2.1.3 Verification Planning

A position on the design team allocated exclusively to make sure that all components of the CanSat comply with all constraints, design goals, compatibility requirements, etc. The Assembly, Integration and Testing engineer (AI&T) will oversee the manufacture and assembly of each component as well as dictate the order at which the subsystems are integrated into the Quality and Flight units. The AI&T position was also created to write and oversee all testing for the CanSat from the subsystem level to the master, full system test. It is the job of the AI&T engineer to relay test results the appropriate team members and keep track of the status of each component in the system. Concurrently, the AI&T engineer also acts as a consultant to each sub-system team with regard to system compatibility and ease of integration. For instance, if a design idea performs a task appropriately but integrates poorly with the CanSat, the AI&T engineer will use their knowledge of the full system architecture to suggest a superior interface for the sub-system with the rest of the CanSat.

2.2 Requirements Analysis and Validation

2.2.1 System Requirements

Table 3 is a verification matrix that outlines the Master Requirements (MR) for the competition. The first column of Table 3 shows the unique requirement identification (i.e MR-1). The second column is a description of the requirement. The third column describes the rationale of the requirement. The fourth column details the priority of the requirement, or the impact that the requirement has on the system. The fifth column shows the "parents" or higher level requirements that the requirement is derived from. The sixth column shows the "children" or lower level requirements that have been derived from the stated requirement. The last column shows the Verification Method (VM) of the requirement (i.e. I – Inspection, T - Test, A - Analysis, and D – Demonstration; for a detailed explanation of these methods refer to Table 24 in the Appendix).

Table 3. Master Requirements (MR) for CanSat.

ID	Requirement	Rationale	Priority	Parents	Children	VM
MR-01	CanSat shall not exceed 600g mass*	Launch Vehicle Constraint	High	---	SSD-02, EPS-04, DCS-02, MS-07	I
MR-02	CanSat shall not exceed 279mm in length	Launch Vehicle Constraint	High	---	DCS-03	I
MR-03	CanSat shall not exceed 72mm in diameter	Launch Vehicle Constraint	High	---		I
MR-04	The CanSat, while in flight configuration, shall have no protrusions that exceed dimensions outlined in MR-02, MR-03	Launch Vehicle Constraint	High	---	SSD-01, EPS-03, DCS-04, MS-06	I
MR-05	Descent rate shall be between 2.2 m/s and 4.6m/s	Mission Requirement	High	---	DCS-09	T,D
MR-06	During flight, CanSat shall transmit data at 0.02Hz	Mission Requirement	High	---		T,D
MR-07	During flight, CanSat shall telemeter GPS position, number of satellites tracked, altitude by means other than GPS, and housekeeping telemetry at rate specified in MR-06	Mission Requirement	High	---	SSD-03, COM-03	T,D
MR-08	Upon landing, CanSat shall switch communications to channel 0-000 with a 57600 bit/sec data rate	Mission Requirement	High	---		T,D
MR-09	CanSat shall collect science data for 3 hours	Mission Requirement	High	---	EPS-02	T,D
MR-10	CanSat shall measure ground temperature via direct contact	Mission Requirement	High	---	SSD-04, MS-04	T,D
MR-11	A time stamp shall accompany all temperature measurements	Mission Requirement	High	---	FSW-03	T,D
MR-12	CanSat shall respond to unique telemetry requests with collected science data at least 10 times an hour	Mission Requirement	High	---	COM-04	T,D
MR-13	The apogee altitude in meters and the landing coordinates shall be provided as part of the post flight review	Mission Requirement	High	---	SSD-05	T
MR-14	The Cansat and GCS shall be less than $1000 (US)	Cost Limit	Low	---	SSD-06, COM-05, EPS-09, DCS-11, MS-09	I

Table 4. Sensor System Design (SSD) Requirements.

ID	Requirement	Rationale	Priority	Parents	Children	VM
SSD-01	The SSD shall be no more than TBD in size	Internal Space Constraint	Medium	MR-04		I
SSD-02	The SSD shall have a mass no more than TBD	Mass Constraint	Low	MR-01		I
SSD-03	The GPS unit shall be accurate to within 10m	Mission Requirement	High	MR-07		I,T
SSD-04	The method of determining temperature shall be accurate within 2 deg Celsius	Mission Requirement	High	MR-10		T
SSD-05	The altimeter shall be accurate within 4m	Mission Requirement	High	MR-13		T
SSD-06	The SSD shall cost less than TBD	Cost Limit	Medium	MR-14		I

Table 5. Communications (Com) Requirements.

ID	Requirement	Rationale	Priority	Parents	Children	VM
COM-01	CanSat communications shall utilize an Aerocomm AC4790-200 transceiver configured to operate on an assigned channel	Mission Requirement	High	---		I
COM-02	Within ten (10) seconds of landing, the CanSat shall configure to meet MR-08, MR-12	Mission Requirement	High	---	FSW-03	T
COM-03	GPS data shall be communicated in NMEA formatted data packets	GPS Standard	Medium	MR-07	FSW-03	D
COM-04	All data shall be transferred to and processed by the ground station within five seconds of a telemetry request	Mission Requirement	Medium	MR-12		T,D
COM-05	The communications system shall cost less than TBD	Cost Limit	Medium	MR-14		I

Table 6. Electrical and Power System (EPS) Requirements.

ID	Requirement	Rationale	Priority	Parents	Children	VM
EPS-01	The CanSat shall have external power control with confirmation of the cansat power state	Mission Requirement	High	---		I,D
EPS-02	The EPS shall provide power to all CanSat systems and components through launch, descent, and the post landing operation time or as needed	Mission Time Requirement	High	MR-09	EPS-05, EPS-06, EPS-07, EPS-08, DCS-07	T
EPS-03	The EPS shall be no more than TBD size	Internal Space Constraint	Low	MR-04		I
EPS-04	The EPS shall have a mass less than TBD	Mass Constraint	Medium	MR-01		I
EPS-05	The EPS shall provide TBD Watts of power	System Requirement	High	EPS-02		I,T
EPS-06	The EPS shall provide power at TBD Volts	System Requirement	High	EPS-02		I,T
EPS-07	The EPS shall provide power at TBD Amps	System Requirement	High	EPS-02		I,T
EPS-08	Once on the ground, the EPS shall provide power by converting the energy of sunlight	Bonus Mission	Medium	EPS-02		I,T
EPS-09	The EPS shall cost less than TBD	Cost Limit	Medium	MR-14		I

Table 7. Flight Software (FSW) Requirements.

ID	Requirement	Rationale	Priority	Parents	Children	VM
FSW-01	FSW shall control DCS	Bonus Mission	Medium	DCS-01		A,T
FSW-02	FSW shall operate within constraints of selected microprocessor	Size and Speed	High	---	FSW-04, FSW-05, FSW-06	A
FSW-03	FSW shall comply with all communications protocols	Communication Standards	Medium	MR-11, COM-02, COM-03		I
FSW-04	FSW shall be programmed in C	Software/Hardware Constraint	Medium	FSW-02		I
FSW-05	FSW shall not exceed 16KB when compiled to machine code	Hardware Constraint	High	FSW-02		I,A

FSW-06	Data memory shall not exceed 1KB at any point in time	Hardware Constraint	High	FSW-02		I,A

Table 8. Descent Control System (DCS) Requirements.

ID	Requirement	Rationale	Priority	Parents	Children	VM
DCS-01	CanSat shall autonomously navigate to within 10m of specified GPS coordinates	Bonus Mission	Low	---	FSW-01, DCS-05, DCS-06	A,T
DCS-02	The DCS module shall NOT exceed 200g	1/3 of mass budget	High	MR-01		I
DCS-03	The DCS module shall NOT exceed 55.8mm in length	20% of length budget	Medium	MR-02		I
DCS-04	Deployable structures shall not protrude MR-02, MR-03 while stowed	Launch Vehicle Constraint	Medium	MR-04		I
DCS-05	The DCS shall determine and control direction of CanSat	Bonus Mission	High	DCS-01		A,T
DCS-06	The DCS module shall be released within 1 meter of the ground	Risk Mitigation	Medium	DCS-01		A,T
DCS-07	The DCS shall NOT exceed TBD Watts of Power	Power Constraint	High	EPS-02	DCS-08	A,T
DCS-08	DCS components shall not exceed TBD VDC	Voltage Constraint	Medium	DCS-07		I,T
DCS-09	DCS operation shall not exceed 8 minutes	DCS constraint	Medium	MR-05		A,T
DCS-10	The DCS shall sustain 20 g's of shock	Launch Vehicle Environment	High	MS-01		A,T
DCS-11	The DCS shall cost less than TBD	Cost Limit	Medium	MR-14		I

Table 9. Mechanical System (MS) Requirements.

ID	Requirement	Rationale	Priority	Parents	Children	VM
MS-01	CanSat shall sustain 20 g's of shock	Launch Vehicle Constraint	Medium	---	DCS-10, MS-02	A
MS-02	CanSat shall safely carry all mission components	Critical to Mission Life	High	MS-01		T
MS-03	Mechanical System shall deploy solar arrays for power generation	Bonus Mission	Medium	EPS-08	MS-06	D,T
MS-04	Mechanical System shall deploy sensory equipment to collect science data	Mission Requirement	Medium	MR-10	MS-06	D,T

MS-05	Mechanical System shall jettison DCS module	Safety, Risk Mitigation	High	DCS-06	MS-06	D,T
MS-06	CanSat shall achieve a ground configuration	Accommodate MS-03	High	MR-04, MS-03, MS-04, MS-05,		D,T
MS-07	Mechanical System and internal structure shall have a mass less than TBD	Mass Constraint	Medium	MR-01		I
MS-08	CanSat shall maintain reasonable internal temperature	Safety, Risk Mitigation	Low	---		T
MS-09	Mechanical System and internal Structure shall cost less than TBD	Cost Limit	Medium	MR-14		I

2.2.2 Reliability, Maintainability, and Survivability

Reliability of the flight unit will depend greatly on the testing and evaluation outlined in section 2.2.6. Maintainability is not of utmost importance due to the fact that the CanSat only has to perform a single flight lasting approximately three hours. Survivability will rely on the design changes made after testing.

2.2.3 Electromagnetic Compatibility

Strong signal strength and flawless microcontroller performance are crucial to completion of the mission. Therefore electromagnetic interference (EMI) has been taken into consideration throughout the design process. We replaced our original carbon fiber design with a fiberglass one after extensive research on carbon fiber's radio signal blocking properties.

Upon completion of the quality model extensive EMI testing will be conducted. Initially the CanSat will be tested without any artificial interference to ensure that its structure and components do not cause any kind of internal interference. Once the basic test is complete artificial sources of interference will be introduced. The CanSat will be tested in the lab placed inside a rocket similar to that used in the competition. This is to test if the rocket will cause any kind of physical interference with the GPS signal and data transmissions from the CanSat. Once any physical interference issues are worked out the final test will consist of a rocket launch. This is to ensure there are no problems keeping a GPS signal lock while in flight. In previous years many teams had issues with loosing the signal during the high speeds of takeoff. We do not want to encounter these problems, therefore testing will be crucial.

2.2.4 Human Engineering and Safety

Most safety issues arise from the fact that CanSat construction primarily takes place within a machine shop. Saws, drills, and other tools pose potential safety hazards. Several precautions have been taken to reduce the risk of bodily injury. Every team member was required to take a safety course run by the head of the shop. Members were educated in proper use of tools and their safety features such as guards and kill switches.

At the competition high altitude rockets and CanSats returning to earth are the major safety hazard. The Panhandle of Texas Rocket Society (POTROCS) will be on site to supervise this aspect of the project. POTROCS is a Tripoli affiliated prefecture #92 with members possessing National Association of Rocketry certifications ranging from Level 1 to Level 3.

2.2.5 Producibility and Product Support

Producibility is a major concern when designing the CanSat because it will be constructed by students with limiting machining experience. Proper functioning of the flight model will rely heavily on producibility. The design uses Common off the Shelf (COTS) components whenever possible. This minimizes the need for custom parts reducing both cost and assembly time. It also allows the team to do most of the construction themselves and reduces outsourcing.

The CanSat will be extremely supportable. All of the microprocessor coding is done in C which most members are familiar with. It utilizes a slot modular product architecture that allows for broken or malfunctioning parts to be quickly and easily replaced. The ultimate goal is to make the CanSat supportable enough that if anything breaks at the competition it can be repaired onsite with little difficulty.

2.2.6 Test and Evaluation

Initial tests will consist of testing individual components in the lab. One of the most important component tests will be the ram-air parachute. It will be tested in the Virginia Tech

Open-Throat Wind Tunnel to gain a better understanding of its flight characteristics as well as tune the Proportional-Integral-Derivative (PID) controller. Once an adequate understanding of how each component works is obtained they will be integrated into the quality unit. This unit will then be tested in the lab as a single system to ensure that all systems are working together properly.

Upon completion of the system test in the lab EMI testing as described in section 2.2.3 and drop testing will begin. Initial drop tests will consist of dropping the CanSat from the third floor of an indoor atrium and timing it to ensure that the ram air parachute provides the proper descent rate. When the results are satisfactory drop tests will be conducted off an eight story building on campus. In these higher drops the Descent and Control (DCS) system will be tested. It will be programmed to land at specific GPS coordinates.

After working out the bugs in the drop tests the CanSat will be ready for the rocket test. This will simulate the exact circumstances of the competition launch. Every system will be tested simultaneously. A successful rocket launch will verify that the CanSat has met its system requirements and is ready for competition flight.

2.2.7 Integrated Diagnostics and Transportability

The "housekeeping telemetry" bonus mission will take care of integrated diagnostics. It will consist of sensors placed throughout the CanSat to monitor its overall health. The sensors will measure temperature of various parts, voltages, forces exerted upon the can, and anything else essential to the survival of the CanSat.

Transportability will not be a major issue with the CanSat. It is small and compact in the first place and will be transported folded up in its launch configuration. This allows the outer shell to protect the internal components from damage. The team will be driving to the competition so the risk of damage during airline travel will be avoided.

2.3 Functional Analysis and Allocation

Functional Analysis and Allocation is an essential initial step in the design and synthesis of a complex system such as the CanSat. Before decomposing a system into subsystems, the functions of the original system as a whole must be understood. A valuable preliminary tool is to consider the system as a "black box" and outline only the inputs and outputs. This technique is shown in Figure 3 for the CanSat project. By starting with a completely blank concept of the system, the team is better able to pursue all viable ideas after functional analysis has concluded. The next logical step in this method is to decompose the "black box" into several main functions. At this stage, it is still important to avoid limiting the final design with the functions; however, predetermined constraints may be incorporated. To achieve higher detail for complex systems, this method could be repeated for each function introduced in Figure 3 until a sufficient description has been synthesized. With this method, the CanSat functions are organized by their relation to the overall system's external interactions, but not necessarily to the system's Concept of Operations. Furthermore, functions that do not have a direct impact on inputs and outputs but are still critical (such as structural support) will not arise in this functional analysis method. Therefore, it is beneficial to use multiple techniques to ensure the system has been analyzed from all perspectives.

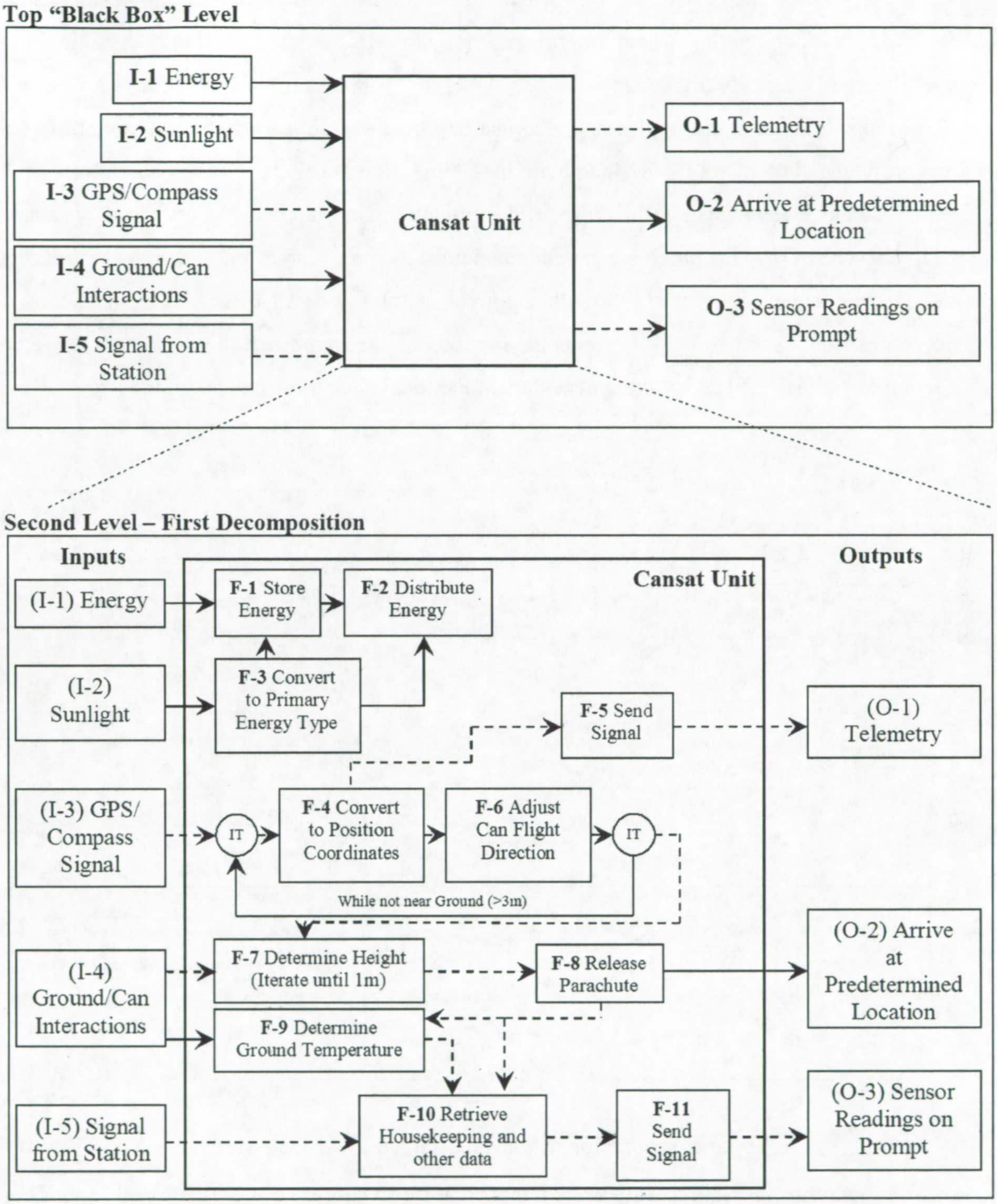


Figure 3: Functional Analysis: Input/Output Method.

This is not the only method by which a function can be decomposed, however. Another technique is to look at the system in terms of time. For this method, it is more beneficial to start with the system already divided into major blocks; so it is necessary to already have a Concept of Operations defined. This step should also use large, general divisions and not attempt to solve the problems, but merely describe them in a time flow manner. The second step of this technique is to decompose each of the primary functions into their own Functional Flow Block Diagrams (FFBD). This process can be iterated until the precision of the functions has reached a satisfactory level. Figure 4 shows the entire CanSat top level FFBD as well as the first decomposition of function 6.0 (Generate/Supply long term power). For this function, one decomposition is sufficient and the next stage, functional allocation, can begin.

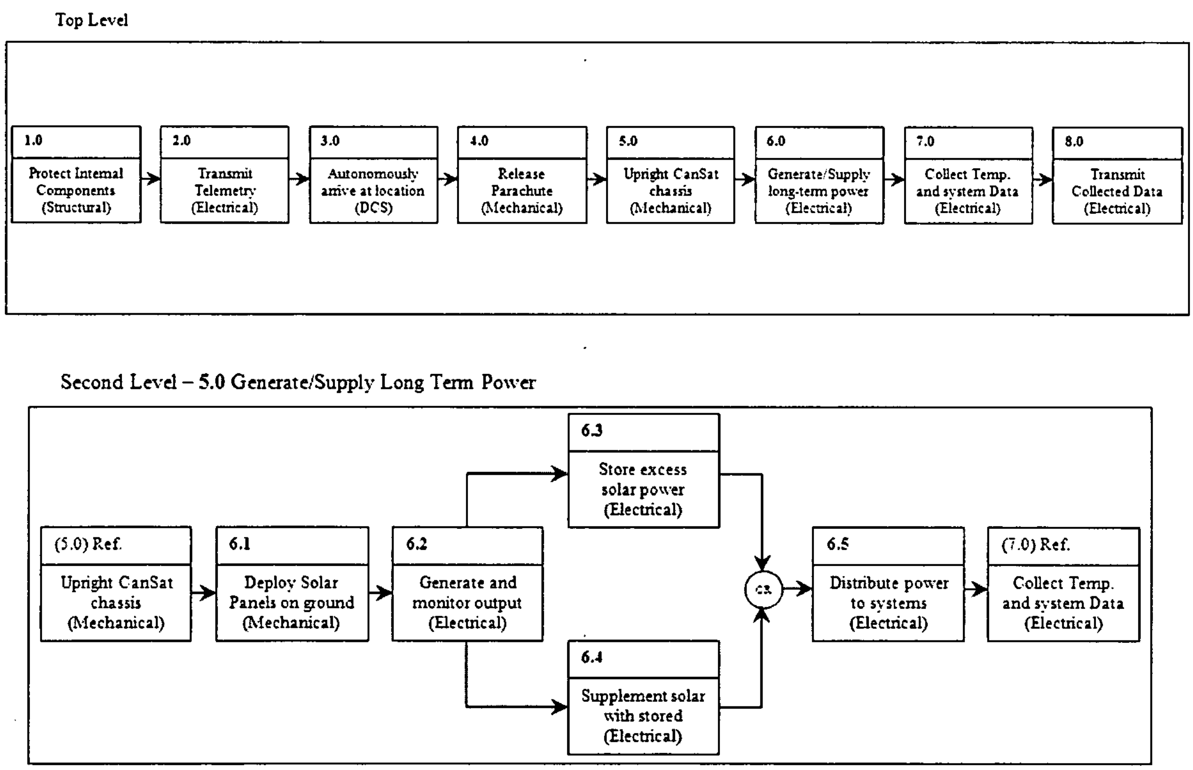


Figure 4: Functional Analysis: Time Flow Block Method

Once the functions are generated and organized using both the FFBD and Input/Output methods, the team now has sufficient knowledge to effectively allocate the functions and sub-functions into sub-systems. By using both methods sub-system divisions can be created more effectively by the consideration of both the physical proximity (one function relies on another for input) and time proximity (one function cannot start until the other has completed). For the CanSat project, the effects of both methods are evident. For the Electrical major sub-system, functions were allocated based on their reliance on the generation and storage systems for power (thus all functions that have an input of power are allocated to or interface with the electrical sub-system). For the minor sub-system of long-term energy generation, however, the sub-functions were allocated by time since each had to wait for or relied on the previous to complete. Figure 5 outlines the system divisions for the CanSat project.

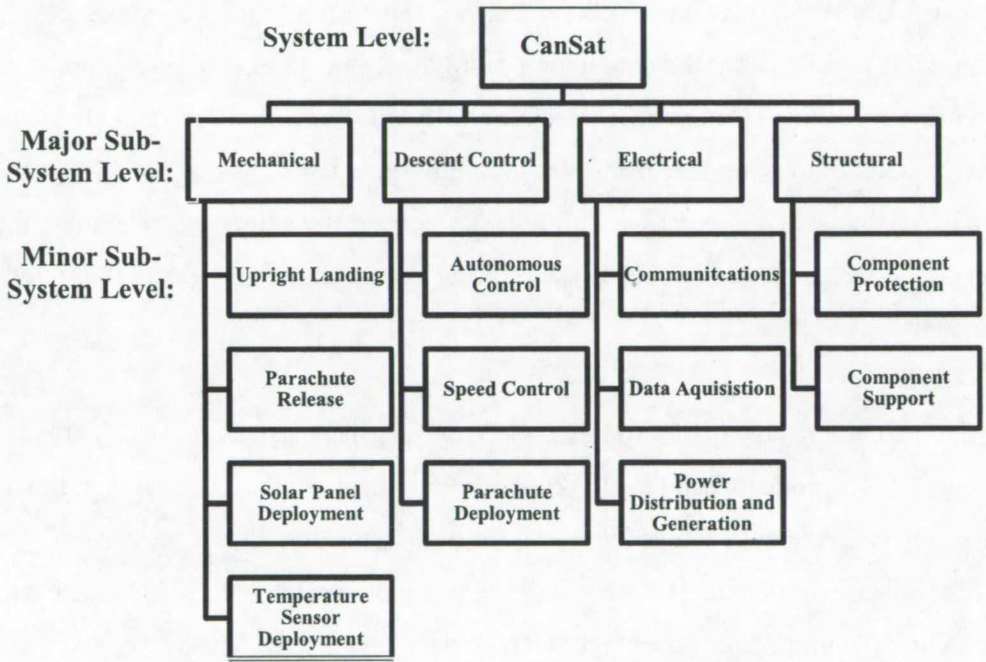


Figure 5: System Divisions and Allocation

2.4 Synthesis

2.4.1 Commercial-Off-The-Shelf (COTS) vs. Developmental Items (DI)

COTS items are defined as either software or hardware, that are ready-made and available for sale, lease, or license to the general public. COTS items are advantageous to any design project, especially CanSat, due to the financial savings they provide from general testing and maintenance of the product. The only testing needed with a COTS item is the interaction between the COTS product and the other systems within the design. The COTS item's functionality has already been solidified through the vendor's development of the product and thus does not require testing concerning its operation. However, the major disadvantage to any COTS item is its limiting nature to the design. This is especially true concerning future changes of a design. To change a design, a team is now constrained and must change around the COTS item which can present a conflict to the overall efficiency and perhaps completion of the design.

COTS items reduce the overall system development cost and development time of a design project. Eliminating the need for developing new systems that could require many trial and errors further helps reduce the possibility of failure in the project. This is because a team can better prepare for potential difficulties in a design be catching them earlier before competition. Because of these advantageous characteristics, this year's CanSat team has taken certain key components necessary for the completion of mission objectives, and researched certain COTS items to be utilized for them. This is especially true concerning the parachute and servo needed for the autonomous landing bonus mission this year's team has decided to undertake. Because of the team's inexperience all together concerning autonomous landing, the more COTS items used for the descent control system leads to a more simplified and thus a more approachable design.

Though there are many advantages to the use of COTS items, disadvantages can also arise. A reliance on COTS products can lead to problems with the overall systems integration of the design. This problem can lead to a dependence on third party vendors to replace certain components. This could be disadvantageous because the need for components adds to the cost, but time, counteracting the immediate advantages COTS items presented. This proved to be a major problem with the teams from the past two years. For example, because of an inefficient time allotted to the integration of systems, the team from two years ago (2006-2007 CanSat Team) was left with the need to pay for a hundred dollar overnight shipping bill for a camera only costing ten dollars to the competition site. To reduce this dependence, a balancing in the use of COTS items and DIs are essential not only to provide for a more simple design but also prevent such dependence and see the full advantages that COTS products incorporate. A comparison of COTS items used between the three teams from the past three years can be seen in tables three through five. Table 10, Table 11, and Table 12 lists the team's use of COTS items and DIs over the past three years of participation in the competition.

Table 10. COTS vs. DI (2006-2007 Competition).

COTS	DI
Servos	Release Mechanism
Microcontroller	Ram-air Parachute
Structural Components (Outer Shell)	Camera Controller
Digital Cameras	
Batteries	
Arduino (Open – Source) Software	
Communications	

Table 11. COTS vs. DI (2007-2008 Competition).

COTS	DI
Servos	Release Mechanism
Microcontroller	Drilling Tool (Bonus Mission)
Parachute	Structural Components (Outer Shell)
Cameras	Software
Batteries	
Communications	

Table 12. COTS vs. DI (2008-2009 Competition).

COTS	DI
Servo	Module Release Mechanism
Microcontroller	Partition Bracket
Arduino (Open – Source) Software	Payload Partitions
Batteries	Descent Control Software (PID Controller)
Communications	Solar Panel Doors Release Mechanism
Remote Sensing Sensors	Ram-air Parachute
	Solar Panels (Bonus Mission)

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" [3]. This also implies that open system architecture is essentially any layered structure or configuration in which a system can be distributed, so that each layer can be implemented without affecting the implementation of other layers. Furthermore, any changes needed to the system can be performed at any given layer within the structure. The CanSat's design for the upcoming competition incorporates an overall modular design providing for an open systems architecture and thus lead to a more efficient integration of each system within the CanSat.

The modular design developed by the mechanical team facilitates partitioning the CanSat into three sections with a central spinal column between each partitioning. The three sections allow for easy movement and placement of electronic parts exhibiting an open system architecture within the CanSat. This central spinal column allows space for wires providing a distribution of power to the various subsystems as needed. Because of this spinal column, each subsystem can be freely moved to any part of the CanSat and still be provided with power. Essentially, the CanSat structure does not dictate where each electronic part has to go, giving freedom to the design and easy maintenance to each part. This modular design can best be seen in Figure 6.

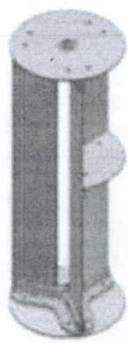


Figure 6. CanSat Modular Design.

2.4.3 Reuse

A major advantage in any design project is experience. Experience provides a team with essential information on components that work, but more importantly, components that do not work. The advantage to reusing certain components in a design is the development time. Having participated as a team for the past two years in the CanSat competition provides us with this opportunity.

Due to this year's goal of implementing an autonomous landing system, the team is not able to reuse certain important components that have proved to be essential in previous year's designs. However, one physical component that could be reused is the ram air parachute due to its stability in descent. The use of servos is another component that has proved to be essential in the design and will be implemented in the CanSat's autonomous landing. Reusing components are not limited to physical components however because certain ideas can be reused. One important idea that is being reused is the position the CanSat will be in upon landing. A sideways configuration proved to be most efficient and has thus been implemented for this year's design.

2.5 Systems Analysis and Control

2.5.1 Trade Studies

The first trade study performed was for the Global Positioning System (GPS) receivers. The functional divisions involved in the trade study were the Electrical and Computer Engineering (ECE) Team and the Descent Control System (DCS) Team. The GPS receiver is used to determine the position and direction of the CanSat from the landing zone. The selection matrix shown in Table 13 was used to determine the GPS receiver for the CanSat system.

Table 13. Selection Matrix for GPS Receivers

		Concept			
		(Reference)			
		Parallax GPS		MN1010 GPS	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
COTS	15%	3	0.45	3	0.45
Accuracy	25%	3	0.75	4	1
Size	20%	2	0.4	4	0.8
Mass	15%	3	0.45	4	0.6
Power Consumption	15%	3	0.45	3	0.45
NMEA Standard	10%	3	0.3	3	0.3
	Total Score	2.8		3.6	
	Rank	2		1	
	Continue?	No		Develop	

From Table 13, it is clear that the MN1010 GPS receiver has a better performance than the Parallax GPS receiver. The only criteria where the Parallax GPS receiver has better performance than the MN1010 GPS receiver is the team's previous experience.

The Parallax GPS receiver has been used for the past two years by the CanSat Team and has had limited success. In 2007, the Parallax GPS receiver performed well during testing but was not proven to work in competition due to a failure with the communications system. In 2008, the Parallax GPS receiver performed as expected during testing but had a failure before prelaunch due to poor wiring and soldering. Therefore, the team has selected the MN1010 GPS receiver for further study and testing.

The next trade study performed was to determine a method for measuring the ground temperature via direct contact. The functional division directly responsible for conducting this trade study was the ECE Team. Table 14 shows the selection matrix used to determine the ground temperature method. From Table 14, it is clear that the thermocouple method is the preferred method for determining the ground temperature via direct contact.

Table 14. Selection Matrix for Ground Temperature Sensor.

		Concept					
		(Reference) Thermocouple		Infrared Temperature Sensor		Thermistor	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
COTS	15%	3	0.45	3	0.45	3	0.45
Low Cost	10%	3	0.3	1	0.1	3	0.3
Low Mass	10%	4	0.4	2	0.2	3	0.3
Small Volume	15%	4	0.6	3	0.45	2	0.3
Durability	20%	4	0.8	3	0.6	3	0.6
All Inclusive	10%	3	0.3	3	0.3	2	0.2
Accuracy	20%	3	0.6	3	0.6	2	0.4
	Total Score	3.45		2.7		2.55	
	Rank	1		3		2	
	Continue?	Develop		No		No	

The next trade study was to determine a close-range sensor method for the CanSat. The close range sensor is used to determine when the CanSat is near the ground. The functional divisions involved in the trade study were the ECE Team and the DCS Team. Table 15 is the selection matrix used to determine which method the CanSat would use for determining when it is close to the ground.

Table 15. Selection Matrix for Close-Range Method.

		Concept					
		(Reference) Ultrasonic		Infrared		Triangulation Based	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
COTS	10%	3	0.3	3	0.3	2	0.2
Large Range	25%	3	0.75	3	0.75	2	0.5
Low Mass	20%	3	0.6	3	0.6	3	0.6
Small Volume	15%	3	0.45	3	0.45	3	0.45
Experience	15%	3	0.45	2	0.3	2	0.3
Low Cost	10%	3	0.3	2	0.2	2	0.2
Needs Reference Distance	5%	3	0.15	3	0.15	2	0.1
	Total Score	3		2.75		2.35	
	Rank	1		2		3	
	Continue?	Develop		No		No	

Table 15 determined that both ultrasonic and infrared methods have good performance and that both should be further researched and tested to determine the best option for a close-range sensor. Thus, the team selected both the ultrasonic and infrared sensors for further study.

The next trade study performed was to establish CanSat's method for altitude determination. The functional divisions involved in the trade study were the ECE Team and the DCS Team. Table 16 is the selection matrix for the altitude determination method.

Table 16. Selection Matrix for Altitude Determination Method.

		Concept					
		(Reference) Digital Barometric Pressure Sensor		Mechanical Pressure Sensor		Laser Altimeter	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
COTS	15%	3	0.45	3	0.45	2	0.3
Low Power	20%	3	0.6	3	0.6	2	0.4
Low Mass	20%	4	0.8	2	0.4	2	0.4
Small Volume	15%	3	0.45	2	0.3	2	0.3
Experience	15%	4	0.6	3	0.45	3	0.45
Low Cost	10%	3	0.3	2	0.2	2	0.2
Needs Calibration	5%	3	0.15	3	0.15	3	0.15
	Total Score	3.35		2.55		2.2	
	Rank	1		2		3	
	Continue?	Develop		No		No	

Table 16 shows that the altitude determination method with the best performance is the barometric pressure sensor. The 2007 and 2008 both CanSat teams used a barometric pressure sensor for determing altitude. In 2007, the barometric pressure sensor performed well during testing but was not proven to work in competition due to a failure with the communications system. In 2008, the barometric pressure sensor worked perfectly in the competition and transmitted accurate atmospheric pressure data back to the ground station for analysis that was presented in the post-flight debrief. Due to last year's success and the results from the selection matrix, the team has selected the barometric pressure sensor for determining altitude during the descent of the CanSat.

The ECE Team the performed the trade studies for the power system. Both the 2007 and 2008 CanSat Teams used one lithium ion battery to power all the systems on the CanSat. The 2007 and 2008 CanSats required to be powered for at least one hour. The 2009 CanSat will require more than three hours of power. Table 17 shows the selection matrix used to determine a power system that would be able to support a three hour mission.

Table 17. Selection Matrix for Power System.

		Concept									
		(Reference)									
		Lithium Polymer Battery		Nickel Metal Hydride Battery		Solar Panels		Solar Panel with UltraCap		Solar Panels with Lithium Polymer Battery	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
COTS	10%	4	0.4	3	0.3	3	0.3	2	0.2	4	0.4
No Additional Mechanisms Required	10%	4	0.4	4	0.4	3	0.3	3	0.3	3	0.3
Low Mass	15%	3	0.45	2	0.3	3	0.45	2	0.3	3	0.45
Experience	5%	3	0.15	3	0.15	2	0.1	1	0.05	2	0.1
Large Voltage Range	15%	3	0.45	3	0.45	3	0.45	3	0.45	3	0.45
Large Current Range	20%	3	0.6	2	0.4	2	0.4	2	0.4	3	0.6
Large Power Capacity	15%	3	0.45	2	0.3	2	0.3	2	0.3	3	0.45
Solar Powered	10%	1	0.1	1	0.1	5	0.5	4	0.4	4	0.4
	Total Score	3		2.4		2.8		2.4		3.15	
	Rank	2		4		3		5		1	
	Continue?	No		No		No		No		Develop	

Table 18 determined that the solar panel and lithium ion battery combination performed the best. Additionally, a selection matrix specific to the solar panels performance was performed by the ECE and Mechanical Engineering (ME) Teams to determine the optimization of the power system. Table 18 shows the selection matrix for the solar panels. Table 18 determined that the best optimization for the power system was to use rigid panels.

Table 18. Selection Matrix for Solar Panels.

		Concept					
		a) Flexible Panel		b) Rigid Panel		c) Rigid Supported by Flexible	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Weight	20%	3	0.6	5	1	4	0.8
Mounting Flexibility	20%	2	0.4	3	0.6	3	0.6
Durability	10%	5	0.5	2	0.2	2	0.2
Complexity of Mount	10%	4	0.4	4	0.4	2	0.2
Volume / Surface Area Required	40%	2	0.8	4	1.6	3	1.2
	Total Score	2.7		3.8		3	
	Rank	3		1		2	
	Continue?	No		Develop		No	

The DCS Team performed the trade studies for the descent control hardware. The main system driver for the descent control hardware was the ability to navigate the CanSat to a specified set of landing coordinates. Table 19 shows the selection matrix used to determine the descent control hardware for the CanSat.

Table 19: Selection Matrix for Descent Control Hardware.

Criteria/Options	Ram-air parachute	Deployable Wings	Ram-air with a Fan	Round Parachute	Paraglide with a Fan
COTS Product	Yes	No	No	Yes	No
Low Mass	Yes	No	No	Yes	No
Experience	Yes	No	No	Yes	No
No Propulsion	Yes	Yes	No	Yes	No
Controls direction of CanSat	Yes	Yes	Yes	No	Yes

Table 19 shows that the best performance for descent control hardware that will control the direction of the CanSat is the ram-air parachute. In 2007, the CanSat team attempted controlling the direction of the CanSat with a ram-air parachute and the design showed promising results. In 2008, the CanSat team was more cautious and decided to use a standard round parachute and focus on the primary requirements of the CanSat design. Thus, the team has selected the ram-air parachute as their primary descent control hardware and the round parachute as a backup.

The last trade study performed by the ME and DCS teams was to determine the DCS actuator. Table 20 describes the options and criteria used to determine the actuator with the best performance.

Table 20: Selection Matrix for CanSat Actuator.

		Metal Geared Servo		Linear Actuators		Nylon Geared Servo	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
COTS Item	25%	3	0.75	2	0.5	3	0.75
Strength	30%	3	0.9	3	0.9	1	0.3
Low Mass	20%	2	0.4	1	0.2	3	0.6
Complexity	15%	3	0.45	1	0.15	3	0.45
Volume	10%	2	0.2	1	0.1	1	0.1
	Total Score		2.7		1.85		2.2
	Rank		1		3		2
	Continue?		Develop		No		No

Table 20 confirms that the metal geared servo has the best performance of the three options. Metal geared servos come in a wide variety of sizes, torque, masses, and brands. The team will be required to purchase and test multiple types so that the metal geared servo is optimized.

Additional selection matrices performed were Table 21 for the material selection and Table 22 for the up-righting system.

Table 21. Material Selection Matrix for CanSat Interior and Exterior.

		Carbon Fiber		**G10 Fiberglass**		6061 Al Alloy		Wood	
Selection Criteria		Rating	Score	**Rating**	**Score**	Rating	Score	Rating	Score
Strength	30%	5	1.50	**5**	**1.50**	4	1.20	2	0.60
Price	15%	2	0.30	**3**	**0.45**	4	0.60	5	0.75
Workability	10%	3	0.30	**3**	**0.30**	4	0.40	5	0.50
Experience	5%	3	0.15	**5**	**0.25**	4	0.20	4	0.20
Fatigue Resistance	20%	5	1.00	**5**	**1.00**	2	0.40	1	0.20
EM safe	20%	1	0.20	**4**	**0.80**	3	0.60	4	0.80
Total Score			3.45		**4.30**		3.40		3.05
Rank		2		**1**		3		4	
Continue?		No		**Develop**		No		No	

Table 22. Selection Matrix for Up-righting System.

	Weighting	Spring loaded hinge		Three legged up righting		Two legged up righting	
		Rating	Score	Rating	Score	Rating	Score
Up righting force	35%	2	0.7	3	1.05	3	1.05
Ability to correct inverted landing	35%	2	0.7	4	1.40	3	1.05
Weight	20%	4	0.8	1	0.2	3	0.6
Ease of construction	10%	4	0.4	1	0.1	3	0.3
Total	100%		2.60		2.75		3.
Develop			No		No		Yes

2.5.2 Budget Management

The Virginia Tech CanSat Team received funding for the 2008 – 2009 academic year from BAE Systems, Inc. in Manassas, Virginia. A proposal for $3,000 to BAE Systems, Inc. was completed in September and was accepted in October. The total expenses for the 2008 CanSat team and the projected expenses for the 2009 CanSat team are described on pages 28 and 29.

2008 Summary:

Flight Unit:

Mechanical/Structural Subsystem:	$104.87
Electrical & Computing:	$420.86
Power:	$35.90
Recovery:	$15.95
Subtotal:	$577.58

Ground Station and Testing:

Ground Station Equipment:	$284.80
Testing:	$131.00
Subtotal:	$415.80

Travel Costs for Competition:

Hotel:	$840.00
Vehicle Rental & Gas:	$660.00
Subtotal:	$1,500.00

Total Cost of CanSat Project: $2,493.38

2009 Projections:

Flight Unit:

Mechanical/Structural Subsystem:	$100.00
Electrical & Computing:	$450.00
Power:	$150.00
Recovery:	$200.00
Subtotal:	$900.00

Ground Station and Testing:

Ground Station Equipment:	$250.00
Backup Supplies:	$150.00

Testing Equipment:	$200.00
Subtotal:	$600.00
Travel Costs for Competition:	
Hotel:	$840.00
Vehicle Rental & Gas:	$660.00
Subtotal:	$1,500.00
Projected Cost of CanSat Project:	**$3,000.00**

2.5.3 Data Management

The data management for the CanSat is formatted by competition requirements. "Requests for science data packets shall be generated by the competition science Ground Control Station (GCS)" (CanSat Competition, 2008). The commands shall be addressed for specific CanSats via the CanSat identification (ID) number. The science data packet request command shall be an ASCII text string formatted as shown in Table 23.

Table 23: Science Data Packet.

# of Char*	**2**	**2**	**1**	**6**	**1**	**7**	**1**	**8**	**1**	**5**	**1**	**5**	**1**	**40**	**1**
Data	SP	<ID>	T	<TIME>	N	<LAT>	W	<LON>	H	<ALT>	C	<TEMP>	U	<HT>	;

*Number of characters

The following list describes the abbreviations and acronyms used in Table 23.

1. SP – 1st character and start of package (stands for Science Package), (cc)*
2. <ID> - unique CanSat ID (##)**
3. T – 5th character (stands for time), (c)
4. <TIME> - time tag, (hhmmss)***
5. N – 12th character (stands for North), (c)
6. <LAT> - latitude, (##.####)
7. W – 20th character (stands for North), (c)
8. <LON> - longitude, (###.####)
9. H – 29th character (stands for Height), (c)
10. <ALT> - altitude in metes, (###.##)
11. C – 34th character (stands for Celsius), (c)
12. <TEMP> - temperature, (##.###)
13. U – 40th character (stands for start of housekeeping telemetry), (c)
14. ; - data package terminated

* "c" stands for a letter character

** "#" stands for a number (0 - 9)

*** "h" stands for hour, "m" stands for minute, and "s" stands for second (all numbers)

Figure 7 illustrates the method in which multiple CanSat teams will be able to transmit science data packets during the mission. The Mission Data Relay Configuration consists of a weather balloon that has a data relay attached to it, CanSats from all the teams, the ground stations for all the teams, and the central ground station.

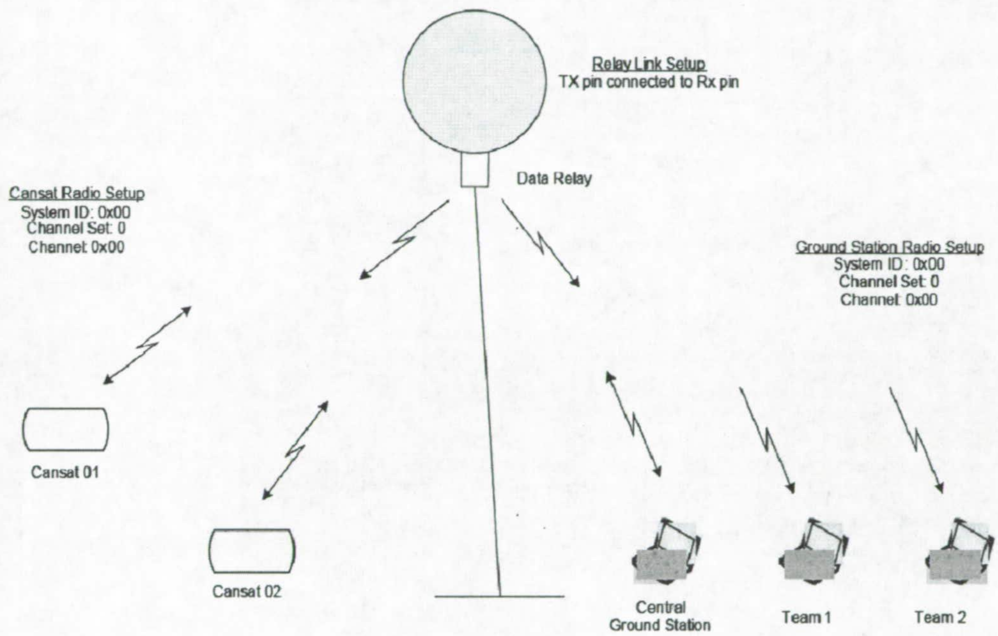


Figure 7: Mission Data Relay Configuration.

Figure 8 shows the mission timeline for the science data collection. After landing, the CanSats will transmit science data for one hour to the relay weather balloon which will relay data to the team ground stations. After one hour has passed on the ground, CanSats will be able to transmit the optional landing image data for one hour. After two hours have passed on the ground, teams will transmit the science data packet as described in science data collection (2) part of Figure 8.

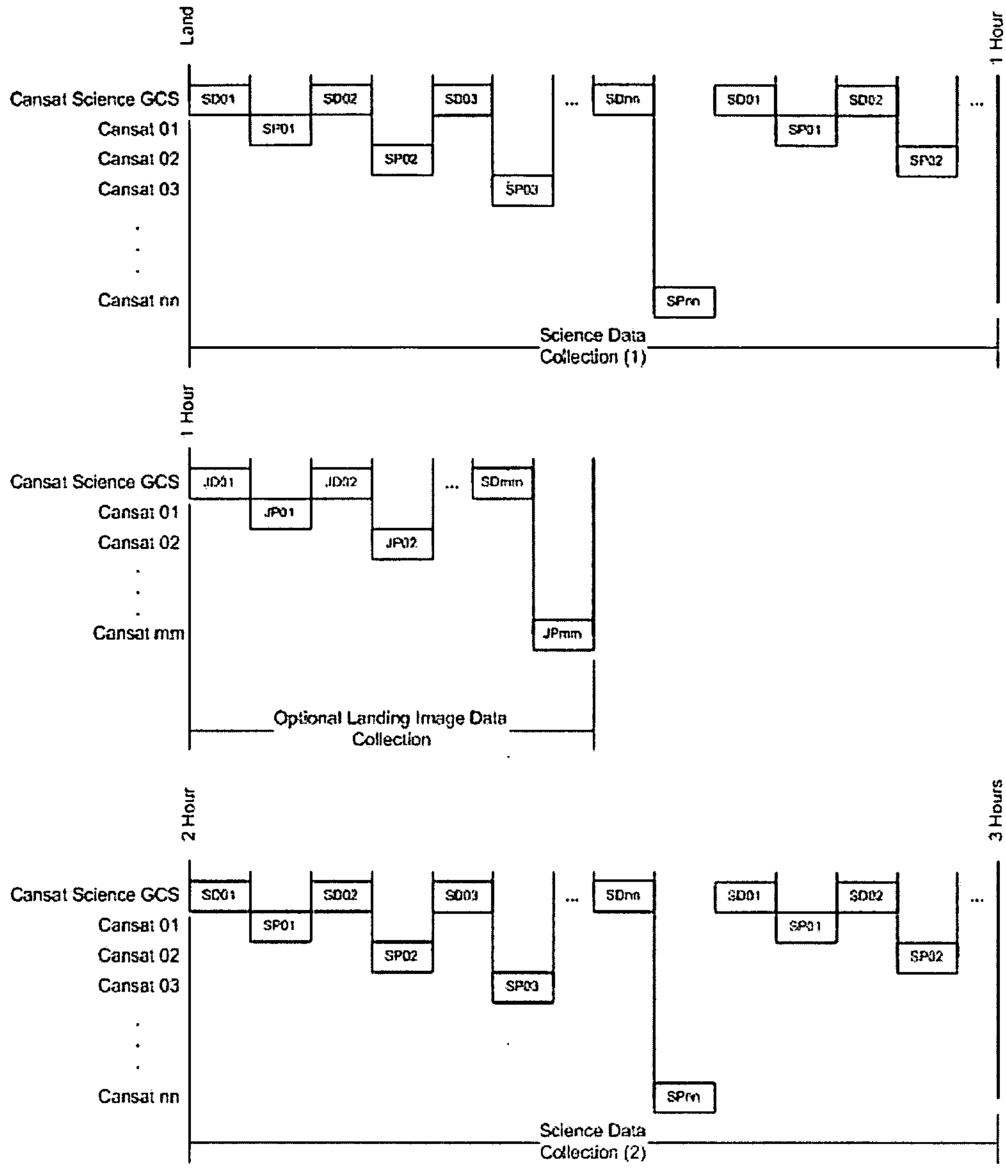


Figure 8: Mission Data Collection Timeline.

2.5.4 SE Master Schedule

The SE Master Schedule is a required deliverable of the CanSat Competition. For clarity, the SE Master Schedule is organized by functional division (i.e. Systems, Descent Control System, Electrical and Power System, and Mechanical System). Refer to the Appendix to view the Gantt charts of the SE Master Schedule.

3 Transitioning Critical Technologies

3.1 Mechanical Engineering Subsystem

3.1.1 Criteria

The CanSat project requires the utilization of many items that are either not readily available or are not optimum in terms of cost, weight, or performance. Therefore, the designs and technologies to implement these functions must be developed or modified. From the mechanical side, this usually focuses on the modification of existing technologies or products to satisfy the requirements. The main concerns in this case are that the design is feasible to fabricate and that the new product does not exceed or dramatically change (in which case the results of the modification would be unpredictable) the loading on the original part. From the structural perspective, this process may center more on the selection of the optimum material as it is very unlikely that anything resembling the required structure is being produced. In this case, the primary concerns are the mechanical performance of the technology as well as its interactions with other systems. An excellent illustration of the importance of analyzing the effects across systems occurred with the structural team this year. Initially, carbon fiber was chosen as the best combination of weight, cost, and strength. However, upon further analysis (and thanks to some members with remote control plane experience) it was realized that extensive use of carbon fiber could shield or significantly reduce the range of the radio system. With this new information, the team resumed research into other materials and selected G10 fiberglass due to its excellent mechanical performance and no significant radio disruption.

3.1.2 Activities and Risks

To describe the Critical Technology Transitioning methodology the team implemented, I will present our process in terms of the mechanical team's selection and development of the release for the solar panel doors. Initially, the team explored the use of a COTS item (such as a positive lock pin) to simplify the process. Although several promising products were found, when the team tried to create designs around them it was determined that they required a disproportionate amount of volume and weight of the can. Furthermore, all products would have required significant modifications to the current designs (and thus necessitate more integration time). From this, the team decided to focus on new technology that would work in unison with the existing bulkheads, mounts, and the solar panels themselves. From here, we determined the major potential risks: unit jamming, releasing prematurely, and interfering with other components. With these in mind, the team turned to choosing a COTS component to be the center of the design and selected a solenoid due to its very low mass and reasonable size. While the team did not have extensive experience with solenoids, we did know from our previous year's competition that even small shear forces on the plunger could result in the solenoid jamming. Since our goal was to minimize this risk, we designed the mechanical aspect of the release to support the plunger and increase the horizontal displacement of the release pin while keeping the solenoid in its optimum force range as shown in Figure 9.

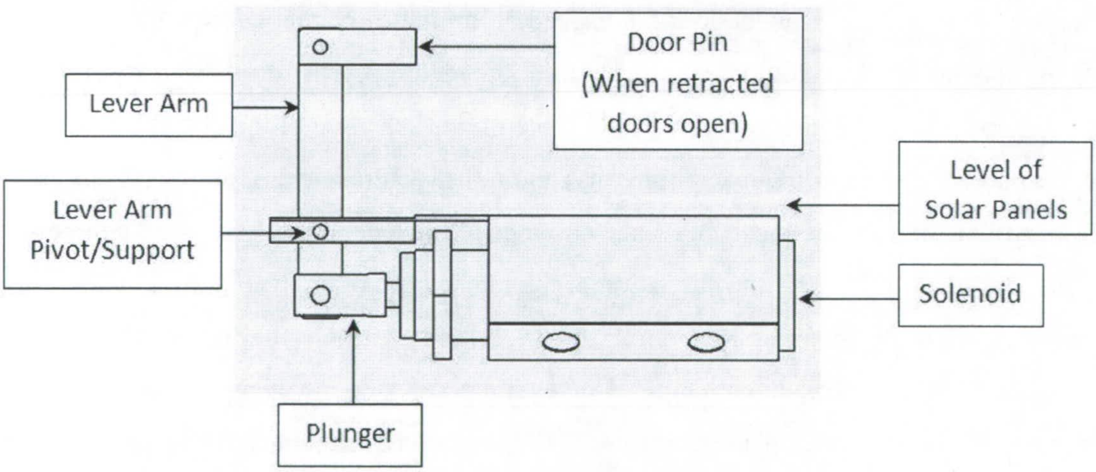


Figure 9. Mechanical Critical Technology Transitioning – Solar Door Release Mechanism.

While this mitigates the risk of the release jamming to an acceptable level, it does nothing to alleviate the second major risk that is for the unit to release prematurely. To address this, we first determined that the most likely way for this unwanted release to occur was by a force or vibration that would cause the plunger to drop. Although testing is required to confirm our plans, we currently think that the shear forces in the door pin will create a sufficient amount of friction to keep the release locked. If this is not the case, the team will add a plunger restoring spring to ensure that the system stays locked until desired. Finally, this design addresses the space and mass requirements we set so that it does not interfere with other components. One of the key features of this design, the supported lever arm, not only improves the mechanical durability of this design, but it also allows the team to place the solenoid below the solar arrays and firmly attached to the can central structure and thus reduce interference and improve strength. With the critical technologies of the solar release now designed and transitioned, we can now focus on fabrication, integration, and testing of this component.

3.2 Electrical and Computing Engineering (ECE) Subsystem

3.2.1 Criteria

This CanSat electrical system is required to interface with many different components. In order to collect and transmit the required data the minimal system had to include GPS, altimeter, processor, transceiver, and temperature sensor. However, because we chose to pursue both an autonomous landing and solar power missions the electrical system was expanded to include components needed to collect additional data and add additional outputs to control the autonomous landing system. Most of the system is made up of COTS components including the processor, altimeters, GPS and temperature sensor.

3.2.2 Activities

Due to the nature of the power system required to implement the autonomous landing and the solar power missions a COTS power system was not available and one had to be developed (Refer to Figure 13 in the Appendix). The power system requires a battery, to provide power during the autonomous landing, and solar panels to provide power while on the ground. While the battery needed was a COTS lithium polymer battery with an output of 7.2V, a comparable solar panel with a similar output was not available off the shelf that would fit within the mechanical structure of the CanSat. Because a COTS solar panel was not available one ad to be developed from COTS materials. By using small rigid solar panels, shown in Figure 10, and combining them in series we were able to achieve the needed voltage and current levels to supply power to the electrical system while on the ground.

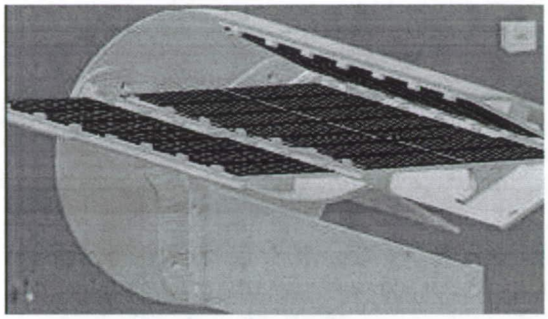


Figure 10: Solar Panel System.

Another aspect of the power system needed to address the issue of different electrical system components requiring different voltage levels to power the devices. Some devices required a nominal voltage of 3V and others required a nominal voltage of 5V. By placing the limit of these two voltage levels, which are the most common for small electronics, we avoided having to use a different voltage regulator for each component. With this design only two voltage regulators are required one to regulate the 3V and one to regulate the 5V.

3.2.3 Risks

There are inherent risks associated with not using an entirely COTS power system. While most of the components of the power and electrical systems are COTS items the power system includes the solar panel design which is not. The risk of not using a COTS solar panel was outweighed by the customizability of using the individual panels in a way that custom fits within our system. In order to minimize the risk of the solar panel not working or not performing to the standards we have set, extensive testing will be done on the custom solar panel to ensure proper function.

3.3 Descent Control Subsystem (DCS)

3.3.1 Criteria

The DCS is a system meant to provide controlled descent for the CanSat while autonomously guiding it to a predetermined target location. To complete this overall objective the DCS uses a combination of sensors and actuators to control the system. Because of the complex nature of the small autonomous system, the DCS team developed stringent criteria that will ensure the success of the system. By keeping the overall objective of the DCS in mind, the DCS team developed the three main criterions that will guide the design and development of the

DCS. The DCS must first be small enough to fit the CanSat payload and the two inch module allocated by the mechanical team to the DCS. Secondly, the DCS must minimize power usage. The last criterion is the DCS must function without propulsion.

3.3.2 Activities

Taking the above DCS criteria into consideration we were able to decide upon certain sensors and actuators that would best suit the CanSat. To minimize volume, power usage, and make the DCS independent of propulsion the team decided on using a metal geared servo. The servo will control deployable arms that will be attached to the ram air and thus control direction of the CanSat. We also decided on the sensors needed to provide the necessary data to the DCS to complete the fully controlled descent while still meeting the above criteria. We decided to use a barometric sensor for our altimeter while deciding to use a GPS to determine CanSat location. Because the competition requires telemetry data to be provided during descent we can minimize power usage by using barometric sensor and GPS for both DCS and telemetry functions. A sensor specific to DCS is the ultrasonic sensor for close ground detection from about 20 ft. from the ground. This sensor is meant to provide extra data in order to properly dislodge the DCS module before ground impact to avoid the ram air from being entangled with the CanSat and preventing base missions of the CanSat from being accomplished.

3.3.3 Risks

There are always inherit risks with any system being developed. One of the biggest risks related to the DCS is the unpredictability of the ram-air parachute. The ram air's full deployment is essential to the success of controlling descent rate, which is a requirement of the CanSat. Having one cell of the ram air not inflate could cause the loss of the rigid wing needed to control such descent and thus cause the CanSat to descend to the ground at an uncontrollable rate and would result in the loss of the CanSat. With the addition of turning during descent due to autonomous control, descent rate can be even more unpredictable and thus fall out of the allowable requirement range provided by the competition.

Risks are further presented with the additional mass and volume contributed by the DCS. These extra factors place further constraints on base features of the CanSat and thus could cause a better probability of failure concerning the base missions of the CanSat.

4 Integration of Systems Engineering Effort

4.1 Expectation of Reviews and Frequency of Reviews

The CanSat competition has three reviews; a Preliminary Design Review (PDR), a Hardware Review (HWR), and a Critical Design Review (CDR). These allow the team to inform the judges about what we have been working on and what direction our design is moving in. The preliminary design review's purpose is to demonstrate that the team understands the rules, and is able to meet the mission requirements within the budget, time, and risk constraints. The PDR took place in February and the judges agreed that our design is sound and ready for further development. The hardware review is a more informal review that takes place in March to prove to the team's mentor that hardware selection and procurement is leading the team to the successful completion of the CanSat. The critical design review is a multi-disciplinary technical review that takes place in May and allows the team to show the judges that we have a solid final design that is ready for production.

4.2 Organization and Integration of Design Disciplines

The design of the CanSat was organized by sub-system, as outlined in section 2.3, and illustrated in Figure 3, to facilitate greater efficiency in the design phase of the project and a better product through specialization of tasks. This team and system break-down worked as intended and the outcome was a strong design that should work well and is expected to be competitive in the long run. In the short run, this organization break-down creates an integration task more involved, but one that will ultimately improve the quality of the CanSat.

It was with this foreknowledge that the CanSat was designed and the result was a modular structure that favored component integration. The design allows the team to assemble and test sub-system components off the main structure and then mate them quickly and easily to the main structure. As discussed earlier, a major facet of the design is an electrical spine that runs up the center of the CanSat allowing components to be attached and immediately access power wherever they are mounted. In addition, panels in the payload module of the CanSat that act as mounting plates for electrical and mechanical components can be slid in and out of mounting brackets on either end of the module so components can be mounted to the plate with plenty of room for tools and hands, and then simply slid into place and anchored on the main structure.

Software integration was also a strong consideration when choosing components for the computing sub-system. Software integration will be handled by the software engineers. Hardware was chosen to assist with software integration and components were chosen that already had native control libraries and were capable of running higher level code such as C and C++. Hardware integration will be fairly simple and overseen by the AI&T engineer who will direct wire routing and placement inside the payload module – yet another reason for the central electrical spine.

5 Implementation Tasks

5.1 Electrical and Computing Subsystem

5.1.1 Proof of Concept

The electrical and power system had several design goals. These goals were split up into electrical system goals and power system goals. The main electrical system goal was to collect all of the science data required to be transmitted back to the ground station and to use this data to control the autonomous descent system. The power system goal was to integrate a solar panel system into the mechanical design of the CanSat and provide continuous, reliable power to the electrical system. In order to design an overall system that would accomplish these goals the design was dispersed within the team so each goal could be focused on individually. The electrical system was designed by the electrical sub-team in conjunction with the descent control team in order to ensure that all the necessary sensors were included in the design to collect and transmit the data required for the science mission and control the autonomous landing system. The power system was designed by the electrical sub-team in conjunction with a subset of the mechanical team. Together they were able to design a solar power system that would fulfill the power needs of the electrical components and physically fit within the CanSat.

5.1.2 Electrical System Software Development

The electrical system is heavily dependent on software. The software to control the processor, sensors and transceiver was developed in the C language. By modifying and using open source code provided by the component manufacturers we were able to communicate with all of our sensors and translate their data outputs into the information that we are required to transmit back to the ground station. By using these provided sections of code rather than developing an original code to accomplish the same task from scratch we are able to ensure that the code correctly communicates with the different components. The entire program will first be tested in sections, to ensure that each component individually is functioning correctly. Once we confirm that each section is working individually we will begin to test the program and the electronic system as a whole.

5.1.3 Electrical Power System Development

Once a couple of design concepts were developed for the solar power system some materials were ordered so we could do concept testing on them. One of the designs was to use sheets thin-film solar panels rolled up within the CanSat that would deploy upon landing. However, when we got the material and began testing it, it was found that the sheets were not pliable enough to be rolled tight enough to fit inside the CanSat. Then the second design idea of using multiple rigid solar panels and mounting them inside the CanSat was tested. A conceptual model was built to test this structure and it was found to be a viable concept.

5.1.4 Electrical and Power System Testing

The electrical and power system is composed of many individual sensors and other components; because of this it is very important to compartmentalize the testing procedure of this system. Each sensor and component will be tested individually before being integrated into the CanSat to ensure proper function. This testing of each component before it is integrated will greatly reduce and simplify the troubleshooting of the system once it is entirely installed and tested as a whole. Another design implementation that will greatly reduce the time and effort required in testing is the use of connectors between many of the components rather than soldering the components directly to the connective wires. This use of connectors will make it simple to remove a component for further individual testing or for replacement.

After the concept of rigid panels was proven to be the most viable option the design was further developed. The panels will be assembled together and mounted within the structure of the CanSat. The mechanical sub-team is developing a mechanism to control the opening of the solar panel bay doors. This mechanical system will be tested to ensure proper opening of the solar panel bay. Additional testing will be done on the solar panels themselves to test their construction and power output. Once the power output of the panels is confirmed the solar panels will be connected to the rest of the power system and the whole system will be tested under multiple temperature and sunlight conditions. It is important to test the power and electrical system in multiple temperature and sunlight environments because the high temperatures reached in the summer could have an effect on the electrical components and the amount of sunlight reaching the solar panels can greatly affect their power output.

5.2 Mechanical Subsystem

The implementation of each component of the CanSat can be classified into three categories: purchase, make, or reuse. For illustration purposes, I will continue with the product introduced in the Mechanical section of the Transitioning of Critical Technologies (Section 3), the Solar Door Release, we see that two of the implementation types are utilized. The solenoid is a purchased COTS item while the mount and lever system is a unique fabricated item. While each of these presents distinctive challenges to employ successfully, they both have the same basic goal: to reproduce the functions of our idealized design as accurately as possible. To ensure that this is the case the COTS solenoid needs to be tested to confirm that it meets the manufacturer's specifications (or at least is sufficient for pulling the door pin). For the fabricated unit similar tests must be conducted, however they are conducted in several phases. First, the team assembles the unit in a test rig to ensure the concept works (and this is repeated under various conditions to determine reliability). After we complete these tests successfully or make necessary changes, we assemble the component in the final unit and test again to ensure that there are no conflicts with the other systems in the can.

The critical step in the implementation stage is designing the tests to accurately simulate (or are) the real conditions that the CanSat may experience. If the tests are not correct representations, then our confidence in the probability of success we found from the tests is low and the data we collected meaningless. For the Solar Deployment system, the primary potential causes of failure were determined to be landing on the door, vibrations, and the acceleration at launch, apogee, and landing. Therefore, once the test unit is created, the team will focus on these situations. To ensure realism in the tests, the unit will be dropped for the tests analyzing the effects of door landings or shocks and launched in a rocket (or have launch vibrations simulated if possible) to test vibrations. By utilizing tests such as these, the team ensures that the result we obtain is robust and that we can be confident in the performance of the component.

The realization of the design is of course the goal of the vast majority of projects, and standing at the front end of a project can seem like a daunting task. With the proper preparation and organization however, the implementation of the countless hours of work put into the project up to this point is quite straight forward. It is important to point out that while, typically up to this point project teams are divided into subsystem task groups, all task groups need to reconvene into a single unit, with their specialized perspectives on the implementation, for the overall process to run smoothly. For the CanSat project, the perspective on implementation brought to the table by the mechanical engineering group primarily concerns the verification of the physical integration of all the subsystem components.

During integration, at the direction of the AI&T engineer, the ME group oversaw the assembly of all system components onto the main CanSat structure. At implementation the ME group, again at the direction of the AI&T engineer, is responsible for the verification of not only the mechanical tasks the CanSat must perform, but for the verification of its structural ability to transport and protect all the components (mechanical and otherwise) during operation.

Tests at this stage no longer evaluate the viability of a technology but the performance of the final design. Drop tests no longer verify the selection of a material or the strength of a part, but verify the ability of all the subsystems to work together control descent. Drop tests verify the ability of the structure survive protect the components that are now integrated onto it rather than the ballast that was used before. Vibration tests verify the torques on fasteners are adequate to resist backing out. Additionally, processes are now tested vigorously to affirm that components perform as designed and do not interfere with other subsystems that may be operating concurrently and that all contingencies are accounted for. Even routine electrical tests are of concern to the ME group because the tests are being performed while mated to the structure – which could alter the results from the sub-system verification tests done before integration.

5.3 Descent Control Subsystem

5.3.1 Proof of Concept

The focus of the DCS design was the completion of the autonomous landing bonus objective. To achieve the best and most appropriate design, the DCS team worked together to create a design through collaboration and can be seen in Figure 11. To control AoA and the descent of the CanSat, the design introduced the use of ram-air control arms (RCA) to translate the servo arm movement over a longer area to better control the ram air. To prevent unwanted movement in the RCAs (past 90°), a partition was fitted to the RCA's connection with the servo arm. Therefore the only movement experienced by the RCAs is the upward movement provided by the upward force of the ram air, and once deployed they remain stiff to provide the needed ram air control. To insure design quality for the DCS, a proof of concept was developed and can be seen in Figure 11.

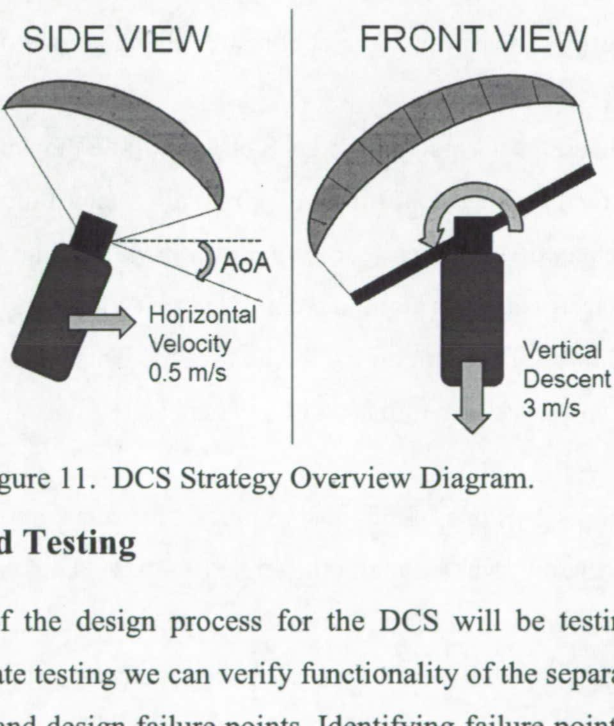


Figure 11. DCS Strategy Overview Diagram.

5.3.2 Development and Testing

The second stage of the design process for the DCS will be testing of the proof of concept. Through appropriate testing we can verify functionality of the separate parts making up the DCS and better understand design failure points. Identifying failure points within the design allows the DCS team to identify any challenges with construction or components which may need to be replaced.

It is important to develop and test two key components within the DCS which is the software and hardware of the system. Testing of these two components will allow the team to verify the system meets the CanSat competition requirements for the autonomous bonus mission and verify the design concept. To best do this the DCS must undergo five tests concerning many aspects of the entire system.

5.3.2.1 Controlled Environment Drop Tests

The first of many tests is meant to test four hardware aspects of the DCS in a controlled no wind environment.

The first DCS hardware component being tested is the deployment of the ram air control arms (RCAs). Testing of this component will give the team a better picture of the friction the arms may experience upon deployment from the CanSat and the upward force the arms will experience. This test will verify the connection strength and the structural integrity of the RCAs.

The second and third aspect of the DCS tested will be the determination of the RCA lengths which is directly related to testing of the ram air. Determining the best combination of ram air to DCS connection can provide for the best control over the CanSat upon descent. Each RCA have 0.5m spaced out holes along the entire length of the arm in order to test different positions the chord lines of the ram air can be tied off to. This test will help verify the best length of the RCA and where the ram air will be connected to the RCAs.

The last and perhaps one of the most important aspects being tested and analyzed is the vertical velocity, horizontal velocity, and the angle of attack. Understanding these three aspects can better prepare integration of the software with the hardware concerning the DCS. This test will verify that the CanSat will have a vertical descent velocity between 2.4 m/s - 4.6 m/s, a requirement set by the CanSat competition. The test will further verify that we have a horizontal velocity of around 0.5 m/s, a value determined by the DCS team. In completion, the test will also verify the angle of attacks the CanSat will experience upon drop and help the team better understand the movement of the CanSat under certain angle of attacks.

5.3.2.2 Variable Wind Drop Tests

The variable wind drop test will be performed outside with the presents of wind to provide a more real time scenario. The test will verify all the results from the controlled environment drop test with the presents of wind.

5.3.2.3 Wind Tunnel Tests

The wind tunnel test in a more hardware aspect of the DCS is meant to test the servos capabilities and verify its functionality under real scenario conditions. From a software perspective, the wind tunnel test will allow the DCS team to perform PID tuning and determine angular rates for control. This test will verify the overshoot and steady state error the CanSat will experience and thus provide values the team can use for competition.

5.3.2.4 Remote Control Drop Tests

Further along in testing and once determining positioning of the ram air, remote controlled testing will take place. This will verify the controllability of the ram air and further test the capability of ram air aerodynamics.

5.3.2.5 Rocket Launch Tests

To verify the entire DCS system before competition, a rocket launch test and deployment of the CanSat will take place. This will test the entire autonomous system under real conditions and verify the results of previous testing.

6 Additional Systems Engineering Activities

Working on a set budget of one thousand dollars makes design to cost and value engineering plays a large role in CanSat development. It has been essential to minimize cost wherever possible in order to be able to fund more expensive aspects of the launch unit. One of the largest design changes that have been made in order to save money is altering the internal structure design. It initially depended upon machined aluminum base plates to hold the CanSat together. It would have cost over five hundred and fifty dollars to have a machine shop produce the plates. This was unacceptable since that was over half of the budget. Therefore we opted for a simpler fiberglass base plate design that can be built by the team in house for less than twenty dollars. By eliminating the need for skilled labor we were able to drastically reduce construction costs. Use of common of the shelf components whenever possible has played a critical role in the value and design to cost engineering efforts.

Long-Lead items were also minimized by keeping as many construction aspects as possible in house. By not relying on custom out of house components the team is able to remain in complete control of when and how components are produced. The few long-lead items that were encountered (mostly shipping times for certain components) were accounted for by ordering early in the design process as soon as it was established that they would be needed. This allowed plenty of shipping time while the team finalized the design. This minimized the time spent by the team waiting on parts.

7 Conclusion

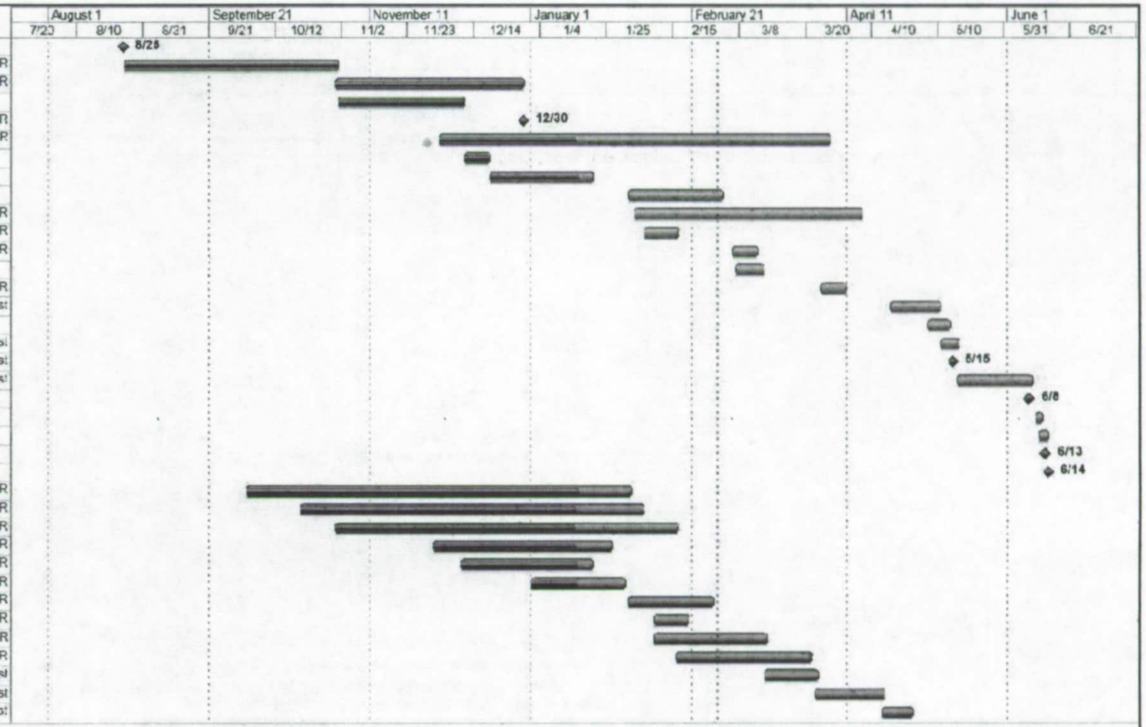
The CanSat project is a complex systems engineering project which spans many technical disciplines. Through the application of system engineering tools; however, a complete solution to the 2009 mission has been developed. Currently, the team is on schedule to meet all of the competition requirements necessary for a successful mission.

8 APPENDIX

Table 24. Verification Method Definitions [1].

Verification Method	Definition
Analysis	Verification method that utilizes evaluation of data generated by accepted analytical techniques or simulations under defined conditions to show the item will meet the specified requirements.
Demonstration	Verification method that utilizes a qualitative exhibition of function performance, usually accomplished with no or minimal instrumentation.
Inspection	Verification method that utilizes an examination of the item against applicable documentation to confirm compliance with requirements.
Test	Verification method utilizing operation of all or part of the item under controlled conditions, either real or simulated, to determine that the quantitative design or performance requirements have been met.

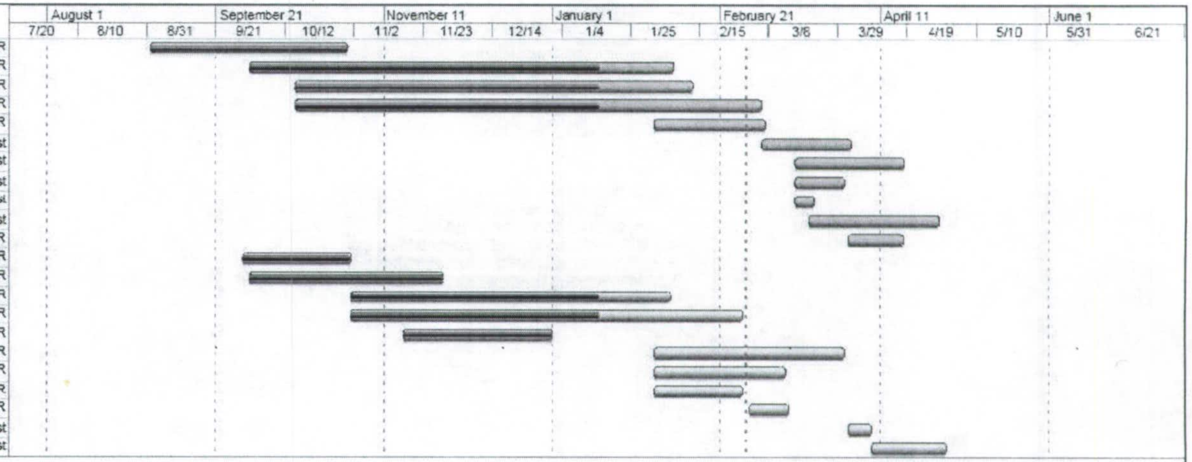
ID		Task Name	Duration	Start	Finish	Phase
1	✓	Project Start	0 days	Mon 8/25/08	Mon 8/25/08	
2	✓	Preliminary Design	50 days	Mon 9/25/08	Fri 10/31/08	PDR
3	✓	Design Refinement	43 days	Fri 10/31/08	Tue 12/30/08	PDR
4	✓	Systems Engineering Paper Rough Draft	29 days	Sat 11/1/08	Wed 12/10/08	
5	✓	Design Completion	0 days	Tue 12/30/08	Tue 12/30/08	PDR
6		Construction	91 days	Wed 12/3/08	Sun 4/5/09	PDR/CDR
7	✓	Exams (Fall)	6 days	Thu 12/11/08	Thu 12/18/08	
8		Winter Break	23 days	Fri 12/19/08	Tue 1/20/09	
9		Systems Engineering Paper Final Draft	22 days	Sun 2/1/09	Mon 3/2/09	
10		Module Integration	54 days	Tue 2/3/09	Wed 4/15/09	CDR
11		PDR	7 days	Fri 2/6/09	Mon 2/16/09	PDR
12		Hardware Review	7 days	Fri 3/6/09	Fri 3/13/09	CDR
13		Spring Break	6 days	Sat 3/7/09	Sun 3/15/09	
14		CDR	7 days	Fri 4/3/09	Fri 4/10/09	CDR
15		Final Integration	12 days	Sat 4/25/09	Sun 5/10/09	Test
16		Exams (Spring)	6 days	Thu 5/7/09	Wed 5/13/09	
17		Rocket Test	6 days	Mon 5/11/09	Sat 5/16/09	Test
18		Graduation	0 days	Fri 5/15/09	Fri 5/15/09	Test
19		Final Cansat Refinement	17 days	Sat 5/16/09	Mon 6/8/09	Test
20		CanSat Completion	0 days	Mon 6/8/09	Mon 6/8/09	
21		Travel to Competition	2 days	Wed 6/10/09	Thu 6/11/09	
22		CanSat Competition	3 days	Thu 6/11/09	Sat 6/13/09	
23		Flight Operations	0 days	Sat 6/13/09	Sat 6/13/09	
24		Post Flight Review	0 days	Sun 6/14/09	Sun 6/14/09	
25		DCS Control Program Development	88 days	Fri 10/3/08	Sun 2/1/09	PDR
26		DCS Module Design	81 days	Mon 10/20/08	Thu 2/5/09	PDR
27		DCS Ram-air Design	79 days	Fri 10/31/08	Mon 2/16/09	PDR
28		DCS Servo Study & Selection	41 days	Mon 12/1/08	Mon 1/26/09	PDR
29		DCS Altimeter Study & Selection	30 days	Wed 12/10/08	Tue 1/20/09	PDR
30		DCS Release Design	22 days	Thu 1/1/09	Fri 1/30/09	PDR
31		DCS Release Construction	21 days	Sun 2/1/09	Fri 2/27/09	PDR
32		DCS Servo Testing	9 days	Mon 2/9/09	Thu 2/19/09	PDR
33		DCS Module Construction	27 days	Mon 2/9/09	Mon 3/16/09	PDR/CDR
34		DCS Ram-air Construction	32 days	Mon 2/16/09	Mon 3/30/09	CDR
35		DCS Module Testing	13 days	Mon 3/16/09	Wed 4/1/09	CDR/Test
36		DCS Ram-air Testing	17 days	Wed 4/1/09	Wed 4/22/09	CDR/Test
37		DCS Drop Testing	9 days	Wed 4/22/09	Fri 5/1/09	Test



Project: CanSat Project.mpp
Date: Sun 3/1/09

Task | Progress | Summary | External Tasks | Deadline
Split | Milestone | Project Summary | External Milestone

ID		Task Name	Duration	Start	Finish	Phase
38	✓	EPS System Design	44 days	Mon 9/1/08	Thu 10/30/08	PDR
39		EPS Component Selection	95 days	Wed 10/1/08	Fri 2/6/09	PDR
40		EPS Component Acquisition	89 days	Wed 10/15/08	Thu 2/12/09	PDR
41		EPS Control Program Development	104 days	Wed 10/15/08	Thu 3/5/09	PDR/CDR
42		EPS Construction	26 days	Sun 2/1/09	Fri 3/6/09	CDR
43		EPS Control Program Testing	20 days	Fri 3/6/09	Wed 4/1/09	CDR/Test
44		EPS System Testing	26 days	Mon 3/16/09	Fri 4/17/09	CDR/Test
45		EPS Power System Testing	11 days	Mon 3/16/09	Mon 3/30/09	CDR/Test
46		EPS Communications Testing	5 days	Mon 3/16/09	Sat 3/21/09	CDR/Test
47		EPS Sensor Testing	30 days	Fri 3/20/09	Tue 4/28/09	CDR/Test
48		EPS System Integration	14 days	Wed 4/1/09	Fri 4/17/09	CDR
49	✓	ME Structure Design	25 days	Mon 9/29/08	Fri 10/31/08	PDR
50	✓	ME Solar Mounting Design	44 days	Wed 10/1/08	Fri 11/28/08	PDR
51		ME Solar Door Release Design	71 days	Sat 11/1/08	Thu 2/5/09	PDR
52		ME Acquisition of Parts/Materials	87 days	Sat 11/1/08	Fri 2/27/09	PDR
53	✓	ME Uprighting System Design	33 days	Mon 11/17/08	Wed 12/31/08	PDR
54		ME Solar Deployment Construction	43 days	Sun 2/1/09	Mon 3/30/09	PDR/CDR
55		ME Component Layout	31 days	Sun 2/1/09	Thu 3/12/09	PDR/CDR
56		ME Uprighting Construction	21 days	Sun 2/1/09	Fri 2/27/09	PDR/CDR
57		ME Structure Construction	11 days	Mon 3/2/09	Fri 3/13/09	CDR
58		ME Solar Deployment Testing	6 days	Wed 4/1/09	Tue 4/7/09	CDR/Test
59		ME Solar Deployment Integration	18 days	Wed 4/8/09	Thu 4/30/09	CDR/Test



Project: CanSat Project.mpp
Date: Sun 3/1/09

Task, Progress, Summary, External Tasks, Deadline, Split, Milestone, Project Summary, External Milestone

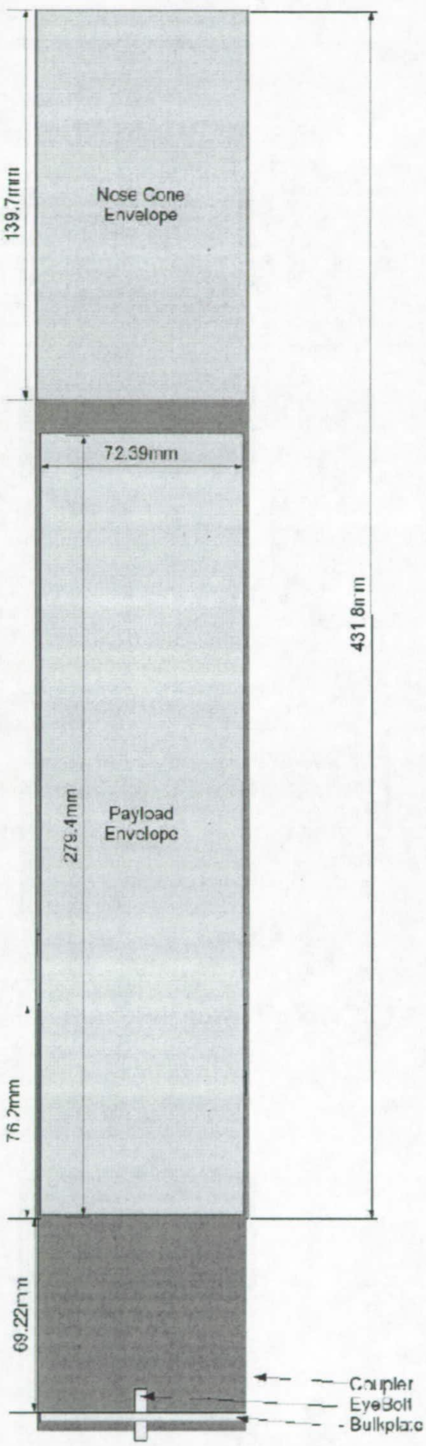


Figure 12. Launch Vehicle Layout for CanSat.

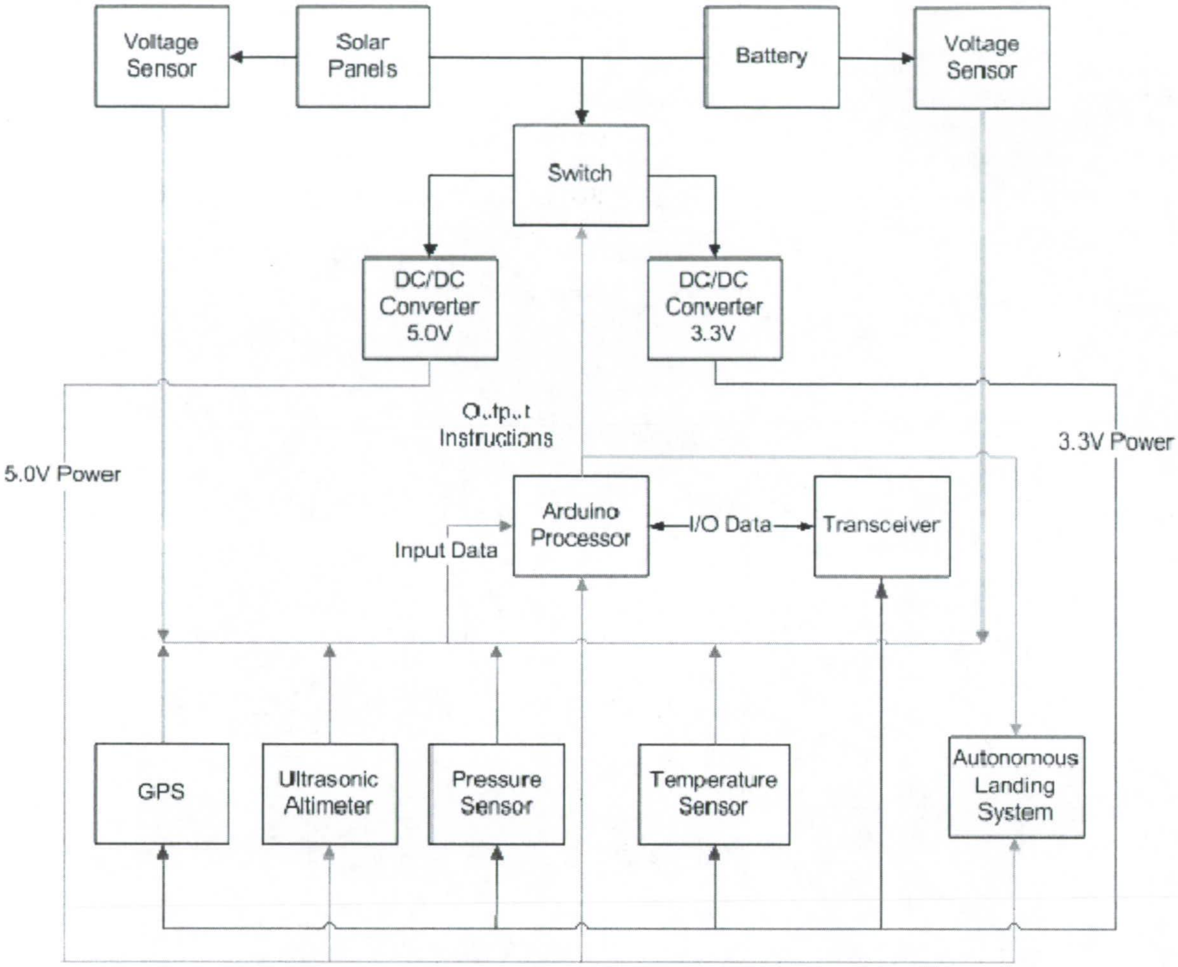


Figure 13. CanSat Power System Block Diagram.