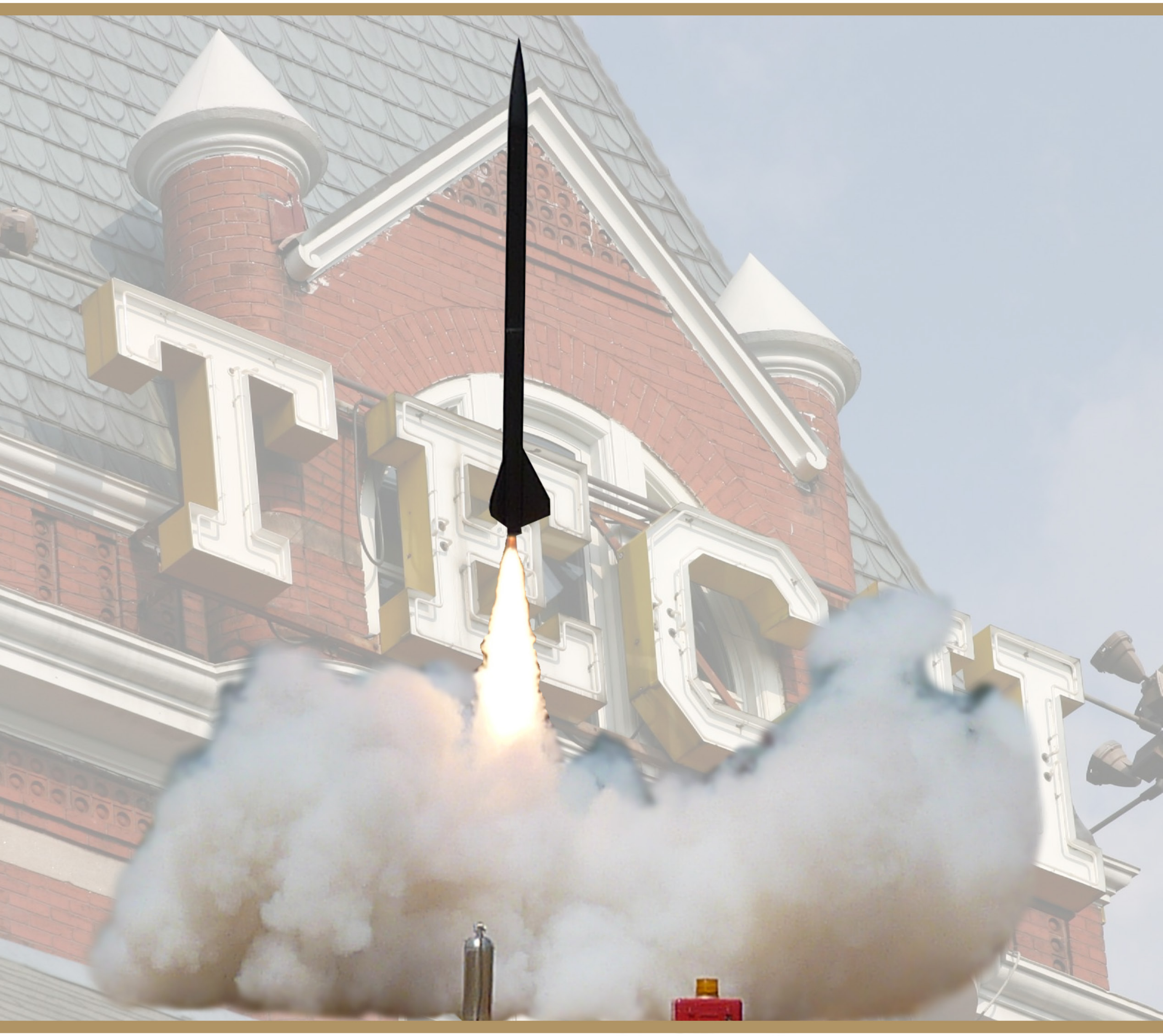
Georgia Tech, University Student Launch Initiative

Project A.P.E.S.

Active Platform Electromagnetic Stabilization



Post-Launch Assessment Review

http://usli.gatech.edu

May 2012

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1. Team Summary

Team Summary	
School Name	Georgia Institute of Technology
Team Name	Mile High Yellow Jackets
Project Title	Active Platform Electromagnetic Stabilization (A.P.E.S.)
Launch vehicle Name	Vespula
Project Lead	Richard
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Team Advisors	Dr. Eric Feron, Dr. Marilyn Wolf
NAR Section	Primary: Southern Area Rocketry (SoAR) #571 Secondary: GA Tech Ramblin' Launch vehicle Club #701
NAR Contact	Primary: Matthew Vildzius Secondary: Jorge Blanco

2. Project A.P.E.S. Overview

2.1. *Mission Statement*

The mission of the Mile High Yellow Jackets is:

> To maintain a sustainable team dedicated to the gaining of knowledge through the designing, building, and launching of reusable launch vehicles with innovative payloads in accordance with the NASA University Student Launch Initiative Guidelines.

2.2. *Requirments Flow Down*

The requirements flow down is illustrated in Figure 1. As illustrated by the requirements flow down, the Mission Success Criteria flow down from the Mission Objectives of Project A.P.E.S. All system and sub-system level requirements flow down from the either of the Mission Objectives, Mission Success Criteria, or the USLI Handbook.

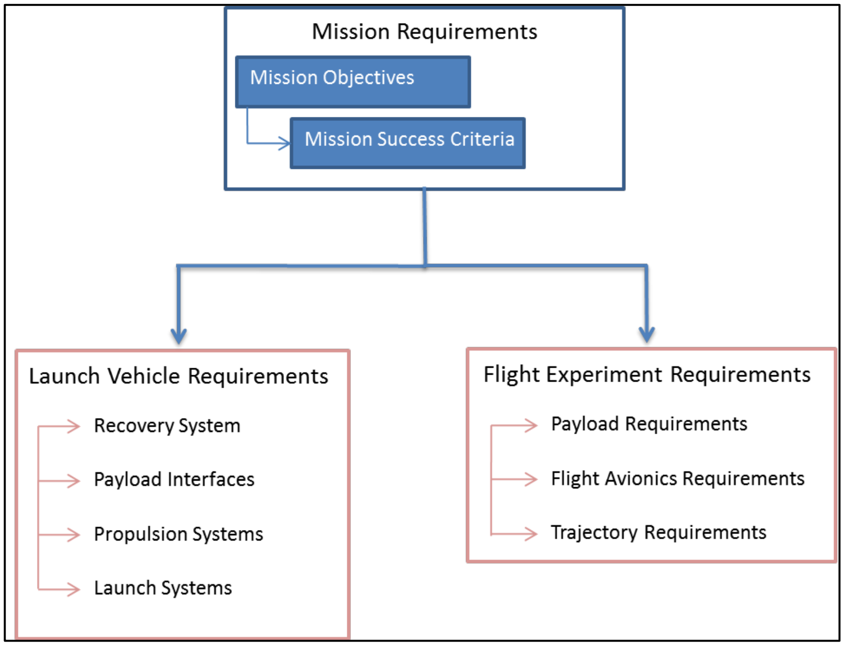


Figure 1. Flow down of requirements.

2.3. *Mission Objectives and Mission Success Criteria*

The Mission Objectives and Mission Success Criteria for Project A.P.E.S. are listed in Table 1.

Table 1. Project A.P.E.S. Mission Objectives & Mission Success Criteria.

MO	*Mission Objectives*
MO-1	An altitude of 5,280 ft. above the ground is achieved.
MO-2	Stabilize and isolate the A.P.E.S. platform from the induced vibrations of the Launch Vehicle.
MO-3	Closed-loop control of the platform via real-time image processing.
MO-4	Successful recovery of the launch vehicle resulting in no damage to the launch vehicle.

MSC	*Mission Success Criteria*	*Source*	*Verification Method*	*Status*
MSC-1	Achieve an altitude of 5,280 ft., with a tolerance of +320 ft./-640 ft.	MO-1	Testing, Analysis	**Completed**
MSC-2	The Flight Experiment is successfully activated and data is collected.	MO-2, MO-3	Inspection, Analysis	**Completed**
MSC-2.1	*Minimum Mission Success*: Platform is stabilized and isolated during the coast phase of flight	MO-2	Testing	**Not Met**
MSC-2.2	*Minimum Mission Success*: Relative position and rotation data of the platform to the camera is collected during all phases of the experiment.	MO-2, MSC-2	Testing	**Not Met**
MSC-2.3	*Minimum Mission Success*: The flight experiment terminates at apogee.	MO-4, MSC-2	Inspection	**Not Verified**
MSC-2.4	*Full Mission Success*: Platform is stabilized and isolated from environmental vibrations during the powered and un-powered portions of the flight.	MO-2, MSC-2	Testing	**Not Verified**
MSC-2.5	*Full Mission Success*: Platform does not come into contact with any other components of the A.P.E.S. System.	MO-3, MSC-2.4	Testing	**Not Verified**
MSC-3	The launch vehicle experiences no in-flight anomalies.	MO-4	Testing	**Not Met**
MSC-3.1	*Minimum Mission Success*: The launch vehicle is recovered with no damage.	MO-4, MSC-3	Testing	**Not Met**
MSC-4	*Minimum Mission Success:* The cost of the all the components, including the Launch Vehicle, Flight Experiment, Flight Avionics, and Motor, shall cost no more than $5,000.	USLI Handbook	Inspection, Analysis	**Completed**

2.4. *System Level Requirements*

The System requirements for Project A.P.E.S. are listed in Table 2.

Table 2. Project A.P.E.S. system requirements.

LV	***Launch Vehicle***	***Source***	***Verification Method***	***Status***
`LV-1	The Launch Vehicle shall carry a scientific or engineering payload.	USLI Handbook	Inspection	**Completed**
LV-1.1	The maximum payload weight including any supporting avionics shall not exceed 15 lbs.	LV-1	Inspection	**Completed**
LV-1.2	The Launch Vehicle shall have a maximum of four (4) independent or tethered sections	LV-1	Inspection	**Completed**
LV-2	The Launch Vehicle shall carry the payload to an altitude of 5,280 ft. above the ground.	USLI Handbook, MSC-1, MO-1	Inspection, Testing	**Completed**
LV-2.1	The total impulse provided by the Launch Vehicle shall not exceed 5,120 N-s.	LV-2	Inspection	**Completed**
LV-2.2	The Launch Vehicle shall use a commercially available solid motor.	LV-2	Inspection	**Completed**
LV-2.3	The Launch Vehicle shall remain subsonic throughout the entire flight.	LV-2	Analysis	**Completed**
LV-3	The Launch Vehicle shall be safely recovered and be reusable.	USLI Handbook, MSC-3.1, MO-4	Testing, Inspection	**Completed**
LV-3.1	The Launch Vehicle shall contain redundant altimeters.	LV-3, USLI Handbook	Inspection	**Completed**
LV-3.2	The Launch Vehicle shall carry one altimeter for recording of the official altitude used in the competition scoring.	LV-3, USLI Handbook	Inspection	**Completed**
LV-3.3	The recovery system shall be designed to be armed on the pad.	LV-3, USLI Handbook	Inspection	**Completed**
LV-3.4	The recovery system electronics shall be completely independent of the payload electronics.	LV-3, USLI Handbook	Inspection, Testing	**Completed**

LV	*Launch Vehicle*	*Source*	*Verification Method*	*Status*
LV-3.5	Each altimeter shall be armed by a dedicated arming switch.	LV-3, USLI Handbook	Inspection	**Completed**
LV-3.6	Each altimeter shall have a dedicated battery.	LV-3, USLI Handbook	Inspection	**Completed**
LV-3.7	Each arming switch shall be accessible from the exterior of the airframe.	LV-3, USLI Handbook	Inspection	**Completed**
LV-3.8	Each arming switch shall be capable of being locked in the "ON" position for launch.	LV-3, USLI Handbook	Testing	**Completed**
LV-3.9	Each arming switch shall be a maximum of six (6) feet above the base of the Launch Vehicle.	LV-3, USLI Handbook	Inspection	**Completed**
LV-3.10	The Launch Vehicle shall stage the deployment of its recovery devices	LV-3, USLI Handbook	Testing	**Completed**
LV-3.11	Removable shear pins shall be used for both the main and drogue parachute compartments	LV-3, USLI Handbook	Inspection	**Completed**
LV-3.12	All sections shall be designed to recover within 2,500 ft. of the launch pad assuming 15 MPH winds.	LV-3, USLI Handbook	Analysis	**Completed**
LV-3.13	Each section of the Launch Vehicle shall have a maximum landing kinetic energy of 75 ft-lb_f.	LV-3, USLI Handbook	Analysis	**Completed**
LV-3.14	The recovery system electronics shall be shielded from all onboard transmitting devices.	LV-3, USLI Handbook	Testing, Analysis	**Completed**
LV-4	The Launch Vehicle shall be launched standardized launch equipment	USLI Handbook	Inspection	**Completed**
LV-4.1	The Launch Vehicle shall not require any external circuitry or special ground support equipment to initiate the launch other than what is provided by the range.	LV-4, USLI Handbook	Inspection	**Completed**

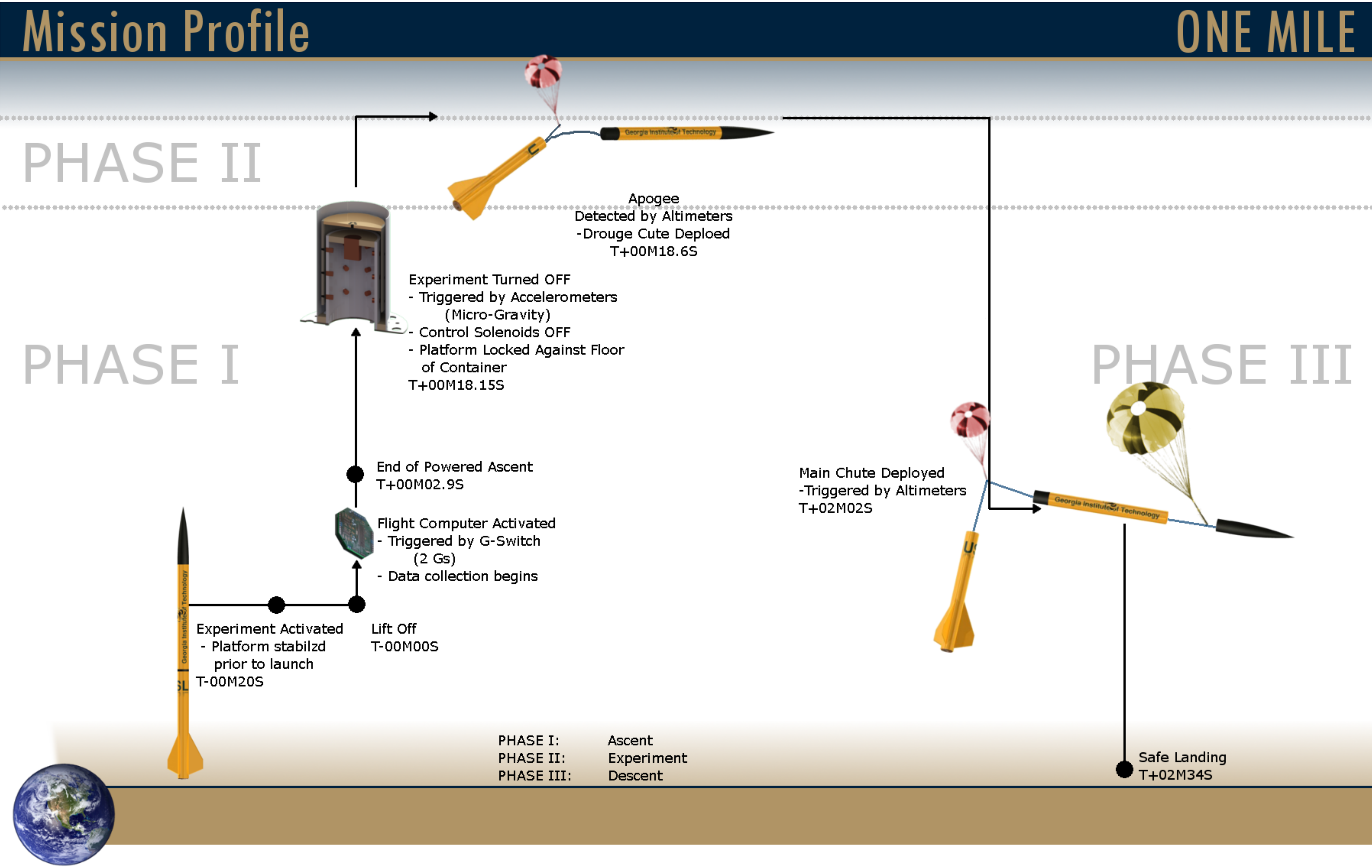
LV	***Launch Vehicle***	***Source***	***Verification Method***	***Status***
LV-4.2	The Launch Vehicle shall be launched from a standard firing system using a 10 second countdown.	LV-4, USLI Handbook	Inspection	**Completed**
LV-4.3	The Launch Vehicle shall have a pad stay time on one (1) hour.	LV-4, USLI Handbook	Testing, Analysis	**Completed**
LV-4.4	The Launch Vehicle shall be capable of being prepared for flight at the launch site within 2 hours from the time the waiver opens.	LV-4, USLI Handbook	Testing	**Completed**
FS	***Flight Systems***	***Source***	***Verification Method***	***Status***
FS-1	The platform shall be stabilized and isolated during ascent.	MSC-2.4, MO-2	Testing	**Completed**
FS-1.1	The platform shall not deviate more than 0.1 inches from the center of experiment cylinder.	FS-1	Analysis, Testing	**Completed**
FS-1.2	The platform shall not come into contact with any components of the A.P.E.S. System.	FS-1, MSC-2.5	Testing	**Completed**
FS-1.3	The platform shall not rotate more than 1 rad per second for than 1/10 of a second with respect to the camera.	FS-1	Analysis, Testing	**Completed**
FS-2	All elements of the A.P.E.S. Systems shall weigh no more than 15 lbs.	LV-1.1	Inspection	**Completed**
FS-2.1	The A.P.E.S. Flight Experiment shall not weigh more than 10 lbs.	FS-2	Inspection	**Completed**
FS-2.2	The A.P.E.S. supporting electronics shall not weigh more than 5 lbs.	FS-2	Inspection	**Completed**
FS-3	The A.P.E.S. experiment shall be terminated at apogee.	MSC-2.3	Testing	**Not Verified**
FS-3.1	The platform shall be secured during descent and landing.	FS-3	Testing	**Not Verified**

FA		***Flight Avionics***	***Source***	***Verification Method***	***Status***
	FA-1	All Flight Avionics shall have a burn-in time of no less than 20 hours	MSC-2.2, MO-4	Inspection	**Completed**
	FA-2	The Flight Computer shall collect Launch Vehicle position data, environment conditions (e.g. acceleration), and data from the A.P.E.S. experiment.	MSC-2.5, MSC-2.4, MSC-2,MO-2	Testing	**Partially Completed**
	FA-3	The A.P.E.S. computer shall be able to perform real-time image processing and control the A.P.E.S. experiment.	MO-3	Testing	**Partially Completed**
	FA-3.1	The A.P.E.S. computer shall secure the platform at apogee for descent and landing	FS-3.1	Testing	**Not Verified**
	FA-4	The Flight Avionics shall operate on independent power supplies	MSC-2.5, MSC-2.4, MSC-2,MO-2	Inspection	**Completed**
	FA-4.1	The power supplies shall allow for successful payload operation during the Launch Vehicle flight with up to 3 hours of wait time.	USLI Handbook	Analysis, Testing	**Not Verified**
	FA-5	The Flight Avionics shall downlink telemetry necessary to a Ground Station for the recovery of the Launch Vehicle	USLI Handbook	Analysis, Testing	**Comp8leted**
	FA-5.1	The GPS coordinates of all independent Launch Vehicle sections shall be transmitted to the Ground Station	MO-4	Inspection	**Completed**
	FA-6	The Recovery Avionics and Recovery System shall be separate from the Flight Avionics.	USLI Handbook	Inspection	**Completed**

2.5. *Mission Profile*

Figure 2 graphically illustrates the Mission Profile of Project A.P.E.S.

Mission Profile ONE MILE



PHASE II

Apogee
Detected by Altimeters
-Drouge Cute Deploed
T+00M18.6S

Experiment Turned OFF
- Triggered by Accelerometers
(Micro-Gravity)
- Control Solenoids OFF
- Platform Locked Against Floor
of Container
T+00M18.15S

PHASE I

PHASE III

End of Powered Ascent
T+00M02.9S

Main Chute Deployed
-Triggered by Altimeters
T+02M02S

Flight Computer Activated
- Triggered by G-Switch
(2 Gs)
- Data collection begins

Experiment Activated
- Platform stabilzd
prior to launch
T-00M20S

Lift Off
T-00M00S

PHASE I: Ascent
PHASE II: Experiment
PHASE III: Descent

Safe Landing
T+02M34S

Figure 2. Project A.P.E.S. Mission Timeline

3. Launch Vehicle Flight Analysis

3.1. *Launch Vehicle Summary*

The *Vespula* launch vehicle features a modular design which allows for simplified integration of various payloads up to 10 lbs with a maximum launch weight of approximately 40 lbs utilizing an AeroTech L1390 motor. The A.P.E.S configuration, however, has a mass of approximately 25 lbs and uses a Ceseroni L730. The structure of the launch vehicle features a rib-and-stringer design covered by a thin skin to minimize weight with a diameter of 5.125". The recovery system utilizes a 48" drogue parachute slowing the launch vehicle down to 50 feet per second (ft/s) and a 120" main parachute to slow the launch vehicle down to 17 ft/s from an apogee of approximately one mile above ground level.

3.2. *Launch Configuration*

A summary of *Vespula's* flight configuration and achieved altitude is listed in Table 1.

Table 3: Vehicle Characteristics Summary

Characteristic	Vehicle Height	Vehicle Diameter	Vehicle Mass (w/ Motor)	Motor Used	Altitude Reached
Value	110"	5.125"	25 lbs	L730	4,712 ft

3.3. *Altitude Profile*

The launch vehicle contained two (redundant) PerfectFlite StratoLogger altimeters. The average altitude collected from both altimeters is compared to the modeled performance in Figure 3. Using the 10° angle that has been apparent in previous flights and was present here, and the conditions of Toney, Alabama from wunderground.com for the launch time of approximately 1:00pm, 22 April 2012, a flight profile was created using OpenRocket. These conditions include a 17 mph north wind and an air temperature of 60 °F.

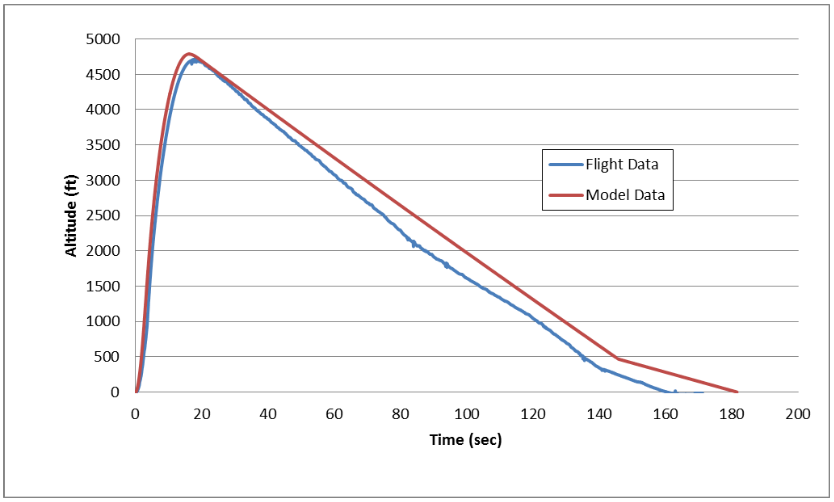


Figure 3: Model and flight altitude profile of Vespula

As seen in Figure 3, the rocket's time to apogee is longer than expected. This delay could be caused by increased drag that is not modeled. A source of this drag could be the oscillation in the structure discussed in section 3.7.1. Because of this, the apogee is a little lower than predicted. The drogue chute is deployed at apogee, but had a higher than expected fall rate, which could have been caused by decreased drag of the chute due to the high crosswinds at altitude. The main chute deployed at the first charge set at an altitude of 500 ft. Its behavior is similar to previously observed test flight data.

3.4. *Launch Vehicle Acceleration*

The *Vespula* launch vehicle flight avionics suite includes a 3-axis accelerometer. However, due to the turbulence experienced in the high speed crosswinds, the data is difficult to interpret. Only the longitudinal data could be accurately analyzed and is displayed in Figure 4.

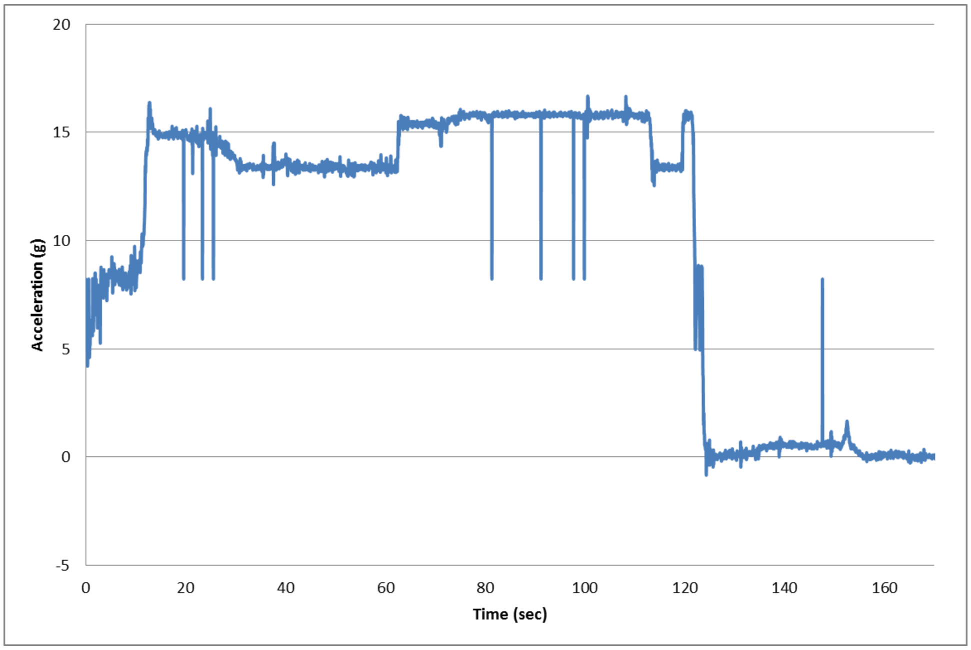


Figure 4: Longitudinal Acceleration during flight

Both the drogue and main parachute deployments can be seen in Figure 4 – despite the presence of, high accelerations during descent. These high accelerations can be attributed to centrifugal acceleration caused by violent spinning of the payload section – which was seen in the recorded launch footage.

3.5. *Launch Vehicle Rotation Rates*

The *Vespula* launch vehicle flight avionics suite also includes a 3-axis gyroscope. The spin rate about the longitudinal axis of the launch vehicle is illustrated in Figure 5.

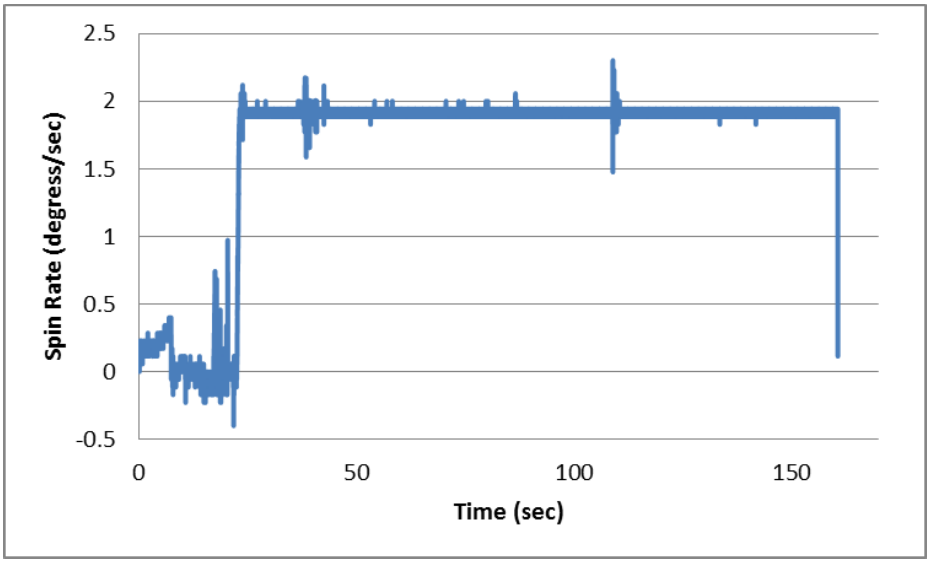


Figure 5: Spin Rate of the Rocket during flight

In Figure 5, it can be seen that the rocket spins very little during launch and coast. During descent, the payload section – which houses the rate gyros – began to spin at an average rate of 1.9 degrees per second until landing. A spike in the spin rate of the launch vehicle corresponds to the main parachute ejection event.

The pitch rate about the lateral axis of the launch vehicle is illustrated in Figure 6.

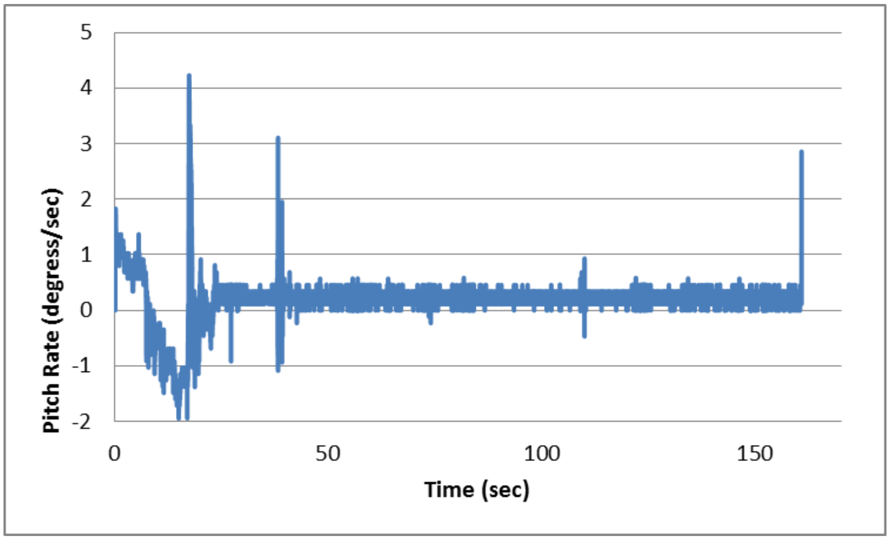


Figure 6: Pitch Rate of Rocket during flight

Due to the slight tilt of the airframe and of a strong tendency to weathercock, the launch vehicle can be seen to pitch rapidly after launch in Figure 7 – which validates the pitch rate data illustrated in Figure 6 where the launch vehicle can be seen to pitch quickly in one direction and back in the opposite direction quickly. While the launch vehicle is observed to be pitching after the drogue deploys, the pitch rate was seen to decrease during descent. Additionally, both the main parachute ejection and landing events can be observed in Figure 6.

Figure 7: Vehicle weathercocking during launch

The large weathercocking angle was determined to be caused by a large stability margin. The fins were designed for a 40 lbs launch vehicle and could not be changed due to scheduling constraints when the rocket came in underweight.

3.6. *Drift*

The launch vehicle was designed to land within the 2,500 ft field from the launch pad in a 20 mph wind. However, according to the GPS locations recorded on the launch pad and after landing, the vehicle drifted 5,233 ft., as illustrated in Table 4. This drift of nearly a mile is evidence for winds higher than 20 mph during the flight.

Table 4: GPS Data

Recording Location	*GPS Location*
Launch pad location	N34º 53.8295 W086º 36.9792
Landing Location	N34º 52.9836 W086º 37.1724
Distance	*1.595 km*

3.7. *Flight Anomalies*

During the flight, various minor flight anomalies occurred. These are summarized in Table 5.

Table 5: Flight Anomalies and Effects on Vehicle

Anomaly	*Determined Cause*	*Effect on Flight*
Low Frequency Structural Oscillations	Inadequate QA and machining tolerances	Increased Drag resulting in lower than expected apogee
Loss of Motor Aft Enclosure	Inadequate QA during motor assembly	None
Puncturing of Flight Skin	Barbed wire fence in landing zone	None (occurred at end of flight)

3.7.1. Structural Oscillations

The low frequency oscillations, as seen in Figure 8, occurred during the coast phase of the flight, once the structure was no longer under compression from the motor. These oscillations were caused by give in the structure caused from inadequate quality assurance during manufacturing of the rib and stringer structure. Some of this motion may have been the modal bending of the structure and for future iterations of the design, a modal analysis of the entire structure is recommended.

Figure 8: Bending of Vespula during flight

3.7.2. Loss of Aft Motor Enclosure

The aft enclosure on the motor case was missing when the rocket was recovered, but because the motor fired until burnout and all the internals remained inside the case, it can be concluded that the enclosure was lost post launch, during the coast or recovery sections of the flight. The only damage caused by the missing enclosure was a small chip on the nozzle as illustrated in Figure 9. To mitigate this in the future, a strap wrench will be utilized to tighten the enclosure.

Figure 9: Damage on nozzle

3.7.3. Skin Puncture

The only other damage that occurred to the vehicle during the flight was to the skin. A large hole was torn in the cellulose-polymer composite skin near the main chute recovery section as seen in Figure 10.

Figure 10: Damage of skin that occurred during landing

This tear is most likely caused by the barbed wire fence in which the rocket landed. No other damage occurred to the vehicle. This type of damage can be mitigated in the future by designing the vehicle to drift less from the launch pad.

4. Payload Flight Analysis

4.1. *Payload Overview*

The Mile High Yellow Jackets designed, built, tested, and flew an electromagnetically levitated and stabilized platform in one-dimension (1-D) within their launch vehicle. The platform is isolated from flight perturbation and rapid acceleration by using a control algorithm that compensates for the forces on the platform with an electromagnetic field. The experiment known as A.P.E.S., or Active Platform Electromagnetic Stabilization, utilizes custom built solenoids, platform, and control and driving actuator electronics. The localization was performed using an image processing routine running on a TI DM3730 DaVinci Multimedia Processor as part of the BeagleBoard xM development platform. All data collection activities will utilize an Arduino Mega.

It is important to note that the flight experiment was completed and ground tested, however, it was not flown due to a last minute of hardware failure of the A.P.E.S. Flight Computer (BeagleBoard xM).

4.2. *Motivation & Scientific Merit*

4.2.1. Motivation

Today, many entrepreneurs are beginning to build newer and more cost-effective launch vehicles. Every one of these launch vehicles must address a specific challenge in their design process: integration with the spacecraft payload. This integration presents difficulties in launch vehicle design because harmonic oscillations of the spacecraft mass could cause structural damage to either the launch vehicle or the spacecraft itself. To solve this dilemma, industry typically utilizes large mechanical springs – in addition to the placement of certain structural constraints on the payload spacecraft for use of a particular launch vehicle. Repeated deformation on vibration dampers and springs used in launch vehicles presents a further issue in providing reusability, as these parts must be intermittently replaced. Furthermore, modifications must be made to both payload and launch vehicle to tune the natural frequencies of both and prevent harmful oscillation. The net result of the present situation is an increase in overall structural mass, which combined with the necessary increase in fuel required and maintenance, dramatically increases the launch cost to the detriment of mission capability. The Mile High Yellow Jackets intend to provide a possible alternative solution in a demonstration of the ability of electromagnetic levitation to lower the necessary structural masses currently required to prevent harmonic oscillation, decreasing launch cost.

In addition to payload isolation, magnetically stabilized platforms can also be used to isolate both terrestrial and space-based optics and digital sensing devices from their housings ensure image stability and virtually eliminating image distortion that is commonly associated with long-duration exposures. For example, while the Hubble Space Telescope is in a micro-gravity environment, small perturbations due to thermal cycling may introduce unwanted distortion into images. Currently, these distortions are compensated for by training the optics and digital sensing devices real-time during the exposure in addition to post-processing of the collected image. However, the magnetic isolation techniques being pursued by the Mile High Yellow Jacket would isolate the optics or digital sensing devices– say, on a future space-based telescope collecting EM radiation of any spectrum – eliminating the need for this thermal characterization and post-processing directly resulting in not only lower development costs but would also result in a shorter turn-around time for releasing the data for analysis.

4.2.2. Scientific Merit

The problem of magnetic force interactions from n-solenoids on a single sample is a non-trivial problem in electromagnetics. The difficulty in describing complex field relationships is similar to the difficulty in aerodynamics for describing complex fluid flows, and many of the computational techniques are similar. However, due to the nature of the complexity, the study of complex magnetic interactions must be a data-driven process, as in aerodynamics. The A.P.E.S. system will depend upon a theory-informed, data-driven model for control. This data will be generated through a series of ground test experiments that gradual increase the complexity of the problem. Final model testing on the ground will involve only permanent magnets and solenoids, simplifying the force interactions to compensate for complex geometry.

The A.P.E.S. project may be considered as a dual scientific-engineering payload. A period of scientific analysis is necessary, as stated above. However, the actual product flown in the launch vehicle will be flown for verification and validation purposes after the conclusion of ground testing; the flight will test the performance of the derived model, and engineering design, during the dynamics of the ascent phase. This process of scientific investigation followed by engineering development is not entirely unlike the development of experimental aircraft and spacecraft, where some scientific investigation may be needed before the engineering can proceed.

More information on the science behind Project A.P.E.S. can be found in Appendix I.

4.3. *Platform Localization, Controller Development & Data Analysis*

4.3.1. Platform Localization

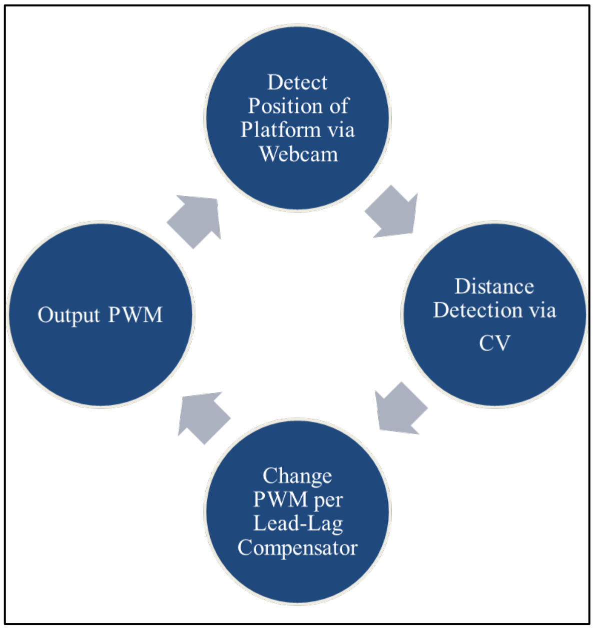


Figure 11. Platform localization algorithm.

In order to ensure proper dampening, the location of the platform must be determined quickly and reliably. Figure 11 illustrates the general methodology utilized. The unique environment of rapidly oscillating powerful electromagnetic fields and limited room inside of the *Vespula* launch vehicle made traditional distance detection methods such as ultrasonic and/or infrared ranging detection methods infeasible. The method utilized for platform detection uses an optical camera to capture an image of the platform. To aid in detection and localization, a square was placed on the side of the platform. The process of classifying pixels is performed via image thresholding. Once the image is captured and preprocessed, an edge detection algorithm running on top of the Linux OS and OpenCV on the A.P.E.S. Flight Computer to find the location and orientation of the square in the image – and subsequently the location of the platform relative to the payload section. The specific computer vision algorithm is illustrated in Figure 12. The position output of the computer vision algorithm is then feed into the A.P.E.S. controller.

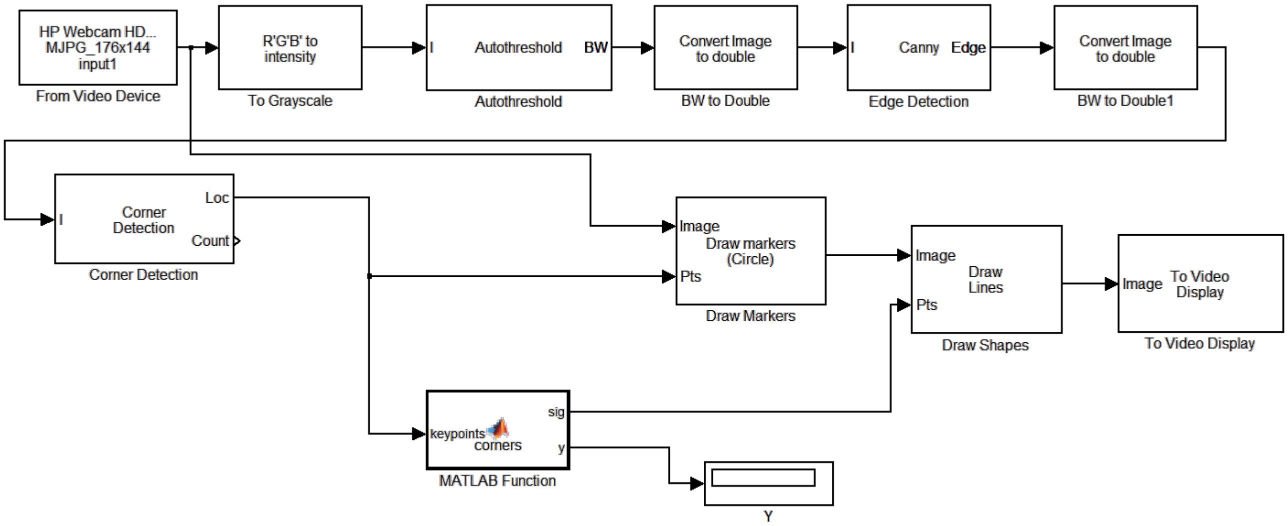


Figure 12. Computer vision localization diagram

4.3.2. Controller Design

The Open-Loop poles and response of the platform is illustrated in Figure 13.

Open-Loop Poles
-16.9075 + 31.4082*i*
-16.9075 - 31.4082*i*

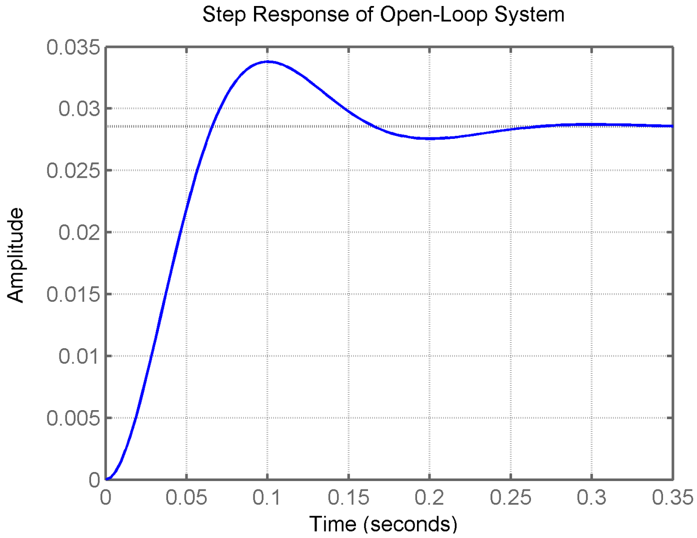


Figure 13. Open-loop poles and response of A.P.E.S.

The A.P.E.S. controller was designed using standard root-locus techniques in MATLAB. In order to achieve the desired response times, a lead-lag controller was utilized. The lead compensator provides phase lead at high frequencies enhancing responsiveness and stability of the system; the lag compensator provides phase lag at low frequencies which reduces steady-state error. The resulting root-locus and compensator are shown in Figure 14.

Item	*Value*
Lead Compensator	$\frac{s+45}{s+1000}$
Lag Compensator	$\frac{s+20}{s+0.025}$
Gain	27,777.7778

Closed-Loop Poles
-48.2, -19.3
-483 ± 861i

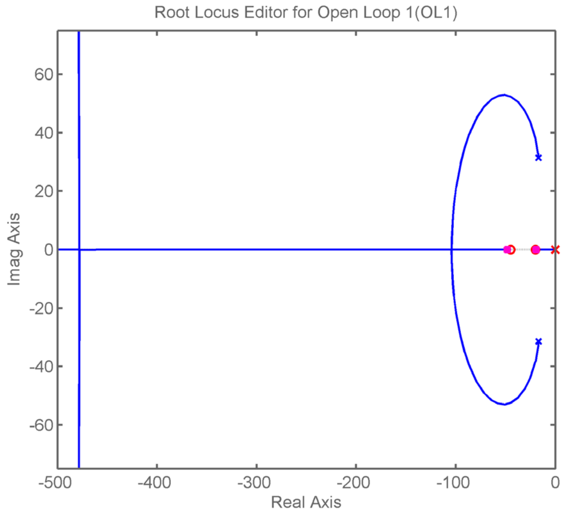


Figure 14. Root – locus design results of the A.P.E.S. controller.

A Simulink model illustrated in Figure 15 was created to verify the controller design for both a steady-state (DC) and PWM (AC) inputs. The results are illustrated in Figure 16. The system characteristics for both the DC and AC inputs are listed in Table 6.

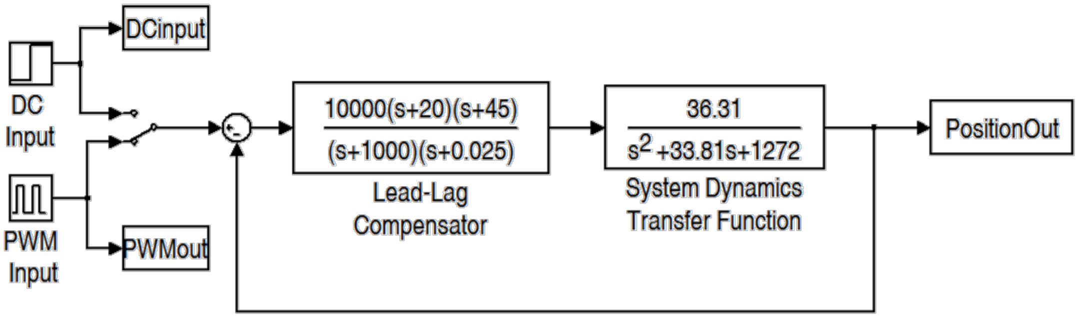


Figure 15. A.P.E.S. controller Simulink diagram.

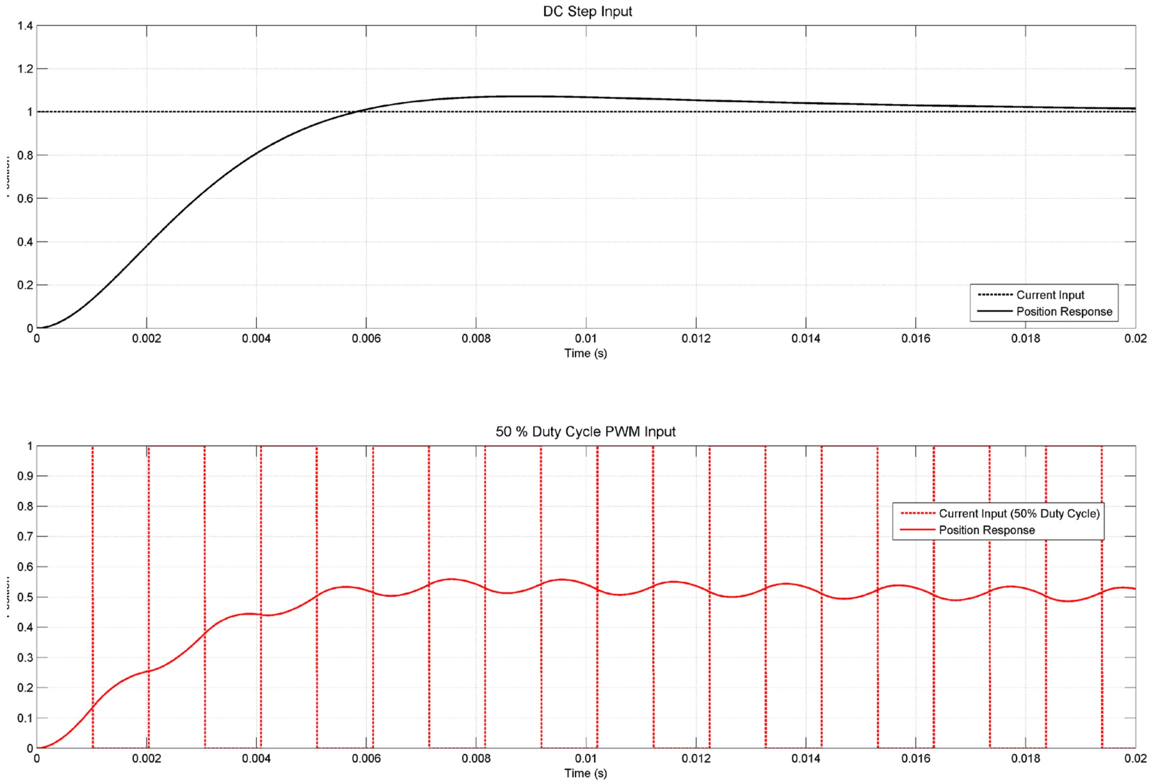


Figure 16. A.P.E.S. controller Simulink model results.

Table 6. A.P.E.S. controller characteristics.

Item	*Value*	
	DC Input	*AC Input*
Rise Time	< 5 ms	< 5 ms
Settling Time	< 10 ms	< 10 ms
Error	< 0.1 %	N/A

Once the required PWM signal properties were calculated, the corresponding PWM value was written to a DAC connected to the Beagleboard xM via I2C and a level shifter. The duty cycle of the PWM output of the TI DRV103 solenoid driver IC is controlled via analog input to a dedicated solenoid driver chip. This allowed for precise digital control of the magnetic forces on the platform and thus its position.

5. Overall Experience

5.1. *Educational Outreach*

The goal of Georgia Tech's outreach program is to promote interest in the Science, Technology, Engineering, and Mathematics (STEM) fields. The Mile High Yellow Jackets' intend to conduct various outreach programs targeting middle school students and educators. The Mile High Yellow Jackets have an outreach request form on their webpage for educators to request presentations or hands-on activities for their classroom. Table 7 summaries the three (3) outreach activities performed by the team this year.

Table 7. Educational Outreach summary

Event	*Date*	*Participants*
FIRST Lego League	28 January 2012	700
Civil Air Patrol	5 April & 12 April 2012	55
National Air & Space Museum Discovery Station	24 March 2012	137

The team involved participants in hands-on lessons and demonstrations in an effort to expose them to the STEM fields. Lesson plans for the activities can be found in Appendix II, Appendix III , and Appendix VI respectively.

5.2. *Budget Summary*

5.2.1. Funding Overview

In order to fund the 2011-2012 Competition year, the Mile High Yellow Jackets have sought sponsorships from academic and industry sources. The current sponsors of the Mile High Yellow Jackets and their contributions can be found in Table 8. As of PLAR, the Mile High Yellow Jackets have received $7,600 in funding. Additionally, the Team has also received a dedicated room in which the Team can construct and store their launch vehicle, payload, and other non-explosive components. Furthermore, the Georgia Tech Invention Studio supported all fabrication needs of the Team.

Table 8. Summary of sponsors for the Mile High Yellow Jackets.

Sponsor	Contribution	Date
Georgia Space Grant Consortium	$3,500	Sept. 2011
Georgia Tech School of Aerospace Engineering	$1,000	Oct. 2011
Georgia Tech Student Government Association	$1,000	Nov. 2011
SCITOR Corp.	$500	Nov. 2011
SpaceX	$1,000	Dec 2011
ATK Travel Stipend	$400	Apr 2011
ATK Motor Stipend	$200	Apr 2011
Total	$7,600	

5.2.2. Project Expenditure Summary

Figure 17 illustrates the budget breakdown as of the PLAR Milestone. The summary is broken down into three (3) main categories: Launch Vehicle, Flight Systems, and Operations. The Launch Vehicle and Flight Systems categories are further broken down into two (2) sub-categories: Flight Hardware and Testing. Operational expenses include: non-system specific test equipment, Team supplies, non-system specific fabrication supplies, as well as any travel and outreach expenses. Any system-specific equipment bought for testing is charged against that specific system, whereas generic equipment.

2011-2012 Budget Breakdown	
LV - Testing	$ 1,603.25
FS - Testing	$ 1,100.29
LV - Flight Hardware	$ 891.38
FS- Flight Hardware	$ 692.67
Operations	$ 1,341.29
Total	$ 5,628.88

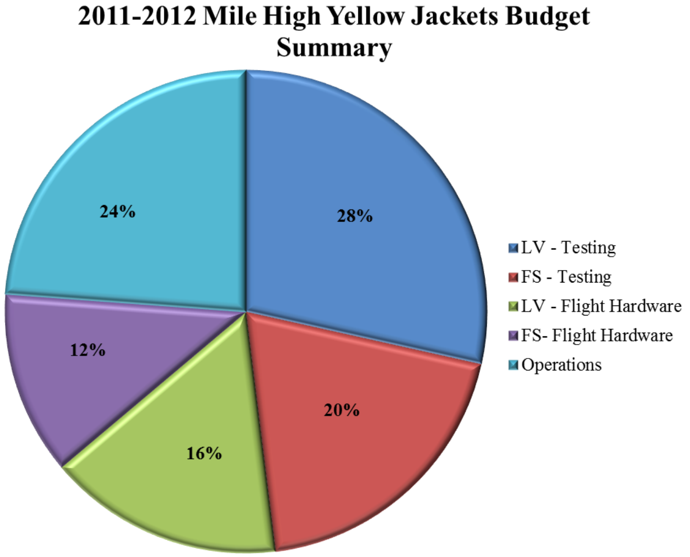


Figure 17. Project expenditures summary as of the PLAR milestone.

Figure 18 illustrates the actual total project costs - as of PLAR - at each milestone. At PLAR, the actual project costs are approximately 24.5% less than the estimated costs. The increased costs at the Launch milestone – compared to those reported at FRR – is attributed to the issuance of reimbursements to team members for Operations related expenditures.

	Actual Cost	*Project Reserves*
PDR	$ 985.61	61.2 %
CDR	$2,055.34	90.0 %
FRR	$5,423.58	28.7 %
Launch	$7,179.48	--

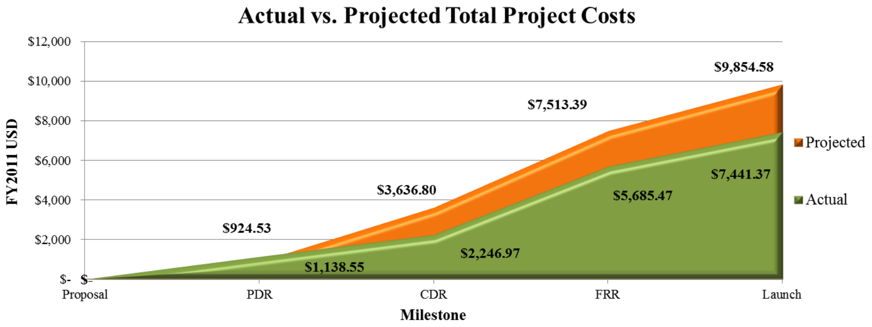


Figure 18. Actual total project costs and project reserves at each milestone.

Table 9 and Table 10 list the bill of materials – with cost breakdowns – for the Flight Experiment, Flight Avionics, and Launch Vehicle.

Table 9. Flight Systems Bill of Materials with Cost Breakdown

Flight Experiment			
Item Description	*Unit Price*	*Qty*	*Cost*
A.P.E.S. Hardware	***$83.94***	***1***	***$290.31***
Neodymium Magnets	$33.12	1	$33.12
5/8” Iron Rod	$6.62	1	$6.62
30 AWG Magnet Wire	$25.89	1	$25.89
Cardboard Tube	$5.32	1	$53.19
Plywood	$7.99	1	$7.99
Fasteners	$5.00	1	$5.00
LiFePo Battery	$48.00	1	$48.00
LiFePo Battery Bracket	$110.50	1	$110.50
Total Flight Experiment Costs			$***290.31***

Flight Avionics			
Item Description	*Unit Price*	*Qty*	*Cost*
Solenoid Driver Board	***$8.75***	***5***	***$43.75***
10 µF Capacitor	$0.43	1	$0.43
22 µF Capacitor	$0.91	1	$0.91
0.1 µF Capacitor	$0.26	1	$0.26
Flyback Schottky Diode	$0.45	1	$0.45
DRV103	$4.38	1	$4.38
Green LED	$0.38	2	$0.76
5.6 kΩ Resistor	$0.02	1	$0.02
205 kΩ Resistor	$0.04	1	$0.04
150 Ω Resistor	$0.02	1	$0.02
10 kΩ Resistor	$0.02	2	$0.04
D-to-A Converter	$1.19	1	$1.19
Trimpot	$0.25	1	$0.25
Flight Computer	***$255.10***	***1***	***$255.10***
Arduino Mega 2506	$58.95	1	$58.95
UP-501 GPS Receiver	$49.95	1	$49.95
OpenLog	$24.95	1	$24.95
ADXL321 Accelerometer	$17.31	1	$17.31
Xbee Pro 900 XSC RPSMA	$71.95	1	$71.95
L3G4200D Rate Gyro	$31.99		$31.99
A.P.E.S. Computer	***$192.18***	***1***	***$192.18***
BeagleBoard xM	$149.00	1	$149.00
Logitech C170 Webcam	$21.59	1	$21.59
HP HD-2200 Webcam	$21.59		$21.59
Ground Station	***$96.90***	***1***	***$96.90***
Xbee Pro 900 XSC RPSMA	$71.95	1	$71.95
XBee Explorer USB	$24.95	1	$24.95
Total Flight Avionics Cost			***$587.93***

Table 10. Launch Vehicle Bill of Material with Cost Breakdown

Launch Vehicle			
Item Description	*Unit Price*	*Qty*	*Cost*
Booster Section	***$644.87***	***1***	***$644.87***
Thrust Plate	$1.76	1	$ 1.76
1/4-20 Threaded Rod	$2.62	4	$10.48
1/4-20 Nuts	$0.06	16	$1.03
1/4" Washers	$0.07	16	$1.06
Centering Ring	$0.45	1	$0.45
Fin	$51.67	3	$55.00
Motor Tube	$5.14	1	$5.14
Motor Case	$256.00	1	$256.00
Motor	$160.00	1	$160.00
Retention Ring	$ 7.02	1	$7.02
Epoxy	$15.67	1	$15.67
Rail Button	$1.54	2	$3.07
Primer	$5.49	1	$5.49
Paint	$5.99	3	$17.97
Clearcoat	$3.98	1	$3.98
Gasket	$0.25	3	$0.75
iMPS	***$225.57***	***1***	***$225.57***
G-10 Rib	$19.57	4	$78.26
G-10 Stringer	$5.45	12	$65.42
8-32 Bolts	$0.08	36	$3.05
Skin	$27.90	1	$27.90
Sealing Tape	$2.97	1	$2.97
Hook And Loop Fasteners	$17.97	1	$17.97
Nose Cone	***$30.00***	***1***	***$30.00***
Recovery Section	***$648.95***	***1***	***$648.95***
60 Ft. – 1" Wide Nylon Webbing	$10.80	2	$21.60
Main Chute	$145.00	1	$145.00
Nomex Cloth	$12.00	2	$24.00
PVC Cup	$ 0.51	4	$2.04
Ematch	$1.33	4	$5.33
Black Powder (14 G)	$1.59	1	$1.59
D- Links	$7.36	3	$22.08
Steel Cable (8")	$3.33	2	$6.67
G-10 Tube (12")	$34.10	1	$34.10
Bulkhead	$2.54	2	$5.09
Ferrules	$1.92	2	$3.84
Arming Switch	$5.00	2	$10.00
Arming Switch Bracket	$68.00	1	$68.00
Stratologger	$80.00	2	$160.00
9V Battery	$2.50	2	$5.00
9V Battery Holder	$1.19	2	$2.38
G-10 Tube (6")	$17.05	1	$17.05
G-10 Coupler (5")	$20.63	1	$20.63
G-10 Tube (5")	$14.21	1	$14.21
Drogue Chute	$66.00	1	$66.00
U-Bolt	$8.81	1	$8.81
JB Weld	$5.27	1	$5.27
Shear Pins	$0.03	8	$ 0.27
Total Launch Vehicle Cost			$1,519.39

5.3. *Overall Experience*

5.3.1. Summary of Experiences

Overall, the rocket's performance was near expected, but somewhat subpar. Due to inadequate analyses and quality assurance, there are modal flaws in the structural design of the vehicle. If these can be addressed, the next iteration of the design can have even higher performance. The booster section performed exceptionally considering that there were many design changes made to it during the timeframe between PDR and FRR. The overall design was robust enough to survive three flights without damage, including landing under only drogue validating the strength of this novel rib and stringer design.

Because of the ability to see a design from inception, through the manufacturing and testing process, and finally to a flight vehicle, the USLI program was an invaluable experience to all of the Mile High Yellow Jackets. The USLI program also exposed all members of the Mile High Yellow Jackets to the challenges and rewards of an ambitious engineering project. The USLI program is an invaluable complement to standard coursework.

5.3.2. Lessons Learned

Proceeding the competition launch in Huntsville, a "Lessons Learned" session was held in order to better understand "what went right, what went wrong, and how things could be changed" in order to make next year's team more successful. The following is a summary of the major 'Lessons Learned' during the 2011 – 2012 competition cycle:

- Start building and testing as soon as possible and/or practical.
- Focusing on documentation and simulation is important, but there are always unforeseen difficulties in hardware development that are impossible to fully account for ahead of time.
    - Putting development earlier in the schedule may have abated some hardware issues by allowing for more time to modify design.
- Common problem of "over-engineering" or overthinking problems.
    - It is important to be mindful of trying to do something more than the requirements call for as this can quickly conflict with budget and time constraints.
- The importance of the manufacturability of parts was learned when the well-designed parts were too expensive or had too long of a lead-time.

    - A revised design would then have to be created and implemented to stay on schedule (e.g. thrust plate material and design change from machined billet aluminum to waterjeted marine-grade plywood).
- The use of jigs, tighter machining tolerances, and better quality assurance (QA) could have eliminated the off-axis bending of the launch vehicle.
    - Fin attachment would have been easier with the use of a jig.
- Due to minimal surface area of the recovery bulkheads, the use of epoxy was not sufficient. As a result, mechanical fasteners should be used to transfer the load from one component to another.
- Given the power and size of *Vespula*, a longer and larger rail size should be used, such as 1515 rail.

Appendix I: Mathematical and Physical Modeling of Magnetic Fields

In order to accomplish the objective of stabilizing a platform with magnetic fields during the ascent of a launch vehicle, a control system must be developed with inputs of voltages and currents supplied to solenoids and optical sensing feedback for kinematics data. To create the control system, equations and experimentation to model the fields and resultant forces on an object in the field will be derived and conducted, respectively, from the scientific principles governing electromagnetism. Typically, electromagnetic equations are focused on defining axial interactions, while the A.P.E.S. experiment requires a comprehensive understanding of three-dimensional magnetic fields. The following sections will define the governing equations and concepts that are the foundation for the experimental testing and will serve as the basis for a data-centered control system.

Modeling General Magnetic Fields

If two magnets or electromagnets are at a large enough distance from each other, or small enough compared to the distances involved, then they can be modeled as being magnetic dipoles. A magnetic dipole can be thought of as a small current loop; this still creates a non-vanishing magnetic field at distances much larger than the radius of the loop. The magnetic dipole moment of a single current loop is defined as

$$\mathbf{m} = I\boldsymbol{S} \qquad (1)$$

where the **S** vector, and hence **m** as well, is oriented perpendicular to the planar area of the loop so that curling the fingers of one's right hand in the direction of the current gives the direction of **S** as the direction of the thumb. The magnetic potential due to a magnetic dipole of moment **m** is

$$\mathbf{A}(\mathbf{r}) = \frac{\mu}{4\pi}\frac{\mathbf{m} \times \mathbf{r}}{r^3} \qquad (2)$$

where **r** is the vector from the dipole to the field point where the potential is being calculated, r is the magnitude of vector **r**, and μ is the permeability of the medium at the field point. The magnetic flux density **B** and the magnetic field **H** due to the dipole are, respectively,

$$\mathbf{B}(\mathbf{r}) = \nabla \times \mathbf{A} = \frac{\mu}{4\pi r^3}(3(\mathbf{m}\cdot\hat{\mathbf{r}})\hat{\mathbf{r}} - \mathbf{m}) \tag{3}$$

$$\mathbf{H}(\mathbf{r}) = \frac{\mathbf{B}}{\boldsymbol{\mu}} = \frac{1}{4\pi r^3}(3(\mathbf{m}\cdot\hat{\mathbf{r}})\hat{\mathbf{r}} - \mathbf{m}) \tag{4}$$

Where $\hat{\mathbf{r}}$ is the unit vector in the direction of $\mathbf{r}$, and the distance r is much greater than the radius of the loop.

There are two ways to approximate model the vector potential field, the magnetic field, and the magnetic induction field as produced by a solenoid using these equations. The first method is to model the solenoid as a single dipole of moment $\mathbf{m} = NI\mathbf{S}$ at the center of the solenoid, where N is the number of turns in the solenoid, as a solenoid has N current loops each of moment $I\mathbf{S}$. However, this does not take into account the fact that each loop of the solenoid is not at the same location. Therefore, a more precise way of modeling the solenoid – albeit still an approximation – would be to place one dipole of moment $I\mathbf{S}$ at the center of each loop that makes up the solenoid, or perhaps one moment per k loops of moment $kI\mathbf{S}$, where we have a choice of k. However, computational difficulty is greatly increased due to the necessity of finite-element solver techniques as the mathematics progresses. The magnetic $\mathbf{H}$ field produced by each model are shown below, where N is taken to be 11 loops (distributed over 2 cm of length for the second model) and $\frac{1}{4\pi}I\mathbf{S}$ is taken to be $\mathbf{k}\ \mathrm{A}\cdot\mathrm{cm}^2$. One dipole of moment $11\mathbf{k}\ \mathrm{A}\cdot\mathrm{cm}^2$ is placed at the origin in the typical cartesian plane in Figure 19, and 11 dipoles of moment $\mathbf{k}\ \mathrm{A}\cdot\mathrm{cm}^2$ are distributed from -1 to 1 along the y-axis in Figure 20, for the sake of simplicity.

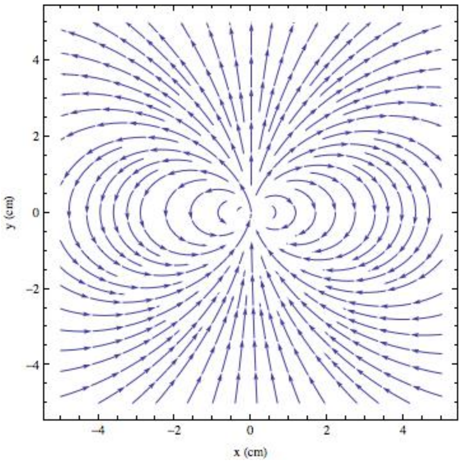


Figure 19: field generated by a single dipole

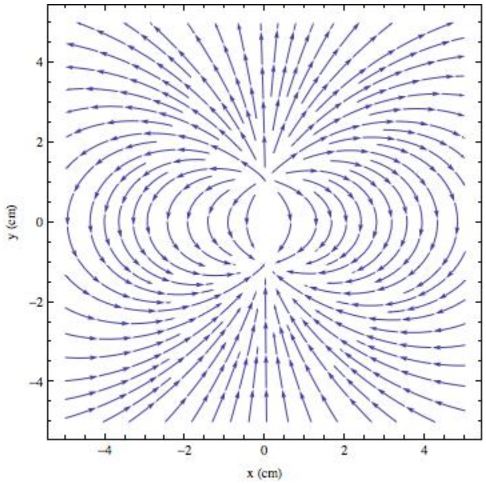


Figure 20: field generated by multiple dipoles

Generation of Magnetic Forces in Materials

All materials are composed of atoms, with a positively charged nucleus and negatively charged electrons. The movement and rotation of these charges form microscopic magnetic dipoles, which have magnetic dipole moments. The magnetization vector, **M,** of a material at a point is defined as the volume "density" of magnetic dipole moment, i.e.

$$\mathbf{M} = \lim_{\Delta v \to 0} \frac{\sum \mathbf{m}_k}{\Delta v} \qquad (5)$$

where each $\mathbf{m}_k$ is the magnetic moment of the kth atom in the volume Δv, and the sum is over all the atoms. The force on a magnetic material can be determined by summing the forces on the dipoles in the material due to the field that it is placed in. The magnetization of a material depends on the field it is placed in, and the flux density depends on the field, as follows:

$$\mathbf{M} = \chi_m \mathbf{H} \qquad (6)$$

$$\mathbf{B} = \mu_0(\mathbf{H} + \mathbf{M}) = \mu_0 \mathbf{H}(1 + \chi_m) = \mu_0 \mu_r \mathbf{H} = \mu \mathbf{H} \qquad (7)$$

where χ_m is the material's magnetic susceptibility, μ_r is its relative permeability, and μ is the absolute permeability. The parameters χ_m and μ_r are not always constant, especially in the case of ferromagnetic materials. However, assuming a linear relationship between **M** and **H** –

approximately true in the case of magnetically soft ferrite – or a constant **M** in the case of a permanent neodymium magnet, using the **H** field of a dipole or multiple dipoles as the field of the solenoids, the force on the platform due to the fields interacting with the microscopic dipoles in the material can be calculated.

Forces on Materials in Magnetic Fields

The force on an object is the sum of the forces on all of the magnetic dipoles that make up the object. By definition, the magnetic dipole moment of an infinitesimal volume of the object dV is $\mathbf{m} = \mathbf{M}\, dV$. The force due to the field of a magnetic dipole of moment $\mathbf{m}_s$ on a magnetic dipole of moment $\mathbf{m}$ that is in a material of permeability μ is:

$$\mathbf{F}(\mathbf{r}, \mathbf{m}_s, \mathbf{m}) = \frac{3\mu}{4\pi r^4}\left[(\mathbf{m}_s \cdot \hat{\mathbf{r}})\mathbf{m} + (\mathbf{m} \cdot \hat{\mathbf{r}})\hat{\mathbf{m}}_s + (\mathbf{m}_s \cdot \mathbf{m})\hat{\mathbf{r}} - 5(\mathbf{m}_s \cdot \hat{\mathbf{r}})(\mathbf{m} \cdot \hat{\mathbf{r}})\hat{\mathbf{r}}\right] \tag{8}$$

Where **r** is the vector from $\mathbf{m}_s$ to **m**, and $\hat{\mathbf{r}}$ is again the unit vector in the direction of **r**. First the case of a ferrite platform is considered, with approximate constant χ_m and μ. In this case, the force on the platform is calculated to be:

$$\mathbf{F}(\mathbf{r}, \mathbf{m}_s) = \iiint \frac{3\mu\chi_m}{16\pi^2 r^7}\left[(\mathbf{m}_s \cdot \hat{\mathbf{r}})\mathbf{m}_s - (\mathbf{m}_s \cdot \mathbf{m}_s)\hat{\mathbf{r}} - 4(\mathbf{m}_s \cdot \hat{\mathbf{r}})^2\hat{\mathbf{r}}\right] dV \tag{9}$$

Where $\mathbf{m}_s$ is now used as $\mathbf{m}_s = NI\mathbf{S}$ for the solenoid and the integral is evaluated over the volume of the platform. If it is assumed that the object is small such that the quantity integrated does not vary significantly over the volume, the force on the platform of volume V, due to the solenoid of moment $\mathbf{m}_s = NI\mathbf{S}$, is:

$$\mathbf{F}(\mathbf{r}, \mathbf{m}_s, \mathbf{m}) = \frac{3VN^2I^2S^2\mu\chi_m}{16\pi^2 r^7}\left[(\hat{\mathbf{n}} \cdot \hat{\mathbf{r}})\hat{\mathbf{n}} - \hat{\mathbf{r}} - 4(\hat{\mathbf{n}} \cdot \hat{\mathbf{r}})^2\hat{\mathbf{r}}\right] \tag{10}$$

Where $\hat{\mathbf{n}}$ is the unit vector in the direction of **S** – the unit normal to the loop area of the solenoid – and **r** is the position vector from the solenoid center to the center of mass of the platform. While approximate, it is clear that the force will vary as the square of current and inversely by the seventh power of the distance between the solenoid and the platform assuming a magnetically-soft ferrite material. To check the validity of this equation, and assuming that both $\hat{\mathbf{n}}$ and $\mathbf{r}$ are in the positive $\mathbf{k}$ direction in a Cartesian plane, such that the platform is above the dipole, it is found that:

$$\mathbf{F} = \frac{-3VN^2I^2S^2\mu\chi_m}{4\pi^2r^7}\mathbf{k} \tag{11}$$

Or that the platform is pulled towards the dipole, which matches the basic experience of magnetic materials attracted to magnets due to induction.

The equations given above are derived in Appendix 3. However, the validity of these equations is primarily for the case of a single solenoid acting on a platform with constant permeability. Forces originating from more than one solenoid do not add in the conventional sense, as the induction of a ferrite material is highly non-linear. These equations must be re-derived from equation (8), as the fields and magnetization of the platform change in the n-solenoid problem.

Much easier is the case of a permanent neodymium magnet with constant magnetization $\mathbf{M}$ throughout. In this case, the force on the platform is the sum o0f the force on each $\mathbf{M}\,dV$ segment,

$$\begin{aligned}\mathbf{F}(\mathbf{r},\mathbf{m}_s,\mathbf{M}) = \iiint \frac{3\mu_0}{4\pi r^4}[&(\mathbf{m}_s\cdot\hat{\mathbf{r}})\mathbf{M} + (\mathbf{M}\cdot\hat{\mathbf{r}})\hat{\mathbf{m}}_s + (\mathbf{m}_s\cdot\mathbf{M})\hat{\mathbf{r}} \\ &- 5(\mathbf{m}_s\cdot\hat{\mathbf{r}})(\mathbf{M}\cdot\hat{\mathbf{r}})\hat{\mathbf{r}}\,]\,dV\end{aligned} \tag{12}$$

Here, the constant involves μ_0 rather than just μ, since the $\mathbf{M}$ vector is constant and is largely independent of $\mathbf{H}$. Again, the exact value of the expression is highly dependent on the shape of the volume integrated upon. However, if the volume V is small, the force can be taken due to the solenoid field $NI\mathbf{S}$ as:

$$\mathbf{F}(\mathbf{r},\mathbf{m}_s,\mathbf{m}) = \frac{3VNIS\mu_0}{4\pi r^4}[(\hat{\mathbf{n}}\cdot\hat{\mathbf{r}})\mathbf{M} + (\mathbf{M}\cdot\hat{\mathbf{r}})\hat{\mathbf{n}} + (\hat{\mathbf{n}}\cdot\mathbf{M})\hat{\mathbf{r}} - 5(\hat{\mathbf{n}}\cdot\hat{\mathbf{r}})(\mathbf{M}\cdot\hat{\mathbf{r}})\hat{\mathbf{r}}\,] \tag{13}$$

Where $\hat{\mathbf{n}}$ is defined as before. Equation (11) is also an approximate solution, but here it is evident that the force on a permanent magnet varies only directly on the current in the solenoid and inversely by the fourth power of the distance, rather than by the square of current and inversely by the seventh power of distance in the case of forces from induction in a ferrite platform. The force will also depend on the orientation of **M**. Unlike for the case of a material with constant permeability, the forces on a permanent magnet due to multiple solenoids *do* add in the conventional sense, greatly simplifying computational analysis.

Appendix II: FIRST LEGO League Lesson Plan

Electricity and Magnetism

January 28th , 2012

Main Concepts

- ✓ How electricity works.
- ✓ The difference between conductors and insulators.
- ✓ How electricity is related to magnetism.

Activities

ACTIVITY ONE: Electric Bug

To make a bug:

- 1 D battery
- 1 light blub
- poster putty
- colored paper
- wire
- pipe cleaners

Materials:

- compass

Hook: Do you think you can get the bug to light up?

- ❖ Make the bug light up. Right now the light bulb is lit. *How do you think the light is on?* It's not connected to the wall. *Is it magic?*
- ❖ Inside the bug is a battery and when the bulb is on the circuit is complete and electricity is flowing. *Do any of you know what electricity? Can you explain it?*
- ❖ Everything is composed of atoms and in atoms there are these things called electrons. Sometimes electrons jump from one atom to another. When there are a lot of atoms doing this we call it an electric current. In some materials the electrons can jump a lot and in other materials they can't jump at all. When the electrons can jump around the material is called a conductor and when the electrons can't jump the material is called an insulator.
- ❖ I have a bunch of different materials here. *Which ones do you think are conductors? Which ones do you think are insulators?*
- ❖ Try to make the bulb light with the different materials. Once you have tried all the materials put the conductors on one side and the insulators on the other.
- ❖ Okay, so these are conductors and these are insulators. *What is different about them?*

- The conductors are all metal and the insulators are not metal. So in metals the electrons can jump around a lot.

End: This is how electricity works. This is how the lights in your house turn on when you flip the switch.

Appendix III: Civil Air Patrol (CAP) Model Rocketry Program Lesson Plan

Model Rocketry Program

March 2012

Main Concepts

The CAP Model Rocketry Program is broken up into three (3) stages.

Stage One – REDSTONE

- ✓ Identify historical facts about the development of rockets
- ✓ Describe the major contributions of the four great rocket pioneers.
- ✓ Recall facts about the rocket pioneers' lives and accomplishments.
- ✓ Design, build and launch two non-solid fuel hands-on rocket options

Stage Two – TITAN

- ✓ Explain Newton's three Laws of Motion. -Describe the aerodynamics of a rocket.
- ✓ Design, build and launch two of the hands-on rocket options.
- ✓ Demonstrate knowledge of the NAR safety code.

Stage Two – SATURN

- ✓ Describe altitude tracking.
- ✓ Explain baseline distance.
- ✓ Describe the ingredients of a model rocket engine.
- ✓ Define Newton seconds. -Define total impulse.
- ✓ Demonstrate knowledge of the NAR safety code.
- ✓ Design, build and launch one rocket in the Saturn stage.

Activities

ACTIVITY ONE: Electric Bug

Materials:

- Civil Air Patrol Model Rocketry Handbook
- Appropriate supplies for all rocket builds

Appendix VI: National Air & Space Rocket Discovery Station Lesson Plan

Lift Off!

March 2012

Main Concepts

- ★ Role of oxidizer in combustion
- ★ Differences and similarities between airplanes and rockets
- ★ Newton's 3rd Law

Teaching Objects

- ★ Balloons
- ★ String
- ★ Scissors
- ★ Tape
- ★ Engine poster
- ★ Rocket poster
- ★ optional: Balloon pump

Constructing the Rocket Demonstration

Put the string through the straw and tie each end to an object so that the string is taught. Tape the inflated balloon to the straw. When you are ready, let go of the balloon.

Hook: Do you know what a rocket is?

***Ask:** What is a rocket?*

Explain: A rocket is an object that can be propelled by the combustion of its contents.

***Ask:** Can you name any rockets?*

Explain: (in chronological order)

- ★ Redstone: used for the sub-orbital launches in the Mercury program
- ★ Atlas D: used for the orbital launches in Mercury Program
- ★ Titan II: used for all the Gemini Program launches
- ★ Saturn V: used for the Apollo Program Launches
- ★ Space Shuttle: has two solid rocket booster (they are white) and are reusable

Ask: *Have you ever seen a rocket launch? On tv or in person? What did you see and notice? Did you see flames coming out the back?*

Explain: Rockets uses fire to make them go forward.

Ask: *What do you know about fire? What are the three things every fire needs?*

Explain: Every fire needs a fuel, oxygen, and a spark. When people talk about engines they call oxygen an oxidizer.

Ask: *We know that rocket engines make a fire but how exactly do you think rocket engines work?*

Explain: Rockets have a tank for fuel and a tank for an oxidizer, or oxygen. When they want to make the rocket go forward they combine the fuel and the oxidizer and light it on fire. They then push it out the back and that's why you see a flame when rockets launch.

Ask: *How are rockets and planes alike?*

Explain: They both use a fuel and an oxidizer, or oxygen, and they can both fly.

Ask: *How are rockets and planes different?*

Explain: A plane has wings and a rocket doesn't, ect. The main difference between rockets and planes is that planes use the oxygen in the air as their oxidizer while rockets carry their oxidizer with them. This means that planes can only fly where there is enough oxygen in the air while rockets can fly anywhere. This is why rockets work in space and why planes are sometimes called air breathers.

***Ask:** So rockets use a fuel and an oxidizer to create thrust, which is any force that pushes the rocket forward. But how does pushing the fire out the back of the rocket make it move forward?*

Explain: Newton was a physicist who lived over 280 years ago and he discovered three laws which all objects obey. His third law says that every action has an equal and opposite ______ (wait for them to say reaction). This means that by pushing the flame out the back of the engine a reaction force which pushes the rocket forward is created. When you are swimming and push backwards against the water you go forwards right? Its the same thing with the rocket. By pushing the flame out the back of the engine a reaction force is created which pushes the rocket forward.

***Ask:** Would you guys like to see a rocket in action?*

Explain: So this is a balloon attached to a string. When the air is pushed out the back of the balloon a reaction force is created which pushes the balloon forward.

***Ask:** Are you guys ready to see Newton's third law in action? Can you guys count down from five?*

Explain: Five, four, three, two, one. ***Let go of the balloon.*** This is how rockets work.