Project A.P.E.S.

Preliminary Design Review (PDR) Documentation

Georgia Institute of Technology

Mile High Yellow Jackets

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1. Team Overview

1.1. 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
Safety Officer	Matt
Team Advisors	Dr. Eric Feron, Dr. Marilyn Wolf
NAR Section	Primary: Southern Area Launch vehiclery (SoAR) #571 Secondary: GA Tech Ramblin' Launch vehicle Club #701
NAR Contact	Primary: Matthew Vildzius Secondary: Jorge Blanco

1.2. Mission Statement

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.

1.3. Launch Vehicle Summary

The *Vespula* launch vehicle weighs approximately 40 pounds and the preferred motor is the AeroTech L1390G-P. The structure of the launch vehicle features a rib-and-stringer design covered by a thin skin to minimize weight. The recovery system utilizes a 36" drogue parachute slowing the launch vehicle down to 120 feet per second (fps) and a 120" main parachute to slow the launch vehicle down to 25 fps.

1.4. Payload Summary

The Mile High Yellow Jackets will design, build, test, and fly an electromagnetically levitated plate within their launch vehicle. This plate will be stabilized against the motion of the launch vehicle providing a vibration-free environment for a theoretical payload in an experiment known as A.P.E.S., or Active Platform Electromagnetic Stabilization. Flight Systems will utilize an ATmega 2560 for all data collection activities and the ARM Cortex M3 for the A.P.E.S. control law implementation.

2. Changes since PDR

2.1. Changes to the Launch Vehicle System

No changes were made to the launch vehicle

2.2. Changes *to the Payload and Flight Systems Design*

The following changes have been made since the Proposal:

- Removal of the accelerometers from the feedback loop for the control system
- The laser Infrared systems have been substituted with a Camera Cube and IR Sensor
- The design paradigm of the platform has changed
- The Universal Mounting System is now known as the Universal Mounting Bracket
- Changed the Flight Computer from the Parallax Propeller Chip to the ATmega 2560

2.3. Changes to the Activity Plan

No changes were made to the activity plan.

3. Launch Vehicle

3.1. Overview

The purpose of the launch vehicle is to carry a payload up one mile in altitude and safely return it to the surface of the Earth. Additionally, the launch vehicle will also be designed to carry a wide range of possible experiments so that the launch vehicle can be reused in the future. The overall design is to be as flexible as possible, encouraging reuse for future research and multiple launches.

The chosen launch vehicle design would provide an adequate amount of space for a variety of payload designs. Prior to test flights, extensive ground testing will be performed to verify successful integration of the payload into the fully assembled launch vehicle. A subscale test flight will occur in December 2011 to test the launch vehicle's skin design and a full scale test will be performed in the spring. The objective of the full scale test launch, from a vehicle perspective, is to verify the recovery system with delayed apogee ejection and the integrity of the overall structure during flight. These tests will ensure a successful launch and recovery of the vehicle to meet all requirements for the final launch

Though a kit launch vehicle would be easier to construct, a custom internal structure was designed to have lower mass and lower cost. The launch vehicle will have a 5 inch outer diameter to fit the chosen nose cone. The vehicle's diameter of 5 inches supports a wide range of payloads on a level two motor, while providing support for up to a 40-inch-long payload bay. Strength, durability, and safety are ensured as the structure is solely composed of fiberglass components.

Mission Success Criteria

The criteria for mission success are shown in Table 1.

Table 1: Mission Success Criteria

Requirement	*Design feature to satisfy that requirement*	*Requirement Verification*	*Success Criteria*
Provide a suitable environment for the payload	The payload requires a steady, but randomly vibrating platform to test the APES system. Unsteadiness in the motor's thrust and launch vehicle aerodynamics cause vibrations.	By measuring the acceleration with the payload's accelerometers	The APES system dampens out a recordable amount of vibration.
To fly as close to a mile in altitude as possible without exceeding 5,600 ft.	A motor will be chosen to propel the vehicle to a mile in altitude	Through the use of barometric altimeters	The altimeters record an altitude less than 5,600 ft
The vehicle must be reusable	The structure will be robust enough to handle any loading encountered during the flight	Through finite element analyses and structural ground testing of components	The vehicle survives the flight with no damage

3.2. System Design Overview

Table 2, Table 3, and Table 4list the derived system-level requirements in order to meet the success criteria.

Table 2: System design requirement overview

Requirement	Design feature that will satisfy that requirement	Requirement Verification
The launch vehicle shall carry a science or engineering payload	The launch vehicle will carry the A.P.E.S. experiment in the integrated modular payload section (iMPS)	The A.P.E.S. experiment will undergo extensive ground testing prior to flight testing
The launch vehicle shall deliver the payload to an altitude of 1 mile above ground level	The motor will be chosen per the final launch vehicle mass	Verification via OpenRocket vehicle simulations of the design
The launch vehicle shall carry one approved altimeter for recording purposes	An approved altimeter will be included in the recovery design	Engineering inspection from manufacturer
The recovery system shall meet all requirements listed in requirement 4 in the handbook	The recovery system will feature a drogue and main parachute	Ground testing of the independent recovery systems and flight testing of the integrated system
The recovery system electronics shall be shielded from all interference	Faraday shielding will be incorporated into design to protect electronics from payload interference	Ground testing of the independent recovery systems and flight testing of the integrated system
The launch vehicle shall have a pad stay time of one (1) hour	The hardware and battery will be able to function after remaining on the pad for a hour	Ground testing of the integrated system
The launch vehicle shall have aerodynamic stability before leaving the launch rail	The launch vehicle will have launch buttons mounted to the booster section and will launch from a rail of adequate length	OpenRocket vehicle Simulations
The launch vehicle shall remain subsonic throughout flight	The motor will be chosen per the final launch vehicle mass	Through OpenRocket vehicle simulations of the design
The launch vehicle shall be recoverable and reusable	The recovery system will feature a drogue and main parachute	Ground testing of the independent recovery systems and flight testing of the integrated system
The launch vehicle shall stage the deployment of its recovery devices	The recovery system will feature a drogue and main parachute	Ground testing of the independent recovery systems and flight testing of the integrated system

Table 3: System design requirement overview

Requirement	*Design feature that will satisfy that requirement*	*Requirement Verification*
Removable shear pins shall be used for both the main and drogue chute compartments	*Plastic shear pins are designed to be installed in the recovery compartments*	Ground testing of the independent recovery systems and flight testing of the integrated system
The launch vehicle shall have a maximum of four (4) independent or tethered sections	There are three (3) sections: nosecone, payload, and booster	Engineering inspection
Each section shall have a maximum kinetic energy of 75 ft-lb_f	The recovery system will feature a drogue and main parachute	Analysis and simulation
All sections shall be designed to recover within 2,500 feet of the launch pad assuming 15 mph wind	The recovery system will feature a drogue and main parachute	OpenRocket vehicle simulations
The launch vehicle shall be capable of being prepared for flight at the launch site within 2 hours from the time the waiver opens	Assembly Checklist	Construction testing and instructions will be made before launch day
The launch vehicle shall be launched from a standard firing system using a 10 second countdown	NAR launch regulations will be followed	Range Safety Officer
The launch vehicle shall require no external circuitry or special ground support equipment to initiate the launch other than what is provided by the range	The vehicle will implement standard ground support equipment	Analysis and Ground Testing

Table 4: System design requirement overview

Requirement	*Design feature that will satisfy that requirement*	*Requirement Verification*
The launch vehicle shall use a commercially available solid motor	An L-class NAR approved motor will be incorporated into the design	Engineering inspection from manufacturer
The total impulse provided by the launch vehicle shall not exceed 5,120 N-s	An L-class NAR approved motor will be incorporated into the design	Engineering inspection from manufacturer

3.3. Recovery System

The recovery system is intended to mitigate difficulties encountered due to variable wind speeds and to prevent destruction from impact. These objectives will be accomplished with a dual-deployment system. OpenRocket vehicle analysis of the drogue chute indicates that the maximum descent rate will be 120 fps with deployment at apogee. Main chute deployment will slow the launch vehicle to a maximum descent rate of 25 fps and will be deployed at 650 ft AGL altitude. The drogue chute is assumed to have a C_D of 1.2, and the main chute is assumed to have a C_D of 1.4. Figure 1 shows a section drawing of the launch vehicle and where the parachutes are contained.

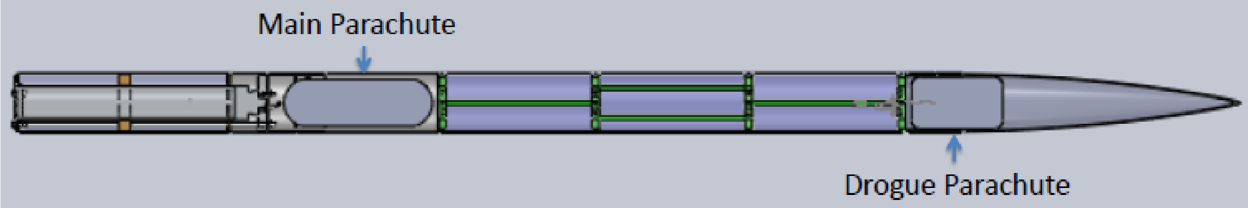


Figure 1: Section View of Launch vehicle

Parachute Dimensions

The drogue chute will be placed inside the nose cone – which has an outer diameter of 5 inches, an inner diameter of 4.7 inches, and a length of 25.5 inches. A bulkhead connected only to shock cord will serve to take the impulse of the gun powder blast and prevent the drogue chute from being stuck inside of the nose cone. Once ejected, the inertia of the nose cone will allow the drogue chute to be pulled freely from storage. The main chute will be housed in a cylindrical compartment attached to the thrust plate within the launch vehicle. The main chute compartment has a 5 inch outer diameter and a height of 15 inches. Shock cords will connect the parachutes to all sections of the launch vehicle such that in the recovery phase the entire system remains a single unit. For the main chute, the shock cord is attached to a U-Bolt that is on the reverse side of the thrust plate, and will be connected through a steel wire drilled into a fiberglass bulkhead. Similarly, the shock cord of the drogue parachute is connected to the nose cone and to the steel wire on the upper end of the payload section bulkhead. Table 5 outlines the dimensions and the weights of the parachutes.

Table 5: Parachute parameters

	Main Parachute	*Drogue Parachute*
Dimensions	10 ft diameter	3 ft diameter
Surface Area	78.54 ft^2	7.07 ft^2
Estimated C_D	1.4	1.2
Weight	2.3 lb	1.5 lb
Target Descent Rate	25 fps	120 fps

Ejection Charges

Black powder masses were calculated using Equation (1) with variables defined in Table 6..

$$W = \frac{V \Delta P}{RT} \quad (1)$$

Table 6: Ejection charge equation variables

Variable	*Description*	*Units*
W	Weight of the black powder in pound mass	$454 \cdot W_{gram}$
V	Volume of the container to be pressurized	in^3
DP	Pressure Differential	psia
R	Gas Combustion Constant for black powder	$\frac{22.16\, ft \cdot lb_f}{lb_m \cdot R}$
T	Gas Combustion Temperature	3307 ˚R

Volume, *V*, is set by the design, while the black powder sets the gas constant and temperature. In order to find the pressurization, the strength and number of shear pins that will hold the parachute compartments together is needed. A quarter-inch shear pin can take up to 35 pounds of shear force before it fails. The two compartments will be held together with four shear pins, thus implying only a force of 70 pounds per compartment is needed to achieve separation. However, accounting for frictional resistance from the tubes, 87.5 pounds of force per compartment will be targeted. The corresponding amounts of black powder are summarized in Table 7. Figure 2 shows how the two (2) chutes will be detach throughout the launch vehicle.

Table 7: Ejection pressurization and black powder charge

	Main Parachute	*Drogue Parachute*
Total Pressurization	24.7 psia	23.7 psia
Differential Pressurization	10.0 psia	9.00 psia
Amount of Black Powder	1.52 grams	0.91 grams

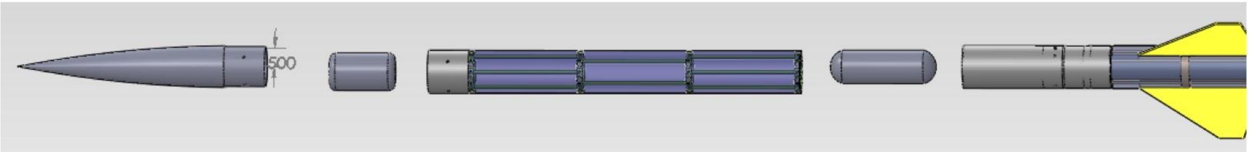


Figure 2: Parachutes after Deployment Full

Altimeters

The StratoLogger collects flight data at a rate of twenty samples per second throughout the flight and stores them for later download to a computer. The altimeter is capable of recording flights of up to 100,000 feet altitude. A picture of the StratoLogger is shown in Figure 3. Two (2) altimeters will be used, each with an independent power supply. The system for each altimeter will be set up as shown in Figure 4, while the pin connections to be used are shown in

Table 8.

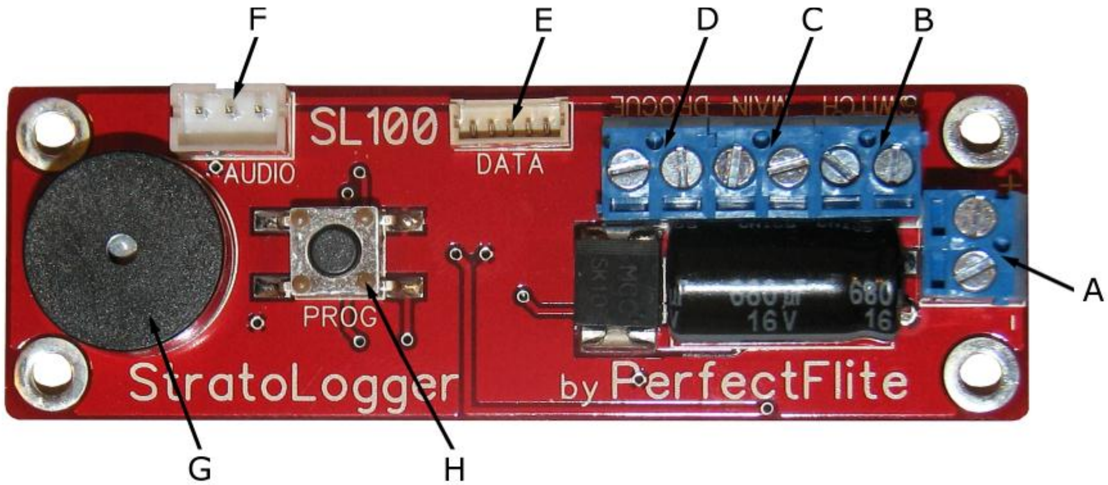


Figure 3: Electrical schematics for recovery system 0

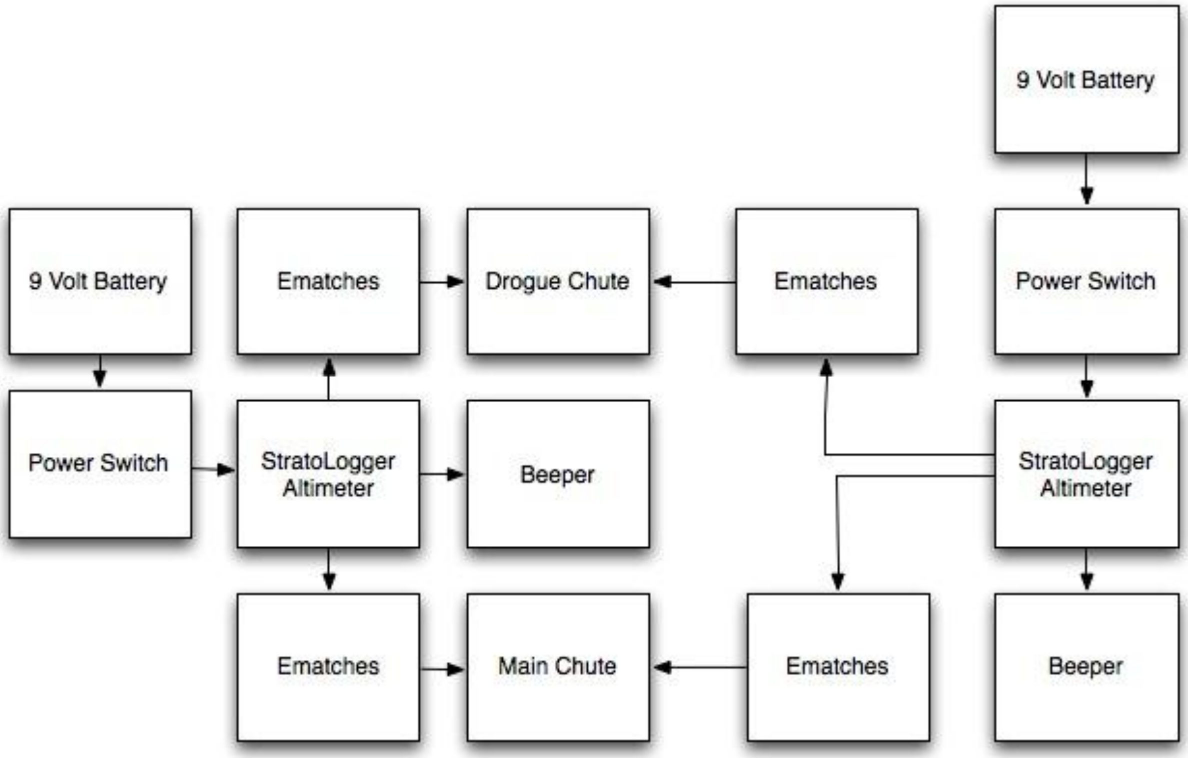


Figure 4: Electrical schematic of Stratologger

Table 8: Summary of the electrical schematics for recovery system

Port	*Name*	*Description*
A	Battery Port	Connect to a 9 V power source
B	Power Switch Port	Connect to a power switch
C	Main Chute Port	Connect to Main Chute E-matches
D	Drogue Chute Port	Connect to Drogue Chute E-matches
G	Beeper	Audibly reports settings, status, etc. via a sequence of beeps

Assembly

Launch Vehicle Recovery

Both the main and drogue parachutes are legacy hardware and the casings are made of G10 fiberglass. The bulkhead that goes underneath the main parachute will be made out of aluminum, since it will serve a dual function as the thrust plate. Four shear pins will hold the assembly in launch configuration. The ejection charge will be directed with the use of PVC end-caps to protect the casings from thermal shock. Shredded cellulose will be used to protect the chutes from thermal shock. The charges will be ignited by an e-match. Each casing will undergo two tests: a distance test and a feasibility test that will estimate the mass to be placed both forward and aft of each compartment. These tests will confirm whether the black powder charges are enough to achieve separation. Supporting equipment will be provided to prevent launch vehicle parts or debris from hitting anyone.

Recovery Ground Test

Assembly will be straightforward. The main coupler will be fixed to the compartment using epoxy. The top half of the compartment will then slide onto the coupler up to the inner wall of the compartment and will be held in place by shear pins. The ejection charges will be placed on the outer side of the payload bulkheads and will be detonated by an e-match, which will be manually controlled by a switch box at a safe distance from the test structure. The actual chutes will be inside the compartments; a NOMEX/cloth shield will protect them.

Testing

For testing to be considered a success, it must meet all of the success criteria (shown in Table 10.

Table 9). Meeting some of the criteria can be considered partial success. Only if none of the criteria are met, or if one of the failure modes occurs, would the test be considered a failure. The failure modes are shown in Table 10.

Table 9: Success Criteria

Success Criteria
Ejection charge ignites
Shear pins break
Launch vehicle moves half the distance of shock cord

Table 10: Failure Modes

Failure Criteria
The fiberglass or the tube coupler shatters due to the charge
The shear pins don't shear, and the launch vehicle stays intact
The NOMEX/Cloth shield fails and the parachute is burned
Ematches fail to ignite black powder

3.4. Booster Section

The booster system of the Mile High Yellow Jackets launch vehicle uses traditional motors combined with a unique structure. The main focus is to have a highly integrated design and to lighten the total weight of the launch vehicle. The primary components of launch vehicle booster section would be the launch vehicle motor itself and the thrust retention system. Both of these primary components are shown in Figure 5 and Figure 6 below.

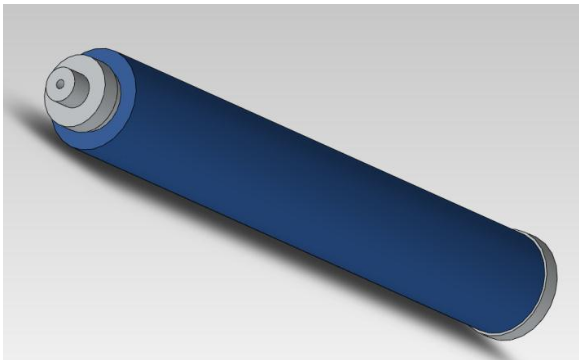


Figure 5: AeroTech 75/3840 Motor Casing

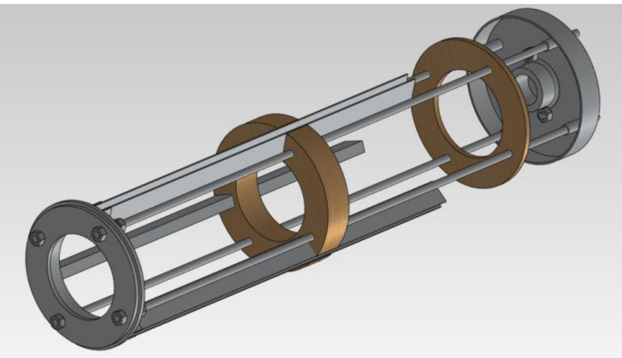


Figure 6: Thrust Retention System

The Motor Retention System (MRS) can be broken down to several modular parts. The first part is the thrust plate located at the top of the MRS. The thrust plate will provide contact area for the ignited launch vehicle motor to provide thrust to the rest of the launch vehicle. The thrust plate will also be part of the recovery system for chute deployment as it will serve as a bulkhead with a U-bolt for attachment of the main chute. Finally, thrust plate will prevent the motor from penetrating through the booster section and it will provide torsional rigidity to the mounting rods that run along the MRS. The assembly of the thrust plate with the motor casing and mounting rods is shown in Figure 7.

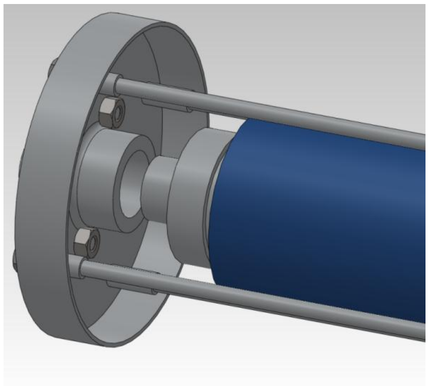


Figure 7: Thrust Plate Assembly

Two (2) major components of the MRS are the support plates at the rear of the booster section. Their main purpose is to prevent the motor from falling out of the launch vehicle. The secondary function is to provide support for three (3) aluminum (or plastic) U-Channel tabs. These tabs are slots that will be used to attach the fins to the booster section. The last two (2) major components are the centering rings that provide additional support to the fin tabs and recovery section tubes. The rear support assembly and the total assembly including the recovery system are shown in Figure 8 and Figure 9.

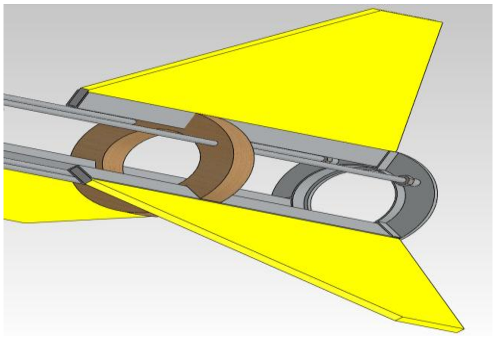


Figure 8: Rear Support Assembly

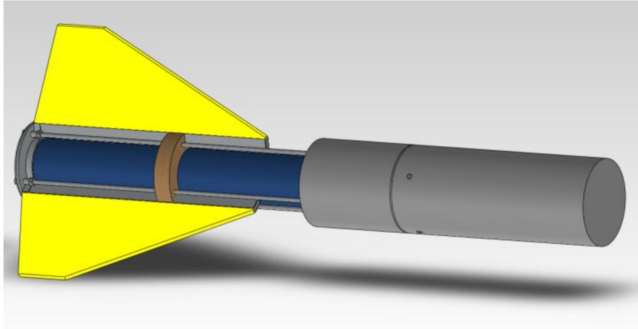


Figure 9: Booster Section with Recovery

Material Requirements

Most of the booster section will be constructed from plywood and sheets of aluminum. These materials will reduce the weight of the system while maintaining structural integrity. However, the thrust plate will require a stronger aluminum alloy to minimize deformation.

Manufacturing and Quality Assurance

Quality will be assured by utilizing proper facilities that are appropriate for the materials and part designs of the booster section. First, the thrust plate and rear support plates require complex cutting. This will be done using a CNC milling machine provided by the Georgia Tech School of Mechanical Engineering Invention Studio. Also, a water jet will be used for cutting out the plywood for the centering rings. Afterwards, the booster section will be assembled using epoxy and hex nuts on threaded rod. For motor preparation, the rear support plates will be removed by unscrewing the hex nuts. Afterwards, the motor propellant will be placed inside the motor casing and the rear support plates will be reattached. The booster section will undergo several test firings to ensure reliability and quality for the official launch date. Five motors will be used for testing and the final launch. Furthermore, the MRS will undergo torsional buckling tests for structural integrity.

Finite Element Analysis

Finite Element Analysis (or FEA) is a method of finding approximate solutions to partial differential equations 0. This method is helpful in analyzing complex structures for design and development analysis. Solidworks contains a design validation tool that carries out basic FEA, which was used to structurally analyze the thrust plate and the overall booster section. The force applied is 408 lb_f, which is the maximum thrust expected for an Aerotech L1390G-P. The first simulation is with only the thrust plate shown in Figure 10 through Figure 13. It resulted in a maximum displacement of 0.00318 inches and an induced maximum stress of 10,053 psi. The next simulation is for the entire booster section (see Figure 14 andFigure 15). It is important to note both figures have deformation scaled to a high level so that it appears as if the rods are buckling when they are not. To reduce complexity, the shape was generalized as a single part similar to the actual booster section which included the thrust plate, mounting rods, fin centering

ring, and the two support plates. The material used for the simulation was Aluminum 6061-T6. This simulation resulted in a maximum displacement of 0.00417 inches and an induced maximum stress of 9,620 psi. The results of these simulations are summarized in Table 11 below.

Table 11: FEA results for the thrust plate and the assembly

	Force Applied (lb_f)	*Max. Displacement (inches)*	*Max. Stress (psi)*	*Factor of Safety*
Thrust Plate	408	0.00318	10,053	3.65
Assembly	408	0.00417	9,620	3.72

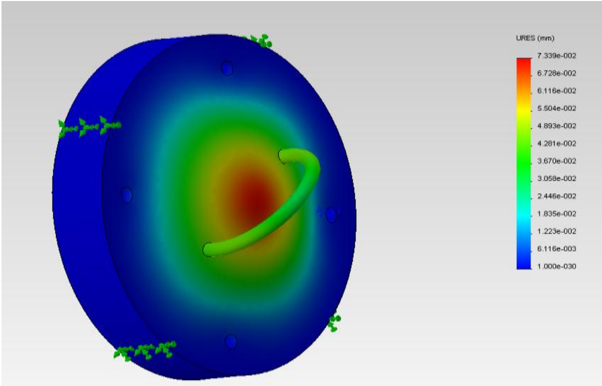


Figure 10: Thrust Plate Displacement (top-view)

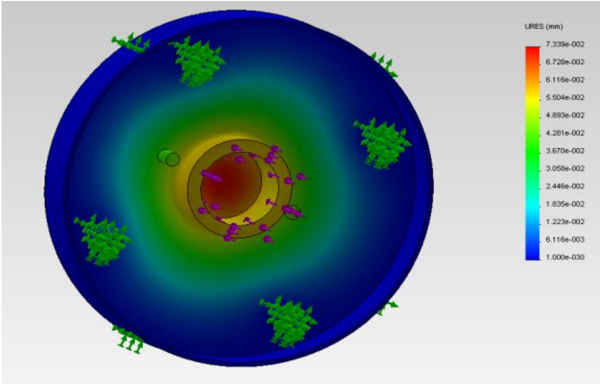


Figure 11: Thrust Plate Displacement (bottom-view)

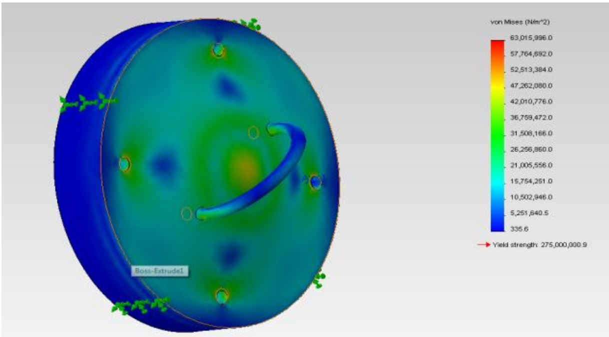


Figure 12: Thrust Plate Stresses (top-view)

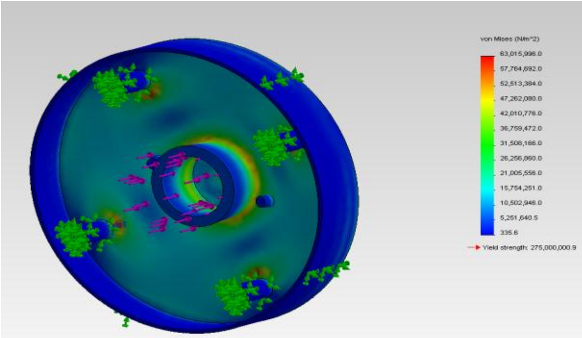
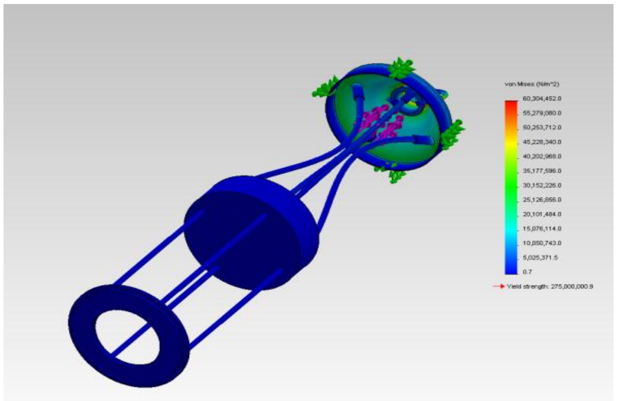


Figure 13: Thrust Plate Stress (bottom-view)



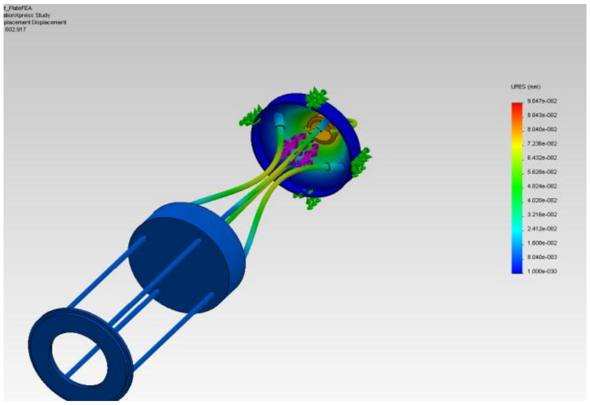


Figure 14: Booster section stresses ***Figure 15: Booster section displacement***

3.5.

Fin Overview

Fins are used to keep the launch vehicle stable and the flight path straight. The fins will be made out of a composite honeycomb core with carbon fiber skins on both sides. This sandwich design provides strength to the fin structure while reducing weight. The fins will connect to the launch vehicle structure through plastic U-channels attached to the centering rings. The U-channels will run across the entire length of the fin providing the maximum contact area and epoxy will be used to attach the U-channel and the fin. During flight, if the drag becomes too great the fins can detach from the launch vehicle structure due to the high moment acting at the interface between the fins and the structure of the launch vehicle. Calculations of the max drag force per fin was performed utilizing Equation (2) and the moment was calculated as the product of force and the distance from the tip of the fin.

$$D = \frac{1}{2} r v^2 C_D A \qquad (2)$$

Due to the small or zero angle of attack, compressibility effects are negligible and therefore neglected 0. Further, the maximum velocity occurs at an altitude of 1,015 feet, which corresponds to a density of 0.07423 lb_m/ft^3. The results are summarized in Table 12.

Table 12: Drag calculation values

Variable	*Value*
Density	0.07423 lb_m/ft^3
Velocity	613.88 ft/sec
Cross section area	0.0695 ft^2
C_D	0.295 0
Max drag force per fin	8.9 lb_f
Moment	6.78 lb_f*ft

Testing Facility

The test rig that will be used for testing the fin structures is designed to test the worst case scenario by applying the force at the maximum moment. The fin test rig will be portable and consists of an L-structure that can be attached to any flat surface with a clamp. The fin structure connects directly to the test rig with the U-channel screwed into the L-structure.

Static Loading Testing

Various tests will be used to determine the capabilities of the test article while undergoing static loading. This is representative of the thrust during the boost phase of flight. The weight will be applied until part failure. The weight will be added in 2 lb_m increments starting at 2 lb_m and ending at 22 lb_m. The fin must withstand the force of the weight for one minute for the run to be considered a success. Additionally, a 2.5 factor of safety shall be achieved for the testing to be considered a success.

3.6. iMPS – Integrated Modular Payload System

A lightweight structure is essential to maximizing payload mass fraction. Most launch vehicles use a thick walled body tube as structural member of the launch vehicle. Though simple, this design is inefficient in its use of material. The Mile High Yellow Jackets' launch vehicle will be unique amongst high power launch vehicles as it utilizes an internal structure consisting of ribs and stringers as illustrated by Figure 16. These ribs and stringers are fashioned out of G-10 fiberglass. The skin of the launch vehicle will consist of a minimum thickness, flexible material. Possible skin materials include fiberglass sheets, heavy-weight paper, or transparent plastic.

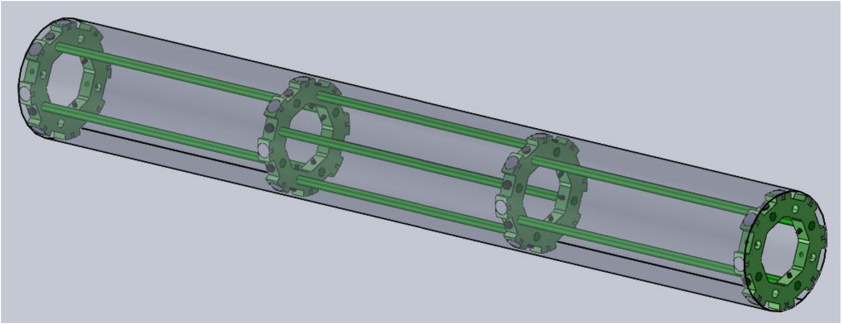


Figure 16: CAD model of the iMPS

To ensure the validity of the design, structural calculations were performed in order to ensure a factor of safety (F.S.) of at least 2.5 on the static loading for the structure. Consider a two dimensional view of the stringer in Figure 17. As a result of the hole, the loading path of the rod has changed significantly. That is, instead of the load being transferred through the entire cross-section of the rod, only a smaller cross-sectional area is carrying the load. The smallest cross-sectional area occurs along the diameter of the fastener hole. Thus, the point of failure will be about this hole due to increased stresses.

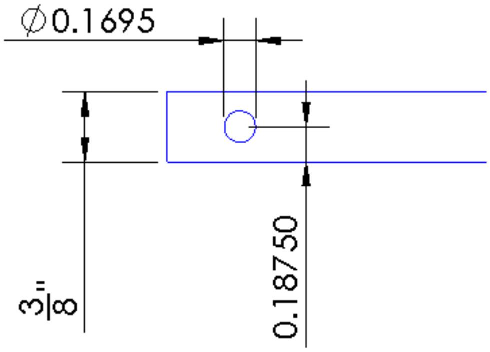


Figure 17: Dimensions for the stringer

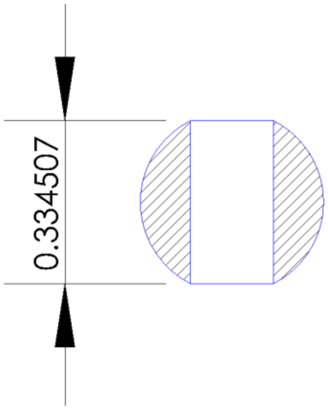


Figure 18: Cross-sectional view of the rod with the fastener hole

The smallest cross-sectional area that will carry the load is 0.0537 in^2 (see Figure 18). The stress concentration factor (SCF) for this particular geometry is 2, and was calculated utilizing Equation (3)

$$SCF = \frac{A_{rod}}{A_{\min}} \qquad (3)$$

Essentially, this implies that for a given load, the area around the hole will experience at least twice the amount of stress than compared to any other part. Therefore, for maximum stress of 38,000 psi 0, the maximum force that one rod can handle before breaking is 995.4 lb_f and was calculated utilizing Equation (4).

$$F_{\max} = \frac{s_{\max}}{SCF} \qquad (4)$$

Since four stringers will be used, and the max thrust from the motor is known, the factor of safety was calculated to be 9.75, and the results are summarized in Table 13. The size of the stringers and ribs were mostly determined for adequate fastener edge clearance. This is the cause of the high factor of safety.

Table 13: Values for factor of safety calculation

Condition	*Values*
Max thrust from motor	408 lb_f
A_{rod}	0.1104 in^2
A_{min}	0.0537 in^2
SCF	2.05
F.S.	9.75

Structure Fabrication and Manufacturing

Because fiberglass is a laminate composite, machining can be difficult. To simplify manufacturing, the ribs were limited to being 2-D designs. This allows the ribs to be cut from a sheet using a water-jet. Starter holes are drilled in the plate in order to prevent delamination of the G-10 when the water-jet pierces the material. The cutting jet can then be traversed from these starter holes to the part. The stringers are cut from lengths of 3/8 inch diameter G-10 rods. They are match drilled to the ribs so that the fasteners fit well into them. To attach the skin, snaps are secured using epoxy to the outer surfaces of the holes in the ribs and to the inner surface of the skin.

Structure Testing & Results

Testing was performed to ensure a F.S. 3.0 on the impact energy during launch. The test rig that was used for these tests was designed to complete multiple types of test, such as static and dynamic structural loading – this was done to decrease test costs through the use of a multipurpose test device as shown in Figure 19. The testing device features a rail-mounted impact machine that can hold various amounts of mass and can be lifted to various heights up to five feet for various sized test articles and/or impact energies.

Figure 19: Impact testing rig

Each test consisted of a known mass (3.98 kilograms) being dropped from a known distance, whose energy correlated to a design impulse (I) of 9.35 N*s. This value was determined from the calculated acceleration on the launch vehicle from the OpenRocket vehicle simulation. The height for the mass was derived using conservation of energy in Equation (5), where m_t is the drop mass. Table 14 features the details of the test runs.

$$height = \frac{1}{2}\frac{1}{g}\left(\frac{I}{m_t}\right)^2 \quad (5)$$

Table 14: Impact test runs

Test Number	*Impactor mass (kg)*	*Factor of Safety*	*Impact Energy (J)*	*Impactor Height (m)*	*Impactor Height (in)*
1	3.98	1.0	5.23	0.064	11.08
2	3.98	1.5	7.85	0.096	16.62
3	3.98	2.0	10.47	0.128	22.16
4	3.98	2.5	13.08	0.160	27.70
5	3.98	3.0	15.70	0.192	33.24

The test article, which consisted of half of the iMPS structure illustrated in Figure 20, was inspected at various locations after each run, and passed the performance criteria, with only minor damage. The results are listed in Table 15.

Table 15: Testing results matrix, where X signifies damage, P signifies pass.

Fastener location	*F.S. = 1.0*	*F.S. = 1.5*	*F.S. = 2.0*	*F.S. = 2.5*	*F.S. = 3.0*
1	p	P	p	p	P
2	P	P	P	P	P
3	P	P	P	P	P
4	P	P	P	P	P
1A	P	P	P	P	X
2A	P	P	P	X	X
3A	P	P	P	X	X
4A	P	P	P	P	P
5	P	P	P	P	P
6	P	P	P	P	P
7	P	P	P	P	P
8	P	p	P	P	P

Figure 20: iMPS structure test article

The damage was very minor and featured discoloration from compression of the fiberglass at the faster locations in the stringers, but no fracturing occurred as seen in Figure 21.

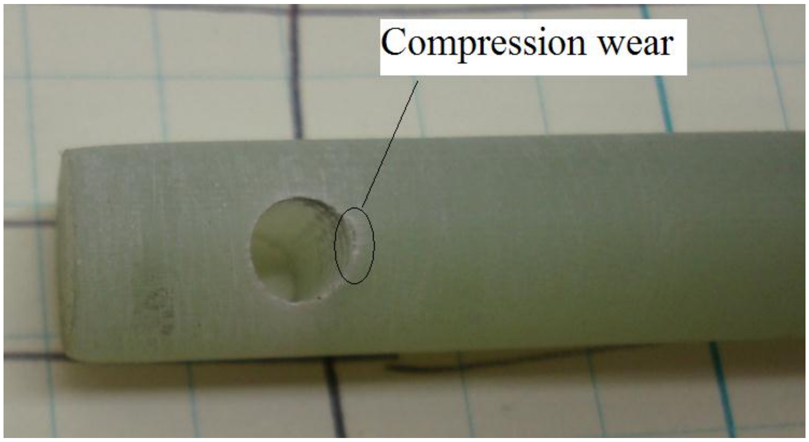


Figure 21: Evidence of minor compression damage occurring at F.S = 2.5

An internal review for this novel structural design was held to decide to continue with this option. Future testing will include full scale impact testing using a payload mass simulator.

3.7. Vespula Mass Breakdown

Mass breakdown for each subsystems are summarized in Table 16 and Table 17 with systems level summary shown in Table 18. The values obtained for the booster section were mostly estimated utilizing Solidworks. However, since material properties were entered manually, the estimated weight should be fairly accurate. The values for nose cone, drogue chute, main chute, shock cords, iMPS structures, and the motor case are actual weights obtained from a scale. Note that the ribs make up the most mass for the iMPS structure. This component is overbuilt structurally in order to have a satisfactory fastener edge clearance. Additionally, the mass breakdown is also presented in terms of mass fractions, as illustrated in Figure 22.

Table 16: iMPS component weight

Payload Section	*Weight (lbs)*	*Quantity*	*Total Weight (lbs)*
G10 Fiberglass Ribs	0.4233	4	1.69
Fiberglass Stringers	0.11	12	1.32
1" bolts	0.004409	24	0.105
Snaps	0.004409	32	0.141
Skin	0.1	1	0.1
Total			**3.27**

Table 17: Booster Section Weight Budget

Booster Section	*Weight (lbs)*	*Quantity*	*Total Weight (lbs)*
Mounting Rod	0.10	4	0.40
Fin Tab	0.14	3	0.42
Fin Centering Ring	0.07	1	0.07
Empty Motor Casing	2.60	1	2.60
Skin	0.23	1	0.10
Fin	0.50	3	1.50
Rear Plate	0.21	1	0.21
Rear Cap	0.16	1	0.16
Thrust Plate	0.58	1	0.58
Booster fiberglass tube (6")	0.42	1	0.42
TC Centering Ring	0.01	1	0.01
Nuts	0.011	14	0.154
Total			**6.624**

3.8.

Table 18: Subsection Mass Break

Component	*Weight (lbs)*
Nose Cone	1.61
Drogue Chute + Shock Cords	1.50
Main Chute + Shock Cords	2.30
Avionics System	5.00
Payload	10.0
Payload & Recovery Structure	5.41
Booster Structure	6.62
AeroTech L1390	8.55
Total	**41.0**

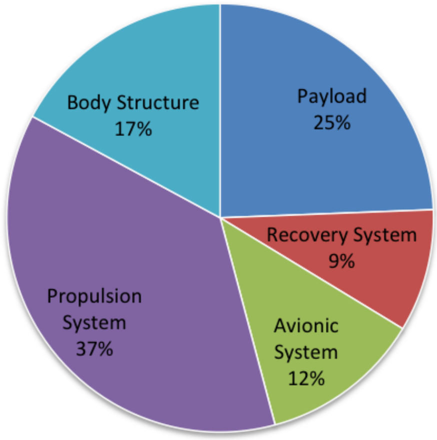


Figure 22: Mass Fraction for Vespula

3.9. Vespula Overall Dimension

Finally, a complete CAD model of Vespula and dimensions are shown in Figure 23.

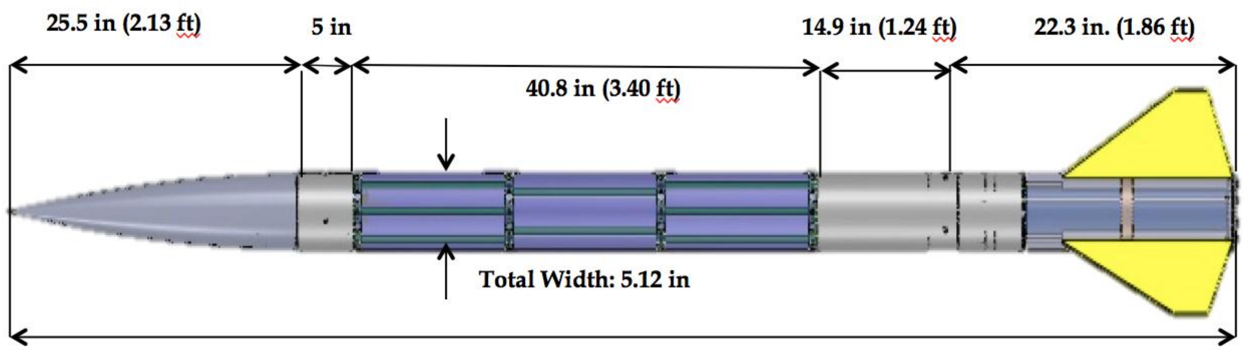


Figure 23: Dimensions for Vespula

4. Launch Vehicle Performance Predictions

Current mission performance predictions are based on a worst case scenario assuming a launch vehicle mass of approximately 41 pounds and an AeroTech L1390G launch vehicle motor. As the payload is finalized, mission performance predictions will be updated to reflect a more accurate mass and appropriate motor selection.

For the launch vehicle to fly along the predicted trajectory, the launch vehicle must leave the launch rail at a certain velocity. For the preliminary launch vehicle design, the launch vehicle becomes stable, with a stability margin caliber of 1, at 47 feet per second, which occurs at 60 inches up the launch rail. Thus so long as our launch rail is at least 97 inches, the launch vehicle will be stable when the rail buttons leave the guide rail. 97 inches is 60 inches to reach stability plus the necessary distance between rail buttons – 37 inches. The current proposed launch pad is the Apogee "Gun Turret" Pad. The system consists of a rail and a base. Altogether the system costs roughly $500.00. The rail is a T-slot aluminum extrusion of approximately eight (8) feet in length and satisfies the requirements of the distance required for the launch vehicle to reach an acceptable static stability margin. Depending on how much of the budget will be left after testing and building of the initial prototype of Vespula, we may build our own launch pad to reduce cost. During recovery, the drogue and main chutes will perform as previously discussed. Table 19 takes a range of possible launch weights, without motor, for the launch vehicle and an optimal motor selection for each weight.

Table 19: Best motor per launch vehicle weight and altitude reached

Total Weight without Motor (lbs)	*Total Weight with Motor (lbs)*	*Motor Required*	*Apogee (ft)*
28.0	36.0	AeroTech L1150R-P	5242
30.0	38.0	AeroTech L850W-P	5253
32.0	40.0	AeroTech L1520T-PS	5170
32.0	40.5	AeroTech L1390G-P	5440
33.0	41.5	AeroTech L1390G-P	5259

All simulations utilized the highest gross launch weight on the chart and the corresponding motor selection. The assumptions for all simulations are listed in Table 20,

Table 20: Flight Simulation Conditions

Condition	*Value*
Windspeed	0 mph
Temperature	60.8^0 F
Latitude	34^0 N
Pressure	1013 mbar
Gross launch weight	41.5 lb
Motor	Aerotech 1390G-P

4.1. Flight Simulation

Figure 24 shows the flight profile of the launch vehicle utilizing flight simulation conditions from Table 20. Velocity, altitude, and acceleration were plotted as a function of time. Apogee occurs at approximately 19 seconds. At apogee, the ejection charge for the drogue chute will fire, slowing the decent rate to 120 fps. Deployment of the main chute will occur at 650 feet above ground level to further decelerate the launch vehicle to 25 fps. The entire flight duration is approximately 72 seconds.

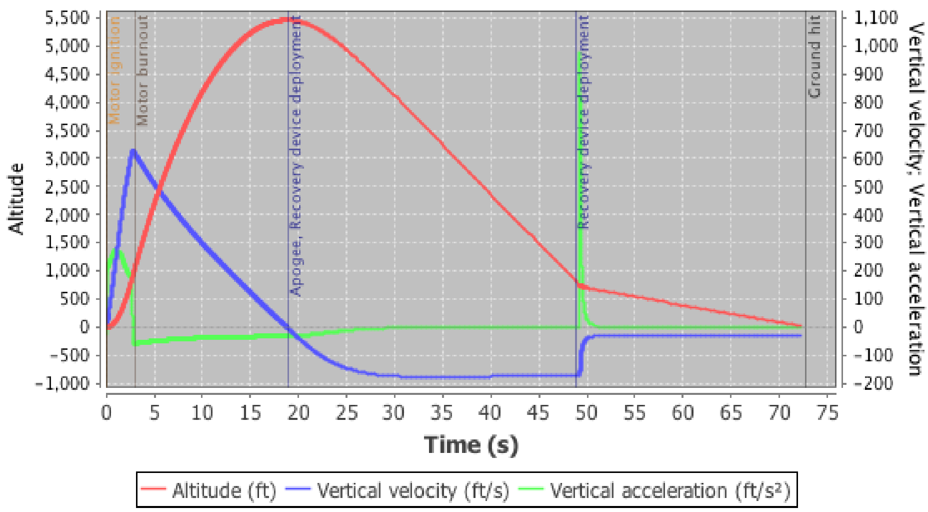


Figure 24: Flight profile with AeroTech L1390 motor for a total takeoff weight of 41.5 pounds

4.2. AeroTech L1390G-P Simulated Thrust Curve

The simulated thrust curve for Aerotech L1390G-P is shown in Figure 25. It is the optimum projected motor for the preliminary launch vehicle to reach an altitude of 5,280 feet. The motor will follow this thrust curve closely, however it is important to keep in mind that the performance of the motor may vary slightly in actual flight.

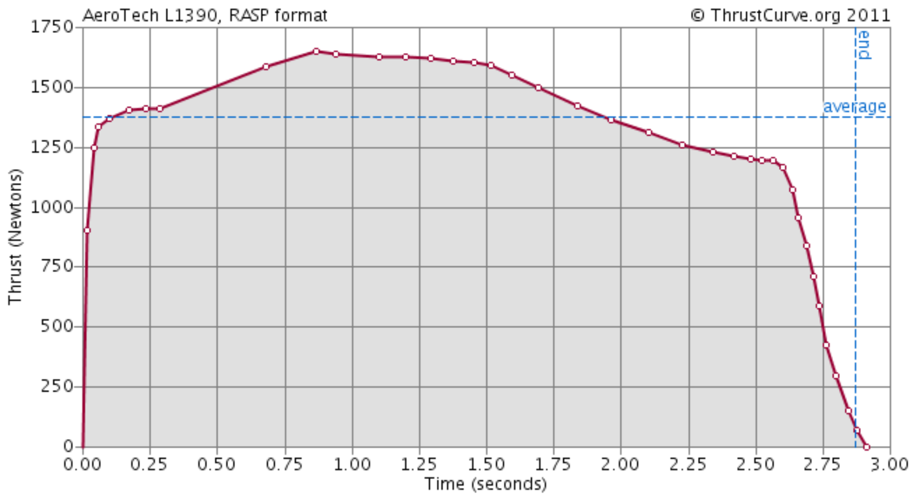


Figure 25: Thrust curve for Aerotech L1390 motor

4.3. Stability Margin

In addition, a stability analysis was performed to ensure a safe flight profile as shown in Figure 26. The stability margin of our launch vehicle during most of the flight is four calibers, where one caliber is the maximum body diameter of the launch vehicle. This is higher than the general rule of thumb among model rocketeers that the C_P should be one (1) to two (2) calibers aft of the C_G. However, being over-stable is not bad; it simply means that the launch vehicle will have a greater tendency to weathercock if there is any wind at launch. To counter this, our launch rod will be at least 97 inches long to ensure stability when the rail buttons leave the guide rail as mentioned previously; additional length will be added to prevent weathercock.

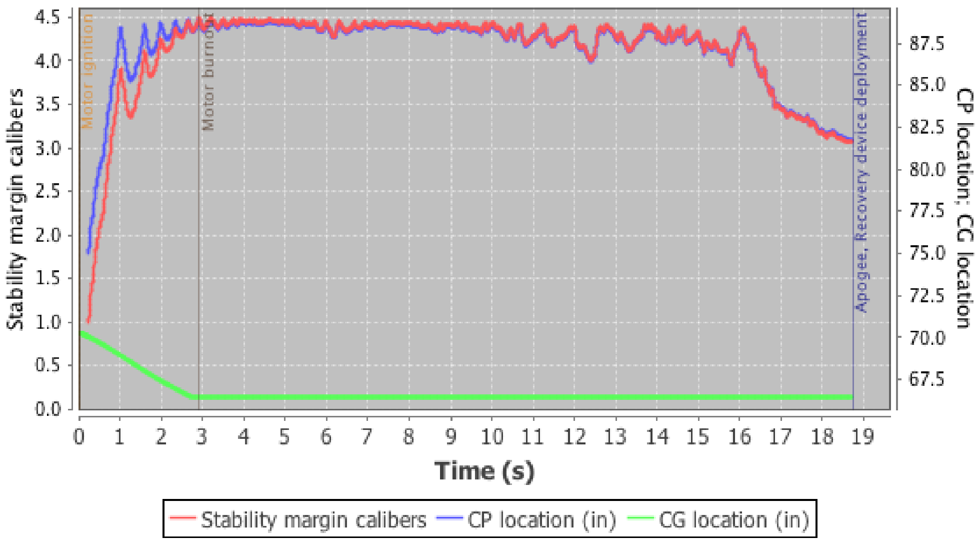


Figure 26: Stability margin calibers vs. Time

4.4. Drift Profile Simulation

The effect of windspeeds on launch vehicle apogee is clearly demonstrated in Figure 27. The green curve illustrates our simulation data, the red triangles is to better assist the reader to visualize apogees reached at windspeed of 0, 5, 10, 15 and 20 MPH. As illustrated, there is a monotonic relationship between windspeed and apogee; the higher the windspeed, the lower the apogee. This is fundamentally due to a horizontal force created by the wind, which ultimately alters the angle of attack of the launch vehicle, and thus a lower apogee. However, from past experience with USLI, it has been shown that OpenRocket vehicle has an intrinsic tendency of over predicting the apogee. For this reason, a 3% correction factor was applied to better estimate the real result. The black line denotes our desired altitude of 5,280 feet.

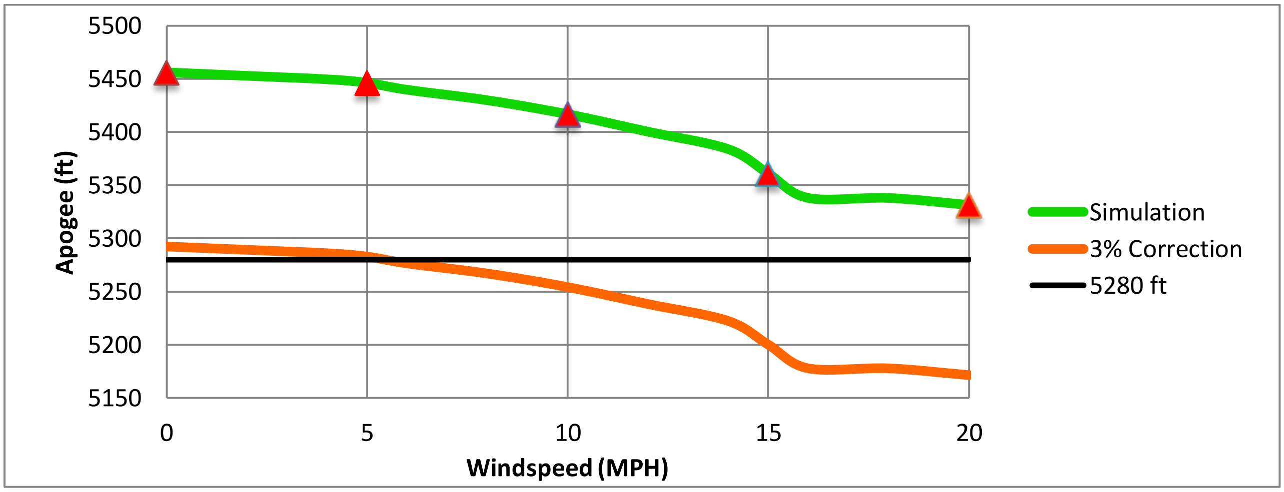


Figure 27: Effect of Windspeed on Apogee

To further prove this point, actual flight experiments were conducted by Mr. Niskanen, author of OpenRocket vehicle software, to demonstrate the validity of his program 0. In his experiment, two different launch vehicles were built, one utilizing B4-4 motor and the other C6-3 motor. For maximum accuracy, each component was individually weighed and the weight of the corresponding component was overridden in the software. Finally, the mass and C_G position of the entire launch vehicle was overridden with measured values. Both launch vehicles were flown and the results are shown as follows, with the left figure for B4-4 motor and the right figure for C6-3 motor.

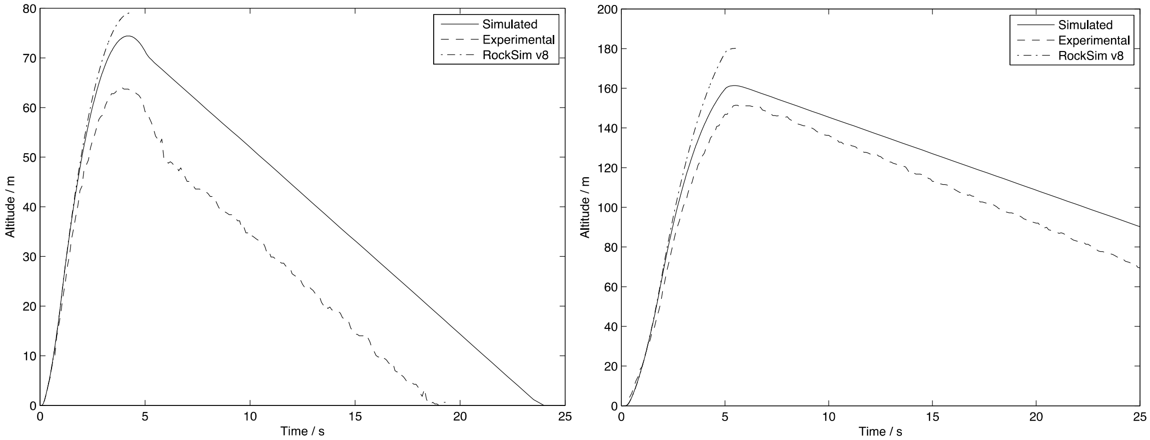


Figure 28: A comparison of OpenRocket vehicle Simulation vs. actual data acquired.

The solid lines represent simulated data from OpenRocket vehicle. The upper dash lines represent simulated data from RockSim, which is truncated at apogee due to limitations of the demonstration version of the software. The lower dash lines represent the actual measured data. Clearly, both simulation software products produce optimistic data as mentioned previously, with errors in apogee about 7-10%. Thus the 3% correction is appropriate.

4.5. Kinetic Energy Upon Landing

The kinetic energy at landing for each independent and tethered section of Vespula was calculated utilizing Equation (6) where m is the mass of each section and v is the velocity. The results are summarized in Table 21.

$$KE = \frac{1}{2} m v^2 \qquad (6)$$

Table 21: Kinetic energy upon landing for each section of Vespula

	Mass (lbs)	*Velocity (ft/sec)*	*KE (ft-lb)*	*KE (joules)*
Nose Cone	1.610	25	15.60	21.20
Booster Section	6.620	25	64.20	87.10
Payload Section	20.42	25	198.1	268.5

5. Launch Vehicle Testing

5.1. Subscale Testing

A subscale flight test will be performed prior to CDR to determine the feasibility of certain aspects of our design. This testing primarily focuses on the performance of our exterior skin covering the booster and payload section during flight. The basic design of our subscale launch vehicle, to be called "Korsakov" features a smaller diameter body tube, that is covered by a non-load bearing, thin-walled skin. Korsakov will utilize two (2) 0.5 inch diameter launch lugs, one placed on the top section and one on the bottom. They will be two (2) inches long and epoxied onto the sides. The thrust is transfer through the internal cardboard tube from the booster section to the nose cone. Due to the configuration of the launch vehicle, a dummy mass of 0.3 pounds was added right after the nose cone to provide at least one (1) caliber of stability margin (see Figure 29). The characteristic of Korsakov is summarized in Table 22.

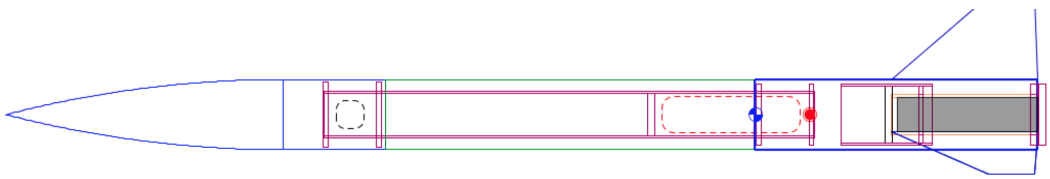


Figure 29: Korsakov launch vehicle layout

Table 22: Characteristics of Korsakov vehicle

Condition	*Value*
Length	45 inches
Outer Diameter	3 inches
Motor	Aerotech H242T
Max Mach Number	0.44

Again, a stability analysis was performed to simulate the C_G and C_P translations in flight as shown in Figure 30. The stability margin of Korsakov is around 2.4 calibers for most of the flight, thus it will be stable.

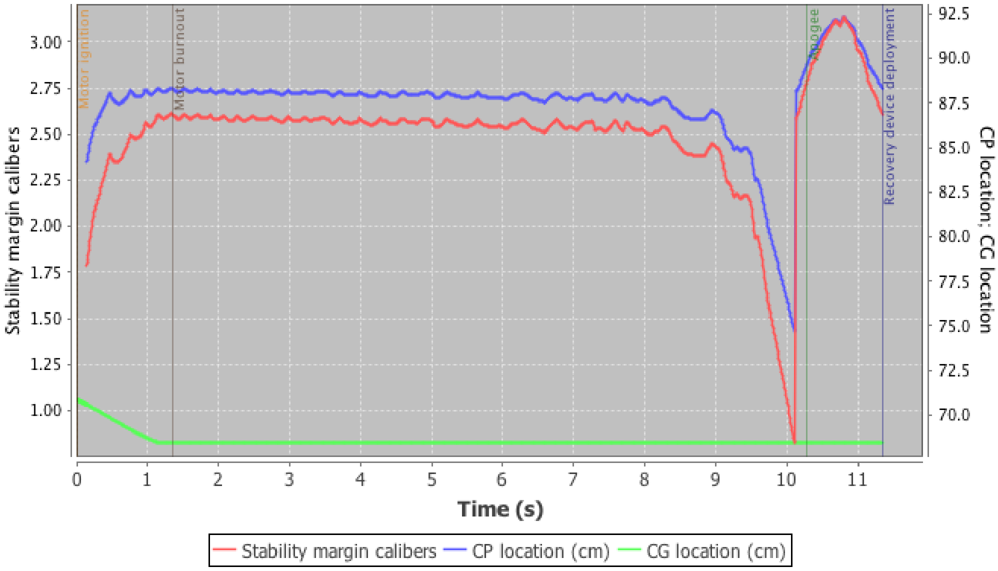


Figure 30: Stability profile for Korsakov vehicle

Table 23 shows all the materials required for building Korsakov with a total projected cost of \$165.28. The total weight was estimated to be 3.4 lb_f utilizing OpenRocket vehicle software.

Table 23: Material and cost for Korsakov

Item	*Use*	*Cost ($)*
Motor reload kit	Launch vehicle motor	31.99
Airframe Tube 74/18 (Thin Wall 3" tube)	Main body	20.57
Airframe Tube 29/13	Inner body	8.790
Airframe Tube 56/18 (Estes BT-70 size)	Motor tube	11.52
Baltic Birch Plywood 6mm-1/4" x 24" x 30"	Fins	8.99
1/4" plywood	Centering rings	10.00
U-bolts	Recovery	2.000
Poster board	Skin	4.990
Snaps	Skin fasteners	14.58
Parachute	Recovery	33.00
Nose cone	Aerodynamics	18.85
Total		**165.28**

6. Launch System and Platform

As mentioned previously, the launch system that is showing the most promise is the Apogee "Gun Turret" Pad. The system consists of the "rail" and the base. Altogether the system costs $500.00. The rail is a T-Slot aluminum extrusion of approximately 8 feet in length and satisfies the requirements of the distance required for our launch vehicle to reach an acceptable static stability margin. The blast deflection pad is angled with dimensions 9 inches x 9 inches x 0.25 inches, and is made of "heavy-gauge" steel. The rail and the deflection pad are attached to the "head" of the base, which can pivot horizontally for easy loading of launch vehicles. Three legs with leveling screws are attached to the base so that the launch angle can be adjusted to desired conditions, with all parts also being constructed from heavy-gauge steel. The entire system weighs roughly 30 pounds, and is collapsible for transportation.

Our launch vehicle will have a two rail buttons attached such that they do not interfere structurally with any other components. The rail buttons slide into T-shaped aluminum extrusion and limit the launch vehicle's motion except in the desired launch direction. The first button will be attached to the thrust plate in the booster section, where components exist to easily create an attachment interface with minimal structural interference. The second button will be attached the rear thrust retention plate. This will ensure that both buttons will be on the rail for a time, and at least one button will be on the rail for the length required of the launch vehicle to reach an acceptable static stability margin upon launch.

The launch procedure checklist is presented in Appendix I.

7. Payload

7.1. Introduction to the Experiment and Payload Concept Features & Definition

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.

7.2. Overview of the Experiment

Hypothesis and Premise

The premise of the experiment is that –

> *If a platform can be levitated and stabilized in a dynamic magnetic field during the flight of a launch vehicle, then greater stability and lower structural mass may be achieved.*

The payload will utilize dynamic three-dimensional magnetic fields to create an Active Platform Electromagnetic Stabilization, or A.P.E.S., system for use during the ascent phase of the launch vehicle's trajectory. The launch vehicle ascent will provide a high vibrational intensity environment in which to test the stabilization system. Two further premises are necessary for this A.P.E.S. system, namely:

1. *Under appropriate conditions, it is possible to control complex oscillating magnetic fields such that a system of ferromagnetic materials or permanent magnets may be levitated in non-rotational stability.*

2. *A design exists such that a platform of some size and low mass may be levitated using ferromagnetic materials or permanent magnets.*

Therefore, after completing a thorough analysis of the dynamics of materials being levitated and stabilized in magnetic fields, the Mile High Yellow Jackets will implement a design to apply this science to a platform within the Vespula launch vehicle.

Experimental Method and Relevance of Data

The parameters to be measured in the experiment are the coordinates of the position of a test sample – in the case of ground testing – and the coordinates of the platform for the ascent of the launch vehicle. To ensure full implementation of the scientific method, the experiments will be carried out such that the results are controlled by comparison – i.e. a series of tests of increasing complexity will be conducted such that the control theory of the A.P.E.S. system is constructed methodically. Analysis of optical and infrared data will provide Cartesian coordinates, which, in a known design, can be used to specify the position and displacements of the platform, defining all kinematics to a level of accuracy proportional to the sample and computational rates of the data acquisition system. This data provides an empirical basis for confirmation or rejection of an experimental hypothesis – a newly written control program can be considered as a hypothesis – and for the improvement of the system as a whole.

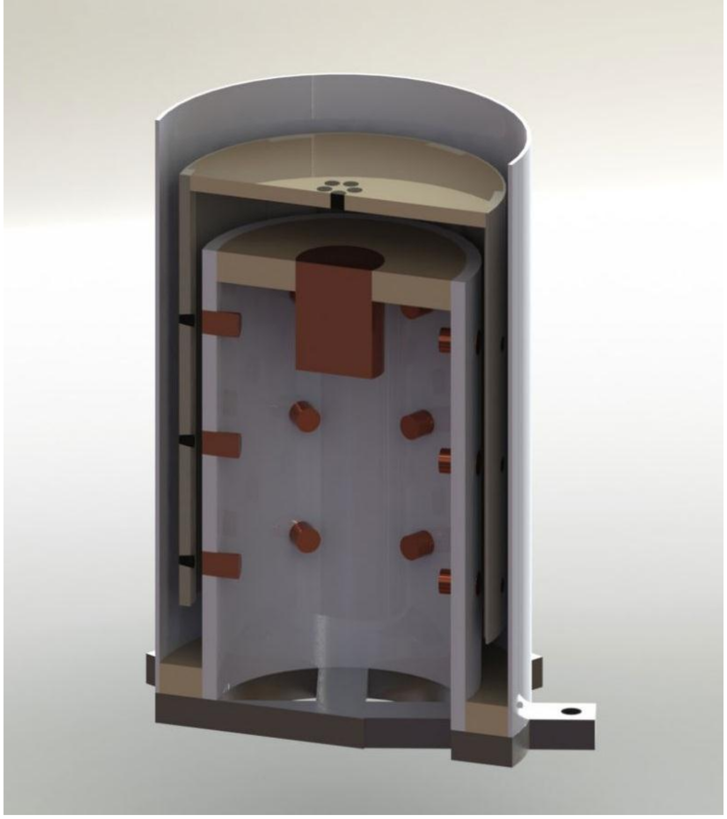


Figure 31: Section view of the proposed flight model of the A.P.E.S. system

Ground Test Plan

Ground testing will serve two general purposes: (1) the development of data algorithms and control laws, and (2) the verification and validation of theory and control systems. By understanding and predicting the kinematics of a sample plate driven by dynamic magnetic fields, steady-state models can be formed allowing for stable non-rotating levitation with oscillation dampening. The testing process will ramp the complexity of the model, beginning with simple 1-dimensional tests, and increasing the number of solenoids and dimensions until a 3-dimensional multi-solenoid model has been created. Data collected from ground testing will directly inform the control of the flight A.P.E.S. system design. The flight design is depicted in Figure 31, and the ground test platform design is illustrated in Figure 32.

.

Figure 32: The A.P.E.S. system ground test platform

Test Sequences

Ground testing will undergo test sequences. Preliminary testing will calibrate instruments for use in the experiments. The first sequence will simply lift a ferrite toroid ring within a tube, constricting motion to a single axis. The ring will be lifted to an equilibrium position. This test will provide a validation of the force equations moving forward. Subsequent tests will increase the number of dimensions and the number of solenoids involved. In each case, an equilibrium position will be sought. For two- and three-dimensional testing, computer vision will be used to provide kinematics data for controlling solenoid current. An Arduino Mega may be used for simplicity during ground testing; however, some team members do possess an ARM Cortex M3 “Blueboard,” so this is also an option for control of solenoids and receipt/analysis of sensor feedback. The preliminary testing plan is included in Appendix 2.

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

$$\mathbf{m} = I\boldsymbol{S} \tag{1}$$

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

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

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,

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

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

Where $\hat{\mathbf{r}}$ is the unit vector in the direction of **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 $\mathbf{m} = NI\boldsymbol{S}$ 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 **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 $\frac{1}{4\pi} I\boldsymbol{S}$ 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 33, 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 34, for the sake of simplicity.

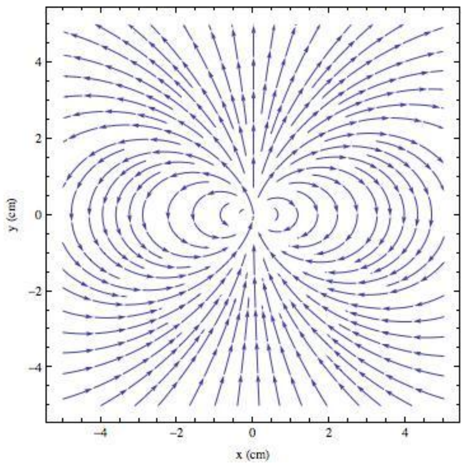


Figure 33: field generated by a single dipole

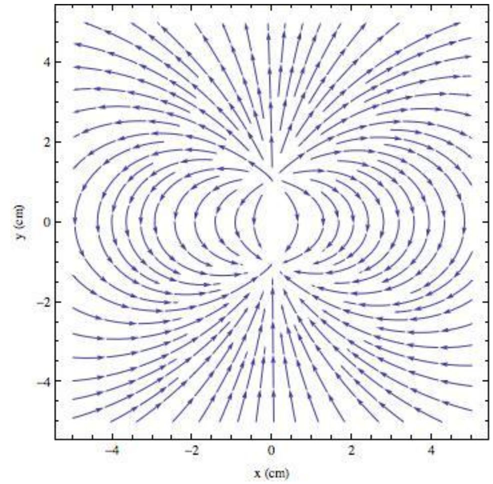


Figure 34: field generated by multiple dipoles

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.

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

where each $\mathbf{m}_k$ is the magnetic moment of the *k*th 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:

$$\mathbf{M} = \chi_m \mathbf{H} \tag{6}$$

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

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:

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

Where $\mathbf{r}$ is the vector from $\mathbf{m}_s$ to $\mathbf{m}$, and $\hat{\mathbf{r}}$ is again the unit vector in the direction of $\mathbf{r}$. 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:

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

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:

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

Where $\hat{\mathbf{n}}$ is the unit vector in the direction of $\mathbf{S}$ – the unit normal to the loop area of the solenoid – and $\mathbf{r}$ 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,

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

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.

Scientific Merit and Success Criteria

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.

1.1.1.1. Experimental Requirements and Objectives

Included within the Mile High Yellow Jackets terminology of "Flight Systems" is included all avionics and experimental material necessary for a successful mission. Therefore, the Flight Systems group must deliver based on two sets of functional requirements. Requirements for

A.P.E.S. are detailed in Table 24. These four basic requirements have been updated for functionality from those originally listed in the proposal and all elements necessary to the smooth operation of the experiment are tied to these requirements.

Table 24: A.P.E.S. system requirements

Requirement Number	*Requirement Definition*
1	A platform shall be levitating without rotation during the ascent of the launch vehicle and coordinate data provided through optical and infrared sensing shall be used as verification metrics.
2	All elements of the A.P.E.S. system shall weigh no more than 10 pounds total, including all hardware and electronics in direct support of the A.P.E.S. system.
3	The A.P.E.S. system must actively correct for accelerations of the launch vehicle.
4	The A.P.E.S. system must shut down safely at apogee.

There are several options available to Flight Systems to satisfy the functional requirements. The use of the word "platform" is necessarily open-ended as the team investigates several types of platforms. Ground testing requirements necessitate that several platform configurations be used to formulate the final system model. Table 25 outlines some of the ground testing objectives for A.P.E.S.

Table 25: A.P.E.S. ground testing objectives

Objective Number	*Objective Definition*
1	Ground testing should develop a data-driven model for the interaction of ferromagnetic materials and permanent magnets in one-, two-, and three-dimensional dynamical systems of magnetic fields.
2	Ground testing should test the feasibility of de-scope and full flight designs.
3	Ground testing should provide the computational basis for control of the A.P.E.S. system during ascent of the launch vehicle.

If ground testing results are successful and combined with a thorough theoretical understanding of the phenomena involved in dynamic magnetic fields, ground testing will enhance the ability of Flight Systems to successfully accomplish the most important objective of the A.P.E.S. system –

– that the A.P.E.S. platform shall not touch any part of the container during the ascent phase.

Optical sensing of either the infrared or visible spectrum will serve to inform the control system of the location of the platform. A full flight model – illustrated in a section view in Figure 31 –

would include a series of concentric cylinders, wherein the center cylinder would contain permanent magnets and a platform, while the inner cylinder would store solenoids and a CMOS camera for optical detection of fiducial markers.

Success Criteria

A fully successful launch of the A.P.E.S. system will demonstrate a capability to respond and dampen impulses delivered to the levitated platform from the launch vehicle during ascent. Namely, the platform shall, ideally, not touch any other A.P.E.S. components during ascent. However, failure to achieve total isolation of the platform is only a partial failure, as conditions during launch could lead to unforeseen perturbations of the launch vehicle. Any failure to levitate the platform, dampen motion, shutdown, or start up, would be a critical failure. Specified preliminary success criteria are given in Table 26: Success Criteria. An attempt has been made to provide a reasonable goal for system performance before any physical testing has begun. It is not certain whether it will be possible to provide the same level of control for many disturbances.

Table 26: Success Criteria

Success Criteria	
The A.P.E.S. system shall be successful if	
1	For an impulse response the system shall have a 2% settling time of less than 0.5 seconds
2	And for the flight of the launch vehicle that the platform should not touch other components of the A.P.E.S. system.

8. Flight Systems

8.1. Flight Avionics

Overview and Requirements

To successfully complete the USLI mission, flight systems is further responsible for providing a fully functional flight computer system. Avionics is the second subsystem of Flight Systems, responsible for data acquisition, experimental control, recovery electronics, and features necessary as per the USLI Handbook. Avionics requirements are listed in Table 27.

Requirements and Products

Two major products of the Avionics subsystem are the flight computer and the experiment computer for A.P.E.S as detailed in Figure 35. The flight computer interfaces with all sensors not directly involved with A.P.E.S. and controls most sensing, logging, and telemetry for the launch vehicle. The A.P.E.S. computer focuses entirely on the control of the A.P.E.S. system.

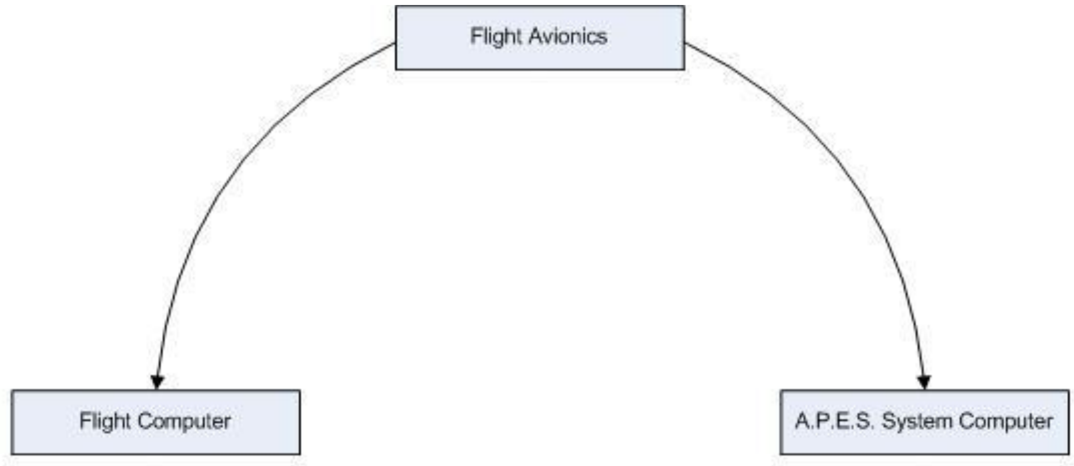


Figure 35: General products of Flight Avionics

The A.P.E.S. computer will calculate the position of the platform and control the solenoids in order to change the magnetic field and stabilize the platform. Independent computing systems provides modularity for ease of implementation and debugging. The methodology for component selection shall include consideration of clock speed, I/O, and voltage requirements. Electromagnetic interference will be shielded by a Faraday cage. The system will incorporate redundancy to tolerate the loss of one or more sensors and/or communication lines.

Table 27: Flight Avionics Requirements

Requirement Number	*Requirement Definition*
1	The avionics shall be a thoroughly tested custom design.
2	The flight computer shall be based off of the ATMEGA 2560 chip.
3	The A.P.E.S. computer shall be a commercially purchased board based upon the ARM Cortex M3 microprocessor.
4	The flight avionics shall collect data on acceleration, altitude, and data necessary to the A.P.E.S. payload and execute the A.P.E.S. control laws.
5	Key elements of the flight systems shall operate on independent power supplies.
6	Power supplies should allow for successful payload operation during launch vehicle flight with up to 1 hour of wait on the launch pad and 2 hours of wait during launch vehicle preparation.
7	The flight avionics, with the exception of the recovery avionics, shall begin at launch and these systems should be capable of being armed externally to the launch vehicle structure.
8	The avionics should provide for the communication of ground location to base station for recovery.
9	Separate elements shall trigger ejection charges for parachutes, and a competition altimeter shall be included.
10	GPS coordinates of all independent launch vehicle sections shall be transmitted to a base station.
11	The recovery avionics and system shall be separate from the main flight avionics.
12	The base stations shall be capable of receiving and displaying data transmitted from on board the launch vehicle.

Flight Computer

The flight computer will run the ATMEGA 2560AU processor with the Arduino bootloader and other necessary components for ease of programming. The chip has sufficient I2C, serial, and analog inputs to read data from all sensors and log to an SD card based on Sparkfun's OpenLog break-out board. Additionally, the chip will run the Fastrax UP501 GPS module and send the data to an Xbee PRO for transmission to the ground station. An OpenLog board will provide logging capabilities. The chip will be programmed in the Arduino language, a subset of C++ with some additional libraries. Figure 36 provides a generalization of proposed flight computer software.

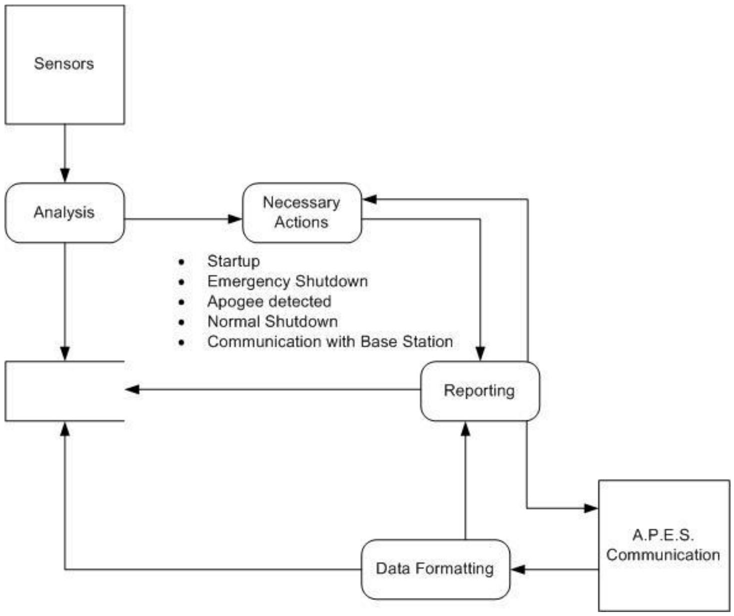


Figure 36: Generalization of flight computer software

The flight computer must accomplish several tasks and handle multiple responsibilities. The main goal of this system is to collect and monitor all the relevant data from the environment around it such as the strain on the launch vehicle, environmental factors such as temperature, stray magnetic flux from the A.P.E.S system, launch vehicle acceleration, and GPS position. During flight, the flight computer must also monitor the payload's control system and data through a serial bus and provide an emergency secondary disengage for the A.P.E.S. system in the case of a necessary emergency shutdown. During flight the avionics will log all data to a SD card. Solid state memory should allow recovery of flight data if a recoverable failure occurs. Post-recovery, the flight computer must switch to location and communication systems to transmit a GPS signal through the telemetry system to the ground station. Figure 37 and Table 28 provide the current proposed flight computer schematic and major components, respectively.

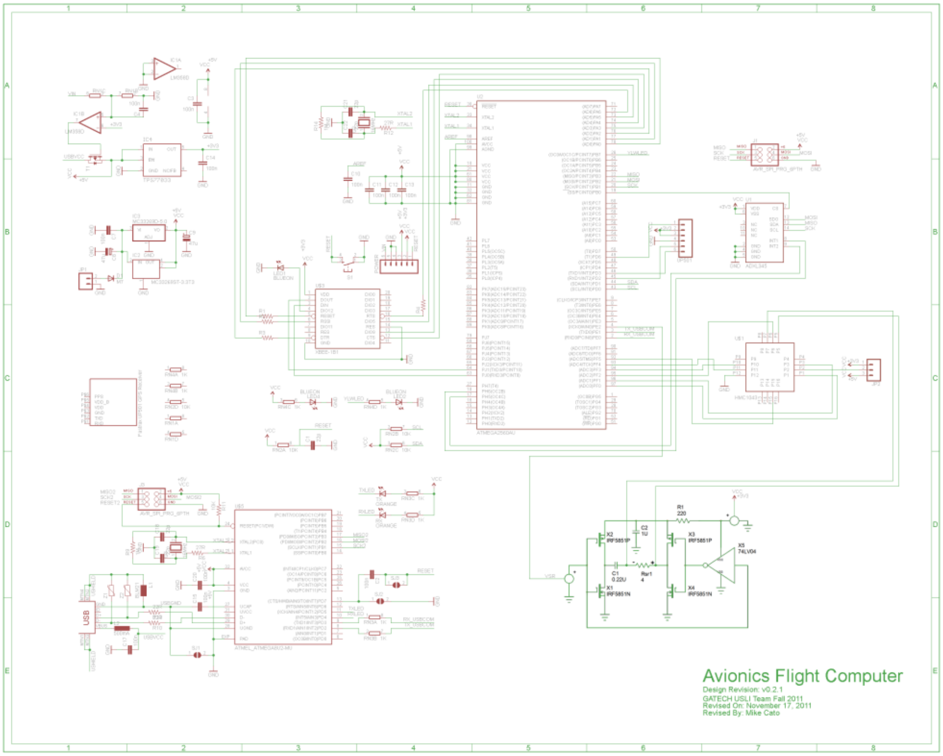
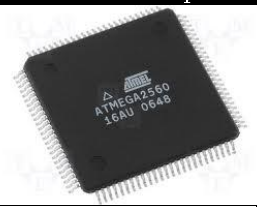


Figure 37: Proposed layout of flight computer. Larger copy included in Appendix 4

Table 28: Major Flight Computer Components

Part Number	*Component Picture*	*Description*
1		The flight computer microprocessor, the ATmega 2560
2		The GPS receiver, the Fastrax UP501 GPS module
3		The Xbee PRO 900-XSC module for communication between launch vehicle and ground station
4		The OpenLog board will provide logging capability

A.P.E.S. System Computer

The A.P.E.S. system and its computer will focus on the stabilization of the isolated platform. The computer system will be a commercially purchased ARM Cortex M3 breakout board named a “Blueboard”. The Cortex M3 will provide up to 100 MHz of clock speed for the rapid computation necessary in analyzing optical data. The Blueboard will also allow the Cortex M3 to handle all control of the magnetic fields through pulse-width modulation (PWM), and delivery of data to the flight computer. A.P.E.S. system software will also include steps to shut down the experiment at or around apogee, and physical constraints will be built into the A.P.E.S. system structure to improve shutdown and recovery safety. An outline of the A.P.E.S. system software is given in .

and a rough layout of A.P.E.S. computer hardware is given in Figure 39.

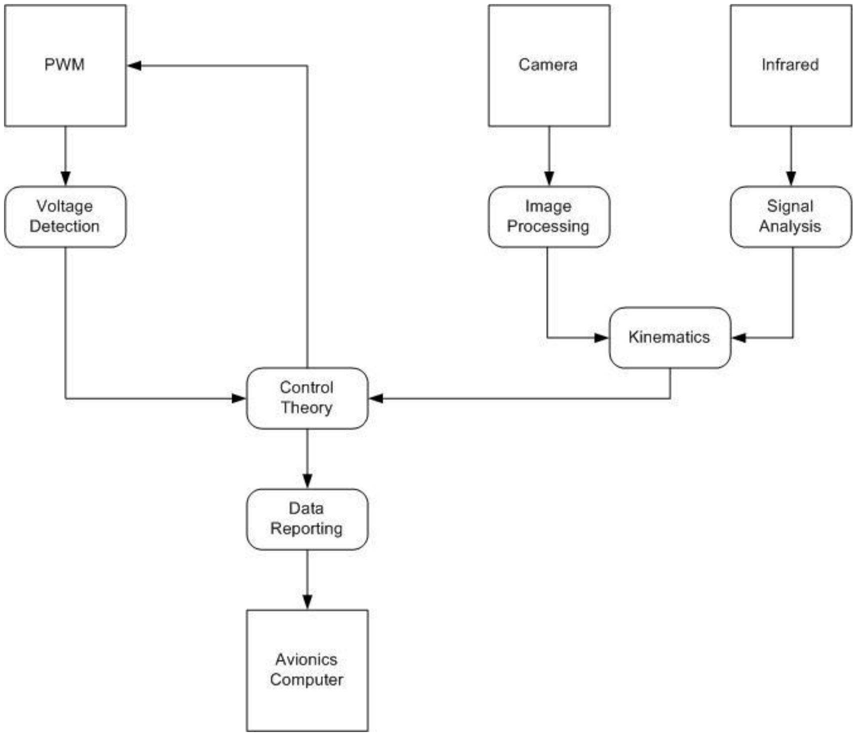


Figure 38: Generalization of A.P.E.S. system software

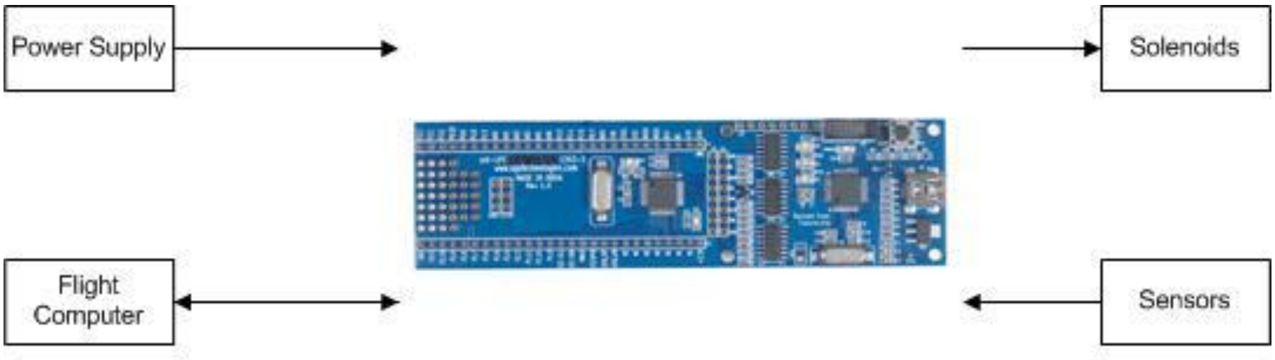


Figure 39: Layout of A.P.E.S. computer system hardware

8.2. Power Systems

Power Supply

The avionics system, including computers and sensors, will be powered by a 9V battery. The supply will be attached to the Avionics Computer Board which is designed to have a voltage regulator circuit providing 3.3V and 5V rails. The supply will provide 1200mAh of power.

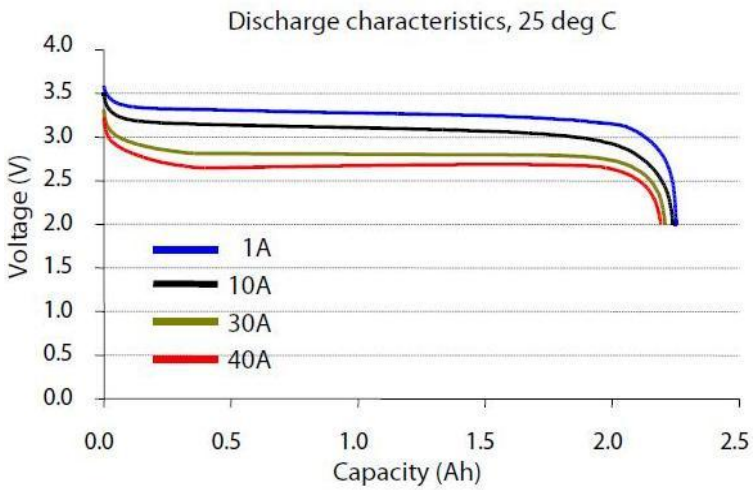


Figure 40: Discharge characteristics of the A123 battery

The avionics use a negligible amount of power in sleep mode providing a minimum of 5 hours of wait capability for the launch pad. Upon launch the system is activated and will have greater then needed power capacity to perform its duties until the launch vehicle is retrieved. Separately, the A.P.E.S. system will utilize a four-pack of A123 lithium iron phosphate (LiFePO) rechargeable batteries, one of which is shown in Figure 41. These batteries have a per-unit nominal capacity and voltage of 2.3 ampere-hours and 3.3V, respectively. Furthermore, the A123 batteries provide a maximum discharge rate of 70 amperes. Figure 40 illustrates the discharge characteristics of the A123 at four discharge rates. The ability of the A123 to provide a large current is critical to the A.P.E.S. system, which will rely on pulse-width modulation to change magnetic field intensity via manipulation of a root-mean-square current.

Figure 41: A single A123 LiFePO battery

8.3. Telemetry and Recovery

Ground station

The ground station for receipt of data shall consist of a laptop connected via USB to an Xbee Pro and Xbee Explorer with a rubber duck antenna. This will ensure simplicity, portability, and operability of the ground station.

Transmitter Design

In order to satisfy recovery requirements that the launch vehicle be found, a GPS module is included with the avionics in addition to radio communication equipment. The Fastrax UP501 provides a 10Hz update rate, rapid satellite acquisition, and low current draw. Position data is logged on-board and transmitted over the 900MHz radio band to our ground station. The telemetry system is designed to utilize two Xbee PRO 900-XSC modules for one-way communication from the launch vehicle to the ground station. Using a simple, loss-tolerant protocol with reliable delivery ensures the data is received if at all possible and that the information is correct. To extend the range beyond 1 mile, each module has a 900MHz monopole-monopole vertically polarized rubber duck antenna with 2 dBi gain and 10W of power. This antenna's performance is depicted graphically in ory.

. Receipt of GPS data via radio to the ground station will satisfy the recovery requirement and bolster kinematics data of the launch vehicle trajectory.

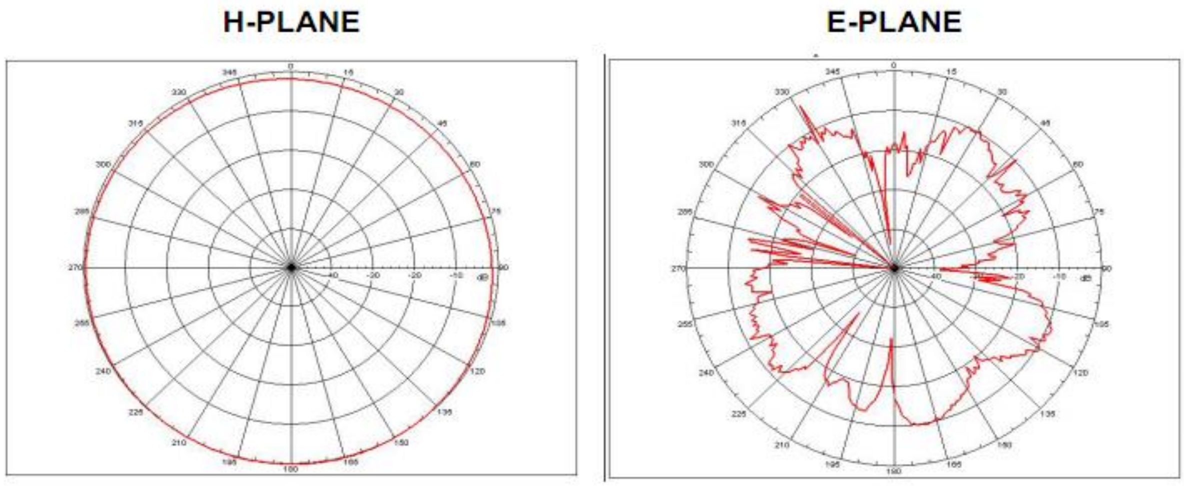


Figure 42: Antenna performance as a function of range

8.4. Integration

Modularity and Motivation

The modular internal launch vehicle structure permits integrating the payload with minimal effort. A section of the internal launch vehicle structure is reserved for the altimeters, payload experiment, and flight computer. The ends of the modular section are fitted structurally with solid fiberglass to sustain the bursts of the recovery system. These solid fiberglass sections are fitted with shear pins to maintain stability during flight. The entire system stacks together for dual deployment. The volume designed for the payload is an area between the struts 8 inches long with an average diameter of 3.2 inches within the hexagonal inner side of the ribs. The A.P.E.S. device will be anchored to the top of this section via a "universal bracket" to one of the ribs, shown in

. Below A.P.E.S. will be the flight system computer will in a shielded compartment. The computer will also be mounted to a rib using a universal bracket.

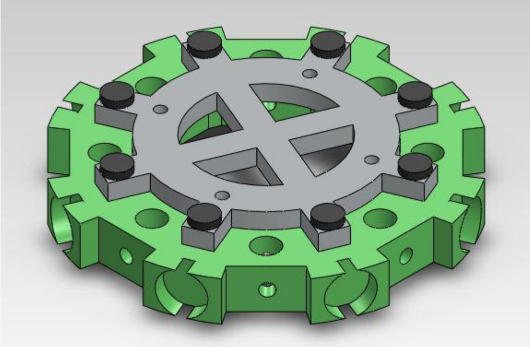


Figure 43: Universal mounting bracket bolted to rib

Universal Mounting Bracket

The unique and robust structure of the Vespula launch vehicle will allow greater reusability and modularity for integration of the flight and payload subsystems. In order to speed up integration time a generalized universal mounting system will be employed so that current and future subsystems can be quickly and effectively mounted to the major rib sections of the launch vehicle structure. When these and future internal components are designed and produced, minimal design consideration will be needed to account for attachment to the universal mounting bracket. This continues on the Georgia Tech Mile High Yellow Jackets tradition of simplifying and unifying the structural elements of the launch vehicle, simplifying design and improving construction time and structural robustness. The universal mounting bracket shall be built to accommodate structures such as the A.P.E.S. device with minimal fabrication and design requirements, and to fit within rib structures with few necessary design parameters on the ribs themselves, increasing the potential reusability of the universal mounting bracket should future teams alter the modular structure further. As shown in Figure 31, the proposed A.P.E.S. structure mounts easily with the universal bracket. The use of the bracket also allows for the whole A.P.E.S. system to be removed more easily in case there any modifications are required. Furthermore this frees up the designs for the payload structure as it is fundamentally non-load bearing as the internal launch vehicle structure is taking care of that already.

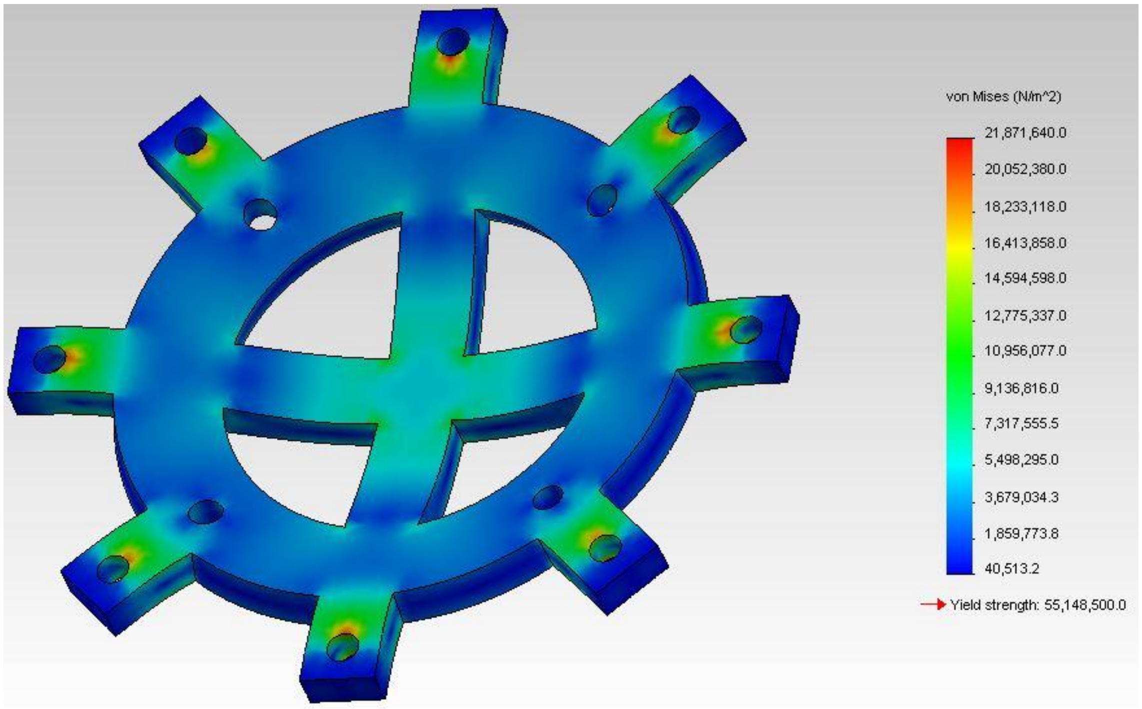


Figure 44: Basic finite-element-analysis of the universal mounting bracket

Finite-element-analysis carried out in the Solidworks Office environment details an axial load of 100 lb_f placed in the center of the mounting bracket. High stress regions appear due to the fallibilities of the Solidworks finite-element-analysis software and the difficulty of specifying distributed reaction loads. The results of the finite-element-analysis appear in Figure 44. While quarter inch (0.25”) aluminum was necessary to provide a factor of safety of 2 in the case of point application of resistive loads, it is more likely that 7/32” or 15/64” thickness of material shall suffice. Further study will be done to specific an exact safety factor and the design may be modified to ensure a minimum safety factor of 2.

The universal mounting bracket will mount into the launch vehicle structural ribs at approved attachment points using number 8 bolts. Initial designs allow for the A.P.E.S. structure to then bolt directly to the bracket also using number 8 bolts. Table 29 provides further characteristics of the universal mounting bracket.

Performance evaluation metrics will be developed further as elements of Flight Systems begin to be produced. However, several basic metrics exist already, namely, the reduction of all motion of the A.P.E.S. plate in a timely manner, i.e. a well-damped impulse response. The flight computer must survive for several hours on the launch pad. All data must be handled and recorded accurately by both the flight and experimental computers.

Table 29: Universal Mounting Bracket Specifications

Universal Mounting Bracket Parameter	*Design Value*
Thickness	0.25 in.
Diameter	3.999 in.
Bolt Hole Diameter	0.164 in.
Rib Mount Bolt Radius from Center	1.809 in.
Number of Bolts to Rib	8 bolts maximum
A.P.E.S. System Mount Bolt Radius from Center	1.282 in.
Avionics System Mount Bolt Radius from Center	1.282 in.
Mounting Bracket Material	6061-Aluminum

8.5. Sensing Capabilities

Flight Avionics Sensors

General Sensing

Sensing data will be provided to the flight computer through ten (10) different sensors chosen to give the most relevant data regarding experimental and launch vehicle performance. The sensing system must account for difficulties arising in communication interfaces, voltage requirements, and material sourcing. Components must survive periods of potentially strong magnetic flux density and sensors placed in launch vehicle modules which undergo separation must resist explosive impulses which may interfere or damage sensing components.

Kinematics and Location

The accelerometer ADXL345 (shown in Figure 45) will provide acceleration data and, combined with the GPS module, provide rotation and position data for the launch vehicle trajectory. Three axis capabilities will implicitly define velocity, position, and rotational motion. The ADXL345 accelerometer can record up to ±16G. The ADXL345 is capable of entering a "standby" mode for periods of inactivity, an advantage for periods of inactivity during setup and preparation to launch.

Figure 45: ADXL345 accelerometer

Magnetic Fields

The chosen magnetometer for detection of potentially harmful fields in the vicinity of the avionics is the HMC1043, and will determine the effectiveness of our shielding to contain the magnetic fields from the APES system. The sensor detects the magnetic field in three dimensions and "static" testing will allow for compensation for the contributions of the Earth's magnetic field. The sensor will be used to determine the flux within the avionics bay of the launch vehicle to help monitor the influence of the magnetic field to our other equipment. The HMC1043, in

, can sense up to ±6 gauss. A combination of distance and mu-metal shielding should diminish the A.P.E.S. fields significantly that such a small range should be appropriate.

Figure 46: HMC1043 Magnetometer

A.P.E.S. System Sensing

The A.P.E.S. computing system will require two types of sensors for feedback and control. Position of the levitating test platform inside of A.P.E.S. will be tracked and displacement data used for derivation of platform kinematics. The magnetic fields generated by the solenoids will also be monitored and compared to models and thresholds developed during ground testing. There are several serious issues to sensing in the A.P.E.S. experiment. First is the possibility of large magnetic flux – potentially as large as several hundred gauss. Strong magnetic flux will induce current in wiring often destroying sensitive digital electronics. High current such as the solenoids power cables may also risk induced current in electronics. To counteract these issues, mu-metal Faraday shielding and distancing from the computational elements will be utilized. However, sensors and detection equipment will be chosen to satisfy the expected parameters of the environment around the A.P.E.S. system.

Table 30: Possible A.P.E.S. distance sensors

Sensor	*Cartesian Coordinate Axes*	*Viewing Angle >45 Degrees*	*Range <5cm*	*Resolution <1mm*	*Delay <20ms*	*Interference*	*Flux Sensitive*	*Reliable under Shock and Vibrations*	*Small Form Factor <15mm*
Ultrasonic Distance	1	No	No	No	No	No	No	No	No
IR Distance	1	No	Yes	Yes	Yes	No	Yes, w/Shielding	Yes	Yes
Laser Distance	2	Yes	Yes	Yes	No	No	Yes, w/Shielding	Yes	No
CMOS Camera	2	Yes	Yes	Yes	Yes	Yes	Yes, w/Shielding	Yes	Yes

A.P.E.S. Distance Sensing

The full three-dimensional design would utilize two to three CMOS cameras. The OVM7690 Camera Cube CMOS camera meets all current design requirements and expected environmental conditions, as outlined in Table 30. The camera sensor is a small form factor (2x2x1mm) color image camera module, as illustrated in Figure 47, with integrated optical glass lens and on-chip image processing. A test pattern is used for initial software pixel-to-distance mapping and calibration for the camera output data and is mounted on the opposite side of the test structure as the camera. The test pattern must be an easily identifiable pattern – this will be made of fiber optic cables mounted on a panel attached to a specific color light emitting diode (LED). A second camera and test pattern are mounted perpendicular to the first, using a second specific color.

Figure 47: OVM7690 Camera Cube

Once the calibration is complete, the cameras output is read at 30-60 frames per second (FPS). The levitating platform is painted another specific color which is not the same as the colors already used for calibration patterns of the two cameras. Several white LEDs are used for flooding light to make the painted platform visible. A simple edge detection algorithm is used to find the displacement of the platform in each sample frame. Using the pixel to distance mapping from the initial calibration, the displacement between samples is calculated which in turn is used to update the Cartesian coordinate for the platform in three dimensions. The use of one camera for sensing on three axes was rejected because the small movements along the forward line of sight (depth perception) would not be interpreted with high enough resolution. Movement along the horizontal and vertical plane will be sufficient, so two axes can be used.

A.P.E.S. Magnetic Field Sensing

While not critical to the flight mission of the A.P.E.S. system, sensing of magnetic fields during ground testing of the A.P.E.S. system will allow for better model generation as well as full confirmation of the theoretical basis of the project. Therefore, the MLX90363 magnetometer has been proposed for use in ground testing applications. The sensor is sensitive up to 0.7-1.0 Tesla, has a sample rate of 1 millisecond, and outputs magnetic field direction as a three coordinate vector. This sensor was chosen for its high magnetic flux sensitivity, decent resolution increments, and three axis direction vector output. The magnetometer controls on-chip digital signal processing.

8.6. "De-Scope" Options

Payload "De-Scope"

The de-scope option for the payload will utilize a single infrared distance detection along a single axis of linear motion, where a sample plate is levitated vertically at constant distance between the sensor and a solenoid during the ascent of the launch vehicle. The objective of the flight experiment would be to then maintain a constant position with a 2% settling time of less than 0.5 seconds for a unit impulse. This option provides an opportunity to develop many of the same control theories without the necessity to grapple complex 3-dimensional magnetic fields.

Flight Computer "De-Scope"

The de-scope option for the flight computer is to use a commercially available Arduino Mega board, rather than fabricate a custom board. This option provides full capability should timelines not permit the completion of design and construction of the custom board.

9. Safety

9.1. General Safety

Ensuring the safety of our members during building, testing and implementation of the payload experiment is an ideal condition. Procedures have been created and implemented in all of our build environments to ensure safety requirements are met and exceeded. A key way the Yellow Jackets ensure team safety is to always work in teams of at least two when using equipment or during construction. This guarantees that should an incident occur with a device the other member could provide immediate assistance or quickly get addition help if required. The Invention Studio where the team does a majority of its work is equipped with safety glasses, fire extinguishers, first aid kits, and expert personnel in the use of each of the machines in the area. All the members of the payload and flight systems teams have been briefed on the proper procedures and proper handling of machines in the labs.

9.2. Payload Hazards

As already mentioned in General Safety, the same methodology to identify and assess risks for vehicle safety will be used to identify hazards for the payload. The entire payload and flight systems teams have been briefed on the possible hazards they may encounter while working with the payload and how to go about avoiding them. Hazards that relate specifically to the payload are listed in Table 31. Payload failure modes are outlined in Table 32.

Table 31: Hazards, Risks, and Mitigation

Hazard	*Risk Assessment*	*Control & Mitigation*
Electrocution	Serious Injury/death	Do not touch wires that are hot and not insulated. Wear rubber gloves when the device is in operation. Handle leads to the power supply with care. Use low voltage settings whenever possible.
Electromagnetic Fields	Interfere with electronic devices inside the body	Ground test equipment, keep people with electronic components in them away from the coil when the electromagnetic coil is in use.

Hazard	*Risk Assessment*	*Control & Mitigation*
Epoxy/glue	Toxic fumes, skin irritation, eye irritation	Work in well ventilated areas to prevent a buildup of fumes. Gloves face masks, and safety glasses will be worn at all times to prevent irritation.
Fire	Burns, serious injury and death	Keep a fire extinguisher in the lab. If an object becomes too hot or starts to burn, cut power and be prepared to use a fire extinguisher.
Soldering Iron	Burns, solder splashing into eyes	Wear safety glasses to prevent damage to eyes. Do not handle the soldering lead directly only touch handle. Do not directly hold an object being soldered.
Drills	Serious injury, cuts, punctures, and scrapes	Only operate tools under supervision of team mates. Only use tools in the appropriate manner. Wear safety glasses to prevent debris from entering the eyes
Dremel	Serious injury, cuts, and scrapes	Only operate tools under supervision of team mates. Only use tools in the appropriate manner. Wear safety glasses to prevent debris from entering the eyes
Hand Saws	Cuts, serious injury	Only use saws under supervision of team mates. Only use tools in the appropriate manner. Wear safety glasses to prevent debris from entering the eyes. Do not cut in the direction of yourself or others.
Exacto Knives	Cuts, serious injury, death	Only use knives under supervision of team mates. Only use tools in the appropriate manner. Do not cut in the direction of yourself or others.
Hammers	Bruises, broken bones, and serious injury	Be careful to avoid hitting your hand while using a hammer.
Power Supply	Electrocution, serious injury and death	Only operate power supply under supervision of team mates. Turn of power supply when interacting with circuitry.

Hazard	*Risk Assessment*	*Control & Mitigation*
Batteries Explode	Eye irritation, skin irritation, burns	Wear safety glasses and gloves. Make sure there are no shorts in the circuit. If a battery gets too hot stop using it an remove any connections to it.
Improper Dress during construction	Serious injury, broken bones	Wear closed toe shoes, clothing that is not baggy, and keep long hair tied back.
Exposed construction metal	Punctures, scrapes, cuts, or serious injury	Put all tools band materials away after use.
Neodymium Magnets	Pinching, bruising, and snapping through fingers.	Do not allow magnets to fly together from a distance, do not play with powerful magnets, keep free magnets away from powered solenoids.

Table 32: A.P.E.S. payload failure modes

Potential Failure	*Effects of Failure*	*Failure Prevention*
No power	Experiment cannot be performed	Check batteries, connections, and switches
Data doesn't record	No experimental data	Ensure power is connected to the payload computer and that all connections are firmly secured
Magnetic field interferes with flight computer	No experimental data	Shield the flight computer from any EMF interference
Accelerometers	Record erroneous acceleration values	Calibrate and test accelerometers
Solenoids	Experiment cannot be performed, wires melt	Check connections, ensure over heating will not occur during testing
Too much current goes into the solenoids	The wires in the solenoids get very hot	Make sure current is only pulsed into the solenoids

Potential Failure	*Effects of Failure*	*Failure Prevention*
Improper dress during construction	Maiming, cuts, scrapes, serious injury.	Do not wear open toed shoes in the build lab. Keep long hair tied back. Do not wear baggy clothing.
Avionics	Chips or boards are manufactured incorrectly causing equipment failures and misfires	Test avionics operations, and perform a flight test.

9.3. Vehicle Safety

To assist in the elimination of risks to all members and bystanders involved the launch vehicle risks must be identified to a reasonable degree. Relevant risks will be identified through the use of a four step method and tabulated afterwards. To mitigate potential failures of the launch vehicle potential failure modes will be developed as well as ways to prevent them from taking place. The specific hazards will also be classified according to how likely it is to occur under normal operating procedures.

Risks continue to be identified for the launch vehicle and payload by exploiting a four-step risk management process. This process helps by pinpointing risks that could cause damage or harm to the environment or people. The steps are listed in Table 33.

Table 33: Risk Identification and Mitigation Steps

Step Name	*Step Definition*
1. Hazard Identification	The first step is to correctly identify potential hazards that could cause serious injury or death. Hazard identification will be achieved through team safety sessions and brainstorming.
2. Risk and Hazard Assessment	Every hazard will undergo extensive analysis to determine how serious the issue is and the best way to approach the issue.
3. Risk Control and Elimination	After the hazards are identified and assessed a method is produced to avoid the issue.
4. Reviewing Assessments	As new information becomes available the assessments will be reviewed and revised as necessary.

The steps outlined above are being used to develop a set of standard operating procedures for launch vehicle construction, payload construction, ground testing, and on all launch day safety checklists. Materials Safety Data Sheets of all materials used in construction are listed in Appendix 5.

Failure modes for the launch vehicle were developed to better ensure success of the entire project. Possible modes, resultant problem, and mitigation procedures are given for each failure mode. These modes will continue to evolve and expand in scope as the project progresses. The mitigation methods will be continuously incorporated into preflight checklists. The mitigation items detailed therein will be incorporated into the preflight checklist. Launch vehicle failure modes and mitigation are listed in Table 34.

Table 34: Launch vehicle failure modes and mitigation

Potential Failure	*Effects of Failure*	*Failure Prevention*
Fins	Launch vehicle flight path becomes unstable	Test fin failure modes at connection to launch vehicle to ensure sufficient strength
Structural ribs buckle on take off	Launch failure, launch vehicle destroyed, possible injury from shrapnel	Wear eye wear protection, test the internal structure to ensure a factor of safety against buckling
Thrust retention plate	Motor casing falls out	Test reliability of thrust retention plate
Skin zippering	Internal components are exposed to flowing air currents, launch vehicle becomes unstable	Test skin adhesion reliability
Launch buttons	Launch vehicle becomes fixed to launch rail, or buttons shear off	Ensure buttons slide easily in launch rail, ensure rail is of the proper size
Drogue separation	Main shoot takes full brunt of launch vehicle inertia, launch vehicle becomes ballistic	Do a ground test of drogue separation as well as a flight test

Potential Failure	*Effects of Failure*	*Failure Prevention*
Main shoot	Launch vehicle becomes ballistic, severe injury, irrecoverable launch vehicle	Do a ground test of main shoot deployment, as well as a flight test.
Land directly on fins	Fins break, and launch vehicle cannot be flow twice without fixing	Test fin failure modes at connection to launch vehicle to ensure sufficient strength
Ignition failure	Launch vehicle does not launch	Follow proper procedure when setting up launch vehicle ignition system
Motor failure	Motor explodes	Install motors properly according to NAR standards

10. Budget

Our team is in contact with many Georgia Tech faculty members, many of whom are our professors, for their expertise as well as any resources they can spare. To gain additional funds needed to build the rocket and the scientific experiment along, as well as to pay for travel expenses, we plan to solicit help from local companies. For companies that donate money to our Georgia Tech USLI team, they will be acknowledged in the team reports. For those that donate large sums of money will have their logo placed on the rocket. For the rocket test launches, the team plans to work with SoAR to coordinate launches and minimize costs

As shown in Table 35, the total budget for the 2011-2012 Mile High Yellow Jackets is $5,500. Of that amount, $1,000 dollars from the Georgia Tech is specifically allocated for rocket motors. Additionally, Figure 48 illustrates the percentage breakdown of the budget while Table 36 lists the actual money allotted to each subsystem.

Table 35. Sponsors of the Mile High Yellow Jackets.

Organization	*Amt.*
GA Space Grant Consortium	$3,500
GA Tech AE Department	$1,000
GA Tech SGA	$1,000
Total:	$5,500

Table 36. Subsystem budget breakdown

Subsystem	*Amt.*
Launch Vehicle & Motors	$2,750
Flight Systems	$1,750
Operations	$1,000
Total:	$5,500

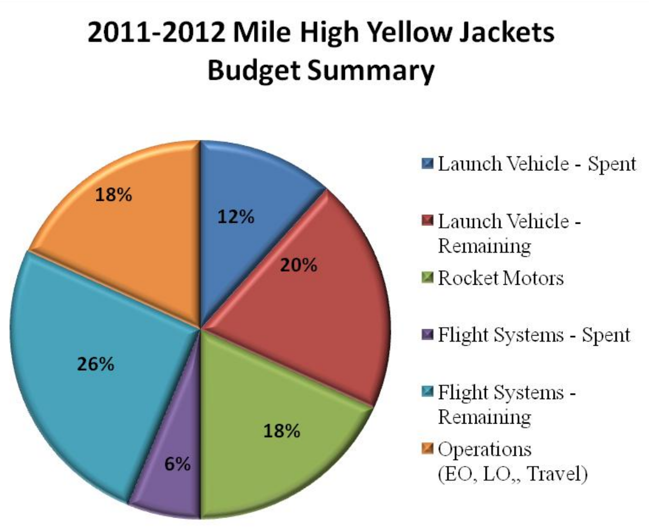


Figure 48. Breakdown of the 2011-2012 Mile High Yellow Jackets Budget.

11.Project Scheduling

The Mile High Yellow Jacket's project is driven by the design milestone's set forth by the USLI Program Office. These milestones – and their dates – are listed in Table 37. It is important to note that due to the complexities of both the Mile high Yellow Jackets' rocket and payload designs, the Gantt chart will contain only high-level activities. In order to visualize the major tasks/steps in our design, the Team will utilize a PERT Chart/Network Diagram. This will allow for the identification of the critical path(s) that will ensure a successful launch.

Table 37. Design milestones set by the USLI Program Office.

Milestone	*Date*
Proposal	26 SEP
Team Selection	17 OCT
Web Presence Established	4 NOV
PDR Documentation	28 NOV
PDR Telecon	5-14 DEC
CDR Documentation	23 JAN
CDR Telecon	1-10 FEB
FRR Documention	26 MAR
FRR Telecon	2-11 APR
Competition	18-21 APR
PLAR Documentation	7 MAY

12.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 will have an outreach request form on their webpage for Educators to request presentations or hands-on activities for their classroom.

Young Astronauts Program

The Mile High Yellow Jackets are planning to work in conjunction with the Georgia Tech Space Systems Design Lab (SSDL) to put on the Young Astronauts program at Madras Middle School in Newnan, Ga. The intent of this program is to expose Middle School Students to various topics in the Aerospace and STEM fields. This will be accomplished by meeting twice a month and discussing a topic followed by a related hands-on project that actively engages both Students and Educators.

FIRST Lego League

FIRST Lego League is an engineering competition designed for middle school children in which they build and compete with an autonomous MINDSTORMS robot. Every year there is a new competition centered on a theme exploring a real-world problem. The Mile High Yellow Jackets plan to have a booth at the Georgia State FIRST Lego League Tournament and illustrate how the skills and ideas utilized in the competition translate to real world applications, like a launch vehicle with autonomous capabilities. In addition we plan to help judge the tournament.

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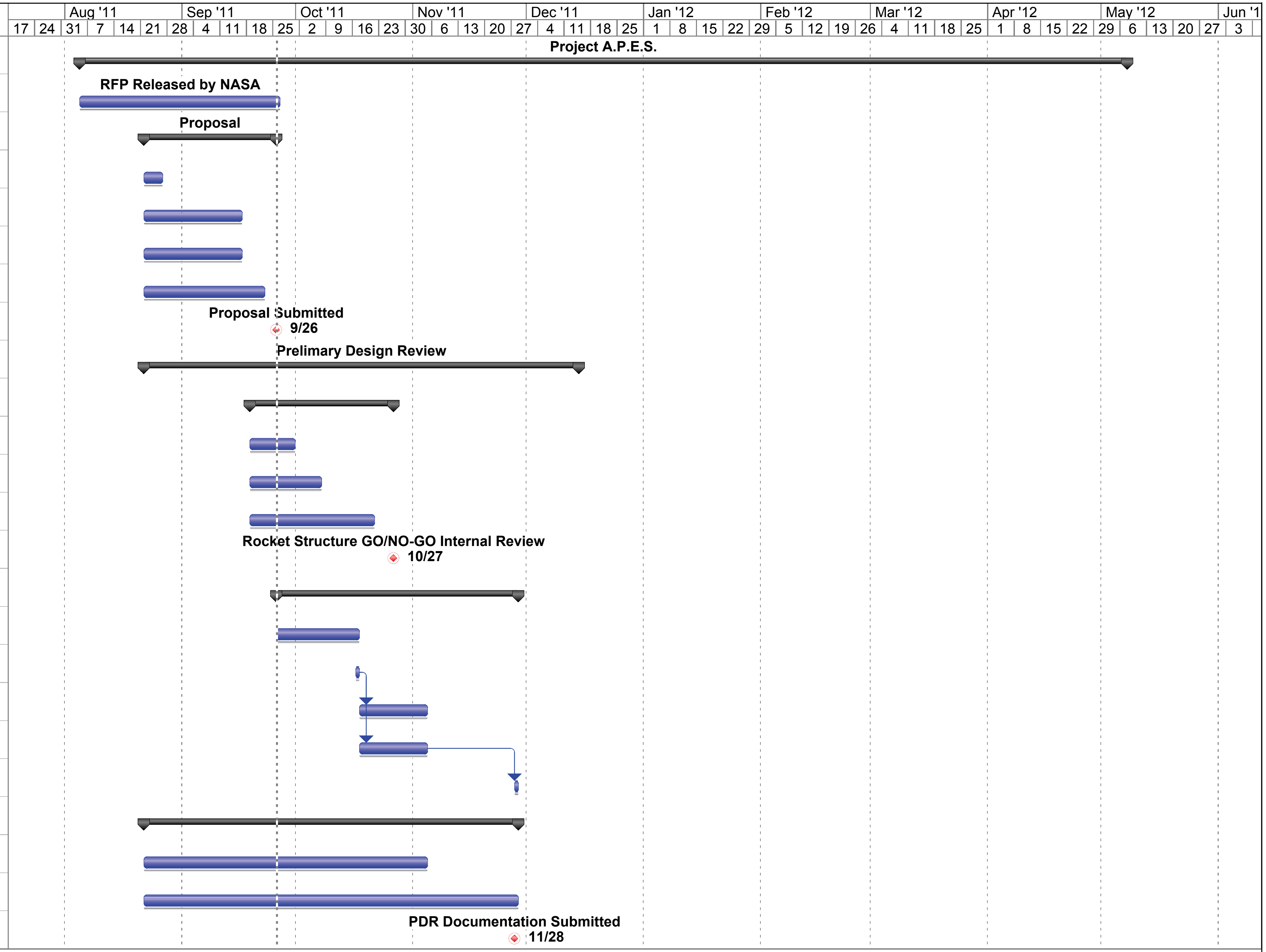
Appendix 1: Project A.P.E.S. Schedule

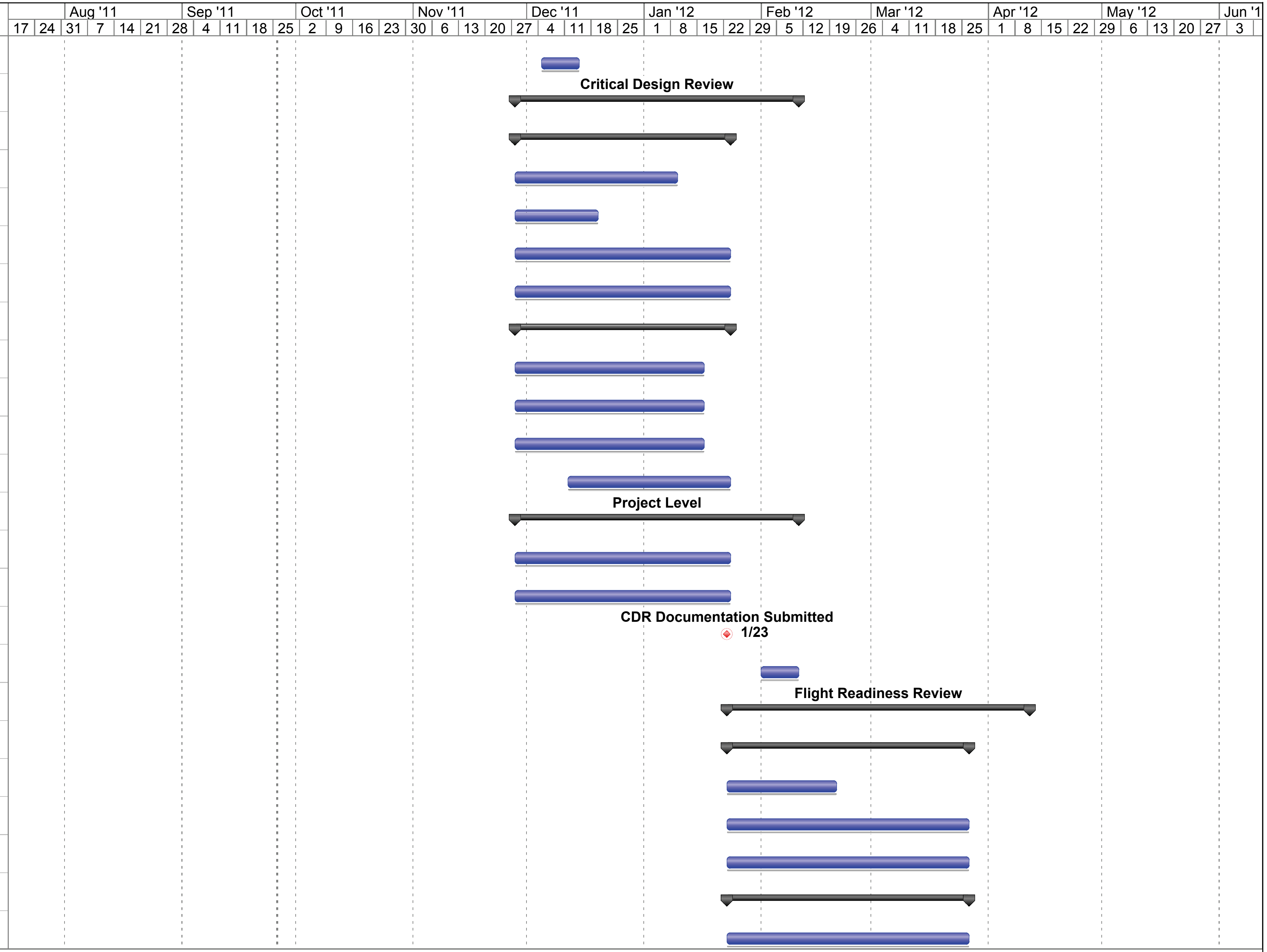
ID	Task Name
1	**Project A.P.E.S.**
2	RFP Released by NASA
3	**Proposal**
4	Team Formation
5	Initial Rocket Design
6	Flight Experiment Definition
7	Internal Proposal Review
8	Proposal Submitted
9	**Prelimary Design Review**
10	**Rocket**
11	Structure Test Rig Design and Fabrication
12	Rocket Stucture Design and Simulations
13	Rocket Structure Component Testing
14	Rocket Structure GO/NO-GO Internal Review
15	**Flight Systems**
16	Component Downselection
17	Scientifc Theory Refinement
18	Experiment Modeling and Preliminary Design
19	Control System Preliminary Design
20	Preliminary Ground Testing
21	**Project Level**
22	Establish Web Presence
23	Fundrasing / Sponsorhip
24	PDR Documentation Submitted



Project: 2011-2012 USLI Gnatt Chart
Date: Mon 9/26/11

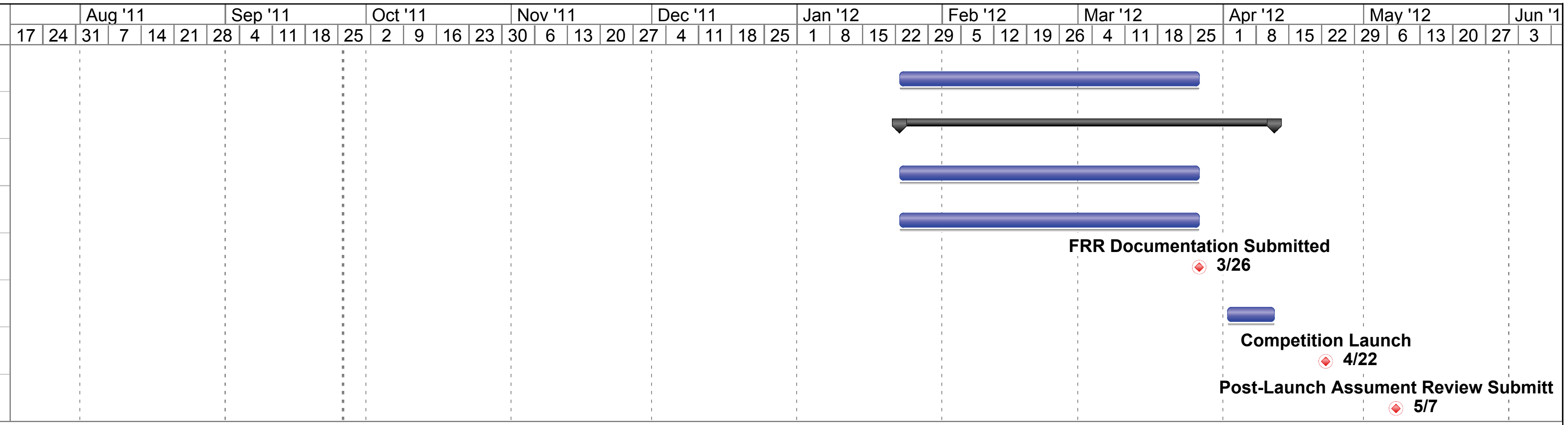
Task		Progress		Summary		External Tasks		Deadline	
Split		Milestone		Project Summary		External Milestone			

ID	Task Name
25	PDR Telecon
26	**Critical Design Review**
27	**Rocket**
28	Full-Scale Structure Build
29	Recovery System Ground Test
30	Competition Rocket Build
31	Initital Test Flight
32	**Flight Systems**
33	Flight Systems Integration
34	Control System Detailed Design
35	Detailed Experiment Modeling
36	Experiment Refinement
37	**Project Level**
38	Website Updates
39	Outreach Events
40	CDR Documentation Submitted
41	CDR Telecon
42	**Flight Readiness Review**
43	**Rocket**
44	Final Test Preparation
45	Final Test Flight
46	Competition Launch Preparation
47	**Flight Systems**
48	Experiment Refinement



Project: 2011-2012 USLI Gnatt Chart Date: Mon 9/26/11	Task	Progress	Summary	External Tasks	Deadline
	Split	Milestone	Project Summary	External Milestone	

ID	Task Name
49	Control System Refinement
50	**Project Level**
51	Website Updates
52	Outreach Events
53	FRR Documentation Submitted
54	FRR Telecon
55	Competition Launch
56	Post-Launch Assument Review Submitted



Project: 2011-2012 USLI Gnatt Chart
Date: Mon 9/26/11

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

Appendix 2: Launch Checklist

1. Prepare payload bay
    a. Ensure batteries and switches are wired to the altimeters correctly
    b. Ensure batteries, power supply, switch, data recorder and pressure sensors are wired correctly
    c. Install fresh batteries into battery holders and secure with tape
    d. Insert altimeter and payload into the payload bay
    e. Connect appropriate wires
    f. Verify payload powers on correctly and is working properly. If it is not, check all wires and connections
    g. Turn off payload power
    h. Arm altimeters with output shorted to verify jumper settings. This is to check battery voltage and continuity
    i. Disarm altimeter, un-short outputs
    j. Close altimeter bay
2. Assemble charges
    a. Test e-match resistance and make sure it is within spec
    b. Remove protective cover from e-match
    c. Measure amount of black powder determined in testing
    d. Put e-match on tape with sticky side up
    e. Pour black powder over e-match
    f. Seal tape
    g. Retest e-match
3. Ensure altimeter is disarmed
4. Connect charges to altimeter bay
5. Turn on altimeter and verify continuity
6. Disarm altimeter
7. Connect drogue shock cord to booster section and altimeter bay
8. Fold excess shock cord so it does not tangle
9. Add cellulose wadding to ensure only the Kevlar shock chord is exposed to ejection charge
10. Insert altimeter bay into drogue section and secure with shear pins
11. Pack main chute
12. Attach main shock cord to payload bay
13. Fold excess shock cord so it does not tangle
14. Add wadding under main chute and shock cord ensuring that only the Kevlar part of the shock cord will be exposed to the ejection charge
15. Attach altimeter bay to the main section with nylon rivets
16. Connect shock cord to nose cone, install nose cone and secure with shear pins

17. Assemble motor
    a. Follow manufacturer's instructions
    b. Do not get grease on propellant or delay
18. Do not install igniter until at pad
19. Install motor in launch vehicle
20. Secure positive motor retention
21. Inspect launch vehicle. Check CG to make sure it is in safe range; add nose weight if necessary
22. Arm altimeter and ensure both charges read continuity
23. Disarm altimeter
24. Bring launch vehicle to the range safety officer (RSO) table for inspection
25. Bring launch vehicle to pad, install on pad, verify that it can move freely (use a standoff if necessary)
26. Install igniter in launch vehicle
27. Touch igniter clips together to make sure they will not fire igniter when connected
28. Make sure clips are not shorted to each other or blast deflector
29. Arm altimeters via switches and wait for continuity check for both
30. Turn on payload via a switch and start stopwatches
31. Return to front line
32. Launch. Stop the stopwatches and record time from arming payload and launch
33. Watch flight so launch vehicle does not get lost
34. Recover launch vehicle
35. Disarm altimeter(s) if there are unfired charges
36. Disassemble launch vehicle, clean motor case, other parts, inspect for damage
37. Record altimeter data
38. Download payload data

Appendix 3: Ground Test Plan

Ground Test Plan

Goals

The A.P.E.S. ground test data will provide the basis for empirical modeling of the force interactions for various configurations of the experiment at various voltages. All actions will be incremented to allow for a detailed model for extrapolation and interpolation of the data for future flight control systems. Goals are detailed in Table 38: Ground Test goals.

Table 38: Ground Test goals

Ground Test Goal	*Ground Test Goal Definition*
1	Calibrate Sensing Data
2	Map Magnetic Fields
3	Detect force equilibrium
4	Develop model for control of voltage

Test Sequence 1 – Calibration

The static field of a solenoid in the ground test platform configuration to be tested will be mapped at RMS voltage increments of 0.25 V from 0.25 V to 6 V. For each RMS Voltage, no fewer than nine (9) points of data shall be produced with Hall-effect sensors, measuring 3D field vectors on at least three (3) sets of axes.

The IR distance sensor will be calibrated. Materials of varying IR reflectivity will be used and the results will be compared to provide a recommendation for the marking of the test article.

The Camera Cube will be calibrated with visual targets.

Test Sequence 2 – 1-Dimensional testing

Equilibrium testing with no internal magnetism. A single vertically-oriented solenoid will be utilized to lift the test article – covered in IR reflective material – to equilibrium points within a cylinder, from 1 cm to 7 cm in steps of 1 cm. Hall-effect sensors will be used to map fields at each equilibrium point identically to the static field mapping. The IR sensor will detect distance from below the cylinder. The IR sensor will be lowered to the minimum read distance using MakerBeam. The minimum read distance shall be confirmed by data sheets and calibration.

Test Sequence 3

Equilibrium de-scope testing with internal magnetism. One (1) neodymium magnet shall be placed in the center of the test article and covered with IR reflective material. A single vertically-oriented solenoid will be utilized to lift the test article to equilibrium points within a cylinder, from 1 cm to 7 cm in steps of 1 cm. Hall-effect sensors will be used to map fields at each equilibrium point identically to the static field mapping. The test setup should allow for both pulling of the test article as well as pushing of the test article.

Test Sequence 4

Similar testing will be completed using a horizontal sheet with the sample placed on top. Solenoids will be used to pull and hold the sample in the middle of the platform at equilibrium. These tests will be completed with the permanent magnet sample. The Camera Cube will allow for object detection. Fields will be mapped at equilibrium.

Test Sequence 5

A permanently magnetic test article will be levitated from rest in 3-dimensions to equilibrium at central points in the test stand. Incrementing of the equilibrium point will allow for greater control of the test article. Object detection will be accomplished with the Camera Cube. Fields will be mapped at equilibrium.

Test Sequence 6

The flight model will be tested and disturbances will be introduced.

Appendix 4: Derivation of Force Equations for a Ferrite Platform

Derivation of Force Equation for Ferrite Platform

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

1.1.3. $$\mathbf{F}(\mathbf{r},\mathbf{m}_s,\mathbf{m}) = \frac{3\mu}{4\pi r^4}[(\mathbf{m}_s\cdot\hat{\mathbf{r}})\mathbf{m} + (\mathbf{m}\cdot\hat{\mathbf{r}})\widehat{\mathbf{m}}_s + (\mathbf{m}_s\cdot\mathbf{m})\hat{\mathbf{r}} - 5(\mathbf{m}_s\cdot\hat{\mathbf{r}})(\mathbf{m}\cdot\hat{\mathbf{r}})\hat{\mathbf{r}}] \quad (14)$$

where $\mathbf{r}$ is the vector from $\mathbf{m}_s$ to $\mathbf{m}$, and $\hat{\mathbf{r}}$ is again the unit vector in the direction of $\mathbf{r}$.

At any location inside the platform, the microscopic magnetic dipole moment is $\mathbf{m} = \mathbf{M}\,dV$. Therefore, the total force on the platform is given by the following equation.

1.1.4.

1.1.5. $$\mathbf{F}(\mathbf{r},\mathbf{m}_s) = \iiint \frac{3\mu}{4\pi r^4}[(\mathbf{m}_s\cdot\hat{\mathbf{r}})\mathbf{M} + (\mathbf{M}\cdot\hat{\mathbf{r}})\widehat{\mathbf{m}}_s + (\mathbf{m}_s\cdot\mathbf{M})\hat{\mathbf{r}} - 5(\mathbf{m}_s\cdot\hat{\mathbf{r}})(\mathbf{M}\cdot\hat{\mathbf{r}})\hat{\mathbf{r}}]\,dV \quad (15)$$

As it is assumed that the ferrite has constant susceptibility,

1.1.6.

1.1.7. $$\mathbf{M} = \chi_m\mathbf{H} = \frac{\chi_m}{4\pi r^3}(3(\mathbf{m}_s\cdot\hat{\mathbf{r}})\hat{\mathbf{r}} - \mathbf{m}_s) \quad (16)$$

where the field is generated by a solenoid of $\mathbf{m}_s = NI\boldsymbol{S}$. Substituting this equation in for $\mathbf{M}$ in Equation (2), it can be found that

1.1.9. $$\mathbf{F}(\mathbf{r},\mathbf{m}_s) = \iiint \frac{3\mu}{4\pi r^4}\frac{\chi_m}{4\pi r^3}\Big[(\mathbf{m}_s\cdot\hat{\mathbf{r}})(3(\mathbf{m}_s\cdot\hat{\mathbf{r}})\hat{\mathbf{r}} - \mathbf{m}_s) + \big((3(\mathbf{m}_s\cdot\hat{\mathbf{r}})\hat{\mathbf{r}} - \mathbf{m}_s)\cdot\hat{\mathbf{r}}\big)\widehat{\mathbf{m}}_s + \big(\mathbf{m}_s\cdot(3(\mathbf{m}_s\cdot\hat{\mathbf{r}})\hat{\mathbf{r}} - \mathbf{m}_s)\big)\hat{\mathbf{r}} - 5(\mathbf{m}_s\cdot\hat{\mathbf{r}})\big((3(\mathbf{m}_s\cdot\hat{\mathbf{r}})\hat{\mathbf{r}} - \mathbf{m}_s)\cdot\hat{\mathbf{r}}\big)\hat{\mathbf{r}}\Big]\,dV \quad (17)$$

1.1.11. $$\mathbf{F}(\mathbf{r},\mathbf{m}_s) = \iiint \frac{3\mu}{4\pi r^4}\frac{\chi_m}{4\pi r^3}\Big[(3(\mathbf{m}_s\cdot\hat{\mathbf{r}})^2\hat{\mathbf{r}} - (\mathbf{m}_s\cdot\hat{\mathbf{r}})\mathbf{m}_s) + (3(\mathbf{m}_s\cdot\hat{\mathbf{r}})\widehat{\mathbf{m}}_s - (\mathbf{m}_s\cdot\hat{\mathbf{r}})\widehat{\mathbf{m}}_s) + (3(\mathbf{m}_s\cdot\hat{\mathbf{r}})^2 - (\mathbf{m}_s\cdot\mathbf{m}_s)\hat{\mathbf{r}}) - 5(\mathbf{m}_s\cdot\hat{\mathbf{r}})\big(3(\mathbf{m}_s\cdot\hat{\mathbf{r}}) - (\mathbf{m}_s\cdot\hat{\mathbf{r}})\big)\hat{\mathbf{r}}\Big]\,dV \quad (18)$$

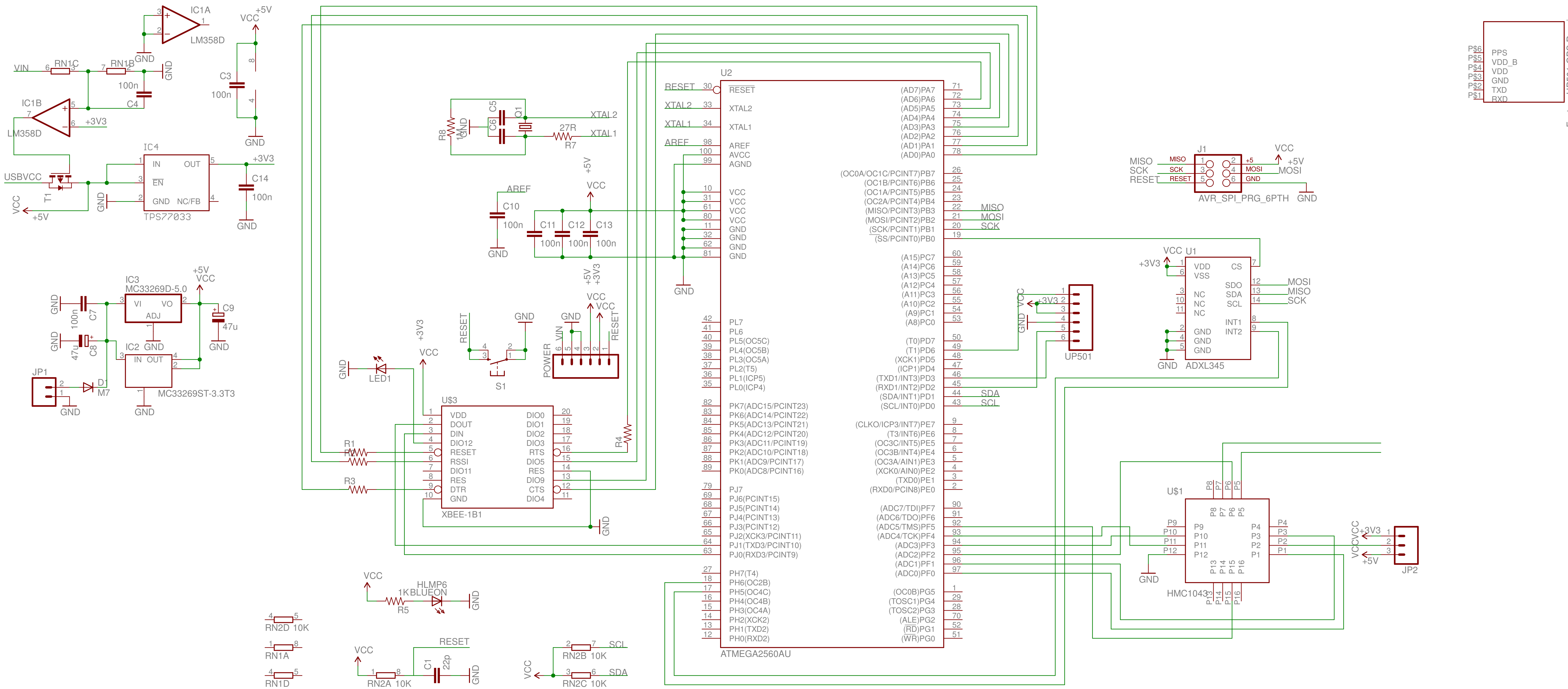
1.1.13. $$\mathbf{F}(\mathbf{r},\mathbf{m}_s) = \iiint \frac{3\mu}{4\pi r^4}\frac{\chi_m}{4\pi r^3}[(3(\mathbf{m}_s\cdot\hat{\mathbf{r}})^2\hat{\mathbf{r}} - (\mathbf{m}_s\cdot\hat{\mathbf{r}})\mathbf{m}_s) + (2(\mathbf{m}_s\cdot\hat{\mathbf{r}})\widehat{\mathbf{m}}_s) + (3(\mathbf{m}_s\cdot\hat{\mathbf{r}})^2\hat{\mathbf{r}} - (\mathbf{m}_s\cdot\mathbf{m}_s)\hat{\mathbf{r}}) - 10(\mathbf{m}_s\cdot\hat{\mathbf{r}})^2\hat{\mathbf{r}}]\,dV \quad (19)$$

And therefore,

1.1.14 1.1.15. $$\mathbf{F}(\mathbf{r}, \mathbf{m}_s) = \iiint \frac{3\mu\chi_m}{16\pi^2 r^7}\left[(\mathbf{m}_s \cdot \hat{\mathbf{r}})\mathbf{m}_s - (\mathbf{m}_s \cdot \mathbf{m}_s)\hat{\mathbf{r}} - 4(\mathbf{m}_s \cdot \hat{\mathbf{r}})^2\hat{\mathbf{r}}\right] dV \quad (20)$$

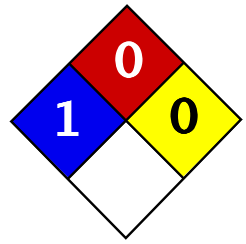
which was the result that was to be derived.

Appendix 5: Flight Computer Schematic



IC1A
LM358D
IC1B
LM358D
VIN
RN1C
RN1B
100n
C4
+3V3
GND
+5V
VCC
C3
100n
USBVCC
T1
IC4
IN
OUT
EN
GND
NC/FB
TPS77033
+3V3
C14
100n
IC3
MC33269D-5.0
VI
VO
ADJ
C7
100n
C8
47u
C9
47u
IC2
IN
OUT
MC33269ST-3.3T3
JP1
D1
M7
U2
RESET
XTAL2
XTAL1
AREF
AVCC
AGND
VCC
(AD7)PA7
(AD6)PA6
(AD5)PA5
(AD4)PA4
(AD3)PA3
(AD2)PA2
(AD1)PA1
(AD0)PA0
(OC0A/OC1C/PCINT7)PB7
(OC1B/PCINT6)PB6
(OC1A/PCINT5)PB5
(OC2A/PCINT4)PB4
(MISO/PCINT3)PB3
(MOSI/PCINT2)PB2
(SCK/PCINT1)PB1
(SS/PCINT0)PB0
(A15)PC7
(A14)PC6
(A13)PC5
(A12)PC4
(A11)PC3
(A10)PC2
(A9)PC1
(A8)PC0
(T0)PD7
(T1)PD6
(XCK1)PD5
(ICP1)PD4
(TXD1/INT3)PD3
(RXD1/INT2)PD2
(SDA/INT1)PD1
(SCL/INT0)PD0
(CLKO/ICP3/INT7)PE7
(T3/INT6)PE6
(OC3C/INT5)PE5
(OC3B/INT4)PE4
(OC3A/AIN1)PE3
(XCK0/AIN0)PE2
(TXD0)PE1
(RXD0/PCIN8)PE0
(ADC7/TDI)PF7
(ADC6/TDO)PF6
(ADC5/TMS)PF5
(ADC4/TCK)PF4
(ADC3)PF3
(ADC2)PF2
(ADC1)PF1
(ADC0)PF0
(OC0B)PG5
(TOSC1)PG4
(TOSC2)PG3
(ALE)PG2
(RD)PG1
(WR)PG0
PL7
PL6
PL5(OC5C)
PL4(OC5B)
PL3(OC5A)
PL2(T5)
PL1(ICP5)
PL0(ICP4)
PK7(ADC15/PCINT23)
PK6(ADC14/PCINT22)
PK5(ADC13/PCINT21)
PK4(ADC12/PCINT20)
PK3(ADC11/PCINT19)
PK2(ADC10/PCINT18)
PK1(ADC9/PCINT17)
PK0(ADC8/PCINT16)
PJ7
PJ6(PCINT15)
PJ5(PCINT14)
PJ4(PCINT13)
PJ3(PCINT12)
PJ2(XCK3/PCINT11)
PJ1(TXD3/PCINT10)
PJ0(RXD3/PCINT9)
PH7(T4)
PH6(OC2B)
PH5(OC4C)
PH4(OC4B)
PH3(OC4A)
PH2(XCK2)
PH1(TXD2)
PH0(RXD2)
ATMEGA2560AU
MISO
MOSI
SCK
SDA
SCL
C5
C6
Q1
R8
1M
27R
R7
C10
C11
C12
C13
100n
POWER
S1
LED1
U$3
VDD
DOUT
DIN
DIO12
RESET
RSSI
DIO11
RES
DTR
GND
DIO0
DIO1
DIO2
DIO3
RTS
DIO5
RES
DIO9
CTS
DIO4
XBEE-1B1
R1
R2
R3
R4
Fastrax UP501 GPS Receiver
PPS
VDD_B
VDD
GND
TXD
RXD
J1
AVR_SPI_PRG_6PTH
U1
CS
VSS
SDO
SDA
SCL
NC
INT1
INT2
ADXL345
UP501
U$1
HMC1043
JP2
HLMP6
1K
BLUEON
R5
RN2D 10K
RN1A
RN1D
RN2A 10K
C1
22p
RN2B 10K
RN2C 10K

Appendix 6: Material Safety Data Sheets (MSDS)



Health	1
Fire	0
Reactivity	0
Personal Protection	E

Material Safety Data Sheet
Ferrosoferric Oxide, Black Powder MSDS

Section 1: Chemical Product and Company Identification

Product Name: Ferrosoferric Oxide, Black Powder

Catalog Codes: SLF1477

CAS#: 1317-61-9

RTECS: Not available.

TSCA: TSCA 8(b) inventory: Ferrosoferric Oxide, Black Powder

CI#: Not available.

Synonym: Iron Oxide

Chemical Name: Ferrosoferric Oxide, Black Powder

Chemical Formula: Fe3-O4

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Ferrosoferric Oxide, Black Powder	1317-61-9	100

Toxicological Data on Ingredients: Ferrosoferric Oxide, Black Powder: ORAL (LD50): Acute: 5000 mg/kg [Rat].

Section 3: Hazards Identification

Potential Acute Health Effects: Slightly hazardous in case of skin contact (irritant), of eye contact (irritant), . Non-irritant for lungs.

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Classified None. by NTP, None. by OSHA, None. by NIOSH.
MUTAGENIC EFFECTS: Not available.
TERATOGENIC EFFECTS: Not available.
DEVELOPMENTAL TOXICITY: Not available.
The substance is toxic to lungs, upper respiratory tract.
Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures

Eye Contact: No known effect on eye contact, rinse with water for a few minutes.

Skin Contact:
After contact with skin, wash immediately with plenty of water. Gently and thoroughly wash the contaminated skin with running water and non-abrasive soap. Be particularly careful to clean folds, crevices, creases and groin. Cover the irritated skin with an emollient. If irritation persists, seek medical attention.

Serious Skin Contact: Not available.

Inhalation: Allow the victim to rest in a well ventilated area. Seek immediate medical attention.

Serious Inhalation: Not available.

Ingestion:
Do not induce vomiting. Loosen tight clothing such as a collar, tie, belt or waistband. If the victim is not breathing, perform mouth-to-mouth resuscitation. Seek immediate medical attention.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Non-flammable.

Auto-Ignition Temperature: Not applicable.

Flash Points: Not applicable.

Flammable Limits: Not applicable.

Products of Combustion: Not available.

Fire Hazards in Presence of Various Substances: Not applicable.

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available.
Risks of explosion of the product in presence of static discharge: Not available.

Fire Fighting Media and Instructions: Not applicable.

Special Remarks on Fire Hazards: Material is not combustible. Use extinguishing media suitable for other combustible material in the area

Special Remarks on Explosion Hazards: Not available.

Section 6: Accidental Release Measures

Small Spill:
Use appropriate tools to put the spilled solid in a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and dispose of according to local and regional authority requirements.

Large Spill:
Use a shovel to put the material into a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and allow to evacuate through the sanitary system.

Section 7: Handling and Storage

Precautions:

Do not ingest. Do not breathe dust. If ingested, seek medical advice immediately and show the container or the label.

Storage:
No specific storage is required. Use shelves or cabinets sturdy enough to bear the weight of the chemicals. Be sure that it is not necessary to strain to reach materials, and that shelves are not overloaded.

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Use process enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below recommended exposure limits. If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

Personal Protection: Safety glasses. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Dust respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits: Not available.

Section 9: Physical and Chemical Properties

Physical state and appearance: Solid. (Solid powder.)

Odor: Odorless.

Taste: Not available.

Molecular Weight: Not available.

Color: Black

pH (1% soln/water): Not available.

Boiling Point: 1000°C (1832°F)

Melting Point: Not available.

Critical Temperature: Not available.

Specific Gravity: 4.6 (Water = 1)

Vapor Pressure: Not applicable.

Vapor Density: Not available.

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: Not available.

Solubility: Not available.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Not available.

Incompatibility with various substances: Not available.

Corrosivity: Not available.

Special Remarks on Reactivity: Not available.

Special Remarks on Corrosivity: Not available.

Polymerization: No.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Dermal contact. Eye contact. Inhalation.

Toxicity to Animals: Acute oral toxicity (LD50): 5000 mg/kg [Rat].

Chronic Effects on Humans:
CARCINOGENIC EFFECTS: Classified None. by NTP, None. by OSHA, None. by NIOSH.
The substance is toxic to lungs, upper respiratory tract.

Other Toxic Effects on Humans:
Slightly hazardous in case of skin contact (irritant), .
Non-irritant for lungs.

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans: Not available.

Special Remarks on other Toxic Effects on Humans: Not available.

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The product itself and its products of degradation are not toxic.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:

Section 14: Transport Information

DOT Classification: Not a DOT controlled material (United States).

Identification: Not applicable.

Special Provisions for Transport: Not applicable.

Section 15: Other Regulatory Information

Federal and State Regulations:
California prop. 65: This product contains the following ingredients for which the State of California has found to cause cancer, birth defects or other reproductive harm, which would require a warning under the statute: Ferrosoferric Oxide, Black Powder
Massachusetts RTK: Ferrosoferric Oxide, Black Powder
New Jersey: Ferrosoferric Oxide, Black Powder
TSCA 8(b) inventory: Ferrosoferric Oxide, Black Powder

Other Regulations:
OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200).
EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada): CLASS D-2B: Material causing other toxic effects (TOXIC).

DSCL (EEC):
This product is not classified according to the EU regulations.

HMIS (U.S.A.):

Health Hazard: 1

Fire Hazard: 0

Reactivity: 0

Personal Protection: E

National Fire Protection Association (U.S.A.):

Health: 1

Flammability: 0

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves.
Lab coat.
Dust respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate.
Safety glasses.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

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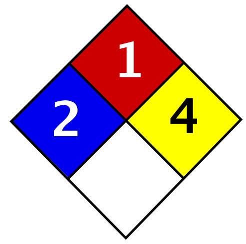
Last Updated: 11/06/2008 12:00 PM



Health	2
Fire	1
Reactivity	4
Personal Protection	E

Material Safety Data Sheet
Ammonium perchlorate MSDS

Section 1: Chemical Product and Company Identification

Product Name: Ammonium perchlorate

Catalog Codes: SLA2725

CAS#: 7790-98-9

RTECS: SC7520000

TSCA: TSCA 8(b) inventory: Ammonium perchlorate

CI#: Not available.

Synonym:

Chemical Formula: NH4ClO4

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Ammonium perchlorate	7790-98-9	100

Toxicological Data on Ingredients: Ammonium perchlorate LD50: Not available. LC50: Not available.

Section 3: Hazards Identification

Potential Acute Health Effects:
Hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation. Prolonged exposure may result in skin burns and ulcerations. Over-exposure by inhalation may cause respiratory irritation.

Potential Chronic Health Effects:
Hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation.
CARCINOGENIC EFFECTS: Not available.
MUTAGENIC EFFECTS: Not available.
TERATOGENIC EFFECTS: Not available.
DEVELOPMENTAL TOXICITY: Not available.
The substance is toxic to blood, kidneys.
Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures

Eye Contact:
Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Cold water may be used. Get medical attention.

Skin Contact:
In case of contact, immediately flush skin with plenty of water. Cover the irritated skin with an emollient. Remove contaminated clothing and shoes. Cold water may be used.Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek medical attention.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.

Serious Inhalation:
Evacuate the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or waistband. If breathing is difficult, administer oxygen. If the victim is not breathing, perform mouth-to-mouth resuscitation. Seek medical attention.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. If large quantities of this material are swallowed, call a physician immediately. Loosen tight clothing such as a collar, tie, belt or waistband.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: May be combustible at high temperature.

Auto-Ignition Temperature: Not available.

Flash Points: Not available.

Flammable Limits: Not available.

Products of Combustion: Not available.

Fire Hazards in Presence of Various Substances: Flammable in presence of shocks, of heat, of reducing materials, of combustible materials, of organic materials.

Explosion Hazards in Presence of Various Substances:
Extremely explosive in presence of open flames and sparks, of shocks, of heat, of reducing materials, of organic materials.
Slightly explosive in presence of acids.

Fire Fighting Media and Instructions:
Oxidizing material.
Do not use water jet. Use flooding quantities of water. Avoid contact with organic materials.

Special Remarks on Fire Hazards: Not available.

Special Remarks on Explosion Hazards: Not available.

Section 6: Accidental Release Measures

Small Spill: Use appropriate tools to put the spilled solid in a convenient waste disposal container.

Large Spill:
Oxidizing material.
Stop leak if without risk. Avoid contact with a combustible material (wood, paper, oil, clothing...). Keep substance damp using water spray. Do not touch spilled material. Prevent entry into sewers, basements or confined areas; dike if needed. Eliminate all ignition sources. Call for assistance on disposal.

Section 7: Handling and Storage

Precautions:
Keep away from heat. Keep away from sources of ignition. Keep away from combustible material.. Empty containers pose a fire risk, evaporate the residue under a fume hood. Ground all equipment containing material. Do not breathe dust. Take precautionary measures against electrostatic discharges. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment. If you feel unwell, seek medical attention and show the label when possible. Avoid contact with skin and eyes. Keep away from incompatibles such as reducing agents, combustible materials, organic materials, acids.

Storage:
Keep container tightly closed. Keep container in a cool, well-ventilated area. Separate from acids, alkalies, reducing agents and combustibles. See NFPA 43A, Code for the Storage of Liquid and Solid Oxidizers.

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Use process enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below recommended exposure limits. If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

Personal Protection:
Splash goggles. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Dust respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits: Not available.

Section 9: Physical and Chemical Properties

Physical state and appearance: Solid. (Crystals solid.)

Odor: Not available.

Taste: Not available.

Molecular Weight: 117.49 g/mole

Color: Colorless.

pH (1% soln/water): Not available.

Boiling Point: Not available.

Melting Point: Decomposes.

Critical Temperature: Not available.

Specific Gravity: 1.95 (Water = 1)

Vapor Pressure: Not applicable.

Vapor Density: Not available.

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water, methanol, acetone.

Solubility:
Soluble in cold water, methanol.
Partially soluble in acetone.
Insoluble in diethyl ether.

Section 10: Stability and Reactivity Data

Stability: Unstable.

Instability Temperature: Not available.

Conditions of Instability: No additional remark.

Incompatibility with various substances:
Extremely reactive or incompatible with reducing agents, combustible materials, organic materials.
Reactive with acids.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity: Not available.

Special Remarks on Corrosivity: Not available.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Eye contact. Inhalation. Ingestion.

Toxicity to Animals:
LD50: Not available.
LC50: Not available.

Chronic Effects on Humans: Causes damage to the following organs: blood, kidneys.

Other Toxic Effects on Humans: Hazardous in case of skin contact (irritant), of ingestion, of inhalation.

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans: Not available.

Special Remarks on other Toxic Effects on Humans: Not available.

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation: Possibly hazardous short/long term degradation products are to be expected.

Toxicity of the Products of Biodegradation: The products of degradation are more toxic.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:

Section 14: Transport Information

DOT Classification: CLASS 5.1: Oxidizing material.

Identification: : Ammonium Perchlorate UNNA: UN1442 PG: II

Special Provisions for Transport: Not available.

Section 15: Other Regulatory Information

Federal and State Regulations:
Pennsylvania RTK: Ammonium perchlorate
Massachusetts RTK: Ammonium perchlorate
TSCA 8(b) inventory: Ammonium perchlorate

Other Regulations: OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200).

Other Classifications:

WHMIS (Canada): CLASS C: Oxidizing material.

DSCL (EEC):
R8- Contact with combustible material
may cause fire.
R36/38- Irritating to eyes and skin.

HMIS (U.S.A.):

Health Hazard: 2

Fire Hazard: 1

Reactivity: 4

Personal Protection: E

National Fire Protection Association (U.S.A.):

Health: 2

Flammability: 1

Reactivity: 4

Specific hazard:

Protective Equipment:
Gloves.
Lab coat.
Dust respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate.
Splash goggles.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

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Last Updated: 11/06/2008 12:00 PM

MATERIAL SAFETY DATA SHEET

Prepared to U.S. OSHA, CMA, ANSI and Canadian WHMIS Standards .This Material Safety Data Sheet is offered pursuant to OSHA's Hazard Communication Standard (29 CFR 1910.1200). Other government regulations must be reviewed for applicability to these products.

WARNING: PRODUCT COMPONENTS PRESENT HEALTH AND SAFETY HAZARDS. READ AND UNDERSTAND THIS MATERIAL SAFETY DATA SHEET (M.S.DS.). ALSO, FOLLOW YOUR EMPLOYER'S SAFETY PRACTICES. This product may contain Chromium and/or Nickel which are listed by OSHA, NTP, or IARC as being a carcinogen or potential carcinogen. Use of this product may expose you or others to fumes and gases at levels exceeding those established by the American Conference of Governmental Industrial Hygienists (ACGIH) or the Occupational Safety and Health Administration (OSHA) The information contained herein relates only to the specific product. If the product is combined with other materials, all component properties must be considered. **BE SURE TO CONSULT THE LATEST VERSION OF THE MSDS. MATERIAL SAFETY DATA SHEETS ARE AVAILABLE FROM HARRIS PRODUCTS GROUP** salesinfo@jwharris.com 513-754-2000

www.harrisproductsgroup.com

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PART I *What is the material and what do I need to know in an emergency?*

1. PRODUCT IDENTIFICATION

TRADE NAME (AS LABELED): **LEAD SOLDER**
CHEMICAL NAME/CLASS: Metal Alloy
SYNONYMS: Not Applicable
PRODUCT USE: Soldering
DOCUMENT NUMBER: 0126
SUPPLIER/MANUFACTURER'S NAME: **HARRIS PRODUCTS GROUP**
ADDRESS: 4501 Quality Place, Mason, Ohio 45040
EMERGENCY PHONE: CHEMTREC: 1-800-424-9300
BUSINESS PHONE: 513-754-2000 **FAX** 513-754-8778
DATE OF PREPARATION: July 12, 2007 **REVIEWED** October 22, 2004

2. COMPOSITION and INFORMATION ON INGREDIENTS

NOMINAL COMPOSITION WEIGHT % Wire							
TRADE NAME	**30/70**	**40/60**	**50/50**	**60/40**	**63/37**	**70/30**	**90/10**
Tin (Sn)	30%	40%	50%	60%	63%	70%	90%
Lead (Pb)	70%	60%	50%	40%	37%	30%	10%

NOMINAL COMPOSITION WEIGHT % Flux Core				
TRADE NAME	**Activated Rosin CAS # 8050-09-7**	**Ammonium Chloride CAS #**	**Zinc Chloride CAS # 7646-85-7**	**Water CAS #**
ACID CORE		< 20%	< 70%	Balance
ROSIN CORE	100%			

2. COMPOSITION and INFORMATION ON INGREDIENTS (Continued)

CHEMICAL NAME	CAS #	% w/w	EXPOSURE LIMITS IN AIR					
			ACGIH-TLV		OSHA-PEL		NIOSH	OTHER
			TWA mg/m^3	STEL mg/m^3	TWA mg/m^3	STEL mg/m^3	IDLH mg/m^3	mg/m^3
Activated Rosin Exposure limits are for Rosin Core Solder Decomposition Products, as resin-acids-colophony	8050-09-7	See Table Previous Page	Sensitizer; reduce exposure to as low as possible	NE	NE	NE	NE	DFG MAK: TWA = Danger of sensitization of the skin.
Ammonium Chloride Exposure limits are for Ammonium Chloride, fume	12125-02-9	See Table Previous Page	10	20	10 (Vacated 1989 PEL)	20 (Vacated 1989 PEL)	NE	NIOSH REL: TWA = 10 STEL = 20
Lead Exposure limits are for Lead, elemental & inorganic compounds, as Pb	7439-92-1	See Table Previous Page	0.05 , A4 (Not Classifiable as a Human Carcinogen)	NE	0.05 (see 29 CFR 1910.1025)	NE	100	NIOSH RELs: TWA = < 0.1 (blood Pb < 0.060 mg/100 g whole blood) DFG MAKs: TWA = 0.1 (Inhalable Fraction) PEAK = 10•MAK 30 min., average value DFG MAK Pregnancy Risk Classification: B Carcinogen: EPA-B2, IARC-2B, TLV-A3
Tin Exposure limits are for Tin, Metal	7440-31-5	See Table Previous Page	2	NE	2	NE	100	NE
Zinc Chloride Exposure limits are for Zinc Chloride, fume	7646-85-7	See Table Previous Page	1	2	1	2 (Vacated 1989 PEL)	50	NIOSH RELs: TWA = 1 STEL = 2 Carcinogen: EPA-D

NE = Not Established. See Section 16 for Definitions of Terms Used.

NOTE (1): The ACGIH has an established exposure limit for Welding Fumes, Not Otherwise Classified. The Threshold Limit Value is 5 mg/m^3. NIOSH classifies welding fumes as carcinogens. Single values shown are maximum, unless otherwise noted.

NOTE (2): ALL WHMIS required information is included in appropriate sections based on the ANSI Z400.1-1998 format. These products have been classified in accordance with the hazard criteria of the CPR and the MSDS contains all the information required by the CPR.

3. HAZARD IDENTIFICATION

EMERGENCY OVERVIEW: These products consist of odorless, lead/tin alloy wires, which have a metallic luster and may have a flux core. There are no immediate health hazards associated with these products, as wires. When heated during soldering operations, these products may generate irritating and toxic fumes of lead oxide, tin oxides, hydrogen chloride, zinc oxides, and ammonium compounds. There is a danger of cumulative effects if fumes or dusts from these products are inhaled or ingested. Contact with the rosin core of these wires can result in allergic reaction and sensitization to the skin in susceptible persons. These products are not reactive. If involved in a fire, these products may generate irritating fumes and a variety of metal oxides, as described above. Finely divided dusts of these products may result in explosive air/dust mixtures. Emergency responders must wear personal protective equipment suitable for the situation to which they are responding.

SYMPTOMS OF OVER-EXPOSURE BY ROUTE OF EXPOSURE: During soldering operations, the most significant route of over-exposure is via inhalation of fumes.

INHALATION: Inhalation of large amounts of particulates generated by these products during soldering operations may be physically irritating and cause deposits of dust in nasal passages. Due to the presence of lead, inhalation of fumes or dusts from these products can result in lead poisoning. Symptoms of poisoning include headache, fatigue, nausea, metallic taste in the mouth, abdominal cramps, joint pain, metallic taste in the mouth, vomiting, constipation, bloody diarrhea, and harmful effects on the central nervous system. Exposure to lead can cause significant cumulative toxic effects, effects on the reproductive system and may cause cancer. See information under “Other Health Effects” for additional information. When heated to decomposition, the rosin core of some of these products can include toxic compounds, including formaldehyde, acetaldehyde, or malonaldehyde. Inhalation of these fumes can result in irritation to the respiratory system.

3. HAZARD IDENTIFICATION (Continued)

FOR WIRES

HAZARDOUS MATERIAL IDENTIFICATION SYSTEM

HEALTH	(BLUE)	0
FLAMMABILITY	(RED)	0
REACTIVITY	(YELLOW)	0
PROTECTIVE EQUIPMENT		X

EYES	RESPIRATORY	HANDS	BODY
	See Section 8		See Section 8

For routine industrial applications for the rods

See Section 16 for Definition of Ratings

FOR FUMES OR DUSTS

HAZARDOUS MATERIAL IDENTIFICATION SYSTEM

HEALTH	(BLUE)	3
FLAMMABILITY	(RED)	0
REACTIVITY	(YELLOW)	0
PROTECTIVE EQUIPMENT		X

EYES	RESPIRATORY	HANDS	BODY
	See Section 8		See Section 8

For routine industrial applications for the rods

See Section 16 for Definition of Ratings

INHALATION (continued): Exposure to dust or fumes of the Tin components is known to cause a benign pneumoconiosis (stannosis). This form of pneumoconiosis produces distinctive progressive x-ray changes of the lung as long as exposure persists, but there is no distinctive fibrosis, no evidence of disability, and no special complicating factors. In addition, inhalation of large amounts of dusts or fumes of these products, can cause metal fume fever. Symptoms of metal fume fever include flu-like symptoms, metallic taste, fever, sweating, chills, cough, weakness, chest pain, muscle pain, cardiac abnormalities, and increased white blood cell count. Damage to lungs can occur. Symptoms of metal fume fever can be delayed 24-48 hours. Refer to Section 10 (Stability and Reactivity) for information on the specific composition of soldering fumes and gases. There is some evidence that inhalation of fumes from the Ammonium Chloride component of these products may cause respiratory sensitization in susceptible individuals. Symptoms may include difficulty breathing, persistent coughing and wheezing.

CONTACT WITH SKIN or EYES: Contact of the wire form of these products with the skin is not anticipated to be irritating. Contact with the wire form of these products can be physically damaging to the eye. Fumes generated during soldering operations can be irritating to the skin and eyes. Symptoms of skin over-exposure may include irritation and redness; prolonged or repeated skin over-exposures may lead to dermatitis. Contact with the rosin core can result in allergic reaction and skin sensitization in susceptible individuals. Symptoms could include dermatitis, itching and persistent rash. Contact with the molten core or wire will burn contaminated skin or eyes.

SKIN ABSORPTION: Skin absorption is not known to be a significant route of over-exposure for any component of these products.

INGESTION: Ingestion is not anticipated to be a route of occupational exposure for these products; however, if proper hygiene (e.g. washing of hands) is not followed during handling and use of these products, ingestion of lead from contamination of the hands can occur, resulting is Lead poisoning.

INJECTION: Though not a likely route of occupational exposure for these products, injection (via punctures or lacerations in the skin) may cause local reddening, tissue swelling, and discomfort.

OTHER HEALTH EFFECTS: Due to the presence of Lead in these products, exposure to dusts or fumes may result in significant adverse acute and chronic health effects, as follows. Long-term, low-level lead exposure has resulted in harm to the central nervous system and brain function. Symptoms of chronic, low to moderate levels include forgetfulness, irritability, tiredness, headache, fatigue, impotence, decreased libido, dizziness, altered mood states and depression.

(continued on following page)

OTHER HEALTH EFFECTS (continued): Symptoms of chronic exposure to moderate to high lead levels include disturbances in hand to eye coordination, reaction times, visual motor performance, mental performance, gradual decrease in visual acuity with slow recovery or possible blindness, changes in hearing ability, and in worse cases, encephalopathy (a progressive degeneration of the brain and its functions). Early symptoms of encephalopathy include dullness, irritability, poor attention span, muscular tremor, headache, and loss of memory and hallucinations. Severe, chronic exposure to Lead at high concentration can result in symptoms on the central nervous system, including delirium, lack of coordination, convulsions, paralysis, coma and death.

Exposure to Lead can also result in significant adverse results on the peripheral nervous system, including harm to nerves in hands, legs and feet. These effects can be reversible if exposure is short term (5 months or less) and treatment is received; if not, these effects can become permanent. A syndrome known as "Lead Palsy" can occur, with symptoms such as weakness of legs or arms, weakness and paralysis of the wrist, fingers and ankles. At lower exposure levels decreased hand dexterity has been reported. At higher exposure levels an ability to hold the foot or hand in extended position can occur.

Exposure to Lead can also cause adverse effects on the gastrointestinal system, including loss of appetite, inflammation of the stomach walls (gastritis), colic, severe abdominal pain, cramps, nausea, vomiting, constipation, anorexia, weight loss and decreased urination. In severe cases of Lead poisoning, a deposit of Lead occurs in the gums near the base of the teeth, resulting in a visible blue-gray line. Reversible kidney injury has been observed in some cases of workers exposed to Lead at chronic, low to moderate levels. Death due to kidney failure has occurred to workers chronically exposed to Lead at moderate levels.

Exposure to Lead can cause harmful effects to certain types of blood cells, including reduced hemoglobin production and reduced life-span and function of red blood cells. This harm can cause anemia in workers exposed to moderate levels. Low, moderate and high level exposure to Lead may increase blood pressure, especially in men. Some studies have indicated that moderate exposure to Lead can result in electrocardiographic abnormalities. There is some evidence that low-level exposure to Lead can cause harmful effects on the thyroid and immune systems, including possible susceptibility to colds and flu infections.

Exposure to Lead, especially at high levels, has resulted in significant adverse effects in the reproductive systems of both men and women. Refer to Section 11 (Toxicological Information, Reproductive Toxicity Information) for additional information.

HEALTH EFFECTS OR RISKS FROM EXPOSURE: An Explanation in Lay Terms. Symptoms associated with over-exposure to these products and the fumes generated during soldering operations are as follows:

ACUTE: Inhalation of large amounts of particulates generated by these products during metal processing operations may be physically irritating and cause deposits of dust in nasal passages. Inhalation of dusts and fumes of these products can cause metal fume fever or irritation of the respiratory system. Contact with the molten material will burn contaminated skin or eyes. Significant adverse effects on the blood, kidneys, gastrointestinal system, central and peripheral nervous systems.

CHRONIC: Chronic skin over-exposure to the fumes of these products during soldering operations may produce dermatitis (red, inflamed skin). Repeated or prolonged over-exposures, via inhalation, to the dusts generated by these products may cause pulmonary fibrosis (scarring of lung tissue). Chronic inhalation of fumes or dusts of the components of these products, can result in severe, adverse effects on the blood and heart, kidneys, thyroid and immune systems, and central and periphery nervous system, due to the presence of Lead. Contact with the rosin core of some of these products can cause an allergic skin reaction and sensitization in susceptible individuals. Due to the presence of the Ammonium Chloride compound in the flux core of some of these products, inhalation of fumes from soldering may cause allergic respiratory reaction and respiratory sensitization in susceptible individuals. Due to the Lead component in these products, contact may result in significant adverse effects on the reproductive system. See Section 11 (Toxicological Information) for additional information.

TARGET ORGANS: For fumes: ACUTE: Skin, eyes, respiratory system, blood system, central nervous system, peripheral nervous system, gastrointestinal system. CHRONIC: Skin, central nervous system, kidneys, heart, blood, central nervous system, thyroid, immune system, reproductive system.

PART II *What should I do if a hazardous situation occurs?*

4. FIRST-AID MEASURES

Victims of chemical exposure must be taken for medical attention. Rescuers should be taken for medical attention, if necessary. Take a copy of label and MSDS to health professional with victim.

SKIN EXPOSURE: If fumes generated by soldering operations involving these products contaminate the skin, begin decontamination with running water. If molten material contaminates the skin, immediately begin decontamination with cold, running water. <u>Minimum</u> flushing is for 15 minutes. Victim must seek medical attention if any adverse reaction occurs.

4. FIRST-AID MEASURES (Continued)

EYE EXPOSURE: If fumes generated by soldering operations involving these products enter the eyes, open victim's eyes while under gently running water. Use sufficient force to open eyelids. Have victim "roll" eyes. <u>Minimum</u> flushing is for 15 minutes. Victim must seek immediate medical attention.

INHALATION: If fumes generated by soldering operations involving these products are inhaled, remove victim to fresh air. If necessary, use artificial respiration to support vital functions.

INGESTION: If swallowed call physician immediately! Do not induce vomiting unless directed by medical personnel. Rinse mouth with water if person is conscious. Never give fluids or induce vomiting if person is unconscious, having convulsions, or not breathing.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: Skin, respiratory, blood, central nervous system and peripheral system, and kidney disorders, may be aggravated by prolonged over-exposures to the dusts or fumes generated by these products.

RECOMMENDATIONS TO PHYSICIANS: Basic Treatment: Establish a patent airway. Suction if necessary. Watch for signs of respiratory insufficiency and assist ventilations if necessary. Administer oxygen by non-rebreather mask at 10 to 15 L/minutes. Monitor for shock and treat if necessary. Anticipate seizures and treat if necessary. For eye contamination, flush eyes immediately with water. Irrigate each eye continuously with normal saline during transport. Do not use emetics. For ingestion, rinse mouth and administer 5 mL/kg up to 200 mL of water for dilution if the patient can swallow, has a strong gag reflex, and does not drool. Administer activated charcoal.

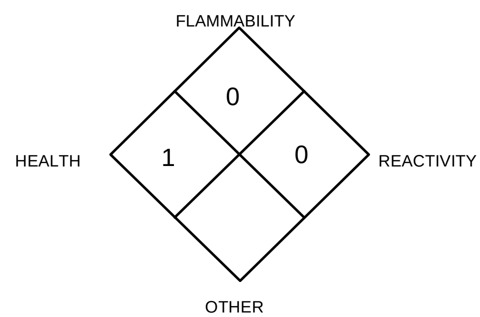
Advanced Treatment: Consider orotracheal or nasotracheal intubation for airway control in the patient who is unconscious. Use hyperventilation to help control increased intracranial pressure. Start an IV with lactated Ringer's to support vital signs. For hypotension with signs of hypovolemia, administer fluid cautiously. Watch for signs of fluid overload. Treat seizures with diazepam (Valium). Use proparacaine hydrochloride to assist eye irrigation. The treatment of lead poisoning is based on the prompt termination of exposure and on the use of chelating agents. The first requirement is categorical. The second is determined by the severity of poisoning; at present, the greatest issue is whether a symptomatic patients should be treated or not. The most commonly used therapeutic chelating agents are CaEDTA, BAL, and D-penicillamine can be given. DMSA should also be considered.

5. FIRE-FIGHTING MEASURES

FLASH POINT: Not flammable.

AUTOIGNITION TEMPERATURE: Not applicable for products. Dust clouds of Lead, a possible main component of these products, have a minimum ignition temperature range of 270-790°C (518-1454°F).

NFPA RATING



<u>See Section 16 for Definition of Ratings</u>

FLAMMABLE LIMITS (in air by volume, %):

<u>Lower (LEL)</u>: Not applicable.
<u>Upper (UEL)</u>: Not applicable.

FIRE EXTINGUISHING MATERIALS: These products are not flammable; use fire-extinguishing agents appropriate for surrounding materials.

<u>Water Spray</u>: YES	<u>Carbon Dioxide</u>: YES
<u>Halon</u>: YES	<u>Foam</u>: YES
<u>Dry Chemical</u>: YES	<u>Other</u>: Any "ABC" Class

UNUSUAL FIRE AND EXPLOSION HAZARDS When involved in a fire, these products may decompose and produce lead oxide, tin oxides, hydrogen chloride, zinc oxides, and ammonium compounds. The hot material can present a significant thermal hazard to firefighters.

<u>Explosion Sensitivity to Mechanical Impact</u>: Not sensitive.

<u>Explosion Sensitivity to Static Discharge</u>: Although these products are not sensitive to static discharge, dusts of these products can form explosive air/dust mixtures and can be ignited by static discharge.

SPECIAL FIRE-FIGHTING PROCEDURES: Lead and its decomposition products are hazardous to health. Fire-fighters should not enter an area in which a fire involves these products without wearing specialized protective equipment suitable for potential Lead exposure. Normal fire-fighter bunker gear is not adequate to protect against exposure to Lead and its decomposition products. A full-body, encapsulating chemical resistant suit with positive-pressure Self-Contained Breathing Apparatus may be necessary.

6. ACCIDENTAL RELEASE MEASURES

SPILL AND LEAK RESPONSE: Not applicable.

7. HANDLING and STORAGE

WORK PRACTICES AND HYGIENE PRACTICES: As with all chemicals, avoid getting these products ON YOU or IN YOU. Wash thoroughly after handling these products. Do not eat or drink while handling these products. Use ventilation and other engineering controls to minimize potential exposure to these products. If dusts or fumes of these products are present, use of a suitable NIOSH approved respirator must commence immediately to protect against possible Lead poisoning. Unprotected workers must avoid all contact with these products.

STORAGE AND HANDLING PRACTICES: All employees who handle these products should be trained to handle it safely, following the requirements of the OSHA Lead Standard (29 CFR 1910.1025). Use in clearly posted areas(s) indicating Lead hazard. Access doors must remain closed while these products are being used or stored. When handling Lead powder on a large scale, closed-handling systems for processes should be used. If this is not possible, use in the smallest possible amounts in appropriate labeled, containment devices (e.g. fume hood). Containment devices should be made of smooth, unbreakable compatible material. Maintain containment devices at appropriate air-flow and negative pressure. Check regularly. Use in a well-ventilated location. Avoid the generation of dusts and prevent the release of fumes to the workplace. Avoid breathing fumes of these products generated during soldering operations. Open containers on a stable surface. Cover surfaces in which these products are being used with compatible, chemical resistant and/or disposable material for easier containment and clean-up. Good housekeeping is very important. Keep work areas clean. Packages of these products must be properly labeled. When these products are used during soldering operations, follow the requirements of the Federal Occupational Safety and Health Welding and Cutting Standard (29 CFR 1910 Subpart Q) and the safety standards of the American National Standards Institute for welding and cutting (ANSI Z49.1). Store packages in a cool, dry location. Store away from incompatible materials (see Section 10, Stability and Reactivity).

PROTECTIVE PRACTICES DURING MAINTENANCE OF CONTAMINATED EQUIPMENT: Not applicable.

8. EXPOSURE CONTROLS - PERSONAL PROTECTION

VENTILATION AND ENGINEERING CONTROLS: As per the OSHA Lead Standard, 29 CFR 1910.1025, the employer shall assure that no employee is exposed to Lead at concentrations greater than 50 μg/cubic meter averaged over an 8-hour period. If an employee is exposed to Lead for more than 8 hours in any work day, the permissible exposure limit, as a TWA for that day, shall be reduced according to the following formula: Maximum permissible limit (in μg/cubic meter) = 400 divided by the number of hours worked in the day. Use with adequate ventilation to ensure exposure levels are maintained below these limits and the limits for Lead and other components of these products provided in Section 2 (Composition and Information on Ingredients). Prudent practice is to ensure eyewash/safety shower stations are available near areas where these products are used.

RESPIRATORY PROTECTION: Maintain airborne contaminant concentrations below guidelines listed in Section 2 (Composition and Information on Ingredients). If respiratory protection is needed (i.e. a Weld Fume Respirator, or Air-Line Respirator for welding in confined spaces), U.S. Federal OSHA Standard (29 CFR 1910.134), applicable U.S. State regulations, or the Canadian CSA Standard Z94.4-93 and applicable standards of Canadian Provinces. Respiratory Protection is recommended to be worn during welding operations. Oxygen levels below 19.5% are considered IDLH by OSHA. In such atmospheres, use of a full-facepiece pressure/demand SCBA or a full facepiece, supplied air respirator with auxiliary self-contained air supply is required under OSHA's Respiratory Protection Standard (1910.134-1998). The following are NIOSH recommendations for respirator selection for Ammonium Chloride, Lead, Welding fumes, Rosin Core, Pyrolysis Products, Tin and Zinc Chloride, and are provided for additional information:

LEAD

CONCENTRATION	**RESPIRATORY PROTECTION**
Up to 0.5 mg/m^3:	Any Air-Purifying Respirator with a high-efficiency particulate filter, or any Supplied-Air Respirator (SAR).
Up to 1.25 mg/m^3:	Any SAR operated in a continuous-flow mode, or any powered, air-purifying respirator with a high-efficiency particulate filter.
Up to 2.5 mg/m^3:	Any Air-Purifying, Full-Facepiece Respirator with a high-efficiency particulate filter, or any SAR that has a tight-fitting facepiece and is operated in a continuous-flow mode, or any powered, air-purifying respirator with a tight-fitting facepiece and a high-efficiency particulate filter, or any Self-Contained Breathing Apparatus (SCBA) with a full facepiece, or any SAR with a full facepiece.
Up to 50 mg/m^3:	Any SAR operated in a pressure-demand or other positive-pressure mode.
Up to 100 mg/m^3:	Any SAR that has a full facepiece and is operated in a pressure-demand or other positive-pressure mode.

(continued on following page)

RESPIRATORY PROTECTION (continued): NIOSH recommendations for respiratory protection, continued.

LEAD CONCENTRATION **RESPIRATORY PROTECTION (continued):**

Emergency or Planned Entry into Unknown Concentrations or IDLH Conditions: Any SCBA that has a full facepiece and is operated in a pressure-demand or other positive-pressure mode, or any SAR that has a full facepiece and is operated in a pressure-demand or other positive-pressure mode in combination with an auxiliary SCBA operated in pressure-demand or other positive-pressure mode.

Escape: Any Air-Purifying, Full-Facepiece Respirator with a high-efficiency particulate filter, or any appropriate escape-type, SCBA.

ROSIN FLUX PYROLYSIS PRODUCTS

CONCENTRATION **RESPIRATORY PROTECTION**

At Concentrations above the NIOSH REL, or where there is no REL, at any Detectable Concentration: Any Self-Contained Breathing Apparatus (SCBA) that has a full facepiece and is operated in a pressure-demand or other positive-pressure mode, or any Supplied-Air Respirator (SAR) that has a full facepiece and is operated in a pressure-demand or other positive-pressure mode in combination with an auxiliary SCBA operated in pressure-demand or other positive-pressure mode.

Escape: Any Air-Purifying, Full-Facepiece Respirator (gas mask) with a chin-style, front- or back-mounted organic vapor canister having a high-efficiency particulate filter, or any appropriate escape-type, SCBA.

TIN CONCENTRATION **RESPIRATORY PROTECTION**

Up to 10 mg/m^3: Any dust and mist respirator.

Up to 20 mg/m^3: Any dust and mist respirator except single-use and quarter-mask respirators, IF NOT present as a fume, or any Supplied-air Respirator (SAR).

Up to mg/m^3: Any SAR operated in a continuous-flow mode, or any Powered, Air-Purifying Respirator with a dust and mist filter, IF NOT present as a fume.

Up to 100 mg/m^3: Any Air-Purifying, Full-Facepiece Respirator with a high-efficiency particulate filter, or any Self-Contained Breathing Apparatus (SCBA) with a full facepiece, or any SAR with a full facepiece.

Emergency or Planned Entry into Unknown Concentrations or IDLH Conditions: Any SCBA that has a full facepiece and is operated in a pressure-demand or other positive-pressure mode, or any SAR that has a full facepiece and is operated in a pressure-demand or other positive-pressure mode in combination with an auxiliary SCBA operated in pressure-demand or other positive-pressure mode.

Escape: Any Air-Purifying, Full-Facepiece Respirator with a high-efficiency particulate filter, or any appropriate escape-type, SCBA

WELDING FUMES

CONCENTRATION **RESPIRATORY EQUIPMENT FOR WELDING FUMES**

At Concentrations above the NIOSH REL, or where there is no REL, at any Detectable Concentration: Any self-contained breathing apparatus that has a full facepiece and is operated in a pressure-demand or other positive-pressure mode; or any supplied-air respirator that has a full facepiece and is operated in a pressure-demand or other positive-pressure mode in combination with an auxiliary self-contained breathing apparatus operated in pressure-demand or other positive-pressure mode.

Escape: Any air-purifying, full-facepiece respirator (gas mask) with a chin-style, front- or back-mounted organic vapor canister having a high-efficiency particulate filter; or any appropriate escape-type, self-contained breathing apparatus

NOTE: IDLH Concentration: Potential NIOSH carcinogen. [Not determined yet].

ZINC CHLORIDE

CONCENTRATION **RESPIRATORY PROTECTION**

Up to 10 mg/m^3: Any dust, mist, and fume respirator, or any Supplied-Air Respirator (SAR).

Up to 25 mg/m^3: Any SAR operated in a continuous-flow mode, or any Powered, Air-Purifying Respirator (PAPR) with a dust, mist, and fume filter.

Up to 50 mg/m^3: Any Air-Purifying, Full-Facepiece Respirator with a high-efficiency particulate filter, or any PAPR with a tight-fitting facepiece and a high-efficiency particulate filter, or any Self-Contained Breathing Apparatus (SCBA) with a full facepiece, or any SAR with a full facepiece.

Emergency or Planned Entry into Unknown Concentrations or IDLH Conditions: Any SCBA that has a full facepiece and is operated in a pressure-demand or other positive-pressure mode, or any SAR that has a full facepiece and is operated in a pressure-demand or other positive-pressure mode in combination with an auxiliary SCBA operated in pressure-demand or other positive-pressure mode.

Escape: Any Air-Purifying, Full-Facepiece Respirator with a high-efficiency particulate filter, or any appropriate escape-type, SCBA.

EYE PROTECTION: Safety glasses. When these products are used in conjunction with soldering, wear safety glasses, goggles, or face-shield with filter lens of appropriate shade number (per ANSI Z49.1-1988, "Safety in Welding and Cutting") and U.S. OSHA 29 CFR 1910.133 and appropriate Canadian Standards.

HAND PROTECTION: Wear gloves for routine industrial use. When these products are used in conjunction with soldering, wear gloves that protect from sparks and flame (per ANSI Z49.1-1988, "Safety in Welding and Cutting"). If necessary, refer to U.S. OSHA 29 CFR 1910.138 and appropriate Standards of Canada.

BODY PROTECTION: Use body protection appropriate for task. If a hazard of injury to the feet exists due to falling objects, rolling objects, where objects may pierce the soles of the feet or where employee's feet may be exposed to electrical hazards, as described in U.S. OSHA 29 CFR 1910.136.

9. PHYSICAL and CHEMICAL PROPERTIES

The following information is for Lead, a possible main component:

RELATIVE VAPOR DENSITY (air = 1): Not applicable.
EVAPORATION RATE (nBuAc = 1): Not applicable.
SPECIFIC GRAVITY @ 20°C (water = 1): 11.34
FREEZING/MELTING POINT: 327.4°C (621.36°F)
SOLUBILITY IN WATER: Insoluble.
pH: Not applicable.
VAPOR PRESSURE, mm Hg @ 980°C: 1
BOILING POINT: 1740°C (3164°F)
ODOR THRESHOLD: Not applicable.
VAPOR DENSITY (air = 1): 7.14
COEFFICIENT OF OIL/WATER DISTRIBUTION (PARTITION COEFFICIENT): Not applicable.

The following information is for Tin, a possible main component:

RELATIVE VAPOR DENSITY (air = 1): Not applicable.
EVAPORATION RATE (nBuAc = 1): Not applicable.
SPECIFIC GRAVITY @ 20°C (water = 1): 7.28
FREEZING/MELTING POINT: 232°C (4506°F)
SOLUBILITY IN WATER: Insoluble.
pH: Not applicable.
VAPOR PRESSURE, mm Hg @ 1492°C: 0
BOILING POINT: 2270°C (4118°F)
ODOR THRESHOLD: Not applicable.
VAPOR DENSITY (air = 1): Not applicable.
COEFFICIENT OF OIL/WATER DISTRIBUTION (PARTITION COEFFICIENT): Not applicable.

The following information is for the products:

APPEARANCE AND COLOR: These odorless products consist of tin/lead alloy with a metallic lust and may have a flux core.

10. STABILITY and REACTIVITY

STABILITY: Normally stable. These products can oxidize rapidly to form an insoluble layer of basic lead carbonate.
DECOMPOSITION PRODUCTS: Lead oxide, tin oxides, hydrogen chloride, zinc oxides, and ammonium compounds.
NOTE: The composition and quality of soldering fumes and gases are dependent upon the metal being soldered, the process, the procedure, and the alloys used. Other conditions that could also influence the composition and quantity of fumes and gases to which workers may be exposed include the following: any coatings on metal being welded (e.g. paint, plating, or galvanizing), the number of work stations and the volume of the work area, the quality of ventilation, the position of the work stations with respect to the fume plume, and the presence of other contaminates in the atmosphere. When the alloy is consumed, the fume and gas decomposition products generated are different in percent and form from the ingredients listed in Section 2 (Composition and Information on Ingredients). Fume and gas decomposition products, and not the ingredients in the solders, are important. Concentration of the given fume or gas component may decrease or increase by many times the original concentration. New compounds may form. Decomposition products of normal operations include not only those originating from volatilization, reaction, or oxidation of the product's components but also those from base metals and any coating (as noted previously). The best method to determine the actual composition of generated fumes and gases is to take an air sample from the breathing zone. For additional information, refer to the American Welding Society Publication, "Fumes and Gases in the Welding Environment".
MATERIALS WITH THESE PRODUCTS ARE INCOMPATIBLE: These products will be attacked or can react with strong acids, strong bases, hydrogen peroxide (52% or greater- in presence of manganese dioxide), sodium azide, ammonium nitrate, sodium acetylides, sodium carbide, zirconium, or chlorine trifluoride. The flux or rosin core of these products are incompatible with potassium, strong acids, alkalis, interhalogens, strong oxidizers, ammonium nitrate, hydrogen cyanide, potassium chlorate and lead salts (not lead metal) and silver salts.
HAZARDOUS POLYMERIZATION: Will not occur.
CONDITIONS TO AVOID: Avoid uncontrolled exposure to extreme temperatures and incompatible materials.

PART IV *Is there any other useful information about this material?*

11. TOXICOLOGICAL INFORMATION

TOXICITY DATA: Presented below are human toxicological data available for the components of these products present in concentration greater than 1%. Other data for animals are available for the components of these products, but are not presented in this Material Safety Data Sheet.

LEAD:
Cytogenetic Analysis-Human-Unreported 50 µg/m
TCLo (Inhalation-Human) 10 µg/m^3: Gastrointestinal tract effects: LIV
TDLo (Oral-Woman) 450 mg/kg/6 years: Peripheral nervous system effects: Central nervous system effects

ZINC CHLORIDE:
TCLo (Inhalation-Man) 4800 mg/m^3/30 minutes: Pulmonary system effects
TCLo (Inhalation-Human) 4800 mg/m^3/3 hours
LCLo (inhalation, human) = 300 µg/m^3/ 10 years/ intermittent; systemic effects

ZINC CHLORIDE (continued):
TDLo (Oral-Child) 169 mg/kg: Lungs, Thorax, or Respiration: dyspnea; Blood: changes in serum composition (e.g. TP, bilirubin, cholesterol); Skin and Appendages: dermatitis, other (after systemic exposure)

SUSPECTED CANCER AGENT: The components of these products are listed as follows:

LEAD: ACGIH TLV-A3 (Confirmed Animal Carcinogen), EPA-B2 (Probable Human Carcinogen - Sufficient Evidence from Animal Studies; inadequate evidence or no data from epidemiologic studies); IARC-2B (Possibly Carcinogenic to Humans)

ZINC CHLORIDE: EPA-D [dusts & mists] (Not Classifiable as to Human Carcinogenicity)

The other components of these products are not found on the following lists: FEDERAL OSHA Z LIST, NTP, IARC, and CAL/OSHA and therefore are not considered to be, nor suspected to be, cancer-causing agents by these agencies.

IRRITANCY OF PRODUCT: Dusts or fumes of these products may be irritating to contaminated skin and eyes. Fumes may be irritating to the respiratory system.

SENSITIZATION TO THE PRODUCT: There is some evidence that inhalation of fumes from the Ammonium Chloride component of some of these products may cause respiratory sensitization in susceptible individuals. Symptoms may include difficulty breathing, persistent coughing and wheezing. Contact with the rosin core can result in allergic reaction and skin sensitization in susceptible individuals.

REPRODUCTIVE TOXICITY INFORMATION: Listed below is information concerning the effects of these products and their components on the human reproductive system.

Mutagenicity: These products are not reported to produce mutagenic effects in humans. Cytogenic analysis studies of human cells (cell type and duration of exposure unreported) have produced positive results at a level of 50 µg/mL. In *vitro* assays of human lymphocytes indicate that the Zinc Chloride may cause chromosomal aberrations. In animal studies, positive mutagenic results (chromosome aberrations) have been reported in rats, mice and monkeys exposed orally to the Lead component of these products. Positive results were obtained in chromosomal aberrations tests involving the Ammonium Chloride component of these products using cultured Chinese hamster fibroblast cells, with no metabolic agitation.

Embryotoxicity These products are not reported to produce embryotoxic effects in humans. There is evidence that high Lead levels in human mother's blood can significantly increase the risk of spontaneous abortions. The Lead, and Zinc Chloride components of these products have produced embryotoxic effects in animal studies.

Teratogenicity: These products are not reported to cause teratogenic effects in humans. Lead has an adverse effect on human fetuses, particularly in the later stages of development. Distribution of lead in fetal tissues was examined in a case in which a woman was exposed during pregnancy. The female worker was exposed to lead dust for 8 hours daily when conception occurred. Measurements of Lead content were started after the end of the exposure and continued for 6 months until normal values were obtained. Because of half-life of nearly 20 days for lead elimination from blood, the estimated body burden at the end of exposure was about 1200 ppb. The fetal tissue samples contained between 0.4 (brain) and 7.9 (liver) µg Pb/grams dry weight. The fetal lead was stored mainly in bone, blood, and liver. The Lead component of this product has produced teratogenic effects in animal studies.

Reproductive Toxicity: These products are not reported to cause reproductive effects in humans; however, the Lead component of this product has produced embryotoxic effects in humans. There is convincing evidence that Lead is transferred to neonates via maternal milk. It appears that maternal milk might be a source of Lead for the neonates, particularly when metal levels are elevated in the mother. Chronic exposure to Lead in human males has been found to produce infertility, germinal epithelium damage, oligospermia and testicular degeneration, decreased sperm motility, and prostatic hyperplasia. The Lead component of this product has produced reproductive effects in animal studies. Injections of the Zinc Chloride component of these products has produced testicular tumors in animal tests.

A mutagen is a chemical, which causes permanent changes to genetic material (DNA) such that the changes will propagate through generational lines. An embryotoxin is a chemical, which causes damage to a developing embryo (i.e., within the first eight weeks of pregnancy in humans), but the damage does not propagate across generational lines. A teratogen is a chemical, which causes damage to a developing fetus, but the damage does not propagate across generational lines. A reproductive toxin is any substance, which interferes in any way with the reproductive process.

BIOLOGICAL EXPOSURE INDICES: The following BEIs are applicable to the Lead component of these products.

CHEMICAL DETERMINANT	SAMPLING TIME	BEI
LEAD • Lead in blood Note: Women of child-bearing potential, whose blood Pb exceeds10μg/dl, are at risk of delivering a child with a blood Pb over the current Centers for Disease control guideline of 10μg/dl. If the blood Pb of such children remains elevated, they may be at increased risk of cognitive deficits. The blood Pb of these children should be closely monitored and appropriate steps should be taken to minimize the child's exposure to environmental Lead.	• Not Critical	• 30 μg/100 mL

12. ECOLOGICAL INFORMATION

ALL WORK PRACTICES MUST BE AIMED AT ELIMINATING ENVIRONMENTAL CONTAMINATION.

ENVIRONMENTAL STABILITY: Components of these products will react with water and air to form a variety of stable metal oxides.

EFFECT OF MATERIAL ON PLANTS or ANIMALS: Due to the Lead component, adverse effect may occur to animals which come into contact with these products. No data is available on the components of these products and plants

EFFECT OF CHEMICAL ON AQUATIC LIFE: Due to the Lead component of these products, a release of product to an aquatic environment may have a significant adverse effect.

13. DISPOSAL CONSIDERATIONS

PREPARING WASTES FOR DISPOSAL: Waste disposal must be in accordance with appropriate Federal, State, and local regulations. These products, if unaltered by use, may be disposed of by treatment at a permitted facility or as advised by your local hazardous waste regulatory authority.

EPA WASTE NUMBER: Wastes of these products should be tested per the Toxicity Characteristic Leaching Procedures requirements of RCRA to determine if such wastes meet the following characteristics: D008 (Lead).

14. TRANSPORTATION INFORMATION

THESE PRODUCTS ARE NOT HAZARDOUS (Per 49 CFR 172.101) BY THE U.S. DEPARTMENT OF TRANSPORTATION.

PROPER SHIPPING NAME: Not applicable.
HAZARD CLASS NUMBER and DESCRIPTION: Not applicable.
UN IDENTIFICATION NUMBER: Not applicable.
PACKING GROUP: Not applicable.
DOT LABEL(S) REQUIRED: Not applicable.
NORTH AMERICAN EMERGENCY RESPONSE GUIDEBOOK NUMBER, 2000: Not applicable.
MARINE POLLUTANT: No component of these products is designated as a marine pollutant by the Department of Transportation (49 CFR 172.101, Appendix B).

TRANSPORT CANADA TRANSPORTATION OF DANGEROUS GOODS REGULATIONS: These products are not considered as dangerous goods, per regulations of Transport Canada.

15. REGULATORY INFORMATION

ADDITIONAL U.S. REGULATIONS:

U.S. SARA REPORTING REQUIREMENTS: The components of these products are subject to the reporting requirements of Sections 302, 304 and 313 of Title III of the Superfund Amendments and Reauthorization Act, as follows:

CHEMICAL NAME	SARA 302 (40 CFR 355, Appendix A)	SARA 304 (40 CFR Table 302.4)	SARA 313 (40 CFR 372.65)
Ammonium Chloride	NO	YES	NO
Lead	NO	YES	YES
Zinc Chloride	NO	YES	NO

U.S. SARA THRESHOLD PLANNING QUANTITY: There are no specific Threshold Planning Quantities for any component of these products. The default Federal MSDS submission and inventory requirement filing threshold of 10,000 lb (4,540 kg) may apply, per 40 CFR 370.20.

ADDITIONAL U.S. REGULATIONS (continued):

U.S. TSCA INVENTORY STATUS: The components of these products are listed on the TSCA Inventory.

U.S. CERCLA REPORTABLE QUANTITY (RQ): Ammonium Chloride = 5000 lb (2270 kg); Lead = 10 lb (4.540 kg); Zinc Chloride = 1000 lb (454 kg)

OTHER U.S. FEDERAL REGULATIONS: Components of these products have requirements under other U.S. Federal regulations, as follows:

AMMONIUM CHLORIDE: EPA: Ammonium Chloride is designated as a hazardous substance under Section 311(b)(2)(A) of the Federal Water Pollution Control Act and further regulated by the Clean Water Act Amendments of 1977 and 1978. These regulations apply to discharges of this substance.

LEAD: EPA: Lead is listed as a hazardous air pollutant (HAP) generally known or suspected to cause serious health problems. The Clean Air Act, as amended in 1990, directs EPA to set standards requiring major sources to sharply reduce routine emissions of toxic pollutants. EPA is required to establish and phase in specific performance based standards for all air emission sources that emit one or more of the listed pollutants. Lead is included on this list. Lead is designated as a toxic pollutant, pursuant to Section 307(a)(1) of the Clean Water Act and is subject to effluent limitations. Lead is designated as a hazardous substance under Section 311(b)(2)(A) of the Federal Water Pollution Control Act and further regulated by the Clean Water Act Amendments of 1977 and 1978. These regulations apply to discharges of Lead.

OSHA: Employers are required to follow the exposure limits and other requirements as defined under the Lead Standard, 29 CFR 1910.1025.

ZINC CHLORIDE: EPA: Zinc Chloride is designated as a hazardous substance under Section 311(b)(2)(A) of the Federal Water Pollution Control Act and further regulated by the Clean Water Act Amendments of 1977 and 1978. These regulations apply to discharges of this substance. Zinc Chloride is a designated as a toxic pollutant designated pursuant to Section 307(a)(1) of the Clean Water Act and is subject to effluent limitations.

U.S. STATE REGULATORY INFORMATION: The components of these products are covered under specific State regulations, as denoted below:

Alaska-Designated Toxic and Hazardous Substances: Ammonium Chloride, Lead, and Zinc Chloride.

California-Permissible Exposure Limits for Chemical Contaminants: Ammonium Chloride, Lead, Tin, and Zinc Chloride.

Florida-Substance List: Ammonium Chloride, Lead, Tin, and Zinc Chloride.

Illinois-Toxic Substance List: Ammonium Chloride, Lead, and Zinc Chloride.

Kansas-Section 302/313 List: Lead.

Massachusetts-Substance List: Ammonium Chloride, Lead, Tin, and Zinc Chloride.

Michigan - Critical Materials Register: Lead.

Minnesota-List of Hazardous Substances: Ammonium Chloride, Lead, Tin, and Zinc Chloride.

Missouri-Employer Information/Toxic Substance List: Ammonium Chloride, Lead, Tin, and Zinc Chloride.

New Jersey-Right to Know Hazardous Substance List: Ammonium Chloride, Lead, Tin, and Zinc Chloride.

North Dakota-List of Hazardous Chemicals, Reportable Quantities: Ammonium Chloride, Lead, and Zinc Chloride.

Pennsylvania-Hazardous Substance List: Ammonium Chloride, Lead, Tin, and Zinc Chloride.

Rhode Island-Hazardous Substance List: Ammonium Chloride, Tin, and Zinc Chloride.

Texas-Hazardous Substance List: Lead, Tin, and Zinc Chloride.

West Virginia-Hazardous Substance List: , Tin, Zinc Chloride.

Wisconsin-Toxic and Hazardous Substances: Lead, Tin, and Zinc Chloride.

CALIFORNIA SAFE DRINKING WATER AND TOXIC ENFORCEMENT ACT (PROPOSITION 65): The Lead component of these products is on the California Proposition 65 Lists. **WARNING: These products contain a chemical that is known to the State of California to cause cancer and reproductive harm. In addition, these products, when used for soldering may produce fumes or gases containing chemicals, known to the State of California to cause cancer, and/or birth defects (or other reproductive harm.)**

LABELING (Precautionary Statements): DANGER OF CUMULATIVE EFFECTS IF DUSTS OR FUMES ARE INHALED! POSSIBLE CANCER AND REPRODUCTIVE HAZARD. CONTAINS POTENTIAL TERATOGEN AND/OR MUTAGEN.

WARNING:

PROTECT yourself and others. Read and understand this information.

FUMES AND GASES can be hazardous to your health.

ARC RAYS can injure your eyes and burn skin.

ELECTRIC SHOCK can kill.

- Before use, read and understand the manufacturer's instructions. Material Safety Data Sheets (MSDSs), and your employer's safety policies.
- Keep your head out of the fumes.
- Use enough ventilation, exhaust at the arc, or both, to keep fumes and gases from your breathing zone and the general area.
- Wear correct eye, ear, and body protection.
- See American National Standard Z49.1 *Safety in Welding, Cutting, and Allied Processes*, published by the American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126. OSHA Safety and Health Standards, *29 CFR 1910*, available from the U.S. Government Printing Office, Washington, DC 20402.

DO NOT REMOVE THIS INFORMATION

15. REGULATORY INFORMATION (Continued)

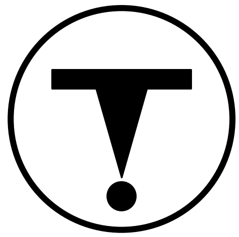
ADDITIONAL CANADIAN REGULATIONS:

CANADIAN DSL/NDSL INVENTORY STATUS: The components of these products are on the DSL Inventory.

OTHER CANADIAN REGULATIONS: Not applicable.

CANADIAN ENVIRONMENTAL PROTECTION ACT (CEPA) PRIORITIES SUBSTANCES LISTS: No component of these products are on the CEPA Priority Substances Lists (PSL).

CANADIAN WHMIS SYMBOLS: **D2A:** Poisonous and Infections Material - Other Effects: Very Toxic (chronic toxicity, embryotoxicity, teratogenicity, reproductive toxicity, carcinogenicity); **D2B:** - Poisonous and Infections Material - Other Effects: Toxic (mutagenicity).



16. OTHER INFORMATION

PREPARED BY: CHEMICAL SAFETY ASSOCIATES, Inc.
9163 Chesapeake Drive, San Diego, CA 92123-1002
858/565-0302

DATE OF PRINTING: July 13, 2007

This Material Safety Data Sheet is offered pursuant to OSHA's Hazard Communication Standard (29 CFR 1910.1200). Other government regulations must be reviewed for applicability to these products. The information contained herein relates only to the specific products. If the products are combined with other materials, all component properties must be considered. To the best of the Harris Products Group knowledge, the information and recommendations contained in this publication are reliable and accurate as of the date of issue. However, accuracy, suitability, or completeness are not guaranteed, and no warranty, guarantee, or representation, expressed or implied, is made by Harris Products Group., Inc. assumes no responsibility in connection therewith; nor can it be assumed that all acceptable safety measures may not be required under particular or exceptional conditions or circumstances. Data may be changed from time to time. Be sure to consult the latest edition.

DEFINITIONS OF TERMS

A large number of abbreviations and acronyms appear on a MSDS. Some of these, which are commonly used, include the following:

CAS #: This is the Chemical Abstract Service Number, which uniquely identifies each constituent.

EXPOSURE LIMITS IN AIR:

ACGIH - American Conference of Governmental Industrial Hygienists, a professional association which establishes exposure limits. **TLV -** Threshold Limit Value - an airborne concentration of a substance, which represents conditions under which it is generally believed that nearly all workers, may be repeatedly exposed without adverse effect. The duration must be considered, including the 8-hour Time Weighted Average **(TWA)**, the 15-minute Short Term Exposure Limit, and the instantaneous Ceiling Level **(C)**. Skin absorption effects must also be considered.

OSHA - U.S. Occupational Safety and Health Administration.

PEL - Permissible Exposure Limit - This exposure value means exactly the same as a TLV, except that it is enforceable by OSHA. The OSHA Permissible Exposure Limits are based in the 1989 PELs and the June, 1993 Air Contaminants Rule (Federal Register: 58: 35338-35351 and 58: 40191). Both the current PELs and the vacated PELs are indicated. The phrase, "Vacated 1989 PEL," is placed next to the PEL, which was vacated by Court Order. **IDLH -** Immediately Dangerous to Life and Health **-** This level represents a concentration from which one can escape within 30-minutes without suffering escape-preventing or permanent injury. **The DFG - MAK** is the Republic of Germany's Maximum Exposure Level, similar to the U.S. PEL. **NIOSH** is the National Institute of Occupational Safety and Health, which is the research arm of the U.S. Occupational Safety and Health Administration (**OSHA**). NIOSH issues exposure guidelines called Recommended Exposure Levels (**REL**s). When no exposure guidelines are established, an entry of **NE** is made for reference.

HAZARD RATINGS:

HAZARDOUS MATERIALS IDENTIFICATION SYSTEM: Health Hazard: **0** (minimal acute or chronic exposure hazard); **1** (slight acute or chronic exposure hazard); **2** (moderate acute or significant chronic exposure hazard); **3** (severe acute exposure hazard; onetime overexposure can result in permanent injury and may be fatal); **4** (extreme acute exposure hazard; onetime overexposure can be fatal). Flammability Hazard: **0** (minimal hazard); **1** (materials that require substantial pre-heating before burning); **2** (combustible liquid or solids; liquids with a flash point of 38-93°C [100-200°F]); **3** (Class IB and IC flammable liquids with flash points below 38°C [100°F]); **4** (Class IA flammable liquids with flash points below 23°C [73°F] and boiling points below 38°C [100°F]. Reactivity Hazard: **0** (normally stable); 1 (material that can become unstable at elevated temperatures or which can react slightly with water); **2** (materials that are unstable but do not detonate or which can react violently with water); **3** (materials that can detonate when initiated or which can react explosively with water); **4** (materials that can detonate at normal temperatures or pressures).

NATIONAL FIRE PROTECTION ASSOCIATION: Health Hazard: **0** (material that on exposure under fire conditions would offer no hazard beyond that of ordinary combustible materials); **1** (materials that on exposure under fire conditions could cause irritation or minor residual injury); **2** (materials that on intense or continued exposure under fire conditions could cause temporary incapacitation or possible residual injury); **3** (materials that can on short exposure could cause serious temporary or residual injury); **4** (materials that under very short exposure causes death or major residual injury). Flammability Hazard and Reactivity Hazard: Refer to definitions for "Hazardous Materials Identification System".

FLAMMABILITY LIMITS IN AIR:

Much of the information related to fire and explosion is derived from the National Fire Protection Association (**NFPA**). Flash Point - Minimum temperature at which a liquid gives off sufficient vapors to form an ignitable mixture with air. Autoignition Temperature: The minimum temperature required to initiate combustion in air with no other source of ignition. LEL - the lowest percent of vapor in air, by volume, that will explode or ignite in the presence of an ignition source. UEL - the highest percent of vapor in air, by volume, that will explode or ignite in the presence of an ignition source.

TOXICOLOGICAL INFORMATION:

Human and Animal Toxicology: Possible health hazards as derived from human data, animal studies, or from the results of studies with similar compounds is presented. Definitions of some terms used in this section are: **LD_{50}** - Lethal Dose (solids & liquids) which kills 50% of the exposed animals; **LC_{50}** - Lethal Concentration (gases) which kills 50% of the exposed animals; **ppm** concentration expressed in parts of material per million parts of air or water; **mg/m^3** concentration expressed in weight of substance per volume of air; **mg/kg** quantity of material, by weight, administered to a test subject, based on their body weight in kg. Other measures of toxicity include **TDLo**, the lowest dose to cause a symptom and **TCLo** the lowest concentration to cause a symptom; **TDo**, **LDLo**, and **LDo**, or **TC**, **TCo**, **LCLo**, and **LCo**, the lowest dose (or concentration) to cause lethal or toxic effects. **Cancer Information:** The sources are: **IARC** - the International Agency for Research on Cancer; **NTP** - the National Toxicology Program, **RTECS** - the Registry of Toxic Effects of Chemical Substances, **OSHA** and **CAL/OSHA**. IARC and NTP rate chemicals on a scale of decreasing potential to cause human cancer with rankings from 1 to 4. Subrankings (2A, 2B, etc.) are also used. **Other Information: BEI** - ACGIH Biological Exposure Indices, represent the levels of determinants which are most likely to be observed in specimens collected from a healthy worker who has been exposed to chemicals to the same extent as a worker with inhalation exposure to the TLV. **Ecological Information:** EC is the effect concentration in water. **BCF** = Bioconcentration Factor, which is used to determine if a substance will concentrate in lifeforms which consume contaminated plant or animal matter. Coefficient of Oil/Water Distribution is represented by **$\log K_{ow}$** or **$\log K_{oc}$** and is used to assess a substance's behavior in the environment.

REGULATORY INFORMATION:

This section explains the impact of various laws and regulations on the material. **U.S.: EPA** is the U.S. Environmental Protection Agency. **DOT** is the U.S. Department of Transportation. **SARA** is the Superfund Amendments and Reauthorization Act. **TSCA** is the U.S. Toxic Substance Control Act. **CERCLA (or Superfund)** refers to the Comprehensive Environmental Response, Compensation, and Liability Act. Labeling is per the American National Standards Institute (**ANSI Z129.1**). **CANADA: CEPA** is the Canadian Environmental Protection Act. **WHMIS** is the Canadian Workplace Hazardous Materials Information System. **TC** is Transport Canada. **DSL/NDSL** are the Canadian Domestic/Non-Domestic Substances Lists. **The CPR is the Canadian Product Regulations.** This section also includes information on the precautionary warnings, which appear, on the materials package label.

MATERIAL SAFETY DATA SHEET

Section 1: Product and Company Information

Product Name(s): Woven Unidirectional Fiberglass Fabric (A-Style Warp Unidirectional), Stitchbonded Fiberglass Fabric, Woven Fiberglass Fabric

Manufacturer: Owens-Corning, World Headquarters, One Owens-Corning Parkway
Attn. Product Stewardship, Toledo, OH, 43659,
Telephone: 1-419-248-8234 (8am-5pm ET weekdays).
OC Fabrics, 1851 S. Sequin Ave., New Braunfels, TX, 78130
Telephone: 1-210-629-4009 (8am-5pm CT weekdays).

Emergency Contacts:
Emergencies ONLY (after 5pm ET and weekends): 1-419-248-5330,
CHEMTREC (24 hours everyday): 1-800-424-9300,
CANUTEC (Canada- 24 hours everyday): 1-613-996-6666.

Health and Technical Contacts:
Health Issues Information (8am-5pm ET):1-419-248-8234,
Technical Product Information (8am-5pm ET): 1-800-GET-PINK.

Section 2: Composition and Ingredient Information

Common Name	Chemical Name	CAS No.	Wt. %
Non-Hazardous Ingredients			
Fiber Glass Continuous Filament (non respirable)	Fibrous Glass	65997-17-3	94-100
Size	Size	None	0-2
Polyester Yarn	Polyester Yarn	None	0-4

Note: See Section 8 of MSDS for exposure limit data for these ingredients.

Section 3: Hazards Identification

Appearance and Odor: White/off-white colored solid with no odor.

Emergency Overview

No unusual conditions are expected from this product

Primary Route(s) of Exposure: inhalation, skin, eye

Potential Health Effects:

ACUTE (short term): Fiber glass continuous filament is a mechanical irritant. Breathing dusts and fibers may cause short term irritation of the mouth, nose and throat. Skin contact with dust and fibers may cause itching and short term irritation. Eye contact with dust and fibers may cause short term mechanical irritation. Ingestion may cause short term mechanical irritation of the stomach and intestines. See Section 8 for exposure controls.

CHRONIC (long term): There is no known health effects connected with long term use or contact with this product. See Section 11 of MSDS for more toxicological data.

Medical Conditions Aggravated by Exposure: Long term breathing or skin conditions that are aggravated by mechanical irritants may be at a higher risk for worsening from use or contact with this product.

Section 4: First Aid Measures

Inhalation: Move person to fresh air. Seek medical attention if irritation persists.

Eye Contact: Flush eyes with running water for at least 15 minutes. Seek medical attention if irritation persists.

Skin Contact: Wash with mild soap and running water. Use a washcloth to help remove fibers. To avoid more irritation, do not rub or scratch affected areas. Rubbing or scratching may force fibers into skin. Seek medical attention if irritation persists.

Ingestion: Ingestion of this material is unlikely. If it does occur, watch the person for several days to make sure that intestinal blockage does not occur.

Section 5: Fire Fighting Measures

Flash Point and Method: None

Flammability Limits (%): None.

Auto Ignition Temperature: Not Applicable.

Extinguishing Media: Water, foam, CO_2 or dry chemical.

Unusual Fire and Explosion Hazards: None known.

Fire Fighting Instructions: Use self contained breathing apparatus (SCBA) in a sustained fire.

Hazardous Combustion Products: Primary combustion products are carbon monoxide, carbon dioxide and water. Other undetermined compounds could be released in small quantities.

Section 6: Accidental Release Measures

Land Spill: Scoop up material and put into suitable container for disposal as a non-hazardous waste.

Water Spill: This material will sink and disperse along the bottom of waterways and ponds. It can not easily be removed after it is waterborne; however, the material is non-hazardous in water.

Air Release: This material will settle out of the air. If concentrated on land it can then be scooped up for disposal as a non-hazardous waste.

Section 7: Handling and Storage

Storage Temperature: Not applicable.

Storage Pressure: Not applicable.

General: No special storage or handling procedures are required for this material.

Section 8: Exposure Controls and Personal Protection

Ingredient	OSHA PEL (8-hr TWA)	ACGIH TLV (8-hr TWA)
Fiber Glass Continuous Filament	5 mg/m^3 (respirable dust) 15 mg/m^3 (total dust 1 fiber/cc (proposed)	10 mg/m^3 (inhalable) 3 mg/m^3 (respirable)
Size	None Established	None Established
Polyester Yarn	5 mg/m^3 (respirable dust) 15 mg/m^3 (total dust	10 mg/m^3 (inhalable) 3 mg/m^3 (respirable)

Ventilation: General dilution ventilation and/or local exhaust ventilation should be provided as necessary to maintain exposures below regulatory limits.

Personal Protection:

Respiratory Protection: A properly fitted NIOSH/MSHA approved disposable dust respirator such as the 3M model 8210 (or 8710) or model 9900 (in high humidity environments) or equivalent should be used when: high dust levels are encountered; the level of glass fibers in the air exceeds the OSHA permissible limits; or if irritation occurs. Use respiratory protection in accordance with your company's respiratory protection program, local regulations and OSHA regulations under 29 CFR 1910.134.

Skin Protection: Loose fitting long sleeved shirt that covers to the base of the neck, long pants and gloves. Skin irritation is known to occur chiefly at pressure points such as around neck, wrist, waist and between fingers.

Eye Protection: Safety glasses or goggles.

Work and Hygienic Practices: Handle using good industrial hygiene and safety practices. Avoid unnecessary contact with dusts and fibers by using good local exhaust ventilation. Remove material from the skin and eyes after contact. Remove material from clothing using vacuum equipment (never use compressed air and always wash work clothes separately from other clothing. Wipe out the washer or sink to prevent loose glass fibers from getting on other clothing). Keep the work area clean of dusts and fibers made during fabrication by using vacuum equipment to clean up dusts and fibers (avoid sweeping or using compressed air as these techniques re-suspend dusts and fibers into the air.) Have access to safety showers and eye wash stations.

Section 9: Physical and Chemical Properties

Vapor Pressure (mm Hg @ 20^{o}C): Not Applicable

pH: Not Applicable

Vapor Density (Air=1): Not Applicable

Specific Gravity (Water=1): 2.60

Boiling Point: Not Applicable

Solubility in Water: Insoluble

Viscosity: Not Applicable

Appearance: Solid

Physical State: Solid

Odor Type: None

Freezing Point: Not Applicable

Evaporation Rate (n-Butyl Acetate=1): Not Applicable

Section 10: Stability and Reactivity

General: Stable

Incompatible Materials and Conditions to Avoid: None

Hazardous Decomposition Products: Sizings or binders may decompose in a fire. See Section 5 of MSDS for combustion products statement.

Hazardous Polymerization: Will not occur.

Section 11: Toxicological Information

CARCINOGENICITY: The table below indicates whether or not each agency has listed each ingredients as a carcinogen:

Ingredient	ACGIH	IARC	NTP	OSHA
Fiber Glass Continuous Filament	A4	3	No	No
Size	No	No	No	No
Polyester Yarn	No	No	No	No

	LD_{50} Oral (g/kg)	LD_{50} Dermal (g/kg)	LC_{50} Inhalation (ppm, 8 hrs.)
Fiber Glass Continuous Filament	Not Available	Not Available	Not Available
Size	Not Available	Not Available	Not Available
Polyester Yarn	Not Available	Not Available	Not Available

Fiber Glass Continuous Filament: The International Agency for Research on Cancer (IARC) in June, 1987, categorized fiber glass continuous filament as not classifiable with respect to human carcinogenicity (Group 3). The evidence from human as well as animal studies was evaluated by IARC as insufficient to classify fiber glass continuous filament as a possible, probable, or confirmed cancer causing material.

Section 12: Ecological Information

This material is not expected to cause harm to animals, plants or fish.

Section 13: Disposal Considerations

RCRA Hazard Class: Non-hazardous.

Section 14: Transport Information

DOT Shipping Names: Not regulated

Hazard Class or Division: None

Secondary: None

Identification No.: None

Packing Group: None

Label(s) required (if not excepted): None

Special Provisions: None

Packaging Exceptions: None

Non-bulk Packaging: None

Bulk packaging: None

EPA Hazardous Substances: None

RQ: None

Quantity Limitations: **Passenger Aircraft:** None
Cargo Aircraft: None

Marine Pollutants: None

Freight Description: None

Hazardous Material Shipping Description: None

MATERIAL SAFETY DATA SHEET

Transportation of Dangerous Goods - Canada

<u>Proper Shipping Name</u>: Not Regulated

<u>TDG Hazard Classification</u>: (Primary): None **(Secondary):** None

<u>IMO Classification</u>: None

<u>ICAO/IATA Classification</u>: None

<u>Product Identification Number</u>: None

<u>Packing Group</u>: None

<u>Control Temperature</u>: None

<u>Emergency Temperature</u>: None

<u>Schedule XII Quantity Restriction</u>: None

<u>Reportable Quantity for US Shipments</u>: None

<u>IATA Packing Instructions</u>:

Passenger/Cargo: None
Cargo Only: None
Limited Quantity: None

<u>Maximum Net Quantity per Package</u>:

Passenger/Cargo: None
Cargo Only: None
Limited Quantity: None

<u>Special Provisions</u>: None

MATERIAL SAFETY DATA SHEET

Section 15: Regulatory Information

TSCA Status: Each ingredient is on the Inventory.

NSR Status (Canada): Each ingredient is on the DSL.

SARA Title III:

Hazard Categories:

Acute Health:	Yes
Chronic Health:	No
Fire Hazard:	No
Pressure Hazard:	No
Reactivity Hazard:	No

Reportable Ingredients:

Sec. 302/304:	None
Sec. 313:	None

California Proposition 65: No ingredient is listed.

Clean Air Act: No ingredient is listed.

WHMIS (Canada): **Status:** Not Controlled
WHMIS Classification(s): None

Section 16: Other Information

HMIS and NFPA Hazard Rating:

Category	HMIS	NFPA
Acute Health	1	1
Flammability	0	0
Reactivity	0	0

NFPA Unusual Hazards: None.
HMIS Personal Protection: To be supplied by user depending upon use.

Revision Summary: This is a new MSDS. (Reformatted 11/25/98)

MATERIAL SAFETY DATA SHEET

REVISION DATE: 04-1-2001 SUPERSEDES: 08-21-2001

SECTION 1. CHEMICAL PRODUCT AND COMPANY IDS IDENTIFICATION

COMPANY INFORMATION

Global Coatings Division
H.B. Fuller Company
2900 Granada Lane
Oakdale,MN 55128
Phone: 651-236-3700

Medical Emergency Phone Numbs (24 Hours): 1-888-853-1758

Transport Emergency Phone Number (CHEMTREC): 1-800-424-9300

PRODUCT INFORMATION

PRODUCT IDENTIFIER: 810564PM
PRODUCT NUMBER: IF1947T
PRODUCT DESCRIPTION: Powder coating

SECTION 2: COMPOSITION/INFORMATION ON INGREDIENTS

Unlisted ingredients are not ‘hazardous’ per the Occupational Safety and Health Administration Hazard Communication Standard (29 CFR 1910.1200) and/or are not found on the Canadian Workplace Hazardous Materials Information System ingredient disclosure list See Section 8 for any additional exposure limit guidelines.

Chemical Name	CAS #	PERCENT	OSHA PEL
Epoxy resin	25036-25-3	50 - 70	Not established
Calcium carbonate	1317-65-3	10 - 30	TWA (Total dust) 15 MG/M3 TWA (Respirable dusty 5 MG/M3
Epoxy resin	28064-14-4	10 - 30	Not established
Bisphenol A	80-05-7	1-5	No established
Iron oxide	1332-37-2	1-5	TWA (as Fe) Fume 10 MG/M3
Aromatic amine	693-98-1	0.1-1	Not established
Crystalline silica	14808-60-7	0.1-1	TWA (Respirable dust) 0.1 MG/M3

SECTION 3: HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

Dust clouds in air can be ignited by electric sparks, hot surfaces and open flame.

MATERIAL SAFETY DATA SHEET

Can cause skin imitation. May cause allergic skin reaction.
May cause an allergic respiratory reaction.
Harmful if swallowed.
Cancer hazard.

HMIS RATING: HEALTH -- 1 FLAMMABILITY -- 1 REACTIVITY -- 0
See SECTION 8: EXPOSURE CONTROLS/PERSONAL PROTECTION for personal protective equipment recommendations.

POTENTIAL HEALTH EFFECTS BY ROUTE OF ENTRY

EYE: Can cause minor irritation, tearing and reddening. Can cause mechanical irritation if dusts are generated.
SKIN: Continued or prolonged contact may irritate the skin and cause a skin rash (dermatitis). May cause sensitization.
Can cause light sensitivity that results in a skin rash when exposed to sunlight or ultraviolet light sources.

INHALATION: Can cause minor respiratory irritation Dust may be slightly irritating to the respiratory tract.
Inhalation of dusts produced during cuffing, grinding or sanding of this product may cause irritation of the respiratory tract
May cause allergic respiratory reaction.
Overexposure to iron oxide dust/fume may cause siderosis. Overexposure to crystalline silica may cause silicosis.

INGESTION: Ingestion is not an anticipated route of exposure. Harmful if swallowed.

LONG-TERM (CHRONIC) HEALTH EFFECTS
TARGET ORGAN(S): Skin, Lungs

REGULATED CARCINOGEN STATUS:
Unless noted below, this product does not contain regulated levels of NTP, IARC, ACGIH, or OSHA listed carcinogens.

Crystalline silica

EXISTING HEALTH CONDITIONS AFFECTED BY EXPOSURE: Skin disease including eczema and sensitization; Lung disease

SECTION 4: FIRST AID MEASURES

IF IN EYES: Immediately flush eyes with plenty of water for at least 20 minutes retracting eyelids often. Tilt the head to prevent chemical from transferring to the uncontaminated eye. Get immediate medical attention and monitor the eye daily as advised by your physician Flush eye with water for 20 minutes. Get medical attention.

IF ON SKIN: Wash with soap and water. Remove contaminated clothing, launder immediately, and discard contaminated leather goods. Get medical attention immediately.

If VAPORS INHALED: Remove to fresh air. Call a physician if symptoms persist.

IF SWALLOWED: No hazard in normal industrial use. Do not induce vomiting. Seek medical attention if symptoms develop. Provide medical care provider with this MSDS.

SECTION 5: FIRE FIGHTING MEASURES

FLASH POINT:	Not applicable
AUTOIGNITION TEMPERATURE:	Not established
LOWER EXPLOSIVE LIMIT (% in air):	Not established
UPPER EXPLOSIVE LIMIT (% in air):	Not established
EXTINGUISHING MEDIA:	Use water spray, foam, dry chemical or carbon dioxide.

MATERIAL SAFETY DATA SHEET

UNUSUAL FIRE AND EXPLOSION HAZARDS: Material will burn in a fire. Normal LEL for powder coatings 0.04 to 0.07 ounces/cubic foot. Strong explosions are not expected below 0.4 to 0.7.

SPECIAL FIRE FIGHTING INSTRUCTIONS: Persons exposed to products of combustion should wear self contained breathing apparatus and full protective equipment.

HAZARDOUS COMBUSTION PRODUCTS: Carbon dioxide, Carbon monoxide

SECTION 6: ACCIDENTAL RELEASE MEASURES

SPECIAL PROTECTION: No health effects expected from the cleanup of this material if contact can be avoided. Follow personal protective equipment recommendations found in Section 8 of this MSDS.

CLEAN-UP: Avoid creating dusts. Eliminate ignition sources. If a vacuum is used, ensure that the material is wetted or otherwise treated so an explosive dust atmosphere is not created within the vacuum.

Transport Emergency Phone Number (CHEMTREC): 1-800-424-9300

SECTION 7: HANDLING AND STORAGE

Handling: Mildly irritating material. Avoid unnecessary exposure. Avoid creating dusts as an explosive dust air mixture can be created at high concentrations. If dusts are created, ensure no sources of ignition are present. Take precautionary measures to prevent electrostatic discharges.

Storage: Store in a cool, dry place.

Consult the Technical Data Sheet for specific storage instructions.

SECTION 8: EXPOSURE CONTROLS/PERSONAL PROTECTION

EYE PROTECTION: Wear safety glasses with side shields when handling this product. Wear additional eye protection such as chemical splash goggles and/or face shield when the possibility exists for eye contact with splashing or spraying liquid, or airborne material. Have an eye wash station available.

SKIN PROTECTION: Prevent contact with this product. Wear chemically resistant gloves, long sleeved shirt, an apron, and other protective equipment depending on conditions of use.

GLOVES: Nitrite

RESPIRATORY PROTECTION: Respiratory protection may be required to avoid overexposure when handling this product. Use a respirator if general room ventilation is not available or sufficient to eliminate symptoms. NIOSH approved air ~ Expiator with dust/mist filter. Respirators should be selected by and used following requirements found in OSHA's respirator standard (29 CFR 1910.134).

VENTILATION:

EXPOSURE LIMITS:

Chemical Name	ACGIH EXPOSURE LIMITS	AIHA WEEL
Epoxy resin	Not established	Not established
Calcium carbonate	TWA (Total dust) 10 MG/M3	Not established

MATERIAL SAFETY DATA SHEET

Epoxy resin	Not established	Not established
Bisphenol A	Not established	Not established
Iron oxide	TWA (as Fe) Fume 5 MG/M3	Not established
Aromatic amine	Not established	Not established
Crystalline silica	TWA (Respirable dust) 0.05 MG/M3	Not established

SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES

PHYSICAL STATE:	Solid
COLOR:	Red
ODOR:	Neutral
ODOR THRESHOLD:	Not established
WEIGHT PER GALLON (Ibs.):	11.58
SPECIFIC GRAVITY:	1.39
SOLIDS (% by weight):	100.0
	Not applicable
pH:	Not established
BOILING POINT (deg. C):	Not established
FREEZING/MELTING POINT (dew C):	Not established
VAPOR PRESSURE (mm Hg):	Not established
VAPOR DENSITY:	Not established
EVAPORATION RATE:	Not established
OCTANOL/WATER COEFFICIENT:	Not established

SECTION 10: STABILITY AND REACTIVITY

STABILITY:	Stable under normal conditions.
CHEMICAL INCOMPATIBILITY:	Not established
HAZARDOUS POLYMERIZATION:	Will not occur.
HAZARDOUS DECOMPOSITION PRODUCTS:	Carbon monoxide, Carbon dioxide

SECTION 11: TOXICOLOGICAL INFORMATION

CHEMICAL NAME	**LD50/LC50**
Epoxy resin	Oral LD50 Rat > 30 g/kg Inhalation LC50 Rat > 800 mg/cu m/4H Dermal LD50 Rabbit > 3 g/kg
Calcium carbonate	Not established

MATERIAL SAFETY DATA SHEET

Epoxy resin	Not established
Bisphenol A	Oral LD50 Ret = 3250 mg/kg Dermal LD50 Rabbit = 3 ml/kg
Iron oxide	Not established
Aromatic amine	Not established
Crystalline silica	Not established

TOXICOLOGY SUMMARY: No additional health information available.

SECTION 12: ECOLOGICAL INFORMATION

OVERVIEW: No ecological information available

No levels of volatile organic compound emissions are expected at ambient temperatures and pressure. Depending on powder chemistry, however, higher levels of VOC and low molecular weight hydrocarbons may be emitted at cure temperatures. Emissions data are best developed by monitoring actual plant conditions.

SECTION 13: DISPOSAL CONSIDERATIONS

To the best of our knowledge, this product does not meet the definition of hazardous waste under the U.S. EPA Hazardous Waste Regulations 40 CFR 261. Disposal via incineration at an approved facility is recommended. Consult state, local or provincial authorities for more restrictive requirements.

SECTION 14: TRANSPORTATION INFORMATION

Consult Bill of Lading for transportation information.

SECTION 15: REGULATORY INFORMATION

INVENTORY STATUS

U. S. EPA TSCA: This product is in compliance with the Toxic Substances Control Act's Inventory requirements.

CANADIAN CEPA DSL: This product is in compliance with the Canadian Domestic Substance List requirements.

If you need more information about the inventory status of this product call 651-236-5858.

TSCA Section 12(b) - Export Notice Requirements
This product contains a chemical substance that is currently on the EPA's Section 12(b) Export List. Contact the company Global Regulatory Group at 651/236-5858 for the identity of the Section 12(b) chemical(s).

FEDERAL REPORTING
EPA SARA Title III Section 313
Unless listed below, this product does not contain toxic chemical(s) subject to the reporting requirements of section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA) and 40 CFR part 72. EPA has advised that when a percentage range is listed the midpoint may be used to fulfill reporting obligations.

Chemical Name	CAS#	%
4,4'-Isopropylidenediphenol	80-05-7	1- 5

MATERIAL SAFETY DATA SHEET

WHMIS STATUS: Unless listed below, this product is not controlled under the Canadian Workplace Hazardous Materials Formation System.

D2B D2A

STATE REPORTING
This MSDS is not prepared for distribution in California.

SECTION 16: ADDITIONAL INFORMATION

This Material Safety Data Sheet is prepared to comply with the United States Occupational Safety and Health Administration (OSHA) Hazard Communication Standard (29 CFR 1910.1200) and the Canadian Workplace Hazardous Materials Information System (WHMIS).

Prepared by: The Global Regulatory Department
Phone: 651-236-5842

The information and recommendations set forth herein are believed to be accurate. Because some of the information is derived from information provided to the H.B. Fuller Company from its suppliers, and because the H.B. Fuller Company has no control over the conditions of handling and use, the H.B. Fuller Company makes no warranty, expressed or implied, regarding the accuracy of the data or the results to be obtained from the use thereof. The information is supplied solely for your information and consideration, and the H.B. Fuller Company assumes no responsibility for use or reliance thereon. It is the responsibility of the user of H.B. Fuller Company products to comply with all applicable federal, state and local laws and regulations.

MATERIAL SAFETY DATA SHEET

Neodymium-Iron Magnet Alloy

May be used to comply OSHA's Hazard Communication Standard, 29 CFR 1910.1200. Standard must be consulted for specific requirements.	**U.S. Department of Labor** Occupational Safety and Health Administration (Non-Mandatory Form) Form Approved OMB No. 1218-0072

IDENTITY *(As Used on Label and List)*

Neodymium-Iron Magnet Alloy

Section I

Manufacturer's Name: Sino American Products, ltd.	**Emergency Telephone Number:** 212-947-0820
Address: 358 Fifth Avenue New York, New York 10001	**Telephone Number for Information:** 212-947-0820 **Date Prepared:** July 3, 1992

Section II - Hazard Ingredients/Identity Information

Hazardous Components *(Specific Chemical Identity; Common Name(s))*	**ACGIH TLV**	**CAS No.**	**%*(optional)***
Nd-Fe-B Alloy	Unknown	92131-46-9	100%
Neodymium	Unknown	7440-00-8	30-36%
Iron	5 mg/cm3	7439-89-6	bal.
Boron	10mg/cm3	7440-42-8	1-2%

Dysprosium	Unknown	7429-91-6	0-5%
Praseodymium	Unknown	7440-10-0	0-5%

Section III - Physical/Chemical Characteristics

Boiling Point	Unknown	**Specific Gravity (H_2O = 1)**	7.1-7.6
Vapor Pressure (mm Hg.)	Unknown	**Melting Point**	Above 1000° C
Vapor Density (AIR = 1)	Heavier than air	**Evaporation Rate (Butyl Acetate = 1)**	Very low
Solubility in Water Not determined(very low)			
Appearance and Odor Dark metallic, no odor			

Section IV - Fire and Explosion Hazard Data

Flash Point (Method Used) N/A	**Flammable Limits** N/A	**LEL** N/A	**UEL** N/A
Extinguishing Media Dry chemicals for fighting magnesium or metal fires.			
Special Fire Fighting Procedures Isolate and contain burning materials. Smother with Argon gas or non-reactive dry chemicals. Avoid water. Do not use Halon.			
Unusual Fire and Explosion Hazards For solid dense magnet: none. Powders from chipping, crushing, grinding, slicing, etc. may ignite spontaneously and burn intensely. Rare earth metal powders burn vigorously in halogen or oxidizing atmospheres.			

Section V - Reactivity Data

Stability	**Unstable**	**Conditions to Avoid**	
	Stable **X**		
Incompatibility ***(Materials to Avoid)*** Acids, highly active oxidizers.			
Hazardous Decomposition or Byproducts Hydrogen may be released when powders react with water.			
Hazardous Polymerization	**May Occur**	**Conditions to Avoid**	
	Will Not Occur	**X**	

Section VI - Health Hazard Data

Route(s) of Entry:	**Inhalation?** YES	**Skin?** YES	**Ingestion?** NO
Health Hazards ***(Acute and Chronic)***			
Entry through skin injuries may irritate and produce granulomas.			
Carcinogenicity:	**NTP?** NO	**IARC Monographs?** NO	**OSHA Regulated?** NO
Signs and Symptoms of Exposure			
Skin or eye irritations			
Medical Conditions Generally Aggravated by Exposure			
Skin cuts, abrasions, punctures.			
Emergency and First Aid Procedures			
Remove victim from dust and fume environment. Flush sin and eyes with			

water.

Section VII - Precautions for Safe Handling and Use

Steps to Be Taken in Case Material is Released or Spilled
Fine chips and powders should be gathered up by damp mop or broom. Do not use a vacuum cleaner.

Waste Disposal Method

Metal recycling.

Precautions to Be taken in Handling and Storing

Powders may ignite and burn - store under inert gas or vacuum. Storage in water may generate hydrogen gas.

Other Precautions

Use water during machining processes to control sparking of the swarf.

Section VIII - Control Measures

Respiratory Protection *(Specify Type)*
Use dust mask whenever dust is present.

Ventilation	**Local Exhaust** Use for dust and iron fumes when machining or pulverizing.	**Special**
	Mechanical *(General)*	**Other**

Protective Gloves
Use

Eye Protection
Use

Other Protective Clothing or Equipment
Garments to protect skin from direct contact.

Work/Hygienic Practices
Avoid skin injuries. If powders generated are inhaled, train workers in safe practices for combustible powders. Magnetized parts are strongly attracted to each other and to steel - handle firmly to avoid injury causing impacts.

TOP