NC STATE UNIVERSITY

College of Engineering

Department of Mechanical and Aerospace Engineering

Critical Design Review Document

Tacho Lycos

NC STATE UNIVERSITY

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Comment [C1]: Could be put into a table perhaps

Comment [C2]: Each should include Final Drawings and Specs,Final Analysis and model results anchored to test data

Comment [C3]: Need to finalize motor selection and justify

Comment [C4]: Need to compare to predictions

Comment [C5]: Discuss how Subscale flight has impacted the Full Scale vehicle

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Comment [C6]: Need to discuss this at each significant phase, especially landing

Comment [C7]: Recovery system FMECA's

Comment [C8]: Need to show actual Cp and Cg relationships and locations

Comment [C9]: Need to Update with new information

Comment [C10]: Need to show that safety hazards have been reached

Comment [C11]: Need to discuss remaining manufacturing and assembly to be completed

Comment [C12]: Discuss with special consideration given to transmitters

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Comment [C13]: Need to Make GANTT chart

1. Summary of CDR Report

1.1. Team Summary

1.1.1. Name and Mailing Address

Tacho Lycos
911 Oval Drive
Raleigh, NC 27695

1.1.2. Location

Raleigh, NC

1.1.3. Mentors

Alan Whitmore
TRA Certification: 05945

In 2002, Alan was elected prefect of the East North Carolina chapter of TRA. In 2006, he was made a member of TRA's Technical Advisory Panel (TAP), a group that advises the TRA board of directors on technical aspects of propellants, construction material, recovery techniques, etc. and which supervises individual members during the process of designing, construction, and initial flight rockets used for TRA level 3 certification. Alan has a level 3 certification with Tripoli.

James Livingston
TRA Certification: 02204

In 1993, James joined Tripoli Rocketry Association and was certified level 3 in 1997. In 1998 James became a member of the Technical Advisor Panel, TAP committee. Since then, James has assisted over 20 Tripoli members in their level 3 certifications. James has also been involved in Tripoli research since 1997 and no manufactures all the motors he uses sizes I through N.

1.2. Launch Vehicle Summary

1.2.1. Vehicle Specifications

1.2.1.1. Size, Weight, Recovery, Motor, and Rail Size

Table 1: CDR Overview

CDR	
Length	131 inches
Diameter	5.5 inches
Loaded Weight	75.1 lbs
CP (inches from nose)	95.59
CG (inches from nose)	86.44
Stability	1.66 cal
Apogee	12500 feet
Max Velocity	1261 ft/s
Max Acceleration	618 ft/s^2
Recovery	Three Main Parachutes
Motor	Cesaroni N5600WT-P

Table 2: Weight Summary

Weight (lb)	N5600WT-P	N10000-VM-P
Launch	75.10	72.10
Burnout	61.00	60.30
Nose Cone	6.10	6.10
Body Tube	20.29	20.29
Fin Section Launch	48.71	45.71
Fin Section Burnout	34.61	33.91

Table 3: Recovery Data

	Weight (lb)	Descent Rate (ft/s)	Kinetic Energy (lbf-ft)	Parachute Size (in)
Nose Cone	6.10	26.6	67.1	34
Body Section	20.29	15.3	73.8	112
Fin Section N5600	34.61	11.8	74.9	180
Fin Section N10000	33.91	11.9	74.6	180

Table 4: Motor Selections

Motor	N5600WT-P	N10000-VM-P
Total Impulse (lbf*s)	3065	2320
Average Thrust (lbf)	1264	2306
Maximum Thrust (lbf)	1517	2580
Burn Time (s)	2.42	1.01
Launch Weight (lb)	24.9	21.9
Empty Weight (lb)	10.8	10.1

Table 5: Launch Rail Selection

Motor	N5600WT-P	N10000-VM-P
Rail Length (in)	120	120
Rail Size	1515	1515
Rail Exit Velocity (ft/s)	107	151

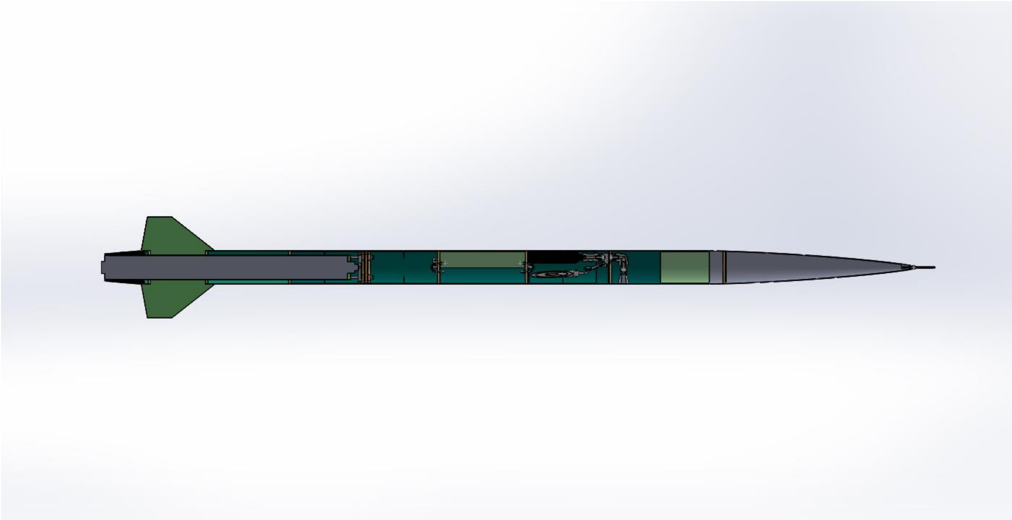

Figure 1: Rocket Assembly

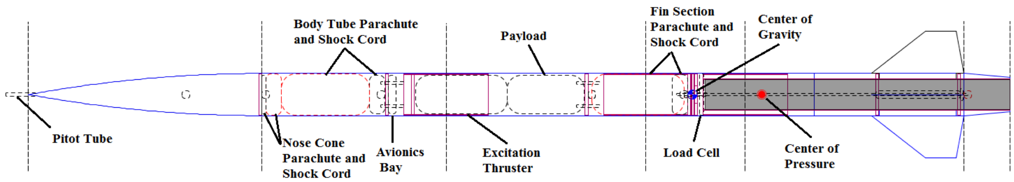

Figure 2: Labeling of Rocket Components

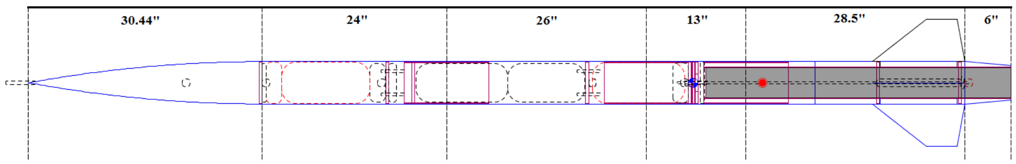

Figure 3: Rocket Section Dimensions

1.2.2. Milestone Review Flysheet

Milestone Review Flysheet

Institution	North Carolina University	Milestone	CDR

First Stage (Both Stages Together or Single Stage)		Second Stage (If Applicable)	
Vehicle Properties		**Vehicle Properties**	
Total Length (in)	131	Total Length (in)	
Diameter (in)	5.5	Diameter (in)	
Gross Lift Off Weight (lb)	75.1	Gross Weight (lb)	
Airframe Material	Blue Tube w/ Fiberglass Sock	Airframe Material	
Fin Material	1/16" FG and 1/8" Plywood	Fin Material	
Motor Properties		**Motor Properties**	
Motor Manufacturer(s)	Cesaroni	Motor Manufacturer(s)	
Motor Designation(s)	N5600WT-P	Motor Designation(s)	
Max/Average Thrust (lb)	1517/1264	Max/Average Thrust (lb)	
Total Impulse (lbf-sec)	3065	Total Impulse (lbf-sec)	
Stability Analysis		Ignition Altitude (ft)	
Center of Pressure (in from nose)	95.59	Ignition Timing (From 1st Stage Burnout)	
Center of Gravity (in from nose)	86.44	Igniter Location	
Static Stability Margin	1.66	**Stability Analysis**	
Thrust-to-Weight Ratio	20.2	Center of Pressure (in from nose)	
Rail Size (in)	1515	Center of Gravity (in from nose)	
Rail Length (in)	120	Static Stability Margin	

Rail Exit Velocity (ft/s)	107				Thrust-to-Weight Ratio				
Ascent Analysis					**Ascent Analysis**				
Maximum Velocity (ft/s)	1261				Maximum Velocity (ft/s)				
Maximum Mach Number	1.14				Maximum Mach Number				
Maximum Acceleration (ft/s^2)	618				Maximum Acceleration (ft/s)				
Target Apogee (1st Stage if Multiple Stages)	12500				Target Apogee (ft)				
Recovery System Properties					**Recovery System Properties**				
Drogue Parachute					**Drogue Parachute**				
Configuration	No Parachute				Configuration				
Size	N/A				Size				
Deployment Velocity (ft/s)	Apogee				Deployment Velocity (ft/s)				
Terminal Velocity (ft/s)	85 (From mentor's past flight data)				Terminal Velocity (ft/s)				
Fabric Type	N/A				Fabric Type				
Shroud Line Material	N/A				Shroud Line Material				
Shroud Line Length (in)	N/A				Shroud Line Length (in)				
Thread Type	N/A				Thread Type				
Seam Type	N/A				Seam Type				
Recovery Harness Type	1/2" Tubular Kevlar				Recovery Harness Type				
Recovery Harness Length (ft)	20				Recovery Harness Length (ft)				
Harness/Airframe Interface	5/16" U-bolts and 5/16" Quicklinks				Harness/Airframe Interface				
Main Parachute					**Main Parachute**				
Configuration	Round Hemispherical				Configuration				
Size	34	112	180		Size				
Deployment Velocity (ft/s)	85				Deployment Velocity (ft/s)				
Terminal Velocity (ft/s)	26.6	15.3	11.8		Terminal Velocity (ft/s)				
Fabric Type	MIL-C-44378 Type III Rip-Stop Nylon				Fabric Type				
Shroud Line Material	MIL-T-C-2754 Type 1 Flat Dacron 3/16"				Shroud Line Material				
Shroud Line Length (in)	51	168	270		Shroud Line Length (in)				
Thread Type	No. 69 Size E Nylon Thread				Thread Type				
Seam Type	Needle Hem				Seam Type				
Recovery Harness Type	1/2" Tubular Kevlar				Recovery Harness Type				
Recovery Harness Length (ft)	5	15	25		Recovery Harness Length (ft)				
Harness/Airframe Interface	5/16" U-bolts and 5/16" Quicklinks				Harness/Airframe Interface				
Kinetic Energy of Each Section (ft-lbs)	Nose Cone	Body Tube	Fin Section		Kinetic Energy of Each Section (ft-lbs)	Section 1	Section 2	Section 3	Section 4
	67.1	73.8	74.9						

Milestone Review Flysheet

Institution	North Carolina State University	Milestone	CDR

First Stage (or Single Stage)		Second Stage (If Applicable)	
Recovery System Properties		**Recovery System Properties**	
Altimeter(s)/Timer(s) (Make/Model)	PerfectFlite StratoLogger SL100	Altimeter(s)/Timer(s) Make/Model	
	Entacore AIM 3		

Transmitters (Model-Frequency-Power)	DIGI XV09/VK-900 MHz-9v	Locators/Frequencies (Model-Frequency-Power)	
	XBEE-Pro 900 - 900MHz - 50mW		
Black Powder Charge Size Drogue Parachute (grams)	2.40	Black Powder Charge Size Drogue Parachute (grams)	
	2.40		
Black Powder Charge Size Main Parachute (grams)	2.75	Black Powder Charge Size Main Parachute (grams)	
	2.75		

Payloads	
Mandatory Payload	Overview
	The dynamic modes of the vehicle are to be excited using a reaction thruster. Structural loading data from the vehicle, force data from the motor, and atmospheric data will be relayed to the ground in real-time. In addition to facilitating real-time preliminary data analysis, down linking the data ensures that data will be preserved in the unlikely event of a loss of vehicle. Development and integration of the data down link and excitation thruster bring a suitable level of challenge to the payload.
3.1	
Optional Payload 1	Overview
Optional Payload 2	Overview

Test Plans, Status, and Results	
Ejection Charge Tests	Ejection charge tests will be performed as soon as soon as the parachute bays have been constructed in the rocket. Charge sizes have been calculated using an equation provided by our mentor.
Sub-scale Test Flights	A successful sub-scale test flight has been conducted at Bayboro, NC. An apogee altitude of 2200 ft was achieved. All flight events went as planned with the exception of nosecone separation from the main vehicle. This was due to a structural failure in the plastic ring provided from the manufacturer under the loads from the ejection charge. Minimal damage to boat tail was induced at impact. A second sub-scale was launched on January 18th in Bayboro, NC. This flight successfully demonstrated the dual deploy recovery technique. The following are the results from the SL100 altimeter with the deviations from the expected results in parenthesis. Apogee: 5079 ft (-186ft) Max Velocity: 986 ft/s (+84 ft/s) Max Acceleration: 1100 ft/s^2 (+169 ft/s^2)
Full-scale Test Flights	A full-scale test flight is planned to be conducted on March 22nd at Bayboro, NC. Additional back up dates include the weekend of April 12th and 13th and the weekend of April 26th and 27th. Each of these launch events are also in Bayboro, NC.

Milestone Review Flysheet

Institution	North Carolina University	Milestone	CDR

First Stage (Both Stages Together or Single Stage)	Second Stage (If Applicable)

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Vehicle Properties			
Total Length (in)	131		
Diameter (in)	5.5		
Gross Lift Off Weight (lb)	72.1		
Airframe Material	Blue Tube w/ Fiberglass Sock		
Fin Material	1/16" FG and 1/8" Plywood		
Motor Properties			
Motor Manufacturer(s)	Cesaroni		
Motor Designation(s)	N10000-VM-P		
Max/Average Thrust (lb)	2580/2306		
Total Impulse (lbf-sec)	2320		
Stability Analysis			
Center of Pressure (in from nose)	95.59		
Center of Gravity (in from nose)	85.54		
Static Stability Margin	1.83		
Thrust-to-Weight Ratio	35.78		
Rail Size	1515		
Rail Length (in)	120		
Rail Exit Velocity (ft/s)	151		
Ascent Analysis			
Maximum Velocity (ft/s)	1058		
Maximum Mach Number	0.95		
Maximum Acceleration (ft/s^2)	1189		
Target Apogee (1st Stage if Multiple Stages)	9300		
Recovery System Properties			
Drogue Parachute			
Configuration	No Parachute		
Size	N/A		
Deployment Velocity (ft/s)	Apogee: 0 ft/s		
Terminal Velocity (ft/s)	85 (Figured from mentor's past flight data)		
Fabric Type	N/A		
Shroud Line Material	N/A		
Shroud Line Length (in)	N/A		
Thread Type	N/A		
Seam Type	N/A		
Recovery Harness Type	1/2" Tubular Kevlar		
Recovery Harness Length (ft)	20		
Harness/Airframe Interface	5/16" U-bolts and 5/16" Quicklinks		
Main Parachute			
Configuration	Round Hemispherical		
Size	34	112	180
Deployment Velocity (ft/s)	85		
Terminal Velocity (ft/s)	26.6	15.3	11.9
Fabric Type	MIL-C-44378 Type III Rip-Stop Nylon		
Shroud Line Material	MIL-T-C-2754 Type 1 Flat Dacron 3/16"		
Shroud Line Length (in)	51	168	270

Vehicle Properties	
Total Length (in)	
Diameter (in)	
Gross Weight (lb)	
Airframe Material	
Fin Material	
Motor Properties	
Motor Manufacturer(s)	
Motor Designation(s)	
Max/Average Thrust (lb)	
Total Impulse (lbf-sec)	
Ignition Altitude (ft)	
Ignition Timing (From 1st Stage Burnout)	
Igniter Location	
Stability Analysis	
Center of Pressure (in from nose)	
Center of Gravity (in from nose)	
Static Stability Margin	
Thrust-to-Weight Ratio	
Ascent Analysis	
Maximum Velocity (ft/s)	
Maximum Mach Number	
Maximum Acceleration (ft/s)	
Target Apogee (ft)	
Recovery System Properties	
Drogue Parachute	
Configuration	
Size	
Deployment Velocity (ft/s)	
Terminal Velocity (ft/s)	
Fabric Type	
Shroud Line Material	
Shroud Line Length (in)	
Thread Type	
Seam Type	
Recovery Harness Type	
Recovery Harness Length (ft)	
Harness/Airframe Interface	
Main Parachute	
Configuration	
Size	
Deployment Velocity (ft/s)	
Terminal Velocity (ft/s)	
Fabric Type	
Shroud Line Material	
Shroud Line Length (in)	

Thread Type		No. 69 Size E Nylon Thread			Thread Type				
Seam Type		Needle Hem			Seam Type				
Recovery Harness Type		1/2" Tubular Kevlar			Recovery Harness Type				
Recovery Harness Length (ft)		5	15	25	Recovery Harness Length (ft)				
Harness/Airframe Interface		5/16" U-bolts and 5/16" Quicklinks			Harness/Airframe Interface				
Kinetic Energy of Each Section (ft-lbs)	Nose Cone	Body Tube	Fin Section		Kinetic Energy of Each Section (ft-lbs)	Section 1	Section 2	Section 3	Section 4
	67.1	73.8	74.6						

Milestone Review Flysheet

Institution	North Carolina State University	Milestone	CDR

First Stage (or Single Stage)		Second Stage (If Applicable)	
Recovery System Properties		**Recovery System Properties**	
Altimeter(s)/Timer(s) (Make/Model)	PerfectFlite StratoLogger SL100	Altimeter(s)/Timer(s) Make/Model	
	Entacore AIM 3		
Transmitters (Model-Frequency-Power)	DIGI XV09/VK-900 MHz-9v	Locators/Frequencies (Model-Frequency-Power)	
	XBEE-Pro 900 - 900MHz - 50mw		
Black Powder Charge Size Drogue Parachute (grams)	2.4	Black Powder Charge Size Drogue Parachute (grams)	
	2.4		
Black Powder Charge Size Main Parachute (grams)	2.75	Black Powder Charge Size Main Parachute (grams)	
	2.75		

Payloads

Mandatory Payload	Overview
3.1	The dynamic modes of the vehicle are to be excited using a reaction thruster. Structural loading data from the vehicle, force data from the motor, and atmospheric data will be relayed to the ground in real-time. In addition to facilitating real-time preliminary data analysis, down linking the data ensures that data will be preserved in the unlikely event of a loss of vehicle. Development and integration of the data down link and excitation thruster bring a suitable level of challenge to the payload.
Optional Payload 1	Overview
Optional Payload 2	Overview

Test Plans, Status, and Results

Ejection	Ejection charge tests will be performed as soon as soon as the parachute bays have been constructed in the rocket. Charge sizes

Charge Tests	have been calculated using an equation provided by our mentor.
Sub-scale Test Flights	A successful sub-scale test flight has been conducted at Bayboro, NC. An apogee altitude of 2200 ft was achieved. All flight events went as planned with the exception of nosecone separation from the main vehicle. This was due to a structural failure in the plastic ring provided from the manufacturer under the loads from the ejection charge. Minimal damage to boat tail was induced at impact. A second sub-scale was launched on January 18th in Bayboro, NC. This flight successfully demonstrated the dual deploy recovery technique. The following are the results from the SL100 altimeter with the deviations from the expected results in parenthesis. Apogee: 5079 ft (-186ft) Max Velocity: 986 ft/s (+84 ft/s) Max Acceleration: 1100 ft/s^2 (+169 ft/s^2)
Full-scale Test Flights	A full-scale test flight is planned to be conducted on March 22nd at Bayboro, NC. Additional back up dates include the weekend of April 12th and 13th and the weekend of April 26th and 27th. Each of these launch events are also in Bayboro, NC.

1.3. Payload Summary

1.3.1. Payload Title

Effects of High Boost, Super Sonic Flight Environment, and Dynamic Excitation Response on Electrical Systems and Structural Integrity of a Sounding Rocket

1.3.2. Payload Requirements Selected

3.2.1.3 Structural and dynamic analysis of air frame, propulsion, and electrical systems during boost.
3.2.2.2 Aerodynamic analysis of structural protuberances.

1.3.3. Experiment Summary

The experiment to be done in the flight vehicle has many facets reaching many aspects of engineering. The experiment is designed to complete a multitude of tasks as requested from NASA and some set forth by the team. During flight the payload will gather data including structural stresses induced on different portions of the vehicle, motor performance and thrust output, telemetry and acceleration data and the dynamic response to an explicit disturbance produced by a cold gas reaction thruster. The data gathered is to be transmitted in real time to a ground station for some real time processing and recording for later analysis. In addition, an experimental hazard detection system will be used to determine safe landing zones post main parachute deployment. The complexity of the experiment forces the team to exercise knowledge in all aspects of STEM and will help to solidify concepts and techniques learned in the class room in a real world environment.

2. Changes Made Since PDR

The changes made to the flight vehicle, payload experiment, and project plan have been made to ensure ease of construction, launch assembly, reliability of systems and team, spectator, and environmental safety. These changes include modifications to the fin-section, These changes will be described in detail in the fin section subsystem section.

There have been no major modifications to the experimental payload or the project plan. All minor modifications are a result of design refinement.

2.1. Vehicle Criteria

The only subsystem with major modifications since PDR is the fin section. The fin section has been split into two pieces aft of the load cell. This modification was made in order to allow access to the load cell after fin section construction. Previously, upon completion, the load cell would have been sealed inside. In the event of a failure from a broken wire or detached strain gage, the fin section would have had to of been destroyed to repair the problem. Also, this made it impossible to inspect the load cell post flight for damage or fatigue. The new design allows for easy access and increased structural strength with the addition of 5/16 threaded rod from the aft most centering ring to the forward most bulkhead in the fin section assembly. Additionally, all couplers are now two times the diameter at 11 inches.

The interface between the load cell and the load bearing bulkhead has been reinforced as requested by the RSO. The steps taken to ensure the safe transfer of thrust from the motor to the flight vehicle include the addition of two additional partial bulkheads and two 1/8” G10 FR4 fiberglass bulkheads. Post initial testing, it has been shown that this interface is more than adequate to with stand the force exerted by the both motors proposed.

As mentioned previously, the new design will be detailed fully in the subsection overview.

Table 6: Overview of Changes to Rocket

	PDR	CDR	
Motor	N5600WT-P	N5600WT-P	N10000-VM-P
Length (in)	128	131	131
Diameter (in)	5.5	5.5	5.5
Loaded Weight	69	75.1	72.1
CP (inches from nose)	95.38	95.59	95.59
CG (inches from nose)	87.03	86.44	85.54
Static Margin (cal)	1.52	1.66	1.83
Apogee (ft)	13900	12500	9300
Max Velocity (ft/s)	1385	1261	1058
Max Acceleration (ft/s^2)	678	618	1189
Thrust to Weight Ratio	21.99	20.20	35.78
Rail Length (in)	96	120	120
Rail Exit Velocity (ft/s)	102	107	151
Time to Apogee (s)	26.2	26.1	22.6
Recovery	One Parachute for Nose, Body, and Fin Sections		

2.2. Payload Criteria

No major changes have been made to the payload since PDR.

2.3. Project Plan

No major changes have been made to the project plan since PDR.

3. Vehicle Criteria

3.1. Selection, Design and Verification of Vehicle

3.1.1. Mission Statement

To design, manufacture, test, and launch a structurally sound rocket with integrated systems specifically built to record data on varying aspects of the rocket's performance, all while keeping safety a priority.

3.1.2. Requirements

A successful mission involves:

The rocket must be reusable such that it is able to be launched again on the same day without any repairs or modifications.

The rocket must stay under the 20,000 feet AGL apogee limit.

The parachute system must be manufactured by the team.

Each independent section must be under a maximum kinetic energy of 75 ft-lbf and must all have electronic tracking devices.

The rocket must contain redundant altimeters with separate power supplies for the recovery system.

The recovery electrical system must be separate from the payload.

A hazard detection system must transmit data in real time to the ground.

The payload must meet the requirements from the options listed in the NASA Student Launch Handbook.

Launch and safety checklists must be used.

3.1.3. Mission Success Criteria

Intelligent application of research

Proper planning and scheduling

Critical analysis of design simulation and results of testing

Enforcement of mission requirements

Strict adherence to NASA requirements and criteria

Successful data acquisition

3.1.4. Major Milestone Schedule

Milestone	Date
Project Initiation	12 September 2013
Initial Design Concepts (NCSU Senior Design)	24 September 2013
Initial Design Proposal (NCSU Senior Design)	3 October 2013
Initial Design Refinement (NCSU Senior Desing)	29 October 2013
NASA SLI Program Announced	8 November 2013
Initial Experimental Designs (NCSU Senior	14 November 2013

Design)	
Preliminary Design Review (NCSU Senior Design)	14 November 2013
Proposal Submitted to NASA (unchanged from NCSU Senior Design)	20 November 2013
Stability Demonstration Launch (Senior Design Configuration)	24 November 2013
With faculty support, replaced/combined Senior Design requirements with SLI requirements	2 December 2013
Revised Proposal Submitted to NASA	6 December 2013
PDR Submitted to NASA	10 January 2014
Dual Deploy Demonstration Launch	18 January 2014
Review of (Re)Design Progress	28 January 2014
Further Experiments Designed for Full Scale Vehicle	11 February 2014
CDR Submitted to NASA	28 February 2014
FFRR for Prime Launch Window	14 March 2014
Full Scale Launch Prime Window	22 March 2014
FFRR for Secondary Launch Window	4 April 2014
Full Scale Launch Secondary Window	12 April 2014
FFRR for Contingency Launch Window	18 April 2014
NCSU Senior Design Final Presentation	23 April 2014
Contingency Launch Window	26 April 2014

3.1.5. Review by Subsystems

3.1.5.1. Nose Cone

The nose cone of the rocket can be optimized for a wide range of flight conditions. Depending on the speed regime and mission, different nose cone shapes are better suited. From an early phase of the design, it was determined that purchasing a nosecone would be more cost effective and time efficient than custom fabricating a nosecone. This constrained the nose cone geometry to those available from commercial vendors. Based off preliminary estimates of the rocket's top speed, it was determined that supersonic velocities would not be encountered. The payload was located well aft of the nose cone and imposed no constraints on the geometry of the nose cone.

A filament wound Von Karman nose cone was selected due to its low drag characteristics and availability from vendors. The diameter of the nose cone is 5.5 inches and the length is 30.44 inches. The tip of the nose cone is a removable aluminum point that will be drilled out in order to accommodate a Pitot tube. Figure 4 shows the location of the Pitot tube. A bulkhead will be fitted in the aft portion of the nose cone. A U-bolt and carabiner will attach the nosecone bulkhead to a shock cord connected to the upper body tube bulkhead. A four inch shoulder will interface the nose cone and upper body tube. Shear pins will secure the shoulder to the upper body tube until parachute ejection.

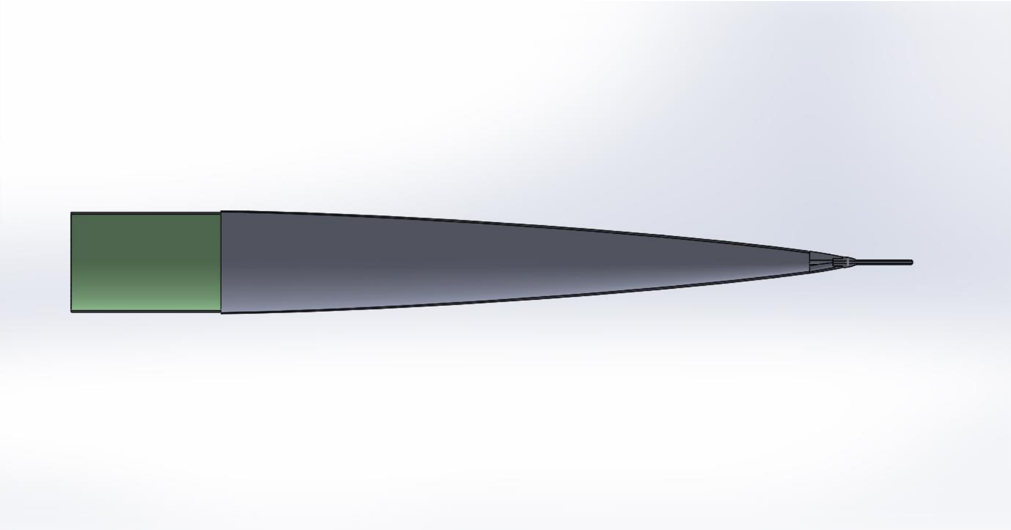

Figure 4: Full Scale Nose Cone Assembly

3.1.5.2. Airframe

The body tube of the flight vehicle will be constructed of 5.5" diameter Blue Tube. Blue Tube offers greater strength than unreinforced cardboard while maintaining a lower weight than standard filament wound fiberglass tubing. Some of the high strength attributes of fiberglass can be imparted on the Blue Tube airframe by wrapping the fuselage with a single layer of fiberglass. This can be easily accomplished by enveloping each section of the body tube in a fiberglass sleeve which also permits smoother finishing of the airframe.

Internally, the fiberglass wrapped Blue Tube will be reinforced by a number of bulkheads and centering rings constructed of 3/8-inch birch aircraft plywood. The bulkheads nearest to the motor will be reinforced with flock for additional strength.

The motor itself will interface to the vehicle via a load cell securely mounted to a series of birch aircraft plywood and G10 FR4 fiberglass bulkheads in the aft section of the rocket. A fiberglass sleeve will surround the motor casing, providing additional structural strength as well as heat mitigation.

The body tube of the rocket is separated in three locations. The farthest aft split, located aft of the load cell. This interface is for ease of access to the load cell for inspection and repairs if necessary. It is to be secured by 4 5/16 threaded rods run from the aft most centering ring to the fin section bulkhead assembly. The next split occurs just forward of this bulkhead and will be secured by nylon shear pins and will allow for easy fin section separation at apogee. The aft portion of the rocket at this connection is the fin section and has a length of 49.5 inches. This section will include the fin configuration as well as the load cell, rocket motor, and house one of the main parachutes. The third split is located near the middle of the body tube and is secured with stainless steel screws as it is not designed to separate in flight. The aft portion of this separation is the lower body tube and has a length of 26 inches. The lower body tube will contain the payload bay. A Blue Tube coupler will hold the upper and lower body tubes together. Disassembly of the rocket at this joint will provide convenient access to the payload bay for installation and servicing. The upper body tube portion will extend from the second separation to the nose cone and will be 24 inches long. The upper body tube will contain the excitation thruster, avionics bay, and the second main parachute. During preparations for launch, a hatch covering, an opening through the body tube, will provide access to the avionics bay and thruster.

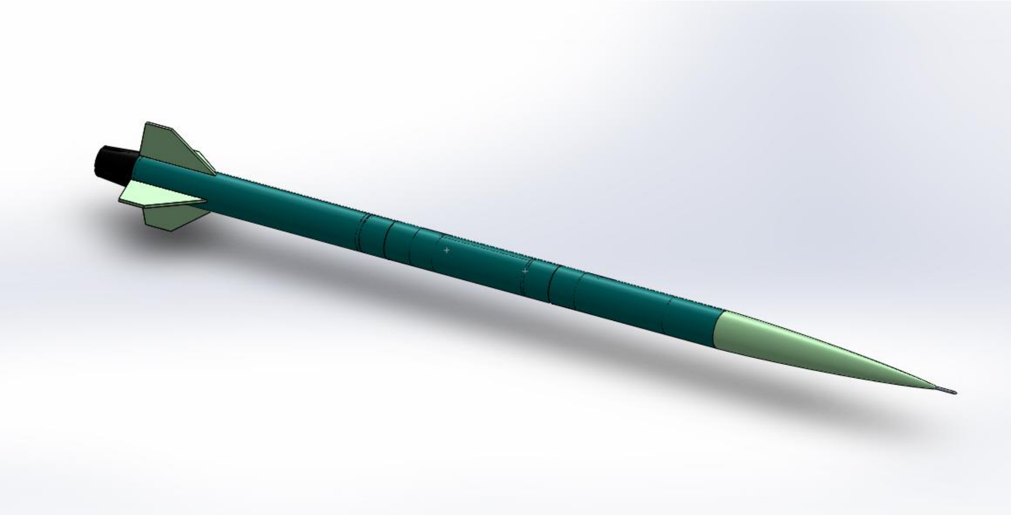

Figure 5: Rocket Assembly

Figure 6: Exploded Fin Section

Figure 7: Exploded Rocket View

A conical boat tail was added to the initially proposed airframe in order to reduce drag on the rocket and move the center of pressure forward. The conical boat tail has a length of 6 inches, fore diameter of 5.5 inches, and an aft diameter of 4.38 inches. The addition of the boat tail will also move the engine mount 6 inches aft where it was initially positioned. This will provide additional room in the lower section of the body tube fin section main parachute is located.

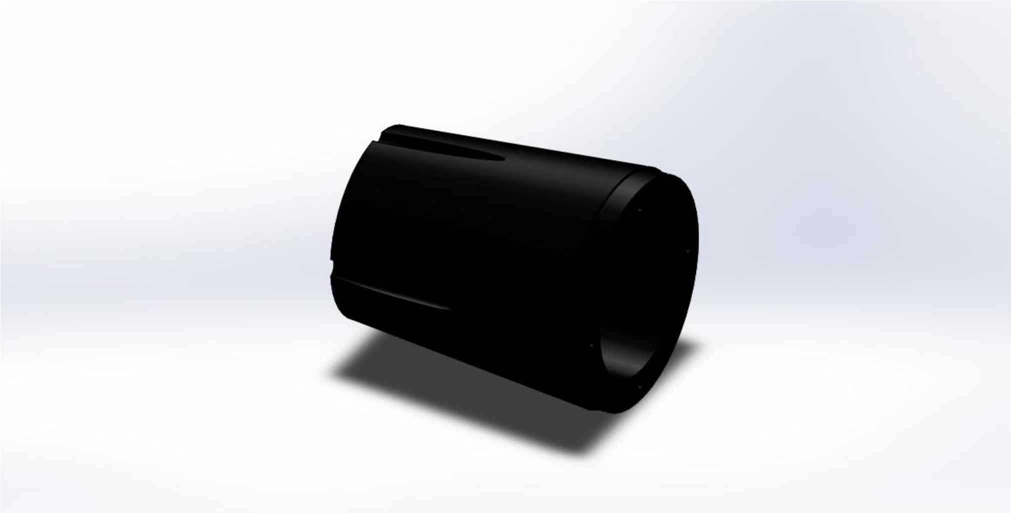

Figure 8: Boat Tail

3.1.5.3. Avionics

The vehicle avionics include the redundant altimeters responsible for setting off the black powder charges that deploy the main and drogue parachutes. As a primary vehicle system, the altimeters will be included on every flight of the rocket including those carrying the customer's payload. An avionics bay will also be included in the dual deploy subscale rocket. The avionics bay includes two altimeters and two 9 volt batteries that are attached to a fiberglass sled. A PerfectFlite StratoLogger SL100 and an Entacore AIM 3.0 are the altimeters to be used. These altimeters will be connected to a charge for fin section separation and the main parachutes. The altimeters will also record maximum altitude.

3.1.5.4. Stability

While significant throughout the entirety of powered and coasting flight, the stability of the flight vehicle is of particular concern during actuation of the cold gas thruster. The experimental goal of predicting and observing the response of the vehicle to a disturbance requires simulation of the behavior of the flight vehicle after perturbation. In addition, the impact of the disturbance on the vehicle's flight path must be considered and any potential safety impacts mitigated.

Initial analysis focused on determining the location of the flight vehicle's center of pressure. Barrowman's method of normal force coefficients was used and a MATLAB script (included in Appendix 7.1.1) written to accomplish the necessary operations. $C_{N\alpha}$ for the whole flight vehicle was predicted to be 10.6 with the aerodynamic center located 95.3 inches aft of the datum (tip of the nosecone).

Preliminary analysis predicted the force required to perturb the flight vehicle by a desired angle of attack, α. The rocket was treated as a rigid body and aerodynamic forces were neglected. Since thruster actuation will occur after motor burnout, a constant moment of inertia was used for the calculation. The MATLAB script written for thrust prediction is included in Appendix 7.1.2. For a moment of inertia of 4407 slug-in^2, a desired perturbation of 3°, and a "firing time" of 0.61 s, 1240.3 in-lb of torque is required. Given a moment arm of 35 in, 35.4 lb of thrust is required.

Preliminary prediction of the dynamic response of the vehicle to the 3° disturbance assumed that the vehicle started from rest at its displaced position and was then allowed to oscillate freely. The observed response is shown as Figure 9. The dynamic characteristics of the vehicle's response are included in Table 7.

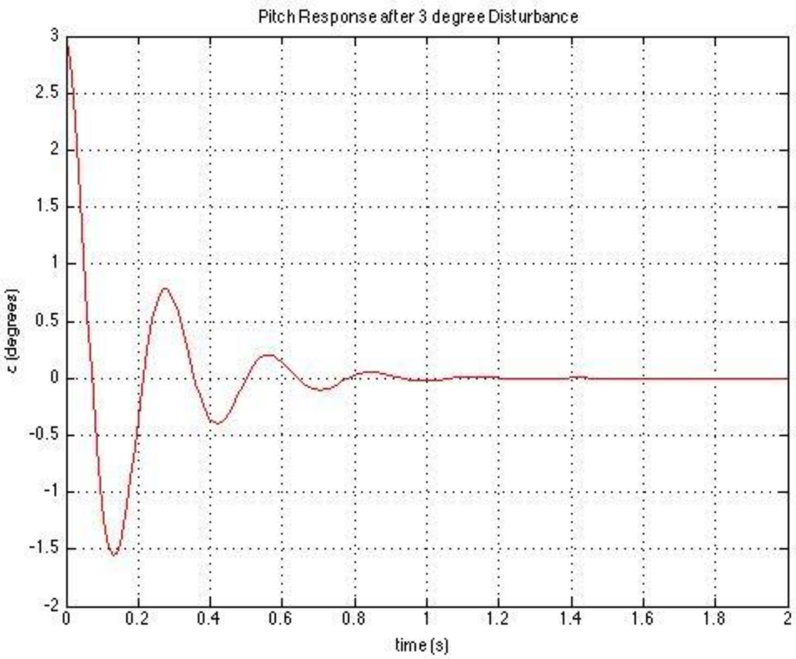

Figure 9: Dynamic Response to 3° Disturbance

Table 7: Flight Vehicle Dynamic Response Parameters

Parameter	Value	Unit
Frequency	22.5 (3.6)	rad/s (Hz)
Damping Ratio	0.21	-
Period	0.28	s
Time-to-Half	0.15	s

The time-to-half of the vehicle's dynamic response is significant when determining the sampling rate for the onboard systems that will record the behavior of the vehicle. Sufficient data points must be taken over 0.145 s in order to reconstruct the significant features of the response. The preliminary analysis allowed for sizing of the thruster and initial determination of the requirements placed on the payload electronics.

Obtaining a more complete simulation of the dynamic response of the vehicle required that the angle of attack be calculated both under forced and free oscillation. The dynamic system represented by equation 1 was modeled in Simulink and subject to a step-wise input equal to the disturbing torque.

(1) $$\alpha'' + C_2/I_L\,\alpha' + C_1/I_L\,\alpha = \Gamma_e/I_L$$

Note that in equation 2 and 3, C_2 is the damping moment coefficient, C_1 is the corrective moment coefficient, I_L is the longitudinal moment of inertia, and Γ_e is the effective torque acting to excite the vehicle. Equations for the damping and corrective moment coefficients are given below.

(2) $$C_1 = \tfrac{1}{2}\,\rho\,V^2 A_r\,C_{N\alpha}\,(Z - W)$$
(3) $$C_2 = \tfrac{1}{2}\,\rho\,V A_r\,[C_{N\alpha,component}\,(Z_{component} - W)]$$

In the above equations, ρ is density, V is flight vehicle velocity, and A_r is the reference area. $C_{N\alpha}$ represents the normal force coefficient of the whole vehicle or of a particular component, if so noted. Likewise, Z represents the center of pressure of the whole vehicle or a particular component, if so noted. W represents the center of gravity of the entire flight vehicle during the phase of flight being evaluated. The Simulink model constructed to represent the above equations is included as Figure 10.

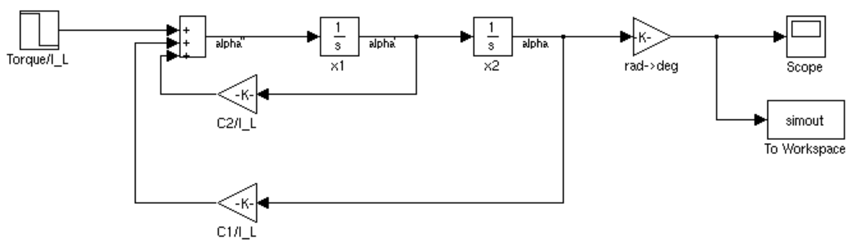

Figure 10: Simulink Model for Alpha Response Prediction

Using the Simulink model, the complete response of the vehicle to the perturbing moment and subsequent free oscillation was simulated. Figure 11 shows this response.

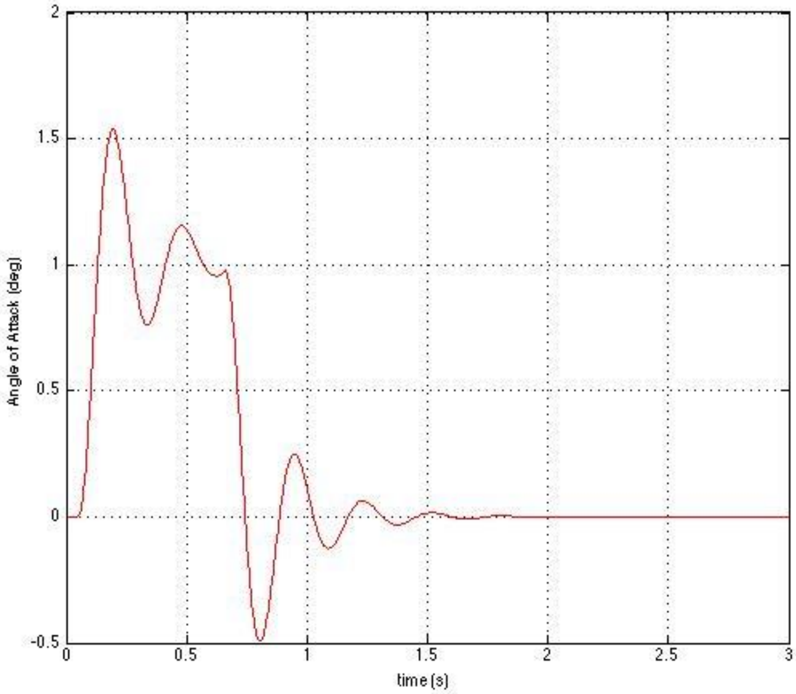

Figure 11: Complete Response of Flight Vehicle to Disturbance

The full response simulation reveals that the applied torque will only achieve a disturbance of approximately 1.5°. Due to the fact that the thruster will be operated for nearly three times the period of oscillation, the vehicle begins to oscillate under the constant torque from the thruster before returning to a free oscillation state approximately 0.6 s from thruster activation (t = 0). This finding suggests that thruster operation time could be decreased without affecting the maximum displacement of the vehicle. Alternatively, the current time of 0.61 s allows observation of the dynamic response both under forced and free oscillation.

From a safety standpoint, the net flight path change resulting from the thruster disturbance is important. Intuition suggests that the 1.5° maximum $\Delta\alpha$ would not produce a significant change in flight path. This intuition was verified by estimating the flight path angle under a number of assumptions. Velocity and density were assumed to be constant and the normal force was taken to remain orthogonal to the vertical flight direction. Zero roll rate was assumed and the constant velocity was assumed to be in the vertical direction. Under these assumptions, the normal force coefficients estimated with Barrowman's method were used to calculate a horizontal acceleration. Numeric integration by the trapezoid rule produced an estimate of velocity and trajectory. Flight path angle was estimated by determining the angle between the constant vertical velocity and the horizontal velocity after thruster actuation. Equation 4 shows the trigonometric relationship used to estimate flight path angle.

(4) $\Theta \sim tan^{-1}(V_x / V_y)$

Figure 12 and 13 show the horizontal acceleration and velocity estimated from the angle of attack profile and normal force coefficients. Note that the horizontal velocity asymptotically approaches a constant value of 1.84e-02 ft/s. Vertical velocity was estimated to be constant at 550 ft/s (approximately 8.5 s after motor burnout). Using the approximation, the change in flight path angle was estimated to be 0.11°. The assumptions made to enable the approximation also introduce a range of potential error. As such, it is not possible to treat the estimated flight path angle change as an exact value. Rather, the estimated flight path angle change of 0.11° suggest that the perturbation from the thruster will have minimal impact on the flight path of the vehicle. Especially when compared with the potential effect of wind shift and gusts on the vehicle, the flight path angle change due to the thruster actuation poses minimal risk to safety of flight.

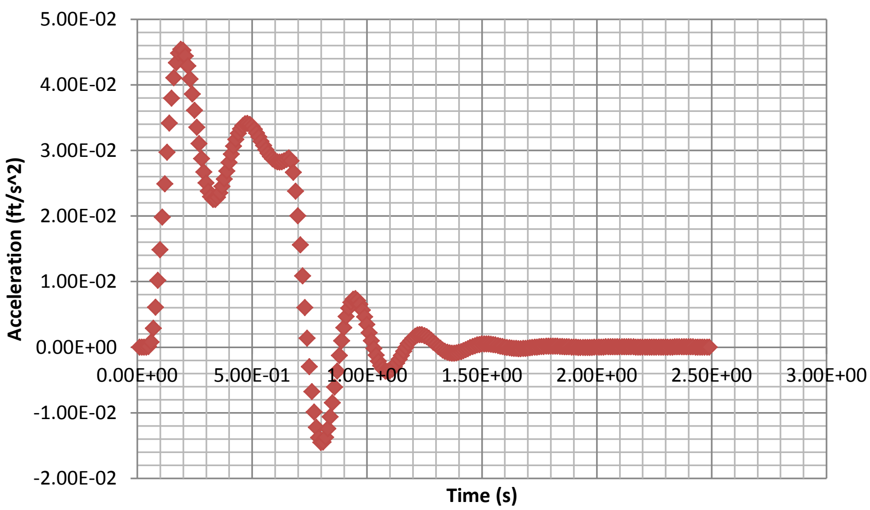

Figure 12: Horizontal Acceleration Determined from α and $C_{N\alpha}$

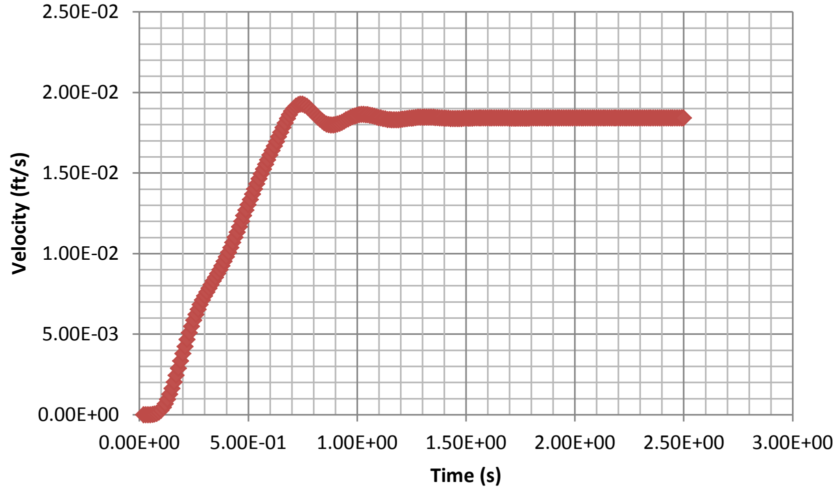

Figure 13: Horizontal Velocity Approximated via Numeric Integration

3.1.5.5. Exciter

The dynamic modes of the rocket are to be excited and its response recorded. This is to be accomplished by utilizing a N_2 gas fueled reaction thruster. Preliminary calculations have shown that the rocket can support a thruster design capable of producing up to 25 lbs of thrust without becoming overly heavy and impractical. The general layout of the exciter can be seen in Figure 14.

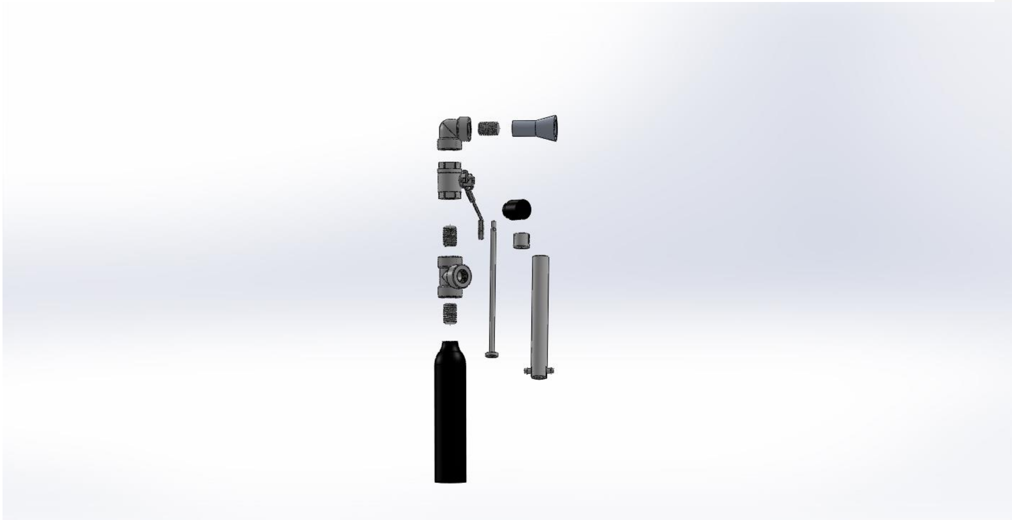

Figure 14: Exciter General Layout

Figure 15: Exciter Cut View

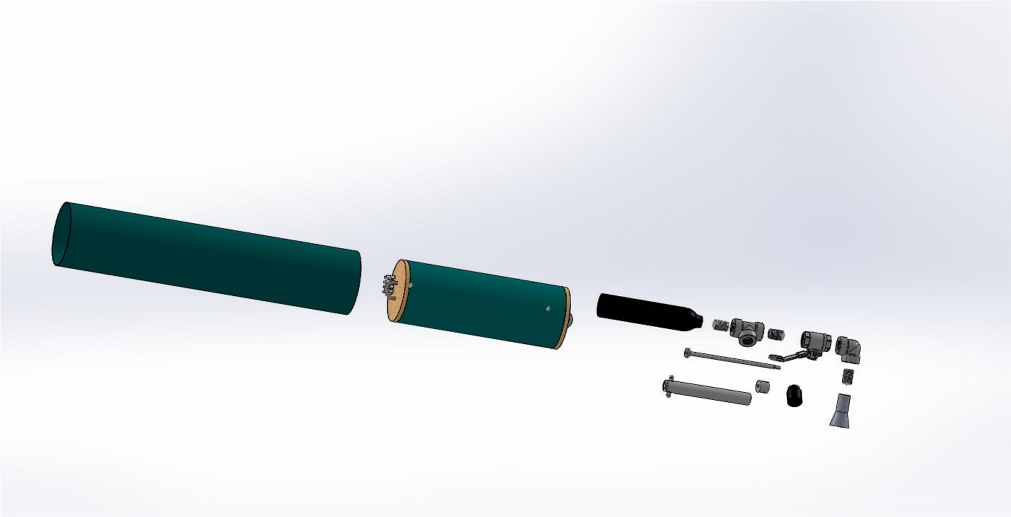

Figure 16: Exciter Location Above Payload

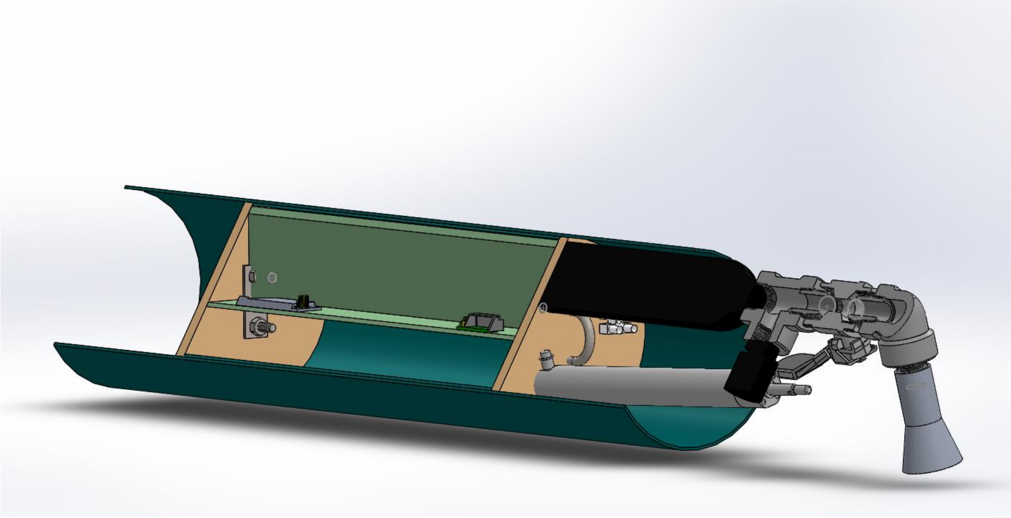

Figure 17: Exciter Layout

The rocket will have an on board pressure vessel to store the compressed nitrogen gas at an estimated 100 psi. This pressure is sufficient to support 3-15 lbs of thrust utilizing a C-D nozzle with throat diameters ranging from 0.24” – 0.50”. The system will be activated via a full-flow solenoid valve controlled by the Arduino in the payload bay. In order to mitigate valve shut-off failure, the system is designed to exhaust the entire contents of its pressure vessel in order to achieve the desired disturbance. Further testing is required to certify the exact mass of propellant required for the desired disturbance.

3.1.5.6. Fin Section

Many parameters have been taken into consideration during the design of the rockets fin can. There are many options when designing the fin can, all of which can dramatically affect the rockets stability, maximum velocity, maximum altitude, etc. The design rendered in Figure 18 is the product of careful consideration of these parameters and their effects on overall performance.

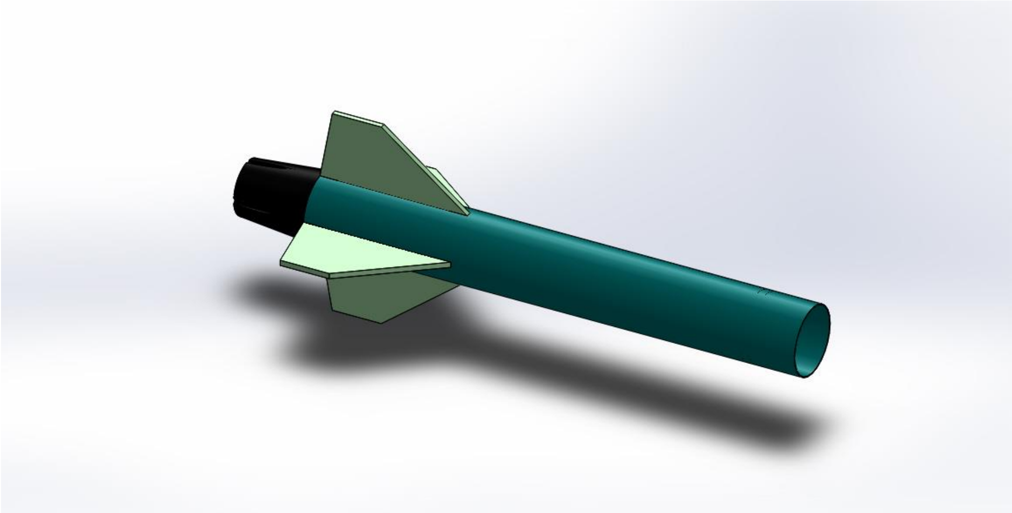

Figure 18: Fin Section

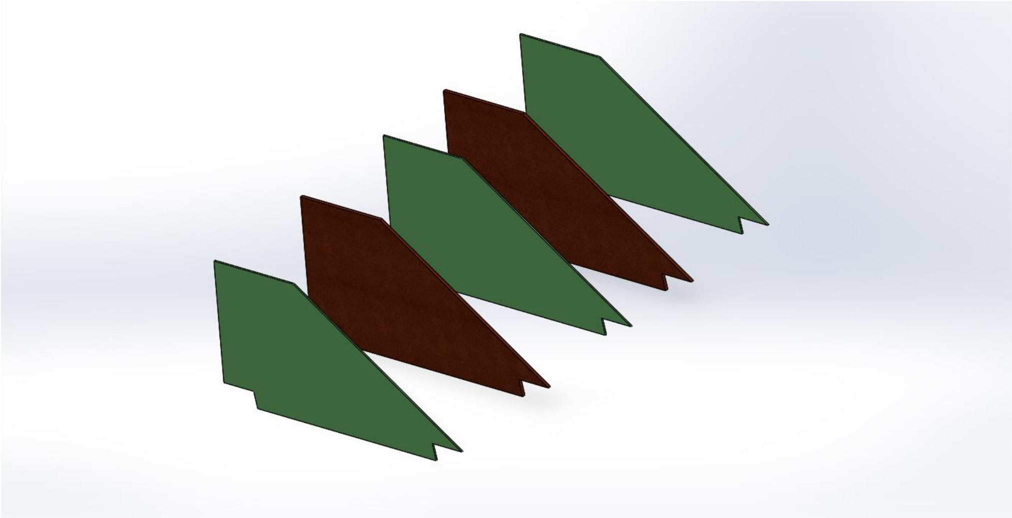

Figure 19: Fin Composite Layers

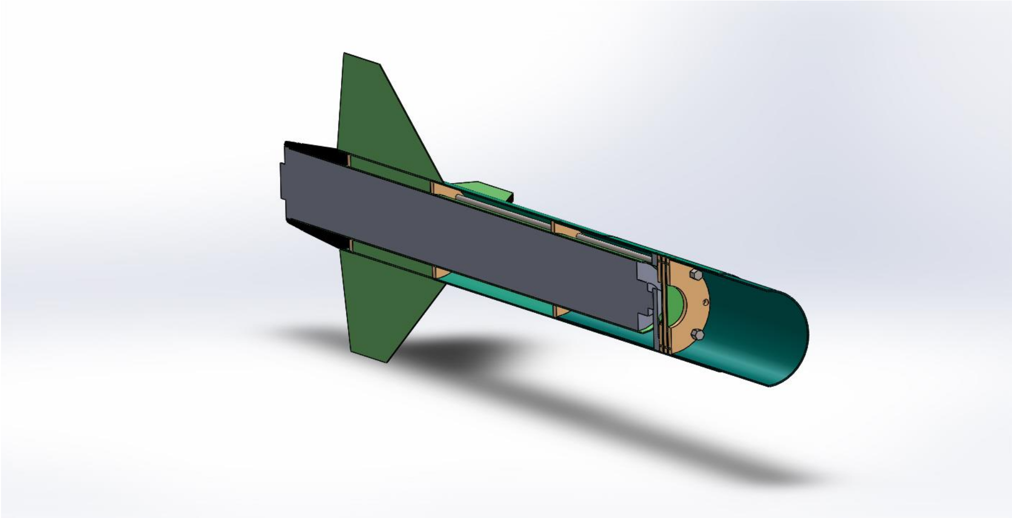

Figure 20: Cut Fin Section

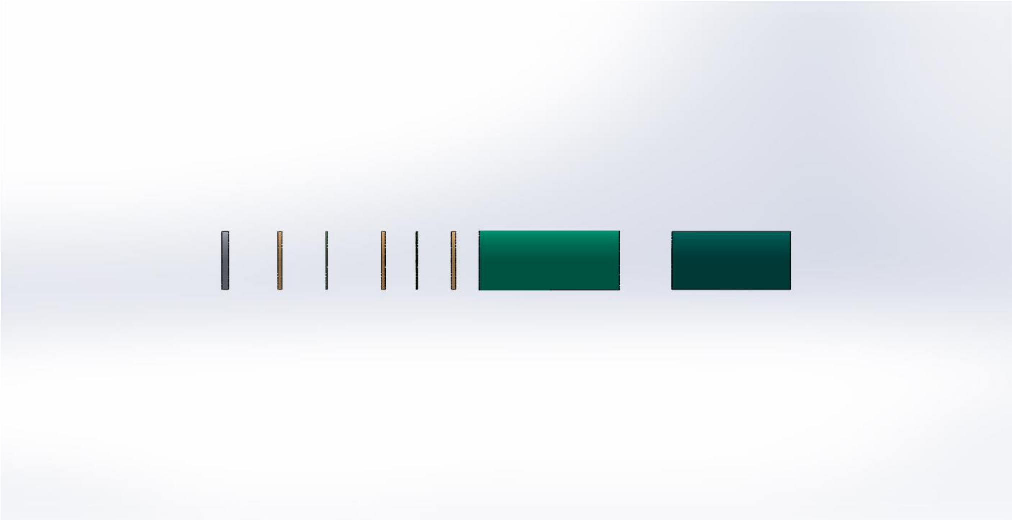

Figure 21: Exploded Bulkhead Design

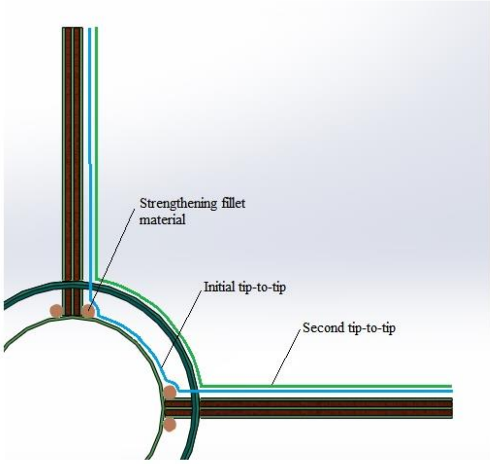

Figure 22: Fin Section Layup

The fin shape and size design focused on drag reduction, tip impact damage reduction, and aesthetics. The fins are trapezoidal, clipped delta, in shape with a 51.8 degree sweep on the leading edge and 79.7 degree forward sweep on the trailing edge and root and tip chords 12" and 4", respectively. The overall span of the fins is 16.5". The leading edge sweep is included to improve the aerodynamic performance of the fins by reducing the lateral incident angle of the incoming flow on the leading edge of the fin. In addition to this leading edge sweep, all exposed sides of the fins will be rounded to avoid stagnation as the flow impedes on the leading edge and reduce turbulent trailing edge flow. The trailing edge forward sweep reduces the chance of fin tip impact upon fin can impact with the ground during recovery.

Due to the extreme conditions the fins will endure during supersonic flight, careful consideration was taken to strengthen the fin design and avoid "fin flutter" which could lead to fin failure. They shall be constructed of multiple layers using five layers of material, three 1/16" fiberglass layers and two 1/8" birch plywood layers. Each ply of the fins will be epoxied together prior to assembly of the fin section. Upon assembly the fins will be attached to the fiberglass motor sleeve and wrapped tip-to-tip with multiple layers of fiberglass cloth. The body tube, notched out for the fins, will then be slid over the inner assembly and again wrapped tip-to-tip on the exterior of the fin section. Though the extra fiberglass layers add unwanted weight to the vehicle, the extra strength provided is most valuable to avoid catastrophic fin failure during flight.

The fin can exploded view in Figure 24 shows the internal structure of the fin can. The internal structure consists of 2 centering rings positioning a fiber glass motor sleeve to the fin can body tube. The motor will be mounted to the 6061-T aluminum load cell via 3/8" threaded rod. The load cell will then be attached to a 3/8" Birch plywood bulkhead epoxied to the fin can body tube. The fin can load cell-bulk head-body tube connection was designed specifically to ensure the thrust produced by the rocket acts solely through the load cell. In order to reduce failure modes, the load cell was designed with two thicknesses such that it will bottom out, prior to experiencing plastic deformation, on the bulk head forward of the load cell and on the fiberglass motor sleeve aft of the load cell.

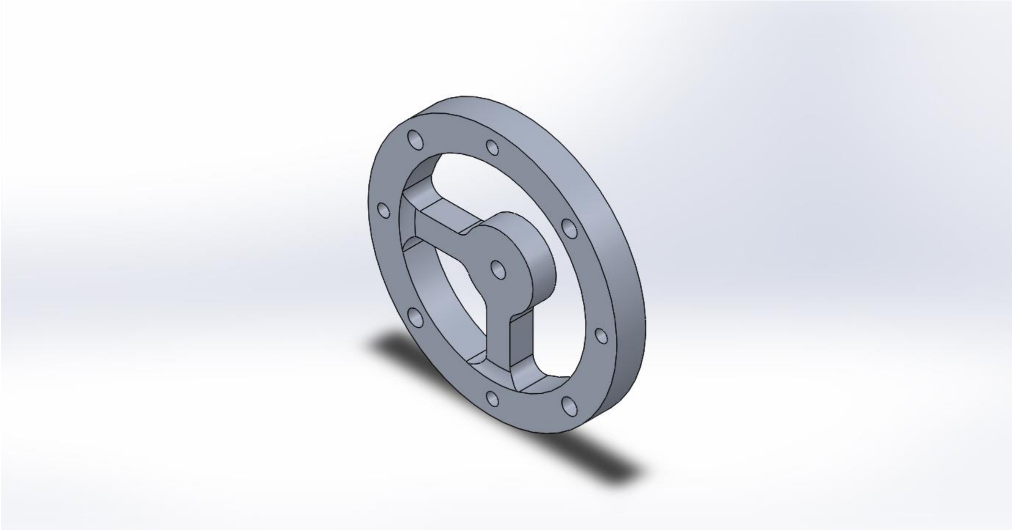

Figure 23: Load Cell

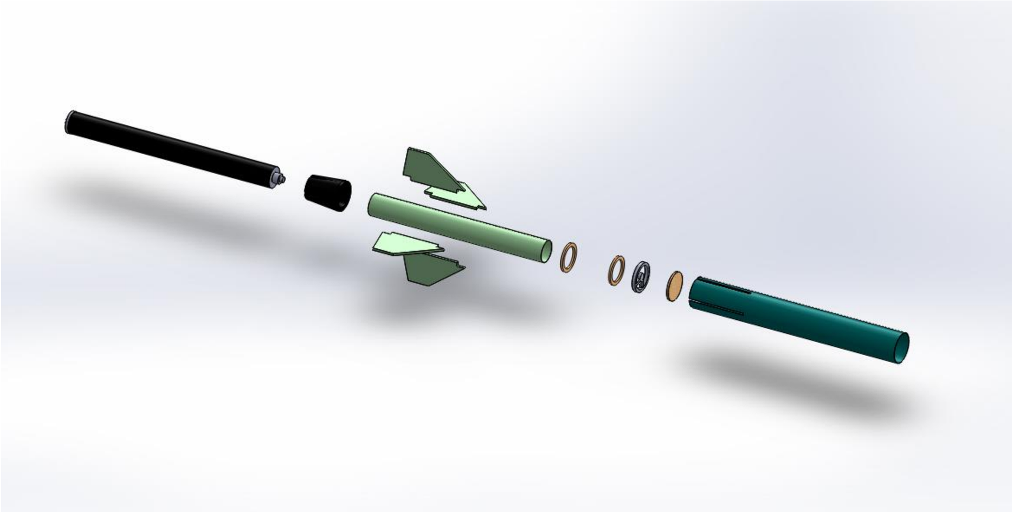

Figure 24: Exploded Fin Section

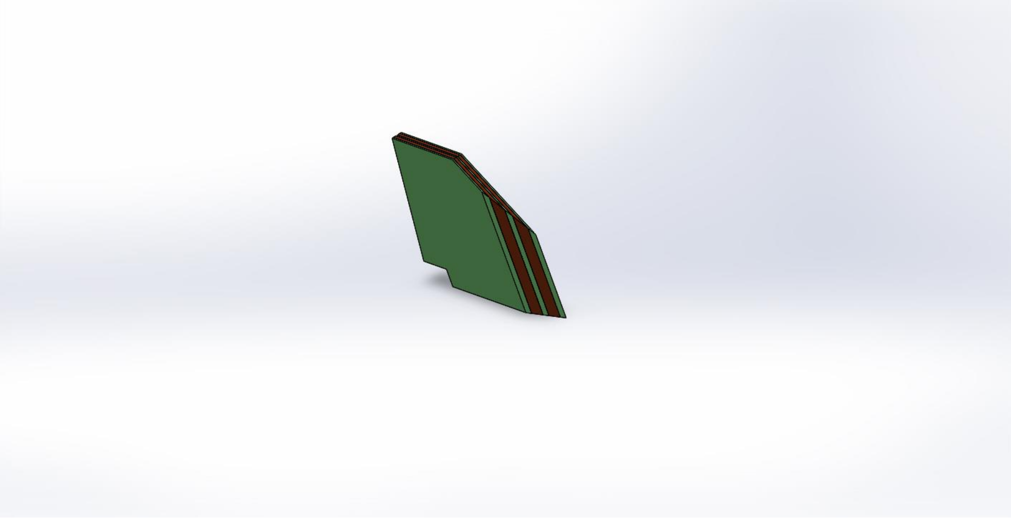

Figure 25: Cut View of Fin Composite

The final component of the fin can is the aft boat tail. The boat tail is designed to be 5.5" in diameter at the forward section and 4.38" in diameter and extends 6" beyond the end of the rocket. The addition of the boat tail greatly reduces the turbulent trailing flow reducing the overall drag the rocket experiences and increasing apogee.

3.1.5.7. Motor

The current motor selected for the rocket is the Cesaroni Technology Incorporated N5600WT-P. This motor was chosen after a full model of the rocket was made in Open Rocket. Open Rocket calculated an estimate of the mass of the rocket and a motor was paired that would propel it to supersonic speeds. The total impulse of the N5600WT-P motor is 13633 Ns. The average thrust is 5622 N with a maximum thrust of 6750 N. The burn time is expected to be 2.42 seconds. The launch weight of the rocket motor is 24.9 lbs with an empty weight of 10.8 lbs. This means that 14.1 lbs of propellant is expelled during flight and should be accounted for when determining parachute sizes. The maximum velocity from Open Rocket is 1385 ft/s (M=1.29) with a maximum acceleration of 678 ft/s2. The projected apogee for the proposed rocket is 13900 feet.

3.1.6. Subscale Flight Results

3.1.6.1.1. Overview

The subscale flight vehicle launch occurred on January 18th, 2014 at approximately 4:00pm. Launch conditions were cool with a recorded temperature of 49^0, partly cloudy, and brisk winds of 10-12 mph. There was not any low cloud cover so conditions were favorable for a good launch and recovery. The rocket was a (1:2.149) scale with a J350W motor and the following specs:

Table 8: Subscale Overview

Length	59.56 in.
Diameter	2.56 in.
Weight	5.6 lbs.
Center of Gravity	38.2 in.
Center of Pressure	42.7 in.
Static Margin	1.7 cal.
Recovery	24 in. main

The launch went off without major incident, the only concern being a 10 second delay between the button pushed and launch. This was later traced back to operator error and had nothing to do with the rocket itself. After initial burn, the vehicle reached an apogee of 5079 ft. and separation of the main body caused by black powder charge was witnessed as well as a successful deployment of the main parachute. The rocket landed about a half mile away in a water filled ditch in the surrounding field and was successfully recovered by the team.

3.1.6.1.2. Flight Data

Table 9: Initial Performance Predictions

Apogee	5260 ft. AGL
Max Velocity	816 ft/s
Max Acceleration	839 ft/s^2

Table 10: Recorded Performance

Apogee	5079 ft.	(-186 ft.) difference
Max Velocity	986 ft/s	(+84 ft/s) difference
Max Acceleration	1100 ft/s^2	(+169 ft/s^2) difference

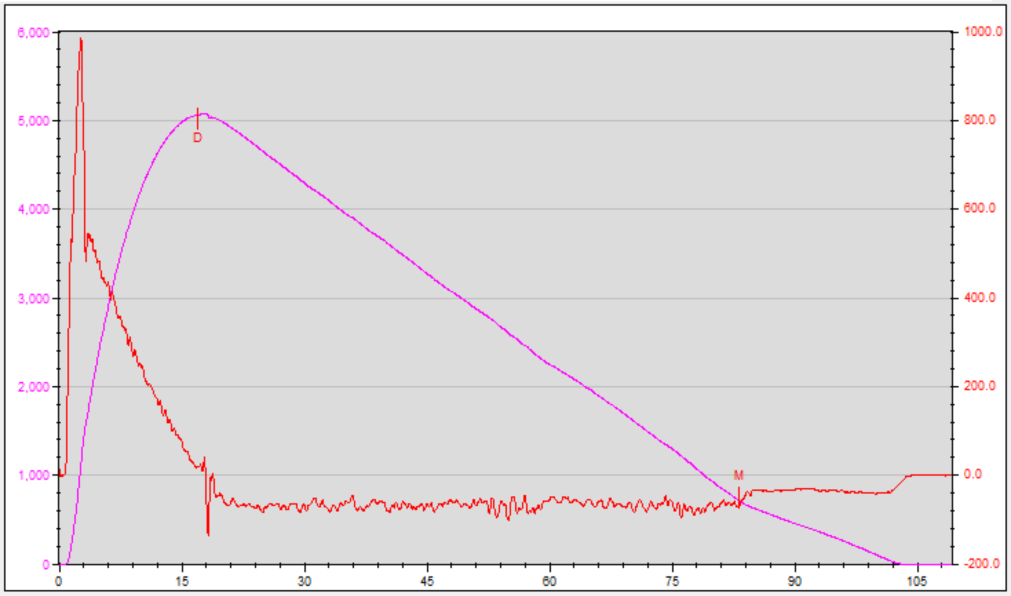

Figure 26: Chart of velocity and Acceleration vs. Time

Legend
Red line: Velocity in ft/s
Pink line: Altitude in feet

3.1.6.1.3. Analysis

Differences in initial and recorded data were expected in some cases due to the volatility of the atmosphere and the acceleration turned out to be slightly higher than expected but still within an acceptable range, meaning the rocket was still within 200 ft. of the predicted altitude. After analysis of the acceleration, a max force of 34 g's was experienced by the rocket with a -186 ft. difference in altitude, +84 ft/s difference in maximum velocity, and +169 ft/s^2 difference in maximum acceleration.

On the ground observations of the rocket's landing led to some quick action to preserve data after it was found in a water-filled ditch completely soaked. The avionics bay leaked water when recovered and team members quickly worked to dry off both of the two altimeters inside to prevent any loss of data. Enough data was found to ensure mission success but one of the altimeters did fail and one of the black powder charges responsible for separation also failed. The black powder charge was connected to the failed altimeter and failed as a result of the first. The cause of the altimeter failure has yet to be determined.

3.1.6.1.4. Conclusions

The launch went off well and a good separation occurred at apogee which led to a successful parachute deployment and vehicle recovery. An unlucky landing that could not have been avoided was slightly detrimental but did not cause a mission failure thanks to the data that was later collected from one of the altimeters and from observations of the flight made by the team on the ground. While the team was not able to determine a cause for the failure of the altimeter, another success became apparent in the form of redundancy. The rocket's flight demonstrated that multiple precautions built into the system worked perfectly and avoided what could have proved disastrous. Both failed pieces of equipment were investigate d but there is no clear answer to why either one failed. This subscale launch turned out to be excellent proof of a strong design and correct application of redundancy to give the rocket every chance of performing the way it was designed.

3.1.7. Further Verification Testing

In order to further validate the aerodynamic parameters calculated from Barrowman's method of normal force coefficients, computational fluid dynamics simulation, and analysis of the subscale flight, wind tunnel testing is planned. Both subsonic and supersonic tests will be conducted in order to investigate the flight vehicle in both regimes. The subsonic wind tunnel test will seek to validate the aerodynamic coefficients previously predicted. The supersonic test will focus on overall shock geometry and seek to identify potential problem areas. Both tests will seek to engage team members who have not yet experienced wind tunnel experimentation in order to prepare them for later laboratory courses.

Initial sizing of the subsonic wind tunnel experiment was driven by both the geometric constraints of the test section as well as limitations on the Reynolds number that can be achieved in the subsonic tunnel. In order to accommodate the 6DOF balance while remaining within the confines of the test section, a 5/22 scale model was selected. Table 11 shows the velocities and corresponding Reynolds numbers for the computational fluid dynamics simulations conducted.

Table 11: Conditions for CFD Simulations

Velocity (ft/s)	Re	
103	9.01E+05	velocity at tip of rail
550	4.81E+06	arbitrary subsonic velocity

Table 12 indicates the tunnel velocities that would be necessary to achieve the Reynolds numbers used for CFD simulations.

Table 12: Required Tunnel Velocity for Comparable Re

Temperature (deg F)	Velocity (ft/s)	Re @ 103 ft/s	Velocity (ft/s)	Re @ 550 ft/s
65	1.39E+03	9.01E+05	7.42E+03	4.81E+06
70	1.41E+03	9.01E+05	7.55E+03	4.81E+06
75	1.44E+03	9.01E+05	7.67E+03	4.81E+06
80	1.46E+03	9.01E+05	7.80E+03	4.81E+06

The velocities required to achieve comparable Reynolds numbers are beyond the capabilities of the NCSU subsonic wind tunnel. Table 13 indicates a tunnel velocity that is achievable in the tunnel and its corresponding Reynolds number.

Table 13: Wind Tunnel Test Conditions

Temperature (deg F)	Tunnel Velocity at 10psf	Re
65	92.23	5.98E+04
70	92.67	5.91E+04
75	93.11	5.84E+04
80	93.54	5.77E+04

Application of this wind tunnel test data can be made due to the fact that the aerodynamic coefficients would remain constant throughout the low subsonic flight regime. At transonic velocities, the aerodynamic properties change and have no correlation to the subsonic wind tunnel test results. A comparison will be made between the wind tunnel test results and the results from a CFD case run at the lower Re of the wind tunnel tests. If good correlation is observed, more confidence can be placed in the CFD simulations at higher Re.

The test article for the subsonic wind tunnel experiment will be fabricated in three sections. The nose cone and fin can/boat-tail will be rapid-prototyped out of PLA plastic. The body tube connecting these components will be 6061 aluminum tube. The angle of attack will be swept from -10° to 10° following the α schedule from the CFD simulations (0°, 1°, 2º, 3º, 5º, 7.5º, 10º). Two data points will be taken at each α in both an ascending and descending direction in order to mitigate hysteresis error. Forces and moments about each of the three axes will be recorded and the respective aerodynamic coefficients and stability derivatives will be calculated (C_L, C_D, $C_{M\alpha}$, etc.).

The supersonic wind tunnel experiment will be conducted at a Mach number significantly higher than that encountered by the flight vehicle (~ M2.0 as opposed to M1.15). This discrepancy dictates that no direct transfer of information between wind tunnel and flight vehicle can be made. However, the educational purpose of the experiment will be maintained. In addition, the overall structure of the shock pattern will be consistent even at the higher Mach number. Preliminary sizing is underway for the supersonic test article, which will be fabricated out of 6061 aluminum. Design of the subsonic test article is nearly complete.

3.2. Recovery Subsystem

3.2.1. Mechanical Configuration

The hemispherical parachute was chosen because of its ease of manufacturing compared to an ellipsoidal parachute and a higher coefficient of drag. The parachute was created in 6 equilateral triangular panels because a six gore hexagonal parachute will create a large area compared to the total diameter. Triangular shaped panels to create a symmetrical hemispherical shape. Each panel was cut from MIL-C-44378 Type III Rip-Stop Nylon Fabric chosen for its high strength and lightweight nature.

The six equal panels were cut from a pattern using a soldering iron**.** The edges of each panel were laid flat over one another and folded over 2 times at the edge to create a thick fold to sew. The unfolded edges were moved apart from one another as to not get caught in the sewing machine. No. 69 size E nylon thread was used for sewing all the parts of the parachutes.

Figure 27: No. 69 Size E Nylon Thread

The panels were sewed along their perimeter edges with 2 inches overlap to maximize strength along the panel connections and minimize excess fabric and weight. A French Fell stitch was used to sew the panels together as this is a common stitch used in parachute manufacturing. After all six panels were sewed together the bottom 2 inches of the parachute's large opening were folded inward and sewed together to create a hem. A Needle Hem stitch was used to create the hem of the parachute, as this is a common stitch used in parachute manufacturing. The stitches were sewn at 8 stitches per inch because less than six would not be strong enough and more than ten would sacrifice the strength of the fabric. In Figure 28**,** Picture A shows the French Fell seam, which is used to sew the panels together and the outside of the V-tab. Picture B shows the needle hem which will hem the bottom edge of the parachute. Picture C demonstrates how zig-zag stitching will be used in combination with French Fell to attach the V-tab. The final view in Picture D shows the V-tab from the outside of the parachute.

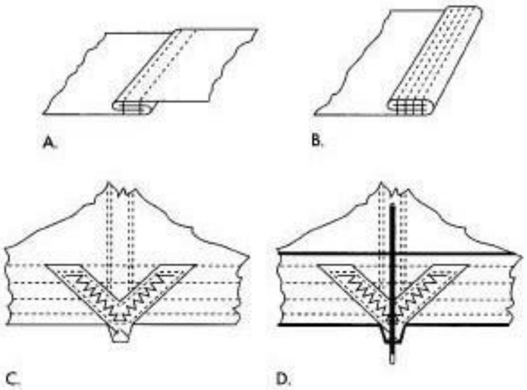

Figure 28: Types of Stitching and Seams

Six V-Tabs made from MIL-T-C-2754 Type 1 Flat Dacron 3/16" were sewed across the seams of the panels at the hemline to strengthen the weakest part of the parachute. MIL-T-C-2754 Type 1 Flat Dacron 3/16" was chosen because of a tensile strength of 600 lbs.

Figure 29: Flat Dacron 3/16"

Each tab was created by cutting two 6 inch straps of webbed nylon. The straps were crossed over each other to create an X shape. The top of the X was placed 2 inches from the edge of the hem and folded over. The overlapping portion of the straps created a basket to thread the cord to the parachute. The bottom of the X was placed on the backside of the parachute to mirror that of the front side. An initial framing French Fell stitch will be used to attach each side of the X straps to each other and through the hem of the parachute. A zig-zag stitch will be used inside of the French Fell outline. An outer French Fell was used for initial attachment of the V-tabs to the hem and the zig-zag stitch was used to reinforce the strength of the strapping. After assembly each stitch was inspected using a light table to make certain that each seam was correctly folded and sewn properly and that there are no imperfections in the parachute. The shroud cord is threaded through the opening created by the V-Tab basket. The two free ends of each shroud line will be gathered and all twelve free ends will be tied together using a bowline knot. A swivel will be attached to the top of a 5/16" carabineer which will be clipped through the loop created by the bowline knot for the parachutes and the loop created by the double alpine butterfly knot of the ½" Tubular Kevlar shock cord. The use of the double alpine butterfly knot was an act of redundancy to ensure that a single point of failure in the knot would not cause a parachute failure.

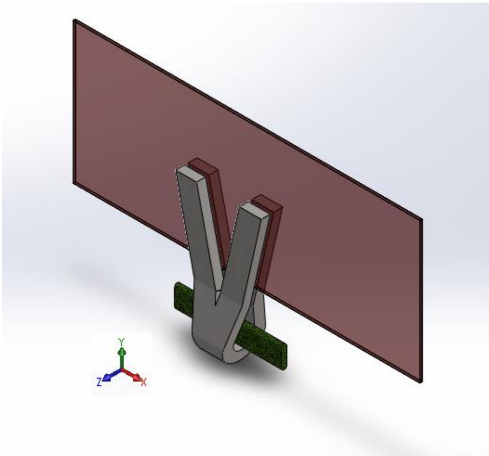

Figure 30: Assembly of V-Tabs Attached to Parachute and Shroud Line

The shroud cord will be braided nylon cord that is one and half times the diameter of the parachute. The cord has to be long enough to separate from the parachute during deployment. If the cord is longer than required for the size of parachute the parachute will not fully open. Further tests are needed after construction of the parachute to find exact length of the shroud lines for ideal deployment of the parachute for maximum drag.

Each parachute following the nosecone is housed in a Kevlar deployment bag. The Kevlar bag was cut into two square sheets with a shallow semicircular top. With a maximum width of 5.36 inches, and a maximum length of 16 inches the Kevlar sheet was rolled around the properly folded parachute and pinned for sewing. The Kevlar bag was turned inside out and sewn using a zig-zag stitch to create a fabric cylinder slightly smaller than the inner circumference of the rocket body. The bag was turned right side out and had a small nylon strap sewn to the top portion. The deployment bag is open at the bottom for ease of removal of the parachute during deployment. The deployment bag was designed to easily slide out of the inner body of the rocket thus avoiding parachute failure.

Figure 31: Deployment Bag Design

Due to the low porosity of the MIL-C-44378 Type III Rip-Stop Nylon Fabric a low amount of air passes through the fabric of the parachute. This required a vent hole at the top of the dome with a diameter of 10% of the diameter of the parachute. We have found that the lift coefficient and glide ratio increase when the vent hole size increased while causing a negligible decrease in drag. A streamer is attached to the fin section that will act as a drogue parachute to reduce kinetic energy to an acceptable level for parachute deployment. The steamer will be made from the waste material from the construction of the main parachute. The streamer will be fifteen feet long and will give visual cues to the ground crew to the location of the rocket during descent.

The three parachutes will be deployed in a multi-stage event. The first deployment will happen two seconds after apogee when the fin can section separates from the main body by a black powder charge. This releases the streamer that will act as a drogue parachute while the three sections are still attached by shock cord. When the rocket assembly reaches one thousand feet above the ground a second black powder charge will separate the nose cone from the main body tube. This separation will allow the nose cone parachute to be deployed. The nose cone parachute is attached to the main body parachute deployment bag. Simultaneously, the AARD will fire and separate the eyebolt that holds the shock cord connecting the fin can to the main body. The main body is also attached to the fin can parachute deployment bag and the separation will release the fin can parachute. These events leave the rocket in three separate pieces that will return safely to the ground.

3.2.2. Electronics

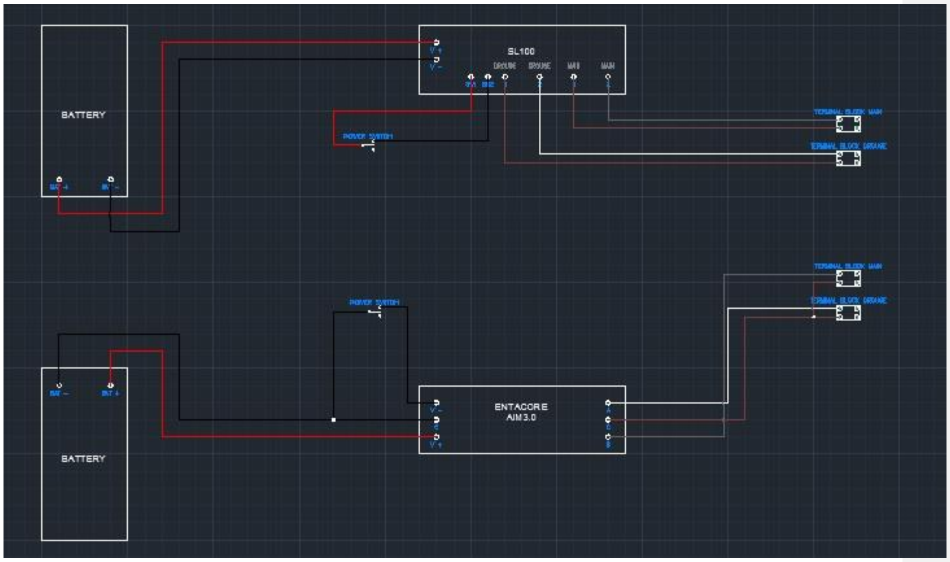

Figure 32: Avionics Electronics

3.2.3. Kinetic Energy Analysis

Table 14: Kinetic Energy Analysis of Each Section

	Weight (lb)	Descent Rate (ft/s)	Kinetic Energy (lbf-ft)	Parachute Size (in)
Nose Cone	6.10	26.6	67.1	34
Body Section	20.29	15.3	73.8	112
Fin Section N5600	34.61	11.8	74.9	180
Fin Section N10000	33.91	11.9	74.6	180

3.2.4. Test Results

The ARRD performed as hypothesized during experiments using only .1 grams of black powder. The experiment initially called to add more black powder in each subsequent test, but that was impossible due to the inner design of the device. The device features a molded cavity designed to fit a maximum of .1 grams and by simply following the instructions on filling, wiring, and preparing the device that are provided in the accompanying manual, a successful and safe separation is guaranteed. Experiments were conducted during a warm, dry day in open air with limited wind with a 5 kilogram weight used to allow for forced separation of the eyebolt from the stationary device.

3.2.5. Safety and Failure Analysis

The flight vehicle's recovery system is designed such that each portion of the rocket will fall with kinetic energy below 75 ft-lbf. In order to accomplish this, the vehicle will separate into three sections at 1000 ft. The following describes how this will be accomplished.

At apogee, the fin section of the rocket will be separated from the rest of the vehicle at attached at set length via a shock cord tether. No drogue parachute will be used to reduce the drift of the vehicle during descent. The tether will keep the fin section attached to the midsection of the vehicle from apogee to the main parachute deployment event at 1000 ft. Upon reaching this altitude, two Rattworks ARRD's (Advanced Retention Release Device) will release the tether allowing the fin section to travel further away from the midsection of the vehicle. In doing so the midsection will then pull a deployment bag from within the fin section deploying the fin section's main parachute and releasing the fin section to descend free of the remainder of the rocket. In addition to this tether separation, the nose cone will be ejected. Connected to the nose cone will another parachute attached to an additional deployment bag located inside the upper portion of the midsection of the vehicle. As the nose cone separates, it will pull this deployment bag out of the midsection and deploy the midsection's main parachute. A diagram of how the deployment bags, parachutes and tethers will be attached can be seen in Figure 33 below.

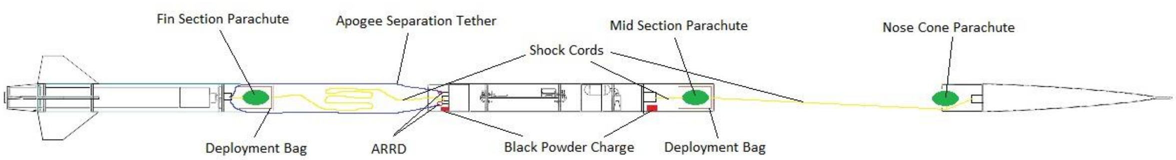

Figure 33: Recovery System Diagram

Figure 34: Rattworks ARRD

3.3. Mission Performance Predictions

The mission will be a success if the rocket meets the predicted performance values such as altitude and maximum velocity. Most importantly, the rocket must be stable and not sustain any damage during the flight that would result in it not being able to be reused on the same day. All experiments must work as they were intended too and the data must be useful.

3.3.1. Mission Performance Criteria

The rocket's performance goal is to match predictions as close as possible. This includes but is not limited to max altitude, max speed, and safe flight. The rocket is to perform as designed with no failure and meet design specifications. In doing so, it must reach the predicted values as follows.

3.3.2. Flight Simulations

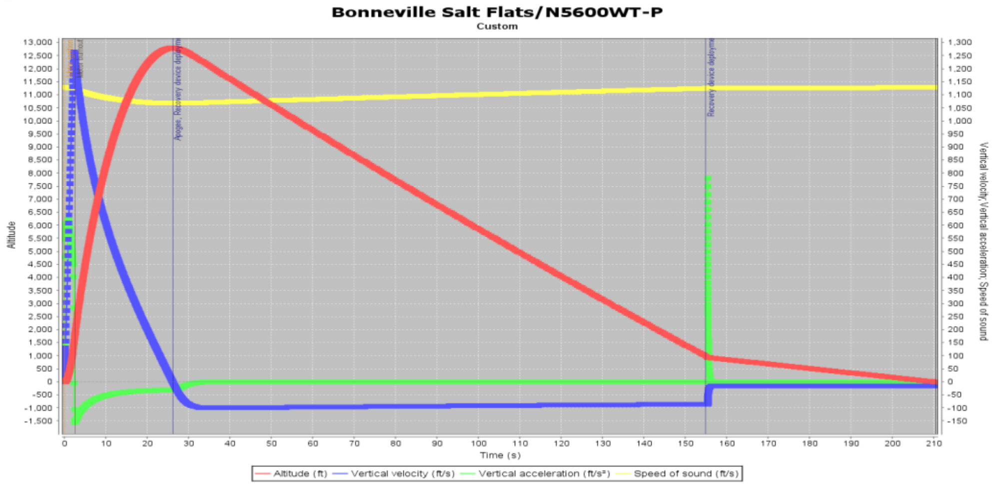

Figure 35: Flight Simulation of Rocket with N5600WT-P

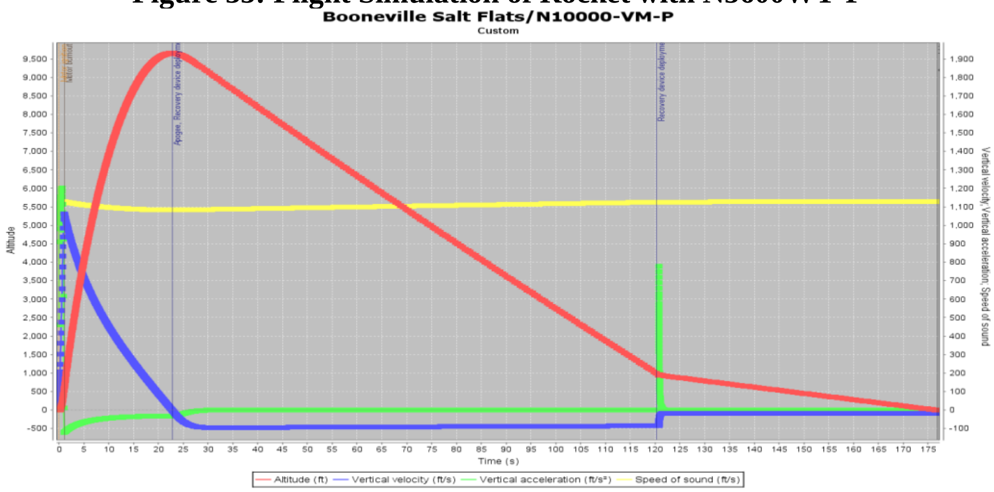

Figure 36: Flight Simulation of Rocket with N10000-VM-P

3.3.3. Altitude Prediction

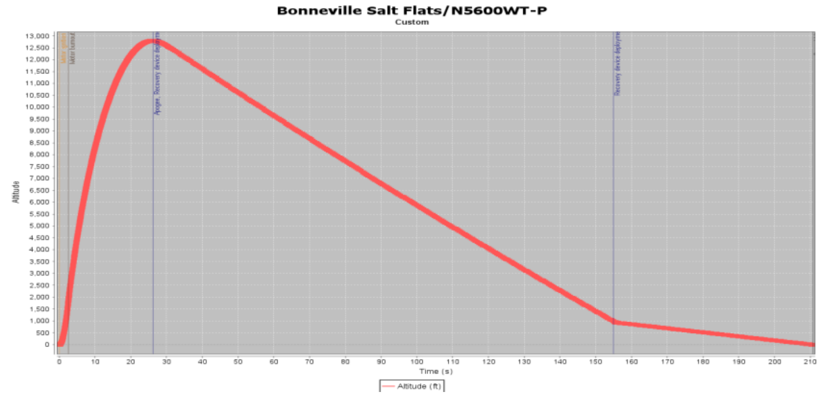

Figure 37: Altitude Projection with N5600WT-P

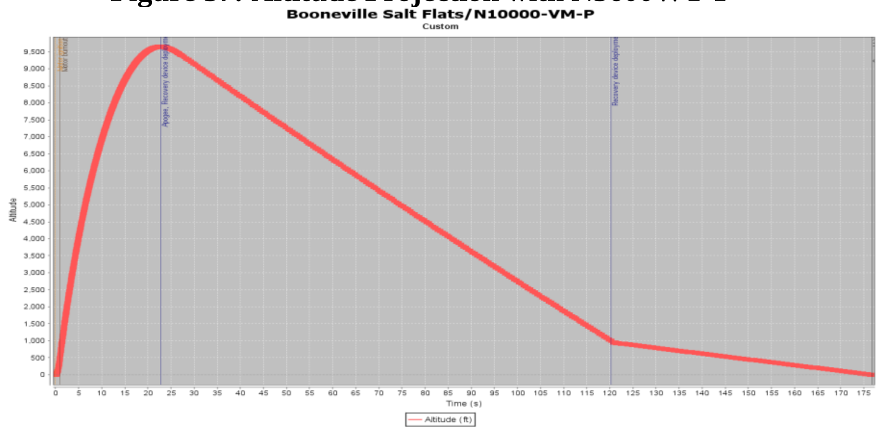

Figure 38: Altitude Projection with N10000-VM-P

3.3.4. Final Vehicle Weight

Table 15: Final Weight of Vehicle with Different Motors

Loaded Weight (lb)	
Nose Cone	6.10
Body Section	20.29
Fin Section N5600	48.71
Fin Section N10000	45.71
Total with N5600	75.10
Total with N10000	72.10

3.3.5. Motor Thrust Curve

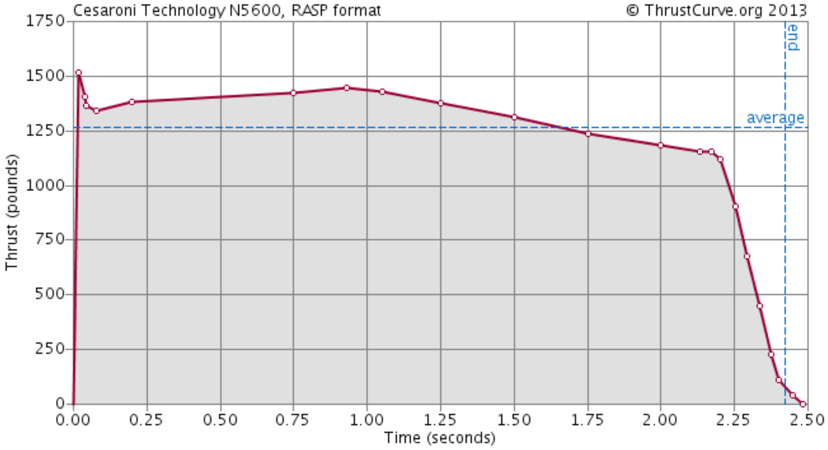

Figure 39: Thrust Curve for N5600WT-P

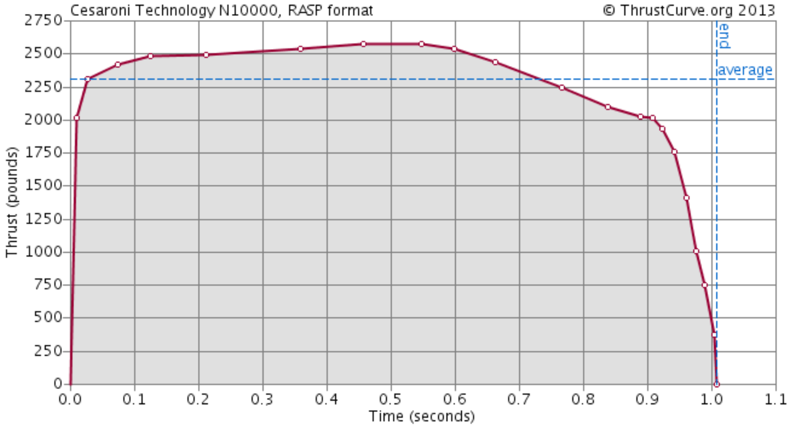

Figure 40: Thrust Curve for N10000-VM-P

3.3.6. Drag Assessment

Assessment of the drag experienced by the flight vehicle was completed using Barrowman's method of normal force coefficients as well as computational fluid dynamics software. In order to estimate the drag from the normal force coefficients determined using Barrowman's method, the United States Air Force Stability and Control Datcom Method proposed by Mandell et al in 1973 was combined with E.V. LaBudde's coefficient of drag formula (equation 5).

(5) $$C_D = C_{D,0} \cos(\alpha) + C_{N\alpha} \sin^2(\alpha)$$

A MATLAB script was written to compute $C_{D,0}$ and pertinent aerodynamic characteristics ($C_{L\alpha}$, $C_{M\alpha}$). For C_L and C_D, a range of α values from -10° to 10° was examined. Figures 41 shows a plot of C_D over the range of α.

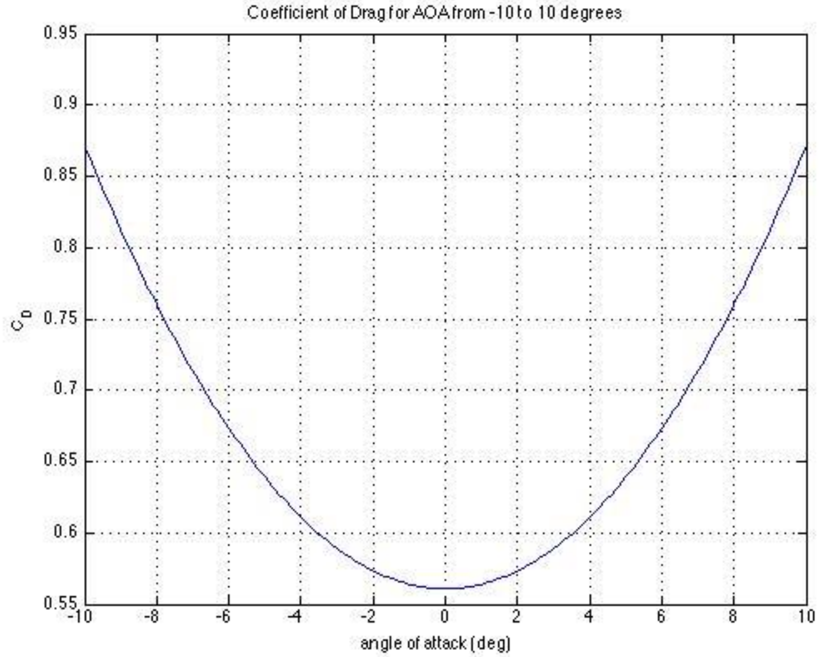

Figure 41: Variation of C_D with α

Table 16: Drag Assessment of Rocket

Component	Pressure C_D	Base C_D	Friction C_D	Total C_D
Nose Cone	0.00 (0%)	0.00 (0%)	0.05 (8%)	0.05 (8%)
Body Tube	0.00 (0%)	0.00 (0%)	0.19 (28%)	0.19 (28%)
Fin Section	0.00 (0%)	0.00 (0%)	0.05 (8%)	0.05 (8%)
Fins	0.22 (32%)	0.00 (0%)	0.06 (9%)	0.28 (40%)
Boat Tail	0.00 (0%)	0.08 (13%)	0.02 (2%)	0.10 (15%)
Total	0.22 (32%)	0.08 (13%)	0.37 (55%)	0.67 (100%)

3.3.7. Scale Modeling Results

The data returned from the subscale flight on 18 January consisted of altitude, velocity, and atmospheric temperature over time. The data was recorded by the SL100 altimeter. Post-flight analysis of the data focused on estimating the actual C_D experienced by the subscale vehicle. Since the drag coefficient is scaled by vehicle reference area, correlation should be observed between the actual results from the subscale vehicle and the predicted results for the full-scale vehicle.

Acceleration was estimated at each time increment beginning when velocity started to decrease. Equation 6 illustrates this estimation scheme. Note that *a* is the acceleration, *V* the velocity, and *T* the time.

$$a = dV/dT = (V_i - V_{i-1})/(T_i - T_{i-1}) \qquad (6)$$

Drag was calculated according to equation 7 where *D* is the vehicle drag force, *m* is the mass, *a* the acceleration, and *W* the vehicle weight.

$$D = -ma - W \qquad (7)$$

From the drag force, C_D was calculated under the assumption of constant density. In equation 8, ρ is density and A_r is the reference area of the flight vehicle.

$$C_D = D/(0.5\, \rho\, V^2 A_R) \qquad (8)$$

Due to signal noise in the altimeter's recorded velocity, the range of C_D's was wide and clearly erroneous. Data points at low dV values were excluded in order to remove excessively high C_D values (in excess of 100). The remaining data points were averaged and the resultant C_D values reported in Table 17.

Table 17: Averaged C_D Values from Subscale Flight – 18 January

C_D	$n_{samples}$
0.97	79

0.83	129
0.73	179

Table 18 reveals that the averaged C_D decreased as more samples were included in the average. Samples were included in the average in temporal order (e.g. the 100 samples added between the first and third averages were taken at a later time step than the 79 samples included in the first average). It is possible that the vehicle experienced a changing angle of attack as it approached apogee that accounted for the change in C_D. From the subscale results, the range of C_D's predicted by the Barrowman analysis is confirmed as reasonable. The C_D ranges from approximately 0.56 to 0.87 over an angle of attack range of 0° to 10°

3.3.8. Wind Drift Calculations

Table 18: Wind Drift with N5600WT-P

		N5600WT-P			
		Wind Speed in MPH			
		5	10	15	20
Drift in Feet	Nose Cone	1268	2536	3804	5071
	Body Section	1471	2943	4414	5886
	Fin Section	1614	3227	4841	6455

Table 19: Wind Drift with N10000-VM-P

		N10000-VM-P			
		Wind Speed in MPH			
		5	10	15	20
Drift in Feet	Nose Cone	954	1908	2862	3816
	Body Section	1117	2234	3350	4467
	Fin Section	1226	2453	3679	4905

3.3.9. Stability

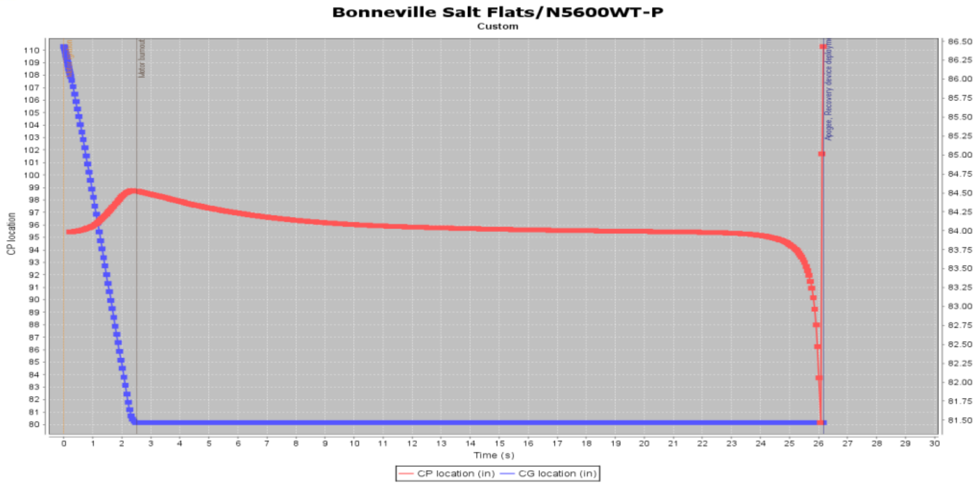

Figure 42: CP and CG Locations through Flight with N5600WT-P

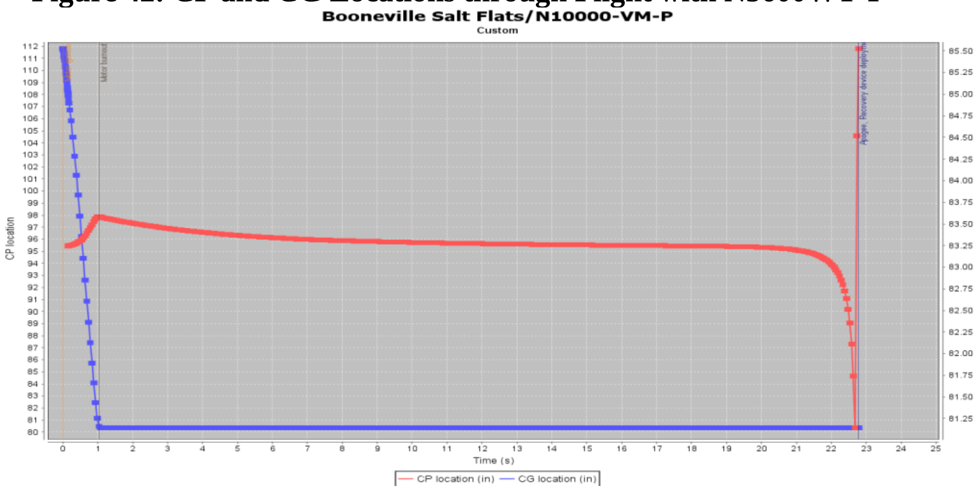

Figure 43: CP and CG Locations through Flight with N10000-VM-P

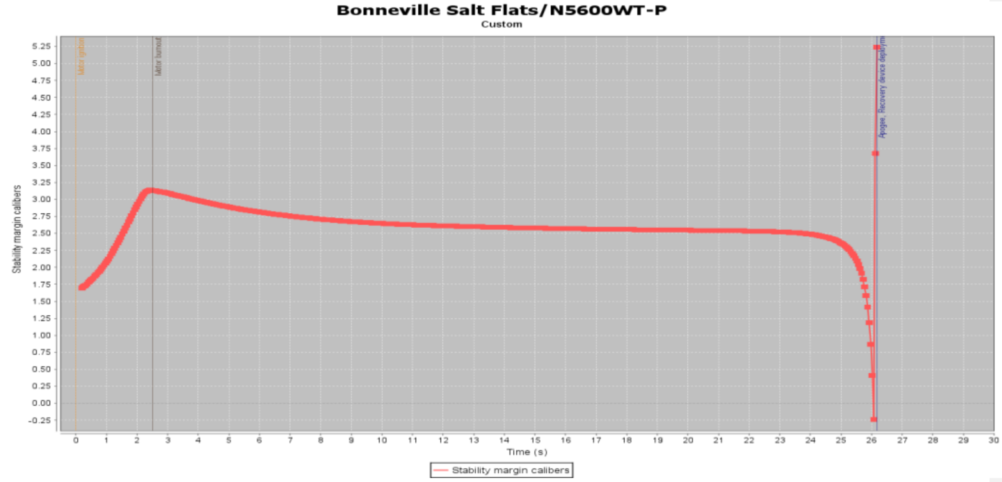

Figure 44: Stability Margin through Flight with N5600WT-P

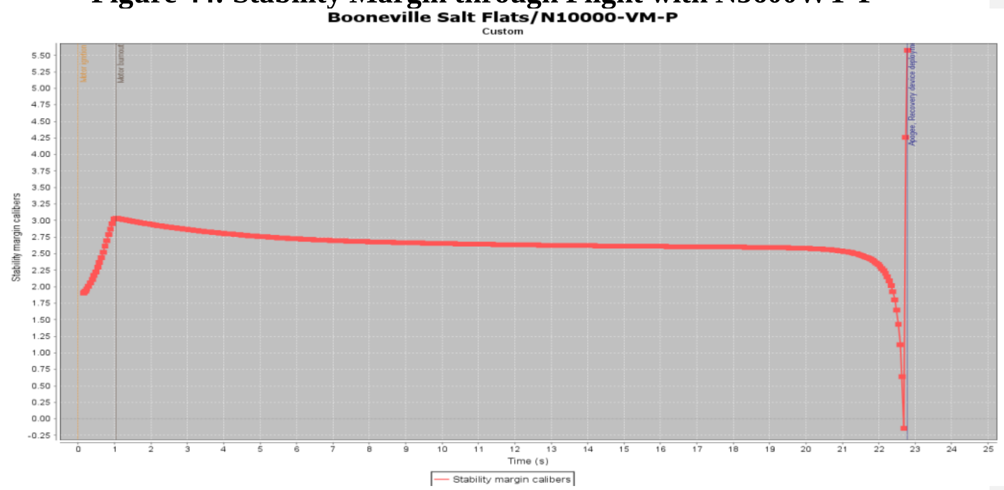

Figure 45: Stability Margin through Flight with N10000-VM-P

Table 20: CP and CG Locations with Each Motor

	Center of Pressure (in)	Center of Gravity (in)	Stability (cal)
N5600WT-P	95.59	86.44	1.66
N10000-VM-P	95.59	85.54	1.83

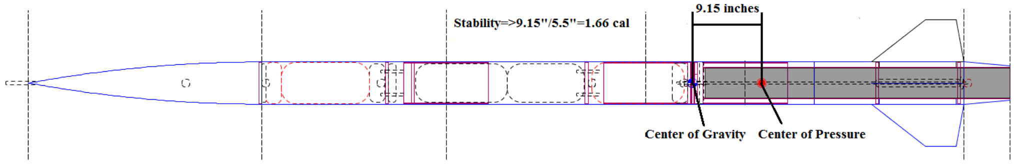

Figure 46: Static Margin Calculation with N5600WT-P

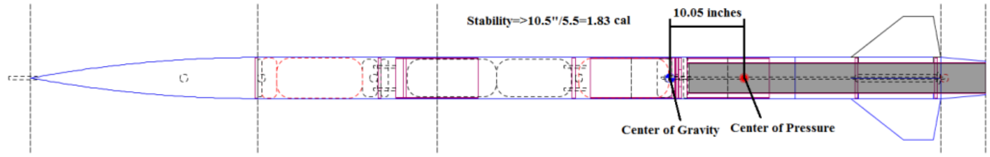

Figure 47: Static Margin Calculation with N10000-VM-P

3.4. Interfaces and Integration

The launch vehicle and payload have been designed with compatibility in mind. The location of the payload electronics bay has been determined to permit easy access and servicing between launches. The payload bay will be located just aft of the center split in the two mid sections of the vehicle.

Figure 48: Empty Full Scale Cross Sectional View

3.5. Launch Concerns and Operation Procedures

3.5.1. Recovery Preparation

Prior to Arrival at the Launch Site

Retrieve following materials

Do not proceed to step one until all materials are accounted for.

- One180” parachute - Fin Can or Third Parachute
- One 112” parachute - Mid Section or Second Parachute
- One 34” parachute - Nose Cone or First Parachute
- One 15’ streamer - Fin Can
- Six Shroud cords per parachute - Different lengths for each parachute. Each set of cords should be bundled with those of the same length and tagged for each parachute.
- One Shroud cord for the streamer
- Three Swivels
- One dozen or more Rubber bands

FIN CAN PARACHUTE

Lay the 180” parachute out flat on the ground.

Shroud Lines

Thread each of the six shroud cords through their basket created by the V-Tabs at the hem of the parachute. You will finish with 12 cord ends pointed in straight parallel lines away from the canopy of the parachute.

Make sure these are the cords specific to the *180”* parachute.

Gather each of the twelve lines, ensuring that they remain equal length, and thread through the swivel.

Tie a simple bowline knot with the 12 threaded ends.

Starting at the base of the swivel fold the lines of cord in a zig-zag pattern into your hand. Make sure the cords do not get tangled during this process.

Wrap a rubber band around the base of the bundle making sure that upon deployment the bundle will unravel.

Canopy

Fold the canopy of the parachute so each seam of the equilateral triangles lay flat on top of each other.

Fold the seam side over in half to meet the unseamed side in a fan fashion. This step will be complete when the parachute is roughly the width of the compartment.

Starting at the top and working towards the bundle of shroud line, fold the parachute downwards in a fan fashion. This may take more than one person as this is a rather large parachute.

Secure the bundle using a rubber band that will be removed before launch.

Streamer

Thread the streamer specific shroud line through the basket created by the V-Tab at the end of the streamer.

Fold the streamer in a fan fashion from the end towards the V-Tab.

This may take more than one person as this is a rather large streamer.

Secure the folded streamer using a rubber band that will be removed before launch.

STOP: Before proceeding asses the work you’ve just completed.

MID SECTION PARACHUTE

Lay the 112” parachute out flat on the ground.

Shroud Lines

Thread each of the six shroud cords through their basket created by the V-Tabs at the hem of the parachute. You will finish with 12 ends of cord pointed in straight parallel lines away from the canopy of the parachute.

Make sure these are the lines specific to the *112”* parachute.

Gather each of the twelve lines, ensuring that they remain equal length, and thread through the swivel.
Tie a simple bowline knot with the 12 threaded ends.
Starting at the base of the swivel fold the lines of cord in a zig-zag pattern into your hand.
Make sure the cords do not get tangled during this process.
Wrap a rubber band around the base of the bundle making sure that upon deployment the bundle will unravel.

Canopy

Fold the canopy of the parachute so each seam of the equilateral triangles lay flat on top of each other.
Fold the seam side over in half to meet the unseamed side in a fan fashion. This step will be complete when the parachute is XX across.
Starting at the top and working towards the bundle of shroud line, fold the parachute downwards in a fan fashion. This may take more than one person as this is a rather large parachute.
Secure the bundle using a rubber band that will be removed before launch.

STOP: Before proceeding asses the work you've just completed.

NOSE CONE PARACHUTE

Lay the 34" parachute out flat on the ground.

Shroud Lines

Thread each of the six shroud cords through their basket created by the V-Tabs at the hem of the parachute. You will finish with 12 ends of cord pointed in straight parallel lines away from the canopy of the parachute.
Make sure these are the cords specific to the ***34"*** parachute.
Gather each of the twelve lines, ensuring that they remain equal length, and thread through the swivel.
Tie a simple bowline knot with the 12 threaded ends.
Starting at the base of the swivel fold the lines of cord in a zig-zag pattern into your hand.
Make sure the cords do not get tangled during this process.
Wrap a rubber band around the base of the bundle making sure that upon deployment the bundle will unravel.

Canopy

Fold the canopy of the parachute so each seam of the equilateral triangles lay flat on top of each other.
Fold the seam side over in half to meet the unseamed side in a fan fashion. This step will be complete when the parachute is the width of the compartment.
Starting at the top and working towards the bundle of shroud line, fold the parachute downwards in a fan fashion.

STOP: Before proceeding asses the work you've just completed.

At the Launch Site

Retrieve following materials

Do not proceed to step one until all materials are accounted for.

- Bundled Fin Can Parachute
- Bundled Mid Section Parachute
- Bundled Nose Cone Parachute
- Bundled Fin Can Streamer
- Two Kevlar deployment bags - One for the third (largest) and second parachute **only**
- Three 5/16" Carabiners

- One dozen or more Rubber bands
- XX ½" Tubular Kevlar cords of length XX - shock cords
- XX black powder charges
- Flat head screw driver

FIN CAN

Thread the ½" Tubular Kevlar cord through the Nylon Webbing loop at the top of the Fin Can parachute deployment bag.
Use a bowline knot to secure.
With the free cord tie a double alpine butterfly knot near the center of the cord.
Thread the free end of the cord through the U-bolt bulkhead of the middle section and tie a bowline knot.
Have another member check the strength of the knot around the bulkhead.
Tuck the folded third parachute into the largest deployment bag and tuck the package into the fin section.
It is alright if a portion is revealed past the coupler.
Connect E-match that is connected to black powder canister to ignitor block.
Connect the shroud line for the stream to the double alpine butterfly knot at the center of the shock cord.
At this time remove the rubber band holding the streamer together.
Piece together the fin can section and the middle section.

STOP: Before proceeding, asses the work you've just completed. Make sure the streamer, third parachute, deployment bag and black powder charges are within the structure.

MID SECTION

Thread the ½" Tubular Kevlar cord through the U-Bolt of the exposed section of the bulkhead of the middle section of the rocket.
Secure using a bowline knot.
Have another team member check the strength of your knot and the bulkhead.
Thread the free end through a 5/16" carabiner and tie a bowline knot.
Bundle the cords as before and tie a rubber band.
Connect E-match that is connected to black powder canister to ignitor block.
Remove the rubber band securing the mid section parachute.
Tuck the second parachute into the smaller parachute deployment bag.
Tuck the second parachute package into the open mid section.

STOP: Before proceeding, asses the work you've just completed. Make sure the second parachute, deployment bag and black powder charges are within the structure.

NOSE CONE

Thread the final ½" Tubular Kevlar cord through the Nylon Webbing loop at the top of the smaller parachute deployment bag.
Secure using a bowline knot.
Tie a double alpine butterfly knot off set from the center of the cord.
Thread the free end of the cord through the U-Bolt at the bulkhead of the nose cone of the rocket.
Secure using a bowline knot.
Attach the 5/16" carabiner through both loops of the double alpine butterfly knot.
Bundle the shock cord and secure using a rubber band.
Tuck the bundled shock cord into the exposed section of the nose cone.

Attach the first parachute swivel to the carabiner.
Tuck all parts into the nose cone cavity.
Piece the middle section and nose cone together.
Before proceeding, asses the work you've just completed. Make sure the first parachute is within the structure.

3.5.2. Motor Preparation

Figure 49: Cesaroni Motor
(Image obtained from the Cesaroni Pro 98 mm Motor Assembly Kit Instructions)

1. Forward Closure Assembly
   1.1. Apply a light coating of o-ring lubricant or grease to the inside of the cavity in the forward closure. Insert the smoke tracking charge insulator into this cavity and ensure it is seated fully.
   1.2. Apply a liberal layer of grease or o-ring lubricant to one end of the smoke tracking grain. Be sure the entire face is coated.
   1.3. Insert the smoke tracking grain into the smoke tracking charge insulator, coated end first. Push the grain in with sufficient force to fully seat it and spread the lubricant as shown. The excess lubricant will help prevent gas leakage forward as well as protecting the forward closure from heat and combustion products from the smoke tracking charge.

2. Pro98 Hardware
   2.1. Check both ends of the phenolic case liner to ensure that the inside ends have been chamfered or deburred. If not, use a hobby knife or coarse sandpaper to remove the sharp inner edge to allow components to be inserted easily.
   2.2. Fit the nozzle to one end of the paper/phenolic case liner tube. It may be a

snug fit. Push it carefully but with sufficient force to seat the shoulder on the nozzle all the way into the insulator tube.

2.3. Locate the smaller o-ring in the P98-ORK o-ring kit. Fit the o-ring to the internal groove of the nozzle holder. Push the nozzle holder over the nozzle until fully seated. Apply additional lubricant to the nozzle exit section if necessary to facilitate assembly.

2.4. For steps 2.5-2.6 work with the nozzle/case liner assembly and motor case horizontally on the work surface.

2.5. Insert one propellant grain into the forward end of the case liner and push it a short way into the tube. Fit one grain spacer o-ring to the top face of the grain, ensuring it sits flat on the end of the grain. Insert the second grain, push it in a short ways, then add another grain spacer, and so on until you have loaded all propellant grains into the case liner.

- 2.5.1There should be sufficient space after the last grain is inserted to fit the forward insulator in place and seat it to the tube with light pressure. If there is less clearance than this, you may remove the last gran spacer and recheck the fit. Only this spacer may be omitted and only if necessary to fit.

2.6. Carefully install the two larger o-rings into the external grooves of the nozzle holder and forward closure. Handle these components with care from this point on so as not to damage or contaminate the o-rings.

2.7. Place the case liner/nozzle assembly on your work surface with the nozzle end down, and slide the motor case down rear end first (end with thrust ring) over the top of the liner towards the nozzle. Note: a light coat of grease on the liner exterior will aid assembly, disassembly and cleanup!

2.8. Lay the motor case assembly down horizontally, and push on the nozzle ring until the assembly is far enough inside the case that the threads are partly exposed and the screw ring can be threaded into the rear of the case. Don’t push on the nozzle itself as you will push it out of the nozzle holder.

2.9. Screw in the nozzle retaining ring using the wrench, pushing the nozzle/nozzle ring/case liner assembly forward as you proceed. Screw it in only until the retaining ring is exactly even with the end of the motor case - do not thread it in as far as it will go. Then, back the retaining ring out one half of a turn.

2.10. Fit the forward insulating disk to the top of the case liner, checking that the top grain spacer (if used) is still properly in place.

2.11. Fit the forward insulating disk to the top of the case liner, checking that the top grain spacer (if used) is still properly in place.

2.12. Insert the assembled forward closure into the top of the motor case, pushing it down carefully with your fingers until you can thread in the retaining ring. Thread in the forward retaining ring using the wrench, until you feel it take up a load against the top of the case liner. At this point the ring should be approximately flush with the end of the motor case, or slightly submerged. If it extends out the case at this point by more than about one half a turn, check the nozzle end to make sure the ring is not screwed in too far forward. If so, unscrew the nozzle retaining ring another half turn and screw the forward closure retainer in further.

NOTE: it is best to have the forward closure retaining ring flush or slightly submerged and the nozzle retaining ring protruding by a half turn or so, than vice versa. There is more tolerance for o-ring location at the nozzle end. There will always be some minor variation in the length of internal components due to manufacturing tolerances.

3.5.3. Igniter Installation

The igniter will be installed by designated personnel who are properly trained.

3.5.4. Post-Flight Inspection

1. Post Flight Cleanup of Motor

   Do not try to dismount or disassemble your motor until it has thoroughly cooled down after firing. Some components such as the nozzle may be extremely hot for some time after firing.

   Perform motor cleanup as soon as possible after firing, however, as combustion residues are corrosive to motor components, and become very difficult to remove after several hours.

   1.1. Unthread and remove the forward and rear closures. Remove the nozzle holder from the nozzle.
   1.2. Remove the phenolic tracking smoke charge insulator from the forward closure.
   1.3. Remove all o-rings.
   1.4. Discard all reload kit components witch regular household waste, once they have returned to room temperature.
   1.5. Use wet wipes, or paper towels or rags dampened with water or vinegar to thoroughly clean all residue, grease etc. off all hardware components. Pay close attention to internal and external o-ring grooves. A cotton swab or small stick of balsa is an excellent tool for cleaning these grooves.
   1.6. Apply a light coat of grease or o-ring lubricant to all threaded sections and reassemble threaded components for storage.

Launch operations procedures are to be followed at all times by all members of the team. Local TRA or NAR, whichever the host maybe, regulations shall be reviewed by all attending team members prior to launch day as part of prelaunch preparations. While at the launch site members of the team are to keep in mind that the team is a guest to the local rocketry club hosting the launch.

3.6. Safety and Environment

3.6.1. Safety Officer

Collin Bolton

3.6.2. Failure Mode Effects and Criticality Analysis (FMECA)

1	2	3	4
Catastrophic	Critical	Major	Minor

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
Blue Tube airframe	Cracks or breaks	Poor Design	Loss of containment for other vehicle components	Separation or destruction of vehicle	1	ANSYS structural analysis and compression failure tests
		Manufacturing Defect			1	ANSYS structural analysis and compression failure tests
		Loads beyond design specification			1	Maintain vehicle within design specifications
		Damaged during handling			1	Adhere to proper handling procedure
		Improper Maintenance			1	Pre/post launch inspections

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
Bulkheads	Separation of bulkhead from other structural members	Poor Design	Unable to transfer loads	Increased loads on other structural members	2	ANSYS structural analysis of bulkhead fixed support
		Manufacturing Defect			2	QC of manufacturing process
		Loads beyond design specification			2	Maintain vehicle within design specifications
		Damaged during handling			2	Ensure analysis includes handling loads. Adhere to proper handling procedure
		Improper Maintenance			2	Pre/post launch inspections
	Damage/separation from parachute deployment	Poor Design	Unable to support loads of chute deployment	Loss of safe and effective recovery system	2	ANSYS structural analysis of bulkhead stress
		Manufacturing Defect			2	QC of manufacturing process

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
		Loads beyond design specification			2	Maintain operations within design specifications
		Improper Maintenance			2	Pre/post launch inspections
	Non-compromising cracks	Poor Design	Potential for future damage	No system level safety effect	4	ANSYS structural analysis of bulkhead stress
		Manufacturing Defect			4	QC of manufacturing process
		Loads beyond design specification			4	Maintain operations within design specifications
		Damaged during handling			4	Adhere to proper handling procedure
		Improper Maintenance			4	Pre/post launch inspections
Loadcell	Separation of loadcell from other structural members	Poor Design	Unable to transfer loads	FC: Motor is forced through the vehicle body nFC: Loss of stabilized flight	1/2	ANSYS structural analysis of fixed supports
		Loads beyond design specification			1/2	Maintain vehicle within design specifications

Function / Component	Failure Mode	Causal Factors	Failure Effects: Subsystem	Failure Effects: System	Hazard	Recommendations
		Damaged during handling			1/2	Adhere to proper handling procedure
		Improper Maintenance			1/2	Pre/post launch inspections
	Breaks due to loads from motor	Poor Design	Retention loss of motor casing	Loss of stabilized flight/ destruction of other components	1	ANSYS structural analysis
		Manufacturing Defect			1	QC of manufacturing and process
		Loads beyond design specification			1	Design bulkhead to stop load cell before critical deflection is reached
		Damaged during handling			1	Adhere to proper handling procedure
		Improper Maintenance			1	Pre/post launch inspections
Boattail	Melting from heat of exhaust	Poor Design	Deformation of structure	Increased drag/loss of motor casing protection	3	Test material through test launch
		Manufacturing Defect			3	QC of manufacturing process
		Improper Maintenance			3	Pre/post launch inspections

Function / Component	Failure Mode	Causal Factors	Failure Effects: Subsystem	Failure Effects: System	Hazard	Recommendations
	Cracking from impact	Poor Design	Loss of future tailcone use	Possible damage to other components	3	ANSYS structural analysis
		Manufacturing Defect			3	QC of manufacturing process
		Loads beyond design specification			3	Maintain operations within design specifications
		Damaged during handling			3	Adhere to proper handling procedure
		Improper Maintenance			3	Pre/post launch inspections
Fins	Damage from impact	Poor Design	Loss of future fin use	Possible damage to other components	2	ANSYS structural analysis
		Manufacturing Defect			2	QC of manufacturing process
		Damaged during handling			2	Adhere to proper handling procedure
		Loads beyond design specification			2	Maintain operations within design specifications

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
		Improper Maintenance			2	Pre/post launch inspections
Shear Pins	Breaking before charge detonation	Manufacturing Defect	Loose assembly of compartmen t	Separation of vehicle compartmen ts	3	QC of parts received
		Loads beyond design specification			3	Maintain vehicle within design specifications
		Improper Maintenance			3	Use of new pins after each launch
Avionics Sled	Detaches from secured position	Poor Design	Damage to/loose wiring of avionics components	Loss of recovery system initiation	3	Design to ensure secure sled with redundancy
		Manufacturing Defect			3	QC of manufacturing process
		Damaged during handling			3	Adhere to proper handling procedure

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
		Loads beyond design specification			3	Maintain operations within design specifications
		Improper Maintenance			3	Pre/post launch inspections
Nose Cone	Non-compromising cracks	Manufacturing Defect	Potential for future damage	No system level safety effect	4	QC of part received
		Damaged during handling			4	Adhere to proper handling procedure
		Loads beyond design specification			4	Maintain vehicle within design specifications
		Improper Maintenance			4	Pre/post launch inspections
	Damage from impact	Manufacturing Defect	Loss of future nosecone use	No system level safety effect	3	QC of part received

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
		Damaged during handling			3	Adhere to proper handling procedure
		Loads beyond design specification			3	Maintain vehicle within design specifications
		Improper Maintenance			3	Pre/post launch inspections
	Pre-mature separation from other structural members	Damaged during handling	Potential for structural damage	Loss of controlled and stabilized flight	1	Adhere to proper handling procedure
		Improper Maintenance			1	Pre/post launch inspections
Fiberglass Covering	Delamination of fiberglass layering	Manufacturing Defect	Damage to fiberglass layup	Potential for other structural member damage	4	QC of manufacturing process
		Damaged during handling			4	Adhere to proper handling procedure

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
		Loads beyond design specification			4	Maintain vehicle within design specifications
		Improper Maintenance			4	Pre/post launch inspections

Payload/Exciter

Function / Componen t	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
Exciter System	Solenoid Valve Fails	PSI too large	Failure to eject gas on command	Unable to perform excitation action	4	Install pressure gauges and perform pre-flight checks
		Electrical signal too low			4	Check Arduino output
		Not installed properly			4	Check manual and perform pre-flight checks
		Improper maintenance			4	Inspect connections often and perform pre-flight checks of system

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
		Damage during handling			4	Inspect connections often and perform pre-flight checks of system
	Gas Leak	Improper connections	Gas is ejected into avionics bay and loss of pressure in system		2	Check tubing specifications and perform pre-flight checks to ensure all connections are correct
		PSI too large			2	Check tubing specifications and maintain proper psi in system
	C/D Nozzle	PSI too large	Loss of pressure in system	Unable to perform excitation action	4	Install pressure gauges and perform pre-flight checks
		Poor design			4	Analysis of flow and airspeed
	Excessive force	Valve does not close on time	Thruster produces too much thrust	Larger displacement than expected. Dangerous trajectory .	1	Test valve operation. Design so all the gas is needed for the excitation

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
		Poor design			1	Complete experiment to determine thrust produced
Sensor Input	Sensor Output Failure	Intake blockage	Failure to collect sensor data	No effect on vehicle flight	4	Perform pre-flight checks on sensors
		Wires crossing			4	Bundle wires together and perform pre-flight checks on all wiring
		Wrong connection port on Arduino unit			4	During pre-flight check, ensure all connections are correct
	IMU Overload	Pressure input too large	Failure to collect sensor data	No effect on vehicle flight	4	Ensure pressure transducers are installed properly during pre-flight checks
	Arduino Overload	Data input too large	Failure to collect sensor data	No effect on vehicle flight	4	During design, check all sensor output packet sizes
Data Collection	Arduino freezes	Software does not work properly	Data is not collected during flight	Experimental payload is a failure	3	Complete experiment to ensure Arduino can handle data

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
	Loss of power	Dead battery/ battery disconnects			3	Use new batteries and inspect battery installment
	Remote sensor disconnection	Vibration and forces during flight			3	Construct sensor wiring to withstand forces
	Loss of radio signal	Interference and obstruction of transmitter	Data is not transmitted during flight	Real-time data transmission is a failure	4	Complete experiment to test transmission efficiency with obstruction

Recovery

Function / Componen t	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
Black powder charges	Deployment failure	Charge is too small	Unsuccessfu l parachute deployment	Rocket is not safely recovered	1	Complete experimental testing to ensure proper charge sizing
	Violent ejection causes accidental separation	Charge is too big			1	
Avionics	No power to avionics or ignitors	Dead battery	No ejections	Rocket is not safely recovered	1	Use new batteries for each launch

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
	Interference from RF transmitter	Improper design	No ejections or mistimed ejections	Damage from high velocity ejection	2	Complete testing of electronic devices
	Bug in altimeter coding	Manufacturer defect		Large drift from early ejection	4	Test two altimeters for redundancy
Bulkhead and U-bolt	U-bolt failure	Improper attachment	Separation of rocket section from parachute	Rocket is not safely recovered	1	Make sure components are adequately constructed
	Bulkhead failure	Improper attachment			1	
Parachute deployment	Parachutes (3) fail to deploy correctly	Parachute tangling	Parachutes do not correctly deploy	Rocket is not safely recovered	1	Ensure that parachutes and shock cord are folded correctly
		Remote sensor of rocket section from parachutes			3	Construct the rocket so the wires are out of the way
		Parachute bags do not fully open			1	Fold bags correctly and make sure nothing can snag the parachutes

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
		Shock cord connections come loose			1	Check all shock cord
Exploding eyebolts	Eyebolts (2) fail to detonate	Improper wiring/attachment	Lower and middle airframes do not separate	Rocket is not safely recovered	1	Make sure components are adequately constructed
		Manufacturer defect			4	Test two eyebolts for redundancy
	Premature detonation	Improper wiring/attachment	Premature separation of connections between lower and middle airframe	Large drifting distance of lower airframe	3	Make sure components are adequately constructed
		RF interference			3	Complete testing of electronic devices

Aerodynamics

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
Fins	Fins layout cause unexpected trajectory	Fins are not attached at the correct angle	Aerodynamic forces from fins are not the same from each fin	Trajectory is different than expected	3	Use fin jig to ensure angles are correct
		Fins are not			4	Shape fins to

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
		symmetric				specifications before installation
Nose cone	Nose cone imperfections lead to altered trajectory	Manufacture defect	Aerodynamic forces are greater on one side of the nose cone	Trajectory is different than expected	4	Inspect nose cone and sand to correct shape
Boat tail	Boat tail imperfections lead to altered trajectory	Manufacture defect	Aerodynamic forces are greater on one side of the boat tail	Trajectory is different than expected	4	Inspect boat tail and sand to correct shape
Thruster	Thruster causes too large of a disturbance	Thruster force is greater than expected	Thruster force cause a greater disturbance angle	Large effect on trajectory of rocket	1	Complete experiments to measure the thrust
Rocket sections	Rocket sections separate before charges ignite	Deceleration of the rocket	Sections separate early	High velocity separation	1	Make sure shear pins and screws can hold
				Premature parachute deployment at high altitudes	4	

Propulsion

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
Bulkhead and loadcell	Motor breaks through load cell and bulkhead	Material or construction flaws	Motor system is compromise	Motor damages rocket frame	1	Inspect bulkhead and loadcell prior to launch

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
			d	or contents		
Motor casing	Damage to motor casing	Superficial damage	Motor is not safe if major damage occurs	Rocket is not safe to launch if damage is major	4	Check motor casing before launch, remove foreign objects from motor area.
		Motor inoperable			2	
		Motor casing fracture			1	
Fuel	Contamination of fuel	Rocket fails to launch	Reduced performance of rocket motor	Rocket does not launch or perform as expected	2	Store and maintain motor fuel properly and in isolation. Order from reputable source.
		Over-oxidized reaction			2	
		Reduced fuel efficiency			3	
Constructio n	Motor misalignment	Construction or measurement error	Thrust is not in expected direction	Unpredicted trajectory	1	Check motor alignment during construction
		Rocket frame fracture			1	
Launch	Launch interference from foreign object	Unpredictable rocket trajectory	Launch when clear		3	Launch in an open area, wait for clear airspace before launch
		Rocket frame fracture			2	

Stability

Function / Componen t	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
Cg	Expected numbers are different from actual	Error in calculations and measurements	Stability characteristics are different than projected	Natural frequency, damping ratio, thruster sizing, and stability are all effected	1	Physically measure the location of the center of gravity
Cp						Use Barrowman's method to determine location of center of pressure
Static Margin						Calculate by using the locations of the center of gravity and pressure
Weight Shift	Weight shift causes center of gravity shift	Large acceleration or deceleration forces an object to shift	Static margin change due to shift in center of gravity		1	Ensure all rocket components are secure during construction process

3.6.3. Personnel Hazards

3.6.3.1. MSDS

ALCOA

Material Safety Data Sheet

Product Name: 6061/AL2O3/22P-T6P **ID: 807**

*** Section 1 - Chemical Product and Company Identification ***

Chemical Formula: Mixture, metal matrix with particulate reinforcement
Product Use: Various fabricated aluminum parts and products
Other Designations: C291, 6061/AL2O3/20P-T6P

Alcoa Inc.
201 Isabella Street
Pittsburgh, PA 15212-5858

Phone: Health and Safety: 1-412-553-4649

Emergency Information:
USA: Chemtrec: 1-800-424-9300 or 1-703-527-3887 Alcoa: 1-412-553-4001

Website:
For a current MSDS, refer to Alcoa websites: www.alcoa.com or Internally at my.alcoa.com EHS Community

*** Section 2 - Composition / Information on Ingredients ***

Complete composition is provided below and may include some components classified as non-hazardous.

CAS #	Component	Percent
7429-90-5	Aluminum	>76
1344-28-1	Aluminum oxide (non-fibrous)	20-24
7440-47-3	Chromium	<0.23

Component Information
Additional compounds which may be formed during processing are listed in Section 8.

*** Section 3 - Hazards Identification ***

EMERGENCY OVERVIEW

Solid. Silvery. Odorless. Non-combustible as supplied. Small chips, fine turnings and dust from processing may be readily ignitable.

Explosion/fire hazards may be present when (See Sections 5, 7 or 10 for additional information):
* Dust or fines are dispersed in the air.
* Chips, dust or fines are in contact with water.
* Dust or fines are in contact with certain metal oxides (e.g. rust).
* Molten metal is in contact with water/moisture or certain metal oxides (e.g. rust).

Dust and fume from processing can cause irritation of eyes, skin and upper respiratory tract.

POTENTIAL HEALTH EFFECTS
(If dusts or fumes are generated by processing)

Eyes
Can cause irritation.

Skin
Can cause irritation.

Inhalation
Can cause irritation of upper respiratory tract and other health effects listed below. Cancer hazard.

Material Safety Data Sheet

Product Name: 6061/AL2O3/22P-T6P **ID: 807**

Health Effects of Ingredients

Chromium dust and mist Can cause irritation of eyes, skin and respiratory tract. **Chromium and trivalent chromium** IARC/NTP: Not classified by IARC.

Aluminum dust, fines and fumes Low health risk by inhalation. Generally considered to be biologically inert (milling, cutting, grinding).

Alumina (aluminum oxide) Low health risk by inhalation. Generally considered to be biologically inert.

Some products are supplied with a lubricant/oil coating or have residual oil from the manufacturing process. **Oil** Can cause irritation of skin. Skin contact (prolonged or repeated): Can cause dermatitis. **Mineral oils, untreated or mildly refined** IARC/NTP: Listed as "known to be a human carcinogen" by the NTP. Listed as carcinogenic to humans by IARC (Group 1)*. Additional information: Studies with experimental animals by skin contact have found skin tumors.

Health Effects Of Additional Compounds That May Be Formed During Processing
(The following could be expected if welded, remelted or otherwise processed at elevated temperatures.)

Hexavalent chromium (Chrome VI) Can cause irritation of eyes, skin and respiratory tract. Skin contact: Can cause irritant dermatitis, allergic reactions and skin ulcers. Chronic overexposures: Can cause perforation of the nasal septum, respiratory sensitization, asthma, the accumulation of fluid in the lungs (pulmonary edema), lung damage, kidney damage, lung cancer, nasal cancer and cancer of the gastrointestinal tract. IARC/NTP: Listed as "known to be a human carcinogen" by the NTP. Listed as carcinogenic to humans by IARC (Group 1)*.

If the product is heated well above ambient temperatures or machined, oil vapor or mist may be generated. **Oil vapor and mist** Can cause irritation of respiratory tract. Acute overexposures: Can cause bronchitis, asthma, headache, central nervous system effects (nausea, dizziness and loss of coordination) and drowsiness (narcosis)

Welding, plasma arc cutting, and arc spray metalizing can generate ozone. **Ozone** Can cause irritation of eyes, nose and upper respiratory tract. Acute overexposures: Can cause shortness of breath, tightness of chest, headache, cough, nausea and narrowing of airways. Effects are reversible on cessation of exposure. Acute overexposures (high concentrations): Can cause respiratory distress, respiratory tract damage, bleeding and the accumulation of fluid in the lungs (pulmonary edema). Effects can be delayed up to 1-2 hours. Additional information: Studies with experimental animals by inhalation have found genetic damage, reproductive harm, blood cell damage, lung damage and death.

Welding fumes IARC/NTP: Listed as possibly carcinogenic to humans by IARC (Group 2B)*. Additional Information: In one study, occupational asthma was associated with exposures to fumes from aluminum welding.

Plasma arc cutting can generate oxides of nitrogen. **Oxides of nitrogen (NO and NO_2)** Can cause irritation of eyes, skin and respiratory tract. Acute overexposures: Can cause reduced ability of the blood to carry oxygen (methemaglobin). Can cause cough, shortness of breath, the accumulation of fluid in the lungs (pulmonary edema) and death. Effects may be delayed up to 2-3 weeks. **Nitrogen dioxide (NO_2)** Chronic overexposures: Can cause scarring of the lungs (pulmonary fibrosis).

***IARC Classification Definitions**

Group 1: The agent is carcinogenic to humans. There is sufficient evidence that a causal relationship existed between exposure to the agent and human cancer.
Group 2B: The agent is possibly carcinogenic to humans. Generally includes agents for which there is limited evidence in humans and less than sufficient evidence in experimental animals.

Medical Conditions Aggravated By Exposure to the Product and/or Components

Dust or fume from processing: Asthma, chronic lung disease, and skin rashes.

Material Safety Data Sheet

Product Name: 6061/AL2O3/22P-T6P **ID: 807**

*** Section 4 - First Aid Measures ***

First Aid: Eyes

Dust or fume from processing: Flush eyes with plenty of water or saline for at least 15 minutes. Consult a physician.

First Aid: Skin

Dust or fume from processing: Wash skin with soap and water for at least 15 minutes. Consult a physician if irritation persists.

First Aid: Inhalation

Dust or fume from processing: Remove to fresh air. If unconscious or severely injured, check for clear airway, breathing and presence of pulse. Perform CPR if there is no pulse or respiration. Consult a physician.

*** Section 5 - Fire Fighting Measures ***

Flammable/Combustible Properties

Non-combustible as supplied. Small chips, turnings, dust and fines from processing may be readily ignitable.

Fire/Explosion

May be a potential hazard under the following conditions:

* Dust or fines dispersed in the air can be explosive. Even a minor dust cloud can explode violently.
* Chips, dust or fines in contact with water can generate flammable/explosive hydrogen gas. Hydrogen gas could present an explosion hazard in confined or poorly ventilated spaces.
* Dust or fines in contact with certain metal oxides (e.g., rust). A thermite reaction, with considerable heat generation, can be initiated by a weak ignition source.
* Molten metal in contact with water/moisture or other metal oxides (e.g., rust, copper oxide). Moisture entrapped by molten metal can be explosive. Contact of molten aluminum with other metal oxides can initiate a thermite reaction. Finely divided metals (e.g., powders or wire) may have enough surface oxide to produce thermite reactions/explosions.

Extinguishing Media

Use Class D extinguishing agents on dusts, fines or molten metal. Use coarse water spray on chips and turnings.

Unsuitable Extinguishing Media

DO NOT USE:

* Halogenated agents on small chips, dusts or fines.
* Water around molten metal.

These agents will react with the burning material.

Fire Fighting Equipment/Instructions

Fire fighters should wear NIOSH approved, positive pressure, self-contained breathing apparatus and full protective clothing when appropriate.

*** Section 6 - Accidental Release Measures ***

Small/Large Spill

If molten: Contain the flow using dry sand or salt flux as a dam. Do not use shovels or hand tools to halt the flow of molten aluminum. Allow the spill to cool before remelting as scrap.

*** Section 7 - Handling and Storage ***

Handling/Storage

Product should be kept dry. Avoid generating dust. Avoid contact with sharp edges or heated metal. Hot and cold aluminum are not visually different. Hot aluminum does not necessarily glow red.

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Product Name: 6061/AL2O3/22P-T6P **ID: 807**

Requirements for Processes Which Generate Dusts or Fumes

If processing of these products includes operations where dust or extremely fine particulate is generated, obtain and follow the safety procedures and equipment guides contained in Aluminum Association Bulletin F-1 and National Fire Protection Association (NFPA) brochures listed in Section 16. Cover and reseal partially empty containers. Use non-sparking handling equipment. Provide grounding and bonding where necessary to prevent accumulation of static charges during dust handling and transfer operations. (See Section 15).

Local ventilation and vacuum systems must be designed to handle explosive dusts. Dry vacuums and electrostatic precipitators must not be used. Dust collection systems must be dedicated to aluminum dust only and should be clearly labeled as such. Do not co-mingle fines of aluminum with fines of iron, iron oxide (rust) or other metal oxides.

Do not allow chips, fines or dust to contact water, particularly in enclosed areas.

Avoid all ignition sources. Good housekeeping practices must be maintained.

Requirements for Remelting of Scrap Material and/or Ingot

Molten metal and water can be an explosive combination. The risk is greatest when there is sufficient molten metal to entrap or seal off the water. Water and other forms of contamination on or contained in scrap or remelt ingot are known to have caused explosions in melting operations. While the products may have minimal surface roughness and internal voids, there remains the possibility of moisture contamination or entrapment. If confined, even a few drops of water can lead to violent explosions.

All tooling and containers which come in contact with molten metal must be preheated or specially coated and rust free. Molds and ladles must be preheated or oiled prior to casting. Any surfaces that may contact molten metal (e.g., concrete) should be specially coated.

Drops of molten metal in water (e.g. from plasma arc cutting), while not normally an explosion hazard, can generate enough flammable hydrogen gas to present an explosion hazard. Vigorous circulation of the water and removal of the particles minimize the hazards.

During melting operations, the following minimum guidelines should be observed:
* Inspect all materials prior to furnace charging and completely remove surface contamination such as water, ice, snow, deposits of grease and oil or other surface contamination resulting from weather exposure, shipment, or storage.
* Store materials in dry, heated areas with any cracks or cavities pointed downwards.
* Preheat and dry large or heavy items such as ingot adequately before charging into a furnace containing molten metal. This is typically done by use of a drying oven or homogenizing furnace. The drying cycle should bring the internal metal temperature of the coldest item of the batch to 400°F and then hold at that temperature for 6 hours.

* * * Section 8 - Exposure Controls / Personal Protection * * *

Engineering Controls

If dust or fumes are generated through processing: Use with adequate explosion-proof ventilation to meet the limits listed in Section 8, Exposure Guidelines.

Personal Protective Equipment

Respiratory Protection

If dust or fumes are generated through processing: Use NIOSH-approved respiratory protection as specified by an Industrial Hygienist or other qualified professional if concentrations exceed the limits listed in Section 8, Exposure Guidelines. Suggested respiratory protection: P95

Eye Protection

Wear safety glasses/goggles to avoid eye injury.

Skin Protection

Wear impervious gloves to avoid repeated or prolonged skin contact with residual oils and to avoid any skin injury.

Material Safety Data Sheet

Product Name: 6061/AL2O3/22P-T6P **ID: 807**

General

Personnel who handle and work with **molten metal** should utilize primary protective clothing like polycarbonate face shields, fire resistant tapper's jackets, neck shades (snoods), leggings, spats and similar equipment to prevent burn injuries. In addition to primary protection, secondary or day-to-day work clothing that is fire resistant and sheds metal splash is recommended for use with molten metal. Synthetic materials should never be worn even as secondary clothing (undergarments).

Minimize breathing **oil vapors and mist**. Remove oil contaminated clothing; launder or dry-clean before reuse. Remove oil contaminated shoes and thoroughly clean and dry before reuse. Cleanse skin thoroughly after contact, before breaks and meals, and at the end of the work period. Oil coating is readily removed from skin with waterless hand cleaners followed by a thorough washing with soap and water.

Exposure Guidelines

A: General Product Information

Alcoa recommends an Occupational Exposure Limit for Oil Mist of 0.5 mg/m3 TWA
Alcoa recommends an Occupational Exposure Limit for Chromium (VI) Compounds [both soluble and insoluble forms] of 0.25 ug/m3 TWA as chromium.

B: Component Exposure Limits

Aluminum (7429-90-5)
ACGIH 10 mg/m3 TWA (metal dust)
OSHA 15 mg/m3 TWA (total dust); 5 mg/m3 TWA (respirable fraction)

Aluminum oxide (non-fibrous) (1344-28-1)
ACGIH 10 mg/m3 TWA (particulate matter containing no asbestos and < 1% crystalline silica)
OSHA 15 mg/m3 TWA (total dust); 5 mg/m3 TWA (respirable fraction)

Chromium (7440-47-3)
ACGIH 0.5 mg/m3 TWA
OSHA 1 mg/m3 TWA

C: Exposure Limits for Additional Compounds Which May Be Formed During Processing

Chromium (II) compounds (Not Available)
OSHA 0.5 mg/m3 TWA (as Cr)

Chromium (VI) compounds- water soluble (Not Available)
ACGIH 0.05 mg/m3 TWA (as Cr)

Chromium (VI) compounds (certain water insoluble forms) (Not Available)
ACGIH 0.01 mg/m3 TWA (as Cr)

Chromic acid and chromates (7738-94-5)
OSHA 0.1 mg/m3 Ceiling

Ozone (10028-15-6)
ACGIH 0.05 ppm TWA (heavy work); 0.08 ppm TWA (moderate work); 0.10 ppm TWA (light work); 0.20 ppm TWA (heavy, moderate or light workloads, less than or equal to 2 hours)
OSHA 0.1 ppm TWA; 0.2 mg/m3 TWA

Nitrogen dioxide (10102-44-0)
ACGIH 3 ppm TWA
ACGIH 5 ppm STEL
OSHA 5 ppm Ceiling; 9 mg/m3 Ceiling

Nitric oxide (10102-43-9)
ACGIH 25 ppm TWA
OSHA 25 ppm TWA; 30 mg/m3 TWA

Material Safety Data Sheet

Product Name: 6061/AL2O3/22P-T6P **ID: 807**

*** Section 9 - Physical & Chemical Properties ***

Physical State:	Solid	**Appearance:**	Silvery
Boiling Point:	Not applicable	**Melting Point:**	Range: generally 895-1220°F (480-660°C)
Vapor Pressure:	Not applicable	**Vapor Density:**	Not applicable
Solubility in Water:	None	**Specific Gravity:**	See Density
Density:	Range: generally 2.50-3.0 g/cm3 (0.090-0.108 lb/in3)	**pH Level:**	Not applicable
Odor:	None	**Odor Threshold:**	Not applicable
Octanol-Water Coefficient:	Not applicable		

*** Section 10 - Chemical Stability & Reactivity Information ***

Stability

Stable under normal conditions of use, storage, and transportation.

Conditions to Avoid

Chips, fines, dust and molten metal are considerably more reactive with the following:

* **Water:** Slowly generates flammable/explosive hydrogen gas and heat. Generation rate is greatly increased with smaller particles (e.g., fines and dusts). Molten metal can react violently/explosively with water or moisture, particularly when the water is entrapped.

* **Heat:** Oxidizes at a rate dependent upon temperature and particle size.

* **Strong oxidizers:** Violent reaction with considerable heat generation. Can react explosively with nitrates (e.g., ammonium nitrate and fertilizers containing nitrate) particularly when heated or molten.

* **Acids and alkalis:** Reacts to generate flammable/explosive hydrogen gas. Generation rate is greatly increased with smaller particles (e.g., fines and dusts).

* **Halogenated compounds:** Many halogenated hydrocarbons, including halogenated fire extinguishing agents, can react violently with finely divided aluminum.

* **Iron oxide (rust) and other metal oxides (e.g., copper and lead oxides):** A violent thermite reaction generating considerable heat can occur. Reaction with aluminum fines and dusts requires only very weak ignition sources for initiation. Molten aluminum can react violently with iron oxide without external ignition source.

* **Iron powder and water:** An explosive reaction forming hydrogen gas occurs when heated above 1470°F (800°C).

*** Section 11 - Toxicological Information ***

Health Effects of Ingredients

A: General Product Information

No information available for product.

B: Component Analysis - LD50/LC50

Aluminum oxide (non-fibrous) (1344-28-1)

Oral LD50 Rat: >5000 mg/kg

Carcinogenicity

A: General Product Information

No information available for product.

B: Component Carcinogenicity

Aluminum oxide (non-fibrous) (1344-28-1)

ACGIH A4 - Not Classifiable as a Human Carcinogen

Chromium (7440-47-3)

ACGIH A4 - Not Classifiable as a Human Carcinogen

IARC Monograph 49, 1990 (listed under Chromium and Chromium compounds); Supplement 7, 1987

Material Safety Data Sheet

Product Name: 6061/AL2O3/22P-T6P **ID: 807**

*** Section 12 - Ecological Information ***

Ecotoxicity
A: General Product Information
No information available for product.
B: Component Analysis - Ecotoxicity - Aquatic Toxicity
No ecotoxicity data was found for this product's components.
Environmental Fate
No information available for product.

*** Section 13 - Disposal Considerations ***

Disposal Instructions
Reuse or recycle material whenever possible. Material may be disposed of at an industrial landfill.
US EPA Waste Number & Descriptions
A: General Product Information
RCRA Status: Not federally regulated in the U.S. if disposed of "as is". Otherwise, characterize in accordance with applicable regulations (40 CFR 261 or state equivalent in the U.S.)
B: Component Waste Numbers
RCRA waste codes other than described under Section A may apply depending on use of product. Refer to 40 CFR 261 or state equivalent in the U.S.

*** Section 14 - Transportation Information ***

Special Transportation

	PSN #1	PSN #2	PSN #3	PSN #4
Notes:	(1)			
Proper Shipping Name:	Not regulated			
Hazard Class:	-			
UN NA Number:	-			
Packing Group:	-			
RQ:	-			
Other - Tech Name:	-			
Other - Marine Pollutant:	-			

Notes:

(1) When "Not regulated", enter the proper freight classification, "MSDS Number", and "Product Name" on the shipping paperwork.

Canadian TDG Hazard Class & PIN:	Not regulated

*** Section 15 - Regulatory Information ***

US Federal Regulations
A: General Product Information
All electrical equipment must be suitable for use in hazardous atmospheres involving aluminum powder in accordance with 29 CFR 1910.307. The National Electrical Code, NFPA 70, contains guidelines for determining the type and design of equipment and installation that will meet this requirement.
In reference to Title VI of the Clean Air Act of 1990, this material does not contain nor was it manufactured using ozone-depleting chemicals.

Material Safety Data Sheet

Product Name: 6061/AL2O3/22P-T6P **ID: 807**

B: Component Analysis

This material contains one or more of the following chemicals required to be identified under SARA Section 302 (40 CFR 355 Appendix A), SARA Section 313 (40 CFR 372.65) and/or CERCLA (40 CFR 302.4).

Aluminum (7429-90-5)

SARA 313: 1.0 % de minimis concentration (dust or fume only)

Chromium (7440-47-3)

CERCLA: 5000 lb final RQ (no reporting of releases of this hazardous substance is required if the diameter of the pieces of the solid metal released is equal to or exceeds 0.004 inches); 2270 kg final RQ (no reporting of releases of this hazardous material is required if the diameter of the pieces of the solid metal released is equal to or exceeds 0.004 inches)

SARA 311/312 Physical and Health Hazard Categories:

Immediate (acute) Health Hazard: Yes, if particulates/fumes generated during processing.
Delayed (chronic) Health Hazard: Yes, if particulates/fumes generated during processing.
Fire Hazard: No
Sudden Release of Pressure: No
Reactive: Yes, if molten

State Regulations

A: General Product Information

PENNSYLVANIA "Special Hazardous Substance": Chromium
Chemical(s) known to the State of California to cause cancer: Chromium (hexavalent compounds)

B: Component Analysis - State

The following components appear on one or more of the following state hazardous substances lists:

Component	CAS #	CA	FL	MA	MN	NJ	PA
Aluminum	7429-90-5	Yes	No	Yes	Yes	Yes	Yes
Aluminum oxide (non-fibrous)	1344-28-1	No	No	Yes	Yes	Yes	Yes
Chromium	7440-47-3	Yes	No	Yes	Yes	Yes	Yes

Other Regulations

A: General Product Information

No information available for product.

B: Component Analysis - WHMIS IDL

The following components are identified under the Canadian Hazardous Products Act Ingredient Disclosure List:

Component	CAS #	Minimum Concentration
Aluminum	7429-90-5	1 %
Aluminum oxide (non-fibrous)	1344-28-1	1 %
Chromium	7440-47-3	0.1 %

C: Component Analysis - Inventory

Component	CAS #	TSCA	DSL	EINECS	AUST.	MITI
Aluminum	7429-90-5	Yes	Yes	Yes	Yes	No
Aluminum oxide (non-fibrous)	1344-28-1	Yes	Yes	Yes	Yes	Yes
Chromium	7440-47-3	Yes	Yes	Yes	Yes	No

MITI Inventory: Pure metals are not specifically listed by CAS or MITI number on the MITI Inventory. However, the class of compounds for each of these metals is listed.

Material Safety Data Sheet

Product Name: 6061/AL2O3/22P-T6P **ID: 807**

*** Section 16 - Other Information ***

MSDS History
Original: October 14, 1992
Supersedes: December 20, 1999
Revised: January 20, 2006
MSDS Status
01/20/06: Reviewed on a periodic basis in accordance with Alcoa policy.
Changes in Sections 1, 2, 3, 4, 5, 8 and 15.
12/20/99: New Format.
Prepared By
Hazardous Materials Control Committee
Preparer: Jon N. Peace, 412-553-2293
MSDS System Number
132892
Other Information
* Aluminum Association's Bulletin F-1, "Guidelines for Handling Aluminum Fines Generated During Various Aluminum Fabricating Operations." The Aluminum Association, 900 19th Street, N.W., Washington, DC 20006.
* Aluminum Association, "Guidelines for Handling Molten Aluminum, The Aluminum Association, 900 19th Street, N.W., Washington, DC 20006.
* NFPA 65, Standard for Processing and Finishing of Aluminum (NFPA phone: 800-344-3555)
* NFPA 651, Standard for Manufacture of Aluminum and Magnesium Powder
* NFPA 70, Standard for National Electrical Code (Electrical Equipment, Grounding and Bonding)
* NFPA 77, Standard for Static Electricity
* Guide to Occupational Exposure Values-2005, Compiled by the American Conference of Governmental Industrial Hygienists (ACGIH).
* Documentation of the Threshold Limit Values and Biological Exposure Indices, Sixth Edition, 1991, Compiled by the American Conference of Governmental Industrial Hygienists, Inc. (ACGIH).
* NIOSH Pocket Guide to Chemical Hazards, U.S. Department of Health and Human Services, February 2004.
* Patty's Industrial Hygiene and Toxicology: Volume II: Toxicology, 4th ed., 1994, Patty, F. A.; edited by Clayton, G. D. and Clayton, F. E.: New York: John Wiley & Sons, Inc.
* expub, www.expub.com, Expert Publishing, LLC.

Material Safety Data Sheet

Product Name: 6061/AL2O3/22P-T6P **ID: 807**

Key-Legend:

ACGIH	American Conference of Governmental Industrial Hygienists
AICS	Australian Inventory of Chemical Substances
CAS	Chemical Abstract Service
CERCLA	Comprehensive Environmental Response. Compensation, and Liability Act
CFR	Code of Federal Regulations
CPR	Cardio-pulmonary Resuscitation
DOT	Department of Transportation
DSL	Domestic Substances List (Canada)
EC	Effective Concentration
ED	Effective Dose
EINECS	European Inventory of Existing Commercial Chemical Substances
EPA	Environmental Protection Act
IARC	International Agency for Research on Cancer
LC_{50}	Lethal concentration (50 percent kill)
LC_{Lo}	Lowest published lethal concentration
LD_{50}	Lethal dose (50 percent kill)
LD_{Lo}	Lowest published lethal dose
LFL	Lower Flammable Limit
MITI	Ministry of International Trade & Industry
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
NTP	National Toxicology Program
OEL	Occupational Exposure Limit
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PIN	Product Identification Number
PSN	Proper Shipping Name
RCRA	Resource Conservation and Recovery Act
SARA	Superfund Amendments and Reauthorization Act
STEL	Short Term Exposure Limit
TCLP	Toxic Chemicals Leachate Program
TDG	Transportation of Dangerous Goods
TLV	Threshold Limit Value
TSCA	Toxic Substance Control Act
TWA	Time Weighted Average
UFL	Upper Flammable Limit
WHMIS	Workplace Hazardous Materials Information System
atm	atmosphere
cm	centimeter
g, gm	gram
in	inch
kg	kilogram
lb	pound
m	meter
mg	milligram
ml, ML	milliliter
mm	millimeter
mppcf	million particles per cubic foot
n.o.s	not otherwise specified
ppb	parts per billion
ppm	parts per million
psia	pounds per square inch absolute
u	micron
ug	microgram

INFORMATION HEREIN IS GIVEN IN GOOD FAITH AS AUTHORITATIVE AND VALID; HOWEVER, NO WARRANTY, EXPRESS OR IMPLIED, CAN BE MADE.

This is the end of MSDS # 807

6061/AL2O3/22P-T6P

WARNING

Hazards: Non-combustible as supplied. Small chips, fine turnings and dust may ignite readily.

Explosion potential may be present when: (1) dusts or fines are dispersed in the air, (2) fines, dust or molten aluminum are in contact with certain metal oxides (i.e., rust) or (3) chips, fines, dust or molten aluminum are in contact with water or moisture.

Overexposures to dusts can cause irritation of eyes, skin, and upper respiratory tract.

If coated with oil, may cause skin irritation/dermatitis by contact.

Potential health effects from welding or remelting:

Overexposure to dust/fume containing chromium compounds may cause nasal and lung cancer by inhalation.

WARNING: Chromium (hexavalent compounds) are chemicals known to the State of California to cause cancer (Proposition 65).

Precautions: Avoid generating dusts. Use with adequate explosion-proof ventilation. Keep material dry.

Wear appropriate eye and skin protection (safety glass/goggles, gloves) to prevent injury. Use respiratory protection (P95) if exposures exceed the permissible limits.

First Aid (dust and fume from processing): EYES: Flush with plenty of water or saline for at least 15 minutes. Consult a physician. SKIN: Wash with soap and water for at least 15 minutes. Consult a physician if irritation persists. INHALATION: Remove to fresh air. If unconscious or severely injured, check for clear airway, breathing and presence of pulse. Perform CPR if there is no pulse or respiration. Consult a physician.

Read Alcoa Material Safety Data Sheet No. 807 for more information about use and disposal.

Emergency Phone: (412) 553-4001.

INGREDIENTS:	CAS NUMBERS:
Aluminum	(7429-90-5)
Aluminum oxide (non-fibrous)	(1344-28-1)
Chromium	(7440-47-3)

Alcoa Inc.
201 Isabella Street, Pittsburgh, PA 15212-5858 USA
1/06 807

ALCOA

FORMAX E-GLASS PRODUCTS
MATERIAL SAFETY DATA SHEET

Section 1: Identification of the substance

1.1 Identification of the substance or preparation: Fibrous Glass, continuous filament.

Chemical Formula: E-glass
Product Types: Stitched, parallel laid fibre fabrics

Section 2: Composition / Information on Ingredients

Ingredients	% Weight	Control Limit
Fibrous Glass (E-type, continuous filament) Composition consisting principally of oxides, silicon, aluminium, calcium, boron and magnesium, fused in an amorphous vitreous state.	90.0% min	To be considered as a (non respirable) "nuisance" dust. Control limits according to local regulations.
Surface Sizing (complex mixture; in general, of silanes and polymers	2.0% max	None established

Glass fibre does not meet the classification for a "dangerous substance" according to 67/548/EEC and 97/69/EC. Glass fibre carries no CA and no EPA designation number. CAS number: see under 65997-13-3. Glass fibre is considered to be an article as defined in section 710.2 (F) of the US TSCA and, as such, is exempt from section 5 and section 8 (B) reporting requirements.

Section 3: Hazards Identification

Emergency Overview: This product is stable and not flammable under normal industrial conditions. Exposure to continuous filament glass fibres sometimes causes irritation of the skin and, less frequently, irritation of the eyes, nose or throat. The primary route of entry into the body is inhalation. The glass fibres used by Formax UK Limited have diameters greater than 3.5 microns and are therefore NOT respirable, nor can they become respirable by any normal industrial processing.

Primary Route(s) of Entry: Inhalation

Signs and Symptoms of Overexposure: Rash, itching, conjunctivitis, coughing, sneezing

Health Hazards (acute): Exposure to continuous filament glass fibres sometimes causes irritation of the skin and, less frequently irritation of the eyes, nose, or throat.

(Chronic)/Carcinogenity Status: see Section 11

Medical Conditions Aggravated by Exposure: None known

EC Labelling Classification: Not a dangerous substance or preparation

Section 4: First-Aid Measures

Eye Contact: Flush eyes with clear water for at least 15 minutes – seek medical attention
Skin Contact: Rinse contact areas with room temperature to cool water, then wash gently with mild soap. If glass fibre becomes embedded, seek material attention
Inhalation: If irritation persists, seek medical attention. Product is NOT respirable.

If swallowed: Seek medical attention

Section 5: Fire-Fighting Measures

Flash Point:	Non-burning
Flammable Limits:	Not applicable
Extinguishing Media:	Not applicable
Special Fire Fighting Procedures:	In sustained fire self-contained breathing apparatus should be worn
Unusual Fire and Explosion Hazards:	Not applicable
Special Exposure Hazards from Fire:	Hazardous products of combustion of sizings and binders may be released in a sustained fire. The larger part off the glass fibre product is non-flammable E-glass

Section 6: Accidental Release Measures

Steps to be taken in case material is released or spilled: No special precautions
Waste Disposal Method: Dispose of as a solid waste in accordance with Government regulations.

Section 7: Handling and Storage

Precautions to be taken in Handling: Non relative to health and safety. This product is to be considered as a non-respirable "nuisance dust". Control limits according to local regulations.
Precautions to be taken in Storage: For optimum performance, Formax UK Limited fabrics should be stored at a temperature less than 25°C and a relative humidity less than 65%.

Section 8: Exposure Controls/Personal Protection

Respiratory Protection: None normally required. If airborne glass fibre concentrations exceed the control limit, respiratory protection for nuisance dusts should be provided.
Ventilation: Use local exhaust ventilation if necessary to maintain airborne levels to below established limit.
Skin Protection: Protective gloves may reduce skin irritation in some operations.
Eye Protection: Safety glasses with side shields should be worn
Other Protective Equipment: Use of overalls, long trousers, and good personal hygiene will maximise comfort.
Measurement Procedures/References: The American Conference of Governmental Hygienists has adopted a Threshold Limit Value (TLV) for fibrous dust of 15mg/m3 (total) and 5mg/m3 (respirable). The Occupational Safety and Health Administration (OSHA) does not prescribe a Permissible Exposure Limit (PEL) for fibrous glass but relies on the PEL-TWA's for nuisance dust of 15mg/m3 (total) and 5mg/m3 (respirable).

Section 9: Physical and Chemical Properties

Appearance: Yellow to white fibres bound together in strands
PH: Not applicable
Melting Point (softening): 800°C
Flash Point: Non-burning
Auto-ignition/explosion limits: Non applicable
Electrical conductivity: E-glass is an electrical insulator
Evaporation Rate: Not applicable
Specific Gravity (bare glass): 2.6-2.7
Percent Volatile: Wet chopped strands: 15%, Mat: 6.5%, Other 2%
Octanol/water Partition Coefficient: Not applicable

Odour: None
Boiling Point: Not applicable
Freezing Point: Not applicable
Flammability: Not applicable
Oxidation Risk: Non applicable
Autoflammability: Non applicable
Vapour Pressure: Not applicable
Vapour Density: Not applicable
Solubility: Insoluble in water

Section 10: Stability and Reactivity

Stability: Stable
Conditions to avoid: None known
Incompatibility (Material to Avoid): None known

Hazardous Decomposition Products: In a sustained fire, sizings and binders may decompose releasing hazardous products of combustion (see Section 5)
Hazardous Polymerisation: Will not occur

Section 11: Toxicological Information

Factors in fibre toxicity include: Fibre dimensions and degree of exposure

Fibre Dimensions: fibres of diameters larger than 3.5 microns are deemed as being non-respirable. The fibres do not become respirable upon the sanding/machine processing activities of our customers. Upon fibre breakage, the fibres break horizontally into smaller lengths, but not longitudinally into smaller diameters.

Degree of Exposure: Not applicable

Carcinogenicity: The International Agency for Research on Cancer has designated continuous filament fibre glass, as a group 3, "not classifiable as to human carcinogenicity". This means that evidence is not sufficient to link that fibre to cancer.

Section 12: Ecological Information

Because glass fibre is generally considered to be an inert solid waste, no special precautions should be taken in case it is released or spilled.

Section 13: Disposal Considerations

Glass fibre is generally considered to be an inert solid waste not requiring hazardous waste disposal procedures.

Section 14: Transport Information

There are no special precautions or restrictions involving transport of glass fibre known to Formax UK Limited

Section 15: Regulatory Information

Glass fibres are considered in Europe under the EC regulations as being additives when used as reinforcements for plastics that are intended to come into direct or indirect contact with food and as such have been listed in Annex III of Directive 96/11/EC under PM/Reference No. 55520 with no restrictions mentioned in the pertaining table.

Section 16: Other information

Ask for the APFE brochure "Some Facts on Continuous Filament Fibre Glass and Human Health".

Valid from: 1st January, 2005

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RAYOVAC®

SAFETY DATA SHEET

The sheets are supplied as a service to you. For related information, visit: http://www.rayovac.com/Consumer-Services/Technical-OEM/Material-Safety-Data-Sheets.aspx

1. IDENTIFICATION

PRODUCT NAME: **9-Volt Lithium Battery**

SIZES: 9 Volt

EMERGENCY TELEPHONE NUMBER: 800-424-9300 (24 hr, Chemtrec)

2. HAZARD IDENTIFICATION

We would like to inform our customers that these batteries are exempt articles and are not subject to the 29 CFR 1910.1200 OSHA requirements, Canadian WHMIS requirements or GHS requirements.

Emergency Overview

OSHA Hazards-not applicable
Target Organs-not applicable
GHS Classification-not applicable
GHS Label Elements, including precautionary Statement-not applicable
Pictogram-not applicable
Signal words-not applicable
Hazard statements-not applicable
Precautionary statements-not applicable

3. COMPOSITION/INFORMATION ON INGREDIENTS

INGREDIENT NAME	CAS #	%	TWA/TLV
Stainless Steel	--	40-50	--
Manganese Dioxide	1313-13-9	35-40	C5.0 as fume
1,3 Dioxolane	646-06-0	5-9	None Established
Lithium Hexafluoroarsenate (LiAsF6)	29935-35-1	1-4	No data available
Lithium (metal)	7439-93-2	1 - 4	None Established
Propylene Carbonate	108-32-7	8-10	None Established

**Source: OSHA 29 CFR 1910.1000 Table Z-1, 2 or 3 11-01-2012*

4. FIRST AID INFORMATION

THRESHOLD LIMIT VALUE (TLV) AND SOURCE: NA

EFFECTS OF OVEREXPOSURE: None. (In fire or rupture situation see section 2 and section 4)

EMERGENCY FIRST AID PROCEDURES:
Skin and Eyes:
In the event that battery ruptures, flush exposed skin with copious quantities of flowing lukewarm water for a minimum of 15 minutes. Get immediate medical attention for eyes. Wash skin with soap and water.

LITHIUM metal contact-remove lithium particles from skin or eyes and flush with copious amounts of water May cause burns-seek medical attention immediately.

5. FIRE FIGHTING MEASURES

FLASH POINT:	NA
LOWER (LEL):	NA
FLAMMABLE LIMITS IN AIR (%):	NA
UPPER (UEL):	NA
AUTO-IGNITION:	NA

Extinguishing media: For consumers (small number of batteries)-use water to extinguish combustible materials and cool any batteries involved. Flood any combustible materials ejected from the fire with water.

For bulk shipments (large number of bulk of packaged batteries in a fire) use foam or Lithex™ to smother and cool the fire. Caution-once the suppressant is removed the batteries may re-ignite if exposed to moist air under normal ambient conditions.

For industrial situations place battery materials into Lithex™ to suppress fire potential and allow to slowly discharge to prevent fires. Keep away from combustible materials.

SPECIAL FIRE FIGHTING PROCEDURES: As with any fire, wear self-contained breathing apparatus and protective clothing to avoid contact or inhalation of hazardous decomposition products (See section 2). Significant amount of batteries involved in a fire may release flammable vapors intensifying the fire or creating flashback situations. If a battery is damaged and overheats, place in a safe non-combustible surface until cool, then containerize in a non-combustible container.

SPECIAL FIRE EXPLOSION HAZARDS: Like any sealed container, battery cells may rupture when exposed to excessive heat; this could result in the release of reactive, flammable or corrosive materials. Use cold water if water is used as an extinguishing medium. Lithium metal could be ejected from the fire

6. ACCIDENTAL RELEASE MEASURES

PROCEDURES TO CONTAIN AND CLEAN UP LEAKS OR SPILLS: In the event of a battery rupture, prevent skin contact. Allow any hot material to cool before containerizing. Open lithium will react with moisture-prevent introducing water or moisture to open battery contents (see fire section for batteries involved in a fire). Collect all cool battery material in a sealed plastic lined metal container. Spilled undamaged batteries require no special safety handling. Avoid short circuits.

REPORTING PROCEDURE: Report all spills in accordance with Federal, State and Local reporting requirements.

NA = Not Applicable

7. HANDLING AND STORAGE

Store batteries in a dry place. Storing unpackaged cells together could result in cell shorting and heat build-up. Do not recharge. Do not puncture or abuse. Do not use new and old batteries in the same device at the same time as this could cause cell reversal resulting in overheating or rupture.

8. EXPOSURE CONTROL/PERSONAL PROTECTION

RESPIRATORY PROTECTION (SPECIFY TYPE): NA

VENTILATION:
- Local Exhaust: NA
- Mechanical (General): NA
- Special: NA
- Other: NA

PROTECTIVE GLOVES: NA

EYE PROTECTION: NA

OTHER PROTECTIVE CLOTHING: NA

9. PHYSICAL AND CHEMICAL PROPERTIES

Boiling Point @ 760 mm Hg (°C):	NA	Evaporation Rate (Butyl Acetate = 1):	NA
Vapor Pressure (mm Hg @ 25°C):	NA	Physical State:	NA
Vapor Density (Air = 1):	NA	Solubility in Water (% by Weight):	NA
Density (grams/cc):	NA	pH:	NA
Percent Volatile by Volume (%):	NA	Appearance and Odor:	geometric solid object

10. STABILITY AND REACTIVITY

STABLE OR UNSTABLE: Stable

INCOMPATIBILITY (MATERIALS TO AVOID): NA

HAZARDOUS DECOMPOSITION PRODUCTS: None under normal use

REACTIVITY: None normally-lithium from severely damaged batteries could react with water or moisture.

HAZARDOUS POLYMERIZATION: Will Not Occu

CONDITIONS TO AVOID: Avoid electrical shorting-DO NOT recharge.

NA = Not Applicable

11. TOXICOLOGICAL INFORMATION

INGREDIENT NAME	CAS #	%	TWA/TLV
Stainless Steel	--	40-50	--
Manganese Dioxide	1313-13-9	35-40	5.0 (Mn Ceiling)
1,3 Dioxolane	646-06-0	5-9	None Established
Lithium Hexafluoroarsenate (LiAsF6)	29935-35-1	1-4	No data available
Lithium (metal)	7439-93-2	1 - 4	None Established
Propylene Carbonate	108-32-7	8-10	None Established

**Source: OSHA 29 CFR 1910.1000 Table Z-1, 2 or 3 11-01-2012*

12. ECOLOGICAL INFORMATION

Consumers should dispose of discharged batteries through waste disposal services or legitimate collection outlets. Those collecting batteries should follow state and federal regulations.

Partially discharged damaged batteries can overheat and cause fires in the presence of other combustible materials.

13. DISPOSAL CONSIDERATIONS

Comply with all Federal, state and local regulations. http://www.nema.org/Policy/Environmental-Stewardship/Documents/Companies%20Claiming%20to%20Recycle.MARCH2005.pdf

14. TRANSPORTATION INFORMATION

TRANSPORTATION-SHIPPING: These are lithium batteries, also known as primary or non-rechargeable lithium. These Lithium 9V batteries are regulated as Class 9, see UN3090. Our Lithium 9V meet the general regulatory requirements for shipping Lithium batteries and, when in our original packaging, meet the requirements listed in the Special Instructions or Packing Instructions noted below.
USDOT – See 49 CFR 173.185 and Special Provision 188. Also note: these batteries are forbidden on passenger aircraft to/from or within the US and must be labeled accordingly even for ground or ocean transport.
IMO/Ocean – See Special Provisions 188 and 230.
ICAO/IATA – Effective January 1, 2013 these Rayovac Lithium 9V cells can be shipped by air in accordance with International Air Transport Association (IATA) 54th edition, Section 1B, since these batteries have more than 0.3 g but less than 1 g of Lithium per battery. See Packing Instructions: PI 968 (Batteries), PI 969 (Batteries, packed with equipment) and PI 970 (Batteries, contained in equipment) as applicable.

15. REGULATORY INFORMATION

SARA 313-Notification is not required because these products are article(s) that do not release a covered toxic chemical under the normal conditions of processing or use.

NA = Not Applicable

16. SDS INFORMATION

Environmental Health & Safety Information:	1-800-237-7000
EDITION DATE:	02-14-2013
APPROVED BY:	Kevin J. Domack

NOTICE: The information and recommendations set forth are made in good faith and are believed to be accurate at the date of preparation. Rayovac Corporation makes no warranty expressed or implied.

NA = Not Applicable

Material Safety Data Sheet

Henkel

Revision Number: 001.1 **Issue date:** 01/27/2012

1. PRODUCT AND COMPANY IDENTIFICATION

Product name:	**Loctite Super Glue Ultra Gel**	**IDH number:**	1363589
Product type:	Super glue	**Item number:**	1363589
		Region:	United States

Company address:
Henkel Corporation
One Henkel Way
Rocky Hill, Connecticut 06067

Contact information:
Telephone: 800.624.7767
MEDICAL EMERGENCY Phone: Poison Control Center
1-877-671-4608 (toll free) or 1-303-592-1711
TRANSPORT EMERGENCY Phone: CHEMTREC
1-800-424-9300 (toll free) or 1-703-527-3887

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

		HMIS:	
Physical state:	liquid	**HEALTH:**	2
Color:	colourless	**FLAMMABILITY:**	2
Odor:	irritating	**PHYSICAL HAZARD:**	1
		Personal Protection:	See MSDS Section 8

WARNING: BONDS SKIN IN SECONDS.
MAY CAUSE EYE AND RESPIRATORY TRACT IRRITATION.
COMBUSTIBLE LIQUID AND VAPOR.

Relevant routes of exposure: Skin, Inhalation, Eyes

Potential Health Effects

Inhalation: Exposure to vapors above the established exposure limit results in respiratory irritation, which may lead to difficulty in breathing and tightness in the chest.

Skin contact: Bonds skin in seconds. May cause skin irritation. Cyanoacrylates have been reported to cause allergic reaction but due to rapid polymerization at the skin surface, an allergic response is rare. Cyanoacrylates generate heat on solidification. In rare circumstances a large drop will burn the skin. Cured adhesive does not present a health hazard even if bonded to the skin.

Eye contact: Irritating to eyes. Causes excessive tearing. Eyelids may bond.

Ingestion: Not expected to be harmful by ingestion. Rapidly polymerizes (solidifies) and bonds in mouth. It is almost impossible to swallow.

Existing conditions aggravated by exposure: Eye, skin, and respiratory disorders.

This product is considered hazardous under 29 CFR 1910.1200 (Hazard Communication).

See Section 11 for additional toxicological information.

3. COMPOSITION / INFORMATION ON INGREDIENTS

Hazardous components	**CAS NUMBER**	**%**
Ethyl 2-cyanoacrylate	7085-85-0	60 - 100

4. FIRST AID MEASURES

Inhalation: Move to fresh air. If symptoms persist, seek medical advice.

Skin contact:	Do not pull bonded skin apart. Soak in warm soapy water. Gently peel apart using a blunt instrument. If skin is burned due to the rapid generation of heat by a large drop, seek medical attention. If lips are bonded, apply warm water to the lips and encourage wetting and pressure from saliva in mouth. Peel or roll lips apart. Do not pull lips apart with direct opposing force.
Eye contact:	Immediately flush with plenty of water for at least 15 minutes. Get medical attention. If eyelids are bonded closed, release eyelashes with warm water by covering with a wet pad. Do not force eye open. Cyanoacrylate will bond to eye protein and will cause a lachrymatory effect which will help to debond the adhesive. Keep eye covered until debonding is complete, usually within 1-3 days. Medical attention should be sought in case solid particles of polymerized cyanoacrylate trapped behind the eyelid caused abrasive damage.
Ingestion:	Ensure breathing passages are not obstructed. The product will polymerize rapidly and bond to the mouth making it almost impossible to swallow. Saliva will separate any solidified product in several hours. Prevent the patient from swallowing any separated mass.
Notes to physician:	Surgery is not necessary to separate accidentally bonded tissues. Experience has shown that bonded tissues are best treated by passive, non-surgical first aid. If rapid curing has caused thermal bums they should be treated symptomatically after adhesive is removed.

5. FIRE FIGHTING MEASURES

Flash point:	80 - 93.4 °C (176°F - 200.12 °F) Tagliabue closed cup
Autoignition temperature:	Not available.
Flammable/Explosive limits - lower:	Not available.
Flammable/Explosive limits - upper:	Not available.
Extinguishing media:	Dry powder. foam Carbon dioxide.
Special firefighting procedures:	Fire fighters should wear positive pressure self-contained breathing apparatus (SCBA).
Unusual fire or explosion hazards:	Not available.
Hazardous combustion products:	Trace amounts of toxic and/or irritating fumes may be released and the use of breathing apparatus is recommended.

6. ACCIDENTAL RELEASE MEASURES

Use personal protection recommended in Section 8, isolate the hazard area and deny entry to unnecessary and unprotected personnel.

Environmental precautions:	Do not allow product to enter sewer or waterways.
Clean-up methods:	Do not use cloths for mopping up. Flood with water to complete polymerization and scrape off the floor. Cured material can be disposed of as non-hazardous waste.

7. HANDLING AND STORAGE

Handling:	Avoid contact with eyes, skin and clothing. Avoid breathing vapors or mists of this product. Wash thoroughly after handling. Avoid contact with fabric or paper goods. Contact with these materials may cause rapid polymerization which can generate smoke and strong irritating vapors, and cause thermal burns.

Storage: Keep in a cool, well ventilated area away from heat, sparks and open flame. Keep container tightly closed until ready for use.
Keep in a cool, well ventilated area away from heat, sparks and open flame. Keep container tightly closed until ready for use.

For information on product shelf life, please review labels on container or check the Technical Data Sheet.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

Employers should complete an assessment of all workplaces to determine the need for, and selection of, proper exposure controls and protective equipment for each task performed.

Hazardous components	ACGIH TLV	OSHA PEL	AIHA WEEL	OTHER
Ethyl 2-cyanoacrylate	0.2 ppm TWA	None	None	None

Engineering controls: Use positive down-draft exhaust ventilation if general ventilation is insufficient to maintain vapor concentration below established exposure limits.

Respiratory protection: Use NIOSH approved respirator if there is potential to exceed exposure limit(s).

Eye/face protection: Safety goggles or safety glasses with side shields.

Skin protection: Use nitrile gloves and aprons as necessary to prevent contact. Do not use PVC, nylon or cotton.

9. PHYSICAL AND CHEMICAL PROPERTIES

Physical state:	liquid
Color:	colourless
Odor:	irritating
Odor threshold:	Not available.
pH:	Not available.
Vapor pressure:	< 0.2 mm hg < 0.2 mm hg
Boiling point/range:	> 300 °F (> 148.9 °C) None > 300 °F (> 148.9 °C) None
Melting point/ range:	Not available.
Vapor density:	Not available.
Flash point:	80 - 93.4 °C (176°F - 200.12 °F) Tagliabue closed cup
Flammable/Explosive limits - lower:	Not available.
Flammable/Explosive limits - upper:	Not available.
Autoignition temperature:	Not available.
Evaporation rate:	Not available.
Solubility in water:	Polymerises in presence of water.
Partition coefficient (n-octanol/water):	Not available.
VOC content:	Not available.

10. STABILITY AND REACTIVITY

Stability: Stable under recommended storage conditions.

Hazardous reactions: Rapid exothermic polymerization will occur in the presence of water, amines, alkalis and alcohols.

Hazardous decomposition products: None

Incompatible materials: Water, Amines, Alkalis, Alcohols.

Conditions to avoid: None if used for intended purpose.

11. TOXICOLOGICAL INFORMATION

Hazardous components	NTP Carcinogen	IARC Carcinogen	OSHA Carcinogen (Specifically Regulated)
Ethyl 2-cyanoacrylate	No	No	No

Hazardous components	Health Effects/Target Organs
Ethyl 2-cyanoacrylate	Irritant, Allergen, Respiratory

12. ECOLOGICAL INFORMATION

Ecological information: Not available.

13. DISPOSAL CONSIDERATIONS

Information provided is for unused product only.

Recommended method of disposal: Dispose of according to Federal, State and local governmental regulations.

Hazardous waste number: It is the responsibility of the user to determine if an item is hazardous as defined in the Resource Conservation and Recovery Act (RCRA) at the time of disposal. Product uses, transformations, mixtures, processes, etc., may render the resulting material hazardous, under the criteria of ignitability, corrosivity, reactivity and toxicity characteristics of the Toxicity Characteristics Leaching Procedure (TCLP) 40 CFR 261.20-24.

14. TRANSPORT INFORMATION

The shipping classification in this section are for bulk packaging only. Shipping classification may be different for non-bulk packaging as exceptions may apply. Refer to shipping documents for package specific transportation classification.

U.S. Department of Transportation Ground (49 CFR)

Proper shipping name: Combustible liquid, n.o.s. (Cyanoacrylate ester)
Hazard class or division: Combustible Liquid
Identification number: NA 1993
Packing group: III
Exceptions: (Not more than 450 Liters), Unrestricted

International Air Transportation (ICAO/IATA)

Proper shipping name: Aviation regulated liquid, n.o.s. (Cyanoacrylate ester)
Hazard class or division: 9
Identification number: UN 3334
Packing group: None
Exceptions: Not more than 500 ml (each inner package) - Unrestricted

Water Transportation (IMO/IMDG)

Proper shipping name: Not regulated
Hazard class or division: None
Identification number: None
Packing group: None

15. REGULATORY INFORMATION

United States Regulatory Information

TSCA 8 (b) Inventory Status: All components are listed or are exempt from listing on the Toxic Substances Control Act Inventory.
TSCA 12(b) Export Notification: None above reporting de minimus

CERCLA/SARA Section 302 EHS: None above reporting de minimus
CERCLA/SARA Section 311/312: Immediate Health, Delayed Health, Fire, Reactive
CERCLA/SARA 313: None above reporting de minimus

California Proposition 65: No California Proposition 65 listed chemicals are known to be present.

Canada Regulatory Information

CEPA DSL/NDSL Status: Contains one or more components listed on the Non-Domestic Substances List. All other components are listed on or are exempt from listing on the Domestic Substances List. Components listed on the NDSL must be tracked by all Canadian Importers of Record as required by Environment Canada. They may be imported into Canada in limited quantities. Please contact Regulatory Affairs for additional details.

WHMIS hazard class: B.3, D.2.B

16. OTHER INFORMATION

This material safety data sheet contains changes from the previous version in sections: New Material Safety Data Sheet format.

Prepared by: Karim Nasr, Regulatory Affairs Specialist

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AIR PRODUCTS

MATERIAL SAFETY DATA SHEET

SECTION 1. PRODUCT IDENTIFICATION

PRODUCT NAME: **Nitrogen, compressed**
CHEMICAL NAME: Nitrogen
FORMULA: N_2
SYNONYMS: Nitrogen gas, Gaseous Nitrogen, GAN

MANUFACTURER: **Air Products and Chemicals, Inc.**
7201 Hamilton Boulevard
Allentown, PA 18195 - 1501
PRODUCT INFORMATION: 1-800-752-1597
MSDS NUMBER: 1011 **REVISION:** 5
REVISION DATE: March 1994 **REVIEW DATE:** August 1997

SECTION 2. COMPOSITION/INFORMATION ON INGREDIENTS

Nitrogen is sold as pure product > 99%.
CAS NUMBER: 7727-37-9
EXPOSURE LIMITS:
OSHA: Not established **ACGIH:** Simple asphyxiant **NIOSH:** Not established

SECTION 3. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

Nitrogen is a nontoxic, odorless, colorless, nonflammable compressed gas stored in cylinders at high pressure. It can cause rapid suffocation when concentrations are sufficient to reduce oxygen levels below 19.5%. Self Contained Breathing Apparatus (SCBA) may be required.

EMERGENCY TELEPHONE NUMBERS
800-523-9374 Continental U.S. , Canada and Puerto Rico
610-481-7711 other locations

POTENTIAL HEALTH EFFECTS INFORMATION:

INHALATION: Simple asphyxiant. Nitrogen is nontoxic, but may cause suffocation by displacing the oxygen in air. Lack of sufficient oxygen can cause serious injury or death.

EYE CONTACT: No adverse effect.

SKIN CONTACT: No adverse effect.

EXPOSURE INFORMATION:

ROUTE OF ENTRY: Inhalation

TARGET ORGANS: None

EFFECT: Asphyxiation (suffocation)

SYMPTOMS: Exposure to an oxygen deficient atmosphere (<19.5%) may cause dizziness, drowsiness, nausea, vomiting, excess salivation, diminished mental alertness, loss of consciousness and death. Exposure to atmospheres containing 8-10% or less oxygen will bring about unconsciousness without warning and so quickly that the individuals cannot help themselves.

MEDICAL CONDITIONS AGGRAVATED BY OVEREXPOSURE: None

CARCINOGENIC POTENTIAL: Nitrogen is not listed as a carcinogen or potential carcinogen by NTP, IARC, or OSHA .

SECTION 4. FIRST AID

INHALATION: Persons suffering from lack of oxygen should be moved to fresh air. If victim is not breathing, administer artificial respiration. If breathing is difficult, administer oxygen. Obtain prompt medical attention.

EYE CONTACT: Not applicable.

SKIN CONTACT: Not applicable.

SECTION 5. FIRE AND EXPLOSION

FLASH POINT:	AUTOIGNITION:	FLAMMABLE LIMITS:
Not applicable	Nonflammable	Nonflammable

EXTINGUISHING MEDIA: Nitrogen is nonflammable and does not support combustion. Use extinguishing media appropriate for the surrounding fire.

HAZARDOUS COMBUSTION PRODUCTS: None

SPECIAL FIRE FIGHTING INSTRUCTIONS: Nitrogen is a simple asphyxiant. If possible, remove nitrogen cylinders from fire area or cool with water. SCBA may be required by rescue workers.

UNUSUAL FIRE AND EXPLOSION HAZARDS: Upon exposure to intense heat or flame cylinder may vent rapidly and/or rupture violently. Most cylinders are designed to vent contents when exposed to elevated temperatures. Pressure in a container can build up due to heat and it may rupture if pressure relief devices should fail to function.

SECTION 6. ACCIDENTAL RELEASE MEASURES

Evacuate all personnel from affected area. Increase ventilation to release area and monitor oxygen level. Use appropriate protective equipment (SCBA). If leak is from container or its valve, call the Air Products emergency telephone number. If leak is in user's system close cylinder valve and vent pressure before attempting repairs.

SECTION 7. HANDLING AND STORAGE

STORAGE: Cylinders should be stored upright in a well-ventilated, secure area, protected from the weather. Storage area temperatures should not exceed 125 °F (52 °C) and area should be free of combustible materials. Storage should be away from heavily traveled areas and emergency exits. Avoid areas where salt or other corrosive materials are present. Valve protection caps and valve outlet seals should remain on cylinders not connected for use. Separate full from empty cylinders. Avoid excessive inventory and storage time. Use a first-in first-out system. Keep good inventory records.

HANDLING: Do not drag, roll, or slide cylinder. Use a suitable handtruck designed for cylinder movement. Never attempt to lift a cylinder by its cap. Secure cylinders at all times while in use. Use a pressure reducing regulator or separate control valve to safely discharge gas from cylinder. Use a check valve to prevent reverse flow into cylinder. Do not overheat cylinder to increase pressure or discharge rate. If user experiences any difficulty operating cylinder valve, discontinue use and contact supplier. Never insert an object (e.g., wrench, screwdriver, pry bar, etc.) into valve cap openings. Doing so may damage valve causing a leak to occur. Use a special cap wrench or adjustable strap-wrench to remove over-tight or rusted caps.

Nitrogen is compatible with all common materials of construction. Pressure requirements should be considered when selecting materials and designing systems.

SPECIAL REQUIREMENTS: Always store and handle compressed gases in accordance with Compressed Gas Association, Inc. (ph. 703-412-0900) pamphlet CGA P-1, *Safe Handling of Compressed Gases in Containers*. Local regulations may require specific equipment for storage or use.

CAUTION: Users of nitrogen must be aware of the hazards caused by the accumulation of high concentrations, especially in confined spaces. Compliance with OSHA regulations, especially 29 CFR 1910.146 (confined space entry), is essential

SECTION 8. PERSONAL PROTECTION / EXPOSURE CONTROL

ENGINEERING CONTROLS: Provide good ventilation and/or local exhaust to prevent accumulation of high concentrations of gas. Oxygen levels in work area should be monitored to ensure they do not fall below 19.5%.

RESPIRATORY PROTECTION:

GENERAL USE: None required.

EMERGENCY: Use SCBA or positive pressure air line with mask and escape pack in areas where oxygen concentration is less than 19.5%. Air purifying respirators will not provide protection.

OTHER PROTECTIVE EQUIPMENT: Safety glasses. Safety shoes and leather work gloves are recommended when handling cylinders.

SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE: Colorless gas

ODOR: Odorless

MOLECULAR WEIGHT: 28.01

BOILING POINT (1 Atm): -320.4 °F (-195.8 °C)

SPECIFIC GRAVITY (Air =1): 0.967

SPECIFIC VOLUME (at 70 °F (21.1 °C) and 1 atm): 13.81 ft^3/lb (0.867m^3/kg)

FREEZING POINT/MELTING POINT: -345.8 ϒF (-209.9 °C)

VAPOR PRESSURE: Not applicable at 70 ϒF

GAS DENSITY (at 70 °F (21.1 °C) and 1 atm): 0.072 lb/ft^3 (1.153 kg/m^3)

SOLUBILITY IN WATER (Vol./Vol. at 32°F (0°C)): 0.023

SECTION 10. STABILITY AND REACTIVITY

CHEMICAL STABILITY: Stable

CONDITIONS TO AVOID: None

INCOMPATIBILITY: None

HAZARDOUS DECOMPOSITION PRODUCTS: None

HAZARDOUS POLYMERIZATION: Will not occur.

SECTION 11. TOXICOLOGICAL INFORMATION

Nitrogen is a simple asphyxiant.

SECTION 12. ECOLOGICAL INFORMATION

The atmosphere contains approximately 78% nitrogen. No adverse ecological effects are expected. Nitrogen does not contain any Class I or Class II ozone depleting chemicals. Nitrogen is not listed as a marine pollutant by DOT (49 CFR 171).

SECTION 13. DISPOSAL

UNUSED PRODUCT / EMPTY CONTAINER: Return cylinder and unused product to supplier. Do not attempt to dispose of residual or unused quantities.

DISPOSAL: For emergency disposal, secure the cylinder and slowly discharge gas to the atmosphere in a well ventilated area or outdoors.

SECTION 14. TRANSPORT INFORMATION

DOT HAZARD CLASS: 2.2

DOT SHIPPING LABEL: Nonflammable Gas

DOT SHIPPING NAME: Nitrogen, Compressed

IDENTIFICATION NUMBER: UN1066

REPORTABLE QUANTITY (RQ): None

SPECIAL SHIPPING INFORMATION: Cylinders should be transported in a secure upright position in a well ventilated truck. Never transport in passenger compartment of a vehicle.

Compressed gas cylinders shall not be refilled except by qualified producers of compressed gases. Shipment of a compressed gas cylinder which has not been filled by the owner or with the owner's written consent is a violation of federal law.

SECTION 15. REGULATORY INFORMATION

U.S. FEDERAL REGULATIONS:

ENVIRONMENTAL PROTECTION AGENCY (EPA):

CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act of 1980 requires notification to the National Response Center of a release of quantities of hazardous substances equal to or greater than their reportable quantities (RQ's) in 40 CFR 302.4.

CERCLA Reportable Quantity: None.

SARA TITLE III: Superfund Amendment and Reauthorization Act of 1986

SECTION 302/304: Requires emergency planning on threshold planning quantities (TPQ) and release reporting based on reportable quantities (RQ) of EPA's extremely hazardous substances (40 CFR 355).

Nitrogen is not listed as an extremely hazardous substance.

Threshold Planning Quantity (TPQ): None

SECTIONS 311/312: Require submission of material safety data sheets (MSDSs) and chemical inventory reporting with identification of EPA defined hazard classes. The hazard classes for this product are:

IMMEDIATE HEALTH: No

DELAYED HEALTH: No

PRESSURE: Yes

REACTIVITY: No

FIRE: No

SECTION 313: Requires submission of annual reports of release of toxic chemicals that appear in 40 CFR 372.

Nitrogen does not require reporting under Section 313.

40 CFR Part 68 - Risk Management for Chemical Accident Release Prevention: Requires the development and implementation of risk management programs at facilities that manufacture, use, store, or otherwise handle regulated substances in quantities that exceed specified thresholds.

Nitrogen is not listed as a regulated substance.

TSCA - TOXIC SUBSTANCES CONTROL ACT: Nitrogen is listed on the TSCA inventory.

OSHA - OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION:

29 CFR 1910.119 - Process Safety Management of Highly Hazardous Chemicals: Requires facilities to develop a process safety management program based on Threshold Quantities (TQ) of highly hazardous chemicals.

Nitrogen is not listed in Appendix A as a highly hazardous chemical.

STATE REGULATIONS

CALIFORNIA:

Proposition 65: This product does NOT contain any listed substances which the State of California requires warning under this statute.

SCAQMD Rule: VOC = Not applicable

SECTION 16. OTHER INFORMATION

NFPA RATINGS:		HMIS RATINGS:	
HEALTH:	0	HEALTH:	0
FLAMMABILITY:	0	FLAMMABILITY:	0
REACTIVITY:	0	REACTIVITY:	0
SPECIAL:	SA*		

*Compressed Gas Association recommendation to designate simple asphyxiant.

*** Documents with Review Dates August 1997 and Revision Date March 1994 are identical in content and either may be used.*

MATERIAL SAFETY DATA SHEET

ProX Rocket Motor Reload Kits & Fuel Grains

1.0 PRODUCT / COMPANY IDENTIFICATION

Product Name: Pro24, Pro29, Pro38, Pro54, Pro75, and Pro98 Rocket Motor Reload Kits
Synonyms: Rocket Motor
Proper Shipping Name: Articles, Explosive, N.O.S. (Ammonium Perchlorate)
Part Numbers: Reload kits: P24R-Y-#G-XX, P29R-Y-#G-XX, P38R-Y-#G-XX, P54R-Y-#G-XX, P24R-Y-#GXL-XX, P29R-Y-#GXL-XX, P38R-Y-#GXL-XX, P54R-Y-#GXL-XX,
Propellant grains: P75AC-PG-XX, P98AC-PG-XX, P98AC-MB-PG-XX
Where: Y = reload type (A = adjustable delay, C = C-slot)
# = number of grains &
XX = propellant type

Product Use: Solid fuel motor for propelling rockets

Manufacturer: Cesaroni Technology Inc.
P.O. Box 246
2561 Stouffville Rd.
Gormley, Ont.
Canada L0H 1G0

Telephone Numbers:
Product Information: 1-905-887-2370
24 Hour Emergency Telephone Number: 1-613-996-6666 (CANUTEC)

2.0 COMPOSITION / INFORMATION ON INGREDIENTS

Propellant

Ingredient Name	CAS Number	Percentage
Ammonium Perchlorate	7790-98-9	40-85 %
Metal Powders		1-45 %
Synthetic Rubber		10-30 %

Black Powder Ignition pellet

Ingredient Name	CAS Number	Percentage
Potassium Nitrate	7757-79-1	70-76 %
Charcoal	n/a	8-18 %
Sulphur	7704-34-9	9-20 %
Graphite	7782-42-5	trace

3.0 HAZARDS IDENTIFICATION

Emergency Overview:
There articles contain cylinders of ammonium perchlorate composite propellant, encased in inert plastic parts. The forward closure also contains a few grams of black powder. ProX Rocket motor reload kits are classified as explosives, and may cause serious injury, including death if used improperly. All explosives are dangerous and must be handled carefully and used following approved safety procedures under the direction of competent, experienced personnel in accordance with all applicable federal, state and local laws and regulations. Avoid inhaling exhaust products.

General Appearance:
Cardboard tubes contain various plastic parts. Inside the plastic tube are cylinders of composite propellant (rocket fuel). The forward closure also contains a small quantity of black powder. All parts are odourless solids.

Potential Health Effects:

Eye:
Not a likely route of exposure. May cause eye irritation.

Skin:
Not a likely route of exposure. Low hazard for usual industrial/hobby handling.

Ingestion:
Not a likely route of exposure.

Inhalation:
Not a likely route of exposure. May cause respiratory tract irritation. Do not inhale exhaust products.

4.0 FIRST AID MEASURES

Eyes:
Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical aid.

Skin:
Flush skin with plenty of soap and water for at least 15 minutes while removing contaminated clothing and shoes. Get medical aid if irritation develops or persists.

Ingestion:
Do NOT induce vomiting. If conscious and alert, rinse mouth and drink 2-4 cupfuls of milk or water.

Inhalation:
Remove from exposure to fresh air immediately. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical aid.

Burns: Burns can be treated as per normal first aid procedures.

5.0 FIRE FIGHTING MEASURES

Extinguishing Media:
In case of fire, use water, dry chemical, chemical foam, or alcohol-resistant foam to contain surrounding fire.

Exposure Hazards During Fire:
Exposure to extreme heat may cause ignition.

Combustion Products from Fire:
During a fire, irritating and highly toxic gases may be generated by thermal decomposition or combustion.

Fire Fighting Procedures:
Keep all persons and hazardous materials away. Allow material to burn itself out. As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear.

Special Instructions / Notes:
These articles burn rapidly and generate a significant flame for a short period of time. Black powder is a deflagrating explosive. It is very sensitive to flame and spark and can also be ignited by friction and impact. When ignited unconfined, it burns with explosive violence and will explode if ignited under even slight confinement. Do not inhale exhaust products.

6.0 ACCIDENTAL RELEASE MEASURES

Safeguards (Personnel):

Spills: Clean up spills immediately. Replace articles in packaging and boxes and seal securely. Sweep or scoop up using non-sparking tools.

7.0 HANDLING AND STORAGE

Handling: Keep away from heat, sparks and flame. Avoid contamination. Do not get in eyes, on skin or on clothing. Do not taste or swallow. Avoid prolonged or repeated contact with skin. Follow manufacturer's instructions for use.

Storage: Store in a cool, dry place away from sources of heat, spark or flame. Keep in shipping packaging when not in use.

8.0 EXPOSURE CONTROLS / PERSONAL PROTECTION

Engineering Controls:
Use adequate explosion proof ventilation to keep airborne concentrations low. All equipment and working surfaces must be grounded.

Personal Protective Equipment:

Eyes:
Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166.

Skin:
Clothing should be appropriate for handling pyrotechnic substances.

Clothing:
Clothing should be appropriate for handling pyrotechnic substances.

Respirators:
A respirator is not typically necessary. Follow the OSHA respirator regulations found in 29CFR1910.134 or European Standard EN 149. Always use a NIOSH or European Standard EN 149 approved respirator when necessary.

9.0 PHYSICAL AND CHEMICAL PROPERTIES

Physical State:	solid
Appearance:	rubber cylinders inside plastic parts
Odour:	none
Odour Threshold:	Not available.
pH:	Not available.
Vapour Pressure:	Not available.
Vapour Density:	Not available.
Viscosity:	Not available.
Evaporation Rate:	Not available.
Boiling Point:	Not available.
Freezing/Melting Point:	Not available.
Coefficient of water/oil distribution:	Not available.
Autoignition Temperature:	280°C
Flash Point:	Not available.
Explosion Limits, lower (LEL):	Not available.
Explosion Limits, upper (UEL):	Not available.
Sensitivity to Mechanical Impact:	unprotected black powder can be ignited by impact
Sensitivity to Static Discharge:	unprotected black powder can be ignited by static discharge
Decomposition Temperature:	> 400°C
Solubility in water:	black powder is soluble in water
Specific Gravity/Density:	black powder = 1.7-2.1 Propellant = not available
Molecular Formula:	Not applicable
Molecular Weight:	Not applicable.

10.0 STABILITY AND REACTIVITY

Chemical Stability:
Stable under normal temperatures and pressures.

Conditions to Avoid:
Heat, static electricity, friction, impact

Incompatibilities with Other Materials:
Combustible or flammable materials, explosive materials

Hazardous Products Of Decomposition:
Oxides of nitrogen

Hazardous Polymerization:
Will not occur.

11.0 TOXICOLOGICAL INFORMATION

Routes of Entry:
Skin contact – not likely
Skin absorption – not likely
Eye contact – not likely
Inhalation – not likely
Ingestion – not likely

Effects of Acute Exposure to Product:
No data available

Effects of Chronic Exposure to Product:
No data available

Exposure Limits:

Black Powder Pellets

Ingredient Name	CAS Number	OSHA PEL	ACGIH TLV
Potassium Nitrate	7757-79-1	not established	not established
Charcoal	n/a	not established	not established
Sulphur	7704-34-9	not established	not established
Graphite	7782-42-5	2.5 mg/m^3	15 mmpct (TWA)

Propellant

Ingredient Name	CAS Number	OSHA PEL	ACGIH TLV
Ammonium Perchlorate	7790-98-9	not established	not established
metal powder		varies	varies
Synthetic Rubber		not established	not established

Irritancy of the Product:
No data available

Sensitization to the Product:
No data available

Carcinogenicity:
Not listed by ACGIH, IARC, NIOSH, NTP, or OSHA

Reproductive Toxicity:
No data available

Teratogenicity:
No data available

Mutagenicity:
No data available

Toxically Synergistic Products:
No data available

LD50:
No data available

12.0 ECOLOGICAL INFORMATION

Environmental Data:

Ecotoxicity Data:
Not determined.

EcoFaTE Data:
Not determined.

13.0 DISPOSAL CONSIDERATIONS

Product As Sold: Pack firmly in hole in ground with nozzle pointing up. Ignite motor electrically from a safe distance and wait 5 minutes before approaching. Dispose of spent components in inert trash.

Product Packaging: Dispose of used packaging materials in inert trash.

Special Considerations: Consult local regulations about disposal of explosive materials.

14.0 TRANSPORT INFORMATION

Shipping Information – Canada

TDG Classification:	Class 1.4 Explosive
Proper Shipping Name:	Articles, Explosive, N.O.S. (Model Rocket Motors)
UN Number:	0351
UN Classification Code:	1.4 C
Packing Group:	II
UN Packing Instruction:	101

Shipping Information - USA / IMO

Proper Shipping Name:	Articles, Explosive, N.O.S. (Model Rocket Motors)
UN Number:	0351
UN Classification Code:	1.4 C
DOT / IMO Label:	Class 1 – Explosive – Division 1.4C

Shipping Information - IATA

Proper Shipping Name:	Articles, Explosive, N.O.S. (Model Rocket Motors)
UN Number:	0351
UN Classification Code:	1.4 C
IATA Labels:	Class 1 – Explosive – Division 1.4C Cargo Aircraft Only

15.0 REGULATORY INFORMATION

Canada

This product has been classified according to the hazard criteria of the Canadian Controlled Products Regulations (CPR) and the MSDS contains all of the information required by the CPR.

WHMIS Classification: Not Controlled (explosive)

Domestic Substance List (DSL) Status:
All ingredients are listed on Canada's DSL List.

Canadian Explosives Classification: Class 7.2.5
This product is an authorized explosive in Canada.

These products are not considered "Controlled Good" in Canada under the Controlled Goods Regulations.

United States of America

TSCA Inventory Status:
All ingredients are listed on the TSCA inventory.

Hazardous Chemical Lists

CERCLA Hazardous Substance (40 CFR 302.4)	No
SARA Extremely Hazardous Substance (40CFR 355)	No
SARA Toxic Chemical (40CFR 372.65)	No

European/International Regulations

The product on this MSDS, or all its components, is included on the following countries' chemical inventories:
EINECS – European Inventory of Existing Commercial Chemical Substances

European Labelling in Accordance with EC Directives
Hazard Symbols: Explosive.
Risk Phrases:

R 2 Risk of explosion by shock, friction, fire or other sources of ignition.
R 11 Highly flammable
R 44 Risk of explosion if heated under confinement.

Safety Phrases:

S 1/2 Keep locked up and out of the reach of children.
S 8 Keep container dry.
S 15 Keep away from heat.
S 16 Keep away from sources of ignition -- No smoking.

S 17 Keep away from combustible material.
S 18 Handle and open container with care.
S 33 Take precautionary measures against static discharges.
S 41 In case of fire and/or explosion do not breathe fumes.

16.0 OTHER INFORMATION

MSDS Prepared by: Regulatory Affairs Department
Cesaroni Technology Inc.
P.O. Box 246
2561 Stouffville Rd.
Gormley, ON
Canada L0H 1G0

Telephone: 905-887-2370 x239
Fax: 905-887-2375
Web Sites: www.cesaronitech.com
www.Pro38.com

NC STATE UNIVERSITY

Material Safety Data Sheet

24 Hour Assistance:
1-847-367-7700
Rust-Oleum Corp.
www.rustoleum.com

Section 1 - Chemical Product / Company Information

Product Name:	STRUST SSPR 6PK GLOSS CRYSTAL CLEAR	Revision Date:	05/07/2011
Identification Number:	7701830		
Product Use/Class:	Topcoat/Aerosols		
Supplier:	Rust-Oleum Corporation 11 Hawthorn Parkway Vernon Hills, IL 60061 USA	Manufacturer:	Rust-Oleum Corporation 11 Hawthorn Parkway Vernon Hills, IL 60061 USA
Preparer:	Regulatory Department		

Section 2 - Composition / Information On Ingredients

Chemical Name	CAS Number	Weight % Less Than	ACGIH TLV-TWA	ACGIH TLV-STEL	OSHA PEL-TWA	OSHA PEL CEILING
Acetone	67-64-1	30.0	500 ppm	750 ppm	1000 ppm	N.E.
Liquefied Petroleum Gas	68476-86-8	30.0	N.E.	N.E.	N.E.	N.E.
Toluene	108-88-3	20.0	20 ppm	N.E.	200 ppm	300 ppm
n-Butyl Acetate	123-86-4	10.0	150 ppm	200 ppm	150 ppm	N.E.
Solvent Naptha, Light Aromatic	64742-95-6	5.0	N.E.	N.E.	N.E.	N.E.
1,2,4-Trimethylbenzene	95-63-6	5.0	25 ppm	N.E.	N.E.	N.E.
Aliphatic Hydrocarbon	64742-89-8	5.0	100 ppm	N.E.	100 ppm	N.E.
bis(2-ethylhexyl)-1,4-benzenedicarboxylate	6422-86-2	5.0	N.E.	N.E.	N.E.	N.E.

Section 3 - Hazards Identification

*** Emergency Overview ***: Contents Under Pressure. Harmful if inhaled. May affect the brain or nervous system causing dizziness, headache or nausea. Vapors may cause flash fire or explosion. Harmful if swallowed. Extremely flammable liquid and vapor.

Effects Of Overexposure - Eye Contact: Causes eye irritation.

Effects Of Overexposure - Skin Contact: Prolonged or repeated contact may cause skin irritation. Substance may cause slight skin irritation.

Effects Of Overexposure - Inhalation: High vapor concentrations are irritating to the eyes, nose, throat and lungs. Avoid breathing vapors or mists. High gas, vapor, mist or dust concentrations may be harmful if inhaled. Harmful if inhaled.

Effects Of Overexposure - Ingestion: Aspiration hazard if swallowed; can enter lungs and cause damage. Substance may be harmful if swallowed.

Effects Of Overexposure - Chronic Hazards: May cause central nervous system disorder (e.g., narcosis involving a loss of coordination, weakness, fatigue, mental confusion, and blurred vision) and/or damage. Reports have associated repeated and prolonged occupational overexposure to solvents with permanent brain and nervous system damage.

Primary Route(s) Of Entry: Skin Contact, Skin Absorption, Inhalation, Ingestion, Eye Contact

Section 4 - First Aid Measures

First Aid - Eye Contact: Immediately flush eyes with plenty of water for at least 15 minutes holding eyelids open. Get medical attention. Do NOT allow rubbing of eyes or keeping eyes closed.

First Aid - Skin Contact: Wash with soap and water. Get medical attention if irritation develops or persists.

First Aid - Inhalation: If you experience difficulty in breathing, leave the area to obtain fresh air. If continued difficulty is experienced, get medical assistance immediately.

First Aid - Ingestion: Aspiration hazard: Do not induce vomiting or give anything by mouth because this material can enter the lungs and cause severe lung damage. Get immediate medical attention.

Section 5 - Fire Fighting Measures

Flash Point: -156 F (Setaflash)

Extinguishing Media: Film Forming Foam, Carbon Dioxide, Dry Chemical, Water Fog

Unusual Fire And Explosion Hazards: FLASH POINT IS LESS THAN 20 °. F. - EXTREMELY FLAMMABLE LIQUID AND VAPOR! Perforation of the pressurized container may cause bursting of the can. Isolate from heat, electrical equipment, sparks and open flame. Keep containers tightly closed. Water spray may be ineffective. Closed containers may explode when exposed to extreme heat. Vapors may form explosive mixtures with air. Vapors can travel to a source of ignition and flash back.

Special Firefighting Procedures: Evacuate area and fight fire from a safe distance.

Section 6 - Accidental Release Measures

Steps To Be Taken If Material Is Released Or Spilled: Contain spilled liquid with sand or earth. DO NOT use combustible materials such as sawdust. Remove all sources of ignition, ventilate area and remove with inert absorbent and non-sparking tools. Dispose of according to local, state (provincial) and federal regulations. Do not incinerate closed containers.

Section 7 - Handling And Storage

Handling: Follow all MSDS/label precautions even after container is emptied because it may retain product residues. Use only in a well-ventilated area. Avoid breathing vapor or mist. Wash thoroughly after handling. Wash hands before eating.

Storage: Do not store above 120 ° F. Store large quantities in buildings designed and protected for storage of NFPA Class I flammable liquids. Contents under pressure. Do not expose to heat or store above 120 ° F. Keep containers tightly closed. Isolate from heat, electrical equipment, sparks and open flame.

Section 8 - Exposure Controls / Personal Protection

Engineering Controls: Prevent build-up of vapors by opening all doors and windows to achieve cross-ventilation.

Use explosion-proof ventilation equipment. Use process enclosures, local exhaust ventilation, or other engineering controls to control airborne levels below recommended exposure limits.

Respiratory Protection: A respiratory protection program that meets OSHA 1910.134 and ANSI Z88.2 requirements must be followed whenever workplace conditions warrant a respirator's use. A NIOSH/MSHA approved air purifying respirator with an organic vapor cartridge or canister may be permissible under certain circumstances where airborne concentrations are expected to exceed exposure limits.

Protection provided by air purifying respirators is limited. Use a positive pressure air supplied respirator if there is any potential for an uncontrolled release, exposure levels are not known, or in any other circumstances where air purifying respirators may not provide adequate protection.

Skin Protection: Nitrile or Neoprene gloves may afford adequate skin protection. Use impervious gloves to prevent skin contact and absorption of this material through the skin.

Eye Protection: Use safety eyewear designed to protect against splash of liquids.

Other protective equipment: Refer to safety supervisor or industrial hygienist for further information regarding personal protective equipment and its application.

Hygienic Practices: Wash thoroughly with soap and water before eating, drinking or smoking.

Section 9 - Physical And Chemical Properties

Vapor Density:	Heavier than Air	Odor:	Solvent Like
Appearance:	Aerosolized Mist	Evaporation Rate:	Faster than Ether
Solubility in H2O:	Slight	Freeze Point:	N.D.
Specific Gravity:	0.745	pH:	N.A.
Physical State:	Liquid		

(See section 16 for abbreviation legend)

Section 10 - Stability And Reactivity

Conditions To Avoid: Avoid temperatures above 120 ° F. Avoid all possible sources of ignition.

Incompatibility: Incompatible with strong oxidizing agents, strong acids and strong alkalies.

Hazardous Decomposition: By open flame, carbon monoxide and carbon dioxide. When heated to decomposition, it emits acrid smoke and irritating fumes.

Hazardous Polymerization: Will not occur under normal conditions.

Stability: This product is stable under normal storage conditions.

Section 11 - Toxicological Information

Chemical Name	LD50	LC50
Acetone	5800 mg/kg (Rat)	50100 mg/m3 (Rat, 8Hr)
Liquefied Petroleum Gas	N.E.	N.E.
Toluene	636 mg/kg (Rat, Oral)	>26700 ppm (Rat, Inhalation, 1Hr)
n-Butyl Acetate	13100 mg/kg (Rat, Oral)	2000 ppm (Rat, Inhalation, 4 Hr)
Solvent Naptha, Light Aromatic	4700 mg/kg (Rat, Oral)	3670 mg/kg (Rat, Inhalation)

1,2,4-Trimethylbenzene	N.E.	18000 mg/m3 (Rat, 4Hr)
Aliphatic Hydrocarbon	>5000 mg/kg (Rat, Oral)	N.E.
bis(2-ethylhexyl)-1,4-benzenedicarboxylate	>5000 mg/kg (Rat)	N.E.

Section 12 - Ecological Information

Ecological Information: Product is a mixture of listed components.

Section 13 - Disposal Information

Disposal Information: Dispose of material in accordance to local, state and federal regulations and ordinances. Do not allow to enter storm drains or sewer systems.

Section 14 - Transportation Information

	Domestic (USDOT)	International (IMDG)	Air (IATA)
Proper Shipping Name:	Consumer Commodity	Aerosols	Aerosols
Hazard Class:	ORM-D	2.1	2.1
UN Number:	N.A.	UN1950	UN1950
Packing Group:	N.A.	N.A.	N.A.
Limited Quantity:	No	Yes	Yes

Section 15 - Regulatory Information

CERCLA - SARA Hazard Category

This product has been reviewed according to the EPA "Hazard Categories" promulgated under Sections 311and 312 of the Superfund Amendment and Reauthorization Act of 1986 (SARA Title III) and is considered, under applicable definitions, to meet the following categories:

IMMEDIATE HEALTH HAZARD, CHRONIC HEALTH HAZARD, FIRE HAZARD, PRESSURIZED GAS HAZARD

SARA Section 313:

Listed below are the substances (if any) contained in this product that are subject to the reporting requirements of Section 313 of Title III of the Superfund Amendment and Reauthorization Act of 1986 and 40 CFR part 372:

Chemical Name	CAS Number
Toluene	108-88-3
1,2,4-Trimethylbenzene	95-63-6

Toxic Substances Control Act:

Listed below are the substances (if any) contained in this product that are subject to the reporting requirements of TSCA 12(B) if exported from the United States:

U.S. State Regulations: As follows -

New Jersey Right-to-Know:

The following materials are non-hazardous, but are among the top five components in this product.

Chemical Name	CAS Number
Acrylic Resin	PROPRIETARY

Pennsylvania Right-to-Know:

The following non-hazardous ingredients are present in the product at greater than 3%.

Chemical Name	CAS Number
Acrylic Resin	PROPRIETARY

International Regulations: As follows -

CANADIAN WHMIS:

This MSDS has been prepared in compliance with Controlled Product Regulations except for the use of the 16 headings.

CANADIAN WHMIS CLASS: AB5 D2A D2B

Section 16 - Other Information

HMIS Ratings:
Health: 2* Flammability: 4 Reactivity: 0 Personal Protection: X

NFPA Ratings:
Health: 2 Flammability: 4 Instability: 0

VOLATILE ORGANIC COMPOUNDS, g/L: 586

REASON FOR REVISION: Regulatory Update

Legend: N.A. - Not Applicable, N.E. - Not Established, N.D. - Not Determined

Rust-Oleum Corporation believes, to the best of its knowledge, information and belief, the information contained herein to be accurate and reliable as of the date of this material safety data sheet. However, because the conditions of handling, use, and storage of these materials are beyond our control, we assume no responsibility or liability for personal injury or property damage incurred by the use of these materials. Rust-Oleum Corporation makes no warranty, expressed or implied, regarding the accuracy or reliability of the data or results obtained from their use. All materials may present unknown hazards and should be used with caution. The information and recommendations in this material safety data sheet are offered for the users' consideration and examination. It is the responsibility of the user to determine the final suitability of this information and to comply with all applicable international, federal, state, and local laws and regulations.

NC STATE UNIVERSITY

MATERIAL SAFETY DATA SHEET
West System Inc.

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME:..WEST SYSTEM® 105 Epoxy Resin®.
PRODUCT CODE:..105
CHEMICAL FAMILY:....................................Epoxy Resin.
CHEMICAL NAME:.......................................Bisphenol A based epoxy resin.
FORMULA:..Not applicable.

MANUFACTURER:
West System Inc.
102 Patterson Ave.
Bay City, MI 48706, U.S.A.
Phone: 866-937-8797 or 989-684-7286
www.westsystem.com

EMERGENCY TELEPHONE NUMBERS:
Transportation
CHEMTREC:.................... 800-424-9300 (U.S.)
703-527-3887 (International)
Non-transportation
Poison Hotline: 800-222-1222

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

HMIS Hazard Rating: Health - 2 Flammability - 1 Physical Hazards - 0

WARNING! May cause allergic skin response in certain individuals. May cause moderate irritation to the skin. Clear to light yellow liquid with mild odor.

PRIMARY ROUTE(S) OF ENTRY:... Skin contact.

POTENTIAL HEALTH EFFECTS:

ACUTE INHALATION:... Not likely to cause acute effects unless heated to high temperatures. If product is heated, vapors generated can cause headache, nausea, dizziness and possible respiratory irritation if inhaled in high concentrations.

CHRONIC INHALATION: .... Not likely to cause chronic effects. Repeated exposure to high vapor concentrations may cause irritation of pre-existing lung allergies and increase the chance of developing allergy symptoms to this product.

ACUTE SKIN CONTACT:.. May cause allergic skin response in certain individuals. May cause moderate irritation to the skin such as redness and itching.

CHRONIC SKIN CONTACT:... May cause sensitization in susceptible individuals. May cause moderate irritation to the skin.

EYE CONTACT: .... May cause irritation.

INGESTION:... Low acute oral toxicity.

SYMPTOMS OF OVEREXPOSURE: .... Possible sensitization and subsequent allergic reactions usually seen as redness and rashes. Repeated exposure is not likely to cause other adverse health effects.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE:................ Pre-existing skin and respiratory disorders may be aggravated by exposure to this product. Pre-existing lung and skin allergies may increase the chance of developing allergic symptoms to this product.

3. COMPOSITION/INFORMATION ON HAZARDOUS INGREDIENTS

INGREDIENT NAME	CAS #	CONCENTRATION
Bisphenol-A type epoxy resin	25085-99-8	> 50%
Benzyl alcohol	100-51-6	< 20%
Bisphenol-F type epoxy resin	28064-14-4	< 20%

4. FIRST AID MEASURES

FIRST AID FOR EYES.. Flush immediately with water for at least 15 minutes. Consult a physician.

FIRST AID FOR SKIN.. Remove contaminated clothing. Wipe excess from skin. Remove with waterless skin cleaner and then wash with soap and water. Consult a physician if effects occur.

FIRST AID FOR INHALATION... Remove to fresh air if effects occur.

FIRST AID FOR INGESTION.. No adverse health effects expected from amounts ingested under normal conditions of use. Seek medical attention if a significant amount is ingested.

5. FIRE FIGHTING MEASURES

FLASH POINT:.. >200°F (Tag Closed Cup)

EXTINGUISHING MEDIA: .... Foam, carbon dioxide (CO_2), dry chemical.

SPECIAL FIRE FIGHTING PROCEDURES: .... Wear a self-contained breathing apparatus and complete full-body personal protective equipment. Closed containers may rupture (due to buildup of pressure) when exposed to extreme heat.

FIRE AND EXPLOSION HAZARDS: .... During a fire, smoke may contain the original materials in addition to combustion products of varying composition which may be toxic and/or irritating. Combustion products may include, but are not limited to: phenolics, carbon monoxide, carbon dioxide.

6. ACCIDENTAL RELEASE MEASURES

SPILL OR LEAK PROCEDURES: .... Stop leak without additional risk. Dike and absorb with inert material (*e.g.*, sand) and collect in a suitable, closed container. Warm, soapy water or non-flammable, safe solvent may be used to clean residual.

7. HANDLING AND STORAGE

STORAGE TEMPERATURE (min./max.): .... 40°F (4°C) / 120°F (49°C)

STORAGE:... Store in cool, dry place. Store in tightly sealed containers to prevent moisture absorption and loss of volatiles. Excessive heat over long periods of time will degrade the resin.

HANDLING PRECAUTIONS: .... Avoid prolonged or repeated skin contact. Wash thoroughly after handling. Launder contaminated clothing before reuse. Avoid inhalation of vapors from heated product. Precautionary steps should be taken when curing product in large quantities. When mixed with epoxy curing agents this product causes an exothermic, which in large masses, can produce enough heat to damage or ignite surrounding materials and emit fumes and vapors that vary widely in composition and toxicity.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

EYE PROTECTION GUIDELINES: .... Safety glasses with side shields or chemical splash goggles.

SKIN PROTECTION GUIDELINES:.. Wear liquid-proof, chemical resistant gloves (nitrile-butyl rubber, neoprene, butyl rubber or natural rubber) and full body-covering clothing.

RESPIRATORY/VENTILATION GUIDELINES:.................................. Good room ventilation is usually adequate for most operations. Wear a NIOSH/MSHA approved respirator with an organic vapor cartridge whenever exposure to vapor in concentrations above applicable limits is likely.

Note: West System, Inc. has conducted an air sampling study using this product or similarly formulated products. The results indicate that the components sampled for (epichlorohydrin, benzyl alcohol) were either so low that they were not detected at all or they were significantly below OSHA's permissible exposure levels.

ADDITIONAL PROTECTIVE MEASURES:.. Practice good caution and personal cleanliness to avoid skin and eye contact. Avoid skin contact when removing gloves and other protective equipment. Wash thoroughly after handling. Generally speaking, working cleanly and following basic precautionary measures will greatly minimize the potential for harmful exposure to this product under normal use conditions.

OCCUPATIONAL EXPOSURE LIMITS: .... Not established for product as whole. Refer to OSHA's Permissible Exposure Level (PEL) or the ACGIH Guidelines for information on specific ingredients.

9. PHYSICAL AND CHEMICAL PROPERTIES

PHYSICAL FORM: .... Liquid.
COLOR: .... Clear to pale yellow.
ODOR:.. Mild.
BOILING POINT:.. > 400°F.
MELTING POINT/FREEZE POINT:... No data.
VISCOSITY:.. 1,000 cPs.
pH: .... No data.
SOLUBILITY IN WATER: .... Slight.
SPECIFIC GRAVITY:.. 1.15
BULK DENSITY: .... 9.6 pounds/gallon.
VAPOR PRESSURE:... < 1 mmHg @ 20°C.
VAPOR DENSITY:... Heavier than air.
% VOLATILE BY WEIGHT: .... ASTM D 2369-07 was used to determine the Volatile Content of mixed epoxy resin and hardener. Refer to the hardener's MSDS for information about the total volatile content of the resin/hardener system.

10. STABILITY AND REACTIVITY

STABILITY: .... Stable.

HAZARDOUS POLYMERIZATION: .... Will not occur by itself, but a mass of more than one pound of product plus an aliphatic amine will cause irreversible polymerization with significant heat buildup.

INCOMPATIBILITIES: .... Strong acids, bases, amines and mercaptans can cause polymerization.

DECOMPOSITION PRODUCTS: .... Carbon monoxide, carbon dioxide and phenolics may be produced during uncontrolled exothermic reactions or when otherwise heated to decomposition.

11. TOXICOLOGICAL INFORMATION

No specific oral, inhalation or dermal toxicology data is known for this product. Specific toxicology information for a bisphenol-A based epoxy resin present in this product is indicated below:

Oral:.. LD_{50} >5000 mg/kg (rats)
Inhalation: .... No Data.
Dermal: .... LD_{50} = 20,000 mg/kg (skin absorption in rabbits)

TERATOLOGY: ....Diglycidyl ether bisphenol-A (DGEBPA) did not cause birth defects or other adverse effects on the fetus when pregnant rabbits were exposed by skin contact, the most likely route of exposure, or when pregnant rats or rabbits were exposed orally.

REPRODUCTIVE EFFECTS:...DGEBPA, in animal studies, has been shown not to interfere with reproduction.

MUTAGENICITY:...DGEBPA in animal mutagenicity studies were negative. In vitro mutagenicity tests were negative in some cases and positive in others.

CARCINOGENICITY:
NTP.. Product not listed.
IARC.. Product not listed.
OSHA... Product not listed.

No ingredient of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA, NTP or IARC.

Ethylbenzene, present in this product < 0.1%, is not identified by OSHA or NTP as a carcinogen, but is identified by NTP as a Group 2B substance possibly carcinogenic to humans.

Many studies have been conducted to assess the potential carcinogenicity of diglycidyl ether of bisphenol-A. Although some weak evidence of carcinogenicity has been reported in animals, when all of the data are considered, the weight of evidence does not show that DGEBPA is carcinogenic. Indeed, the most recent review of the available data by the International Agency for Research on Cancer (IARC) has concluded that DGEBPA is not classified as a carcinogen.

Epichlorohydrin, an impurity in this product (<5 ppm) has been reported to produce cancer in laboratory animals and to produce mutagenic changes in bacteria and cultured human cells. It has been established by the International Agency for Research on Cancer (IARC) as a probable human carcinogen (Group 2A) based on the following conclusions: human evidence – inadequate; animal evidence – sufficient. It has been classified as an anticipated human carcinogen by the National Toxicology Program (NTP). Note: It is unlikely that normal use of this product would result in measurable exposure concentrations to this substance.

12. ECOLOGICAL INFORMATION

Prevent entry into sewers and natural waters. May cause localized fish kill.

Movement and Partitioning:
Bioconcentration potential is moderate (BCF between 100 and 3000 or Log Kow between 3 and 5).

Degradation and Transformation:
Theoretical oxygen demand is calculated to be 2.35 p/p. 20-day biochemical oxygen demand is <2.5%.

Ecotoxicology:
Material is moderately toxic to aquatic organisms on an acute basis. LC50/EC50 between 1 and 10 mg/L in most sensitive species.

13. DISPOSAL CONSIDERATIONS

WASTE DISPOSAL METHOD: .... Evaluation of this product using RCRA criteria shows that it is not a hazardous waste, either by listing or characteristics, in its purchased form. It is the responsibility of the user to determine proper disposal methods.

Incinerate, recycle (fuel blending) or reclaim may be preferred methods when conducted in accordance with federal, state and local regulations.

14. TRANSPORTATION INFORMATION

DOT
SHIPPING NAME:............ Not regulated.
TECHNICAL SHIPPING NAME:............ Not applicable.
D.O.T. HAZARD CLASS:............ Not applicable.
U.N./N.A. NUMBER:............ Not applicable.
PACKING GROUP:............ Not applicable.

IATA
SHIPPING NAME:............ Not regulated.
TECHNICAL SHIPPING NAME:............ Not applicable.
HAZARD CLASS:............ Not applicable.
U.N. NUMBER:............ Not applicable.
PACKING GROUP:............ Not applicable.

15. REGULATORY INFORMATION

OSHA STATUS:............ Slight irritant; possible sensitizer.
TSCA STATUS:............ All components are listed on TSCA inventory or otherwise comply with TSCA requirements.

Canada WHIMIS Classification:............ D2B

SARA TITLE III:
SECTION 313 TOXIC CHEMICALS............ None (deminimus).

STATE REGULATORY INFORMATION:
The following chemicals are specifically listed or otherwise regulated by individual states. For details on your regulatory requirements you should contact the appropriate agency in your state.

COMPONENT NAME /CAS NUMBER	CONCENTRATION	STATE CODE
Epichlorohydrin 106-89-8	< 5ppm	[1]CA
Phenyl glycidyl ether 122-60-1	<5ppm	[1]CA
Ethylbenzene 100-41-4	< 0.1%	[1]CA, NJ, PA
Benzyl alcohol 100-51-6	< 20%	MA, PA, NJ

[1.] These substances are known to the state of California to cause cancer or reproductive harm, or both.

16. OTHER INFORMATION

REASON FOR ISSUE:............ Changes made in Sections 10, 11, 14 & 15.
PREPARED BY:............ G. M. House
APPROVED BY:............ G. M. House
TITLE:............ Health, Safety & Environmental Manager
APPROVAL DATE:............ June 22, 2011
SUPERSEDES DATE:............ February 6, 2011
MSDS NUMBER:............ 105-11b

Note: The Hazardous Material Indexing System (HMIS), cited in the Emergency Overview of Section 3, uses the following index to assess hazard rating: 0 = Minimal; 1 = Slight: 2 = Moderate; 3 = Serious; and 4 = Severe.

This information is furnished without warranty, expressed or implied, except that it is accurate to the best knowledge of West System Inc. The data on this sheet is related only to the specific material designated herein. West System Inc. assumes no legal responsibility for use or reliance upon these data.

MATERIAL SAFETY DATA SHEET
West System Inc.

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME:..WEST SYSTEM® 206 Slow Hardener
PRODUCT CODE:..206
CHEMICAL FAMILY:..Amine.
CHEMICAL NAME: ....Modified aliphatic polyamine.
FORMULA:..Not applicable.

MANUFACTURER:
West System Inc.
102 Patterson Ave.
Bay City, MI 48706, U.S.A.
Phone: 866-937-8797 or 989-684-7286
www.westsystem.com

EMERGENCY TELEPHONE NUMBERS:
Transportation
CHEMTREC:.................... 800-424-9300 (U.S.)
703-527-3887 (International)
Non-transportation
Poison Hotline:................ 800-222-1222

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

DANGER Causes burns to eyes and skin. Harmful if swallowed. Harmful if absorbed through the skin. May be harmful if inhaled. Can cause allergic reaction. Aspiration hazard. Clear liquid with ammonia odor.

PRIMARY ROUTE(S) OF ENTRY: .... Skin and eye contact, inhalation.

POTENTIAL HEALTH EFFECTS:

ACUTE INHALATION:... Excessive exposure to vapor or mist is irritating to the upper respiratory tract, causing nasal discharge, coughing, and discomfort in eyes, nose, throat and chest. Severe cases may cause difficult breathing and lung damage.

CHRONIC INHALATION: .... May cause lung damage. May cause respiratory sensitization in susceptible individuals. Repeated exposures may cause internal organ damage.

ACUTE SKIN CONTACT:.. Corrosive. Prolonged contact may cause skin damage with burns and blistering. Wide spread contact may result in material being absorbed in harmful amounts.

CHRONIC SKIN CONTACT:... May cause persistent irritation or dermatitis. Repeated contact may cause allergic reaction/sensitization and possible tissue destruction. Can be absorbed through the skin in amounts that can cause internal organ damage.

EYE CONTACT:.. Corrosive. May cause blurred vision. May cause irritation with corneal injury resulting in permanent vision impairment or even blindness.

INGESTION:... Moderately toxic. May cause gastrointestinal irritation or ulceration. May cause burns of the mouth and throat. Aspiration hazard.

SYMPTOMS OF OVEREXPOSURE:... Skin irritation, burns and blistering. Irritation of the nose and throat, possible headache. Eye irritation and blurred vision.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: .... Existing respiratory conditions, such as asthma and bronchitis. Existing skin conditions.

3. COMPOSITION/INFORMATION ON HAZARDOUS INGREDIENTS

INGREDIENT NAME	CAS #	CONCENTRATION (%)
Polyoxypropylenediamine	9046-10-0	30-50
Polymer of epichlorohydrin, bisphenol-A, and diethylenetriamine	31326-29-1	10-30
Tetraethylenepentamine	112-57-2	10-30
Diethylenetriamine	111-40-0	5-20
Reaction products of triethylenetetramine and propylene oxide	26950-63-0	5-20
Triethylenetetramine	112-24-3	1-10

4. FIRST AID MEASURES

MSDS #206-13a Last Revised: 26APR13

FIRST AID FOR EYES: .... Immediately flush with water for at least 15 minutes. Get prompt medical attention.

FIRST AID FOR SKIN: .... Remove contaminated clothing. Immediately wash skin with soap and water. Do not apply greases or ointments. Get medical attention if severe exposure.

FIRST AID FOR INHALATION: .... Move to fresh air and consult physician if effects occur.

FIRST AID FOR INGESTION: .... Give conscious person at least 2 glasses of water. Do not induce vomiting. Aspiration hazard. If vomiting should occur spontaneously, keep airway clear. Get medical attention.

5. FIRE FIGHTING MEASURES

FLASH POINT: .... > 200°F (Open Cup)

EXTINGUISHING MEDIA: .... Dry chemical, alcohol foam. carbon dioxide (CO_2), dry sand, limestone powder.

FIRE AND EXPLOSION HAZARDS: .... Burning can generate toxic fumes. Products of combustion may include, but not limited to: oxides of nitrogen, volatile amines, ammonia, nitric acid, nitrosamines. When mixed with sawdust, wood chips, or other cellulosic material, spontaneous combustion can occur under certain conditions. If hardener is spilled into or mixed with sawdust, heat is generated as the air oxidizes the amine. If the heat is not dissipated quickly enough, it can ignite the sawdust.

SPECIAL FIRE FIGHTING PROCEDURES: .... Use full-body protective gear and a self-contained breathing apparatus. Use of water may generate toxic aqueous solutions. Do not allow water run-off from fighting fire to enter drains or other water courses.

6. ACCIDENTAL RELEASE MEASURES

SPILL OR LEAK PROCEDURES: .... Stop leak without additional risk. Wear proper personal protective equipment. Dike and contain spill. Ventilate area. Large spill - dike and pump into appropriate container for recovery. Small spill - recover or use inert, non-combustible absorbent material (*e.g.*, sand, clay) and shovel into suitable container. Do not use sawdust, wood chips or other cellulosic materials to absorb the spill, as the possibility for spontaneous combustion exists. Wash spill residue with warm, soapy water if necessary.

7. HANDLING AND STORAGE

STORAGE TEMPERATURE (min./max.): .... 40°F (4°C) / 90°F (32°C).

STORAGE: .... Store in cool, dry place with adequate ventilation.

HANDLING PRECAUTIONS: .... Use only with adequate ventilation. Do not breath vapors or mists from heated material. Avoid contact with skin and eyes. Wash thoroughly after handling. When mixed with epoxy resin this product causes an exothermic reaction, which in large masses, can produce enough heat to damage or ignite surrounding materials and emit fumes and vapors that vary widely in composition and toxicity.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

EYE PROTECTION GUIDELINES: .... Chemical splash goggles, full-face shield or full-face respirator.

SKIN PROTECTION GUIDELINES: .... Wear liquid-proof, chemical resistant gloves (nitrile-butyl rubber, neoprene, butyl rubber or natural rubber) and full body-covering clothing.

RESPIRATORY/VENTILATION GUIDELINES: .... General mechanical or local exhaust ventilation. With inadequate ventilation, use a NIOSH/MSHA approved air purifying respirator with an organic vapor cartridge.

Note: West System, Inc. has conducted an air sampling study using this product or similarly formulated products. The results indicate that the components sampled for (amines) were either so low that they were not detected at all or they were well below OSHA's permissible exposure levels.

ADDITIONAL PROTECTIVE MEASURES: .... Use where there is immediate access to safety shower and emergency eye wash. Provide proper wash/cleanup facilities for proper hygiene. Contact lens should not be worn when working with this material. Generally speaking, working cleanly and following basic precautionary measures will greatly minimize the potential for harmful exposure to this product under normal use conditions.

OCCUPATIONAL EXPOSURE LIMITS: .... Not established for product as whole. Refer to OSHA's Permissible Exposure Level (PEL) or the ACGIH Guidelines for information on specific ingredients.

9. PHYSICAL AND CHEMICAL PROPERTIES

PHYSICAL FORM .... Liquid.

COLOR.. Light-yellow.
ODOR.. Ammonia-like.
BOILING POINT.. > 480°F.
MELTING POINT/FREEZE POINT.. No data.
pH.. 11.4
SOLUBILITY IN WATER.. Appreciable.
SPECIFIC GRAVITY.. 1.01
BULK DENSITY.. 8.45 pounds/gallon.
VAPOR PRESSURE.. < 1 mmHg @ 20°C.
VAPOR DENSITY.. Heavier than air.
VISCOSITY.. 200 cPs
% VOLATILE BY WEIGHT.. ASTM 2369-07 was used to determine the Volatile Matter Content of mixed epoxy resin and hardener. 105 Resin and 206 Hardener, mixed together at 5:1 by weight, has a density of 1176 g/L (9.81 lbs/gal). The combined VOC content for 105/206 is 9.59 g/L (0.08 lbs/gal).

10. STABILITY AND REACTIVITY

STABILITY:.. Stable.

HAZARDOUS POLYMERIZATION:.. Will not occur.

INCOMPATIBILITIES:.. May react violently when in contact with oxidizing materials, acids or halogenated compounds such as methylene chloride. Reactions may be slow initially, then may rapidly generate heat and vapor pressure.

DECOMPOSITION PRODUCTS:.. Very toxic fumes and gases when burned. Decomposition products may include, but not liminted to: oxides of nitrogen, volatile amines, ammonia, nitric acid, nitrosamines.

11. TOXICOLOGICAL INFORMATION

No specific oral, inhalation or dermal toxicology data is known for this product.

Oral:.. Expected to be moderately toxic.
Inhalation:.. Expected to be moderately toxic.
Dermal:.. Expected to be moderately toxic.

CARCINOGENICITY:
NTP.. No.
IARC.. No.
OSHA.. No.

No ingredient of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA, NTP or IARC.

12. ECOLOGICAL INFORMATION

In the non-cured liquid form this product may be harmful if released to the environment. Do not allow into sewers, on the ground or in any body of water.

13. DISPOSAL CONSIDERATIONS

WASTE DISPOSAL METHOD:.. Evaluation of this product using RCRA criteria shows that it is not a hazardous waste, either by listing or characteristics, in its purchased form. It is the responsibility of the user to determine proper disposal methods.

Incinerate, recycle (fuel blending) or reclaim may be preferred methods when conducted in accordance with federal, state and local regulations.

14. TRANSPORTATION INFORMATION

DOT Non-Bulk
SHIPPING NAME:.. Polyamines, liquid, corrosive, n.o.s.
TECHNICAL SHIPPING NAME:.. Polyoxypropylenediamine.
HAZARD CLASS:.. Class 8
U.N./N.A. NUMBER:.. UN 2735
PACKING GROUP:.. PG II

ICAO/IATA
SHIPPING NAME:.. Polyamines, liquid, corrosive, n.o.s.
TECHNICAL SHIPPING NAME:.. Polyoxypropylenediamine
HAZARD CLASS:.. Class 8
U.N. NUMBER:.. UN 2735
PACKING GROUP:.. PG II
MARINE POLLUTANT:.. No

IMDG

SHIPPING NAME: .... Polyamines, liquid, corrosive, n.o.s.
TECHNICAL SHIPPING NAME: .... Polyoxypropylenediamine
HAZARD CLASS: .... Class 8
U.N. NUMBER: .... UN 2735
PACKING GROUP: .... PG II
EmS: .... F-A, S-B
MARINE POLLUTANT: .... No

15. REGULATORY INFORMATION

OSHA STATUS: .... Corrosive; possible sensitizer.
TSCA STATUS: .... All components are listed on TSCA inventory or otherwise comply with TSCA requirements.

CANADA WHMIS CLASSIFICATION: .... D2A – Very toxic material causing other toxic effects. E – Corrosive.
CEPA Chemical Inventory Status: .... All components are listed or are otherwise compliant with CEPA requirements.

SARA TITLE III:
SECTION 313 TOXIC CHEMICALS: .... None.

STATE REGULATORY INFORMATION:

The following chemicals are specifically listed or otherwise regulated by individual states. For details on your regulatory requirements you should contact the appropriate agency in your state.

COMPONENT NAME	STATE CODE
Tetraethylenepentamine 112-57-2	RI, MA, NJ, PA
Tetraethylenetriamine 112-24-3	RI, MA, NJ, PA
Diethylenetriamine 111-40-0	RI, MA, NJ, PA

16. OTHER INFORMATION

REASON FOR ISSUE: .... Changes made in Section 2, 3 and 14.
PREPARED BY: .... G. M. House
APPROVED BY: .... G. M. House
TITLE: .... Health, Safety & Environmental Manager
APPROVAL DATE: .... April 3, 2013
SUPERSEDES DATE: .... February 10, 2011
MSDS NUMBER: 206-13a

GOEX BLACK POWDER
THE TRADITION CONTINUES

Goex Powder, Inc.

Material Safety Data Sheet

MSDS-BP (Potassium Nitrate)

Revised 3/17/09

PRODUCT INFORMATION	
Product Name	Black Powder
Trade Names and Synonyms	N/A
Manufacturer/Distributor	GOEX Powder, Inc.(DOYLINE, LA) & various international sources
Transportation Emergency	800-255-3924 (24 hrs – CHEM TEL)

PREVENTION OF ACCIDENTS IN THE USE OF EXPLOSIVES

The prevention of accidents in the use of explosives is a result of careful planning and observance of the best known practices. The explosives user must remember that he is dealing with a powerful force and that various devices and methods have been developed to assist him in directing this force. He should realize that this force, if misdirected, may either kill or injure both him and his fellow workers.

WARNING

All explosives are dangerous and must be carefully transported, handled, stored, and used following proper safety procedures either by or under the direction of competent, experienced persons in accordance with all applicable federal, state and local laws, regulations, or ordinances. ALWAYS lock up explosive materials and keep away from children and unauthorized persons. If you have any questions or doubts as to how to use any explosive product, DO NOT USE IT before consulting with your supervisor, or the manufacturer, if you do not have a supervisor. If your supervisor has any questions or doubts, he should consult the manufacturer before use.

HAZARDOUS COMPONENTS				
Material or Components	%	CAS NO.	TLV	PEL
Potassium nitrate	70-76	007757-79-1	NE	NE
Charcoal	8-18	N/A	NE	NE
Sulfur	9-20	007704-34-9	NE	NE
Graphite[1]	Trace	007782-42-5	15 mppct (TWA)	2.5 mg/m³
N/A = Not assigned NE = Not established				

[1] Not contained in all grades of black powder.

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P.O. Box 659, Doyline, LA 71023-0659, (318) 382-9300
www.goexpowder.com

PHYSICAL DATA	
Boiling Point	N/A
Vapor Pressure	N/A
Vapor Density	N/A
Solubility in Water	Good
Specific Gravity	1.70 – 1.82 (mercury method) 1.92 – 2.08 (pycnometer)
PH	6.0 – 8.0
Evaporation Rate	N/A
Appearance and Odor	Black granular powder. No odor detectable.

HAZARDOUS REACTIVITY	
Instability	Keep away from heat, sparks, and open flames. Avoid impact, friction and static electricity.
Incompatibility	When dry, black powder is compatible with most metals; however, it is hygroscopic and when wet, attacks all common metals except stainless steel. Black powder must be tested for compatibility with any material not specified in the production/procurement package with which they may come in contact. Materials include other explosives, solvents, adhesives, metals, plastics, paints, cleaning compounds, floor and table coverings, packing materials, and other similar materials, situations, and equipment.
Hazardous decomposition	Detonation produces hazardous overpressures and fragments (if confined). Gases produced may be toxic if exposed in areas with inadequate ventilation.
Polymerization	Polymerization will not occur.

FIRE AND EXPLOSION DATA	
Flashpoint	Not applicable
Auto Ignition Temperature	Approx. Range: 392°F-867°F / 200°C-464°C
Explosive temperature (5 sec)	Ignites @ approx. 427°C (801°F)
Extinguishing media	Water
Special fire fighting procedures	ALL EXPLOSIVES: DO NOT FIGHT EXPLOSIVES FIRES. Try to keep fire from reaching explosives. Isolate area. Guard against intruders. Division 1.1 Explosives (heavily encased): Evacuate the area for 5,000 feet (approximately 1 mile) if explosives are heavily encased. Division 1.1 Explosives (not heavily encased): Evacuate the area for 2,500 feet (approximately ½ mile) if explosives are not heavily encased. Division 1.1 Explosives (all): Consult U.S. DOT Emergency Response Guide 112 for further details.

Unusual fire and explosion hazards	Black powder is a deflagrating explosive. It is very sensitive to flame and spark and can also be ignited by friction and impact. When ignited unconfined, it burns with explosive violence and will explode if ignited under even slight confinement.

HEALTH HAZARDS	
General	Black powder is a Division 1.1 Explosive, and detonation may cause severe physical injury, including death. All explosives are dangerous and must be handled carefully and used following approved safety procedures under the direction of competent, experienced persons in accordance with all applicable federal, state and local laws, regulation and ordinances.
Carcinogenicity	None of the components of Black Powder are listed as a carcinogen by NTP, IARC, or OSHA.

FIRST AID	
Inhalation	Not a likely route of exposure. If inhaled, remove to fresh air. If not breathing give artificial respiration, preferably by mouth-to-mouth. If breathing is difficult, give oxygen. Seek prompt medical attention. Avoid when possible.
Eye and skin contact	Not a likely route of exposure. Flush eyes with water. Wash skin with soap and water.
Ingestion	Not a likely route of exposure. If ingested, dilute by giving two glasses of water and induce vomiting. Avoid when possible.
Injury from detonation	Seek prompt medical attention.

SPILL OR LEAK PROCEDURES	
Spill/leak response	Use appropriate personal protective equipment. Isolate area and remove sources of friction, impact, heat, low level electrical current, electrostatic or RF energy. Only competent, experienced persons should be involved in clean up procedures. Carefully pick up spills with non-sparking and non-static producing tools.
Waste disposal	Desensitize by diluting in water. Open train burning, by qualified personnel, may be used for disposal of small unconfined quantities. Dispose of in compliance with Federal Regulations under the authority of the Resource Conservation and Recovery Act (40 CFR Parts 260-271).

SPECIAL PROTECTION INFORMATION	
Ventilation	Use only with adequate ventilation. (If required)
Respiratory	None
Eye	None
Gloves	Impervious rubber gloves. (If required)
Other	Metal-free and/non-static producing clothes

SPECIAL PRECAUTIONS
• Keep away from friction, impact, and heat and open flame. Do not consume food, drink, or tobacco in areas where they may become contaminated with these materials.   • Contaminated equipment must be thoroughly water cleaned before attempting repairs.   • Use only non-spark producing tools.   • No smoking.

STORAGE CONDITIONS
Store in a cool, dry place in accordance with the requirements of Subpart K, ATF: Explosives Law and Regulations (27 CFR 55.201-55.219).

SHIPPING INFORMATION		
Proper shipping name	Black Powder	
Hazard class	1.1D	
UN Number	UN0027	
DOT Label & Placard	DOT Label	EXPLOSIVES 1.1D
	DOT Placard	EXPLOSIVES 1.1
Alternate shipping	Limited quantities of GOEX black powder (1# cans only) may be transported as "Black powder for small arms – flammable solid" pursuant to U.S. Department of Transportation 49 CFR.	

The information contained in this Material Safety Data Sheet is based upon available data and believed to be correct; however, as such has been obtained from various sources, including the manufacturer, military and independent laboratories, it is given without warranty or representation that it is complete, accurate, and can be relied upon. GOEX, Incorporated, has not attempted to conceal in any manner the deleterious aspects of the product listed herein, but makes no warranty as to such. Further, GOEX, Incorporated, cannot anticipate nor control the many situations in which the product or this information may be used; there is no guarantee that the health and safety precautions suggested will be proper under all conditions. It is the sole responsibility of each user of the product to determine and comply with the requirements of all applicable laws and regulations regarding its use. This information is given solely for the purposes of safety to persons and property. Any other use of this information is expressly prohibited.

For further information contact: GOEX Powder, Incorporated
P. O. Box 659
Doyline, LA 71023-0659
Telephone Number: (318) 382-9300
Fax Number: (318) 382-9303

BLACK POWDER

FRICTION TEST
PA

Steel – Snaps
Fiber – Unaffected

IMPACT TEST
PA

16 Inches (10% Point)

ELECTROSTATIC DISCHARGE TEST

Bureau of Mines
0.8 Joules (Confined)
12.5 Joules Unconfined)

STABILITY

75° C International Heat Test – 0.31% Loss
Vacuum Stability – 0. 5cc @ 100° C

BRISANCE – Sand Test 8 gm.

VELOCITY

In the open, trains of black powder burn very slowly, measurable in seconds per foot. Confined, as in steel pipe, speeds of explosions have been timed at values from 560 feet per second for very coarse granulations to 2,070 feet per second for the finer granulations. Confinement and granulation will affect the values.

CHEMICAL DECOMPOSITION

Use water to dissolve the potassium nitrate. By leeching out the potassium nitrate, the residue of sulfur and charcoal is non-explosive but combustible when dry – dispose separately.

SPECIAL REQUIREMENTS:

Black Powder is very sensitive to flame and spark and can also be ignited by friction and impact. When ignited unconfined, it burns with explosive violence and will explode if ignited under even slight confinement.

When dry, it is compatible with most metals. However, it is hydroscopic and when wet, attacks all common metals except stainless steel.

CAUTION: Explosives must be tested for compatibility with any material not specified in the production/procurement package with which they may come in contact. Materials include other explosives, solvents, adhesives, metals, plastics, paints, cleaning compounds, floor and table coverings, packing materials and other similar materials, situations and equipment. Explosives include propellants and pyrotechnics.

3.6.3.3. NAR Regulations Met

NAR Regulations met:

Acceptance and rejection of model by safety check-in officer

A1) All team members are over the age of 18.
A2) Alan Whitmore and Dr. Charles Hall are the clubs mentor and advisor who are both level 3 certified modelers.
A3) Bayboro NC launch site accepts level 3 rocket launches
A4) Motor is purchased from a certified dealer
A5) Motor falls within recommended liftoff weight with consideration to drag and weather conditions.
A6) Club mentor/advisor consults with RSO to verify if the launch system is “flash bulb safe”.

Inspection of model structure and recovery system

B1) All “slip-fits” are inspected for desired separation efforts including the nosecone, upper, middle, and lower airframes.
B2) Launch lugs are inspected by club advisor/mentor and RSO.
B3) Fins are mounted parallel to the roll axis and checked for wiggle/displacement. 1/8” plywood and fiberglass are used in lamination and checked for delamination.
B4) Motor is properly inspected by club advisor/mentor to confirm retention.
B5) Motor is properly inspected by club advisor/mentor to confirm the motor does not move forward.
B6) CG check is performed and compared to Openrocket simulated results. CG and CP locations are known to ensure flight stability.

Electronic systems for parachute/staging operations

E1) Proper electronics check made by club advisor/mentor.
E2) Team members will be aware of armed electronics by an indication device.
E3) Team members will have a pre/post flight checklist for arming/disarming the system.

Launch pads

F2) RSO, club advisor/mentor, and team members will ensure a blast deflector is present to prevent

Range setup and facilities

G1) Weather condition will be available by observation and reports.
G2) RSO and club advisor/mentor will ensure launch pad equipment is labeled and visible, matches the number on the controller, and is clean and unbent with a proper blast deflector.
G3) RSO and club advisor/mentor ensure sufficient current output to light igniters.
G4) Club mentor/advisor consults with RSO to verify if the launch system is “flash bulb safe”.
G5) RSO, club mentor/advisor, and team members inspect the ground to ensure all flammable materials are cleared. Proper watering of the area will be at the RSO’s discretion.
G6) RSO and club advisor/mentor will ensure personnel are located far enough away from launch pads through flag lines, barriers, etc.

G7) RSO will determine if spectator or non-participant safety is at risk from model trajectory due to model failure or weather cocking into the wind.
G8) Proper firefighting equipment will be provided with location indicated for lab and launch sites.
G9) Club advisor/mentor will properly inspect battery terminals for possible shorting causing fires/explosions.
G10) First aid kits will be provided in the lab and by the RSO for launch sites.
G11) Participants and spectators maintain visual confirmation of model and properly communicate to one another of the models trajectory.
G12) No smoking will be allowed within 50 feet of the launch and preparation areas.
G13) FAA waiver activation is at the NAR personnel's discretion on the launch site. All participants will be aware of waiver limits and contact info in the event of an emergency.
G14) RSO will have loud and clear communication methods.
G15) Binoculars will be the RSO's responsibility for viewing an airborne rocket.
G16) The model will be prepared/armed for flight in a location away from participants/spectators to minimize exposure to inadvertent electronic system activation.

Prelaunch activities
H1) RSO and club advisor/mentor will inspect the launch angle to be within 20 degrees of the vertical
H2) Model stability on the launch pad will be confirmed by the RSO, club advisor/mentor, and members.
H3) Wind speeds will be checked to ensure they are no greater than 20 mph.
H4) Spectators or modelers will be at a safe distance from the launch pad. Operations will be on hold until all people are clear.
H5) Skies will be checked to be clear of aircraft from all personnel present at launch.
H7) All electronics will be manually checked to be armed for flight.

Observations of the flight
J1) Predicted model apogee will be compared to cloud base to prevent penetration into cloud cover.
J2) RSO will inspect model trajectory to prevent traveling over spectator or parking areas.
J3) All club members will observe separated pieces from the staged model to verify recovery systems have been deployed.

1.1.1. J4) All club members will observe model to ensure all planned recovery events occur and warn range personnel if events do not occur. Personnel will be warned to not handle the model if all planned events do not occur to prevent armed electronics hazards.

3.6.4. Environmental Concerns

Obstacles such as trees, houses, roads, power lines, etc. that could be struck during flight are eliminated due to the launch site's location in the Salt Flats. Vehicles will be present but located at a safe distance from the launch site. Primary environmental concerns related to construction and launching of the rocket are fire and proper disposal of hazardous materials.

The motor for the rocket will only use solid propellant purchased from a licensed manufacturer. Before use the motor will be fully inspected to ensure no defects or cracks are present. Misfired and spent motors will be soaked in water until the propellant grains dissolve. The same procedure applies to black powder charges. This eliminates many fire and explosive related dangers that would otherwise be encountered from attempting to construct our own propellant. In the event of a fire, proper firefighting equipment will be provided and used accordingly.

Hazardous materials such as epoxy resin and hardeners used in the lab will be handled and disposed of in a manner that complies with the MSDS. All trash and materials used at the launch site will be properly bagged and disposed of.

4. Payload Criteria

4.1. Testing and Design of Payload Experiment

The experiment is designed to monitor flight conditions, structural loads, motor performance as well as to prove the dynamic stability of the rocket and its ability to return to statically stable flight upon receiving a dynamic excitation. In order to conduct these experiments, a multitude of student designed and commercially available components have been assembled and dispersed throughout the flight vehicle.

4.1.1. Review of Design

Monitoring flight conditions will be accomplished by utilizing a student designed pitot tube and a low noise 10 degree of freedom IMU. The pitot tube will record airspeed in the subsonic and supersonic flight regimes. The subsonic regime airspeed will be determined by pulling the dynamic pressure out using the total pressure recorded by the pitot tube and the static pressure recorded by the IMU. The supersonic regime airspeed will be determined using the Rayleigh pitot formula. The change from one regime calculation is due to the pressure drop experienced as air passes through the shock that is formed while crossing Mach 1. The acceleration data recorded from the IMU will be used to validate the and quantify the values from pitot tube calculations.

In addition to airspeed, the IMU will monitor rotation rates and accelerations in all three axes to verify the vehicle's orientation and position. These quantities will be processed through a Kalman filter and converted to quartonians to move from the earth fixed frame to the body fixed frame position. Quartonians are used rather than Euler angles due to absence of singularities on the vertical poles.

Structural loads will be monitored throughout the rocket via strain gages. Areas under high loads during or at some point during the flight have been determined using ANSYS Fluent coupled with ANSYS Static structural analysis. These areas include the fins, bulk heads and the coupling between the reaction thruster and the center of gravity. The midsection forward bulkhead has also been chosen as a high stress area during main parachute deployment and will be monitored as well.

The rocket's dynamic stability is of special interest to the team. There are many conditions which could impart a disturbance on the flight path of a rocket during flight. Such disturbances can range the minor force exerted by a light wind, strong upper level wind, or worse out gassing from a ruptured tank or pressurized line. The reaction thruster simulates these disturbances by inducing a moment on the rocket about the center of gravity. Preliminary calculations, detailed in the stability section, have been completed in an attempt to predict the vehicles dynamic response to such an excitation. The experiment is to determine the validity of the MatLab Simulink models designed to predict this response. The reaction thruster is designed to exert a force of 35 lbs. at a distance of 35 inches from the center of gravity. At 550 ft/s, this is predicted to produce a 1.5 degree disturbance. The IMU will record the movement of the rocket during and after this event at 300Hz. Using this data we can quantify the models and the predicted dynamic response and return to statically stabile flight.

Finally, a hazard detection system is to be implemented, after main parachute deployment. In order to accomplish this, a small camera has been placed on the aft payload bulkhead. Under main parachute descent, the camera will face down and take multiple still images to be used to determine the presence of hazardous landing areas. The image will then be processed on board in the Arduino by decomposing each image and identifying areas of non-conformity. These areas are deemed to be hazardous as they would represent some sort of drastic terrain change, obstacle, persons, etc. The information will then been sent, via a down link, to the ground station. Future iterations of this experiment could include some sort of guidance device to allow for not just hazard detection but hazard avoidance.

In addition to these major objectives of the payload, other sensors will be utilized to record temperature, pressure changes, and GPS locations throughout the flight. Thermocouples will be placed in the excitation thruster compartment to monitor temperature rise during flight. This data will be used to quantify preflight calculations for temperature build up during supersonic flight. An addition thermocouple is to be mounted against the motor casing to monitor heat transfer rates from the motor to the fiberglass motor sleeve.

4.1.1.1. Design Integrity

The payload is designed to maintain the upmost integrity during flight to ensure proper operation and reliable data acquisition. Components with high power requirements, the RF transmitter, GPS receiver/transmitter, solenoid valve, and Arduino, are to have independent power sources. This is also done to avoid overloading the resources supplied by the Arduino. The strain gage ADC's, temperature transducers, pressure transducer, IMU, and hazard detection camera will be connected to the Arduino's power source.

All of the devices utilized in the payload have been chosen will reliability and ruggedness in mind. These devices will need to endure the g forces associated with launch, main parachute deployment, and landing without exceeding the published limits of each device.

Special attention was given to the thruster components. The Thruster high pressure propellant tank and all fittings under high pressure have been chosen due to their published abilities to with stand pressures of no less than 3000 psi. As the thruster design calls for 500-600 psi, this is well above the factor of safety of 4 explicitly stated by the RSO.

4.1.2. System Level Functional Requirements

On a system level the equipment is relatively simple. The Arduino must record, process and pass through the data gathered by the various peripheral devices. All of the sensors must gather their respective quantities reliably and accurately at a rate of no less than 300 Hz. The RF transmitter must relay the information processed by the Arduino with little to no data packet loss. The thruster solenoid valve must fully actuate the pneumatic cylinder opening the ball valve quickly to activate the ball valve.

4.1.3. Workmanship

Special attention is to be made to the workmanship during the construction of the vehicle with special attention to the payload bay. All wires and components are to be clearly marked and all connections are to be routed through designated pathways and plugs for payload simplification and reduction of prep-time at the launch site.

4.1.4. Planned Testing

Testing has begun on the payload electronics and mechanical devices. The entire electronic system is being tested by adding devices one at a time to avoid multiple programming/compatibility issues. The devices are being added starting with the most simple devices first, continuing on to increasingly complex components.

In addition to this testing, transmitter interference is to be tested by exposing the altimeters and components to the RF transmitter and GPS units and combinations of each. It is vital to guarantee no premature ignitions of parachute deployment charges. An extra precaution is being taken for the altimeters by applying aluminum shielding to the entire avionics bay.

4.1.5. Status Update

Currently, the payload is still undergoing performance, reliability, and longevity tests. The ADC's, temperature transducers and thermocouples, and the hazard detection camera are operational. Programming is currently underway to integrate the RF transmitter and IMU.

4.1.6. Payload Electronics

The payload bay is constructed of 5.36 in Blue Tube that fits snugly within the 5.5 in Blue Tube used for the airframe. One of the reasons the 5.5 in Blue Tube was selected for the body tube is that it permits use of the 5.36 in coupler Blue Tube for payload bay construction. Bulkheads seal either end of the bay. Quarter twenty threaded rods provide additional rigidity to the payload bay. A fiberglass "sled" is mounted inside the bay and supports the rocket's avionics.

The Pay load is designed to record a multitude of engineering quantities during flight. To gather these quantities, several electrical components are required:

- Arduino Due

Core of the experimental payload. Receives and processes Data from peripheral devices. Also controls the hazard detection algorithm.

- Analog Devices ADIS16488AMLZ

Inertial measurement unit, three axis accelerometer, gyroscopes, and magnetometer, static pressure port. Used to gather dynamic response and for trajectory tracking

- Pitot Tube

Measure total pressure for dynamic pressure and airspeed calculations

- Adafruit

Pressure Transducer, Convert pressure received from Pitot tube to an analog signal the Arduino can process

- Thermocouple Type K

Measure temperature at various points throughout the rocket, explicitly the motor housing, and payload bay, Temperature range -200° to 1350° C

- Vishay Strain Gages

Record stresses in specific areas of the rocket for force calculations and structural stress analysis.

- Load Cell (Custom Designed)

Custom designed Load cell mounted forward of the rocket motor. Utilized to extrapolate effective force produced by the rocket motor for comparison with published values.

- GPS Receivers Big Red Bee

GPS receiver for location and trajectory data comparison/checking

- TTL Serial Camera

Digital camera used for the Hazard Detection system.

- Digi XT09-DK

900 MHz RF Transmitter, 115 kb/s transmit rate, 40 km Range. Downlink for real time data acquisition

4.1.6.1. Drawing Spec Sheets

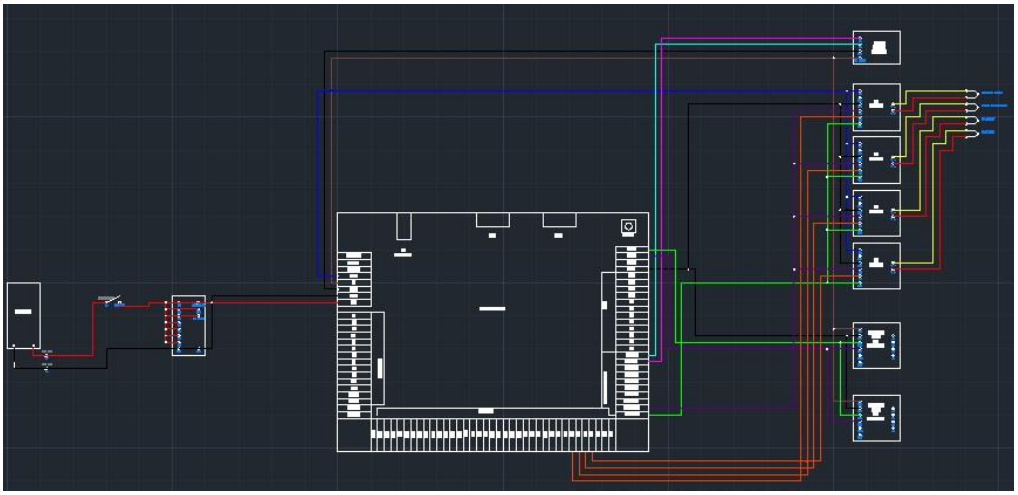

Figure 50: Payload Electronics Diagram

4.1.6.2. Block Diagrams

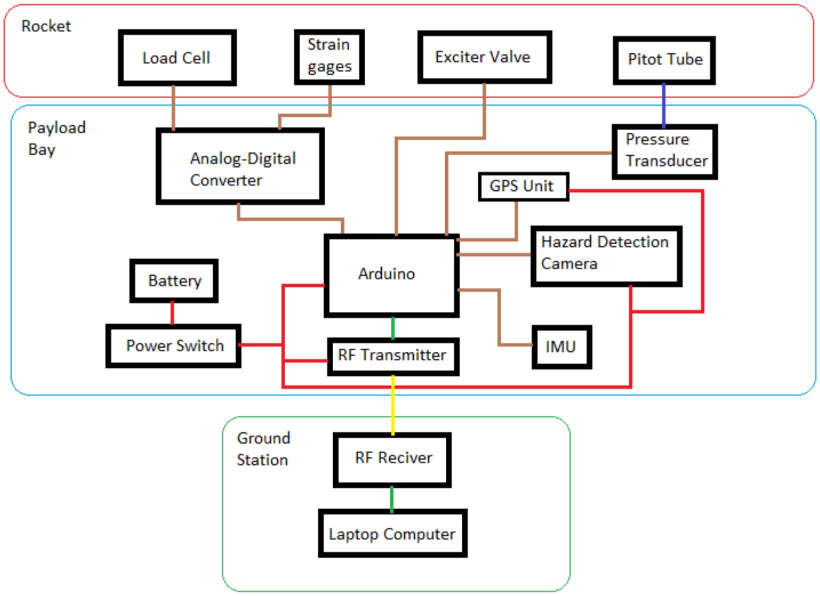

Figure 51: Payload Block Diagram

4.1.6.3. Batteries/Power

Valken Energy 9.6V NiMH Li-PO 1600mAh

4.1.6.4. Transmitters

DIGI XV09/VK-900MHz-9v

XBEE-Pro 900-900MHz-50mw

4.2. Payload Concept Features and Definition

The payload for the 2013-2014 Tacho Lycos rocket incorporates features designed to support the vehicle's mission as a sounding rocket as well as investigate performance of the vehicle itself. The dynamic modes of the vehicle are to be excited using a reaction thruster. Initially, an exciter flap or vane was considered, but the reaction thruster was selected for the level of challenge it would provide as well as the reduction of vehicle failure modes. Structural loading data from the vehicle, force data from the motor, and atmospheric data will be relayed to the ground in real-time. In addition to facilitating real-time preliminary data analysis, down linking the data ensures that data will be preserved in the unlikely event of a loss of vehicle. Development and integration of the data down link and excitation thruster bring a suitable level of challenge to the payload. The dynamic mode analysis is a unique feature that will validate the vehicle dynamics model currently under development.

4.3. Scientific Value

The rocket's payload will be used to gather multiple engineering quantities. These quantities will then be used to verify performance and dynamic response predictions. Also, the structural data obtained from the strain gages attached to key high stress areas can be used to pinpoint failure points for future projects. In particular, the strain gages mounted to the main parachute anchoring bulkheads will reveal how the load applied during parachute deployment ultimate is transferred to these bulkheads. This particular portion of the payload, along with NASA's requirements, was requested by Alan Whitmore as many of his level three candidates have experienced failure of this structure during level three certification launches.

5. Project Plan

5.1. Budget

5.1.1. Full Scale

System	Supplier	Qty	Cost(ea)	Description	Total cost
Airframe	Apogee	4	$56.95	48" by 5.5" Body Tube, High Density, High Strength Paper	$227.80
	Apogee	1	$55.95	48" by 5.5" Coupler, High Density, High Strength Paper	$55.95
	Rocketry Warehous	1	$129.00	Filament wound 5:1 ratio VonKarman Nose Cone	$129.00
	Soller composites	16	$4.69	Fiberglass bi-axial sleeves	$75.04
	Apogee	1	$10.00	Largre Airfoiled Rail Buttons (2 ea)	$10.00
Propulsion	Red Arrow Hobbies	2	$799.00	Full Scale Motor	$1,598.00

System	Supplier	Qty	Cost(ea)	Description	Total cost
	Off We Go Rocketry	1	$460.00	Cesaroni Motor Casing	$460.00
	Apogee	2	$7.00	Center rings for 5.5" dia	$14.00
	Apogee	1	$42.80	Engine retainer plug mount	$42.80
	Rocketry Warehous	1	$85.00	Fiberglass tubing motor sleeve, 48" length	$85.00
Engineering Payload	Allied Electronics	1	$35.00	700 MHz Processor	$35.00
	Digi	1	$499.00	Xtend Development kit	$499.00
	Cooking Hacks	1	$54.33	Arduino Adapter	$54.33
	Undecided	1	$25.00	LiPo Battery For Payload	$25.00
	Undecided	1	$8.00	Battery Adapter for Payload	$8.00
	Amazon	30	$0.99	Mosa 16g Threaded CO2 Cartridges	$29.55
	Palmer-pursuit	3	$15.00	Adapter for CO2 cartridges	$45.00
	Grainger	1	$10.17	50 ft roll of 1/8" nylon tubing	$10.17
	Palmer-pursuit	1	$40.00	Solenoid valve for exciter activation	$40.00
	Palmer-pursuit	1	$109.00	CO2 Pressure regulator	$109.00
	Solutions Direct	2	$61.74	Dwyer Pitot Tube, Stainless, 1/8"	$123.48
	Omega	30	$5.00	Straingages	$150.00
	Hobby King	1	$150.00	GPS receiver for Arduino	$150.00
	MSC Industrial	1	$151.93	Aluminum Bar for Load Cell, 5/8"x6"x12"	$151.93
	Analog Devices	2	$624.00	IMU Sensor	$1,248.00
	TC	1	$35.00	Type K Thermo Couple	$35.00
	ThermocouplModule	1	$10.01	Arduino Thermocouple Module	$10.01
	Adafruit	1	$39.99	Camera	$39.99
	Analog Devices	1	$819.00	Evaluation board for Prototyping with IMU	$819.00
Recovery	TBD	1	$300.00	Parachute Material	$300.00
	TBD	1	$200.00	Deployment Bag for Parachute	$200.00

System	Supplier	Qty	Cost(ea)	Description	Total cost
	Apogee	3	$85.55	PerfectFlite StratoLogger Altimeter	$256.65
	Hobby King	30	Unavailabl e	E-Matches	$50.00
				Full Scale Estimated Budget:	**$7,086.70**
				Items Acquired From HPRC:	**$5,836.70**
				Remaining Balance of Items to be Purchased:	**$1,250.00**

5.1.2. Subscale

System	Supplier	Qty	Cost(ea)	Description	Total cost
Airframe	Apogee	1	$26.95	48" by 2.56" dia Body Tube, High Density, High Strength	$26.95
	Apogee	1	$28.95	48" by 2.56" dia Coupler, High Density, High Strength Paper	$28.95
	Apogee	1	$14.65	9" x 2.63"Nose Cone PNC-2.56" Polly Propylene Nose cone	$14.65
	Soller composites	8	$2.59	Fiberglass bi-axial sleeves	$20.72
	Apogee	1	$7.00	Standard Airfoiled Rail Buttons (2 ea)	$7.00
Propulsio n	Apogee	1	$5.80	Centering rings for 2.56" dia	$5.80
	Apogee	1	$22.47	MotorRetainer Subscale(Jsize)	$22.47
	redarrowhobbies	1	$20.39	Motor for Stability Demonstrition	$20.39
	redarrowhobbies	1	$49.99	Motor for Dual deply Demonstration	$49.99
	Rocketry Warehouse	1	$28.00	Fiberglass tubing motor sleeve, 24" length	$28.00
				Subscale Estimated Budget:	**$224.92**
				Items Purchased:	**$224.92**
				Remaining Balance of Items to be Purchased:	**$0.00**

5.1.3. Shared Items

System	Supplier	Qty	Cost(ea)	Description	Total cost
Misc.	balsausa	2	$18.94	12"x48" Plywood for Fins	$37.88
	Rocketry Warehouse	1	$63.48	Fiber Glass sheet 36"x24"	$63.48
	Apogee	1	$42.95	Fiberglass cloth 26"x25yds 6 oz/yd	$42.95
	West Systems	1	$100.00	Epoxy Resin 1 gallon	$100.00
	West Systems	1	$45.00	Epoxy Hardner	$45.00
	Lowes	1	$50.00	Supplies to Build Stand	$50.00
	Lowes	1	$100.00	Dremel Tool	$100.00
	Lowes	1	$150.00	Misc Hardware(nuts, bolts, etc)	$150.00
			Shared Items Estimated Budget:		**$589.31**
			Items Acquired From HPRC:		**$589.31**
			Remaining Balance of Items to be Purchased:		**$0**

5.1.4. Totals

Project Budgetary Overview

Travel Expenses	**$4,000.00**
Estimated Total Project Cost:	**$7,900.93**
2014 Budget Total:	**$11,900.93**
Items Donated by Sponsors:	**$2,591.92**
Remaining Balance to be Spent:	**$9,309.01**

5.2. Funding

Project Funding Overview

Engineering Technology Fund	**$3,000.00**
NC Space Grant:	**$5,000.00**
Appropriations Committee	**$1,000.00**
Sponsor Donations	**$3,000.00**
Total Budget:	**$12,000.00**

5.3. Timeline

Date	Project Line
1/14/2013	PDR Presentation
1/17/2013	Complete Subscale Construction
1/18/2013	Launch Subscale (Bayboro NC)
1/19/2013	Begin CDR Experiments
1/26/2013	Order Electronics for Payload
2/20/2013	CDR Report Compiled for Review
2/25/2013	Final Draft of CDR Completed
2/28/2013	CDR Presentation Completed
3/1/2013	Begin Full Scale Construction
3/31/2013	Full Scale Construction Completed
4/18/2013	FRR Report and Presentation Completed
4/1/2013 - 4/23/2013	Full Scale Launch
5/14/2013 - 5/18/2013	Competition

5.4. Educational Engagement

One of the main focuses of Tacho Lycos in 2014 is the promotion of science, technology, and engineering in the community. This year's plan involves community attendance at the test launches as well as presentation, demonstrations, and hands on activities at local outreach events. Any member of the community is welcome and encouraged to view the subscale and full-scale test launches which will be held in Bayboro, NC.

On January 25th and 26th the club helped with Astronomy Days and helped to oversee the rocket launches. The Tacho Lycos team has a major outreach event currently planned before the student launch date in May. This day is a "Kite Day" event hosted by the local YMCA group and will be located at the Carter Finley stadium in Raleigh, North Carolina. This event will allow for families to bring kites or pre-built model rockets to fly and launch throughout the day. The team will have two duties at this event: to operate the model rocket launch pad and to demonstrate simple scientific experiments teaching observers about the Bernoulli's Principle and the general design of rockets. The team will demonstrate Bernoulli's Principle using small experiments such as blowing on a piece of paper or blowing air between aluminum cans and will occasionally perform a louder and safer demolitions experiment. The team was invited to this event by Tim "Yeti" Whitehouse who has estimated that the club will be able to reach out to over 4000 children along with their parents.

6. Conclusions

With the conclusion of the CDR, the North Carolina State Rocketry Team, Tacho Lycos will move continue the fabrication of the full scale launch vehicle. As the airframe is being constructed for the full scale, the payload is being tested and configured. Several experiments are underway that will help ensure that the payload functions properly and all data will be successfully acquired.

7. Apendicies

7.1. Matlab Scripts

7.1.1. Stability

Barrowman Method MATLAB Code

```
% VAR Aerodynamics Calculation
% Stephen T. West
% North Carolina State University
%
% Revised 25 February 2014
%
% This code calculates the aerodynamic characteristics for VAR, the Tacho
% Lycos/Space Senior Design 2013-2014 high power rocket.
%
clear all
close all
clc
clf
%% INPUT
% VAR Vehicle Geometry
Ln = 30.438; % length of nosecone, inches
Ltr = 128; % length of total rocket, in
Lb = 91.56; % length of body tube, in
N = 0.466; % .666 for conical, .466 for ogive, .5 for parabolic
d = 5.5; % diameter at base of nose cone, inches
d1 = 5.5; % diameter at top of boattail, inches
d2 = 4.25; % diameter at bottom of boattail
Lcb = 6; % length of conical boattail, inches
xcb = 122; % distance from datum (tip of nose) to front of conical boattail,
inches
n = 4; % number of fins
s = 5.5; % overall width of fin, inches
a = 12; % root chord of fin, inches
b = 4; % tip chord of fin, inches
l = 6.265; % length of line connect root mid chord to tip mid chord, inches
m = 7; % vertical distance from root leading edge to tip leading edge, inches
R = 2.75; % Radius of body tube at fin leading edge
Tf = 0.40; % thickness of fin, inches
xf = 110; % distance from datum to leading edge of fin root, inches
zbar = 81.469; % CG inches aft of datum
Ar = (pi()*d^2)/4; % reference area for coefficients, area at base of nose
cone

% Initialize Variables
alpha = [-10:0.1:10]; % initialize alpha sweep

% Environmental Parameters
T = 59; % deg F
V = 550; % ft/s
mu = 1.57e-4; % ft^2/s
rho = 2.35e-3; % slug/ft^3

%% NORMAL FORCE COEFFICIENTS
```

```
% From Barrowman

% Nose
CNan = 2;
x_n = N*Ln;

% Fins
CNaf = (4*n*(s/d)^2)/(1+sqrt(1+(2*l/(a+b))^2));
Kfb = 1+(R/(s+R)); % for three or four fins
CNafb = Kfb*CNaf;
x_f = xf + ((m*(a+2*b)/(3*(a+b))))+(1/6)*(a+b-((a*b)/(a+b)));

% Conical Boattail
CNacb = 2*((d2/d)^2 - (d1/d)^2);
x_cb = xcb + (Lcb/3)*(1+((1-(d1/d2))/(1-(d1/d2)^2)));

% Total Normal Force
CNa = CNan + CNacb + CNafb;

%% AERODYNAMIC CENTER
% Total Aerodynamic Center
xbar = (CNan*x_n + CNacb*x_cb + CNafb*x_f)/CNa;

Kn = xbar - zbar;
Kn1 = Kn/d;

%% DRAG FORCE ESTIMATION (CD_0)
% From Mandell (1973) via Box, Bishop, and Hunt

% Reynolds Number
Re = rho*V*Ltr/mu;
B = 5e5*((0.074/Re^0.2)-(1.328/sqrt(Re)));

% Body Drag
if Re < 5e5
      Cf_fb = 1.328/sqrt(Re);
else
      Cf_fb = (0.074/Re^0.2)-(B/Re);
end

CD_fb = (1+(60/(Ltr/d)^3)+(0.0025*Lb/d))*((2.7*Ln/d)+(4*Lb/d))*Cf_fb;

% Base Drag
CD_b = 0.029/sqrt(CD_fb);

% Fin Drag
Re_f = rho*V*l/mu;
B_f = 5e5*((0.074/Re_f^0.2)-(1.328/sqrt(Re_f)));

if Re_f < 5e5
      Cf_f = 1.328/sqrt(Re_f);
else
      Cf_f = (0.074/Re_f^0.2)-(B_f/Re_f)
end
```

```
Afe = 0.5*(a+b)*s;
Afp = Afe + 0.5*d*a;
CD_f = 2*Cf_f*(1+2*(Tf/l))*(4*n*Afp/(pi()*d^2));

% Interference Drag
CD_i = 2*Cf_f*(1+2*(Tf/l))*(4*n*(Afp-Afe)/(pi()*d^2));

% Total zero angle of attack drag
CD_0 = CD_fb + CD_b + CD_f + CD_i;

%% AERODYNAMIC COEFFICIENTS
% From E.V. LaBudde (1999)

% Calculate C_D as a function of alpha
C_D = CD_0.*cosd(alpha) + CNa.*sind(alpha).^2;

% Calculate C_L as a function of alpha
C_L = -CD_0.*sind(alpha) + CNa.*sind(alpha).*cosd(alpha);

% Calculate CL_a
diffCL = diff(C_L);
diffa = diff(alpha.*pi()./180);
vectorCLa = diffCL./diffa;
CL_a = mean(vectorCLa);

% Calculate CMa
CMa = -Kn*CL_a;

%% OUTPUT

fprintf('The total normal force is %2.2f and the aerodynamic center (x_bar)
is located at %3.2f.\n',CNa,xbar)
fprintf('The static margin is %2.2f calibre.\n',Kn1)
fprintf('\n\nSTABILITY DERIVATIVES \nunits are 1/rad \n \n')
fprintf('CL_a = %2.2f \n', CL_a)
fprintf('CM_a = %2.2f \n',CMa)

figure(1)
plot(alpha, C_D)
grid on
title('Coefficient of Drag for AOA from -10 to 10 degrees')
xlabel('angle of attack (deg)')
ylabel('C_D')

figure(2)
plot(alpha, C_L)
grid on
title('Coefficient of Lift for AOA from -10 to 10 degrees')
xlabel('angle of attack (deg)')
ylabel('C_L')
```

Thruster Sizing and Dynamic Reponse MATLAB Code

```
% This code calculates preliminary dynamic characteristics of the Tacho
% Lycos Full Scale rocket and estimates the thruster force required to
% excite the rocket
clear all
clc
%% INPUT
rho = 32*1.5961E-3*(1/12)^3; % average density, slugs/in^3 (9000' AGL,
Bonneville Salt Flats = 13,000' MSL)
V = 550*12; % approximate velocity, in/s (8.65 s after burnout)
Ar = pi()*(1/4)*5.5^2; % reference area, in^2
CNa = 10.5915; % total normal force
zbar = 95.29; % aerodynamic center, inches aft of datum
wbar = 81.469; % center of gravity, inches aft of datum
CNan = 2;
znose = 14.18; % inches
CNaf = 9.3973;
zfin = 115.0833; % inches
CNacb = -0.8058;
zcb = 124.8718; % inches
IL = 141907; % lb*in^2
t = [0:0.01:2];
alpha_0 = 3*(2*pi()/360);
delta_t = 0.61; %s
r = 35; % moment arm in inches

%% EXECUTION
IL_slug = IL/32.2; % convert to slug-in^2
C1 = 0.5*rho*V^2*Ar*CNa*(zbar-wbar);
C2 = 0.5*rho*V*Ar*((CNan*(znose-wbar)^2)+(CNaf*(zfin-wbar)^2)+(CNacb*(zcb-
wbar)^2));

omega_n = sqrt(C1/IL_slug);
damp_rat = C2/(2*sqrt(C1*IL_slug));
f_n = omega_n/(2*pi());
t_half = 0.693/(omega_n*damp_rat);
T = 2*pi()/omega_n;

A = C1/IL_slug;
B = C2/IL_slug;

x = (-B+sqrt(B^2-4*A))/2;

alpha = 360/(2*pi()).*(alpha_0.*exp(real(x).*t).*cos(imag(x).*t));

tau = 2*alpha_0*IL_slug/delta_t^2;
thrust = tau/r;

%% OUTPUT
fprintf('The natural frequency is %2.3f rad/s (%2.3f Hz), the damping ratio
is %2.3f, the period is %2.3f s,\n and the time to half is %2.3f
s.\n',omega_n,f_n, damp_rat, T, t_half)
plot(t,alpha,'r')
xlabel('time (s)')
```

```
ylabel('\alpha (degrees)')
title('Pitch Response after 3 degree Disturbance')
grid on
fprintf('The required torque is %2.1f in*lb. For a %2.1f in moment arm, %2.1f lb of thrust are required.\n',tau,r,thrust)
```

7.1.2. Thruster Sizing

```
% Christopher R Buck
% Senior Design
% 10/28/13
% Reaction Thruster Nozzle Design
% This program is used to aid in the design of the reaction thruster for
% the Team 1's Rocket Dynamic Mode Excitation Device. The following data
% was collected and assumes use of N2 (nitrogen) gas. The nozzle is
% designed to opperate at SL for ease of calculations and to ensure that no
% shocks form in the nozzle.

clear
clc

% Density of N2 gas at 5000 PSI
roeb = 24.7; %lbm/ft^3

% Universal Gas constant (R')
Rprime = 8314.14;

% Ratio of Specific heats (k)
k = 1.4;

% Molecular Weight (N2) g/mol
Mw = 28.01; % g/mol

% Advertised Stagnation Pressure (Pc) psi
Po = 500; % psi

% Sea Level Ambient Pressure (P3) Pa
P3 = 101325; % Pa
P2 = 59406;

% Chamber Stagnation Temperature (To) Assuming room temperature
To = 293.15; % k

% desired force in lbs
Fb = 32;

%% Conversions Needed to put all variables in metric Units

% Convert Density to Metric units
roe = roeb*16.0184*1000; % g/m3

% Conversion of P1
P1 = Po*6894.757;

% Specific Gas Constant
R = Rprime/Mw;

% Conversion factor for Force from Pounds-Newtons
ConvF = 4.448221; %N/lb
```

```
%% Calculations



% Convert desired thrust from BTI to Metric
F = Fb*ConvF;

% Pressure at throat
Pt = P1*(2/(k+1))^(k/(k-1));

% Temperature at the throat
Tt = 2*To/(k+1);

% Speed of Sound
at = sqrt(k*R*Tt);

% Exit Velocity v2
v2 = sqrt((2*k)/(k-1)*((Rprime*To)/(Mw))*(1-(P2/P1)^((k-1)/k)));

% Mass Flow Rate
syms At
eq2 = roe*at*At;

% Force (Thrust) Newtons
eq1 = At*P1*sqrt(((2*k^2)/(k-1))*(2/(k+1))^((k+1)/(k-1))*(1-(P2/P1)^((k-
1)/k)))-F;

Cf = sqrt(((2*k^2)/(k-1))*(2/(k+1))^((k+1)/(k-1))*(1-(P2/P1)^((k-1)/k)));

% Throat Area Required
At = F/(Cf*P1);

% Diameter
D = (sqrt((4*At)/pi)*1000)/25.4 % Diameter in in
```

7.1.3. Fluent Matlab

```
function [param]=fluent_parameters(parameters)

% Description: Reads parameter file.
%
% Inputs:   = parameters
%
% Outputs:  = param - structure containing the the parameters for the run
%                     case
%
% Revision Hisotry: 10/17/13 - Created
%                   10/24/13 - Added a data line to define a translation from
```

```
%                              origin
%                   10/28/13 - Added a data line for beta
%
% Lars Soltmann


%% Open file
cd 'Fluent Data'
rawdata=fopen(parameters);
cd ..

%% Start reading the data and assigning it
line=fgetl(rawdata);
param.alfa=sscanf(line,'%f');

line=fgetl(rawdata);
param.bta=sscanf(line,'%f');

line=fgetl(rawdata);
param.theta=sscanf(line,'%f');

line=fgetl(rawdata);
param.phi=sscanf(line,'%f');

line=fgetl(rawdata);
param.psi=sscanf(line,'%f');

line=fgetl(rawdata);
param.q=sscanf(line,'%f');

line=fgetl(rawdata);
param.p=sscanf(line,'%f');

line=fgetl(rawdata);
param.r=sscanf(line,'%f');

line=fgetl(rawdata);
param.elev=sscanf(line,'%f');

line=fgetl(rawdata);
param.ail=sscanf(line,'%f');

line=fgetl(rawdata);
param.rudd=sscanf(line,'%f');

line=fgetl(rawdata);
param.b=sscanf(line,'%f');

line=fgetl(rawdata);
param.s=sscanf(line,'%f');

line=fgetl(rawdata);
param.mac=sscanf(line,'%f');
```

```
line=fgetl(rawdata);
param.V=sscanf(line,'%f');

line=fgetl(rawdata);
param.mp=sscanf(line,'%f,%f,%f');

line=fgetl(rawdata);
param.xmac=sscanf(line,'%f');

line=fgetl(rawdata);
param.trans=sscanf(line,'%f,%f,%f');

line=fgetl(rawdata);
param.rho=sscanf(line,'%f');

line=fgetl(rawdata);
param.g=sscanf(line,'%f');

line=fgetl(rawdata);
param.w=sscanf(line,'%f');


function
[deriv]=fluent_deriv(bodyfilename1,parameters1,model1,bodyfilename2,parameter
s2,model2)

clc

% Description: Computes stability derivatives from two fluent cases.
%
% Inputs:    = bodyfilename1 - export data from Fluent
%            = bodyfilename2
%            = parameter1 - geometry and run case parameters
%            = parameter2
%            = model1 (1-half model, 2-full model (no symmetry plane))
%            = model2
%
%
% Outputs:   = deriv - structure containing calcuated stability derivatives
%
% Revision Hisotry: 10/17/13 - Created
%                   10/24/13 - Added coordinate transformation and
%                              translate information and updated displayed
%                              information
%                   11/4/13 - Added 'q' and 'r' derivatives
%                   11/5/13 - Added control derivatives and updated
%                             displayed information
%                   11/8/13 - Added 'p' derivatives
%
% Lars Soltmann

%% NOTE: Moment reference point should be the same for both cases or else cma
will not be useful
```

```
%% Input processing

if model1 ~=1 && model1 ~=2
    error('Model flag value not recognized!')
end

if model2 ~=1 && model2 ~=2
    error('Model flag value not recognized!')
end

if model1==1
    mtype1='Half Model';
else
    mtype1='Full Model';
end

if model2==1
    mtype2='Half Model';
else
    mtype2='Full Model';
end



%% Run both cases
[param1]=fluent_parameters(parameters1);
[param2]=fluent_parameters(parameters2);

%% Check to see if both cases have the same parameters
if param1.mp(1)~=param2.mp(1) || param1.mp(2)~=param2.mp(2) ||
param1.mp(3)~=param2.mp(3)
    error('Moment reference points do not match!')
elseif param1.xmac ~=param2.xmac
    error('x location of MACs does not match!')
elseif param1.mac ~=param2.mac
    error('MAC values do not match!')
end

[aero1,body1]=fluent_case_analysis(parameters1,bodyfilename1,model1);
[aero2,body2]=fluent_case_analysis(parameters2,bodyfilename2,model2);

%% Calculations
dalfa=(param1.alfa-param2.alfa)*pi/180;
dbeta=(param1.psi-param2.psi)*pi/180;
dp=(param1.p-param2.p)*param1.b/(2*param1.V);
dq=(param1.q-param2.q)*param1.mac/(2*param1.V);
dr=(param1.r-param2.r)*param1.b/(2*param1.V);
delev=(param1.elev-param2.elev);
dail=(param1.ail-param2.ail);
drudd=(param1.rudd-param2.rudd);

deriv.cLa=(aero1.CL-aero2.CL)/dalfa;
deriv.cma=(aero1.CM-aero2.CM)/dalfa;
```

```
deriv.cxa=(aero1.CX-aero2.CX)/dalfa;
deriv.cza=(aero1.CZ-aero2.CZ)/dalfa;

deriv.cnb=(aero1.Cn-aero2.Cn)/dbeta;
deriv.clb=(aero1.Cl-aero2.Cl)/dbeta;
deriv.cyb=(aero1.CY-aero2.CY)/dbeta;
EDH=deriv.clb/(-0.00021*180/pi); % Effective dihedral

deriv.cyp=(aero1.CY-aero2.CY)/dp;
deriv.clp=(aero1.Cl-aero2.Cl)/dp;
deriv.cnp=(aero1.Cn-aero2.Cn)/dp;

deriv.cmq=(aero1.CM-aero2.CM)/dq;
deriv.czq=(aero1.CZ-aero2.CZ)/dq;
deriv.cxq=(aero1.CX-aero2.CX)/dq;

deriv.cyr=(aero1.CY-aero2.CY)/dr;
deriv.clr=(aero1.Cl-aero2.Cl)/dr;
deriv.cnr=(aero1.Cn-aero2.Cn)/dr;

deriv.cmde=(aero1.CM-aero2.CM)/delev;
deriv.cLde=(aero1.CL-aero2.CL)/delev;

deriv.cnda=(aero1.Cn-aero2.Cn)/dail;
deriv.clda=(aero1.Cl-aero2.Cl)/dail;
deriv.cYda=(aero1.CY-aero2.CY)/dail;

deriv.cndr=(aero1.Cn-aero2.Cn)/drudd;
deriv.cldr=(aero1.Cl-aero2.Cl)/drudd;
deriv.cYdr=(aero1.CY-aero2.CY)/drudd;

mpprime1=coordxform(param1,[param1.mp(1),param1.mp(2),param1.mp(3)]');
mppt1=[mpprime1(1)+param1.trans(1),mpprime1(2)+param1.trans(2),mpprime1(3)+pa
ram1.trans(3)];
mpprime2=coordxform(param2,[param2.mp(1),param2.mp(2),param2.mp(3)]');
mppt2=[mpprime2(1)+param2.trans(1),mpprime2(2)+param2.trans(2),mpprime2(3)+pa
ram2.trans(3)];


kn=-deriv.cma/deriv.cLa;
h=(param1.xmac-param1.mp(1))/param1.mac;
hn=kn+h;
xnp=-(hn*param1.mac)+param1.xmac;


%% Data display
fprintf('      Case: %s | %s\n',bodyfilename1,bodyfilename2);
fprintf('Model Type: %s | %s\n',mtype1,mtype2);
disp(' ')
fprintf('***** Stability Derivatives *****\n')
disp(' ')
fprintf('     * Derivatives are /rad *\n')
disp(' ')
fprintf('        CLa: %g\n',deriv.cLa);
```

```
fprintf('         CMa: %g\n',deriv.cma);
fprintf('         CXa: %g\n',deriv.cxa);
fprintf('         CZa: %g\n',deriv.cza);
disp(' ')
fprintf('         Clb: %g\n',deriv.clb);
fprintf('         Cnb: %g\n',deriv.cnb);
fprintf('         CYb: %g\n',deriv.cyb);
fprintf('         EDH: %g deg\n',EDH);
disp(' ')
fprintf('         CYp: %g\n',deriv.cyp);
fprintf('         Clp: %g\n',deriv.clp);
fprintf('         Cnp: %g\n',deriv.cnp);
disp(' ')
fprintf('         CMq: %g\n',deriv.cmq);
fprintf('         CXq: %g\n',deriv.cxq);
fprintf('         CZq: %g\n',deriv.czq);
disp(' ')
fprintf('         CYr: %g\n',deriv.cyr);
fprintf('         Clr: %g\n',deriv.clr);
fprintf('         Cnr: %g\n',deriv.cnr);
disp(' ')
disp(' ')
fprintf('***** Control Derivatives *****\n')
disp(' ')
fprintf('      * Derivatives are /deg *\n')
disp(' ')
fprintf('        CMde: %g\n',deriv.cmde);
fprintf('        CLde: %g\n',deriv.cLde);
disp(' ')
fprintf('        Cnda: %g\n',deriv.cnda);
fprintf('        Clda: %g\n',deriv.clda);
fprintf('        CYda: %g\n',deriv.cYda);
disp(' ')
fprintf('        Cndr: %g\n',deriv.cndr);
fprintf('        Cldr: %g\n',deriv.cldr);
fprintf('        CYdr: %g\n',deriv.cYdr);
disp(' ')
fprintf('-----------------------------------\n')
disp(' ')
fprintf('          kn: %g\n',kn);
fprintf('          hn: %g\n',hn);
fprintf('           h: %g\n',h);
fprintf('         XNP: %g ft (body fixed)\n',xnp);
disp(' ')
fprintf('Case: %s\n',bodyfilename1);
fprintf('Moment reference (%g,%g,%g) ft (body
fixed)\n',param1.mp(1),param1.mp(2),param1.mp(3));
fprintf('     Body origin (%g,%g,%g) ft (earth
fixed)\n',param1.trans(1),param1.trans(2),param1.trans(3));
fprintf('Moment reference (%g,%g,%g) ft (earth
fixed)\n',mppt1(1),mppt1(2),mppt1(3));
disp(' ')
fprintf('Case: %s\n',bodyfilename2);
fprintf('Moment reference (%g,%g,%g) ft (body
fixed)\n',param2.mp(1),param2.mp(2),param2.mp(3));
fprintf('     Body origin (%g,%g,%g) ft (earth
fixed)\n',param2.trans(1),param2.trans(2),param2.trans(3));
```

```
fprintf('Moment reference (%g,%g,%g) ft (earth
fixed)\n',mppt2(1),mppt2(2),mppt2(3));
disp(' ')
disp(' ')


function [aero,body]=fluent_case_analysis(parameters,bodyfilename,model)

% Description: Analsys of Fluent case solution data.
%
% Inputs:    = parameters - geometry and run case parameters
%            = bodyfilename - export data from Fluent
%            = model (1-half model, 2-full model (no symmetry plane))
%
%
% Outputs:   = aero - Calculated aerodynamic data
%            = body - Body data
%
% Revision Hisotry: 09/25/13 - Created
%                   10/14/13 - Option for full or half model analysis
%                            - Calculations for Cn,Cl,CX,CY,CZ,CW
%                   10/24/13 - Coordinate transformation for moment point
%                              from body to earth frame
%                            - Translate moment reference point based on
%                              location of body in earth frame
%                   12/02/13 - Added option to plot aircraft with reference
%                              points and corrected reference point location
%                              error
%
% Lars Soltmann

%% Plotting of Aircraft geo with reference points (1=plot,0=don't plot)
plotflag=1;

%% Input checking
if nargin < 2
    error('Not enough inputs!')
end

if model ~=1 && model ~=2
    error('model flag value not recognized!')
end

if model==1
    mtype='Half Model';
else
    mtype='Full Model';
end


%% Initializations
pmom=0;
rmom=0;
ymom=0;
```

```
%% Process body data
[body]=fluent_body(bodyfilename);

%% Process case parameters
[param]=fluent_parameters(parameters);

%% Calculate body parameters
%% Half model calculations
if model==1
fx=2*sum(body.fx);
fz=2*sum(body.fz);
lift=-fz;
drag=-fx;
[Fprime]=coordxform(param,[fx,0,fz]');
CW=param.w/(0.5*param.rho*param.V^2*param.s);
CL=lift/(0.5*param.rho*param.V^2*param.s);
CD=drag/(0.5*param.rho*param.V^2*param.s);
CX=Fprime(1)/(0.5*param.rho*param.V^2*param.s);  %ForceX,Y,Z are earth fixed
not body fixed so transformation needed for body Cx,y,z
CY=0;
CZ=Fprime(3)/(0.5*param.rho*param.V^2*param.s);

mpprime=coordxform(param,[param.mp(1),param.mp(2),param.mp(3)]');  %Transform
from body to earth coordinates
mppt=[mpprime(1)+param.trans(1),mpprime(2)+param.trans(2),-
mpprime(3)+param.trans(3)];  %Then translate the earth coordinates

for i=1:size(body.x,1)
    pmom=pmom -body.fx(i)*(body.z(i)-mppt(3))-...
                 body.fz(i)*(body.x(i)-mppt(1));
end
CM=(2*pmom)/(0.5*param.rho*param.V^2*param.s*param.mac);
CY=0;
Cl=0;
Cn=0;

%% Full model calculations
else
fx=sum(body.fx);
fy=sum(body.fy);
fz=sum(body.fz);
lift=-fz;
drag=-fx;
CW=param.w/(0.5*param.rho*param.V^2*param.s);
CL=lift/(0.5*param.rho*param.V^2*param.s);
CD=drag/(0.5*param.rho*param.V^2*param.s);
Fprime=coordxform(param,[fx,fy,fz]');
CX=Fprime(1)/(0.5*param.rho*param.V^2*param.s);
CY=Fprime(2)/(0.5*param.rho*param.V^2*param.s);
CZ=Fprime(3)/(0.5*param.rho*param.V^2*param.s);

mpprime=coordxform(param,[param.mp(1),param.mp(2),param.mp(3)]');
mppt=[mpprime(1)+param.trans(1),mpprime(2)+param.trans(2),-
mpprime(3)+param.trans(3)];
for i=1:size(body.x,1)
```

```
    pmom=pmom -body.fx(i)*(body.z(i)-mppt(3))-...
                 body.fz(i)*(body.x(i)-mppt(1));
end
CM=pmom/(0.5*param.rho*param.V^2*param.s*param.mac);
for i=1:size(body.x,1)
    rmom=rmom -body.fy(i)*(body.z(i)-mppt(3))+...
                 body.fz(i)*(body.y(i)-mppt(2));
end
Cl=rmom/(0.5*param.rho*param.V^2*param.s*param.b);
for i=1:size(body.x,1)
    ymom=ymom +body.fx(i)*(body.y(i)-mppt(2))+...
                 body.fy(i)*(body.x(i)-mppt(1));
end
Cn=ymom/(0.5*param.rho*param.V^2*param.s*param.b);
end

%% Data display
fprintf('      Case: %s\n',bodyfilename);
fprintf('Model Type: %s\n',mtype);
disp(' ')
fprintf('      Lift: %g lbs\n',lift);
fprintf('      Drag: %g lbs\n',2*drag);
fprintf('       L/D: %g\n',CL/CD);
fprintf('        CL: %g\n',CL);
fprintf('        CD: %g\n',CD);
fprintf('        CM: %g\n',CM);
fprintf('        Cl: %g\n',Cl);
fprintf('        Cn: %g\n',Cn);
fprintf('        CX: %g\n',CX);
fprintf('        CY: %g\n',CY);
fprintf('        CZ: %g\n',CZ);
fprintf('        CW: %g\n',CW);
disp(' ')
fprintf('Moment reference (%g,%g,%g) ft (body
fixed)\n',param.mp(1),param.mp(2),param.mp(3));
fprintf('     Body origin (%g,%g,%g) ft (earth
fixed)\n',param.trans(1),param.trans(2),param.trans(3));
fprintf('Moment reference (%g,%g,%g) ft (earth
fixed)\n',mppt(1),mppt(2),mppt(3));
disp(' ')
disp(' ')

%% Export data
aero.CL=CL;
aero.CD=CD;
aero.CM=CM;
aero.Cl=Cl;
aero.Cn=Cn;
aero.CX=CX;
aero.CY=CY;
aero.CZ=CZ;

if plotflag==1
subplot(1,2,1),plot(body.x,body.z,'.k',mppt(1),mppt(3),'or',param.trans(1),pa
ram.trans(3),'og')
axis equal
```

```
set(gca,'YDir','reverse');
xlabel('X')
ylabel('Z')
subplot(1,2,2),plot(body.x,body.y,'.k',mppt(1),mppt(2),'or',param.trans(1),pa
ram.trans(2),'og')
axis equal
set(gca,'YDir','reverse');
xlabel('X')
ylabel('Y')
legend('Aircraft','Moment Reference','Origin')
end


function [body]=fluent_body(bodyfilename)

% Description: Reads output file from Fluent to extract body data.
%
% Input Requirements: Fluent should be set to export the data given in
%                     output section below. (x,y,z exported automatically)
%
% Inputs:   = bodyfilename
%
% Outputs:  = x
%           = y
%           = z
%           = force
%           = force x
%           = force y
%           = force z
%           = pressure
%
% Revision Hisotry: 09/25/13 - Created
%                   11/13/13 - Added check to see if .csv file contains
%                              skin friction data and process accordingly.
%
% Lars Soltmann

wsflag=0;

%% Open file
cd 'Fluent Data'
rawdata=fopen(bodyfilename);
cd ..

%% Ignore the header.
for i=1:6
    line=fgetl(rawdata);
end

%% Put all the data into a matrix called dmat.
i=0;
while true
    i=i+1;
    line=fgetl(rawdata);
    if line==-1
```

```
        break
    end
    debugline=i;

    if wsflag==0;
        flagtest=sscanf(line,'%f,%f,%f,%f,%f,%f,%f,%f,%f,%f,%f,%f');
        if numel(flagtest)==12
            wsflag=1;
        end
    end

    if isempty(line)==1
        for j=1:6
            line=fgetl(rawdata);
        end
    end

    if wsflag==1
        dmat(i,:)=sscanf(line,'%f,%f,%f,%f,%f,%f,%f,%f,%f,%f,%f,%f');
    else
        dmat(i,:)=sscanf(line,'%f,%f,%f,%f,%f,%f,%f,%f');
    end
end

%% Generate output matrix
body.x=dmat(:,1);
body.y=dmat(:,2);
body.z=dmat(:,3);
body.f=dmat(:,4);
body.fx=dmat(:,5);
body.fy=dmat(:,6);
body.fz=dmat(:,7);
body.p=dmat(:,8);
if wsflag==1
body.ws=dmat(:,9);
body.wsx=dmat(:,10);
body.wsy=dmat(:,11);
body.wsz=dmat(:,12);
end



function [vout]=coordxform(param,vin)

% Description: Performs a coordinate transformation on 'vin.'
%
% Inputs:    = vin - input vector
%            = param - case parameters (only need theta, phi, psi)
%
% Outputs:   = vout
%
% Revision Hisotry: 10/14/13 - Created
%
% Lars Soltmann
```

```
theta=param.theta;
phi=param.phi;
psi=param.psi;

L=[cosd(theta)*cosd(psi),cosd(theta)*sind(psi),-sind(theta);...
    sind(phi)*sind(theta)*cosd(psi)-
cosd(phi)*sind(psi),sind(phi)*sind(theta)*sind(psi)+cosd(phi)*cosd(psi),sind(
phi)*cosd(theta);...

cosd(phi)*sind(theta)*cosd(psi)+sind(phi)*sind(psi),cosd(phi)*sind(theta)*sin
d(psi)-sind(phi)*cosd(psi),cosd(phi)*cosd(theta);];

vout=L*vin;
```

7.2. Drawings

Figure 52: Ball Valve Drawing

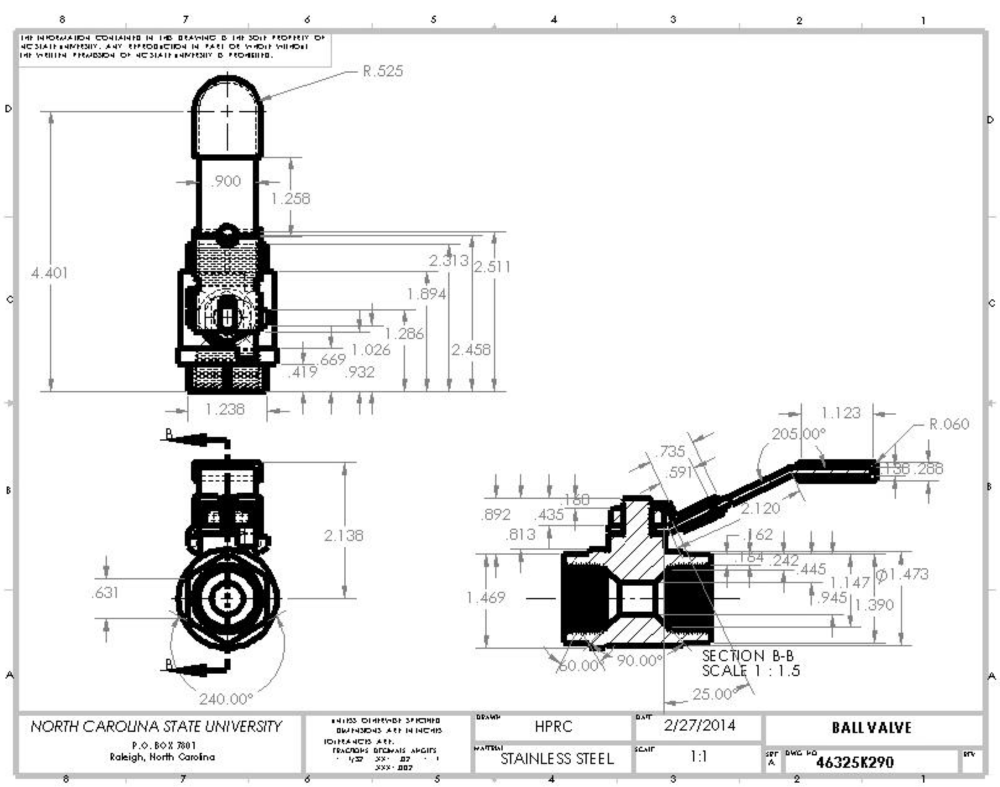

Figure 53: Boat Tail Drawing

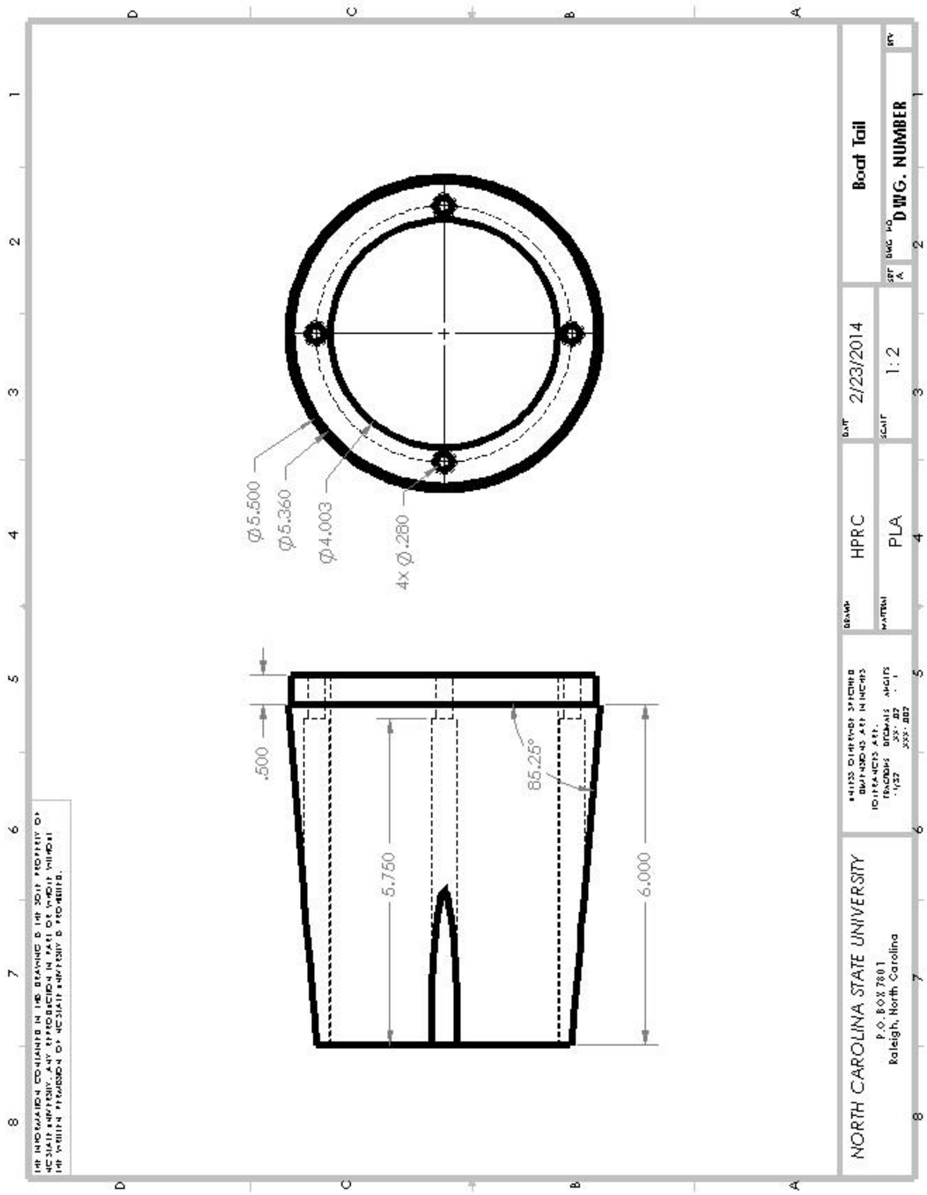

Figure 54: Lower Mid-Section Assembly Drawing

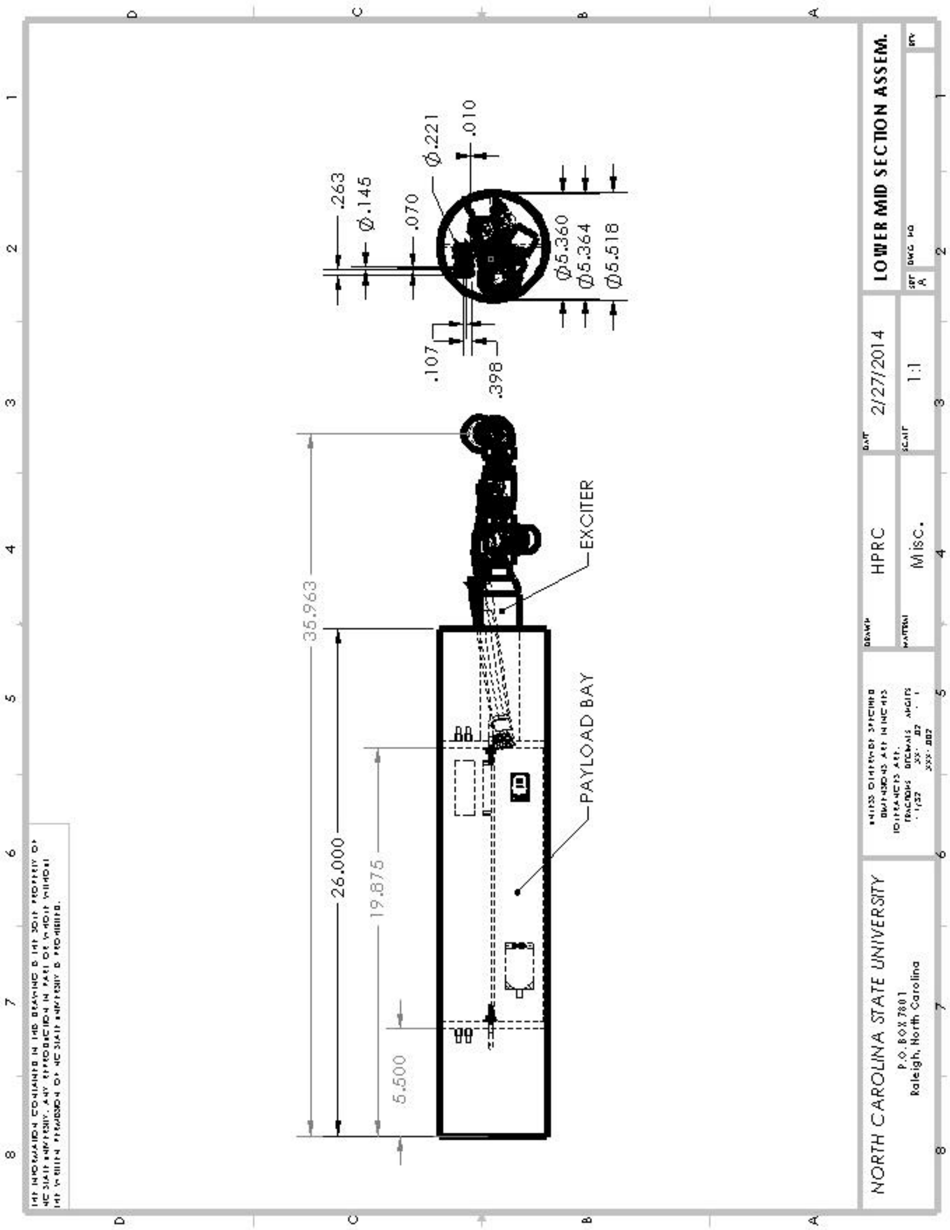

Figure 55: C-D Nozzle Drawing

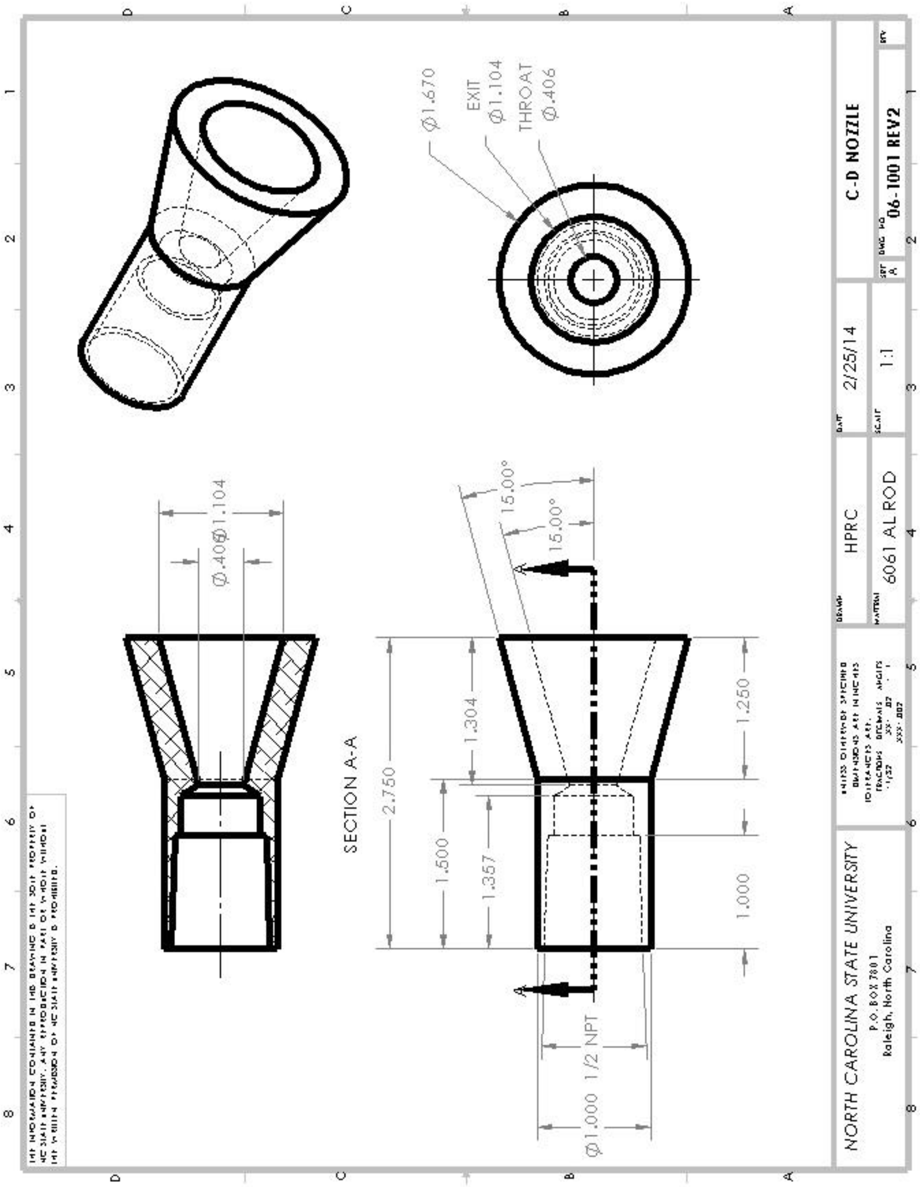

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Figure 56: Centering Ring Drawing

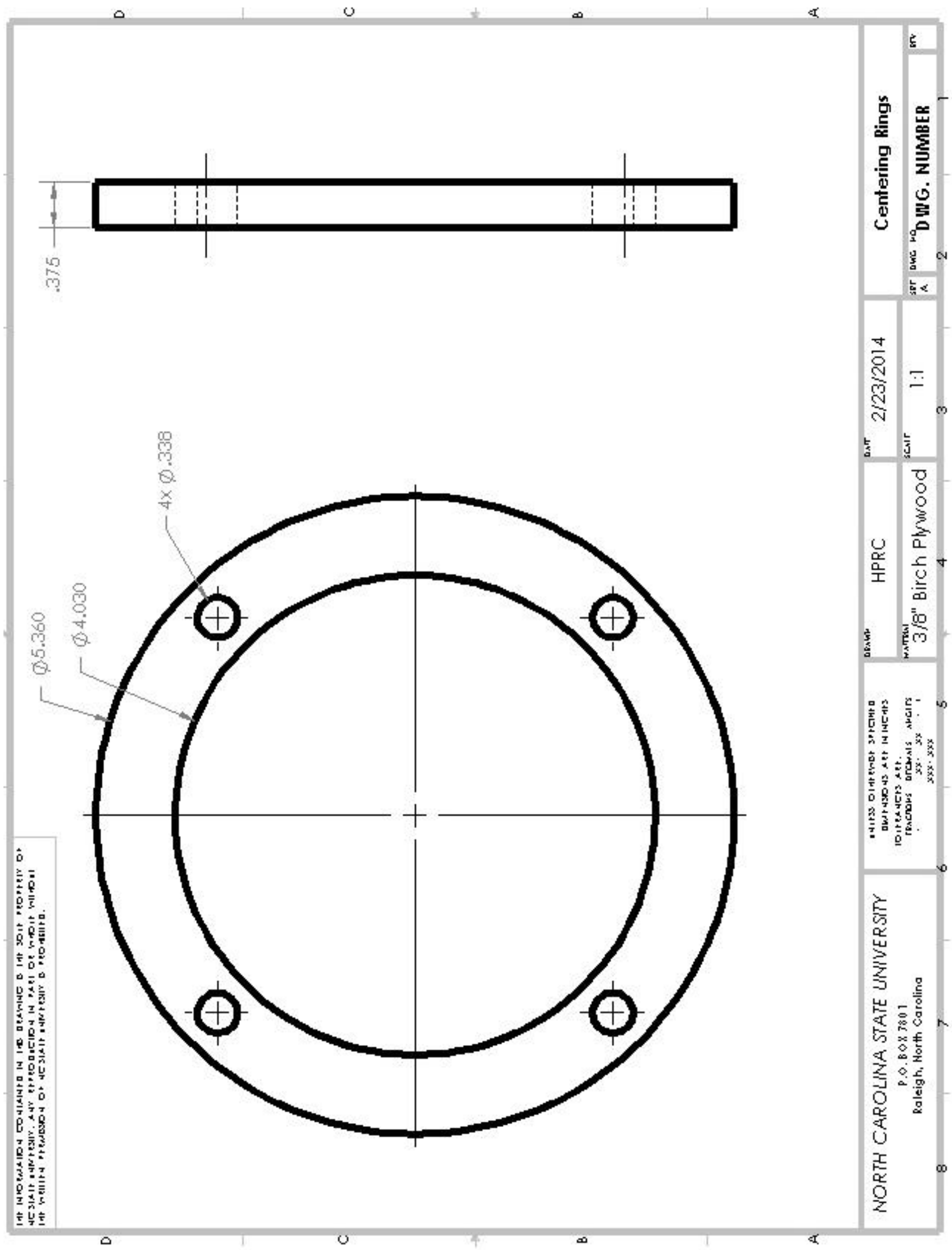

Figure 57: Fin Planform

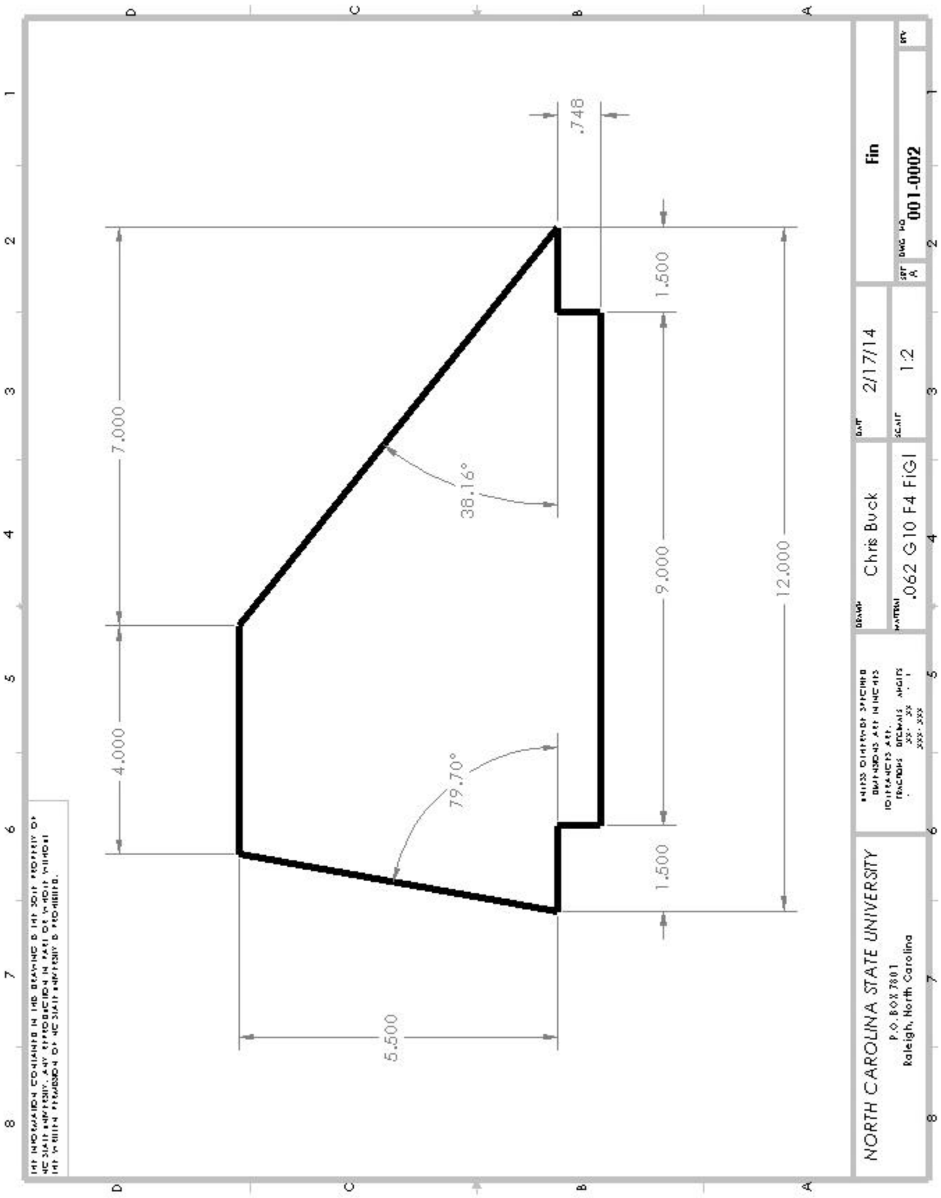

Figure 58: Fin Layup Drawing

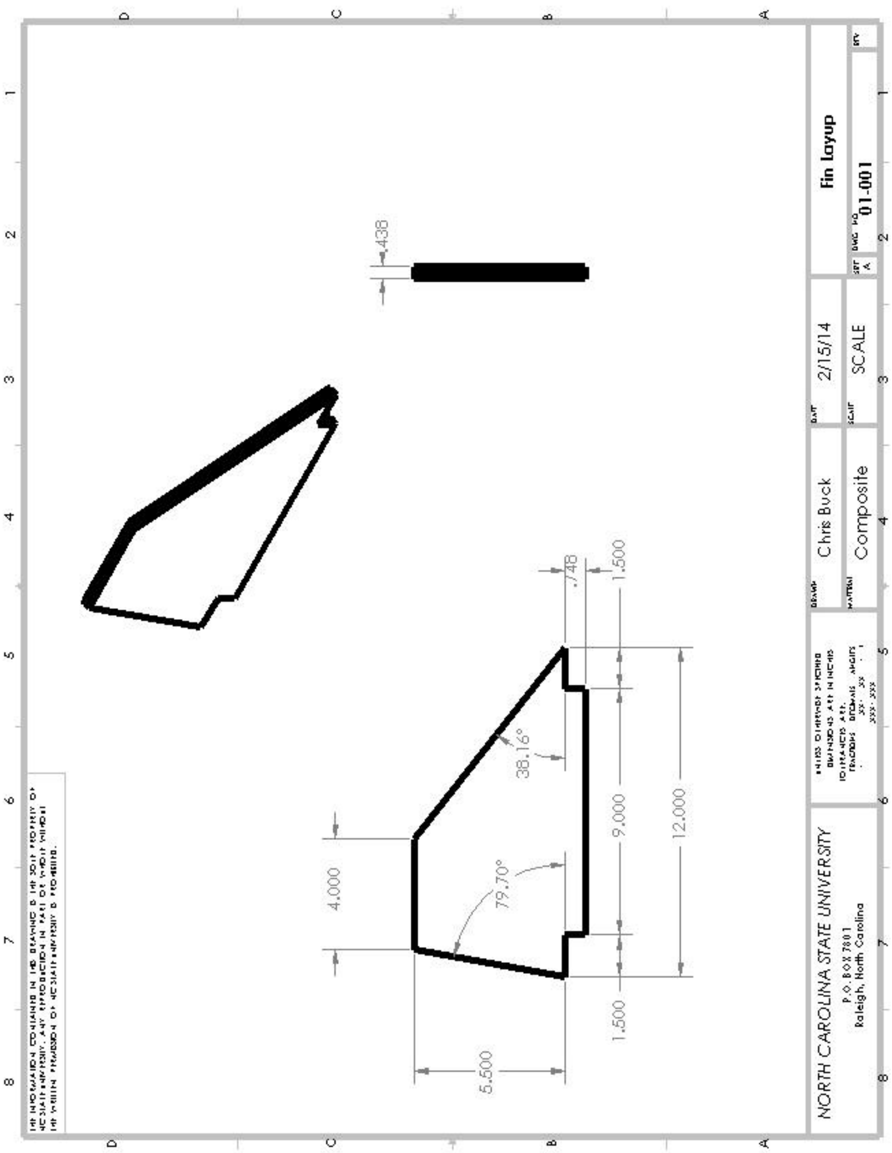

Figure 59: Full Fin Section Drawing

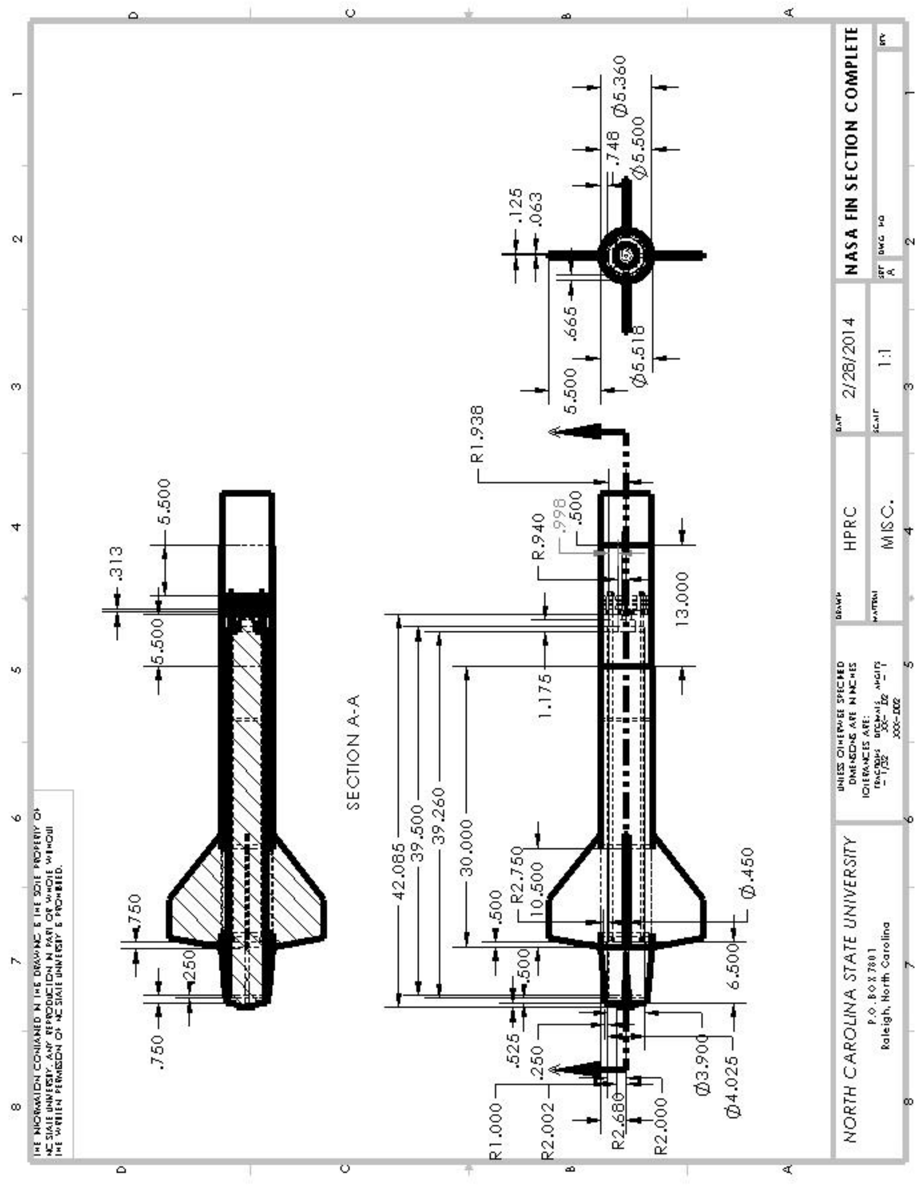

Figure 60: Fin Section with Load Cell Drawing

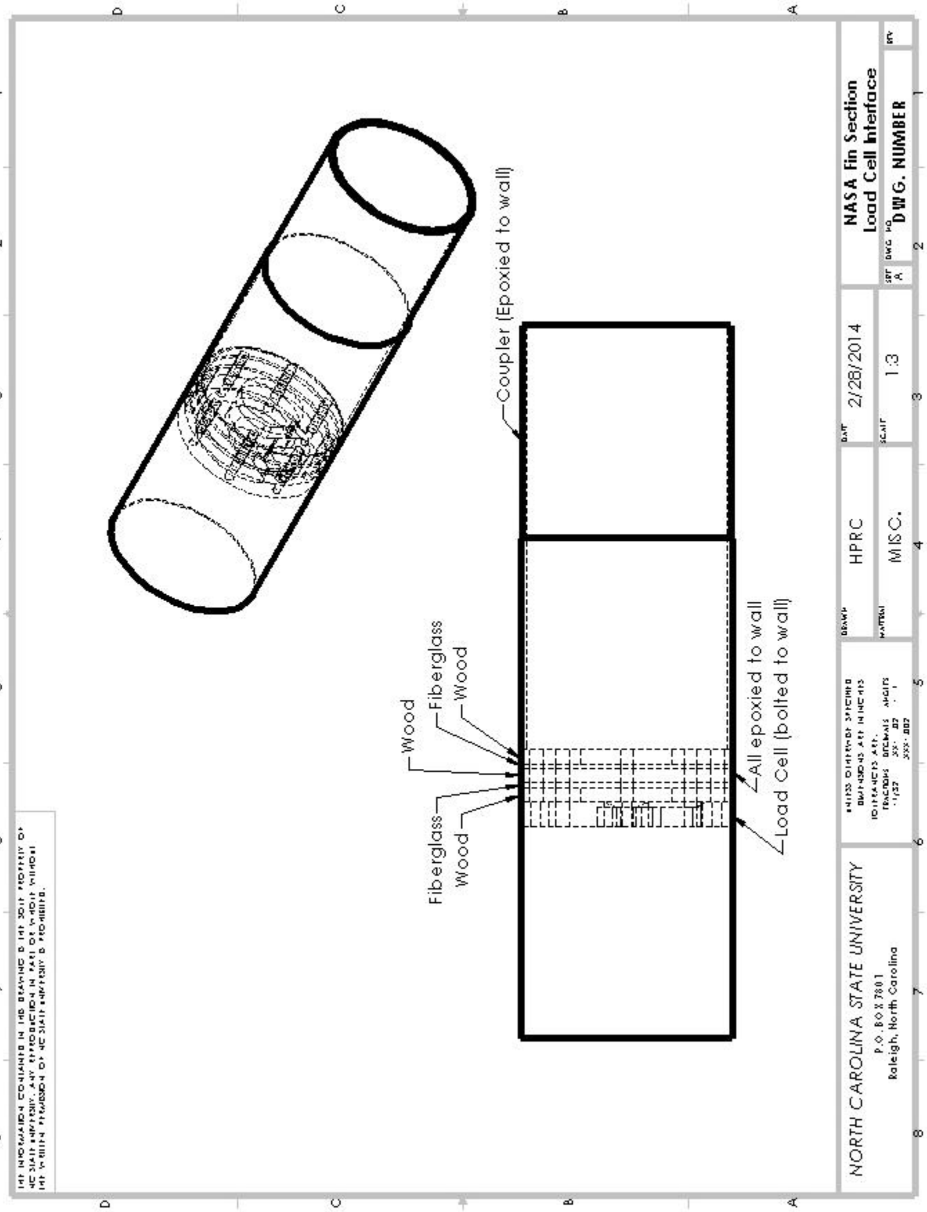

Figure 61: Load Cell Bulkhead

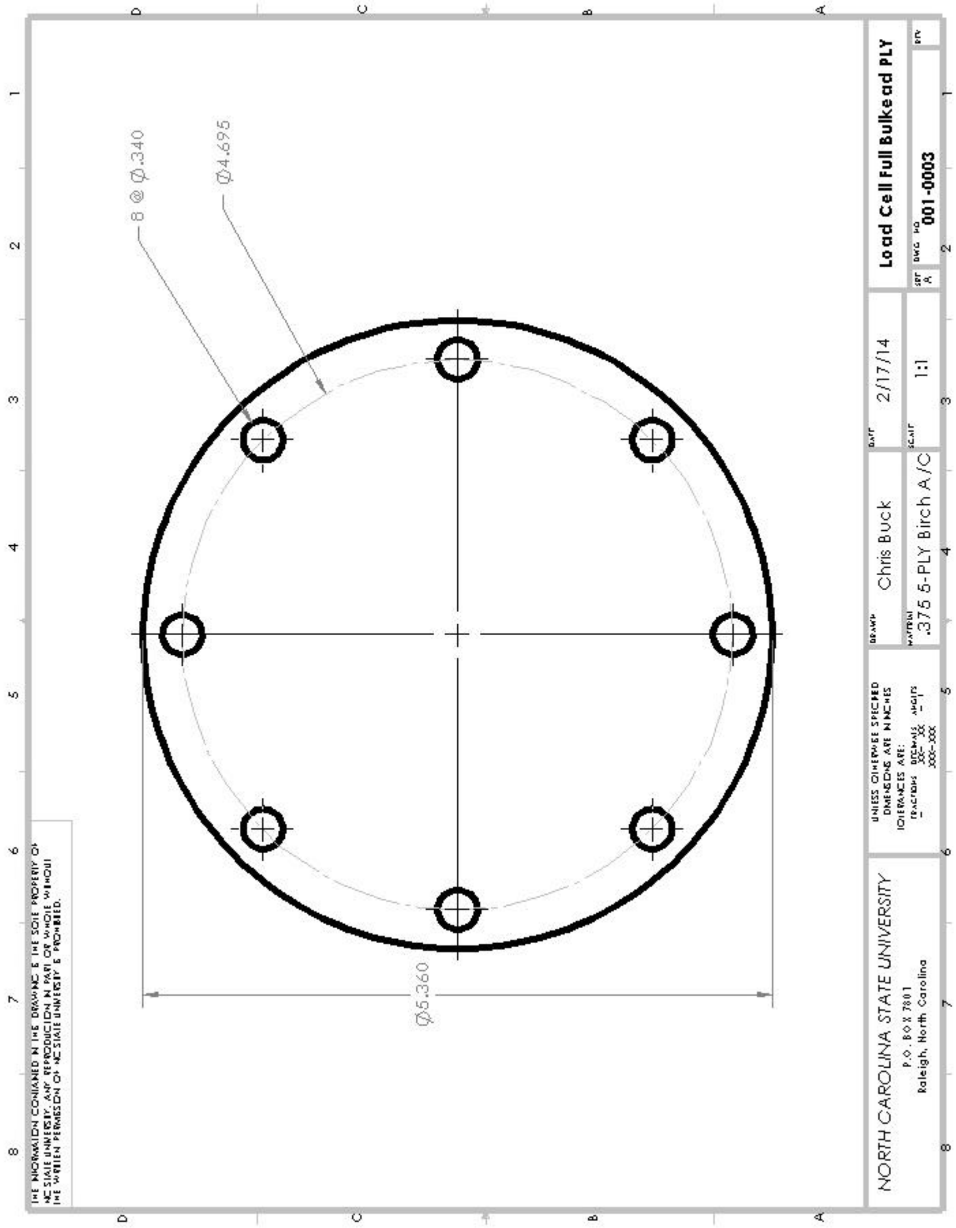

Figure 62: Nose Cone Assembly Drawing

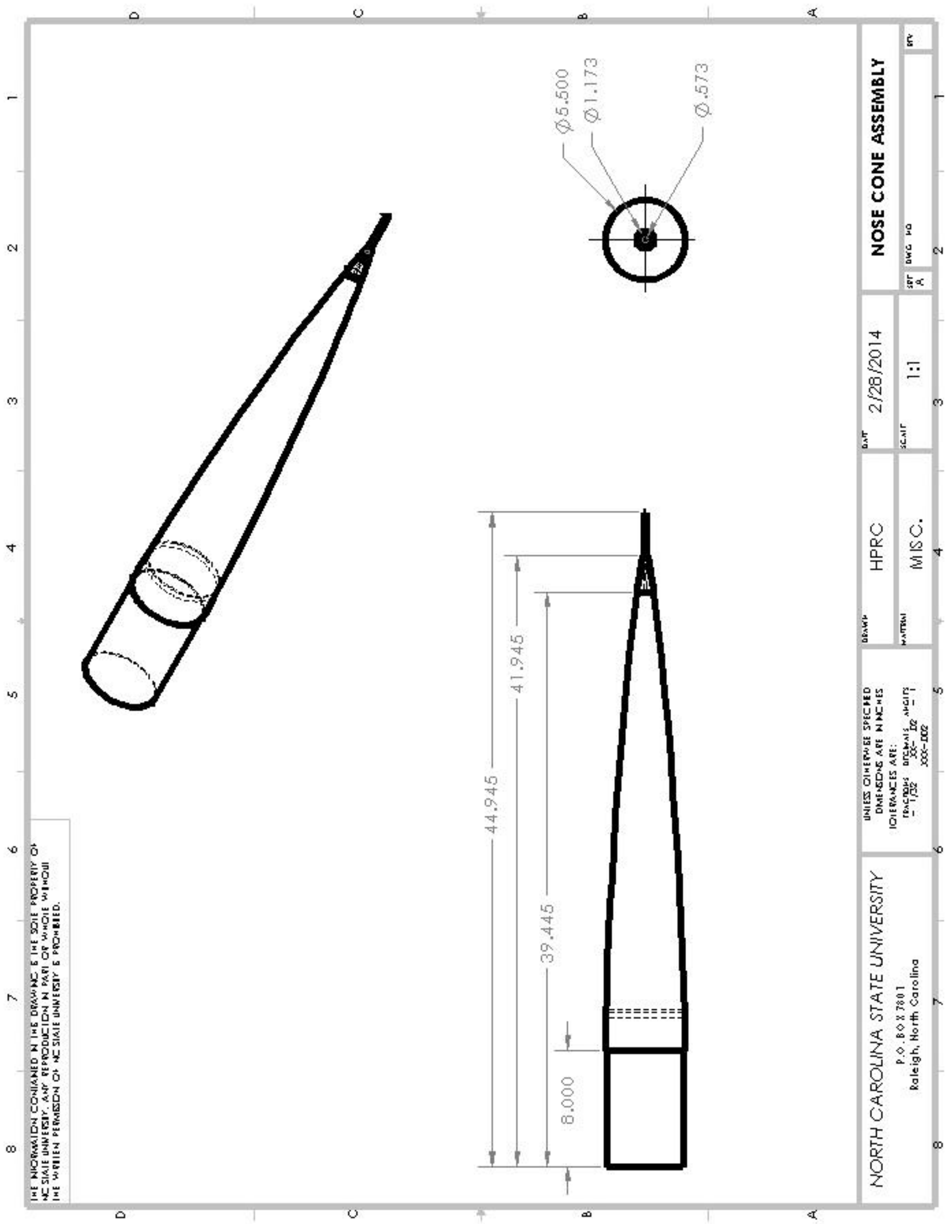

Figure 63: Upper Mid-Section Assembly Drawing