NC STATE UNIVERSITY

College of Engineering

Department of Mechanical and Aerospace Engineering

Preliminary Design Review Document

Tacho Lycos

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1. Summary of PDR 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. Mentor

Alan Whitmore

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.

1.2. Launch Vehicle Summary

1.2.1. Vehicle Specifications

1.2.1.1. Size and Mass

PDR	
Length	128 inches
Diameter	5.5 inches
Loaded Weight	69.0 lbs
Center of Pressure	95.38 inches from nose
Center of Gravity	87.03 inches from nose
Stability	1.52 cal
Apogee	13900 feet
Max Velocity	1385 ft/s
Max Acceleration	678 ft/s^2
Recovery	Three Main Parachutes
Motor	Cesaroni N5600WT-P

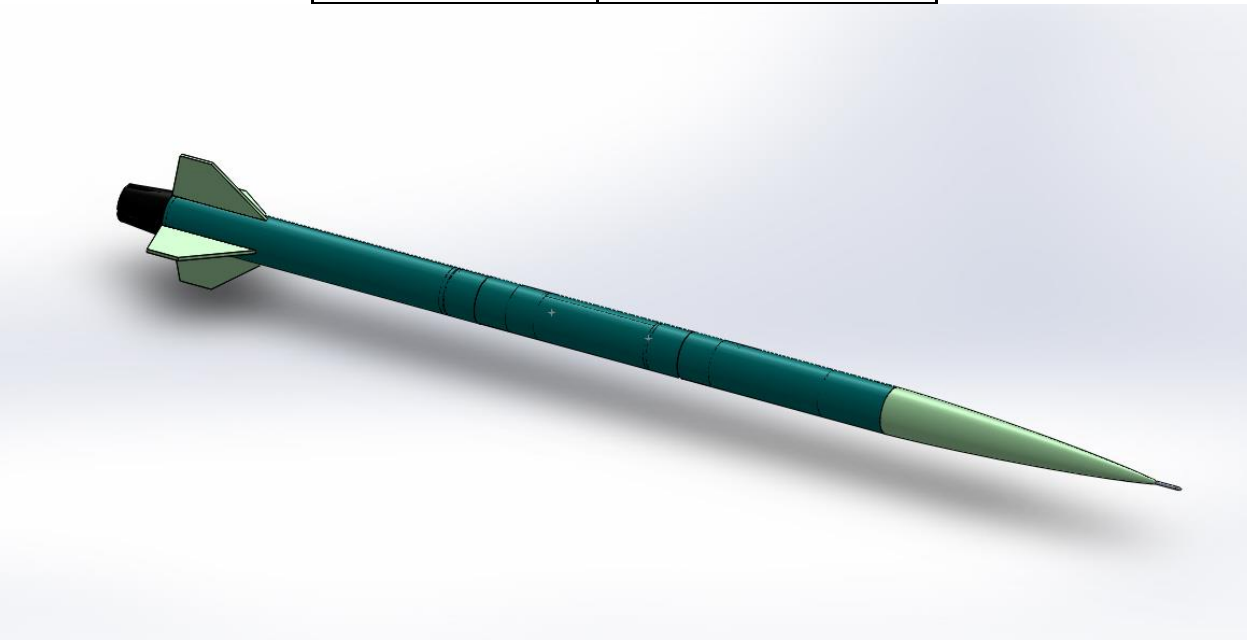

Figure 1: Rocket Assembly

1.2.2. Milestone Review Flysheet

Milestone Review Flysheet

Please see Milestone Review Flysheet Instructions.

Institution	North Carolina State University	Milestone	PDR

First Stage (Both Stages Together or Single Stage)		Second Stage (If Applicable)	
Vehicle Properties		**Vehicle Properties**	
Total Length (in)	128	Total Length (in)	
Diameter (in)	5.5	Diameter (in)	
Gross Lift Off Weight (lb)	69	Gross Weight (lb)	
Airframe Material	Blue Tube w/ fiberglass wrap	Airframe Material	
Fin Material	Plywood/fiberglass	Fin Material	
Motor Properties		**Motor Properties**	
Motor Manufacturer(s)	Cesaroni Technology Inc.	Motor Manufacturer(s)	
Motor Designation(s)	M5600WT-P	Motor Designation(s)	
Max/Average Thrust (lb)	1517/1264 lbf.	Max/Average Thrust (lb)	
Total Impulse (lbf-sec)	3065	Total Impulse (lbf-sec)	
Stability Analysis		Ignition Altitude (ft)	
Center of Pressure (in from nose)	95.38	Ignition Timing (From 1st Stage Burnout)	
Center of Gravity (in from nose)	87.03	Igniter Location	
Static Stability Margin	1.52	**Stability Analysis**	
Thrust-to-Weight Ratio	23:1	Center of Pressure (in from nose)	
Rail Size (in)	TBD	Center of Gravity (in from nose)	
Rail Length (in)	96	Static Stability Margin	
Rail Exit Velocity (ft/s)	102	Thrust-to-Weight Ratio	
Ascent Analysis		**Ascent Analysis**	
Maximum Velocity (ft/s)	1385	Maximum Velocity (ft/s)	
Maximum Mach Number	1.25	Maximum Mach Number	
Maximum Acceleration (ft/s^2)	678	Maximum Acceleration (ft/s)	
Target Apogee (1st Stage if Multiple Stages)	13900 ft	Target Apogee (ft)	
Recovery System Properties		**Recovery System Properties**	
Drogue Parachute		**Drogue Parachute**	
Configuration	N/A	Configuration	
Size	N/A	Size	
Deployment Velocity (ft/s)	N/A	Deployment Velocity (ft/s)	
Terminal Velocity (ft/s)	N/A	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	N/A	Recovery Harness Type	
Recovery Harness Length (ft)	N/A	Recovery Harness Length (ft)	
Harness/Airframe Interface	N/A	Harness/Airframe Interface	

Main Parachute				
Configuration		Round Hemispherical		
Size (in)		160	94	28
Deployment Velocity (ft/s)		TBD		
Terminal Velocity (ft/s)		12.1	16.1	28.6
Fabric Type		Rip-stop Nylon		
Shroud Line Material		Nylon		
Shroud Line Length (in)		TBD		
Thread Type		TBD		
Seam Type		TBD		
Recovery Harness Type		1/2 inch tubular Kevlar		
Recovery Harness Length (ft)		TBD		
Harness/Airframe Interface		3/8" U-bolt/Quicklinks		
Kinetic Energy of Each Section (ft-lbs)	Section 1	Section 2	Section 3	Section 4
	Fin Section	Body Tube Section	Nosecone Section	
	72.1	72.1	66.1	

Main 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				
Kinetic Energy of Each Section (ft-lbs)	Section 1	Section 2	Section 3	Section 4

Milestone Review Flysheet

Institution	North Carolina State University	Milestone	PDR

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 - 900MHz - 9v	Locators/Frequencies (Model-Frequency-Power)	
	XBEE-Pro 900 - 900MHz - 50mW		
Black Powder Charge Size Drogue Parachute (grams)	N/A	Black Powder Charge Size Drogue Parachute (grams)	
	N/A		
Black Powder Charge Size Main Parachute (grams)	TBD	Black Powder Charge Size Main Parachute (grams)	

Payloads		
Mandatory Payload	3.1	**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.
Optional Payload 1		**Overview**
Optional Payload 2		**Overview**

Test Plans, Status, and Results	
Ejection Charge Tests	Ejection charge tests are planned to be conducted for each of the three separable airframe sections.
Sub-scale Test Flights	One 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.
Full-scale Test Flights	Full-scale test flights are planned to be conducted in late February at Bayboro, NC.

1.3. Payload Summary

1.3.1. 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.

1.3.2. 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, and others. The data gathered is to be transmitted in real time to a ground station for some real time processing and recording for later analysis. 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 Proposal

2.1. Vehicle Criteria

There have been a few changes to the design since the proposal was written including the recovery system and the payload.

The recovery system will now have three main parachutes for each independent section in order to maintain a kinetic energy under 75 ft-lbf for each section. This was changed from the proposed idea of having the whole rocket descending under a drogue and a main parachute.

The proposal addendum had removed the thruster experiment that was initially suggested in the proposal. The addendum then proposed a paint coating on the rocket in order to meet the requirement "3.2.2.4 Environmental effects of supersonic flight on vehicle paint/coatings." The PDR now has the thruster as an experiment to meet payload requirement 3.2.2.2 and the paint coating has been removed.

3. Vehicle Criteria

3.1. Selection, Design and Verification of Launch 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 sections 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. Review of Design

3.1.4.1. 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 2 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.

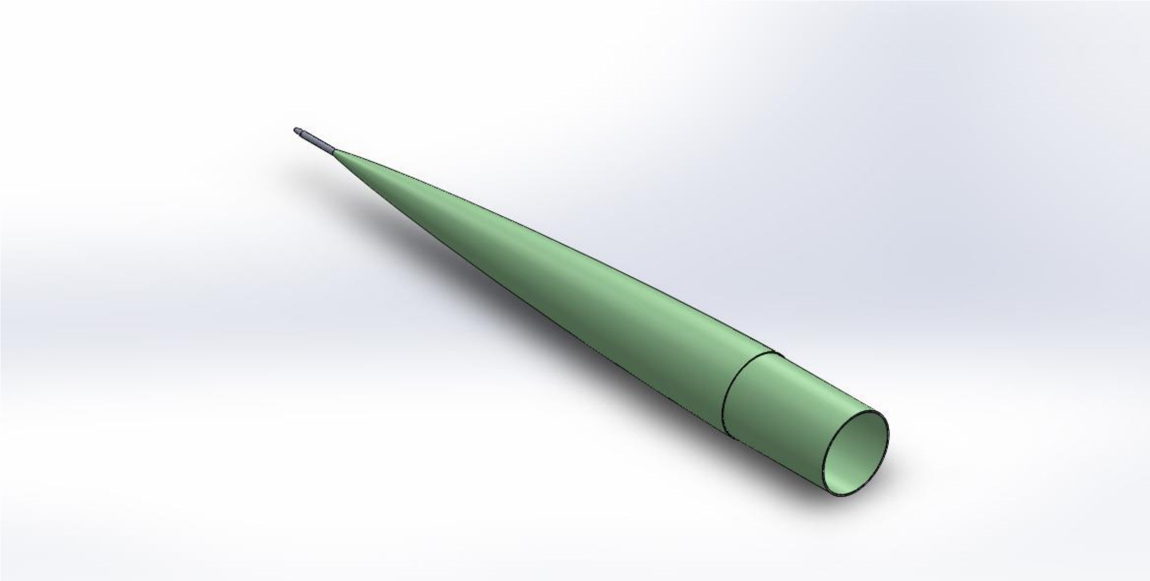

Figure 2: Full Scale Nose Cone with Pitot Tube

3.1.4.2. 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 flox for additional strength.

The motor itself will interface to the vehicle via a minimum diameter motor retainer affixed to a load cell securely mounted to a bulkhead 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 two locations. The farthest aft split, located forward of the engine bulkhead, 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 46 inches. This section will include the fin configuration as well as the load cell, rocket motor, and house one of the main parachutes. The second 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 26 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.

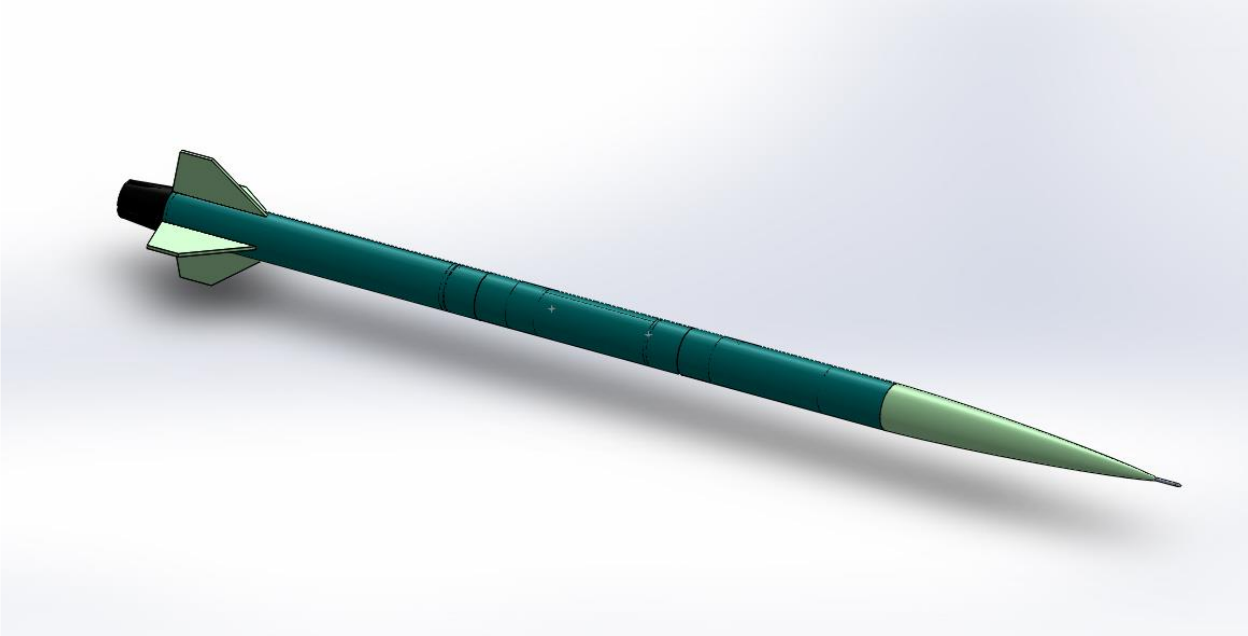

Figure 3: Rocket Assembly

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.

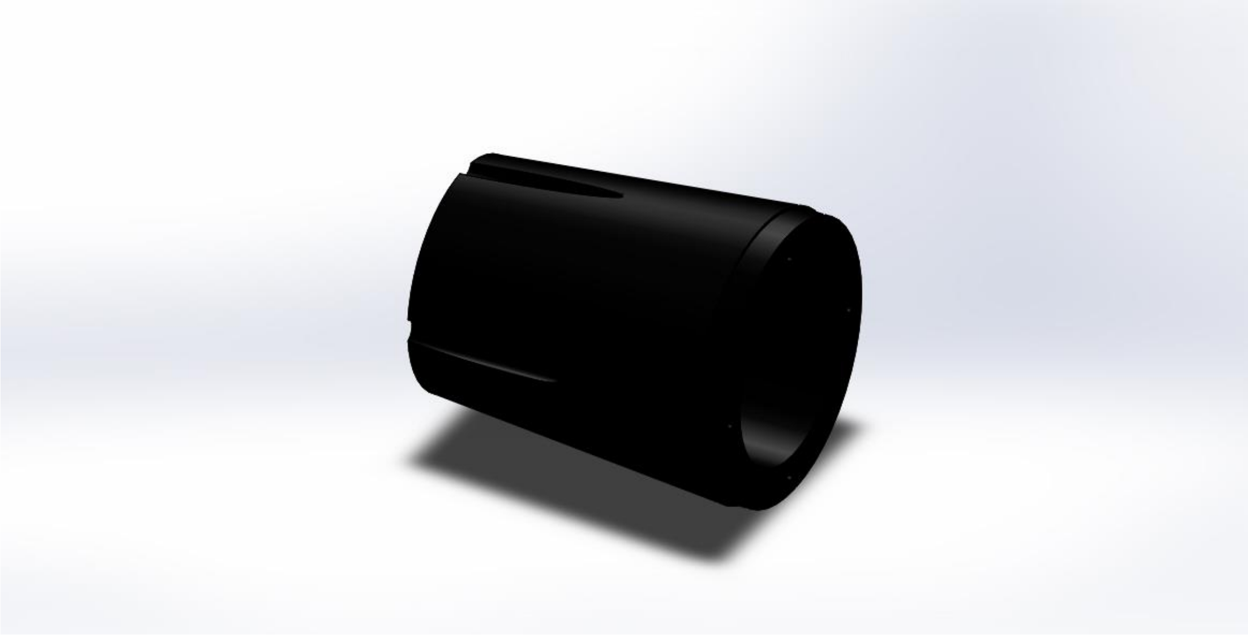

Figure 4: Boat Tail

3.1.4.3. 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.

3.1.4.4. Stability

Stability analysis of the full-scale rocket utilized Barrowman's method of normal force coefficients to calculate the aerodynamic center. For the purposes of stability analysis, the datum was defined such that station 0 was located at the tip of the nosecone. The aerodynamic center was calculated to be 95.38 in aft of the datum. The OpenRocket model of the vehicle calculated the CG at 87.03 in aft of the datum resulting in a static margin of 1.52 calibre.

Using these results, the free response of the vehicle after a 2° disturbance was modeled. The natural frequency was 37.80 rad/s (6.02 Hz), the damping ratio 0.20, and the time to half 0.09 s. Preliminary analysis has indicated that approximately 20 lb of thrust 35 in from the CG will generate sufficient torque to produce the desired deflection.

Future work will seek to improve the precision of the predicted dynamic response. Time dependent velocity and density will be incorporated. The current dynamic model, which only includes the free response of the vehicle, will be expanded to include both the disturbance and the free response. Supersonic effects on stability will be investigated and incorporated into the stability analysis. Of particular interest is the timing of the thruster firing (disturbance) in relation to the transition from supersonic to subsonic flight. In addition to the MATLAB codes currently in use, a SIMULINK model of the vehicle dynamic system is under development and will be employed for future stability analysis.

3.1.4.5. 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 5.

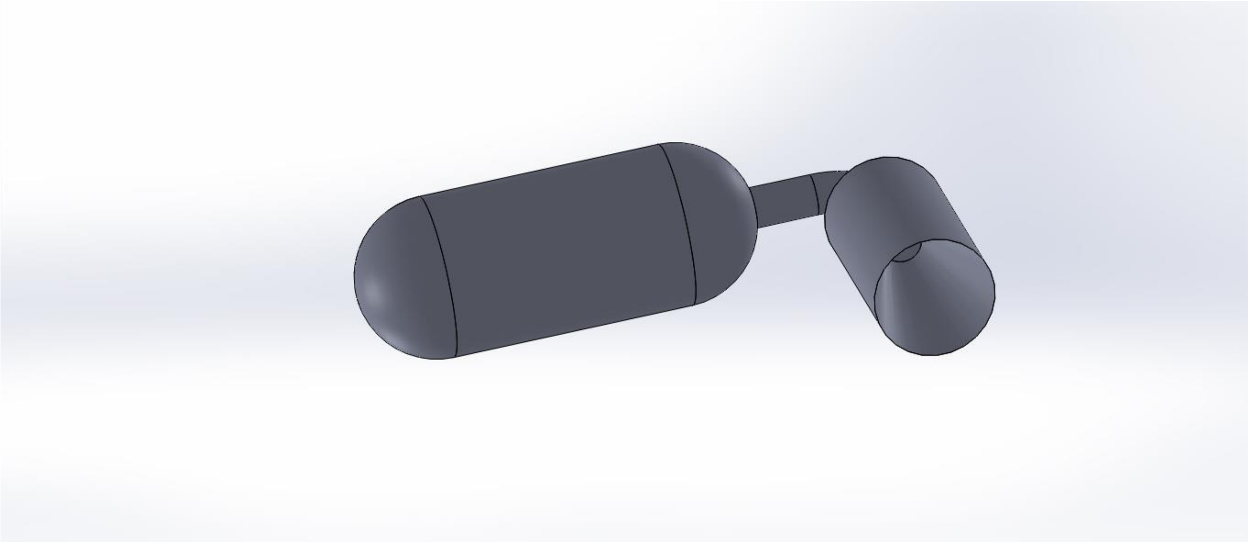

Figure 5: Exciter General Layout

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.

3.1.4.6. 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 6 is the product of careful consideration of these parameters and their effects on overall performance.

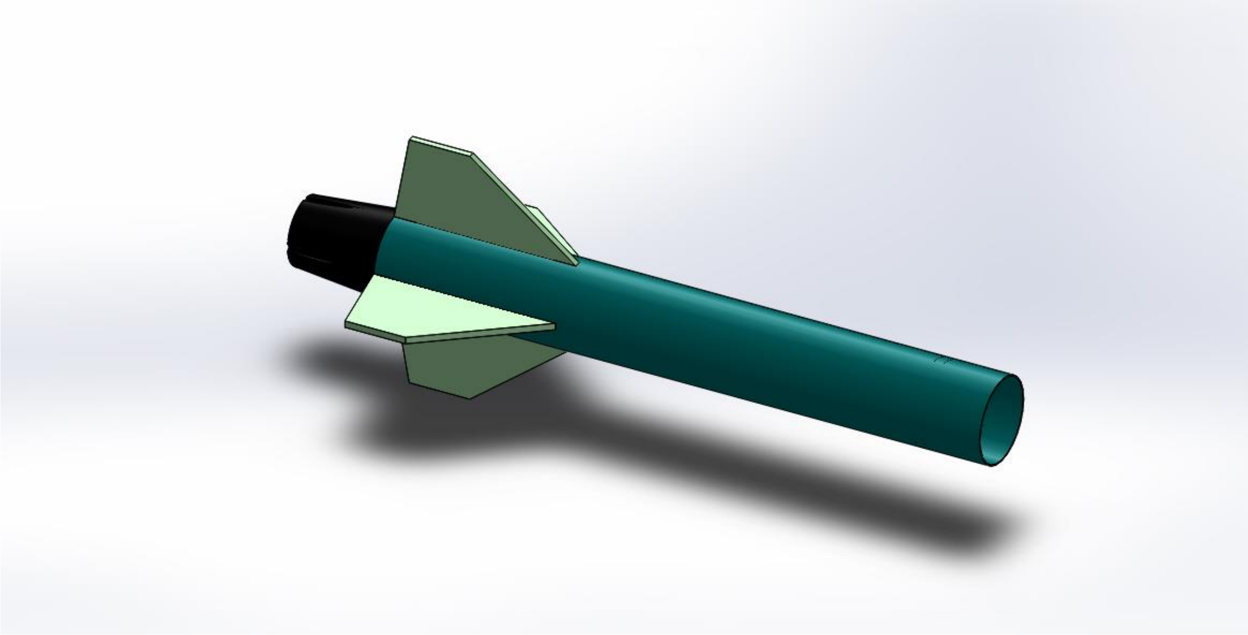

Figure 6: Fin Section Assembly

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 4 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.

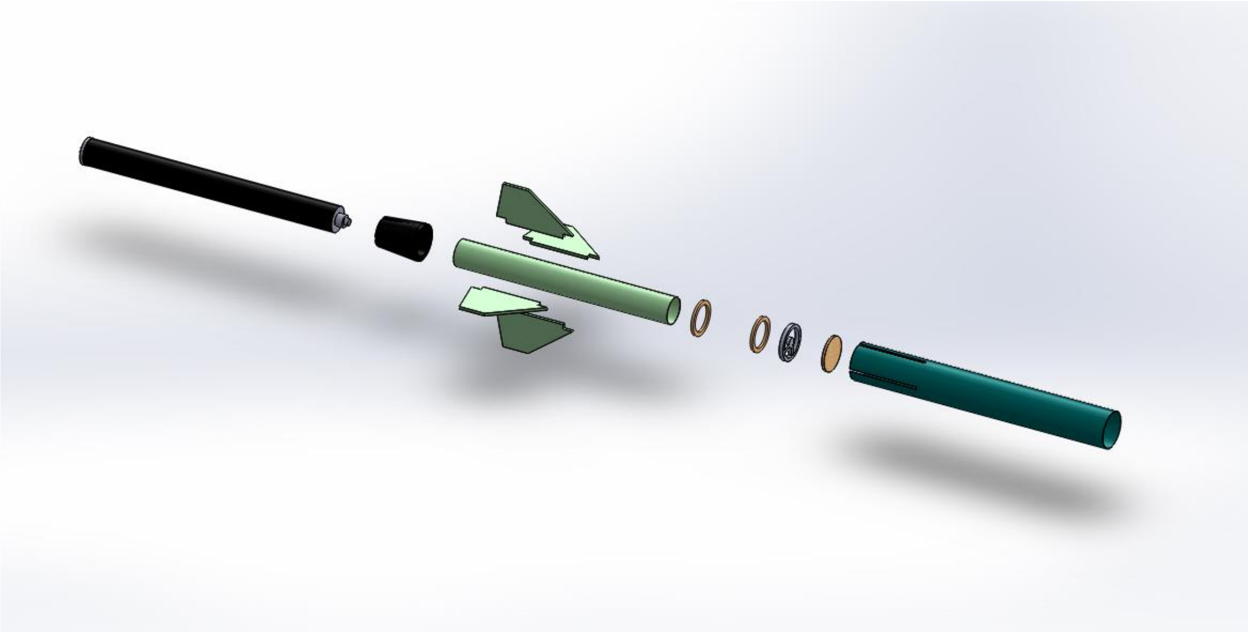

Figure 7: Fin Section Assembly Exploded View

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.

3.1.4.7. 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.

3.1.5. Subscale Vehicle

3.1.5.1.1. Overview

The subscale flight vehicle is to be a 1:2.149 scale model of the full-scale rocket. This scaling factor yields a 2.56 in. diameter rocket which is to be 59.56" in length. This scale model is to be flown in two flights to demonstrate the stability of the full-scale rocket and to demonstrate the team's ability to successfully launch with a dual deploy system.

The subscale rocket is expected to weigh around 5 lbs. The team has opted not to use a drogue parachute but instead will separate the rocket with a black powder charge 2 seconds after apogee. The drag from the two disconnected rocket sections is projected to slow the descent rate to around 90 ft/s and the main parachute will slow it to a ground hit velocity of 26.4 ft/s.

The team will match the static margin in the subscale demonstrations to prove that the full-scale model is dynamically stable. The Open Rocket models currently have the static margin at 1.52. Ballasts may be required to accurately place the flight vehicle's center of gravity in its appropriate location.

3.1.5.1.2. Motor Selection

The subscale rocket will use an AeroTech J350W motor. The team settled with the J350W because it closely matched the thrust to weight ratio of the full-scale. The J350W has a burn time of 1.74 seconds. The total impulse is 157 lbf-s and the average thrust is 90.4 lbf. Using this motor, the dual deploy rocket is expected to have a maximum velocity of 902 ft/s (M=0.81), maximum acceleration of 931 ft/s^2, and an apogee of 5755 feet. The CG and CP for the dual deploy subscale are located 28.34 inches and 31.58 inches aft of the nose cone respectively

3.2. Recovery Subsystem

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 8 below.

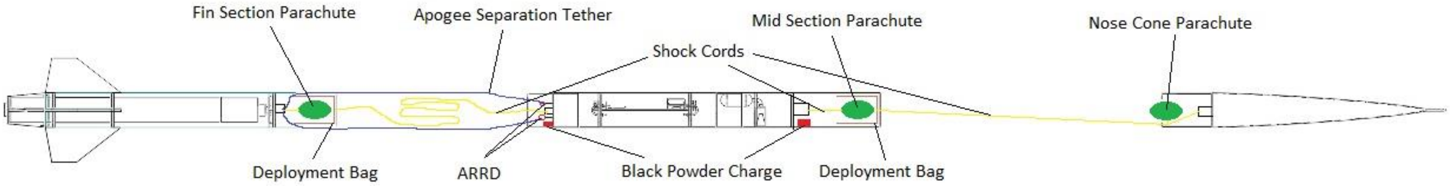

Figure 8: Recovery System Diagram

The parachutes to be used will be designed and manufactured in house. The design chosen is ellipsoidal in shape. Using this shape reduces the amount of fabric needed, versus a conventional hemispherical design, thus reducing weight and area needed inside the vehicle for storage during ascent.

Figure 9: 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

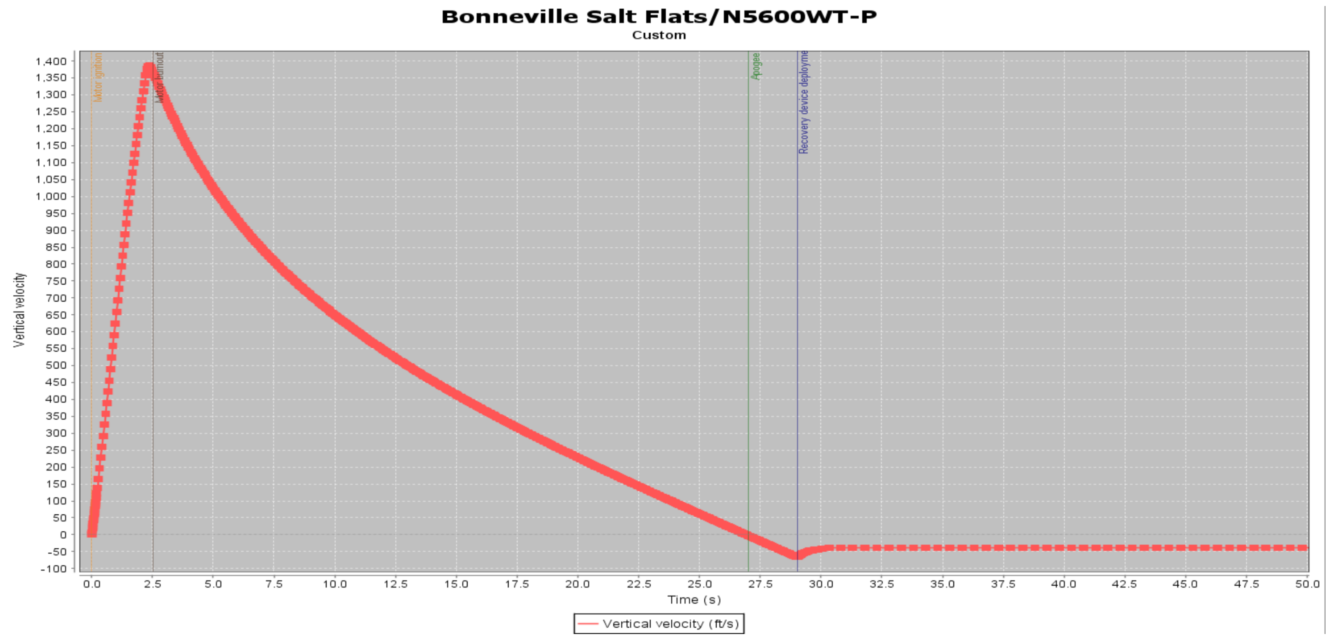

Figure 10: Velocity of Rocket with N5600WT-P

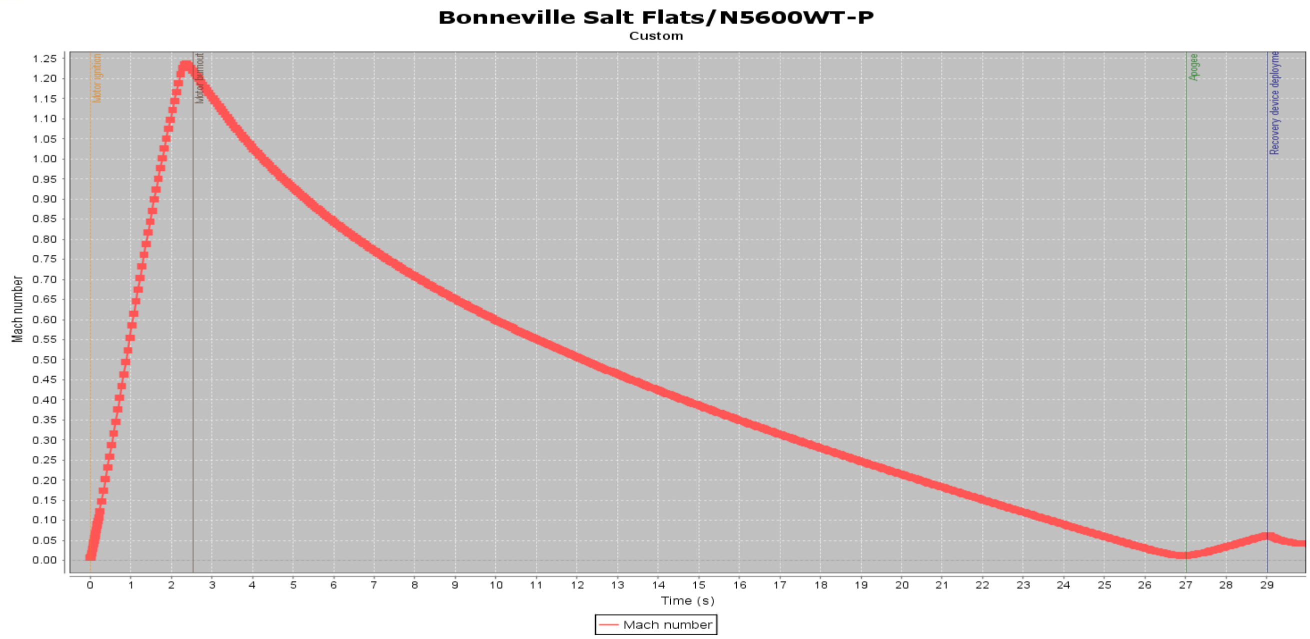

Figure 11: Mach Number of Rocket with N5600WT-P

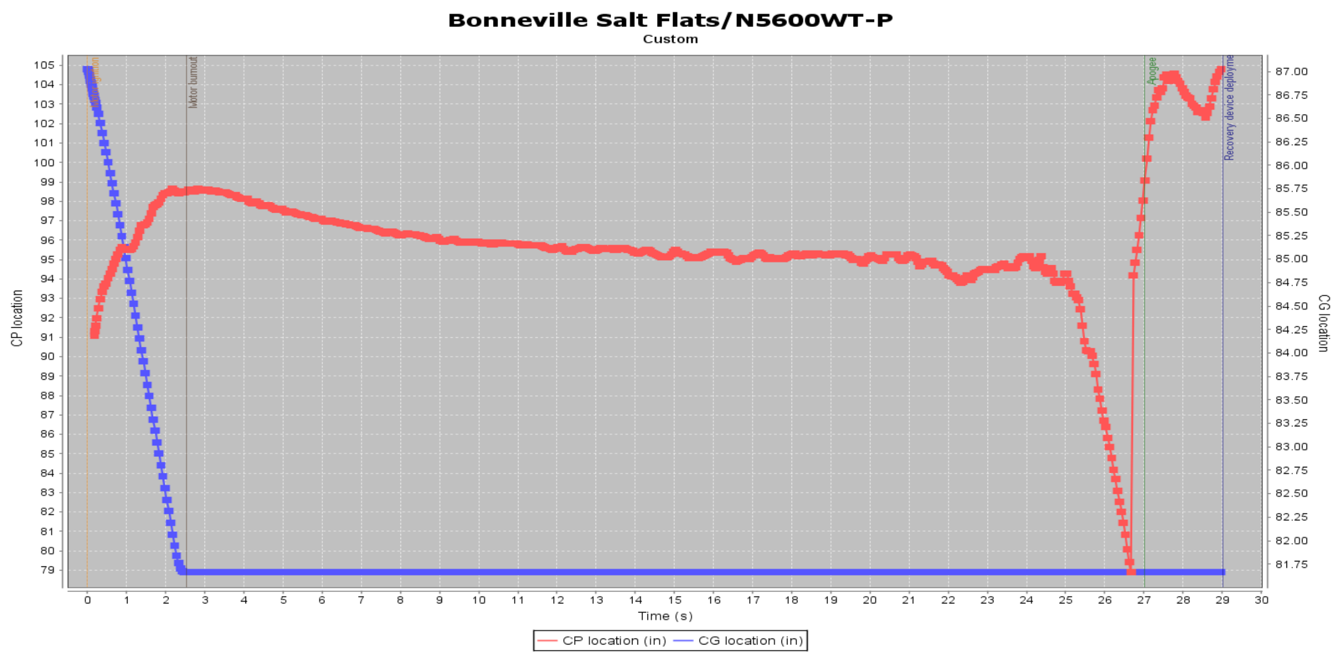

Figure 12: CP and CG Locations through Flight

3.3.3. Altitude Predictions

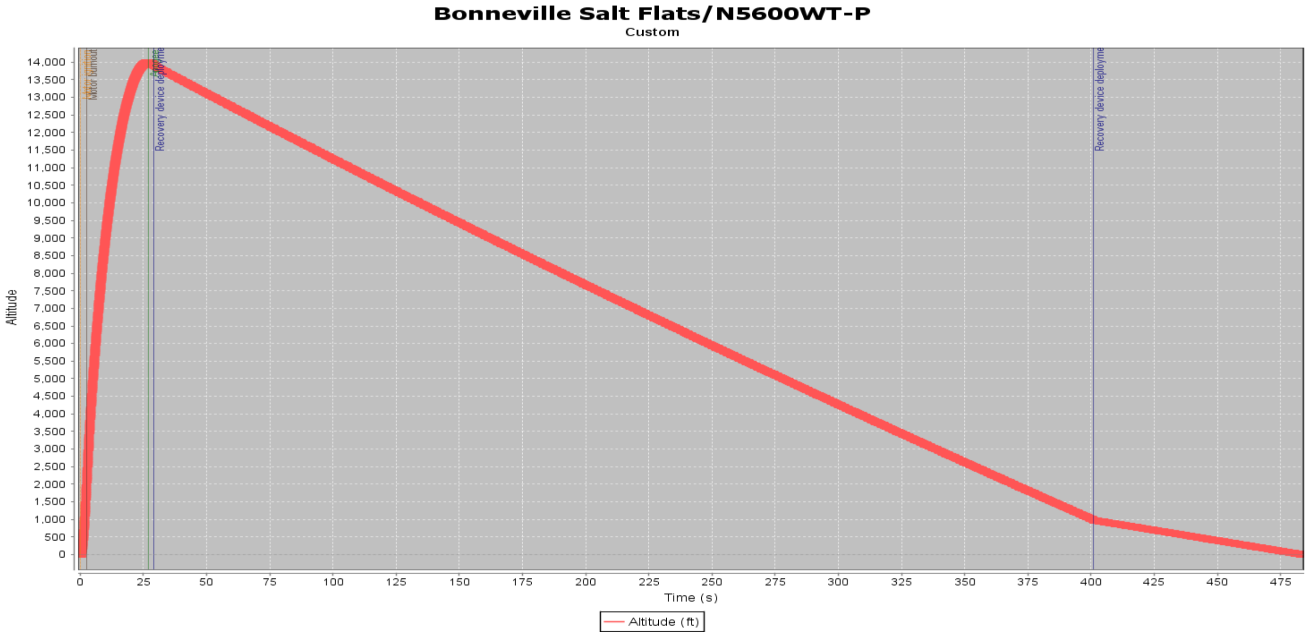

Figure 13: Altitude Projection with N5600 WT-P

3.3.4. Motor Thrust Curve

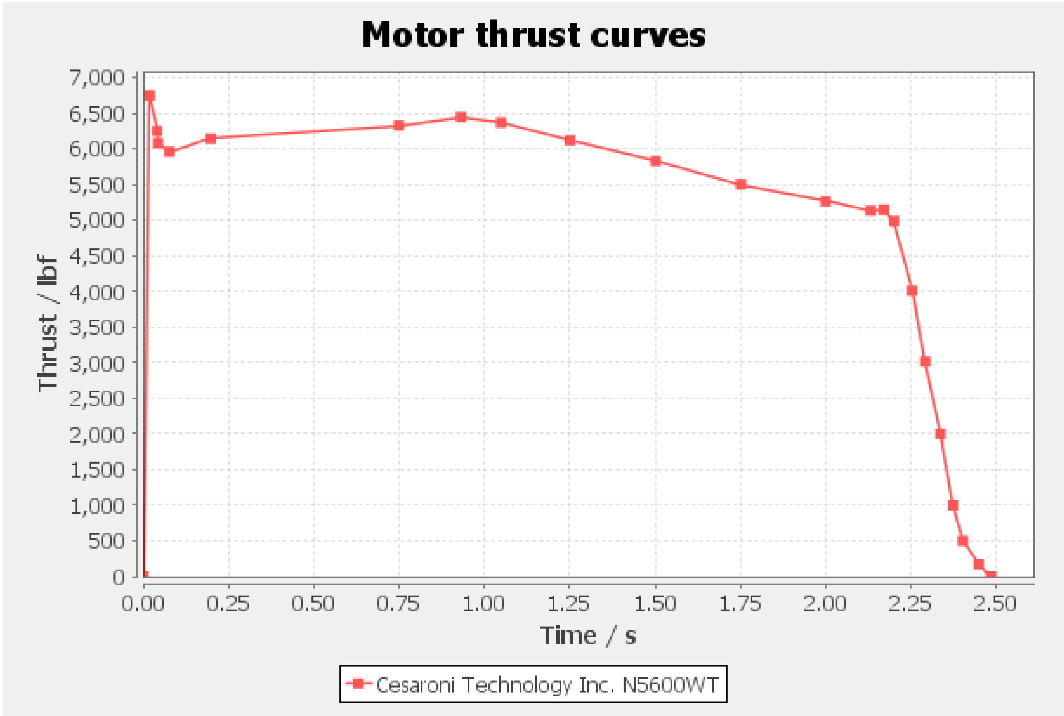

Figure 14: Thrust Curve for N5600WT-P

3.3.5. Kinetic Energy Calculations

	Weight (lb)	Descent Rate (ft/s)	Kinetic Energy (lbf-ft)
Nose Cone	5.2	28.6	66.1
Fin Section	31.7	12.1	72.1
Body Section	17.9	16.1	72.1

3.3.6. Wind Drift Calculations

		Wind Speed in MPH			
		5	**10**	**15**	**20**
Drift in Feet	**Nose Cone**	733	1466	2199	2932
	Fin Section	932	1864	2796	3729
	Body Section	1083	2165	3248	4331

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.

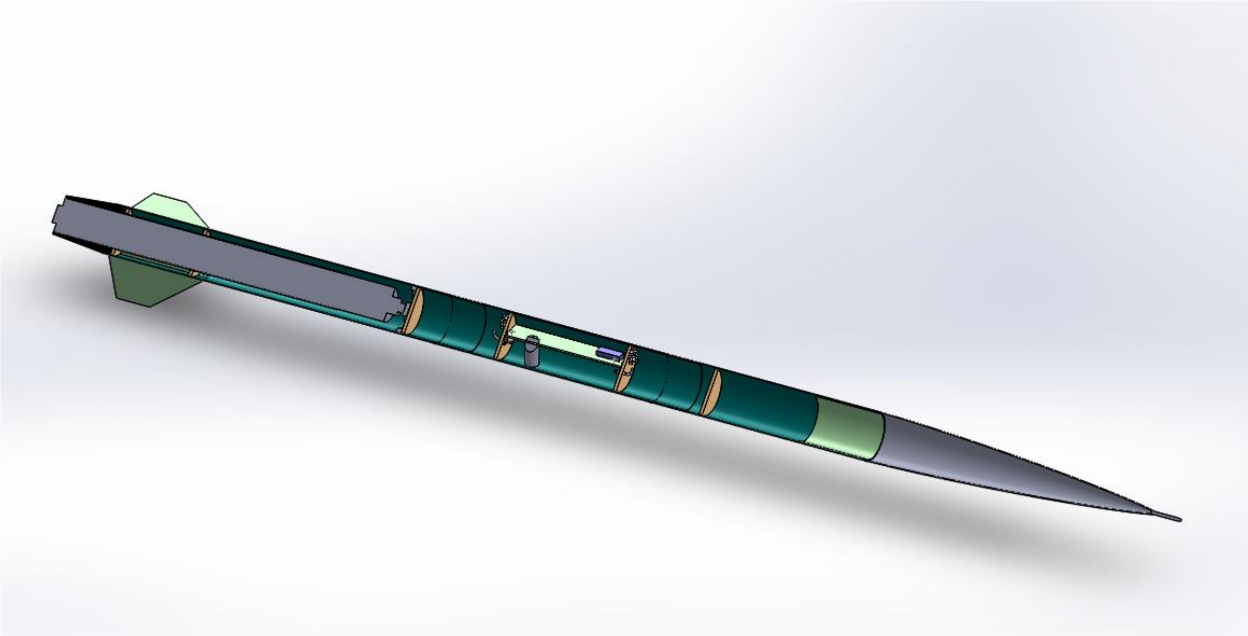

Figure 15: Full Scale Cross Sectional View

3.5. Launch Operation Procedures

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)

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

Function / Component	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
		Improper Maintenance			1	Pre/post launch inspections
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: Subsystem	Failure Effects: System	Hazard	Recommendations
		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		Hazard	Recommendations
			Subsystem	System		
		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		Hazard	Recommendations
			Subsystem	System		
	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

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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 / Component	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 displacemen t 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/attachme nt	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/attachme nt	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 / Componen t	Failure Mode	Causal Factors	Failure Effects		Hazard	Recommendations
			Subsystem	System		
Fins	Fins layout cause unexpected trajectory	Fins are not attached at the correct angle	Aerodynami c 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. 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 weathercocking 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.
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.

4. Payload Criteria

4.1. Selection, Design, and Verification of Payload Experiment

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:

4.1.1.1. Arduino Due

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

4.1.1.2. Analog Devices ADIS16448AMLZ

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

4.1.1.3. Pitot Tube

Measure total pressure for dynamic pressure and airspeed calculations

4.1.1.4. Omega PSXDX-100D

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

4.1.1.5. Thermocouple Type K

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

4.1.1.6. Vishay Strain Gages

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

4.1.1.7. 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.

4.1.1.8. GPS Receiver 3DR UBLOX

GPS receiver for location and trajectory data comparison/checking

4.1.1.9. TTL Serial Camera

Digital camera used for the Hazard Detection system.

4.1.1.10. Digi XT09-DK

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

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. Science 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
	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

System	Supplier	Qty	Cost(ea)	Description	Total cost
	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
	Apogee	3	$85.55	PerfectFlite StratoLogger Altimeter	$256.65
	Hobby King	30	Unavailable	E-Matches	$50.00
				Full Scale Estimated Budget:	**$7,086.70**
				Items Acquired From HPRC:	**$2,367.00**
				Remaining Balance of Items to be Purchased:	**$4,719.70**

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

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
Propulsion	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

System	Supplier	Qty	Cost(ea)	Description	Total cost
	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:	**$0.00**
				Remaining Balance of Items to be Purchased:	**$589.31**

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

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.

There are currently three community outreach events that are planned for the future. On January 25th and 26th the club will help with Astronomy Days and help oversee the rocket launches. February 2nd will be a day in which the club hosts an event for the local YMCA that will teach the basic concepts and parts of a rocket including trajectories, thrust, and the science involved in rocketry. April 19th will be a similar event where the club will teach Boy Scouts the concepts behind rocketry as well as help them build and launch their own rockets.

6. Conclusions

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

7. Artifacts

7.1. Stability

Date: 14 November, 2013

To: Dr. Charles Hall

From: Stephen West - Space Senior Design Team 1

Subject: High Power Rocket Dynamics Model and Analysis

This experiment's objective was to create and analyze a dynamic model of a high power rocket. In order to ensure safety of flight, a rocket's response to small disturbances must exhibit appropriate positive dynamic stability and not excessively disrupt the flightpath. A MATLAB code was created to determine the vehicle's aerodynamic center using Barrowman's method of normal force coefficients. The aerodynamic center was determined to be **. inches aft of the datum. The dynamic model of the rocket was created in SIMULINK. The natural frequency was determined to be **.** s^{-1} and the damping ratio *.**. Further analysis yielded that the excitation thruster designed for the rocket will produce a *.** degree deviation in the vehicle's flightpath. This was determined to be an acceptable disturbance as it only caused a ***** foot lateral displacement from the launch site (assuming no-wind conditions).**

During the coast phase of flight, the rocket will experience numerous small disturbances. The particular disturbance under consideration is the torque produced by an excitation thruster for the purpose of observing the dynamics of the rocket's response. In order to ensure that the response will not compromise safety of flight as well as determine the appropriate sampling rate of the sensors used to record the response, the characteristics of the rocket's motion must be known. Initial estimates of the dynamics were obtained under several simplifying assumptions prior to refinement of the model to increase precision.

Prior to any calculation of dynamics, the aerodynamic center of the rocket was determined using Barrowman's method of normal force coefficients.[1] The aerodynamic center value from an OpenRocket simulation of the vehicle was used to verify the approximate range of the results from Barrowman's method. Due to its greater accuracy, the aerodynamic center from Barrowman's method was incorporated into further dynamics simulation.

The time period of interest is from motor burnout to parachute deployment. During this time, the rocket will be excited by the thruster as well as experience various atmospheric disturbance (e.g. wind gusts, turbulence, etc.). It is assumed that the rocket motor is no longer producing any thrust during the period under consideration. The dynamic model of the rocket follows from the longitudinal equation of motion for a rocket experiencing a torque (Γ_e).

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

In equation (1), I_L is the longitudinal moment of inertia. C_1 and C_2 are coefficients determined as follows.

(2) $$C_1 = 0.5\rho V^2 A_r \sum C_{n,\alpha}(z - w)$$

(3) $$C_2 = 0.5\rho V A_r \sum C_{n,\alpha}(z - w)^2$$

Note that in both equation (2) and equation (3), A_r is the reference area of the rocket (body tube cross sectional area) and the summation is taken of each component's normal force coefficient (from Barrowman's method) multiplied by the difference between that component's local aerodynamic center and the global center of gravity for the vehicle. From the restoring and damping moment coefficients (C_1 and C_2 respectively), the damping ratio and natural frequency were calculated.

The preliminary analysis of the rocket dynamics was simplified by a number of assumptions. The rocket was assumed to start from a perturbed state (some constant angle of attack) with no angular velocity.

Preliminary Boundary Condition: $\alpha(0) = \text{constant}$, $\alpha'(0) = 0$

The assumed boundary conditions allowed the preliminary dynamic model to isolate the rocket's free response to a disturbance without considering motion during the forced displacement. An additional simplifying assumption was that air density and vehicle velocity were constant throughout the period being modeled. In reality, the density and velocity are both decreasing during the coast phase of flight as the vehicle continues to ascend. Simple averages of the range of velocities and densities encountered were used to approximate the time dependent velocity and density functions.

The preliminary analysis was completed and a plot of angle of attack over time was produced (Figure 1). Note that the motion begins from an angle of attack of 2°. The natural frequency was 20.6 s^{-1} (3.28 Hz) and the damping ratio was 0.277. The time to half was calculated to be 0.121 s. Note that since this dynamic response begins from rest at the disturbed state, it is valid for any impulsive disturbance that causes a $\Delta\alpha$ of 2°. The results from the preliminary analysis were used to size the excitation thruster.

Refinement of the dynamic model necessitated that the simplifying assumptions be addressed. First, the entirety of the rocket's motion was modeled starting from equilibrium (zero angle of attack, zero angular velocity), including the disturbance from the excitation thruster (or any other source of disturbance, e.g. wind gust) and subsequent unforced oscillation.

Refined Boundary Condition: $\alpha(0) = 0$, $\alpha'(0) = 0$

Additionally, time dependent functions were developed for density and velocity. Data from the OpenRocket simulation was used to fit time dependent curves to the changing value for density and velocity. These time dependent functions replaced the simple averages used in the preliminary analysis. The effect of the time dependent functions on the accuracy of the model was estimated by comparing free response results from the preliminary model to the same results from the refined model. The percent error introduced by using a simple average instead of the time dependent function was calculated.

From the improved dynamic model, mode shapes were determined for the vehicle's dynamic modes. Additionally, the net effect of the disturbance on the vehicle's flight path was evaluated. While the angle of attack returns to zero, the effect of the excitation thruster is a change in the flightpath angle. This change was quantified and related to the magnitude of the disturbance. From the change in flightpath angle, the lateral displacement was estimated assuming no-wind conditions.

MATLAB and SIMULINK were utilized to complete the dynamic analysis. Multiple iterations of the model were run during development and enabled continuing improvement of the model as more accurate physical vehicle dimensions became available. In addition to sizing the excitation thruster, the dynamic model also provided information on the duration of the free vibration response to excitation. This information was utilized to determine the sampling rate for the avionics package.

The primary failure mode addressed by the dynamics model analysis is a failure of the excitation thruster to shut off. By simulating pitch and flightpath angle changes caused by a longer thruster actuation than intended, a maximum safe thruster size was determined. The thruster was designed with a maximum potential torque (considering actuation until depletion) corresponding to the maximum safe pitch and flightpath angle change. In this manner, the thruster is capable of producing the desired disturbance but will not produce an unsafe disturbance if it fails to shut-off on command.