AC 2011-2303: HIGH POWER ROCKETRY PROGRAM: UNDERGRADUATE RESEARCH EXPERIENCE FOR AN HBCU

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High Power Rocketry Program: Undergraduate Research Experience for an HBCU

Abstract

Involvement of undergraduate students in research or projects related to their discipline have been found to be very effective in improving the students' learning outcome, and prepare them better for their jobs on graduation and/or entering into graduate school. Alabama A&M University, a Historically Black College or University (HBCU), engages a group of about twelve undergraduate engineering students in a challenging project to develop a high power Rocketry Program, in cooperation with NASA and Alabama Space Grant Consortium. The students are involved in the design, construction, testing, launching, and recovery of a reusable rocket with a scientific payload. The activities involve diverse aspects such as planning and scheduling, purchasing, performing calculations and analysis, coordinating logistics, and design reviews. They are mentored by faculty advisors. Alabama A&M University rocketry team is one of the 20 teams selected by NASA nationwide under the University Student Launch Initiative (USLI) program, and financially supported by the Alabama Space Grant Consortium. Students from mechanical, electrical & civil engineering and technology departments, mostly underrepresented minority, are involved in this exciting project. Successful launch and recovery of the rocket and retrieval of the scientific data inspires the next batch of students to continue this rocketry project as a sustainable research program.

1. Introduction

The NASA – MSFC's (Marshall Space Flight Center) University Student Launch Initiative (USLI) program involves undergraduate students in the design, building, and testing of reusable rockets with associated scientific payloads. USLI is a competitive rocket and payload-building challenge designed for university students. The initiative is intended to encourage students to pursue careers in engineering or science related fields. This unique hands-on experience allows students to demonstrate proof-of-concept for their designs and gives previously abstract concepts tangibility. It requires an eight-month commitment to successfully design, construct, test, launch, and recover a reusable rocket with science payload. The vehicle has to carry a science payload (instrumentation) during flight and should be developed so that it delivers the science payload to a specific altitude of 5,280 feet (1 mile) above ground level (AGL).

Alabama A&M University rocketry team is one of the 20 teams selected by NASA nationwide under the University Student Launch Initiative (USLI) program, and financially supported by the Alabama Space Grant Consortium. Students from mechanical, electrical & civil engineering and technology departments, mostly underrepresented minority, are involved in this exciting project. Successful launch and recovery of the rocket and retrieval of the scientific data should inspire the next batch of students to continue this rocketry project as a sustainable research program.

2. Background

The American Competitive Initiative (ACI) program emphasizes that education is the gateway to opportunity and the foundation of a knowledge-based, innovation driven economy, and when it is accompanied with training and retaining it will provide the nation's workforce with opportunities for advancement and the ability to compete in a global economy. However, gaps in race/ethnicity and gender at entry and in completion of science, technology and engineering programs indicate that the U.S. struggles to develop a diverse workforce that can compete globally. Alabama Agricultural and Mechanical University (AAMU) is a historically black (HBCU) land-grant and EPSCoR institution established in 1876 with a mission of providing high quality education for about 5800 underprivileged, mostly low-income African-American students. The university offers baccalaureate, masters and doctoral level degrees that are compatible with the times to all qualified and capable individuals who are interested in further developing their technical, scientific, professional, and scholastic skills and competencies. The ethnic distribution of students at AAMU is 92% black, 4% white, and 4% represented by all others. In the School of Engineering and Technology at AAMU, the distribution of students based on gender is 76% male and 24% female. AAMU has set a priority to provide low-income students with higher education and ensure their success through retention, graduation, and advancement.

AAMU is located in Huntsville, Alabama, which is known internationally as a center of aerospace and defense technology. Huntsville is considered as a leader in high-tech research, engineering services, information systems design and in the manufacturing of computing equipment, telecommunications, space vehicles and rocket propulsion, and attracts some of the greatest minds in the world. It is the home of more than 50 Fortune 500 companies. These industries and government agencies require a large number of qualified engineers.

Alabama A&M University's School of Engineering and Technology offers three engineering programs, Civil Engineering, Electrical Engineering and Mechanical Engineering, in addition to the Technology and Computer Science programs. The School of Engineering and Technology presently enroll about 840 students. The Mechanical, Electrical and Civil Engineering, and Technology programs at AAMU were successfully accredited by the Accreditation Board for Engineering and Technology (ABET)[1]. They also meet the requirements of the Southeastern Association of Colleges and Schools (SACS).

Developed countries like the United States need large engineering workforce. Even in Huntsville, the city where Alabama A&M University is located, it is anticipated that about 15000 new engineers will be needed over the next ten years[2]. But unfortunately, the percentage of minority black engineers is very low compared to the percentage of their population[3-6].

Based on a study conducted[6], involvement of undergraduate students in research or projects related to their discipline, financial assistance and proper mentoring were found to be among the top factors that can improve the learning outcome and retention of underrepresented minority students in engineering. For this reason, the students at Alabama A&M University (AAMU) are involved in the design, construction, testing, launching, and recovery of a reusable rocket with a science payload. The activities involve diverse aspects such as planning and scheduling, purchasing, performing calculations and analysis, coordinating logistics, and design reviews. The involvement of the students in the high power rocketry design and testing will bring excitement in their learning process and will have a tremendous impact on their careers.

3. Project Organization

Rocketry project organization team is composed of faculty advisors and various student groups. The main student groups are public relations, structures, propulsion, payload/avionics, recovery, and mission operations. The Faculty Advisors ensure the overall progress of the project and help provide the logistic support the team needs to deliver the tasks in a timely manner. The Public Relations group is responsible for maintaining the website, advertisement, purchasing of equipment and supplies. The Structures team is responsible for the construction of the main components of the rocket such as the nose cone, booster, fins, and airframe. The main responsibility of the Propulsion group is the motor selection and construction. The Payload/Avionics team is accountable for the scientific objective, component selection, wiring, and programming. The Recovery team is responsible for determining the parachute size, testing and evaluation of the ejection charge, and developing the recovery bay. The Mission Operations group is responsible for integration, ground support equipment, and procedures. Two faculty members from the Mechanical Engineering Department of Alabama A&M University serve as the Faculty Advisors, and 12 undergraduate students from Mechanical, Electrical and Civil Engineering, and Technology programs at AAMU are assigned to the various student groups.

3.1 Rocketry Certifications

Two of the undergraduate students have to receive National Association of Rocketry (NAR) certifications (level 1, 2, & 3) for safety reasons. In addition, AAMU maintains a relationship with the Huntsville Area Rocketry Association (HARA), and members of HARA have assisted AAMU from the beginning of the USLI program.

4. Facilities & Equipment

The following facilities are available to the students

- Advanced Manufacturing Laboratory
- Materials Laboratory
- Experimental Mechanics Laboratory
- Propulsion Laboratory
- Machine Shop
- Paint Booth

The team maintains a web site for the project, and all the members have access to the internet. Other tools and resources include numerous computers uploaded with tools such as RockSIM, MATLAB, Solid Edge, and Microsoft Office. The school provides the IT facility required during the progress of the proposed tasks. As mentioned above, the project will be under the supervision of Dr. Showkat Chowdhury and Dr. Mohamed Seif of the Mechanical Engineering Department at Alabama A&M University. This interdisciplinary project also involves 12 undergraduate students from different departments within the School of Engineering and Technology, AAMU.

The Advanced Manufacturing Lab and Materials Lab are equipped with standard hand tools as well as numerous rocketry specific tools and materials as well as past USLI rockets, literature, and videos. Electrical hardware includes GPS sensors, video leads, and barometric pressure altimeters and accelerometer altimeters to be used for verification of altitude. The rocket workshop is an approximately 600 square foot room located in the School of Engineering and Technology Building on the AAMU campus. All team members have open access to the labs during normal campus hours.

In addition to the resources within the above mentioned labs, AAMU provides Video Teleconferencing facility. The Mechanical Engineering machine shop is equipped with various tools and machines, and employs a full time machinist, to assist and train students on machining and tooling.

5. Safety and Mission Assurance

The National Association of Rocketry (NAR) High Power Safety Code requires the following concerning the construction of high power rockets:

- **Certification:** All personnel flying high power rockets or possessing high power rocket motors must be within the scope of the user's certification and required licensing.
- **Materials:** The use of only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of the rocket.
- **Motors:** Use only certified, commercially made rocket motors that will not be tampered with or used for any purposes except those recommended by the manufacturer. Smoking, open flames, or heat sources will not be allowed within 25 feet of these motors.
- **Ignition System:** Rockets will be launched with an electrical launch system, and with electrical motor igniters that are installed in the motor only after the rocket is at the launch pad or in a designated prepping area. The launch system will have a safety interlock that is in series with the launch switch that is not installed until the rocket is ready for launch. It will use a launch switch that returns to the "off" position when released. If the rocket has onboard ignition systems for motors or recovery devices, these will have safety interlocks that interrupt the current path until the rocket is at the launch pad.
- **Misfires:** If the rocket does not launch when the electrical launch system launch button is pressed, the launcher's safety interlock will be removed or the battery disconnect, and personnel will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.
- **Launch Safety:** A 5-second countdown before launch will be used. Ensure that no person is closer to the launch pad than allowed by the Minimum Distance Table, and

that a signal is available to warn participants and spectators in the event of a problem. The stability of the rocket will be checked before flight and will not fly if it cannot be determined to be stable.

- **Launcher:** The rocket will be launched from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour, a launcher length that permits the rocket to attain a safe velocity before separation from the launcher will be used. A blast deflector to prevent the motor's exhaust from hitting the ground will be used and ensure that dry grass is cleared around each launch pad in accordance with the Minimum Distance table, and increase the distance by a factor of 1.5 if the rocket motor being launched uses titanium sponge in the propellant.
- **Size:** The rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 lb-sec) of total impulse. The rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.
- **Flight Safety:** The rocket will not be launched at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not contain any flammable or explosive payload. The rocket will not be launched if wind speeds exceed 20 miles per hour. Personnel will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that the rocket will not exceed any applicable altitude limit in effect at that launch site.
- **Launch Site:** The rocket will be launched outdoors, in an open area where trees, power lines, buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater.
- **Launcher Location:** The launcher will be at least one half the minimum launch site dimension, or 1500 feet (whichever is greater) from any inhabited building, or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from any boundary of the launch site.
- **Recovery System:** The rocket will use a recovery system such as a parachute so that all parts of the rocket return safely and undamaged and can be flown again, and use only flame-resistant or fireproof recovery system wadding.
- **Recovery Safety:** Personnel will not attempt to recover the rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.

The AAMU rocket design is consistent with NAR requirements. There are several members having NAR certifications (level 1, 2, & 3) to fly the proposed motors. The AAMU USLI Team is aware of and complies with the federal, state, and local laws regarding un-manned rocket launches and motor handling.

5.1 Purchase and Storage of Motor(s)

Our motor vendor for the Contrails Hybrid rocket system is Pratt Hobbies. The reloads and hardware are shipped directly to the school and stored in a locked closet in the manufacturing laboratory. The hybrid rocket engine does not require a LEUP (low explosive user permit) for storage. The nitrous oxide used in the hybrid system is purchased from SECO performance in Huntsville, AL. The Nitrous Oxide tank is stored as per specifications of the manufacturer regarding temperature, tank position, and flammability.

The motor vender for the Cesaroni solid motor hardware is NAR certified on-site vendor. The reloads are purchased through HARA and used during NAR sanction events.

For proper safety and operations of the hybrid motor training, the team test fired scaled model motors in the Propulsion lab in the School of Engineering and Technology building.

5.2 Motor Size

The Hybrid motor selected for the rocket is the Contrails 75mm K888 and the Cesaroni 54mm K-660 motor with the 75 to 54mm adapter supplied. These motor choices were determined based on the weight of previous rockets and increased payload weight. The following table shows a size and performance comparison of the suggested motors.

Table 1: Performance Comparison

Motor	Hybrid Motor	APCP Motor
Make and Model	Contrails K-888	Cesaroni K-660
Length (in)	40	22.6
Weight (g)	4173	1949
Average thrust (N)	896	659
Peak thrust (N)	3024.8	1078.9
Total Impulse (N-sec)	2400	2437
Burn Time (sec)	2.67	3.7

6. Technical Design

The students performed design of the vehicle dimensions, payload placement, and booster design for the various rocket configurations. The rocket has 4 in (100mm) diameter with a 75mm motor mount tube. With the elliptical nose cone, the overall length of the proposed rocket is roughly 9 ft 5 in with 4 swept boat-tail fins mounted to the booster section.

The following Figures 1 – 4 are some current CAD images of the rocket.

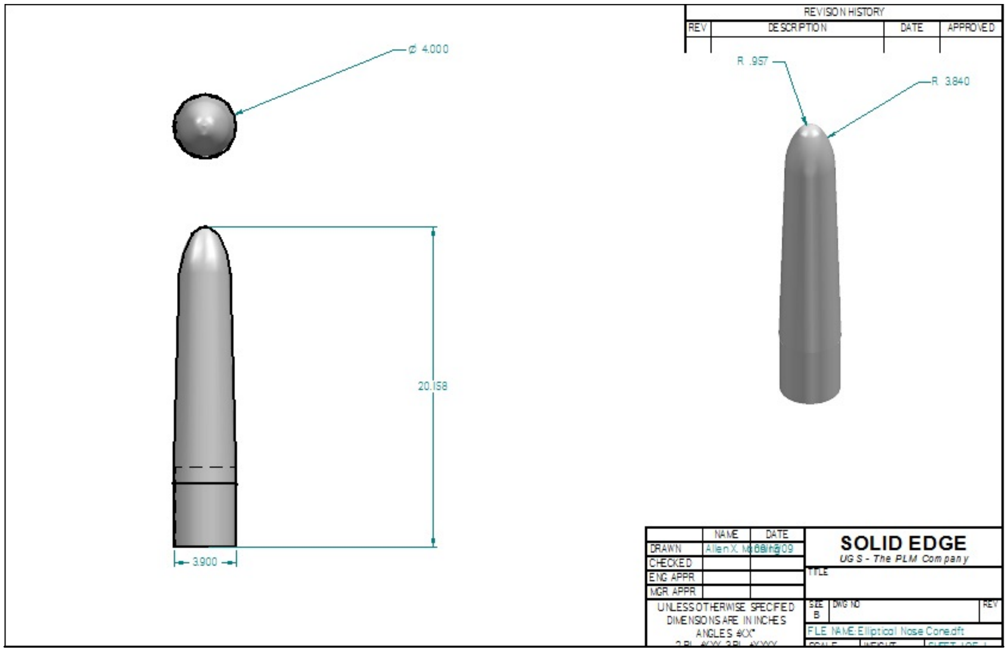

Fig. 1. Elliptical Nose Cone for low drag.

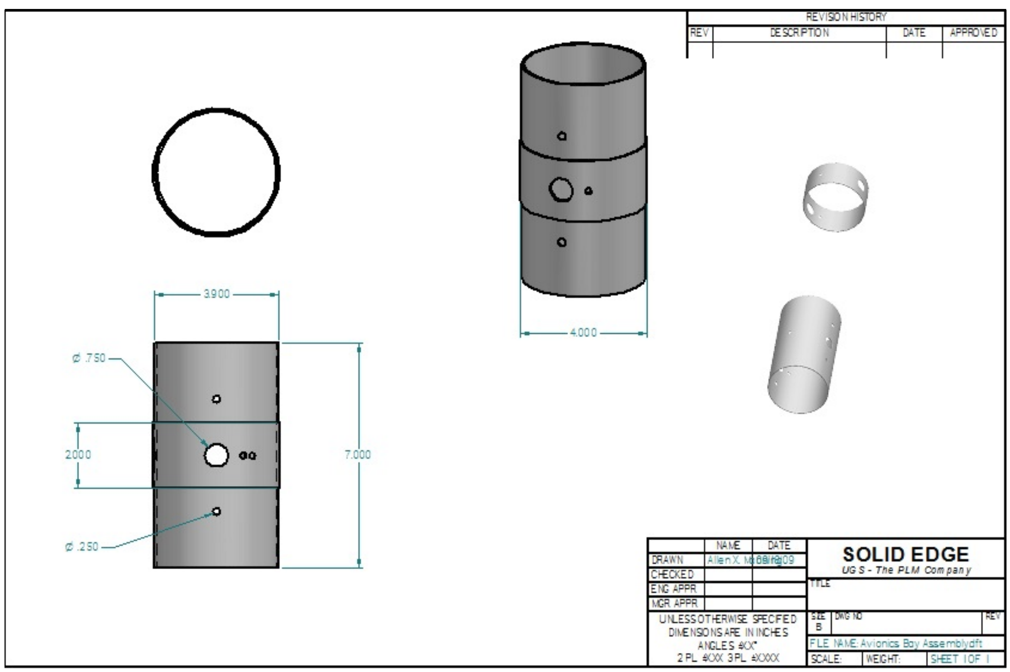

Fig. 2. Avionics Bay.

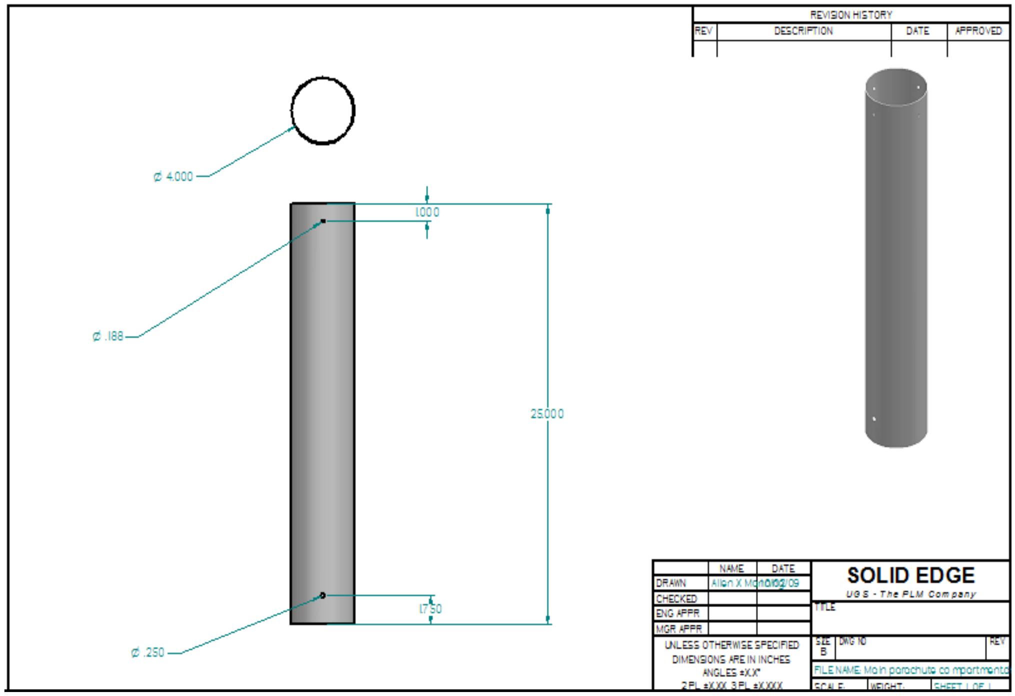

Fig. 3. Main Parachute Compartment

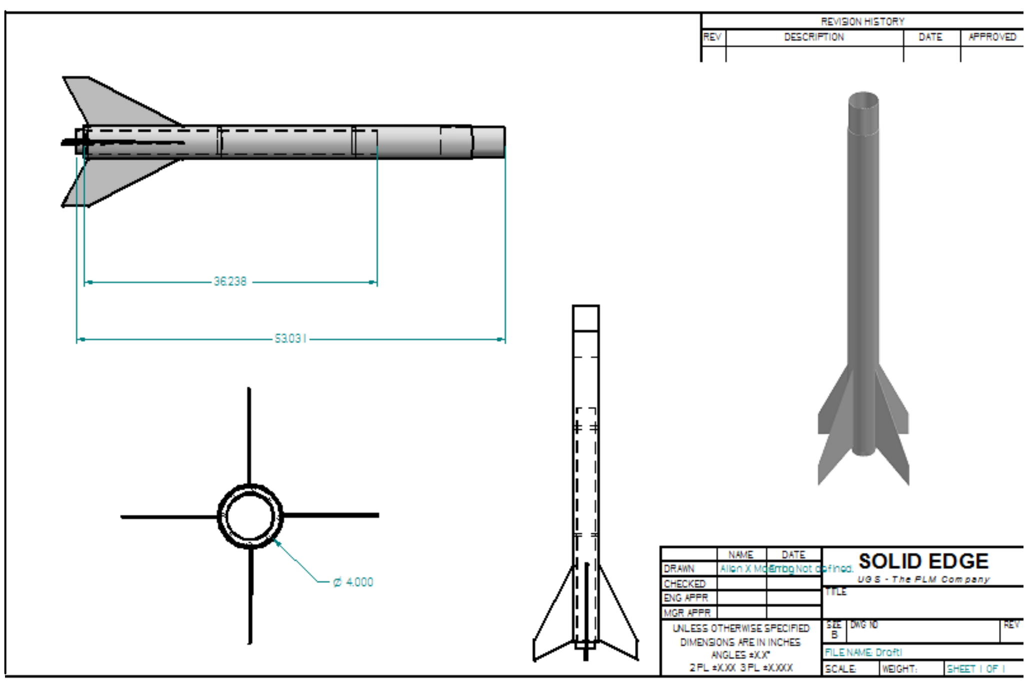

Fig. 4. Booster Section with motor retainer

6.1 Payload

The rocket will carry two payload sections. The first payload section is responsible for dual deployment recovery of the rocket. It contains two Perfect Flight MAWD altimeters. The second payload is planned to have a pure mechanical accelerometer. This accelerometer uses the existing electrical flight components, a spring, a camera, and a series of LED lights. This applies the Newton's law and Hooke's Law, $F = m*a = k*\Delta x$. When the rocket is at rest, the mass of the existing flight electronics rest on the spring. But, when the rocket takes off the acceleration should be close to 16 times the acceleration of gravity, a = 16G based on the previous R-DAS data recorded, where the acceleration due to gravity $G=9.81m/s^2$. With the 16G acceleration times the mass of the payload electronics the spring should compress to a distance where it will activate a series of LED lights. The rocket has a high frequency wireless camera observing the light during flight. The light observed for the mechanical accelerometer will be compared to the Rocket Data Acquisition System (R-DAS) data, to verify Hooke's law. The R-DAS flight Control Computer equipped with GPS, transmitter, and accelerometer will be the existing electronics used for the payload that rests on the pure mechanical accelerometer spring. There was an outboard camera mounted to observe the flight as well. The second payload also has 12 1.2V NIMH batteries wired in series for maximum power usage and efficiency. They are strategically arranged in order to maximize space and balance weight on the rocket.

6.2 Propulsion systems

Figures 5 and 6 show the commercially available rocket engines for the USLI project.

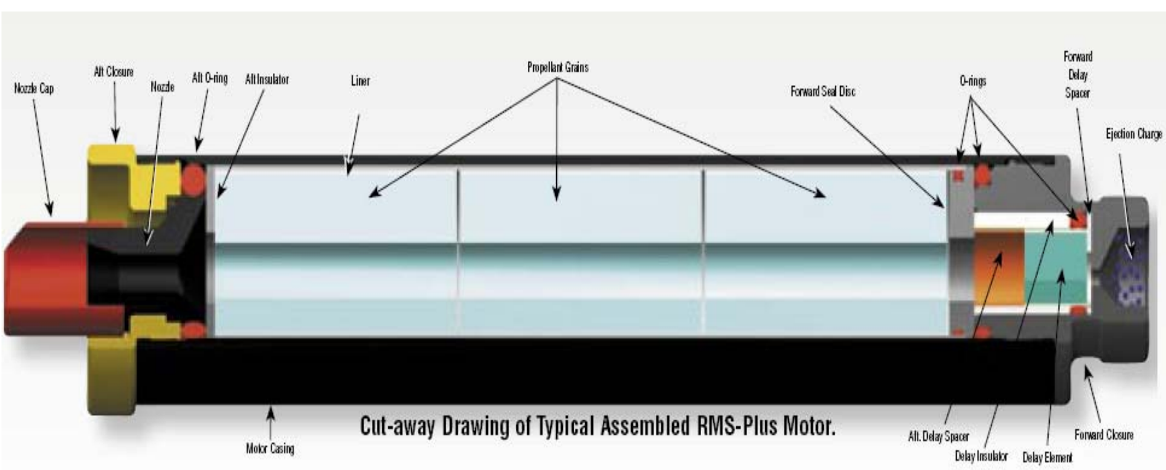

Fig. 5. Solid rocket motor.

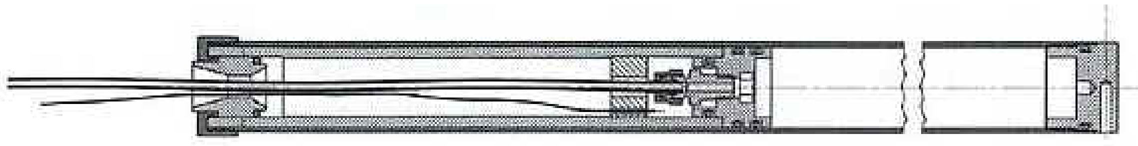

Fig. 6.   Floating Injector Hybrid Motor.

6.3 Dual Deployment Parachute System

The purpose of using a dual deployment system is to increase the probability of safe recovery, which prevents the rocket from drifting at high altitudes. The system consists of two Perfect Flight MAWD barometric pressure-sensing altimeters, a drogue parachute, a main parachute, Kevlar shock cord, electric match, black powder, and stainless steel U-bolts and quick links rated at 880lb. The logic behind using two altimeters is to develop a redundant system. At apogee, the primary altimeter sends a signal through an electric match surrounded by a pre-measured amount of black powder. The resulting pressure build up in the airframe breaks the shear pins attached to the booster section deploying the drogue parachute. This event sends the rocket falling at a high descent rate with minimum drift. At a pre-programmed altitude the primary altimeter will send a signal through an electric match in the main parachute compartment. The pressure build up will break the shear pins attached to the payload bay deploying the main parachute. This event drastically decreases the descent rate of the rocket for a safe landing. The backup altimeter functions the same way as the primary altimeter with the exception of sending the signal to the electric match one second behind the primary for the drogue parachute and two hundred feet behind the primary for the main parachute.

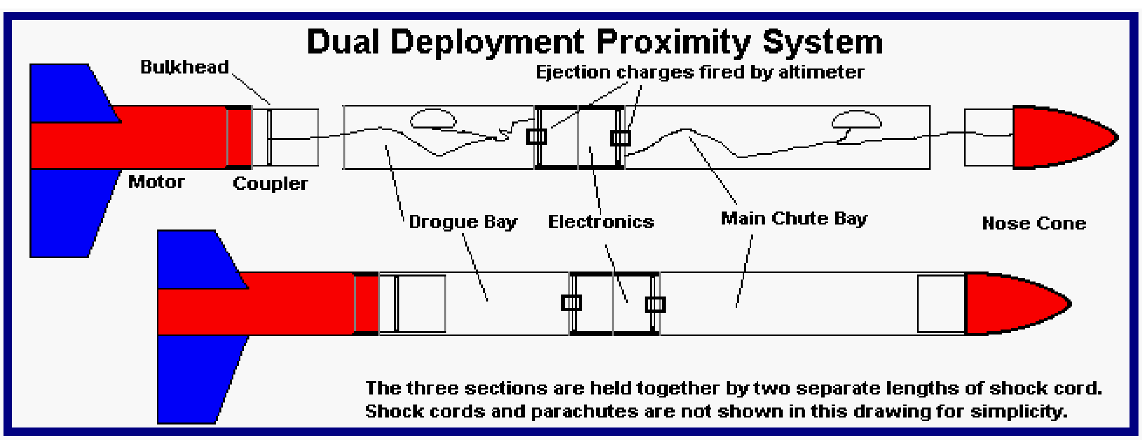

Fig. 7. Typical Dual Deployment Setup

6.4 Parachute Selection

The size of the parachute is based on the weight and a desired decent speed 12-15ft/s. The main parachute is a Giant Leap Rocketry Tac 1 parachute. The website has a descent rate calculator for determining the needed size. This is used to compare with analytical results.

6.5 RockSim Simulations Software:

RockSim is used to check the parameters and analyze the motor systems. Figure 8 shows a snap shot of the software. The program simulation results contain the following information:

1. Engine selection
2. Simulation control parameters
3. Launch conditions
4. Launch guide data
5. Max data values
6. Engine ejection charge data
7. Recovery system data
8. Time data
9. Landing data

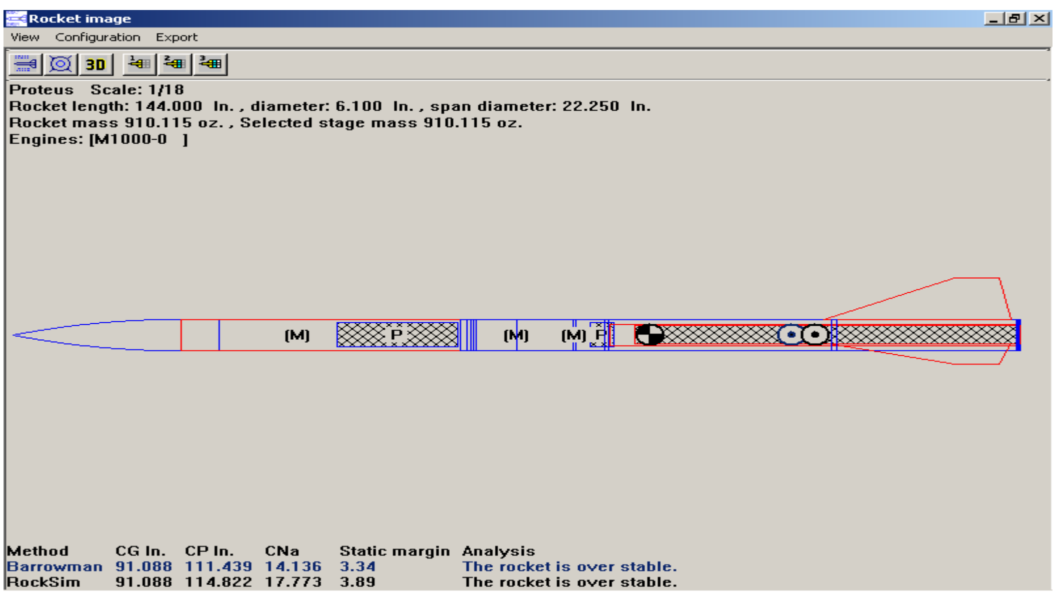

Fig. 8. RockSim Simulations Software

Figure 9 illustrates a sample chart that is produced using RockSim showing the altitude, thrust, velocity, and acceleration changes with time.

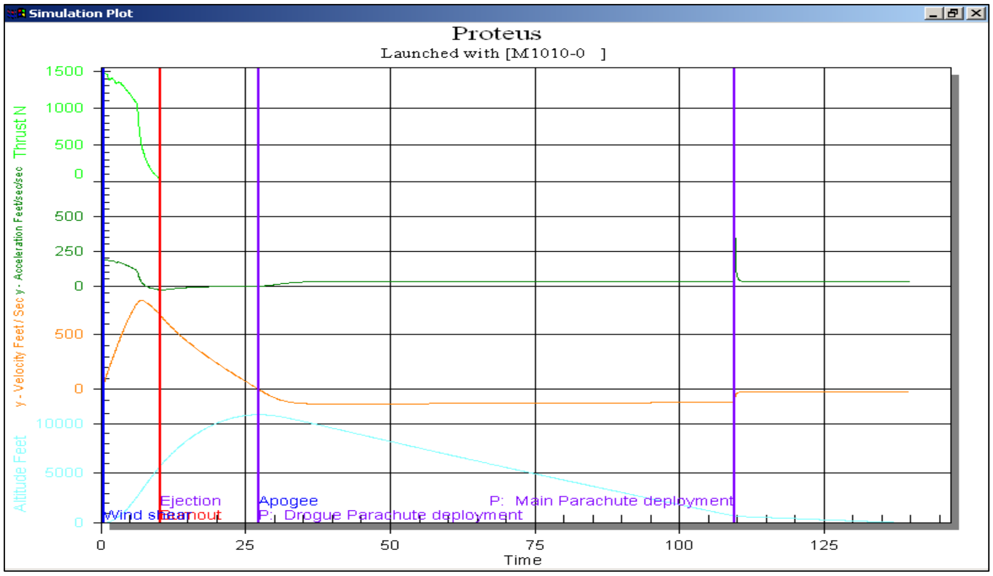

Fig. 9. Altitude, thrust, velocity, and acceleration changes with time using RockSim.

7. Project Management and Documentation

The NASA-USLI program adopted the systems engineering approach which means that the design and documentation must be completed before any fabrication can be done. As already mentioned, this is an eight month commitment project. For the 2009-2010 academic year the work started in August 2009. In September 2009, the students started working with their preliminary design and CAD drawings. In October 2009, they submitted their proposal to NASA USLI Team for approval and had Teleconference presentation. In December 2009 they had to submit their Preliminary Design Review (PDR) to NASA-USLI program staff members and defend. In January 2010 they also had to present their Critical Design Review (CDR). These reviews required written documents specifying all aspects of payload design as it is progressing and an oral presentation highlighting the important aspects. Once the payload design and fabrication of the rocket is complete, the Flight Readiness Review (FRR) had to be submitted in March 2010 to assess the safe operation of the rocket with the payload. Finally, in April 2010 the Rocket was launched successfully.

8. Launch and Recovery

After making sure the rocket was safe to launch, the team took their rocket to the NASA specified launch site at a farm in Tennessee on a particular day in April 2010. Under the supervision of National Association of Rocketry (NAR) and Huntsville Area Rocketry Association (HARA) officials, the AAMU team successfully launched their rocket. The rocket was designed to go to an altitude of 5280 feet with the science payload. After reaching the apogee, while coming back both the drogue parachute and main parachute opened as designed.

The rocket safely landed on a field couple of hundred feet away from the launch site and was recovered in good condition. The data recovered from the rocket showed that it actually went to an altitude of 4600 feet, a little less than designed. Also the video recorded by the camera inside the rocket showed the pictures as seen from the rocket during its flight.

Fig. 10. Testing of rocket motor on ground before fabrication.

Fig. 11. Preparations at the rocket Launch site at Tennessee by different university teams.

Fig. 12. Checking the instruments before launch by AAMU rocket team.

Fig. 13. AAMU Rocket ready to be launched at the launching pad (right).

Fig. 14. The rocket is successfully recovered after return.

9. Sustainable Research Initiative

The intent of the NASA – USLI program is to create a sustainable student led research environment in a group of institutions which will act as a catalyst for promoting the research activity in rocket and space exploration. Alabama A&M University team is one of the 20 teams selected by NASA after nationwide competition. Fortunately we have been able to receive $12000 per year financial support from Alabama Space Grant Consortium which is also matched by another $12000 from Alabama A&M University. In the 2010-2011 academic year another group of students are working on this AAMU Rocketry Team, and plan to carry some additional payloads for scientific analysis.

10. Conclusion

Involvement of undergraduate engineering and technology students in this challenging project to develop a high power Rocketry Program, in cooperation with NASA and Alabama Space Grant Consortium, have been found to be very effective in improving the students' learning outcome and their interest to do research. The students are involved in activities with diverse aspects such as planning and scheduling, purchasing, performing calculations and analysis, coordinating logistics, and design reviews, and are mentored by faculty advisors. Alabama A&M University rocketry team comprising mostly of underrepresented minority students, were excited by this project. Successful launch and recovery of the rocket and retrieval of the scientific data has inspired the next batch of students to continue this rocketry project as a sustainable research program.

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