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New Mexico Aerospace Students Association (NmASA) Technical Report

8th Intercollegiate Rocket Engineering Competition, Experimental Sounding Rocket Association
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Abstract: This document discusses the design, construction, and testing of the New Mexico Aerospace Students Association's (NmASA) 2013 ESRA competition rocket, SCEPTER (Scientific Cargo and Experimental Payload Transportation and Exploration Rocket). Details of unique design features incorporated into SCEPTER will be discussed as well as the results of its April 27th test flight.

1. Introduction

The New Mexico Institute of Mining and Technology (NMT) began its involvement in the ESRA IREC in the fall semester of 2012 as part of its Mechanical Engineering Department Design Clinic Program. In the Design Clinic, students are required to work on a particular project for four semesters. As a part of their grade, the students are required to complete several technical papers and presentations in addition to the project itself.

The student group NmASA was formed to tackle the challenges presented by the IREC competition. Throughout the fall semester, the team spent the majority of its time performing a great deal of research, design, and testing. In order to test the technologies used in the competition rocket, the team built a small test vehicle and performed several flights over the course of the year. The data and experience gathered flying the test vehicle was invaluable in preparing the team for the greater challenges for a larger rocket and in meeting the competition's requirements.

By the end of the fall semester, the team had largely completed its designs for SCEPTER and began ordering materials. Construction began early in the spring semester and was completed in time for a full-scale test flight on April 27th. SCEPTER's test flight was an unqualified success, with all systems performing as expected. Since then, the team has been fine-tuning its operations and preparing for the competition.

Throughout this process, the team's primary objective was to design and build a rocket that would successfully qualify for one or both categories of the IREC. Additionally, the team wanted a vehicle that pursued several features that are not typically found in the designs of high-powered rockets. As a test-bed vehicle, great pains were made to ensure the greatest possible versatility and opportunities for research. A modular design was developed to the greatest extent possible in order to provide the team with a vehicle that could be modified to suit varying mission requirements. As will be discussed below, this versatility of this design allowed the team to buy a larger motor casing and participate in the Advance Category with only minor modifications.

Finally, the team has been designing and building its own data acquisition system and simulation code both with greater capabilities than commercially available items. After further verification, the team will use its own altimeters to fire the recovery charges rather than using commercially available units.

2. Rocket Design and Rationale

2.1 Airframe

Because this is the team's first year in the competition and because it is the first experience most of the team members have had with high-power rocketry, in many cases the team elected to use well-proven, commercially available systems. Since the ultimate goal has been to learn the ropes of high-power rocketry and to successfully qualify in the competition, the team decided against building our rocket from scratch. Greater detail on the airframe components will be given in the next section. Figure 1 provides an overview of the major airframe components.

2.1.1 Body Tubing

In keeping with the team's design philosophy of using proven parts, the airframe consists of commercially available fiberglass tubes. The team did, however, make a number of significant deviations from the traditional methods of building high-power rockets. In every case (excluding the motor casing) the team performed all machining of the parts themselves, including milling the slots in the airframe tubes.

2.1.2 Fins

The rocket's fins were designed to be interchangeable so that with further analysis of the flight characteristics of SCEPTER, their shape and size can be optimized. The team's "fin-rail" design is one major deviation from traditional construction methods.

2.1.3 Bulkheads

Unlike most traditional high-power rockets which use coupler tubing to connect the different sections, the team uses aluminum bulkheads between each airframe section. This design was motivated by the team's desire for versatility and interchangeability of parts. For example, standard bolt patterns were drilled in each bulkhead to permit payloads, data acquisition systems, and counterweights to be placed in any area of the rocket. This standardization also eases the integration of different payloads. Additionally, the team is able to swap out damaged, obsolete, or redesigned airframe sections without difficulty.

2.2 Recovery System

To ensure the greatest possible success and safety of the team's efforts, a tried and true recovery system was utilized. It uses black powder charges, fired by redundant altimeters to separate the rocket at apogee and to deploy the parachute. A much more detailed description of this system is provided in the next section.

2.3 Data Acquisition System and Altimeters

As an integral part of the recovery system, but also as the most immediately useful area of research, the team has spent a great deal of time on the data acquisition system. Dual commercial units are implemented as primary and back-up systems. In addition, the team is developing its own altimeter/data acquisition system.

2.4 Propulsion System

Without having any experience with propulsion system development, the team elected to use commercially available, solid rocket motors. Again, with an eye for versatility, SCEPTER was designed to accommodate several lengths of ninety-eight millimeter motor casings.

2.5 Payload

The team's payload consists of advanced data acquisition and flight observation systems which will be used to characterize the rocket and monitor its flight. Vibrations, stresses, and accelerations will be recorded. The altimeter/data-logger developed by the team will also be considered part of the payload for this flight. This data-logger has the ability to measure the rocket's position with six degrees of freedom (DOF), three translational DOF's and three rotational DOF's. From these measurements, the team hopes they will be able to trace the entire flight path, including the position and orientation of the rocket throughout the flight. This process will be in support of the attitude-based safety response system which was an IREC requirement deleted from this year's competition.

3. System Analysis, Design, and Testing

3.1 Airframe

3.1.1 Body Tubing

The airframe of the team's competition rocket, SCEPTER, consists of 5.5-inch diameter G-10 fiberglass tubing purchased from Mad Cow Rocketry. This tubing was selected for its high strength-to-weight, availability, and versatility. The larger diameter allows for greater volume to house a variety of payloads and eases installation of the recovery system. This diameter tubing is also convenient for the construction of the bulkheads which will be discussed below. A Von-Karman profile nose cone was selected for its advantageous drag profile at a wide range of velocities.

3.1.2 Fins

The team designed a fin-attachment system that allows the team to have interchangeable fins. This "fin-rail" system is shown in Figure 2. The team machined the four fin-rails from 6160 aluminum. They were epoxied into slots in the propulsion bay using Pro-Set 125 epoxy. Each fin is then installed in the fin-rails using six bolts. In the event that one of the fins is damaged, it can simply be unbolted and replaced. In addition, alternative fin designs can be used for research purposes. The fins that the team will use for the competition are a simple trapezoidal shape, sized to locate the rocket's center of pressure approximately two calibers from the center of gravity as stated in the IREC rules.

3.1.3 Bulkheads

Holding the segments of airframe tube together are four bulkheads (Figure 3) the team machined from 6-inch diameter 7075 aluminum round-stock. To ensure the bulkheads could be machined from standard stock and avoid any mismatch between the bulkheads and airframe, the team used 5.5 inch fiberglass tubes. The four bulkheads replace coupler tubing which is the traditional method of assembling high powered rockets. Solid joints are held together by six 8-32 button-head screws, while the shear joints (at the forward end of the propulsion bay and the aft end of the nosecone) are assembled using three 6-32 nylon shear bolts.

The shear connections are designed to be blown apart by 3-gram black powder charges at apogee (aft connection) and at 1500 feet AGL (forward connection). To provide additional stability at the aft shear connection, a coupler-tubing extension was included in the design of the aft bulkhead. Before the bulkheads were machined, several designs were analyzed using the Finite Element Method (Figure 4). Because the bulkheads would absorb all of the stresses due to the recovery system deployment, a sufficient safety factor needed to be ensured while not adding excessive weight. Ultimately, the FE Analysis indicated that a wall-thickness of 0.2 inches is sufficient. This analysis was confirmed by a post-flight inspection of the bulkheads which sustained no damage or deformation during the test flight. To increase structural integrity of the central section of the rocket, four tie-rods run the length of the avionics bay.

3.2 Recovery System

Because of the critical nature of the recovery system, the team wanted use tried-and-true methods. At apogee, a black powder charge is ignited and the propulsion bay separates from the main body of the rocket. They are connected by twenty-five feet of half-inch tubular Kevlar cord, forged steel eye-bolts, and quick-links.

To deploy the parachute, another black powder charge fires, forcing a piston forward and pushing the parachute free and from the forward shear-connection. For the charge-side of the piston, Kevlar cord holds the pieces together. Kevlar is used near the black powder charges because of its high heat resistance. Forward of the piston, thirty feet of nine-sixteenths nylon cord is attached to the nosecone and the parachute.

The parachute inside the recovery bay is protected by a heat-resistant Nomex blanket. A spherical, twelve-foot diameter *Crossfire* parachute was selected to provide a descent rate in accordance to IREC rules.

3.3 Data Acquisition System and Altimeters

The avionics bay (Figure 5) consists of two redundant *G-Wiz* HCX 100 altimeters, one firing the primary black-powder charges, the second firing back-up charges moments later. The team has flown its HCX altimeters multiple times and they have proven themselves to be extremely reliable.

In addition to the commercial systems, the team has designed its own altimeter and data acquisition system. The system consists of three accelerometers, (three three-axis models and one single axis model), two three-axis gyroscopes, a barometric altitude sensor, a temperature sensor, and a GPS tracking system. The package is based on the Teensy 3.0 microcontroller development board.

The data gathered by this system will be used to create an accurate flight profile encompassing the rocket's attitude, rotation, and any effects these have on final altitude.

Additionally, this system is being developed specifically to fulfill the canceled IREC requirement of an attitude-based recovery system. For future competitions when it is expected that this requirement will return, the team will have an altimeter in which this requirement is built-in.

3.4 Propulsion System

SCEPTER was designed to use the Cesaroni Technology Inc. Pro98 motors. Able to accept a wide variety of casing lengths, the rocket's target altitude is highly adjustable. For the Basic Category of the IREC, the team will install a four-grain M1800 *Blue Streak* motor reload in a six-grain casing. For the Advanced Category, the team will use the N3301 motor in a six-grain extra-long casing.

The team's own simulation has been used to estimate the altitudes to which these motors will send SCEPTER. Figure 4 shows a comparison between the team's simulation and the experimental data taken from the *G-Wiz* on the team's recent test flight. The team's simulation predicts the M1800 will send SCEPTER to 10,900 feet AGL and the N3301 will yield an altitude of 23,300 feet AGL.

3.5 Payload

The primary payload will be a suite of sensors designed to characterize several aspects of SCEPTER's flight. At the simplest level, a *GoPro HERO 3* digital video camera is mounted in the avionics bay. In addition to providing high-quality video, this observation system will allow the team to verify the orientation of the rocket measured in-flight by the data acquisition system.

The team's altimeter and data acquisition system developed in-house will be a second part of the payload. This segment of payload is described in detail in the Section 3.3.

The third part of the team's payload consists of an array of sensors that will characterize other dynamic effects of the rocket's flight. Accelerometers attached to dampened and non-dampened masses as well as the structure of the rocket itself will record the frequency and magnitude of any vibrations experienced. This data will be compared to a modal analysis developed from the team's solid model of the rocket.

Finally, strain gages will be attached at points of interest, including on the bulkheads and in several orientations on the airframe tubes themselves.

4. Major Tests and Results

Every system on the rocket has been fully tested prior to the competition. Before the test flight of SCEPTER, several flights of the team's small test vehicle were performed. These test flights verified and validated the performance of onboard instrumentation including altimeters and data acquisition system, as well as verifying the team's flight simulations. Finally, the test-flights provided verification of the team's basic recovery system concept. The test vehicle also allowed the team to increase its readiness level and develop launch checklists for the competition.

Prior to the test flight of SCEPTER, the team verified that the shear connections would work properly given the correct size black powder charge. The results indicated that a 3-gram black powder charge was more than adequate to cause full separation and complete deployment of the parachute.

From the data gathered during the test flight of SCEPTER (Figure 6), the team was able to refine its simulation to more accurately predict final altitudes given a particular motor. The stability of the rocket was exceptional and it experienced very little rotation or vibration. The rocket sustained no damage and, after the first flight, was fully prepared for another launch (Figure 7).

Due to the enormous success of SCEPTER's test flight, a larger motor, easily accommodated, will be used for the Advanced Category flight. Thus, the team will be participating in both the Basic and Advanced Categories of the competition.

5. Final Design Summary

The team's rocket has, so far, met or exceeded all the goals set for it. SCEPTER has proven to be highly reliable, durable, and versatile, meeting the rocket's primary design goals. For the team's first year in the competition, we are very excited to introduce the fruits of our hard work. The following table lists the major components of SCEPTER and their source.

Table : Rocket components and their sources.

Component	Source
Airframe	Procured Commercially
Fins/Fin-rails	Student Built
Bulkheads	Student Built
Recovery System	Procured Commercially
Data Acquisition System/Altimeters	Procured Commercially
Propulsion System	Procured Commercially
Payload	Student Built

6. Acknowledgements

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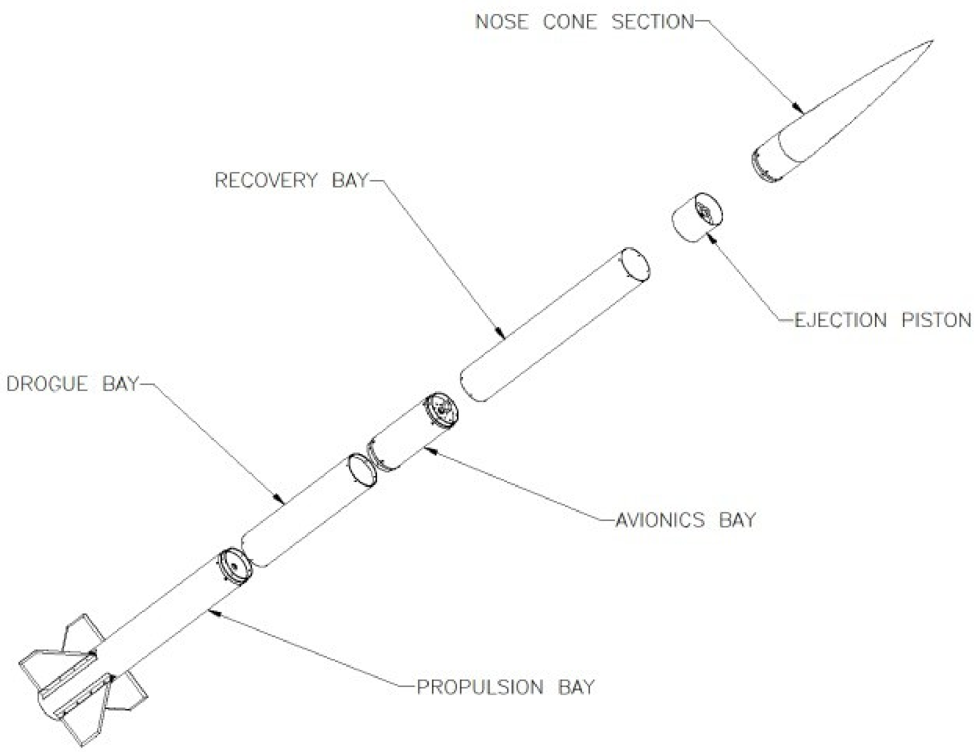
Mr. Ray Caulkins
Mr. Matt Luce
Mr. Kurt Lammon of Pocketprotectors.com

And last but by no means least, Dr. Warren Ostergren, Dr. Keith Miller, Dr. Julie Ford, Dr. Michael Hargather, and the entire NMT faculty and administration.

7. Illustrations



n-rails

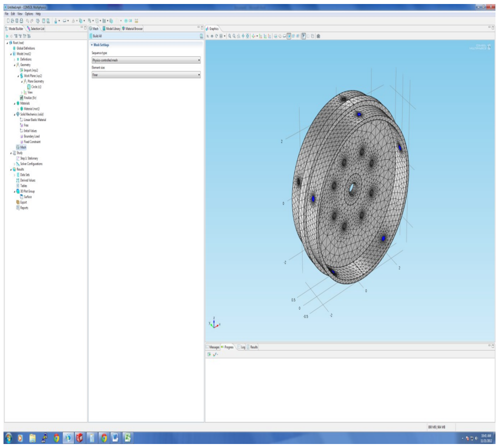


Figure : Detail of the bulkheads used in SCEPTER's design.

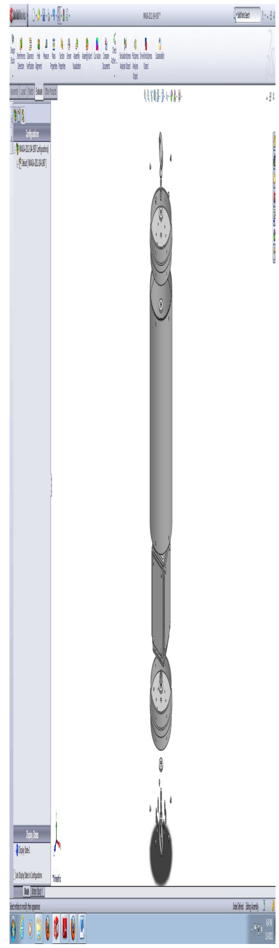


Figure : Exploded view of the avionics bay demonstrating the assembly. Camera, tie-rods, and electronics omitted for clarity.

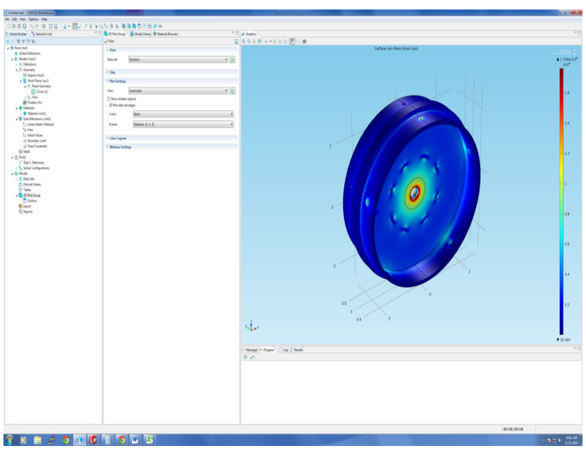


Figure : Finite Element Analysis of the bulkheads showing areas with the highest stresses.

Figure : SCEPTER prepped and ready for launch on the launch rail.

Figure : Post-recovery inspection. All systems were intact with no damage to any component.

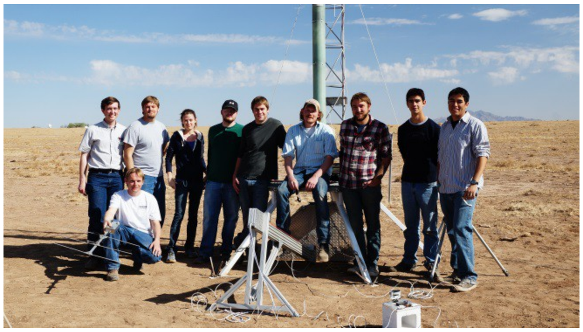


Figure : The whole team assembled around SCEPTER prior to the April 27th test flight.