Rocketry: System Development Experience and Student Outreach

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Abstract

Rocketry can provide students with exciting and stimulating opportunities to advance their systems engineering and design/manufacturing/programming skills. During the last 18 months, an 11 ft tall minimum-diameter aluminum rocket has been developed and instrumented in the School of Aerospace and Mechanical Engineering at the University of Oklahoma, sponsored by OSIDA, the Oklahoma Space Industry Development Authority. It is propelled by a N-size solid rocket engine and is expected to climb to about 22,000 ft with a maximum speed of Mach 1.5. The instrumentation includes an accelerometer, temperature and pressure sensors to measure the location and behavior of the shock wave during the supersonic flight phase, and strain gauges for the determination of the structural behavior of the rocket.

At various times during the planning, assembly, and instrumentation phases of the project, participants included local high school students, college students from sophomores to Graduates, and an OU alumnus with high-power rocketry experience. Students participated in various fashions: on a voluntary basis, by signing up for a Special Project course, or under grant support. The effort was well documented and can easily be repeated at other educational institutions.

At the same time, a student outreach activity took place, involving model rocketry. A senior from OU, again under the Special Projects course designation, was involved in a local model rocket mini course effort, covering various high schools in the Oklahoma City area. The students were exposed to the engineering and scientific aspects of model rocketry and to the design and construction of their own rockets to given specifications, culminating in a fly-off. Thus, in this learning-by-teaching environment, the College student benefited as much from the effort as the high school students who were exposed to engineering principles.

High-Powered Rocketry

A couple of years ago, one of our alumni mentioned an interesting ongoing dispute: where on a high-powered rocket in supersonic flight does the shock wave occur and how hot does the rocket body become from friction heating? We recognized this as an exciting potential student project and sought and received funding for it from OSIDA, the Oklahoma Space Industry Development Authority. Once the initial design requirements for the high-powered rocket had been laid out: to find the location of the shockwave on the rocket, to determine its skin temperature, and to gain some understanding of the structural behavior of the rocket during supersonic flight, it became clear that we had to work with a metal rocket to be able to install reasonable sensors for data acquisition. We decided on using aluminum for minimum weight. Reaching supersonic speeds would only be possible if we used a large motor (N-size) in a minimum diameter casing.

Figure 1. The Rocket

Mechanical Aspects

Since time constraints prevented us from manufacturing our own rocket, we purchased the main mechanical pieces of the minimum-diameter N-size rocket system from Dr. Rocket, an on-line retailer who specializes in custom high-power rocketry. These pieces were then modified to meet the needs of our proposed experiments.

The original cut line between the nosecone and the main trunk of the rocket was the only place that the original rocket separated. Our specifications required the rocket to break down into three sections: an instrumentation bay attached to the nosecone, an altimeter bay with housings for the parachutes, and a lower interface that connected to the motor. Upon determining the amount of space needed for the equipment in each section to ensure a successful launch, test, and recovery, it was noted that a second piece of the outer trunk was necessary for our rocket system. Dr. Rocket was able to supply the required addition

Modifications were relatively simple for the outer trunk of the rocket. Both tubes were cut in specific locations to provide the required lengths for the three sections of the rocket. The nosecone was then attached to the end of one tube. At the opposite end of this tube, a stationary parachute lug was installed along with an eyebolt to serve as the interface between the upper section of the rocket and the altimeter section via the shared parachute. Aluminum tubing was machined from rough stock to serve as the sliding couplers between each of the three sections. These couplers were fixed-mounted in the altimeter (or middle) section of the rocket. The addition of these couplers and a parachute lug on each side created a cell within this section where the three redundant altimeters could function without being exposed to high pressures from the nosecone or parachute deployment.

The nosecone underwent the most significant changes in the rocket structure. It was ported to allow measurements of the outside pressure profile during flight. A hole, approx 0.064-inch in diameter, was drilled through the tip of the nosecone. This through hole was met by a 0.250-inch hole from the backside of the nosecone while taking care not to penetrate the outermost surface of the nosecone. The stair-stepped-hole allowed a larger hose to measure the pressure at a localized point on the surface of the nosecone.

The process was repeated several times down the side of the nosecone. Each additional hole was positioned in a spiral pattern, which radiated back away from the tip of the nosecone, to insure that measurement ports would not disrupt airflow to ports downstream.

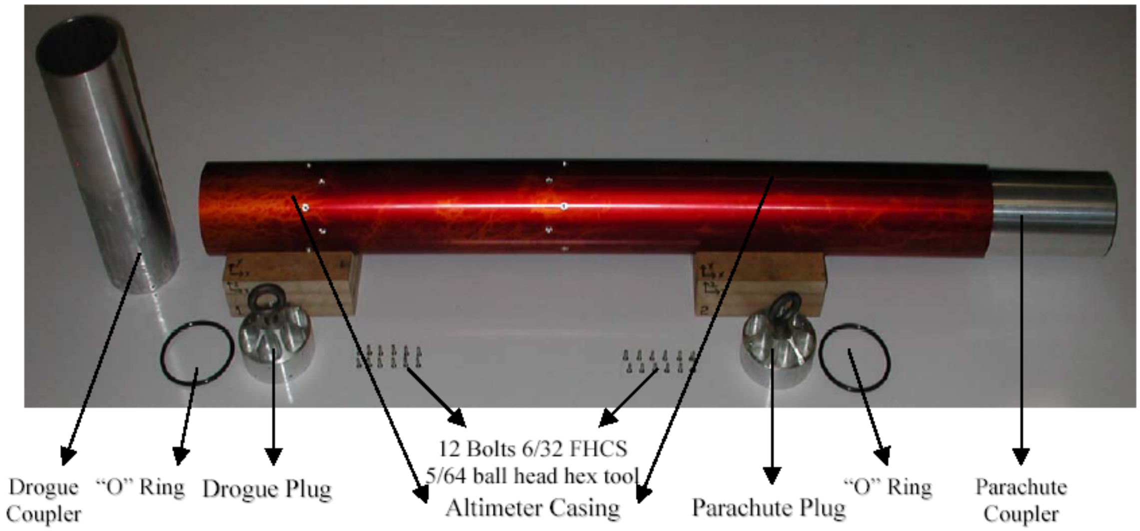

Figure 2: Mechanical Example - Altimeter Bay Assembly

A shortage of high-power solid rocket motors from Aerotech induced a search for another supplier. Upon finding a source for a motor, we were informed that the internal pressures from the new propellant would be higher than the specifications of our current motor housing. This resulted in the need for a stronger motor casing. The new supplier fabricated this casing such that it could utilize the existing interface to the rest of the rocket system.

Electronic Aspects

It was decided that the data acquisition equipment should consist of an accelerometer and a set of pressure and temperature sensors as well as strain gauges along the forward body of the rocket. These would all record to two data loggers, with the data to be downloaded after retrieval of the rocket. The biggest obstacle to our data acquisition efforts was the shortage of inexpensive electronic equipment with sufficient performance specs to perform the required measurements in the hostile environment of supersonic flight. These analog measurements were to be converted to digital signals and stored in two on-board data recorders. This left us to design and build all of our own circuit boards for the electronic system within the rocket. The tasks of developing a list of requirements that met the needs of both the sensors and the digital–to-analog converter (DAC) proved to be very time consuming. Schematics for the thermocouples and strain amplifiers were found in technical guides from Analog Devices. In a similar source, schematics were found for the use of the Motorola accelerometers and pressure sensors, which were modified for their intended use in our rocket system. From the schematics, layouts for the circuit boards were generated and transferred to an outside manufacturer who "burnt" the circuit boards. The rest of the components were soldered to the circuit boards, and the boards were tested. Each of the circuits was calibrated to establish baselines for the sensor behavior. In order to protect the boards during flight, cradles were designed to serve as the mounting interface between the circuit boards and the metal exterior of the rocket.

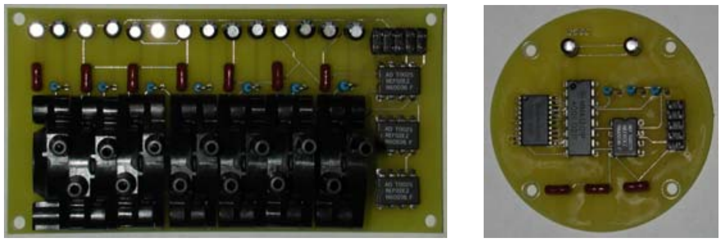

Figure 2: Electronics Example - Pressure Sensor and Accelerometer Boards

Structure and Student Involvement

The project was guided by the two Co-PIs and by two OU alumni, who brought high-power rocketry experience to the team. Together, a focus was determined and held for the tasks of the team members.

Graduate Level: A Graduate Assistant (GA) took on the task of micro-managing the team's day-to-day activities. Project updates were continually discussed with the co-investigators and new action items were generated. The GA was responsible for generating top-level constraints for systems, and finding components that would be utilized to complete the required electronic systems. In addition, he also served as the integrator for pieces that were farmed out to undergrad team members. In numerous cases, he walked undergrads through the design process such that could achieve a better understanding of the overall project goals.

Undergraduate Level: Two different styles of undergraduate participation were tried during the project. At the beginning, the project was opened up to a *"club" environment*. This style of involvement taught us several lessons: The first and foremost problem is to keep everyone busy. Students who were not directly involved soon lost interest. On the other hand, some students were overwhelmed in the early stages of the project due to the number of unknowns involved in achieving the projects goals. As the project progressed, the semester progressed as well. This presented a second challenge because students had problems juggling final exams and class projects with rocket tasks. However, a second method of undergrad involvement proved to be more beneficial. Students participating in the project through a *special projects course* could receive a tangible form of reward, a grade. Thus, course involvement could substitute for a variable number of hours, which would dictate the student's level of involvement, helping to lighten the load for a couple of seniors that still required electives before graduation. In addition, it gave the co-investigators and the managing grad student the ability to set a standard for quality of work acceptable for the project. Using this approach, parts were designed, parts lists and assembly manuals for the rocket were compiled, and performance calculations were made.

High School Level: During the course of the project, high school students from a rocketry class taught by one of the alums were brought in to participate in the discussions and in the design of subsystems such as the launch tower. It was difficult to keep them involved, however, since they were already over committed due to extracurricular activities at the local high school.

As of the writing of this paper, the rocket is expected to be to be launched in the middle of July.

Rocketry Outreach

With our rocketry outreach program, we want to expose local area high school students to the importance and excitement of science and engineering in today's world. The goal of the program is to teach them the engineering concepts needed to safely design, construct, and competitively fly the most effective model rocket. This is intended to prepare the students for such challenging projects as the high-powered instrumented rocket described above and to encourage their pursuit of science and engineering career fields after they leave high school.

Purpose and Goals

For this project, students were given a list of criteria their rocket design had to meet in order to compete effectively with other teams. The responsibility of the outreach instructor was to teach them the fundamentals of mathematics, physics, and engineering as they pertain to model rocket design to ensure that their rocket's flight would be safe, stable, and successful. This allows us to prove to the students that mathematics is not just rote recall and number crunching, but that is an essential skill in engineering that can determine whether their design is safe and stable or unsafe and unsuccessful. Along with the distributed course material, the students were encouraged to do further research about model rocketry in order to gain additional knowledge of the subject.

Teamwork

One important aspect in the field of science and engineering is the concept of teamwork. Four teams of three and one team of four were formed at Moore High School. A leader was chosen from each group and given the responsibility of dividing tasks within the group and making sure tat the tasks were completed on time. In each group, the leaders happened to be those most knowledgeable in math and science or the most motivated.

Program Structure

The high school students were introduced to Newton's Law of Motion, Barrowman's Equation for center of pressure, etc., and were provided with typical rocket flight profiles and information on rocket motors, different types of drag, and design synthesis. They were given a course packet, including instruction on how to calculate center of gravity, center of pressure, lift, thrust, etc. Even though only a few students had the mathematical and science background required for the project, they caught on quickly to the material. The only major problem was that they were committed to other science projects and, thus, had limited time available during the semester.

After learning and understanding initial concepts, students were asked to design a rocket on paper, including a component list and a 3-D drawing. This was combined with outside research and continued until a reasonable design emerged. This design was taken to the Visual Center of Pressure (VCP) software, which outputs data to determine if a rocket is safe. Each design was corrected as necessary. The resulting rockets were built from kits given to each team. Finally, the WRASP software was used to determine the projected altitude based on the F-20 engine provided to the students. The rockets were launched and students finished the project up with a written and graded report.

Conclusions

The design, construction, instrumentation and, hopefully, launch of a minimum diameter high–powered metal rocket provides an exciting means of teaching students from high school to graduate level project planning and coordination skills and giving them hands-on experience in mechanical and electronic component design and manufacturing. It is a repeatable exercise that can be implemented with the help of a local high-powered rocket club at most academic institutions.

Student outreach, such as the described rocketry class, can aid in giving undecided high school students choices for a career in science and engineering, which they might otherwise never consider. For the mentor, it allows for the development of leadership, group interaction, and public speaking skills, while providing a venue to make a difference in a child's life.

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Mr. Ortega graduated with a BS in Mechanical Engineering from the School of Aerospace and Mechanical Engineering at the University of Oklahoma in the spring of 2003. He works for Tinker Air Force Base in Midwest City, Oklahoma. This was his first exposure to student outreach.

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