Document: 2002-2401

Industry, Academia and Government Collaboration on Undergraduate Rocket Research

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Undergraduate engineering students are interacting with government and industry to pursue applied research in reusable launch vehicles for cheaper access to space. Cal Poly State University, San Luis Obispo, is flight testing subscale demonstrators of a reusable glideback booster. A highly productive collaboration has been established between NASA Langley Research Center, Cal Poly and Starcraft Boosters, Inc. to conduct research in reusable first stage booster rockets. The design for the vehicle originated from industry, and NASA supports the industry proposal by funding the university for small scale construction and flight testing. The students interact with both groups for direction and technical advice, which creates a tremendous amount of learning opportunities and motivation for the team. The project is organized as an extracurricular club activity that is purely voluntary and made up of students in several engineering disciplines. The students gain practical knowledge and real world research experience in a team-oriented systems engineering environment, all before completing their bachelors degree.

Introduction

The Aerospace Engineering Department at Cal Poly State University, San Luis Obispo, currently has an active high power rocket program that is studying rocket recovery concepts. The program is organized as an extracurricular engineering student club known as Cal Poly Space Systems. In recent years the club has focused on demonstrating rocket recovery concepts including parafoil recovery and a rocket design that incorporates a vertical launch pattern followed by a horizontal return flight and landing. These projects involve the design, building, testing and optimization of a high power rocket system, incorporating a complete project cycle and an enormous amount of hands on learning. The projects emphasize teamwork and the necessity for each person to take on a small subset of the overall task. Every team member makes a significant contribution to a specific aspect of a rocket that will ultimately only be successful if all the parts function together. The groups' activities attracted the attention of industry and NASA who now follow and fund the project.

Projects of this sort have value on many levels, foremost being the educational opportunity. It is extremely beneficial for the students to take the fundamental concepts learned in class and apply them to real world problems. Experience in meaningful problem solving increases their self-confidence and makes them more independent at their first job after graduation. Employers' value graduates who can be productive quickly after they are hired and who possess communication skills, enthusiasm, leadership and the ability to work on a team. The rocket project organizational structure acclimates students to the complex, systems engineering environment that they will encounter in industry. The undergraduates benefit from the research experience, while industry and government organizations are able to complete small research projects at a low cost, since no special facilities are required to undertake such a project. The loft of an old hangar, some hand tools, and a Tripoli Rocketry Association membership were all that were necessary to make the rockets fly. As long as the project is self-contained and reasonably conceived, students can make a contribution to real world development applications[1].

Background

The Cal Poly Space Systems (CPSS) club is a volunteer organization made up of undergraduate students from Electrical, Mechanical and Aerospace engineering. The group studies launch vehicle concepts using high power rockets, which fall into the same generic category as model rockets, but are larger and are launched on more powerful solid rocket motors. Rockets over 10-ft tall can be considered small sounding rockets, but are not large enough to launch a payload into orbit.

Since 1996, CPSS has worked on two major projects that demonstrate rocket recovery devices. The first project focused on recovery of a high power rocket using a radio-controlled (R/C) parafoil instead of a conventional parachute as the recovery device. A full size parafoil was cut in the middle and the entire mid-section was taken out. The two end pieces were sewn back together so that the control lines remained operational. The control lines were attached to a servo driven winder in the rocket that enabled the control lines to be pulled by R/C to steer the rocket back to the launch pad. A 10.5-ft tall high power rocket was built to carry the parafoil, which was altimeter deployed after apogee. The rocket, shown in Figure 1, launched twice, once to 2500 ft and once over a mile. The first launch saw the rocket land less than 25 ft from the launch pad.

Figure 1 – High Power Rocket with Parafoil Recovery System

The successful completion of the parafoil project led directly into another project that also focuses on rocket recovery. The research explores the concept of remotely controlled, fixed wing, flyable booster rockets that exercise a vertical launch followed by aircraft flight and horizontal landing. The Reusable Launch Vehicle (RLV) application is a fully reusable first stage booster[2]. The first stage RLV would lift a second stage and payload to orbit before flying horizontally back to earth for a runway landing. The rockets would then have very short turn around times and give access to space a less expensive alternative to expendable launch vehicles and the space shuttle.

RLV's represent an idea whose time has come, and CPSS is helping to demonstrate one vision of the future. The vision comes from a company called Starcraft Boosters, Inc., which has designed this completely reusable first stage booster for taking payloads to space. The booster lifts expendable upper stages and payloads to a staging point, then drops off and does a glideback or fly-back to a runway using jet power[3]. Researchers at NASA Langley Research Center are analyzing various configurations of RLV's and were interested in seeing a small scale flight demonstration of the unique StarBooster™ configuration. Cal Poly had just the right high power rocket and radio control experience to take on the project.

The StarBooster configuration that CPSS used for its subscale demonstrator testing is shown in Figure 2. The intent of the project is concept validation and data collection during flight that will aid in design and analysis of the full-scale vehicle. The subsonic rocket demonstrators have a conventional vertical launch, and then as the rocket begins its descent after its peak altitude, an R/C control system is used to fly the rocket as a glider to a controlled landing. The rockets do not have a standard symmetrical fin configuration, so CPSS decided to study the unusual StarBooster configuration by first building and flying very small rockets and having them grow progressively in size toward the ultimate goal of a 10-ft tall rocket.

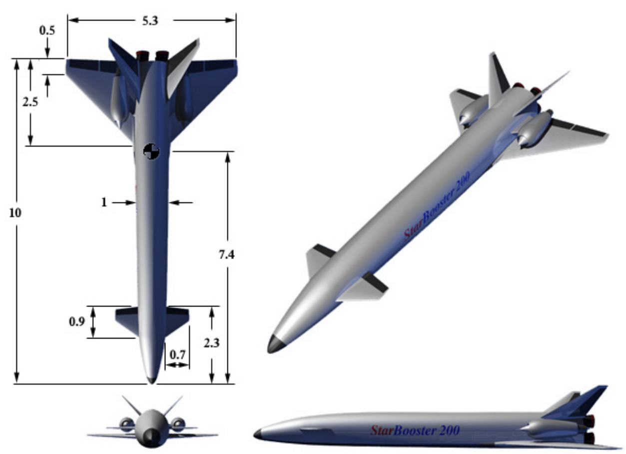

Figure 2 – StarBooster RLV Configuration

Project Description

The rocket construction tasks were divided up into small components with larger rocket tasks being assigned a responsible person based on individual rocket part. More experienced members took charge of the subtasks and trained newer people in order to develop multiple independent groups. This organizational scheme worked very well in terms of getting the group members to take ownership of their contribution to the rocket. In order to have a successful launch, every subsystem of the rocket had to work. Therefore, each person in the group was instrumental, and yet everyone had to operate as a member of a team. The general structure started with the assignment of a Project Manager, with the CPSS club officers becoming the project leaders. The technical sub-groups concentrated on individual rocket parts (body, wings, nosecone, canards, fins, bulkheads, engine mount, control surfaces, ejection system, parachute, etc.) The role of faculty advisor was not to make technical decisions. The students were capable of making plenty of both good and bad decisions and then making corrections themselves also. The club operated extremely effectively with an advisor who provided logistical, organizational, and motivational support for the team while keeping them from getting distracted or discouraged by failure.

The ultimate goal of the project was to build and fly a 10-ft tall model, which was unpractical without first testing the configuration at a more manageable size. The group had no experience with flying a highly swept delta wing/canard shaped rocket, so the flying qualities both for vertical and horizontal flight were unknown. Therefore, the atypical vehicle that was part rocket, part airplane was built and flown in six increasing scales. The organization of the group also started off simple but grew as the size of the rocket grew. New leaders emerged, and the design for each scale model was influenced by different people at different times. Since the students were volunteers, the more ownership they took over their work, the more self-motivation they had, and the better the outcome.

First, many 1-ft tall models were constructed and launched to introduce the group to the design and demonstrate vertical launch stability. Ascending qualities were further assessed with a 2-ft tall model that relied on a parachute to land. A 3-ft glider model was used to test the design in a wind tunnel and then for glide tests in actual flight. When the glide tests were successfully completed, the 3-ft was launched vertically to see if it would fly. Unfortunately, a motor failure prevented the rocket from achieving enough altitude to fly. However, the team was undeterred, and a 4-ft model was built that combined both launch and glide. The two flights of the 4-ft rocket indicated that the rocket/glider could indeed fly, but needed a shift in center of gravity (CG) during flight for stability.

The 5-ft tall model included all of the design improvements needed to achieve vertical launch and a stable glide. Dumping water ballast would shift the CG rearward during flight. The rocket also incorporated a rear deployment emergency parachute that would slow the rocket down just before landing without changing its direction of flight. The 5-ft rocket was flown three times; the last of which included a 30-second horizontal flight, the first real milestone of the StarBooster project. With this momentum, CPSS pursued its goal to develop a 10-ft model.

The first 10-ft tall rocket was built from 1-ft diameter phenolic tubing, using composite construction techniques that were new to the students, but designed to handle the increased forces expected on the larger vehicle. Control of the vehicle was accomplished by the use of four servos, one for each aileron and each canard. Figure 3 shows the 10-ft rocket before being launched on an AeroTech L-1120W motor[4]. The launch occurred at a monthly Tripoli Rocketry Association sponsored event in Fresno, CA. Although the students were concerned because the rocket weighed more than estimated, the launch proceeded as planned with a stable climb during motor burn. Unfortunately, the motor was not powerful enough to push the rocket to the altitude necessary for a reasonable glide. The rocket started to pull up after its dive, but hit the ground before achieving nose up flight and just as the parachute ejection charge fired. All the months of hard work was gone in an instant.

Figure 3 – First CPSS StarBooster 10-ft Rocket Heads for the Launch Pad

Thus ended the first year of work on glideback booster project. However, instead of being discouraged, the students were energized and determined to show that they could make the rocket fly. The designers spent much of the summer debating the best way to take weight off the vehicle and ensure stable glide. A special 3-ft powered R/C airplane was built and flown specifically to find the correct center of gravity and to better understand the horizontal flight characteristics of the StarBooster configuration. Figure 4 shows the gas powered propeller model before its test flight, which showed some horizontal instability that was directly related to its center of gravity location.

In general, it is better to formulate an undergraduate project that can be completed in a one-year timeframe. The students reached their goal to fly a 10-ft rocket in one year, but when the flight wasn't successful, the group was determined to continue for another year, so the project got a second year of life that was driven entirely by the students. In the meantime, NASA collaborators received regular briefings about developments in the project and they provided much needed technical advice for how to solve the weight and center of gravity issues. They agreed to fund an additional grant for the club to pursue the flight test goal. Top representatives of Starcraft Boosters, Inc. also came and visited students on several occasions to offer advice and encouragement. The CPSS team was very excited to have such highly placed industry and government interest in their accomplishments.


Figure 4 – R/C Powered Airplane Model

The new construction goal for the 10-ft vehicle was to make a lighter structure that, combined with a more powerful motor, would achieve a higher altitude. This time composite materials would be used to manufacture the entire rocket. Instead of a phenolic tubing body, carbon fiber was used, and fiberglass and carbon fiber replaced the kevlar skin on the wing, canards, and fin surfaces. Figure 5 shows the individual composite pieces of the StarBooster rocket before assembly. The extensive use of the lightweight foam and the composite materials decreased the overall weight of the vehicle, but the manufacturing techniques were very labor intensive and the students worked many long nights to complete the rocket for the scheduled monthly launch.

After several rain delays, the first 10-ft tall, the new composite StarBooster rocket was finally launched. The rocket weighed 80 lbs., and launched on an AeroTech M-1939W solid rocket motor. The rocket launched vertically and flight during motor burn was excellent up until the moment of greatest aerodynamic force. Suddenly, the left canard ripped off of the nosecone that was evidenced by an immediate perturbation in its vertical flight. Once it reached maximum altitude and pitched over, nothing could be done as the rocket tumbled through the air. Fortunately, the lack of a canard and a misdistribution of weight forced the vehicle into a perfect flat spin as it fell. Spinning on a completely horizontal plane, the rocket landed on the ground directly on its belly and suffered only minimal


Figure 5 – 10-ft Rocket Parts Before Assembly

damages. Amazingly, the rocket was easily repairable. A near disaster had been averted and immediate plans were made to increase the structural integrity of all the control surfaces.

Repairs and improvements were completed and the rocket fired off the launch pad at the next monthly launch. The initial ascent of the third CPSS StarBooster flight is shown in Figure 6. The same M-1939W motor was used and a perfect climb to 4000-ft altitude was again achieved. This time all the aerodynamic surfaces remained attached. However as luck would have it, as the rocket flew skyward toward apogee, the smoke plume blew in the direction of the pilot such that he lost visibility. After about ten seconds of erratic downward flight, the pilot regained visibility and controlled the flight for not more than a few seconds before the rocket quickly digressed into a vertical descent. The parachute was ejected but it detached immediately due to a structural flaw and the rocket continued its dive until it hit the ground. Very little of the rocket remained intact.

Figure 6 – Third 10-ft StarBooster Launch

The mood was grim and the students had to make the tough decision of how best to continue even though after three separate flights with two different 10-ft rockets, they had failed to demonstrate the launch and glide. They could decide to go back to launching 5-ft rockets, or not to build any rockets until they were convinced they would succeed. They knew they had five weeks to prepare for the next available Tripoli launch. Only the truest form of determination enabled them to make the decision to build a completely new 10-ft rocket and fix the design weaknesses.

While construction began for the new rocket, tests were done in order to re-assess the issue of the center of gravity. After observing the second launch, it was thought that the nose was too heavy for a successful glide. Two small, easily manufactured launch and glider models were built and tested to resolve the issue. In the meantime, improvements were made to the rocket design and its construction. The vertical fin was modified to decrease roll sensitivity and the body tube was made out of fiberglass instead of carbon to decrease electrical interference. The main wing, motor mount and parachute were also reinforced. Finally, the color scheme for the rocket was changed. A flight-test orange top and black bottom would hopefully allow the pilot to better distinguish the rockets orientation than the white and black vehicle did.

After many busy days and nights of construction, the fourth and final launch of the season ended with enormous success in that the rocket finally achieved nose-up flight. The ascent was inspiring and the 3500 ft altitude allowed for enough room to dive and gain speed for a spectacular pull up into horizontal flight. The StarBooster made two turns and flew two long (an estimated total of 1500 feet) horizontal paths completely under the control of the pilot. The parachute was deployed at the end of its last flight path, while the rocket was still horizontal. The landing slightly damaged the tip of the nose and the edge of a wingtip, but the structure was essentially unharmed. Figure 7 shows the rocket before launch and again after it landed.

Although it took two full years to accomplish, the goal of launching a 10-ft rocket vertically and then flying it horizontally by radio-control had finally been realized. The jubilant team showed themselves and everyone else watching that determination and perseverance could overcome the disappointment of the multiple failures along the way. Lessons like this are not taught in a classroom, and it stands as a clear demonstration of the power of group experimental projects for undergraduate students.

Figure 7 – Before and after Smooth Landing of Successful Fourth Launch

The next challenge for the determined team of rocket scientists is to launch clusters of booster rockets. Two booster rockets are being launched together with a conventional rocket as a center upper stage to test the separation dynamics of the RLV design. This launch sequence – two StarBoosters lifting off simultaneously, detaching after burnout and gliding back to the ground while the second stage engine lights and continues ascent – is exactly the trajectory the first stage boosters would fly on a full-scale vehicle. The cluster rocket testing will follow the same project development structure. Demonstrators will again be built in increasing scales to test the separation mechanism and flight characteristics of the boosters after separation. The new one-year goal will be to land both of the glideback boosters and obtain flight data.

Summary

Undergraduate engineering students have established meaningful ties with government and industry representatives to pursue applied research in reusable launch vehicles. Cal Poly has been flight testing subscale demonstrators of a reusable glideback booster using high power rocketry as a constructive research medium. The students designed, built and tested a series of high power rockets that launched vertically and landed horizontally like a conventional aircraft to aid the aerospace industry in developing an inexpensive, truly reusable first stage booster with a short turn around time to relaunch.

The collaboration between NASA Langley Research Center, Cal Poly and Starcraft Boosters, Inc. has been a mutually beneficial arrangement. The students interacted with both groups for direction and technical advice, which generated tremendous learning opportunities and overall motivation for the team. The students acquired practical knowledge, and real world research experience in a team-oriented, project engineering environment. The hands-on training was ideal since most aerospace industry jobs put new engineers on a team on day one. Students individually learn fundamental engineering in their classes, but can never have enough multi-disciplinary and team work experience[5].

The project is organized as a purely voluntary extracurricular club activity made up of undergraduate students in several engineering disciplines. The rocket design, construction and flight test were broken down into smaller sub-tasks that simulated a complete project engineering cycle on a small but valuable scale. One of the main benefits of this type of project organization was that each person was responsible for a small part of the larger project. Everyone on the team realized that the complex project required more than any single person could accomplish, and that they had to rely on each other for success. In addition to gaining technical expertise, students participated in communicating their work to industry representatives, which is an equally important skill for new engineers. The project also allowed students to practice leadership in a low risk environment, another important component of a well-rounded education[6].

Finally, several important group dynamics emerged during the course of the project. The accomplishments of the CPSS StarBooster Project team would certainly not have been possible without definition of a reasonable goal for the program and a coherent structure for its project management. However, the team most definitely rose to the level of the expectations for them. Encouragement and support produced amazing results. And consistently throughout the project, it was most fortunate that since the volunteers were self-motivated, the energy of the group was always positive.

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