3D-Printed Model Rockets in Secondary Engineering

Bringing together the technical skills of CAD and 3D printing into the collaborative challenge of designing a safe and operable custom rocket is no small task.

BY DYLAN FEDELL AND DYLAN GERONI

Introduction

Launching a model rocket with high school students is a fun and engaging activity with rich educational opportunities. As the final project in my introductory engineering course, students design, build, and test 3D-printed model rockets, adding an element of excitement to their learning while developing their engineering and interpersonal skills.

At the intersection of design and manufacturing, additive manufacturing (AM) techniques, specifically material extrusion in 3D printing, have important scientific and industrial applications, offering low-cost, rapid prototyping and product development (Williamson, 2015). Also widely accessible to recreational and educational users, 3D printing has helped establish the "maker" movement (Bilen et al., 2015) through relatively inexpensive machines and a slew of free software and open-source project files. As such, printers are now a well-established tool in many of our students' homes and classrooms.

Rocketry in Schools

Originating in the 1950s (Colburn, 2012), model rocketry has been recognized as a valuable educational tool since at least the 1970s (Reese, 1975)—especially in the context of a strong national initiative originating during that time to improve science, technology, engineering, and mathematics (STEM) teaching in schools. Contemporarily, students have opportunities to engage in science and engineering practices through model rocketry that make up the core of *Next Generation Science Standards* (*NGSS*) (NGSS, 2013) and *Standards for Technological and Engineering Literacy* (*STEL*) (ITEEA, 2020). As educational partners, organizations like the National Association of Rocketry (*www.nar.org*) and the American Rocketry Challenge (*www.rocketcontest.org*) are helping to sustain rocketry in schools and after-school programs across the United States.

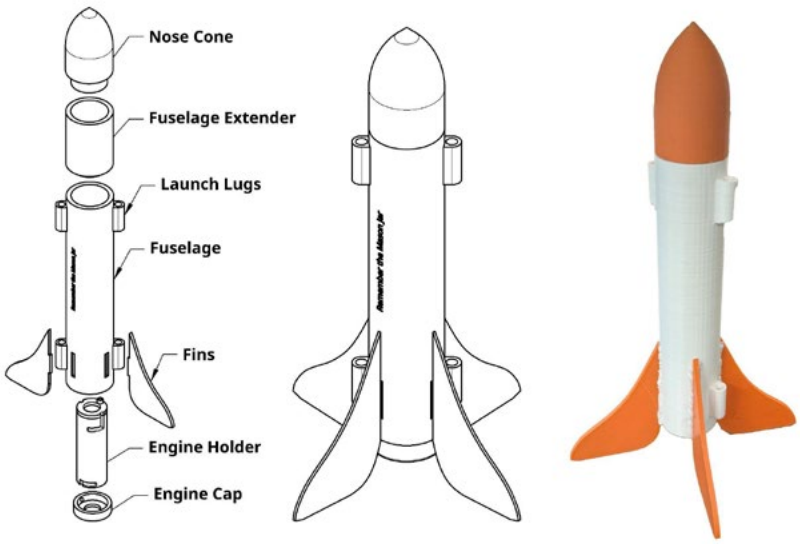

Figure 1. On the left is a component diagram of a student-designed rocket, including the CAD rendering (center) and final assembly (right).

A literature search yields many educational applications of model rocketry, including design-build-test projects in post-secondary engineering (Elger et al., 2000; Bilen et al., 2015) and secondary physics classrooms (Widmark, 1998; Horst, 2004; Keith et al., 2013). Regarding the novelty of 3D printing model rockets in education, I know only a

few published and publicly available examples. One example is Bilen et al. (2015) in post-secondary engineering education, and the second is a now-defunct company called RocketEd (*www.facebook.com/rocketedllc*) that was developing materials for secondary classrooms as recently as 2020.

Project Overview and *STEL* Connections

Positioned as the final project in my Introduction to Engineering Design course, students have a moderate level of skills and experience regarding computer-aided design (CAD) and manufacturing processes, including 3D printing. A three-week timeframe of 90-minute classes is sufficient even with variations in weather conditions, subsequent repair after damage during testing, and the number of prototypes students choose to test. The project aligns with several secondary *STEL* benchmarks, which are detailed in Table 1 and referenced throughout this section.

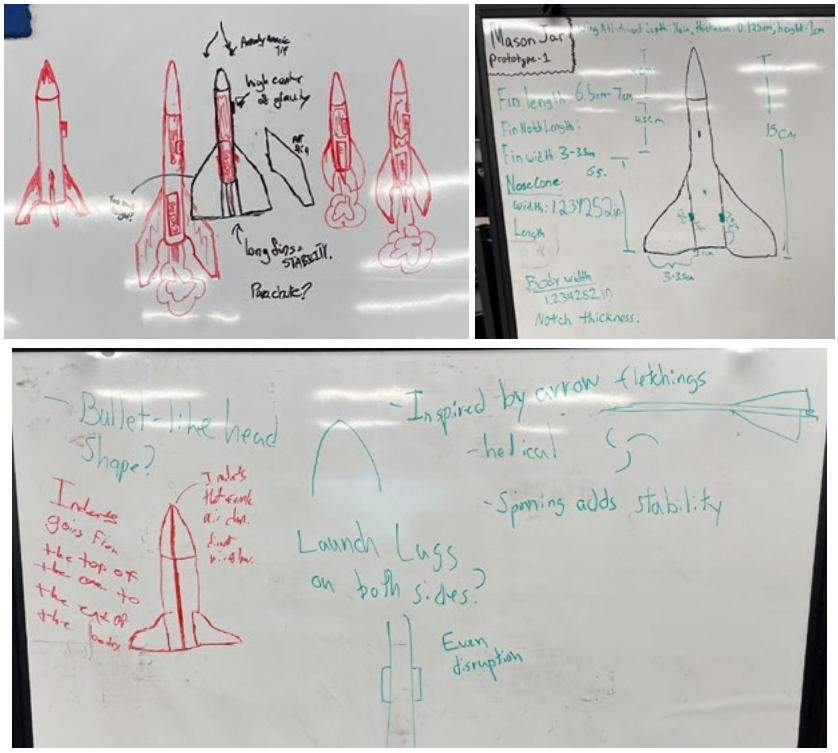

Figure 2. Examples from different classes demonstrate that the initial planning stages between the two build teams are crucial to the process, spanning from students' initial conceptions (top left) to planning dimensions (top right) to other design considerations (bottom).

The rocket comprises five components: propulsion and recovery systems, nose cone, fuselage, and fins. As shown in Figure 1, the nose cone, fuselage, and fins are first developed in CAD before being printed using 3D-printing technology. As discussed later, they must not exceed the printer's dimensions, which are approximately 20 cm square. I also provide some commercially available materials for the build, including solid-propellant rocket engines, engine hooks, fire-resistant wadding, shock cord, and launch site materials. The recovery system, a parachute, utilizes recycled or repurposed materials that are readily available in my classroom or provided by students.

As the culmination of student learning in the course, we begin by discussing how complex products, such as mobile phones, cars, buildings, and spacecraft, require multiple

STEL-2Y - Implement quality control as a planned process to ensure that a product, service, or system meets established criteria.	Students implement quality control as a planned process to ensure the rocket meets established criteria by test-fitting printed components, measuring weight, and using slicing software to ensure their design meets established criteria.
STEL-2Z - Use management processes in planning, organizing, and controlling work.	Teams implement management processes by selecting lead engineers, delegating responsibilities, and managing time and resources to complete their rocket.
STEL-7BB - Implement the best possible solution to a design.	Students implement the best possible rocket design after testing and refining prototypes to optimize performance and meet constraints.
STEL-2X - Cite examples of the criteria and constraints of a product or system and how they affect final design. **STEL-7X** - Document trade-offs in the technology and engineering design process to produce the optimal design.	In their report, students describe the effects of constraints, including 3D printer dimensions, material properties, and weight limits set by engine specifications, as well as their decisions regarding tradeoffs in material usage, weight reduction, and recovery systems in their final design.

Table 1. Connections between *STEL* Benchmarks (Gr. 9-12) and student actions in the classroom.

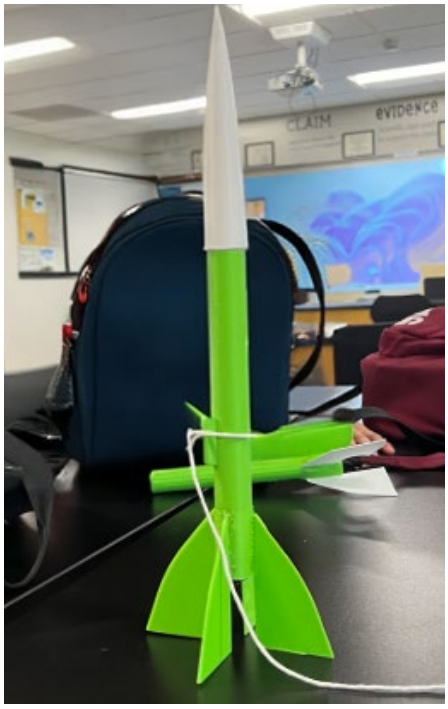

Figure 3. One example of a previous year's rocket on display in the back of the classroom.

teams of engineers. Students then watch Mark Rober's (2022) Egg Drop from Space video. The video does an excellent job portraying the engineering design process and the real-world implications of engineering and manufacturing complex products across multiple teams. Following the video, students reflect on the benefits and challenges of collaborating on projects, and I introduce the challenge, "Safely build, test, and recover a 3D-printed model rocket designed by the class." Next, students research model rocketry using educational materials offered by NASA (NASA, 2023).

On day two, using several whiteboards and plenty of dry-erase markers, students brainstorm the rocket's general design, including aesthetics and dimensions (Figure 2). By developing a consensus, they implement the best possible design as they see it (STEL-7BB). Then, students are split into two teams of six to eight. They implement a management process by selecting lead engineers for each team, delegating responsibilities, and managing time and resources to complete their rocket (STEL-2Z). One team is responsible for designing and building the fuselage, while the other focuses on the nose, fins, and recovery system. Each lead engineer is responsible for final decisions related to the project, not just taking command, but also considering input from other team members and persuading others to move forward with design decisions. Dividing the class replicates the real-world nature of complex engineering projects, where teams are often separated. Designing different aspects of the same product makes communication between teams a key component for success. With their team members, students predict the critical features they must discuss with the other team. The teams then meet to finalize and discuss design features. From then on, students design their parts in CAD during designated work time on days three through six.

Figure 4. A small section of a rocket fuselage with the fin and engine cap attached. You can also see that students were experimenting with welding the fin to the fuselage.

Figure 5. The instructor is preparing to launch the rocket depicted in Figure 1.

While students engage in the project, I circulate and field questions, taking on the role of the most experienced rocket builder in the room. Offering insights on what has worked in the past and providing examples of commercial and previous years' models helps students produce working prototypes with minimal safety hazards and dead ends. The commercial rockets I have available are the Estes Journey, which I purchased as a launch set on Amazon for $40 at the time of writing (Amazon.com, 2025). The added benefit of purchasing the launch set is the launch pad and controller, which we repurpose for launching our custom rockets. The previous year's models, one of which is shown in Figure 3, are displayed in the back of the classroom, allowing me to easily reference them during my consultations with students. In the Materials, Methods, and Insights section, I provide a detailed discussion of the successful and less successful aspects of previous designs, which I also share with students.

I also facilitate the printing process, allowing students to print pieces to test designs before prototyping the entire rocket. As shown in Figure 4, printing a few inches of fuselage from the bottom up allows students to test engine bay dimensions, fin placement, and fastening techniques, with minimal time and materials. Test pieces can be printed at any length by simply stopping the print. Throughout the process, students check the predicted weight of the rocket using the slicing program's filament-use predictions. They ensure their design meets established crite-

Figure 6. Students repurposing kite fabric for their rocket's parachute, learning to sew in the process.

ria by test-fitting printed components and using slicing software to predict the rocket's final assembled weight (STEL-2Y). Once satisfied with their design, the rocket is ready for printing and full assembly.

On days seven and eight, students integrate all aspects of the build, including propulsion and recovery systems, prior to stability testing. Testing may result in modifications, but the rocket is usually ready for lift-off on days nine and ten. Before launch, I check the weather conditions, particularly wind direction and speed. Students then check and recheck their assembly, ensure their recovery system is packaged correctly, and head outside. While launching model rockets has become routine, we follow the Model Rocket Safety Code established by the NAR ("Model Rocket Safety Code - National Association of Rocketry"), which outlines many safety aspects, including launch site requirements. As such, we are fortunate to have a large amount of open space surrounding our school. We set up on the baseball field, which is upwind of our prevailing winds, ensuring that if the rocket is blown off course, it lands on school grounds rather than on a roadway (Figure 5).

The remaining days of the project are spent writing a report on findings, where students discuss the problem and document their solution. In their report, students describe the effects of constraints, such as 3D printer dimensions, material properties, and weight limits set by the engine specifications, as well as their decisions about trade-offs in material usage, weight reduction, and the recovery system in their final design (STEL-2X, STEL-7X). They also detail the information they have gathered, their initial and final design solutions, their implementation of the engineering design process, and a reflection of their contributions to the project.

Materials, Methods, and Insights

This project has two central constraints: the dimensions of each component (fuselage, nose cone, and fins), which cannot exceed the dimensions of the 3D printer, and the rocket's weight, which is determined by the size of the engine. The 3D printer is a Creality Ender 3-Pro using standard PLA, and the rocket engine is an Estes B6-4. The former ensures that no single part can exceed 20 cm square. The latter imposes a total weight limit of 113 grams, which was determined using the Estes Engine Chart (Estes, n.d.), available online through the University of Washington.

As such, students cannot simply choose maximum dimensions in their design. They must discuss and trade off between diameter and length to accommodate the propulsion and recovery systems while staying within the weight requirement. I set the rocket's maximum diameter to 5 centimeters (excluding fins) and length to 40 centimeters, with a minimum wall thickness of one-eighth of an inch. I would consider reducing the minimum wall thickness using stronger and more heat-resistant materials, such as ABS. There are also minimum dimensions, but these are more implied as you cannot have a diameter less than the thickness of the fuselage plus the diameter of the engine. Similarly, you cannot have a rocket any smaller than the length of the engine plus the recovery system (fire-resistant wadding and a parachute), which brings the minimum length to around 20 centimeters; then, a nose cone is required.

Students frequently want to use exact dimensions, which often creates a tight fit between components. An example is the inner diameter of the fuselage, which students want to match exactly to the engine's dimensions. Friction fitting an engine is an appropriate method of securing the engine within the fuselage, but I've found that removing the engine can be difficult. Instead, I require a hook,

Figure 7. Examples of welding and "brazing" 3D-printed components (left and center, respectively) and a combination of both techniques on the final rocket assembly (right).

which makes extraction easier, as you can pull on the hook with pliers if the engine becomes stuck; however, this also makes the inner diameter challenging to predict. In these cases, I encourage students to print a small (one-centimeter) segment of the fuselage to check the actual fit and adjust dimensions in CAD as needed. Other means of securing the engine inside the fuselage are acceptable on a case-by-case basis, such as the removable cap seen in Figure 1.

To remain within the rocket's weight limit, students often decrease the infill of the fuselage (to a minimum of 20%) and the nose (with no minimum requirement) before resorting to other measures that might compromise stability or recovery. For example, replacing or reducing parachute material, or reducing the size, number (minimum 3), and thickness of the fins.

The recovery system, a parachute, requires extensive testing, for which I have students devise their testing protocol. Usually, students attach a 100-gram brass weight to their parachute and drop it from the classroom ceiling; other times, they hold the parachute from outstretched hands and spin rapidly—both have their merits. From a ceiling drop, students can validate the effectiveness of the parachute, and by spinning, they can replicate the entire deployment process from packed to open. For materials, I provide a one-quarter-inch-wide elastic band for the shock cord and painters' plastic, although any material can be used. Students shown in Figure 6 are preparing kite fabric; however, the most effective material to date has been a plastic grocery bag(!). The most frequent recovery system issue is the parachute not deploying. Sometimes, it appears the parachute was packed too tightly and cannot open; other times, it is too snug within the fuselage, and the ejection charge fails to push it out.

Assembling their rocket, students often use traditional fastening and construction techniques (such as glue, tape, and sandpaper) to ensure a proper fit. However, they are encouraged to think outside the box to meet their specific needs. An example of this, as my student writes below, is pioneering techniques for fastening interchangeable fins, such as "welding" pieces together with a soldering iron, "brazing" pieces together with a 3D printing pen, or both (Figure 7).

Once finished with assembly, students check the rocket's stability by employing a swing test. They securely attach a long string (approximately two meters) at the center of gravity of the assembled rocket and swing the rocket above their heads in a relatively horizontal circular motion (Figure 8). If, while swinging, the nose of the rocket points in the direction it is traveling and continues to do so, the rocket is deemed stable. Because the location of the center of gravity coincides with the fulcrum placement to balance the rocket, students rest the fuselage of the assembled rocket on their index fingers, sliding them together, and the location where they come together is the center of gravity. A full description of the swing test my students perform, including a discussion of how center of gravity and forces determine rocket stability, can be found online in *Estes Model Rocketry Technical Manual*, made available by the University of Washington *(Simon et al., 1993, pp. 5-6)*.

Classroom Connection

The following section is written by one of my former engineering students who participates in the Engineering Career Pathway at our school. He served as the lead engineer on this project and helped pioneer new fastening techniques in my classroom (plastic welding and brazing).

Figure 8. A student tests the stability of their class rocket. They swing it around by its center of gravity, observing if it orients itself correctly—this one passes the test!

Student Perspective

As a student who participated in this project, I believe it holds significant value for high school students everywhere by teaching real-world problem-solving and technical skills while fostering communication and collaboration. Personally, this project presented challenges that deepened my understanding of engineering, like effective communication and a higher level of mechanical thinking. It also allowed me to better understand my strengths and weaknesses as a capable and reliable teammate.

Understanding problems in real-world circumstances that need to be solved and finding ways to fix them in a group can put many students a step ahead in life. At the same time, understanding and talking through ideas can be difficult, but effective communication can simplify this task while fostering collaboration. One struggle that my team and I faced was communicating with the nose cone and fin group to make our designs work together seamlessly, finding a way to attach the other group's fins to our fuselage. Both group leaders brought their teams together to discuss the problem and efficiently came up with a solution: to attach a notch to the fins so they could push right into the body. This exemplifies the continuous communication required for the project's success, and I feel that this project helped many students like me learn how to express themselves and their thoughts effectively with people they may have never spoken to before. This specific struggle is one that I found helpful because it improved my ability to convey my thoughts and ideas, something I previously found difficult.

Solving problems that arise in the moment is a difficult task, but this project showed us how to accomplish this while teaching us technical skills that can be used in future applications. As we progressed through the engineering process, issues naturally came up. We had to understand these problems, think of a solution, and then implement these ideas in their entirety. An example of this process was finding a way to glue or fully secure the fins onto the fuselage of the rocket and make them interchangeable. Both groups understood that just snapping the wings on the fuselage would not be strong enough, as the high-speed movement would cause them to break off, and we also decided that glue would be too permanent for our needs. In the end, after experimentation and much testing, we determined that using a wood burner to melt the wings onto the body and then using a 3D printing pen to weld over the seam would be feasible. The benefits included making the connection less permanent, as we could just melt them off, if needed, while creating a much stronger connection than glue or a friction fit could offer. This problem helped me think outside the box in the realm of engineering, by thinking of other techniques and tools to improve our design, which I can use in future projects that require creative thinking.

Through this project, I was part of many great experiences that allowed me to improve my mechanical thinking while practicing teamwork and effective communication. Ultimately, it was an extremely rewarding feeling seeing our rocket fly high after all of the iterations and testing the team had done, which has magnified my love for engineering.

Conclusion

Bringing together the technical skills of CAD and 3D printing into the collaborative challenge of designing a safe and operable custom rocket is no small task. As such, the greatest challenges typically involve the recovery system (parachute) and rocket stability, particularly in terms of fin orientation and design. Thus, several updates could enhance this project, including the use of launch-simulation software and exploring alternative methods of recovery.

OpenRocket (OpenRocket, n.d.) is an exciting software that enables users to build rockets using custom or preloaded components, calculate their stability, and simulate a launch. For this project, its greatest strength would be enabling students to view the relationship between fin design and stability in real time. One of its few limitations is that it cannot run on a Chromebook, which is the district-provided technology at my school. I tried this software on a Raspberry Pi 5, using Java.

Developing a reliable parachute recovery system is one of the most challenging aspects of this project. An alternative that might increase the safety and reliability of recovery would be to utilize a commercially available parachute system. That said, the Estes Model Rocketry Manual *(Simon et al., 1993, p. 9)* offers alternatives including featherweight, tumble, streamer, helicopter, and glide methods. I suggest doing your research and considering the time and materials constraints of your teaching situation before settling on any one.

Overall, for students anticipating a triumphant launch day, their success ultimately lies in the growth they experience along the way. The custom nature of the project offers an authentic learning experience for students to explore the principles of design and manufacturing. It transforms abstract engineering concepts into hands-on, memorable experiences while developing essential skills such as communication, problem-solving, and teamwork. For students, this project marks the end of a course, but it fuels their motivation to continue engineering.

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