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Lessons Learned from Starting a Student-Led Rocket Club and the Collaborative Effort between the Club and a Rocket Course

Jacob Michael Blocker

I am currently a senior in aerospace engineering at Iowa State University. I have worked as an intern at NASA KSC for the past 2 summers (2021/2022) for the Launch Services Program verifying contractor launch vehicle engine performance, and will start full-time in summer 2023 as a propulsion engineer at SpaceX. During my time at Iowa State, I have been highly involved with the Cyclone Rocketry team, leading the propulsion team during the 2021-2022 academic year, and serving as the Vice President of the club during the 2022-2023 school year.

Dr. Benjamin Ahn, The Ohio State University

Dr. Benjamin Ahn is an Associate Professor at The Ohio State University in the Department of Engineering Education.

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Abstract
As the focus of the aerospace industry shifts toward the space sector, increasing numbers of college students across the country are searching for ways to gain practical, hands-on experience in designing, manufacturing, and testing rockets. Student-led clubs are one way for students to obtain that experience. This paper highlights one engineering club at Iowa State University (a Midwestern university in the U.S.), the Cyclone Rocketry club, and focuses specifically on the club's propulsion team. The paper presents the propulsion team's efforts to pioneer new rocket technologies, create several powerful rocket motors, and collaborate with the university's aerospace engineering faculty to create supplementary teaching materials for a new rocket propulsion course. Furthermore, the paper describes lessons learned and provides recommendations for starting and running a propulsion team in a university setting. The paper benefits college students interested in creating similar student-led rocket clubs in their respective universities and engineering faculty members interested in collaborating with such clubs to introduce real-world problems and demonstrations in their rocketry courses.

1. Introduction and History of Cyclone Rocketry Club

The Cyclone Rocketry club is an engineering club at Iowa State University (ISU) in the U.S. that provides students with hands-on experience in designing, manufacturing, and testing large, high-power rockets. Cyclone Rocketry's mission statement is "to educate, challenge, and inspire the Iowa State students, community, and future generations about rocketry, science, engineering, and space exploration." Although Cyclone Rocketry is a relatively new organization, only in its fifth year as of 2022, it is well-respected within the Iowa State engineering community. The club won the title of Newcomer Club of the Year in 2017, received the Iowa State Outstanding Achievement Award, and amassed over 100 active members to become the largest engineering club on campus. The club operates on a yearly design cycle, culminating in manufacturing a sounding rocket for the Spaceport America Cup competition in Las Cruces, New Mexico (see figure 1).

Figure 1. Cyclone Rocketry's rocket "Nova Somnium" lifting off at the 2019 Spaceport America Cup Competition.

The club was founded in 2017. Several engineering students desired a rocket group on campus that was not constrained to particular projects or competitions, and these dedicated undergraduates laid the groundwork for a new rocketry club that would choose a goal at the beginning of each year and build a rocket to achieve that goal. Crucially, this new club introduced more students to high-powered rocketry certifications, allowing students to launch their own personal rockets, which had previously been inaccessible due to the high costs, by subsidizing them with club funds.

Today, Cyclone Rocketry looks different from how it did in its first year, when the club had fewer than ten members. At first, due to the club's small size, members often found themselves working on many different areas of the rocket because there were not enough people to compartmentalize the rocket's design and manufacturing. Nonetheless, the 2017–2018 team built the heaviest rocket Cyclone Rocketry has made to date and competed in the 2018 Spaceport America Cup, placing fourth overall out of 150 teams worldwide.

After its successful first year, the club quadrupled in size to over 60 members in its second year. In the 2019–2020 school year, the club doubled in size again, reaching over 100 members. As the club has grown, it has continued to compete in the annual Spaceport America Cup but now also has the workforce to embark on a broader array of projects and explore specific aerospace subfields in depth.

Now that Cyclone Rocketry possesses over 100 members, the club splits students into six smaller "subteams," each specializing in a particular part of the rocket. Dividing the club into these groups ensures that all students can contribute to the club's overall success and allows students to work on projects that suit their particular interests. The six subteams are as follows:

- The **mechanical team** specializes in the design and manufacture of the rocket's metal components. This team is also responsible for designing and implementing the air-braking system used to throttle the maximum projected altitude of the rocket.
- The **avionics team** develops custom electronic circuitry to log flight data and creates the software necessary to track the rocket's performance characteristics while in flight.
- The **payload team** is responsible for developing a scientific experiment to be launched atop the rocket, which is the main reason the rocket is launched in the first place. The team's past scientific instruments have consisted of piezoelectric sensors and vibration damping mechanisms.
- The **recovery team** is tasked with manufacturing custom parachutes for landing the rocket safely on the ground after ascent. The recovery team also creates parachutes for smaller test rockets used by other subteams to test hardware for the larger rockets the club produces.
- The **aerostructures team** designs and fabricates the composite tubes that are the rocket's external structure. This team also works with several labs on campus to structurally test their components and ensure they are strong enough for rocket flight.
- The **propulsion team** works on all aspects of the rocket's propulsion system, designing and manufacturing the large solid motors that propel the rocket to the desired altitude. The team has developed many novel techniques for casting propellant and manufacturing the large rocket motors needed each year.

The various teams allow students to gain relevant industry experience, and the students leading each team also develop important leadership skills. The student leaders are responsible for ensuring their team's progress without exceeding schedule or budgetary constraints. The club holds two general meetings each week where the subteams touch base and communicate ideas (see figure 2). Additionally, individual teams are encouraged to meet more times throughout the week to hold work sessions, where most of the tangible work on the rocket is completed.

Cyclone Rocketry's positive impact on its members persists even once they have graduated. One club alumnus who now works for a leading rocket technology company has said, "Cyclone Rocketry was a very integral part in helping me obtain my current position, [...] and has fully prepared me for the type of work that I am doing for [my current company] regularly." When asked if Cyclone Rocketry affected their career, another alumnus, who was a member of the propulsion team and now works at one of the largest aircraft corporations in the world, stated that Cyclone Rocketry "was the most valuable thing [...] in terms of gaining experience to get the internships and job opportunities that I got in the aerospace company."

Figure 2. A Cyclone Rocketry weekly general meeting with all teams present.

2. Propulsion Team

2.1 Purpose and Members

This paper spotlights the propulsion team. The propulsion team is of particular interest in discussing Cyclone Rocketry because of how integral the team is to the club. The team's composition changes annually but typically consists of roughly 20 students who work on a variety of tasks. The propulsion team does not have any smaller breakout teams so that any member can work on any aspect of the propulsion development cycle. The team builds the majority of the propulsion components and is responsible for ensuring safety around the propulsion-related devices. Specifically, the propulsion team is tasked with designing and implementing a custom solid rocket motor propulsion system for the rocket and so must handle highly energetic materials safely. Therefore, the propulsion team has two main advisors: a safety advisor who supervises all activities undertaken with energetic materials and a technical advisor who is highly knowledgeable about propulsion. These two advisors permit the team to access on-campus laboratories that specialize in manufacturing energetic materials. Access to those laboratories allows the team to safely mix and cast the solid rocket propellant articles necessary to construct a rocket motor. Once the propulsion team is ready to test a new motor, the two advisors oversee design reviews and closely monitor the physical hardware to ensure that student risk is minimized during testing.

2.2 Past, Current, and Future Propulsion Team Projects

While Cyclone Rocketry was founded in 2017, the propulsion team was not created until after the first year, when the club realized that self-developed propulsion devices would greatly benefit the club in competition and give students more experience working on industry-like projects. In the propulsion team's first year, it gathered necessary background information, recruited the necessary experts to help with the safe design and implementation of rocket motors, and worked on preliminary motor designs. By the end of that first year, the team had fired a motor that produced over 100 pounds of thrust and was a developmental stepping stone toward future propulsion work at not just Cyclone Rocketry but ISU as a whole.

Figure 3. The largest motor ever designed and built at Iowa State was developed by the Cyclone Rocketry propulsion team and produced over 800 pounds of thrust.

Figure 4. The first solid rocket motor developed by the Cyclone Rocketry propulsion team.

Since that first motor, the propulsion team has successfully fired over 30 solid rocket motors, including the largest ever fired by ISU students (see figure 3). The propulsion team is unique among college rocket propulsion groups because it aspires to design and manufacture as many components (and related components) of the propulsion system as possible (see figure 4). The students build everything from test stands to complex data acquisition systems from the ground up. Designing and manufacturing almost every aspect of the rocket motor in-house gives students ample experience working with complex systems. While most rocketry teams usually have large test stands welded by third-party companies, members of the propulsion team learned how to weld and manufacture entire test stands by themselves and demonstrated that their finished test stand exceeded the necessary strength requirement for testing (see figure 5). The propulsion team has also developed custom data acquisition hardware and software to collect performance data during tests while positioned over half a mile away to comply with stand-back distance requirements.

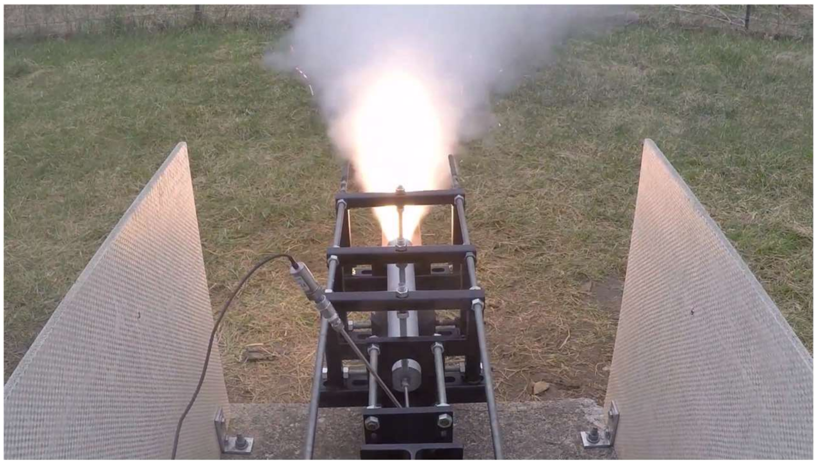


Figure 5. A Cyclone Rocketry propulsion team motor being static fired.

Over the years, the propulsion team has been constructing larger and larger solid rocket motors. For the first two years, the team familiarized itself with the processes for characterizing a novel rocket propellant and designing small motors to verify burn rates. Once the team was comfortable with small motors, its members progressed to larger motors, using design ideas proven with the smaller motors and the now characterized propellant. In just three years, the team progressed from motors ranging from 3 to 4 inches in length to motors over 40 inches long, all while working with university safety officials and the club's two designated advisors. After three years of development, the team designed and tested a motor with enough power to launch the club's flagship competition rocket.

The traditional design process for a motor designed by the propulsion team of Cyclone Rocketry first involves a thorough design for the motor. For the past several years the motors designed by the team have been relatively large and needed a minimum impulse rating in order to lift the rocket to the desired altitude. Once the motor design is matured through an iterative process, a large design review is completed involving both the technical and safety advisors, along with other industry professionals as well as alumni from Cyclone. Through these design reviews, common errors and design oversights can be corrected before motor construction, improving the safety and reliability of the motors the team produces.

Now that the propulsion team has met its primary objective, designing and manufacturing a motor to propel a rocket at the Spaceport America Cup, the members have embarked on projects to push the envelope further. The team is currently working on a motor to take a future rocket as high as 100,000 ft and aims to eventually produce a motor powerful enough to launch a vehicle to the Kármán line (330,000 ft). In completing these truly enormous motors, safety must be the utmost priority due to the amount of rocket propellant involved. Fortunately, the team has demonstrated it can work with university officials to complete activities safely. The propulsion team hopes to soon be able to construct any motor of reasonable size so as to loft club vehicles to any height or velocity required for conducting scientific experiments.

2.3 Lessons Learned

Although the Cyclone Rocketry propulsion team has succeeded in many of its activities, the members have also had to work through obstacles and failures in order to test the solid rocket motors they do today. One of the most difficult hurdles the team has had to overcome was finding a suitable testing site for such motors. Since these devices usually contain significant amounts of solid rocket propellant, which cannot be extinguished once ignited, a large stand-back distance from the test stand location must be observed. The safe distance usually exceeds half a mile, making it difficult to test a motor near the ISU campus. To resolve this issue, the propulsion team worked with advisors and university officials to establish new standard operating procedures for transporting propellant off-campus to privately owned land where the motors could safely be fired from afar.

Another complication the propulsion team has had to work through is motor failures. A motor failure can occur in many ways because the propellant combustion inside solid rocket motors subjects them to immense pressures, temperatures, and forces. There is always a possibility of motor failure, regardless of a design's reliability and robustness. The propulsion team therefore tests many subscale rocket motors to prove aspects of a particular design work before scaling up to larger motor hardware. However, even with smaller motors, the consequences of a motor failure can be serious. For example, in its first year, the propulsion team attempted to test one of its larger motors for a second time to demonstrate repeatable propellant burning rate results. The motor ignited successfully and initially operated as intended but then suffered from thermal burn-through and subsequently failed approximately one second into the test, as shown in figure 6.

Figure 6. One of the propulsion team's early failures on a subscale motor.

After the subsequent failure, the team identified several design flaws with the motor and internal propellant grain geometry. The team then designed and developed a nearly identical motor that implemented countermeasures to avoid a recurrence of the failure. Since the team had correctly followed standard operating procedures, no one was injured, no property was damaged, and the safety and technical advisors remained confident that the team could continue working on solid rocket motors. While motor failure is never desirable, this failure helped the team identify design flaws that may have gone unnoticed until a much larger motor was constructed. The failure of a motor with significantly more propellant inside would have been more catastrophic than the failure the team did experience.

Another challenge for the team is a high turnover rate. Since it is a university extracurricular, students only participate in the club for roughly four years. This presents a challenge as it usually takes several years for members to become sufficiently knowledgeable in their project area. Consequently, students must constantly transfer knowledge to and train other students in the club. The propulsion team accomplishes this by allowing anyone at ISU to join and getting first- and second-year students as involved as possible. The propulsion team consistently trains students who will be with the club for at least several years, giving students time to learn propulsion theory and get as much experience with projects as possible.

2.4 Recommendations for Future Propulsion Teams

The propulsion team has undoubtedly had much success in developing their propulsion systems. Nonetheless, there are several things they would change if given the opportunity to start over again. For instance, they would acquire a test site earlier in the process. Doing so would have allowed for rapid development and iteration of solid rocket motors as the ability to quickly design, build, and test motors would have given students more experience in developing solid rocket motors. The propulsion team is currently acquiring a site that would allow for such a setup, but having access to one several years sooner would have allowed the team to grow much faster than it has.

If allowed to restart, the propulsion team would also have started subscale motor development sooner. Initially, the propulsion team jumped straight to developing a full-scale motor. Initial testing was consequently rushed and resulted in the team's first motor failure. That failure prompted the team to rethink the development of a full-scale motor. The team has since adopted a more sustainable approach, which involves designing and manufacturing several subscale motors to test new technologies at a small scale before making the full-size motor to be used on the club's launch vehicle.

The propulsion team recommends that other student-led organizations aiming to start a rocket propulsion program first learn the theory behind solid rocket propulsion with sufficient rigor. The propulsion team accomplished this by enlisting a technical advisor knowledgeable in energetics and solid rocket propulsion to oversee future motor design work. Team members audited this advisor's class on the theory behind solid rocket motors, the design of such motors, and proper safety protocols to follow when dealing with such devices. Furthermore, the propulsion team appointed the Associate Director of Iowa State Environmental Health and Safety as an advisor. This appointment allowed the team to define proper design, manufacturing, and testing guidelines with an expert safety advisor. The team recommends that other organizations also find an advisor specializing in safety and work with university officials.

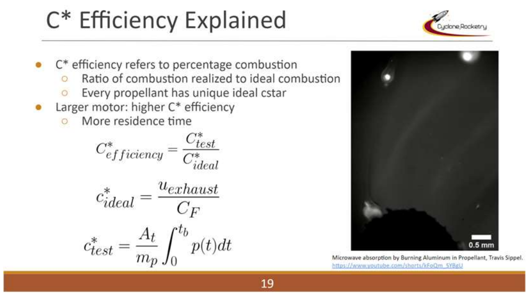
2.5 Comparisons to Other Rocketry Teams

While the Cyclone Rocketry club and the propulsion team within have been instrumental in helping provide students valuable hands-on experience in the very technical field that is rocketry, there have been many other clubs and initiatives which have also been created and are achieving the same results. Notably, Students from Penn State Erie have created a prep-camp which allows high school students to learn relevant hands-on experience working on model rockets, while also helping these students become admitted to the college sponsoring the event [1]. Cal Poly State University is also among universities which host a club rocketry team geared towards undergraduate students [2]. Students from Cal Poly's rocketry group also work with NASA Langley Research Center representatives to design novel rocket booster technologies, similar to the Cyclone Rocketry club discussed in this paper working with university officials to test unique rocket motor hardware, further giving students technical expertise on the subject of rocketry [2].

3. Propulsion Team Curriculum Development Collaboration

The propulsion team has demonstrably benefited the ISU aerospace engineering curriculum by contributing to a new class, Rocket Propulsion (AerE 415). The class is designed for upper-class aerospace engineering students and aims to teach about the components and principles of various rocket engines (e.g., liquid, solid, and hybrid rocket motors), rocket flight performance and staging, cooling and nozzle heat transfer, and other topics. Over 60 aerospace engineering students enrolled in the Rocket Propulsion course in its first semester (spring 2022).

The propulsion team collaborated with the course instructor to distribute actual rocket motor test results and videos showcasing motor hardware to students enrolled in the course. They also produced a supplementary report describing the theory, design, and testing of solid rocket motors. This report contained activities that students could use to practice and solidify the skills they learned in the classroom using real test results. Furthermore, the members of the propulsion team presented in one of the class sessions, showing students actual rocket hardware and explaining how knowledge from the class is directly applicable to rocket propulsion development. This presentation also included an in-class activity that used real data from the club's solid rocket motor testing. The activity called for students to compute important performance parameters from those data (see figure 7). Since propulsion team members regularly analyze test data and determine performance parameters, the activity gave students a taste of solving real-world rocket propulsion problems. Using actual test results gave students a more tangible connection to concepts learned in class.



Pressure (psi)	Start Frame	End Frame	Start Time (s)	End Time (s)	Δt (s)	Δcm	Burn rate (cm/s)
530	648	690	43.2	46	2.8	0.877	0.3132
580	220	264	14.67	17.6	2.93	0.962	0.3283
600	483	527	32.2	35.13	2.93	0.85	0.2901
720	112	150	7.47	10	2.53	0.843	0.3332
815	145	182	9.67	12.13	2.46	0.925	0.3760
900	121	156	8.07	10.4	2.33	0.86	0.3691

Figure 7. A slide and data presented by propulsion team members to the rocket class (Data such as those shown above pertaining to propellant burn rates are often not published, which makes this information especially valuable).

In addition to providing students with empirical data to help reinforce their knowledge, the club also created videos to help students to visualize certain phenomena encountered during rocket motor firings as well as to understand how rocket motors are assembled and how to obtain certain propellant characteristics. A snapshot from a video shown in the supplementary report is shown below (see figure 8). Such video examples allow students to see the effects of the phenomena they are studying in class.

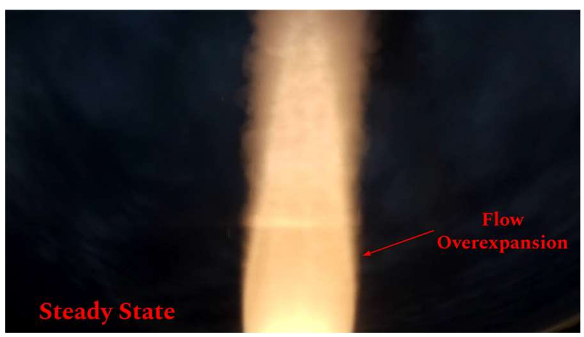


Figure 8. Cyclone Rocketry/AerE 415 video showing effects of flow overexpansion on actual rocket motor test.

While the propulsion team's involvement in Iowa State's rocket course is only in its first year, further cooperation is expected to give students even more insight into how solid rocket motors progress from theory to construction and testing. In the future, collaboration could expand beyond providing a complementary report and presentations to involve hands-on activities to help students understand specific topics. For example, the propulsion team currently tests small motors to be used on test rockets, which the team launches to test electronic hardware, and a project could be designed to have the class design and manufacture motors of this size to be used on such test rockets. Students could potentially use club space to design grain geometries and configurations, predict motor performance, and compare observed and predicted motor results. The project could adopt a team-based approach. The collaboration between student teams and the propulsion team could mimic real-world settings where teams (e.g., analysis and test teams) work together to analyze rocket performance. Such a partnership between the club and class would allow students to apply concepts learned in class on actual rocket hardware. Furthermore, the experience will allow the teams to gain key skills such as teamwork and communication. Although the propulsion team's involvement in the rocket course was not formally evaluated, informal responses from students in the course were overwhelmingly positive. Numerous students expressed a desire to get involved in Cyclone Rocketry and learn more about rocket propulsion. In future papers, new collaborative efforts between the team and the course will be presented along with formal evaluations of those efforts.

Conclusion

In university settings, rocketry teams help students develop professional skills and follow their passion for rocketry and spaceflight. The Cyclone Rocketry propulsion team is an exceptional example of that impact. It works with ISU on novel rocketry courses, gives students opportunities seldom available in college, and allows students to pursue their interest in rocket propulsion. This paper described how a group of passionate students started a new rocketry team at a university and collaborated with various stakeholders to design, manufacture, and test solid rocket motors as well as support an educational effort to enhance students' knowledge of propulsion. This paper can inform students interested in creating similar teams and working with faculty members at their universities to pursue their passion for rocketry.

While the focus of this paper was on the propulsion sub-team and their collaboration with the university to help create a curriculum for the novel propulsion course, the other 5 sub-teams which comprise the Cyclone Rocketry club have also accomplished great feats of engineering, majorly from undergraduate students as well. For instance, the mechanical sub-team has recently pioneered an innovative piston ejection system, which utilized 2 orders of magnitude less energetics to eject the parachute from the rocket. The avionics team has finalized a Kalman filtering algorithm to combine multiple different sensors' outputs to provide a highly accurate prediction of maximum height and velocity. The aerostructures team has also been making custom filament wound tubes with ideal winding angles for maximum tube strength during the ascent and recovery portions of flight. Future papers can spotlight and go much further in depth into these teams from the club.

Acknowledgments

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