STUDENT SUSTAINABILITY COMMITTEE

Final Report

Thank you for your commitment to green initiatives at the University of Illinois. One of the final steps in completing the terms of the funding agreement for your project is the submission of a Final Report with key information about your project. You will also need to submit a detailed report of expenses (if you don't list it within this document) as well as supporting photos to showcase your project.

Please be as accurate as possible in describing the project (including possible setbacks or challenges in meeting the initial goals of the project). Not fully meeting your project's goals will not disqualify you from making future funding requests as long as your reports are as complete and accurate as possible. If you have any questions, please contact the Student Sustainability Committee, at sustainability-committee@illinois.edu.

Project Name: Illinois Space Society Hybrid Rocket

Date of Report Submission: 10/4/2019

Project Purpose:
The Illinois Space Society Hybrid Rocket project was conceived to expose student members to sustainable design practices and considerations in aerospace. The plan was to achieve this through the primary goal of designing, building, and testing an environmentally friendly and reusable rocket. The rocket was built to utilize a hybrid engine using paraffin wax and nitrous oxide as propellants. Magnesium was to be utilized as a more sustainable and equal replacement to aluminum.

With all of this, focus and attention to hybrid propulsion would be increased in the student population. The project would allow students to develop skills in sustainable design and make them aware of sustainability considerations for a rapidly developing industry. Students would bring the completed engine to an international competition this past summer to generate awareness to the benefits of using this kind of engine. Along with the direct student members of the team and other teams, outreach with local schools and at EOH would teach others about hybrid engines and their operation. Research could also have been inspired to look at the implementation of more sustainable materials in aerospace.

Project Summary:
Please summarize the project development process and how it met the goals established in your application.

The project started right away during the school year and benefited gratefully from extra work performed during the summer. A graduate student was chosen to lead the team who already had experience in developing and testing hybrid rocket engines. A team of about 20 students gathered from quad day and other outreach events.

It was realized early in the process that the most beneficial way to develop a newer sustainable design would be to scrap previous design theory and start development from the ground up. This is because the members solely had experience on small scale demo hybrid engines, that do not scale up to rocket grade propulsion. A preliminary timeline was set up that allowed for testing to begin in the second semester and continue up until the competition in June of 2019. A “propulsion school” was also set up to teach approximately a dozen members the more in-depth aspects of hybrid rocket propulsion.

As the first semester progressed, due to a novel management structure, key changes took time to propagate through the rest of the system, pushing back part ordering and testing schedules. Sub-systems of the design proved to be more complex than expected due to the safety considerations brought up from mentors and safety experts. Through this odyssey, team members were provided an ideal example of the iterative process of engineering design and revealed a great deal about this aspect of engineering.

The society’s relationship with the university also began to get more complex and difficult due to changes in university policy. The university made ordering parts much more difficult through the typical ordering systems that had been used for years. The members of the team also found out that they could not hot-fire test the engine at Willard airport due to the lack of insurance, another issue of University policy. These unforeseen events made the project more difficult. The team had to decide not to go to the International Rocket Engineering Competition in April of 2019 with the hybrid engine. The rocket engine was simply not going to be ready in time.

Over the summer of 2019, the team was able to begin assembly of the test stand and obtain some of the first hardware for the engine. These parts included the combustion chamber where the wax would sit and the portable test stand structure. Throughout ongoing discussions with Willard, it became clear that the team could do preliminary “low-energy” tests at the airport, but it has not been confirmed if the team can conduct a full hot fire test without insurance.

Once the Fall 2019 semester began, the team heavily recruited new members. Team leadership has also changed, and two co-leads have been chosen who were both members of the previous year. New positions such as inventory managers, sponsorship managers, and social media managers have been established. These positions should off-load some of the work from members while also retaining new members. These positions were also selected specifically to help mitigate some of the mistakes that were made last year like mismanaging components, not seeking enough sponsors, and increasing our social media presence. The team is currently about 35 members strong.

At the beginning of Fall semester of 2019, the team began its first of many tests at the airport. A pressure test yielded that a slight design change was necessary, but the team is hopeful for the progress it can make this year. This test was in fact successful in evaluating design aspects and introducing new members to the engine.

The project made significant progress towards its stated goals. The design for the propulsion system and test stand has seen significant progress and multiple design iterations that increased reliability and safety. Critical testing hardware has been acquired and will allow the team to continue testing primary components. Testing has only just gotten started, and there are plans to test as much as possible at Willard Airport and, when ready, look for other test sites for hot-fire testing. Paraffin wax and nitrous oxide are still the primary propellants for the engine, in line with the sustainability goals. More attention has been given to the hybrid engine project than ever before in society history and more students are aware of the difficulties that come with ensuring a project is safe, sustainable, and effective. The hybrid engine was also brought to various outreach events. A small-scale demonstration was used to teach students of UIUC and local schools about the operating principles of hybrid motors. This exhibit was seen by over 300 people between Illinois Space Day in Fall 2018 and EOH in Spring of 2019. The exhibit will also be used at both events for Fall 2019 and Spring 2020.

The team was not able to contact the magnesium sponsor after the summer of 2018. This is disappointing since magnesium held promise as a more sustainable alternative to aluminum since it was sourced directly from ocean waters instead of mining. However, this is superior alternative to standard stainless steel. Due to time constraints, aluminum was chosen as the primary material. Getting to the competition was also not possible due to limited time and various complications which will be further explained in the *Problems/Challenges Encountered* section of the report.

Even with these missed goals, the team made significant progress. This is also only a little more than halfway through the typical 2-year timeline for the projects sponsored by SSC. The team still plans to work toward many of the goals as stated in the original application. This will be explained further in following sections.

Summary of Project Expenditures:

Table 1: Summary of Project Expenditures by System Categories

Category	Cost
Hybrid Engine Fabrication	$1,561.63
Test Stand	$2,236.92
Hybrid Electronics & Sensors	$2,149.65
Plumbing & Tanks	$2,468.92
Machined Parts	$1,608.24
TOTAL	$10,025.36

Note that on the statement, the amount spent is 10,025.36. The $25.36 over 10,000 was then reimbursed with our aerospace department account. This mistake occurred when a machining charge was larger than the quote by a large enough margin to take the account into a negative

value. The account has a $0.00 balance. The bank statements will be sent with the additional files submitted in the email with this document.

Problems/Challenges Encountered

Please summarize your project's progress in relation to the milestones and target dates listed in your original application.

The team undertook an ambitious workload which would have been a feasible task, had they not encountered the many unforeseen challenges that they did. It was proposed that the design, manufacturing, and testing could be done within the year to be ready for the competition. The design phase was slower than expected due to various changes accruing from safety reviews. This is in fact a positive as proceeding without appropriate safety levels within the engine is dangerous, especially in a rocket engine. While this was a setback, several issues stemmed from our team's inexperience. Firstly, the team, suffered an inability to design components in a timely manner. This improved as the project progressed, but initially it was an issue. Lastly, manufacturability was ignored in the designing of essential components. This is due to a lack of experience in practical design work, on the part of the students. This issue however, due its nature, has been fixed and will continuously be improved as the project progresses.

Elaborating on the manufacturing side, local machine shops were also highly pressed for time. Originally, it was thought that the team could utilize a student machine shop on campus, but when the team applied for access, they were denied. It was found out that the shop manager had consulted University risk management and they decided the project was too dangerous to allow students to work on, using school-owned equipment. This was unfortunate and unfair as the team did not plan to work with any dangerous materials in the student workshops. However, the team has been in contact with the Engineering Student Project Laboratory over the past year to review this assessment and is in fact now able to manufacture components at that location. At the time however, this access was unavailable and therefore student workshop access was not availed and the manufacturing of parts through professional machine shops was the only option. Consequentially, the cost was driven up and significantly slowed down the timeline of the project.

Sustainability was, as mentioned in our application, a main focus for the project. Coming into the application period, Magnesium Elektron was one of our main sponsors. Shortly after receiving the SSC grant however, Magnesium Elektron cut communication and did not provide the material that they had agreed to give us. This resulted in the team using aluminum for structural components. While this is not ideal, it is still a better option than using stainless steel, which is a commonly used aerospace material.

In parallel with this, the team was finding out that the relationship of the RSO to the university was more complex than previously understood. Since RSO's are not an official part of the university, they are not covered by any sort of university insurance. The team met with officials at Willard airport (where prior testing had occurred), where it was then communicated that to conduct hot-fire testing, the team required some form of insurance. Furthermore, due to the

lack of upkeep at the University's test facility, a new test stand was required. The need for a new test stand then became another unexpected cost. On the positive side, if Willard airport decides not to allow testing to be conducted there, the team will be able to find other locations to test the engine, by virtue of their new mobile test stand.

As for the cost, this would not have been such an issue if the society did not run into another issue with the management of one of its accounts. The NASA Higher Education account is a grant provided by the Illinois Space Grant Consortium for students to do projects in college. It was believed that this account would have approximately $3000 at the start of the year. However, when the account was checked it held a negative balance. Another team the year prior had spent much more than was expected on travel and drained the account. This money would have been able to cover many of the costs of the test stand redesign. This was not a mistake of the hybrid team specifically, but the team paid the price. This mistake of past leadership in the society will not be repeated as hybrid team members are now in charge of their own funding within the society, and therefore can ensure such infringements do not occur.

Unfortunately, ordering components became more complicated as well. Around April of 2019, the university decided to freeze any orders placed by RSOs until a new ordering system could be put in place. Additionally, since the university tax-exempt status did not apply to RSOs, they decided to stop any spending outside of departmental costs. The team was only able to spend funds on machining costs since the shop was internal to the university, but not anything else. Critical parts had to be purchased by students and reimbursed from a separate account, slowing progress significantly.

In essence, although management was initially an issue for a project of this magnitude, it was not the sole cause of the projects result. The unforeseen and unavoidable budgeting, funding, allocation, and miscellaneous issues plagued the project as it progressed. These issues were tough, but the project and the team pushed through and were in fact able to manufacture and test almost 2/3rds of the engine. This is an impressive result considering the climate and issues the project faced over the past year. Additionally, with these experiences the members and management now have the capability to take on this next year with more fervor and attention than ever before.

Student Involvement and Outreach to Date:

How were students been involved in your project?

Last year, the team was a group of approximately 10 members. This year, that number has grown to over 35. The team has generated a lot more excitement as assembly and testing are beginning and the team has hardware to work with. Members of the team have been involved in the feedline plumbing, electrical, and test stand design.

They have worked with various officials on making sure the system is safe. The dean of safety helped assess the hazards of nitrous oxide and ensure they were accounted for. Willard airport

officials and fire safety evaluated testing procedures and locations and offered alternatives for the team. The team connected with a nitrous oxide expert from Airgas to ensure chemical compatibility between the plumbing system and the fuels being used. All of this design work has given them an important look at the extensive verification process required for systems like these. One misstep could make projects like these impossible at the university, lowering the opportunity for more students to learn.

The team also hosts a "propulsion school". In Fall 2018, this was a small get together of interested team members to learn more about the complexities of hybrid rocket engine propulsion. In the beginning of Fall 2019, the propulsion school was revamped and expanded to approximately 35 students, many of whom coming from other technical projects to get their first exposure to propulsion. This group meets twice a week for one-hour, where interactive lectures on hybrid engine design are taught in detail. Students get homework assignments to reinforce what they have learned and get to apply this knowledge towards the development of the test engine.

Engineering Open House has also exposed the hybrid engine concept to a variety of students at the university and in the local area. A demonstration scale engine is used to show the basic concept of hybrid propulsion. This demonstration is also used for Illinois Space Day events which is a similar outreach event hosted by the Illinois Space Society which reaches nearly 200 students between Kindergarten and 8th grade.

Marketing and Promotion Efforts to Date:

What marketing and promotion efforts have you conducted so far?

As the Illinois Space Society has grown, it has begun maintaining a regular social media presence. The Illinois Space Society currently maintains an Instagram account which showcases the club's achievements, events, and milestones as well as the achievements of its members. Plans for social media expansion include live-streaming portions of our testing procedures to generate interest and excitement within the student community for the possibility of more eco-friendly space missions. Special livestreams also include competition rocket launches as well as final tests and presentations.

Our educational outreach program has also been a sensation for a non-university audience. The Illinois Space Society conducts a massive event called Illinois Space Day, where ISS hosts K-8 students from local Illinois school districts for a day enriching STEM activity. A sub-scale hybrid engine is one of the major demonstrations at this event.

Another major opportunity for engagement is the annual Grainger College of Engineering's Open House. Each year at the Engineering Open House, thousands of students K-12 and their families are invited to UIUC to learn more about student STEM projects. ISS actively participates in Engineering Open House, with popular exhibits that include; an orbit simulator, rocket surgery, and liquid nitrogen demonstrations.

While the engine was not launch ready by the Intercollegiate Rocket Engineering Competition, the Student Sustainability Council was listed as a sponsor for the rocket. This increased brand

exposure for the SSC as well as the hybrid engine. Moreover, the culmination of all the work done by the hybrid engine team was not in vain. Some of the engine design team members attended the competition to establish and maintain ties in the hybrid engine community, allowing us to develop our procedures and confirm our design choices.

To summarize, despite not attaining the goals set out in last year's proposal, the hybrid engine team is confident that substantial work can be achieved this year, with a positive test result by the next semester given that most of the hardware has been procured and assembled. Also, the dedicated social media manager will make spreading awareness and eagerness for the project a larger priority. A dedicated team to obtain sponsorship for the hybrid engine has been organized, encouraging the hybrid team to work with outside groups to raise money.

Additional Comments:

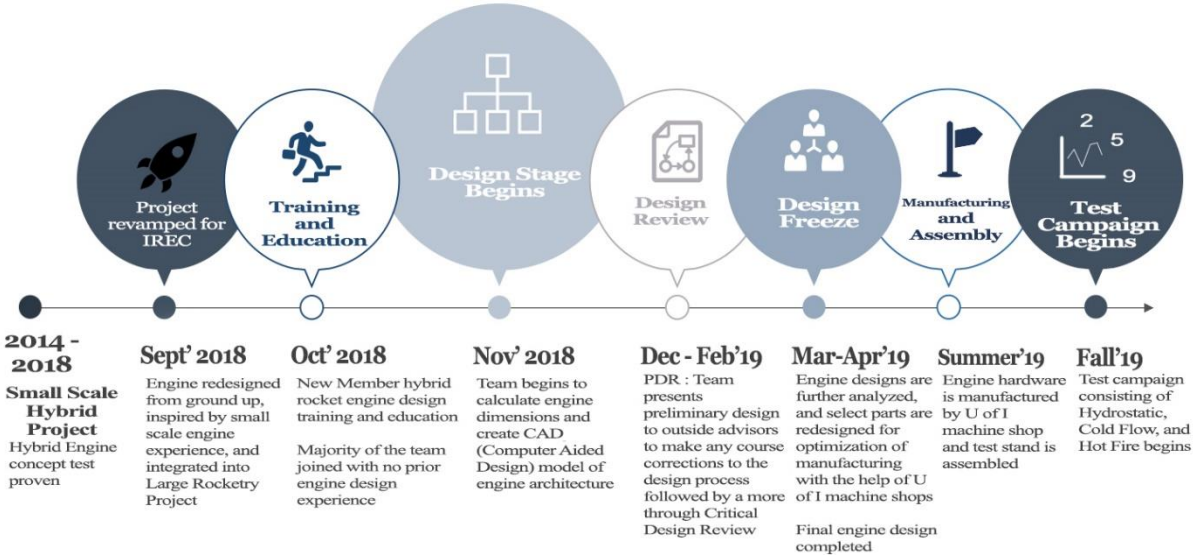
Any additional comments/relevant information for this report

The team was quite disappointed to not reach their original goal, however the team has and will continue to learn from the mistakes and challenges that occurred during this past year. The project is not over. The key takeaway from this project is that the team learned and improved as engineers. They are more than capable to take on the difficult task that is developing a hybrid rocket engine - it is rocket science after all. Hence, the team members are continuing to look for support to finish the project through grants, part sponsors, and mentorship. Some of the main lessons that we have learned include stringent budget management, integrated design, electrical engineering in the scope of rocket avionics, and general design of a full-scale rocket engines.

As the project progressed, improvements were already made on budgeting and design practices. This improved work paid off, as the team manufactured enough components to cold flow and hydrostatic test with the remaining budget. Both hydrostatic and cold flow testing are currently in progress. Once these tests are done, the team will be ready to move forward with full scale hot fire testing. This will require further funding to manufacture more parts; presently, the team is focusing on completing the tests available while working hard to find further financial support on the side.

The team will launch this hybrid engine next year (2021), but the current focus is to complete this task safely and responsibly. This means restructuring the way that the team has been organized and managed based on our past mistakes. This includes creating positions for sponsorship liaisons, an inventory manager, and implementing budget margins when planning for the year. The team has already begun to rectify these highlighted issues. Firstly, the aforementioned positions have been created and students have been selected for them. Secondly, task and project management has been greatly improved by the utilization of Microsoft Teams. This will allow the team leads to have a better grasp of the status of each task to ensure that the team is on track for their testing plans. Furthermore, documentation has

been created to aid the passing of information and to ensure safety when assembling and testing the engine in any capacity. The project timeline is also much more conservative this time around to better set up the team for success. The current schedule allows for two years for testing and integration into a rocket to launch at IREC in 2021. Below is the finalized timeline for the 2018-2019 school year to summarize the great work the team has performed this past year.



In addition to the above fields, please provide a detailed accounting of how the funding was spent as well as pictures of the final project in an email to sustainability-committee@illinois.edu. Thank you again for your commitment to sustainability.