Checklist for Adult Sponsor (1)

This completed form is required for ALL projects.

To be completed by the Adult Sponsor in collaboration with the student researcher(s):

Student's Name(s): Ryan Westcott

Project Title: Development of a Fully Reusable and Autonomously Landing Suborbital Launch Vehicle: Year T

1. ☐ I have reviewed the Intel ISEF Rules and Guidelines.

2. ☐ I have reviewed the student's completed Student Checklist (1A) and Research Plan/Project Summary.

3. ☐ I have worked with the student and we have discussed the possible risks involved in the project.

4. ☐ The project involves one or more of the following and requires prior approval by an SRC, IRB, IACUC or IBC:
   - ☐ Humans
   - ☐ Vertebrate Animals
   - Potentially Hazardous Biological Agents
     - ☐ Microorganisms ☐ rDNA ☐ Tissues

5. ☐ Items to be completed for **ALL PROJECTS**
   - ☐ Adult Sponsor Checklist (1)
   - ☐ Student Checklist (1A)
   - ☐ Research Plan/Project Summary
   - ☐ Approval Form (1B)
     - ☐ Regulated Research Institutional/Industrial Setting Form (1C) (when applicable; after completed experiment)
     - ☐ Continuation/Research Progression Form (7) (when applicable)

Additional forms required if the project includes the use of one or more of the following (check all that apply):

☐ **Humans,** including student designed inventions/prototypes. (Requires prior approval by an Institutional Review Board (IRB); see full text of the rules.)
- ☐ Human Participants Form (4) or appropriate Institutional IRB documentation
- ☐ Sample of Informed Consent Form (when applicable and/or required by the IRB)
- ☐ Qualified Scientist Form (2) (when applicable and/or required by the IRB)

☐ **Vertebrate Animals** (Requires prior approval, see full text of the rules.)
- ☐ Vertebrate Animal Form (5A) - for projects conducted in a school/home/field research site (SRC prior approval required.)
- ☐ Vertebrate Animal Form (5B) - for projects conducted at a Regulated Research Institution. (Institutional Animal Care and Use Committee (IACUC) approval required prior experimentation.)
- ☐ Qualified Scientist Form (2) (Required for all vertebrate animal projects at a regulated research site or when applicable)

☐ **Potentially Hazardous Biological Agents** (Requires prior approval by SRC, IACUC or IBC, see full text of the rules.)
- ☐ Potentially Hazardous Biological Agents Risk Assessment Form (6A)
- ☐ Human and Vertebrate Animal Tissue Form (6B) - to be completed in addition to Form 6A when project involves the use of fresh or frozen tissue, primary cell cultures, blood, blood products and body fluids.
- ☐ Qualified Scientist Form (2) (when applicable)
- ☐ The following are exempt from prior review but require a Risk Assessment Form 3: projects involving protists, archae and similar microorganisms, for projects using manure for composting, fuel production or other non-culturing experiments, projects using color change coliform water test kits, microbial fuel cells, and projects involving decomposing vertebrate organisms.

☐ **Hazardous Chemicals, Activities and Devices** (No SRC prior approval required, see full text of the rules.)
- ☐ Risk Assessment Form (3)
- ☐ Qualified Scientist Form (2) (required for projects involving DEA-controlled substances or when applicable)

Robert Orr

Adult Sponsor's Printed Name | Signature | Date of Review (mm/dd/yy)

orrr@go.oes.edu

Phone | Email

Student Checklist (1A)

This form is required for ALL projects.

1. a. Student/Team Leader: Ryan Westcott Grade: 12

   Email: westcottr@go.oes.edu Phone: (971)777-2352

   b. Team Member: ______ c. Team Member: ______

2. Title of Project:

   Development of a Fully Reusable and Autonomously Landing Suborbital Launch Vehicle: Year Two

3. School: Oregon Episcopal School School Phone: (503)246-7771

   School Address: 6300 SW Nicol Rd, Portland, OR, 97239

4. Adult Sponsor: Rob Orr Phone/Email: orrr@go.oes.edu

5. Does this project need SRC/IRB/IACUC or other pre-approval? ☒ Yes ☐ No Tentative start date: ______

6. Is this a continuation/progression from a previous year? ☒ Yes ☐ No
   If Yes:

   a. Attach the previous year's ☒ Abstract **and** ☒ Research Plan/Project Summary

   b. Explain how this project is new and different from previous years on

   ☒ Continuation/Research Progression Form (7)

7. This year's laboratory experiment/data collection:

   11/15/19 — Actual Start Date: (mm/dd/yy)

   02/20/19 — End Date: (mm/dd/yy)

8. Where will you conduct your experimentation? (check all that apply)

   ☐ Research Institution ☒ School ☐ Field ☒ Home ☐ Other: ______

9. List name and address of all non-home and non-school work site(s):

Name: ______ ______

Address: ______ ______

______ ______

Phone/email: ______ ______

10. **Complete a Research Plan/Project Summary following the Research Plan/Project Summary instructions and attach to this form.**

11. **An abstract is required for all projects after experimentation.**

Ryan Westcott

Research Plan 2019-2020

Title: **Development of a Fully Reusable and Autonomously Landing Suborbital Rocket**

Rationale:

Throughout the past decade, a tremendous amount of research has been put into developing reusable rockets in order to decrease the cost of space exploration. However, most of this reusable technology has only been applied to large, orbital class boosters. This has left the lower powered launch market with relatively high launch prices. I would like to use the techniques and technology developed for large reusable boosters as a model for decreasing the costs of smaller rocket launches. The design and methodology of this year's project builds off of last year's research. Last year, there was insufficient simulation carried out before testing. Thus, a larger emphasis will be put on developing the necessary software simulations this year. Additionally, the propulsion system of the vehicle will be redesigned from the group up. Last year, the propulsion system used 4 independently vectoring motors on 1-axis each, this year the propulsion system will use a single motor vectoring on two axis. In addition to the new propulsion system design, the rest of the vehicle will be redesigned from data and experience gathered last year. The onboard sensors will be capable of determining the vehicle's altitude, attitude, and a variety of other variables, which will be used by the flight computer in real-time to determine when to ignite the retropropulsion system, and how the control the two axes of thrust in order to propulsively land the vehicle.

Research Question:

How can I decrease the cost of rocket launches by developing a fully reusable launch vehicle capable of performing a propulsive vertical landing, while building off of last year's research?

Expected Outcomes:

I expect to develop a system capable of returning all parts of a model proof-of-concept launch vehicle to a predetermined location on the surface of the earth. The hardware should be capable of recording critical data and providing propulsive landing capabilities to the craft, while the software should be capable of controlling its trajectory and recording data. If successful, the system will be capable of reducing launch costs by returning the vehicle to a specified landing zone and diminish the negative environmental effects by eliminating the loss of flight hardware.

Method:

Procedure:

1. Prepare static firing test stand: an instrument that can be used to test the thrust of a rocket motor over time. Perform three static fires for the F15 rocket motor. The static fire should follow the following procedure:
    a. The motor will be securely mounted onto the test fire stand with the metal coupling.
    b. When no one is within 30 feet of the test stand (Model Rocket Safety Code), the motor will be ignited from a safe distance by a computer command and repeated three times.
    c. Load the data off the test stand's computer and into a spreadsheet.

2. Develop the flight simulation using MATLAB, SimuLink, and SimScape packages. The thrust data will be loading into a lookup table and the simulation will be used to output the optimal drop_height, ignition_alt, pid_p, pid_i, and pid_d.
3. Once the simulation is complete, the model launch vehicle can be designed, prototyped, and constructed.
    a. Design the launch vehicle (rocket) from scratch (stability analysis, structural design, etc…). Rocket will be 74mm in diameter and approximately 1 meter tall. This size should provide sufficient space to install all components. The airframe will be constructed from commercially-available airframe tubes and most components will be 3D printed.
    b. Design/prototype the structural frame and mechanism (3D printed parts, carbon fiber manufacturing, etc...)
    c. Design/prototype the flight computer hardware (Sensors, power supply, telemetry, etc…)
    d. Design/prototype the flight software (PID controllers, data filters, telemetry, etc…)
    e. Perform systems integration with drone that will be used for drop tests. Ensure all weight, space, and mechanical requirements allow the system to be integrated fully.
4. Perform a hold-down test to evaluate the performance of the vehicle without the need to perform a real landing (which could damage the flight hardware if not successful). Following this procedure:
    a. Clamp the hold-down test stand to the hold-down test supports.
    b. Slide the vehicle into the test stand, and secure using three M3-0.5x10 screws.
    c. Power on the flight computer and calibrate the sensors.
    d. Connect the wireless ground station to the vehicle and ensure the sensor output is within reason.
    e. Ensure all individuals stand back at least 30 feet (Model Rocket Safety Code), and ignite the motor from the ground station computer.
    f. Repeat until the vehicle can remain with 5º of vertical.
5. Drop-test the system by releasing it from an elevated altitude to simulate the descent stage of flight.
    a. In the test environment (no other individuals, no flammable materials), the launch vehicle will be dropped from a drone at a height determined earlier by the simulation.
    b. The flight computer will initiate the thrust at the designated altitude, obeying all safety commands within the code.
    c. Allow the system to attempt a landing with no intervention.
    d. If the system does not function according to plan, redesign and retest until the system performs optimally.

<u>Data Analysis:</u>

The data from the hold-down tests will be used to further tune the system's PID (proportional, integral, derivative) coefficients. The raw data will be parsed and ran through a transfer-function based proportional integral derivative optimization algorithm to further tune the system. Once the vehicle performs landing attempts, the data will be evaluated on the basis of whether or not the vehicle lands, as well as the IMU (inertial measurement unit) double-integrated position values and the range of the θ_P θ_Y and θ_R (pitch, yaw, roll) values.

The most successful design iteration will be the one with the highest success rate, least translational drift, and lowest range of pitch, yaw, and roll values.

Risk and Safety:

Although rocket propellants can be volatile and explosive, when correct safety measures are followed, working with rockets is very safe. In accordance with the FAA (Federal Aviation Administration), all experimentation will be conducted within class G airspace in order to prevent interference with operations in other airspace (FAA, n.d.). In accordance with NAR (National Association of Rocketry), standard launch safety procedures will be followed closely: I will use a countdown before launch, and will ensure that all observers at the launch site are paying attention and are a safe distance of at least 15 feet away (propulsion system motor is classified as a “D” class or smaller) or 30 feet away (propulsion system motor is classified as a “E” class or larger). If the propulsion system does not ignite when the launcher’s ignition is pressed, I will remove the launcher’s safety interlock, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket ("Model Rocket," 2012). Finally, a fire suppression system (fire extinguisher) will be prepared and present at all times.

Commercially available black-powder motors will be used in accordance with their listed safety, handling, and disposal instructions. No attempt will be made to modify the propellant itself. The expended motor will be soaked in water for at least 10 minutes, where it will disintegrate. These remnants can be safely disposed of in an outside trash receptacle (Estes FAQs). The testing environment for launching rockets and performing static fires will constitute of a large, concrete surface with no flammable materials and access to fire suppression systems.

References

Estes FAQs. (2018). Retrieved December 2, 2018, from https://estesrockets.com/faqs/

FAA. (n.d.). *Airspace*. Retrieved December 2, 2018, from Federal Aviation Administration website: https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/17_phak_ch15.pdf

Innovating sounding-rocket experiments and stimulating use of the rocket. (2013). Retrieved December 2, 2018, from JAEA website: http://www.isas.jaxa.jp/e/forefront/2013/nonaka/02.shtml

Mcroberts, F., Harrower, C., Hutchison, B., Mcgrath, C., McLean, F., & Get Law, W. (2014). Design of Main Propulsion System for a Reusable Suborbital Rocket. Retrieved December 2, 2018, from https://www.researchgate.net/publication/269099079_Design_of_Main_Propulsion_System_for_a_Reusable_Suborbital_Rocket

Model Rocket Safety Code. (2012, August). Retrieved December 1, 2018, from National Association of Rocketry website: https://www.nar.org/safety-information/model-rocket-safety-code/

Nakka, R. (2018, October 10). Richard Nakka's Experimental Rocketry Web Site. Retrieved October 15, 2018, from http://www.nakka-rocketry.net/

Ogawa, H. (2016, July 31). *Reusable Sounding Rocket*. Retrieved December 2, 2018, from http://www.jasma.info/journal/wp-content/uploads/sites/2/2016/07/2016_p330303.pdf

Budget and itemized expenses (all will be paid for from previous ISEF prize money):

Item Name	Individual price	Quantity	Full price
F15 Propellant	$30.02	6	$180.12
Airframes	$22.46	2	$44.92
MCU (T4.0)	$26.95	1	$26.95
IMU	$34.95	1	$34.95
PLA Filament	$19.99	2	$39.98
PCB Manufacturing Service	$150.00	1	$150.00
PCB Parts	$50.00	1	$50.00
BPS TVC	$35.00	1	$35.00
9c Actuators	$10.00	3	$30.00
Solenoids	$8.99	5	$44.95
Static fire load cell	$9.54	1	$9.54
Brushless motors	$41.99	1	$41.99
Brushless FC	$69.99	1	$69.99
Cyanoacrylate adhesive	$15.00	2	$30.00
4s lithium polymer PS	$31.99	4	$127.96
Total:			**$916.35**
Total requested from OES:			**$0.00**

Materials which are already obtained/owned:

- Prototype PCBs
- V-regs
- BME280
- 18/20/22 gauge wiring
- M3-0.5 screws
- M3-0.5 nuts
- M3-0.5 washers
- 2x2 Twill carbon fiber
- CF Epoxy
- Ball bearings
- 3D printers
- General tools
- Dremel
- Epoxy
- UAV
- UAV Ground station
- Drop hardware
- Launch vehicle ground station
- CF epoxy hardener
- Hold-down mount
- Clamps
- Video cameras (data recording)
- Static fire stand
- Static fire stand computer
- Solder
- Solder flux
- 3D printer filament
- Prototype PCB materials

Approval Form (1B)

A completed form is required for each student, including all team members.

1. To Be Completed by Student and Parent

a. Student Acknowledgment:

- I understand the risks and possible dangers to me of the proposed research plan.
- I have read the Intel ISEF Rules and Guidelines and will adhere to all International Rules when conducting this research.
- I have read and will abide by the following Ethics statement

Student researchers are expected to maintain the highest standards of honesty and integrity. Scientific fraud and misconduct are not condoned at any level of research or competition. Such practices include but are not limited to plagiarism, forgery, use or presentation of other researcher's work as one's own, and fabrication of data. Fraudulent projects will fail to qualify for competition in affiliated fairs and the Intel ISEF.

Ryan Westcott — Ryan Westcott — 10/25/19

Student's Printed Name — Signature — Date Acknowledged (mm/dd/yy) (Must be prior to experimentation.)

b. Parent/Guardian Approval: I have read and understand the risks and possible dangers involved in the **Research Plan/Project Summary**. I consent to my child participating in this research.

Kerri Westcott — Kerri Westcott — 10/25/19

Parent/Guardian's Printed Name — Signature — Date Acknowledged (mm/dd/yy) (Must be prior to experimentation.)

2. To be completed by the local or affiliated Fair SRC

(Required for projects requiring prior SRC/IRB APPROVAL. Sign 2a or 2b as appropriate.)

a. Required for projects that need prior SRC/IRB approval BEFORE experimentation (humans, vertebrates or potentially hazardous biological agents).

The SRC/IRB has carefully studied this project's **Research Plan/Project Summary** and all the required forms are included. My signature indicates approval of the **Research Plan/Project Summary** before the student begins experimentation.

SRC/IRB Chair's Printed Name

Signature — Date of Approval (mm/dd/yy) (Must be prior to experimentation.)

OR

b. Required for research conducted at all Regulated Research Institutions with no prior fair SRC/IRB approval.

This project was conducted at a regulated research institution (**not home or high school, etc.**), was reviewed and approved by the proper institutional board before experimentation and complies with the Intel ISEF Rules. **Attach (1C) and any required institutional approvals (e.g. IACUC, IRB).**

SRC Chair's Printed Name

Signature — Date of Approval (mm/dd/yy)

3. Final Intel ISEF Affiliated Fair SRC Approval (Required for ALL Projects)

SRC Approval After Experimentation and Before Competition at Regional/State/National Fair

I certify that this project adheres to the approved **Research Plan/Project Summary** *and complies with all Intel ISEF Rules.*

Regional SRC Chair's Printed Name — Signature — Date of Approval (mm/dd/yy)

State/National SRC Chair's Printed Name *(where applicable)* — Signature — Date of Approval (mm/dd/yy)

Qualified Scientist Form (2)

May be required for research involving human participants, vertebrate animals, potentially hazardous biological agents, and hazardous substances and devices. Must be completed and signed before the start of student experimentation.

Student's Name(s) Ryan Westcott

Title of Project Development of a Fully Reusable and Autonomously Landing Suborbital Launch Vehicle:

To be completed by the Qualified Scientist:

Scientist Name: Rob Orr

Educational Background: ______________________ Degree(s): ______________________

Experience/Training as relates to the student's area of research:

Position: ______________________ Institution: ______________________

Address: ______________________ Email/Phone: ______________________

1) Have you reviewed the Intel ISEF rules relevant to this project? ☐ Yes ☐ No

2. Will any of the following be used?
   a. Human participants ☐ Yes ■ No
   b. Vertebrate animals ☐ Yes ■ No
   c. Potentially hazardous biological agents (microorganisms, rDNA and tissues, including blood and blood products) ☐ Yes ■ No
   d. Hazardous substances and devices ■ Yes ☐ No

3. Will this study be a sub-set of a larger study? ☐ Yes ■ No

4. Will you directly supervise the student? ☐ Yes ■ No
   a. If no, who will directly supervise and serve as the Designated Supervisor? Dave Westcott
   b. Experience/Training of the Designated Supervisor:

   Safety training, CPR, etc…

To be completed by the Qualified Scientist:

I certify that I have reviewed and approved the Research Plan/Project Summary prior to the start of the experimentation. If the student or Designated Supervisor is not trained in the necessary procedures, I will ensure her/his training. I will provide advice and supervision during the research. I have a working knowledge of the techniques to be used by the student in the Research Plan/Project Summary. I understand that a Designated Supervisor is required when the student is not conducting experimentation under my direct supervision.

____
Qualified Scientist's Printed Name

______________________ ______________________
Signature Date of Approval (mm/dd/yy)

To be completed by the Designated Supervisor when the Qualified Scientist cannot directly supervise.

I certify that I have reviewed the Research Plan/Project Summary and have been trained in the techniques to be used by this student, and I will provide direct supervision.

____
Designated Supervisor's Printed Name

______________________ ______________________
Signature Date of Approval (mm/dd/yy)

______________________ ______________________
Phone Email

Risk Assessment Form (3)

Must be completed before experimentation.

Student's Name(s) Ryan Westcott

Title of Project Development of a Fully Reusable and Autonomously Landing Suborbital Launch Vehicle: Year Two

To be completed by the Student Researcher(s) in collaboration with Designated Supervisor/Qualified Scientist: (All questions must be answered; additional page(s) may be attached.)

1. List all hazardous chemicals, activities, or devices that will be used; identify microorganisms exempt from pre-approval (see Potentially Hazardous Biological Agent rules).

   Rocket propellant (charcoal, sulfur, and potassium nitrate), propulsive rocket landing, drone flight.

2. Identify and assess the risks involved in this project.

   Rocket propellant can ignite and burn quickly if not handled properly. While the rocket performs a propulsive landing, any number of issues could occur which would result in a hard impact. While the drone is used to lift the rocket into position, the spinning propellers of the drone could be hazardous upon impact with a person.

3. Describe the safety precautions and procedures that will be used to reduce the risks.

   Appropriate safety equipment is worn at all times while working with a mixed oxidizer and fuel (face shield, long sleeves, gloves, closed-toe shoes). When a landing test is performed, all participants will stand a minimum of 75 feet away to prevent contact with the landing rocket or the flying drone.

4. Describe the disposal procedures that will be used (when applicable).

   Used rocket motor casings will be soaked in water for 5 minutes, then disposed of in household garbage (as per their instructions).

5. List the source(s) of safety information.

   https://www.estesrockets.com/customer-service/enginefaq/
   https://www.nar.org/safety-codes-2/

To be completed and signed by the Designated Supervisor (or Qualified Scientist, when applicable):
I agree with the risk assessment and safety precautions and procedures described above. I certify that I have reviewed the Research Plan/Project Summary and will provide direct supervision.

Dave Westcott		11/01/19
Designated Supervisor's Printed Name	Signature	Date of Review (mm/dd/yy)

	dave@gpafixedincome.com
Position & Institution	Phone or email contact information

General safety, CPR, etc...

Experience/Training as relates to the student's area of research

Continuation/Research Progression Projects Form (7)

Required for projects that are a continuation/progression in the same field of study as a previous project.
This form must be accompanied by the previous year's abstract and Research Plan/Project Summary.

Student's Name(s) Ryan Westcott

To be completed by Student Researcher: List all components of the current project that make it new and different from previous research. The information must be on the form; use an additional form for 2016–2017 and earlier projects.

Components	Current Research Project (2019-2020)	Previous Research Project Year: 2018-2019
1. Title	Development of a Fully Reusable and Autonomously Landing Suborbital Launch Vehicle: Year Two	Development of a Fully Reusable and Autonomously Landing Suborbital Launch Vehicle
2. Change in goal/ purpose/objective	Same goal as last year, while building off of what was learned last year.	Design, build, and test a suborbital rocket capable a propulsive vertical landing.
3. Changes in methodology	Design a propulsion system which uses off-the-shelf components and propellant to provide pitch and yaw control to the vehicle. Design an electronic control system which uses brushless DC motors to provide throttle and roll control. Build more advanced computer simulations before testing in the real-world.	Design a propulsion system which uses custom-developed propellant and a novel quad-nozzle arrangement to provide pitch, yaw, roll, and throttle control to the vehicle.
4. Variable studied	Same as last year, plus throttling coefficients.	- Proportional, Integral, and Derivative coefficients of propulsion system. - Drop altitude - Ignition time - Overall rocket construction
5. Additional changes	Overall: more focused on software simulations before flight, no propellant development, new propulsion system.	

Attached are:

☒ (2018-2019) Abstract and Research Plan/Project Summary

I hereby certify that the above information is correct and that the current year Abstract & Certification and project display board properly reflect work done only in the current year.

Ryan Westcott		11/01/19
Student's Printed Name(s)	Signature	Date of Signature (mm/dd/yy)

Ryan Westcott

Research Plan 2018-2019

Title: **Development of a Fully Reusable and Autonomously Landing Suborbital Rocket**

Rationale:

Throughout the past decade, a tremendous amount of research has been put into developing reusable rockets in order to decrease the cost of space exploration. However, most of this reusable technology has only been applied to large, orbital class boosters. This has left the lower powered, suborbital launch market with still relatively high launch prices. I would like to use the techniques and technology developed for reusable orbital boosters as a model for decreasing costs of smaller rocket launches. To accomplish this, I will develop a novel propulsion system design capable of providing vectorable and throttable thrust to enable the rocket to land at a specific landing zone. This propulsion system will utilize differentiable thrust in a quad-nozzle design to provide 5 degrees of controllable motion. This design will be used due to its ability to be scaled up, it's cost-effectiveness, and ability to move the rocket in all necessary directions. By developing a fully reusable and easily recoverable rocket, we will be able to significantly reduce the cost and environmental impact of suborbital launches.

Research Question:

How can I decrease the cost of suborbital rocket launches by developing a fully reusable launch vehicle capable of autonomously landing at a designated landing zone?

Expected Outcomes:

I expect to develop a system capable of returning all parts of a model suborbital launch vehicle to a predetermined location on the surface of earth. The hardware should be capable of providing propulsive landing capabilities to the craft, while the software should be capable of controlling its trajectory. The system will be capable of reducing launch costs by returning the vehicle to a specified landing zone and diminish the negative environmental effects by eliminating the loss of hardware.

Method:

Procedure:

1. Decide on which propulsion technology I will use: can I use commercially available rocket motors, or will I need to develop my own?
    a. Gather commercially available rocket motors which can provide sufficient thrust for my application.
    b. Design my own comparable rocket motor which functions to my exact standards.
        i. The nozzle will be made of concrete from a 3D printed mold which I will design. The body of the motor will use schedule 80 PVC pipe.
        ii. Custom-developed propellant will constitute of KNO_3 (the oxidizer), Sucrose, and Fructose (the two fuels). With a mixture of 62%, 17%, and 21% (Nakka) by weight, respectively. Oxidizer and fuel will always be stored separately and be mixed immediately before testing. In any given batch, no more than 30 grams of rocket fuel will be generated. The mixing will occur according to the following procedure:

      1. Measure out each of the materials by weight, keeping them in their own beakers.
      2. Turn the hotplate to 200ºC and pour the sucrose and fructose (the two fuels) into the pan on the hotplate.
      3. Mix the KNO3 (the oxidizer) into the mixture on the hotplate and stir until the mixture becomes smooth.
      4. Remove the mixture from the hotplate and pour it into the fuel grain mold.
      5. Since the oxidizer and fuel will be mixed at the testing location, no transportation will be necessary. This location will be in a large, open, outdoor space with a concrete surface on the ground to remove fire hazards.
   c. Prepare static firing test stand: an instrument that can be used to test the thrust of a rocket motor over time. Perform three static fires for each motor: the commercially available motor, as well as the custom developed motor. The static fire should follow the following procedure:
      i. The motor will be securely mounted onto the test fire stand with the metal coupling.
      ii. The thrust test stand computer will be initiated and the igniter will be secured in the motor.
      iii. When no one is within 30 feet of the test stand (Model Rocket Safety Code), the motor will be ignited from a safe distance by a computer signal.
      iv. No one will approach the test stand within 60 seconds of firing (Model Rocket Safety Code).
      v. Repeat for the remaining tests of each motor.
   d. Choose propellant type/motor design based on performance of: long burn time, high total impulse, and low average thrust, and ease of manufacturing/sourcing.
2. Once the propulsion type has been decided on, the rocket can start to be designed, prototyped, and constructed.
   a. Design the launch vehicle (rocket) from scratch (stability analysis, structural design, etc…). Rocket will be 66 mm in diameter and approximately 1 meter tall. This size should provide sufficient space to install all components. The airframe will be constructed from commercially-available body tubes and most components will be 3D printed.
   b. Design/prototype the structural frame and mechanism (3D printed parts, carbon fiber manufacturing, etc...)
   c. Design/prototype the flight computer hardware (Sensors, power supply, telemetry, etc…)
   d. Design/prototype the flight software (PID controllers, data filters, telemetry, etc…)
   e. Perform systems integration with drone that will be used for drop tests. Ensure all weight, space, and mechanical requirements allow the system to be integrated fully.
3. Perform static drop test to evaluate performance and safety of the system without active guidance at an elevated landing altitude
   a. In the test environment (no other individuals, no flammable materials), the launch vehicle will be dropped from a drone at a height determined by my simulation.
   b. The flight computer will initiate the thrust at the designated time and altitude.

    c. If the system does not function according to plan, redesign and retest until the system performs optimally.
    d. Repeat three times.
4. Based on the results from the static drop test, integrate throttling and control technology into launch vehicle.
    a. Enable TVC (thrust vector control) mount actuators to be controlled by the flight computer.
    b. Implement PID (proportional, integral, derivative) control based on simulated values.
5. Perform throttled and vectored drop test
    a. Perform the same procedure as the static drop test, however, with active throttling and gimbaling this time.
    b. Repeat until the landing vehicle performs optimally, making changes to the PID values as needed.

Data Analysis:

At each design iteration, the system will make three landing attempts. The landing success rate will be calculated by the number of successful landings divided by the total number of landing attempts, and the distance to target landing zone and landing velocity will be averaged for each successful flight. Each of these three values will be displayed in their own bar graph which compares the results of each design iteration. As the design progresses, the landing success rate should go up and the landing velocity should decrease. The most successful design iteration will be the one with the highest success rate and the lowest final velocity.

Risk and Safety:

When correct safety measures are followed, working with rockets is very safe. In accordance with the FAA (Federal Aviation Administration), all experimentation will be conducted within class G airspace in order to prevent interference with operations in other airspace (FAA, n.d.). In accordance with NAR (National Association of Rocketry), standard launch safety procedures will be followed closely: I will use a countdown before launch, and will ensure that all observers at the launch site are paying attention and are a safe distance of at least 15 feet away (propulsion system motor is classified as a “D” class or smaller) or 30 feet away (propulsion system motor is classified as a “E” class or larger). If the propulsion system does not ignite when the launcher’s ignition is pressed, I will remove the launcher’s safety interlock, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket ("Model Rocket," 2012). Finally, a fire suppression system (fire extinguisher) will be prepared and present at all times.

Commercially available black-powder motors will be used in accordance with their listed safety, handling, and disposal instructions. No attempt will be made to modify the propellant itself. The expended motor will be soaked in water for at least 10 minutes, where it will disintegrate. These remnants can be safely disposed of in an outside trash receptacle (Estes FAQs).

The testing environment for launching rockets, generating custom propellant, and performing static fires will constitute of a large, concrete surface with no flammable materials and access to fire suppression systems.

Whenever I am working with custom-developed rocket propellant, I will always use a full face mask and work in the testing environment. Additionally, a fire extinguisher will be present at all times.

Potassium nitrate is the oxidizer that will be used in my rocket fuel. Potassium nitrate is a strong oxidizer that may cause eye, skin, and respiratory tract irritation. Because of this, gloves, eye protection, and a respirator will be used whenever I am working with potassium nitrate. A licensed professional will be contacted in order to dispose of this product. (Material Safety Data Sheet)

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Development of a Fully Reusable and Autonomously Landing Suborbital Launch Vehicle

Westcott, Ryan

Throughout the past decade, significant aerospace research has been focused on bending the cost curve of space exploration through the development of reusable boosters. However, the investments in reusable technology have been primarily directed towards developing cost savings for large, orbital class boosters. This has left the smaller, lower-powered launch market without reusable technology which has resulted in relatively high launch prices. The development of technology capable of returning and landing smaller rockets could dramatically reduce launch costs. To achieve this goal, I worked towards developing hardware and software that enables a small booster to propulsively land, ready to be reused. The propulsion system that I engineered utilizes four solid rocket motors, each of which can be gimbaled on one axis. This configuration enables yaw, pitch, roll, and throttle control of the vehicle. I also developed software that utilizes proportional-integral-derivative (PID), sensor fusion, and data filtering algorithms. PID coefficients were determined by developing a mathematical model which simulated the rocket landing. The flight computer I developed runs on a 180 MHz ARM Cortex-M4 processor and contains all necessary sensors and control interfaces. Additional hardware was also designed and built to support the landing and reusability of the rocket. My project analysis indicates that the successful development of this system shows significant potential to save costs for smaller launch vehicles by enabling them to propulsively land and be reused.

Awards Won:

First Award of $3,000

Air Force Research Laboratory on behalf of the United States Air Force: First Award of $750 in each Intel ISEF Category

China Association for Science and Technology (CAST): Award of $1,200

National Aeronautics and Space Administration: Second Award of $750

International Council on Systems Engineering - INCOSE: Certificate of Honorable Mention