EML4551-2

Team 511: Microgravity Machine

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Abstract

The abstract is a concise statement of the significant contents of your project. The abstract should be one paragraph of between 150 and 500 words. The abstract is not indents.

Keywords: list 3 to 5 keywords that describe your project.

Disclaimer

Your sponsor may require a disclaimer on the report. Especially if it is a government sponsored project or confidential project. If a disclaimer is not required delete this section.

Acknowledgement

These remarks thanks those that helped you complete your senior design project. Especially those who have sponsored the project, provided mentorship advice, and materials. 4

- Paragraph 1 thank sponsor!
- Paragraph 2 thank advisors.
- Paragraph 3 thank those that provided you materials and resources.
- Paragraph 4 thank anyone else who helped you.

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Notation

IMU	Inertial Measurement Unit

Chapter One: EML 4551C

1.1 Project Scope

Project Description

Design a reproduceable system that can be dropped from a drone, achieve microgravity during its descent, and be safely recovered for reuse.

Key Goals

The primary goal of this project is to increase the availability and quality of microgravity sources in the state of Florida.

To achieve this goal, the microgravity machine must allow the payload to experience zero gravity for up to 4 seconds or longer. The design must accommodate a 3U sized CubeSat payload while weighing less than 25 pounds. The design must also accelerate downward at 9.81 m/s^2. The design must be easily reproducible, affordable, and reusable.

These key goals must be implemented to successfully accomplish the needs of the Florida Space Institute (FSI) which include increasing space awareness and science amongst middle school, high school, and college students, and furthering research opportunities.

Markets

The primary market for this device is researchers who wish to run experiments in a microgravity environment.

The secondary markets for this device include middle and high schoolers who wish to learn about science. Further secondary markets include private companies/organizations who wish to purchase/use our design for testing.

Tertiary markets include individuals seeking hands-on experience with a microgravity environment for recreational purposes.

Assumptions

The assumptions for this project are as follows: the vehicle's horizonal motion will not be controlled, strong winds will not inhibit the vehicle's motion, device will be safely guided to its starting position, vehicle will be tested in standard earth atmosphere.

Stakeholders

Stakeholders for our project include our project sponsor Mike Conroy, our senior design professor Dr. McConomy, our advising professor Dr. Ali, the colleges Florida Polytechnic University and University of Central Florida for organizing the competition and providing test fields, and the Florida Space Grant Consortium for providing the funding for this project. The last stakeholder for this project is Dr. Oates, chair and professor in Mechanical Engineering.

1.2 Customer Needs

To obtain the customer needs, the team had a meeting with the sponsor, Mike Conroy and asked him questions about what was expected from the machine. Interpreted needs were derived in terms of engineering language to clarify design goals from the responses to these questions. Below Table 1 summarizes the most important needs received from our sponsor. The most important needs are what the team identified to have the largest impact on the project objective. For all questions and customer statements, see Table A in Appendix B.

Table 1 – Summary of Interpreted Needs

Questions:	Customer Statements:	Interpreted Needs:
What are the dimensions for the payload to be contained?	100x100x300 mm (standard 3U CubeSat)	Machine must house a 3U CubeSat sized payload of dimensions 100x100x300 mm.
What phase of the project are we in (how long will we have to experience microgravity?	Phase 2.5	Machine must simulate microgravity for 3-4 seconds
Are there weight restrictions for the machine?	It should be light enough for the drone to lift. The drone can lift 25 lb, but shoot for 21-22 lb.	Machine must be less than 22 lb.
Are there any material restrictions?	No explosives, typically it is intended to be recreated by High School level classes, PLA, ABS stinks, Nylon stinks. Recommend 3D printing.	Use low-cost materials that are accessible.
Why haven't previous teams' designs been successful?	None of the teams' parachutes worked. Their tolerances were too high, or their parachute was installed incorrectly.	Design needs to be recoverable.

1.2.1 Contain 3U CubeSat

The first interpreted need that we derived was that the machine must contain a 3U CubeSat of dimensions 100x100x300 mm. This is a standardized structure to which other things can be attached. This is necessary because this device will have the ability to house a variety of experiments which future researchers may wish to perform.

1.2.2 Microgravity Time

The second interpreted need that we derived was that the machine must experience microgravity for 3-4 seconds. Mike Conroy told us that we are in phase 2.5 of a multiyear project where the aim is to increase the amount of microgravity time experienced each year. Last year none of the groups were able to achieve microgravity so the desired time has not changed.

1.2.3 Low Weight

The third interpreted need that we derived was that the machine needs to weigh less than 22 lbs. Although the drone can lift 25 lbs, a GoPro and accelerometer will be added so the device must be designed to weigh less than the maximum weight lifted by the drone.

1.2.4 Low Cost

The fourth interpreted need that we derived was that the machine needs to be constructed using accessible, low-cost materials. Mike Conroy stated that high schools and other colleges will be recreating this experiment. For them to do this, the machine needs to use materials that these institutions can access and afford.

1.2.5 Recoverable

The fifth interpreted need that we derived was that the machine needs to be recoverable to prevent damage at impact. Mike Conroy needs to access the data from the GoPro and accelerometer. This means that these components must be intact to determine if microgravity conditions were met.

1.3 Functional Decomposition

Microgravity machines are complex, and to efficiently approach the problem it needs to be broken down into manageable parts. By using the needs specified by the customer we were able to create a chart describing the required functions for the project. The four main subsystems of our product are control magnitude, provision, signal, and connect. The two largest subsystems are the control magnitude and the provision systems making them the most integral parts of the product.

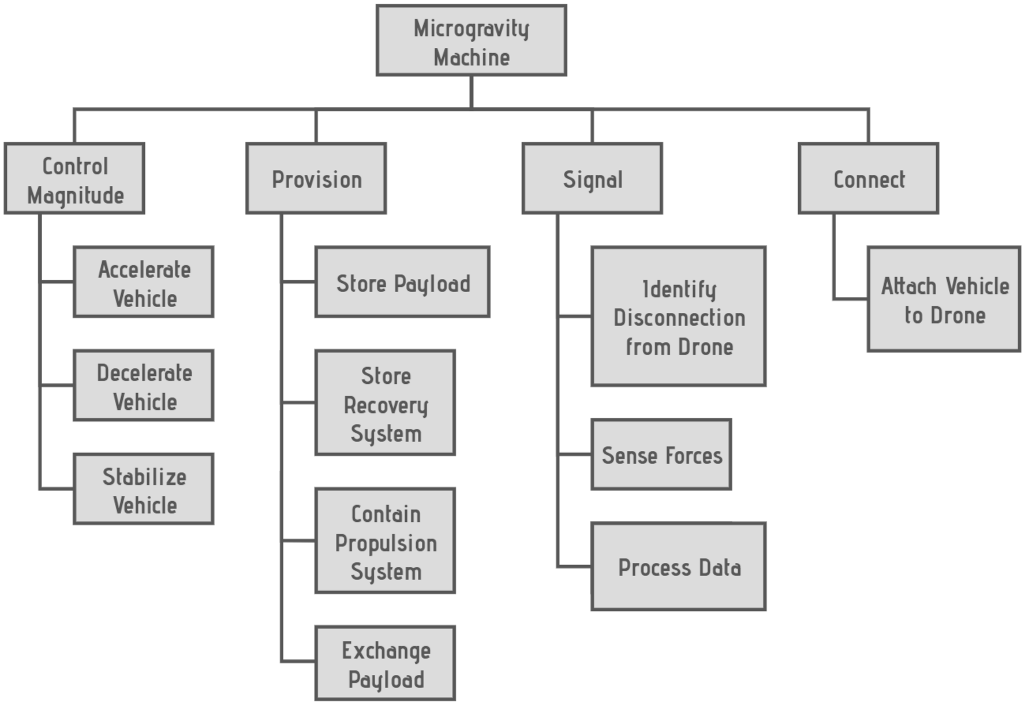


Figure 1: Functional Decomposition Hierarchy Chart

1.3.1 Connection to Systems

The control magnitude subsystem includes four functions: accelerate the vehicle, slow the vehicle, process data, and stabilization of the vehicle during flight. These four functions are the backbone of the product as acceleration to counteract drag allows for microgravity conditions and slowing allows for reusability. Stabilizing the vehicle during flight will aid in minimizing acceleration along the lateral and vertical axes of the vehicle while also minimizing rotation about its longitudinal axis. Control of this subsystem will be handled by an onboard processor.

The provision subsystem stores all the necessary components to the propulsion and deceleration mechanisms as well as the payload housing. The means of acceleration and deceleration have yet to be determined but there will need to be storage devices for any type of propellant or deceleration system that is chosen. The payload housing is what allows the payload to float in the vehicle during the descent. This is what allows for the payload to experience microgravity. The housing is accessible to allow for multiple tests to be performed in succession. These systems will take up most of the space inside the vehicle and will greatly influence the final look of the design.

The signal subsystem's functions detect release from the carrier drone and handle the processing of input/output stream of data between the onboard processor, sensors, and propulsion and deceleration mechanisms.

The connection subsystem's functions manage the attachment of the payload, recovery subsystems, propulsion subsystems, and connection of the carrier drone to the machine.

1.3.2 Smart Integration

By observing each function in Table 2, we can identify the functions which are related to multiple subsystems and are therefore affecting the system in different ways. The acceleration and deceleration components both overlap in the control magnitude and signal subsystems. This relationship exists because in order to accelerate or decelerate the vehicle, we need to detect what forces are influencing the vehicle, so we know how much we need to accelerate/decelerate and when to do this. The connect and provision subsystems have many overlapping functions because while the payload, propulsion, and recovery are all stored in the device, they need to be fastened as well. Since the payload is both stored and connected, the exchange payload function must also be stored and connected. The process data function is integrated in both signal and control magnitude because the signals will be sent to a computer where the signals will be converted/calculated and sent to the other systems, so the systems know how to behave. The function identify disconnection from drone falls under two subsystems: signal and connection. There is opportunity for innovation here because perhaps there can be one component of our design which allows for disconnection and sends a signal.

1.3.3 Action and Outcomes

The actions and outcomes of this project can be obtained from summarizing the functions represented in Figure 1 and comparing these with the customer needs. The machine must provide an alternative solution to create a microgravity environment for experimentation. In order to do this, it must stabilize itself, control its acceleration while falling, and land safely. This requires well timed cooperation between multiple mechanisms. The cooperation will be controlled through an onboard processor. It also needs to have stable and efficient packing to contain all necessary components including, the propulsion system, the recovery system, and the payload.

The machine must be able to connect with a drone so it can be lifted to a start position and know when the drone has released the machine so the automated control can be activated.

Table 2 – Cross Reference Table

Functions	Systems			
	Control Magnitude	**Signal**	**Connect**	**Provision**
Accelerate Body	X	X		
Decelerate Body	X	X		
Stabilize Vehicle During Flight	X			
Store Payload			X	X
Contain Recovery System			X	X
Contain Propulsion System			X	X
Exchange Payload			X	X
Identify Disconnection from Drone		X	X	
Sense Forces		X		
Process Data	X	X		
Attach Vehicle to Drone			X	

https://online.visual-paradigm.com/diagrams/features/functional-decomposition-diagram-tool/

1.4 Target Summary

Summary of Targets			
Function	**Target**	**Metric**	**Description**
Accelerate Body	9.81 m/s^2	Acceleration	The device must accelerate toward the surface at 9.81 m/s^2
Decelerate Body	0 m/s	Velocity	The velocity will be decreased to less than 5 m/s before touchdown.
Stabilize Vehicle	1	Degrees of Freedom	The degrees of freedom of the device while falling will be limited to one direction.
Store Payload	100x100x300mm	Volume	3U sized payload must fit within the vehicle.
Contain Recovery System	100%	Percent of Volume stored in vehicle	Device must house a system to slow decent of device before touchdown.
Contain Propulsion System	100%	Percent of Volume stored in vehicle	Device must house a propulsion system to counteract the force of drag
Exchange Payload	1 hr.	Time	Must be able to exchange the payload within 1 hr.
Identify Disconnection from Drone	0.1 s	Time	Vehicle can recognize when the drone has dropped the vehicle within 0.10 seconds.
Achieve Weight Limit	10kg	Weight	Device must weigh less than 10 kg so the drone can lift it.
Achieve Microgravity	4s	Time	The vehicle must experience microgravity for 4 seconds.

1.4.1 Determination of Targets

From the functional decomposition, our team determined the corresponding targets and metrics. We also determined necessary targets for the design that are not contained in the functions. This section aims to explain the reasoning behind the most important targets and metrics.

Accelerate Body

The purpose of accelerating the body is to overcome the force of drag which will allow for microgravity conditions. To achieve microgravity conditions the design must accelerate at a rate of 9.81 m/s^2.

Decelerate Body

The purpose of decelerating the design is to slow the design before it impacts the ground. The design must not sustain damage and all the components inside must function properly after the test. We determined that in order to reduce the damage/ impact force, we want to slow the vehicle to less than 5 m/s at the time of impact. Doing this will allow our design to meet the recoverable requirement.

Stabilize Vehicle

The purpose of stabilizing the design limits the degrees of freedom during descent. This is necessary to minimize acceleration along the lateral and horizontal axes of the vehicle while also minimizing rotation about its longitudinal axis. This will also minimize the drag experience by the design while also allowing it to be constant. If the design isn't stabilized, the drag will vary during the descent, making it harder to measure. There is also the risk of the design flipping or reorienting itself during the descent, resulting in a failed run.

Store Payload

The purpose of including the store payload function as a target is to emphasize the need for the payload to be able to fit inside the design. If it doesn't, then the design will be invalid and not meet the requirements specified by the sponsor. The payload is 100x100x300 cm, so the design must be large enough to house this payload.

Contain Recovery & Propulsion System

The contain recovery system function is included as a target to emphasize the need for internal space inside the design. Although the only requirement from the sponsor is for the payload, accelerometer and GoPro to fit inside the design, we need to ensure there is room for the entire recovery system and propulsion system to fit inside.

Functionless targets

Although not a function, achieving the required weight limit is crucial for the design to be successful. The design must weigh less than 10 kg (22lbs) so the drone can lift the design up to the specified altitude on the day of the competition. Achieving microgravity is one of the most important targets because the entire purpose of the project is to design a way for the payload to achieve microgravity. The goal specified by the sponsor is 3-4 seconds, which is our target. The design must be repeatable in the sense that we must be able to reattach the design to the drone multiple times after multiple drops. Therefore, whatever propellant that is used in the design must have a way for us to refuel after the drop. We have one hour to reset the vehicle for another test.

To reduce the amount of drag, the design needs to have an aerodynamic design which is quantified by using the drag coefficient. We've estimated a drag coefficient of 0.8 for model rockets. Once we have a finalized design, we can experimentally measure this in a wind tunnel to ensure we are at or below a drag coefficient of 0.8. We've estimated the required propulsive force to be 25N. This is the required force to overcome the drag and was calculated based upon last year's design to give us a rough estimate.

1.4.2 Critical Targets

The mission critical targets are the Achieve Microgravity target and Contain Recovery System target. The first critical target is to achieve microgravity because the purpose of the project is to make testing microgravity conditions in a simpler, cheaper, and more replicable way. The whole project relies on the system achieving microgravity for at least 4 seconds to be considered a success. The second critical target we have set is that the system must successfully contain and deliver the recovery system. In a similar way to our first critical target, the system won't be of any use if this target isn't achieved. The only way we could tell if the system achieved microgravity is by containing and protecting the payload. The best way to protect the payload is by slowing down the device enough so that it is not destroyed, and it can be recovered for reuse.

1.4.3 Validation of Targets

The major systems will be tested before competition day. Each system will be tested individually. Testing will be conducted in this manner because we will not have access to a drone capable of lifting our device to 900ft to simulate the competition. Furthermore, conducting testing by dropping the fully assembled device will result in damage or destruction of the device should the recovery system fail, potentially preventing us from competing.

The provision system will be tested by assembling the device in competition ready configuration (propellant and batteries loaded, Arduino and sensors powered on, parachute loaded, 3U payload stored). Doing so will ensure that all the systems fit within the device and will be ready to go on competition day. Should one of the subsystems not fit correctly, modifications will be made until they do. Moreover, the provision subsystem that holds the payload should be designed to allow the payload to move freely within the device body. This will be tested by measuring the alignment of this subsystem which should allow the payload to move.

The deceleration system is most important to guarantee the reusability of the vehicle. The release and actuation mechanisms will be tested by commanding the systems to deploy while on the ground.

The propulsion system will be tested by first measuring the maximum output thrust of the system on the ground. The device and propulsion system can be placed into a testing setup to measure the max thrust by commanding the system to supply maximum thrust while the device is positioned onto a scale. This will allow us to measure if the system can supply enough thrust for the duration of free fall. If not, adjustments will be made. The critical target of achieve microgravity for 4 seconds can be tested in the following way. A file of sample accelerometer data will be inputted into the code and the force provided by the thrusters will be measured using a scale. The device will be placed on the scale with the thrusters pointed away from the scale. The scale will be zeroed before the thrusters are turned on. We will measure if the force from the thrusters respond properly to the simulated force from the accelerometer data to achieve a net zero force on the payload.

Disconnection from the drone will be tested by plugging the banana jacks into the Arduino and then rapidly pulling them out to test the timing response of the control system.

1.4.4 Derivation of Targets/Metrics

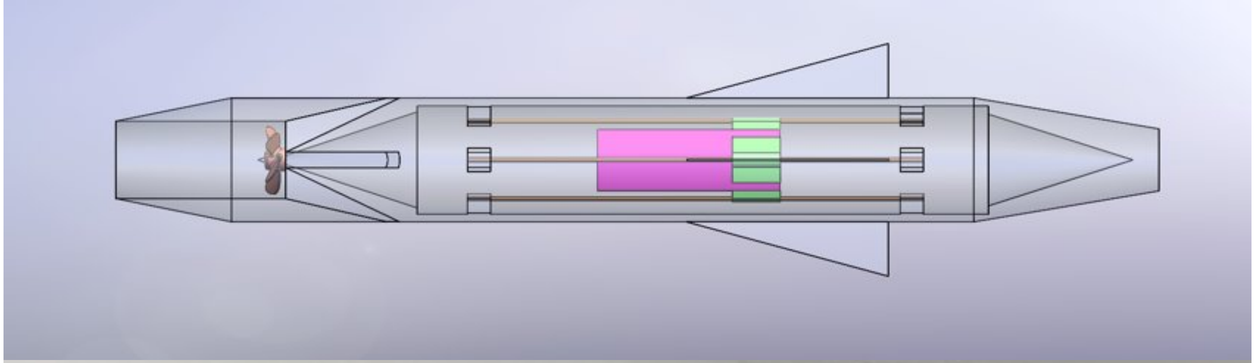
The targets and metrics were determined by analyzing the functional decomposition and customer needs. The team translated the results of these processes into quantifiable variables which will be used as benchmarks for designing the vehicle. For each of the functions, the team considered what measurement would be best for verifying the function and did research to determine the value to shoot for. Even though the function decelerate body describes an acceleration, the actual value of acceleration is not very important. The most important result of the deceleration is that it lands at a slow velocity, so velocity was chosen as a measurement. Some of the customer needs were given in quantifiable forms such as the weight restraint of 10 kg and the required stored payload volume of 100x100x300 mm. Therefore, these targets were given directly by the sponsor and are highly important.

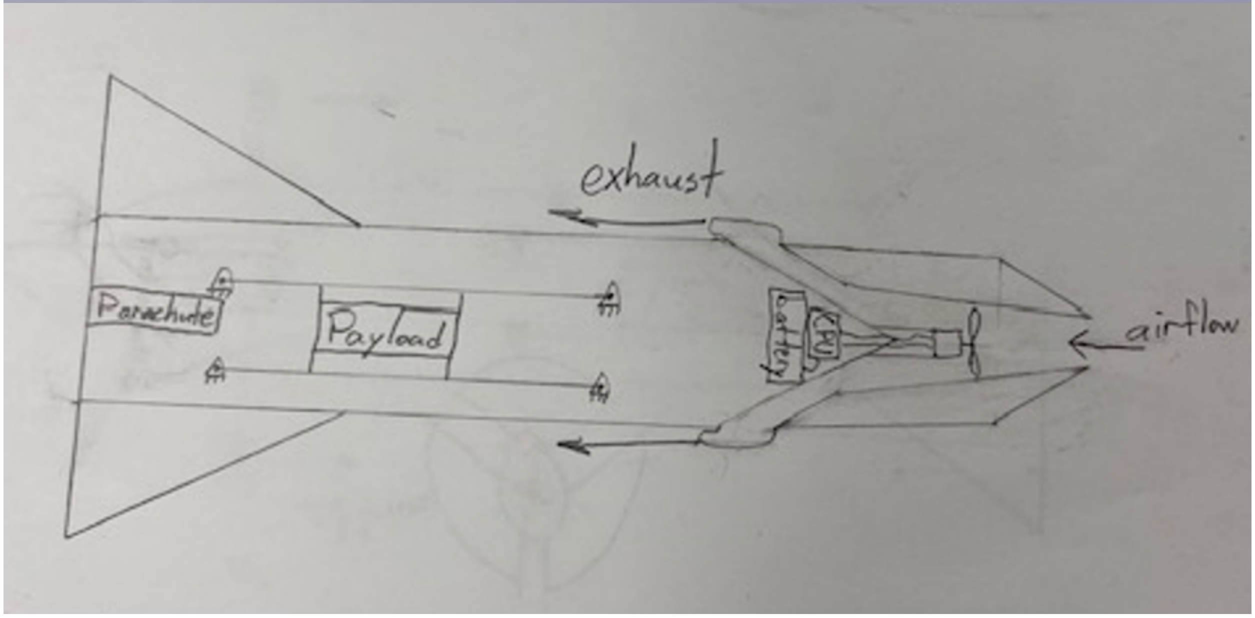
1.5 Concept Generation

High Fidelity Ideas.

Ducted Fan.

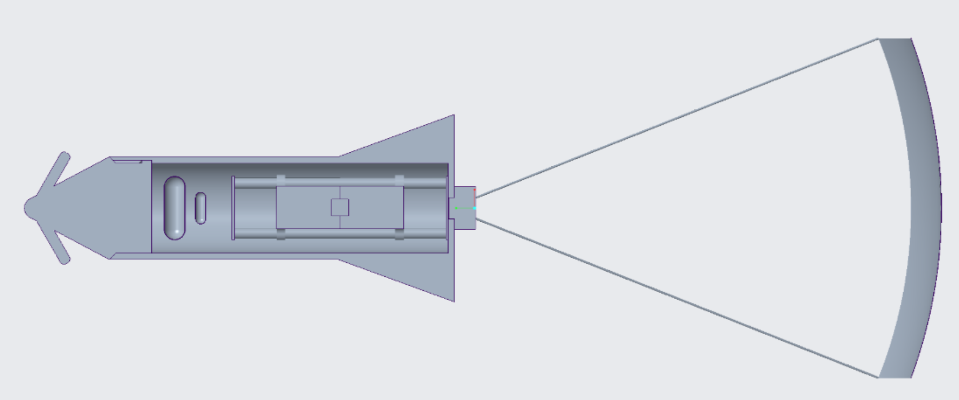
There is an electric ducted fan mounted at the front of the device which pulls air through an intake in the nose and expels it from three to four nozzles on the side of the body. The nozzles allow for the possibility of thrust vectoring to help control the attitude of the device as it falls. Furthermore, the nozzles can be controlled to point toward the surface to help aid in decent. There is also a parachute mounted in the back of the device to safely recover the vehicle.

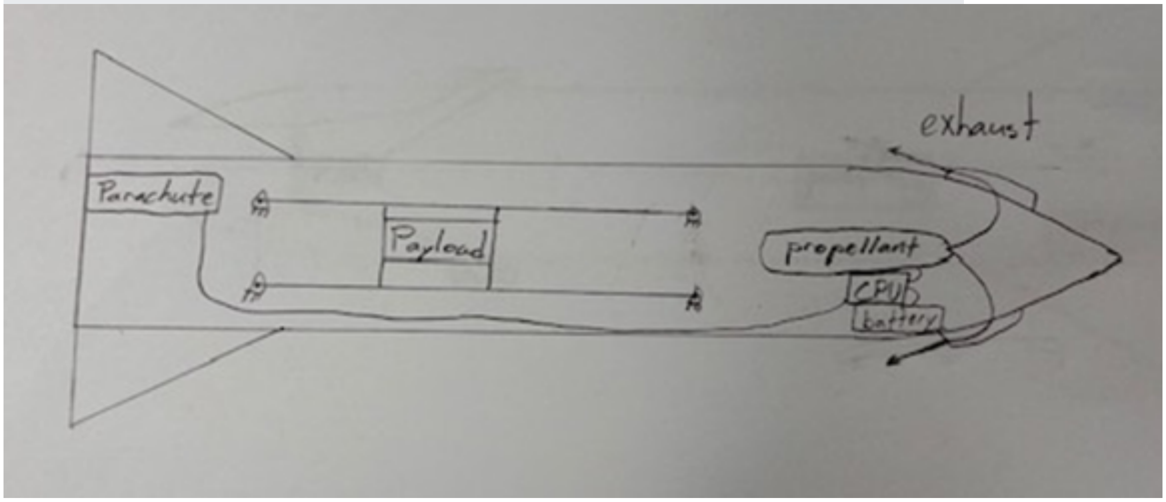




Propulsion from the nozzle.

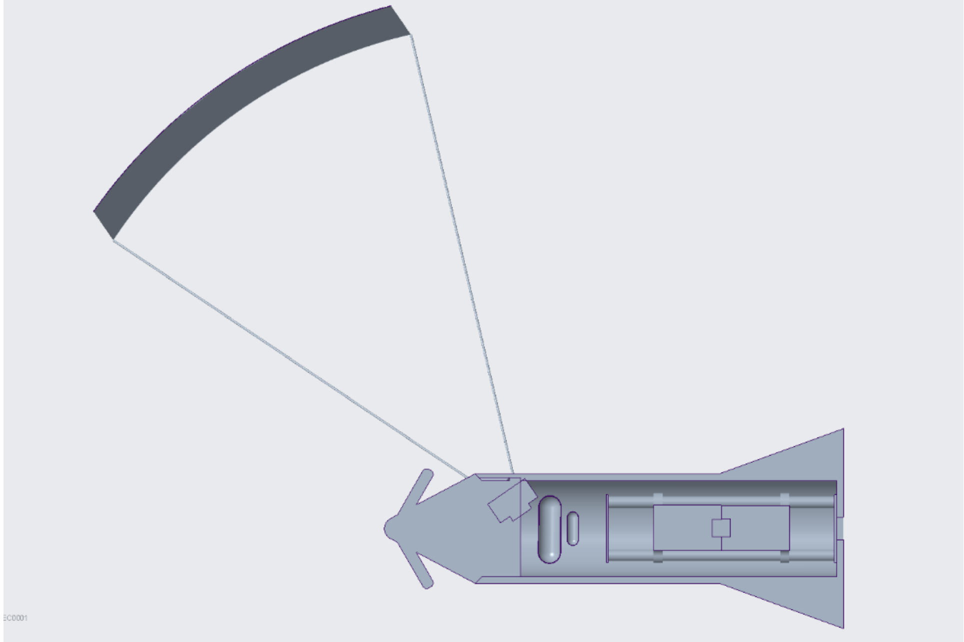
This idea is taken from the previous year's team's solution to this problem. There are nozzles attached to the front of the vehicle which propel water parallel to the nose surface. There is also a parachute attached to the back of the device which can be deployed once sufficient microgravity has been achieved.





Flipping Concept.

This is like the above fluid propelled concept except the parachute is deployed and anchored from the side so that the device partially flips to have a larger area perpendicular to the direction of fluid flow, after parachute deployment. Again, nozzles attached to the nose of the rocket propel water perpendicular to the surface to slow impact.



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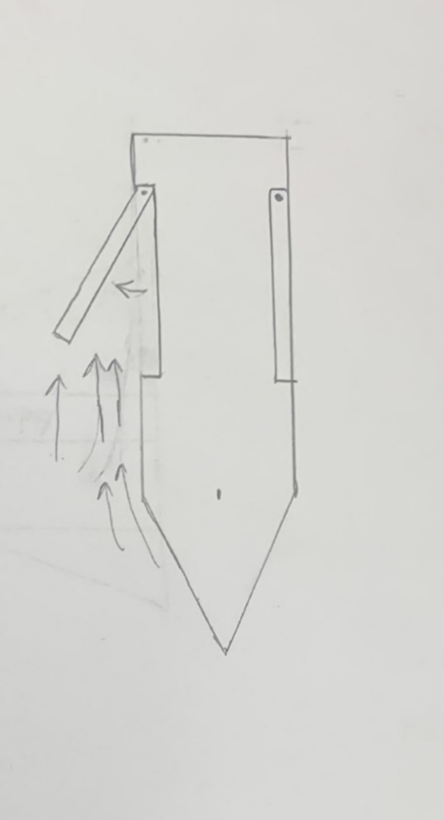
Medium Fidelity.

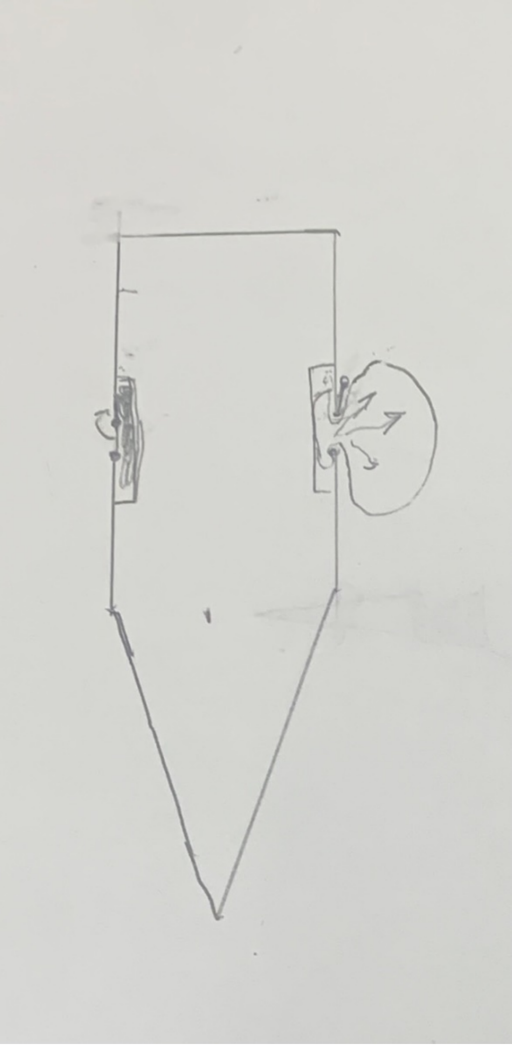
Air Brakes

The body is an aerodynamic shape with propulsion from the nose mounted nozzles. After microgravity is experienced, 4 large air brakes are extended at 90-degree angles around the circumference of the rocket. Cloth connects between extended air brakes to increase the surface area of the brake.



Air Bags

Propulsion is accomplished by propulsion from the nozzles. After microgravity is experienced, air bags inflate around the outside of the rocket to cushion the landing.

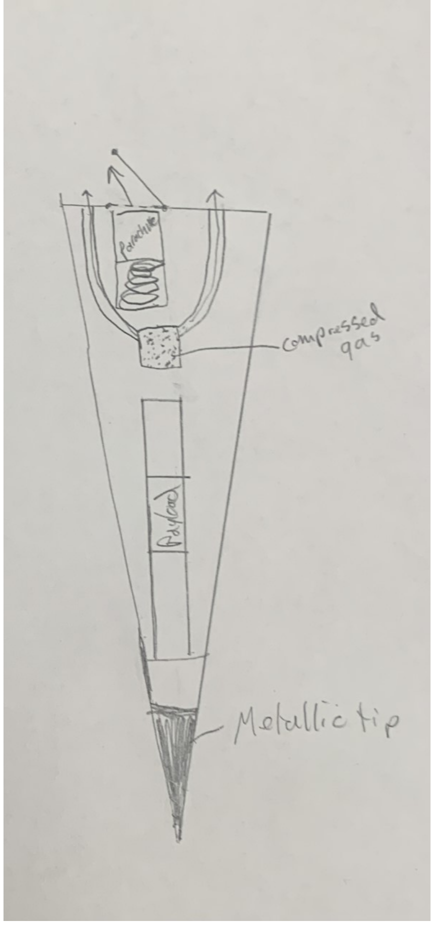


Directional Nozzles

Nozzles are attached to the cone which can shoot fluid either along the body toward the back or away from the body past the point of the cone. A parachute is deployed from the back.

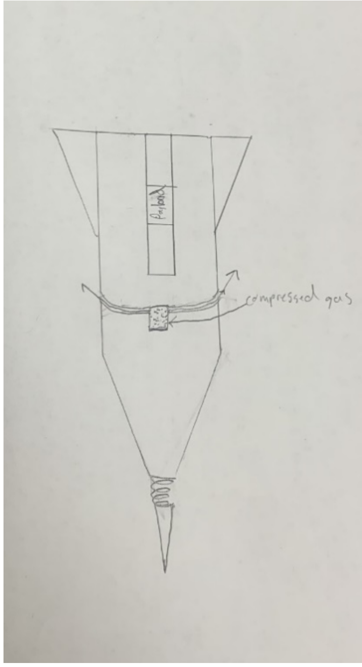
Long Cone

The body is one long cone which is optimized to be aerodynamic. Fluid is ejected from the rear of the cone. The body will pierce the ground and deceleration will happen as the cone digs into the ground. There is a hard plastic shell on the outside of the cone which fits the geometry. The cone can be removed from its shell to make retrieval easier.



Springed Stake

There is a stake at the front of the device attached to the nose via a spring. The device decelerates when the stake cuts through the ground and the spring is compressed. Acceleration is accomplished via fluid ejected from nozzles on the side of the device.



Concept Generation Tools

A few different methods were used to aid in concept generation. One tool which was used was biomimicry. Two animals which move through fluid were used as inspiration for concepts which were generated. From the idea of a fish swimming through the water, the team thought of using a fishtail in the back of the device which could effectively “swim” down through the air. From the idea of a diving bird, which opens its wings to slow down, the team was inspired to have articulating side fins which could adjust to be perpendicular to the direction of air flowing around the body. A morphological chart was also used to put together component ideas into many system ideas.

1.6 Concept Selection

The ducted fan concept was selected as our finalist. This design uses an electrically driven ducted fan in the front section of the device. The ducted fan will pull air through the air intake in the center of the nose cone. The air will be accelerated by the electric motor after which, the air will exit through three or four nozzles placed axis symmetrically around the body or the device which will be pointed downstream. This setup will allow for a large amount of thrust to combat the effects of drag, as ducted fans are more efficient than their ductless counterparts. Also, controlling the thrust will be relatively simple as an Arduino and motor controller can be used to throttle the motor speed.

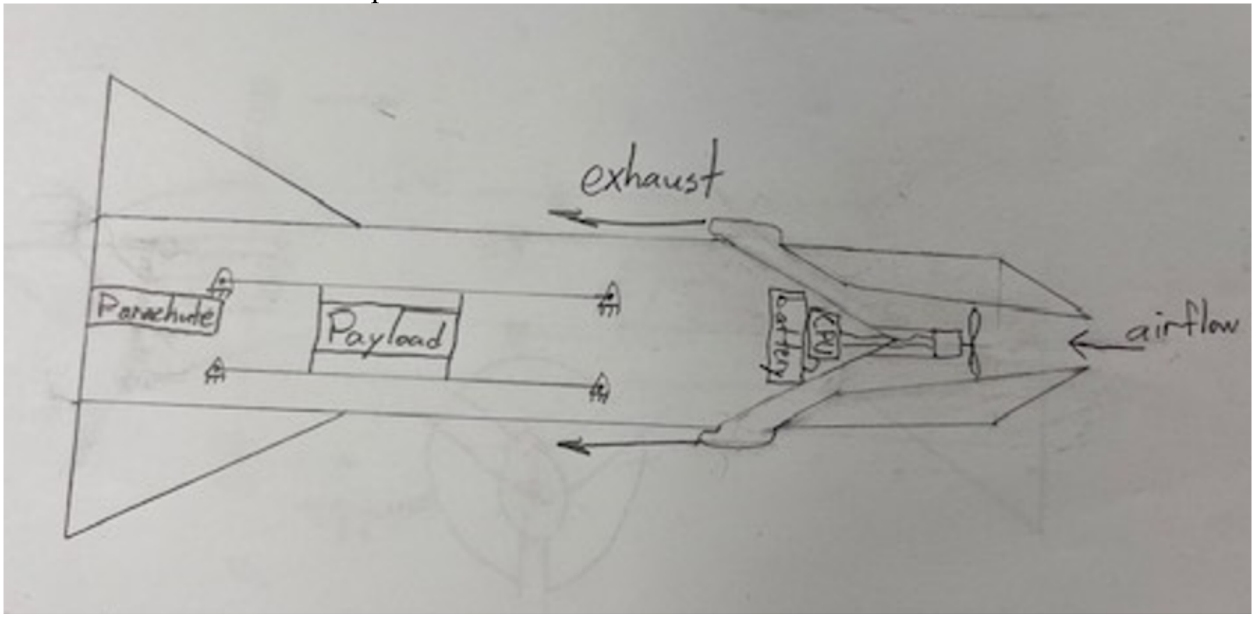
The payload system will be housed behind the propulsion system in the middle portion of the device. The exact payload storage method is to be determined as new information is still needed from our sponsor, Mike Conroy.

The parachute system will be housed at the tail end of the device. A drogue parachute will be spring loaded and actuated by the microcontroller. This smaller drogue chute will act to deploy the full-sized parachute. Arranging the device’s systems in this manner gives each enough operating space.

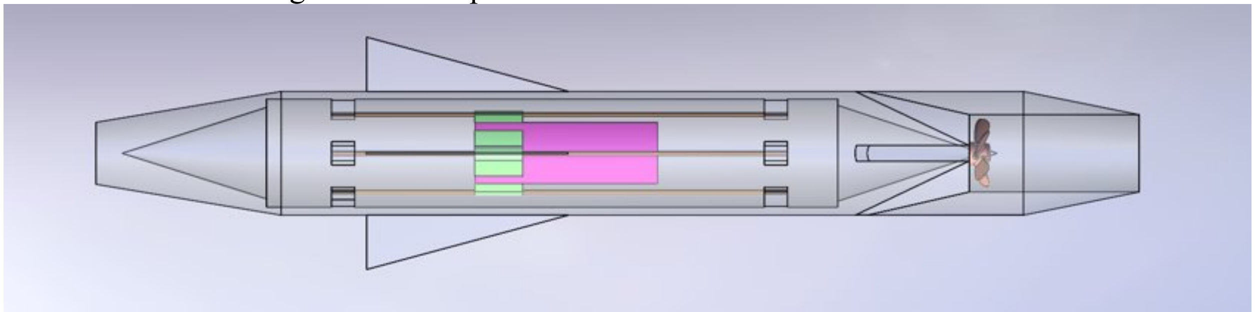
The angular positions of the nozzles could potentially be controlled by servos which will allow for thrust vectoring. Thrust vectoring will allow us to control the attitude of the device as it falls, making it more stable during flight. Furthermore, the nozzles could be pointed toward the ground to soften the landing as the device nears the ground.

The ducted fan concept was selected over the fluid propelled concepts as they have a more complicated control system. The controller would have to regulate the valves of the compressed gas tank and the fluid flow going through the nozzles. This complication was evident in that the previous team could not get this system to work. Our sponsor informed us that the valve system would be rather expensive and difficult to control. Furthermore, the thrust output of the system might be too small to counteract the specific forces of drag, and its output would be difficult to change after designing and assembling the system.

Here is a sketch of the concept.



Here is a CAD drawing of the concept.



Binary Pairwise Comparison

To complete the binary pair wise comparison, we listed the most important customer requirements and compared them with each other. This is done to find out the weight factor that they will have in the House of Quality on the next step. For the customer needs we picked microgravity simulation, lightweight, low-cost materials, recoverable and small dimensions. Using the graph that is featured in Appendix F we were able to see that Microgravity Simulation had the highest weight factor and was considered the most important customer need. The second most important customer need was recoverable which was more important than most customer needs, excluding microgravity simulation. The way we compared them was by placing a 1 if the column was more important than the row, and a 0 if the row was more important than the column.

House of Quality

The whole project has the focus to satisfy the customer requirements to the best of our abilities, so using the customer needs is primordial to making a good concept selection. We choose engineering characteristics that best fit our project like acceleration, stability, deceleration, payload storage and response time, and used a House of Quality chart to rank their importance in accordance with the customer needs. We used the results of the binary pairwise comparison to provide a weight factor for each customer need. As it was mentioned in the previous section, microgravity simulation and recoverability where the highest rated needs, which means they had the highest impact into the rank order for the engineering characteristics. As it can be seen in Appendix F, we compared rows to columns to rank how important each of the characteristics are in relation with the customer requirements. We were able to find out that acceleration was the most important characteristic to achieve success for our project as well as stability and deceleration (Stopping mechanism). Besides this we were able to eliminate one of the characteristics in response time which had a low ranking and seemed hard to measure in our concepts as most of them feature the same electrical components (Arduino) and we decided it would just hamper our future charts rather than improve them.

Pugh Chart

We compared our medium and high-fidelity concepts to the Air Zero Parabolic Plane from the market. We were determining if the designs were better, worse or the same(satisfactory) compared to the reference. The ducted fan design was determined to have better acceleration, deceleration, exchange payload and weight criteria. The only negative is the material toughness. The other categories are all satisfactory. This gives the ducted fan a rating of 3. The propulsion from the nozzle has the same ratings compared to the plane with the acceleration, deceleration, exchange payload and weight criteria all having better scores. The only negative with this design is the material toughness. This also gives the design a rating of 3. The side parachute design was determined to have better acceleration, deceleration, exchange payload and weight criteria. This design has worse stability and worse material toughness with the payload storage being satisfactory. This gives the design a rating of 2. The medium fidelity concepts all have a considerably lower rating than the high-fidelity designs except for the directional nozzles design. This design has better acceleration, deceleration, exchange payload, stability and weight criteria. The only negative is the material toughness. This gives the design a rating of 4 which is higher than our high-fidelity concepts. The long cone and springed stake designs were eliminated

Next, we used last year's design, propulsion from the nozzle, as the reference. The ducted fan had better acceleration, stability, and deceleration capabilities comparatively. The rest of the criteria were determined to be satisfactory due to having a similar body comparatively. This gives the design a rating of 3. The side parachute design only had an advantage with the deceleration aspect. This is because this design is the only design that will be perpendicular to the airflow, generating the most drag. The stability was determined to be worse because it may not flip perpendicular how we want it to and could spiral out of control. The rest of the criteria were satisfactory. This gives the design a rating of 0. The airbrakes design was only satisfactory when comparing the acceleration, payload storage and payload exchange. The rest of the criteria were determined to be worse, giving the design a rating of -4. The air bag design only had an advantage when comparing the material toughness, the rest of the criteria were satisfactory or worse giving the design a rating of -1. The directional nozzles design only has an advantage when comparing the stability component. The rest were satisfactory or worse, giving the design a rating of -1. From these comparisons we've determined the ducted fan to be the best design.

AHP Chart

To check how consistent our analysis was and to help choose the final concept, AHP charts were used in Microsoft Excel. First the team worked together to compare our selection criteria to each other to determine how which criteria are more important than others. Values between 1/9 – 9 were used as quantitative representations of the criteria's relative importance for our project. Using these values inputted into the chart, a consistency check was done as a measure of how consistent the team was with evaluating criteria importance. The observed value for the consistency check was less than 0.1 which means we were reasonably consistent with evaluating the criteria.

Next another AHP chart was also used to observe how the concepts compare for accomplishing each of the chosen criteria. The same values of 1/9 – 9 were used to compare relative importance. After these values were all assigned, they were normalized and then consistency checks were done again to ensure each requirement was evaluated accurately. Then we used Excel to come up with quantitative values called alternative values which describe how well the ideas accomplish the required tasks. From here, the concept was chosen based off the idea with the highest alternative value, the ducted fan with a value of 0.496. The next highest choice was the side nozzle propulsion idea with a value of 0.344.

1.8 Spring Project Plan

Chapter Two: EML 4552C

2.1 Spring Plan

Project Plan.

Build Plan.

Appendices

Appendix A: Code of Conduct

I. Mission statement

Our mission is to collaborate effectively, create something that the team is proud of, and win the competition.

II. Modes of Communication

Microsoft Teams and email. A distribution list was created on OneNote, this should be used for team email communications regarding assignments. Text or phone calls if needed for rapid communication. Email response time should always be as soon as possible.

III. Team Roles

Samuel Duval: Flight dynamics and Propulsion Engineer. Deals with the flight dynamics of the airframe and required propulsion aspects of the project design.
Pedro Siman: Recovery engineer. Test the recovery system of the projectile and research the best way to recover it without damaging it, allowing us to reuse the case and lower our total costs.
John Tietsworth: Controls Engineer. Creates the control system for the vehicle.
Thomas Lenz: Test and Safety Engineer: Testing of the system and analyzing the data. Ensures all components are safe and meet the requirements.
Collin Gainer: Body design and Propulsion Engineer. Primarily focused on the design of the dropped body and propulsion systems with contribution to all aspects of the project.
Other Duties: Team members will be asked to volunteer for new duties. This will be discussed at team meetings.

IV. Outside Obligations

Samuel Duval: I have work for 4 hours per day M-F. I will be able to meet from 2-3:30 everyday and after class at 4:45pm MW. I will be flexible when needed.

Pedro Siman: Monday 8:00 AM – 4:30 PM. Tuesday-Thursday: 8:00 AM – 9:15 AM and 3:30-7:45. Wednesday 8:00 AM – 1:30 PM and 5:30 AM-8:00 PM. Friday 10:00 AM-12:50AM. Out of country during Spring Break. Flexible schedule on weekends
John Tietsworth: Tuesday and Thursday before or after class time. Friday 10:00AM-3:00PM
Thomas Lenz: Monday and Wednesday: 2:00-3:25PM. Tuesday and Thursday: 11:00-12:15AM, 3:30-7:30PM. Available any other time. Out of country during Spring Break.
Collin Gainer: Monday Wednesday 1:00PM – 7:00PM. Tuesday Thursday 10:00AM – 3:30PM. Friday Saturday All Day

V. Meetings

Weekly meeting times: During class time (TR)

As Needed meeting times: Afternoon MW after 5:00, weekends.

Notify the team at least two days before you need to miss a meeting.

VI. Team Rules

Do assigned tasks or give notification two days before missing a task.
Be professional when representing the group.
Notify the team after submitting an assignment.

VII. Dress Code

Design Reviews: Business Professional; Suit and tie.
Sponsor Meetings: Business Casual; Button down shirt/Polo with slacks/Khakis.
Team Meetings: Casual

VIII. Attendance Policy

Attend every meeting unless you have another commitment at the same time. If you know you will miss a meeting let the other team members know through either email or the team's chat. Before meetings, attendance will be taken and uploaded to team's page for archiving.

IX. Conflict Resolution

1st offence: We will reach out in over predefined methods of communications.
2nd offence: We will reach out in over predefined methods of communications **AND** cc Dr. McConomy.
3rd offence: Dr.McConomy will be contacted directly with an explanation of the issues.
Offences include missing team meetings without an excuse, missing deadlines assigned by group, failing to respond to team members in a timely manner (within 24 hours),
For all subsequent offences, Dr. McConomy should subtract 1% from the team member's total grade.

X. Making Amendments

4 people must agree on every amendment.
Amendments should be added at the end of the Code of Conduct
Amendments should include the date they were added

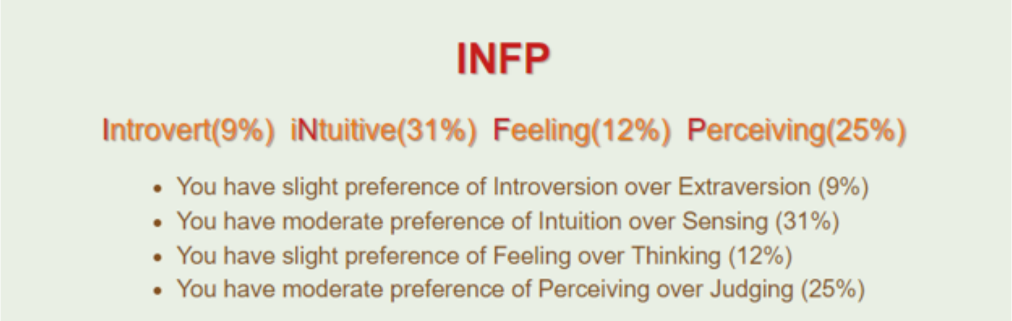
XI. Statement of Understanding

By signing this document below, I affirm that I have read the rules and principles stated above and agree to the terms listed.

Print Name	Signature	Date:
Samuel Duval		09/08/2022
John Tietsworth		09/08/2022
Thomas Lenz		09/08/2022
Collin Gainer		09/08/2022
Pedro Siman		09/08/2022

XII. Personality Test Results

Samuel Duval:

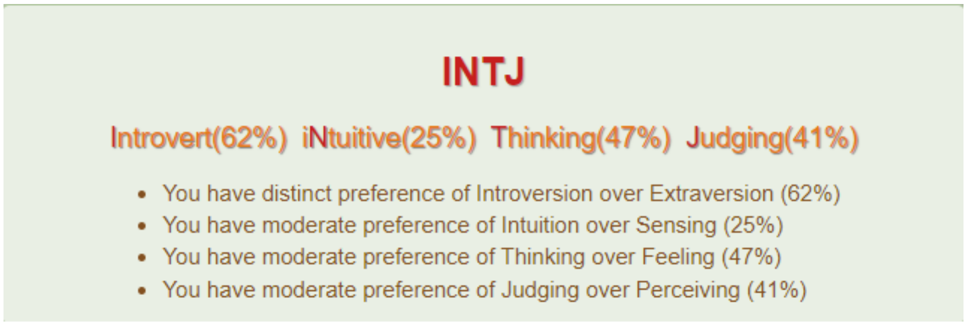


INFP

Introvert(9%) iNtuitive(31%) Feeling(12%) Perceiving(25%)

- You have slight preference of Introversion over Extraversion (9%)
- You have moderate preference of Intuition over Sensing (31%)
- You have slight preference of Feeling over Thinking (12%)
- You have moderate preference of Perceiving over Judging (25%)

Collin Gainer:

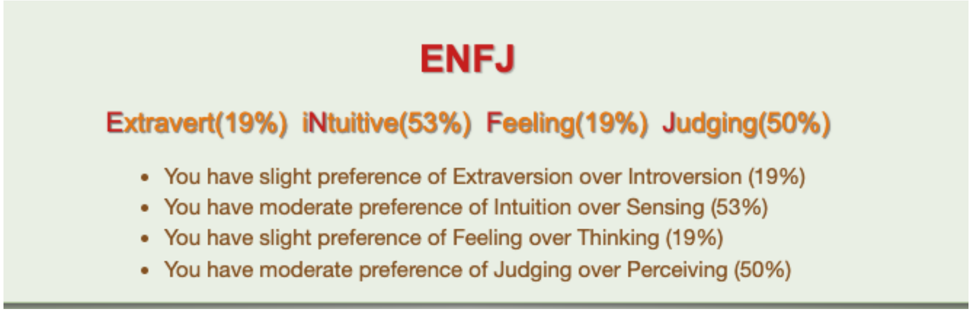


INTJ

Introvert(62%) iNtuitive(25%) Thinking(47%) Judging(41%)

- You have distinct preference of Introversion over Extraversion (62%)
- You have moderate preference of Intuition over Sensing (25%)
- You have moderate preference of Thinking over Feeling (47%)
- You have moderate preference of Judging over Perceiving (41%)

John Tietsworth:

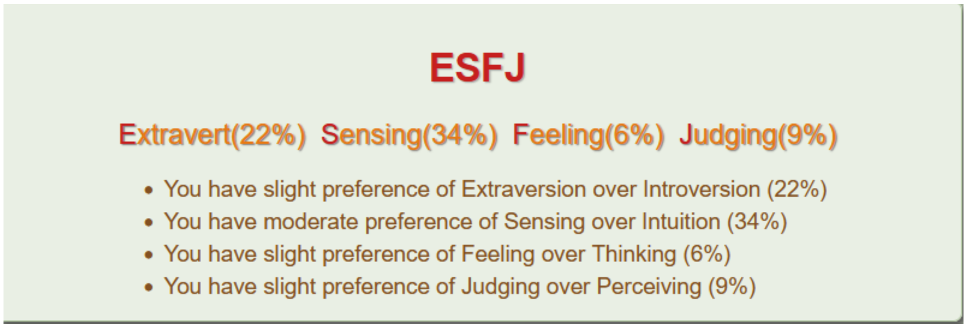


ENFJ

Extravert(19%) iNtuitive(53%) Feeling(19%) Judging(50%)

- You have slight preference of Extraversion over Introversion (19%)
- You have moderate preference of Intuition over Sensing (53%)
- You have slight preference of Feeling over Thinking (19%)
- You have moderate preference of Judging over Perceiving (50%)

Thomas E. Lenz:

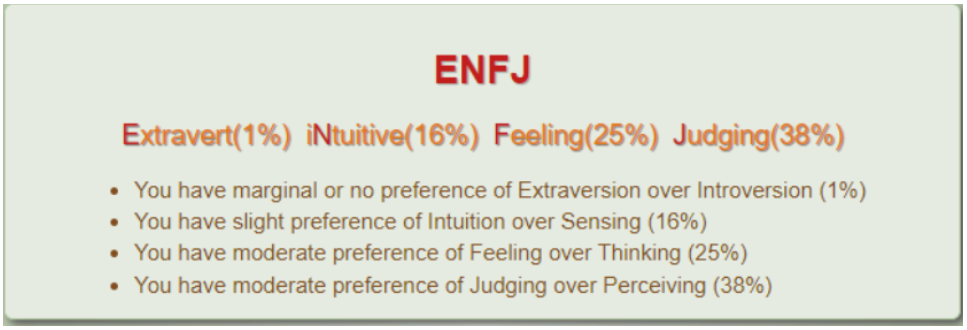


ESFJ

Extravert(22%) Sensing(34%) Feeling(6%) Judging(9%)

- You have slight preference of Extraversion over Introversion (22%)
- You have moderate preference of Sensing over Intuition (34%)
- You have slight preference of Feeling over Thinking (6%)
- You have slight preference of Judging over Perceiving (9%)

Pedro Siman:



ENFJ

Extravert(1%) iNtuitive(16%) Feeling(25%) Judging(38%)

- You have marginal or no preference of Extraversion over Introversion (1%)
- You have slight preference of Intuition over Sensing (16%)
- You have moderate preference of Feeling over Thinking (25%)
- You have moderate preference of Judging over Perceiving (38%)

Appendix B: Customer Needs

Table A – Complete List of Customer Needs

Questions:	Customer Statements:	Interpreted Needs:
What are the dimensions for the payload to be contained?	100x100x300 mm (standard 3U CubeSat	Machine must house a 3U CubeSat of dimensions 100x100x300 mm.
What phase of the project are we in (how long will we have to experience microgravity?	Phase 2.5	Machine must simulate microgravity for 3-4 seconds
Is there a standardized way of loading the payload into the machine?	Whatever you want, last year's group inserted payload through the aft end of the device.	Payload can be removed and added to the device. There are no restrictions on method of payload loading.
What is our budget for this project?	You will need to apply for funding through the Florida Space Grant	Budget is dependent on grants received.
Will we be given any components such as the accelerometer or payload housing?	Payload housing should be 3D printed by the team. Accelerometer and GoPro will be provided	Accelerometer and GoPro will be provided. Payload housing CAD files will be provided, and team must 3D print it.
Are there any size restrictions for the machine?	Must contain the 3U CubeSat payload.	The machine must be large enough to house the 3U CubeSat sized payload.

Are there any weight restrictions for the machine?	It should be light enough for the drone to lift. The drone can lift 25 lb but shoot for 21-22 lb.	Machine must be less than 22 lb.
Do we need to be concerned with attachment of the machine to the drone?	No, the machine will be attached using J hooks and banana jacks	Attachment between microgravity machine and the drone will be J hook and banana jacks.
Will there be any obstacles to avoid during freefall?	No, maybe birds	Machine does not need to control movement in the directions parallel to the earth's surface.
What will be provided to us on launch day?	Power	Some devices can be charged via generator on the competition day.
Are there any other restrictions for this machine?	No explosives	Explosives must not be used for any facet of this project.
Why haven't previous teams' designs been successful?	None of the teams' parachutes worked. Their tolerances were too high, or their parachute was installed incorrectly.	Design needs a suitable recovery mechanism to prevent damage at impact.
Are there any material restrictions?	No explosives, typically it is intended to be recreated by High School level classes, PLA, ABS stinks, Nylon stinks. Recommend 3D printing.	Use low-cost materials that are accessible.
Are we allowed to have a crumple zone in the front of the nose cone?	Sure, but the machine must be reusable for multiple trials.	The Machine must be reusable for multiple trials.

Appendix C: Functional Decomposition

Table 2 – Cross Reference Table

Functions	Systems			
	Control Magnitude	**Signal**	**Connect**	**Provision**
Accelerate Body	X	X		
Decelerate Body	X	X		
Stabilize Vehicle During Flight	X			
Store Payload			X	X
Contain Recovery System			X	X
Contain Propulsion System			X	X
Exchange Payload			X	X
Identify Disconnection from Drone		X	X	
Sense Forces		X		
Process Data	X	X		
Attach Vehicle to Drone			X	

Appendix D: Target Catalog

Function	Target	Metric	Description
Accelerate Body	$9.81\ m/s^2$	Acceleration	The device must accelerate toward the surface at $9.81\ m/s^2$
Decelerate Body	0 m/s	Velocity	The velocity will be decreased to less than 5 m/s before touchdown.
Stabilize Vehicle	1	Degrees of Freedom	The degrees of freedom of the device while falling will be limited to one direction.
Store Payload	100x100x300mm	Volume	3U sized payload must fit within the vehicle.
Contain Recovery System	100%	Percent of Volume stored in vehicle	Device must house a system to slow decent of device before touchdown.
Contain Propulsion System	100%	Percent of Volume stored in vehicle	Device must house a propulsion system to counteract the force of drag
Exchange Payload	1 hr.	Time	Must be able to exchange the payload within 1 hr.
Identify Disconnection from Drone	0.1 s	Time	Vehicle can recognize when the drone has dropped the vehicle within 0.10 seconds.

Functionless targets

Goal	Target	Metric	Description
Testing Frequency	2	Successful tests	On the day of competition, the vehicle will survive 2 tests
Propellant Leakage	0 mL	Volume	The propulsion system will leak 0 mL of fluid.
Achieve Weight Limit	10 kg	Weight	Device must weigh less than 10 kg so the drone can lift it.
Achieve Microgravity	4 s	Time	The vehicle must experience microgravity for 4 seconds.
Refuel propellant	1 hr.	Time	Should be able to recharge batteries, or replenish propellants
Power	9 V	Voltage	Voltage supplied to the Arduino should be 9 V

Aerodynamic Design	0.8	Coefficient of Drag	We want a low coefficient of drag so minimize the drag and reduce the propulsive force required
Propulsive Force	25N	Force	Propulsive Force necessary to overcome drag and achieve net zero acceleration

Appendix E: 100 Concepts

Concept #	Description
1	Use a standard rocket geometry with fluid being ejected in the back and a Trampoline to catch the vehicle
2	Skin of the Vehicle is made of rubber with strong beams acting as the frame. Beams can be separated to lose rigidity and compressed gas inflates the skin into a rubber ball.
3	Air bags are inflated around the front of a standard rocket with compressed CO2. Compressed CO2 is also ejected to accelerate downwards.* (medium)
4	A soft foam cushion is placed on the ground and the rocket uses a guidance system to land on it. Propulsion is done by ejecting fluid.
5	Payload is ejected from the rocket. Both payload and rocket have a parachute which activates separately. Propulsion is accomplished by ejecting fluid from nose.
6	Use compressed gas and water for downward propulsion and deceleration with propulsive landing. * (medium)
7	Nose made of rubber with airbags inflated on the sides with fluid ejected from sides.
8	Aerodynamic design with a lance that touches ground to activate airbag system
9	Fluid is ejected from the nozzle to decelerate the body. After some time, an exterior balloon is exposed to flowing air filling it with gas then we close it.
10	Propulsion by fluid ejected from the sides. Make nose out of some crumpling material to act as a crumple zone, replaced every flight.
11	Standard Rocket with air brakes which activate to slow the vehicle.
12	Propulsion by ejection of fluid from the sides with tubing inside which can be opened to airflow.
13	Standard rocket with air brakes that deploy in the wrong direction, so the air pulls them open.
14	Standard rocket with air brakes controlled with electromagnets and a cloth material between the breaks to slow even more. *(Medium)
15	Helicopter like propulsion and slowing – reversable propeller
16	Use actuating fins to slow after a certain amount of time with propulsion connected to fins.
17	Slick designed body, with minimal propulsion so less propellant will be needed. A stake is connected to the end to drive into the dirt and slow the vehicle.*
18	Porcupine- spikes deploy over the entire body and stick into the ground. - Also increases skin friction drag.
19	CO2 cartridges on the side of the vehicle to control and minimize tilting. This will keep the device vertical. –RCS like system

20	Ducted fan propulsion, have a ducted fan at the nose with tubing exiting the sides of the body. These tube exits can rotate downward to provide upward thrust to minimize impact at landing. This idea is pretty decent because our design will not be limited by fluids for longer drops. Just need an appropriately sized battery to fall as long as the mission plan. (High Fidelity)
21	Magnetic bearings as payload guides, similar to what magnetic trains use. Would need 3 guides space 120 degrees apart. Can also include magnetics at the end of the guide to slow the decent of the payload after breaking
22	Mimic bird beaks to reduce drag
23	Use feather like skin to reduce drag
24	Rotating propellers, like on submarines, to induce downward acceleration and stabilization*
25	Release parachute from the nose with propulsion close to the nose which pulls the vehicle up or down depending on orientation.
26	Encase electronics in an indestructible box to ensure their safety.
27	Attach the vehicle to a rope and use some set of wheels and motors to propel itself downwards and clamps which can press down on the rope to slow it down.
28	Body of vehicle is a long thin cone that just plunges into the ground.
29	Attach a large spring to the front of the vehicle with propulsion from the sides.
30	Have a cone made from silicon (or something) that can collapse to absorb energy, then take its pointy shape back. Propulsion can be done from the sides.
31	Use an airplane like propellor on the nose cone. – P-51 styled
32	Use heaters to melt the material in special places to warp material and increase drag.
33	Shoot trampoline out of nose shortly before the rocket hits the ground.
34	Use retracting grappling hook to grab onto a tree, pull down and once close enough, swing around like a pendulum
35	Shoot out a web on all sides to attach to nearby structures and catch the device. Web can also be ejected to propel the rocket.
36	Hot air balloon inflates with flowing air and is heated to slow vehicle
37	Compressed Helium is stored and then released to a balloons to increase buoyancy and make the device ‘lighter.’
38	Launch parachute from nose causing the device to flip and use extra propellant to slow the device. Fluid is released from the nose normal to the ground. * (High)
39	Expel propellant from the back of the fins. Similar to the Pegasus rocket.
40	Make the fins rotatable to help stabilization.
41	Make a fish tail design to push the vehicle through the air.
42	Make the device watertight and buoyant then drop it over deep water.
43	The vehicle is a long conical shape which digs into the ground to slow it. It is also covered it with a shell that can be removed to easily free the vehicle from the ground. *

44	Multiple Valve System that opens up mid-flight to increase acceleration. *
45	So there would be 4 valve for example that open up sequentially as more thrust is needed.
46	Big magnet ideas to levitate the device
47	Make the device as small as possible, shorter railing (or no rails). This will allow for more propulsive system and lighter weight. Easier to maneuver *
48	Use electromagnets to suspend the payload at the top of the trailing system during the ascent portion of flight. Turn off the electromagnets at disconnect so the payload can float around freely. The banana jacks can be used to 'open' the circuit and turn the magnets off
49	Give the thrust 2 nozzles, one pointing toward the ground and the other pointing up. Will allow for propulsive landing without have to do the flip maneuver with the parachute. *
50	Rotating thruster body that flips after freefall to allow for propulsive landing without flipping. *
51	Use thrust vectoring to aid in the flip maneuver.
52	Design the body to be a ducted fan using an electric motor placed toward the front of the device.
53	Make the device as small as possible with no propulsion at all. This will allow for good enough microgravity (Like that one team did). *
54	Use helicopter like propulsion that can reverse its thrust to do propulsive landing.
55	Reverse motor spin to back drive the fins and generate forward thrust.
56	There can be one large burst of air which comes from the front and sides of the device right before it lands to slow it down. This empties the cylinder of compressed gas.
57	A vacuum pump is placed inside of the vehicle which draws in air from the nozzle and releases air from the back decreasing the pressure differential felt on the rocket. It can also reverse and increase the pressure differential to slow it.
58	A strong magnet is dropped from the drone after the vehicle is dropped which has the charge opposite to the vehicle to propel it downward.
59	Front of the vehicle body is a stake with a spring attached which dampens the sudden change in acceleration as the stake drives through the ground.
60	Front of the vehicle is a stake which upon impact will compress a large piston in the vehicle to dampen acceleration. Also could crush a "crumple box."
61	Rocket has propulsion routed through the fins to minimize geometric inconsistencies.
62	The center of the vehicle is a long open tube with fans inside to propel it downward or switch directions to exert a force upward.
63	Instead of a missile shaped vehicle, have a center fuselage with wings coming off like an airplane

64	Uses alien tech to allow the payload to experience microgravity without the need to overcome drag.
65	Design is ultra aerodynamic, both the front and rear are pointed, design comes in two halves and will clip together with panel clips. *
66	To increase aerodynamic properties, multiple sets of fins.
67	To propel the device downwards, someone will be hoisted up 1000ft by a separate drown and the person will grab the vehicle from the second drown and throw it down at the ground with all his might.
68	To recover the vehicle, hire a sumo wrestle to catch the vehicle.
69	Skydivers drop with it and throw it down to accelerate it, sky divers calculated to be at different altitudes so when the vehicle is passing by, they can add force to accelerate it.
70	Super long (20ft) moves down with respect to the rest of the design, allows it to make the other half accelerate. *
71	Lightning rod that will attract lightning, forcing it downwards.
72	Vehicle that shoots projectiles out the back to make it accelerate.
73	Design is the shape of a bird, has movable wings covered in feathers used to accelerate downwards.
74	Spin it like a football to stabilize the body and keep drag consistent. *
75	Literally make a giant football
76	Make a giant nerf/ foam football with the tail kit on the back.
77	Someone on the ground shoots water from a fire house at the vehicle as its falling to stop it.
78	Use a giant magnetic force field to stop the vehicle
79	Giant ninja star, >>thin, spins, sharp so it will stick in the ground
80	1000ft rope attached to the vehicle, then on the ground a winch pulling the rope super-fast to accelerate it.
81	Steam engine powered rocket to drive propeller
82	Get a bunch of pigeons or doves to fly the vehicle downwards
83	Inverse hot air balloon with cold air pulling vehicle down.
84	Have rapid self producing insulation foam shoot out the nose to make a cushion for the vehicle to land on
85	Solar powered rocket to drive propeller
86	Have a pool of water on the ground and let the vehicle land in it to absorb the impact.
87	Nose cone can unfold (open up), meaning we can make it aerodynamic when we want and not when we don't want it to be.
88	An umbrella is shot out and extended from the back to slow the vehicle down*
89	Use electromagnets to shoot small cubes out the back of the rocket to accelerate it downward.

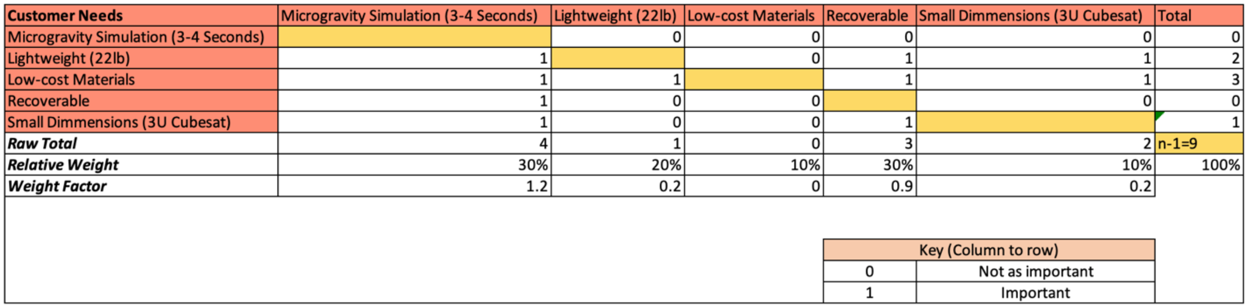
90	Attach a bunch of small springs to the back of the rocket with small pieces of solid material which can be released at different times to accelerate the body down.
91	Utilize chemical reactions to decrease volume of air in front of the rocket to reduce drag.
92	Create a long retractable arm which extends up to the rocket nose and retracts it down to compensate against drag.
93	Attach a horse to the vehicle via a long rope and make it start running as soon as the device is dropped.
94	Eject solid dust particles from the back of the vehicle to slow it down.
95	Use rocket boosters with jet fuel to propel a body downward.
96	Shoot small bombs out of the back of the body causing explosions to accelerate the body.
97	Smart material body which can change its shape based off the conditions experienced to optimize drag.
98	A magnetic rocket shape design which uses the earth’s magnetic field to pull it down and slow it down.
99	Matryoshka dolls design with multiple boxes which can be shot out of other boxes while falling down
100	One Steel Ball which is dropped without any actuation during descent.

Morphological Chart

Propulsion	**Recovery**	**Body**	**Stabilize**	
Shoot fluid out front of vehicle	Parachute*	Front pointy, back flat ~standard rocket shape	Fins *	
Propeller behind vehicle	Airbrakes	Football shape	Use Water to make design spin	
Shoot fluid outside of vehicle	airbag	Rubbery Skin with Beams	Use airbrakes to make it spin	
No propulsion	Flip design and deploy parachute (Propulsive Landing) *	Needle like, long and skinny, both ends pointy. *		
	Design tough and strong enough to withstand impact (javelin)			

Appendix F: Concept Selection Charts

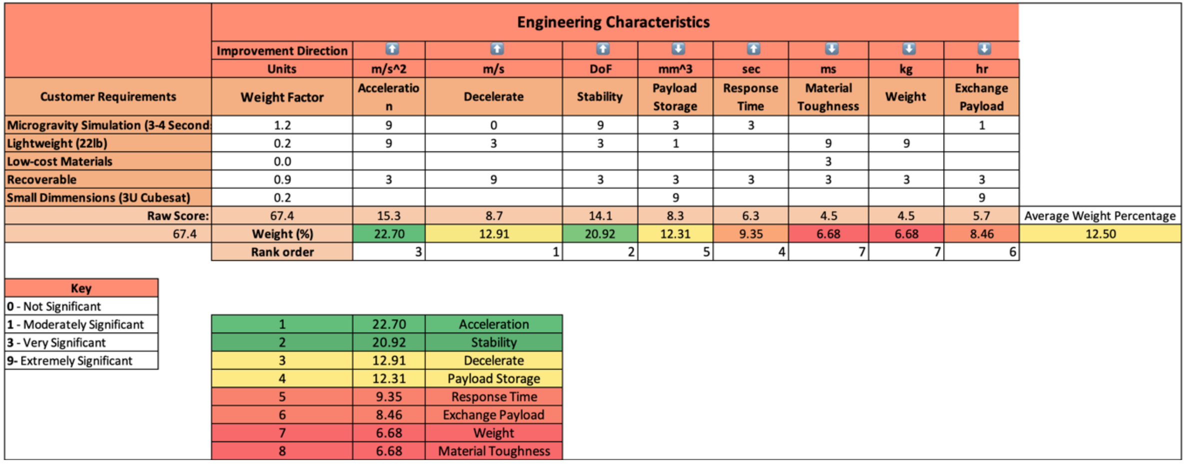
Binary Pairwise Comparison



Customer Needs	Microgravity Simulation (3-4 Seconds)	Lightweight (22lb)	Low-cost Materials	Recoverable	Small Dimmensions (3U Cubesat)	Total
Microgravity Simulation (3-4 Seconds)		0	0	0	0	0
Lightweight (22lb)	1		0	1	1	2
Low-cost Materials	1	1		1	1	3
Recoverable	1	0	0		0	0
Small Dimmensions (3U Cubesat)	1	0	0	1		1
Raw Total	4	1	0	3	2	n-1=9
Relative Weight	30%	20%	10%	30%	10%	100%
Weight Factor	1.2	0.2	0	0.9	0.2	

Key (Column to row)	
0	Not as important
1	Important

House of Quality

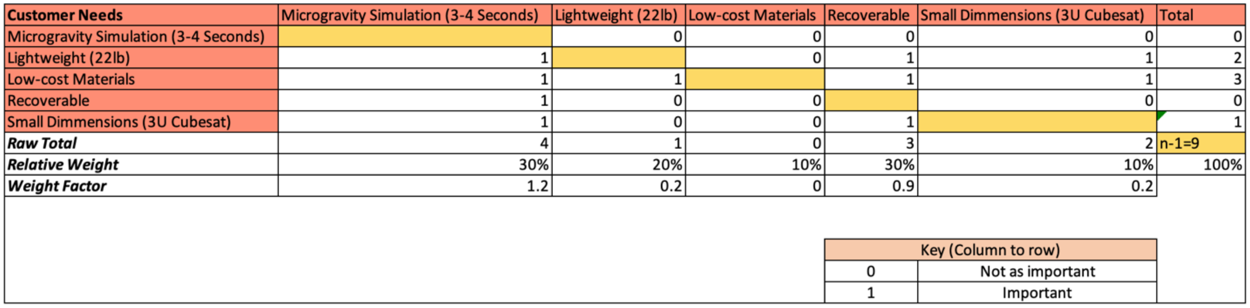


	Engineering Characteristics									
	Improvement Direction	⬆	⬆	⬆	⬇	⬆	⬇	⬇	⬇	
	Units	m/s^2	m/s	DoF	mm^3	sec	ms	kg	hr	
Customer Requirements	Weight Factor	Acceleration	Decelerate	Stability	Payload Storage	Response Time	Material Toughness	Weight	Exchange Payload	
Microgravity Simulation (3-4 Second	1.2	9	0	9	3	3			1	
Lightweight (22lb)	0.2	9	3	3	1		9	9		
Low-cost Materials	0.0						3			
Recoverable	0.9	3	9	3	3	3	3	3	3	
Small Dimmensions (3U Cubesat)	0.2				9				9	
Raw Score:	67.4	15.3	8.7	14.1	8.3	6.3	4.5	4.5	5.7	Average Weight Percentage
67.4	Weight (%)	22.70	12.91	20.92	12.31	9.35	6.68	6.68	8.46	12.50
	Rank order	3	1	2	5	4	7	7	6	

Key
0 - Not Significant
1 - Moderately Significant
3 - Very Significant
9- Extremely Significant

1	22.70	Acceleration
2	20.92	Stability
3	12.91	Decelerate
4	12.31	Payload Storage
5	9.35	Response Time
6	8.46	Exchange Payload
7	6.68	Weight
8	6.68	Material Toughness

Pugh Chart (Market Datum)



Customer Needs	Microgravity Simulation (3-4 Seconds)	Lightweight (22lb)	Low-cost Materials	Recoverable	Small Dimmensions (3U Cubesat)	Total
Microgravity Simulation (3-4 Seconds)		0	0	0	0	0
Lightweight (22lb)	1		0	1	1	2
Low-cost Materials	1	1		1	1	3
Recoverable	1	0	0		0	0
Small Dimmensions (3U Cubesat)	1	0	0	1		1
Raw Total	4	1	0	3	2	n-1=9
Relative Weight	30%	20%	10%	30%	10%	100%
Weight Factor	1.2	0.2	0	0.9	0.2	

Key (Column to row)	
0	Not as important
1	Important

Pugh Chart (Concept Datum)

Selection Criteria	Concept Datum	Ducted Fan	Side parachute (Flipping)	Air Brakes	Air Bags	Directional Nozzles
Acceleration	Propulsion from the nozzle	+	S	S	S	S
Stability		+	-	-	S	+
Decelerate		+	+	-	-	S
Payload Storage		S	S	S	S	S
Exchange Payload		S	S	S	S	S
Weight		S	S	-	-	-
Material Toughness		S	S	-	+	-
	Plus	3	1	0	1	1
	Satisfactory	4	5	3	4	4
	Minus	0	1	4	2	2
	Decision	3	0	-4	-1	-1

Key	
-	Worse
+	Better
S	Satisfactory

Fidelity	Concept #	Description
High	1	Ducted Fan
High	2	Propulsion from the nozzle
High	3	Side parachute (Flipping)
Medium	4	Air Brakes
Medium	5	Air Bags
Medium	6	Directional Nozzles

AHP Engineering Characteristics

Criteria Comparison Matrix [C]

	Acceleration	Stabilization	Deccelerate	Payload Storage	Exchange Payload	Weight
Acceleration	1	5.000	3.000	5	7	7
Stability	0.20	1	1.000	1	3	3
Decelerate	0.33	1.00	1	1	5	5
Payload Storage	0.20	1.00	1.00	1	3	3.000
Exchange Payload	0.14	0.33	0.20	0.33	1	1.000
Weight	0.14	0.33	0.20	0.33	1.00	1
Sum	2.019	8.667	6.400	8.667	20	20.000

Normalized Criteria Comparison Matrix [NormC]

	Acceleration	Stabilization	Deccelerate	Payload Storage	Exchange Payload	Weight	Critical Weights {W}
Acceleration	0.495	0.577	0.469	0.577	0.350	0.350	0.470
Stability	0.099	0.115	0.156	0.115	0.150	0.150	0.131
Decelerate	0.165	0.115	0.156	0.115	0.250	0.250	0.175
Payload Storage	0.099	0.115	0.156	0.115	0.150	0.150	0.131
Exchange Payload	0.071	0.038	0.031	0.038	0.050	0.050	0.046
Weight	0.071	0.038	0.031	0.038	0.050	0.050	0.046
Sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Consistency Check

	{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weights	Cons={Ws}./{W} Consistency Vector
Acceleration	2.957	0.470	6.296
Stability	0.810	0.131	6.184
Decelerate	1.059	0.175	6.038
Payload Storage	0.810	0.131	6.184
Exchange Payload	0.282	0.046	6.076
Weight	0.282	0.046	6.076

λ	6.143
RI	1.250
CI	0.029
CR	0.023

AHP Concept Comparison

Acceleration Comparison [C]

	Ducted Fan	Nozzle Propulsion	Side Parachute
Ducted Fan	1.000	5.000	5.000
Nozzle Propulsion	0.200	1.000	1.000
Side Parachute	0.200	1.000	1.000
Sum	1.400	7.000	7.000

Stability Comparison [C]

	Ducted Fan	Nozzle Propulsion	Side Parachute
Ducted Fan	1.000	0.333	0.333
Nozzle Propulsion	3.000	1.000	1.000
Side Parachute	3.000	1.000	1.000
Sum	7.000	2.333	2.333

Deccelerate Comparison [C]

	Ducted Fan	Nozzle Propulsion	Side Parachute
Ducted Fan	1.000	3.000	0.333
Nozzle Propulsion	0.333	1.000	0.200
Side Parachute	3.000	5.000	1.000
Sum	4.333	9.000	1.533

Payload Storage Comparison [C]

	Ducted Fan	Nozzle Propulsion	Side Parachute
Ducted Fan	1.000	1.000	3.000
Nozzle Propulsion	1.000	1.000	3.000
Side Parachute	0.333	0.333	1.000
Sum	2.333	2.333	7.000

Exchange Payload Comparison [C]

	Ducted Fan	Nozzle Propulsion	Side Parachute
Ducted Fan	1.000	1.000	0.200
Nozzle Propulsion	1.000	1.000	0.200
Side Parachute	5.000	5.000	1.000
Sum	7.000	7.000	1.400

Weight Comparison [C]

	Ducted Fan	Nozzle Propulsion	Side Parachute
Ducted Fan	1.000	5.000	5.000
Nozzle Propulsion	0.200	1.000	1.000
Side Parachute	0.200	1.000	1.000
Sum	1.400	7.000	7.000

Normalized Acceleration Comparison [NormC]

	Ducted Fan	Nozzle Propulsion	Side Parachute	Design Alternative Priorities {Pi}
Ducted Fan	0.714	0.714	0.714	0.714
Nozzle Propulsi	0.143	0.143	0.143	0.143
Side Parachute	0.143	0.143	0.143	0.143
Sum	1.000	1.000	1.000	1.000

Normalized Stability Comparison [NormC]

	Ducted Fan	Nozzle Propulsion	Side Parachute	Design Alternative Priorities {Pi}
Ducted Fan	0.143	0.143	0.143	0.143
Nozzle Propulsion	0.429	0.429	0.429	0.429
Side Parachute	0.429	0.429	0.429	0.429
Sum	1.000	1.000	1.000	1.000

Normalized Deccelerate Comparison [NormC]

	Ducted Fan	Nozzle Propulsion	Side Parachute	Design Alternative Priorities {Pi}
Ducted Fan	0.231	0.333	0.217	0.260
Nozzle Propulsion	0.077	0.111	0.130	0.106
Side Parachute	0.692	0.556	0.652	0.633
Sum	1.000	1.000	1.000	1.000

Normalized Payload Storage Comparison [NormC]

	Ducted Fan	Nozzle Propulsion	Side Parachute	Design Alternative Priorities {Pi}
Ducted Fan	0.429	0.429	0.429	0.429
Nozzle Propulsion	0.429	0.429	0.429	0.429
Side Parachute	0.143	0.143	0.143	0.143
Sum	1.000	1.000	1.000	1.000

Normalized Exchange Payload Comparison [NormC]

	Ducted Fan	Nozzle Propulsion	Side Parachute	Design Alternative Priorities {Pi}
Ducted Fan	0.143	0.143	0.143	0.143
Nozzle Propulsi	0.143	0.143	0.143	0.143
Side Parachute	0.714	0.714	0.714	0.714
Sum	1.000	1.000	1.000	1.000

Normalized Weight Comparison [NormC]

	Ducted Fan	Nozzle Propulsion	Side Parachute	Design Alternative Priorities {Pi}
Ducted Fan	0.714	0.714	0.714	0.714
Nozzle Propulsion	0.143	0.143	0.143	0.143
Side Parachute	0.143	0.143	0.143	0.143
	1.000	1.000	1.000	1.000

Acceleration Consistency Check

{Ws}=[C]{Pi} Weighted Sum Vector	{Pi} Criteria Weights	Cons={Ws}./{Pi} Consistency Vector
2.143	0.714	3.000
0.429	0.143	3.000
0.429	0.143	3.000

λ	3.000
RI	0.520
CI	0.000
CR	0.000

Stabalization Consistency Check

{Ws}=[C]{Pi} Weighted Sum Vector	{Pi} Criteria Weights	Cons={Ws}./{Pi} Consistency Vector
0.429	0.143	3.000
1.286	0.429	3.000
1.286	0.429	3.000

λ	3.000
RI	0.520
CI	0.000
CR	0.000

Deccelerate Consistency Check

{Ws}=[C]{Pi} Weighted Sum Vector	{Pi} Criteria Weights	Cons={Ws}./{Pi} Consistency Vector
0.790	0.260	3.033
0.320	0.106	3.011
1.946	0.633	3.072

λ	3.039
RI	0.520
CI	0.019
CR	0.037

Payload Storage Consistency Check

{Ws}=[C]{Pi} Weighted Sum Vector	{Pi} Criteria Weights	Cons={Ws}./{Pi} Consistency Vector
1.286	0.429	3.000
1.286	0.429	3.000
0.429	0.143	3.000

λ	3.000
RI	0.520
CI	0.000
CR	0.000

Exchange Payload Consistency Check

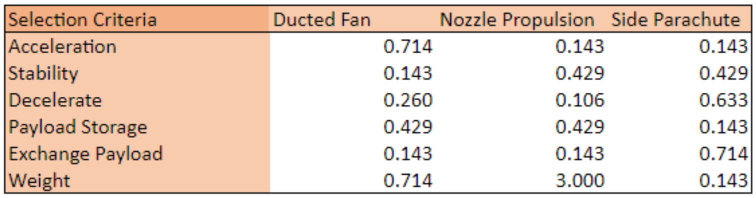
{Ws}=[C]{Pi} Weighted Sum Vector	{Pi} Criteria Weights	Cons={Ws}./{Pi} Consistency Vector
0.429	0.143	3.000
0.429	0.143	3.000
2.143	0.714	3.000

λ	3.000
RI	0.520
CI	0.000
CR	0.000

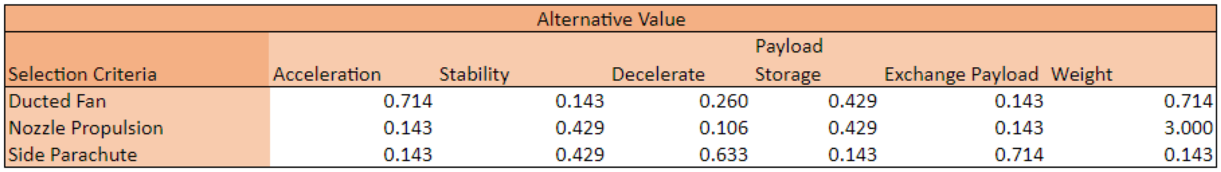
Weight Consistency Check

{Ws}=[C]{Pi} Weighted Sum Vector	{Pi} Criteria Weights	Cons={Ws}./{Pi} Consistency Vector
2.143	0.714	3.000
0.429	0.143	3.000
0.429	0.143	3.000

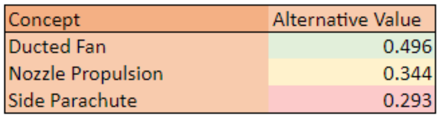
λ	3.000
RI	0.520
CI	0.000
CR	0.000



Selection Criteria	Ducted Fan	Nozzle Propulsion	Side Parachute
Acceleration	0.714	0.143	0.143
Stability	0.143	0.429	0.429
Decelerate	0.260	0.106	0.633
Payload Storage	0.429	0.429	0.143
Exchange Payload	0.143	0.143	0.714
Weight	0.714	3.000	0.143



	Alternative Value					
Selection Criteria	Acceleration	Stability	Decelerate	Payload Storage	Exchange Payload	Weight
Ducted Fan	0.714	0.143	0.260	0.429	0.143	0.714
Nozzle Propulsion	0.143	0.429	0.106	0.429	0.143	3.000
Side Parachute	0.143	0.429	0.633	0.143	0.714	0.143



Concept	Alternative Value
Ducted Fan	0.496
Nozzle Propulsion	0.344
Side Parachute	0.293

Appendix A: APA Headings (delete)

Heading 1 is Centered, Boldface, Uppercase and Lowercase Heading

Heading 2 is Flush Left, Boldface, Uppercase and Lowercase Heading

Heading 3 is indented, boldface lowercase paragraph heading ending with a period.

Heading 4 is indented, boldface, italicized, lowercase paragraph heading ending with a period.

Heading 5 is indented, italicized, lowercase paragraph heading ending with a period.

See publication manual of the American Psychological Association page 62

Appendix B Figures and Tables (delete)

The text above the cation always introduces the reference material such as a figure or table. You should never show reference material then present the discussion. You can split the discussion around the reference material, but you should always introduce the reference material in your text first then show the information. If you look at the Figure 1 below the caption has a period after the figure number and is left justified whereas the figure itself is centered.

Figure 1. Flush left, normal font settings, sentence case, and ends with a period.

In addition, table captions are placed above the table and have a return after the table number. The second line of the caption provided the description. Note, there is a difference between a return and enter. A return is accomplished with the shortcut key shift + enter. Last, unlike the caption for a figure, a table caption does not end with a period, nor is there a period after the table number.

Table 1

The Word Table and the Table Number are Normal Font and Flush Left. The Caption is Flush Left, Italicized, Uppercase and Lowercase

Level of heading	Format
1	**Centered, Boldface, Uppercase and Lowercase Heading**
2	**Flush Left, Boldface, Uppercase and Lowercase**
3	***Indented, boldface lowercase paragraph heading ending with a period***
4	***Indented, boldface, italicized, lowercase paragraph heading ending with a period.***
5	*Indented, italicized, lowercase paragraph heading ending with a period.*

References

There are no sources in the current document.