1. Nova Kinetics

DARPA Competition Drone

Initial Design Report

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DISCLAIMER

EXECUTIVE SUMMARY

This report focuses on the research, study, design, manufacturing and competition in the 2026 DARPA Lift Challenge. The 2026 DARPA Lift challenge, hosted by the DARPA Corporation, aims to find a small UAS that is capable of lifting up to four times the weight of the UAS itself. The competition will be hosted in the summer of 2026, and it will be hosted at Wright-Patterson Air Force Base in Dayton, Ohio.

Beginning the project, the engineers first established a baseline of the most important design metrics that needed the most attention with the client, Jim Corning of Novakinetics. The engineers began by understanding the research into the design of the drone to date, then established a baseline for the most eminent problems established by the client that needed to be solved. This consultation summarized two main parts that needed to be completed; the materials used for the frame and the drone, and the control system and parameters used to properly control the drone. These are the two main points of interest for the engineers to focus on, and the group compartmentalized in order to accommodate both of these fields.

The first step in creating the drone is to establish a baseline for the design that the drone will follow. This baseline was designed with a Quality Function Development, otherwise known as a QFD. This allowed the engineers to visualize the needs of the client, while also being able to understand the numerical goals the drone was mandated to achieve.

Next, the design process led the engineers to making a concept generation chart along with a decision matrix to more efficiently eliminate certain design choices. This decision matrix compared each iteration of the drone to a datum, which allowed the engineers to decide the best course of action for developing the most efficient drone with the given choices.

Each engineer involved in the group was tasked with developing a skill in order to better assist the group establish accurate calculations throughout the course of development. These projects allowed for the most advancement in numerical results, as well as the most progression in design. The project concluded the following information, which is the most “up to date” results for the DARPA Drone lift challenge project.

CFD analysis proves that the use of the Boeing VR-7 is an appropriate rotorblade to use for lift. This analysis used the calculated velocity of the airfoil to produce the minimum required lift the drone must achieve and verified that the calculations done manually match the CFD analysis.

The next analysis was focused on the improvement of the frame of the drone, using Topography Optimization in order to save as much weight on the drone as possible. This design slimmed the weight of the drone down almost 50%, allowing the drone to be significantly lighter.

Another analysis done was to test the shear strength of the drones bolts holding in the rotor, and the results confirmed that the bolts being used will be strong enough to hold the rotors onto the main spinning assembly.

Finally, several calculations and simulations have been done to confirm the control systems will sufficiently moderate the altitude, pitch, roll, and yaw of the aircraft.

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1 BACKGROUND

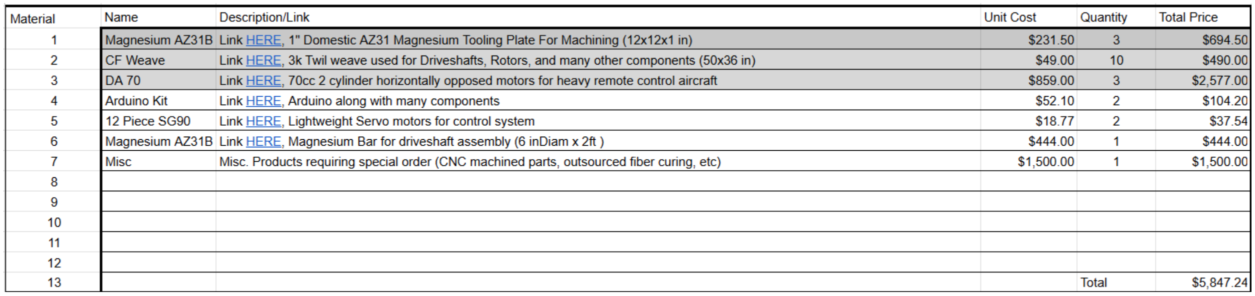
This chapter provides background information on the UAV system being developed for the capstone project. It begins with an overview of the project objectives, motivation, and overall system concept. The chapter then outlines the primary deliverables expected for the project, including design documentation, testing, and demonstration milestones. Finally, the criteria used to evaluate the success of the project are defined, including performance targets, validation methods, and design requirements.

1.1 Project Description

The objective of this project is to design a heavy lift unmanned aerial vehicle (UAV) capable of achieving an extremely high payload to weight ratio as part of the DARPA Lifting Challenge. The system must have the ability to lift a maximum payload of 220 pounds while maintaining a maximum total aircraft weight of 55 pounds. The UAV must perform a mission consisting of vertical takeoff, flight to a distance of four miles at approximately 250 feet altitude, controlled payload deployment and a one mile return flight within a total mission time of 30 minutes.

This project is sponsored by Nova Kinetics and aims to explore innovative solutions to the current heavy lift limitations of UAV. Current UAV platforms often suffer from limited payload capacity relative to their total system weight which restricts their use in logistics, disaster response and military supply missions. By improving payload efficiency and reducing cost per pound of cargo transported the system developed in this project seeks to contribute toward overcoming the heavy lift bottleneck identified by DARPA challenge.

The aforementioned sponsor, Jim Corning of Nova Kinetics, does not specifically have a dollar amount tied to the overall budget of the project. This is crucial because the budget allows the engineers to understand what cuts must be made in order to properly complete the requirements. Since there is no given budget listed by the client, the engineering team has decided to prepare a bill of materials as the running budget, which is subject to change as time progresses. This bill of materials includes nothing but the raw parts used, which is important because many of the components must be custom CNC machined, 3D printed, or cured and sourced outside of Nova Kinetics. See Table 1.1 for a list of the current materials along with overhead to properly account for the budget of the project.



Material	Name	Description/Link	Unit Cost	Quantity	Total Price
1	Magnesium AZ31B	Link HERE, 1" Domestic AZ31 Magnesium Tooling Plate For Machining (12x12x1 in)	$231.50	3	$694.50
2	CF Weave	Link HERE, 3k Twil weave used for Driveshafts, Rotors, and many other components (50x36 in)	$49.00	10	$490.00
3	DA 70	Link HERE, 70cc 2 cylinder horizontally opposed motors for heavy remote control aircraft	$859.00	3	$2,577.00
4	Arduino Kit	Link HERE, Arduino along with many components	$52.10	2	$104.20
5	12 Piece SG90	Link HERE, Lightweight Servo motors for control system	$18.77	2	$37.54
6	Magnesium AZ31B	Link HERE, Magnesium Bar for driveshaft assembly (6 inDiam x 2ft)	$444.00	1	$444.00
7	Misc	Misc. Products requiring special order (CNC machined parts, outsourced fiber curing, etc)	$1,500.00	1	$1,500.00
8					
9					
10					
11					
12					
13				Total	$5,847.24

Table 1: Bill of materials with final estimated price

1.2 Deliverables

Client deliverables have shifted from the last report, and now include a more detailed list of products being asked of the engineers for the upcoming term. This list is similar to the last term's list, but includes less inclusion to detailing the drone and its functionality, and more to increasing its modularity.

Client deliverables include adding a modularity aspect to the landing gear of the drone, which will allow the user to switch the landing gear based on the needs of the user. Some ideas mentioned in a previous meeting with the client were as follows:

1. Materials carrying landing gear: This landing gear will have a tray capable of holding supplies and materials for those who are involved in an on site, remote dilemma. An example of this in use would be to transfer food, water, supplies and additional gear to firefighters who are too close to a forest fire to be reasonably reached by a land vehicle.
2. Surveillance Landing gear: This landing gear will include a variety of tracking devices, which includes an infrared camera, a normal monitoring camera, and other tracking cameras and encoders in order to collect data of a forming forest fire. The lighter aspect of this landing gear will allow for the drone to be much lighter, increasing flight time and efficiency.
3. Stretcher Landing gear: This landing gear would be the most ambitious landing gear in the set, but would include a stretcher for an injured civilian to be strapped into, allowing for autonomous, lightweight rescue in more remote or dangerous areas.

1.3 Success Metrics

The success of this project will be evaluated based on the ability of the proposed UAV design to meet the performance requirements defined by the DARPA lifting challenge. Key success metrics include achieving a payload capacity of at least 220 pounds while maintaining a total system weight less than or equal to 55 pounds. Although the end goal for the DARPA competition drone is to provide a 4:1 payload to weight ratio for 4 miles, to compete properly in the competition, a 2:1 thrust to weight ratio must be achieved. This is why lifting 220 pounds is considered a success. The system must also demonstrate the ability to generate sufficient lift through material design and propulsion analysis while maintaining structural integrity under expected loads.

Testing to ensure success for the team would include many of the following. Firstly, the engineers will perform several CFD and Stress testing to properly satisfy the strength of the components. Firstly, ANSYS is used to prove the flow over the wing at the specific RPM provided by the motors is sufficient at certain angles of attack to provide sufficient lift. This analysis will also evaluate drag and ensure that the motors in question will be able to overcome the drag force from the rotors. Secondly, stress testing will be performed to determine whether the materials used for each component are sufficiently strong enough to withstand the centrifugal, shear, and normal forces exerted on them. A viable factor of safety has not been determined as there is no requirement from the client regarding this.

2 REQUIREMENTS

This chapter defines the requirements that guide the design and development of the drone system. The requirements are split into two categories being customer requirements and engineering requirements. Customer requirements describe the needs and expectations of the end user. Engineering requirements translate those needs into measurable and quantifiable design specifications. These requirements are then organized and analyzed using a House of Quality (HoQ) to establish relationships between customer needs and technical design parameters.

2.1 Customer Requirements (CRs)

The following customer requirements define the primary performance for the drone system. These requirements reflect the needs of the end users and guide the development of engineering specifications and design decisions.

Heavy Payload
The drone must be capable of carrying a payload significantly greater than its own weight while maintaining safe and stable flight. This requirement ensures the system can perform its intended mission of transporting and delivering external loads.

Low Drone Weight
The drone structure and components should be designed to minimize overall weight while maintaining sufficient strength and durability. Reducing vehicle weight improves payload capacity, flight efficiency, and overall system performance.

Endurance
The drone must be capable of maintaining flight for an extended duration to complete mission objectives without requiring frequent refueling. Adequate endurance is necessary for operational reliability and mission completion.

Stable and Controlled Flight
The drone must maintain stable flight during normal operating conditions and respond predictably to control inputs. The system should also remain controllable in the presence of moderate environmental disturbances such as wind.

Autonomous Adjustments
The drone should be capable of making autonomous adjustments during flight using onboard sensors and control algorithms. These adjustments may include stabilization, altitude correction, and navigation control without continuous manual input.

Structural Integrity
The drone structure must withstand all expected operational loads, including aerodynamic forces, payload forces, and vibration during flight. Structural components must maintain integrity throughout the operational life of the system.

Testability
The drone system should be designed in a way that allows individual components and subsystems to be tested and evaluated independently. This requirement supports verification of performance and reliability during development.

Transportability
The drone should be designed to allow for convenient transportation and deployment. This may include modular components, or other design features that make movement and storage easier.

Autonomous Release Mechanism
The drone must incorporate a mechanism of autonomously releasing the payload at the desired location or upon command. The mechanism must function reliably during flight operations.

Speed
The drone should achieve sufficient flight speed to efficiently travel to the mission area and complete operational tasks within an acceptable timeframe.

Safety Features
The drone must incorporate safety features to reduce risk to operators, bystanders, and equipment. These features include emergency shutoff switch, controlled landing procedure, and system fail-safe.

2.2 Engineering Requirements (ERs)

Engineering requirements translate customer requirements into measurable and quantifiable design specifications. These requirements define the performance targets that the drone system must achieve to satisfy the needs of the user. Each requirement is expressed using specific units and target values so that system performance can be verified through analysis and testing.

Lightweight Drone
The total structural weight of the drone, excluding payload, should be minimized to improve payload capacity and energy efficiency. A lighter vehicle allows more lifting capability to be allocated toward payload.
Target: 55 lbs

4× Bodyweight Payload
The drone must be capable of carrying a payload significantly greater than its own weight. This requirement ensures the system can perform heavy payload transport missions.
Target: 220 lbs payload capacity

Long Flight Time
The drone must remain airborne for an extended duration while carrying the design payload. Increased endurance improves operational capability and reduces the need for frequent refueling.
Target: 30 minutes

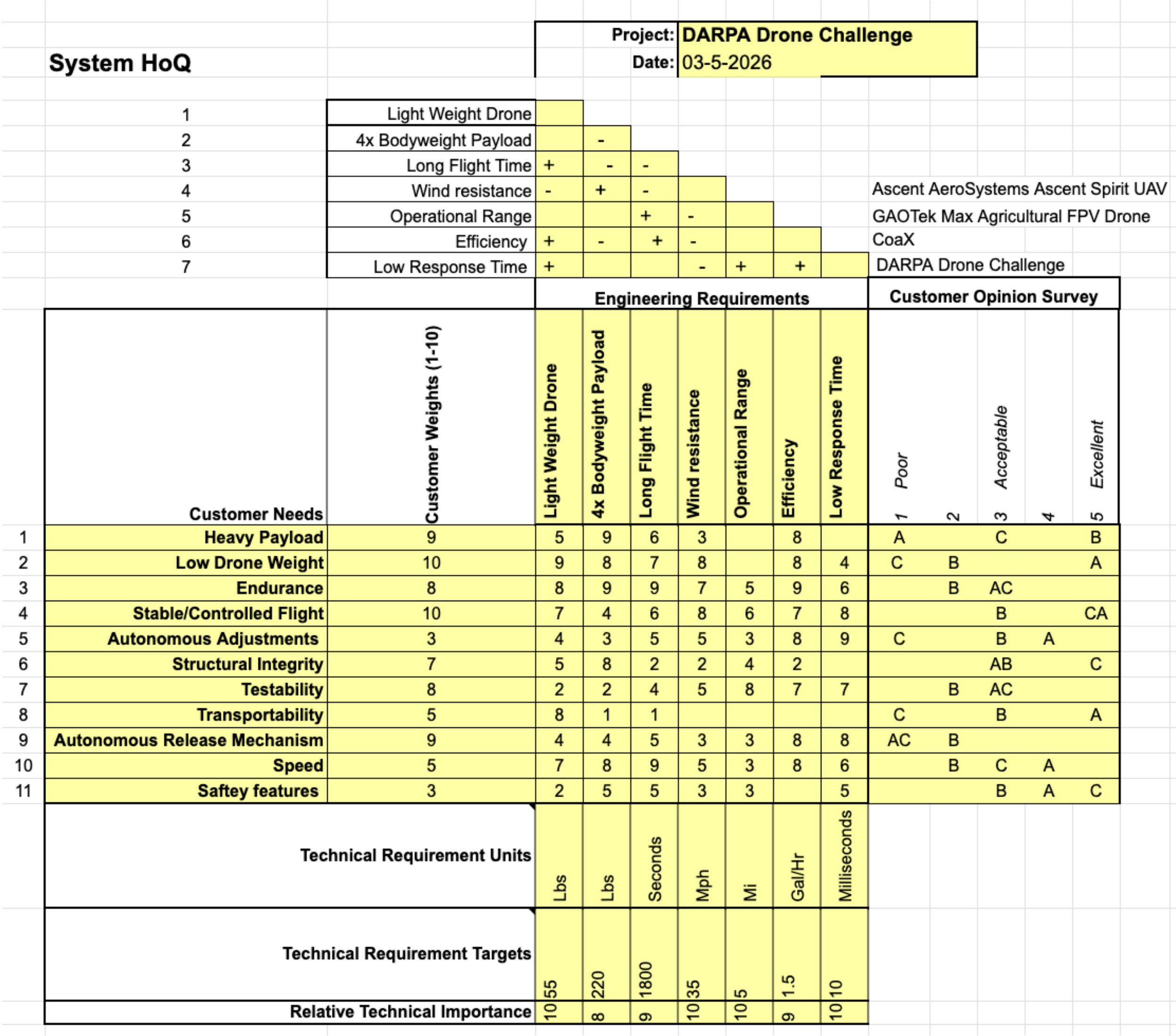
Wind Resistance
The drone must maintain stable and controllable flight in the presence of wind disturbances. The system should be capable of operating in moderate wind conditions without loss of stability or control.
Target: 35 mph

Operational Range
The drone must be capable of traveling a sufficient horizontal distance from the launch location while maintaining communication and control. This requirement determines the operational coverage area of the system.
Target: 5 mi

Efficiency
The drone propulsion and energy system should operate efficiently to maximize range and endurance. Efficiency is measured as the distance traveled per unit of energy consumed.
Target: 1.5 gal/hr

Low Response Time
The flight control system must respond quickly to control inputs and environmental disturbances to maintain stable flight. Faster response times improve maneuverability and system stability.
Target: 10 milliseconds

2.3 House of Quality (HoQ)



System HoQ

Project: **DARPA Drone Challenge**
Date: 03-5-2026

1	Light Weight Drone							
2	4x Bodyweight Payload		-					
3	Long Flight Time	+	-	-				
4	Wind resistance	-	+	-				
5	Operational Range			+	-			
6	Efficiency	+	-	+	-			
7	Low Response Time	+			-	+	+	

Ascent AeroSystems Ascent Spirit UAV
GAOTek Max Agricultural FPV Drone
CoaX
DARPA Drone Challenge

			Engineering Requirements							**Customer Opinion Survey**				
	Customer Needs	**Customer Weights (1-10)**	**Light Weight Drone**	**4x Bodyweight Payload**	**Long Flight Time**	**Wind resistance**	**Operational Range**	**Efficiency**	**Low Response Time**	1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
1	**Heavy Payload**	9	5	9	6	3		8		A		C		B
2	**Low Drone Weight**	10	9	8	7	8		8	4	C	B			A
3	**Endurance**	8	8	9	9	7	5	9	6		B	AC		
4	**Stable/Controlled Flight**	10	7	4	6	8	6	7	8			B		CA
5	**Autonomous Adjustments**	3	4	3	5	5	3	8	9	C		B	A	
6	**Structural Integrity**	7	5	8	2	2	4	2				AB		C
7	**Testability**	8	2	2	4	5	8	7	7		B	AC		
8	**Transportability**	5	8	1	1					C		B		A
9	**Autonomous Release Mechanism**	9	4	4	5	3	3	8	8	AC	B			
10	**Speed**	5	7	8	9	5	3	8	6		B	C	A	
11	**Saftey features**	3	2	5	5	3	3		5			B	A	C
	Technical Requirement Units		Lbs	Lbs	Seconds	Mph	Mi	Gal/Hr	Milliseconds					
	Technical Requirement Targets		55	220	1800	35	5	1.5	10					
	Relative Technical Importance		10	8	9	10	10	9	10					

Figure 1: House of quality

3 Research Within Your Design Space

3.1 Benchmarking

The first benchmark discovered by the engineers was a coaxial drone manufactured by Accent aerosystems called the Spirit UAV [1]. This drone was part of the benchmarking since the engineers that manufacture the spirit UAV were able to create a sub 55lb lightweight, coaxial UAV with an incredibly stable flight control system. It can also fly for over 50 minutes and reach speeds of over 6o mph while being stable. This is intriguing because the control system has been one of the main concerns during the creation of the project, so being able to find a UAV that has an incredibly stable coaxial control system.

The second benchmark discovered is an agricultural drone manufactured by a company called GAOTek [3]. This drone, mainly used for heavyweight agricultural maintenance and surveillance, shows promising lift to weight ratios in their drones, specifically their gas powered agricultural drones. These drones are centered around delivery and pesticide diffusion, and they flaunt impressive ratios for the drones payload capacity compared to the overall weight of the drone. These drones are also gas powered and consume gas at roughly 1.5 gal/ hr, which is similar to our consumption benchmark for the DARPA competition drone.

Finally, the third benchmark is a line of drones manufactured by a company called CoaX Drones [2] , which make heavyweight coaxial drones made for heavy lift applications. This company has a benchmark very similar to the end goal of the engineers working alongside Novakinetics. The only issue with the benchmarking of this company is the lack of information given on their line of drones. There is little to no information about the development of the drones manufactured by this company, but they have a very clear emphasis on high lift to weight ratio being able to support at least its own body weight in payload.

3.2 Literature Review

3.2.1 Joshua Nieto

1. (Chapter 6) Small Unmanned Aircraft : Theory and Practice (Autopilot Design Using successive Loop Closure [4]
    a. This book provides an overview of unmanned aircraft systems including the aircraft design, aerodynamics, propulsion systems and autopilot architecture. Chapter 6 specifically focuses on autopilot design using successive loop closure. The book explains how control loops for roll, pitch , yaw and altitude are structured and tuned to maintain aircraft stability. This information is relevant to this project due to it providing foundational knowledge for the design and modeling of the UAV flight control system. The concepts described in this source supports the development of stable flight control algorithms for the heavy lift coaxial UAV being designed in this project.
2. Flight Control of Unmanned Rotorcrafts for Enhanced Situational Awareness [5]
    a. This book discusses flight control systems specifically designed for rotorcraft based unmanned aerial vehicles. The text explores guidance navigation and control strategies that allow UAVs to maintain stable flight while responding to sensor feedback and environmental situations. It also discusses how onboard sensors such as gyroscopes, accelerometers and GPS systems are integrated to determine aircraft orientation as well as position. This source is important for the project because it provides a background for controlling rotorcraft UAV platforms particularly those using helicopter style rotor systems. The control strategies described in this work support the design of the UAV's flight controller and help make sure the system can maintain stable flight while carrying the heavy payloads.
3. Concept of a Modular Multirotor Heavy Lift Unmanned Aerial Vehicle Platform [6]

    a. This research paper shows the design concept of a modular heavy lift multirotor UAV platform capable of carrying large payloads. The authors analyze structural design possibilities, propulsion requirements and control strategies required for high payload UAV systems. The paper also discusses how a modular system can improve flexibility and scalability in UAV design. This research is relevant to the capstone project because it provides insight into existing heavy lift UAV structures and demonstrates methods used to increase payload capacity relative to vehicle weight. The concepts presented in this work support the design approach used in the DARPA lifting challenge project, particularly in achieving a high payload to weight ratio.

4. PX4: A node-based multithreaded open source robotics framework for deeply embedded platforms [7]
    a. This paper introduces the PX4 autopilot system which is an open source flight control platform widely used in UAV development. The framework provides modular software architecture that allows developers to implement navigation, control algorithms and sensor integration for autonomous flight. PX4 supports real time communication between system components through a node-based architecture making it suitable for complex UAV systems. This reference is important to the project because it provides insight into commercially available flight control platforms that could be used instead of developing a custom control system. Understanding PX4 helps evaluate whether an open source autopilot could provide reliable flight stability and navigation for the heavy lift UAV system.
5. Survey of Advances in Guidance, Navigation, and Control Of Unmanned Rotorcraft Systems [8]
    a. This survey paper reviews the development of guidance, navigation and control technologies for unmanned rotorcraft systems. The research summarizes key algorithms used for UAV stabilization, trajectory control and autonomous flight operations. It also examines how different sensor technologies are integrated into UAV control systems to estimate aircraft position and orientation. This paper is relevant to the project because it provides a broad overview of the control strategies used in modern UAV systems. The information from this study helps inform the design of the control architecture used in the heavy-lift UAV project.
6. https://px4.io/ [9]
    a. The PX4 autopilot website provides documentation, software resources and technical information about the PX4 flight control platform. The site includes system structures with explanations, sensor integration methods and guidance for using UAV control algorithms. PX4 is widely used in both academic and commercial UAV systems due to its flexibility and open source development environment. This resource is useful for the project because it provides practical implementation information for UAV control systems and demonstrates how commercial autopilot platforms can manage flight stability, navigation and mission planning.
7. pyrodrone.com [10]
    a. Pyrodrone is a commercial supplier of UAV components including flight controllers, propulsion systems, sensors and communication hardware. The website provides technical specifications for a wide range of UAV components commonly used in drone development. These specifications are useful when evaluating possible control system hardware and components that could be used in the UAV system. This source supports the project by providing real world examples of commercially available hardware that may be integrated into the UAV control system such as the controller.
8. Qgroundcontrol.com [11]
    a. QGroundControl is an open source ground control station software used to monitor and control UAV systems during flight. The software allows users to communicate with the flight controller, visualize data, plan missions and monitor system status. This resource is

relevant to the project because it shows how operators interact with UAV control systems and how flight data can be monitored in real time. With this understanding ground control systems help inform how the UAV will be operated and monitored during flight testing and mission deployment.

3.2.2 Isaac Lynn

1. *Composite Materials: An Introduction :* Chapters 1&7 [12]
    a. This book discusses what composite materials are and what the different types of composites are best for. Chapter 1 discusses the large variety of composite materials that are used in aerospace applications and the parts that make up the material, such as fibers and polymers. This chapter will be useful for deciding which materials to use and which components they would be most ideal for. Chapter 7 focuses much more on what testing for these materials looks like and why you should test. Combined with the knowledge from both of these chapters and the others about production and alignment patterns for the fibers, we will be able to fully produce a composite for the final design.
2. *Dynamics of Rotating Shafts*: [13]
    a. This book dives into all of the considerations and analysis possible for rotating shafts of all kinds. The main topics are all about highly complex mathematical phenomena such as vibrations or instabilities that can cause disturbance when working at high speeds. These are important considerations to make when tolerating the central shaft and something that is exaggerated when working with high forces and high speeds. Checking these calculations can make all the difference in situations where these small forces can cause catastrophic failure of the drone.
3. NASA, Standard test methods for textile composites [14]
    a. In this research paper, the standard testing methods of composite materials is discussed in detail. Included are several common methods used by leading aerospace companies to test various types of designs including calculations, setups and standards for these tests. Another helpful portion of this paper is the section on materials where they show various methods of weaves for fiber composites and how these can be constructed as well. This is useful for our project because one of the main materials used will be a carbon fiber weave since it is both incredibly strong and lightweight making it a useful asset in maximizing power while keeping our drone below the 55 lbs limit.
4. ASTM Test Methods for Composite Characterization and Evaluation [15]
    a. Similarly to the last paper, this paper discusses common methods of evaluating and testing various composite materials. It also dives into the background of ASTM standards, what their purpose is, and why they are so important. This paper is also from NASA, an industry leader of cutting edge aerospace technology and research into many types of aircraft and materials. One of the more helpful parts of this paper is the discussion of some of the common issues that arise in testing composite materials and how these can be addressed. This paper will be useful when we have started testing our composites and are trying to ensure they meet the safety and strength standards that they need to be able to be viable for our project.

5. *COAXIAL HELICOPTER ROTOR DESIGN & AEROMECHANICS* [16]
    a. This research paper goes over many important aspects of rotor design and control of rotor systems for a coaxial helicopter. It also includes a reference sheet with many other useful sources directly linked to research on coaxial helicopter components. This is an incredibly valuable source since it is directly related to our project and all aspects of it. We can use this information to help our initial design choices and also how we go about testing all the various components.
6. Coaxial Helicopters: The complete guide …[17]
    a. This website provides a basic guide to what coaxial helicopters are, what some of the main benefits and drawbacks are and what some of the main applications are. This was useful since I was unaware of what a coaxial helicopter was before this. It helped me understand some of the challenges we will have to examine and focus on in our design and why Jim chose this specific configuration for the drone.
7. Shafts torsion [18]
    a. This website was very useful for remembering how to perform calculations on shafts given forces and torques. It showed all of the applicable equations including how to modify those for solid or hollow shafts. This website also links to many other pages they have available for other shaft related forces and stresses and the equations that relate to these. This website will continue to be a useful reference for initial calculations to get an idea of how our materials will behave and lead us to further more accurate calculations with simulated validations.

3.2.3 Harrison Harding

1. Unmanned Aircraft Systems: UAVS Design, Development and Deployment [19]
    a. This book provides a comprehensive overview of unmanned aircraft systems (UAS), including their design, development, and operational considerations. It discusses topics such as aircraft structures, payload systems, communication systems, and mission requirements. The book also explains how different subsystems must work together to ensure reliability and safety during flight operations. This source is relevant to the project because it provides foundational knowledge about UAV design and the integration of payload systems. This is important when developing the mechanism for automated payload deployment used in drones such as ours.
2. Drone Development from Concept to Flight [20]
    a. This book focuses on the process of designing and developing drones from the early conceptual stage through prototyping and flight testing. It covers topics such as structural design, propulsion systems, control systems, and payload integration. The author emphasizes practical engineering factors involved in building reliable drone systems and bringing them from theory to real life aircraft. This source supports the project by providing insight into the design process and engineering decisions required when implementing additional systems such as payload release mechanisms.
3. Which Rope Breaks? A Study of Tension Distribution in Multi-Rope Systems [21]
    a. The source analyzes how tension is distributed in multi-rope systems and that both the geometry of the rope configuration, and how the load is applied affect which rope

experiences the greatest stress and ultimately fails. For example, the study demonstrates that in a Y-shaped system there is a critical angle around 60° that determines whether the upper or lower ropes carry more tension, and that adding a mass at the connection point further changes this behavior. Relating this to payload attachment in our project, the research provides valuable insight into how different rope connection designs will perform under load. This indicates that choosing the correct angle, number of ropes, and attachment configuration can minimize excessive tension in any single rope. This allows us to design safer and more efficient payload support systems by selecting a rope arrangement that distributes forces more evenly and reduces the likelihood of failure.

4. Orion Parachute Riser Cutter Development [22]
    a. This technical paper describes the development of the Orion spacecraft parachute riser cutter, a device designed to sever parachute lines at specific stages during descent. The report outlines the engineering challenges involved in designing a reliable cutting mechanism capable of operating under extreme conditions. It also discusses testing methods and safety considerations used to verify the system's reliability. This source is relevant to the project because it provides examples of how engineered cutting devices are used in aerospace systems. This is similar to mechanisms used in UAV payload release or high-altitude balloon cut-down systems.
5. Polyester Rope Analysis Tool [23]
    a. This paper analyzes the structural behavior and strength characteristics of polyester ropes under different loading conditions. It explains how tensile forces, material properties, and environmental conditions affect rope performance and failure limits. The analysis also includes modeling techniques used to predict rope strength and safety margins in engineering applications. This source contributes to the project by providing information about the mechanical properties of rope materials. This is important when designing systems that must reliably cut or release ropes used in payload suspension.
6. Cutdown Mechanisms [24]
    a. This online resource explains the different types of cut-down mechanisms used in high-altitude balloon and payload recovery systems. It describes several methods for releasing payloads or terminating balloon flights. This includes thermal cutters, nichrome wire cutters, and mechanical release systems. The article also explains design considerations such as power consumption, reliability, and environmental conditions encountered at high altitude. This source supports the project by providing practical examples of commonly used cut-down systems and explaining how they function in real-world applications.
7. HAB Cutter [25]
    a. This resource describes cutters used in high-altitude balloon (HAB) missions to separate the payload from the balloon at the end of a flight. The article discusses the construction and operation of these cutters, including how heating elements or mechanical blades can sever the suspension line. It also explains how these systems are triggered either automatically or by remote command. This source is useful for the project because it provides practical design examples for payload separation systems used in balloon and UAV applications.

3.2.4 Jacob Walford

1. Advanced Composite Materials for Aerospace Engineering [26]
    a. This book covers the composite materials in aerospace engineering that help reduce fuel consumption and improve performance. The book covers the most prevalent fiber reinforced composites that combine different materials, fibers, matrices, and curing techniques that make the most efficient and strongest composites. Laminated composites, sandwich composites, braided composites, and many other specific types of composites are the focus of this book.
2. Military Handbook 5G: Metallic Materials and Elements for Aerospace Vehicle Structures Chapter 4: Magnesium Alloys [27]
    a. This military handbook was originally made for the advancement of the US military and their research in material strength and fatigue testing. There are several materials mentioned in this book, but the most prevalent chapter was chapter 4: Magnesium Alloys. The chapter covers several alloys included with magnesium, one of which is AZ31B, a specific aluminum, zinc alloy that the DARPA challenge drone plans to use in the final iteration of their drone. The nice thing about this handbook is that all the testing is in accordance with ASTM Testing standards, which are testing metrics.
3. Advances in Lightweight Composite Structures and Manufacturing technologies [28]
    a. This research paper focuses on composite structures that improve efficiency and versatility of the systems they are involved in. The detailed examination in this research paper determines the most efficient materials depending on their mechanical properties. Their benefits and significance in the engineering field help the engineers decide the most valuable composites to use for non frame materials, such as the propellers, the rotor linkage, swashplates, and other materials that do not need to be as strong.
4. Research Advances of Magnesium and Magnesium alloys worldwide in 2021; Fatigue and Deformation of Light Magnesium Alloys [29]
    a. This research paper offers a lot of information about mechanical properties of cast magnesium alloys. The alloys in this research paper includes the cast method, the heat treatment used, and all of the mechanical properties of each alloy. The amount of magnesium alloys in the research paper spans an incredible amount, and includes so many different casts and mixes. This applies to the project as the main material currently, and could provide good information when making a decision about which magnesium alloy to use specifically.
5. Advanced Composites in Aerospace Engineering Applications [30]
    a. This paper consists of information that covers biocomposites, geopolymers, and hybrid biocomposites. The information listed shows the highlights of each material's mechanical properties which show which materials have the most impressive densities with the highest moduli. The high hardness, high temperature capabilities of the composites listed can be used to find more materials which can be used for essentials, but do not need to be as strong.
6. CompLam - Aerospace Composite Laminates [31]

    a. CompLam is a website that mainly shows the differences of composite materials in the aerospace, automotive, and lightweight industries. The reinforced thermoplastic laminates featured in the websites are available for purchase, and the website is used as a way to source the materials needed to build the drone. Once a decision is made on the proper usage of materials for the design of the DARPA drone, this website was intended to be used to source the materials due to their "Rapid response to meet market trends".

7. Sensqo - Rotorcraft Materials [32]
    a. This website specifically denotes the materials used in rotorcraft applications. This website was used to source information about thermoset and thermoplastic composites which are used in efficient, lightweight rotorcraft applications. The website features more than just information about rotorcraft, but fixed wing aircraft, military applications, and even advanced aircraft applications. They mainly specify highly engineered, complex rotors for complex rotorcraft blades.
8. Signia Aerospace - What Materials are Aircrafts Made of and Why? [33]
    a. This is a simple article that outlines why aircrafts are made of what they are made of, and why. There is information about Titanium, composites, ceramic matrix composites and steel as their main materials, giving detailed reasons for each. Their pros and cons outline why the materials are considered to be used on the DARPA drone.

3.2.5 Jacob Silva

1. Design, Modeling, and control of a coaxial drone [34]
    a. This source encompasses a coaxial drone project and all R&D performed. The paper starts off with the overall mechanical design being a tower-like structure with two blades above and two joints that sit below each blade that controls roll, and pitch. As well as comparing Quadro blade configurations vs their coaxial design. The paper then discusses all their mathematical models, numerical solutions with graphed data and finally their results and testing. This source was nearly a direct comparison to our DARPA lifting drone, so almost every concept of this paper can be considered/applied to our project.
2. Arduino Based Flight Control Card Design and Quadcopter Integration [35]
    a. This paper is about the development of a low-cost quadcopter controller that is built around an Arduino Mega microcontroller as an alternative approach vs buying an over-the-counter commercial controller. The design consisted of a custom printed circuit board, gyroscope, electronic speed controllers, brushless motors and radio receiver all integrated with the Arduino microcontroller. The software itself is written in Arduino IDE utilizing stabilization with sensory feedback and PID algorithms. With this, the controller can interpret orientation data and adjusted motor speeds using PWM circuits to sustain a stable flight. Once all the hardware and software is assembled, the results show that an Arduino-based custom flight controller is a possibly cost-effective solution. Granted our drone is not a quadcopter, but this paper gives the DAPRA team a lot of insight into building a controller from scratch if we are unable to source a commercial unit.
3. Practical Arduino robotics: A hands-on guide to bringing your robotics ideas to life using Arduino [36]
    a. This handbook consists of 334 pages of lessons and steps on how to design and build robots using the Arduino Platform. The book covers basic Arduino components (Arduino itself, breadboard, sensors and actuators). It then discusses how to select the correct hardware, and how to write a control software with Arduino IDE. This handbook also

includes hands-on projects that demonstrate real world design and control system techniques. This handbook will be very handy in assisting with selecting the correct hardware, feedback control, sensory integration, and programming the Arduino microcontroller itself. Despite this book not being drone specific, it will be a foundational reference we can use.

4. Raspberry Pi Zero W Wireless Projects [37]
    a. This source is like the one about, a handbook with project-based guide that teaches how to build wireless systems, but with a Raspberry Pi Zero instead of an Arduino Microcontroller. This book introduces both hardware and operating systems of the Raspberry Pi Zero. It also introduces several hands-on projects that demonstrate hardware, networking and embedding programming with a device utilizing a Raspberry Pi Zero microcontroller. Overall, the book focuses on wireless networks, hardware, Linux setup, python programming and building robotics and projects. This handbook gives the DAPRA team another control system approach that does not involve Arduino IDE. Raspberry Pi's are known to have more powerful microcontrollers, so in the event the DARPA lifting drone does require a more powerful microcontroller, we have this handbook to reference and be used as a foundational reference if we go this route.
5. PX4 Autopilot User Guide [38]
    a. This user guide is an open-sourced software that is used to control multiple autonomous vehicles, including drones. The guide explains the system dynamics of the flight controller hardware and how it manages vehicle stability, navigation, and task execution with sensor data inputs and algorithms. There are sections in this user guide that goes over assembling and configuring PX4 based vehicles with supported hardware, airframes and communication systems. It is a very comprehensive resource for building, programming, and configuring autonomous vehicles with PX4 flight control systems. This resource has a lot of potential information pertaining to our capstone. Our customer has discussed the possibility of controlling our drone via GPS. Now that isn't exactly autonomous operation, but this user guide has information and possibly a control system we can modify to our needs.

6. Ardupilot [39]
    a. This is another open-source platform that is also designed to control multiple autonomous vehicles. This source specifies its use of GPS's, accelerometers, gyroscopes and magnetometers to navigate and stabilize autonomous vehicles. While this source does cover autonomous operations with programmable waypoints and geofencing, it also has modes including manual control, and assisted flight. Ardupilot is a very popular option for hobbyists, commercial use, and research purposes with a large developer community. The use of ground control software is versatile as well, users can configure, monitor flight data, and plan a route off a computer or mobile device if they choose. This source will most likely be the one we reference the most. Our customer is very familiar with this platform and has even given us links to sections of this platform that covers coaxial configured aircraft.

7. MAVLink [40]
    a. This platform is a little different from the previous two sources that encompassed control system software with multiple applications. MAVLink on the other hand, is a lightweight communication protocol. This communication is between onboard components and

ground control stations that enable transmission of telemetry data, commands and system info that users can read and measure. This type of platform is used with systems that are limited to computing resources and low bandwidth communication links. This protocol essentially increases the communication efficiency between all hardware. This may or may not be something we utilize. In the event the DARPA team continues the program with Arduino IDE, then we will be using this protocol. Arduino IDE is not designed for high bandwidth or processing tasks, so integrating Arduino IDE with MAVLink will give us the best of both worlds with simplicity and efficiency.

8-13. Udemy Online Course with Arduino IDE [41-46]

a. This will be a combination of 6 sources from the Udemy website. Each is a course that goes over certain aspects of Arduino IDE or the hardware itself. These six courses went over common functions used in Arduino IDE, and the different data types required in order to code with this software. The next subject that was covered was the three different types of loops Arduino IDE uses, and when each loop is appropriate. The classes reviewed from this source allowed me to start learning the basics of coding with Arduino IDE. With this knowledge, I was able to write our drone's first code function, and will continue to build on top of that code as the project progresses.

3.3 Mathematical Modeling

3.3.1 Controls System

3.3.1.1 Commercial UAV Control System – Joshua Nieto

The UAV flight controller determines the position of the aircraft using measurements from onboard sensors combined with kinematic equations. The onboard sensors such as accelerometers, gyroscopes and GPS receivers provide real time measurements of the vehicle's motion and orientation. Accelerometers measure linear acceleration in the x, y and z directions, gyroscopes measure angular orientation and rotational motion and GPS provides an absolute position reference for correcting accumulated drift. These sensor measurements are processed by the flight controller to estimate the vehicle's velocity and position during flight.

The fundamental equations used to estimate the UAV's motion are based on classical kinematics. Acceleration measurements obtained from the onboard sensors are integrated to determine velocity, and velocity is then integrated to determine position. The velocity update equation is given by

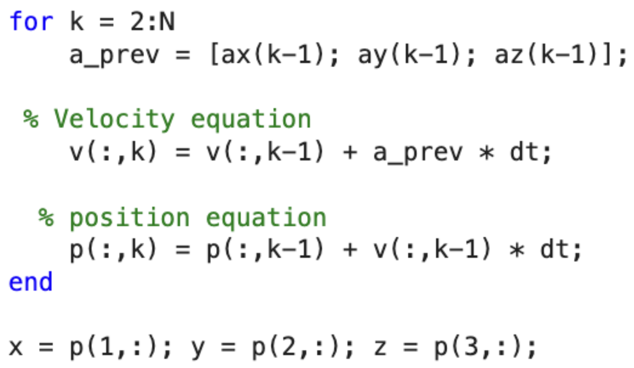
$$v_f = v_i + a\Delta t$$

Where v_f is the final velocity v_i is the initial velocity a is the acceleration and Δt is the time step. Once velocity is known, the position of the UAV can be estimated using

$$p_f = p_i + v_i \Delta t + \frac{1}{2} a (\Delta t)^2$$

Where p_f is the final position and p_i represents the initial position These equations are used computationally within the flight control software to continuously update the UAV's estimated position. At each time step new acceleration data is obtained from the sensors and integrated numerically to update the vehicle's velocity and position estimates. This process forms the basis of inertial navigation used in many UAV control systems. The calculations are executed repeatedly in a control loop to maintain an updated estimate of the aircraft's state during flight.

The mathematical model was validated through simulation by generating trajectories using the same kinematic equations that would be used by the onboard flight controller (Figure 1). The simulation demonstrates how acceleration data can be converted into velocity and position estimates over time (Figure 2). These results help verify that the modeling approach accurately represents the motion of the UAV.



```
for k = 2:N
    a_prev = [ax(k-1); ay(k-1); az(k-1)];

 % Velocity equation
    v(:,k) = v(:,k-1) + a_prev * dt;

  % position equation
    p(:,k) = p(:,k-1) + v(:,k-1) * dt;
end

x = p(1,:); y = p(2,:); z = p(3,:);
```

Figure 2: Portion Code showing use of equations.

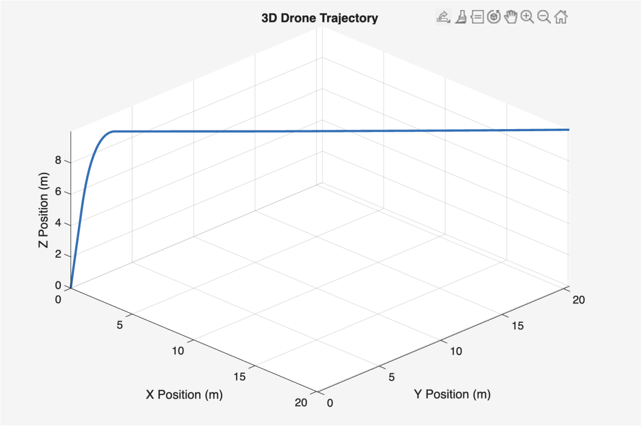


Figure 3: 3-D Drone Trajectory.

Understanding how position is estimated from sensor measurements is critical for the UAV control system design errors in acceleration measurements can accumulate over time and cause drift in the position estimate which must be corrected using additional sensors such as GPS. The update rate of the control loop and the accuracy of the sensors therefore play a major role in maintaining stable flight and accurate navigation. These considerations influence the selection of the UAV flight controller and the overall architecture of the control system used in this project.

3.3.1.2- Jacob Silva

This model does not involve any mathematics, it only consists of Arduino IDE coding, located in Appendix A. Our drone's control system must be capable of performing multiple functions while in flight. This model starts off with programming that will control one servo motor via a potentiometer in TinkerCAD Simulation software (Figure 4, [49]). When the potentiometer is actuated, the servo motor rotates proportionally to the analog input signal. Along with this programming model, a CAD model concept was generated in Solidworks. The CAD model will act as a testing stand where each control system can be tested individually, (Figure 5, [50]). Each seperate system can then be integrated one at a time as the project progresses until we have a complete custom drone control system.

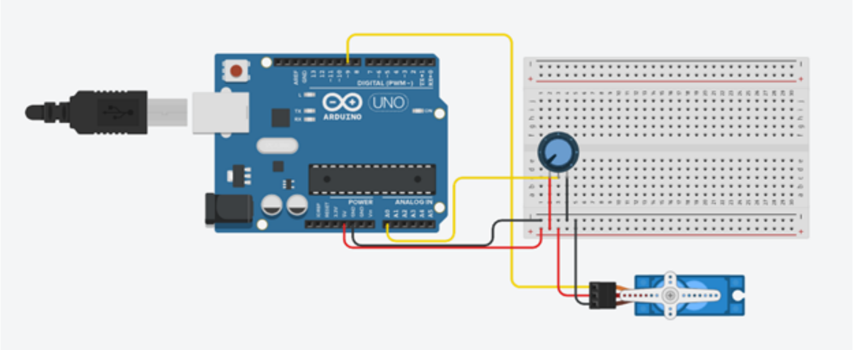


Figure 4: TinkerCAD Simulation of control system hardware

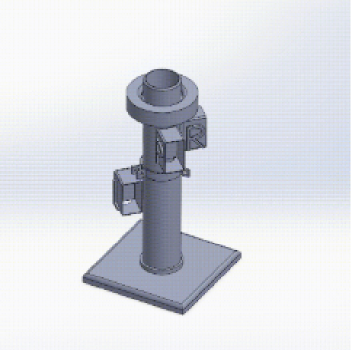


Figure 5: Prototype concept for control system testing

3.3.2 Materials

3.3.2.1 Minimum Lift RPM - Jacob Walford

Lift Equation

$$L = \frac{1}{2}\rho V^2 C_D A$$

ρ = Air density

V = Freestream Velocity

C_D = Coefficient of Lift

A = Wetted area

Since the air density is a constant, we do not need to solve for this variable. The other constant variable in this equation is the amount of lift needed to produce a positive thrust. The variable in question in this equation is the velocity, which represents the velocity the rotor needs to be moving.

A dilemma is produced which states that the rotor does not have uniform velocity across the length of the chord. A good rule of thumb when estimating the average velocity of a rotor is to use 70% of the velocity of the rotor as the average velocity for the airfoil, so this will be used. Finally, the coefficient of lift must be estimated, which can be done by using local sources for a first iteration. For the first iteration, since the laminarity of the air flowing over the foil is unknown, we can use data from Bigfoil.com [47], estimating a coefficient of lift to be 0.5128. This can later be changed depending on the Reynolds number found at the trailing edge of the airfoil. Calculating the wetted area mostly depends on the angle of attack, which will be assumed to be 0 degrees for the sake of simplicity. Using this information, the calculation on the minimum RPM can be determined. See below for the re-written formula along with the calculations.

$$V = \sqrt{\frac{2*L}{\rho C_l A}}$$

$$V = \sqrt{\frac{2*300}{.5028*.002377*4.994}}$$

$$V = 313.95\ ft/s$$

This is the minimum average speed needed to maintain 300 pounds of lift. This means that this number must be divided by the average velocity assumption in order to get the maximum speed of the foil, otherwise known as the tip speed.

$$V_t = \frac{V_{avg}}{V}$$

$$V_t = \frac{313.95}{0.7}$$

$$V_t = 448.5\ ft/s$$

Using this tip velocity, we can now calculate the corresponding airfoil RPM needed to spin the tip of the airfoil at 448.5 feet per second.

$$RPM = \frac{V}{2*\pi*r} * 60$$

$$RPM = 571.04\ RPM$$

See appendix C for Computational Fluid Mechanical analysis screenshots that correlate with the lift force produced by the rotors.

Design impact

The impact on this calculation allows the engineers involved to have a goal for how fast the rotors need to be spinning in order to actually lift the drone. This is incredibly important because it will allow the engineers to make decisions based on the future of the project. If there is a limitation that will prevent the rotors from spinning this fast, the engineers can make an assessment at that time to decide whether the rotors need to change or whether the limitation needs to be worked around. Knowing this information is essential to building a successful drone.

3.3.2.2 Axle Forces - Isaac Lynn

Equations Used:

$$T = \frac{hp * 5252}{rpm}$$

$$\tau = \frac{T * r}{J}$$

$$\sigma_a = \frac{F}{A}$$

$$\sigma_a = \frac{M * c}{I}$$

$$M = F * L$$

$$\sigma' = \sqrt{(\sigma_a + \sigma_b)^2 + 3\tau^2}$$

Known Values:

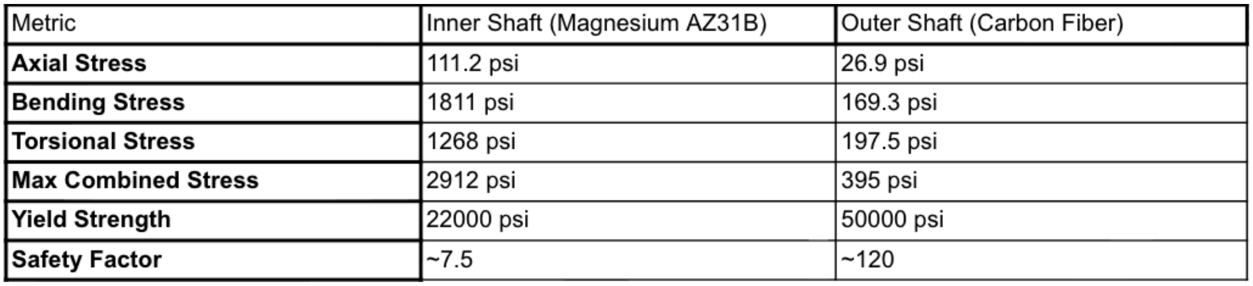
Hollow outer shaft:

- Outer Shaft axial load: 105.84 lbs
- Diameter: 3.0 in
- Thickness: 0.5 in
- Length: 1.5 ft
- Input: 8 hp, 600 rpm
- Material: Carbon fiber weave

Solid Inner Shaft:

- Inner Shaft axial load: 196.56 lbs
- Diameter: 1.5 in
- Length: 2.5 ft
- Input: 8 hp, 600 rpm
- Material: Magnesium AZ31B

Results:



Metric	Inner Shaft (Magnesium AZ31B)	Outer Shaft (Carbon Fiber)
Axial Stress	111.2 psi	26.9 psi
Bending Stress	1811 psi	169.3 psi
Torsional Stress	1268 psi	197.5 psi
Max Combined Stress	2912 psi	395 psi
Yield Strength	22000 psi	50000 psi
Safety Factor	~7.5	~120

Table 2: Results from the Stress Analysis

Design Impact

The calculations done on both the inner and outer shafts showed that our chosen materials and dimensions allow for significantly more strength than will be necessary for the drone. However this is ideal since it's better not to operate near the limit of the shafts because they are one of the most crucial parts of the drone. Another advantage of this extra safety is that the shafts could be given more tolerance (distance between the inner and outer shaft), or could be reduced in diameter if there needs to be even more weight shaved off. The next step to determine if this will be satisfactory is to do a cycle analysis on our shaft dimensions to see if the shafts can withstand the high cycle life since they will spin at 600 rpm constantly.

3.3.2.3 Topology Optimization - Isaac Lynn

Design Impact

Topology optimization is a design method which uses software (in this case Ansys Discovery) and a physics based iteration process to determine how much material can be removed from a given design without compromising the structural integrity of the component. Due to the weight constrictions given by the challenge, it is extremely crucial to eliminate any additional weight that is not required to support the lift components. When designing the frame, this tool became a huge help because it allows us to reduce the weight by as much as possible for parts that are not directly helping produce the lift required to lift the drone and the additional 220 lbs to meet the challenge requirements. When designing the frame, it was possible to save nearly 60% of material from a basic design, without changing its ability to hold and support the engines and driveshaft. The main issue with this method, however, is that it is not easy to validate mathematically since the code is not easily accessible and we can’t show that it is sure to withstand the load unless we test the designs. This can be accomplished using 3D prints of different frame models and applying various scaled loads to it to ensure safety. This would be the next step if we decide to implement the topology optimization into the final design.

See appendix B for the process of modeling and optimization iterations.

3.3.2.4 Payload Forces - Harrison Harding

Equations used

∑Fy=0 , ∑Fx=0

Example

Given: T_1=110 lbs (payload weight tension)
θ = 55° (cable angle relative to the horizontal)
$T_2 = T_3$(cable tension)
Find:T_{2x}
Soln :

$$\sum F_y = 0$$

$$T = T_2 sin\theta + T_3 sin\theta$$

$$110 = = T_2 sin(55°) + T_3 sin(55°)$$

$$110 = 2(T_2 sin(55°))$$

$$T_2 = \frac{55}{sin(55°)} = 67.3\ [lb]$$

$$\sum F_x = 0$$

$$T_2 cos\theta = T_3 cos\theta$$

$$T_{2x} = T_2 cos(55°)$$

$$T_{2x} = 67.3\ [lb]\ cos(55°) = 38.6\ [lb]$$

Design Impact

The horizontal force acting on the frame is approximately 38.6 lb per cable. This value represents the lateral load that the frame structure must resist. Determining this load allows the frame members to be sized appropriately to prevent buckling or structural deformation during payload lifting operations.

3.3.2.5 Shear stress analysis- Harrison Harding

Equations used

$m = W/g$, $\omega = 2\pi N/60$, $F = mr\omega^2$, $A = \pi d^2/4$, $\tau = V/2A$

Example

Given: W=4 lb, N=860 RPM, r_mount=15 in, L=90 in, r_cg=60 in=5 ft, d=0.5 in, g=32.2 ft, n=2bolts
Find: τ
Soln:
Assumptions: Force line passes through the bolt group centroid
Centrifugal loading at 860 [rpm]

Center of gravity radius: $r_{CG} = 15 + (\frac{90}{2}) = 60\ [in] = 5\ [ft]$

Rotor mass: $m = \frac{W}{g} = \frac{4\ [lb]}{32.2\ [\frac{ft}{s^2}]} = 0.124\ [slugs]$

Angular velocity: $\omega = 2\pi(\frac{860}{60}) = 90.1\ [\frac{rad}{s}]$

Centrifugal Force:

$$F = m * r * \omega^2 = (0.124\ [slugs])(5\ [ft])(90.1\ [\frac{rad}{s}])^2 = 5,033\ [lb]$$

Total Forces: $F_1 + F_2 = 5,033\ [lb]$

$F_1 = F_2 = 2516.5\ [lb]$

Bolt Diameter: d = 0.5 [in]

Area per bolt: $\frac{\pi}{4}(0.5\ [in])^2 = 0.1963\ [in^2]$

Total Shear Area (2 bolts): $2A = 0.3926\ [in^2]$

Shear Stress: $\tau = \frac{V}{2A} = \frac{2516.5\ [lb]}{0.3926\ [in^2]} * 10^{-3} \Rightarrow \tau = 6.4\ [ksi]$

Design Impact

The hand calculation predicts a bolt shear stress of approximately 6.4 ksi. I then did a SOLIDWORKS [48] simulation that produced a stress of approximately 7.2 ksi. This results in a 12% difference between the hand calculations and the simulation results. The discrepancy is due to simplifying assumptions made in the hand calculations, such as neglecting moment effects and eccentric loading that are captured in the simulation. As a result, the simulation provides a more realistic representation of the stresses within the assembly and is used to better evaluate the structural performance of the bolt connection. It also verifies that having bolts with a diameter of 0.5in are more than strong enough to safely attach the rotors to.

4 Design Concepts

4.1 Functional Decomposition

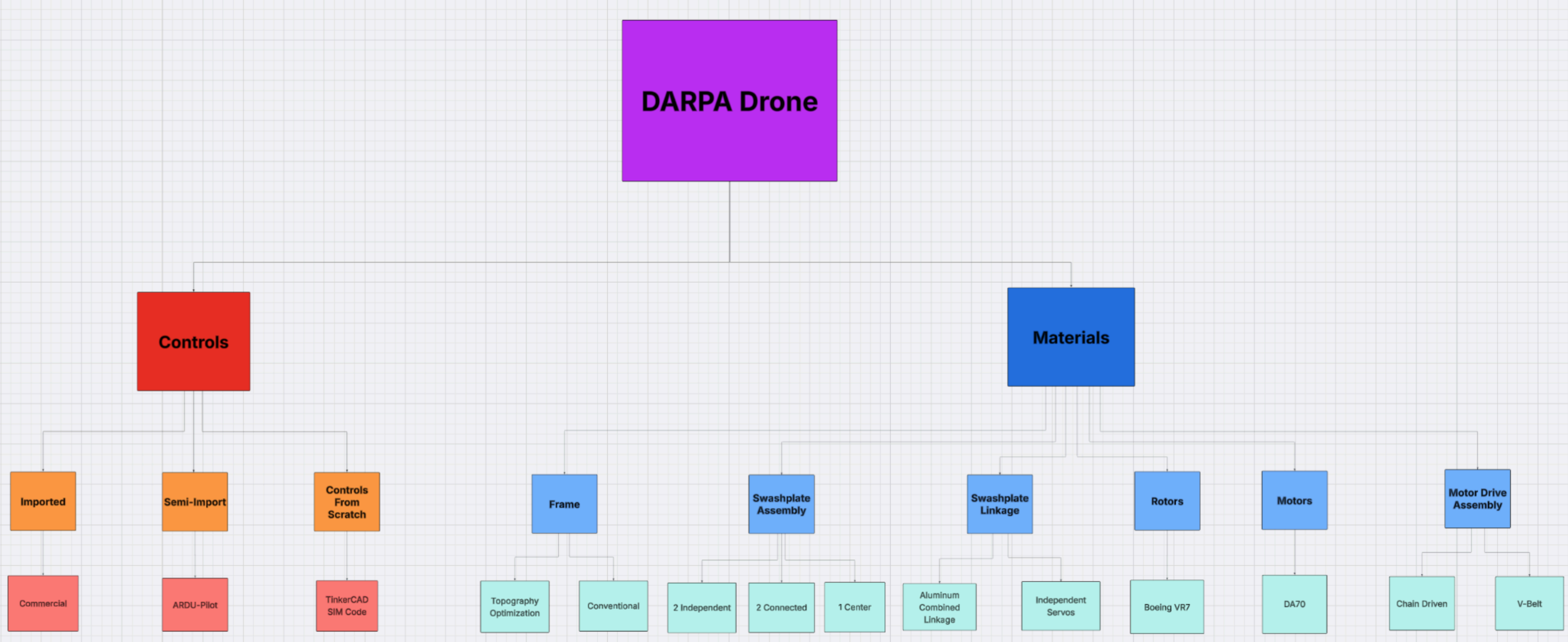


Figure 6: Decomposition Chart

A functional decomposition chart was developed to break the DARPA heavy lift UAV system into its major subsystems and identify the critical functions required for the aircraft to successfully complete its project the top level of the diagram represents the overall system goal, labeled “DARPA Drone,” which includes the complete unmanned aerial vehicle system designed to meet the DARPA lifting challenge requirements. From this top level objective the system is divided into two primary functional branches: the control system and the structural/material subsystem.

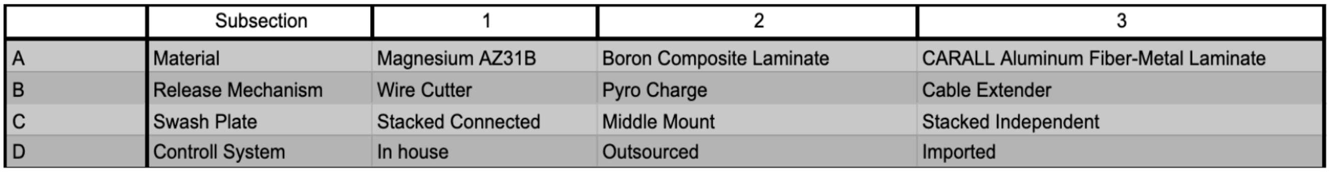
The control system branch represents the components responsible for sensing, navigation and flight stabilization. This includes possible control system implementations such as imported commercial flight controllers, semi-imported systems using platforms such as ArduPilot and custom control systems developed from scratch. These options allow the design team to evaluate different levels of complexity, cost and reliability for the UAV flight controller. The control subsystem determines how the aircraft processes sensor inputs and maintains stability and executes flight commands.

The materials and structural subsystem branch represents the physical components required to withstand lift and support the payload during flight. This portion of the decomposition includes the frame, swashplate assembly, swashplate linkage, rotors, motors, and motor drive assembly. These elements collectively determine the mechanical performance of the UAV including lift generation, structural integrity and payload support. Additional design considerations such as linkage configuration and rotor selection are also included within this branch to guide design decisions.

Creating this decomposition chart is important because it allows the team to organize the UAV system into manageable subsystems. By separating its subsections allows the aircraft into components each subsystem can be analyzed and optimized independently while still contributing to the overall system performance. This approach helps ensure that the engineering requirements such as payload capacity, structural strength and flight stability are addressed throughout the design process. Additionally the decomposition chart helps guide concept generation and decision making by identifying where alternative design solutions may exist within the system.

4.2 Concept Generation

The concept generation process was based on the decomposition of the UAV system. Four key subsystem categories were identified as important to system performance, structural material selection, payload release mechanism, swash plate configuration and the control system (Table 3). These subsystems influence the aircraft's lift capability, reliability, manufacturability and overall system performance.



	Subsection	1	2	3
A	Material	Magnesium AZ31B	Boron Composite Laminate	CARALL Aluminum Fiber-Metal Laminate
B	Release Mechanism	Wire Cutter	Pyro Charge	Cable Extender
C	Swash Plate	Stacked Connected	Middle Mount	Stacked Independent
D	Controll System	In house	Outsourced	Imported

Table 3: Subsystem Options

A morphological chart was developed to explore possible combinations for each subsystem. Three options were considered for each category. Structural material options included Magnesium AZ31B, Boron Composite Laminates and CARALL aluminum fiber metal laminates. Payload release options included a wire cutter, pyrotechnic release and cable extender. Swash plate configurations included stacked independent, stacked connected and middle mounted configurations. Control system options included in house, outsourced and imported commercial systems.

Using the morphological chart, five complete UAV system concepts were generated by selecting one option from each subsystem category. These concepts were compared based on performance, manufacturability, cost and reliability. See table below for aforementioned concepts.

Design	Design 1	Design 2	Design 3	Design 4	Design 5
Material	Boron Comp. Lam	AZ 31B	CARALL	CARALL	AZ31B
Release	Cable Extender	Cable Extender	Wire Cutter	Cable Extender	Pyro Charge
Swash Plate	Stacked Ind.	Middle Mount	Middle Mount	Middle Mount	Stacked Con.
Control System	In House	In House	In House	Outsourced	Imported

Table 4: Design Matrix table showing individual iterations

Design 1

Pros:

Strong (≈29 MSI) and lightweight ($\approx\ 0.095\ \frac{Lb}{in^3}$)

Good fatigue life

Cons:

Expensive material ($\approx\ \$35\ per\ LF$)

Difficult manufacturing

Design 2

Pros:

Low cost ($\approx\ \$3.70$ Per Lb)

Easy to machine (Magnesium is a lightweight, malleable material)

Cons:

Lower strength than composite materials ($\approx\ 6500$ KSI)

Low corrosion resistance

Design 3

Pros:

Good fatigue resistance

Simple release system

Cons:

More complex material

Slower release than pyrotechnic systems

Design 4

Pros:

Strong and durable ($\approx\ 22\ MSI$)

Professional fabrication

Cons:

Longer lead time

Less control over build

Design 5

Pros:

Fast release

Lightweight ($\approx\ 0.064\ \frac{Lb}{in^3}$)

Cons:

Safety concerns with pyrotechnics

Possible shipping delays

This concept generation process allowed the team to explore multiple subsystem combinations before selecting the most promising design during the concept evaluation phase.

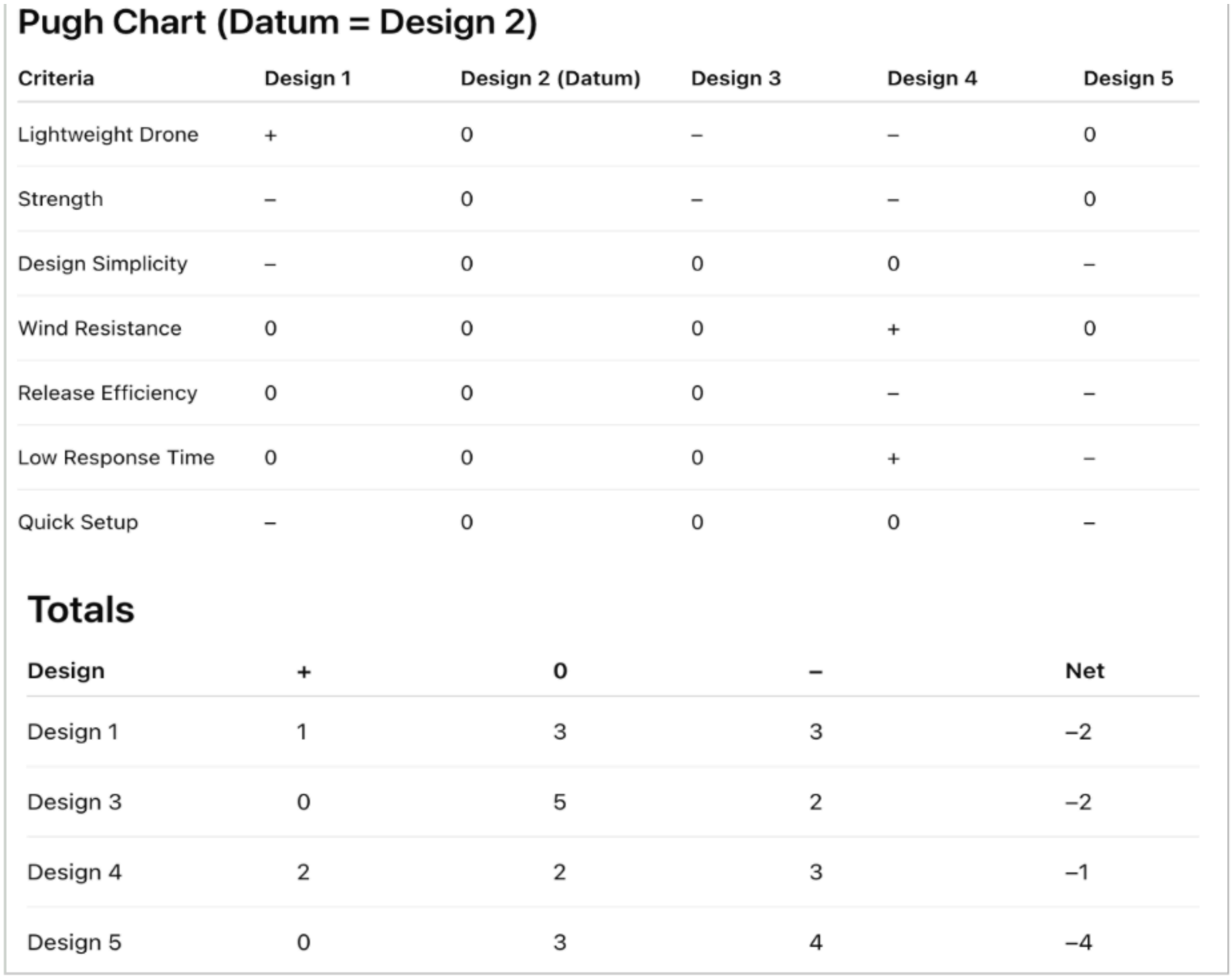
4.3 Selection Criteria

To evaluate the five UAV design concepts a set of engineering based selection criteria was established based on the performance requirements of the DARPA lifting challenge. Each criterion was assigned a weighting factor in the decision matrix to reflect its relative importance to the overall UAV system performance. Minimizing system weight was a major consideration because achieving a high payload to weight ratio is essential for the mission requirements therefore the lightweight drone criterion was assigned a weight of 0.20. Structural strength was also assigned a weight of 0.20 since the UAV must safely support the payload and withstand aerodynamic and operational loads during flight.

Design simplicity and wind resistance were both assigned weights of 0.10. Simpler designs generally improve manufacturability and reduce potential failure points while wind resistance influences flight stability and aerodynamic performance. Payload release efficiency was assigned a weight of 0.15, as the UAV must reliably deploy the payload during the mission. Low response time was assigned a weight of 0.20, reflecting the importance of fast control system response for maintaining stable flight. Quick setup was included as a minor criterion with a weight of 0.05, representing the ease of preparing the system for operation.These criteria were used in both the Pugh chart and the weighted decision matrix to compare the five generated design concepts and identify the most promising system configuration.

4.4 Concept Selection

The concept selection process was performed using both a Pugh chart and a weighted decision matrix to compare the five design concepts generated during the concept development phase. These evaluation methods allowed the team to systematically compare each concept using the selection criteria described in Section 4.3.



Pugh Chart (Datum = Design 2)

Criteria	Design 1	Design 2 (Datum)	Design 3	Design 4	Design 5
Lightweight Drone	+	0	–	–	0
Strength	–	0	–	–	0
Design Simplicity	–	0	0	0	–
Wind Resistance	0	0	0	+	0
Release Efficiency	0	0	0	–	–
Low Response Time	0	0	0	+	–
Quick Setup	–	0	0	0	–

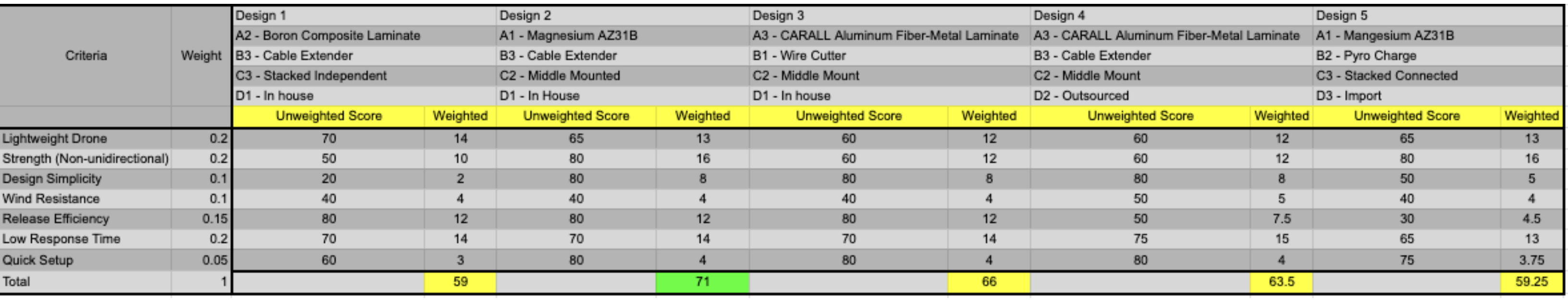
Totals

Design	+	0	–	Net
Design 1	1	3	3	–2
Design 3	0	5	2	–2
Design 4	2	2	3	–1
Design 5	0	3	4	–4

Table 4: Pugh chart.

The Pugh chart (Table 3) was first used to perform a qualitative comparison of the design concepts using Design 2 as the reference datum. Each concept was evaluated against the selection criteria and assigned a positive (+), negative (−), or neutral (0) rating relative to the datum design; this comparison provided an initial assessment of how each concept performed across the different evaluation categories. Based on the Pugh chart results, several concepts showed disadvantages relative to the datum design, while others demonstrated improvements in specific areas such as wind resistance or response time.

Following the qualitative comparison, a weighted decision matrix was used to perform a more detailed quantitative evaluation of the design concepts.



Criteria	Weight	Design 1		Design 2		Design 3		Design 4		Design 5	
		A2 - Boron Composite Laminate		A1 - Magnesium AZ31B		A3 - CARALL Aluminum Fiber-Metal Laminate		A3 - CARALL Aluminum Fiber-Metal Laminate		A1 - Mangesium AZ31B	
		B3 - Cable Extender		B3 - Cable Extender		B1 - Wire Cutter		B3 - Cable Extender		B2 - Pyro Charge	
		C3 - Stacked Independent		C2 - Middle Mounted		C2 - Middle Mount		C2 - Middle Mount		C3 - Stacked Connected	
		D1 - In house		D1 - In House		D1 - In house		D2 - Outsourced		D3 - Import	
		Unweighted Score	Weighted	Unweighted Score	Weighted	Unweighted Score	Weighted	Unweighted Score	Weighted	Unweighted Score	Weighted
Lightweight Drone	0.2	70	14	65	13	60	12	60	12	65	13
Strength (Non-unidirectional)	0.2	50	10	80	16	60	12	60	12	80	16
Design Simplicity	0.1	20	2	80	8	80	8	80	8	50	5
Wind Resistance	0.1	40	4	40	4	40	4	50	5	40	4
Release Efficiency	0.15	80	12	80	12	80	12	50	7.5	30	4.5
Low Response Time	0.2	70	14	70	14	70	14	75	15	65	13
Quick Setup	0.05	60	3	80	4	80	4	80	4	75	3.75
Total	1		59		71		66		63.5		59.25

Table 5: Decision matrix.

In the decision matrix (Table 4) each concept was scored against the evaluation criteria using the weighting factors described in Section 4.3. The weighted scoring method allowed the team to compare how well each design met the performance requirements of the UAV system. The results of the decision matrix showed that Design 2 achieved the highest overall score, indicating that it best satisfied the project requirements across the evaluated criteria.

Based on the results of both the Pugh chart and the weighted decision matrix, Design 2 was selected as the final concept for further development. This design provides a balanced combination of structural performance, manufacturability and system simplicity while maintaining the lightweight characteristics necessary to achieve the required payload to weight ratio. The selected concept will be further developed and refined through detailed modeling, structural analysis and CAD design in the following stages of the project.

Following concept selection, preliminary CAD models were developed to visualize the current configuration of the UAV system and support further design analysis.

Figure 7: Isometric view of Coaxial blade configuration

Figure 8: Isometric view of Coaxial blade configuration

The CAD models shown above illustrate the current conceptual layout of the coaxial rotor system used in the UAV design. The coaxial blade configuration allows two rotors to operate on the same axis which improves lift generation while maintaining a compact design. This configuration also helps reduce torque imbalance that typically occurs in single rotor helicopter systems

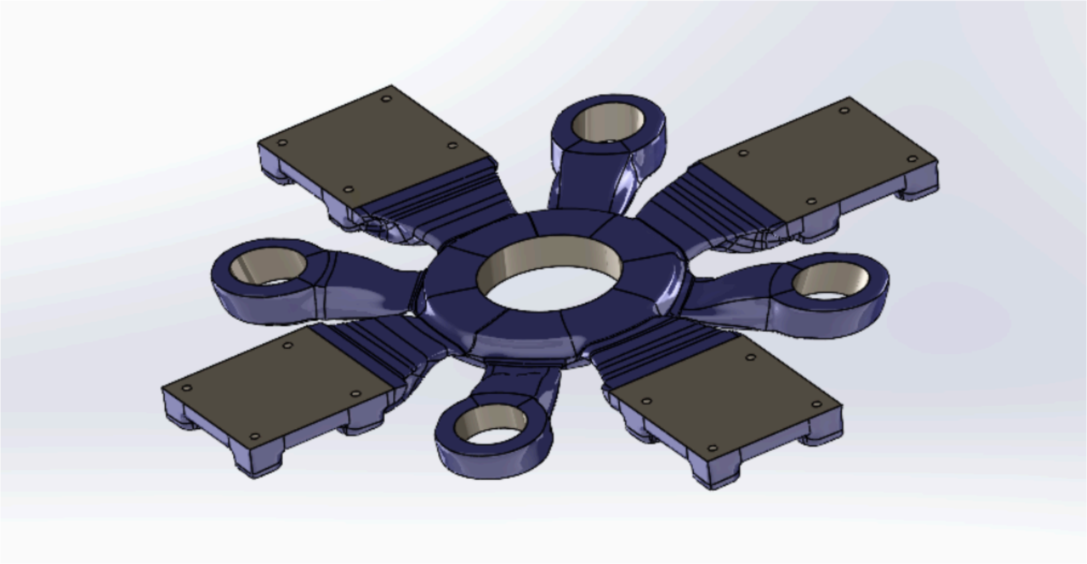


Figure 9: Topographical Optimization iteration of base plate

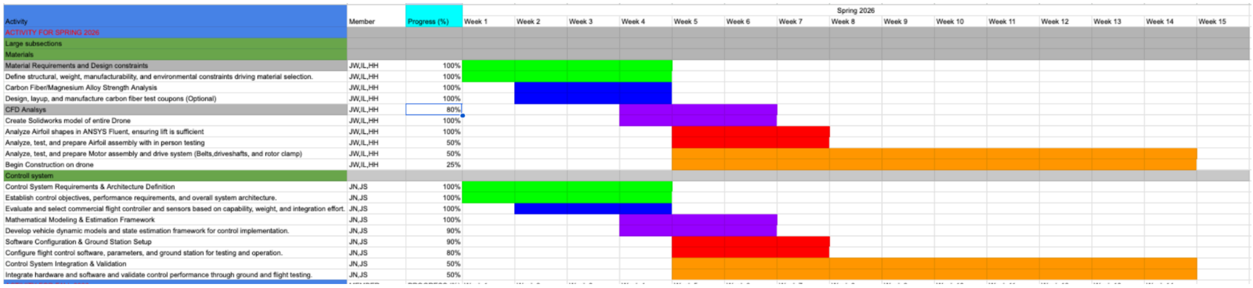
Additional CAD modeling has been performed on the UAV frame structure, including topology studies on the base plate the purpose of this analysis is to remove unnecessary material while maintaining structural integrity allowing the system to remain lightweight while still supporting the required payload loads. Reducing structural weight is critical to achieving the desired payload to weight ratio for the DARPA lifting challenge.These CAD models represent the current stage of the design process and will continue to evolve as further structural analysis, component selection and system integration are completed.

5 Schedule and Budget

5.1 Schedule

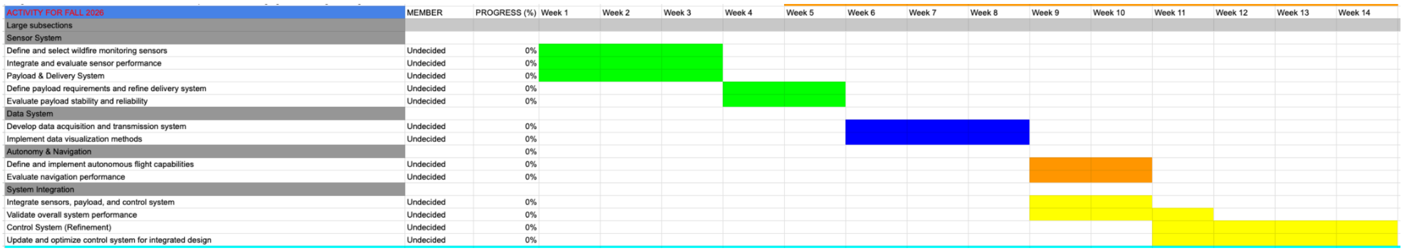
The project schedule is divided into two primary phases first the Spring 2026 (design and initial prototyping) and Fall 2026 (integration, testing, and final validation). A detailed Gantt chart was developed to organize tasks, assign responsibilities and track progress across both semesters.

Spring 2026



			Spring 2026														
Activity	Member	Progress (%)	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
ACTIVITY FOR SPRING 2026																	
Large subsections																	
Materials																	
Material Requirements and Design constraints	JW,IL,HH	100%	🟩	🟩	🟩	🟩											
Define structural, weight, manufacturability, and environmental constraints driving material selection.	JW,IL,HH	100%	🟩	🟩	🟩	🟩											
Carbon Fiber/Magnesium Alloy Strength Analysis	JW,IL,HH	100%		🟦	🟦	🟦											
Design, layup, and manufacture carbon fiber test coupons (Optional)	JW,IL,HH	100%		🟦	🟦	🟦											
CFD Analsys	JW,IL,HH	80%				🟪	🟪	🟪									
Create Solidworks model of entire Drone	JW,IL,HH	100%				🟪	🟪	🟪									
Analyze Airfoil shapes in ANSYS Fluent, ensuring lift is sufficient	JW,IL,HH	100%					🟥	🟥	🟥								
Analyze, test, and prepare Airfoil assembly with in person testing	JW,IL,HH	50%					🟥	🟥	🟥								
Analyze, test, and prepare Motor assembly and drive system (Belts,driveshafts, and rotor clamp)	JW,IL,HH	50%					🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
Begin Construction on drone	JW,IL,HH	25%					🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
Controll system																	
Control System Requirements & Architecture Definition	JN,JS	100%	🟩	🟩	🟩	🟩											
Establish control objectives, performance requirements, and overall system architecture.	JN,JS	100%	🟩	🟩	🟩	🟩											
Evaluate and select commercial flight controller and sensors based on capability, weight, and integration effort.	JN,JS	100%		🟦	🟦	🟦											
Mathematical Modeling & Estimation Framework	JN,JS	100%				🟪	🟪	🟪									
Develop vehicle dynamic models and state estimation framework for control implementation.	JN,JS	90%				🟪	🟪	🟪									
Software Configuration & Ground Station Setup	JN,JS	90%					🟥	🟥	🟥								
Configure flight control software, parameters, and ground station for testing and operation.	JN,JS	80%					🟥	🟥	🟥								
Control System Integration & Validation	JN,JS	50%					🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
Integrate hardware and software and validate control performance through ground and flight testing.	JN,JS	50%					🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	

Fall 2026



ACTIVITY FOR FALL 2026	MEMBER	PROGRESS (%)	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
Large subsections																
Sensor System																
Define and select wildfire monitoring sensors	Undecided	0%	🟩	🟩	🟩											
Integrate and evaluate sensor performance	Undecided	0%	🟩	🟩	🟩											
Payload & Delivery System	Undecided	0%	🟩	🟩	🟩											
Define payload requirements and refine delivery system	Undecided	0%				🟩	🟩									
Evaluate payload stability and reliability	Undecided	0%				🟩	🟩									
Data System																
Develop data acquisition and transmission system	Undecided	0%						🟦	🟦	🟦						
Implement data visualization methods	Undecided	0%						🟦	🟦	🟦						
Autonomy & Navigation		0%														
Define and implement autonomous flight capabilities	Undecided	0%									🟧	🟧				
Evaluate navigation performance	Undecided	0%									🟧	🟧				
System Integration																
Integrate sensors, payload, and control system	Undecided	0%									🟨	🟨				
Validate overall system performance	Undecided	0%									🟨	🟨	🟨			
Control System (Refinement)	Undecided	0%											🟨	🟨	🟨	🟨
Update and optimize control system for integrated design	Undecided	0%											🟨	🟨	🟨	🟨

Table 6: Gantt chart (Split for legibility)

<u>Spring 2026 – Design and Prototype Phase</u>

The Spring semester focuses on developing the core systems of the UAV and beginning initial construction.

Materials and Structural Design

- Defines material selection based on weight, strength, manufacturability and environmental constraints. Includes carbon fiber and magnesium alloy analysis, along with optional material testing.

Aerodynamic Analysis and Airfoil Testing

- Uses CFD tools to evaluate airfoil performance and ensure sufficient lift is generated. This includes both simulation and initial physical testing of airfoil configurations.

Mechanical System Development

- Focuses on the design and analysis of the motor assembly and drivetrain, including belts, driveshafts and rotor mounting components.

CAD Modeling and System Layout

- Development of a full SolidWorks model of the UAV to ensure proper integration of all subsystems and support manufacturing planning.

Control System Development

- Establishes control system requirements and architecture. development of mathematical models for system behavior and preparation of software and ground station setup.

Initial Airframe Construction

- Begins physical assembly of the UAV platform near the end of the semester transitioning from design to hardware implementation.

Fall 2026 – Integration and Testing Phase

The Fall semester focuses on combining all subsystems and preparing for final demonstration and delivery.

Sensor System Development

- Selection and integration of sensors required for wildfire monitoring and data collection.

Payload and Delivery System

- Refinement and testing of the payload system to ensure reliable deployment and stability during flight.

Data System Development

- Implementation of data acquisition, transmission, and visualization systems to support mission objectives.

Autonomy and Navigation

- Development and validation of autonomous flight capabilities, including navigation and control logic.

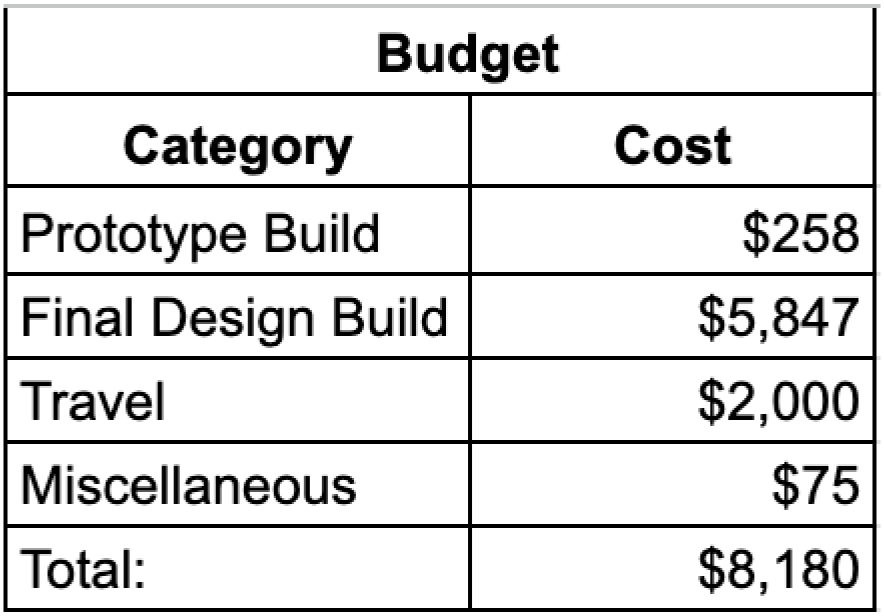
System Integration

- Integration of all subsystems, including structural, control, sensor, and payload components into a complete UAV system.

Control System Refinement

- Optimization and tuning of the control system based on full-system testing and performance evaluation.

5.2 Budget

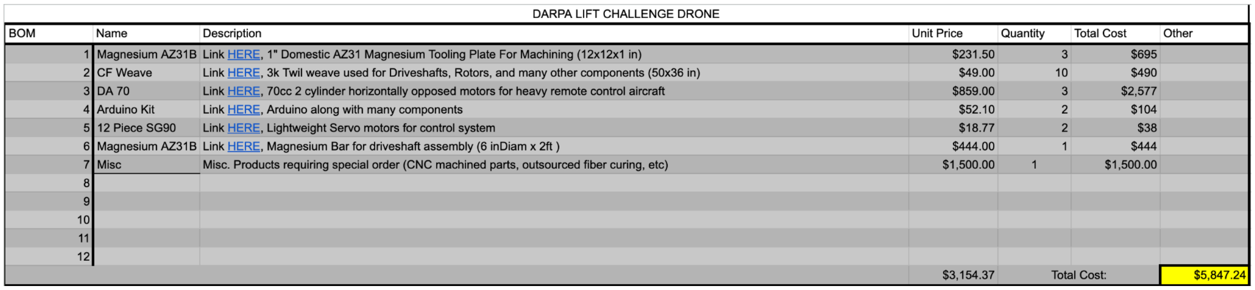


Budget	
Category	**Cost**
Prototype Build	$258
Final Design Build	$5,847
Travel	$2,000
Miscellaneous	$75
Total:	$8,180

Table 7: Total Project Budget

The total project budget above includes costs associated with prototyping, final system construction, travel, and miscellaneous expenses. The prototype phase cost approximately $258 and utilized lower-cost components to allow for quick testing. The final system build accounts for the majority of the budget at $5,847, driven by high-performance components such as the DA-70 engines, magnesium structural materials, and carbon fiber composites. Travel costs were estimated at $2,000 to account for transportation of the drone and team, while an additional $75 was allocated for miscellaneous expenses such as small hardware, and unforeseen costs.

5.3 Bill of Materials



DARPA LIFT CHALLENGE DRONE

BOM	Name	Description	Unit Price	Quantity	Total Cost	Other
1	Magnesium AZ31B	Link HERE, 1" Domestic AZ31 Magnesium Tooling Plate For Machining (12x12x1 in)	$231.50	3	$695	
2	CF Weave	Link HERE, 3k Twil weave used for Driveshafts, Rotors, and many other components (50x36 in)	$49.00	10	$490	
3	DA 70	Link HERE, 70cc 2 cylinder horizontally opposed motors for heavy remote control aircraft	$859.00	3	$2,577	
4	Arduino Kit	Link HERE, Arduino along with many components	$52.10	2	$104	
5	12 Piece SG90	Link HERE, Lightweight Servo motors for control system	$18.77	2	$38	
6	Magnesium AZ31B	Link HERE, Magnesium Bar for driveshaft assembly (6 inDiam x 2ft)	$444.00	1	$444	
7	Misc	Misc. Products requiring special order (CNC machined parts, outsourced fiber curing, etc)	$1,500.00	1	$1,500.00	
8						
9						
10						
11						
12						
			$3,154.37		Total Cost:	$5,847.24

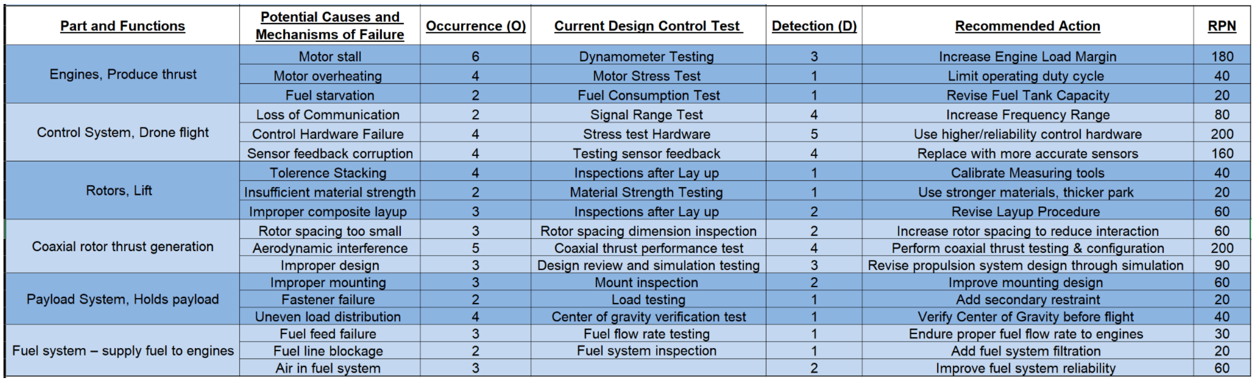
Table 8: Final Bill of Materials

The final Bill of Materials reflects the components required for a fully functional heavy-lift drone system, with a total estimated cost of approximately $5,847. The most significant contributors to cost are the DA-70 engines and the magnesium structural components, which were selected for their high strength-to-weight ratio and ability to withstand the mechanical loads of the system. Carbon fiber weave was used extensively for rotors and drivetrain components to minimize weight while maintaining structural integrity. Lower-cost components such as the Arduino control system and servo motors were selected to provide reliable control functionality without significantly increasing overall cost. A portion of the budget is allocated to miscellaneous manufacturing and outsourced processes, including CNC machining and composite curing, which are necessary to produce custom structural components. The BoM reflects key trade-offs between cost, weight, and performance, with priority given to structural strength and propulsion reliability due to their direct impact on system safety and overall success. A separate Bill of Materials for prototyping is included in the appendix D.

6 Design Validation and Initial Prototyping

6.1 Failure Modes And Effects Analysis (FMEA)

Part and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)
Engines, Produce thrust	Motor Failure in Flight	Loss of thrust; loss of stability; possible crash	10
Control System, Drone flight	Fails to Maintain Stable Flight	Loss of control, unstable flight, possible crash	10
Rotors, Lift	Fracture/Failure	Loss of thrust; severe instability; possible crash	10
Coaxial rotor thrust generation	Rotor interference causing thrust loss	Reduced lift efficiency; instability; possible crash	10
Payload System, Holds payload	Payload shift or detachment	Change in center of gravity; instability; possible crash	10
Fuel system – supply fuel to engines	Insufficient fuel delivery	Loss of thrust; engine shutdown; possible crash	10



Part and Functions	Potential Causes and Mechanisms of Failure	Occurrence (O)	Current Design Control Test	Detection (D)	Recommended Action	RPN
Engines, Produce thrust	Motor stall	6	Dynamometer Testing	3	Increase Engine Load Margin	180
	Motor overheating	4	Motor Stress Test	1	Limit operating duty cycle	40
	Fuel starvation	2	Fuel Consumption Test	1	Revise Fuel Tank Capacity	20
Control System, Drone flight	Loss of Communication	2	Signal Range Test	4	Increase Frequency Range	80
	Control Hardware Failure	4	Stress test Hardware	5	Use higher/reliability control hardware	200
	Sensor feedback corruption	4	Testing sensor feedback	4	Replace with more accurate sensors	160
Rotors, Lift	Tolerence Stacking	4	Inspections after Lay up	1	Calibrate Measuring tools	40
	Insufficient material strength	2	Material Strength Testing	1	Use stronger materials, thicker park	20
	Improper composite layup	3	Inspections after Lay up	2	Revise Layup Procedure	60
Coaxial rotor thrust generation	Rotor spacing too small	3	Rotor spacing dimension inspection	2	Increase rotor spacing to reduce interaction	60
	Aerodynamic interference	5	Coaxial thrust performance test	4	Perform coaxial thrust testing & configuration	200
	Improper design	3	Design review and simulation testing	3	Revise propulsion system design through simulation	90
Payload System, Holds payload	Improper mounting	3	Mount inspection	2	Improve mounting design	60
	Fastener failure	2	Load testing	1	Add secondary restraint	20
	Uneven load distribution	4	Center of gravity verification test	1	Verify Center of Gravity before flight	40
Fuel system – supply fuel to engines	Fuel feed failure	3	Fuel flow rate testing	1	Endure proper fuel flow rate to engines	30
	Fuel line blockage	2	Fuel system inspection	1	Add fuel system filtration	20
	Air in fuel system	3		2	Improve fuel system reliability	60

Table 9: FMEA table (split for legibility)

The FMEA identified several critical failure modes with high risk priority numbers (RPN), particularly control hardware failure at 200, aerodynamic interference in the coaxial rotor system at 200, and motor stall at 180. These failures are critical because they can lead to loss of stability, thrust, and ultimately a crash. To mitigate these risks the design incorporated improvements such as more reliable control hardware, increased rotor spacing to reduce aerodynamic interference, and increased engine load margins to prevent motor stall. A key trade-off in the design was balancing performance and safety against added weight and system complexity. For example, increasing rotor spacing and adding redundancy improved reliability but slightly increased structural weight and design complexity. Overall, the team prioritized reliability and flight stability over minimal weight, as preventing catastrophic failure is more important than marginal performance gains.

6.2 Initial Prototyping

Physical Demo:

1. What question are you trying to answer with the prototype?
    - Does design operate as intended? (Rotor pitch control)
2. What was the answer?
    - Yes, our prototype demonstrates controlled variation of rotor pitch with two (2) servo motors controlled by an arduino via joystick control.
3. How did it inform design/how do you plan to iterate based on this new info?
    - The prototype shows the importance of mounting and integration of our actuators (servo motors) strategies. The mounting locations of rotor pitch actuators will be revised to optimize linkage geometry.

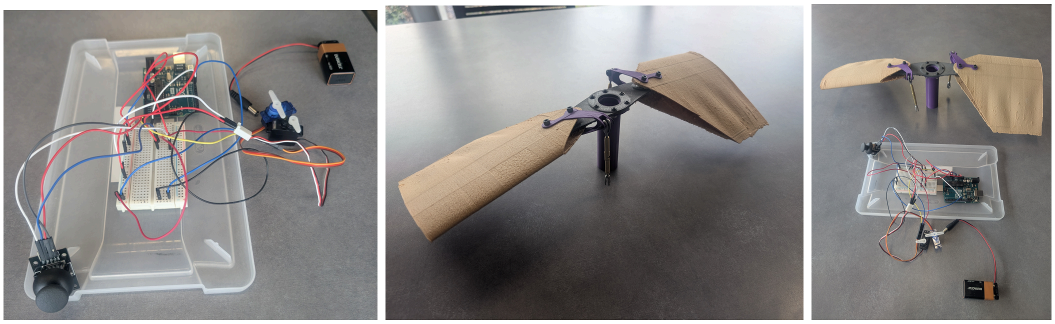
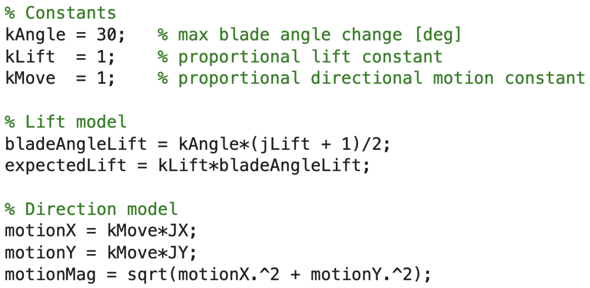


Figure 10: Prototype of rotor assembly and joystick.

<u>Virtual Demo:</u>

1. What question are you trying to answer with the prototype?
    - How does joystick input affect actuator motion and system response?
2. What was the answer?
    - Joystick input produces a predictable change in actuator motion. Lift and directional movement respond consistently to input. Control maps show smooth and linear system behavior.
3. How did it inform design/how do you plan to iterate based on this new info?
    - Confirms feasibility of joystick based control system, supports controllability and stability. Guides future integration of control systems with full drone.



```
% Constants
kAngle = 30;   % max blade angle change [deg]
kLift  = 1;    % proportional lift constant
kMove  = 1;    % proportional directional motion constant

% Lift model
bladeAngleLift = kAngle*(jLift + 1)/2;
expectedLift = kLift*bladeAngleLift;

% Direction model
motionX = kMove*JX;
motionY = kMove*JY;
motionMag = sqrt(motionX.^2 + motionY.^2);
```

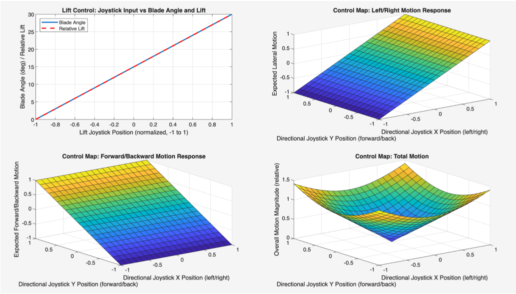


Figure 11: Code and Results of joystick articulation program used in the prototype assembly.

6.3 Other Engineering Calculations

- Fuel Consumption Calculations:

$$V_{fuel}(0.5) = 1.33\ [\frac{gal}{hr}](0.5) = 0.67\ [\frac{gal}{hr}]$$

$$V_{fuel}(0.6) = 1.33\ [\frac{gal}{hr}](0.6) = 0.8\ [\frac{gal}{hr}]$$

$$V_{fuel}(0.75) = 1.33\ [\frac{gal}{hr}](0.75) = 1\ [\frac{gal}{hr}]$$

(Consumptions above at 50, 60, & 75% duty cycles respectfully)

B.S = Brake Specific Fuel Consumption
$\widehat{m}_f$ = Mass flow rate of fuel consumption
V_{fuel} = Volumetric fuel flow
ρ_{fuel} = Fuel density

B.S Fuel Consumption = 0.45-0.5 $[\frac{lb_{fuel}}{hp*hr}]$, assuming 0.5 $[\frac{lb_{fuel}}{hp*hr}]$

P(total) = 16 [hp]

$$\widehat{m}_f = B.S\ Fuel\ Consumption\ *\ P(total) = 0.5[\frac{lb_{fuel}}{hp*hr}]\ *\ 16\ [hp]$$

$$\widehat{m}_f = 8\ [\frac{lb_{fuel}}{hr}],\ \rho_{fuel} = 6\ [\frac{lb}{gal}]$$

$$V_{fuel} = \frac{\widehat{m}_f}{\rho_{fuel}} = \frac{8\ [\frac{lb_{fuel}}{hr}]}{6\ [\frac{lb}{gal}]} = 1.33\ [\frac{gal}{hr}]\ at\ 100\%\ duty\ cycle$$

Calculations done under assumptions:

- No drag force
- Based off of Brake Specific Fuel Consumption
- Linear relationship between power and fuel consumption
- Constant fuel delivery
- No drivetrain/propulsion losses
- Assumed power requirements

6.4 Future Testing Potential

Future testing may include endurance testing to assess long-term component reliability, which will include testing the specific material the engineers decided to proceed with; Magnesium AZ31b. This material can be crafted into coupons that fit within specific ASTM testing standards, measured to find compression and tension strength, along with bending stress resistance and fatigue resistance. All of this information is important because it provides minimum dimensions for the fuselage and other components of the drone, which can be optimized depending on the client's needs. Control system tuning will also be conducted to improve flight stability and responsiveness. This testing will mostly be done after a full scale prototype is assembled, but it will be able to provide insightful feedback for how the commercial control system controls the craft. Payload integration testing will also be important to ensure proper center of gravity and secure attachment under dynamic conditions. Along with some future calculations, some of the current calculations like the fuel consumption calculation or the lift analysis can be tested in real time with more accurate conditions and compared to the paper calculations conducted in section 6.3. This can also only be done once a full scale model is configured. Furthering research into these tests would help refine the design and improve overall system performance and safety.

7 CONCLUSIONS

The main objective of this project was the design and mathematical validation of a heavy lift drone to submit for the 2026 DARPA Lift Challenge. The project successfully addressed the challenge's core requirements by developing a lightweight drone capable of a 4:1 payload to weight ratio. By the end of the semester, the team intends to have fully finished a design capable of lifting a 220 pound payload (or 110 pound minimum payload) with a weight of less than 55 pounds, in order to meet the difficult performance standards from DARPA and the project client, Jim Corning of Novakinetics.

The engineering process began with the QFD phase, which translated the specific competition goals into precise and quantifiable technical specifications. Through functional decomposition and the use of a weighted decision matrix the team examined multiple configurations and eventually selected a final design. This layout was chosen for its superior lift efficiency, small frame, and easy to manufacture materials which are all essential in order to meet the goals of the lift challenge.

After initial designs the team divided to tackle the various challenges of the design. The main two teams are focused on communications and materials respectively. Our validations and accomplishments so far are the aerodynamic lift validation, structural evaluations, and positional orientation for the control system. The aerodynamic validation (appendix C) showed that our selected rotor blades will be able to produce sufficient lift for the drone. This calculation provided the basis for the remainder of the structural components since it is the primary force acting upon the drone. The structural analysis performed also proved that our rotor assembly will be able to hold together under the theoretical loads from the lift and the added weight. This also goes for the drive shaft which has over a 7 times factor of safety at its weakest point. With these validations we are able to prove that the design chosen will be able to theoretically meet the challenge requirements with ease from a structural standpoint. The final iteration of the drone utilizes a hybrid approach to materials and propulsion. The frame is mainly constructed from Magnesium AZ31B, selected for its high strength-to-weight ratio and simple manufacturability. This is complemented by carbon fiber weave for the outer rotor shafts to ensure maximum rigidity under high-torque conditions.

Looking towards the future for this project, the main goals will be taking the research and development thus far and beginning to transition towards the goal for next semester. The final design of the drone is to be modified into a drone with fire fighting capabilities that apply its unique heavy lift capacity to this field. We aim to find the best possible use for this ability in order to assist firefighters with surveillance and swift response times. To do this the team will research various new control systems and how the fire can affect drone performance. However before the transition can be made there are still several other goals that have to be addressed first. Physical material testing and programming of the control system with the Arduinos is the main priority for the team in the following weeks.

In summary, the design presented in this report shows a validated and buildable solution for the 2026 DARPA Lift Challenge. There is integration of advanced aerodynamics, structural analysis, all in a coaxial configuration that should ensure the team is able to meet the competition standards for the May 2026 deadline.

8 REFERENCES

[1] "Spirit UAV," *Ascent AeroSystems*, Feb. 07, 2025. https://ascentaerosystems.com/spirit/ (accessed Jan. 30, 2026)

[2] "CoaX Drones (UAV's) - CoaX Helicopters - Coaxial Rotor Helicopters and Drones," *CoaX Helicopters - Coaxial Rotor Helicopters and Drones*, Oct. 30, 2019. https://www.coaxhelicopters.com/coax-drones-uavs/ (accessed Jan. 30, 2026).

[3] "GAOTek Helicopter Drone for Agricultural-Adjustable Flight Height - GAO Tek," *Tek Dev*, May 23, 2024. https://gaotek.com/product/gaotek-helicopter-drone-for-agricultural-adjustable-flight-height/ (accessed Jan. 30, 2026)

[4] *Small Unmanned Aircraft*. New Jersey: The University Press Group Ltd, 2012.

[5] Igor Astrov, *Flight Control of Unmanned Rotorcrafts for Enhanced Situational Awareness*. Nova Science Publishers, 2014.

[6] D. Kotarski, P. Piljek, M. Pranjić, and J. Kasać, "Concept of a Modular Multirotor Heavy Lift Unmanned Aerial Vehicle Platform," *Aerospace*, vol. 10, no. 6, p. 528, Jun. 2023, doi: https://doi.org/10.3390/aerospace10060528.

[7] L. Meier, D. Honegger, and M. Pollefeys, "PX4: A node-based multithreaded open source robotics framework for deeply embedded platforms," *IEEE Xplore*, May 01, 2015. https://ieeexplore.ieee.org/abstract/document/7140074

[8] F. Kendoul, "Survey of advances in guidance, navigation, and control of unmanned rotorcraft systems," *Journal of Field Robotics*, vol. 29, no. 2, pp. 315–378, Jan. 2012, doi: https://doi.org/10.1002/rob.20414.

[9] "PX4 Open Source Autopilot," *PX4 Open Source Autopilot*, 2019. https://px4.io/

[10] "Pyrodrone - For Racers By Racers," Pyrodrone. https://pyrodrone.com/

[11] "QGC - QGroundControl - Drone Control," QGroundControl - Drone Control, Feb. 25, 2020. https://qgroundcontrol.com/

[12] R. Nijssen, *Composite Materials: An Introduction*. Record Place of publication not identified: Inholland University of Applied Sciences, 2015.

[13] ROCHESTER APPLIED SCIENCE ASSOCIATES INC N Y, LOEWY,Robert G., and Piarulli,Vincent J., *Dynamics of Rotating Shafts*. 1969.

[14] NASA, https://ntrs.nasa.gov/api/citations/19960054333/downloads/19960054333.pdf?attachment=true (accessed Feb. 2, 2026).

[15] N94- 36399 ..... " ASTM test methods for composite characterization and, https://ntrs.nasa.gov/api/citations/19940031892/downloads/19940031892.pdf (accessed Feb. 2, 2026).

[16] B. N. Bourtsev, S. V. Selemenev, and V. P. Vagis, “TWENTY FIFTH EUROPEAN ROTORCRAFT FORUM ,” *COAXIAL HELICOPTER ROTOR DESIGN & AEROMECHANICS* , 1999.

[17] RC Visions, “Coaxial Helicopters: The complete guide to how they work, why they matter, and when to choose one,” RC Visions, https://rcvisions.com/blogs/rc-visons-journal/coaxial-helicopters?srsltid=AfmBOopcTgFLdWvXtPKTq_xabwMPH8JIwsyw3Sf9TEpo1B5XknsbsWD8 (accessed Feb. 2, 2026).

[18] Shafts torsion, https://www.engineeringtoolbox.com/torsion-shafts-d_947.html (accessed Feb. 2, 2026).

[19] R. Austin, *Unmanned Aircraft Systems: Uavs Design, Development and Deployment*. Hoboken, N.J: Wiley, 2013.

[20] S. Sharma, *Drone Development from Concept to Flight: Design, Assemble, and Discover the Applications of Unmanned Aerial Vehicles*. Birmingham, UK: Packt Publishing Ltd, 2024.

[21] A. Eskandari and R. De Luca, “Which Rope Breaks? A Study of Tension Distribution in Multi-Rope Systems,” Which rope breaks? A study of tension distribution in Multi-Rope Systems, https://arxiv.org/html/2509.09973v1 (accessed Feb. 2, 2026).

[22] S. Oguz and F. Salazar, NASA, https://ntrs.nasa.gov/api/citations/20100039628/downloads/20100039628.pdf?attachment=true (accessed Feb. 2, 2026).

[23] J. Beltran and E. Williamson , Polyester rope analysis tool by Juan Felipe Beltran and Eric B. Williamson, https://www.bsee.gov/sites/bsee.gov/files/tap-technical-assessment-program/369ab.pdf (accessed Feb. 2, 2026).

[24] “Cutdown mechanisms,” Cutdown Mechanisms, https://sites.google.com/site/ki4mcw/Home/cutdown-mechanisms (accessed Feb. 2, 2026).

[25] “Hab Cutter,” Balloon Ascent Technologies LLC, https://loonatec.com/product/hab-cutter/ (accessed Feb. 2, 2026).

[26] S. Rana and R. Fangueiro, *Advanced composite materials for aerospace engineering : processing, properties and applications*. Duxford: Woodhead Publishing is an imprint of Elsevier, 2016.

[27] United States. Department Of Defense, *Metallic materials and elements for aerospace vehicle structures.* Washington, D.C.: U.S. Dept. Of Defense, 1998.

[28] R. Phiri, S. Mavinkere Rangappa, S. Siengchin, O. P. Oladijo, and T. Ozbakkaloglu, “Advances in lightweight composite structures and manufacturing technologies: A comprehensive review,” Heliyon, vol. 10, no. 21, p. e39661, Oct. 2024, doi: https://doi.org/10.1016/j.heliyon.2024.e39661.3

[29] J. Song, J. Chen, X. Xiong, X. Peng, D. Chen, and F. Pan, “Research advances of magnesium and magnesium alloys worldwide in 2021,” *Journal of Magnesium and Alloys*, vol. 10, no. 4, pp. 863–898, Apr. 2022, doi: https://doi.org/10.1016/j.jma.2022.04.001.

[30] N. Mazlan, S. M. Sapuan, and R. A. Ilyas, *Advanced composites in aerospace engineering applications*. Cham, Switzerland: Springer, 2022.

[31] "Advanced Aerospace Composite Laminates - CompLam," *CompLam*, Dec. 11, 2020. https://complam.com/aerospace-composite-laminates/ (accessed Jan. 30, 2026).

[32] "syensqo, an advanced materials and specialty chemicals company," *syensqo*, May 16, 2024. https://www.syensqo.com

[33] "What Materials Are Aircrafts Made Of And Why?," *Acornwelding.com*, 2023. https://www.acornwelding.com/blog/post/materials-aircrafts-are-made-of

[34] L. Chen, J. Xiao, Y. Zheng, N. A. Alagappan, and M. Feroskhan, "Design, modeling, and control of a coaxial drone," *IEEE Transactions on Robotics*, vol. 40, pp. 1650–1663, Jan. 2024, doi: 10.1109/tro.2024.3354161.

[35] E. Gunes and H. Düzkaya, "Arduino Based Flight Control Card Design and Quadcopter Integration," *Gazi University Journal of Science Part a Engineering and Innovation*, vol. 11, no. 2, pp. 392–406, Jun. 2024, doi: 10.54287/gujsa.1480315.

[36] L. Kaul, *Practical arduino robotics: A hands-on guide to bringing your robotics ideas to life using Arduino*. Packt Publishing Ltd, 2023.

[37] V. Tzivaras, "<Chapters 2, 4 & 10>," in *Raspberry Pi Zero W Wireless Projects*. Birmingham, U.K.: Packt Publishing Ltd, 2017, ch. <X>, pp. <xx–yy>.

[38] "PX4 Autopilot User Guide | PX4 Guide (main)." https://docs.px4.io/main/en/

[39] ArduPilot, "ArduPilot," *ArduPilot.org*. https://ardupilot.org/

[40] "MAVLink Guide." https://mavlink.io/

[41] Shawn Hymel, *Arduino Programming and Hardware Fundamentals with Hackster*, online course, Udemy. Available: https://nau.udemy.com/course/arduino-programming-and-hardware-fundamentals-with-hackster/ (accessed Feb. 22, 2026).

[42] S. Hymel, *Arduino Programming and Hardware Fundamentals with Hackster*, lecture 6444474, Udemy, [Online]. Available: https://nau.udemy.com/course/arduino-programming-and-hardware-fundamentals-with-hackster/learn/lecture/6444474#overview (accessed Feb. 22, 2026).

[43] S. Hymel, *Arduino Programming and Hardware Fundamentals with Hackster*, lecture 6725330, Udemy, [Online]. Available: https://nau.udemy.com/course/arduino-programming-and-hardware-fundamentals-with-hackster/learn/lecture/6725330#overview (accessed Feb. 28, 2026).

[44] S. Hymel, *Arduino Programming and Hardware Fundamentals with Hackster*, lecture 6725332, Udemy, [Online]. Available: https://nau.udemy.com/course/arduino-programming-and-hardware-fundamentals-with-hackster/learn/lecture/6725332#overview (accessed Feb. 28, 2026).

[45] S. Hymel, *Arduino Programming and Hardware Fundamentals with Hackster*, lecture 6725334, Udemy, [Online]. Available: https://nau.udemy.com/course/arduino-programming-and-hardware-fundamentals-with-hackster/learn/lecture/6725334#overview (accessed Mar. 1, 2026).

[46] S. Hymel, *Arduino Programming and Hardware Fundamentals with Hackster*, lecture 6725352, Udemy, [Online]. Available: https://nau.udemy.com/course/arduino-programming-and-hardware-fundamentals-with-hackster/learn/lecture/6725352#overview (accessed Mar. 1, 2026).

[47] "BOEING-VERTOL VR-7," *Bigfoil.com*, 2021. https://www.bigfoil.com/7ca8b053-8bd2-4a7f-8ab7-3c5b52db23d9_info.php (accessed Mar. 09, 2026).

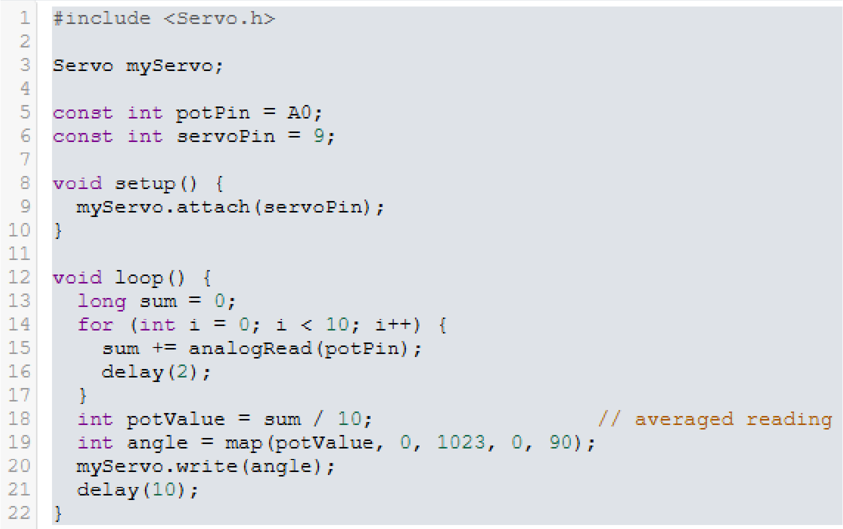
[48] Dassault Systèmes SolidWorks Corporation, *Static Analysis of an Assembly*, SOLIDWORKS Simulation Help, 2024.

[49] "Login - Tinkercad," *Tinkercad*. https://www.tinkercad.com/things/dZqrVjLQ9hs-control-system-/editel?returnTo=https%3A%2F%2Fwww.tinkercad.com%2Fdashboard

[50] SolidWorks 2024, Dassault Systèmes, Waltham, MA, USA. [Online]. Available: https://www.solidworks.com

9 APPENDICES

9.1 Appendix A: Control System Arduino IDE Program



```
#include <Servo.h>

Servo myServo;

const int potPin = A0;
const int servoPin = 9;

void setup() {
  myServo.attach(servoPin);
}

void loop() {
  long sum = 0;
  for (int i = 0; i < 10; i++) {
    sum += analogRead(potPin);
    delay(2);
  }
  int potValue = sum / 10;                  // averaged reading
  int angle = map(potValue, 0, 1023, 0, 90);
  myServo.write(angle);
  delay(10);
}
```

Figure 12- Arduino IDE code that performs lift control

9.2 Appendix B: Topography Optimization

Firstly the design was created in solidworks based on sketches from Novakinetics and Jim. These were made given rough dimensions with the required dimensions of the engines and shaft kept in mind. See below for the initial design.

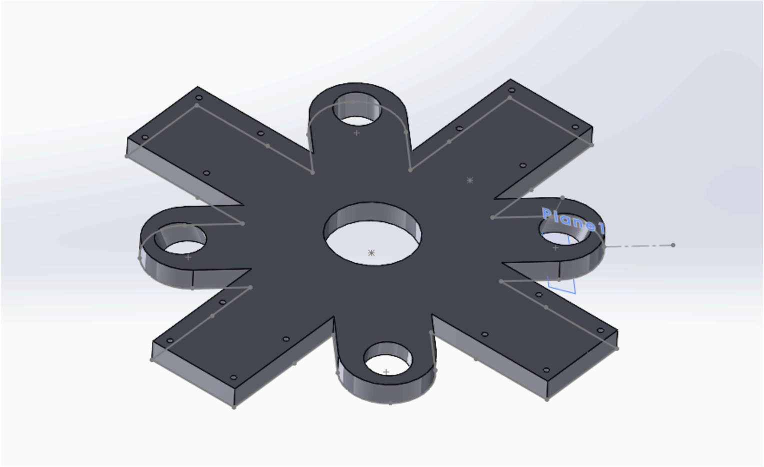


Figure 13: Initial design of the lower baseplate of the drone

After this was complete the design was imported into Ansys Discovery to perform the topology optimization. Using given forces on the component and by specifying regions that had to be maintained as a support the team was able to set up a simulation in order to begin the iteration process. See below for a view of a single iteration stress analysis.

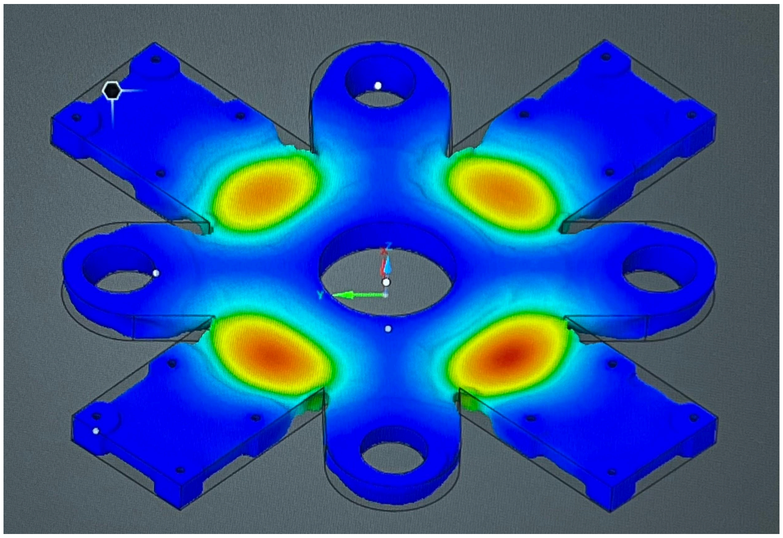


Figure 14: Stress analysis during an iteration of the optimization

After the final iteration is completed and the desired amount of material has been removed, Ansys then fully renders the model and validates the solution to ensure that the component can still withstand the forces with minimal strain. See below for the final design after over 10 minutes of iterations and 50% material removal.

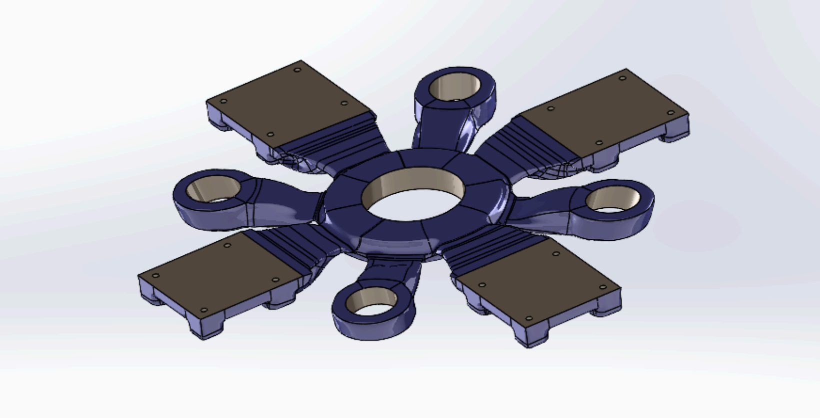


Figure 15: Final model after optimization

9.3 Appendix C: CFD Analysis Process (Rotor Lift)

Firstly, the geometry was imported into ANSYS Geometry. The geometry was originally made in Solidworks 2025, using the "Import XYZ Curve" function. Next, there were two pieces of geometry formed around the airfoil itself. The first one being the "fluid" around the airfoil, which encloses the airfoil, and the second being the "frozen" solid closer around the airfoil. See figure below for visualization.

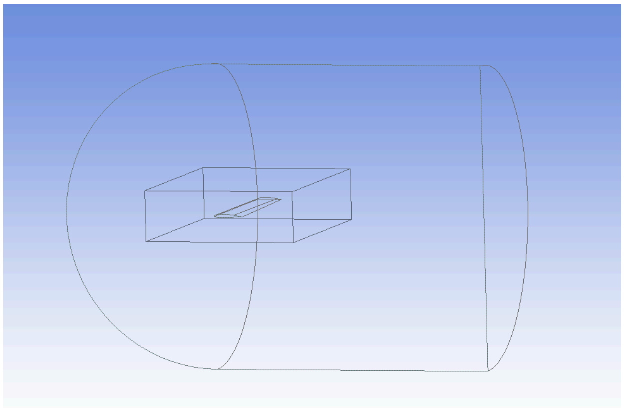


Figure 16: Airfoil enclosed in "frozen" and fluid geometry.

Next, the mesh was created. Using the geometry, and importing the different shapes into ANSYS Meshing, the Mesh was created using appropriate parameters to allow for the most accurate meshing, while also not exceeding the student limitations. See below for visualization.

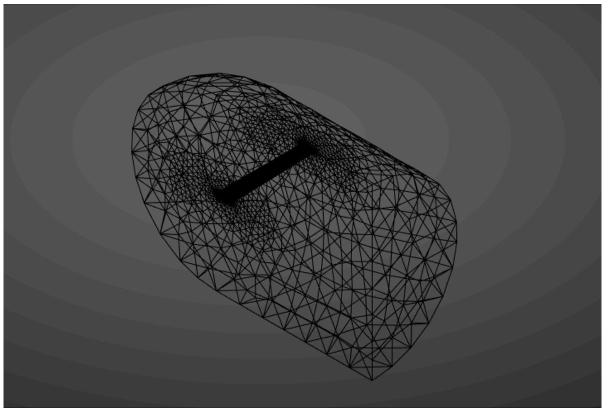


Figure 17: Meshing Software result, Resulting in less than 512,000 nodes.

Finally, the mesh can be imported into ANSYS Fluent, where the boundary conditions can be set. For the entrance, exit, and far side, the boundary of “pressure far field” boundary conditions. For the close wall, the “symmetric” boundary was used, and for the wing surface and tip, the “wall” condition was used. Velocity data is imported in terms of mach number and velocity specification, and the unit vector is adjusted in order to account for different angles of attack. Also, drag and lift forces are measured by creating report definitions of forces. See below for graphs collected for one single blade at 0 degree angle of attack.

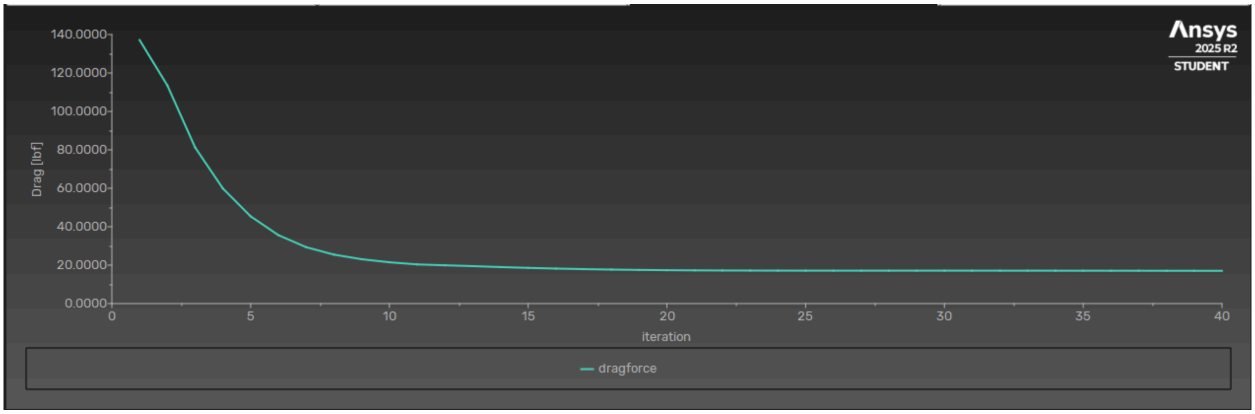
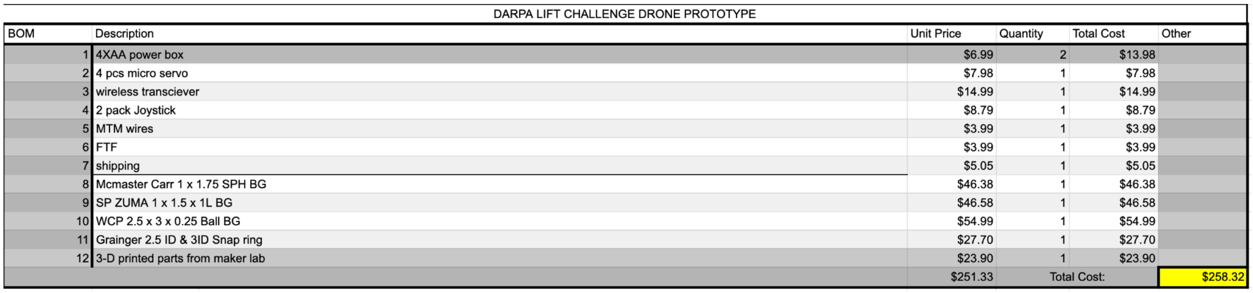


Figure 18: Display of Drag force of rotor at a zero degree angle of attack.

9.4 Appendix D: Prototype BOM

This Bill of Materials corresponds to the prototype used for demonstration and validation of the design. Lower-cost and readily available components were selected to allow for fast assembly and reduce development cost. The prototype helped illustrate the design that will be incorporated into the final system.



DARPA LIFT CHALLENGE DRONE PROTOTYPE

BOM	Description	Unit Price	Quantity	Total Cost	Other
1	4XAA power box	$6.99	2	$13.98	
2	4 pcs micro servo	$7.98	1	$7.98	
3	wireless transciever	$14.99	1	$14.99	
4	2 pack Joystick	$8.79	1	$8.79	
5	MTM wires	$3.99	1	$3.99	
6	FTF	$3.99	1	$3.99	
7	shipping	$5.05	1	$5.05	
8	Mcmaster Carr 1 x 1.75 SPH BG	$46.38	1	$46.38	
9	SP ZUMA 1 x 1.5 x 1L BG	$46.58	1	$46.58	
10	WCP 2.5 x 3 x 0.25 Ball BG	$54.99	1	$54.99	
11	Grainger 2.5 ID & 3ID Snap ring	$27.70	1	$27.70	
12	3-D printed parts from maker lab	$23.90	1	$23.90	
		$251.33	Total Cost:		$258.32

Table : Prototype Bill Of Materials