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Urban Cargo Transport UAV Final Design Review

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ISYE 4803: Urban Cargo Transport UAV Final Design Review

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Executive Summary:

Delivery of goods to homes and offices over the last decades has seen a significant increase as more people and businesses need or want items sent directly to them. With the increase in demand, technology has also experienced a rapid growth, specifically in the field of unmanned aerial vehicles (UAVs). Many major companies are currently researching UAVs as the future of their delivery operations.

With this ever-growing demand, NASA has issued a design competition of a UAV developed for urban deliveries. This unmanned aircraft system (UAS) would need to be able to deliver small packages, in a timely manner, within the city they operate. They must be able to drop off two lightweight packages to destinations without human intervention. They must be safe for the citizens of the cities they operate in and output low levels of sound as to not add to the noise pollution (4.4 Design Requirements and Specifications:).

Various areas of development needed to be considered and analyzed. The UAV body has fixed wings with a boom-tail design and a multi-rotor configuration for the motors (Figure 7). The body of the aircraft underwent analysis in SolidWorks to gather data of its aerodynamics (5.3 Computational Fluid Simulation). With this analysis, the MH-83-iL airfoil was chose to best suit the needs of this craft (3.2.1 Main Airfoil). Through wing loading analysis, NRT's UAV would be able to fly at cruising speed of 27 knots and have a 0.08 thrust.

Other aspects to consider included control systems, budgetary analysis, and government regulations. Controls systems provide data and insurance for collision avoidance, altitude readings, thermal sensors, and GPS guidance. These systems as well as a safety parachute allow for maximum performance and precaution to help integrate it into urban life. The cost of the aircraft (4.7 Budget) comes out to roughly $1700 given our required body, systems, and propulsion systems. Lastly, government regulations with the Federal Aviation Administration (FAA) provide guidelines for registering and flying UAVs in urban environments. Working closely with the FAA would be required to ensure all federal laws are abided by.

The development of and advancement of the urban air mobility (UAM) can provide a more efficient and cost-effective means of delivering packages for companies throughout the nation. This can be achieved with computational and budgetary analysis that best optimize UAV, along with proper safety and government regulations, for company use.

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Chapter 1: Introduction:

This paper represents the Kennesaw State University NTR team's design and development of an Unmanned Arial Vehicle for a delivery service in urban environments, in response to the 2019-2020 NASA Aeronautics University Design Challenge: Urban air Mobility competition. Where a solution for a hub centered aerial unmanned package delivery system will be proposed and designed.

Traditionally delivery designs have a cumbersome, human managed logistic and mechanics that reduces their chance for success and effectiveness when moving packages around city and urban areas. The proposed solution involves a hover efficient aircraft that will utilize a platform for take-off and landing and can be in a normal urban or suburban environment. The craft will be able to manage agitated weather conditions while maintaining safety as paramount with significant crash avoidance and reliable. In addition to propulsion and safety electronics the aircraft will feature connectivity with FAA in order to coordinate delivery logistics and comply with aviation regulation, increasing the effectiveness of the project due to its compliance with this regulation for use in more dense and populated areas of cities. Aerodynamics performance will be developed for an optimum during the cruise segments of the flight mission, reducing power consumption and increasing range.

In the industry companies like DJI drones have developed technologies that reduce the effort that is involved in taking flight and have set a market standard for what is expected from drone use. But the ease of DJI drones does not reflect in the realm of delivery service drones simple because most commercial drones do not carry consumer products and do not have to meet demand or deadlines like a consumers expect from the companies that they purchase from. NTR Aero will ensure that these demands are met with an unmanned aircraft sample in where an efficient aspect ratio will be utilized, all FAA requirements for aircraft to tower communications will be met, and efficient launch and takeoff runway also designed for its implementation.

Chapter 2: Project Information

2.1 Overview:

The field of Urban Air Mobility (UAM) is due to see a large increase of implementation in the next 15 – 20 years as companies look to deliver their goods quicker and more precisely across cities. In recent 2019 study it is said that the UAM market is expected to generate over $5 billion in 2023 alone and follow with a compound annual growth rate of 26.2 % [1]. These UAS have a great potential when working with other larger cargo vehicles that will them form a strong network system that will deliver goods to consumers directly. In the Unites States we benefit from our own federal established shipment company, called the United States Postal Service. They are responsible for sorting over 700 million parcels per day within our borders [Freedman, D.H., (2013) Layer by Layer. Technology Review (2010)115: 50-53] and with its already established network they could benefit from the upcoming technology that Unmanned Aircraft could offer as they try and increase their delivery output. Online retailers will be leading the push for further UAM implementation throughout the world as it helps increase deliveries rates. UPS, Alphabet (Parent to Google), and Amazon all look to increase aerial deliveries [2].

Government agencies are also looking to increase deliveries through urban air space. NASA expects that by the year 2030, 1.25 billion services and packages will be delivered by air per year. They are working with the Federal Aviation Administration (FAA), governments, universities, and developers to help face the challenges needed to be handled to implement UAM more broadly [3].

As a part of this expected growth, they have issued a design challenge to university students to build an unmanned aircraft system (UAS). The goal is to create a UAS that is reliable, profitable, low-noise, and autonomous. Some of the general design criteria include (but are not limited to) no harm to personnel or assets on the ground, on-board communication system, on-bard “detect & avoid” system (DAA), and system must be able to launch a UAS every 2 minutes. Other parameters are outlined by a general design criterion and expected vehicle performance [4].

2.2 Objective:

The objective of this design project is to develop a business case for a UAS to deliver packages to urban environments in a specified (see requirements below) time and range. The unmanned aircraft will be able to deliver goods in the form of a package that can weight up to 5 pounds and meet specific shape criteria for ease of transport. Also, a low noise propulsion system and robust communications system will be installed to reduce the chance of collision and increase efficiency of operations.

2.3 Concept:

Unmanned aircraft systems can provide a means of getting packages delivered to areas in urban environments that have high volumes of traffic. A 10-mile commute in the city of Atlanta, for example, can range from 15 to 60 minutes depending on the time of day. A delay such as this one can result in devastating results depending on the nature of the delivery. Traffic delays and other external sources of interruption cause ineffective methods and unreliable deliveries for consumers, when the combination of mass logistic cargo and Unmanned Aerial System like this are combined, we remove the most complicated delivery trajectory.

2.4 Project Background:

Time has introduced a lot of innovation in the aerial field, driving the cost of deliveries and transportation a lot closer and even lower to the compared service with normal methods including human interaction. Having the system dominated by programmed devices reduces the manpower required and increases the efficiency overall by reducing the error and delays. In the past trials have been performed and deployed to introduce a similar solution but have not been successful in competing with the stablished reliability and compliance that manned delivery and consumer goods shipment can offer. The Federal Aviation Administration played a major role in the absence of these systems in local environments, due to the lack of regulation consideration. The rules in place for aircraft flight around human dense environments has been stablished and systems need to abide these guidelines with robust systems that promise almost no error with redundancy incorporate in the case of faults.

2.5 Problem Statement:

Currently, delivery methods require a significant logistical contribution in order to deliver small packages effectively to small volume clients. With the increase of online purchases and increase of vehicles in public roads, reduced delivery times and customer satisfaction is paramount and can be increased by the addition of an Unmanned Aircraft Delivery Network.

Chapter 3: Configuration

Unmanned Aircrafts have been utilized for many purposes in the past before; on June 11, 1948 the National Aeronautics and Space Administration utilized a V2-Blossom high capacity rocket to send a monkey into outer space [5]. This aircraft was unmanned at the time of its voyage and it was able to return and bring back valuable information that helped man reach the moon. All the controls and other computational flight analysis was done with some to little computational capability. Although this design was successful the National Aeronautics and Space Administration also counts with a yearly budget of almost $26 billion dollars [6], therefore, making it unaffordable for the common people.

A cost analysis study conducted at the University of Tennessee showed that a single package delivery by a driver can cost 6 times more than a single package delivery by a drone. The driver costing roughly $1.20 per package delivered and the drone costing $0.20 per package delivered [7].

Certain design variations will be ideal for the task at hand; therefore, they should be explored. Fixed wing, rotor craft and tiltrotors cover most people think of when they think aerial travel platforms or anything that flies. These four designs offer us the fundamental combinations of various aeronautical layouts that our design can simulate and implement.

The Technique for Order Preference by Similar to Ideal Solution or TOPSIS will be the tool used to blend the strengths that our design will feature. Based in our weighted design priorities we will determine the best form our craft will have to conform to complete the desired mission. To explore configurations, we selected four aircrafts that fit our top chosen platforms, the AAI RQ-2 Pionner a fixed wing UAV used by the US NAVY, the MQ-8 Fire Scout UAV helicopter, and the Bell Eagle Eye a tiltrotor which was then used to the design the V22 Osprey to be compared in the by the categories displayed in Table 1.

	Fuel Efficiency (mi/US-Gal)	***Weight (lbs.)***	***Distance (mi)***	***Cost***	***Power (KW)***
AAI RQ-2 Pioneer	**8.30**	**452**	**100**	**10**	**19**
MQ-8 Fire Scout	**1.92**	**2073**	**110**	**5**	**313**
Bell Eagle Eye	**1.23**	**1300**	**110**	**5**	**478**

Table 1: Data Matrix

We selected the following categories based on what we considered would have the largest impact and will pay the larges dividends if we achieved. Fuel efficiency will ensure that we are able to achieve our determined flight range of 10 miles to the destination and back. This was measured using the allocated range for the aircraft selected and then divided by the manufacturer stipulated range per the full tank. Weight of the aircraft has a tremendous effect in the dynamic of the aircraft, fundamentally it can pay an exponential benefit, when reduced it will increase the distance the craft can travel and reduce the power needed. Cost is scored base in the total infrastructure for the type of aircraft; therefore, the length of runway and other necessary equipment was accounted for in its allocation.

Following, a prioritization matrix was constructed (Table 2), this allowed the team to see some of the most important categories that will need to be met in the design. These were selected based on the needs and goals set before the team. When weighted amongst each other we can select and understand what out of all the goals should be targeted in contrast to the other goals. This was an important step because it orients our resources to achieve the priorities of the team.

	Fuel Efficiency (mi/US-Gal)	***Weight (lbs.)***	***Distance (mi.)***	***Cost***	***Power (KW.)***	***Raw Total***	***Weighted Total***
Fuel Efficiency	0.0	2.0	2.0	0.5	1.0	5.5	0.2
Weight	0.5	0.0	0.5	3.0	3.0	7.0	0.3
Distance	0.5	2.0	0	0.5	2.0	5.0	0.2
Cost	2.0	0.3	2	0.0	3.0	7.33	0.3
Power	1.0	0.3	0.5	0.33	0.0	2.17	0.08
					Grand Total	27.0	

Table 2: Prioritization Matrix

	Closeness to Ideal
AAI RQ-2 Pioneer	**0.688708**
MQ-8 Fire Scout	**0.332845**
Bell Eagle Eye	**0.407394**

Table 3: Final Rankings of Each Craft

Our TOPSIS final ranking shows that based in the initial design criteria, the fixed wing form will achieve the most of requirements. But we understand that there is a limitation that was not reflected in this technique as the quantification is difficult, due to the runway size for a fixed wing is significantly larger than all the others. Large urban environments are not apt for the construction of runways, even when allowed in certain parts of the world there is the risk of strike with neighboring buildings and structures. Following fixed wing is the tiltrotor which does the ability for vertical takeoff, therefore, reducing the runways length and cost to a faction of the fixed wing. Finally placing the MQ-8 last in proximity to our set goals, this is in part due to their efficiency in forward flight and consideration for complexity of the single rotor design.

Still, to achieve a 10-mile travel range in 20 minute, climb and descend 400 feet after 1 mile from takeoff and when approaching landing and be able to cruise between 400 and 500 feet, like shown in Figure 1, even in adverse weather our design will must adapt from the top two variations. TOPSIS helps us solve the configuration features our design will inherit from the considered variations, we now understand that the UAV will have to feature a fixed wing layout and also the ability to take off vertically; while not doing it by tilting its rotors as this seems to fall far from our desired goals for this project.

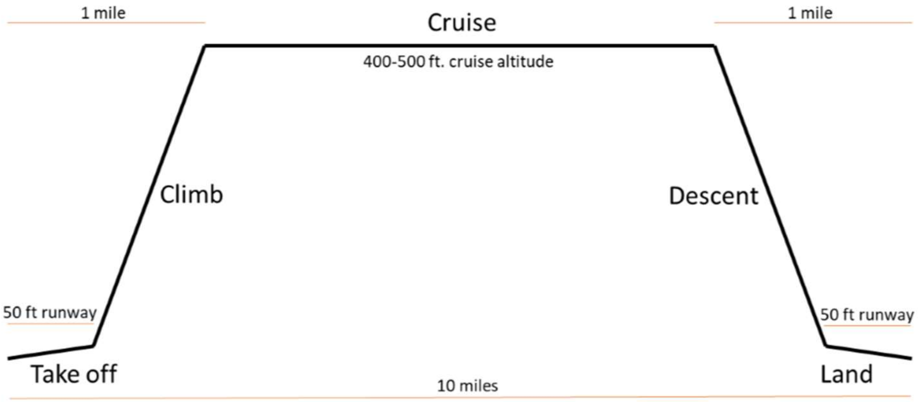
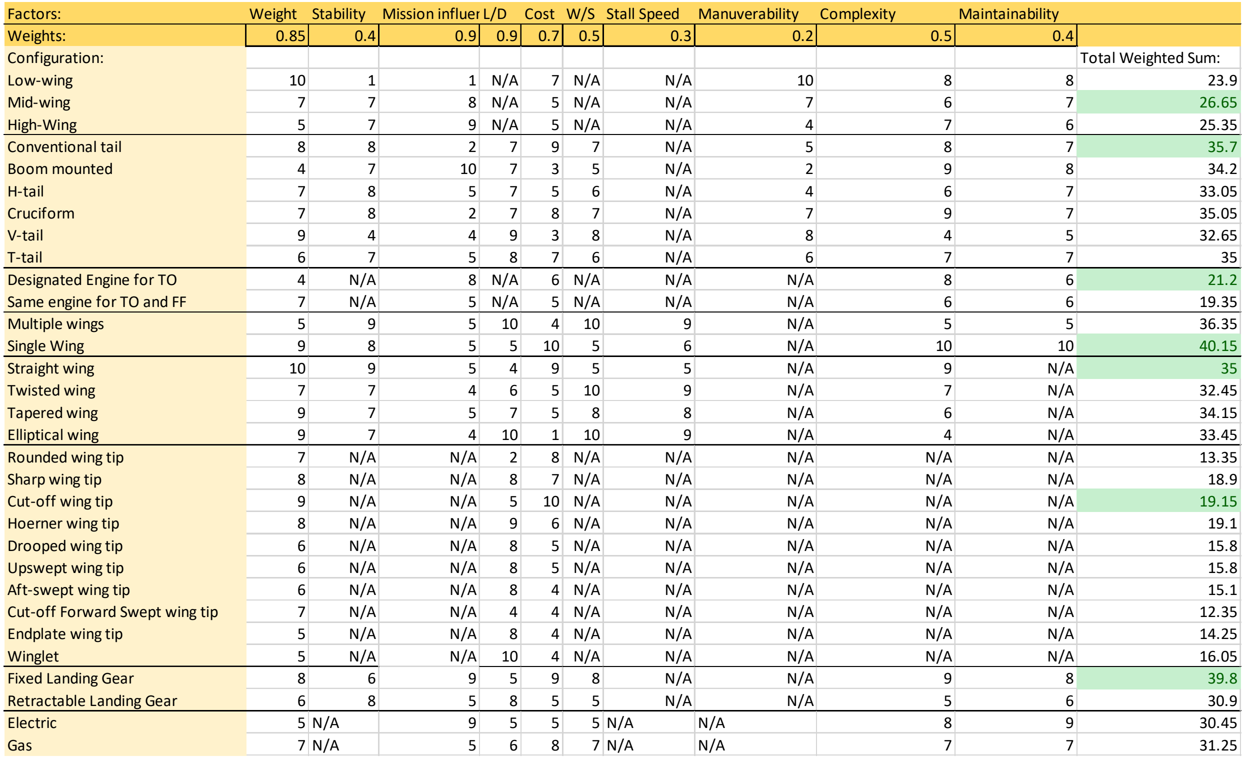


Figure 1: Mission Profile

3.1 Design Constraints and Selection:

The objectives for our craft have been studied and stated as an overall success criterion. But personal design constraints include mechanical simplicity, efficiency, redundancy, modular, and reduce cost after a balance has been struck. A simplified decision matrix was created to weigh potential design solutions of the UAV and how each one will affect several criteria such as performance, cost, complexity and mission influence.



Factors:	Weight	Stability	Mission influer	L/D	Cost	W/S	Stall Speed	Manuverability	Complexity	Maintainability	
Weights:	0.85	0.4	0.9	0.9	0.7	0.5	0.3	0.2	0.5	0.4	
Configuration:											Total Weighted Sum:
Low-wing	10	1	1	N/A	7	N/A	N/A	10	8	8	23.9
Mid-wing	7	7	8	N/A	5	N/A	N/A	7	6	7	26.65
High-Wing	5	7	9	N/A	5	N/A	N/A	4	7	6	25.35
Conventional tail	8	8	2	7	9	7	N/A	5	8	7	35.7
Boom mounted	4	7	10	7	3	5	N/A	2	9	8	34.2
H-tail	7	8	5	7	5	6	N/A	4	6	7	33.05
Cruciform	7	8	2	7	8	7	N/A	7	9	7	35.05
V-tail	9	4	4	9	3	8	N/A	8	4	5	32.65
T-tail	6	7	5	8	7	6	N/A	6	7	7	35
Designated Engine for TO	4	N/A	8	N/A	6	N/A	N/A	N/A	8	6	21.2
Same engine for TO and FF	7	N/A	5	N/A	5	N/A	N/A	N/A	6	6	19.35
Multiple wings	5	9	5	10	4	10	9	N/A	5	5	36.35
Single Wing	9	8	5	5	10	5	6	N/A	10	10	40.15
Straight wing	10	9	5	4	9	5	5	N/A	9	N/A	35
Twisted wing	7	7	4	6	5	10	9	N/A	7	N/A	32.45
Tapered wing	9	7	5	7	5	8	8	N/A	6	N/A	34.15
Elliptical wing	9	7	4	10	1	10	9	N/A	4	N/A	33.45
Rounded wing tip	7	N/A	N/A	2	8	N/A	N/A	N/A	N/A	N/A	13.35
Sharp wing tip	8	N/A	N/A	8	7	N/A	N/A	N/A	N/A	N/A	18.9
Cut-off wing tip	9	N/A	N/A	5	10	N/A	N/A	N/A	N/A	N/A	19.15
Hoerner wing tip	8	N/A	N/A	9	6	N/A	N/A	N/A	N/A	N/A	19.1
Drooped wing tip	6	N/A	N/A	8	5	N/A	N/A	N/A	N/A	N/A	15.8
Upswept wing tip	6	N/A	N/A	8	5	N/A	N/A	N/A	N/A	N/A	15.8
Aft-swept wing tip	6	N/A	N/A	8	4	N/A	N/A	N/A	N/A	N/A	15.1
Cut-off Forward Swept wing tip	7	N/A	N/A	4	4	N/A	N/A	N/A	N/A	N/A	12.35
Endplate wing tip	5	N/A	N/A	8	4	N/A	N/A	N/A	N/A	N/A	14.25
Winglet	5	N/A	N/A	10	4	N/A	N/A	N/A	N/A	N/A	16.05
Fixed Landing Gear	8	6	9	5	9	8	N/A	N/A	9	8	39.8
Retractable Landing Gear	6	8	5	8	5	5	N/A	N/A	5	6	30.9
Electric	5	N/A	9	5	5	5	N/A	N/A	8	9	30.45
Gas	7	N/A	5	6	8	7	N/A	N/A	7	7	31.25

Figure 2: Decision matrix for design constraints

3.2 Airfoils:

This component is at times considered the heart of the plane. Because of its unique geometry this device is responsible for most of the lift generated in small aircraft. Choosing an efficient one, depends on the definition of such efficiency. In our mission we are interested in the ability to cover the most mileage with the least power consumption. Gliders do this very well, designer Steve Pearson says, "the world distance record is 475 miles from point of release, to where it landed 11 hours later, and I believe it can be beaten [8]." Although most do not have a source of propulsion, gliders, take the shape of a long span fixed wing aircraft which we are interested in.

3.2.1 Main Airfoil

We compared four types of airfoils from gliders and from fixed wing aircrafts as shown in Table 4.

	NACA 63-415	**Ranking**	**MH83-iL**	**Ranking**	**NACA 64-418**	**Ranking**	**FX 61-184**	**Ranking**
cl at α=0	0.3226	5	0.4481	10	0.3112	2.5	0.4321	7.5
cd at α=0	0.0137	10	0.0165	5	0.01636	7.5	0.02239	2.5
Max Cl	1.3433	2.5	1.8047	10	1.398	7.5	1.3742	5
Stall α	15.25	7.5	14.75	10	17.25	5	19	2.5
α at max Cl	7.25	7.5	6.5	10	8.75	2.5	8.5	5
cl/cd	75.56	10	59.1	2.5	69.32	5	69.47	7.5
Total (50 max)		42.5		47.5		30		30

Table 4: Comparison of four types of airfoils from gliders and fixed-wing aircrafts

MH-83-iL was chosen due to its features and after being compared and judged against the following criteria

a. Highest Cl at α
b. Lowest Cd at α
c. Maximum Cl
d. Stall α
e. α at max Cl/Cd
f. Cl/Cd

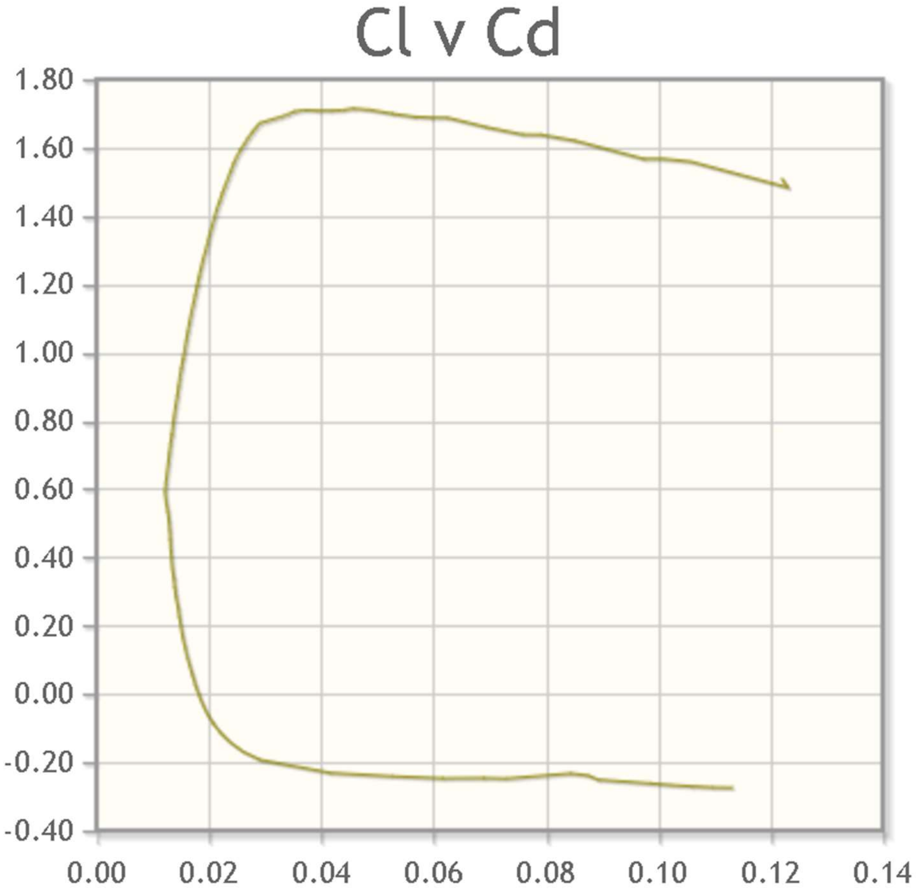


Figure 3: Coefficient of lift vs coefficient of drag

3.2.2 Wing Geometry Calculations

The major factors when determining wing geometry of the aircraft is, the referenced wing area, aspect ratio, wingspan, and wing loading. A reference wing area (S) is first calculated to be approximately 2.92 ft^2 using a starting weight estimate of 35 lb. Wing loading can be initially based on historical data [9].

$$S = \frac{W}{\left(\frac{W}{S}\right)}$$

Using an aspect ratio as 6, wingspan is calculated as approximately 4.18ft using the following equation

$$b = \sqrt{A \cdot S}$$

Desired chord length was calculated to be 1.39 ft. No wing taper was considered and as such mean chord length is also 1.39 ft.

$$C\ root = 2 \cdot \frac{S}{[b(1+\lambda)]}$$

Where λ is taper ratio

3.2.3 Tail Airfoil:

Tail Airfoil geometry varies vastly due to performance that is expected from the component of the plane. This part is used mostly as a control surface, therefore, lift generation is not as desired as it is from the main wings. The NACA 0012 was used for the control surfaces due to its historical data and vast use in light sports aircrafts for their control surfaces [10]. Aircraft like the 1977 produced Cessna 120 to the current Skyhawk, which are a single engine propeller engine aircraft utilize the 0012 airfoil effectively. It is chosen for its symmetrical camber line and great characteristics in subsonic flights. In an Autodesk Simulation CFD External Airflow Validation of the NACA 0012 Airfoil, it was shown that this airfoil shows great lift characteristic for every angle of attack starting from zero lift at α=0, stalling at α=14.75 degrees. Allowing the stall of the main airfoil earlier than the tail in order to prioritize safety and continue to control the aircraft even after a case of stall.

3.2.4Wing Sweep:

The configuration for the airfoil will not include any intricate geometry. Sweep was not introduced in its design due to the considered low speeds that would need to be reached in the design of this unmanned craft, as the sweep angle primarily reduces the structural and parasitic drag wings can produce in transonic flights or greater. [Book 4.3.2] We will not experience such speeds, when compared to UAV like the Parrott Disco reaches speeds above 50mph and weighs in at 26oz [11], does sweep its wings back because of the increased agility and overall lightweight characteristics. ZipLine a UAV utilized for medical payload drop off in Rwanda Africa [12]. Weights about 60lbs and holds the record for longest UAV delivery flight utilizes no sweep for its wings while carrying a payload of 4lbs [12]. Parrot's Disco carries no payload and does not prioritize endurance in its flight mission like ZipLine's UAV.

3.2.5 Aspect Ratio:

This characteristic will be incorporated in the design do its gain in efficiency. A long skinny wing (high aspect ratio) has less drag for a given lift than a short, fat wing (low aspect ratio). [9] For initial wing geometry sizing and aspect ratio of 6 was chosen. This was based on historical data and the desired flight characteristics of a high aspect ratio aircraft.

3.2.6 Wing Tips:

Validating simplicity and efficiency, it was decided to include cutoff wing, where the airfoil has no shape at each of the tips will be incorporated. Most of the now low-drag wing tips use some form of sharp edge. In fact, cutoff tips offer less drag than a rounded tip, due to the sharp edges where the upper and lower air meet [9]. More complicated wing tips could have been chosen to further decrease tip vortices however cut-off was determined to be best suited for its low cost in design and manufacturing.

3.3 Tail Arrangement:

Decision matrix analysis compared several tail configurations. Tail arrangements that were considered included: conventional tail, boom mounted, H-tail, cruciform, V-tail, and T-tail. The conventional tail and cruciform tail were the two highest rated configurations when considered for weight, cost and stability. However, given other design characteristics factor into the design of the UAV, the boom-mounted tail was heavily favored. For a pusher propeller type engine, a boom-mounted tail was considered optimal. Additional with the desire to use additional motors for vertical takeoff, the boom-mounted tail provided additional area for motors and props to be placed.

Modularity in our design will depict the ability to be able to remove and replace components in the UAV without much redesign or extensive disassemble. The rear empennage, if complex can depict a complicated cumbersome repair when damaged. A boom-mounted tail will allow for modularity to take place sue to its simple fixture to the rest of the craft. Although heavier than the usual due to its modularity and benefit for a pusher propeller it has been chosen [9].

Initial sizing estimates of the tail was done by taking historical data of similar sized aircrafts [9]. Sizing of tails are proportional to wing size, are compared using horizontal and vertical tail volumes.

$$S_{VT} = \frac{c_{VT} b_W S_W}{L_{VT}} = 0.222\ ft^3$$

$$S_{HT} = \frac{c_{HT} \bar{C}_W S_W}{L_{HT}} = 0.616\ ft^3$$

Where:

$c_{HT} = 0.50$ and $c_{VT} = 0.40$ are vertical and horizontal tail coefficients chosen from historical data.

b_w is wing area

$\bar{C}_W$ is mean wing chord

And S_W is wing area

3.4 Propulsion:

A tractor setup on an aircraft places the propeller in the front of the aircraft, essentially pulling the air towards it. This design is very common on most propeller aircraft, including turboprop larger aircraft. This is mainly due to the higher thrust efficiency that this set-up can produce as the propeller faces the laminar airflow on the entire surface with no obstruction as in (Figure 4). Although we will utilize a propeller to power the UAV and generate propulsion, it will feature a pusher set up. Pushers place the motor in the front of the propeller and pusher the air back towards the back of the craft as shown in Figure 5. It is less efficient due the surface of the propeller being covered by a portion of the engine or fuselage structure. Our design will demonstrate a pusher, although less efficient in thrust, this setup does increase the laminar flow and exposed surface of the airfoils and controlled surfaces [13]. This will result in an increase lift efficiency of the main wings as a tradeoff.

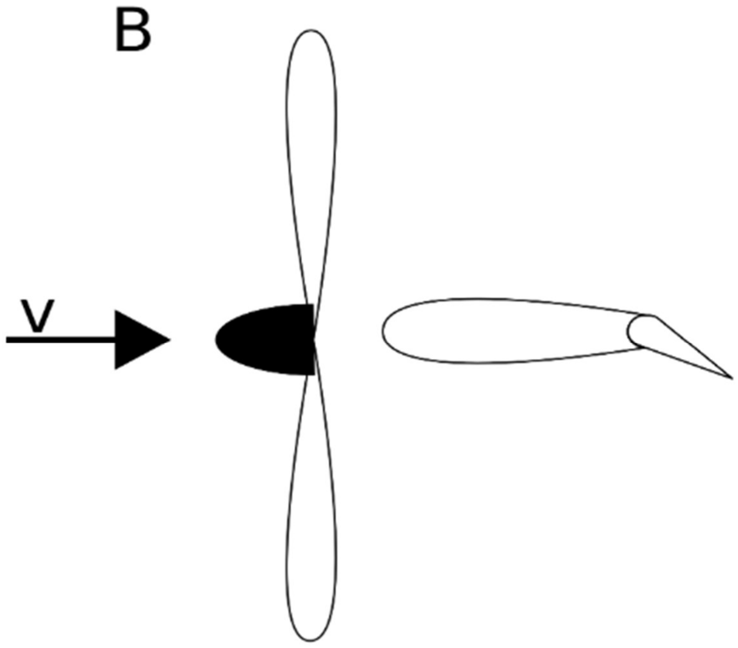


Figure 4: Tractor Setup

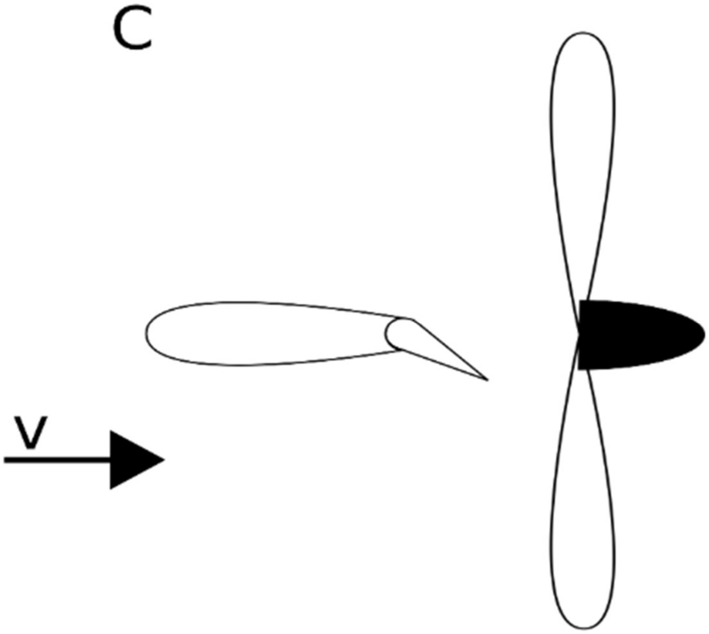


Figure 5: Pusher Setup [14]

3.5 VTOL Configuration:

VTOL stands for Vertical Takeoff and Landing. VTOL capabilities allow aircraft to have the configuration of a normal fixed wing aircraft but at the same time be able to takeoff vertically. Our design will feature a multi-rotor set up with tractor propellers, built in redundancy with four motors will allow the craft to continue to fly even when some of the rotors are damaged or not working. Forbes magazine published on this subject, comparing the single rotor helicopter to a multi-rotor. Although less efficient and harder to control, multi-rotors are cheaper to manufacture and built [15]. Because of the inefficiency of rotorcrafts in forward flight we will use a pusher motor to transfer the UAV to forward flight [15]. Only using the rotors for takeoff and landing and in the case of emergencies in forward flight to continue in the air.

3.5.1 Multi-rotor Configuration:

Arial photography and video recording has commercialized the VTOL style for hobbyist use and photographers. Companies like DJI base their whole product line on this style, reducing the cost of manufacturing because of its popularity. There are different types of arrangements that VTOL that can use and be effective. Depending on the endurance, lift power, and at times safety.

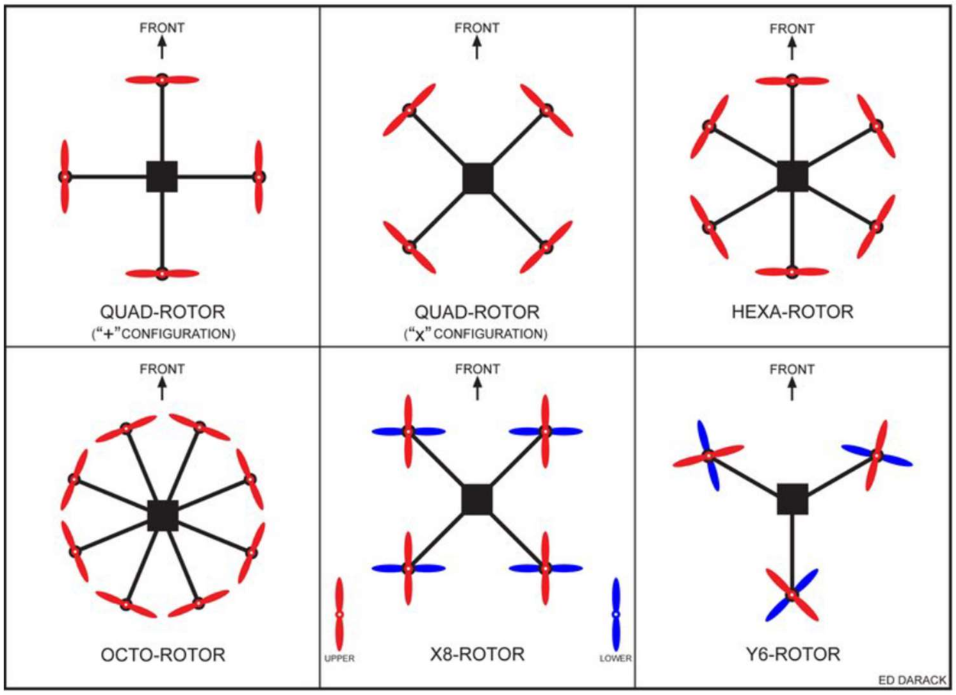


Figure 6: Various rotor configurations

Figure 6 curtesy: Camilli, Luis. (2015). Emerging technologies, applications, regulations, and market challenges in the consumer aerial drone industry: A strategic analysis of the 3D Robotics Business Model.

Figure 6 shows some of the different types of configurations that are used in industry for various types of drones. In these examples none of the configurations have an odd number of blades, this is because of when there is an odd number setup the level of program complexity increases. The drone has a higher chance remaining in flight when there is an even number of rotors.

Having more rotors can increase the stability and reduce the control complexity of the design. But too many can also see increase overall complexity and cost. Table 5 shows what happens when the balance of increasing the rotors is met. Each of the UAVs mentioned are made by the same manufacturer. As the rotors increase, we can see an immense increase in price from the quadrotor to the hexa-rotor. This is not stablished as a rule but seen more of a prediction. Due to the idea that you will always strike a balance between your design goals, therefore, having more is beneficial when increasing your payload is your main goal at no cost. Also, here we can see that the increase in rotors reduces our Max Velocity, something our team is not interested in.

Drone	Configuration	Weight (lbs.)	Max Velocity (m/s)	Flight Time (Min.)	Cost
DJI Inspire	Quad	4.2	26	27	$2,600
DJI AGRAS T16	Hexa	40.5	10	10	$15,000
DJI MG-1P	Octo	24.8	7	9	$12,000

Table 5: Drone Configuration Analysis

We have chosen the Quadrotor design due to its ease of control, low production cost and balance that it strikes. We think that this will provide the necessary endurance to lift our craft and reduce the overall complexity.

3.5.2 Motor Selection:

Two sets of motors have to be selected for the aircraft. Four motors to operate synchronously during vertical takeoff/landing, and 1 main motor for the pusher propeller during cruise. Because of the relatively small size of the UAV, traditional RC UAV designated motors were considered.

KDE Direct manufactures both quadcopter electric motors and RC-helicopter motors. To select a main motor, historical power-to-weight ratio’s for general aviation single engine aircraft can be used as target ratios that can be used for comparison. A general aviation single engine aircraft would have typically, 0.07 hp/lb while a twin engine would have 0.17 hp/lb. [9] The max continuous power given in the motor specifications by the manufacturer, can be divided by the takeoff weight to get an approximate take off power-to-weight ratio.

Motor	Max continuous output (hp)	P/W (hp/lb)	Price
KDE600XF-1100-G3	4.47	0.13	$207.95
KDE600XF-530-G3	5.24	0.15	$229.95
KDE700XF-505-G3	9.65	0.28	$330.95

The KDE600XF-1100-G3 was chosen to due to its lower cost and it being able to match historic (P/W) ranges of other aircraft. Max power continuous power would only be necessary during the initial climb/cruise of the mission. Actual power used during cruise will be lower than takeoff.

Power required for vertical takeoff can be computed using: [9]

$$P_{climb} = \left[\left(\frac{fW}{M}\sqrt{\frac{\frac{fW}{S}}{2\rho}}\right) + \frac{WV_{climb}}{2}\right]\left[\frac{1 + \frac{P_{tail\ rotor}}{P_{rotor}}}{\eta_{mechanical}}\right] = 1085.32W = 1.45\ HP$$

Where *f* = 1.03 is an estimated adjustment factor for downwash on the fuselage.

S = is the rotor disk area which is divided amongst four 8-inch rotors

Ptail/Protor is assumed as unity

$\eta_{mechanical}$ = 0.85.

V_{climb} = 23 mph

M = measure of merit assumed to be 0.7

Because the takeoff power will be split between four motors the required output power of each motor should be less. The KDE2315XF-2050 brushless motor for multi-rotor UAVs was selected due it max continuous power output of 0.7hp per rotor, with it being able to output 0.38 hp per rotor at 75% throttle. [16] This equation can be used to calculate power to hover as well with the aircraft requiring only 0.6 hp for hover.

Motor	Power output at full throttle (hp)	Pclimb	Price per motor
The KDE2315XF-2050	0.75	1.45	$60.95

3.6 Control systems:

3.6.1 GPS Systems:

Positioning of the UAV is an aspect of the controls systems that will be the primary focus. It is crucial for the primary objective of the craft, to be able to deliver packages to its destination with optimal accuracy. GPS systems are listed below (Table 6) with their dimensions and specifications. The GPS chosen for the UAV was the Adafruit Ultimate GPS. This system has a refresh rate of 10 Hz per second providing accurate position of the drone at all time. It also can monitor heights of up to 160000 ft (cruise altitude of NRT UAV to be 400 -500 ft). The Ultimate GPS also allows for an external GPA antenna for more remote capabilities [17].

	Size (mm^3)	Weight (grams)	Temperature Range (C°)	Cost (USD)
uBlox	5 X 5 X 0.59	N/A	-40 to 105	39.99 to 179.00
Adafruite	40 X 25.4 X 6.8	8.1	N/A	39.95
Holybro	26 X 53 10.7	N/A	N/A	39.00

Table 6: Comparison of various GPS systems

3.6.2 Collision Avoidance:

Avoiding obstacles would a primary safety goal of the project to ensure not only property damage but, more importantly, no harm to life. The main types of collision avoidance include stereo vision, ultrasonic sensors, and proximity sensors [18]. The one that was chosen for the UAV is the Connex Falcore Sonar Sensor (not listed) [19].

	Type	Weight (grams)	Cost (USD)
Omron D6T44L06	Collision Detection	N/A	$17.46
RPLidar A1M8	360 View Laser Scanner	190	$99.00
Adafruit BMP085	Altitude and barometric sensor	N/A	$19.95
Boson 320	Thermal Camera	7.5	$1280.00
Omron D6T44L06	Infrared Thermal Sensor	N/A	$63.95

3.6.3 Temperature Sensors:

The temperature/humidity sensors that were compared for this drone are listed below (Table 7). This would be another important system as to assure the craft does not take on too much water or find itself in unfavorable temperature conditions. The one chosen for this UAV is the Adafruit HTSs221. This sensor can read temperature ranging from -40 to 120° C and can measure humidity from 0 -100% rH (relative humidity) It also has a sensitivity of 0.0004% and can connect with computers such as Arduino and Raspberry Pi [20].

	Size (mm^3)	**Weight (grams)**	**Temperature Range (C°)**	**Cost (USD)**
AdafruitHTSS221	N/A	N/A	-40 to 120	$6.95
Adafruit DHT22	27 X 59 X 13.5	2.4	-40 to 80	$9.95

Table 7: Comparison of various Ttemperature sensors

Chapter 4: Design Configuration

Our team has configured the design to meet some of the goals. We know that our design would have to incorporate the use of fix wings due to its efficiency in forward flight. The design we have achieved is shown in Figure 10 - Figure 10.

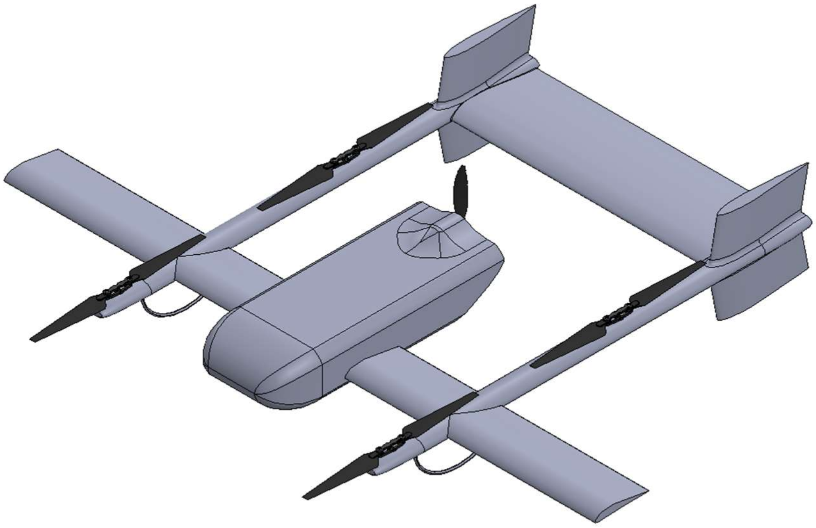


Figure 7: SolidWorks Model of NRT UAV craft (isometric view)

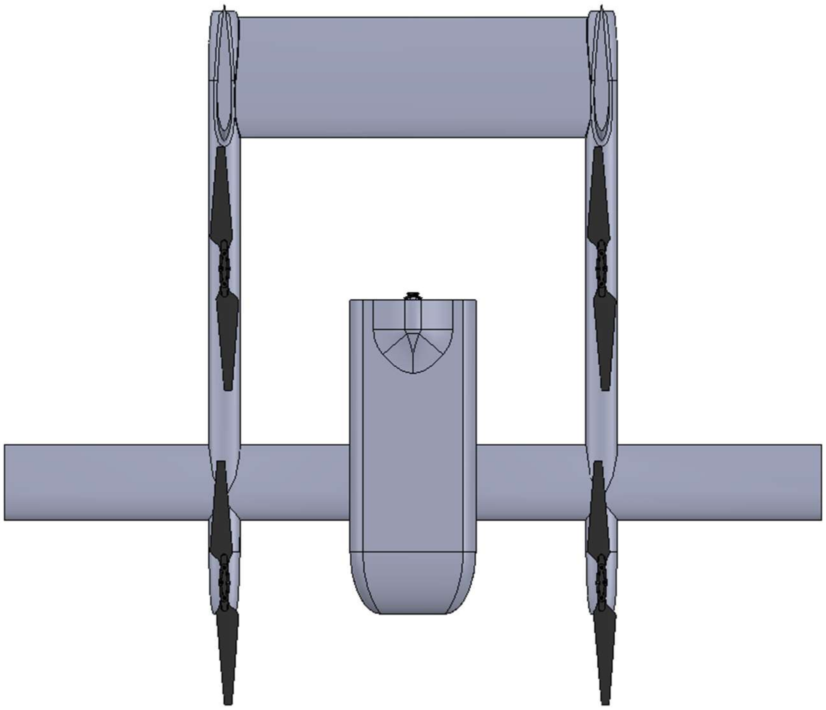


Figure 8: SolidWorks Model of NRT UAV craft (top view facing down)

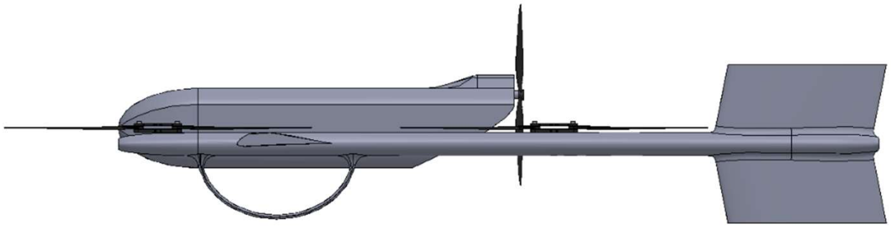


Figure 9: SolidWorks Model of NRT UAV craft (side view facing left)

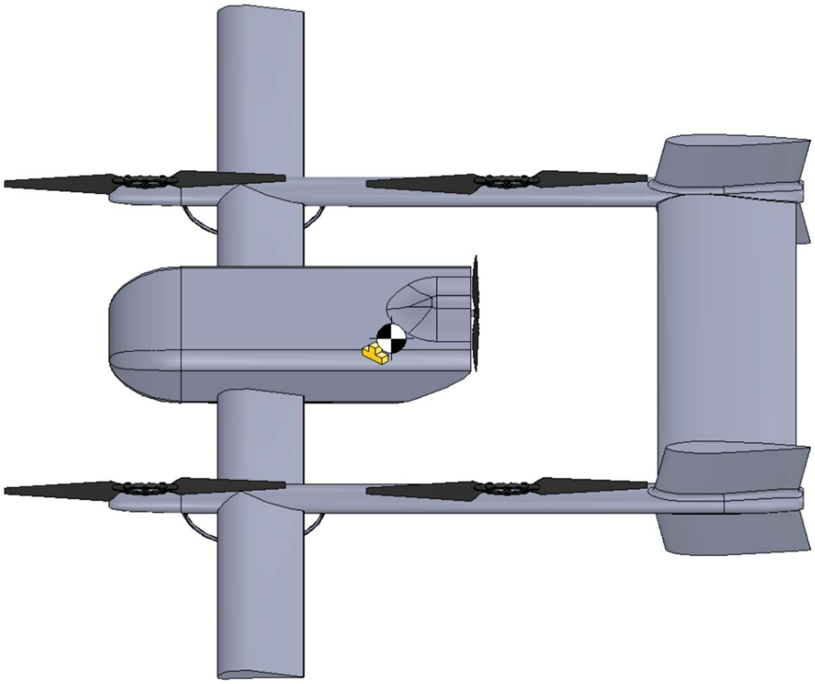


Figure 10: SolidWorks Model of NRT UAV craft (rotated top view facing left)

4.1 Sizing:

Initial concept sizing for the UAV was done, through aircraft weight approximations we can have an insight and begin to set limits in the design to narrow our selection. Based on historical data listed in *Aircraft Design: A Conceptual Approach* [9], fuel and empty weight ratios were calculated through each section of mission profile. Total weight of the aircraft is represented in the following equation

$$W_0 = W_{crew} + W_{payload} + W_{fuel} + W_{empty}$$

Where

$W_{crew} = 0lb$

$W_{payload} = 5lb$

And W_0 is calculated to be approximately 32 lb

W_0 is calculated iteratively. The following graph shows the guessed and calculated starting weight. With the intersection of the two lines being the starting weight approximation. This will serve a rough starting point for more detailed design of the aircraft.

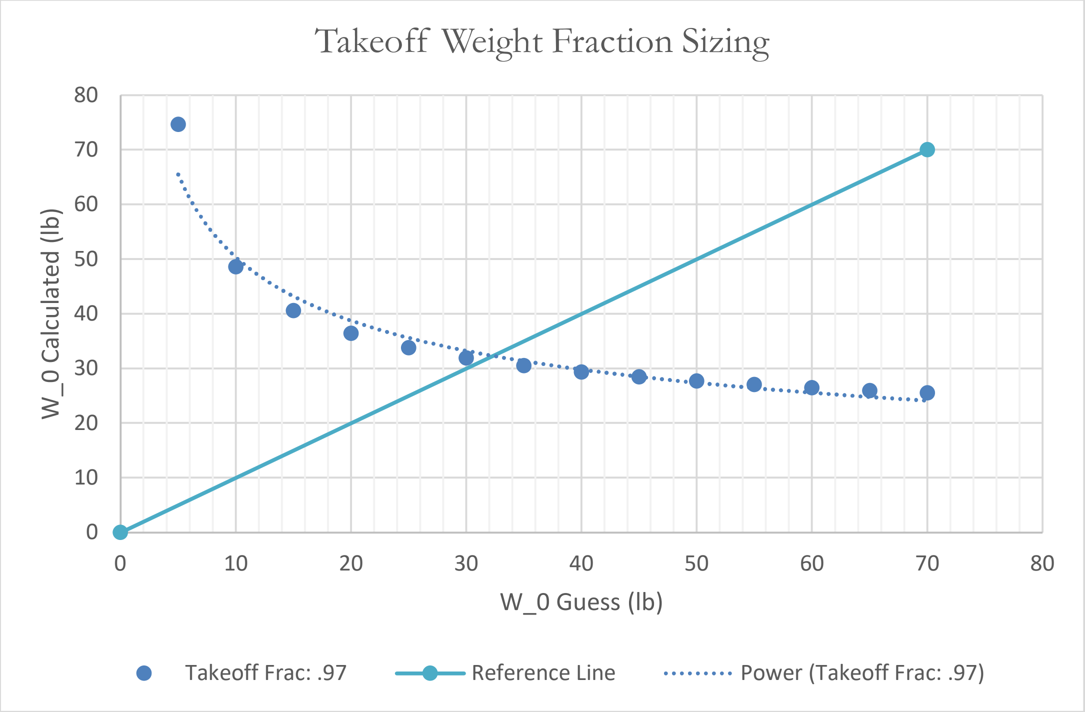


Figure 11: Graphical aircraft sizing approximation

When considering designing an electric aircraft, weight from fuel is not burned off when used. As such weight fractions are replaced with battery mass fractions (BMF) which aim to calculate how much battery mass is require for each section of the mission profile. Using average values of specific energy and density of modern batteries, equation 2 can be solved for the required mass of batteries needed for the aircraft to have an approximate run-time of its mission.

Battery data of Lithium-Sodium batteries were taken from Table 20.1 in Raymer's Aircraft Deisgn [9] with specific energy being 400 Wh/kg

$$BMF = \frac{1000E}{E_{sb}\eta_{b2s}}\frac{P_{used}}{m}$$

Runtime is estimated to 20 min to meet mission requirements.

Individual mass battery fractions can be calculated for separate mission sections.

For climb to 400ft:

$$BMF = \frac{h}{3.6\, V_V E_{sb}\eta_{b2s}}\frac{P_{used}}{m}$$

With V_V is estimated at 33.97 m/s

For cruise:

$$BMF = \frac{R\ g}{3.6\ E_{sb}\eta_{b2s}\eta_p L/D}$$

With range to be 16 kilometers

Battery mass fractions can be summed up to have a total mass fraction for the aircraft at takeoff.

Battery Runtime	Specific Energy	System efficiency	Average power usage	Battery Mass Fraction
1.5 hrs	400 wh/Kg	85%	1KW	0.211
0.83 hrs	400 wh/Kg	85%	1KW	0.195
0.33 hrs	400 wh/Kg	85%	1KW	0.08

Table 8: Battery mass fractions for various run times

For mission flight requirements different runtime battery mass fractions were considered. For 1.5hr, .83 hr and .33 hr which correspond to an estimated one-way flight, 1 round trip flight, and 2 round trip flights. Because of the greatly increase BMF needed for the aircraft to carry used battery weight a one-way battery would be used. Battery is to be replaced with a rechargeable battery unit after every flight. Change can be done when package is loaded and unloaded.

4.2 Aircraft Performance:

Key metrics for judging aircraft performance is thrust to weight ratio (T/W) and wing loading (W/S). Initial values for (T/W) and (W/S) are calculated based on starting sizing values and wing planform. From these values, other key metrics of the aircraft performance can be determined and optimized for the given mission. Thrust to weight ratios change depending on flight conditions and thought sections of the aircraft's flight. As such, key (T/W) values can be taken at takeoff, climb and cruise.

(T/W) for propeller powered aircraft was calculated to be 0.011 where:

$$\left(\frac{T}{W}\right) = \left(\frac{\eta_p}{V}\right)\left(\frac{P}{W}\right) = \left(\frac{550\eta_p}{V}\right)\left(\frac{hp}{W}\right)$$

Where propeller efficiency η_p is taken as 0.8

$(T/W)_{cruise}$ is calculated to be 0.082 where:

$$\left(\frac{T}{W}\right)_{cruise} = \frac{1}{\left(\frac{L}{D}\right)_{cruise}}$$

$(L/D)_{cruise}$ can be initially estimated based on historical data [9] and later updated based on reference wingspan and wetted area where:

$$\left(\frac{L}{D}\right)_{cruise} = \left(\frac{L}{D}\right)_{max} \cdot 0.866$$

Giving a value of 12.124

Using initial sizing weight fractions for $W_{cruise}/W_{takeoff}$, $(T/W)_{takeoff}$ is 0.33

$$\left(\frac{T}{w}\right)_{takeoff} = \left(\frac{T}{W}\right)_{cruise}\left(\frac{W_{cruise}}{W_{takeoff}}\right)\left(\frac{T_{takeoff}}{T_{cruise}}\right)$$

While initial takeoff weight was found using tradition sizing calculations, all weights for (T/W) and (W/S) were kept constant to better reflect aircraft flight performance with batteries.

Because our UAV is designed for vertical takeoff and landing, wing loading during cruise and stall were calculated.

Where wing loading for stall was calculated to be 0.334 lb/ft^2

$$\frac{W}{S} = \frac{1}{2}\rho V_{stall}^2 C_{L_{max}}$$

With V_{stall} = 12.47 ft/s

Wing loading for cruise was calculated to be 0.019 lb/ft^2 using the max propeller range equation:

$$\frac{w}{S} = q\sqrt{\pi AeC_{D_0}}$$

Where q is the dynamic pressure of the aircraft cruising at approximately 400 ft

4.3 Block Diagram:

Figure 12: Block diagram organizing project design factors

4.4 Design Requirements and Specifications:

I. **Vehicle Flight Characteristics**
    1. **Flight Range:** Point-to-point distance from takeoff point to landing point is 10 miles. Vehicle will not land at any point within the 10-mile point-to-point distance.
    2. **Travel Time:** The vehicles 10-mile point-to-point (takeoff to landing) flight time should be no more than 20 minutes.
    3. **Climb:** Vehicle must climb to a minimum altitude of 400 feet within 1 mile of takeoff.
    4. **Decent:** Vehicle must descend from 400 ft. altitude no further than 1 mile from designated landing sight.
    5. **Altitude:** "Cruise" operations are to occur between 400 and 500 feet and there must be redundant onboard altitude measurement systems to insure flight within this altitude range. Please describe in detail.
    6. **Cruise Characteristics:** "Cruise" operations are to occur between 400 and 500 feet and there must be redundant onboard altitude measurement systems to insure flight within this altitude range. Please describe in detail.
    7. **Adverse Weather:** Vehicle must fly in rainy weather conditions (not snow or ice).

II. **Ground System Requirements**
    1. **Landing Platform size:** The landing platform will be 50 feet long by 25 feet wide with no accommodation to touch the ground outside of the designated area.
    2. **Landing side altitude:** Vehicle landing sites may be up to 8000 feet above sea level.
    3. **Automation:** Vehicle and ground system must demonstrate the ability to conduct at least two round trip point-to-point package delivery missions over a 10-mile radius (40 miles total trip distance) without human intervention (i.e. package loading and re-fueling / re-energizing must be automated).

III. **Payload Requirements**
    1. **Payload Size:** Package dimensions are 6.0 x 6.0 x 6.0 inches
    2. **Payload Weight:** Package maximum weight is 5.0 pounds
    3. **Payload Delivery:** The package will be loaded and unloaded autonomously from a landed vehicle, not dropped or lowered from a hovering vehicle via a tether.

4.5 Verification Approach:

Conceptual Verification will happen through basic mathematical computations and free-body diagrams if necessary. This method will render a foundation that will then be progressed into further studies and finalized after ongoing methods of simulation and testing.

Logical and physical preliminary architecture of the drafted design or prototype will have to be tested and compared before it is presented. Having specifications to meet and characteristics of the flights our design will endure we will have to develop a CAD simulation for all aspects of the Unmanned Aircraft. Structural testing will be conducted through SolidWorks FEA Simulations and calculations of lift will be conducted through Flow Simulations of the Airfoil and overall fuselage.

Final and detailed modeling will combine FEA analysis and further studies of the overall implementation, deployment and use in the field through simulation. Continued testing will be suggested after prototype development in next phases.

4.6 Minimum Success Criteria:

For successful completion of our design our team will have to meet a minimum design criterion for the overall design. The Unmanned Aircraft will have to be safe, reliable, cost effective while being able to deliver packages to and from a designated landing platform. Onboard automatic communications, position sensing and identification should be implemented. Finally, any type of propulsion system can be adopted, and any design layout can be implemented to create fully functional design.

4.7 Budget:

The costs of this project can be broken down into 3 main components. First, the unmanned aircraft that will be delivering the packages. Second/third the landing and takeoff sites where they will frequent, both locations will provide the same services. Lastly, regulation fees (see section 4.9) for the drones and the overall operation. A current budget (not all inclusive) can be seen in Table 9.

System:	**Cost (USD):**
GPS	$39.95
360 Camera	$99.00
Collision Avoidance	$17.46
Temperature/Humidity	$6.95
Battery (16000 mAh)	$325.00 to 579.00
Body (Carbon Fiber)	$500.00 ($10.00/pound)
Pusher Motor (KDE600XF-1100-G3)	$207.95
VTOL Motor (4X)	$60.95 X 4
Total*	$1694.11

Table 9: Current breakdown of budget needed to complete UAV

4.8 Resources:

As part of our resources we have availability of basic simulation through SolidWorks Packages. In pre-production we have the access to 3D-Print components necessary to simulate or demonstrate the overall design. Not having secured any sponsorship the team does not currently account with any budget for these items and will fund any necessary materials on our own. Overall, the project will need to be finalized and submitted to NASA by June 15th of 2020.

4.9 Government Regulations:

Regulations for the Federal Aviation Administration (FAA) require commercially operated drones under 55 lbs. to be flown under the “Part 107” guidelines. Part 107 outlines the regulations for commercial UAV in urban environments [21]. As of now, companies must receive an Air Carrier Certificate from the FAA to be able to deliver packages [22].

Registration for unmanned vehicles are outlined in 14 Code of Federal Regulations (CFR) Part 47 in FAA’s regulations. Registration would be required for corporate use of drone deliveries. Registration fees would also have to be paid for each drone used in the company.

(1) Certificate of Aircraft Registration (each aircraft)	$5.00
(2) Dealer's Aircraft Registration Certificate	10.00
(3) Additional Dealer's Aircraft Registration Certificate (issued to same dealer)	2.00
(4) Special registration number (each number)	10.00
(5) To change, reassign, or reserve a registration number	10.00
(6) Replacement Certificate of Aircraft Registration	2.00
(7) Re-registration or Renewal Certificate of Aircraft Registration	5.00

Table 10: List of CFR fees required to be paid for each drone §47.17 [23]

For a cooperation (not US citizen) they would have to be required to provide certain documents such as a certificate of incorporation, certification that it is lawfully qualified to do business in one or more states, and evidence of ownership. Each drone would also have to have its own registration number as outline in portion §47.15 of the guidelines [23].

Chapter 5: System Design

5.1 Design Tools

Some of the tools used are listed below, there are limitations to these due to their computational limitations.

Tool	Type	Use
Solidworks 2019	CAD and Solid Models	Create Models
Solidworks 2019	FEA	Structural Analysis
Solidworks Flow Simulation 2019	CFD	Aerodynamics Confirmation

Table 11: CAD software used in analysis

5.2 Structural Design

Consideration was taken for the material utilized for all structures and skin of the UAV; Carbon Fiber Composite will be used. Aircraft grade aluminum will be used for fasters as this is a very popular and vast used material in the industry. Table 12 points out some of the differences that have been considered. The it is clear of the immediate gain of the increase in tensile strength. The main reason for the use of this material is the decrease in density over the 7075 Aluminum. This material is also great for molding due the fact that it can be shaped into the desired shape and baked into rigidity

	Carbon Fiber	7075 Aluminum
Density (lb/in^3)	0.052	0.098
Shear Modulus (psi)	0.270	0.214
Tensile Strength (psi)	83690.00	82700.00
Yield Strength (psi)	43510.00	73200.00

Table 12: Material Selection

Frame is a no-compromise component, here the carbon fiber will be ideal as it works well when it makes simple shapes like a square internal frame or piping. This workability arises because the fiber material can be cut in simple shapes.

5.3 Computational Fluid Simulation

Computational Fluid Simulation was done on the design, this was used to create a fundamental understanding of the dynamic behavior of the aircraft. Figure 13 shows the flow trajectories over the whole aircraft, this simulation complies the result for the overall behavior of the flow over the craft. Here we understand that our aircraft encounters laminar flow in the main control surfaces like we designed for. The main airfoil does not have any turbulent airflow over its surfaces.

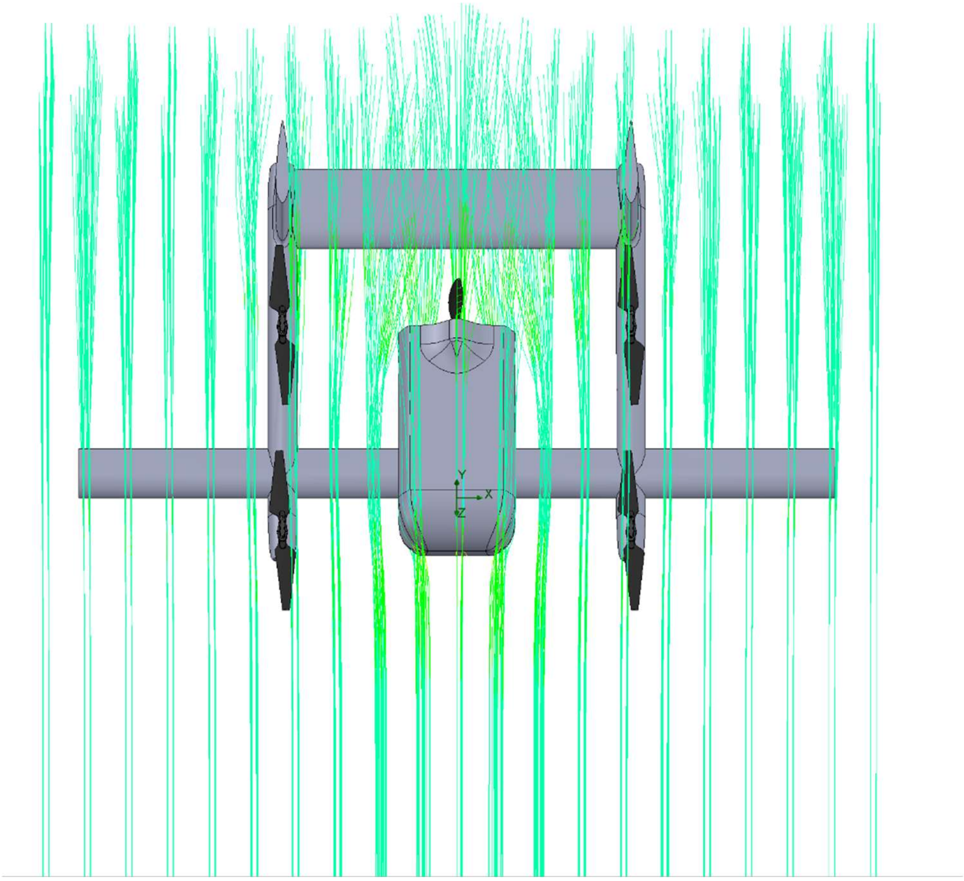


Figure 13: Flow Trajectories

This laminar flow over the main airfoil ensures that the most lift will be achieved over this surface. We know that the if the aircraft has the any turbulence over this surface this can cause early stall and no lift in that moment. Figure 13 shows a closer look over the individual flow trajectories and the low-pressure zone over the top of the wing. Here we can also see the undisturbed airflow over the upper and lower parts of the aircraft.

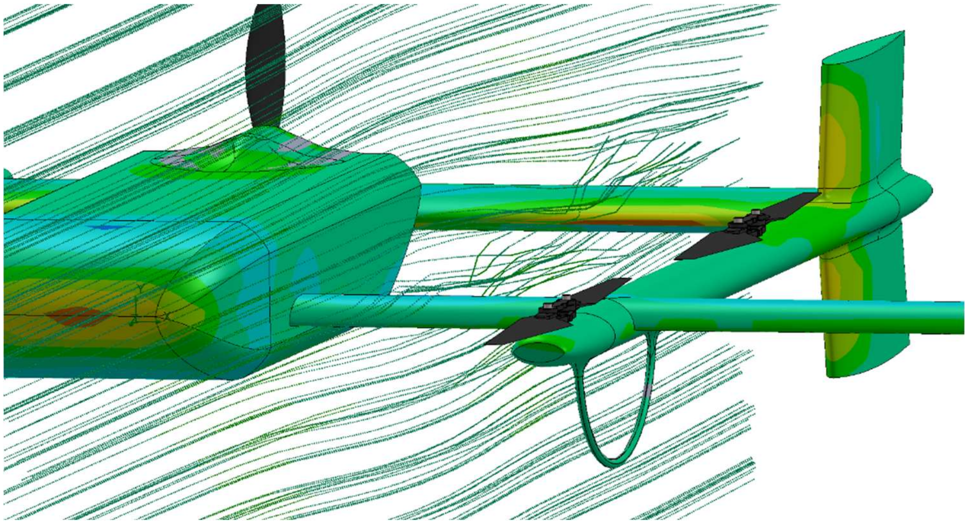


Figure 14: Flow trajectories front

The rear of the aircraft has more turbulent trajectories because of the incline in the body at this part of the craft. This part is needed because of the motor placement and flow necessary to keep the propeller from stalling. This part of the aircraft has a 25-deg. angle of inclination ensuring that there is no flow separation in this part of the aircraft [9]. Unfortunately, our simulation tools limit us to assume that this turbulence and flow deviation will be corrected when the propeller turns. Solidworks does now simulate how the UAV will behave with the propeller turning.

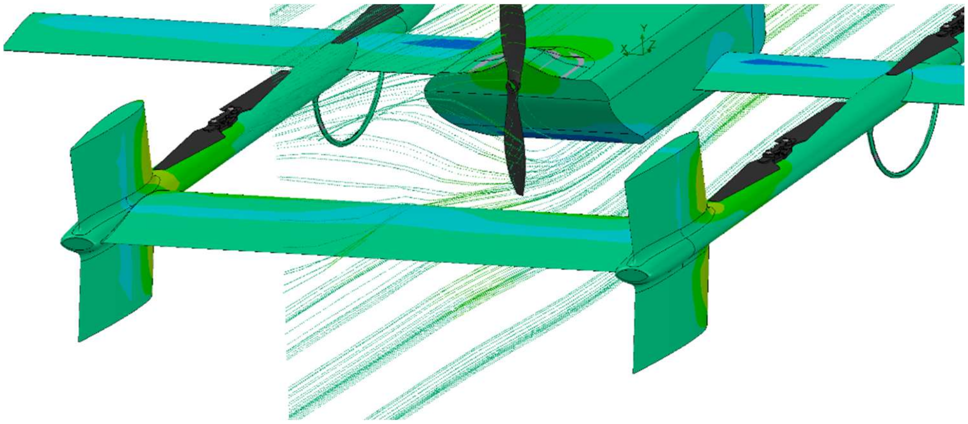


Figure 15: Flow trajectories tail

The pressure surface plot is a great way to see the dynamics of the airfoils in function and identify the areas that cause lift and drag. Figure 15 shows the pressure over the whole UAV. Low pressure areas are shown in blue and cause lift, while the red areas show high pressure and drag can be assumed to happen there. This initial simulation helped the team see that the UAV dynamically performs as theoretically designed. This converges all the initial ideas and assumption of the configuration we choose.

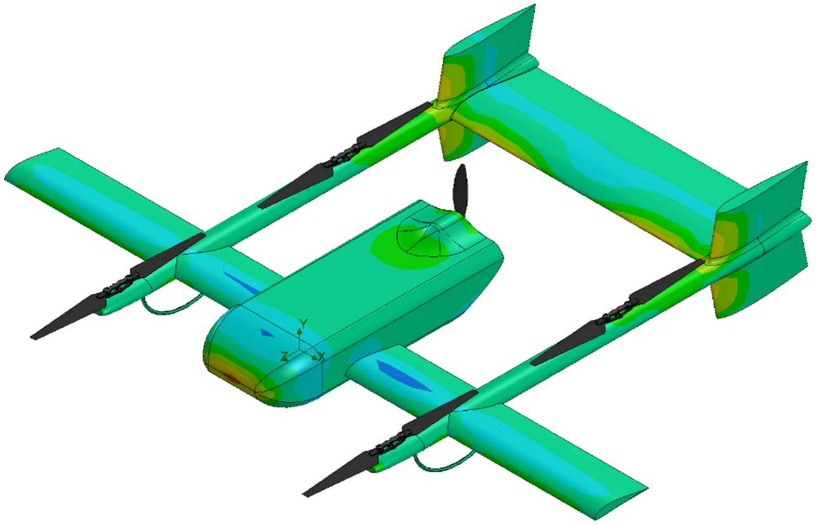


Figure 16: Pressure surface plot

5.4 Accessories Configuration

Our design will feature certain design configurations for specific components that the design features. These are not the common aircraft features as these are geared towards the design goals of the system.

5.4.1 Safety Systems

Safety is a priority in the design and system in flight, to have a method of ensuring pedestrian safety is vital for this design to succeed. We have placed the four VTOL motors and their propellers in the main structure near the exterior of the craft.

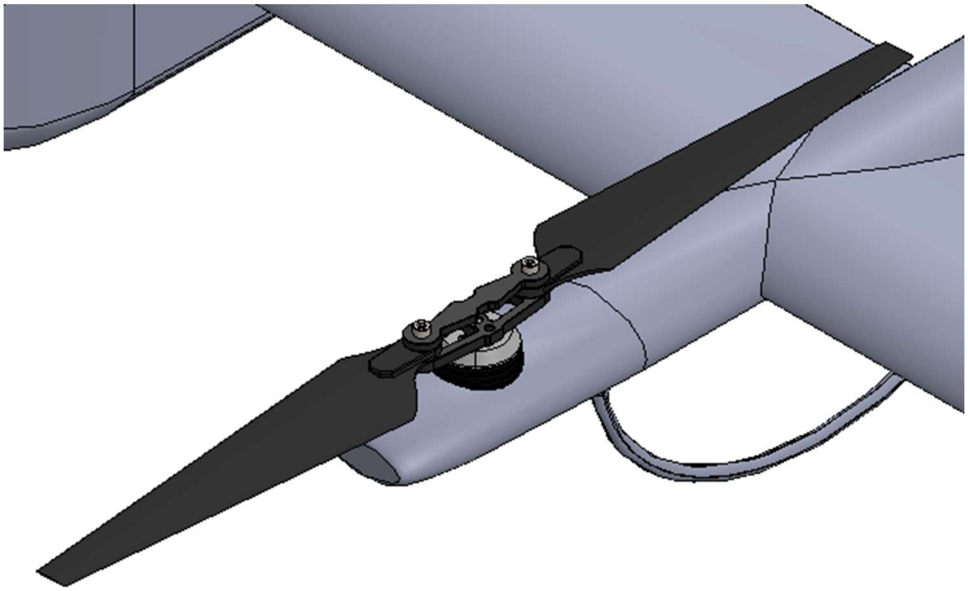


Figure 17: Folding Propellers

Figure 17 shows our design for folding propellers, these are described as propellers that will fold when obstructed by structures crossing in their paths [24]. Instead these will fold when they are touched and reduce the damage imposed in the obstructer in this case the human and the motors. These are used in most drones that are in the market currently, having the ability to recover from a crash or mid-air strike is vital when in consumer use. We believe this will improve the chances that the drone can recover from propeller strike and reduce scientifically the damage injuries caused to a person in case of a crash.

If stuck the UAV will hopefully recover but there is time when this will not be case. Having an external restriction to the fall is vital for an autonomous device, if human operated it is easy for individuals to realize danger and employ strategies to avoid larger damages, this will not be the scenario.

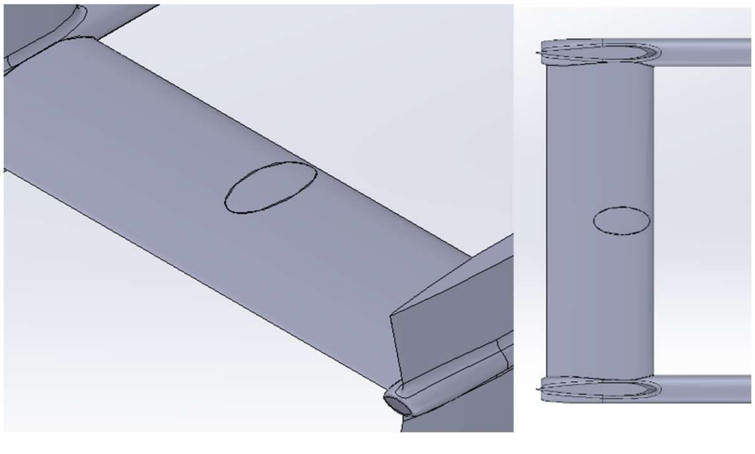


Figure 18: External compartment housing parachute

In Figure 18 we can see and external compartment where a parachute will be fitted in the case of a total engine failure and cannot land on its own. A 5 m/s decent is considered a slow descending speed where people will be able to identify the falling object and react in this scenario [25]. With this data we can calculate the size of the parachute to about one-square meter when deployed.

5.5 Cargo Compartment / Platform

The cargo compartment is where the payload will be carried, the UVA is designed to carry a 6x6x6 box that can weight up to 5lbs. This process will need to be completed autonomously without any intervention. A platform will be the landing area for the drone, here under the platform a 2-link robot with a minimum reach of 40 inches to the maximum of 80 inches. This robot will be dedicated to motion of the cargo in and out of the UAV after landing with the payload.

Like a locker system the robot will be in also allocate the service area where the payload will be placed and delivered to. Here the robot will also place the return package in the craft for it return voyage.

In order to decrease the time in between the package shift, the UAV electronic components will all be unloaded with the package. Flight hardware like motors and some sensors will be the only electronics left in the craft when the package is removed from the chassis. This means all avionics and flight plans including the GPS will be physically attached, loaded and programmed in the loading tray shown in figure 18 before the UAV departures. Therefore, when a package delivery is created and loaded to a tray there is a tail number associated to that tray and when loaded to the craft it departs with all the info the FAA and the UAV needs to complete the shipment.

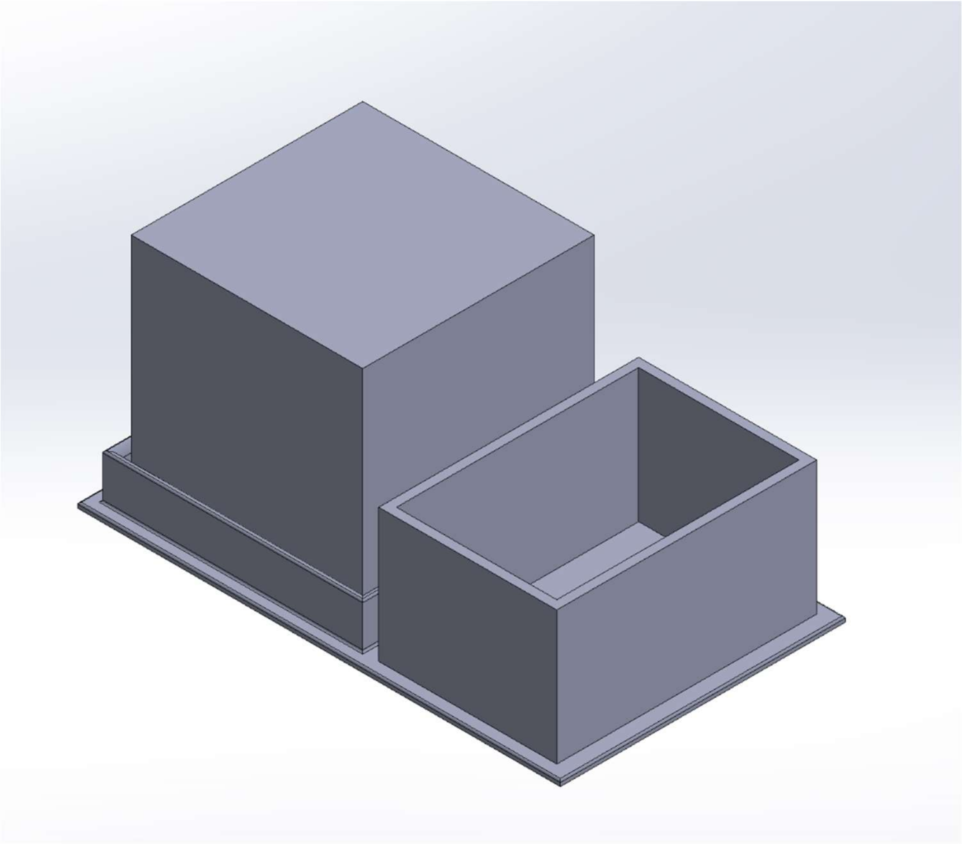


Figure 19: UAV Avionics plus Package tray

Chapter 6: Conclusion

Solution for urban transport have been a challenge for larger logistic management companies. With traditional designs having a cumbersome and human packed step in the delivery chain. Their cost for this current method can be a burden for any company's success and can affect the effectiveness of moving the packages in city centers.

The NRT team developed a design where larger package logistic companies can utilize the skies to enhance the delivery process. This is first and foremost done through the requirements and design criteria set for this project. The decision to create a fixed-wing hybrid VTOL configuration helped address core aircraft requirements, such as the minimum climb distance and runway platform. The payload requirements focused our design for packages averaging 5lbs, which cover's a large portion of the weights of most packages that are shipped. The ground system/automation requirements help create an innovative design feature consisting of a preloaded payload and flight data on a separate tray that is then loaded to the craft.

Our UAV performs, deliver and makes the current logistical structure wholesome by adding a versatile tool that when used in tandem with the current tools can increase the productivity by significant folds.

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Appendix A:

Initial

Alternative designs were considered for solving the problem set forth. Fixed wing vs rotating, all electric vs gas powered, horizontal vs vertical takeoff. All provide their own advantages and disadvantages when it comes to cost, efficiency, and ease of use.

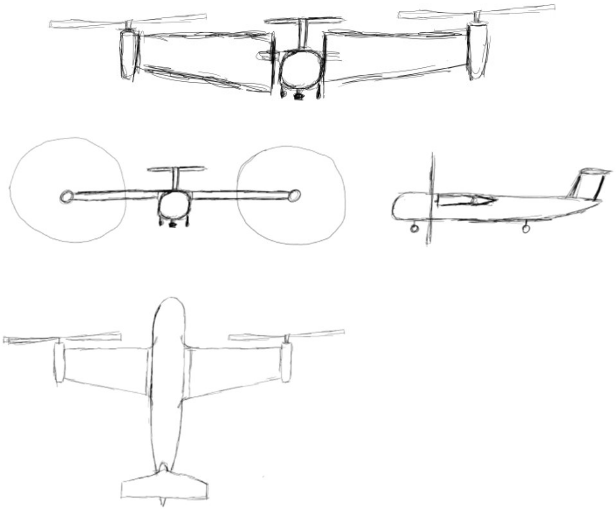

Figure 16: Solution Design 1

Figure 16 is a design for a tilt wing VTOL UAV. Key points for the design is use of two motors for both takeoff/landing and cruise. While use of same motors for takeoff/landing as well would reduce cost and weight, design of the tilt wing mechanism and motor needs to be accounted for.

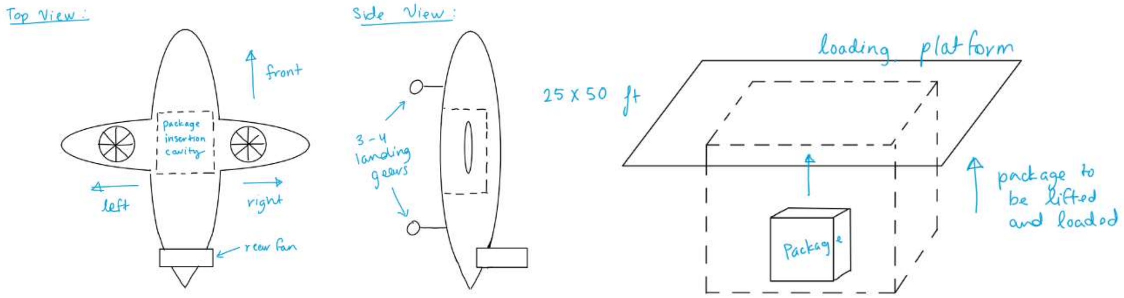

Figure 17: Design Solution 2

Figure 17 shows another solution to the design. This configuration would have two VTOL motors as well as a push motor on the back of the craft. The loading position on the craft would be in the middle and it would land on the middle of the platform (shown to the right). This system would allow for quickly retrieving packages and delivering them as loading and take-off would all be done on the platform.

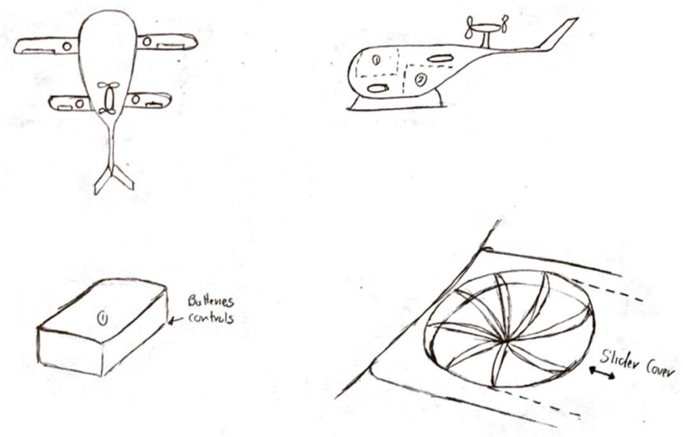

Figure 18: Design Solution 3

This initial iteration shows a format of the UAV where many design cues derived from. Figure 18 shows a strong desired design as the main load is placed in the center in the aircraft where it’s the most desired. Main control surfaces in the front and the rear were also highly desired as this allowed for placement of the 4 VTOL rotors. This design solution also places the motor and main propeller in the rear aircraft, allowing the control surfaces to have laminar airflow over them increasing their efficiencies. Finally, removing the controls of the aircraft in a singular unit with the batteries was optimal given the mechanics of the whole landing and take-off process.

Appendix B:

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- Dr. Adeel Khalid – Class Professor

Contributors:

Chapter:	**Contributor:**
Executive Summary/Formatting	Rafael Barreto Gutierrez, Tejas Bhavsar
Chapter 1: Introduction	Niko Giannakakos, Rafael Barreto Gutierrez
Chapter 2: Project Information	Tejas Bhavsar, Niko Giannakakos
Chapter 3: Configuration	Tejas Bhavsar, Rafael Barreto Gutierrez
Chapter 4: Design Configuration	Tejas Bhavsar, Niko Giannakakos
Chapter 5: System Design	Rafael Gutierrez, Niko Giannakakos
Chapter 6: Conclusion	Niko Giannakakos, Rafael Barreto Gutierrez

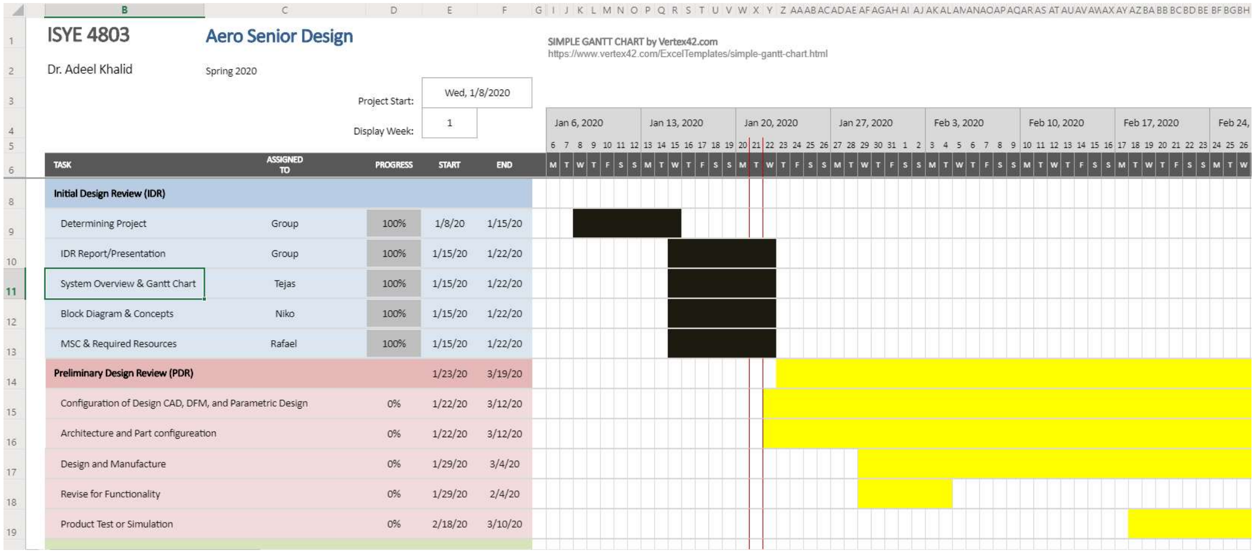
Table 13: Group member Contributions

Detailed Technical Contributions:

Niko	Lead on all aircraft calculation. Including: sizing,BMF, wing geometries, (T/W), (W/S), (P/W). Chose motors, conrtibuted to configuration decision matrix. Developed poster and video.
Rafael Barreto Gutierrez	Helped stucture and configure the features of the craft. Airfoil selction and the computatonal fluid analisys was done by this member. While other minnor details like the safety and flight dynamics were weighted, researched and developed.
Tejas Bhavsar	Helped with the overall formatting of report, control systems analysis, literature review, goverenment regulations, NASA contact, budgeting

Table 14: Detailed technical contributions of individual team members

Appendix C:



ISYE 4803 Aero Senior Design

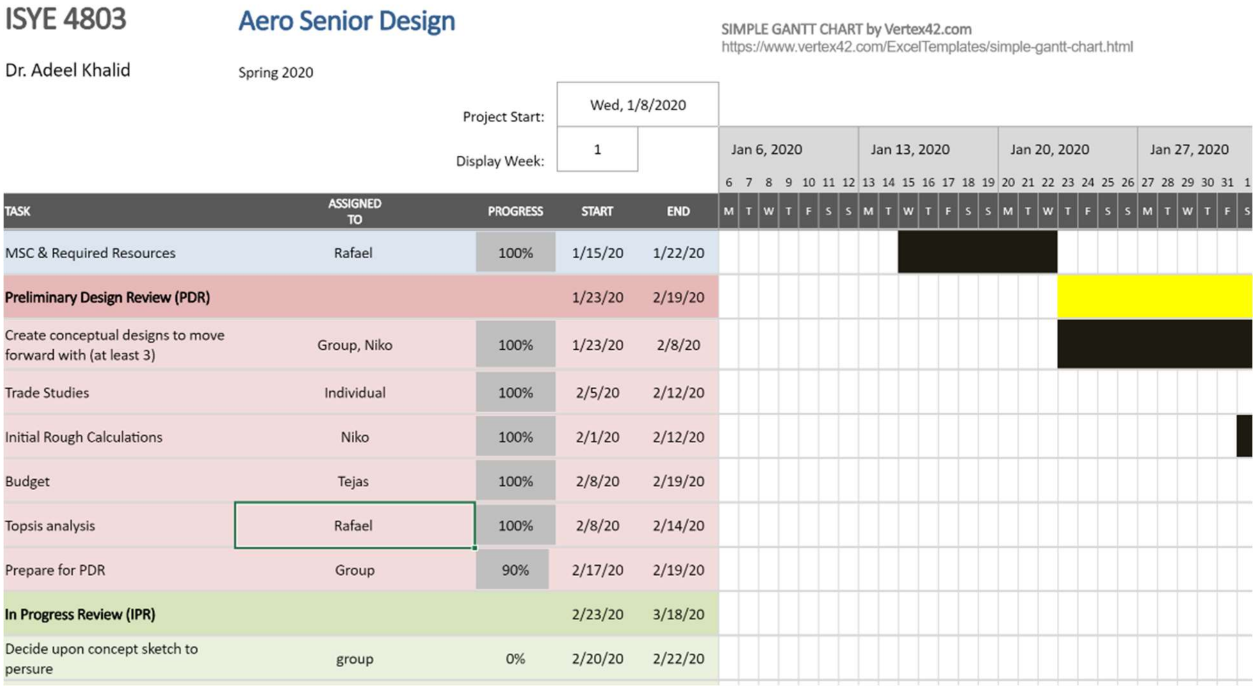
Dr. Adeel Khalid Spring 2020

Project Start: Wed, 1/8/2020

Display Week: 1

TASK	ASSIGNED TO	PROGRESS	START	END
Initial Design Review (IDR)				
Determining Project	Group	100%	1/8/20	1/15/20
IDR Report/Presentation	Group	100%	1/15/20	1/22/20
System Overview & Gantt Chart	Tejas	100%	1/15/20	1/22/20
Block Diagram & Concepts	Niko	100%	1/15/20	1/22/20
MSC & Required Resources	Rafael	100%	1/15/20	1/22/20
Preliminary Design Review (PDR)			1/23/20	3/19/20
Configuration of Design CAD, DFM, and Parametric Design		0%	1/22/20	3/12/20
Architecture and Part configureation		0%	1/22/20	3/12/20
Design and Manufacture		0%	1/29/20	3/4/20
Revise for Functionality		0%	1/29/20	2/4/20
Product Test or Simulation		0%	2/18/20	3/10/20

Figure 20: In-Progress Gantt Chart



ISYE 4803 Aero Senior Design

Dr. Adeel Khalid Spring 2020

Project Start: Wed, 1/8/2020

Display Week: 1

TASK	ASSIGNED TO	PROGRESS	START	END
MSC & Required Resources	Rafael	100%	1/15/20	1/22/20
Preliminary Design Review (PDR)			1/23/20	2/19/20
Create conceptual designs to move forward with (at least 3)	Group, Niko	100%	1/23/20	2/8/20
Trade Studies	Individual	100%	2/5/20	2/12/20
Initial Rough Calculations	Niko	100%	2/1/20	2/12/20
Budget	Tejas	100%	2/8/20	2/19/20
Topsis analysis	Rafael	100%	2/8/20	2/14/20
Prepare for PDR	Group	90%	2/17/20	2/19/20
In Progress Review (IPR)			2/23/20	3/18/20
Decide upon concept sketch to persure	group	0%	2/20/20	2/22/20

Figure 21: Updated Gantt Chart (2/19/20)