Aero One OH 600-A

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Abstract

This report documents various aspects of the design process of the OH 600-A, a zombie crisis rescue aircraft. The mission of the aircraft is to airlift survivors of the zombie apocalypse and transport them back to the West Lafayette campus of Purdue University. The criteria for success is the number of survivors rescued. After analyzing the mission, needs, stakeholders, risks and list of priorities, the final design is a long range, vertical takeoff capable, high capacity aircraft. The concepts of airborne aircraft carrier, multi-engine rotate wing aircraft and twin tiltrotor aircraft were all eliminated due to their technological infeasibility or unreliability. The final concept is a fan-in-wing aircraft which uses duct fans and thrust vectoring engines to generate lift. The aircraft is able to carry 40 people and perform a flight over a range of 2726 km. Basic design of the aerodynamics, structurse, powertrain, control systems and performance data are included in this report.

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1 Introduction

With the advent of the second decade of the second millennium came the dawn of the apocalypse. The 2019 zombie apocalypse has left the world in chaos, overrun by the undead. They roam the world, mostly around the densely populated cities of the past. Insatiable, they seek the flesh of living humans. By nature, they are slow-walking beings with a diminished consciousness as they are stimulated and attracted to the sight of living flesh and loud noises. Their bodies are rotten, yet they possess great strength, enough to tear a human apart. They do not possess the ability to bear arms or swim--however, scouts have taken note that zombies have been found wading through water up to their necks. By nature, they seem to be subject to a hive mentality and travel in large hordes of hundreds, and in some cases, thousands.

Despite the grim state of the world, the worst has passed and humanity is rebuilding, The survivors that remain have gathered resources and built safe zones in order to fight back. Purdue University is among one of the safe zones and is leading the effort of search and rescue missions. Our task, as Purdue engineers, is to develop an efficient, adaptable, and reliable, “search and rescue” vehicle that can transport goods and survivors in the post apocalyptic world. With the aid of the Purdue rocket teams, our team will be able to fly out to specified coordinates, conduct a rescue mission, and return safely to Purdue University. Our vehicle must be able to conduct missions in harsh weather and terrain and must be able to withstand zombies for a limited time.

Our team has concluded that a V/STOL search and rescue vehicle serves the circumstances of the zombie apocalypse best; there are no operational airports and most of our missions will take place over land and possibly densely populated cities. Hover capabilities seem to be favorable since the aircraft will be able to hover at a safe height and drop ladders, or rescue survivors in difficult terrain by landing on narrow strips or uneven terrain which would otherwise only be accessible to helicopters. Our design is based on the Dornier Do 31, an early transport VTOL aircraft developed in 1967 by the Germans. The Do 31 was retired after a short life span due to the lack of VTOL technology at the time in order to make the aircraft more efficient than regular contemporary transports. We strongly believe that in the 53 years since the Do 31, research and development in VTOL technology has been furthered exponentially enough to make V/STOL applications an efficient and viable form of transport that is swiftly manufactured and easily maintainable.

2 Needs and Requirements Analysis

2.1 Stakeholders

Stakeholders are groups that may be directly or indirectly affected by the aircraft at any point from idea conception to daily operation, whether it is through rescue missions, supply drops, or the long term objective completion of locating and rescuing all survivors.

- Team Aero One (us) - We design, manufacture, and conduct initial rescue missions. The success of our design is vital as failure may result in our demise.
- Survivors (Subjects of mission) - They rely on our work to provide support, transportation, and ultimately, hope of rescue at the cost of their lives.
- Purdue (Main Client) - We use Purdue resources for R&D. Purdue depends on our work for its success as a safe zone.
- World governments (Potential sponsors/partners) - They can pursue relief efforts using our aircraft and thus are dependent on our success.
- Zombies (Adversary) - We are taking away from their food supply of humans and combatting their existence.
- Rocket teams (Partners) - We are using their technology to track survivors and thus we are both dependent on each others' operations.
- Operators (end users) - They will be operating this aircraft, thus the design of the aircraft directly impacts their jobs and their safety.

2.2 Needs

To identify our specific needs we reviewed needs and requirements for aircraft that operate similar missions such as military airlifters such as the Bell-Boeing V-22 Osprey and the Lockheed Martin C-130 Hercules. We drew inspiration from both of these aircraft as well as from entertainment sources such as movies and TV shows portraying similar circumstances in our process of envisioning the various environments our aircraft would need to combat. Such settings tend to have harsh conditions including, but not limited to: a lack of usable runways suitable for aircraft, groups of survivors that are gathered in small areas of land, immediate threat of a zombie attack upon arrival, and limited availability of fuel and other aircraft maintenance supplies . Such elements differ from military missions in use today because the airspace is safe, but shares a commonality with the military missions because the ground environment is still hostile. From our collective understanding of the apocalyptic world, we have discerned the following needs for our aircraft:

1. The aircraft is capable of landing in crowded environments without a runway so it can rescue survivors in urban areas, which contain the highest concentration of people.
2. The entrances of the aircraft can load and unload passengers and cargo quickly, to minimize the time the aircraft is exposed to a hostile environment.
3. The aircraft can carry relief supplies for survivors, to help survivors in situations where the home base resources are urgently required but not immediately available.
4. The aircraft can loiter close to the ground for a prolonged period of time to allow the loading/unloading of passengers and cargo without exposing the aircraft to a dangerous environment.
5. The aircraft offers protection from zombie threats to safely conduct its mission.
6. The aircraft is protected from severe weather conditions to safely conduct its mission.
7. The cockpit offers adequate information displays for the pilots so that they can safely operate the aircraft.
8. The aircraft can carry survivors, which is necessary to complete its mission.
9. The aircraft can travel to most of the United States from Purdue. So it can rescue survivors anywhere in the continental US.

These needs allowed us to map out a generalized mission diagram as shown below in Figure 1. At the very minimum, our aircraft must be able to complete one cycle of this outlined mission during each use.

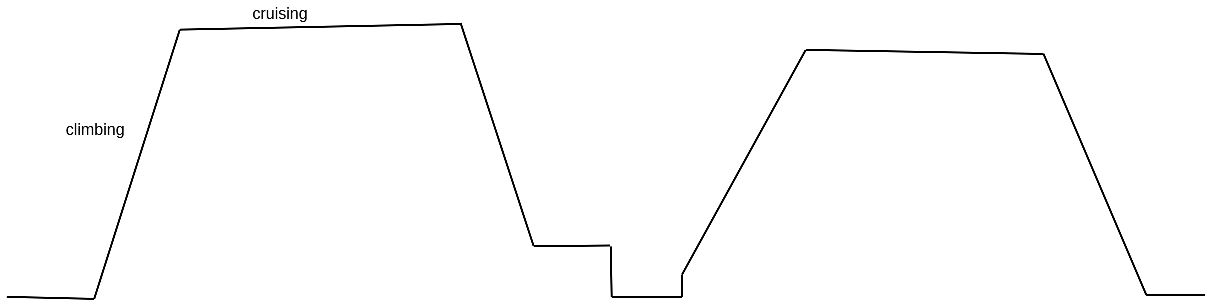

Fig 1: Mission diagram

2.3 Requirements

The requirements for this vehicle are based on the needs given above. Each need was expanded to include a metric, a value for the metric, and a reason for the overall requirement.

We have discerned the following requirements for our aircraft

1. The aircraft can land in densely populated urban environments in a clearing of length less than 60 meters to facilitate easy access to survivors.
2. The aircraft doors must have the capacity to fit at least two people at a time side by side in order to hasten loading and unloading time of passengers.
3. Hull of aircraft has a minimum payload capacity of 4000 kg of payload in order to conduct effective supply drops.
4. The aircraft can maintain steady, level flight in an area close enough to the ground for passengers and cargo to enter/exit without compromising the safety of the aircraft or its contents from ground melee attacks so that the aircraft can safely load/unload passengers and cargo while remaining invulnerable to zombie attacks.
5. The hull can mount at least one armament in order to defend the aircraft from zombies.
6. The aircraft can operate in temperatures ranging from -30 to 50 C, as well as winds up to 15 m/s so that the aircraft can perform its mission even in adverse weather.

7. Avionics of the aircraft offer typical flight parameter information as well as external information regarding zombie concentrations of surroundings in order for the pilots to be fully aware and in control of the aircraft operation
8. Hull of aircraft has capacity for roughly 30 passengers excluding pilot, copilot, and flight engineer in order to carry out effective SAR missions.
9. The aircraft has a range of 2500 km so it can perform SAR missions to any point in the continental US.

2.4 Preliminary Risk Analysis

Once a general idea for a solution to Apocalypse 2019 came to fruition, our team conducted an extensive preliminary risk analysis for the aircraft as showcased in Table 1, which can be viewed in Appendix A. We chose to categorize potential risks into four subsections: mechanical failure, loss of command, foreign object damage (FOD), and weather conditions. For each potential risk, we documented the hazard it poses, parameters to measure the risk, overall effect of the risk, the "danger zone" within which the risk is prominent, and methods of mitigation to avoid the risk.

3 Concept Generation, Selection, and Development

In this section, we will discuss the priority of the mission and some tradeoffs that we chose to accept. We will also explain some of the concept designs and discuss their advantages and disadvantages. Finally, we will present the final design and its specifications.

3.1 Concept Generation and Selection

3.1.1 Priority Features of the Mission

Based on the list of requirements we have made in section 2, we made a list of priorities. The most critical features are the ones we have to include. The requirements at lower priority list are the ones we will make the trade-offs to if needed.

The list of requirements in sequence of priority is shown below:

1. Successful flight

The top priority of the design is to make an aircraft that is reliable and safe to fly. To make it safe and reliable, sizing the aircraft properly and use of a reliable engine are crucial. In order to maximize safety, the design considerations are made with direct correlation to the risk analysis. The aircraft should be operable in an all weather conditions, during any given time of day or night, and capable of detecting and forecasting critical weather before and during the mission.

2. Successful rescue

The main mission of the aircraft is to rescue survivors in the zombie world. The design needs to be able to locate the survivors, load up the survivors, and carry them back to base. Based on the current situation, all of the airports are occupied by zombies and most of the survivors have retreated behind fortifications in cities using buildings to block the zombie attack. To make a successful rescue, the aircraft first needs to identify the location of the survivors and be able to land and takeoff in a relatively small area. Therefore, we concluded that the vehicle needs to have the capability of vertical takeoff. The aircraft also needs to have mounted firearms to be able to secure the landing zone from zombies.

3. Deliver supply resources to survivors

For accurate delivery, we require the plane be able to fly in relatively low altitude and low speed. The aircraft will also need to have a cargo bay that can be opened in air for dropping the supplies.

4. Price / Resources

The amount of money and resources needed to build a unit should not be overly excessive. For this mission, the aircraft should not be too expensive to build. For this mission, the cheaper and easier it is to build each unit, the more units we can afford. This is very important in order to be able to successfully launch a large scale rescue operation/.

5. Payload capacity

As previously stated, the main purpose of the aircraft is to deliver supplies to and rescue survivors of the 2019 zombie apocalypse. As such, the payload capacity will be an important factor of our design. The larger capacity the aircraft has has, the more survivors and resources it can carry in one flight.

6. Range

The range of the aircraft is also highly important. The longer the range, the more distance it can cover and more people can be saved. This requires the aircraft to be fuel efficient and aerodynamically efficient.

7. Fast loading/ refueling

The aircraft should be able to refuel and reload in a short amount of time. This not only allows the aircraft to go on mission continuously but also ensure the aircraft to pick up survivors and refuel fast during the mission so it can get out of the danger zone.

8. Speed

The aircraft needs to be relatively fast. Since the range of the aircraft is large, we need aircraft to be fast so we can reach the destination in time and improve the emission efficiency.

3.1.2 Tradeoffs

Many of the trade-offs that were made stem from the aircraft's vertical takeoff capability, which is a critical feature for rescuing in a city environment. To achieve vertical takeoff, another type of engine will have to be used on the aircraft. The addition of such would increase the inert mass of the aircraft, thereby decreasing aerodynamic efficiency. This reduction of aerodynamic efficiency implies a relatively reduced lift coefficient, which means a large amount of fuel is needed to generate the required thrust, airspeed and therefore lift. Also, the structural reinforcements required to secure the additional engines would add more weight to the aircraft, increasing the fuel consumption rate. This tradeoff also affects two other variables, namely, range and endurance of the aircraft. A reduced aerodynamic efficiency implies a reduced range and endurance.

The aircraft must also have a weapon systems in place for defense against zombie attacks. This is another addition to the already high inert mass of the aircraft. This slightly reduces the number of personnel and amount of cargo that may be carried on board.

3.1.3 Airborne aircraft carrier

The idea of the airborne aircraft carrier is an aircraft that can release and recapture smaller size aircraft and store them inside the fuselage. The idea is generated from science fiction media and the Boeing 747 airborne carrier concept. Figure 2 is a side view of the Boeing 747 airborne aircraft carrier.

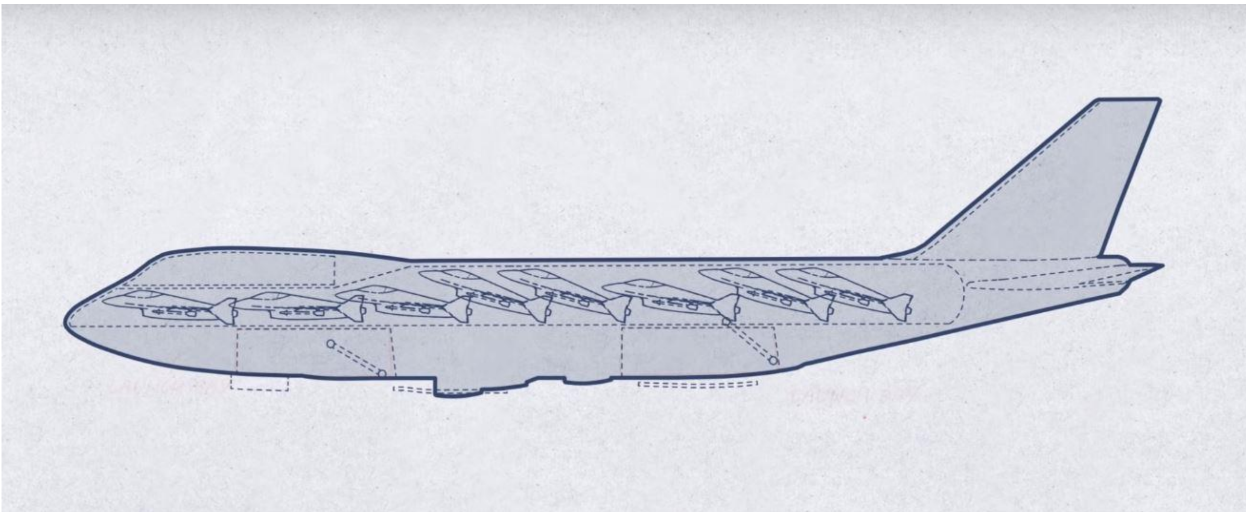

Fig 2: Boeing 747 airborne aircraft carrier (Gavine, 2019)

The “mothership” 747 like aircraft will carry the smaller aircraft to the rescue area. Once the destination is reached, the smaller aircraft can deploy to land and rescue survivors.

In the city environment, smaller aircraft are much easier to land than a large aircraft. Multiple small aircraft also allows quick pickup from multiple locations. The size of the carrier also allows transportation of a large number of people.

Reasons for abandonment

This design was vetoed very quickly due to the size of the aircraft we can build and the complexity of the system. For the maximum size we can build, about that of a Boeing 737, only two or three planes can be carried. It is much less efficient than initially thought.

The launch and recovery of the vehicle is another problem. The main reason that the aircraft carrier failed is the difficulty of recovering the carried aircraft. It's hard to keep the two aircraft at the same speed and stable with respect to each other. For this project and our current engineering abilities, this design would be far too difficult to achieve and overall seems like an engineering, piloting, and logistical nightmare. (Nelson, 1973)

Systems that can be used in this design:

- Engine Fuel and Fuel Metering Systems
- Induction and Exhaust Systems
- Ignition Systems
- Lubrication Systems
- Engine Cooling Systems
- Fan Control System
- Communication and Navigation
- Landing Gear Systems
- Ice and Rain Protection
- Cabin Environmental Control Systems

3.1.4 Multi-engine wing rotary aircraft

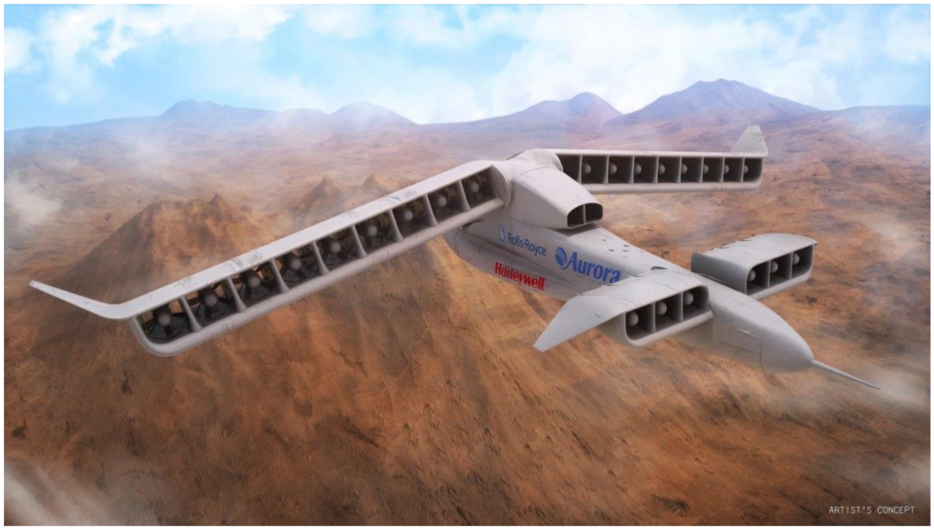

Fig 3: Aurora XV-24A (Aurora Flight Sciences, 2019)

The idea of this multi-engine wing rotary aircraft is modeled after the Rolls-Royce XV-24A LightningStrike, as displayed above in Figure 3, which shows the latest design from Aurora and Rolls Royce company. The XV-24A uses 24 turboshaft engine to power the aircraft. This is a vertical take-off and landing vehicle with lots of advantages.

First is the risk of engine failure - with the amount of engines operating, it can easily deal with the risk of losing power. Even if one or two engines lost power, the plane is still able to fly. The second advantage is the economic considerations. This plane has lots of small engines which are very small and can be taken from Cessna or similar aircraft. These engines are very cheap and with lots existing., we can take them from the existing planes. The total price of one engine would be only about 10% of a large turbofan engine. (ASH, 2016)

We have further analyzed this design.

Sizing: about the same size as XV-24A (approximation)

Wing span: 18.59m

Max takeoff weight: 11000kg

The XV-24A uses an electrical system to power the aircraft, but the endurance and load of the drone are small. Therefore, we are planning to change the power system to conventional engines.

Reasons for abandonment

According to the specifications and calculations for this aircraft, the diameter of each fan would be 30 inches, and the thrust required by each fan would be for vertical takeoff would be 4600N. At this thrust rating, a small Honda engine won’t be able to power the aircraft. (Honda, 2019) The aircraft must be powered by something much bigger. This takes away one of the initial advantages of the design. More importantly, a system with so many engines is hard to manage and not reliable. Therefore, we abandoned this design. The main ystems that can be taken from the design is the ducted fan and the fan in the wing concept, which will go on to our final design. The main advantage of a fan-in-wing concept is that it can lower the aerodynamic drag during the cruising stage. The fan can be covered up by a movable skin, so it won’t affect the aerodynamic shape of the plane. We are also using a ducted fan instead of open propeller due to its greater efficiency for the area. The effect will be discussed in later sections.

3.1.5 Twin tiltrotor aircraft

The V-22 Osprey is a conventional helicopter with the long-range, high-speed cruise performance of a turboprop aircraft designed by Boeing in 1980s. One of the biggest missions of this aircraft is quite similar to our mission: to perform transport missions on all terrain including city environments. Since a V-22 satisfies most of our design requirements, we decided to make modifications on the V-22 for this specific mission. This would not only save us lots of money that would be otherwise spent designing a new aircraft, but we would also experience much lower risk and a shorter development period. The modified V-22 would be named V-22 Doomsday.

Fig 4: V-22 Osprey tiltrotor engine aircraft

Specifications of the V-22 (Boeing, 2017) (Bell, 2014)

Length: 57 ft 4 in (17.5 m)

Rotor diameter: 38 ft 0 in (11.6 m)

Wingspan: 45 ft 10 in (14 m)

Width with rotors: 84 ft 7 in (25.8 m)

Wing area: 301.4 ft^2 (28 m^2)

Empty weight: 33,140 lb (15,032 kg)

Loaded weight: 47,500 lb (21,500 kg)

Max. takeoff weight: 60,500 lb (27,400 kg) (self-deploy/long runway)

Maximum rolling takeoff weight: 57,000 lb (25855 kg) (STOL)

Maximum vertical takeoff weight: 52,600 lb (23,859 kg)

Power plant: 2 × Rolls-Royce Allison T406/AE 1107C-Liberty turboshafts, 6,150 hp (4,590 kW) each

Range: 879 nautical mile (1,011 mi, 1,627 km)

Doomsday modification package:

One of the problems with V-22 is the range. The range of 1627 km is far below what we need for the mission. We are only able to cover the range of 800 km around Purdue. To solve the range issue, we have come up with the internal disposable fuel tank solution.

The disposable fuel tank is a modular designed fuel tank that can be placed in the cargo bay. During a rescue mission, we don't need to carry any survivors with the plane on our way to them, and we can use the runway to take off. The aircraft can use that empty weight to carry more fuel inside the cargo bay. The aircraft will consume the fuel from the internal fuel tank. After the aircraft locates survivors, the aircraft can simply detach the internal fuel tank and abandon it to lower the dead weight. The space freed up will be used to accommodate survivors.

Ideally, we can use all the fuel from the tank on the way to the rescue, and the return segment will be powered by the original fuel system on the aircraft.

The volume of the disposable fuel tank would be 1.1 times the volume of the airplane fuel tank, which would be 1400 gallon (~5300 L).

Another modification we will make to the V-22 is adding a turbofan engine to its back. The turbofan engine provides horizontal thrust that can be used during cruising. Figure 5 shows how propulsion efficiency changes for various types of gas turbine engine configurations. The turbofan engine has a much higher efficiency at higher speed and higher altitude.

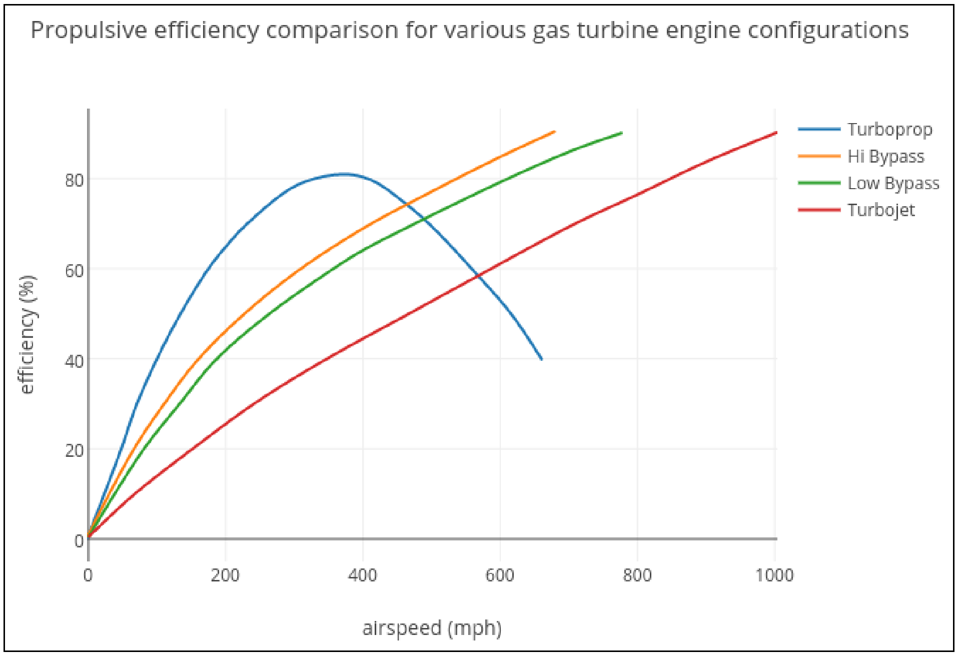

Fig 5: Engine Efficiency (Rolls-Royce,1992)

The turbofan engine would be mounted on the back of the aircraft, providing horizontal thrust for cruising.

The blades of the propeller also need to be foldable. During cruising, the blades will be folded to reduce drag.

The weapon systems will also need to be modified. Two M134D Gatling machine guns and a Hydra-70 Rocket System will added to the front of the aircraft, so there will be enough firepower to clean up a landing zone and cover the survivors when they are moving to the aircraft.

The reasons of abandonment:

1. Based on the environment of the zombie world, all the military bases are occupied by the zombies. All the V-22s are probably damaged or destroyed by the zombies.

2. The tiltrotor aircraft has very low reliability, and the development of the V-22 took decades and there are still lots of problems with them today. The lack of dedicated pitch, yaw and roll control makes it vulnerable to any extreme weather conditions. In a zombie world, the V-22 is not the best choice.
3. The low aerodynamic efficiency; Even though we have the folded propeller design, the tiltrotors are still going to create lots of drag.
4. Since we are using the turbofan engine for cruising, the tiltrotors are only used as lift engines. They will become dead weight in flight. This is not a favorable design since the weight of the two engines would be equivalent to allowing us to carry more than 10 more people per flight.

Systems that can be used

1. The disposable fuel tank will be adopted for our final design, as it can significantly increase the range.
2. The weapon systems will also be applied to the final design. The weapons on this design will be powerful enough for the air support.

3.1.6 VTOL generation and design possibility analysis

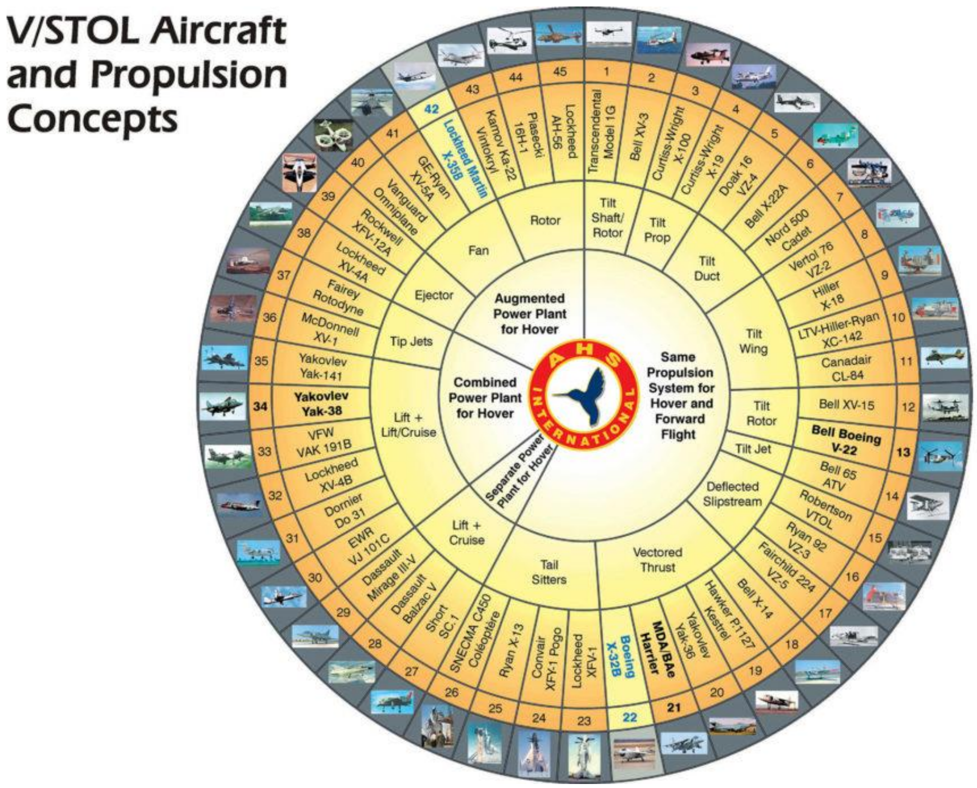

Fig 6: Wheel of misfortune. Failed V/STOl concepts (Anon,2018)

Our group has gone to the vertical takeoff lecture to gain insight on the topic for our design. We have noticed there are four generations of vertical takeoff vehicles. Figure 6 displays the variety of V/STOL aircraft and propulsion concepts and arranges them in each subcategory. The first generation of VTOL such as Convair XFY-1 has to rotate the entire airplane for vertical take off. It’s basically a helicopter that can turn rotate to level flight. The drawback of this design is obvious: lack of control and the low efficiency aerodynamic shape.

The second generation of VTOL has a rotating engine system. For example, the V-22 has tiltrotors on both ends of the wings. The basic idea is still a helicopter that can turn its propellers to the front to become a turboprop airplane. Compared to the first generation of the VTOL, the aerodynamic efficiency of the aircraft has significantly improved so that it can perform longer range flight and carry more cargo.

The third generation of VTOL uses separate engines for liftoff and for cruising, Lots of experiments on this design are made as we can see from the wheel of misfortune. This design is mainly used for large transport aircraft such as the Dornier Do 31. Several testing aircraft of this design were made but it never went into production because of its low efficiency. Because one set of engines can only be used for vertical takeoff, they becomes dead weight in cruising stage, and vice versa for cruising engines in the VTOL stage.

The fourth generation of VTOL is has vectoring thrust and separation of flow. The only aircraft that designed under the latest concept is the F-35, which use the engine to power the lift fan, vectoring the exhaust thrust and separating flow from the combustion chamber for control. This system maximizes the use of the engine power and optimizes the aerodynamic shape of the aircraft.(Bevilaqua,2019) Figure 7 is an animation of the lift off system on F-35.

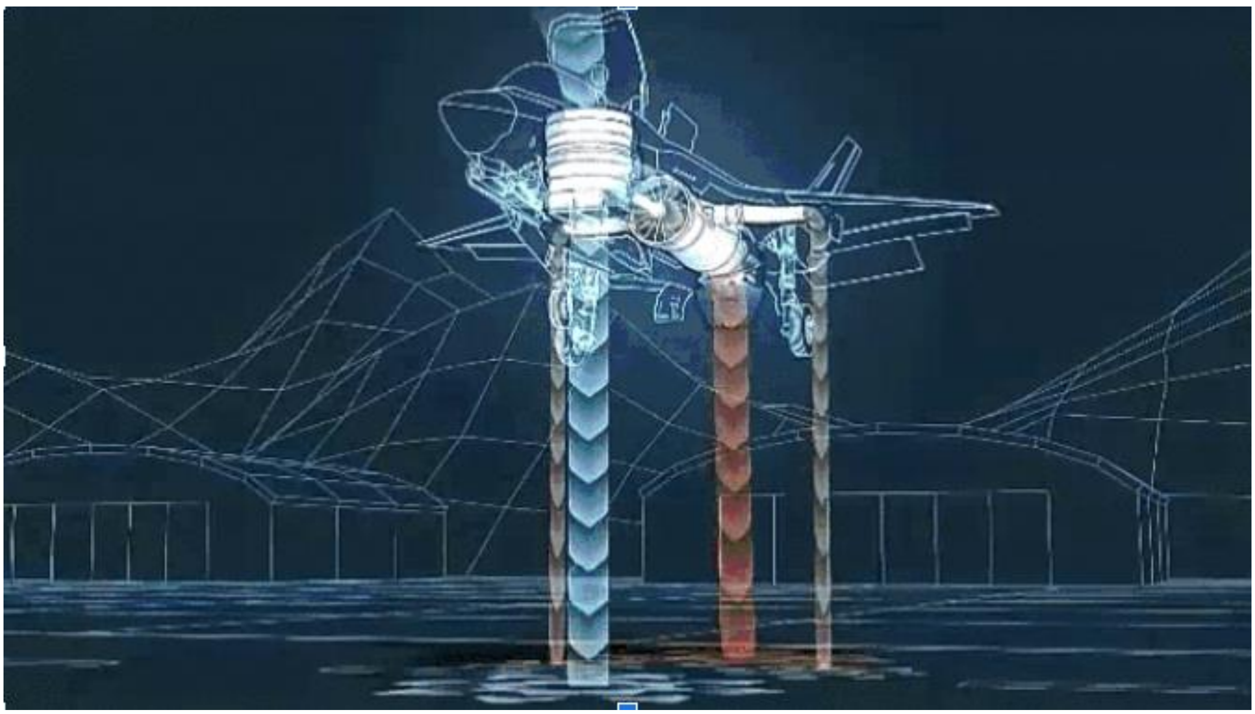

Fig 7: Animation of the F-35 vertical liftoff system (thaimilitaryandasianregion.wordpress.com, accessed 2019)

The hardest part for VTOL is the control over the vertical takeoff stage due to the lack of aerodynamic forces. According to the control theory, a VTOL aircraft needs to have pitch and roll control through alternating thrust. For an optimized stable system, we need to have thrust at the wing to maximize the bending moment for roll, at the tail and the nose for the pitch control.

We found that most third generation VTOL aircraft are tested in the 60s and the reason for abandonment is the deadweight created by the vertical engines. This problem can be solved using technology from the fourth generation of VTOL using vectoring thrust and separating flow. (Ferit,2016)

3.2 Detailed Concept Development

From our preliminary concept development, we have ultimately concluded our design and present our solution to the rescuing survivors of the 2019 zombie apocalypse, the Aero One OH 600-A. Figures 8 and 9, which are listed below, are the top and side views model of our rescue aircraft. Our support aircraft is multi-faceted and capable of heavy supply drops, armed support against zombie resistance, and can safely transport up to 30 survivors (excluding crew of the aircraft). Detailed specifications regarding sizing and configurations are provided below as well.

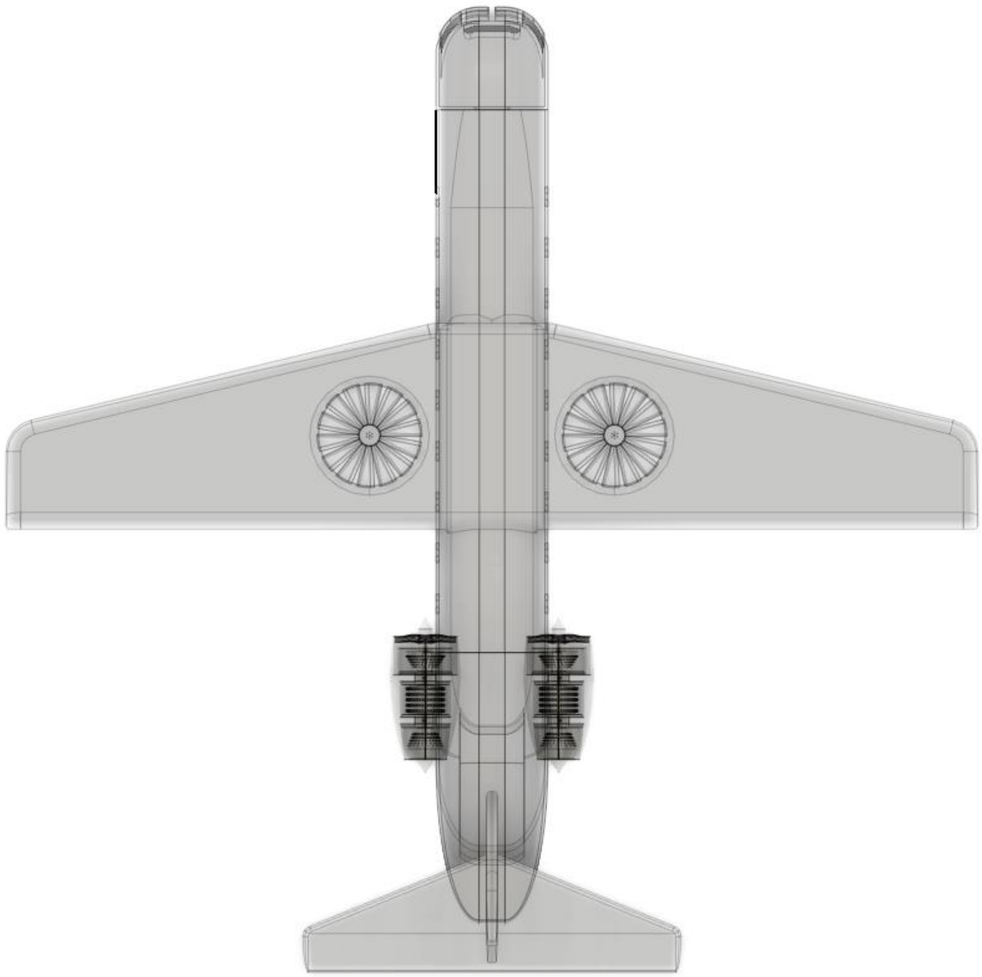

Fig 8: Top view of the concept aircraft

Fig 9: Side view of the concept aircraft

3.2.1 Sizing

Table 2: Aircraft specifications

Length	85 ft	25.9 m
Wingspan	65 ft	19.8 m
Height	30 ft	9.1 m
Wing area	700 ft^2	65 m^2
Empty weight	33535.40 lb	15211.4 kg
Max takeoff weight	60000 lb	27216 kg
Duct fan diameter	6.56 ft	2m
Fuselage diameter	10 ft	3 m
Fuselage height	12 ft	3.7 m

To determine these aircraft sizing parameters, we first looked at historical data of aircraft designed for a similar mission or similar payload. Aircraft considered were the V-22, V-280, Do-31, E-170, and others. These aircraft were designed for either search and rescue, vertical takeoff and landing, or transportation of a similar sized payload as that specified in our requirements. We then attributed characteristics of these aircraft to their mission performance, for example, the Do-31 has a smaller wing area for its fuselage size(Green,1968), compared to the E-170 because it has larger engines, and therefore more thrust available to convert into lift, whereas the E-170 must rely on a larger wing and less thrust to generate the same amount of lift. Then, we generated estimates for our aircraft parameters by first identifying characteristics our aircraft requires, and then identifying the associated parameter from the historical aircraft. For example, the Do-31 is of a comparable size and mission profile to our aircraft, particularly with the VTOL aspect. Therefore, our aircraft’s wing area will be similar to that of the the Do-31. Because we would aim for a higher capacity than the Do-31 (more like E-170 size), we scaled the wing area (and the maximum takeoff weight, etc) up slightly, to a value larger than the Do-31 but still smaller than the E-170. This basic process was applied to all aircraft parameters identified.

Fig 10: Dornier Do-31 (modelersite.com, Accessed 2019)

3.2.2 Aerodynamic design

For our wing design, we decided that our aircraft needs to have good low-velocity performance for VTOL to cruise transition, as well as high-velocity performance for the cruise segment. An airfoil with high degrees of laminar flow up to 60 percent is preferable, since high laminar flow reduces drag and increases lift. The 60 percent margin was decided since the leading airfoil designs have values up to 60 percent laminar flow. Higher numbers are more desirable since real-world factors are certain to lower the laminar flow percentage--crosswinds, turbulence etc. (National Advisory Committee for Aeronautics, Accessed 2019)

The primary candidate for the aircraft's airfoil is the NACA 66-415 which is characterized by the 60 percent laminar flow at a neutral angle of attack.

Table 3: Wing specifications

Breakdowns of key wing dimensions	
Wingspan	19.8 m
Aspect ratio	6.03

Mean chord	3.96m
Sweep angle	22°
Cd_0	0.025

Fig 11: NACA 66-415 airfoil cross section

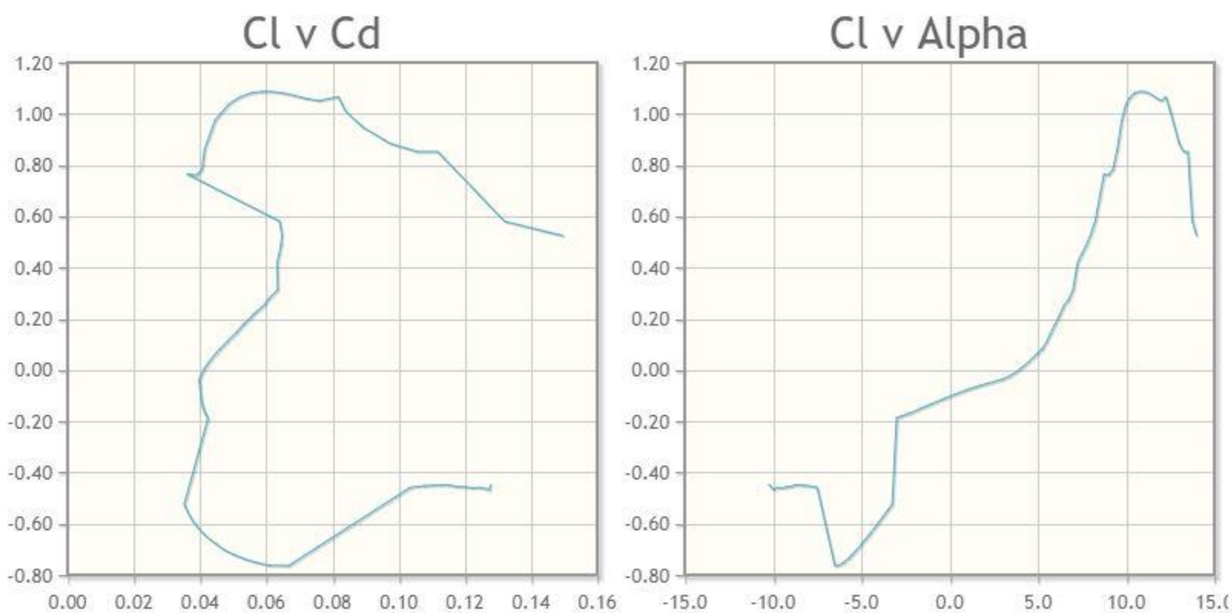

Fig 12: C_L and C_D and angle of attack relationships

(National Advisory Committee for Aeronautics, Accessed 2019)

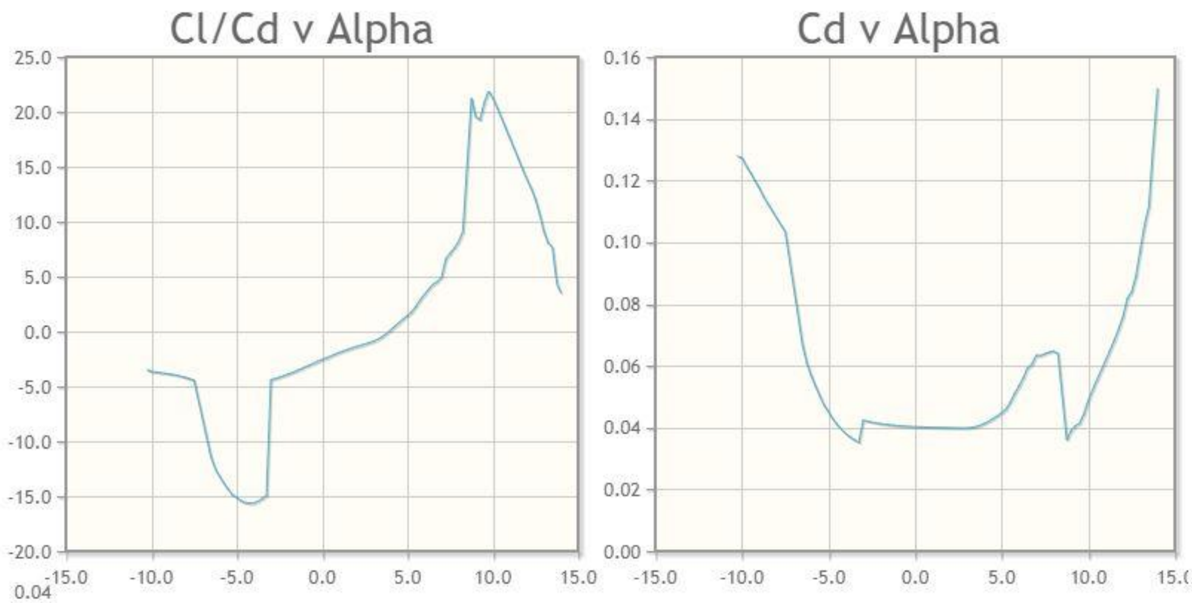

Fig 13: C_L and C_D and angle of attack relationships (part 2) (National Advisory Committee for Aeronautics, Accessed 2019)

3.2.3 Mass budget

Breakdowns of key components & weight	
Component	Weight (kg)
Engine	3270.4
Structure	10741
Transmission	800
Flight system	1000
Fuel	8000
Payload	4000
Empty weight	15211.4
Loaded weight	23211.4
Max takeoff weight(1.1 times full load)	29932.54

Table 4: Weight breakdown of key components & weight

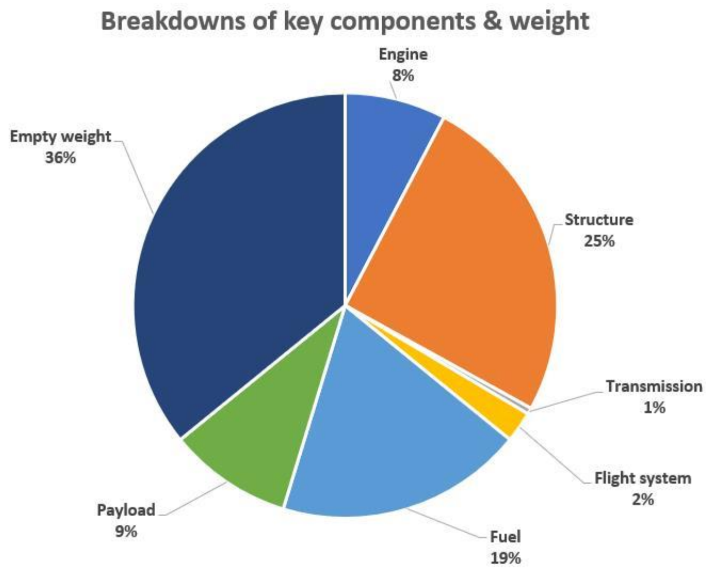

Fig 14: Key components of weight breakdown

The mass budget is calculated by adding up the weight of each component. We used a base model of a similar size/function aircraft, the Dornier-31 and subtracted the mass of the engines and flight system. (Tayler,1969) We then multiplied by a factor of 0.8 since that is the weight we can save normally on a composite aircraft. Transmission system mass is an estimation based on existing gearboxes and shafts. Payload and fuel are based on the maximum thrust the engines can produce during takeoff. Figure 14 shows the mass breakdown of each component. The center of mass should located in between the duct fan and the the turbofan engine. The Maximum weight is the maximum lift it can provide during a vertical take off. We also need some redundant thrust for the aircraft because we need extra force to let the plane lift off. The maximum thrust is also necessary because we might not be able to use full throttle on all the engines and fans in order to achieve control. The redundant amount is 10 percent of the loaded weight. This percentage is based on the past design experience (Keen,1981), 10 percent of redundancy is enough for the aircraft.

3.2.4 Powertrain

The plane will be powered by two engines along with in-wing lift fans which are powered by the two engines. The max thrust to weight ratio is 1.1. So during a vertical takeoff, we will need 300 kN of thrust.

We have chosen an in-wing duct fan design for two reasons. First is the drag. An in-wing duct fan can be covered up during the cruising stage and won't cause extra drag as a propeller would. Second, a duct fan will produce more thrust with a smaller area than a propeller. (Bevilaqua, 2019)

Figure 15 and 16 show a theoretical pressure analysis of the rotor and duct fan.

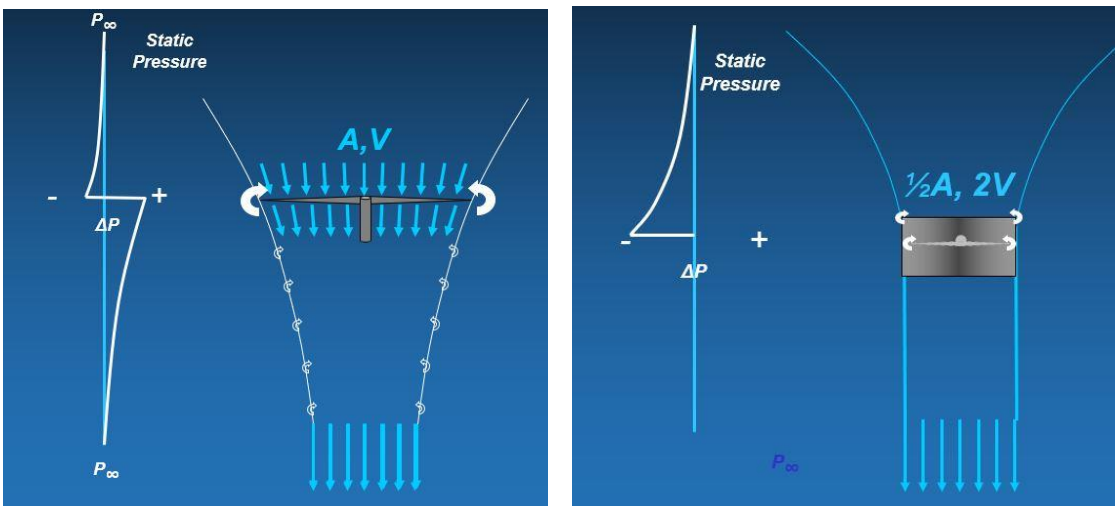

Fig 15/16: Rotor and duct fan pressure analysis

For producing the same amount of thrust, the area of the duct fan is half of the area of the rotor.

Using the area equation $A = \pi r^2$. The radius of the fan will be decreased by 30%. So for a fan in wing design, a duct fan will be more efficient.

3.2.5 Power Plant

Engine selection: Rolls Royce BR725A1

Engine company choice: Rolls Royce

Reasoning:

We chose this existing engine for two reasons. First is the high design cost and long design cycle. To design a new aircraft engine, lots of money and people are needed. For a typical aircraft engine, the design period is usually around 10 years. There is also a high risk of failure for a new engine. For that reason, we should use an existing engine design.

The second reason is we can reuse the existing engines. For each of the engines we recycle, we can save over a million dollars. Therefore, the number of existing engines will also be a factor in out engine choice.

The reason we choose engine from Rolls Royce is that Rolls Royce is a cooperative company with Purdue and they have a research center next to Purdue. We should be able to get the engine design from them and have the capability to produce more engines in their labs.

Engine type choice:

Based on the mission of the aircraft, we need an engine that is rather efficient at high altitude and high speed cruising, and the engine needs to produce enough power for vertical take off and the engine need to be light as well. Among those requirements, we have picked a low-bypass turbofan/ turboshaft engine.

Engine choice: Rolls Royce BR725A1 engines (Rolls-Royce Deutschland, 2018)

Reasoning: fuel efficiency; high thrust to weight ratio.

Max Thrust: 75.72 kN

Max- extract shaft horsepower: 13500 shp

Weight: 1,635.2 kg

Thrust to weight ratio: 4.69

Cruising altitude: 15544 m

Max cruising speed: 0.925 mach

Fuel burn rate: 2041 kg/h for taking off and climbing

1387 kg/h for cruising

This engine is commonly used on business aircraft and proved to be efficient and reliable. The power it provides allows for vertical takeoff. The maximum shaft horsepower is calculated through the conversion of turbine power output from the engine. Figure 17 below is a sectional view of the Rolls Royce BR725A1 engine.

Fig 17: Rolls-Royce BR-725A1 engine (Cross section of BR-725A1 engine, 2009)

Power configuration and Vertical takeoff control:

The power plant will have power transmitted to shaft power and exhaust thrust power. Each powerplant will drive one duct fan and their thrust can be vectored downward during vertical takeoff.

Thrust vectoring for a turbofan engine is an existing technology, and there are multiple designs that can be applied to a existing turbofan engine to vector its thrust. Rolls-Royce has modified their existing designs by adding a vector nozzle. This design can also be applied to our aircraft during a vertical takeoff.

The thrust control is achieved through the fuel system between the two power plants. A valve could control the fuel flow between the two power plants. The fan control is achieved by the gearbox. The transmission system will have a Multitronic that allows fine tuning of the rotation speed of the duct fans. During a level flight, the duct fan will shut down and the gearbox will be put into neutral. The thrust will be vectored to the back and all the power be used as thrust for level flight.

The takeoff control is achieved by thrust control of the engine and duct fan. Pitching control can be achieved by the distribution of power between the turbofan engine and the duct fan. The rolling control is achieved by distribution of power of the two duct fans.

Figures 18 and 19 below provide the basic information about the power system configuration and the physical shape. Both fans are connected with an interconnected duct between them. Valves right below the duct fans convert the power supplied into the motion of the fans.

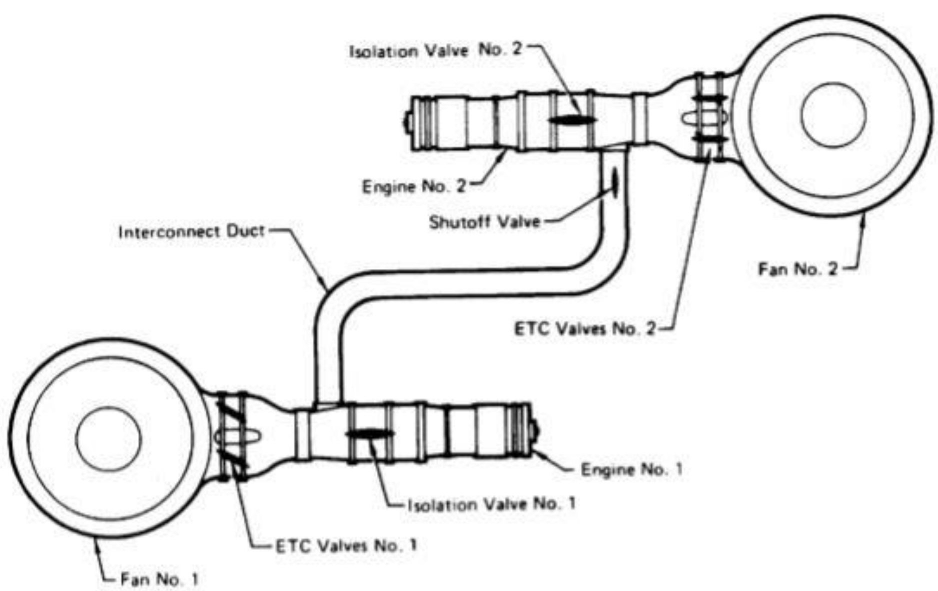

Fig 18: Power system configuration (Deckert, accessed 2019)

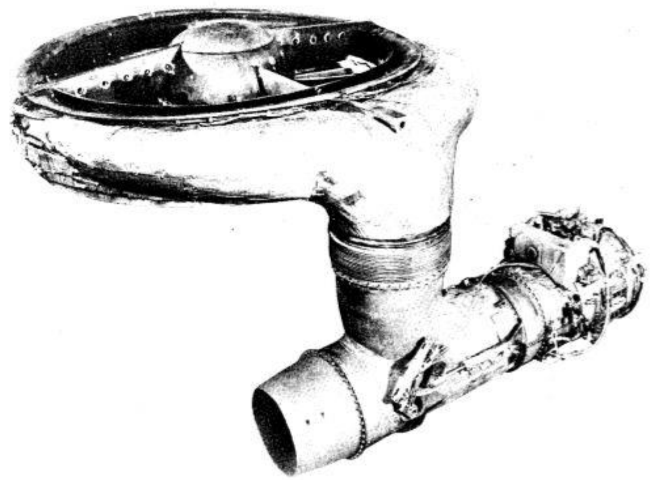

Fig 19: Power system configuration (Deckert, Accessed 2019)

Duct fan analysis

The duct fan is the main source of lift during a vertical takeoff. Except for the thrust provided by the turbofan exhaust, each turbofan needs to deliver at least 75 kN of thrust.

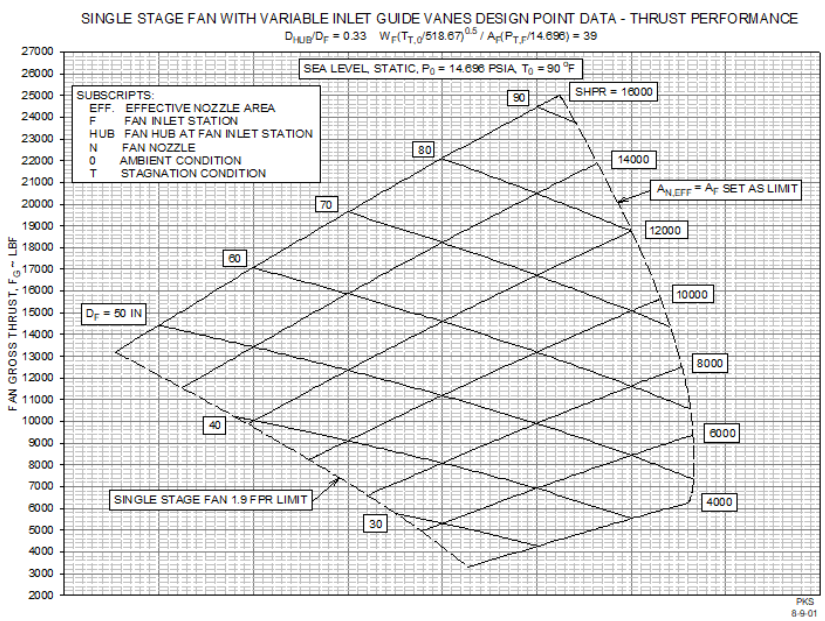

Fig 20: Power required vs. fan area (Bevilaqua, 2019)

Figure 20 above depicts the relationship between the available thrust from the fan and the diameter along with the power required. Since the thrust is mainly determined by diameter and power, the relationship is in a form of a web. Thrust increases as the diameter and power increases. Based on the maximum shaft horsepower (shp) the engine can provide, the duct fan needs to have a diameter of at least 2m to provide enough lift. We assume the fan has an efficiency of 0.8 since that is an average efficiency of any duct fan engine.

3.2.6 Dynamics and Control

The hardest thing for the vertical takeoff vehicle to achieve is control during the vertical takeoff stage. Because the plane is lacking aerodynamic forces from the control surfaces, all the control needs to be generated by the thrust. It needs to achieve roll, yaw and pitch during a takeoff.

The roll control is achieved by adjusted the power distribution between the two sides of the aircraft. In the powertrain section, we have discussed the technology to achieve this power distribution through fuel distribution. With a slightly smaller amount of power on one side, the aircraft can achieve roll control. The momentum and control is shown in the following diagram.

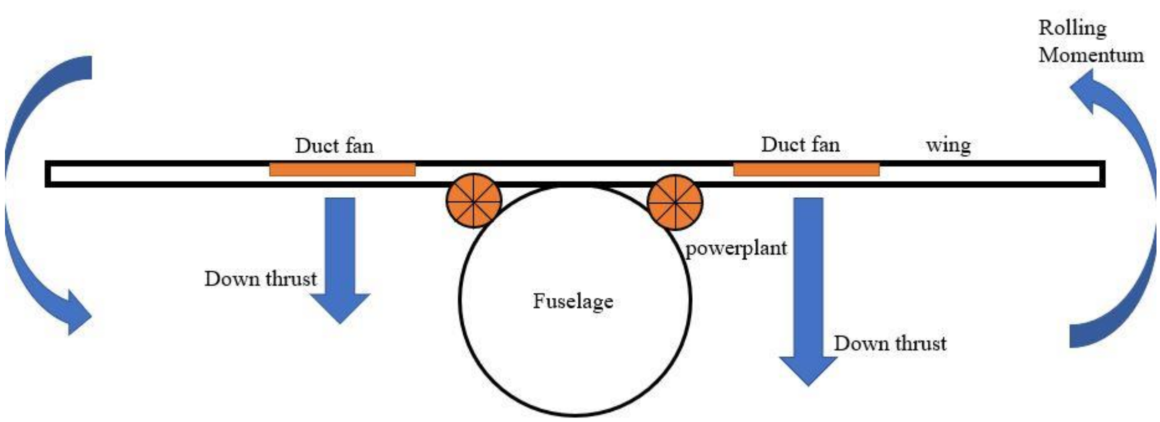

Fig 21: Roll control

The Yaw control is achieved by the flow separation from the side of the engine. Shown in the following figure, the engines are mounted on the tail side of the aircraft, and thrust from the side of the engine will create a momentum pushing the aircraft to yaw.

Top Down View

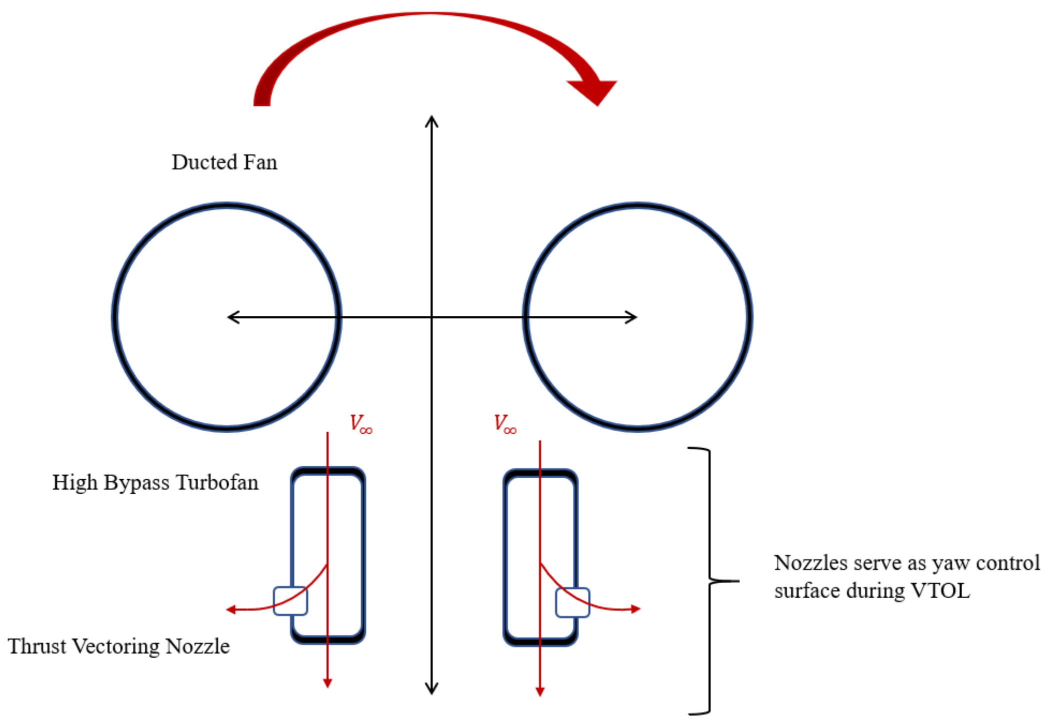

Fig 22: Yaw control

The pitch control is achieved through the thrust distribution between the engine and the lift fan. The technology to achieve this is through the gear box, discussed in the powertrain section. By delivering slightly less power from the powerplant to the duct fan, it will reduce or increase the lift from the front of the aircraft, and this thrust will cause the aircraft to pitch.The momentum and the control is shown in the following figure.

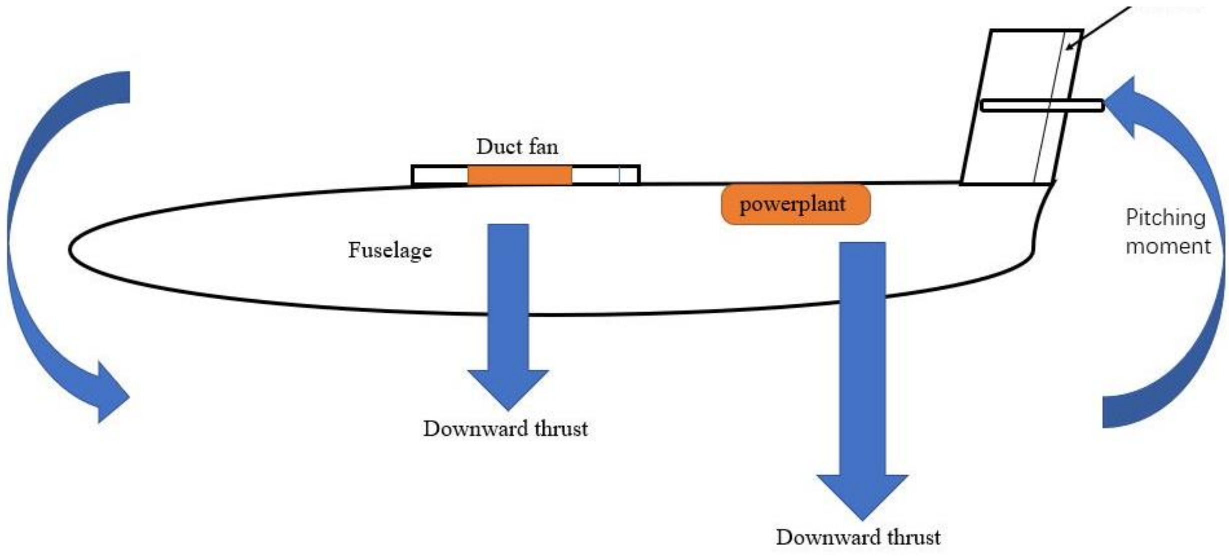

Fig 23: Pitch control

After the vertical takeoff, the control system will switch to cruising mode. The control in this will be achieved by conventional means (rudder, ailerons, and flaps).

3.2.7 Performance calculations

Maximum cruise speed: The minimum thrust required for steady, level, unaccelerated flight would be about 23000 N, which corresponds to a maximum steady, level, unaccelerated flight velocity at sea level of 108 m/s or about 240 mph. This also corresponds to a maximum steady, level, unaccelerated flight velocity at cruise altitude (12000 m) of about 215 m/s, or about 480 mph. This was calculated using the maximum speed code in the appendix.

<u>Max take-off weight(long runway): 29932.54 kg</u>

We assume that the full takeoff and landing process both takes one hour. This helps us determine the mass at the end of takeoff and beginning of the landing. At the same time, we used the mass information for the one-way trip to the destination as using half of the fuel, which is 5500 kg. The reason why the way to the destination is more important than the way back is because that we carry more fuel and thus more weight on the way to the destination. Our mission is to do a round trip instead of a one way trip, so the change in mass due to fuel loss and the inability to refuel until returning to Purdue must be considered. Thus, range and endurance should be less in the forward trip to there, since we use half amount of the fuel each time. We also assume that we are using 20000 N as gulfstream thrust during the whole process, and setting up a maximum throttle efficiency. This may slightly vary according to the pilot.

Endurance:

Based on the thrust, the endurance is 3.4003 hours. This is a reasonable number since we are going to cover the north America area. Also, the average speed is acceptable when we got range later, which is 801 km/h. The calculation process is attached in the appendix.

Range:

The calculated range is 2726 km. This distance fits our expectations, which is approximately to Las Vegas and all the east coast cities. Part of Canada and Mexico can also be covered. We divided the entire flight into three phases. The first one is takeoff, we considered the variation of air density and chose the average calculated range value. The second one is the cruising phase. Since we are operating at cruise altitude, we used the air density at cruise altitude. At last, landing phase also takes the average value corresponding to each air density from maximum altitude to sea level. The final range is the sum of the ranges from three phases. The calculation process is attached in the appendix. Figure 24 shows the relationship between the maximum range of the the aircraft from Purdue to the rescue spot and the throttling setting which is controlled by pilots. As the throttling setting number increases, the range increases proportionally.

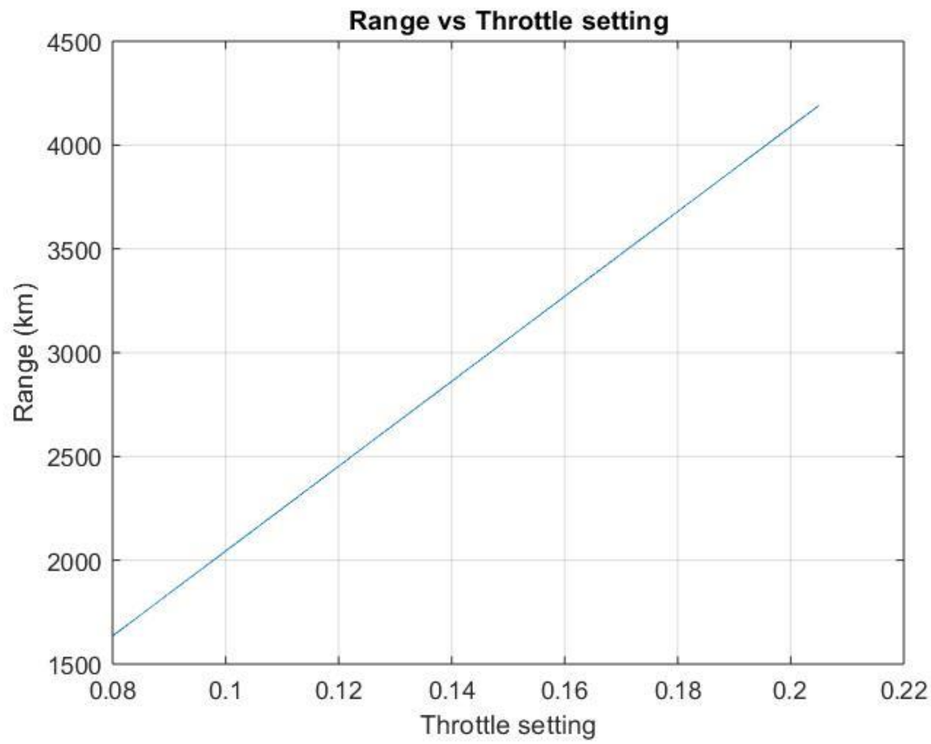

Fig 24: Range vs. throttle efficiency setting

Flight ceiling:

The theoretical flight ceiling at maximum thrust is 22500m or about 73800 ft. However, our aircraft will never exceed 15000 m (~49200 ft) because of cabin pressure limitations. This was calculated using the flight ceiling code in the appendix. Figure 25 below displays the relationship between the required/available thrust and altitude The x-axis value of the intersection between two curves determines the maximum altitude, which is flight ceiling.

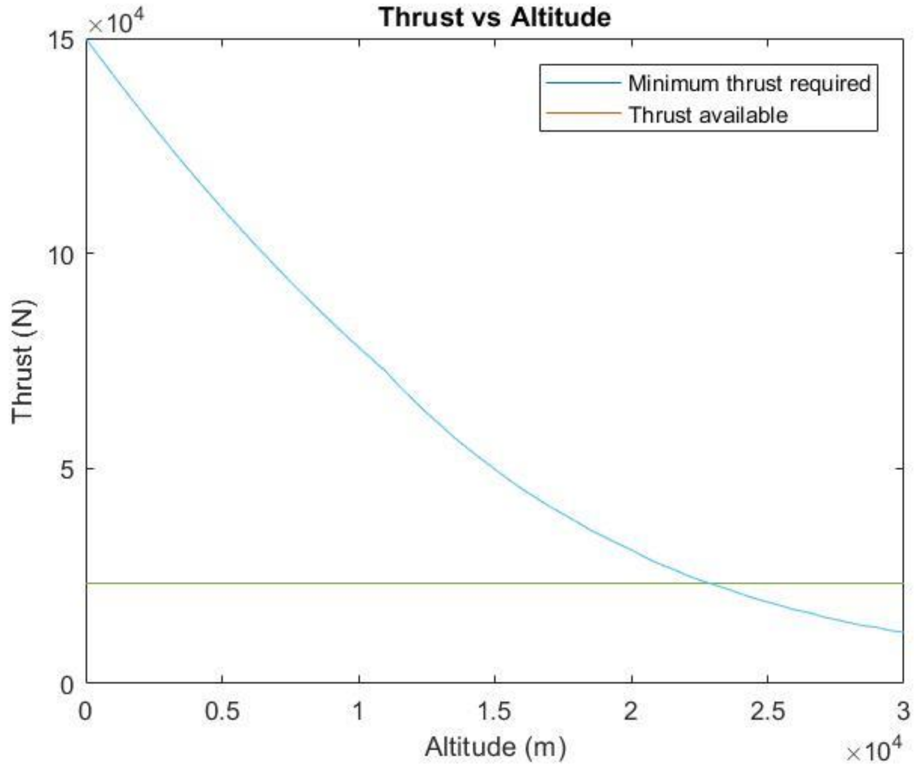

Fig 25: Required and available thrust vs altitude

3.3 Configuration Suggestions

Although the primary mission of this aircraft is to conduct rescue missions, there is rooms for expansion to the role of this aircraft. The rescue missions for survivors have a finite life span and eventually there will be a need for zombie counter attacks in order to reclaim habitable zones, resources, and land for sustainable food production. If a cure to the zombie disease is not found and humanity has to rely on non nuclear warfare, our aircraft can be converted to a heavy gunship, support gunship, or a light all purpose transporter with supply drop capabilities.

3.3.1 Heavy Gunship - OH 600-AG

For our mission, we require the heavy gunship configuration to have the ability to defend a 60 x 60 m area for at least 1 hour. It is expected that these aircraft will be the first to encounter a zombie ridden area and clear them out to create a safe space to rescue survivors from. For this mission, the aircraft will need to be equipped with anti zombie weapons, which we categorized as weapons capable of destroying large amounts of "soft", slow moving targets. We have determined the weapons used based off military aircraft designed for a similar mission in active service today. Aircraft considered were the AH-64 Apache and the AH-1 Super Cobra. These weapons will be acquired from existing stockpiles near our manufacturing site. We have identified the following weapons that the aircraft will be equipped with.

1. 70mm Hydra Rockets
2. M230 chain gun
3. M2 machine gun

3.3.2 Support Gunship - OH 600-AS

The support gunship has a similar mission to the heavy gunship. However, the support gunship will only be required to defend its immediate area from the occasional zombie as it provides cover for survivors entering itself or other rescue aircraft. As such, we have determined the weapons this model will carry based on military aircraft satisfying a similar mission Aircraft considered were the UH-60 Blackhawk and the MH-6 Little Bird. Similarly to the heavy gunship, modifications for this configuration will be sourced from existing stockpiles.

1. M2 Machine gun
2. M134 minigun

3.3.3 Light Transporter - OH 600-AT

The light transporter model will be the primary passenger transporting aircraft configuration. This configuration will have no mounted armaments and is meant to be operated in conjunction with other aircraft for the successful completion of the mission.

4 Conclusions

In the conclusion section, we have included the Design evaluation of our final design; The next step for this design will be the detailed system engineering and testing. This section also included the lessons we learnt from this design process.

4.1 Design Evaluation

We designed the OH 600-A around requirements that we thought were best suited for a post apocalyptic search and rescue aircraft. Despite meeting all of the requirements, hindsight inevitably points out potential flaws. We stand behind our decision to proceed with a VTOL design since it offers advantages to STOL aircraft, conventional takeoff and landing aircraft, and rotary wing aircraft. The OH 600-A is able to land and take off from dense terrain with small clearings, whereas other aircraft require large, open, even spaces. The advantages come at a cost, though. The aircraft is prone to losing control and perishing in strong gusts of wind due to the large aspect ratio of the wings. If strong gusts strike the aircraft from the side flanks, there could be enough lift generated by one wing to cause a large rolling moment, flipping the aircraft over. We believe that with the help of on board computers and sensors, the aircraft may be able to adjust itself, however, that is an additional expense. Furthermore, we do not have sufficient knowledge of or experience with ground effects, especially those caused by the upwash of ducted fans. These effects may prove to render the aircraft inoperable in terrain with an abundance of loose debris.

4.2 Next Steps

In this report, we have discussed the process of analysis the mission, interpret the needs and requirement, risk analysis. We have also did the general concept generation of the basic parameters and configuration of the aircraft. The next step of the design is to specify the design of each system. The power system needs to dive deeper into the thrust distribution, duct fan design and vectoring thrust design. The Aerodynamic team needs to focusing on designing the fuselage shape, specified the shape and parameters of main wing / vertical and horizontal stabilizer. A flap would also be necessary in this design. Structure system need to design a airframe that is able to hold this aircraft, they need to design and model the frame and go through force and pressure analysis. etc. During this process, we will need to solve all the engineering problems and make a specified design.

After the first round of specification design, the initial small scaled model will go through CFD analysis and small scale wind tunnel test to check the design. Then, some changes and updates need to be made based on the test results.

The second round of testing will be a small scale test, by building a small scaled model, we can test fly it and determine the problems and refine the model appropriately.

We will also need to come up with a budget report and production solution. Including price for each unit, operational cost, manufacture process, time and solution.

4.3 Lessons Learned

During the course of the project, the team learned multiple lessons. The first was that we needed to seek assistance when required, and to get assistance as soon as possible (after all, asking questions is how one learns). Going to office hours gave the team an entirely new perspective of the design, and a large number of trade-offs relevant to S/VTOL design were made evident.

Regarding team dynamics, two main lessons were learned. The first was to designate a person in the team to keep track of progress covered during each meeting. Trying to remember what was talked about during the previous meeting is unreliable (and quite dangerous too if ever done in industry). Having written evidence of what was covered forms solid ground for more reliable work output (and possibly a higher level of the same) from the team.

Another lesson learned in the same area was the need for a moderator in the group. The designated moderator would remind the group to stay on focus when the topic of conversation drifts too far from the goal at hand, and help the group decide on an agenda to be covered in the current and future meetings. This would ramp up productivity of each team meeting held.

A final lesson learned during the project was that Google docs has significant room for improvement. When five people are typing content into parts of a document while a single other person is editing something on an earlier page, Google's software miscalculates the amount by which it must scroll on each of the five peoples' screens to ensure that they do not lose track of what they are typing. (Google Docs tends to scroll past the user's cursor, which has been a repeated source of frustration in the team.)

References

1. Gavine, A., 2019. The crazy Boeing 747 aircraft carrier concept. *Aircraft Interiors International*. Available at: https://www.aircraftinteriorsinternational.com/videos/the-crazy-boeing-747-aircraft-carrier-concept.html (Accessed April 24, 2019).
2. Nelson, B.D., 1973. INVESTIGATION OF A -MICRO-FIGHTER /AIRBORNE AIRCRAFT CARRIER CONCEPT
3. "Lightning Strike is…" . (Accessed 15th April 2019). LightningStrike X-Plane. Retrieved from https://www.aurora.aero/lightningstrike/
4. ASH, staff, 2016. Lightning Strikes Aurora. Available at: https://vtol.org/files/dmfile/10AuroraDarpa2.pdf (Accessed April 24, 2019).
5. Company, H., Honda Global | Aircraft Engine. *Honda Global | Aircraft Engine*. Available at: https://global.honda/products/HondaJet/aircraft-engine.html.
6. Company, Boeing. "V-22 Osprey Technical Specifications." *Boeing*, 2017, www.boeing.com/defense/v-22-osprey/#/technical-specifications.
7. V-22 Osprey Guidebook, 2013/2014. Archived October 20, 2014, at the Wayback Machine Bell-Boeing, 2013. Retrieved: 6 February 2014. Archived in 2014.
8. *11.3 Implications of Propulsive Efficiency for Engine Design*, web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node82.html.
9. Anon, 2018. Lessons from The V/STOL Wheel of Misfortune. *Passerine Aircraft Corporation*. Available at: https://passerineaircraft.com/lessons-from-the-vtol-circle-of-misfortune-821/.
10. Bevilaqua, Paul. "S/VTOL Short Lecture." Apr. 2019, West Lafayette, Purdue University.
11. Çakici, F. & Leblebicioğlu, M.K., 2016. Control System Design of a Vertical Take-off and Landing Fixed-Wing UAV. *IFAC-PapersOnLine*, 49(3), pp.267–272.
12. Green, William (1968). The Observer's Book of Aircraft. London: Frederick Warne & Co. Ltd. p. 88.
13. Taylor, John W.R., ed. (1969). Jane's all the World's Aircraft 1969–70 (60th ed.). London: Sampson Low, Marston & Company. pp. 90–92.

14. Keen, J. “Reliable Power (Rolls-Royce Aircraft Engine Designs).” International Aircraft Maintenance Engineering Exhibition and Conference, Zurich, Switzerland, Paper; Switzerland; 10-12 Feb. 1981, 1981, p. 20.
15. Thai Military and Asian Region. (Accessed 15th April 2019). Lockheed Martin F-35 Lightning Retrieved from https://thaimilitaryandasianregion.wordpress.com/2015/12/15/lockheed-martin-f-35-lightning-ii/
16. John Horst, *Building the Dornier Do 31 E3, S/VTOL from Planet models 1/72 scale*, modelersite.com. Available at: http://www.modelersite.com/en/1876/building-the-dornier-do-31-e3--s-vtol-from-planet-models-1-72-scale [Accessed April 24, 2019].
17. Bevilaqua, P. (2019), *Thrust developed by a rotor*. [Accessed 20th April 2019].

Appendix A: Risk analysis table

Risk Analysis					
Source	**Hazard**	**Parameters**	**Effect**	**Danger zone**	**Mitigation**
Mechanical failure	Landing gear loss	Number and size of free debris particles per unit volume	Unable to land normally	Ground	Multiple systems ensure the system work. electrical/ hydraulic/ manual. If jammed, use vertical landing.
Mechanical failure	Vertical engine power loss	Effective maximum thrust generated by affected engine	Unable to perform vertical takeoff	Ground/ near ground	Try to find a runway and switch to horizontal takeoff
Mechanical failure	Fuel leak	Decrease of mass of fuel tank per unit time	Lost range; engine choke	In air	In air refuel system/ multiple fuel tanks/ multiple layer fuel tank
Mechanical failure	Broken rudder	Degrees of yaw bias	Loss of yaw control. unstable flight	In air	Multiple systems ensure the system work. electrical/ hydraulic/ manual. Use vertical landing in emergency situation

Mechanical failure	Cargo door won't lock	Pressurization of air inside the cargo bay	Lost pressurized cabin. air dynamic loss	In air	Fly at a lower altitude/ slower speed.
Mechanical failure	Air speed indicator failure	Reliable/Unreliable readings	Unable to identify speed	In air	Back up system. GPS etc.
Mechanical failure	Altimeter failure	Inaccurate altitude readings	Unable to identify altitude	In air	Back up system. GPS altitude.
Mechanical failure	Reverse thrust malfunction	Effective maximum deceleration contributed by affected engine upon touchdown	Unable to slow down aircraft	On ground	Backup system such as parachutes, strong mechanical brakes
Mechanical failure	Brake malfunction	Rate of deceleration of the aircraft after touchdown	Unable to slow down aircraft	On ground	Backup system such as parachutes, use strong reverse thrust
Mechanical failure	Flat tires	Pressurization of air in the tires of the landing gear	Unable to slow down aircraft, risk of structural damage	While landing/ on ground	Land as gently as possible, make use of vertical landing,Hover in place while tires are refilled/replaced.
Mechanical failure	Flaps malfunction	Damage/flap extension may be visually inspected through window	Unable to provide sufficient lift during takeoff	During takeoff	Abort takeoff, fix flaps or takeoff with additional velocity

Mechanical failure	Horizontal engine lost power	Effective maximum thrust contribution of affected engine	Unable to power aircraft	In air	Find nearest possible landing area, glide and switch to vertical landing
Loss of Command	Unconscious or injured pilot	Loss of pilot input to the aircraft	Loss of vehicle control	Ground & Air	Life support & Copilot or autonomous capabilities
Loss of Command	Loss of pilot's life	Loss of pilot input to the aircraft	Loss of vehicle control	Ground & Air	Copilot or autonomous capabilities
Loss of Command	Communication loss from ground control	Distortion/loss of pilot voice with ground control	Inability to communicate with ground control and possibility of mission failure due to lack of communications	Ground & Air	Backup communications devices
Loss of Command	Vehicle severely damaged or destroyed	Cabin depressurization, amount of thrust contribution from each engine, Pressurization of landing gear tires, Changes in airworthiness of airframe	Inability to operate vehicle, mission failure, & crew life at high risk	Ground & Air	Emergency communications, life support, & defensive capabilities
FOD	Bird Strike	Loss of thrust contribution from the affected engine	Destroy power system/ damage structure	Air	Switch between engine/ emergency landing plan

FOD	Zombie attack	Cabin depressurization, amount of thrust contribution from each engine, Pressurization of landing gear tires, Changes in airworthiness of airframe	Structural damage	Ground	Equip aircraft with zombie repellent and sufficient defense mechanisms
FOD	Sand	Structural integrity of windshield, maximum thrust contribution of each engine	Functionality of engines and windshield may be compromised	Ground	Use vertical landing for sandy surface to avoid engine damage
Weather conditions	Heavy precipitation	Inches/hour, information will be relayed from ground control	Low visibility, disruption of airflow over the airfoils	Takeoff/landing, in air	Backup proximity sensors, GPS navigation
Weather conditions	Dense fog	Feet or miles of visibility	Low visibility	Takeoff/landing, in air	Backup proximity sensors, GPS navigation
Weather conditions	Heavy wind/storms	Wind speed and direction, speeds and directions of gusts	Flight stability	In air	Rely on vertical engines for flight, ground fleet if necessary
Weather conditions	Extreme temperatures (cold/hot)	Degrees Centigrade	Engine efficiency, structural damage, limits horizontal takeoff ability	On ground	Deicing procedures, coolant to keep aircraft cool, use vertical takeoff

Weather conditions	Lightning strikes	Number of strikes, effective electrical power discharged from the strike (can be estimated via calculation)	Structural damage, Loss of electric systems	In air	Use copper mesh EMF layer on top of composite to alleviate effect of lighting strikes

Table 1: Risk Analysis

Appendix B: Matlab Code

Flight Ceiling Code

```
m = 29932.54; % kg
g = 9.8; % m/s^2
e = .8;
AR = 6.3;
K = 1/(pi*e*AR);
CD0 = .025;
p0 = 1.225; % kg/m^3
Mad = .6;
T0max = 150000; % N

alt = [0:.5:30]*1000; % altitude, m
p = [1.225,1.167,1.112,1.058,1.007,0.957,0.909,0.863,0.819,0.777,0.736,0.697,0.660,0.624,0.590,
    0.557,0.526,0.496,0.467,0.440,0.414,0.389,0.365,0.337,0.312,0.288,0.267,0.246,0.228,0.211,
    0.195,0.180,0.166,0.154,0.142,0.132,0.122,0.112,0.104,0.096,0.089,0.081,0.074,0.069,0.063,
    0.058,0.054,0.050,0.046,0.042,0.039,0.036,0.033,0.031,0.028,0.026,0.024,0.022,0.021,0.019,
    0.018]; % air density corresponding to alt, kg/m^3

Tmin = 2*m*g*sqrt(K*CD0)+zeros(length(alt));

Tav = (p./p0).^.6 * T0max;

plot(alt, Tmin)
hold on;
plot(alt, Tav)
xlabel('Altitude (m)')
ylabel('Thrust (N)')
legend('Minimum thrust required', 'Thrust available')
```

Maximum Speed Code

```
pSL = 1.225; % kg/m^3, at sea level
pCr = .311; % kg/m^3, at 12000 m (cruise altitude)
S = 65; % m^2
CD0 = .025;
e = .8;
AR = 6.3;
K = 1/(pi*e*AR);
m = 29932.54; % kg
g = 9.8; % m/s^2
Tmax = 150000; % N
%throttle = .17;

Tmin = 2*m*g*sqrt(K*CD0);
VminSL = sqrt(((2*m*g)/(pSL*S))*sqrt(K/CD0));
VminCr = sqrt(((2*m*g)/(pCr*S))*sqrt(K/CD0));
```

Range Calculation Code

Constants

```
mad=0.6; %air density exponent
n=0.8; %propeller efficiency
rho0=1.225; %(kg/m^3) air density at sea level
throt=1; %maximum throttle setting
h=[0:1:12500]; %(m) set up altitude
s=65; %(m^2) wing area
e=0.8;
AR=6.3;
m0=23211.4; %(kg)mass

g=9.80665; %(m/s²)Earth gravitational constant
k=1/(pi*e*AR); %1/(pi*e*AR)
cd0=0.025; %zero-lift drag ratio
p0=101325; %Pa pressure at sea level
T0=288.15; %K
L=0.0065; %K/m
R=8.31447; %J/(mol·K)
M=0.0289644; %kg/mol
T=T0-L*h;
p=p0*((1-(L*h)/T0).^(g*M/(R*L)));
rho=p.*M./(R.*T); %set up air density

maxclcd2=(9/16)*sqrt(1/(3*k*cd0^3));

c1=2041*g/20000/3600;
c2=1387*g/20000/3600;
```

Calculation of range

```
% takeoff
R1=(2/c1)*(sqrt(m0)-sqrt(m0-2041))*sqrt((2*g./(rho*s))*maxclcd2);
R1=mean(R1);

% taxi
R2=(2/c2)*(sqrt(m0-2041)-sqrt(m0-5500+1387))*sqrt((2*g/
(rho(12500)*s))*maxclcd2);

% landing
R3=(2/c2)*(sqrt(m0-5500+1387)-sqrt(m0-5500))*sqrt((2*g./
(rho*s))*maxclcd2);
R3=mean(R3);



R=(R1+R2+R3)/1000

% variation is throttle
trt=[0.08:0.00001:0.205];
trst=150000*trt;
c11=2041*g./trst/3600;
c22=1387*g./trst/3600;

%

for n=1:1:12501

R11=(2./c11(n)).*(sqrt(m0)-sqrt(m0-2041)).*sqrt((2*g./
(rho*s))*maxclcd2);
R11=mean(R11);

R22=(2./c22(n)).*(sqrt(m0-2041)-sqrt(m0-5500+1387)).*sqrt((2*g/
(rho(12500)*s))*maxclcd2);

R33=(2./c22(n)).*(sqrt(m0-5500+1387)-sqrt(m0-5500)).*sqrt((2*g./
(rho*s))*maxclcd2);
R33=mean(R33);

RR(n)=R11+R22+R33;
end
RR=RR/1000;


R =

   2.7259e+03
```

Plot

```
plot(trt,RR)
xlabel('Throttle setting')
ylabel('Range (km)')
title('Range vs Throttle setting')
```

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Endurance calculation code:

Constants

```
mad=0.6; %air density exponent
n=0.8; %propeller efficiency
rho0=1.225; %(kg/m^3) air density at sea level
throt=1; %maximum throttle setting
h=[0:1:12500]; %(m) set up altitude
s=65; %(m^2) wing area
e=0.8;
AR=6.3;
m0=23211.4; %(kg)mass

g=9.80665; %(m/s²)Earth gravitational constant
k=1/(pi*e*AR); %1/(pi*e*AR)
cd0=0.025; %zero-lift drag ratio
p0=101325; %Pa pressure at sea level
T0=288.15; %K
L=0.0065; %K/m
R=8.31447; %J/(mol·K)
M=0.0289644; %kg/mol
T=T0-L*h;
p=p0*((1-(L*h)/T0).^(g*M/(R*L)));
rho=p.*M./(R.*T); %set up air density

maxclcd=(1/2)*sqrt(1/(k*cd0));

c1=2041*g/20000/3600;
c2=1387*g/20000/3600;
```

Calculation of endurance

```
% takeoff
E1=(1/c1)*maxclcd*log((m0)/(m0-2041));

% taxi

E2=(1/c1)*maxclcd*log((m0-2041)/(m0-5500+1387));

% landing

E3=(1/c1)*maxclcd*log((m0-5500+1387)/(m0-5500));

E=E1+E2+E3;
E=E/3600
```

```
E =

    3.4003
```

Appendix: Weekly Update Emails

01/21

This week, our team focused on planning and organization by setting up a shared Google Drive folder in which we created designated subfolders for each aspect of the design project. We then established the needs, requirements, and key stakeholders of our project as well as the mission statement of our team, Aero One.

For next week, we want to move forward on refining our requirements into measurable, attainable, and verifiable engineering problems for which we can begin to brainstorm solutions.

The main issue we ran into this week was with arranging an in person meeting because of our differing schedules, but we have resolved this issue.

01/27

This week, our team focused on editing the work we'd previously done. We reviewed and refined our needs and requirements and began thinking about how to begin solving our engineering problem. We also made sure our mission statement was a presentable and workable sentence that we all still agreed with.

For next week, we plan to begin our brainstorming of designs and making sure that we have at least an idea of how to solve each of the requirements that we set forth.

The main issue we ran into this week was that our schedule was thrown off by MLK day this past week which made us unable to meet in person. But starting tomorrow we should be back on track.

02/03

This week, our team needed to take a step back and review what we've done. We received a lot of valuable feedback on our first project update and we realized that we weren't as on schedule as we thought. We began working on implementing the recommended changes to our design report, paramount of which was to make our needs and requirements much more detailed.

This upcoming week, we plan on continuing to implement these changes and following up with you guys to see if we are at a good point before moving forward with our brainstorming.

As alluded to above, the main issue we ran into was that we did not realize we were behind schedule, so the update 1 feedback was a very good wake up call for us.

02/10

This week, our team focused on researching specific requirements for our aircraft based on our needs and requirements and "zombie behavior." We collectively pooled the information we knew about zombies from the sources listed in the project description and determined combat, flight, and maneuverability requirements. We'd also determined early on that vertical takeoff capability is something that must be included, so we also began conducting extensive research on aircraft such as the V-22 Osprey and the V-280.

Fortunately, we did not run into any issues this week, things went very smoothly.

For next week, we plan on conducting our preliminary risk assessment as well as getting started on our concept generalization brainstorming.

02/17

This week our team focused on starting our concept generation. We were able to brainstorm quite a few ideas that blended multiple existing aircraft. We also began our hazards analysis and established zombie behavior so that we can design our aircraft with these requirements in mind.

We did not run into any issues this week.

For next week, we plan on establishing the pros and cons for aircraft that we can use as a basis for a Search and Rescue mission.

02/24

Our team reviewed the feedback from the second project update and worked on correcting and adjusting the project report based on the feedback given. The primary points were describing hazards in the risk analysis with more detail, specifying the aircraft weight by using the iterative mass calculation we covered in class, and planning modifications to the base aircraft model in order to meet mission objectives.

Next week we plan on finalizing an empty mass for the aircraft and determining what type of engine to use.

03/04

Our team chose an engine type and cabin modifications for our aircraft design. Overall, we computed some specifications such as the fuel mass and inner cabin dimensions. Looking forward, our team plans to start research on the VOTW so that we can present after spring break.

We are currently having trouble determining an optimal weight and empty weight for the aircraft due to a misunderstanding of the iterative process.

03/24

This week our team distributed roles for the VOTW and made major corrections on our report based on the feedback we received.

Next week we plan on finishing research for our VOTW as well as working towards finishing or final report.

The issues we have had so far have been related to our aircraft. We have been discussing whether a VTOW aircraft is a good idea or not.

03/31

This week our team focused on regrouping our idea after spending some time working on VOTW. We have quite a bit of work in front of us incorporating the ideas given to us by both Professor Marais, the TAs, and from the discussion we were fortunately able to have with Dr. Paul Bevilaqua of Lockheed Martin. After many setbacks, we are finally at a point where work is being done completely in the template format.

Due to all the guidance that we've received, we had a clear direction as to where our project is headed and thankfully didn't run into any obstructions.

For this upcoming week, we are aiming to dive further into our detailed concept development as well as continually fine tuning our previous work.

04/10

This week we have solely focused on our VOTW presentation and report. We finished our slideshow and finalized the VOTW report. This email is quite late, we are aware and do apologise for the tardiness. Working on the VOTW made us forget about the project and the weekly update emails.

We have did not run into any issues. This week we plan on working on the project and getting as far as we can with the report before the peer evaluation. We have decided to stay with the VTOL design since we have come too far at this point to start from scratch again--our team members simply do not have the time to meet.

04/14

This week our team focused on engine specifications and thrust calculations for our aircraft. We have also been working on team evaluations and are waiting for our feedback.

We have not had any significant issues this week. We look forward to completing our report this week and next week.

04/21

Last week we concluded CAD modelling for the final design and worked extensively on the final report. Additionally, we finished the filming for the final video and will be completing the editing this week before Thursday.

We had some difficulties calculating aircraft parameters, but we were able to overcome these issues. This will be our second to last update since we will be completing the project this upcoming week.