INDIAN INSTITUTE OF TECHNOLOGY KANPUR

NACDeC-VI: The Design Challenge 2022 - Air Ambulance

SYNOPSIS REPORT

Faculty Advisor

Prof.Mangal Kothari | Aerospace Engineering | mangal@iitk.ac.in

Authors

Vardhaman Jain | Aerospace Engineering

Aaryansh Mohan Bansal | Aerospace Engineering

Lavanya Ingle | Aerospace Engineering

Dikhit Pragada | Aerospace Engineeirng

Tushar Kumar | Mechanical Engineering

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1 Introduction

1.1 Motivation for Air-Ambulance Design

E-VTOL technology will enlarge the sphere of urban transport system. It will aim to bring aerial transport system at intra-city levels as contrast to the present air flights which deliver long range inter city flights. The technology is expected to provide platform for a new phase of revolution in transport systems. A smart innovator would henceforth would not like to miss upon this golden opportunity to explore various potentials that could be extracted out from E-VTOL applications.

1.2 Importance of Air-Ambulance

The concept of air-ambulance is one such application born-out of VTOL systems. It will serve the basic purpose of medical evacuation of needy patients, but apart from this there can be other use cases. Such as:-

- There is a hierarchy of medical trauma centres depending upon the geography and average income per capita of the region. More and advanced medical facilities are provided in multi-speciality hospitals in contrast to average first-aids being provided in rural medical centers. The specialised medical centres are licensed to treat people with severe traumatic injuries. Thus their availability is mostly in high income cities. However, severe and critical injuries may create need for transport of patient from sight of the accident to these specialised trauma centers and within the effective ”golden hour”. Therefore only an air ambulance would be able to cater to the needs of the patient in this case.

- Regular car ambulances would not be able to deliver solutions in situations of road damage or natural disasters. In such cases since road routes would be inaccessible, only way of medical evacuation can be via aerial routes. use of military helicopters are a common sight in such situation, however since these vehicles are not engineered to cater specifically to the medical needs, usually a compromise is done towards the safety and comfort of patient. Such scenarios can be overcome by the availabily of an efficient air ambulance.[5]

2 Understanding of the Problem Statement

Lets Split the question in half. First, we get a big-picture look, then we go deeper. We need an Air Ambulance that can take off vertically and has room for the patient and paramedics. Even while we may get a helicopter that can serve the function, it's vital to highlight that it's not fully equipped with medical facilities or fully autonomous. Besides, economically also, it's not easy or readily available. We must construct an autonomous VTOL employing existing technology rather than creating new design challenges. Also, the design must use as many off-the-shelf tools and components as feasible to reduce dependency on OEMs (OEMs). Last, we must track aircraft size. This implies its footprint should be between 10 x 10 metres and precisely within 12 x 12 metres, and the design should correspond to EASA's vertical takeoff and landing aircraft standards (VTOLs).

Now as we progress, we move towards a finer scale. Make sure there is adequate space for a stretcher and all of the medical equipment indicated in the issue description. It's vital to examine several aircraft layouts and then pick the best one for our needs. Other system subassemblies, such the rotor, tail, etc., require the same activities. Computer-aided designs must be developed for the aircraft, including all the other subassemblies. To illustrate the three distinct perspectives of the vehicle as it goes through its many stages of deployment, orthographic projections can be created using either the first or third aspect. In-depth study and analysis must be done on the vehicle's dynamic features, such as flying height, system power, and energy utilisation.

The next step in the process involves analyzing it through the lens of the design of the vehicle's propulsion system, which serves as the design's central nervous system. It is necessary to carry out research before arriving at a decision on whether a hybrid or an electric kind of propulsion system should be utilised. It is imperative that enough consideration be given to the effectiveness of the energy conversion process, as well as the dimensions of the batteries and the secondary battery charging equipment, such as internal combustion engines. Other critical components like the propeller, motor, gearbox, and controller need to be compatible with other previously described difficulties and equipment in order to satisfy the design requirements of the aircraft.

In conclusion, but certainly not least, we must not overlook the importance of the aircraft's total gross weight, which includes all of its parts. As a result, we need to do research on the appropriate method of selecting materials for the production of a variety of aircraft interior equipment and the aircraft as a whole. It is necessary to do research on a variety of physical parametres, such as the centre of gravity, the products of inertia, and the moment, in order to carry out additional analysis of maximum bending and torsional loading.

3 Key Design challenges and Design Drivers

Successful application of air ambulance will depend on the feasibility of scalability, acceptance by the society and it's advantages over the existing mode of medical evacuation facilities. Broadly there would be two major types of challenges:

- Commercial Design Challenges: These refers to the barriers that one would had to face in order to commercialize the air ambulance service. These would involve
  - Certifications from the authoritative organizations.
  - Development of relevant infrastructure apart from the air ambulance eVTOL.
  - Sustainable urban air mobility plan.
- Design Challenges: They correspond to the associated challenges with the conceptual design of the air ambulance evtol. Any new product would be marketable if it has unique selling proposition(USP). There already exists air ambulances that are being manufactured and being already in use by many medical service providers globally. Therefore, key design challenges would be driven by a bunch of existing engineering challenges with the evtols and incorporate other parametres that could have the potential to make our vehicle advantageous over the existing and possibly upcoming designs. In the following sections we list the design drivers and major issues that we aim to deal with through our design.
- Design Drivers:
  1. **Safety:** The need for air ambulance would be in life-saving scenarios where sometimes even reaching and landing safely could be critical. When we talk about safety of design, we are dealing with the safety of a casual or unobservant individual who may be not be fully aware of his her surroundings. Therefore the vehicle

in general should not have sharp, cutting outer body that could cause injury. For example many accidents have been reported due to tail rotors. Thus incorporating ducted tail rotors in design would add up to more safety. Thus safety in our context refers to the physical design being soft to the user and having back up technical options.

2. **Speed:** Speed should be one of the most important design drivers since we are dealing with emergency services. The utility of air ambulance would depend upon whether it can help in proving medical aid to the patient within the "golden hour".

3. **Size:** Apart from intra-hospital transfer of patients or from buildings to hospital, the requirement of an air ambulance can be in scenarios where there is no road accessibility or road connectivity from the sight of accident to medical center. Therefore the vehicle should have compact design so as to be capable of landing in most congested situations. The size we are aiming is comparable to a car parking on four lane city road.

4. **Acoustics:** Air ambulance would be an urban air mobility product and generally operated at lower altitudes(for patient comfort and safety) as compared to conventional helicopters. Therefore noise levels of the vehicle should be considerably low to gain social acceptance and cause lesser comfort to nearby people. Any seriously injured patient who is concious should not feel discomfort due to noise at the time of arrival of ambulance at accident site.

5. **Transition:** The transition phase should be very comfortable and easy process. There should be no compromise on this aspect specially due to critical medical equipment's, sensitive senors and the utmost care of the patient. We consider the fact that the paramedic may need to constantly attend the patient and thus it he or she may not be seated at transition phase. Therefore transition should be very comfortable and should not be much noticeable from inside.

6. **Ease of Certification:** This category took into account how easily and likely it would be for the vehicle to receive government approved certification. Positive evaluations were given to aircraft configurations that have already received certification and may be in use in another weight class. Another important issue in this category was the readiness of the technology.

7. **Cost:** Every marketable product has cost as important aspect associated with it. Lesser costs would make the product more accessible and thus increasing market revenue. However, no compromise on quality should be there. Thus we compare designs on the basis of minimum expected technological costs or manufacturing costs that the configuration would have to bear.

8. **Maintainability and reliability:** The more the number of runs that the vehicle would be able to perform, the more will be its usability and feasibility. This will happen when the eVTOL needs lesser maintenance. The eVTOL is engineered to operate in an emergency. Therefore, this category includes the logistical support the VTOL needs, such as ground transportation, refueling/recharging, and recovery from emergency landings. Being able to operate in a medical evacuation with ease and without adding to its logistical weight favours an eVTOL with a smaller logistical footprint.

9. **Maneuverability:** The vehicle must have good maneuvering capability as it would operate at somewhat lower altitudes. Moreover, unlike conventional airplanes which operate on fixed routes, the air ambulance should be able to take any route under adverse weather conditions and operate in day and night. Therefore the vehicle should have good maneuvering.

10. **Hover efficiency:** Since we are targeting eVTOL, the vehicle should have hover capability. Also it may be possible that landing conditions are not appropriate so patient may have to be uplifted. Moreover, the air ambulance may have to loiter so as to wait for ground clearance.

11. **Payload fraction:** This section took into account the payload to maximum take-off weight ratio. Increased payload fraction results in higher productivity. Inherently heavy configurations thus received lower marks in this area.

- **Battery:** eVTOLs are difficult to glide or auto-rotate without the right battery management system. These planes would need a lot of battery power to take off in addition to having enough battery storage for an eVTOLs flight. It will be necessary to recharge eVTOLs after couple of lights since they would be making several flights each day. The largest difficulty is in power management because of this.

- **Electric propulsion:** The requirement for many electronic systems to communicate

Prioritization Matrix	Safety	Speed	Acoustics	Maintainability & Reliability	Size	Hover Efficiency	Payload Fraction	Maneuverability	Ease of Certification	Transition	Cost
Safety	1	2	4	9	3	9	8	9	6	5	7
Speed	1/2	1	3	8	2	9	7	9	5	4	6
Acoustics	1/4	1/3	1	6	1/2	8	5	7	3	2	4
Maintainability & Reliability	1/9	1/8	1/6	1	1/7	3	1/2	2	1/4	1/5	1/3
Size	1/3	1/2	2	7	1	9	6	8	4	3	5
Hover Efficiency	1/9	1/9	1/8	1/3	1/9	1	1/4	1/2	1/6	1/4	1/5
Payload fraction	1/8	1/7	1/5	2	1/6	4	1	3	1/3	1/2	1/4
Maneuverability	1/9	1/9	1/7	1/2	1/8	2	1/3	1	1/5	1/6	1/4
Ease of Certification	1/6	1/5	1/3	4	1/4	6	3	5	1	0.500	2.000
Transition	1/5	1/4	1/2	5	1/3	4	2	6	2	1.000	3.000
Cost	1/7	1/6	1/4	3	1/5	5	4	4	1/2	1/3	1.000
Column Sum	**3.051**	**4.940**	**11.718**	**45.833**	**7.829**	**60.000**	**37.083**	**54.500**	**22.450**	**16.950**	**29.033**

Figure 1: AHP matrix

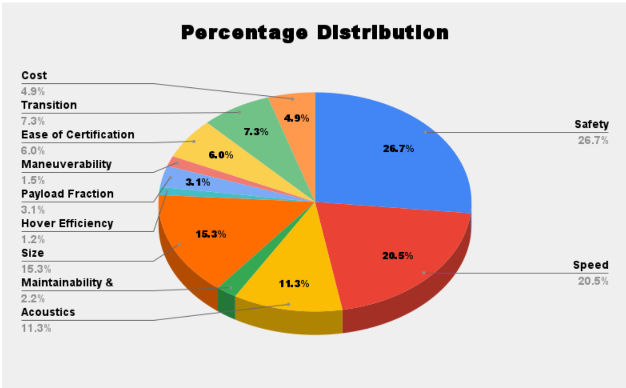


Figure 2: Percentage Distribution of design drivers

with one another is a difficulty made more difficult by expanding platform electrification. Larger and more complicated platforms have typically been expected to have this. An increase in development complexity is a direct result of increased electrification. This can cause issues down the road if not understood or intentionally addressed.

- **Autonomous Behaviour:** Till now all commercial flights have been done with flight crew or at-least a pilot. It has been a challenge to even reach level3+ autonomy in cars which are running on roads. A driver has to be present at the driving seat to ensure complete safety. Thus, making fully autonomous eVTOLs would be a big challenge. Although cruise phase and hover do not require rigorous engineering to achieve autonomy, the transition and maneuvering phases would be critical.

4 Survey of existing a/c and technologies

Air ambulances are an important component of the emergency medical system and play a crucial role in saving lives. Those transferred by air ambulance had a much greater survival rate than patients transported by land ambulance, according to one research.

In 2018, the University of Toronto's Remotely Operated Aerial Vehicle for Emergency Response (ROVER) team successfully completed the first air ambulance mission with a VTOL aircraft. A defibrillator was transported to a patient in cardiac arrest using a drone. The patient was successfully revived with the defibrillator.

Numerous well-known businesses provide these kinds of services all around the world, and many more are exploring how to turn this into an entirely autonomous operation or are in the development stage of doing so. Some of the popular companies include:

- Royal Flying Doctor Service
- CareFlight
- Urban Aeronautics
- ADAC Luftrettung and many more.

When it comes to the Australian firm CareFlight, it has a fleet of turboprop planes for long flights to move patients from accident scenes and between hospitals. It is propelled by two gas turbine engines and features four-bladed propellers as well as a pressurised cabin. The most essential feature of this aircraft is that it has a cruise speed of 484 kph and a top speed of 570 kph, and it can carry a pilot, a paramedic, and a patient. It also has notable characteristics including a range of 1900 kilometres, a length of only over 13 metres, and a maximum altitude of 10 km. It also has an endurance limit of up to 6 hours.

Royal Flying Doctor Service is an additional well-known one. It is a nonprofit organisation in Australia that offers emergency and primary healthcare services to people in remote and rural locations. Their whole fleet of aircraft has a maximum speed of around 560 kph and a 2800-kilometer range. They all have two stretcher beds with two seats each for a nurse and, occasionally, a doctor, aside from the flying crew.[1]

The important thing to keep in mind is that, up until this point, the notable thing these aircraft have in common is that they are fixed-wing types, meaning that they need a runway to take off and land. As a result, there has been a rise in interest in using vertical lift-off aircraft for air ambulance missions in recent years. This is because VTOL aircraft have several benefits over conventional fixed-wing aircraft, including the capacity to hover, the ability to take off and land in restricted locations, and the lack of a runway.

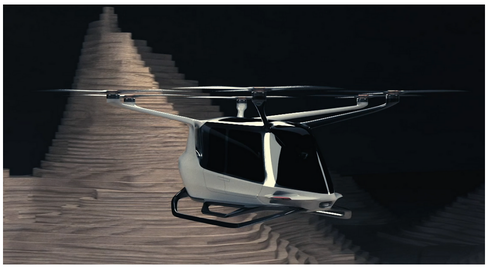
Numerous studies have been done to determine if employing VTOL aircraft for air ambulance missions is feasible. In one investigation, it was discovered that VTOL aircraft can safely transport a patient and a paramedic while hovering and flying. Another research examined the possible application of VTOL aircraft for the provision of air ambulance services in hilly areas. As they can take off and land in small places and can hover in position, it was discovered that VTOL aircraft are ideally suited for this kind of activity[4].

Air ambulance operations use various aircraft. The first thought that comes to one's mind are the helicopters. It can land on rooftops or uneven surfaces, which is its main utility. Despite these benefits, patient care decisions require a few concerns. Exposed tail rotors threaten the crew and bystanders around the landing spot. The helicopter's noisy rotors may irritate the patient inside and other hospital patients. ADAC Luftrettung, Norsk Luftambulanse, Leonardo Helicopters, and other firms provide helicopter ambulance services. The autogyro and tilt-rotor aircraft, for example, are being investigated and developed.

Now that VTOLs are being utilised or are in the development stage, let's look at some advancements in the sector.

Volocopter, a German firm, comes in first. The company became the first eVTOL startup to be approved as a design organisation by the European Union Aviation Safety Agency (EASA) in December 2019. The company's most current electric aircraft, the VoloCity, is a multi-copter that has a cargo capacity of 200 kg and a maximum gross weight of 900 kg. It can transport two passengers. It was thought that improving emergency medical treatment by using eVTOL technology would begin with bringing doctors to patients. Its 110 kph top speed, 35 km range, maximum breadth of about 12 metres, and quick battery change time of just 5 minutes are some of its standout characteristics. It has 18 motors and propellers, and 9 lithium-ion battery packs power both. Volocopter and the EASA are currently certifying VoloCity's air taxi operations. The ADAC study demonstrates that air rescue using piloted multi-copters like Volocopter is feasible, useful, and improves emergency care.

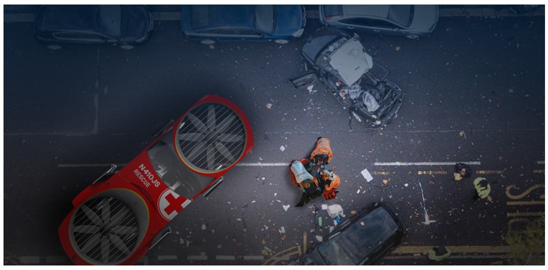
Urban Aeronautics, another proud firm, just unveiled CityHawk to the globe. This VTOL was developed by the Israeli firm Metro Skyways, a branch of Urban Aeronautics. It will be equipped with the exclusive Fancraft technology from Urban Aeronautics, which blends internal rotors with aerodynamic advancements and eliminates the need for external wings or rotors to take off and land, resulting in a safe flight and silent navigation. The aircraft can accommodate a pilot, two caregivers, one patient, and 400 pounds of supplies. It has a tiny footprint of 7.7 x 2.56 metres, has a range of 144 kilometres, and a top speed of 250 kph. Additionally, it includes hydrogen fuel cell technology for increased performance and zero carbon emissions.



(a) Alakai's Skai

(b) CityHawk's eVTOL

(a) Volocopter



(b) CityHawk

Alaka'i Technologies comes next. An industry innovator in the field of air travel is a US business with headquarters in Boston. Its technology and design can spur fresh innovation even though it does not offer air ambulance services. Its aircraft equipped with six silent motors, 115 mph top speed, 150-mile range, and hydrogen fuel cell power all contribute to its impressive performance. It can fly for up to four hours and support a weight of 1000 lbs. One of its other interesting aspects is fault tolerance technology, which is simplifying and adding backup systems to remove potential failure spots that are not present in helicopters. Even if numerous systems fail, the vehicle will still land without incident. An airframe-mounted parachute serves as an additional fail-safe redundancy on Skai in the case of a catastrophe.

The XTI Aircraft Company is another company we come to later. Its tagline, "No runway....No problem," refers to the way it blends fixed-wing aircraft with the ease of vertical takeoff and landing. Some standout characteristics of its aircraft are: It is a hybrid eVTOL that uses hydrogen fuel cells to cut CO_2 emissions by ninety percent. The company's turbo-shaft engines can run on 100% sustainable aviation fuel (SAF). It features an electric propulsion system that emits no carbon. It has a cruising speed of 555 kph, a maximum capacity of 7 passengers, including the pilot, and ranges of 1400 and 1100 km for CTOL (airport to airport/helipad) and VTOL (helipad to helipad), respectively.

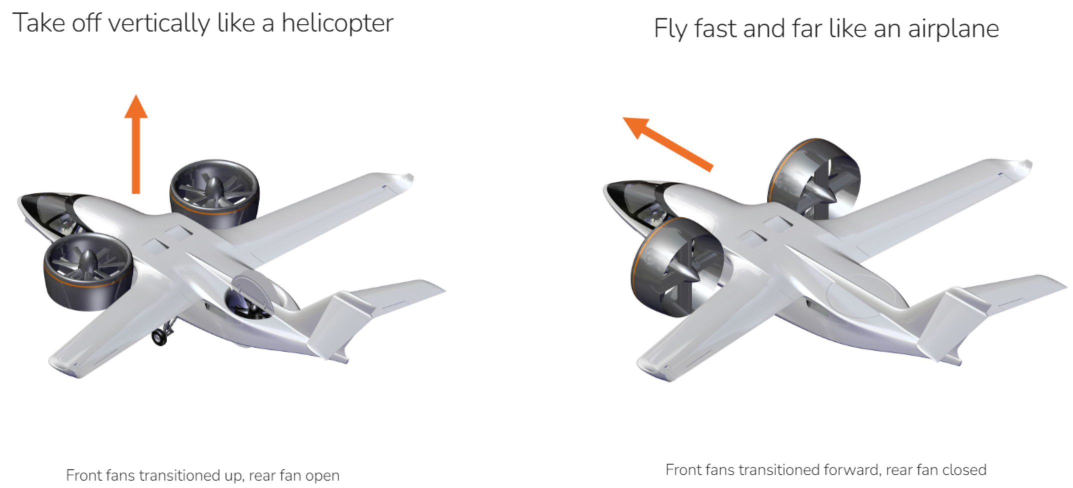


Figure 5: XTI

Although concept is still in its infancy, using VTOL aircraft for air ambulance missions has obvious potential advantages. Patients may be transported to and from remote regions safely and effectively using VTOL planes. Additionally, they have the potential to lessen noise pollution and save lives.

The goal of this literature review was to determine if vertical lift-off air ambulances carrying patients and a paramedic were practical. The investigations usually concluded that carrying patients and a paramedic in vertical lift-off air ambulances was practical. Although to make air ambulances a common form of transport for future generations, there are still many design elements that require more study and investigation.

Overall, the research points to vertical lift-off air ambulances as a practical choice for transporting patients and a paramedic. Additional research is necessary in order to validate these results[2].

5 Configuration Selection and Trade-Off Study

Some of the possible configurations present out there are:

- *Single Main Rotor*: It is the most common type of VTOL, and it is best known for how reliable and efficient it is at hovering. It has a single rotor that makes lift and a tail rotor at the back that counteracts the torque made by the main rotor. The SMR has a higher safety standard because of its autorotative capabilities. The SMR configuration also has some disadvantages like the decrease in rotor performance in edgewise flight, which can be improved with thrust compounding like in case of Europcopter X3. The exposed tail rotor is also a factor that sabotages safety.

- *Co-axial Rotor*: A coaxial rotor helicopter has two rotors that are vertically offset from one another and rotate in opposite directions around the same axis. Because of this, it can fulfil operational space limits and improve loading and unloading times without the use of a tail rotor. But the mechanical complexity of the rotor hub is increased by the counter-rotating rotors.The increased drag from the larger hub compared to the SMR arrangement is problematic for a mission where cruise speed is the primary factor.Increased velocity can be attained by the use of thrust compounding.

- *Tandem Rotor*: The tandem rotor configuration, which consists of two longitudinally separated counter-rotating rotors, has a higher CG tolerance and is thus advantageous for package delivery, especially in an emergency. Thanks to its lack of a tail rotor, it can withstand strong lateral winds and poses little danger to the ground crew. Since a tail boom is no longer necessary, it is possible to install a ramp for easy loading and unloading. To minimize interference with the forward rotor's wake, the rear rotor is mounted higher than the forward one.

- *Tiltrotor*: Tilting proprotors are attached to the ends of the wings of a tiltrotor aircraft. Tiltrotors are ideally suited for this cruise-dominant mission, as their forward flight characteristics are similar to those of fixed-wing aircraft. As the proprotors are situated at the wing's edge, it would be challenging to accommodate the operational space constraints. Due to the necessity of making the wing and props so robust, the payload fraction would also be decreased.

- *Tilt-wing:* In a tiltwing aircraft, the wing flips up during vertical takeoff and landing while remaining horizontal during regular forward flight. It is comparable to the tiltrotor design, in which only the engine and propeller revolve. The majority of tiltwing aircraft can do VTOL missions. In comparison to a tiltrotor, the tiltwing design has some benefits in vertical flight. The tiltwing can use more of its engine power to lift the aircraft because the slipstream from the rotor hits the wing at its thinnest point.

- *Multi-copter:* A rotorcraft with more than two lift-generating rotors is called a multicopter. The less complicated rotor mechanics needed for flight control are a bene-

Figure 6: Different Configurations of VTOLs (Images taken from web)

fit of multirotor aircraft. Multirotors frequently use fixed-pitch blades, as opposed to single- and double-rotor helicopters, which use complex variable pitch rotors whose pitch changes as the blade rotates for flight stability and control. Vehicle motion is controlled by changing the relative speed of each rotor to change the thrust and torque produced by each.

- *Lift+Cruise:* These aircraft employ lift engines only for hovering, while different engines are used exclusively for cruising. A lift engine is a type of jet engine that is positioned vertically and is highly designed to create a very significant level of thrust for the comparatively short length of time that is required for takeoff and landing.

- *Compound Helicopter:* A helicopter that has an additional propulsion system to give thrust that is more than what the rotor(s) alone could create, allowing it to move at higher speeds; wings may or may not be included to lessen the lift that the rotor system is required to produce. It generally has short fixed wings and an auxiliary thrust mechanism. By offloading it during cruise, the rotor's spin may be slowed down, improving the aircraft's top speed.

Design Drivers	Weights	Tilt Wing	Fan in Wing	Coaxial Rotor	Tilit Duct with fixed wing	Muticopter	Lift+Cruise	Single Main Rotor	Compund Helicopter	Fan in body
Safety	0.272	-1.000	3.000	1.000	3.000	1.000	2.000	0.000	1.000	3.000
Speed	0.202	4.000	-2.000	-1.000	1.000	-3.000	1.000	0.000	2.000	-2.000
Size	0.150	-2.000	2.000	1.000	2.000	3.000	4.000	0.000	-1.000	2.000
Acoustics	0.111	1.000	1.000	-1.000	3.000	2.000	1.000	0.000	-1.000	1.000
Transition Phase	0.072	-4.000	0.000	0.000	3.000	0.000	4.000	0.000	3.000	0.000
Ease of Certification	0.060	-2.000	1.000	-1.000	-1.000	4.000	3.000	0.000	-1.000	-4.000
Cost	0.049	3.000	-3.000	-1.000	2.000	2.000	2.000	0.000	1.000	-3.000
Payload fraction	0.032	-3.000	2.000	1.000	2.000	1.000	2.000	0.000	1.000	2.000
Maintainability and reliability	0.023	3.000	-4.000	-1.000	2.000	2.000	2.000	0.000	1.000	-4.000
Maneuverability	0.016	-2.000	1.000	0.000	2.000	1.000	2.000	0.000	2.000	1.000
Hover Efficiency	0.013	-3.000	-2.000	1.000	-2.000	1.000	0.000	0.000	1.000	-2.000
Score	1.000	-0.012	0.698	0.022	2.021	0.783	2.165	0.000	0.720	0.398
RANK		9	5	7	2	3	1	8	4	6

Figure 7: Pugh Matrix

5.1 Wing configuration for Cruise

Our air ambulance would be an urban air mobility product. Thus top priority apart from safety and size of design would be low noise levels and good cruise speed of the vehicle, both of which can be achieved by wing configuration. High speed would be desirable to satisfy customer requirements and get social acceptance. Any air ambulance client would target quick and immediate medical attention to the patient. The product would primarily be aimed to deliver within the"golden hour" and have longer range coverage to increase it's usability. With the consideration of present technology, there would always be a certain amount of noise emitted by the vehicle when passing over your house, office buildings or any other infrastructure. Though certain minimum levels of noise can be acceptable, yet everyone would desire to get past the noise as soon as possible. Efficient cruise and avoiding sole dependence on rotors for lift during cruise may solve the issue. Therefore with the specified arguments we look for wing configuration among the possible evtol configurations[3].

5.2 No Single Main Rotor

The decision to have a wing configuration somewhat eliminates the feasibility of having a single main rotor for the vtol process. There has to be a separate propulsion system apart from the main rotor due to trade off between nose down and nose up for main rotor and wing respectively. Thus 3-fixed thrusters(main rotor, tail rotor and propulsion rotor) adds to the complexity of design. Moreover, the main rotor would have to be large enough to cover a significant portion of the wing span. During take-off and landing the downward airflow generated by the rotors would cause structural load on the wings. Apart from structural stress, the wings

Lilium Jet Data		
SNo.	Parameter	Value
1	Fuselage width	$1.4m$
2	Fuselage length	$3.6m$
3	Wingspan	$6m$
4	Total Mass	$490kg$
5	Cruise Speed	$100km/h$
6	Practical Range	$200km$

Table 1: Lilium Jet Specifications taken from standard resources

would cause interference with the airflow of the rotors. This may increase the inner ground effect. Other big disadvantages of a big main rotor would be increased dead weight during cruise and increased parasitic drag. These reasons eliminate the compound helicopter configuration which comes with wing plus rotor configuration.

5.3 Trade-off study among Top Performers in PUGH Matrix

We have taken all the listed configurations into our PUGH matrix and then multiplied each of them with the design drivers. Although we have removed titlrotor and compared tilt duct with fixed wings. Moreover we have added fan in wing and fan in body configurations into the matrix. The scores from Pugh matrix gives top ranks to tilt ducted fans with fixed wings and Lift+Cruise configuration. We compare these two designs in our subsequent discussion.

5.3.1 Tilt ducted Fans with Fixed Wings

Lilium jet has been one of the prominent designs in this category. They have multiple small tilt duct fans beneath the wing and canard. Multiple duct fans offer redundancy to the system, since failure of any one would not cause critical issues. The ducted fans offer great safety and their vectoring capability makes them useful in every flight phase. The ref paper lists down the following specifications for their jet:

- **Advantages:**

    1. Small and compact design: From the estimated values of the size of vehicle, the vehicle dimensions lies within the maximum limit of our requirements.

    2. Light aircraft

3. High speed for evtol category: The wing and duct fans beneath the wings offer less drag in cruise ephase and hence more speed. The cruise speed claimed by the design is one of the highest among evtols.
4. Provides higher spectrum of range

- **Disadvantages:**

1. Acoustics: multiple duct fans seem to be a noisy design. Also, the ducted fan sound would be of high frequency noise, as compared to loud and flat noise of a main rotor of a helicopter. The type of noise can cause much discomfort when the vehicle is in use.
2. Extreme downwash and temperature.
3. Complexity of design: Efficient design of tilt duct fans would be a challenge since the duct fans would have to rotated in the transition phase.
4. Very poor loiter efficiency.

The overall design in reference to the Lilium jet is good for air ambulance design. The design seems to meet the requirements of the problem statement but there are serious underlying issues such as noise and complexity that questions its feasibility for use in urban mobility at scale.

5.3.2 LIFT + CRUISE

This configuration gains confidence from it's simplicity of design and recent developments of evtol in this category. The researchers from caltech university have designed a fully autonomous air ambulance based on this configuration. Most of the mission requirements and the target audience are the same. Thus there already exists a proof of concept design. The separate, decoupled propulsion system and wings for efficient cruise are characteristic features. We estimate the average design configurations given in the ref paper from the values derived for Kitty Hawk's Cora.

- Advantages:

1. Non complex design.
2. Separate propulsion system for lift and hover.

Kitty Hawk Cora Data		
SNo.	Parameter	Value
1	Fuselage width	$4.8m$
2	Wing surface	$10m^2$
3	Wingspan	$11m$
4	Total Mass	$1224kg$
5	Cruise Speed	$180km/h$
6	Practical Range	$100km$

Table 2: Kitty Hawk Cora Specifications taken from standard resources

3. Many eVTOLs already built in this configuration.
4. Both cruise and hover are efficient.
5. Speed and range specifications within requirements.
6. Lower vibrations and noise as compared to vectored thrust.

- Disadvantages:

1. Multiple small rotors cause dead weight and increase drag during cruise.
2. Ducted fans in this configuration, would add more dead weight and make the deisgn inefficient. But their absence can have some safety issues due to sharp and high temperature of rotors at landing and take-off.

There clearly seems to be more advantages of this configuration as compared to tilt duct with fixed wings. The simplicity of design would enable us to focus more on it's optimization rather than completing the basic design. Optimization of design can be done via foldable wings to make a compact vehicle for landing and parking, having propellers geometry aligned in a fashion so as to reduce drag during cruise. More recent innovations have shown that complex design of folding propellers into the fuselage in cruise makes morecruise phase more efficient.

Therefore from our study of different possible configurations and their trade-offs in evtol category, we finally come-up with **LIFT+CRUISE configuration.**

6 PLAN OF ACTION

The end product of this whole process will result in a conceptual design that can go on to the preliminary design phase and some minor changes could be expected even after that.

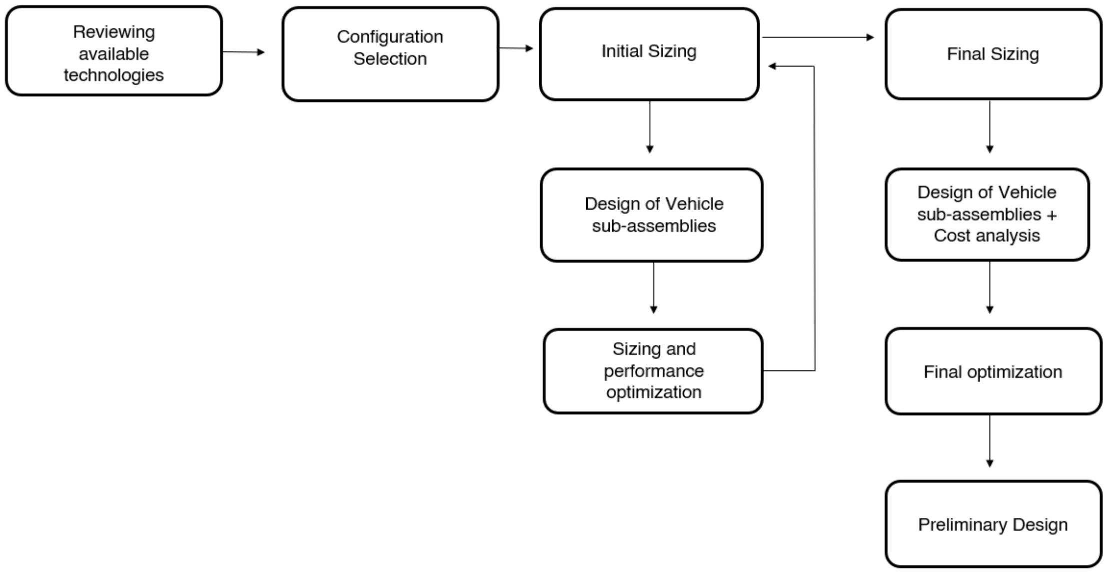


Figure 8: Flowchart of path followed to achieve final design

7 TIMELINE

Date	Work to be completed
30 Nov 22	Synopsis Report submitted
23 Dec 22	Powertrain to be fixed
31 Dec 22	Shortlisting of teams for Task-I
17 Jan 23	Vehicle sub-assemblies CAD
24 Jan 23	First iteration of assembly
31 Jan 23	Task-I Report Submission
10 Feb 23	Rough complete assembly
13 Feb 23 - 25 Feb 23	Mid-semester examinations
28 Feb 23	Shortlisting for Task-II
10 Mar 23	Selection of navigating devices
20 Mar 23	Communication systems selection
14 Apr 23	Detailed analysis and trade-off study of Propulsion System
15 Apr 23- 3 May 23	End semester examination
17 May 23	Selection of material for the structure
31 May 23	CAD of structural sub-assemblies
8 Jun 23	Cabin Design
15 Jun 23	Structural and Aerodynamic analysis
22 Jun 23	Complete CAD assembly
30 Jun 23	Task-II Report Submission
13 Jul 23	Cost analysis
26 Jul 23	Minor changes due to cost analysis
8 Aug 23	Documentation of Final DR

Figure 9: Complete project timeline

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