ISTANBUL TECHNICAL UNIVERSITY ★ FACULTY OF AERONAUTICS AND ASTRONAUTICS

PRELIMINARY DESIGN OF A CARGO UAV

GRADUATION PROJECT

Yeshar Kamal Mustafa MUSTAFA

Department of Aeronautical Engineering

Thesis Advisor: Dr. Hayri ACAR

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Yeshar Kamal Mustafa MUSTAFA, student of ITU Faculty of Aeronautics and Astronautics student ID 110110902, successfully defended the graduation entitled "**PRELIMINARY DESIGN OF A CARGO UAV**", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor :	**Prof. Dr. Hayri ACAR** İstanbul Technical University	....
Jury Members :	**Prof. Dr. İbrahim ÖZKOL** Istanbul Technical University	....
	Doç.Dr.Aytaç ARIKOĞLU Istanbul Technical University	....

Date of Submission : 02 June 2020
Date of Defense : 20 June 2020

To my family and good friends,

FOREWORD

First of all, I would like to thanks to my mentor Dr. Hayri ACAR for his help, guidance, patience and above all for his time during my graduation assignment.

I would like to thank all my teachers for everything I learned from them over the years. I would be deprived of many wonderful memories if I did not have friends in the ATA Team and Target Team, where we participated in many competitions together during my undergraduate studies.

Finally, I would like to thank Onur KÜÇÜKOĞLU and Yusuf DEMİROĞLU who have always been there for me at every moment since the first day I started school.

January 2020 Yeshar Kamal Mustafa
MUSTAFA

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ABBREVIATIONS

UAV **:** Unmanned Air Vehicle

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BİR KARGO İHA ÖN TASARIMI

ÖZET

İnsansız sistemler uzun süredir sivil ve askeri alanlarda pekçok farklı amaçta kullanılmaktadır. Bu amaçlar arasında en yaygın olanları keşif ve gözlemdir. Bu tür görevlerde ek olarak hava taşımacılığı da çeşitli uluslar arası firmalar tarafından denenmektedir. Hava aracının içerisinde bulunan bir uçuş ekibi hem maliyet olarak hem de insan yaşamı açısında risklidir. Kargo İHA ile beraber bu maliyette azalmaya ve daha lokal taşımacılık yapılarak süre bazında adrese hava aracı ile teslim ön görülmektedir.

Bu bitirme ödevinde yukarıda bahsedilen imkanlara sahip olacak ödev içerisinde belirtilen görevleri başarabilecek bir kargo insansız hava aracının ön tasarımı yapılmıştır. kargo insansız hava aracının ön tasarımı oldukça fazla sayıda değişkenin hesaba katılıdığı klasik uçak tasarımından farklı olarak konsept tasarım fazında yapılan ihmallerin görevin başarısız olmasına yol açacağı zahmetli bir süreçtir. Bu sebeple tasarımcı tasarım esnasında tüm değişkenlerin nihai tasarıma dahil edebileceği bir modeli tasarım öncesinde oluşturmalıdır. Kargo İHA birçok yönden piyasada hazır bulunan birleşenlerle oluşturulabilir ancak tasarım esnasında bütün hesaplamalar özgü olmalıdır. Bu sebeple bu ödev kapsamında uçağın performans isterlerini karşılayan bu uçağa özgü bir yapısal ve aerodinamik tasarım yapılmıştır. Kanat tasarımı program tarafından önerilen geometriye uygun olarak Prandlt taşıyıcı çizgi modeli kulanılarak uygun profil seçildikten sonra istenilen perforans değerleri sağlanılacak şekilde boyutlandırılmış. Daha sonra XFLR5 programında son hali verilmiştir. Enerji tüketiminin neredeyse tamamı itki sistemine ayrılmıştır. Bu sebeple itki sistemini oluşturan motor pervane uyumu ödev içerisinde ayrıca ele alınmıştır. Yapısal tasarımda CATIA V5 uygulamasıyla en ince detaylar çizilmiş ve üretim metodları dikkate alınmıştır.

PRELIMINARY DESIGN OF A CARGO UAV

SUMMARY

Unmanned systems have been used for many different purposes in civil and military fields for a long time. The most common of these objectives are exploration and observation. In addition to these tasks, air transportation is being tried by various international companies. A flight crew within the aircraft offers both a cost and a definite airport requirement. Together with the Cargo UAV, it is foreseen that this cost will be reduced and delivery by aircrafts to the address on a time basis with more local transportation.

1 INTRODUCTION

Within the past ten years interest in commercial utilization of Unmanned Aerial Vehicles (UAVs) has skyrocketed [Choi-Fitzpatrick, 2016]. Many large corporations such as Google, Amazon, and Domino's Pizza have taken to the challenge of integrating drones into their businesses. After Jeff Bezos, Amazon CEO, announced the up-and-coming package delivery system marketed as Amazon Prime Air, the perception of drones as "killing machines" has dissipated, being replaced by enthusiasm for this transformative technology to fully emerge in commercial industry [CBS, 2013].

Drones have potential in the private business sector in terms of improving security, reducing business costs, and reducing time-to-market [Bamburry, 2015]. According to information provided by the Federal Aviation Administration (FAA), the use of UAVs is predicted to grow as shown in Figure 1. Figure 1 - Prediction of small Unmanned Aerial System (sUAS) units sold per year (in mil) [FAA, Fiscal report, 2016] Due to this expected growth in the drone industry, it is becoming evident that this technology will berelevant in the near future as businesses realize the value UAVs may add to their mission and revenue. Battery-powered Unmanned Aerial Vehicles may potentially play a key role in surveillance and delivery, to name a couple of applications.

1.1 Purpose of Thesis

Due to safety concerns and public perception of drone safety it is believed that unmanned cargo aircraft will be developed before large scale use of autonomous passenger aircraft.

1.2 Literature Review

The selection of available UAVs has greatly expanded over the last few years and it has become difficult to keep track of the entire range. The market offers diverse systems, and there is no universal classification. The US military uses a tier system with specific UAV requirements (e.g., they must offer particular levels of range or endurance). In general, systems tend to be classified by measurements or specifications, which can relate not only to range and endurance but also to size, maximum take-off weight, service ceiling, and price. Other major distinctions are the build type and the engine used. The following table gives a brief overview of the advantages and disadvantages of different build types.

Table 1.1 : UAV build types

	Advantage	Disadvantage	Visual
Fixed-Wing	• Long range • Endurance	• Horizontal take-off, requiring substantial space (or support, e.g., catapult) • Inferior maneuverability compared to VTOL (Vertical Take-Off and Landing	
Multicopter	• Inexpensive • Easy to launch • Low weight	• Limited payloads • Susceptible to wind due to low weight	
Unmanned Helicopter	• VTOL • Maneuverability • High payloads possible	• Expensive • Comparably high maintenance requirements	

.

The main types of engine used today in non-military UAVs are the electric engine and the internal-combustion engine. The electric engine is environmentally friendly and operates without much noise; these are important advantages especially in densely populated areas. It is relatively inexpensive to charge the battery, but battery weight is a drawback and UAV range can be limited by battery capacity.

Figure 1.1 : DHL-“Paketcopter”

A UAV powered by a comparable internal-combustion engine is likely to have superior range, due to the energy density advantages of fossil fuels and because range can be simply extended by adding fuel tanks. Hybrid systems are currently being developed, trying to combine the best of both worlds – the internal-combustion engine is used for longer distance flights, and the electric engine is used for take-off and landing in areas requiring quiet operation. This report does not exclude any specific type, but its focus is rather on electrical engines and multicopters, because these appear to be the most promising choice for the logistics industry applications that are discussed in this report (see Figure 4 and 5). This reflects both cost and feasibility arguments: While long ranges and high payloads are technically feasible today, UAVs of this type tend to be expensive and may be a bad choice in densely populated environments such as cities, because of horizontal take-offs and noisy engines. This matters less outside urban areas, and in the following chapter we review the varied tasks being carried out by UAVs today.

After taking a broad look at use cases from a range of different industries, this report now examines implications for the logistics industry. While many of the above applications are already common today, the use cases in and for logistics are still in its early stages. The use cases illustrated below must therefore be seen as visionary; the intention is to provide inspiration and trigger discussion. These logistics use cases are not intended as a precise prediction of future developments. As previously mentioned, electrical multicopters (characterized by vertical take-off and landing) appear to be the most promising for the logistics industry. Accordingly we focus on use cases within short distances instead of considering long distance operations. DHL Trend Research divides logistics industry use cases into four categories: Urban First and Last-Mile, Rural Delivery, Surveillance of Infrastructure, and Intralogistics.

Rapid urbanization is one of the megatrends of recent years and the near future, especially in emerging markets. The insurance company Swiss Re forecasts the global urban population will “grow by about 1.4 billion to 5 billion between 2011 and 2030, with 90% of the increase coming in the emerging markets”.25 Negative implications of this trend include congested roads, pollution, and decreased efficiency caused by delays in the flow of people and goods. It is often difficult for city planners to keep up with the pace of urbanization and population growth. In many cases, infrastructure projects can only provide temporary relief. Part of the problem is urban first and last mile delivery, and demand for this is likely to increase as e-commerce volumes grow. China posted an impressive compound annual growth rate of 120% between 2003 and 2011 for its e-tailing market (consumer-facing e-commerce transactions excluding financial services, job search, and travel)26 and, even if growth rates are likely to come down, future increases will still be substantial. UAVs could provide major relief for inner cities, taking traffic off the roads and into the skies. So far, payloads are limited but a network of UAVs could nevertheless support first and last-mile logistics networks. For instance, aerial delivery company Flirtey plans to introduce the worlds -first commercial UAVs for delivery. Student text book rental service Zookal will use Flirtey to deliver parcels directly to a customer. Customers will receive a smartphone notification that will enable them to track the parcel via GPS and receive the parcel directly at an outdoor location. Once the UAV arrives at the outdoor delivery destination, it hovers and carefully lowers the parcel through a delivery mechanism that is attached to a retractable cord (see Figure 13). This aims to significantly reduce waiting times from two to three days, to as little as two to three minutes.27 An airborne first and last-mile network could look as follows: Shipments that arrive from outside the city limits are sorted at existing facilities (hubs, warehouses, crossdocking sites), and shipments meeting certain criteria are separated automatically. In addition to size, weight, and time criticalness, these criteria could also include dynamic metrics (e.g., current road conditions, air pollution, and network load). Each UAV automatically picks up assigned shipment(s) from a conveyer belt and takes off. On its way back to the hub, the UAV could carry out point-to-point deliveries that lie on its route.

Its routing decisions would always be dynamic, meaning

an intelligent network would redistribute all resources in

real-time, depending on the load and urgency of certain shipments. When an assignment for emergency transport comes in (e.g., time-critical delivery of blood from a blood bank), this is prioritized. End customers are equipped with an app that allows them to see nearby UAVs and order a dynamic pick-up – this system would use GPS data from the customer's smartphone to meet him or her wherever they are, even if they move to a different location after placing the order. There would be the same flexibility for deliveries – as soon as the customer sends a notification, a UAV leaves the hub and makes delivery direct to the customer location or in case of returns, picks it up right from the first mile of the customer. AMP Electric vehicles even plans to test the pairing of delivery trucks with UAVs that will deliver parcels that are outside of the main delivery route of the truck. The UAV would be positioned on top of a delivery truck, waiting for a parcel from the driver. When loaded, the UAV will scan the barcode on the parcel, schedule the route to the delivery point via GPS and take off to the destination. In the meantime, the truck will continue its rounds. After a successful delivery, the UAV will fly back to the truck for its next delivery run, where it can also recharge its battery wirelessly. (see Figure 14).28

Figure 1.3 UAV teams up with AMP; Source: AMP Electric Vehicles

The first and last meters of the delivery process are likely to be the most technically challenging. If the customer is outdoors and moving, the UAV could meet them and 'hand-over' the delivery after identifying the customer via NFC or QR code on their smartphone. But if the customer is at home, things gets trickier. With a garden or balcony available, the UAV could drop the parcel onto this. With large buildings and skyscrapers, the UAV could land on the roof. The most problematic delivery would be to mid- sized buildings with pitched roofs – structures that are prevalent in European locations – necessitating an alternative delivery point, perhaps some sort of collection point. The existing DHL Packstation or Paketkasten network could be upgraded to handle shipments of this kind (see Figure 15).

In recent news, Google has revealed its latest program called Project Wing to build autonomous delivery systems capable of bringing parcels to nearly every person within one to two minutes. Google has been working on Project Wing for more than two years and it is already currently testing UAVs for rural deliveries in Queensland, Australia (see Figure 17). However, Google recognizes that the project is far away from actually being ready for any sort of commercial or governmental use especially for UAV delivery in urban areas. “It‘s years from a product,” explained Google Project Wing founder Nicholas Roy. “But it is sort of the first prototype we can stand upon.”30 The obstacles Google will have to clear will go far beyond engineering. As previously mentioned rival Amazon floated its own aerial delivery service earlier this year and the UAV delivery project was quickly subdued in the US by the FAA.

To gain valuable insight into a comparable application, Deutsche Post DHL partnered with the UAV manufacturer Microdrones in December 2013 to deliver pharmaceuticals to employees at DHL’s headquarters in Germany. This joint project took place in the city of Bonn, but the setting was comparable to a rural location as the UAV flew across the Rhine river – both the take-off and landing areas and the flight path were free of any buildings.

1.3 Hypothesis

The future demand for wide scale use of it will be for long haul point to point service of high value cargo.

2 Aircraft Design

Before starting discussions about the design configurations, airfoil selection and dimensioning, it is necessary to understand all the competition rules. Therefore, our team members at first read the regulations, afterwards members have started discussions about the aircraft. In order to find the best design, scoring is analyzed and the priory missions are selected.

2.1 Mission Requirements

Air Cargo Challenge 2019 has following rules, which directly affects the aircraft design.

- Aircraft must fit in a box with outer dimensions of 700mm*250mm*400mm
- Due to scoring, payload weight must be maximized.
- Due to scoring, aircraft must complete track as fast as possible.
- Every configuration must be selected according to highest efficiency.
- Aircraft assembly must be easy.
- Weight must be accessed easily.
- Aircraft must be labeled with university names and sponsors for distinction.

2.2 Numerical Expectation

Total score of each team will be calculated according to fallowing formula,

$=(Flown\ Weight(kg) Flown\ Time(s) * 2000 + a + b + c) * d$

a = 10 for no parts lost/ 0 for parts lost

b = 10 for landing on field

c = 10 for landing in 60 m area

d = 0 for crashes or invalid starts (jury decision)

We have conducted a sensitivity analysis using Matlab in order to find ideal payload weight as well as predict lap time and score. Scoring parameters, a, b and c are taken as 10 at this prediction.

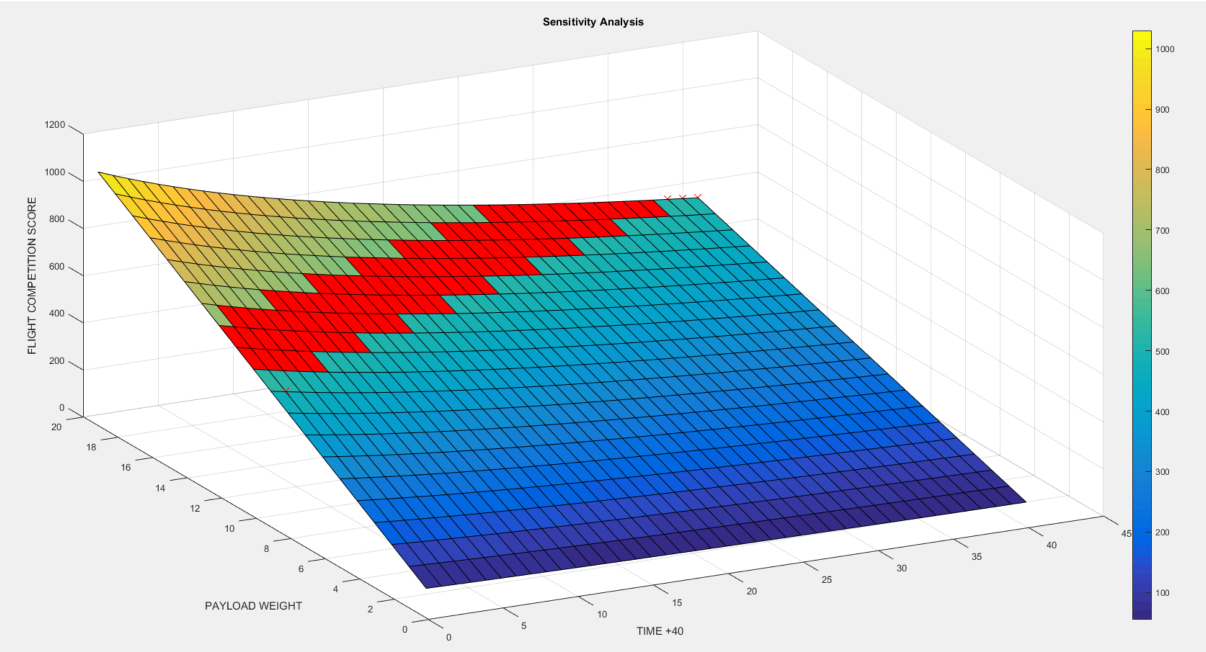


Figure 2.1 : Sensitivity analysis

Red region presents achievable and optimum values with maximum score. We find it necessary to highlight this area since thrust system is fixed and aircraft must fit in a box. These restrictions limit our maximum mass and flight time. Therefore, we have to choose and ideal payload value and flight time goal. We have chosen to design an aircraft which is capable of carrying at least 13 kilograms.

2.3 Aircraft Configuration Trades

It is necessary to introduce configuration selection approach we have used before explaining these selections. Each aircraft specification requiring a trade selection is determined initially. Most suitable configurations for design selections are narrowed to 2 or 3 possibilities after hours of consideration and research as well as advices of our highly experienced members.

In all trade studies conducted for preliminary design, we have used figure of merit tables in which trade study is examined in each parameter. These parameters have a weight in overall score according to their importance. Each configuration is scored between -1 and 1. “1” indicates that the configuration has a certain advantage. “0” indicates that the configuration has no effect and “-1” is given for configurations having disadvantage

2.3.1 Aircraft configuration

Conventional

Conventional configuration is the most used one in modern aviation. Most of the civil and military aircrafts are design as conventional. This configuration is easiest to design, manufacture and analyze.

Biplane

Biplane configuration doubles the wing area while maintaining wing span. However, doubling wing area drastically increases drag force. Addition to drag force, weight is increased due to additional wing.

Canard

Canard is a special type of aircraft where control fins are positioned at the front of the fuselage rather than rear. This trade offers excellent pitching moment control since airflow directly comes to the elevators. Nonetheless, canard creates a downwash affecting airflow at the main wing and perfect canard design is difficult and requires more time.

Figure of Merit	FoM weight	Conventional	Biplane	Canard
Aerodynamic efficiency	0.2	0	0	0
Speed	0.2	0	-1	0
Weight	0.1	0	-1	0
Manufacturability	0.2	1	-1	0
Stability	0.2	1	1	1
Control	0.1	1	1	0
Total	**1**	**0.5**	-0.2	0.2

Figure 2.2 : Therefore, we have selected conventional aircraft configuration.

Advantages	Disadvantages
Easy to manufacture	Biplane produces higher lift
Good stability and control for pitot	
Weight is reduced	
Safest design	

Table 2. Pros and cons table of conventional aircraft configuration.

2.3.2 Airfoil Configuration

In the process of airfoil selection, our team has analyzed different types of airfoils in order to maximize total lift. Considering the flight conditions, our team has decided to search for low Reynoulds number - high lift coefficient airfoils. All airfoils considered for aircraft, typically show maximum Cl/Cd behavior below 500000 Reynoulds.

We have prepared a figure of merit chart in order to make airfoil selection easily. We have scored each airfoil according to their lift and drag coefficients, stall angles and manufacturability.

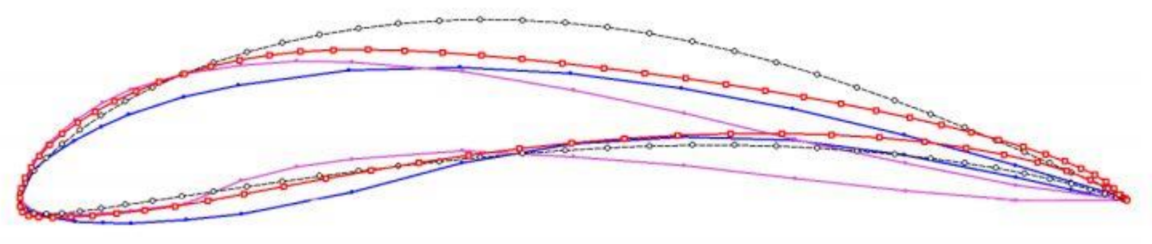


Figure 5. Presentation of 4 airfoil considered for aircraft. S1223 is red, CH10 is black, NACA M8 is pink and GOE233 is blue.

Figure of Merit	FoM weight	S1223	CH10	NACA M8	GOE 233
Lift	0.4	1	1	1	1
Drag	0.2	0	0	-1	0
Stall Angle	0.2	1	0	1	0
Manufacturability	0.2	0	0	0	0
Total	**1**	**0.6**	0.4	0.4	0.4

According to scoring analysis, S1223 airfoil is optimum trade.

Advantages	Disadvantages
High lift coefficient	Difficult to manufacture
High stall angle than other trades	Higher drag coefficient than most airfoils
Higher Cl/Cd ratio than other trades	
Optimal for low speed cargo aircrafts	

Table 3. Pros and cons table of S1223 airfoil configuration.

2.3.3 Wing Vertical Position Configuration

Vertical wing position relative to the fuselage is an important parameter affecting aircrafts aerodynamics and manufacturability. Therefore, low-wing, mid-wing and high-wing configurations are carefully examined with a figure of merit table. Parasol wing configuration is not considered due to its difficulty in manufacture and aerodynamic effects.

Low-Wing

Low wing configuration has various advantages. Induced drag is reduced. They offer high maneuverability and low lateral stability due to dihedral effects. Landing gears can be placed under the wing. Also wing structure does not intersect with the fuselage. Nevertheless, low wing configuration can reduce total lift, increasing stall speed.

Mid-Wing

This configuration lowers the drag force and have better ground clearance than low-wing. Even though there is an aerodynamic advantage, mid-wing causes a volume loss in fuselage for structural integrity. Structural enhancements also cause weight.

High-Wing

High wing configuration offers excellent ground clearance, therefore it is widely used in cargo aircrafts. Large flaps can be used and lift force is larger. Main disadvantage of this configuration is that induced drag is higher, fuselage must hold landing gear and the take-off distance is expected to be longer due to lower ground effect.

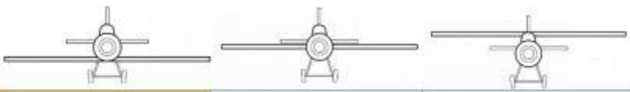


Figure of Merit	FoM weight	Low-wing	Mid-wing	High-wing
Aerodynamics	0.3	1	1	0
Weight	0.2	1	0	0
Manufacturability	0.2	0	1	1
Speed	0.2	1	1	0
Take-off Distance	0.1	1	0	-1
Total	**1**	**0.8**	0.7	0.1

From our Figure of merit study, low wing configuration is the best configuration for our purposes.

Advantages	Disadvantages
Less induced drag	Lift is reduced
Shorter take-off distance	Stall speed is higher
Manufacturing is easy and lightweight	
Excellent maneuverability	

Table 4. Pros and cons table of low-wing aircraft configuration.

2.3.4 Empennage Configuration

We have analyzed different empennage configurations. Our inspections are conducted in terms of aerodynamic efficiency, control, maneuverability, weight and stability.

Conventional Tail

Conventional tail is widely used in modern aircrafts. Conventional tail provides lightweight stability control. It is the safest design in terms of control and structural stiffness.

T Tail

T tail is another widely used empennage configuration. Due to a phenomenon called end plate effect, vertical tail area is minimized. Propeller wash and horizontal tail is not affected by wing stream, improving aerodynamic efficiency. However, this configuration has disadvantages. Deep stall situation may occur at high angle of attack resulting with a total loss in pitch control. In addition to deep stall, vertical tail must be supported to prevent structural failures.

V Tail

V tail can drastically reduce wetted area at tail, resulting with a reduced drag. However, V shape causes difficulty in control actions since rudder and elevator is mixed.

Boom Tail

It is primarily used to control vertical tail with undisturbed air. Even though there is a control advantage, structural challenges exist.

Figure of Merit	FoM weight	Conventional	T Tail	V Tail	Boom Tail
Aerodynamics	0.25	0	1	0	-1
Speed	0.25	1	1	1	0
Stability	0.1	1	1	0	1
Control	0.05	1	1	0	1
Weight	0.15	1	0	1	-1
Manufacturability	0.1	1	1	0	0
Maneuverability	0.1	1	1	-1	0
Total	**1**	0.75	**0.85**	0.4	-0.35

Therefore, we have decided to design an aircraft with T tail configuration.

Advantages	Disadvantages
High performance aerodynamics	Deep stall must be prevented
Reduced turbulent and induced drag	Vertical stabilizer must be durable
Reduced tail area due to end plate effect	

Table 5. Pros and cons table of T-tail configuration.

2.3.5 Landing gear configuration

Our inspection and analysis for most convenient landing gear configuration showed that tricycle and tail dragger configurations are overall best selections.

<u>Tail dragger</u>

Tail dragger is a configuration in which two wheel is placed in front of the fuselage and third smaller wheel is placed aft of the aircraft. It has certain advantages. For instance, aircraft takes off easier since there is an angle of attack. However, landing gear which is positioned at the aft must be structurally safe. Moreover, landing can be difficult at touchdown and there is a risk of propeller hit to the ground.

Tricycle

In contrast to the tail dragger, tricycle configuration places the third wheel to the front of the aircraft. It is commonly used in civil aviation due to its stability at taxing, easiness at landing and reduced risk of nose up hit at landing. Moreover, tricycle configuration needs longer take-off distance with tail crash possibility at landing

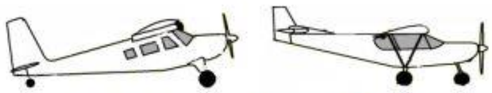


Figure of Merit	FoM weight	Tail Dragger	Tricycle
Manufacturability	0.3	-1	0
Aerodynamic effect	0.3	1	0
Weight	0.2	-1	1
Risk of ground hit	0.1	-1	1
Total	**1**	-0.3	0.3

As stated in the figure of merit, tail dragger configuration is more suitable for our mission.

Advantages	Disadvantages
No risk of propeller hit	Risk of aft hit at landing
Easy to manufacture	Longer take of distance
Weight is reduced	

Table 6. Pros and cons table of tail dragger configuration.

2.3.6 Control Surface Configuration

Considering the scale of the aircraft, speed and 60 meters of runway limitation, adding flaps to the wing will increase the control of aircraft. Moreover, during the take-off flaps are going to increase lift force and during the landing increased drag produced by flaps are going to shorten runway. As a result, bonus take of distance mission will be achieved.

Plain flap

Plain flap is most widely used control surface configuration in model aircrafts due to its simplicity. Specific section is cut at the trailing edge of the airfoil which moves as a whole.

These flaps can also rotate upwards leading better control.

Fowler flap

Thin section at the trailing edge of the airfoil is used to control the airflow. Fowler flap differs from split flap in terms of the fully open position. Control section is positioned at the trailing edge, resulting increase in wing area.

Slotted flap

Slotted flaps are widely used in modern aircrafts. It allows air transfer between the wing and the flap. Therefore, slotted flaps reduce separation risk while allowing increase in lift and minimum increase in drag. However, manufacturability is difficult due to its complexity.

Split flap

Thin section directly moves downwards at this configuration. It increases loft by increasing maximum camber. However, drag is also maximized with less change in pitching moments.

Figure of Merit	FoM weight	Plain	Fowler	Slotted	Split
Aerodynamic	0.4	1	1	1	0
Manufacturability	0.2	1	0	-1	1
Change in wing area	0.2	0	1	1	0
Change in pitching moment	0.2	0	0	0	0
Total	**1**	**0.6**	**0.6**	0.4	0.2

Our team decided to use two different flap type at different sections of wing. Plain and Fowler flaps are going to use in wing design.

Advantages	Disadvantages
Ideal for aileron design	Fowler and slotted flaps produce more lift
Easy to design and manufacture	

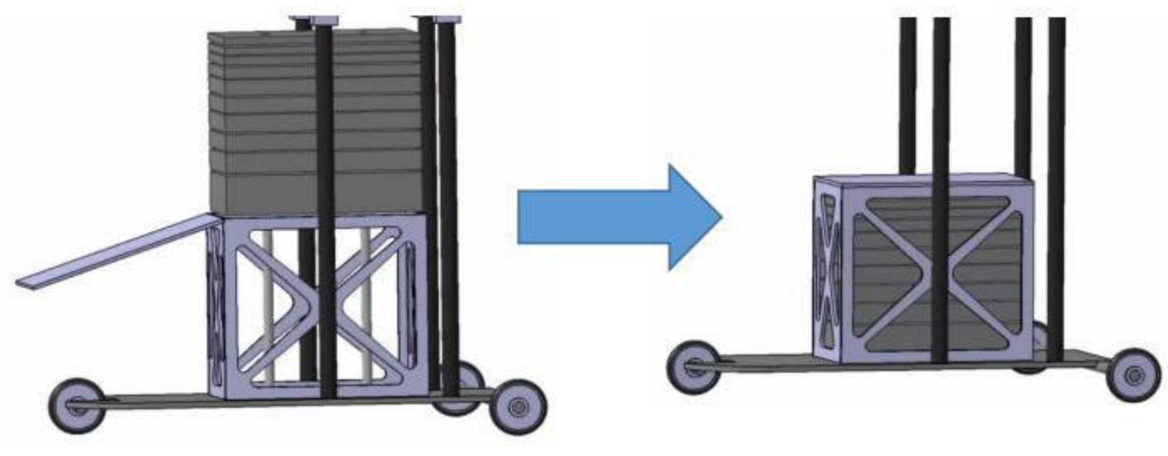
Table 7. Pros and cons table of plain flap configuration.

Advantages	Disadvantages
High lift due to increased area	Difficult to manufacture

Table 8. Pros and cons table of fowler flap configuration.

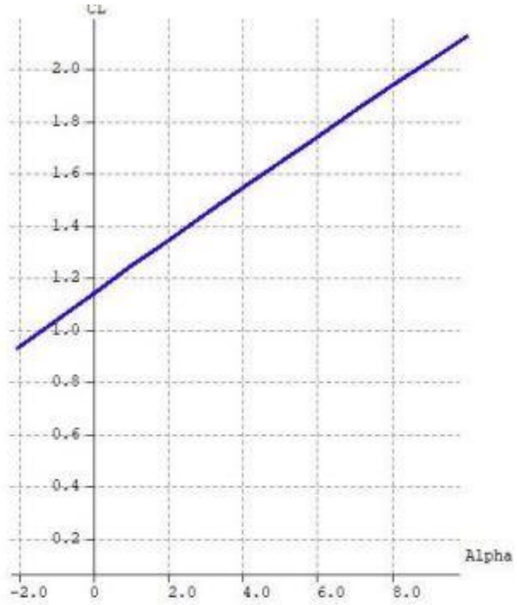
Cargo Bay

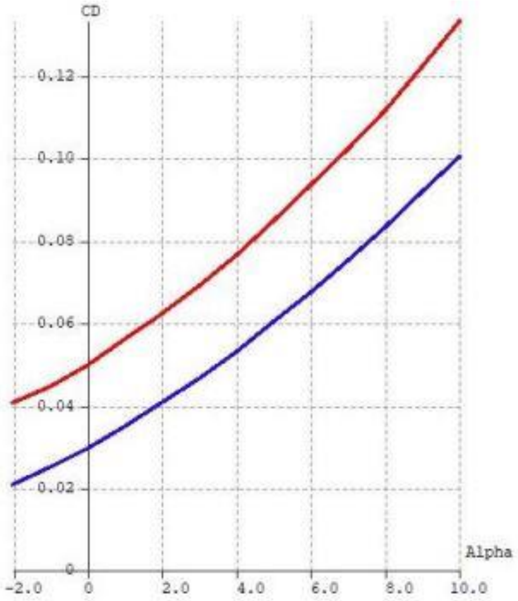
Payload bay design is based on two crucial parameters, firstly, payload must be inserted fast and secondly, without any hooking to cause delay in payload placement. To overcome first design criteria, the cargo bay will be positioned under the fuselage. Placement is made in order to place cargo fast. For second criteria, plate dimensions are indicated in regulations. Therefore, by using steel density (7850 kg/m3), total volume of 13 kg is predicted. Plates will be secured after they are inserted into two reference rod.

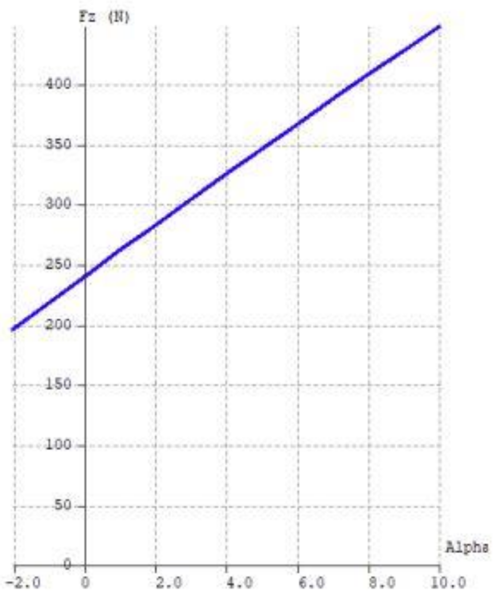


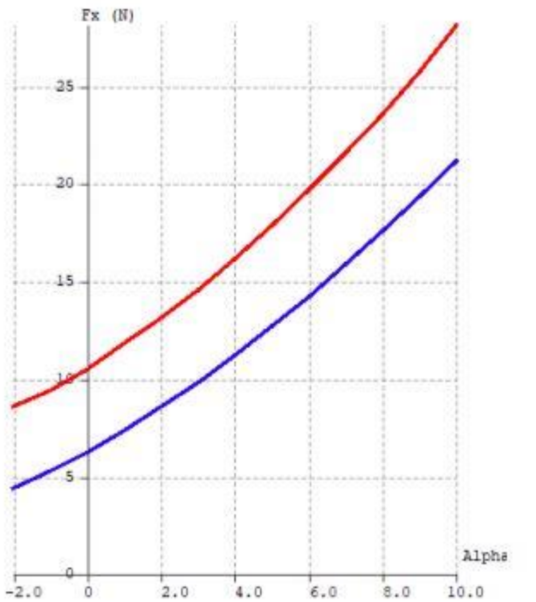
2.4 Aerodynamic Design

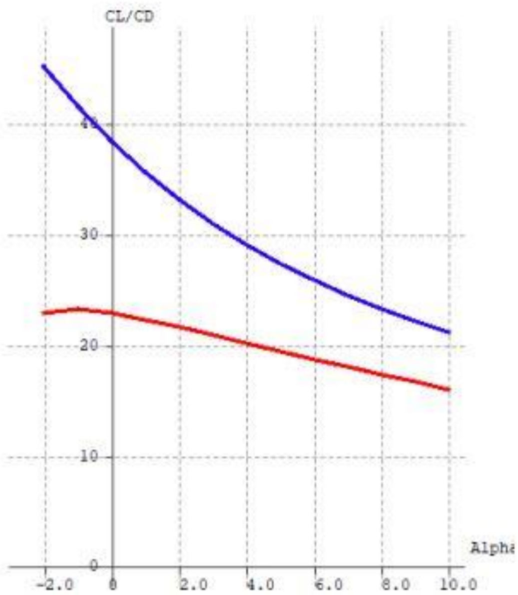
Since various types of aircraft configurations are determined, preliminary design and aerodynamic analysis of aircraft can be conducted. ATA team has been using Xflr-5 software for years to conduct aerodynamic and stability analysis for aircrafts. This software is our chose due to accuracy in aerodynamic solutions. Aerodynamic analysis is conducted for aircraft using vortex lattice method at 20m/s for both viscid and inviscid flow. Our results are shown in following figures. In following graphics Red line presents viscid flow and blue line presents inviscid flow

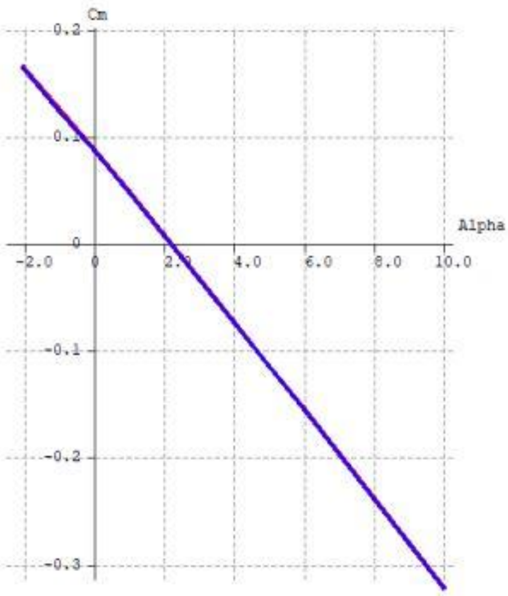












2.4.1 Results of the analysis:

- According to the lift-alpha graphic total lift is equal to 240 N which equals to 24.3 kg. However, due to fuselage, propeller effects of air flow and manufacturing imperfections lift is expected to reduce at least 20%.

- Drag-alpha graphic presents that, for a flight regime between 0 to 3 degree, total drag force is range between 10 to 14 Newton which equals to 1.01 to 1.47 kg. According to data sheets, AXI Gold 2826/10 with 12x7 propeller and 3S battery, can provide up to 2.5 kg of thrust. We are going to verify these results with thrust test in order to approve that aircraft can accelerate and maintain cruise speed.

 In both viscid and inviscid solutions, 0 angle of attack is the most efficient flight.

 Pitching moment graphic shows that the aircraft has a positive pitching moment. Cmalpha line is interpreted to be ideal for a stable flight.

2.4.2 Dimensioning

Summary of aircraft dimensions are shown in following table.

Wing span	3.5 m
Length	1.75 m
Fuselage length	2.06 m
Tail span	1.3 m
Wing area	0.86 m2

Detailed version of aircraft dimension table is shown in following table.

WING		HORIZONTAL TAIL	
Wing span	3.5 m	**Tail span**	1 m
Root chord	0.27 m	**Tail root chord**	0.15 m
Tip chord	0.15 m	**Tail tip chord**	0.15 m
Taper position	1.05 m	**Taper position**	0 (Root)
Taper ratio	0.556	**Taper ratio**	1
Wing area	0.86 m2	**Tail area**	0.15 m2
Aspect ratio	14.24	**Aspect ratio**	6.66
VERTICAL TAIL		**DISTANCES**	
Tail span	0.25 m	**Tail-Leading edge**	1.6 m
Tail root chord	0.15 m	**CoM-Leading edge**	0.12 m
Tail tip chord	0.15 m	**Weight-Fuselage**	1.18 kg
Taper ratio	1		
Tail area	0.0375 m2		
Aspect ratio	3.33		

3 Structural design

3.1 Chosen materials

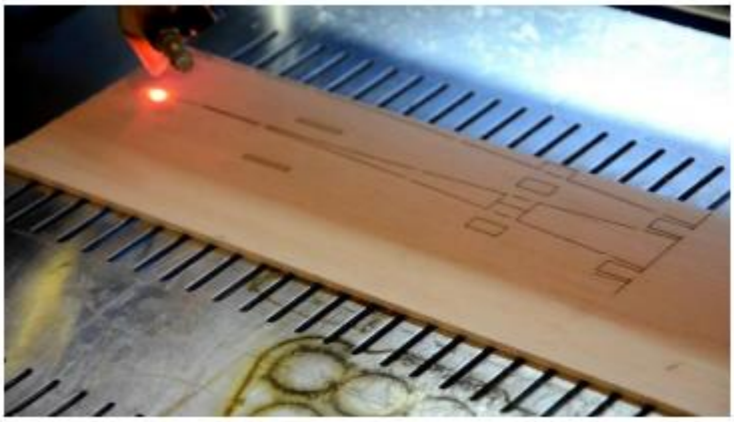
Aircraft is designed to withstand various forces. It is based on the idea of hybrid design. Consequenlty.different types of materials are going to be used in different sections of aircraft. Following table presents our material selections, place of use and selection rationale.

Material	Used section	Rationale
Carbon fiber rod	Wing spar&moment rod	High buckling resistance
Carbon fiber	Fuselage&landing gear	High strenght
Balsa wood	Wing&Tail Ribs	Lightweight&easy manufacture
Plywood	Cargo bay	Optimal strenght/weight ratio
Polymer	Connection elements	

3.2 Manufacturing Techniques

3.2.1 Laser cut

For wing and tail ribs, it is decided to use balsa wood in these sections. Balsa woods and plywood will be cut by using 2D laser machine with known tolerances.



3.2.2 Vacuum infusion

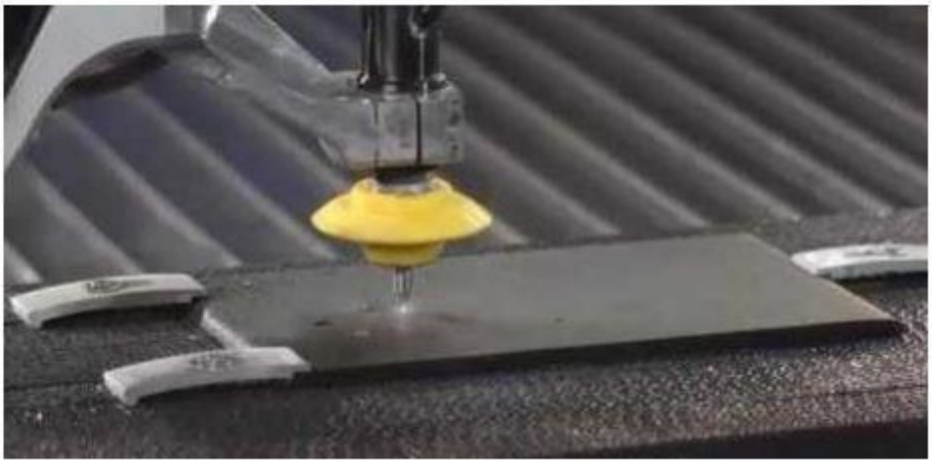
These techique is used to manufacture the fuselage. For prototypes, carbon fiber clothing is moulded with this tecnique and cured for 24 hours.

3.2.3 CNC machining

Some of the connection elements is shaped with CNC machines. Some parts requires high precision that can be only achieved by CNC machines. These machinese accurately cuts, drills etc according to the uploaded g-codes. Block is placed and adjusted relative to origin. After that machine starts to shape the block precisely.However, CNC machining can be time consuming especially on large scales.

3.2.4 Water jet

Finally, prepared carbon fiber plates will be shaped using water jet with known tolerances.



4 Power System and Efficiency Improvements

One of the most important parameters in the competition is the thrust sytem and its efficiency. Power diagram of the aircraft can be presented as;

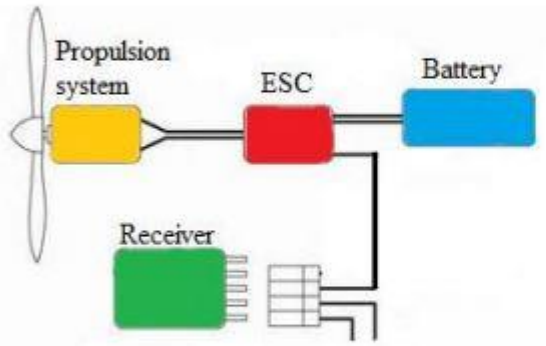


Figure 12. Power diagram of aircraft.

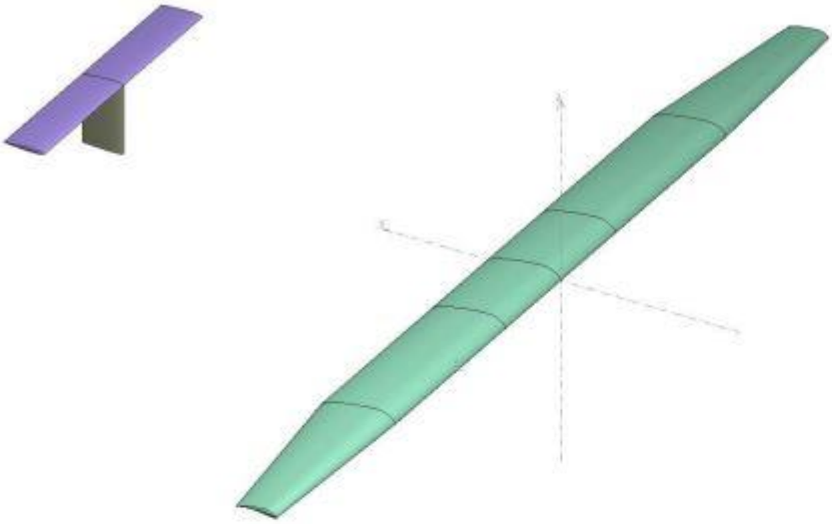
Competition demands every participant to use same propulsion system. Propulsion system consist of one AXI Gold 2826/10 and 12x7 propeller. Our mission is to design most efficient power diagram as possible. Therefore, our approach to power system design is,

- Propulsion system is fixed, however our research showed that it is much more efficient to put the motor far from the fuselage in order to prevent airflow to be perverted by fuselage. Fuselage and motor should be connected with a thin section.
- Motor should not be enclosed to cause overheating leading to a decrease in efficiency.
- ECS selection is made according to efficiency. Selected ESC is Castle Talon 90. This model is especially designed for fixed wing UAVs.
- A commercial li-po battery is selected for power system. Battery which have lowest internal resistance is selected to prevent tremendous voltage drops during the flight. It is highly necessary to stabilize voltage during all potions of flight to complete track as fast as possible.
- Selected battery is Gens ACE Lithium polymer 4000mAh 11.1V 25C 3S1P. 11/1 V is a regulation, 25C is optimal C for high continuous voltage transfer. 4000 mAh is necessary battery capacity for calculated flight time.
- For flap and elevator control SAVOX SC-0252MG, torque value is 6.0V: 10.5kg, aileron and rudder control SAVOX SH-0256, torque value is 6.0v 4.6 Kg/Cm servo motors are selected.
- Cables are going to be short. Any additional extend in wiring cause small increase in resistance.

Figure 13. An outlook of selected ESC and battery configurations.

Figure 14. An outlook of selected Flap-Elevator (left) servo and Rudder-Aileron (right) servo configurations.

5 OUTLOOK



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