**Advances in Aircraft and Spacecraft Science**, *Vol. 4, No. 1 (2017) 65-80*
DOI: http://dx.doi.org/10.12989/aas.2017.4.1.065

# Design optimization of a fixed wing aircraft

Ugur C. Yayli[1], Cihan Kimet[1], Anday Duru[1,2], Ozgur Cetir[1], Ugur Torun[1],
Ahmet C. Aydogan[1], Sanjeevikumar Padmanaban[3] and Ahmet H. Ertas*[2]

[1]*Department of Mechanical Engineering, Karabuk University, Karabuk, 78050, Turkey*
[2]*Department of Biomedical Engineering, Karabuk University, Karabuk, 78050, Turkey*
[3]*Ohm Technologies, Research and Development, Chennai, India*

*(Received June 6, 2016, Revised August 27, 2016, Accepted September 19, 2016)*

**Abstract.** Small aircrafts, Unmanned Aerial Vehicles (UAVs), are used especially for military purposes. Because landing fields are limited in rural and hilly places, take-off or landing distances are very important. In order to achieve a short landing or take-off distance many parameters have to be considered, for instance the design of aircrafts. Hence this paper represents a better design to enlarge the use of fixed wing aircrafts. The document is based on a live and simulated experiments. The various components of designed aircraft are enhanced to create short take-off distance, greater lift and airflow without the need for proper runway area. Therefore, created aerodynamics of the remotely piloted aircraft made it possible to use fixed wing aircrafts in rural areas.

**Keywords:** fixed wing; aircraft; take-off distance; design optimization

## 1. Introduction

Finite element analysis (FEA) plays important roles in design. This is important especially for big structures like airplanes, ships etc. Somehow prototypes are used in experimental based studies to decrease expenses. Hence Unmanned Aerial Vehicles (UAVs) can be considered prototypes of big airplanes. There are currently lots of researches about the Unmanned Aerial Vehicles (UAVs) underway around the world because UAVs provide unique features that mankind cannot do (Liu, Chen *et al.* 2014). UAVs are aircrafts with no pilot on board. These vehicles can be autonomous or controlled remotely from the ground for different purposes (Yildiz, Eken *et al.* 2015). For instance, UAVs are used as aerial distribution system (Nedjati, Vizvari *et al.* 2015) to supply large amount of demand in small amount of time for emergency cases and it can also serve as a complementary system for non-accessible areas. Geothermal features of environment can also accurately be mapped and sampled to research physical and biological characteristics by UAVs (Nishar, Richards *et al.* 2016). An effective algorithm has been developed by Chen and his colloquies (Chen, Wang *et al.* 2016) to detect vehicles by aerial images. Therefore, law enforcement, border protection, security monitoring, wild-life monitoring may also be considered as application areas of UAV systems in the modern world. Instead of on-board aircraft pilots, these unmanned systems are suitable for dirty,

---

*Corresponding author, Associate Professor, E-mail: ahmeth.ertas@gmail.com

http://www.techno-press.org/?journal=aas&subpage=7 ISSN: 2287-528X (Print), 2287-5271 (Online)

dangerous, long and tiring missions. Low operational cost and low-risk for the operator make UAVs more popular in nowadays. However, short flight endurance is the biggest constraint (Linchant, Lisein *et al.* 2015). Thus, design of the UAVs plays an important role to increase short flight time and speed.

In spite of the fact that UAV engines are generally driven by internal combustion engines, there are many propulsion systems in UAVs. The three main types of propulsion systems can be specified as alternative thermal, electrical and hybrid systems. The first type of system is the alternative thermal systems and they are the engines powered by gasoline (Fahlstrom and Gleason 2012, Khardi 2014). On the other hand, the required energy in the electrical propulsion systems is generated by electrical motors and the power can be supplied different ways. The last propulsion system type is the hybrids, they are the combination of fuel cells and batteries (González-Espasandín, Leo *et al.* 2014).

Design of the body and wings of UAVs is very crucial because it directly forms the aerodynamic structure of the aircraft. Since there is no limit in the design of both body and the wing structure, their design is an important factor that affects the capabilities of the UAV. In general, two types of wing structure are used in UAVs for different purposes. Rotary wing is one of the wing type and it has the biggest advantage which is the ability for take off and land vertically (VTOL) (Petrolo, Carrera *et al.* 2014). However, due to their low speeds, mechanical complexity and shorter flight range, this makes rotary wing UAVs well suited to applications like facility inspections, which require maneuvering around tight spaces and the ability to maintain visual on a single target for extended periods. For instance, Chia and his colleagues (Chi, Cheng *et al.* 2014) also stated that they can also be used as swarms for rescue and search operations. On the other hand, they can also solve the challenges of uncertainty in planning, building and maintaining infrastructure in civil engineering by maneuvering around tight spaces. Also, Liu and his colleagues (Liu, Chen *et al.* 2014) concluded that seismic risk assessment, transportation, disaster response, construction management, surveying and mapping, and flood monitoring and assessment is possible applications of UAVs. The fixed-wing type UAVs has simpler structure, and more efficient aerodynamics that provide the advantage of longer flight durations at higher speeds (Sun 2007).

Within this paper, new design parameters are considered to increase the advantages of fixed wing type UAVs. Specifically, shorter takeoff and landing distances will erase the need for proper runway area. Thus, it will add another crucial advantage for fixed wing aircrafts and also, it will enlarge the use of fixed wing aircrafts.

## 2. Mission requirements

Before designing the UAV, it is considered that the aircraft should met and demonstrate some flight capabilities. These capabilities have been chosen to create fast, reliable and precise design. Thus, three missions are chosen to test the designed aircraft. The first experiment relies on measuring speed and take-off capability of aircraft. Therefore, the aircraft has to take off in 60ft (18.28 m) under three seconds and it has to fly as fast as possible. Therefore, flight course (Fig. 1) is prescribed to test these features.

In the first mission, aircraft will take-off in the prescribed distance and fly off 500 ft (152.4 m). Then, there will be a 180° turn, after that the aircraft will make a 360° upside turn and move forward 1000 ft (304.8 m) and it will turn back 180° again. This mission will continue until the 4 minutes of time has been finished. Thus, the speed and the take-off capability will be measured by

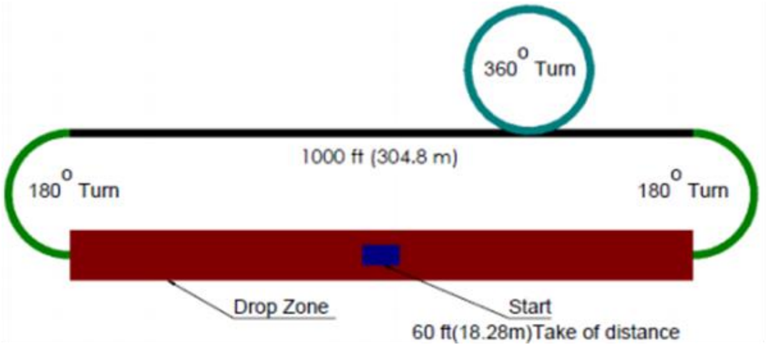

Fig. 1 Flight course for missions

the first mission.

Second mission will require that aircraft has to complete three laps with an internal payload. Payload is chosen as around 5lb (2.268 kg) and its nominal overall size is 4.5”×5.5”×10” (11.43 cm×13.97 cm×25.4 cm). The payload must be carried reliably and the aircraft must take-off and land successfully. Flight course (Fig. 1) has to be completed three times with a given payload. This will give the cargo carriage capability information of the designed aircraft.

Last mission will test the drop capability of the aircraft. Therefore, there needs to be a drop mechanism inside or outside of the aircraft and also there will be a prescribed area to measure how precisely the aircraft will drop payloads. Payloads are going to be Champro 12” plastic balls and the weight of a ball is 4oz (100 gr). Balls have to be dropped remotely from an aircraft, and one ball will be dropped at each lap in the drop zone (Fig. 1).

All the given missions are chosen to create unmanned- electrically powered, radio controlled aircraft with a balanced, high quality, affordable design (AIAA Student Design/Build/Fly Competition).

## 3. Aircraft configuration

### *3.1 Wing types*

Fixed-Wing aircrafts can have number of different wing types. The first and most common configuration is known as monoplane or one wing plane (Miller, Vandome *et al.* 2010). Low-wing, mid-wing, shoulder-wing, high-wing, parasol-wing are some of the wing types that are used in the conventional monoplane aircrafts (Fig. 2).

Conventional monoplane is chosen because it has different advantages. Design is simple and easy to manufacture. Also, aerodynamic performance is more predictable and it has low induced drag when compared to others biplanes or triplanes (Stinton 2001).

Flying Wing is described as tailless fixed wing aircraft configuration. In spite of the fact that flying wing is the aerodynamically most efficient type design, unfortunately, it is unstable and difficult to control in the air (Eken and Kaya 2015). The configuration of the lifting body only consists of the body that produces lift itself. It is just the fuselage without the conventional wing. Since this type of wing configuration is designed for high speed applications, it is not appropriate for short take-offs. Biplanes and triplanes are not useful for the mission requirements. All in all,

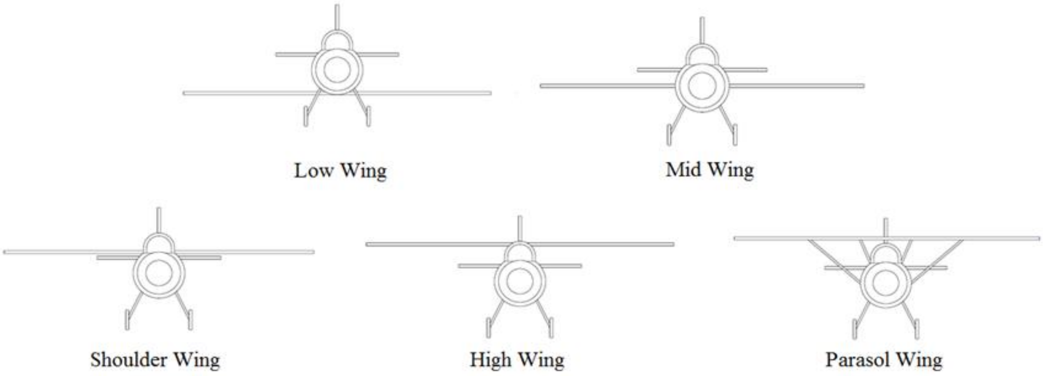

Fig. 2 Wing types for Monoplanes

Table 1 Comparison of wing types

| Figure of Merit | Score of Factor | Monoplane | Biplane | Flying Wing |
|---|---|---|---|---|
| Weight | 40 | 2 | 1 | 2.5 |
| Lift / Drag | 30 | 2.5 | 3 | 2.5 |
| Stability | 10 | 3 | 1.5 | 1.5 |
| Manufacturability | 10 | 2.5 | 2 | 1.5 |
| Aerodynamic Performance | 10 | 3 | 2.5 | 2.5 |
| Total | 100 | 240 | 190 | 230 |

high wing type is chosen to maximize lifting capacity, and monoplane fixed-wing type is chosen for better movement capacity and speed. Weight, lift/drag capacity, stability, manufacturability and aerodynamic performance are taken into account while creating the most suitable configuration that meet the mission requirements (Table 1). Score factors in Table 1 represent the data taken from AIAA. Score factors represent the importance of the parameters in the design.

### *3.2 Tail types*

In the conventional configuration the horizontal stabilizer is a small horizontal tail or tail-plane located to the rear of the aircraft. Also, this is the most common configuration according to Raymer and his colleagues (Raymer 1999). In addition, the tail-plane helps adjusting the changes in the center of pressure, and center of gravity caused by changes in speed and attitude, or when fuel is burned off, or when cargo or payload is dropped from the aircraft. V-tail is advantageous because this type of tail produces less induced and parasitic drag. On the other hand, combining the pitch and yaw controls is difficult and requires a more complex control system (Arifianto and Farhood 2015). The V-tail arrangement also places greater stress on the rear fuselage when pitching and yawing T-tail type gives smoother and faster air flow and also, it has better pitch control. However, vertical stabilizers should be made of strong and stiff material. Thus, expensive composite materials are needed for T-tail type. Also blanking of the airflow over the tail-plane and elevators by a stalled wing at high angles of attack can lead to total loss of pitch control (Warsi, Hazry *et al.* 2014). The tail types Conventional, V-Tail and T-Tail is compared to find out the best-fit tail type for the missions while comparison is made weight, drag and stability factors are considered (Table 2).

Table 2 Comparison of tail types

| Figure of Merit | Score of Factor | Conventional | V-Tail | T-Tail |
|---|---|---|---|---|
| Weight | 55 | 3 | 1 | 1 |
| Drag | 20 | 2 | 2 | 3 |
| Stability | 25 | 2 | 3 | 1 |
| Total | 100 | 255 | 170 | 140 |

Table 3 Comparison of landing gear types

| Figure of Merit | Score of Factor | Tricycle | Tail Dragger | Bicycle |
|---|---|---|---|---|
| Weight | 20 | 2.5 | 2.5 | 1.5 |
| Take Off | 30 | 2.5 | 2.5 | 2 |
| Payload Interference | 20 | 2.5 | 2.5 | 2 |
| Ground Handling | 10 | 2.5 | 3 | 1.5 |
| Manufacturability | 10 | 2 | 2 | 2.5 |
| Durability | 10 | 3 | 2 | 1.5 |
| Total | 100 | 250 | 245 | 185 |

Table 4 Comparison of motor types

| Figure of Merit | Score of Factor | Pusher | Tractor | Push-Pull |
|---|---|---|---|---|
| Weight | 40 | 3 | 3 | 1 |
| Landing Gear Interference | 30 | 1 | 3 | 1 |
| Efficiency | 30 | 1 | 2 | 1 |
| Total | 100 | 180 | 270 | 100 |

### 3.3 Landing gears

There are basically three different gears as Tricycle, tail dragger and bicycle. The bi-cycle gear configuration is used in cases where placement of essential components prohibits the use of either tricycle or the tailwheel configuration. The important consequence of bicycle gear arrangement is that take-off rotation is difficult to control (Schibani 2014). Tail-wheel type configuration is generally lighter than other type of gears, but it has strong tendency to ground-loop (Ma, Sun *et al.* 2013). However, in tricycle configuration, the aircraft is more stable and it is easier to control in take offs instead of any other type landing gear configuration. The table compares the best-fit option to complete given missions considering six different factors (Table 3).

### 3.4 Motor placement

Choosing motor type in the aircraft for given missions may be the most important factor that affects take-off, speed and landing properties. Tractor, pusher, double tractor, push-pull type motors are compared to find out the best option to complete given missions (Table 4). In the tractor type motor, motor and propeller is placed on nose of the aircraft. It maintains stability of an aircraft and reduces the weight of overall system. On the other hand, pusher type motor use one propeller so, it reduces system weight. However, if the propeller was placed on the tail of the aircraft, it would affect the efficiency of system. In addition to this, pusher type motor may cause a problem and it may lead to bad effect on take-off performance. In the push-pull type motor, propellers are placed individually on the nose and tail of the aircraft. It also increases the weight of aircraft.

## 4. Final design of the aircraft

### *4.1 Airfoil selection*

Before last design, lots of analyses have been made. First of all, airfoil is selected (Fig. 3) considering aerodynamic characteristics. Aerodynamic characteristics of aircraft would be better with increasing angle of attack (AOA) (Raymer and Daniel 1999). However, large angle of attack causes stall. Thus, critic angle of attack (AOA) is determined as 15°. On the other hand, a lift-to-drag ratio Cl/Cd is calculated to compare various scenarios. Also, Cl value of airfoils is considered because Cl is an important factor that affects lifting force. Aerodynamic team analyzed selected airfoils between 0° and 15° AOA and compared them according to Cl/Cd and Cl-$\alpha$ value. Compared airfoils are; SA7025, SA7038, SA7035, SD7090, MH 114. These airfoils were analyzed using XFLR-5. XFLR5 is an analysis tool for airfoils, planes, and wings which operate at low Reynolds Numbers. Wing design and accordingly wing analysis have been conducted using the Lifting Line Theory, the Vortex Lattice Method and 3D Panel Method. The corresponding results are shown in Fig. 4. Figure of Merit chart (Table 5) is generated according to results of analyses. In Table 5, five different airfoils have been selected just because of both their popularities and also their suitability for UAVs.

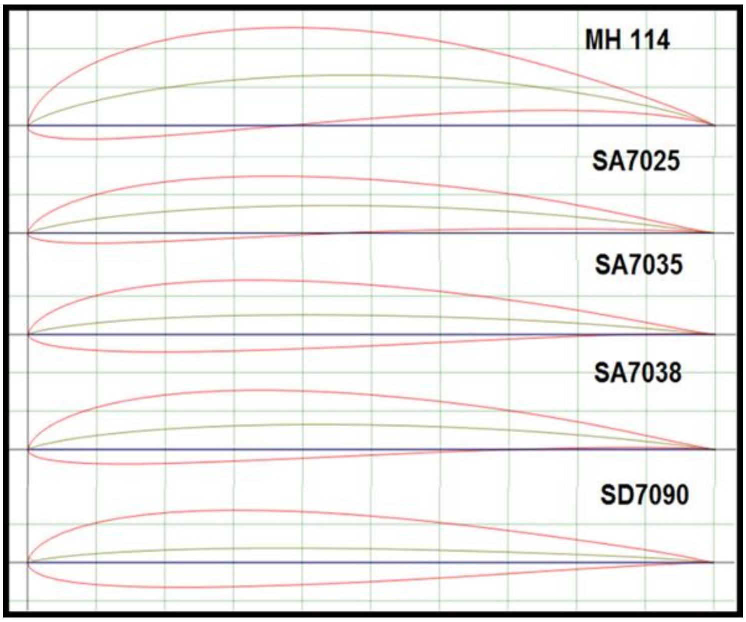

Fig. 3 Selected airfoil types

Table 5 Figure of merit analysis of selected airfoils

| Figure of Merit | Score of Factor | MH 114 | SA7025 | SA7035 | SA7038 | SD7090 |
|---|---|---|---|---|---|---|
| Cl/Cd-$\alpha$ | 40 | 3 | 1.5 | 2 | 2.5 | 1 |
| Cl-α | 60 | 3 | 2 | 2 | 2.5 | 2.5 |
| Total | 100 | 300 | 180 | 200 | 250 | 190 |

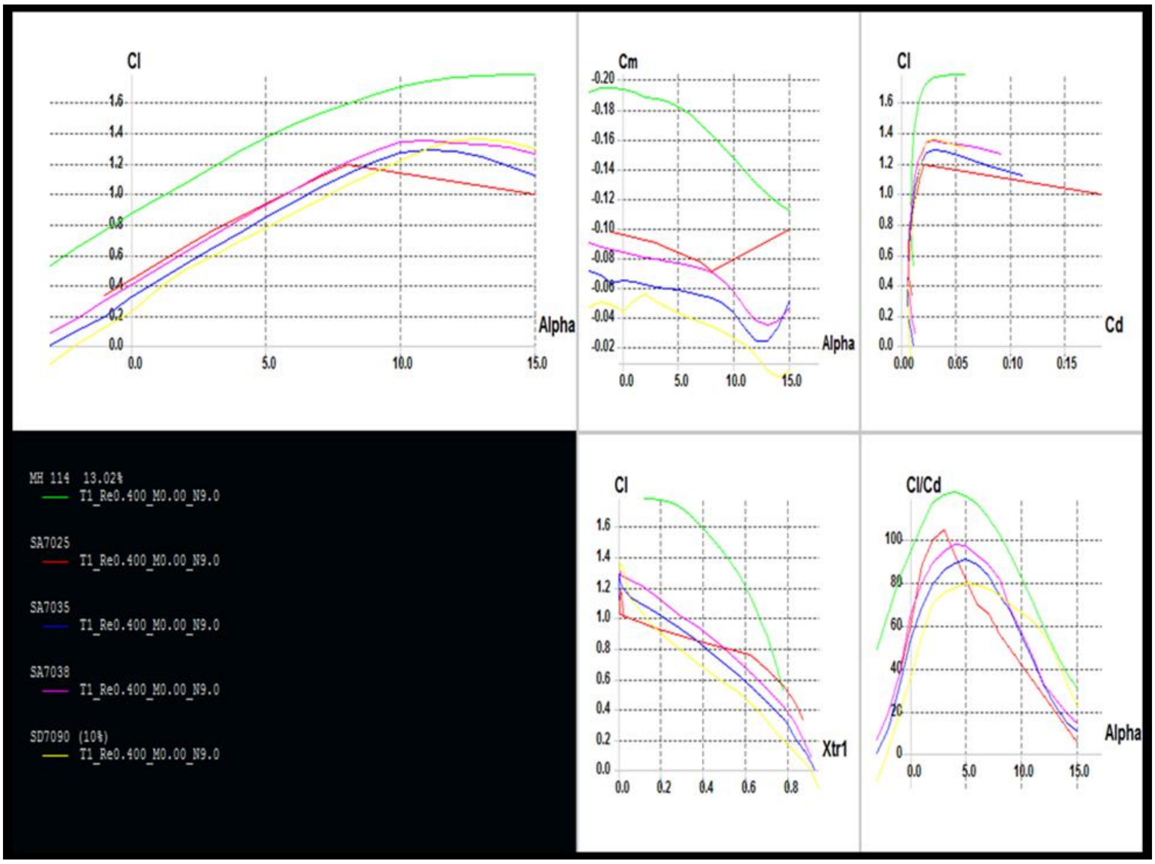

Fig. 4 Analysis of airfoils

Dinesh, Kenny *et al.* (2014) states that increase in lift occurs because the up-wash field effectively rotates the lift vector forward, reducing the induced drag. Analyze results of selected airfoil, which is MH 114, are shown in the Fig. 5. Re=400 000. Cl-$\alpha$, Cl-Cd and Cl/Cd-$\alpha$ graphs were examined particularly in committed analyses. The airfoil which has the best result is the Cl (lift coefficient)-Cd (drag coefficient) graph and it would be the best choice for designed aircraft because Cl/Cd ratio is an important factor to take-off (Petrolo, Carrera *et al.* 2014). Aircraft which has an airfoil that provides the highest Cl value when Cd value is low, will have an easy takeoff. Airfoil which has the best graph result is MH 114. When analyzed other graphs it can be seen that MH 114 has the best results. While determining AOA, Cl-$\alpha$ and Cl/Cd-$\alpha$ graphs are examined. Best AOA is found out as 4° but if Cl-$\alpha$ graph is considered, AOA can be chosen between 4° and 14°. Resulted comparisons MH 114 selected as the airfoil and AOA (angle of attack) is selected as 5°.

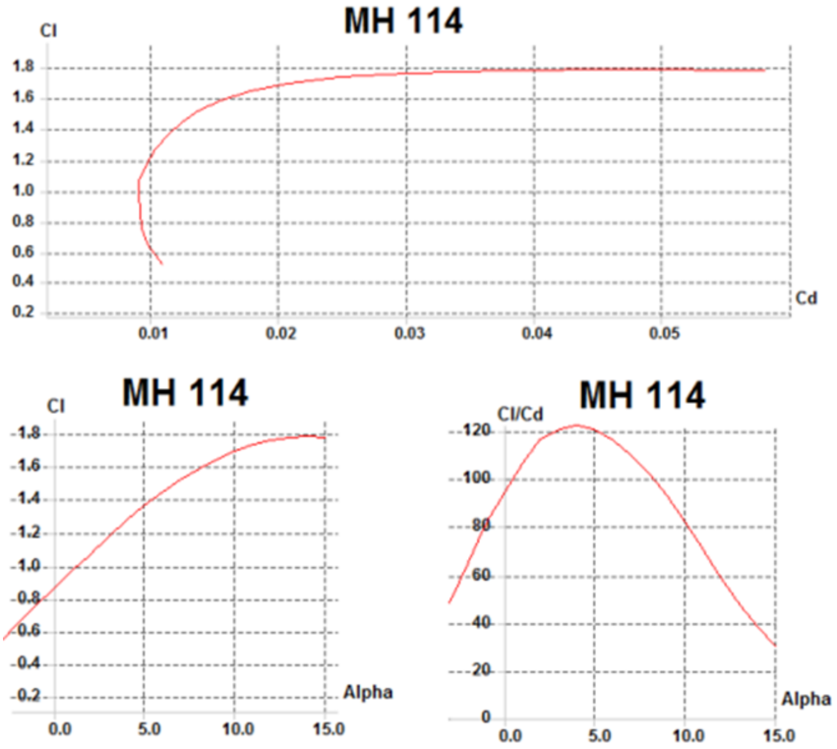

Fig. 5 Analyze results of MH 114

### *4.2 Aerodynamic performance of aircraft*

Sizing control surfaces on aircraft, locating of center of gravity (Cg), and adjusting static margin are made to create well stability and better movement capability. Cg point is placed ahead of neutral point (Reymar and Daniel 1999); if the Cg is ahead of the neutral point (positive static margin), the pitching moment derivative is negative so the aircraft is stable. Aircraft is designed with positive static margin (5-10%) to make more stable aircraft.

Aileron is the most effective control surface for banking turn of the aircraft. Therefore, aircraft would have better movement capability (Ajaj, Friswell *et al.* 2013). Also, flaps can be placed on aircraft's wings. However, flaps can also be used to assist take-off not for movement capability and more control surface means more servo. Number of servo effects contest score, so wing span is not designed too long. Aileron's size is approximately 25% of wing chord and 80% of wing span. Controlling the aileron was provided with servos that placed on each wing. Long ailerons make control of aircraft more sensitive and increase maneuverability. There are 180° and 360° turns in the missions, so movement capability should be considered specifically. Wings with long ailerons have been produced, so aircraft would have more movement capability.

The horizontal stabilizer prevents an up-and-down motion of the nose, which is called pitch. Horizontal stabilizer is an indispensable component for takeoffs and landings. Necessary analyses have been made according to the aircraft design and it is decided that NACA 0012 horizontal stabilizer should be used on the aircraft. Appropriate elevator has been designed according to the design characteristic of the aircraft. Designed elevator comprises approximately 25% of horizontal

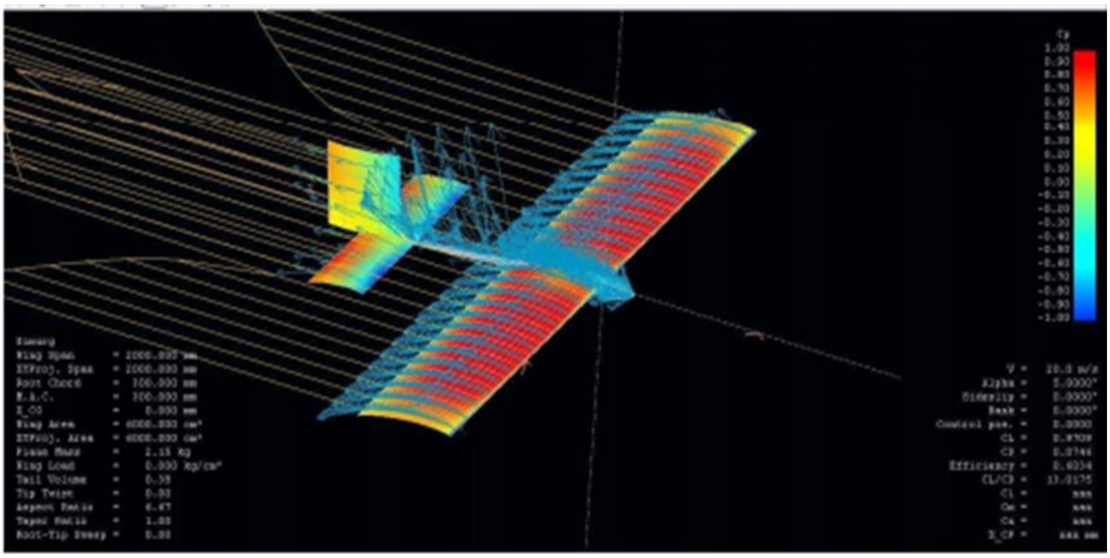

Fig. 6 Aerodynamic performance

Table 6 Motor selection

| Motor | RPM / Volt | Weight (oz-kg) | | Max. RPM | Watts |
|---|---|---|---|---|---|
| Neu 1110 2.5Y | 1814 | 4.02 oz | 0.113 kg | 60000 | 500 |
| Neu 1110 3Y | 1512 | 4.02 oz | 0.113 kg | 60000 | 500 |
| Neu 1110 6D | 1400 | 4.02 oz | 0.113 kg | 60000 | 500 |
| Neu 1112 3Y | 1175 | 4.88 oz | 0.138 kg | 60000 | 600 |

stabilizer chord.

The vertical stabilizer keeps the nose of the plane from swinging from side to side, which is called yaw. Rudder's move causes torque at the center of gravity of aircraft and this provides yaw (side to side) motion to aircraft. Tail moment arm has been kept as long as possible to get more torque with movement of rudder (Zhang, Zhen *et al.* 2010). Rudder has been designed as 40% of vertical stabilizer's chord. Fig. 6 shows estimated aerodynamic performance of the design and simulated results using XFLR-5 software.

### *4.3 Propulsion system*

Propulsion system has been designed considering following factors. In order to achieve high speed especially in the first mission, motor with high thrust power is required to complete each mission successfully. It is carefully considered when choosing motor to get maximum efficient energy from batteries and the other factor that affects propulsion was also creating a lightweight aircraft. Gearbox model will help us when achieving second and third mission. Gearbox will supply to aircraft desired thrust. High powered motor will discharge batteries quickly and have higher weight so the team has tried to choose optimum powered and weighted motor.

In the Table 6, it is obvious that all motors have same weight. Neu 1110 2.5Y which has the highest Kv (RPM/Volt) value is selected as the motor of aircraft. Additionally, P29 6.7 Gear Ratio

Table 7 Propeller comparison for first and third mission

| Propeller | Stall Speed (mph) | Optimal Speed (mph) | Thrust (oz) | Rate of Climb (ft/s) |
|---|---|---|---|---|
| 13×10 | 13 | 17 | 30.4 | 3.01 |
| 13×7 | 14 | 19 | 44.7 | 9.18 |
| 14×9 | 14 | 19 | 79.3 | 13.63 |
| 14×7 | 14 | 19 | 57.1 | 11.3 |
| 15×13 | 13 | 17 | 27.5 | 8.01 |
| 15×12 | 13 | 17 | 31.8 | 8.61 |
| 12×10 | 14 | 18 | 21.5 | 4.91 |
| 11×8 | 14 | 19 | 25.3 | 5.61 |

Table 8 Propeller comparison for the second mission

| Propeller | Stall Speed (mph) | Optimal Speed (mph) | Thrust (oz) | Rate of Climb (ft/s) |
|---|---|---|---|---|
| 17×10 | 14 | 19 | 105.82 | 28.08 |
| 13×10 | 13 | 17 | 15.9 | 3.01 |
| 13×7 | 14 | 19 | 44.7 | 9.18 |
| 11×8 | 14 | 19 | 25.3 | 5.61 |

Gearbox, is selected for proper gearbox.

### 4.4 Propeller analysis

Choosing the right sized propeller is very important factor to achieve all the missions successfully. High pitch propeller is used for high speed flight. Therefore, high pitch propeller should be used in the first and third mission. However, low pitch propeller would be proper for the second mission. Propellers have been compared according to the supplied information and Table 7 is obtained. MotoCalc 8 is used for the analysis of variety of propellers.

When the table is analyzed, it is obvious that 14x9 is the most suitable propeller for the first and third mission. The propeller comparison table that is created for the second mission is given in the Table 8.

### 4.5 Structural design

Fuselage system of the aircraft is designed considering important factors such as increasing flow-time with maximum load and achieving successful landing. Carbon fiber fuselage is found out as it is more suitable than balsa or other type of fuselages as a result of experiments and analyses that have been done. Therefore, the decision has been made to use carbon fiber as the material of fuselage. On the other hand, plywood is used for interior structure of aircraft. The fuselage structure of plywood can be seen in the Fig. 7.

Low-drag aerodynamic design will present long endurance aircraft (Jin and Lee 2015). Therefore, the computational analyses focused on wing structures to carry maximum fuselage weight, create maximum lift force with low-drag in the missions. Balsa type wing is produced because low aircraft weight is desired. Simulated 3g forces applied to each tip of the wing. After the

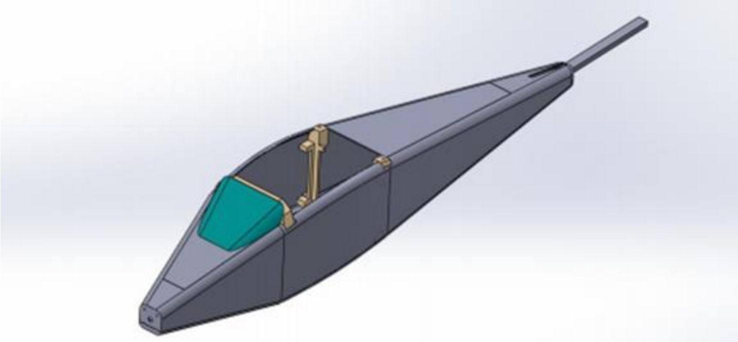

Fig. 7 Final design of fuselage

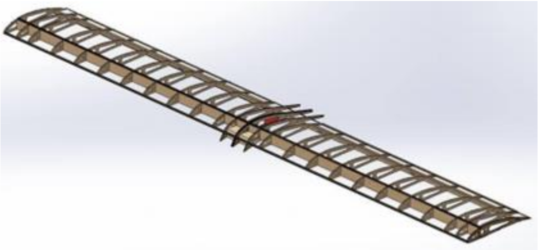

Fig. 8 Final design of the wing

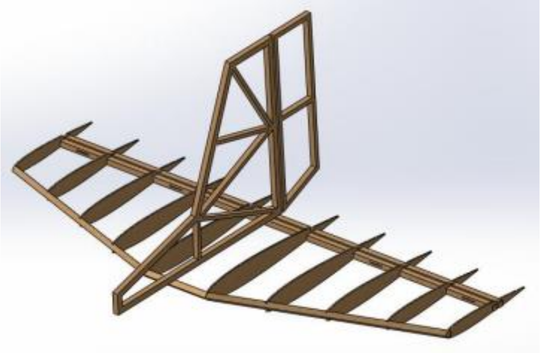

Fig. 9 Final tail design

successful wing tests, Balsa type and plywood wings are used for final aircraft. Final structure of wings can be seen in the Fig. 8.

After the analysis has been made on aircraft's design, conventional type tail is used because it has light weight and easy to control and less complicated to manufacture. Also, lightweight structural flexible design will provide more aero-elastic design (Palma, Paletta *et al.* 2009). The model type of horizontal stabilizer which used in the design is NACA 0012. Tail part of final design can be seen in the Fig. 9.

Landing gear is the critical component for the safety of aircraft, so knowing the stress distribution is a key to observe working condition of the gears (Li and Yang 2013). Steel landing gears have been tested for the first prototype to see whether it can complete all the missions or not. Selected steel landing gears have been simulated using total deformation analysis via ANSYS and

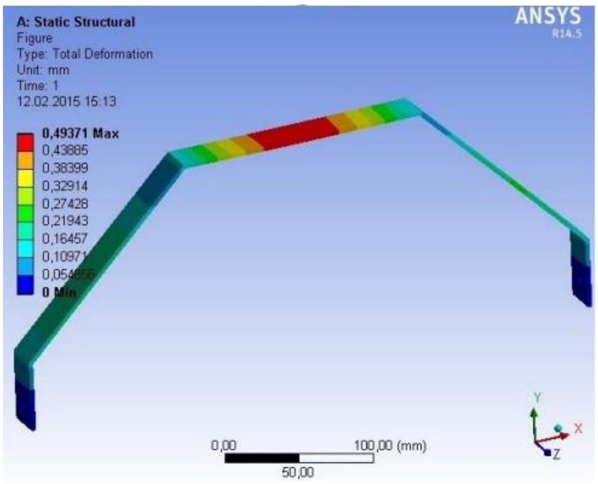

Fig. 10 Deformation analysis

Table 9 Propeller test results

| Propeller | Thrust | |
|---|---|---|
| | oz | kg |
| M1-14×9 | 104.05 | 2.95 |
| M2-17×10 | 114.64 | 3.25 |
| M3-14×9 | 98.76 | 2.80 |

results are shown in the Fig. 10. When 98.1 N (10 kg×9.81 m/s$^2$) force is applied to steel landing gear in *y* axis, obtained deformation results are shown in the Fig. 10. It is obvious that location of steel landing gears should stand the most deformation which are fuselage connection points and wheel connection points. Since aircraft weight is important parameter for flight performance, Eslami and his collogue (Eslami and Fazaeli 2012) stated in their study that carbon fibers-reinforced composites due to unique properties (including high specific strength and specific modulus, low thermal expansion coefficient, high fatigue strength, and high thermal stability) can be replaced with common industrial and structural materials. Therefore, carbon fiber material is chosen for landing gear material.

Selection of convenient propeller is very important to maximize mission performances. Different propellers were analyzed in computer and the best resulted propellers are chosen for the given work. Thrust test has been done on prototype aircraft to verify resulted analysis. Committed thrust test results are given in the Table 9.

## 5. Aircraft test results

Final design parameters have been decided and the aircraft has been manufactured according to the parameters listed in Table 10. After the manufacturing process, flight tests have been performed in different weather conditions and good results have been obtained. Wing strengths and stabilizers against *g* force which occurs when aircraft turns were tested. Each flight mission has been

Table 10 Final design parameters

| Wing | | | Motor | |
|---|---|---|---|---|
| Airfoil | MH 114 | | Model | Neu 1110-2.5Y |
| Span | 2000 mm | | Gearbox | 6.7:1 |
| Chord | 300 mm | | $KV_{off}$ | 1814 |
| Wing Area | 0.60 m$^2$ | | Power Rating | 500 W C. /1000 W S. |
| Aspect Ratio | 6.66 | | Weight | 0.164 kg |
| AOA | 5 | | Fuselage | |
| Battery | | | Length | 1370 mm |
| Model | Elite 1500 A | | Width | 190 mm |
| Capacity | 1500 mAh | | Height | 192 mm |
| Cell Voltage | 1.2 V | | Propeller | |
| Number of Cells | 26 | | Mission 1 | 14×9 |
| Pack Voltage | 31 Volts | | Mission 2 | 17×10 |
| Pack Weight | 0.659 kg | | Mission 3 | 14×9 |
| | Tail | | | |
| Horizontal | | Vertical | Controls | |
| Airfoil | NACA 0012 | - | ESC | Castle Creations Phoenix Edge 40A HV |
| Span | 700 mm | 250 mm | Receiver | Futaba T8J |
| Chord | 254 mm | 231 mm | Servos | Hitech 70 mg |
| Wing Area | 0.14 m$^2$ | 0.49 m$^2$ | | |
| AOA | 0 | 0 | | |
| Tail Arm | 0.981 m | 0.981 m | | |

Table 11 Experiment results

| Parameters | Mission 1 | | Mission 2 | | Mission 3 | |
|---|---|---|---|---|---|---|
| Take Off Weight | 4.973 lb | 2.256kg | 9.956 lb | 4.516 kg | 5.423 lb | 2.460 kg |
| Thrust | 104.05 oz | 2.95 kg | 114.64 oz | 3.25 kg | 98.76 oz | 2.80 kg |
| Take Off Length | 21.3 ft | 6.5m | 36.08 ft | 11 m | 29.5 ft | 9 m |
| Stall Speed | 20.53 ft/s | 6.258 m/s | 24 ft/s | 7.31 m/s | 21.5 ft/s | 6.55 m/s |
| Optimal Flight Speed | 27.85 ft/s | 8.49 m/s | 34.3 ft/s | 10.45 m/s | 28.5 ft/s | 8.68 m/s |
| Flight Time | 359 s | | - | | - | |
| Number of Laps | - | | 4 | | - | |
| Number of Balls | - | | - | | 3 | |

completed successfully without any damage. Performance characteristics are documented considering all the missions in the Table 11.

All in all, it is achieved that designed aircraft without payload can take-off under two seconds (Fig. 11). Also, live tests showed that it does not need a proper run-way area. Since take-off distance is lowered and fixed wing type aircraft create more speed, this type of aircrafts can be used in a more efficient way and more different areas.

Fig. 11 Take off under two seconds

## 6. Conclusions

The design of an aircraft is a complex procedure just because there are many parameters that affect the velocity, take-off capability, flight performance and landing distance of the aircraft. Thus, simulated experiments, material selection regarding analysis with computer software, and tests have big importance to meet required capabilities of the aircraft. Other investigations may concentrate on image acquisition, fuel efficiency, design of automatic formation flight controllers, or economic efficiency (Jackson 2011). It has been aimed to widen the use of fixed wing aircrafts. Therefore, design phase creates the vital part of the study, so component selections are made considering variety of parameters to fit best take-off and landing performance. In this way, greater lift and airflow were forming the main scope of the study. As a result, the use of remotely piloted fixed-wing aircraft can be enlarged and greater velocities and maneuver capability can be achieved. In other words, an aircraft has been designed and made to meet the requirements of shorter take-off distance and a higher flight speed. This will upgrade the fixed wing aircrafts and made them possible to use in rural areas for greater velocity intended applications.

## Acknowledgments

We are thankful for the constructive comments and suggestions of the anonymous reviewers that help the authors a lot to improve the manuscript quality. It is also worth mentioning “Karabuk University-Coordinator of Research Projects (BAP)” for supporting this research under BAP project (No: KBÜ -BAP-15/2-KP-062).

## References

AIAA Student Design/Build/Fly Competition. (n.d.), Retrieved February 10, 2016, from http://www.aiaadbf.org/

Ajaj, R.M., Friswell, M.I., Flores, E.I., Keane, A., Isikveren, A.T., Allegri, G. and Adhikari, S. (2013), “An integrated conceptual design study using span morphing technology”, *J. Intel. Mater. Syst. Struct.*, **25**(8), 989-1008.

ANSYS/ED (1997), Upper Saddle River, NJ: Prentice Hall.

Arifianto, O. and Farhood, M. (2015), “Optimal control of a small fixed-wing UAV about concatenated trajectories”, *Control. Eng. Pract.*, **40**, 113-132.

Chen, Z., Wang, C., Wen, C., Teng, X., Chen, Y., Guan, H. and Li, J. (2016), “Vehicle detection in high-resolution aerial images via sparse representation and superpixels”, *IEEE Tran. Geosci. Remote Sens.*, **54**(1), 103-116.

Chi, T., Cheng, H., Page, J. and Ahmed, N. (2014), “Evolving swarm of UAVs”, *Adv. Aircraft Spacecraft Sci.*, **1**(2), 219-232.

Dinesh, M., Kenny, M.V., Dharni, V.V., Santhosh, K.B., Sree, R.R. and Kumar, V.R.S. (2014), “Diagnostic investigation of aircraft performance at different winglet cant angles”, *World Acad. Sci. Eng. Technol.*, **8**(12), 2028-2037.

Eken, S. and Kaya, M.O. (2015), “The effect of sweep angle on the limit cycle oscillations of aircraft wings”, *Adv. Aircraft Spacecraft Sci.*, **2**(2), 199-215.

Fahlstrom, P.G. and Gleason, T.J. (2012), *Introduction to UAV systems*, John Wiley & Sons, Chichester, West Sussex.

Farsani, R. and Fazaeli, R. (2012), “Applications of carbon fibers produced from polyacrylonitrile fibers”, *Int. J. Chem. Molec. Nucl. Mater. Metal. Eng.*, **6**(8), 836-839.

González-Espasandín, Ó , Leo, T.J. and Navarro-Arévalo, E. (2014), “Fuel cells: a real option for unmanned aerial vehicles propulsion”, *Scientif. World J.*, **1**, 1-12.

Jackson, S.P. (2011), “Controlling small fixed wing UAVs to optimize image quality from on-board cameras”, PhD Thesis, University of California, Berkley, U.S.A.

Jin, W. and Lee, Y. (2015), “Drag reduction design for a long-endurance electric powered UAV”, *Int. J. Aeronaut. Space Sci.*, **16**(2), 311-324.

Khardi, S. (2014), “Optimization of aircraft fuel consumption and reduction of pollutant emissions. Environmental impact assessment”, *Adv. Aircraft Spacecraft Sci.*, **1**(3), 311-330.

Li, J.Y. and Yang, Z.B. (2013), “Fatigue analysis for the aircraft landing gear connecting parts”, *AMM Appl. Mech. Mater.*, **300-301**, 870-873.

Linchant, J., Lisein, J., Semeki, J., Lejeune, P. and Vermeulen, C. (2015), “Are unmanned aircraft systems (UASs) the future of wildlife monitoring? A review of accomplishments and challenges”, *Mammal Rev.*, **45**(4), 239-252.

Liu, P., Chen, A.Y., Huang, Y., Han, J., Lai, J., Kang, S. and Tsai, M. (2014), “Review of rotorcraft unmanned aerial vehicle (UAV) developments and applications in civil engineering”, *Smart Struct. Syst.*, **13**(6), 1065-1094.

Ma, W.Y., Sun, H., Liu, B. and Jia, H.G. (2013), “Analysis of UAV main landing gear loads during wheel spin-up process”, *AMR Adv. Mater. Res.*, **753-755**, 1595-1598.

Miller, F.P., Vandome, A.F. and McBrewster, J. (2010), *Ground effect in aircraft*, Alphascript Publishing, Lexington, KY.

MotoCalc 8, Computer software. MotoCalc, Capable Computing, Inc., n.d.

Nedjati, A., Vizvari, B. and Izbirak, G. (2015), “Post-earthquake response by small UAV helicopters”, *Nat. Hazard.*, **80**(3), 1669-1688.

Nishar, A., Richards, S., Breen, D., Robertson, J. and Breen, B. (2016), “Thermal infrared imaging of geothermal environments and by an unmanned aerial vehicle (UAV): A case study of the Wairakei-Tauhara geothermal field, Taupo, New Zealand”, *Renew. Energy*, **86**, 1256-1264.

Palma, L.D., Paletta, N. and Pecora, M. (2009), “Aeroelastic design of a joined-wing UAV”, SAE Technical Paper Series, 2009-01-3150.

Petrolo, M., Carrera, E., D’ottavio, M., Visser, C.D., Patek, Z., and Janda, Z. (2014), “On the Development of the Anuloid, a Disk-Shaped VTOL Aircraft for Urban Areas”, *Advances in Aircraft and Spacecraft Science,* **1**(3), 353-378.

Raymer, D. P. (1999), Aircraft design: A conceptual approach. Reston, VA: American Institute of Aeronautics and Astronautics.

Schibani, A., Festa, B., D'Apuzzo, M. and Nicolosi, V. (2014), "Some remarks on landing kinematic characteristics of aircrafts", *Sustainability, Eco-efficiency, and Conservation in Transportation Infrastructure Asset Management*, 385-392.

Stinton, D. (2001), *The design of the aeroplane*, Blackwell Science, Malden, MA.

Sun, X., Chen, W., Patterson, B.C., Florence, D.E., Fischer, R.L., Jones, M. and Adams, J. (2007), "An advanced airborne multisensor imaging system for fast mapping and change detection applications", *Proceedings of 2007 IEEE International Geoscience and Remote Sensing Symposium*, Barsalona, Spain, Jululy.

Warsi, F.A., Hazry, D., Ahmed, S.F., Joyo, M.K., Tanveer, M.H., Kamarudin, H. and Razlan, Z.M. (2014), "Yaw, pitch and roll controller design for fixed-wing UAV under uncertainty and perturbed condition", *IEEE 10th International Colloquium on Signal Processing & its Applications (CSPA2014)*, Kuala Lumpur, March.

Yildiz, K., Eken, S. and Kaya, M.O. (2015), "Optimal control procedure application for dynamic response of adaptive aircraft wings modeled as thin-walled composite beams", *Appl. Mech. Mater*., **798**, 292-296.

Zhang, C., Zhen, Z.Y., Wang, D.B. and Meng, X.Y. (2010), "Optimal control for thrust vectoring unmanned aerial vehicle", *International Conference on Advanced Measurement and Test*, Sanya, China, May.

*EC*