Design and Optimization of an Unmanned Aerial Vehicle (UAV) for Pipe Line Inspection

Muhammed Hasnain Kabir Nayeem[1*], Md. Thariqul Islam Pranto[1], Raad Shahmat Haque[1], Taimum Al-Nafis[1]
[1]*Department of Aeronautical Engineering, Military Institute of Science and Technolog (MIST), Dhaka-1216, Bangladesh*
**Corresponding author*

Abstract: **- Gas, oil and electrical power companies usually carry out a regular inspection to check the status of their transmission lines to ensure safe and economical working condition. This inspection process may be completed by using helicopter fitted with external gimbals housing infrared and ultraviolet camera to recognize the heat difference or on foot and requires individuals to inspect power lines from the ground level. This solution is fairly expensive and time-consuming, sometimes injurious for the inspection crew. In this present study, we try to demonstrate a design process of a lightweight unmanned aerial vehicle which incorporated with an extremely lightweight airborne laser scanner to perform the concerning task. The UAV is advanced and designed to carry 5kg of payload covering a range of 50km. Using gasoline-powered engine enables it to carry extra gasoline and fly for a long period of time. Tapered wing configuration creates a dihedral effect which gives the aircraft more lift and stability and reduces the load on the engine. This paper presents the design methodology, performance analysis and manufacturing process of the UAV.**

***Keywords*—UAV, Pipe line inspection, gimbal housing, laser-scanner, gasoline powered engine**

I. INTRODUCTION

The advancement of low power consumption propulsion system, low cost and high durable airframe structure manufacturing process and easy control system has made the commercial unmanned aerial vehicle more popular. Adaptability in any change makes the unmanned aerial vehicle suitable to do any kind of work. There is a lot of latent commercial unmanned aerial vehicle mission that has great economic prospects. One of the major mission is the inspection of linear infrastructure which includes the electrical power transmission lines, gas lines and oil lines. Much of the electric power transmission infrastructure is above ground, sometimes oil lines and gas lines too, and therefore they are prone to damage due to vegetation interference and other phenomena. Companies clean the corridors for vegetation periodically, but growth persistently continues power outages are often caused by trees or branches falling on power lines. This frequently occurs in a storm with high winds. In addition, to the loss of power, vegetation interference can cause safety hazards such as fires and electrocution. Electrical power, gas lines and oil lines companies perform regular visual check mainly using a helicopter or on foot. However, this solution is quite expensive, Line-Rover Technology, a trolley operated via remote, was in operation at 2000, is initially used for deicing but also can be used on live 365-Kv for visual monitoring and infrared inspection [1, 2]. In [3, 4], power line robots are considered as 'high-value application' and key components in developing a smart transmission grid. Considering this background, the main objective of this project is to design and manufacture a drone which can do high-quality inspection with a longer period of time.

II. DESIGN PROCESS

The design process starts with a set of specifications or requirements for a new aircraft or much less frequently as the response to the desire to implement some pioneering, innovative new ideas and technology. The mission requirements are the pre-requisite that has to be addressed during the design phase of an aircraft. The mission requirements are given below.

TABLE I Mission Requirements

Parameters	Mission requirements
Range	30km
Maximum operating speed	310 ft/s
Operating altitude	500ft
Payload	5kg
Load factor	+3

The actual design effort started with chalking out the necessary key points from the mission requirements and translating it into the design requirements.

TABLE II Translation of Mission Requirements into Design Requirements

Mission requirements	Design requirements
Short take-off	High static thrust and low stall velocity
Payload	High lift ability
Low altitude flight	Efficient propulsion system and high lift to drag ratio
Scanner	High-resolution still camera
Fail safety	High lifting devices and emergency recovery system

The translation of the mission requirements into design requirements is the main lead to select a configuration for the conceptual design. The conceptual design phase determines such fundamental aspects as the shape of the wings, the location of the wing relative to the fuselage, the shape and location of the horizontal tail and vertical tail, the configuration of the fuselage, engine size and placement, etc. A final aircraft configuration is selected among various proposed configuration by comparing their merits on different features and the beneficiary of them on completing the required objective. Different characteristics of the configuration were converted into a numerical model using the design requirements and constraints. The parameters are selected by considering the design requirements and weight basing on their importance to maximize the performance. The design constraints are studied for allocating the weights of each performance criteria. The major drivers during the conceptual design process are aerodynamics, propulsion and flight performance. For carrying the payload, scanner and other necessary equipment structural strength is necessary for the safety of the UAV. After the figure of merit analysis, the following morphological matrix is found.

TABLE III Selected Conceptual Aircraft Configureation

Components	Configuration
Aircraft configuration	Monoplane
Wing location	Low wing
Wing type	Rectangular
Tail configuration	Conventional
Engine type	Piston engine
Engine location	In front of the nose
Fuselage	Semi mono-coque
Landing gear	Tri-cycle
Fuel tank	Inside fuselage

Design take off gross weight calculation is the most significant step of the preliminary design stage. From the preliminary design step, after a set of iteration process maximum take-off weight is found 105.95lbs, as the weight to thrust ratio is 1 so the required thrust is same. For that weight and thrust the required wing area found 4.595ft^2. Using this values in the detail design process the other parameters are selected.

Straight rectangular, low and cantilever wing configuration is selected for this UAV, as it is easy to build and mount with the wing location of the fuselage. For low wing configuration, due to the ground effect take-off performance is better and the aircraft is lighter that the high wing configuration. As low wing configuration generates less lift than high wing configuration because the low wing configuration is out of prop wash region. Because of prop wash the velocity increases, so as the lift increases. In case of a high wing, to reduce the effect 3^o dihedral angle is introduced in the configuration. The dihedral angle increases the lateral stability of the aircraft. Again as lateral stability guided by dihedral low wing enables the fuselage to carry the maximum fuel, payload and the scanner to perform the design objective.

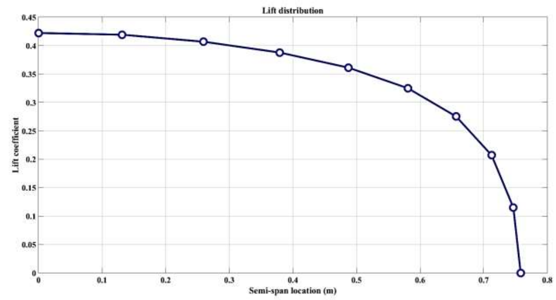


Fig. 1 Lift distribution curve over the wing

After deriving the wing parameters, the airfoil for the wing was selected. Because lifting surfaces can be thought of as span-wise arrangements of airfoils. The basic characteristics of airfoils have a major effect on the behavior of lifting surfaces. To design an airfoil the important considerations are drag, lift to drag ratio, thickness distribution, stall and pitching moment characteristics. After a series of iteration, it is found NACA- 65(2)-415 airfoil satisfies the required lift coefficient of 1.654. NACA 6-digits airfoils have some advantages. They have a higher maximum lift coefficient with a low pitching moment and good stall behavior so that we can achieve higher Cl with lower Cd or drag coefficient [5]. For short takeoff and in an unimproved runway high lifting device flap is used and the maximum flap deflection angle found 24 degree. At which the wing produces maximum lift for taking and reduces the engine load at take-off.

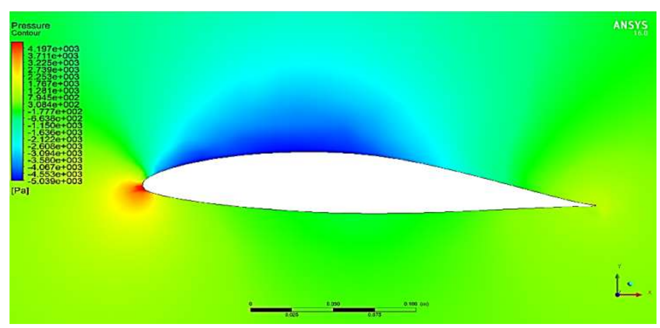


Fig. 2 Pressure distribution over the NACA 65(2)-415 airfoil at AOA 3-degree

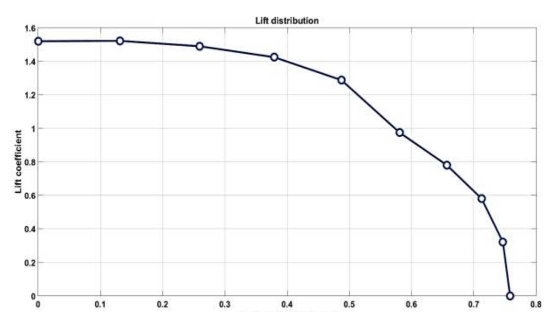


Fig. 3 Wing lift distribution curve with flap deflected

The fuselage is constructed as the semi-monocoque configuration as the main purpose of the fuselage to accompany the required fuel to complete the mission and other components which generating less drag. The engine cowling is being installed in the fuselage, a computational study shown that in the presence of cowling the drag produces by the UAV is lesser than without cowling.

The primary function of the tail section is trim, stabilize and smooth control of the UAV horizontally and directionally. The conventional tail configuration was selected and it's position at the behind of the fuselage. As low wing configured aircraft, the tail section is free form the down-wash effect propagated by the wing and is able to fulfill the requirements.

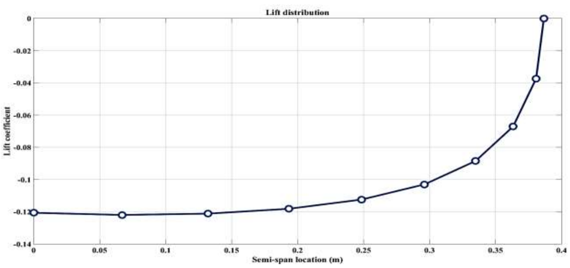


Fig. 4 Horizontal tail lift curve

Tractor engine configuration is selected for the aircraft, as the scanned is attached in the empennage section so that the reason for CG forwarding movement due to tractor configuration is fulfilled. After comparison between some engines the 3W-157XiB2 engine is selected. Another major component is the landing gear. The landing gear is the structure that supports an aircraft on the ground and allows it to taxi, takeoff and land. Tricycle configuration is selected.

For controlling the UAV a 433 MHz UHF system was used, in TX half-wavelength UHF antenna was used and for RX 433 MHz 120 deg V antenna was fabricated manually by analyzing RSSI. For video transmission 1.2 circular polarized antenna in TX and omnidirectional patch antenna in RX with antenna tracked was incorporated [6]. An 8-bit autopilot system based on Atmel's ATMEG4A2560 and ATMEGA32U-2 function respectively [7]. For scanning, the RIEGL mini VUX-1UAV scanned was selected. It is extremely lightweight, compact and 360 deg field of view and other features makes it the more suitable from the design perspective [8].

TABLE IV Final UAV components parameters

Components	Configuration
Fuselage overall length	47.04 inch
Fuselage width	9 inch (maximum)
Fuselage height	16.65 inch
Wing angle of attack	3 degree
Wing span	60 inch
Wing area	4.95 ft^2
MAC (Mean aerodynamic chord)	12 inch
Aspect ratio	5
Engine thrust	17 HP or 12.5 KW

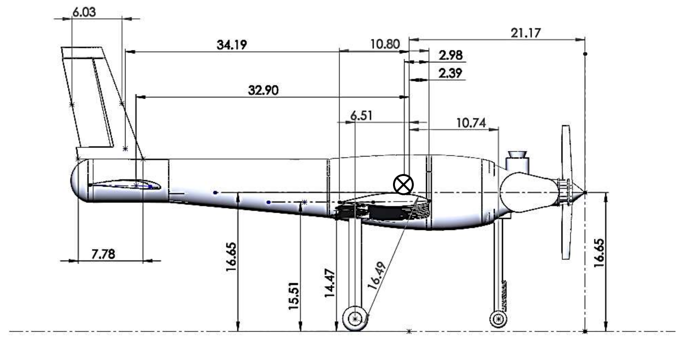
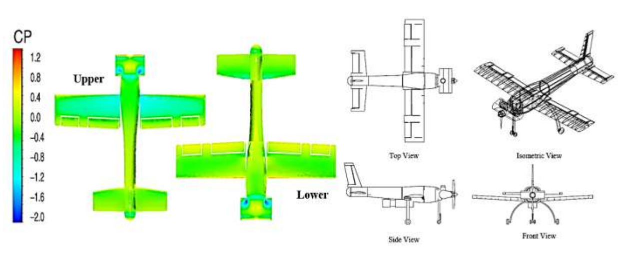


Fig. 5 Distance of UAV components from center of gravity (all are in inch)

III. Results and Discussion

System engineering design process was used to design the UAV to translate the mission requirements into design requirements. The final configuration satisfies the design requirements and mission requirements, Fig. 6(b). Fuel efficiency with maximum endurance is the key factor that dictates to choose the other parameter of the UAV. The wing configuration reduces the required thrust produces by the engine, which makes the engine perform in the better condition. The fuselage shape enables the UAV to carry the maximum fuel to complete a longer extended range incorporated with a high-resolution scanner fo the pipeline inspection. The figure showed the pressure coefficient distribution on the upper and lower surface of the UAV at an angle of attack (AOA) of 3 degree and lowest possible speed of 80ft/s, the inwards pressure on the wing is represented as positive pressure and outward pressure on the wing represented as negative or suction pressure. From the figure-6, it is also seen that positive pressure dominant on the lower surface of the wing and suction pressure dominant on the top surface of the body. It is due to setting the wing at an incidence angle of 3 degree. Which ensure the generation of desired lift coefficient during cruise flight with minimum drag. The scanned used in the UAV creates exceptionally detailed inspection of the pipeline and digital model of landscape, buildings and other assets. This makes it a process for surveying not only the pipelines but also floods, forestry, roads and infrastructure.



(a) (b)

Fig. 6 (a) The pressure coefficient distributions on the upper and lower surface of the UAV model at an angle of attack of 3 degree and speed of 80ft/s (stall speed), (b) Final model of the UAV

IV. CONCLUSIONS

The UAV is equipped with devices which enables making precise aerial measurement. It is a key feature in pipelines inspection where the combination of thermal camera and UltraHD 4k camera images can provide with the comprehensive and complete mapping of the inspected object's technical condition. Again using UAV in inspection rather than other traditional methods available is cheaper while maintaining the same image quality. The system's mobility and its ability to rapidly analyze gathered data reduces the time of defect detection and repair to a minimum. Low costs and short time of taking photos make the most effective way of pipeline inspection. Using highest quality thermal imaging cameras are able to detect even the slightest leak.

REFERENCES

[1]. Montambault, S., Cote, J., St-louis, (2000). Preliminary results on the development of a tele-operated compact trolley for live-line working, (9th International conference on Transmission and Distribution Construction, Operation and Live-line Maintenance, ESMO, pp-21.)

[2]. Montambault, S., Pouliot, N., (2003). The HQ LineRover: Contributing to innovation in transmission line maintenance. (10th International Conference on Transmission and Distribution Construction and Live-line Maintenance, pp.-33)

[3]. Montambault, S., Pouliot, N., (2004). On the Economic and Strategic Impact of Robotics Applied to Transmission Line Maintenance. (7th International Conference on Line Maintenance, ICOLIM)

[4]. Montambault, S., Pouliot, N., (2010). About the future of Power Line Robotics, (1st International Conference on Applied Robotics for the Power Industry)

[5]. Dr. Jan Roskam, Dr. Chaun-Tan Edward Lan (1997). Airplane Aerodynamics and Performance.

[6]. EzUHF R/C Control System, Overview & Operation Instructions, (2010), Firm ware v1.18

[7]. Ardupilot.org/copter/docs/common-apm25-and-26-overview. Html

[8]. RIEGL miniVUX-1UAV manual, (2017)

[9]. Reg Austin (2010), Unmanned Aerial Vehicles, Wiley, Aerospace Series

[10]. Robert C Nelson, (2007). Flight Stability and Automatic control

[11]. John D Anderson Jr, (2011), Fundamental of Aerodynamics, McGraw Hill

[12]. Mohammad H Sadraey, (2013). Aircraft Design: A Systems Engineering Approach, Wiley, Aerospace Series.