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Conceptual Drone Design For Delivering Goods

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Abstract - *Drones which are used in delivery applications are developing faster, to make the delivery process easier and faster than preceding methods. These drones are incorporated with advanced technology in order to meet the autonomous flight requirements. They have their own drawbacks, the capacity of the battery and payload carried by the drone affects their efficiency during the delivery missions. Many classes of drones are used and tested for the delivery application by many companies in order to increase the efficiency during the flight. To overcome this problem, in this paper a new conceptual drone is designed, modeled and their aerodynamic characteristics are analyzed by numerical simulation using ANSYS CFX. The method which is used to control the drone is explained and their influence in the design of the drone is also added. The design is made and slight modifications are done comparing the other existing models in order to meet the requirement of increased efficiency during both horizontal and vertical flight and the payload placement in the drone is mounted in such a way that the drone lands on its payload and supports the control method.*

***Key Words*: Drones, Autonomous Flight, Battery, Efficiency, Numerical, Payload**

1. INTRODUCTION

In this drone era, there is an exponential growth in development of commercial and military drones. Commercial purpose drones include delivery, photography, surveillance etc. Among these, delivery was one of the most important applications. The roadway based delivery is common among the urban cities and some rural areas. Various essential supplies are provided to the customers by the markets and companies but due to heavy traffic congestion the delivery time increased and essentials are delayed in reaching the customer. In this development of technology, various innovations are upcoming for this problem and the drone delivery is one of the promising solutions. Many companies are currently developing drones for delivering products to the customers in urban as well as the remote areas. There are many controversies in using drone delivery systems in urban areas since the drone payload is restricted, it is able to deliver only single supply at a time and it is considered as inefficient when compared with normal product delivery system but midst these controversies and restrictions in urban areas due to emerging pandemics and other emergencies ,the demand for them in those areas are increasing. Using drones for delivery in rural areas is much more efficient than normal roadway delivery, there they face problems like sparse population, lack of necessary goods, commodities and medical supplies that might solve them by instant supplies and transportation cost and time.

In the beginning the idea of delivery drones were first initiated by the Amazon they were planning rapid delivery of lightweight commercial products using UAVs and met with skepticism, with perceived obstacles including approval, public safety, reliability, individual privacy, operator training and certification, security , payload thievery, and logistical challenges. In a research project of DHL, a sub-kilogram quantity of medicine was delivered via a prototype Micro drones "Parcel-copter", raising speculation that disaster relief may be the first place the company will use the technology, eventually various Chinese companies started delivery products by drones .Various startups started developing and investing in drones and their deliveries .Various new designs like VTOL drones and multi-rotors are made for delivery purposes.

Most Transition Aircrafts are designed for its increased endurance capability, they are Project Wing, Prime Air, DHL, Uber etc. VTOL, Hexacopter, quadcopter are the various types of drones used for delivering products. Increasing endurance in both vertical and horizontal flights is one of the challenges faced in developing the VTOL drone. In this paper, a conceptual drone is designed and analyzed to overcome the problems.

1.1 PROBLEM DEFINITION

Endurance and payload became a very big constraint while developing an UAV for commercial delivery application. Fixed wing UAVs are known for their endurance and they are used in various applications. Since they require ground for takeoff and landing. Those UAVs were replaced with Vertical takeoff and landing (VTOL) UAVs which takeoff like multi rotor drones and transit to cruise mode like fixed wing UAVs and it does not require runway to land, these class of UAVs were in intense development.

The Rwanda model is a good example for fixed wing class UAVs which are used to deliver medical supplies in rural areas. Tail-sitter VTOL UAVs like Wingtra uses two rotors to propel the model in air and with the help of elevators, they can transit from vertical flight to horizontal cruise flight whereas project wing uses four rotors to push the body in air. Amazon's prime air has quadcopter, hexa-copter and VTOL with separate rotors for horizontal and vertical flights to deliver products. It is clear that VTOL is equipped with separate rotors or distributive rotors or rotors combined with elevators.

1.2 INNOVATIVE IDEA

VTOL which are characterized above have some advantages and disadvantages compared to other types, the common constraint is the restricted endurance and payload capacity. To overcome this problem, a model will be designed and analyzed. This model will make use of the efficiency of bicopter in vertical flight and for transition to horizontal flight, it uses thrust vectoring method and changes to cruise mode. The idea innovated is to bring the thrust vectoring method to control the direction of the VTOL (tilt rotors for direction), greatly helps in take-off and landing.

2. DESIGN METHODOLOGY

The design is generated by analyzing the needs and drawbacks in existing models for the delivery application as per problem statement and after brainstorming and breaking down the problem to solve effectively, the design proposed in this paper, initially the basic design calculations were made to estimate the assumptions and constraints for the design. The model is the modification of the VTOL Tail-sitter class in UAVs, in which the elevators are eliminated and make use of thrust vectoring method to hover and transit to cruise flight. It is propelled with the help of two rotors and makes use of the advantages of bi-copter efficiency while hovering. Since, the model is only using two rotors, it adds more efficiency in cruise flight too where drag will be over-come by the thrust generated by the rotors. In this design the tail or the empennage section of a tail sitter is replaced by a payload and the mechanism of landing and take-off is same as the tail sitter and payload is in the base and aircraft lands on its payload .The wing is designed with better airfoil to give maximum coefficient of lift and it is rectangular wing with good aspect ratio .The propeller is designed such that is large sized with diameter and pitch connected to a motor to provide the necessary thrust to overcome the weight in vertical take off .

2.1 DESIGN OF WING

To design a wing two major considerations are the coefficient of lift and the wing area. Wing loading is considered for the initial sizing of the wing. The airfoil used here is NACA 6412. Mid wing configuration [3] is selected as it is aerodynamically streamlined compared to the other configurations as it has less interference drag and for its parallel leading and trailing edges. Coefficient of lift for wing is calculated using the formula,

CL of wing = (CL of airfoil) / (1+k CL of airfoil)

Oswald efficiency (e) depends upon the wing platform. Considering aspect ratio and wing area is very important for a wing for more aerodynamic performance. Taper ratio is zero as rectangular wing is selected as the platform.

2.2 DESIGN OF FUSELAGE

The fuselage is made like conventional ones which has long cylindrical shell with nose cone seen in aircraft and this VTOL mostly travels in airplane mode. Its designed to provide good aerodynamic performance i.e. produce low drag and mainly less flow separation at moderate angles of attack during its flight. Fuselage here is mainly for carrying all the electronics and main the payload area is separated from it unlike the usual design

2.3 DESIGN OF PAYLOAD

In delivery drones, designing the payload and its placement is one of the crucial aspects. The payload is designed in the rear side of the drone. It is made in a cube shape as seen in FIG-1

2.4 SKETCHING

The model has some basic requirements that need to be satisfied to get the desired outcome of increased efficiency and endurance in UAVs used for delivery application. The following parameters are the assumptions made to begin our model sketching.

Table -1: Mission Requirements

Payload Requirements	**Structural Requirements**
Payload: ~0.5 KG	FRPs and composites

Flight Requirements	**Maneuverability**
Endurance: 30 minutes	VTOL - Tilt Rotors
Cruise Speed: 30 m/s	Hover mode
Propulsion: Electric	Cruise mode
MTOW: ~2 KG	Transition

2.3 MODELLING

Using Fusion 360, the drone was modelled using the sketch made previously. In the modelling phase, the payload carrier structure and the fuselage parts are remodeled again and again until their structure does not affect the flight requirements assumed before. The wing span is increased to attain the minimal thrust requirement in forward flight conditions. The electric motor and propeller were included in the main model presented in the following based on the flight requirement and followed by it will be discussed in detail in the next section. Things considered with high priority while designing are the induced drag, compatibility in transition, hover and forward flight, wing type to attain minimum drag during forward flight.

FIG – 1: Rendered Model Image

3. PROPULSION SYSTEM

UAVs which are used for delivering goods are usually VTOL drones, Fixed-wing drones, Hexa-copter, quadcopter. These models differ in the number of rotors. From [1], multirotor drone categories in UAVs, a bicopter is most efficient. Bicopter uses two motors to produce thrust and replacing four motors with equal two motors are less power consuming than quadcopter or any other multirotor drones, current drawn from the battery, the more is the flight time.

Factors considered while selecting motors are thrust(Tc) produced in cruise mode(flight) and thrust(Th) required for hovering during delivering goods, taking off and landing. As we know that in Tc is only used to overcome the drag force which is less than Th. So, the motor should be selected for hovering mode, since it is the maximum requirement in flight. In cruise mode, it can be operated with less power which is needed to overcome drag force.

For assumed weight to thrust ratio of 1.5 and MTOW of drone as 2 KG, the thrust required is 1.5 times of MTOW

Thrust =1.5*MTOW = 3 KG

Number of rotors = 2

Normally thrust should be achieved at 75% of throttle rate for better performance and sustainability. Since in this model hovering mode lasts only for a few seconds. So, we select the throttle rate of 70-90% for hovering mode and in cruise mode 20 - 30% of throttle only used to overcome the drag force.

Required thrust per motor = 1.5 KG at 70-90% throttle rate with suitable propeller.

FIG – 2: Motor and Propeller Data

Motor KV	Propeller	Voltage (V)	Current (A)	Throttle	Power (W)	Thrust (g)	RPM	Efficiency(g/W)
400	15*5	22.2	4.3	50%	95.46	990	4200	10.37
			7.9	**65%**	**175.38**	**1490**	**5200**	**8.5**
			11.6	75%	257.52	1900	5700	7.38
			14.5	85%	321.9	2220	6200	6.9
			17.2	100%	381.84	2480	6500	6.49
400	16*5.4	22.2	5.2	50%	115.44	1200	4050	10.4
			9.4	**65%**	**208.68**	**1750**	**4850**	**8.39**
			13	75%	288.6	2120	5400	7.35
			16.9	85%	375.18	2650	5850	7.06
			20	100%	444	2850	6250	6.42

From Fig. 1, it is clear that the required thrust for hovering mode can be achieved using T-Motor U3 KV700 with T-Motor 16*5.4 inch propeller with less power consumption produces nominal thrust required, 1400 g at 75% of throttle with discharge current of 12.3 A.

Table -2: Model Data

Span = 1 m	e = 0.7	Cd0 = 0.01	Cl = 1.2
Velocity = 20 m/s	Chord = 0.3 m	A.R. = 2.33	k = 0.195

Theoretical thrust required in cruise mode: T_{req} = 14.9 N

4. CONTROL METHOD

Normally UAVs are remotely controlled by different methods and their control authority varies with model. Most commonly UAVs have four control parameters, they are pitch, roll, yaw, throttle to control them in flight. Drones used for delivery supplies are usually controlled by these general control parameters. Our drone model is controlled by gimballed thrusters (motors) and it performs VTVL (Vertical Takeoff and Vertical Landing). Rockets are controlled by this thrust vector control method (gimbaled nozzle). In VTOL UAVs during hovering mode, it has four motors to generate thrust which is less efficient than bi-copter hovering mode [5]. To solve this problem, our model is propelled using two motors and thus the power loss is reduced in hovering mode. And by using the thrust vectoring method we can control the model in air during cruise flight as a fixed wing drone by tilting the thrusters and not by using ailerons or elevators.

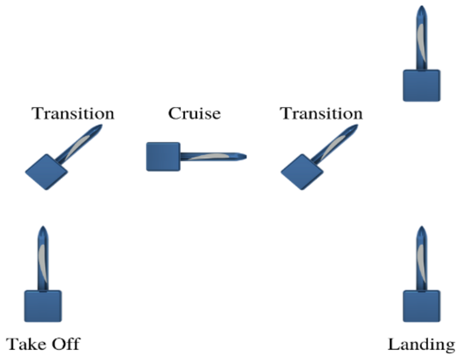

FIG – 3: Flight Transition

In tail-sitter UAVs [4], the motors are mounted in front of the model, they transit from hovering mode to cruise mode using the ailerons and the center of gravity of the model lies below the propulsion system which is important for transition using ailerons for cruise flight. But in this model, the center of gravity lies above the propulsion as in rockets in order to use Thrust vectoring to control the motion of the model. Since the motor number is reduced to half, the weight of the model is reduced compared to the other tail-sitter UAVs and thus efficiency in cruise flight also increases.

5. AEROFOIL SELECTION AND PERFORMANCE

This VTOL UAV model is basically combinations of both fixed wing aircraft and bicopter. The wing designed is a mid-wing which has a rectangular wing form with no sweep angle. The airfoil used here NACA 6412 which has a high lift as well as less drag coefficient. The airfoil has a good behavior at lower angles of attack and reaches its maximum lift at 11 degree.

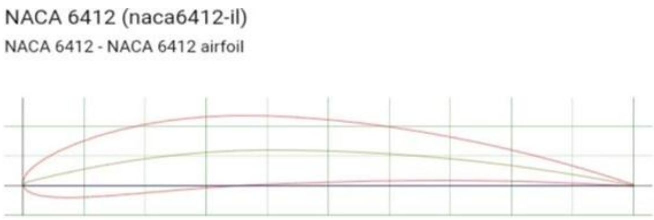

FIG-4: Airfoil 6412

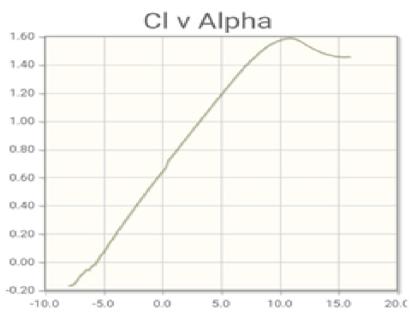

FIG- 5: CL vs Alpha

The wingspan of the model is 1m. The weight of the fixed wing model is compensated with lift generated by the wings. Lift produced mainly depends on the size of the wing, proportional to the wing area. It is often convenient that lift of a given airfoil and its lift coefficient defines its overall lift in terms of a unit area of the wing.

6. CFD ANALYSIS

The design was generated in Autodesk Fusion 360 and imported into ANSYS, solved using CFX Solver and velocity at 20 m/s was given as input with angle of attack at 5° to the wing. The pressure distribution and velocity streamline [1], drag and lift forces are estimated from the analysis report.

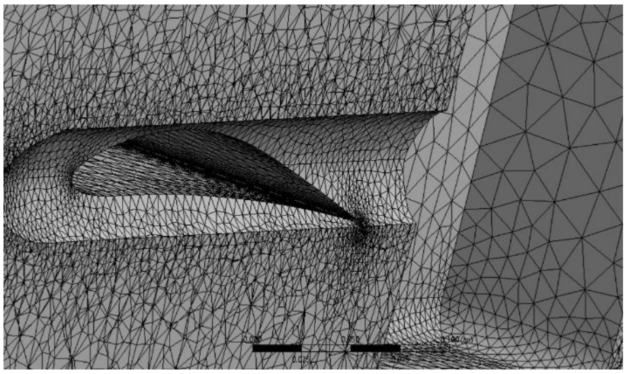

FIG – 6: Meshing

The CFD simulation is done for the entire VTOL design to investigate the flow fields and to determine the total lift and drag coefficients. Simulation is done with varying angle of attacks from 0 to 20 degrees [6].

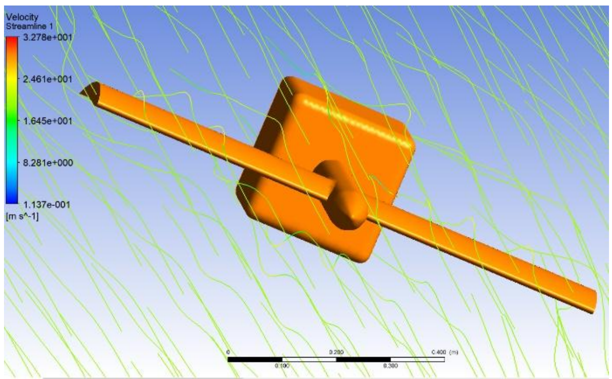

FIG – 7: Velocity Streamline

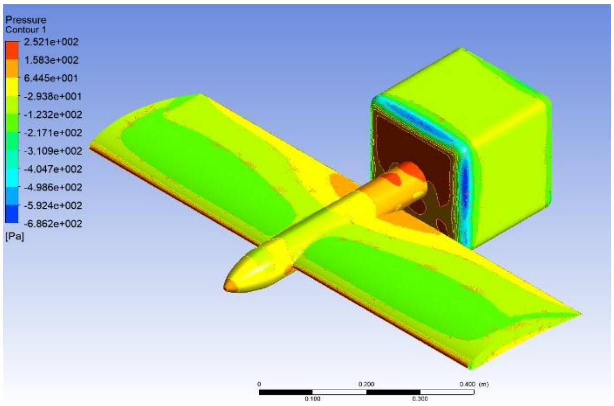

FIG – 8: Pressure Contour

The lift and drag were obtained in integration with velocity and pressure distributions and the results are plotted in a graph. From the resulting lift and drag forces and their coefficients are obtained.

7. RESULTS AND CONCLUSIONS

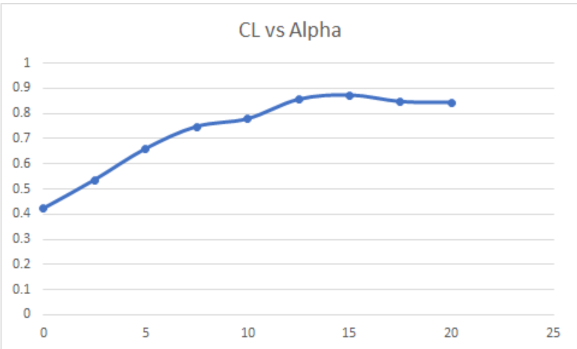

Chart -1: CL vs Alpha

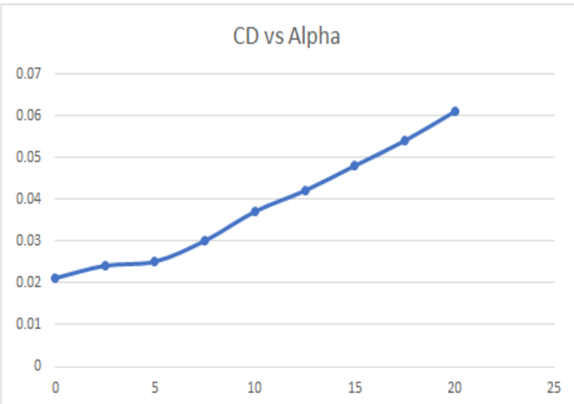

Chart -2: CD vs Alpha

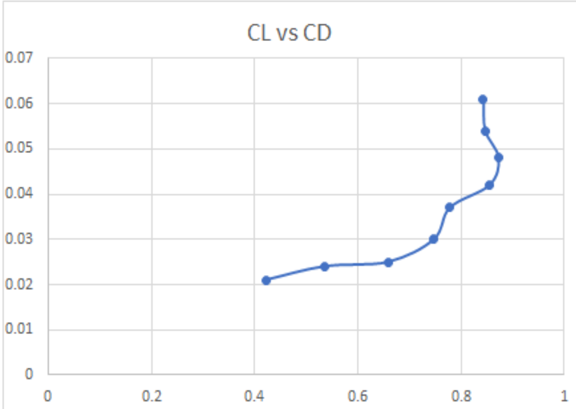

Chart -3: CL vs CD

The aerodynamic characteristics of the design after analyzes in CFX are shown above. From the results, it's clear that payload structure doesn't affect the efficiency of the UAV comparatively with existing multirotor and other VTOL models used for delivering goods. By combining the TVC (Thrust Vector Control) method with bicopter power efficiency, we can increase the endurance of UAV distinctly. In future, the model will be fabricated and control system algorithm will be tested in simulation and then in real time.

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