

Design and Analysis of Ducted Fan Micro Aerial Vehicle

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ABSTRACT: A micro aerial vehicle (MAV) is a class of unmanned aerial vehicles (UAV) that has a constraint in size and self-governing automatic control unit. Micro Air Vehicles (MAVs) conveniently operate with compact sized and low weight components, thus enable to operate against high wind velocity and capture high quality image data. For a new design of MAV system require to integrate multiple controlled components, accomplishing the overall performance of MAV mission. In this project a new design of ducted fan MAV was modeled with a size limited below 20cm. The vertical take-off and landing (VTOL) type was configured with fixed wing of newly design compact MAV to overcome the issues of low Reynolds number aerodynamics issue. The aerodynamics performance such as coefficient of lift (CL) and coefficient of drag (CD) was determined and validated with existing model of VTOL type UAV. The conceptual model of ducted fan micro aerial vehicle (DMAV) was designed in CAD software and aerodynamic analysis such as CL and CD was analyzed using CFD- fluent software. The dynamic pressure over the DMAV was determined and found that the value is within the limit and also the flow visualization for full-scale model of ducted fan MAV was stimulated for various angle of attack such as 5°, 10°, 15° and predicted the CL and CD for the performance characteristics of the newly designed model DMAV.

KEYWORDS: DMAV, UAV, coefficient of lift, coefficient of drag, angle of attack and CFD.

I. INTRODUCTION

An unmanned aerial vehicle (UAV), known in the mainstream as a drone and also referred to as an unpiloted aerial vehicle and a remotely piloted aircraft (RPA) by the International Civil Aviation Organization (ICAO), is an aircraft without a human pilot aboard. Unmanned air vehicles with a largest linear dimension no greater than 6 inches. Micro air vehicle is a class of UAV. Micro air vehicles (MAVs) are intended to operate in close proximity to a point of interest without being detected and should provide surveillance teams with critical information. Small vehicle size is intended to lower the total system cost when compared to larger military UAVs and will also allow these aircraft to be man portable. A typical MAV mission consists of flying 1km to a point of interest, loitering in close proximity for 1/2 hour, and then returning. The aircraft must be able to fly in turbulent winds up to 25 mph, perform tight turns near buildings, and climb repeatedly to 350 feet altitude. Currently, there are no MAV designs which meet these criteria and many technical issues must be resolved before a successful MAV can be produced. This project addresses the issues of how propulsion and configuration influence the mission capability of MAV's. A numerical optimization procedure is used to find the smallest aircraft that meets the mission performance constraints given the assumed propulsion, aerodynamic, structural, and payload models. Our study concludes with several observations on the influence of vehicle size on mission capability. Our experience has shown that with present technologies the maximum capability of an MAV system is realized with aircraft in the 50 to 100 cm

II. RELATED WORK

Daisuke Kubo and Shinji Suzuki (2008) [1] "Tail-Sitter Vertical Takeoff and Landing Unmanned Aerial Vehicle Transitional Flight Analysis", Journal says about the vertical takeoff and landing features and advantages during the flight path. Zamri Omar [2] have investigated Vertically Takeoff and Landing (VTOL) type Unmanned Aerial Vehicle (UAV) control system and its working, also it explains about the designing of the ducted fan type UAV and its important nomenclature regarding the aerodynamic properties and components selection for UAV. Mohd. Shariff Ammoo and Md. Nizam Dahalan [3] have studied about technological review and design study of Micro Aerial

Vehicle (MAV), it explains about the shape, MAV requirements and design study about configuration and components needed for full scale model of UTM MAV model.

Sergey Sarajevo, 2007 [4] studied about the aerodynamic design of the VTOL type MAV consisting of contra rotating motor propellers in the propulsion system. Also author investigated the velocity profile in the slipstream. Apart from this it also describes about drag during the transition phase from horizontal flight to vertical flight. William .E .Green and Paul.Y Oh [5] investigated about the hovering of the fixed wing Micro Aerial Vehicle, it explain how the hovering is done with the help of controls. Further it emphasis about the need of autonomous control for hovering by using the control surface. Hui Wen Zao [6] has helped us to know about development of dynamic model of Ducted fan VTOL type UAV use of Duct fan in UAV and its advantage Further it explains about the aerodynamic characteristics for predicting the longitudinal and lateral stability and control of UAV, also it describes about usage computational fluid dynamics along for determining varies parameters during low speed cruise flight. Zhao strategy to simulate a dynamic model of a vertical takeoff and landing (VTOL) unmanned aerial vehicle (UAV) in hovering, vertical climb and horizontal flight is clarified The optimization of a tail-sitter UAV (Unmanned Aerial Vehicle) that uses a stall-tumble manoeuvre to transition from vertical to horizontal flight and a pull-up manoeuvre to regain the vertical is investigated by stone et al. [7].

Abershitz et al. [8], have undertaken three development stages and developed a final mini UAV configuration was designed, manufactures and tested in flight, and demonstrated in operation. The system was demonstrated to the military and to the Dutch police and included few days of flights in the vicinity of Neunen and over the central station of Amsterdam. Taylor et al. [9] developed a new approach to deliver cargo precisely. They have discussed the preliminary concept, development, problems in developing the system and the flight test program. Jhonson et al. [10] discussed the use of dynamic inversion with neural network adaptation to provide an adaptive controller for the GTSpy, a small ducted fan autonomous vehicle based on the Micro Autonomous Systems' Helispy.

III. METHODOLOGY

The focus of this project deals with the developing the new type of MAV known as Ducted Fan Micro Aerial Vehicle. Collecting data about the vehicle configuration, weight estimation and power calculations are done. CAD model of DMAV are prepared according to the data collected. Analytical result of the DMAV where the Coefficient of Lift & Coefficient of Drag is calculated along with the dynamic pressure acting along the surface of the DMAV with flow visualization is done.

GEOMETRICAL LAYOUT AND PROPERTIES

The vehicle has the total height of **156.5mm**, with the wing span of **210mm**. Note for this wing span; a large portion is contributed by the duct section. Duct has the outer diameter of **97.43mm**, and the chord of **69.04mm**, while the wing has a shorter chord of **27.18mm**. Also, the wing is straight and untapered. The following figures represent the entire geometrical view of the DMAV designed using CATIA V5 R18.

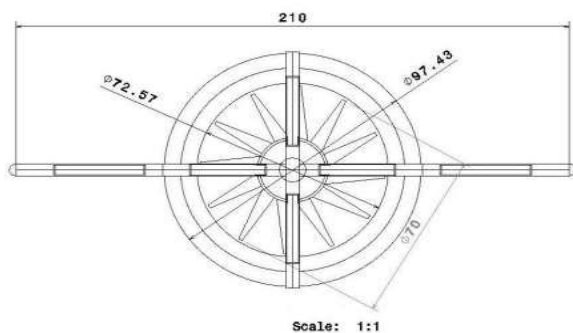


Fig 1: Front View of the DMAV

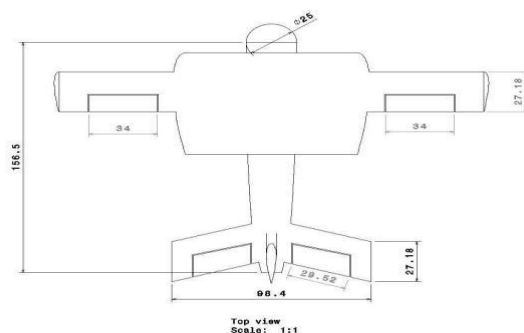


Fig 2 Top View DMAV



Geometrical detail for the DMAV

The table 1 describes the geometrical details of the DMAV with parameters and accurate values.

Airfoil selection

The selected airfoil is NACA 0018($C_L1.09$).The following figure3 represents the geometrical airfoil shape and graphs for lift coefficient to drag coefficient and lift coefficient to angle of attack. NACA 0018 was selected due to have high lift to drag coefficient ratio compare to some other airfoils. The following Figure 4 represents lift coefficient curves of NACA0018 Airfoil for varies angle of attack

Table 1 DMAV design data

Parameter	Value	Parameter	Value
Wing span	210mm	Tail sweep angle	14 ⁰
Wing chord	27.18mm	Tail taper ratio	0.9
Duct inner dia.	85mm	Tail span	98.4mm
Duct outer dia.	97.43mm	Fore body dia.	25mm
Duct chord	69.04mm	Fan dia.	80mm
Tail chord	27.18mm		

Table 2. Different components, materials, volume and weight

No.	Component	Material	Volume	Density	Weight
1	Duct	Carbon	71900	0.0016	115.04
2	Wings	Carbon	12100	0.0016	19.36
3	Fuselage	Carbon	49625	0.0016	79.4
4	Stators	Carbon	53437.5	0.0016	85.5
5	Empennage	Carbon	17925	0.0016	28.68
6	Propulsion unit (motor, fan, accessories)				90
7	Electronics (boards, sensors, batteries, wirings,				180
Total Weight					597.98

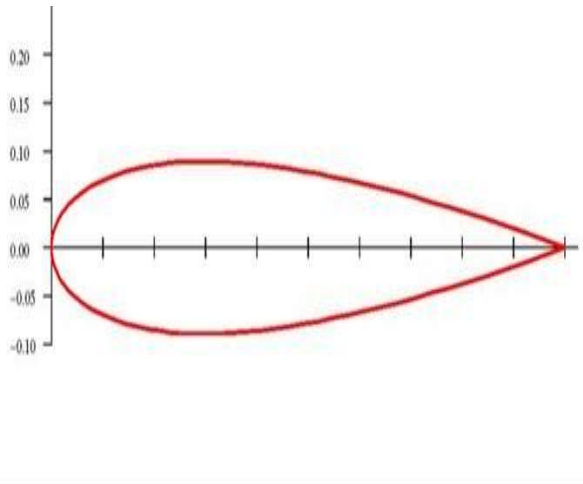


Fig 3 NACA 0018

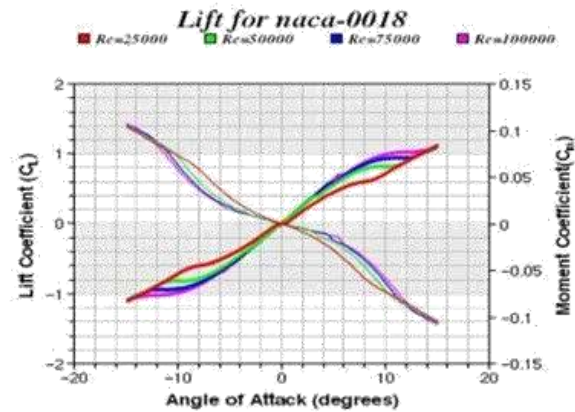


Fig 4 Angle of attack vs Lift

MODEL OF DUCTED FAN MAV

The modeling of the ducted fan micro aerial vehicle was done using the CATIA V5 software. The components of DMAV were designed and assembled. The following figure 5 represents the assembled part model of the ducted fan micro aerial vehicle (DMAV).

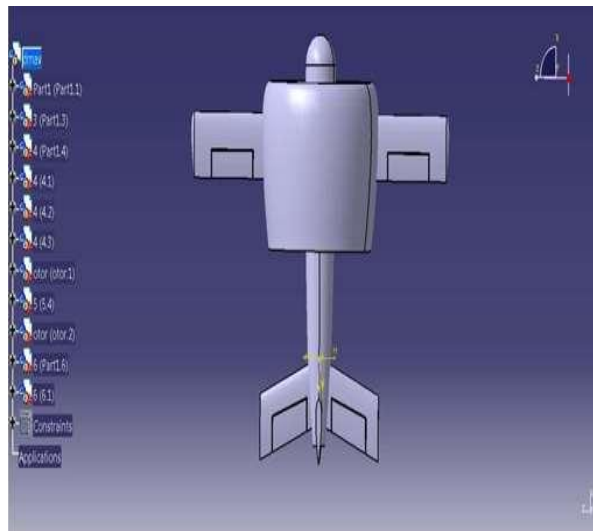


Fig 5 CATIA model Of DMAV

CFD ANALYSIS

Computational Fluid Dynamics (CFD) is one of the most popular numerical approaches for predicting the external flow around different kinds of vehicles and analyzing the internal flow through many types of tube or duct. For instance, in aerospace engineering the use of CFD is quite frequent as a wind tunnel simulation tool during the preliminary design of aircraft and following analysis of aerodynamic coefficients. Normally, CAD software is essential to build up a 3D solid model in preliminary design, it is also easy to be imported into CFD tool. After running simulation in CFD codes the 3D model is able to be modified back to CAD software. Thus repeating this cycle between CAD and CFD can not only optimize design but also save time and costs.

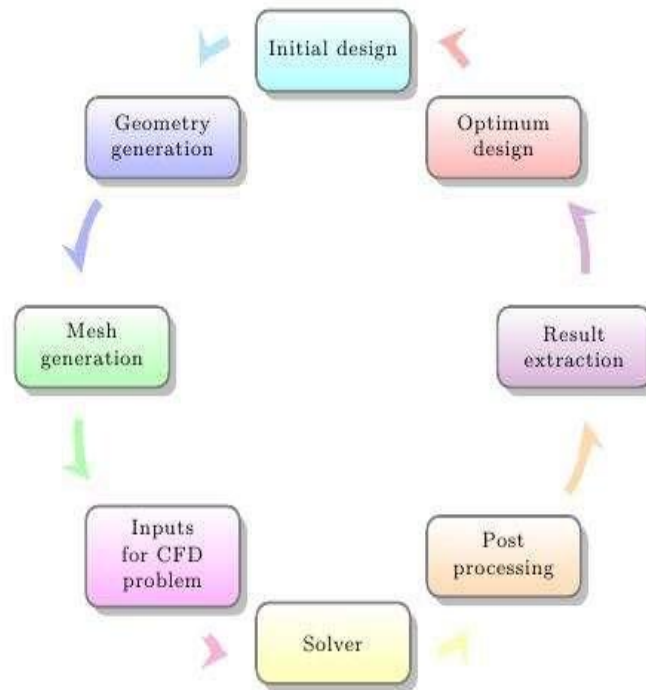


Fig 6 Flow process

Governing equations of CFD

All of the CFD methods are based on the fundamental governing equations of fluid dynamics, such as the continuity, momentum, and energy equations which are the mathematical statements of three physical principles: Law of Mass Conservation, Newton’s Second Law, and Law of Energy Conservation.

Navier-Stokes Equations for Viscous Flow

Viscous flow includes the transportation phenomena of friction, thermal conduction or mass diffusion. Usually, the momentum equations for a viscous flow were identified as the Navier-Stokes equation due to historical experience. Therefore, in the CFD literature, a “Navier-Stokes solution” simply means a solution of a viscous flow problem using the full governing equations.

Euler Equations for Inviscid Flow

Compared with viscous flow, inviscid flow has totally different characteristics. In inviscid flow the transport phenomena of viscosity, mass diffusion, and thermal conductivity are ignored. The continuity and momentum equations could be defined as the Euler equation which is used to resolve an inviscid flow problem.

DISCRETIZATION

By discretization the partial differential equations can be replaced by some algebraic equations that are resolved for the value of the flow-field variables at the discrete grid points as shown in figure 4.2 then the partial differential equations have been discretized. This method of discretization is called the method of finite differences which is widely applied in CFD domain.

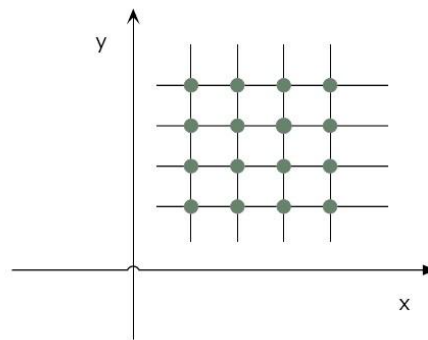


Fig 7 Discrete grid points

Grid generation

Structured Grid Scheme

To analyze the flow field through an aerofoil, the structured body-fitted grids are always applied, in particular to deal with curved boundary flows around aerofoil. Below structured grid is of C type.

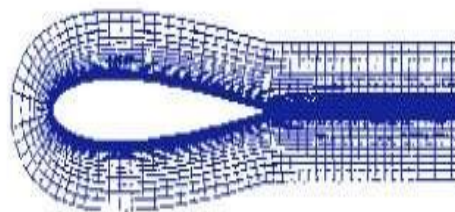


Fig 8 C type

Unstructured Grid Scheme

The advantage of an unstructured grid scheme is that only explicit structure of coordinate lines is formed by the grids, hence the mesh can be easily concentrated and generated around a complex geometry shape.

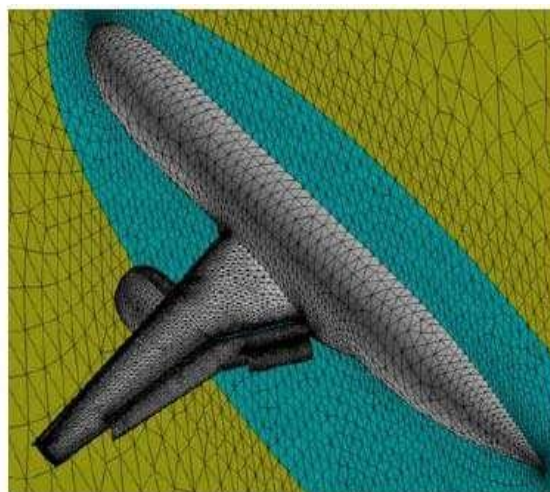


Fig9 Unstructured Grids around an Entire Configuration of Airplane

Mesh Generation

The geometry of the MAV is quite complex (Fig 3.7), it consists of several components. Unstructured mesh approaches for complex geometry configuration is more efficient and less time consuming as shown in figure 4.7. The density of the grid near the surface of the MAV is much higher than far field to simulate the boundary layer accurately and obtain a realistic value for the drag coefficient.

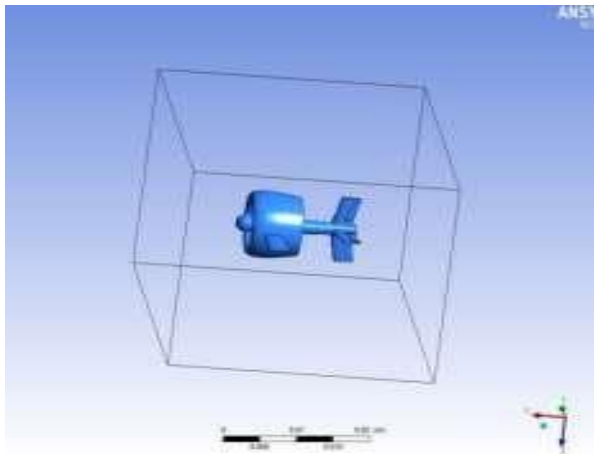


Fig 10 Domain of DMAV

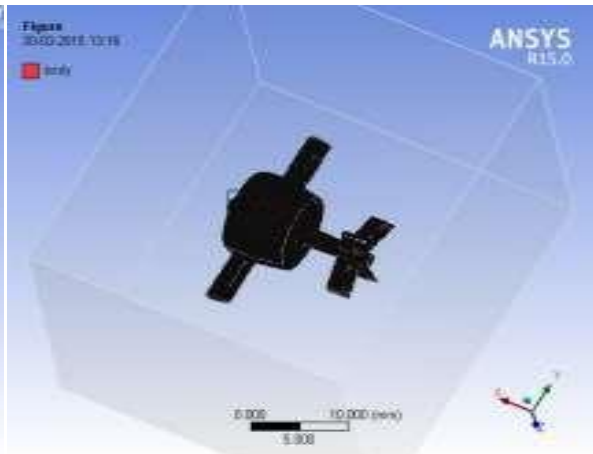


Fig 11 Meshed DMAV

Number of Nodes = 130966

Number of Elements = 740938

IV. RESULTS AND ANALYSIS

Flow Patterns around DMAV

The full scale model of MAV with ducted fan is simulated in Fluent to analyze the process of flow transition. We can clearly see that the free flow via wings is still laminar flow at low Mach number, whereas the uniform free flow passes through the rotors, and gradually becomes turbulent flow which is irregular and unstable.

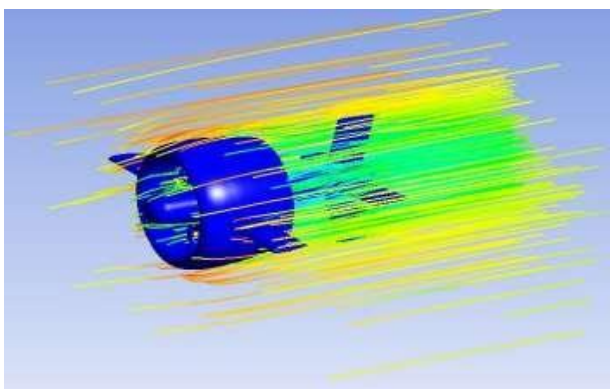


Fig 12 Flow Pattern of DMAV

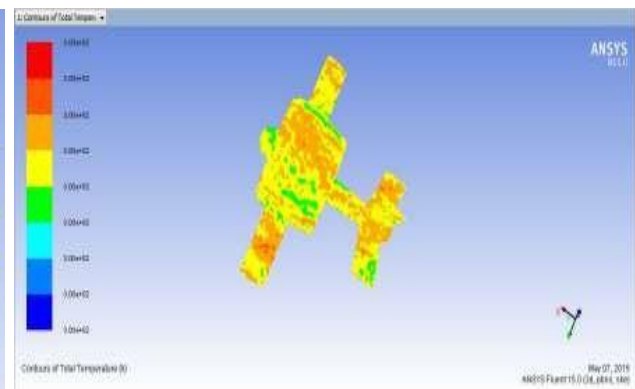


Fig 13 Turbulent intensity of DMAV

Fig 13 shows that most of the turbulent flow passes along the control surface of the tail, because the yellow and orange parts of DMAV reflect the high value of turbulent intensity.

Pressure Contour at 0° angle of attack

The figure 14 and 15 represents the pressure contour and pressure distribution over the full scale model of DMAV at 0° angle of attack.

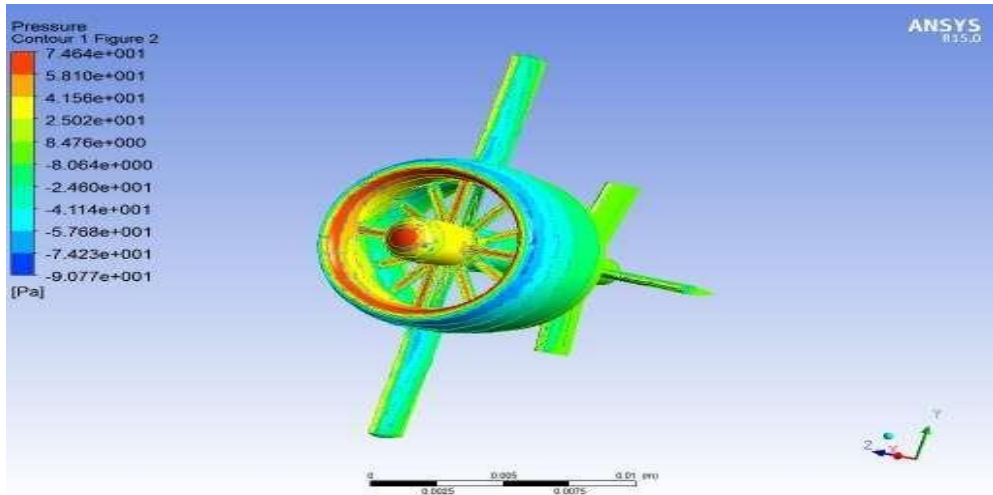


Fig 14 Pressure over DMAV at 0°

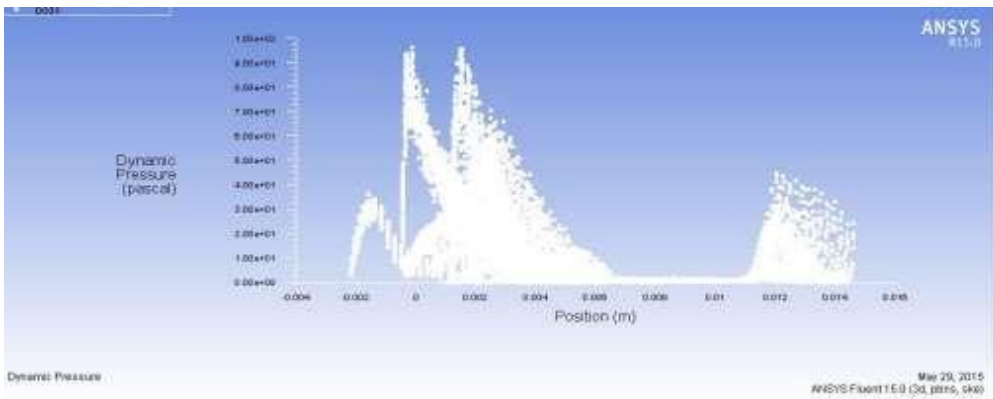


Fig 15 Profile of Dynamic pressure over DMAV at 0°

The figure 15 shows the distribution of pressure over the DMAV at 5° angle of attack. From this we can observe the change of pressure by variation of color changes. The maximum pressure obtained over surface of DMAV is 7.46e+01.

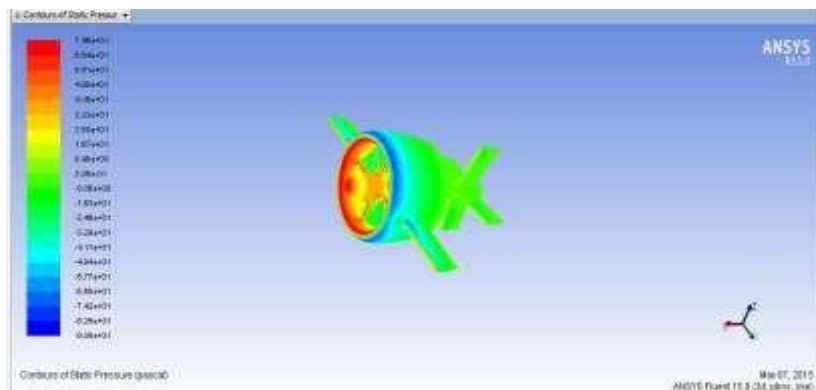


Fig. 16 Pressure over DMAV

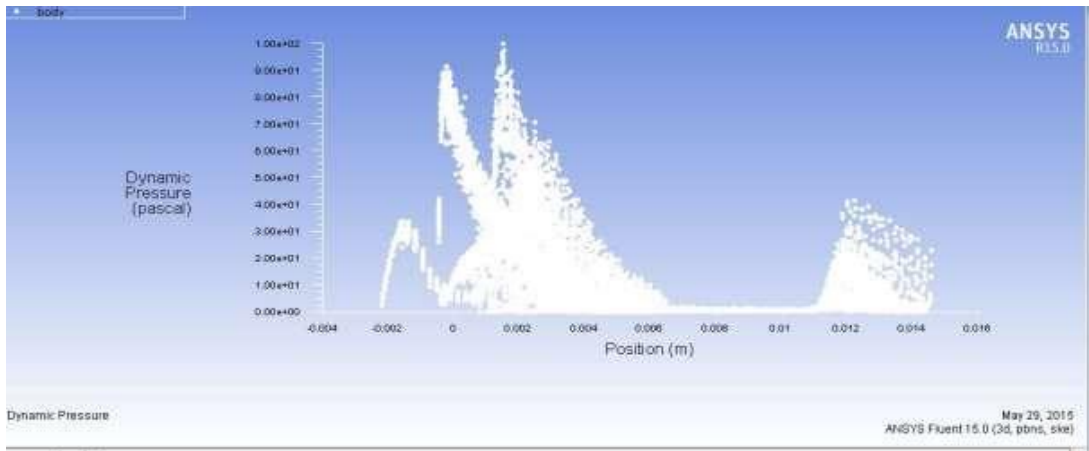


Fig 17 Profile of Dynamic pressure over DMAV at 5°

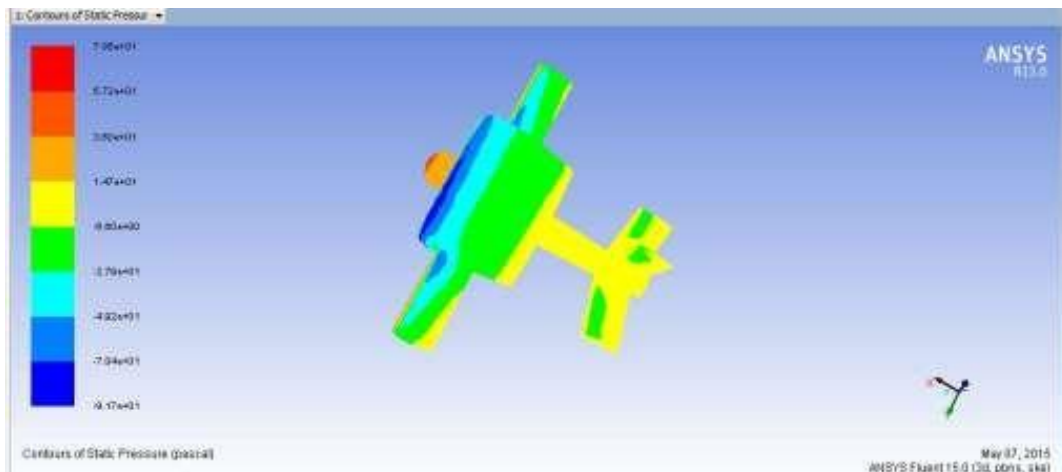


Fig 18 Pressure contour over DMAV at 10°

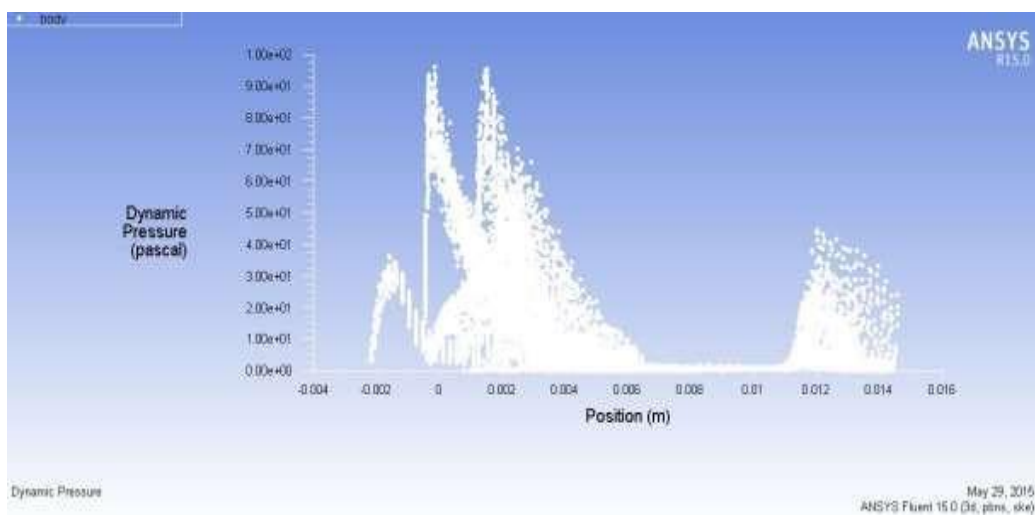


Fig 19 Profile of Dynamic pressure over DMAV at 10°

The figure 19 shows the Dynamic pressure of DMAV with the varied of angle of attack. At zero angle of attack there is no apparent pressure difference between upper and lower surface. We can see that the pressure difference rises with the increase of angle of attack. Furthermore, compared with the wing’s pressure difference increasing the tail’s variation is more obvious.

The CFD results represent the aerodynamic parameters of DMAV such as coefficient of lift and coefficient of drag. These two parameters play important role in determining the lift and stability of the DMAV. In this we compare the CL for different angle of attack similarly the CD

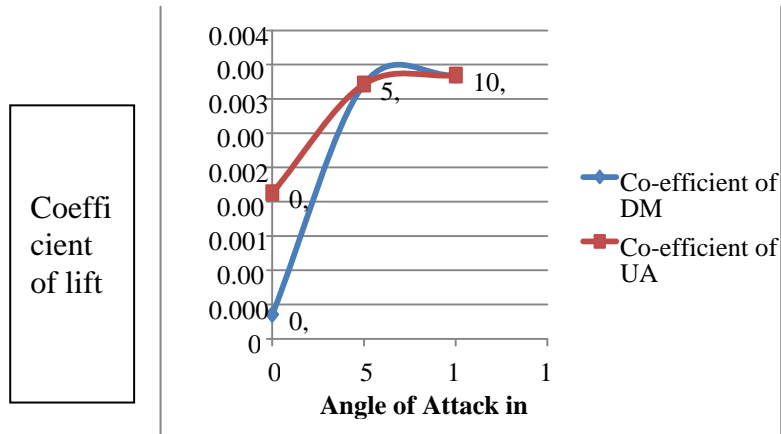


Fig 20 Graph of AOA v/s CL

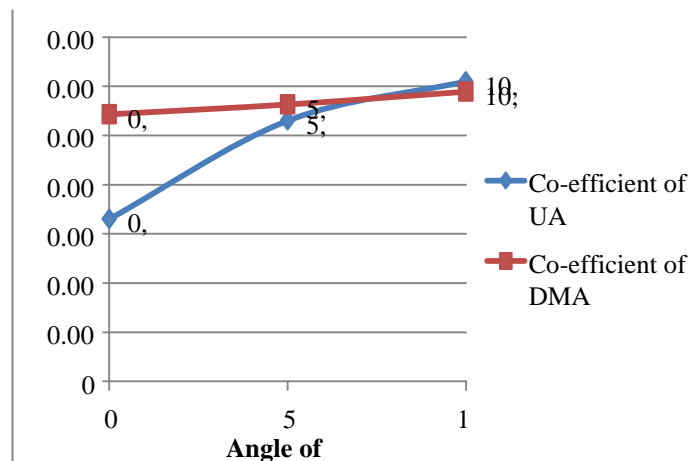


Fig 21 Graph of AOA v/s CD

The graph 20 and 21 shows the comparison of Coefficient of lift and Coefficient of Drag for existing UAV model and the newly developed DMAV for the angle of attack such as 0°, 5°, and 10°. From these we can say that the newly developed DMAV has CL and CD values approximately similar to that of UAV model. Therefore our model DMAV can produce the enough lift of mission purpose with stable condition. The table 2 and 3 shows the values of CL and CD for angle of attack of UAV and DMAV.

Table 3 Coefficient of Lift

ANGLE OF ATTACK	CL OF DMAV	CL OF UAV
0	0.000352	0.00213
5	0.003713	0.003713
10	0.003845	0.003845



Table 4 Coefficient of Drag

ANGLE OF ATTACK	CL OF DMAV	CL OF UAV
0	0.0054	0.0033
5	0.00563	0.0053
10	0.00589	0.0061

Table 5 Summary of Power Required

Flight	Power(W)
Hover	63.66
Normal Ascend	70
Max Ascend	119.842
Cruise	20.66

V. CONCLUSION

This project has presented a comprehensive study on Ducted-fan MAV including design configuration and aerodynamic data estimation. While CAD model of the Ducted Fan Micro Aerial Vehicle (DMAV) had been done by using CATIA V5 modeling software according to the geometrical configuration.

From the analytical part coefficient lift and coefficient of drag of DMAV was determined using the FEA software and result is compared with existing UAV model and it is found that the new model of DMAV is in line with the UAV. In addition, from data we can clear see that the flight performance of UAV is improved by assembling two wings which provide sufficient lift for UAV to keep horizontal flight. Indeed, the two wings play a critical role in achieving longitudinal flight transition. Also from the power estimation, power required for the lift of DMAV for different flight mission was calculated.

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