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COMPARATIVE ANALYSIS OF AIRFOIL SELECTION FOR MINIATURE AIR VEHICLE

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Abstract: **This article outlines factors to take into account when choosing an MAV airfoil (Miniature Air Vehicle). A MAV is mostly used in hazardous and defense regions that are inaccessible to humans. The MAV has some specified range of speed in which it has travel, i.e.: - 9 to 20m/s. Here, a few airfoils are chosen, and after doing a comparison analysis, the airfoil that produces the best results is chosen. The airfoil is chosen with a flat lower surface for comparative examination. In order to choose the right airfoil, "ANSYS FLUENT" is used to analyze the airfoil and calculate the lift to drag ratio. The reason for this criterion is that the MAV should have a stable flight. This article provides guidance on choosing the ideal airfoil for gliding. The airfoil with the maximum lift to drag ratio is being selected. According to the study of the data, NACA-2205 would be the ideal for MAV since it has a high lift to drag ratio at a high angle of attack and a high capability of gliding.**

Keywords: **ANSYS FLUENT, Comparative Analysis, Defense, Lift to Drag ratio, Miniature Air Vehicle**

I. INTRODUCTION

MAV (Miniature Air Vehicle) is a small aircraft with a wingspan of 15cm and is capable of operating at 9 to 20 m/s. The idea behind creating MAV is practical and affordable. This has the ability to go at lower altitudes and be utilized for monitoring. Also, it has some payload capacity for things like cameras, explosives, chemical sensors, and communication equipment. Defense is where MAV is most frequently used. These days, MAV is also employed for video recording in a fire zone, a defensive zone, a function, etc.

The MAV's airfoil is primarily responsible for its carrying capacity. Any aeroplane needs an airfoil as a crucial tool. There are numerous types of airfoils. The capacity of the airfoil to glide is the primary criterion for selection. The airfoil that will be used must be carefully selected. The choice of airfoil for MAV is made in this study. Due to the MAV's diminutive size, an airfoil must lift all of its weight; as a result, the chosen airfoil must create enough lift to support the flight even at a zero-degree angle of attack. A stable flight should also be produced by the airfoil. The airfoil, which typically has a flat lower surface, has been observed to have a steady flight. One other benefit of stable flight is that it increases gliding angle. The gliding angle determines how quickly an aircraft falls and how far it travels in a horizontal direction; it should be smaller. The lift to drag ratio should be significant for a suitable gliding angle, meaning that the lift force will outweigh the weight force and the thrust will outweigh the drag force. Less drag is necessary for a high lift to drag ratio since it will result in less thrust, which will use less fuel and boost flying economy.

II. LITERATURE REVIEW

Quadrotor Biplane Tail-sitter (QBiT) was created by Peter Ryseck et al. [1] for hover and high cruise speed. Depending on the needs of the task, it can operate at a variety of speeds. Due to design limitations, it has speed restrictions. The effects of wing morphing were investigated during static bird pitching by C. Harvey et al. [2]. He also looks at the design of gliding wings. To create a crash-proof air vehicle, K.G. Thirugnanasambantham et al. [3] created and built the ornithopter tiny air vehicle. Little control board created by S. Aurecianus et al. [4] to operate flapping-wing mini air vehicle (FWMAV). A technique to gauge attitude and altitude was developed throughout the project. The flapping mechanism with six-bar connections has been successfully designed for lower altitudes by JaeHyeok Jeon et al. [5].Wind tunnel results for wings with low to moderate aspect ratios and low Reynolds numbers were presented by Ananda et al. [6]. In order to demonstrate the existence of a critical Reynolds number and a change in performance characteristics, tests were conducted in a low-turbulence wind tunnel. A control board and remote have been created by S. Aurecianus et al. [7] to manage the flight and collect real-time flying data. With the use of simulated experiments, Brusov and Petruchik [8] investigated the issues related to aerodynamics and flight dynamics for several types of unmanned aerial vehicles (UAV).In his work on the lift, drag, and pitching moment of wings with low aspect ratios and low Reynolds numbers, Torres [9] published his findings. In their study of the aerodynamics of gliding flight, Tucker and Parrott [10] focused on the impact of several parameters on gliding performance. The low speed airfoil data was compiled by Selig et al. [11], who also emphasized the significance of airfoil profiles and associated performance graphs.

Buckley et al. [12] highlighted airfoil optimization by employing practical design requirements. To identify the best solution, a variety of strategies for optimising various parameters were explored. The mechanism for a 20cm wing span flapping MAV was created by Lung-Jieh Yang and al. [17] with the aid of iterative scenario & experimentation. According to Steven Ho et al. [18], flexible membranes increase lift and thrust performance by lowering negative peak forces rather than by increasing positive peak forces. Carbon fiber was used to construct the flapping wing mechanism by Che-Shu Lin [19]. The four bar linkage is driven by a flapping mechanism, and testing in a wind tunnel is done to determine the list and thrust force in the system. According to J. M. Wakeling et al. [20], if the forces are generated by quasi-steady mechanisms, then there should be a link between the thrust and the kinematics parameters governing the force production. Dan Hou et al. [21] used the finite element approach to analyze a 3-D model of dynamic deformation using the quantitative comparison of inertial and aerodynamic forces on a dragonfly forewing. This article outlines factors to take into account when choosing an MAV airfoil. In order to choose the right airfoil, "ANSYS FLUENT" is used to analyze the airfoil and calculate the lift to drag ratio.

III. DEVELOPMENT CONSIDERATION

While choosing an airfoil, a number of elements are taken into account, including aerodynamics, stability, and maneuverability. The paper builds on the airfoil geometry depicted in picture 1 throughout. The angle of attack of the airfoil is (α), and the wind speed is (V∞). An essential factor is the attack angle. An airfoil's co-efficient of lift and co-efficient of drag both rise as the angle of attack does. Increased lift results in a higher lift to drag ratio because it increases the force on the airfoil's bottom surface while decreasing the force on the top surface.

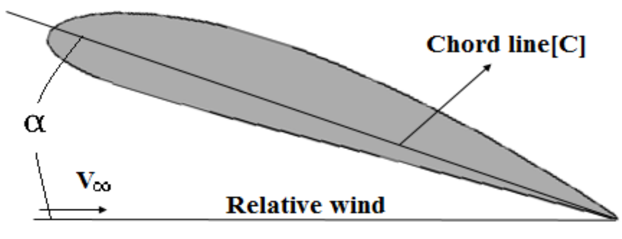

Fig 1. Airfoil with the angle of attack

There is a limit to the angle of attack, after which it cannot be increased. The attack angle in this article ranges from -5° to 5°. The drag co-efficient will rise more than the lift co-efficient when the angle of attack rises farther. The primary cause of increased drag is pressure on the lower surface, which grows to such an extent that it raises the lift component rather than the lift, resulting in decreased flying efficiency [7]. The MAV's velocity affects the lift coefficient as well. The MVA's maximum speed in this article is 20 m/s. Since lift is exactly proportional to velocity when the MAV is moving at maximum speed, or -20m/s, it will generate enough lift even at a low angle of attack.

3.1. Efficiency and airfoil selection:

When choosing an airfoil, the goal is to maximize lift and minimize drag. This can be done by maximizing the lift coefficient and decreasing the drag coefficient. The equation below illustrates the relationship between Lift and Lift Coefficient as well as Drag and Drag Coefficients. A wing's overall effectiveness must also be taken into account. The lift to drag ratio and this potency are connected. This lift to drag ratio has to do with the airflow situation, which is velocity-dependent. Reynolds number (Re) and Mach number are two more words that are crucial for flight that are introduced by the velocity of a flight (M).Re and M both fluctuate as the velocity varies. As a result of the Mach number not exceeding 0.3 and our operational range of approximately 9–20 m/s, our MAV is classified as subsonic flight.

$L = 0.5\rho V^2 S C_l$ ……………… (1)[13]
$D = 0.5\rho V^2 S C_d$ ……………… (2)[13]

However, there are a few additional categories of drag, including pressure, skin, wave, and generated friction. Just shape and skin friction drag are taken into account since MAV is a subsonic flight in this case. As demonstrated below, using the wing geometry, we can calculate the induced drag.

$$D_i = \frac{C_l^2}{\pi A R D_i} \text{……………………… (3)}$$

It is easier to comprehend thanks to the level and steady flying. The self-weight will be balanced by lift and the opposing resistive force (drag) will be balanced by thrust in level, steady flight. Figure 2 displays level flight.

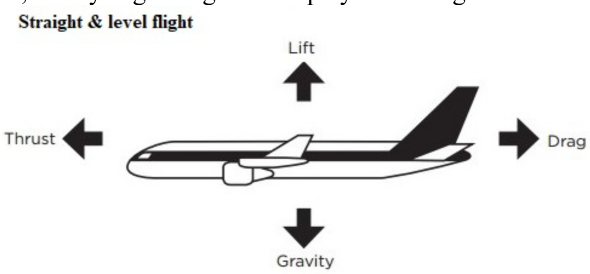

Fig 2. Level flight condition [14]

$$T = D$$
$$L = W$$

We can infer from the equation above that as the lift increases, so does the ability to support weight. Because the lift to drag ratio is so crucial, as was already mentioned, the drag must be reduced to increase the ratio. With a reduction in gliding angle, efficiency is increased because to the lift to drag ratio. The significant distance will move in the horizontal direction and decrease with decreasing glide angle, and vice versa. As it moves, it descends steadily, losing altitude. The glider will travel in a straightforward straight course. A glide angle is the location where the flight path and the ground converge. Trigonometric calculations may be used to determine the glide angle if the distance travelled (d) and height change (h) were known. The guiding angle is illustrated in Figure 3.

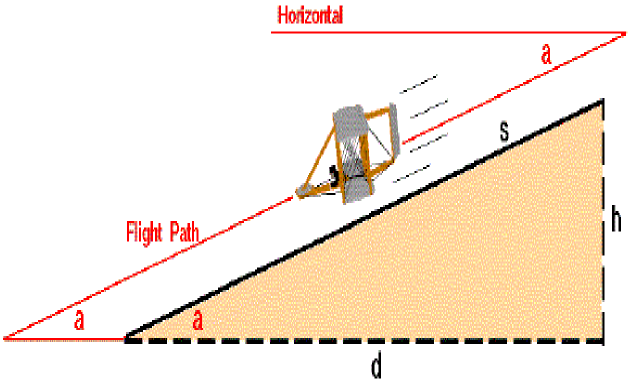

Fig 3. Gilding angle with formula [15]

As previously mentioned, the airfoil with a comparatively flat surface was chosen for study, and the best airfoil was chosen for MAV. The NACA (National Advisory Committee for Aeronautics)-2203, NACA-2204, and NACA-2205 are chosen in accordance with this. Table 1 below displays an airfoil's characteristics [16].

Table 1. Physical Characteristics of Selected Airfoils

Parameter	NACA-2203	NACA-2204	NACA-2205
Thickness	0.03	0.04	0.05
Camber	0.022	0.022	0.022

Figure 4, 5 and 6 shows the airfoil characteristics for different parameters.

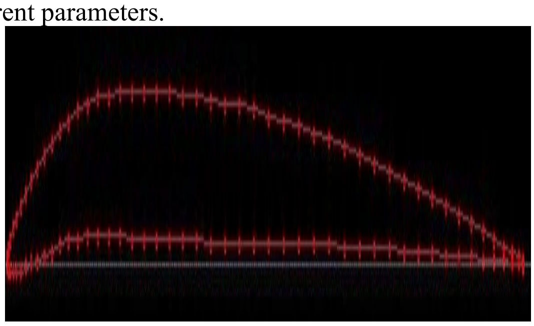

Fig 4. NACA-2203

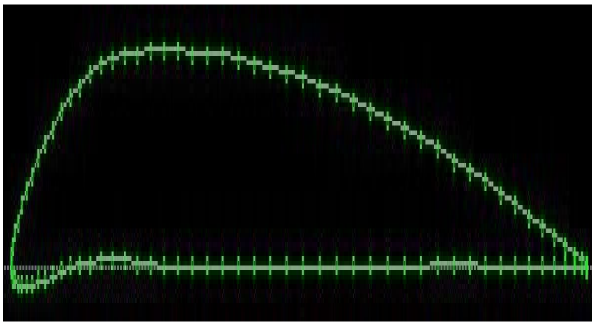

Fig 5. NACA-2204

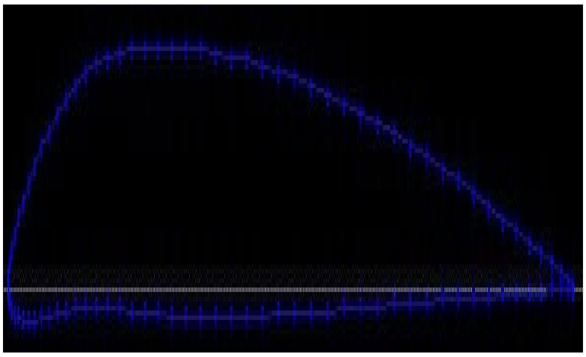

Fig 6. NACA-2205

There are several reasons for choosing this kind of airfoil, including the fact that it has a flat surface when used to create a wing, which prevents air from flowing away from the bottom surface and helps to retain air, allowing MAVs to maintain height.

3.2. CFD analysis of Airfoil:

The analysis is the most important section of this study since it can show why a specific airfoil is chosen for MAV on the basis of it. CFD analysis is carried out in ANSYS. The lift and drag coefficients are calculated in CFD at different angles of attack and speeds. For analysis reasons, the CAD model is made in CAD software. The CAD model is meshed in ICEM; the mesh of an airfoil is shown in figure 7.

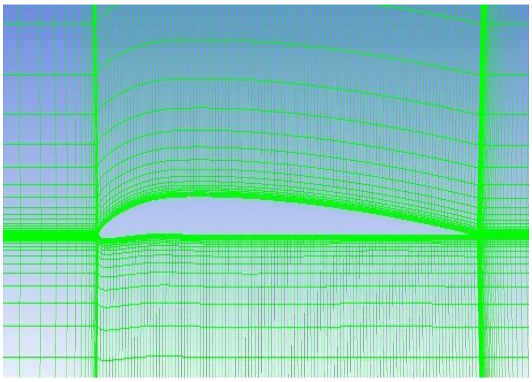

Fig 7. Mesh of an airfoil

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Figure 7 shows that the mesh is significantly denser close to the airfoil surface. To get accurate results when calculating the lift and drag coefficient on the airfoil, the mesh must be denser close to the airfoil. The accuracy is determined by mesh quality, and a mesh of great quality produces accurate results. There are several different types of mesh, including tri-, quad-, tetra-, and hex-mesh. As we are working with a 2-D model, we utilize a quad mesh to mesh airfoils because it produces correct results. The meshed airfoil is imported into ANSYS for analysis reasons; the speed range is set at 9–20 m/s, the angle of attack ranges from 5° to -5°, and in viscid flow is assumed because the MAV will be moving through an incompressible flow and at a low altitude.

3.3. Fluent assumptions:

For the two-dimensional air foil with the incompressible flow, without shock waves, and taking into account the in-viscid flow, fluent assumptions are made. It determines the momentum, mass, and energy conservation across the air foil's domain, where the Mach number ranges from 0.026 to 0.054. Since the mesh is much denser close to an air foil's surface, analysis is performed at the inlet, outlet, and boundary where the mesh is coarse.

3.4. Realizable K - ε Solution Method and boundary conditions

The realizable k- solution approach is a crucial step in analysis and design. Realizable, following turbulent flow physics satisfies the standard stress mathematical restriction. The equation given below can be used to compute the Normal Reynolds stress in an incompressible strained mean flow using the Boussinesq relation and eddy viscosity.

$$\overline{u^2} = \frac{2}{3}k - 2V_\tau \frac{du}{dx} \;\ldots\ldots\ldots\ldots\ldots (4)$$

The revised representation of the dissipation rate (ε) contains the shortcoming of conventional models or standard models. The refined dissipation expression is mostly taken into account while discussing the round-jet anomaly. The boundary condition known as velocity inlet determines how the meshed airfoil will flow at a domain's inlet. Since the total characteristics are not constant, they will increase as the inlet's velocity is increased. Since this velocity is best described for incompressible flow alone, it has occasionally been utilised for compressible flow, which prevents it from producing the expected results or values because it allows for stagnation circumstances and floats to any level. The inflow stagnation qualities must be kept from becoming excessively non-uniform by taking the necessary precautions to ensure that the velocity input is not close to any impediment. The meshed airfoil's outlet boundary condition will be a pressure outlet that calls for the definition of static pressure. It only makes sense for this condition to apply when the flow is subsonic. The pressure outlet won't be used if it's being used for supersonic flow; instead, pressure will be deduced from the stream inside. The term "backflow" refers to the pressure outlet's reverse flow direction. The issues with convergence are minimized by using realistic backflow values. In order to contain the liquid and powerful region, a wall is used. The no-slip boundary condition is automatically applied at walls since a viscous flow is being taken into consideration. The wall boundary's translation motion can, however, be used to determine tangential velocity components [7].

IV. RESULTS

The best airfoil will be chosen in this paper. The analysis's findings provide evidence that the airfoil choice was made. Each airfoil's polar plot is plotted since it aids in providing a clear view of the results. The lift to drag ratio of NACA airfoils at various angles of attack—ranging from -5° to 5° with a 1-degree interval—is compared in the graph below in Figure 8. NACA 2204 has the largest angle of attack when the angle of attack is 0°.The higher angle of attack is given preference in this instance though. It is abundantly obvious from the graph below that NACA 2205 has the best lift to drag ratio at greater angles of attack. It would be helpful to choose an airfoil because some educated predictions were previously given for one. Usually, it takes 10000 iterations for the Realizable k-solution to reach convergence.

Table 2. AirfoilsComparative analysis based on the lift to drag ratio between NACA airfoil at the variousangle of attack.

Alpha	NACA 2203 **C_l/C_d**	NACA 2204 **C_l/C_d**	NACA 2205 **C_l/C_d**
-5		-6.82808	
-3	-5.44269	-6.22678	-7.5937
-2			-3.23336
-1	5.138889	10.21898	14.16327
0	30.58383	53.24257	52.17184
1	77.65281	72.18182	67.69068
2	80.07692	76.06171	72.95337
3	56.77348	76.48175	75.34286
4		61.55972	79.77358
5		50.25677	62.48506

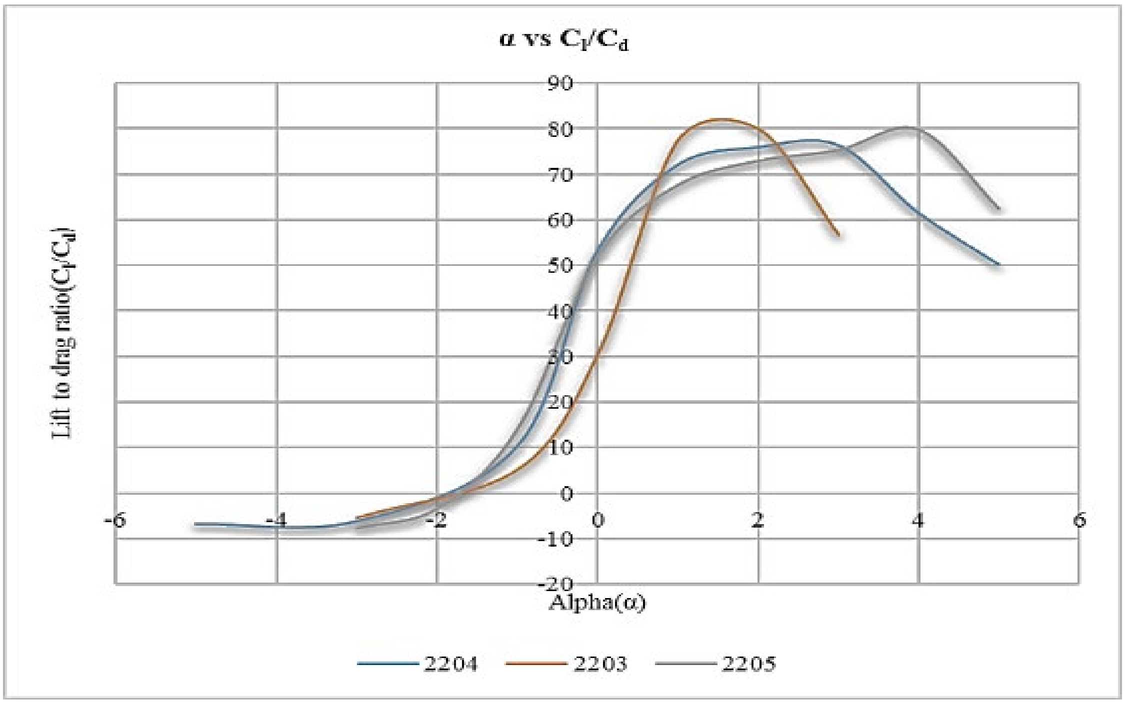

Fig 8. Comparative analysis based on the lift to drag ratio between NACA airfoil at the various angle of attack

The lift to drag ratio is a valid concern and the basis for choosing an airfoil. Figure 8's graph illustrates the relationship between lift to drag ratio and angle of attack. The lift and drag are significantly impacted by the pressure distribution as well. The pressure distribution graph is also created during investigation at various angles of attack. To be clear, the pressure distribution in the following figure is a plot for NACA-2204 at a 0° angle of attack. Given that it is virtually flat; the bottom surface will experience higher lift or pressure. Figures 9 and 10 depict the relationship between the pressure coefficient and chord length on the surface of an airfoil, respectively.

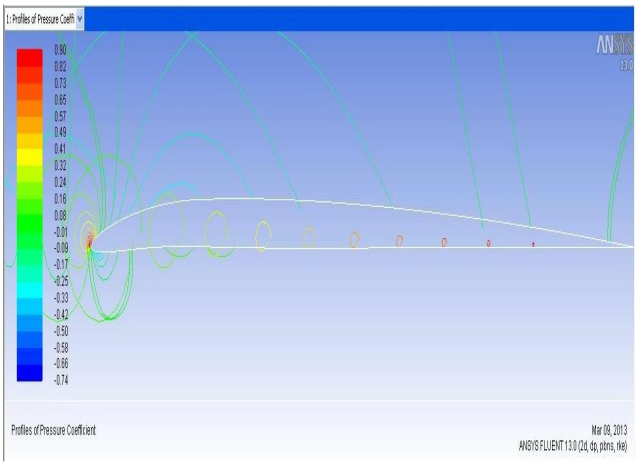

Fig 9. Pressure coefficient on the surface of an airfoil

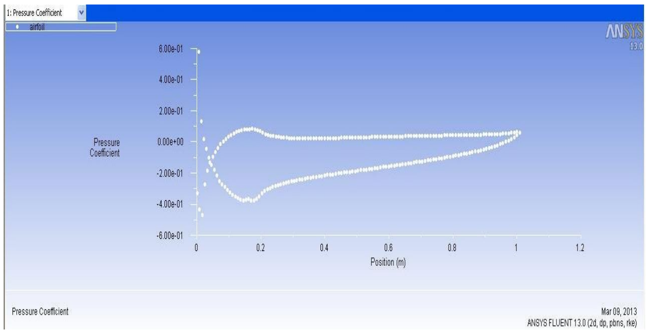

Fig 10. Pressure coefficient Vs. chord length graph

V. CONCLUSION

This study examined the airfoil's incompressible, in viscid flow, which would be ideal for MAV. This article offers advice on how to choose the appropriate airfoil for gliding. With minimal thrust, the glider can travel a long distance. The study's findings suggest that the performance of MAVs is influenced by three key characteristics: the ability to provide more lift than the existing glider, the propensity to reduce more drag, and the capacity to store and release energy as needed. The MAV may perform surveillance tasks for the military while also transporting payloads like explosives. The drone, a sophisticated MAV, is increasingly being utilized for defence or surveillance. Realizable K-solution approach with 10,000 iterations has been employed in this case for analysis. The ideal NACA for an MAV would have a high lift to drag ratio at a high angle of attack and a high capability of gliding, according to the examination of the aforementioned results for NACA 2203, NACA 2204, and NACA 2205. Recent years have seen considerable advancements. The improvements might be made in the flying machine of the future in terms of Low Reynolds number aerodynamics, Lightweight, biologically adaptive system, Robust flight navigation and Miniaturized control system. The key to advancing MAV technology is in the hands of the natural world. Advancement is possible by careful study of flying birds seen in nature. Pitch, yaw, and roll motions can be modelled or developed for creating flight control as well. These motions can be achieved with the use of numerous joint and motion combinations, which will produce the aerodynamic force of each individual wing.

VI. REFERENCES

[1]. Ryseck P, Yeo D, Hrishikeshavan V, Chopra I. Aerodynamic and mechanical design of a morphing winglet for a quadrotor biplane tail-sitter. In Proceedings of the Vertical Flight Society 8th Autonomous VTOL Symposium 2019 (pp. 29-31).
[2]. Harvey C, Baliga VB, Lavoie P, Altshuler DL. Wing morphing allows gulls to modulate static pitch stability during gliding. Journal of the Royal Society Interface. 2019 Jan 31;16(150):20180641.
[3]. Thirugnanasambantham KG, Manohar B, Rangasamy R, Pearson T, Naidu G. Development of Biological Inspired Ornithopter Micro Air Vehicle (MAV). International Journal of Pure and Applied Mathematics. 2018;119(16):3623-34.
[4]. Aurecianus S, Phan HV, Nam SL, Kang T, Park HC. Flapping wing micro air vehicle (FW-MAV) state estimation and control with heading and altitude hold. In10th International Micro Air Vehicle Competition and Conference (IMAV), Melbourne 2018 (pp. 216-221).
[5]. Jeon J, Cho H, Kim Y, Lee J, Gong D, Shin S, Kim C. Design and analysis of the link mechanism for the flapping wing MAV using flexible multi-body dynamic analysis. International Journal of Micro Air Vehicles. 2017 Dec;9(4):253-69.
[6]. Ananda G, Sukumar P, Selig M. Low-to-moderate aspect ratio wings tested at low Reynolds numbers. In30th AIAA applied aerodynamics conference 2012 Jun (p. 3026).
[7]. Brusov V, Petruchik V, Tiumentsev Y. Theoretical and experimental investigations of aerodynamics and flight dynamics for micro-UAVs. InProc. ICAS-2010 Congress, Nice, France 2010 Sep.
[8]. Brusov VS, Petruchik VP. Theoretical and experimental investigations of aerodynamic characteristics for micro-UAV. InProc. 3rd US-European Competition and Workshop on Micro Air Vehicle Systems (MAV07) & European Micro Air Vehicle Conference and Competition (EMAV2007) 2007 Sep (pp. 17-21).
[9]. Torres GE. Aerodynamics of low aspect ratio wings at low Reynolds numbers with applications to micro air vehicle design. University of Notre Dame; 2002.
[10]. Tucker VA, Parrott GC. Aerodynamics of gliding flight in a falcon and other birds. Journal of Experimental Biology. 1970 Apr 1;52(2):345-67.
[11]. Selig MS. Summary of low speed airfoil data. SOARTECH publications; 1995.
[12]. Buckley HP, Zhou BY, Zingg DW. Airfoil optimization using practical aerodynamic design requirements. Journal of Aircraft. 2010 Sep;47(5):1707-19.
[13]. Anderson JD, Bowden ML. Introduction to flight.
[14]. https://www.scienceworld.ca/resource/four-forces-flight/ (Last visited on 24th July 2021)
[15]. https://wright.nasa.gov/airplane/glidang.html (Last visited on 24th July 2021)
[16]. Miller SD. Lift, Drag and moment of a NACA 0015 Airfoil. Department of Aerospace engineering. 2008 May;28.
[17]. Lung-Jieh Yang, Balasubramanian Esakki, Udayagiri Chandrasekhar, Kuan-Cheng Hung, Chieh-Ming Cheng, Practical Flapping Mechanisms for 20 cm-span Micro Air Vehicles. International Journal of Micro Air Vehicles, Volume 7 · Number 2 · 2015
[18]. Steven Ho, Hany Nassef, Nick Pornsinsirirak, Yu-Chong Taib, Chih-Ming Ho, Unsteady aerodynamics and flow controlfor flapping wing flyers. Progress in Aerospace Sciences 39 (2003) 635–681.
[19]. Che-Shu Lin, Chyanbin Hwu, Wen-Bin Young. The thrust and lift of an ornithopter's membrane wings with simple flapping motion. Aerospace Science and Technology 10 (2006) 111–119
[20]. J. M. Wakeling, C. P. Ellington. Velocities, Accelerations and Kinematics of Flapping Flight. The Journal of Experimental Biology 200, 557–582 (1997)
[21]. Dan Hou, Zheng Zhong. Comparative analysis of deformation behaviors of dragonfly wing under aerodynamic and inertial forces. Computers in Biology and Medicine.Volume 145, June 2022, 105421