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A COMPARATIVE STUDIES ON VARIOUS MODEL BIRD'S WING & STANDARD AIRFOIL & ALSO TRACK DOWN THE MOST EFFECTIVE AIRFOIL USING CFD SOLVER SOFTWARE

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Abstract: *The subsistent work describes the comparative analysis on various prototype model bird's wing and standard airfoil. For proceeding our experimental studies we fabricated several types model bird's, insect's wing like Dove wing, Fly's wing, Mosquito wing and other standard airfoil like NACA 64A012 mod airfoil. To seek out the better airfoil we also fabricated various supersonic combat aircraft like Mig-29, F-7 BG, F-22 raptor, Supermarine Spitfire Elliptical wing as well. The fundamentals of bird and insect flight are similar to those of aircraft flight. The action of air flow that produces lift forces on the wing which is known as airfoil. These airfoil is structured such that the air stream provides a net upward force on the airfoil. Since aerodynamic characteristics of an aircraft (wing loading, aerodynamic efficiency) are greatly rely on wing or airfoil, it should be varied from aircraft to other aircraft. This is why low speed aircraft has normal shaped symmetrical wing and supersonic combat aircraft has special shaped wing because it needs greater lift with small angle of attack. Secondly, we analyze those model wing on CFD solver software like SOLIDWORKS (flow simulation) to evaluate its flying ability such as lift force, drag force at different angle of attack. Finally, our ultimate goal is to track down the better airfoil or wing of these model bird's or insect's wing and different combat aircraft airfoil.*

Key words: Model wing, Wing loading, Aerodynamic characteristics, CFD solver software, Flow simulation.

1. INTRODUCTION

Aerodynamics is the study of forces and the resulting motion of objects through the air. Studying the motion of air around an object allows us to measure the forces of lift, which allows an aircraft to overcome gravity, and drag, which is the resistance an aircraft "feels" as it moves through the air. [1] Aerodynamic force is exerted on a body by the air (or some other gas) in which the body is immersed, and is due to the relative motion between the body and the gas. Aerodynamic force arises from two causes. They are the normal force due to the pressure on the surface of the body and the shear force due to the viscosity of the gas, also known as skin friction. When an airfoil (or a wing) is moving relative to the air it generates an aerodynamic force, in a rearward direction at an angle with the direction of relative motion. This aerodynamic force is commonly resolved into two components. Which are the drag is the force component parallel to the direction of relative motion and the lift is the force component perpendicular to the direction of relative motion. The design and analysis of the wings of aircraft is one of the principal applications of the science of aerodynamics, which is a branch of fluid mechanics. The properties of the airflow around any moving object can in principle be found by solving the Navier-Stokes equations of fluid dynamics. [2]

In this paper comparative analysis has been done on various model standard airfoils and prototype bird's wing at low- Mach number. The goal of this paper is to seek out that, which airfoil is the most suitable and efficient to be used in a low-speed aircraft and having maximum lift with respect to minimum drag on the basis of their Lift-to-Drag ratio, Lift coefficient, Drag coefficient and Moment coefficient under the specified boundary conditions and the value of Mach number varies from 0.10 to 0.30.

2. METHODOLOGY

2.1 AIRFOIL MODELLING:

The geometry of all airfoil and wing like F 22 raptor, F7 BG, Mig 29, Spitfire Elliptical Wing, NACA 64A012 mod airfoil, Dove wing, Fly wing & Mosquito wing are generated in SOLIDWORKS.

Above mentioned those airfoil NACA 64A012 mod airfoil is the only standard airfoil. Here the coordinates of NACA 64A012 mod airfoil are taken from UIUC official website. For achieving practical unsteady aerodynamics knowledge we also select many bird wing like DOVE wing, Fly wing & Mosquito wing. Those bird wing are also modeled by using SOLIDWORKS. We don't use any conventional parameter to model those wing. It's just replica of DOVE wing, Fly wing & Mosquito wing actual image. We just see the actual top view of DOVE wing, Fly wing & Mosquito wing as our model bird's wing cross section. For further wing analysis we also model supersonic fighter aircraft wing like model: F 22 raptor, F 7 BG, MIG 29 & Spitfire Elliptical wing. As we mentioned earlier that while we modelling those wing on SOLIDWORKS we don't use any conventional parameter to model those wing. From the cross sectional images of those wing are the approximate cross section of our model wing.

2.2 MESH GENERATION:

SOLIDWORKS Flow simulation is a new class of CFD (Computational Fluid Dynamics) analysis software (called concurrent CFD) that is fully embedded in the mechanical design environment, for all general engineering application. The idea is underpinned by the choice of meshing technology in SOLIDWORKS Flow simulation and the impact that impact that choosing a Cartesian based mesh has on the way the geometry is handled. Special character of SOLIDWORS Flow simulation that is the automatic meshing system will create mesh in accordance with the specified minimum gap size, minimum wall thickness and result resolution level. Different model wing has been built using the above data table and coordinates using the 'Curves using XYZ point' function. Chord length was taken 171mm and span taken 94 mm for the convenience of using the airfoil in wind tunnel.

2.3 PROTOTYPE:

For practical aerodynamic analysis we also made prototype model airfoil of F 22 raptor, F7 BG, Mig 29, Spitfire Elliptical Wing, NACA 64A012 mod airfoil, Dove wing, Fly wing & Mosquito wing. In this this sense wind tunnel testing is the best way to determine and calculate aerodynamic characteristics of airfoil. Those wing was built for wind tunnel experiment with the predefined chord length (171 mm) and span (94 mm) with the average height of those airfoil in between '3.2 cm'. The prototype was built in the workshop of Mechanical dept. of CUET. Beech wood (Gamahr) was used as material to make those airfoil model.

Fig 1: NACA 64A012 mod (model)

Fig 2: Elliptical Wing (model)

Fig 3: Dove Wing (model)

Fig 4: F7 BG wing (model)

Fig 5: F22 raptor Wing (model)

Fig 6: Fly's Wing (model)

Fig 7: MIG 29 wing (model)

Fig 8: Mosquito Wing (model)

2.4 AIRFOIIL SELECTION:

The most important and valuable task is to choice an airfoil and suitable bird wing on which the analysis will be done. This study will extremely vary from foil to foil. Consequence that came out from one foil can't be used to predict behavior of another foil. In this project F 22 raptor, F7 BG, Mig 29, Spitfire Elliptical Wing, NACA 64A012 mod airfoil, Dove wing, Fly wing & Mosquito wing was selected and all these prototype wing and model bird wing are shown above. The standard airfoil like NACA 64A012 mod airfoil is the first family of NACA airfoils developed in the 1930s, was the "five-digit" series, such as NACA 64A012 mod airfoil. This airfoil is used in L-39 Albatross light combat subsonic training aircraft By Bangladesh Air Force, China Air Force, Russian Air Force and Czech Air Force as well. We also choose bird's wing like 'Dove' wing and insect's wing like 'Fly's wing' & 'Mosquito wing'. The prime function of the wing is to generate lift force. This will be generated by special wing cross section called airfoil. Wing is a three dimensional component, while the airfoil is two dimensional section. Because of the airfoil section, two other outputs of the airfoil, and consequently the wing, are drag and pitching moment. The wing may have a constant or anon-constant cross-section across the wing. On the other hand, The Supermarine Spitfire aircraft used elliptical wing. And we select elliptical wing because furthermore studies of aerodynamics equation and Prandtl's lifting line equation about finite wing theory we realize that the elliptical wing has much higher aerodynamics efficiency than any other wing. On the other hand, as proceeding our experiment we fabricate model wing of F-22 raptor and also F7 BG wing to analyze the practical result of supersonic aircraft flight in nature. The wing may have a constant or anon-constant cross-section across the wing.

There are two ways for airfoil selection. They are:
1) Airfoil Design
2) Airfoil section

2.5 BOUNDARY CONDITIONS:

The Simulation was ran using these parameters and the wind tunnel testing as well. Fluid (Air) was assumed incompressible and the flow was taken laminar.

Fluid	: Air
Temperature	: 298.2 K
Pressure	: 101325 Pa
Air Velocity	: 4.7 m/s
Air Density	: 1.15 Kg/m^3
Surface Area	: 16074 mm^2 or 0.016074 m^2
Prototype Material	: Beech Wood (Gamahr)

3. RESULTS & DISCUSSION

3.1 *Lift to Drag Ratio:*

The higher value of L/D ratio which is known as the Aerodynamic Efficiency of a wing is the most desirable and preferable factor for any aircraft wing design. The value of Lift to Drag ratio can be increased either by increasing the value of lift or lift coefficient of corresponding wing or by decreasing the value of drag or drag coefficient of corresponding wing but in case of an aircraft design the lift directly depends on the weight of an aircraft and the drag depends upon the aerodynamic design of aircraft and its wings. For finding the almost accurate values of related wing and airfoil we done our project in ways. As we said earlier that one of these is theoretical analysis like using simulation software (SOLIDWORKS) and the other one is practical analysis which is WIND TUNNEL testing. All these project work were done by using above boundary conditions. [3]

Table 1: Aerodynamic Efficiency (L/D) of Wings and Airfoil (Experimental)

Angle of Attack	0^0	5^0	10^0	12^0	14^0	15^0
F 22 Raptor	0.70803	1.60959	2.19522	3.16901	3.40984	4.12067
F 7 BG	1.66667	2.84214	2.06914	2.49979	2.57322	2.30778
MIG-29	3.875	1.20082	0.4495	4.17407	3.91827	4.3295
Elliptical Wing	0.46630	0.70288	1.26667	1.35550	1.41004	1.38152
NACA 64A012 mod	0.333	0.531	1.333	1.925	1.8462	1.852
Dove Wing	0	0.45455	0.08325	0.78431	1.29032	1.17021
Fly's Wing	0.625	1.40513	1.8241	1.8889	2.41538	2.42857
Mosquito Wing	0.251	0.9048	1.62791	1.69231	1.4857	0.18904

Table 1: Aerodynamic Efficiency (L/D) of Wings and Airfoil (Experimental)

Angle of Attack	0^0	5^0	10^0	12^0	14^0	15^0
F 22 Raptor	0.785714	2.388429	3.503423	3.642534	2.173077	2.127596
F 7 BG	1.77646	3.36431	4.61833	2.99562	3.81207	1.583161
MIG-29	1.5307	3.408696	3.526379	3.322695	2.858612	2.394273
Elliptical Wing	0.10628	0.81961	2.40426	1.57557	1.17068	1.93805
NACA 64A012 mod	0	0.6	3.250	3.35714	2.6522	3.06604
Dove Wing	2.98569	0.77586	0.18665	0.72518	0.90625	1.77778
Fly's Wing	0.64912	0.254237	2.181818	3.170731	2.830189	1.384615
Mosquito Wing	0.3684	2.889	1.467	2.3509	0.20482	2.1

From the Table 1 and 2 values showing the different aerodynamic efficiency and various characteristics of those eight airfoil and wing. The project was done in 6 consecutive angle of attack that showing upper portion of the two tables. From the table we can see that the maximum of L/D is (for Experimental= 4.3295) which belong to model MIG 29 wing at 15^0 AOA (**A**ngle **O**f **A**ttack) & (for simulation= 3.526379) which also belongs to model MIG 29 wing at 10^0 AOA. As we see from the table 1 and 2 both experimental and simulation analysis model MIG 29 wing shows the better aerodynamic efficiency.

3.2 *Drag Coefficient:*

The drag force works in the converse direction of the moving object in a medium of a fluid. It not only opposes the motion of an object in a medium of fluid but also reduces its lift. The drag depends on the density of the fluid, velocity of flowing fluid or an object, compressibility and viscosity of flowing fluid or a fluid around a moving object and the size and shape of the object. The Coefficient of Drag is a dimensionless quantity, used to evaluate resistance of a moving object in a fluid. [3]
The Drag or co efficient of Drag is the dimensionless quantity, used to resistance moving object in a fluid.

$$C_d = \frac{D}{(^1/_2)\rho V^2 S}$$

Where, D is the Drag force (N), ρ is the density of fluid, V is the flow speed of fluid and S the area of wing.

Table 3: Drag forces of Different Wing and Airfoil at different AOA (Experimental)

Angle of Attack	0^0	5^0	10^0	12^0	14^0	15^0
F 22 Raptor	0.0028	0.03	0.041	0.044	0.05	0.06
F 7 BG	0.03	0.038	0.058	0.06	0.068	0.091
MIG-29	0.01	0.05	0.18	0.023	0.0255	0.03
Elliptical Wing	0.06	0.064	0.075	0.08	0.085	0.105
NACA 64A012 mod	0.09	0.001	0.0015	0.0012	0.0013	0.00135
Dove Wing	0.01	0.011	0.013	0.0153	0.0155	0.0188
Fly's Wing	0.0032	0.004	0.005	0.0054	0.0065	0.007
Mosquito Wing	0.004	0.0042	0.0043	0.0052	0.007	0.073

Table 4: Drag forces of Different Wing and Airfoil at different AOA (Simulation)

Angle of Attack	0^0	5^0	10^0	12^0	14^0	15^0
F 22 Raptor	0.00023	0.0248	0.0354	0.0361	0.0638	0.069
F 7 BG	0.03704	0.040674	0.0497	0.110331	0.08918	0.21639
MIG-29	0.00797	0.0115	0.02521	0.0282	0.0389	0.0454
Elliptical Wing	0.01242	0.0255	0.0235	0.0311	0.0457	0.0452
NACA 64A012 mod	0	0.0002	0.00012	0.00014	0.00023	0.000212
Dove Wing	0.001	0.0012	0.0015	0.00142	0.00197	0.00129
Fly's Wing	0.00057	0.00059	0.00055	0.00082	0.00053	0.0013
Mosquito Wing	0.00057	0.00045	0.00075	0.00057	0.0083	0.001

As we know that in aircraft movement of flying stability of insect and bird there are four basic force acting on those flying body. Where Lift force counter the weight of the body thrust force counter the drag forces of aircraft body. Proper equivalence of these four forces the aircraft gain stability and move forward. So, for finding the better one wing or airfoil we must concern about that it must have low drag coefficient with respect to much higher lift coefficient. From the table 3 and 4 we can see that the minimum drag is (for Experimental= 0.001) which belong to NACA 64A012 mod airfoil at 5^0 AOA and (for Simulation= 0) which also belong to NACA 64A012 mod airfoil at 0^0 AOA. In this drag forces analysis the model wing of NACA 64A012 mod airfoil showing good wing design performance.

3.3 *Lift Coefficient:*

Lift is a mechanical aerodynamic force that is generated by a solid object passing through a fluid and this force opposes the weight of flying object and hold it in the air. It is a vector quantity and it acts through the center of pressure of the flying object. The lift is generated by the difference in velocity of flying object and fluid, around that flying object. It takes no difference whether the object is passing through the fluid or the fluid is flowing over an object. [3]

Lift force is also a non-dimensional force. Coefficient of Lift is known as C_L

$$C_L = \frac{L}{(^1/_2)\rho V^2 A}$$

Where, L is the Lift force (N), ρ is the density of fluid, V is the flow speed of fluid and S the area of wing.

Table 5: Lift forces of Different Wing and Airfoil at different AOA (Experimental)

Angle of Attack	0^0	5^0	10^0	12^0	14^0	15^0
F 22 Raptor	0.002	0.048	0.09	0.138	0.17	0.18
F 7 BG	0.05	0.108	0.12	0.15	0.175	0.21
MIG-29	0.038	0.06	0.081	0.096	0.1	0.13
Elliptical Wing	0.028	0.045	0.095	0.11	0.12	0.145
NACA 64A012 mod	0.03	0.00531	0.002	0.00231	0.0024	0.0025
Dove Wing	0	0.005	0.0011	0.012	0.02	0.022
Fly's Wing	0.002	0.0056	0.0091	0.0102	0.0157	0.017
Mosquito Wing	0.001	0.0038	0.07	0.088	0.0104	0.0138

Table 6: Lift forces of Different Wing and Airfoil at different AOA (Simulation)

Angle of Attack	0^0	5^0	10^0	12^0	14^0	15^0
F 22 Raptor	0.00018	0.0592	0.1244	0.1315	0.1386	0.1465
F 7 BG	0.0658	0.13684	0.229531	0.33051	0.33996	0.34258
MIG-29	0.0122	0.0392	0.0889	0.0937	0.1112	0.1087
Elliptical Wing	0.00132	0.0209	0.0565	0.049	0.0535	0.0876
NACA 64A012 mod	0	0.00012	0.00039	0.00047	0.00061	0.00065
Dove Wing	0.003	0.00092	0.00028	0.00103	0.00179	0.0023
Fly's Wing	0.00037	0.00015	0.0012	0.0026	0.0015	0.0018
Mosquito Wing	0.00021	0.0013	0.0011	0.00134	0.0017	0.0021

As we mentioned earlier the basic four forces of an aircraft or flying body. But the lift is the most important and useful force of wing or airfoil and while designing of an efficient wing maximum lift is the prime factor to considered. A better wing or airfoil should have maximum or moderate lift generating capability. From the table 5 and 6 we can see that the maximum lift is (for experimental= 0.18) which belong to model F22 raptor wing at 15^0 AOA and (for Simulation= 0.34258) which belong to F7 BG model wing at 15^0 AOA. Finding different wing max lift criteria may be bemused us. As we see the table, both of those wing are showing better lift criteria at different AOA.

3.4 *Theoretical lift force comparison*:

Aerodynamic forces result from the pressure distribution over the surface. One useful way to evaluate the aerodynamic forces is to use pressure taps to record the distribution and to integrate the distribution to find the net force. For lift this integration is concerned with the pressure distribution in the vertical direction, while for drag the horizontal pressure distribution is important. We can see from the tapping point of the wing surface that how the surface "pushes back" with a force against the pressure, which always acts normal to the surface.[4] Surface curvature is important two mechanisms are used to generate Lift. The first is an asymmetric profile (about the chord – defined in previous slide). This is often used for subsonic flight applications. The second is to incline the airfoil at an angle relative to horizontal, which is usually the "relative wind angle". For low values of this angle (angle of attack) the flow remains attached on both surfaces. For higher angles of attack separation occurs that increases drag and reduces lift. Eventually, the airfoil (and vehicle!) reaches a stall condition, where the pressure distribution on the top and bottom are equal.[5] As we proceeding our project work firstly we calculate the experimental value that we get from wind tunnel manometric pressure reading at different angle of attack 0^0, 5^0, 10^0, 12^0, 14^0, 15^0 respectively. By integrating the corresponding upper and lower pressure difference finally we aggregated the specific theoretical lift for those wing or airfoil.

Table 7: Different Theoretical of Different Wing and Airfoil

Model Wing Name	Theoretical Lift Force (N)
F 22 Raptor	0.02245
F 7 BG	0.0795
MIG-29	0.062
Elliptical Wing	0.0165
NACA 64A012 mod	0.061
Dove Wing	0.012
Fly's Wing	0.017
Mosquito Wing	0.005

From the above table we can see that F 7 BG has the maximum theoretical lift (0.0765 N/m^2) and relative worse wing performance is given by the model mosquito wing (0.005 N/m^2).

4. CONCLUSION

Wing is the part and parcel of aircraft flying. More accurate shape and size of airfoil more stable in flying and clearly showing aerodynamic characteristics. Without wing an aircraft is nothing but a piece of metal. Wing is the main part of an aircraft that create lift with which those aircraft fly in air. Also stability of aircraft this wing portion can play an important role to maintain this. How long the aircraft will be and how much load an aircraft can carry that is only depends on the wing shape and size. This is why different aircraft has different wing shape according to their purpose. We used eight different wing and airfoil. Three of those wing F-22 raptor, F-7 BG & MIG 29 except Supermarine Spitfire aircraft the other three aircraft are supersonic 4^{th} generation combat aircraft and Spitfire is the sonic combat aircraft used World War II. We also know that Fly's has great ability to fastest flight and Dove has more stable, steady flight and sharp maneuverity during flying. Our project work is to analyze those characteristics wing and airfoil's lift force, drag force and aerodynamic characteristics during flight. From the theoretical and practical analysis we found out that the supersonic combat aircraft wing like M=model wing of F22 raptor. MIG 29, F7 BG and NACA 64A012 mod airfoil showed better aerodynamic characteristics during higher **AOA** (Angle of Attack). On the other hand, the left model wing that showed different results but not as expected. Our project work is based on some practical theory which may vary in practical wing experiment. Since some error may found out because of shape error of wing design and tapping pressure leakage and backlash error of wind tunnel.

5. REFERENCES

[1] howthinsfly.si.edu/aerodynamics
[2] http://en.wikipedia.org/wiki/Aeodynamic_force
[3] An aerodynamic comparative analysis of airfoils for low speed aircrafts/ Sumit Sharma
[4] naca.central.cranfield.ac.uk/reports/arc/r/2884.pdf
[5] www.dtic.mil/dtic/tr/fulltext/u2/b805722.pdf