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**Research paper**

# Design of Fixed Wing Unmanned Aerial Vehicle based on Magnificent Frigatebird

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**Abstract**

The Magnificent Frigate Bird has been investigated extensively in the past because of its extraordinary flying capabilities. In this technical paper an effort has made to present a model of a soaring UAV (Unmanned Aerial Vehicle) based on the bird and we end the process by validating our model through CFD analysis of the model on ANSYS FLUENT. Solid-works 2016 was used to model the UAV, Wingspan of the UAV was kept 2.39 m with an Aspect Ratio of 11.6 and fuselage of 1.1m having comfortable cavity for avionics. (Navier Stokes equation) and Energy equation is used to analyze mathematical model of UAV, It is important to note that embracing the nature is how we should proceed even in scientific ways.

***Keywords***: *Frigate, Magnificent, Soaring, (Unmanned Aerial Vehicle) UAV, Modeling, CFD.*

## 1. Introduction

The magnificent frigate-bird is a large, lightly built seabird with brownish-black plumage, long narrow wings and a deeply forked tail. Most of its life is spent in the air, Frigate can stay a long continuously for months, All of these astounding facts about Frigate bird point towards its aerodynamic anatomy and preferred flight mode, Soaring It has astounding flying capabilities and weird living habits which contributes to its body shape. It occurs over tropical and subtropical water of America, between northern Mexico and Ecuador on the Pacific coast and between Florida and southern Brazil along the Atlantic coast. Frigate Bird has been inspected for a long time by Ornithologists and extensive research has been done on its aerodynamic body and flight modes. Frigate spends most of its life airborne. They even hunt their prey while in flight. In a recent survey, frigatebirds were found to stay along for over 2 months without rest. They covered over 55000 km in 185 days with only 4 days of rest. Frigate birds preferred flight mode is soaring. Soaring describes the use of thermal convective flow in the earth's atmosphere as an ascending mechanism. By flying a spiraling circular path within these columns of rising air, birds are able to ride the air currents and climb to higher altitudes while expending very little energy in theprocess.

The wings of Frigate birds have a remark- able shape and size. While soaring, the torso of the bird is suspended between the wings, lowering the center of gravity. High quality data on aerodynamics can hardly be found. Few authors have investigated the specific aerodynamics, amongst others are (Pennycuick, 1983; Weimerskirch et al., 2003[1]; Cone, Akos et al. [7] base their work on data published by the aforementioned authors. Pennycuick) [1] notes that the birds can be observed using thermal soaring, gliding and flapping flight to cross distances. Pennycuick also provides morphological data which can be found in Table-1. Furthermore he notes the tremendous difference between frigate birds and other seabirds, which is probably due to the unique lifestyle these birds lead. Pennycuick compares the requirements of the frigate bird wings to the requirements of swing wings. These birds also spend most of their lives airborne. Pennycuick provides airspeed for different flight states (flapping-gliding, gliding, slope-soaring). Highest speed is achieved in flapping/flapping- gliding light with an average velocity of 9.3 m/s with a standard deviation of 1.96 m/s. Pure gliding yields speeds of 8:67 m/s +/- 3.27 m/s, where slope soaring is significantly slower with an average velocity of 6:22 m/s, 1:74 m/s. Pennycuick argues that the large wing area induces a low wing loading and therefore enables those birds to soar in narrow circles in open-water cumulus-thermals which are significantly smaller in diameter The Reynolds number for circling-soaring

**Table-1:** Body Measurements

| | |
|---|---|
| Mass (kg) | 1.51 |
| Span (meter) | 2.3m |
| Wing Area ($m^2$) | 0.41 |
| Wing Loading (N/m2) | 36.5 |
| Aspect Ratio | 12.9 |

is around 7.4 x 104, based upon the speed, the average chord length of 0.178 m and the kinematic viscosity of air at around 1.5 x 10-5 m2s-1[8],[9]. More recent work confirmed the soaring theories proposed by Pennycuick (whose observations have been based upon the work of Cone (e.g. Weimerskirch et al., [3] Akos et al.[7],.However, the frigate bird is an evolutionary extreme, since, together with the common swift apes, they are the only birds that stay airborne at night. This is due to the scarcity of food. The thermals in the caribbean are driven by the rise of warm air due to the cooling effects of trade winds. Since these thermals are weak, Fregata needed to adapt and therefore ended up with the lowest wing loading of all birds.

Their wing shape is quite unique and differs from other soaring birds; their wing tips are tapered, whilst other soaring birds such as storks show wings with lower aspect ratios and slotted wing tips. Due to their low wing loading, these birds are able to turn in very close circles, even though their wingspan is magnificent. As noted by Akos et al. [7], the soaring capabilities of birds may serve as role models for technical applications like UAVs (Unmanned Aerial Vehicles).

## 2 Airfoil Selection

Using XFOIL, analysis of two different airfoil was done. NACA 4412 was used by Aljoscha Sander [2] to display advantages of a wing based on Magnificent Frigate. But for soaring purposes, an under cambered Airfoil will be much better. In this study the Cambered airfoil is used as shown if Fig-1 for the analysis ie for finding the lift coefficient of the airfoil at different angles.

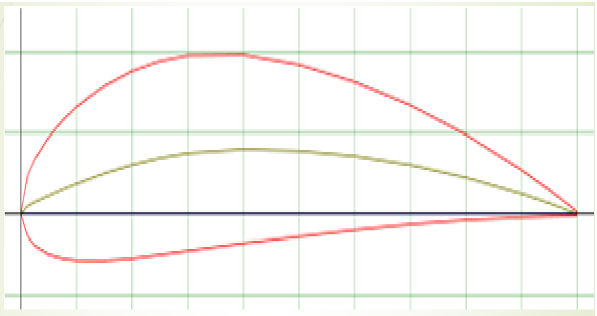

**Fig 1:** NACA 4412

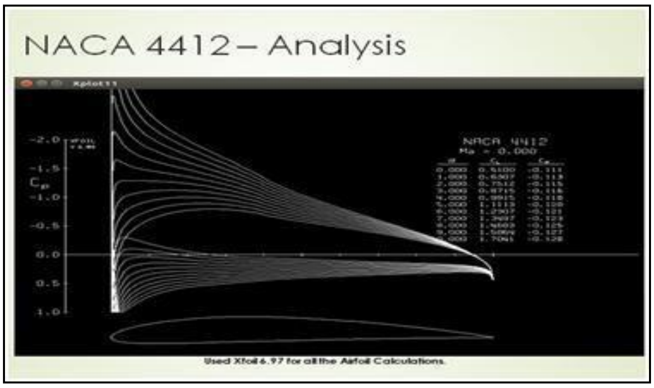


**Fig 2:** NACA 4412 Analysis

Fig-2 showed the analysis of NACA 4412 that provides a lift coefficient of 0.5100, 1.1113 and 1.7041 at angle of attack of 0o, 5o and 10o respectively.
When converted to wing, Lift coefficient will be much lesser than 1.6 (Frigate's CL). Hence, using NACA 4412 for imitating Frigate bird is discouraged.
Using X Foil, analysis of S1223RTL was carried out. Results found were motivating to carry the design process with S1223RTL

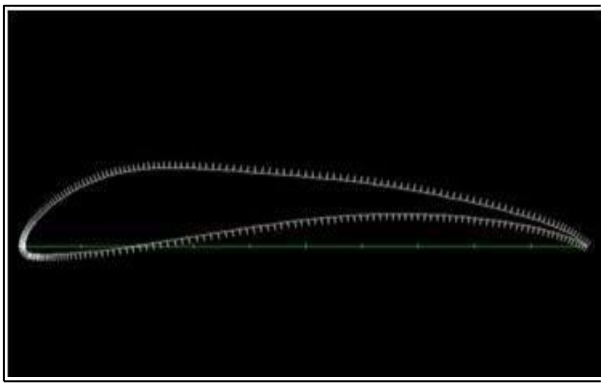

**Fig 3:** S1223 RTL Airfoil

It is an under cambered airfoil which produces high lift even at low Reynolds number at comfortable AOAs. S1223RTL provides lift coefficient of 1.5355, 2.1251 and 2.6896 at angle of attack of 0o, 5o and 10o respectively.

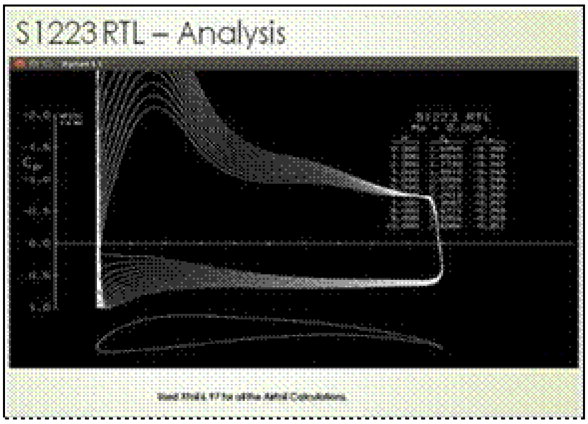


**Fig 4:** S1223RTL Analysis

## 3. UAV Modeling

Solid-works 2016 was used to model the UAV. Using the anatomy presented in Pennycuick 1983 papers and vastly available pictures of Magnificent Frigatebird, an appropriate imitated model was made. Wingspan of the UAV was kept 2.39m with an Aspect Ratio of 11.6 and fuselage of 1.1m having comfortable cavity for avionics

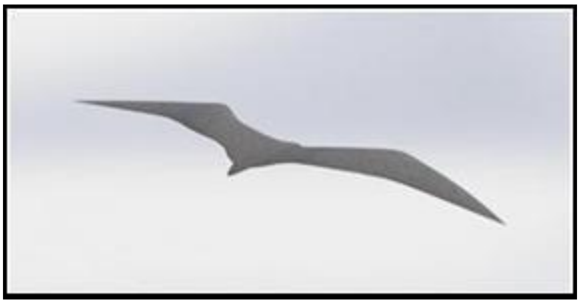

**Fig 5:** Isometric view of the rendered model

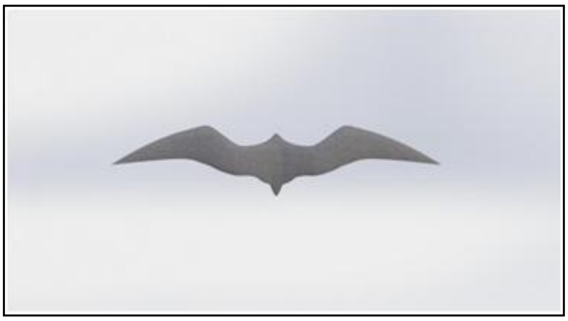

**Fig 6:** Top view of the rendered model

## 4. UAV CFD Analysis

Basiclly three equations we need to analysis computational fluid dynamics problem. They are continuity equation, momentum equation and energy balance equation. The fluid flow analyzed mathematically by using two equations. The first equation known as continuity Equation, needs the mass of fluid entering a fixed control volume either leaves that volume or accumulates within it. The other governing equation known as momentum Equation or also be known as Navier-Stokes Equation these all Equation can be given as following.

### 4.1 Continuity Equation

$$\int_{cs} \rho V dA + \frac{\partial \int_{cv} \rho dA}{\partial t} = 0$$

### 4.2. Momentum Equations

$$\rho \frac{\partial u}{\partial t} + \rho u \frac{\partial u}{\partial x} + \rho v \frac{\partial u}{\partial y} + \rho w \frac{\partial u}{\partial z} = \rho g_{x-} \frac{\partial p}{\partial x} + \mu \frac{\partial^2 u}{\partial x^2} + \mu \frac{\partial^2 u}{\partial y^2} + \mu \frac{\partial^2 u}{\partial z^2}$$

$$\rho \frac{\partial v}{\partial t} + \rho u \frac{\partial v}{\partial x} + \rho v \frac{\partial v}{\partial y} + \rho w \frac{\partial v}{\partial z} = \rho g_{y-} \frac{\partial p}{\partial y} + \mu \frac{\partial^2 v}{\partial x^2} + \mu \frac{\partial^2 v}{\partial y^2} + \mu \frac{\partial^2 v}{\partial z^2}$$

$$\rho \frac{\partial w}{\partial t} + \rho u \frac{\partial w}{\partial x} + \rho v \frac{\partial w}{\partial y} + \rho w \frac{\partial w}{\partial z} = \rho g_{z-} \frac{\partial p}{\partial z} + \mu \frac{\partial^2 w}{\partial x^2} + \mu \frac{\partial^2 w}{\partial y^2} + \mu \frac{\partial^2 w}{\partial z^2}$$

### 4.3.Energy Equation

$$\frac{\partial}{\partial t}\left(\rho e + \frac{1}{2}\rho v^2\right) + \frac{\partial}{\partial x}\left(\rho u e + \frac{1}{2}\rho u v^2\right) + \frac{\partial}{\partial y}\left(\rho v e + \frac{1}{2}\rho v v^2\right) + \frac{\partial}{\partial z}\left(\rho w e + \frac{1}{2}\rho w v^2\right)$$

$$= k(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}$$

$$-\left(u\frac{\partial p}{\partial x} + v\frac{\partial p}{\partial y} + w\frac{\partial p}{\partial z}\right) + \mu[u\frac{\partial^2 u}{\partial x^2} + \frac{\partial}{\partial x}\left(v\frac{\partial v}{\partial x} + w\frac{\partial w}{\partial x}\right) + v\frac{\partial^2 u}{\partial y^2} + \frac{\partial}{\partial y}\left(u\frac{\partial u}{\partial y} + w\frac{\partial w}{\partial y}\right) + w\frac{\partial^2 u}{\partial z^2} + \frac{\partial}{\partial z}\left(u\frac{\partial u}{\partial z} + w\frac{\partial y}{\partial z}\right) + 2\mu\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial u}{\partial y}\frac{\partial y}{\partial x} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial y}{\partial z}\frac{\partial w}{\partial y} + \frac{\partial^2 w}{\partial z^2} + \frac{\partial w}{\partial x}\frac{\partial u}{\partial z}\right] + \rho u g_x + \rho v g_y + \rho w g_z$$

ANSYS CFX is more powerful tool than CFD code. Incorporation with ANSYS platform offers greater bi-directional influences to all CAD systems, commanding geometry amendment and creation tools with ANSYS Design modeler, innovative meshing technologies in ANSYS meshing.

### 4.4. Mesh Forming

Fluent meshing has all the key technology requried to mesh geometry quickly: CAD import, hole and gap fixing, good-quality surface mesh creation and fast volume mesh creation. We made an unstructured mesh using the software. Analysis Outcomes
After CFD analysis we were able to justify our model to be at par for soaring purposes. We calculated the Lift and Drag Coefficients with Angle of Attacks of 0o, 5o, 10o, 15o, 20o.

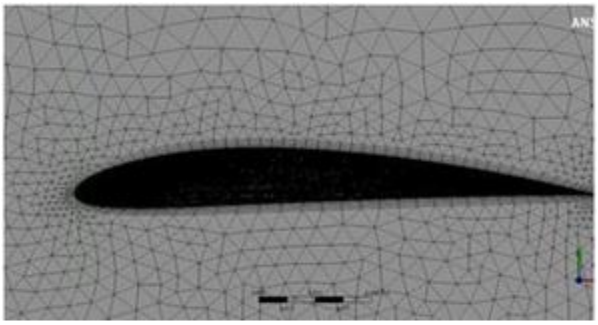

**Fig. 7:** Side View Mesh Formation

Results were found to be in cohesion with our initial thoughts about the wings. Lift Coefficient reached values of 1.55 at 60 AOA which is very high CL just like Pennycuick estimated for Frigatebird (1.6). This confirmed that going with S1223RTL to model the UAV was a good choice

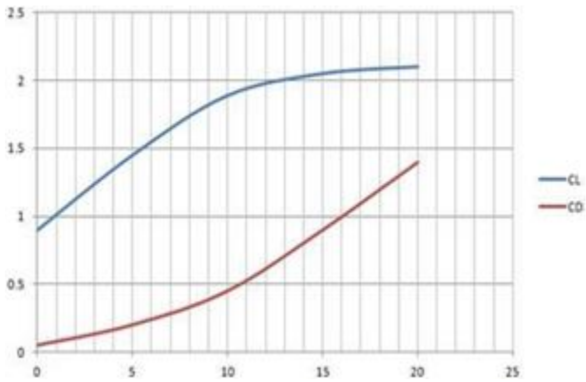


**Fig-8**: $C_L$ , $C_D$ Vs Alpha

## 5. Conclusion

We designed a UAV based on Pacific Bird Magnificent Frigate-bird. The modeled UAV, through Computational Fluid Analysis, proved to be a good choice for Soaring UAV. It is important to note that embracing the nature is how we should proceed even in scientific ways.
We propose Carbon Fiber for manufacturing the UAV as it is light and very durable. Since the design of UAV is challenging, it has to be modeled through CNC made dyes. This will give it a high quality finish as required for it.

## 6. Future Scope

The future endeavor of this research is it can be pursued for designing Ornitho copter based on Frigate-bird or any other birds demanding clear understanding of Mechanics. The Smart Bird Ornitho Copter based on this research is as shown in Fig-10

**Fig-10:** A Smart Bird Ornitho Copter

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