ICMIEE22-047

2D Simulation Analysis of Sailfish Inspired Fuselage Design

*Samira Tasnim**

Department of Mechanical Engineering, Khulna University of Engineering & Technology, Khulna-9203,
BANGLADESH

ABSTRACT

Biomimicry is a promising technology that mimics natural mechanisms to solve human design problems. Nature-inspired aerodynamic models have always been a part of Aerospace Engineering. The fuselage is a part of an aerodynamic vehicle that plays an important role in flight performance. A sailfish has specific structural features which make its swimming more efficient. According to the National Ocean Service, and the U.S. Department of Commerce, Sailfish is the fastest fish in the world. The target of the project is, to apply the sailfish structure to a modern aircraft model (taking Airbus320 neo as a reference), then to compare the drag coefficient and force of the designs, and finally, to find out the efficient model. 2D surfaces of the fuselage, sailfish, and the modified design were drawn in SpaceClaim and the simulations were done in ANSYS Fluent. The modifications and meshings of fuselages were done. Material properties, cell zone conditions, and boundary conditions were placed. Each design was simulated under the same pressure and velocity conditions. The results show the difference in drag coefficient and force between reference and modified designs. A flow with better smoothness was observed in the case of the modified designs. The model which had the minimum drag coefficient was a unique design of cross-section which was inspired by the sailfish structure. The main change was done around the nose region of the fuselage resulting in a higher reduction of 0.01291699 in drag coefficient with increasing speed. However, the speed was limited to 31 m/s.

Key Words: Biomimicry, Fuselage, Drag Coefficient, Drag Force, Fusion Design

1. Introduction

Biomimicry has given humanity a huge range of opportunities for research and development, from massive aircraft to tiny robots. There are many examples of models and designs that are naturally inspired, such as airplanes, velcro, the Shinkansen train, etc. Given that sailfishes are the fastest fish in the ocean, their properties are employed in a variety of ways, including reshaping hull construction and redesigning sails by imitating their fins. A renowned car company called McLaren used sailfish's special properties of scales to enhance the speed of the cars and launched a new model of the P1 Hybrid Supercar [1]. The fuselage is one of the most important components of an aircraft. Changes to its design may result in less drag on the aircraft, which will use less fuel for the same flight path and speed. And so, the fuselage design may be modified with the help of sailfish structures to find out whether it reduces the drag force or not. AWWA the Sky Whale designed by Oscar Viñals is a concept fuselage with modifications such that it will have a reduced drag because of its shape and curvature and will be called the future "green" plane of the 21st century [2].

The study of drag reduction with the help of hydrodynamic characteristics of sailfish under different conditions in cruise speed was done in a wind turbine [3]. But the result was not very satisfying. However, the studies indicated that the high-speed sailfish has some important characteristics which can be applied to reduce the drag coefficient of dynamic high-speed models. Later, the 3D analysis of the sailfish and fuselage (Airbus320 as reference) was done in ANSYS software where the sailfish-inspired model showed promising results [4]. But the 2D analysis of the sailfish-inspired fuselage was an unventured region where the relationship between the cross-sectional area and the drag coefficient was undefined. Also, there might be other successful models which can be proposed with the help of such studies.

2. Numerical setup

Usually, the dimensions of the sailfish are taken from the actual measurement of its body. Since the sailfish is only available in the Pacific oceans, the Atlantic coast, and the Indian oceans, the morphological data needed to create the 2D sailfish model for this project was collected from previous studies.

*Corresponding author. Tel.: +8801688139298
E-mail address: samira.kuet.me@gmail.com

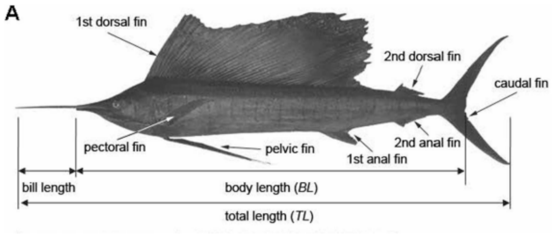

Figure.1 Morphological dimension of sailfish [3]

Table 1 Morphological Parameters (sailfish) [3].

Parameters (Morphological)	**Measurements (m)**
Length (total)	2.82
Length (body)	2.31
Length (bill)	0.3045
Width (max)	0.14
Height (max)	0.30
Position of maximum height (from the bill tip)	0.538

The 2D sketch and surface formation of the sailfish model was done in the ANSYS SpaceClaim 3D Modeling software, and the simulation was done in the ANSYS Fluent. As the analysis is based on fuselage design, the sailfish model will also be analyzed in the air medium. After finishing the sketching surface was added to it. Then the surface was opened in the DesignModeler section of the ANSYS software. For better understanding and comparison, the length of the sailfish was reduced by a factor of 17.32 resulting in a length of 0.1628 m which will also be used for the fuselage length. The dimensions were changed according to the factor. The fins were excluded for better comparison. The equations are written in the equations section.

2.1 Equations

Continuity Equation:

$$\frac{\partial \rho}{\partial t} + \partial\left(\frac{\rho u}{\partial x}\right) + \partial\left(\frac{\rho v}{\partial y}\right) + \partial\left(\frac{\rho w}{\partial z}\right) = 0 \tag{1}$$

Momentum Equation:

$$\partial\left(\frac{\rho u}{\partial t}\right) + \frac{\partial(\rho u^2)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} + \frac{\partial(\rho uw)}{\partial z} = -\frac{\partial p}{\partial x} + \frac{1}{Re_r}\left(\frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z}\right) \tag{2}$$

SST-K-ω Equations:

$$\frac{\partial}{\partial t}(\rho k u_i) + \frac{\partial}{\partial x_j}\left(\Gamma_k \frac{\partial k}{\partial x_j}\right) + \overline{G_k} - Y_k + S_k \tag{3}$$

$$\frac{\partial}{\partial}(\rho \omega) + \frac{\partial}{\partial x_i}(\rho \omega u_i) = \frac{\partial}{\partial x_j}\left(\Gamma_\omega \frac{\partial \omega}{\partial x_j}\right) + G_k - Y_\omega + D_\omega + S_\omega \tag{4}$$

K-ε Equation:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k + G_b + \rho\varepsilon - Y_M + S_k \tag{5}$$

$$\frac{\partial}{\partial t}(\rho \varepsilon) + \frac{\partial}{\partial x_i}(\rho \varepsilon u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}\left(G_k + C_{3\varepsilon}G_b\right) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} + S_\varepsilon \tag{6}$$

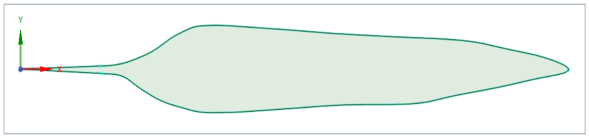

Figure.2 Surface of sailfish sketched in SpaceClaim

The sailfish surface was opened in the DesignModeler section where the environment around it was created with sketches. Then the surface from sketches option was selected. Hence, two surfaces were created. The Boolean option was selected where the sailfish surface was subtracted. Then, taking another sketch, the sailfish surface was divided into 6 sections for better meshing quality. After selecting lines from sketches, the projection was taken to generate the 6 sections. In the Mesh section, meshing was done by selecting the edges and entering the number of divisions with a bias factor. Mesh sizing and Face Meshing were done and inflation layers were used.

Table 2 Boundary conditions

Name	Type of Boundary	Boundary (Details)
Inlet	Velocity inlet	Turbulence: intensity 5% Magnitude: 8 m/s, 31 m/s
Symmetry	Symmetry	
Body	Wall	No slip, smooth wall
Outlet	Pressure outlet	Gauge Pressure normal to the boundary with intensity and viscosity ratio (turbulence methods)

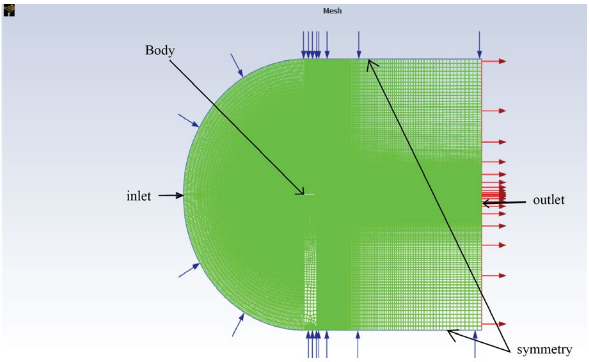

Figure.3 Numerical Setup

Then the mesh was generated. After the meshing, boundaries needed to be selected naming inlet, outlet, and sailfish boundaries. For setup, table 2 was followed to set the boundary conditions and in the general section, the pressure-based, steady calculation was selected for simplification. The Viscous-SST-K-omega model was selected. Air was selected for materials with its usual properties. In the inlet section of the boundary, the velocity component of 8 m/s was given for an angle of 6 degrees. From Reference values, the length of the sailfish was given as 0.1628 m. For getting the results, report definitions of drag force and drag coefficient were chosen. Hybrid initialization was selected for this simulation. Then the calculation was completed with 1000 iterations. Table 3 was followed for fuselage dimensions.

The simulation of the Airbus320 neo and modified designs were done in a similar manner with velocities of 8 and 31 m/s. The length of the fuselage was converted to 0.1628 m for simulations. The model lengths were the same in the length for better comparison. In the 8 m/s simulations, some of the cases contained a buffer layer (5< y plus < 30) non-dimensional distance to the wall. For that reason, the K-epsilon model was also used with scalable wall functions with which the errors could be minimized (mentioned in table 4). These hybrid concepts had a number of A320-neo features, including the tail and its location with the cockpit's top and bottom smooth curves. The nose portion underwent the majority of the modifications in the modified version of the fuselages.

The only change in length was of the model (b) from figure 5. The length was changed from 0.1628 m to 0.1699 m in order to extend the nose further with a similar curvature as the sailfish. In the third model, further, the nose was extended as much as in the reference sailfish sketch. A hybrid design that satisfied all the flow conditions in contrast to the A320-neo and demonstrated to be a better aerodynamic design was created after carefully evaluating the velocity and turbulence contour, CD, and drag force connected with the modified design.As the meshings were done with inflation layers, the y-plus value was calculated and modified as needed.

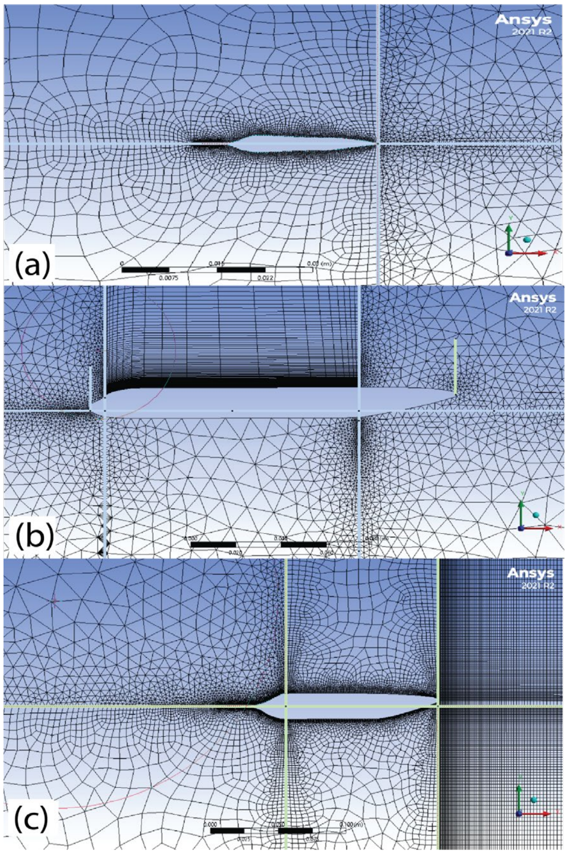

Figure.4 Meshing of the sailfish (a), fuselage (b), and modified design 3 (c)

Table 3 Dimension parameters of A320-neo[5].

Parameters	**Measurement in meters(m)**
Length (overall)	37.57
Length (cabin)	27.51
Height	11.76
Width (max cabin)	3.70
Width (fuselage)	3.95

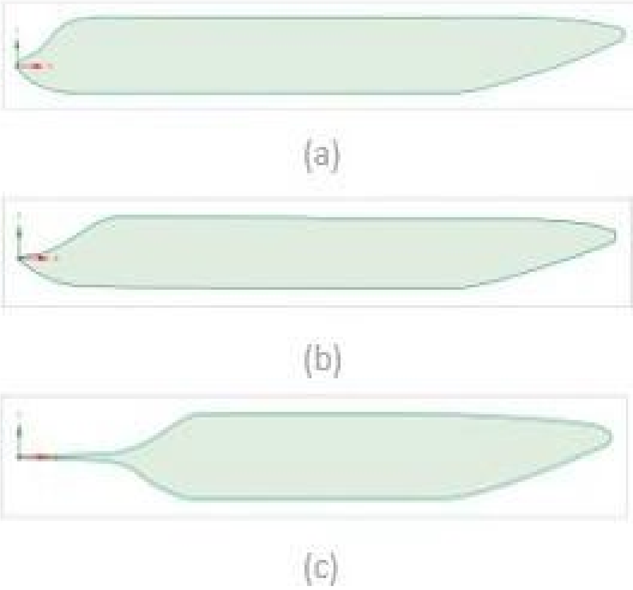

Figure.5 The modified designs of fuselage (a) Nose smoothed out, (b) Nose extended till the starting of the sailfish bill and (c) Nose replaced with the sailfish frontal bill. The results of these designs, (a), (b), and (c), varied depending on the extension of the nose length.

Table 4 The y plus values acquired.

	K-SST (8 m/s)	**K-epsilon (8 m/s)**	**K-SST (31 m/s)**	**K-epsilon (31 m/s)**
Sailfish	1.8735	–-	95.84846	–-
Fuselage	16.14301		95.94428	—
Design (a)	3.132454	—	<5	—
Design (b)	9.436056	<5	31.74366	—
Design (c)	3.03585	—	5.70291	<5

3. Result

The 2D model was examined in air at 31 m/s to understand the sailfish's aerodynamics at a higher speed. The drag coefficient of the sailfish gives a clear perception of the evidence of its low drag. For the 8 m/s simulations, the drag coefficient was 0.0092429536 and for 31 m/s it was 0.0084467958. The following data from table 5 shows the drag coefficients and forces for each model. The drag forces are computed in relation to their predetermined short lengths. The pace at which the study was completed, the reference size used for simulation, and the element sizes were the key differences between this study and the one before it. As neither the element size nor the number of nodes was specified, the number was first assumed with the aid of ANSYS Fluent, as shown in table 6, and the final result was discovered with the use of mesh independence. The change in drag coefficient and drag force are noticed in the hybrid models. In the 8 m/s study, models (a), (b), and (c) showed reduced drag coefficients and hence reduced drag force compared to the A320-neo fuselage model.

Table 5 The drag coefficient and drag force for different models.

Models (8 m/s)	**Drag Coefficient**	**Drag Force (N)**
A320 neo	0.029649873	0.18892685
Design (a)	0.028268771	0.18012656
Design (b)	0.027603509	0.1829101
Design (c)	0.0015560326	0.14910646
Models (31 m/s)	**Drag Coefficient**	**Drag Force (N)**
A320 neo	0.31937429	2.0350299
Design (a)	0.34490504	2.1977099
Design (b)	0.33836577	2.2421251
Design (c)	0.013297298	1.2742105

However, at a higher speed (31 m/s), the fuselage contained less drag coefficient and force than the modified design (a) and (b). The modified design (c) contained the lowest drag coefficient and force among all the other models. For modified design (a): For 0.1628 m, the nose was extended with a length of 7 mm. The upper bump was smoothed with a curve. For modified design (b): The nose was extended 0.0123 m and the upper curvature starting from the nose was 0.0159 m. The lower curvature was smoothened. For modified design (c): The bill shaped nose with an angle of 2.24 degrees and a length of 0.0296 m was taken. The upper and lower curvature were smoothened. From the velocity contours, wake regions and flow separations were detected for the modified designs. Though the separation in models (b) and (c) started earlier than in model (a), the region of separation, or stagnation area, seemed to be less in the last two models. Hence, their drag elements were reduced.

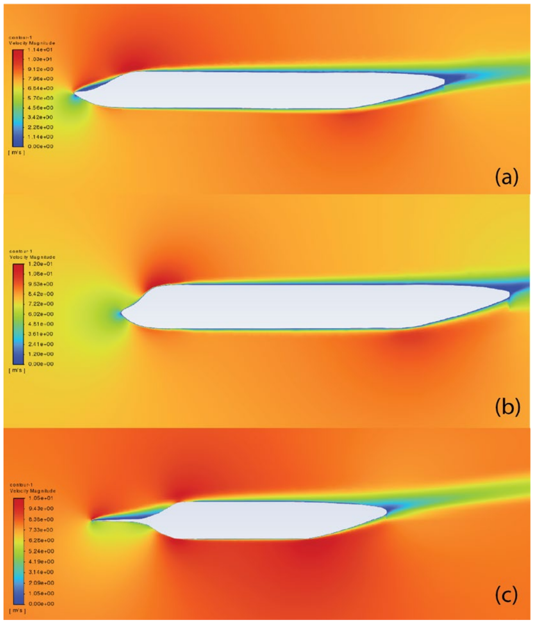

Figure.6: The velocity contours of the modified design (a), (b), and (c) sequentially

The turbulence contour of the modified designs showed maximum turbulence regions after the separation. As the frontal part was modified in each of the designs, the turbulence contour in each case differs in those regions. However, the final model encounters less turbulence in the trail region. The Mesh independency of the third modified design is shown in table 5.

The mesh independency test revealed that the second mesh sizing is the most efficient to determine the drag coefficient.

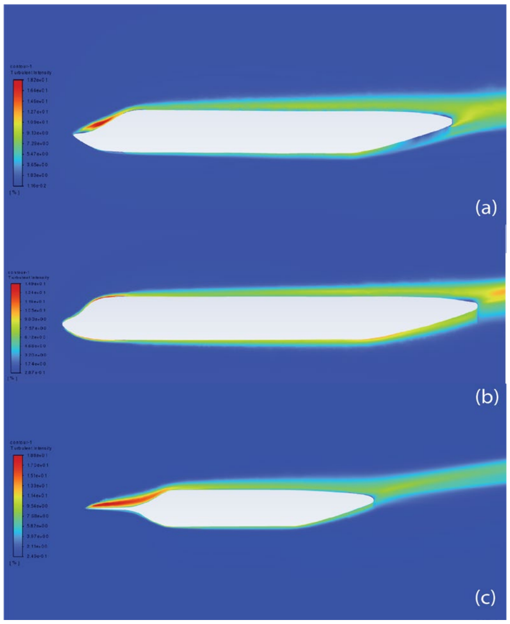

Figure.7: The turbulence contour of the modified designs (a), (b), and (c) sequentially

Table 6 The mesh independency of modified design (c) at 31 m/s

Element Size (m)	Nodes	Elements	Cd
0.1	83211	87353	0.01329729
0.07	84555	89337	0.01291699
0.03	90140	88467	0.01291699
0.01	141439	139470	0.01291699

4. Conclusion

The simulation guides to a very interesting result. The overall drag coefficient and force of model (c) (both in 8 and 31 m/s) was less than the reference Airbus 320 neo. The rest of the models' drag coefficient was higher than the reference fuselage model in the higher speed setup. The result indicates that the longer the length of the nose, the more reduction in the drag coefficient and force can be achieved. The reduction in the drag force was done successfully by 21% (for 8 m/s) and 37% (for 31 m/s) with the help of the final modified design. However, the 2D simulation results are not precise as three dimensional curvature, which plays a vital role in the drag coefficient reduction calculation. Moreover, the simulation was done at low velocities for incompressible flow analysis. The compressible flow mode could help the 2D analysis further. However, higher speed simulation should be done to extend the study of the fuselage with practical higher speeds. If engineers and builders pick up on this design approach in time, there is a good possibility of building a sustainable design to help the future planet by reducing carbon emissions in fuel usage. To conclude, sailfish properties are beneficial when applied to the models or designs. If those properties are studied well, modifications or extensions can be obtained which might be very effective.

5. References:

[1].https://www.bbc.com/future/article/20140828-how-afish-inspired-a-supercar (2022, October 6).
[2].http://www.tuvie.com/awwa-skywhale-concept-plane-by-oscar-vinals/ (2022, October 5).
[3] Sagong, W., Jeon, W., & Choi, H., Hydrodynamic Characteristics of the Sailfish (Istiophorus platypterus) and Swordfish (Xiphias gladius) in Gliding Postures at Their Cruise Speeds. *PLoS ONE*, 2013.
[4] Chhavi, C., & Selvakumaran, T., Adaptation of sailfish topology in fuselage design and performance comparison with the modern fuselage. *2018 IEEE Aerospace Conference*, 2018.
[5].https://aircraft.airbus.com/en/aircraft/a320-the-most-successful-aircraft-family-ever/a320neo (2022, August 31).

NOMENCLATURE

F: Drag Force, N
V: Velocity, m.s^{-1}
P: Pressure
ρ: Density, m^{3}
U: Free stream velocity, m$\cdot$s^{-1}
A: Area, m^{2}
C_d: Drag coefficient, dimensionless
Re: Reynolds number, dimensionless