A STUDY ON A NEW BIO-INSPIRED WING DESIGN AND 2D ANALYSIS OF ITS AERODYNAMIC CHARACTERISTICS

YENİ BİYOESİNLENMELİ KANAT TASARIMININ 2 BOYUTLU ANALİZİ VE AERODİNAMİK KARAKTERİSTİKLERİ ÜZERİNE BİR ÇALIŞMA

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Abstract

Airfoils which are designed to take advantage of aerodynamic forces, are standardized and widely used in air vehicles and turbomachinery. However, non-standard airfoil designs are also being investigated. These also include studies inspired by the wings of insects and birds and the tails of fish. This study is devoted to maple seeds which can be carried far away by the wind. Size ratios of the maple seed were obtained from the measurements taken on different seeds. Besides, the 3D model of a sample seed was transferred to a computer environment by means of a 3D scanner. A CFD study was performed to obtain aerodynamic characteristics of this model airfoil.

The two-dimensional airfoil formed by considering the mid-section of the 3D model was examined in the CFD study. The solution area was divided into hexa mesh, and inlet and outlet boundary conditions were defined. In the solution, Spalart Almaras and k-ε was used as a turbulence model. Also the k-omega turbulence model was used together with the standard wall function and SST. The mathematical and numerical models used in the solution were first applied to the standard NACA 0015 profile with known characteristics, and a validation study was performed. Then, the analysis of the new bio-inspired design was carried out. Analyzes were repeated at different Re numbers and attack angles. The results obtained in this study were compared and evaluated.

Keywords: airfoils, computational fluid dynamics, bio-inspired wing, biomimicry, aerodynamics, samara (maple seed).

1. Introduction

There is a new discipline called biomimicry that is followed by designer while being inspired by nature. The term biomimetic-bionic (biology and technique) was first proposed in 1960 by doctor and engineer Jack Steele, who was the initiator of learning, copying and imitating from biology [1]. Inventions made by nature inspired by our lives every day. There are designs inspired by many nature, from many home appliances to ships, from under the sea to Olympic stadiums. Maple seeds are also known as samaras in the literature. Bio-inspired wing profile has become one of the interesting aerodynamic research topics. Investigation of the wing profile of maple seed is beyond CFD (Computational Fluid Dynamics) application; Due to the autorotation (self-rotation) properties of the maple seeds, it provides new perspectives in the field of biomimicry. Different types of wing profiles are used for aerodynamic advantage in aircraft, wind turbines and various vehicles. NACA wing profiles, which are standard wing profiles created according to a certain system, are the most used wing profiles.

In addition to these wing profiles, there are wing profiles created by taking advantage of biomimicry science and inspired by nature. Başak and Demirhan create the tubercle wing profile, inspired by the fins of humpback whales; they tried to compare with the flat wing profile. As a result, they found that the efficiency at 100m/s velocity in tubercle wing profile increased up to approximately 42,09% compared to normal flat wing profile [2]. Holden et al (2015) made a wind turbine blade design project from maple seed in their study, they calculated in the CFD results that when the maple seed profile was tested on the wind turbine blade biomimetically, the C_P power factor increased up to a maximum of 0,59. They also compares C_L lift coefficient values, which are important in the wing profile design for values ranging between Re= 2000-20000 for different Reynolds values. They reached the value of C_L up to 0,8 for maximum Re=10000 [3]. Jeh designed the wind turbine blades biomimetically from the leaves of the tree type, known as Kapur tree, from the seeds of Dryobalanops aromatic tree, which is the type o tree grown in Malaysia. He used OPENFOAM, the coding program for CFD flow analysis. The C_P power factor calculated and the C_T thrust coefficient values analysis on this type of seed [4]. Islam et al experimentally tested the aerodynamic performance of the NACA0015 wing profile in the wind tunnel in the mechanical engineering department of KUET in Bangladesh at different attack angles. Attack angles range from 0 to 20 degrees; The free flow velocity in the wind tunnel was kept constant at 12m/s and $Re=1.89*10^5$. The pressure change measurement around the wing on the upper and lower surface was measured with a digital pressure manometer [5]. In their study in 2017, Li et al examined aerodynamic forces acting on the horizontally installed turbine blade with different Reynolds values for different turbulence densities [6]. In the wind tunnel tests they performed this year, Tanürün et al. worked experimentally and numerically by naming of AR1 and AR2 NACA0018 wing profile in different aspect ratios [7]. Erişen et al. obtained new wing section geometries with the changes made in NACA0012 and NACA4412 wing section geometries. They have studied the aerodynamic performance of these new wing profiles [8].

In this study, maples seeds were used to create a bionic wing. A preliminary study of the performance of the leaf surrounding the seed when used as a wing profile has been made. In the study, the aerodynamic performance of this seed was numerically examined. At the beginning of the study; Maple seeds of different varieties were collected from Bursa National park.

2. Research and Results

1. Geometry and Mesh Design

A. Geometry Design

Different varieties of maple seeds were collected to create the design. In general, two structurally different types of maple seeds have been observed in nature. This difference is due to the shape of the seed portion. The structure of one seed is more like a spherical structure while the other has a more flat structure. Two different types of maple seed can be seen in the Fig. 1.

Fig. 1. Different types of maple seed

When creating design of maple seed as a 3D, the maple seed was cut at certain intervals and the profile and dimensions of the maple seed were determined at certain intervals. When these profiles are examined, if we consider the maple seed as an airfoil, at the leaf section, an elliptical structure at the leading edge and a structure that linearly narrows towards the trailing edge is observed. The general structure of the maple seed consisting of these profiles is shown in the Fig.2.

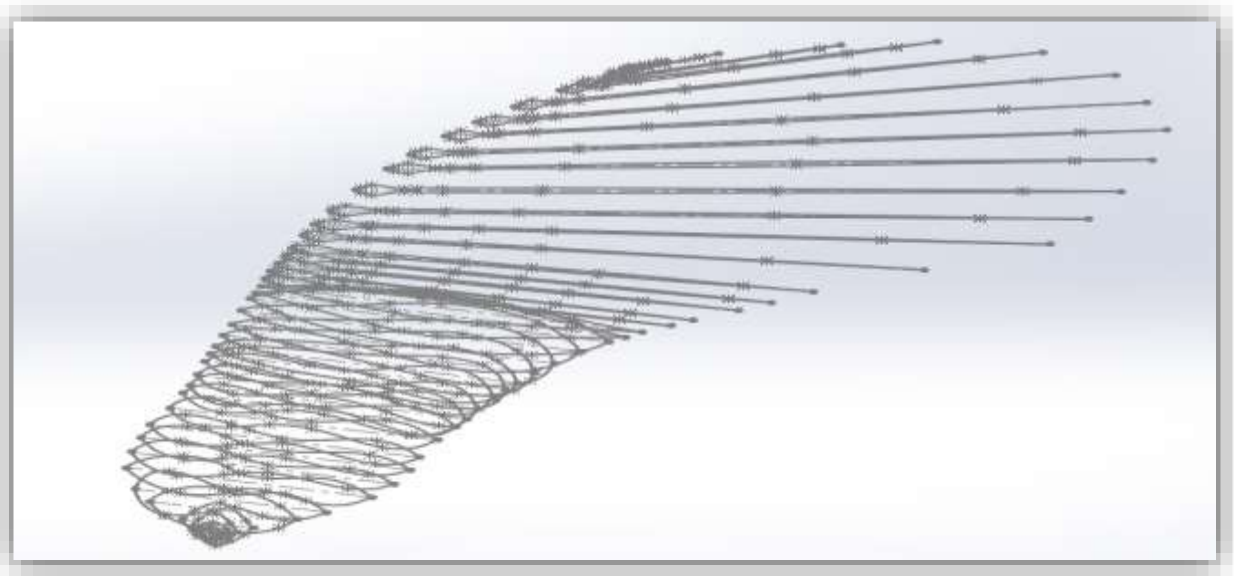


Fig. 2. General structure of the maple seed wit profiles

For analysis, a profile was selected from the leaf part of the maple seed. This profile is shown in the Fig.3 with dimensions.

Fig. 3. 2D profile that used in the analysis with dimensions. (Dimensions are mm).

A computational flow domain must be covered this maple seed airfoil profile. There are many flow domain types that used in numerical analysis. In this study, C type geometry was used as a flow domain. Because C type mesh structure allows to create less mesh. Also C type domain is more convenient to create a real flow area. Ansys fluent tutorials was used to determine the sizes of flow areas. Ansys fluent tutorials lectures suggest 10x chord length between air inlet and center of profile. Also it suggests 20x chord length between air outlet and center of airfoil profile (Fig. 4.).

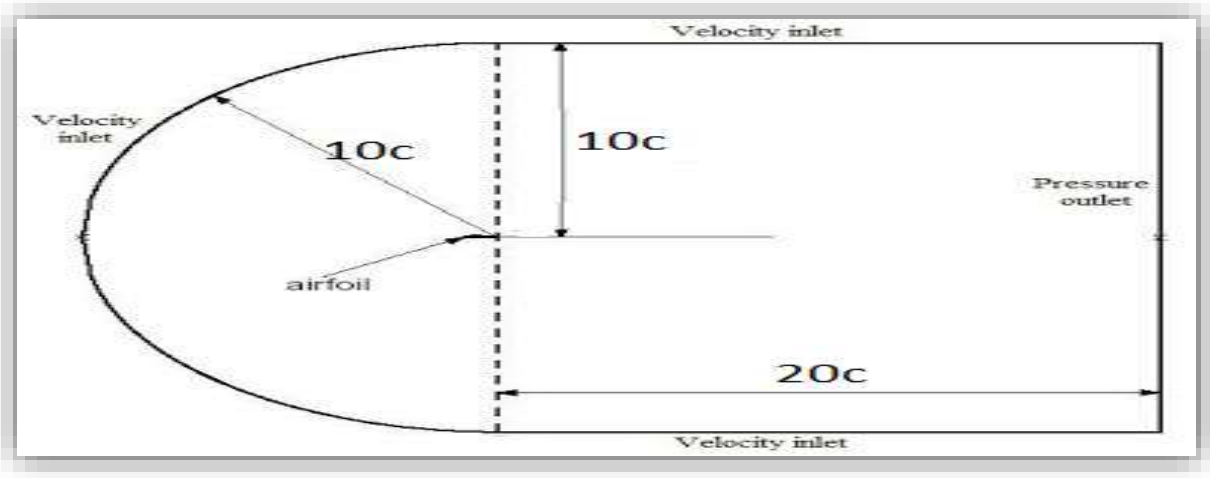


Fig. 4. Certain distances about the C type geometry.

B. Mesh Generation

Mesh generation was made on mesh module of Ansys program. The mesh around the airfoil profile was formed as thin as possible. This was done to keep the magnitude of Y-plus as small as possible. Because, in the ANSYS tutorials, the max. Y-plus magnitude should not exceed 1. The mesh structure created was shown in Fig. 5.

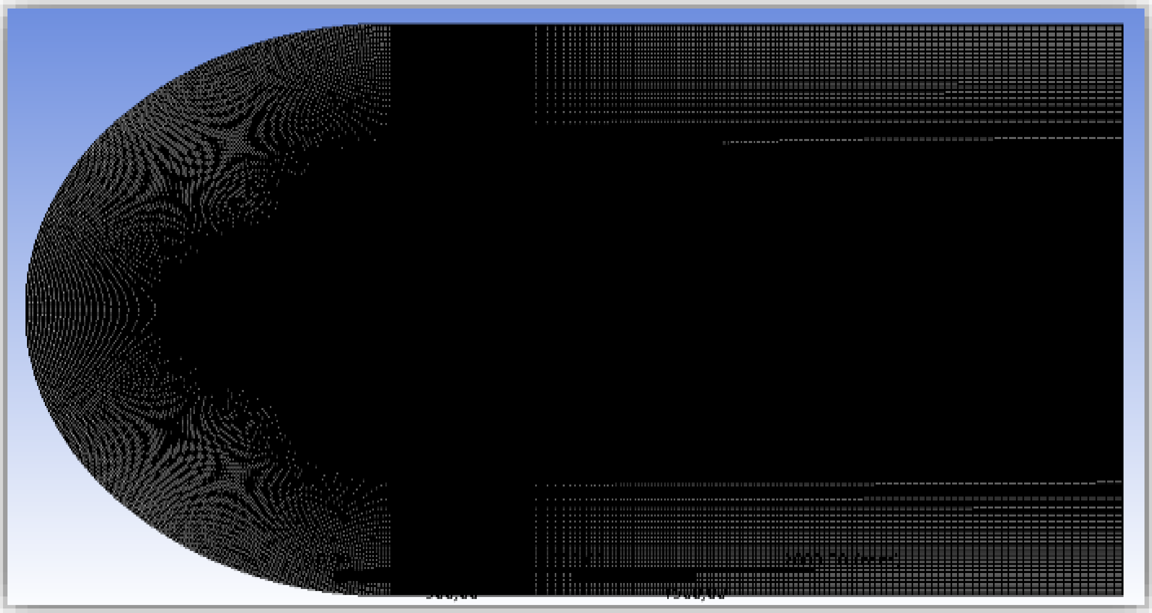


Fig. 5. The mesh structure of 2D Samara (maple seed).

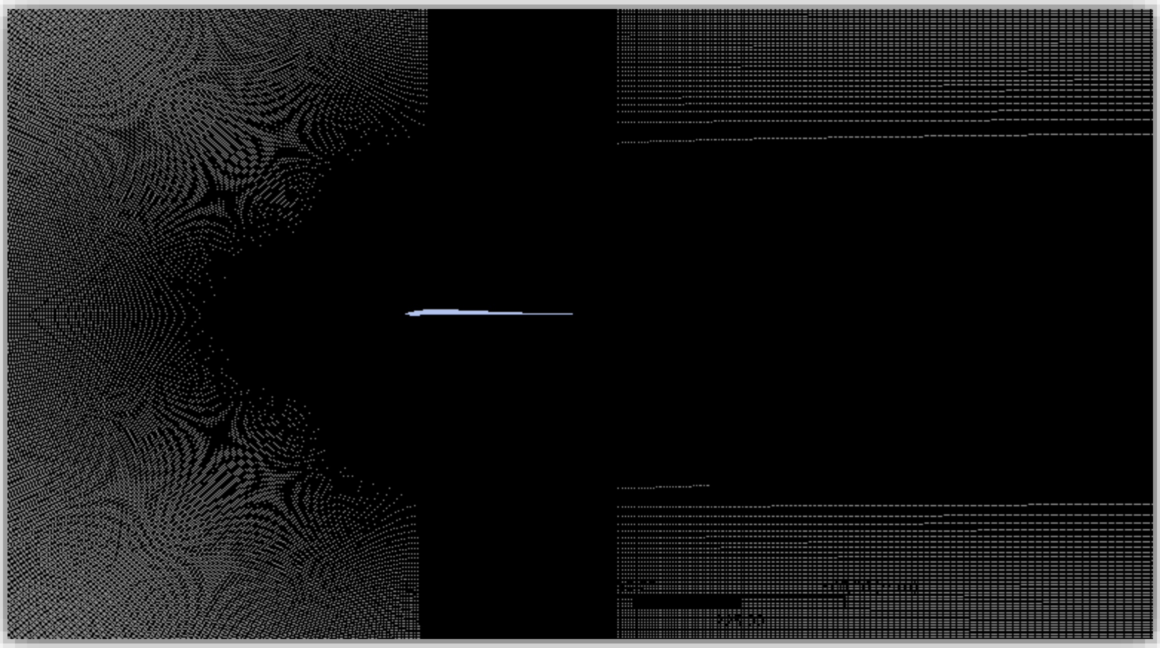


Fig. 6. Closer view of mesh structure.

Also, the dense, strong mesh structure formed around the airfoil is also shown in the Fig. 7.

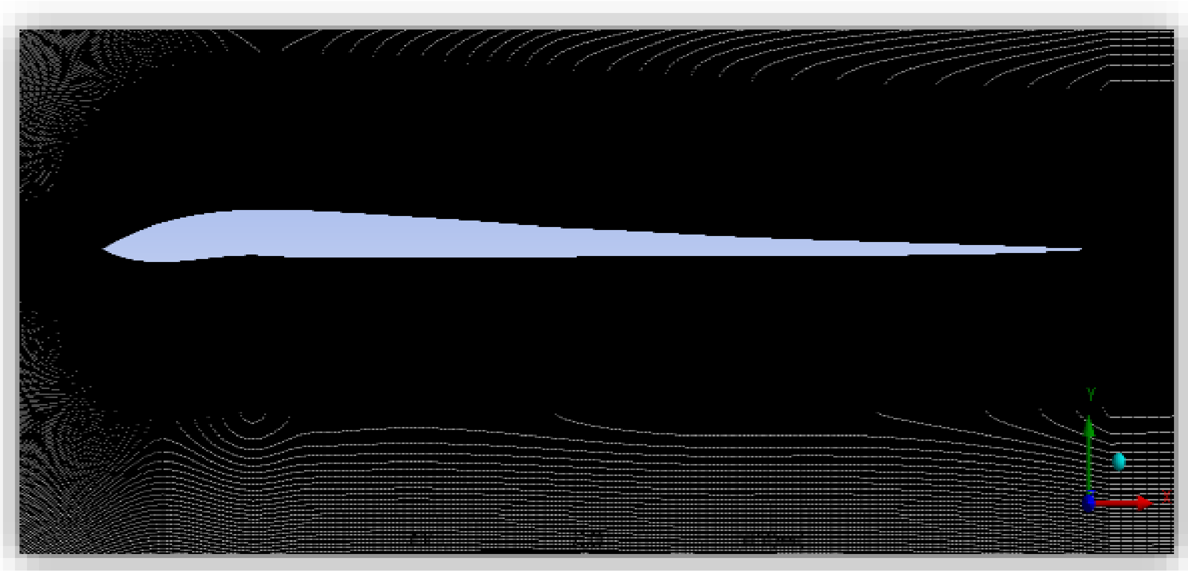


Fig. 7. The dense mesh structure formed around the airfoil (2D Maple Seed)

The flow domain is formed by quad mesh structure. This mesh structure's number of elements is 975000 and number of nodes 976800 (Fig. 8.).

Statistics	
Nodes	976800
Elements	975000
Mesh Metric	Aspect Ratio
Min	1,
Max	952,66
Average	23,173
Standard Deviation	68,236

Fig. 8. Some features of mesh structures.

2. Samara Wing Design Analysıs

For numerical analysis of maple seed 2D profile, ANSYS 16.2 fluent software was used. During the analysis, the effect of several parameters on the lift and drag coefficient of this airfoil was examined. For this, certain setups have been made on the program. For solution type, Pressure-Based and Steady Type have been used in the analysis.

The aerodynamic performance of maple seed was defined with lift coefficient C_L and drag coefficient C_D. These coefficients were calculated by numerical analysis.

Also analyzes were calculated in Re=10000 and Re= 40000 numbers, with an angle of attack ranging from= $3° \ to \ 30°$.

$$C_L = F_L/(0{,}5 * \rho * u^2 * A) \quad [1]$$

$$C_D = F_D/(0{,}5 * \rho * u^2 * A) \quad [2]$$

The turbulence model selected for the analysis is the k-ω (SST) turbulence model that gives good results for flow analysis over the wing. Other selected features of this turbulence model are as follows. Y-plus value for Re=40000 and $\alpha = 25°$, which id s critical configuration in terms of accuracy of mesh structure, is below 1 ($y \leq 1$) around the wing as seen on the down.

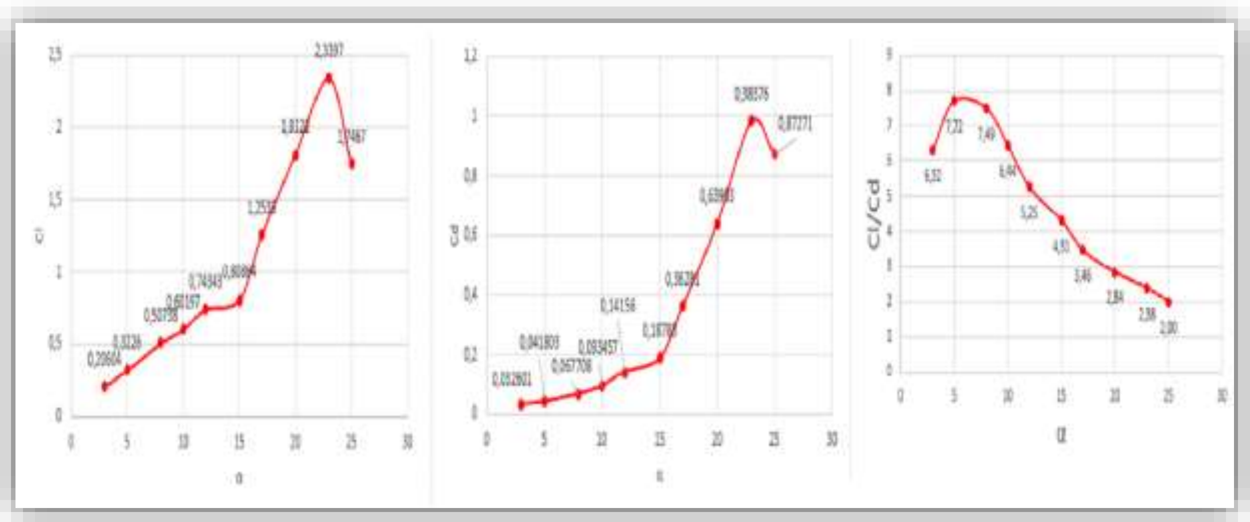
This shows that the turbulence model used gives correct results in accordance with the determined initial and boundary conditions.

3. Conclusion and Suggestions

Aerodynamic characteristics for different Reynolds numbers depending on the angle of the samara wing profile were investigated.

1. For Re=10000 2D Maple Seed Profile Analysis Results

A. Maple Seed Aerodynamic Coefficients at Re=10000 C_L and C_D values



Aerodynamic performance of 2D maple seed analysis in different attack angles varying $= 3° \; to \; 30°$.

Fig. 9. For Re=10000 maple seed performance C_L, C_D and C_L/C_D values at different angles of attack.

When the aerodynamically lift and drag coefficients for the stall point of maple seed are examined, it appears to be 23°. Lift coefficient is up to maximum 2,3397 and maximum drag coefficient value is 0,98376 at stall point of attack angle 23°. Also, when we accounted C_L/C_D ratios for maple seed, the maximum rate was achieved at 5 degrees.

The velocity distribution is analyzed for Re=10000, it is seen that the contours of the design and performance point show uniform distribution at the angle of attack degree 5º. As the attack angle increases, the velocity scale also increases. The velocity scale increases from 1.483 to 2.108 m/s when the attack angle increases from 5 to 25 degrees. Red and orange colors represent high velocity contours; green and blue colors represent low speed on maple seed surfaces. The red contours are dense at 5 degrees with also the highest rate of C_L and C_D At 25 degrees, it began to slide upward from the front surface of the wing.

The pressure distribution of maple seed for Re=10000 at 5 degrees attack angle red contours seen on the bottom surface of maple seed; this mean high pressure values occurance on the bottom surface approximately 1.096 Pa. But at the angle of attack 25 degrees reverse pressure occurance maple seed on the front surface, also this distribution seen as velocity contours.

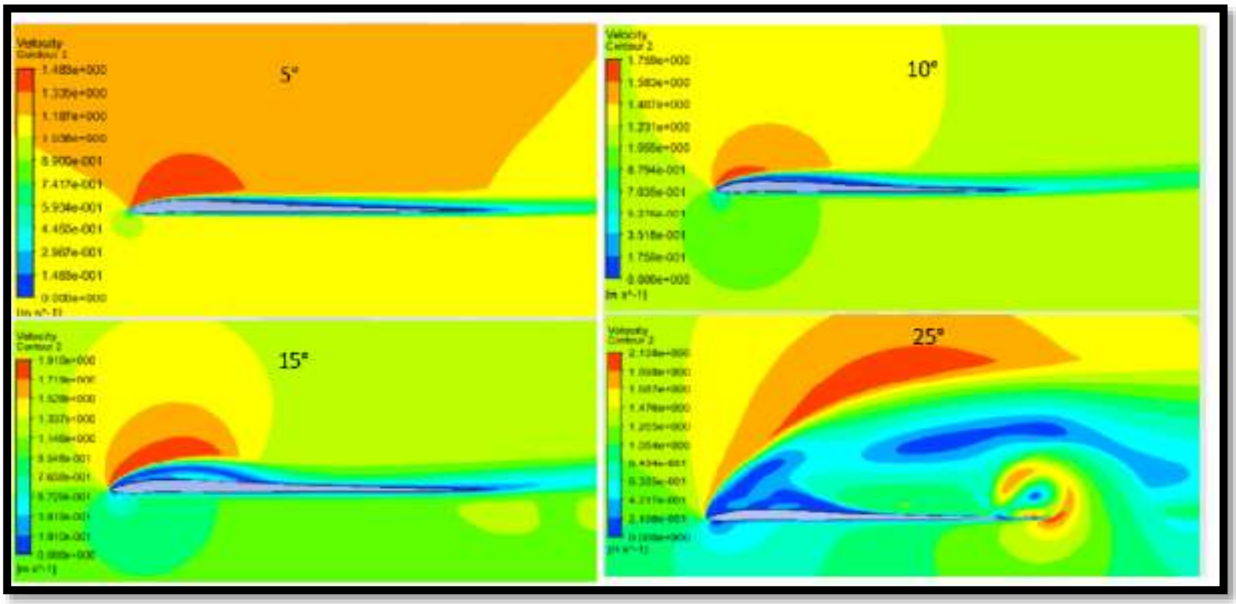


Fig. 10. Velocity distribution on maple seed (samara) for Re=10000.

Static pressure increases at the lower surface of maple seed wing design with increasing angle of attack while reversely velocity magnitude increases at the upper surface as depicted by contours of velocity magnitude in Figure 10 and contours of pressure in Figure 11 .

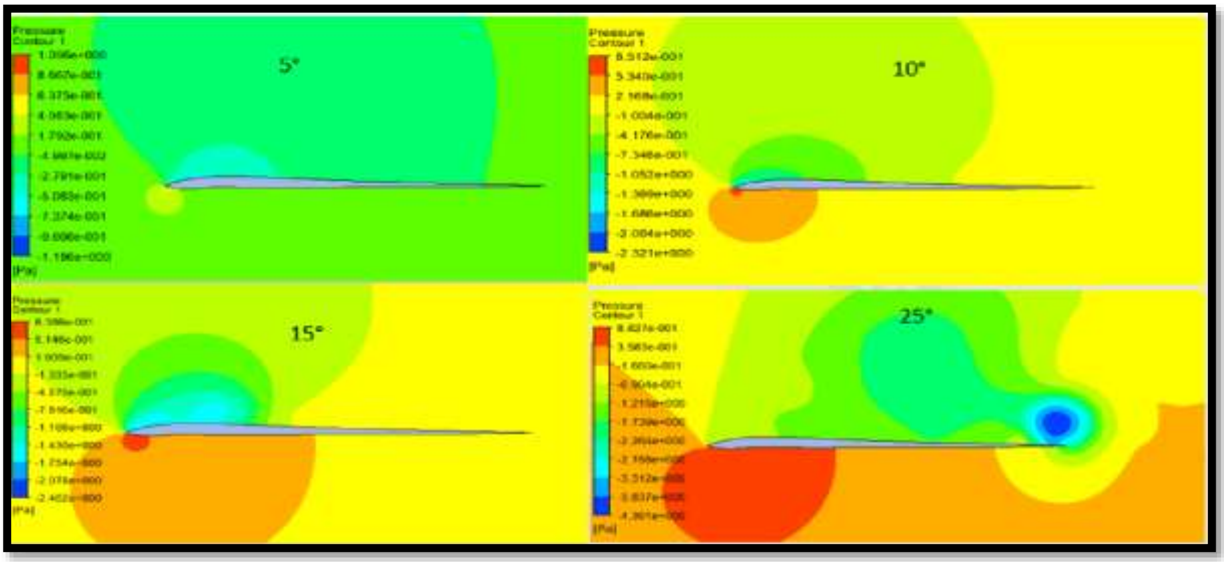


Fig. 11. Pressure distribution on maple seed (samara) for Re=10000.

2. 2D Maple Seed Profile Analysis Results For Re=40000

A. Maple Seed Aerodynamic Coefficients at Re=40000 C_L and C_D values

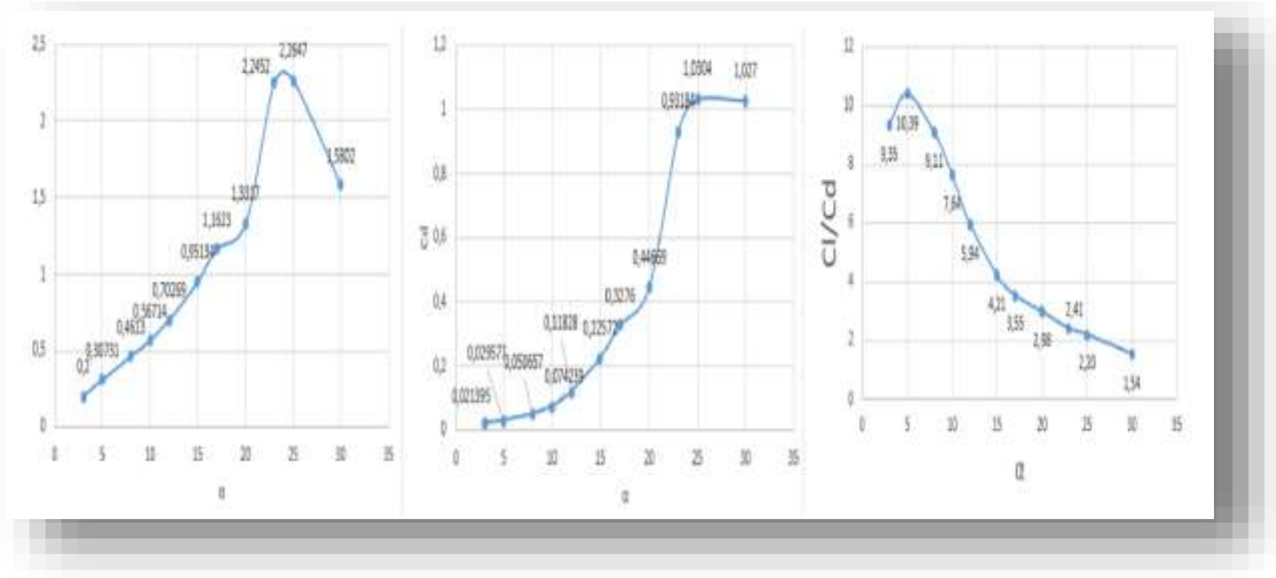


Fig. 12. For Re=40000 maple seed performance C_L, C_D and C_L/C_D values at different angles of attack.

For Re=40000 Maple seed aerodynamic characteristics are also investigated; The stall angle, which is the angle were C_L starts to decrease as α increases, is seen 25 degrees. This stall point C_L value is maximum reaching 2,2647. As expected, C_D showed a steady increase as the angle of attack increased. In these charts, max. CL/CD value; While Re=10000 was 7,8 but Re=40000 increasing with Reynolds number aerodynamic ratio also increase and this ratio was found to be 10,4 at 5 degrees.

The velocity contours are examined, the velocity was 1,483 m/s for Re=10000 started here with 6,056 and reached up maximum the velocity of 9,356 m/s at angle of attack 25 degrees.

Pressure distributions are similar to the distribution at Re=10000. Especially at 25 degrees reverse flow occurs at Re=40000. But if the part where the reverse flow is formed is examined there; it is formed on the bottom middle of the wing rather than at the behind of the wing surface as differently in Re=10000.

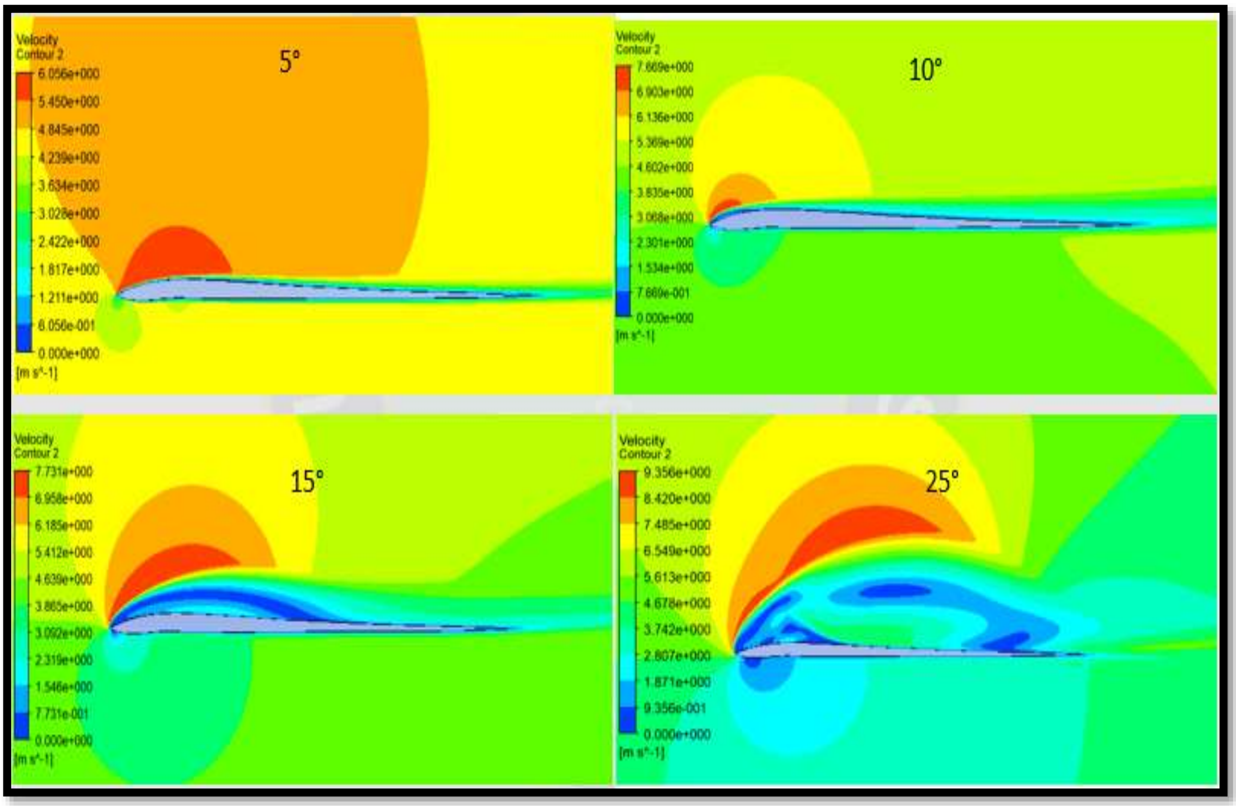


Fig. 13. Velocity distribution on maple seed (samara) for Re=40000.

As seen as Fig. 13 for Re=40000, at this point angle of attack degrees 25º is the stall angle for this regime. Laminar boundary becomes unstable at some distance from the leading edge and is unable to suppress disturbances imposed on it by surface roughness or fluctuations in the free stream. It is depicted from the figure 14 that, magnitude of pressure on the samara wing is more in lower surface than that of the incoming flow stream.

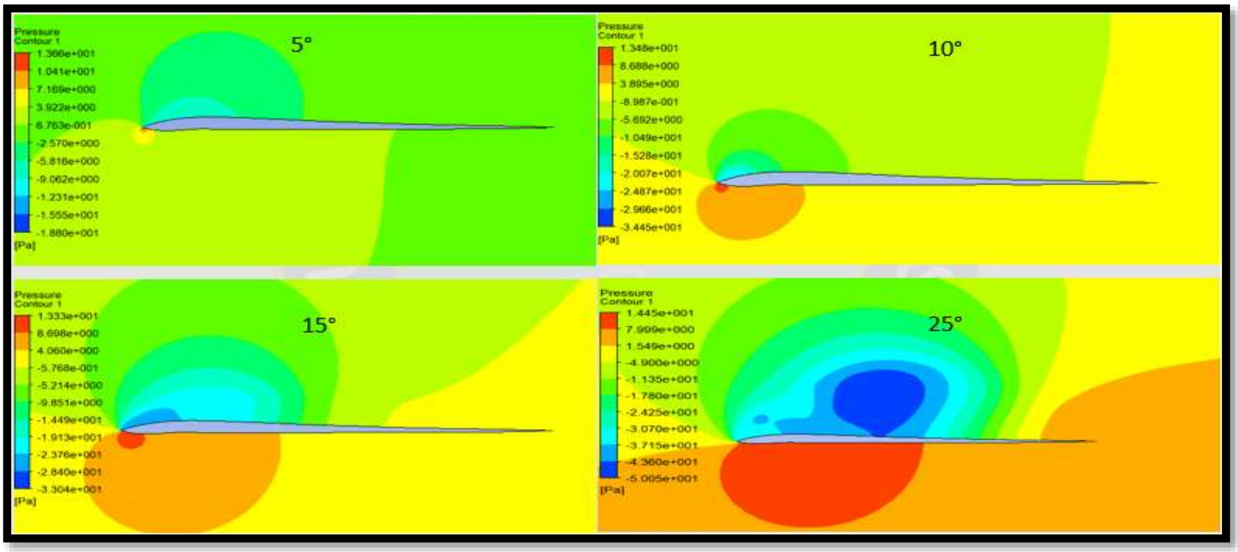


Fig. 14. Pressure distribution on maple seed (samara) for Re=40000.

References

[1] Bionics and Engineering: The Relevance of Biology to Engineering, presented at Society of Women Engineers Convention, Seattle, WA, 1983, Jill E. Steele.

[2] Başak H., Demirhan H., Investigation of Wing Profile Efficiency Inspired by Humpback Whale by CFD Analysis, Gazi Journal of Engineering Sciences 2017,3(2):15-20.

[3] Holden, Jacob & Caley, Thomas & Turner, Mark. (2015). Maple Seed Performance as a Wind Turbine. 10.2514/6.2015-1304.

[4] Chu YJ, A New Biomimicry Marine Current Turbine: Study of Hydrodynamic Performance and Wake Using Software OpenFoam, Journal of Hydrodynamics 28(1),125-141.

[5] Rubel, R. I., Uddin, M. K., Islam, M. Z., & Rokunuzzaman, M. D. (2016). Numerical and experimental investigation of aerodynamics characteristics of NACA 0015 aerofoil. International Journal of Engineering Technologies, 2(4), 132-141.

[6] Li Q., Kamada Y., Maeda T., Nishida Y., Experimental İnvestigations of Boundary Layer Impact on The Airfoil Aerodynamic Forces of Horizontal Axis Wind Turbine in Turbulent Inflows, Energy 135 (2017) 799-810

[7] Tanürün H. E., Ata İ., Canlı M. E. ve Acır A., “Farklı açıklık oranlarındaki NACA-0018 rüzgâr türbini kanat modeli performansının sayısal ve deneysel incelenmesi”, Politeknik Dergisi,2020.

[8] ERİŞEN, A., & BAKIRCI, M. (2014). Modifications of NACA 0012, NACA 4412 Airfoils And Analysis Them By CFD.Journal of Engineering and Technology Sciences , 2(1), 50-82.