Investigation of the effect of depth and shape on the aerodynamics of airfoil

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الملخص

يبحث هذا البحث في تأثيرات عمق وقطر وشكل الجناح (airfoil) على أدائه الديناميكي الهوائي. كان الهدف من هذه الدراسة هو اكتشاف التصميم المناسب للنقرات (dimples) لشكل (airfoil) تم اختياره من وكالة ناسا تحت رقم NACA 0012 والذي يقلل قوة السحب إلى الحد الأدنى مقارنة بالنموذج الأصلي بدون نقرات (dimples). تم إجراء العديد من التقييمات على الجناح (airfoil) مع وبدون النقرات (dimples)؛ تم استخدام برنامج جامبت (Gambit) لتصميم شكل الجناح (airfoil) . تم تصميم نموذجي الجناح (مع وبدون النقرات)، على برنامج Gambit أولاً ، ثم تم تحليلهما على برنامج فلونت Fluent وبعد ذلك تم جمع النتائج وتحليل العلاقة بين قوتي الرفع والسحب ومعامل والرفع ومعامل السحب. تم أيضًا جمع عدة أنواع من المتغيرات (ضغط السكون، متجهات السرعة، إلخ). أظهرت مقارنة النتائج أنه كلما زادت الزاوية الأعلى للهجوم، كلما زاد الرفع والسحب في حالة وجود نقرات. علاوة على ذلك، أظهرت النتائج أن هناك حاجة إلى تطبيق زوايا مختلفة للهجوم من أجل التمكن من إجراء دراسة أطول.

كلمات مفتاحية: Airfoil. NACA0012 ، تصميم نقرة ، قامبت ، فلونت ، قوى سحب ورفع.

Abstract

This paper investigates effects of depth, diameter and shape of airfoil on its aerodynamic performance. The goal of the study was to find out the right dimpled design of NACA 0012 that reduces the drag to the minimum compared to the original smoothed model. Several assessments have been conducted on airfoil with and without dimples; Gambit and Fluent disappeared software were used. The two airfoil models (with and without dimples), were assessed as Gambit first, then they were exported into Fluent. The fluent results were collected from lift, drag, lift coefficient and drag coefficient. Several types of graphics (static pressure, velocity vectors, etc) were also collected. Comparing the results showed that the higher angle of attacked incidence, the greater the lifted and drag. Moreover, results showed that different angles of attack would need be applied in order to be able to conduct a longer study.

Keywords: Airfoil. NACA0012, dimple design, Gambit, Fluent, drag and lift forces.

1 Introduction

Air flowing past an aero plane or any other body must be diverted from its original path, and such deflections lead to change in the speed of the air. Bernoulli's equation shows that the pressure exerted by the air on the aero plane is altered from that of the undisturbed stream. Also the viscosity of these processes, the aero plane experiences a resultant aerodynamic force and moment. The force and moments depend on the shape of the body and its orientation and its movement or rotation in relation to the stream [1].

The flight of an airplane, a bird, or any other object involves four forces that may be measured and compared: lift, drag, thrust, and weight. As can be seen in the figure below for straight and level flight "Fig. 1,", these four forces are distributed with the, [1] lift force pointing upward, weight pushing downward, thrust pointing forward in the direction of flight, and the drag force opposing the thrust. In order for the plane to fly, the lift force must be greater than or equal to the weight. The thrust force must be greater than or equal to the drag force .[2]

The dimple has the potential to reduce the drag compared to the smooth airfoil. This fact has a very important impact on the economical and environmental field as an aircraft, a car or a train will burn less fuel if their drag is reduced.

Indeed, the environment is a very important issue in this time and all the ways to take care of this in the industry are used. The dimple is a very simple way but very efficient to reduce the drag and then to protect the environment. The two basic forces that act on a powered aircraft are thrust, weight, lift and drag, but this investigation is only going to be cantered in lift and drag.

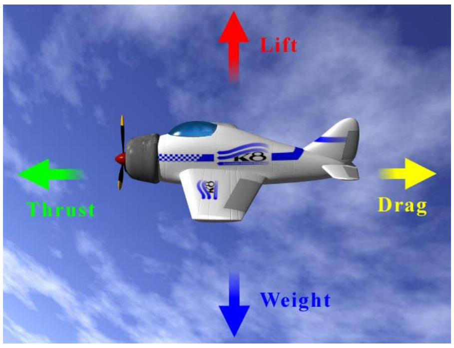

Figure 1. Direction of Forces in Straight and Level Flight. [6]

Lift and drag, are forces due to the motion of the vehicle through the air. Lift is defined as the aerodynamic force acting perpendicular to the airflow and drag is defined as the aerodynamic force acting parallel to the relative airflow. Lift is positive upwards and drag is positive rearwards. The main force, that the aircraft has to win, is the drag, since; this is the resistance or force that opposes the motion of the airfoil through the air. Reducing the drag, it can be obtained improvements in the top speed and acceleration.

2 Drag force.

Any physical body being propelled through the air has drag associated with it. In aerodynamics, drag is defined as the force that opposes forward motion through the atmosphere and is parallel to the direction of the free-stream velocity of the airflow. Drag must be overcome by thrust in order to achieve forward motion "Fig. 2,".

All of these types of drag must be accounted for when determining drag for subsonic flight. The total drag is the sum of parasite and induced drag.

Total Drag = Parasite Drag + Induced Drag

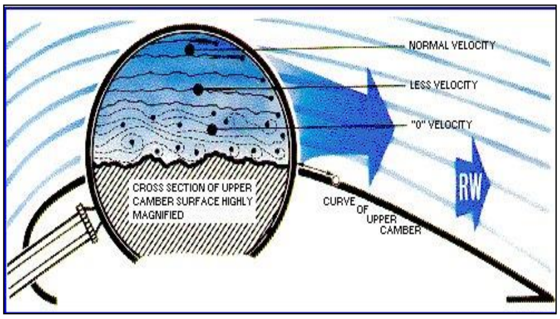

Figure 2. Friction drag

Lift and drag vary directly with the density of the air. As air density increases, lift and drag increase and as air density decreases, lift and drag decrease. Thus, both lift and drag will decrease at higher altitudes [3].

The equation (1) used to calculate drag is:

$$D = {}^{1}/_{2}\ \rho V^2 A C_D \qquad (1)$$

Where:

ρ −The density of the air
V − Velocity of the air (air speed)
A − Surface area of the aircraft
C_D − Coefficient of drag.

3 Lift Force

The most important, and usually the single largest, component of force acting on an aircraft in flight is the left, which helped the aircraft maintain its altitude against the pull of gravity and determines its rate of ascent or descent

The lift force L acting on an aircraft in flight is expressed in the form of the following simple equation (2):

$$L = C_L \times \rho \times {}^{V^2}/_{2} \times A \qquad (2)$$

Where :

ρ − The density of the air
V − Velocity of the air (air speed)
A − Surface area of the aircraft
C_L − Lift Coefficient.

4 Boundary Layer

In physics and fluid mechanics, a boundary layer is that layer of fluid in the immediate vicinity of a bounding surface. In the Earth's atmosphere, the planetary boundary layer is the air layer near the ground affected by diurnal heat, moisture or momentum transfer to or from the surface. "Fig. 3,"On an aircraft wing the boundary layer is the part of the flow close to the wing. The boundary layer effect occurs at the field region in which all changes occur in the flow pattern. The boundary layer distorts surrounding no viscous flow. It is a phenomenon of viscous forces. This effect is related to the Reynolds number.

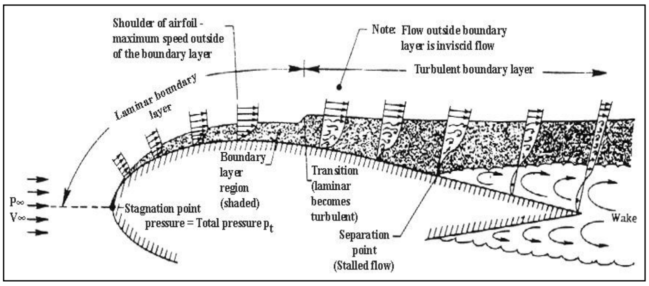

Figure 3 Real fluid about an airfoil [3].

5 The Effect of The Dimples On A Golf Ball

As it has been commented before, for this investigation the golf ball is going to be studied to observe the effect of dimples.

Before the purpose of dimples is explained, first the aerodynamic properties of a sphere have to understand. Firstly, a smooth sphere without any dimples, like a Ping-Pong ball is going to be observed [8].

This explanation leads us to an important conclusion: the drag on a sphere is dominated by the flow separation over its rear face. If we could somehow minimize that separation, the drag experienced by the sphere would be significantly reduced. We can see this effect in experimental data, like that pictured "Fig. 4,".

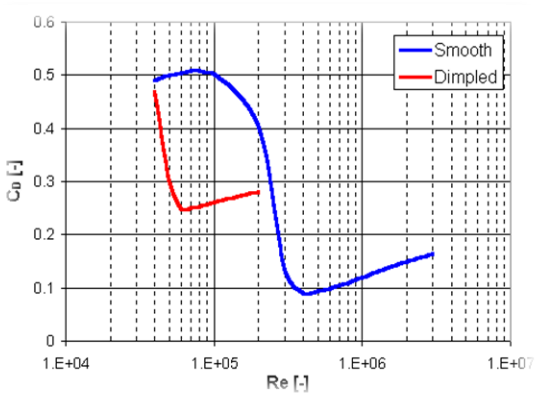

Figure 4. Variation of drag coefficient with Reynolds number for a sphere [2]

This diagram illustrates how the drag of a sphere varies with the Reynolds number. Reynolds number (Re) is an important non-dimensional parameter that is used to relate the size of an object to the flow conditions it experiences, and is defined by the equation [9].

6 (CFD) Computational Fluid Dynamics

To study the effect of dimples of an aerofoil is going to be used CFD. The software that have been used, are Gambit 2.2.16 and Fluent 6.3.26. Computational fluid dynamics (CFD) is the use of computers to analyze problems in fluid dynamics
Basically, the compelling reasons to use CFD are these three:

6.1. Insight

There are many devices and systems that are very difficult to prototype. Often, CFD analysis shows you parts of the system or phenomena happening within the system that would not otherwise be visible through any other means. CFD gives you a means of visualizing and enhanced understanding of your designs.

6.2. Foresight

Because CFD is a tool for predicting what will happen under a given set of circumstances, it can answer many ‘what if?’ questions very quickly. You give it variables. It gives you outcomes. In a short time, you can predict how your design will perform, and test many variations until you arrive at an optimal result. All of this is done before physical prototyping and testing. The foresight you gain from CFD helps you to design better and faster.

6.3. Efficiency

Better and faster design or analysis leads to shorter design cycles. Time and money are saved. Products get to market faster. Equipment improvements are built and installed with minimal downtime. CFD is a tool for compressing the design and development cycle [1].

7 Improved Airfoils Design Process

Obviously, there is not only one design which improves the performance of the airfoil. Indeed, there are several of them and they have got all their own dynamic and geometric characteristics.

The new designs can be classified into different criterions: the size, the shape, the position and the number of the dimples on the airfoil. In the following parts, all of these criterions are detailed below.

8 The Meshing of The Improved Design

The meshing process of the improved designs is the same than the one detailed in the meshing process part of the smooth airfoil chapter (chapter 3). Indeed, the meshing of the design is one

of the most important points of the project, and then two things are important to compare two airfoils:
The meshing must be the better possible the meshing of the two airfoils compared must be the same

That means that the interval and the shape of the meshing must be identical to do a coherent analysis. The size and the position do not influence the look of the meshing; only the shape of the dimple does. Then a meshing of each kind of dimple shape is illustrated on the following pictures “Fig. 5,”.

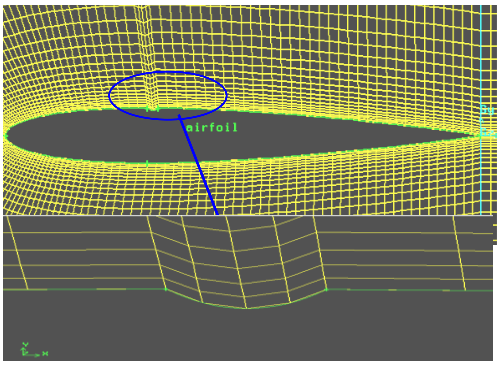

Figure 5. Conic dimple meshing

9 Analysis

This is the summary of the work for the airfoil without dimples (α =O^°)
Title:
Models

Model	settings
Space	2D
Time	Steady
Viscous	Standard k-epsilon turbulence model
Wall Treatment	Standard Wall Functions
Heat Transfer	Disabled
Solidification and Melting	Disabled
Species Transport	Disabled
Coupled Dispersed	Disabled
Pollutants	Disabled
Soot	Disabled

10 Results And Discussions

In this section, the results that have been obtained in Fluent, are going to be shown. In these results, graphics of static pressure, velocity vector and something else, are going to be able to be observed. Also, the results of lift, drag, lift coefficient and drag coefficient, are going to be shown “Fig. 6,”.

Firstly, the results of the wing without dimples can be seen, and then the wing with dimples and after this, a comparison between both cases will be done to study the differences that exist “Fig. 7,”.

Each case has been studied for different angles of attack to have more cases of study. Therefore, more comparisons and a longer study, will be able to be made.

Each airfoil has been studied for the following angles of attack: 0^° , 4^°
, 8^° and 14^0 .

11 Airfoil without Dimples

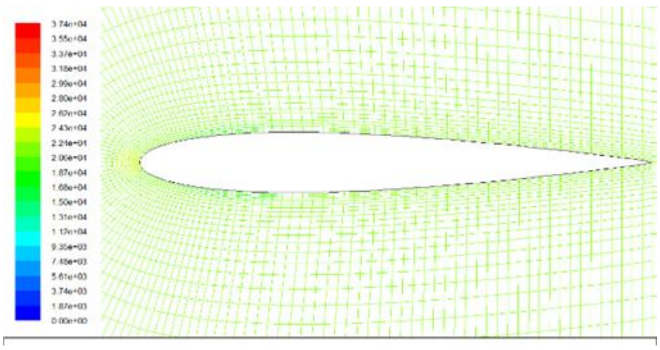

Figure 6. static pressure of the airfoil without dimples

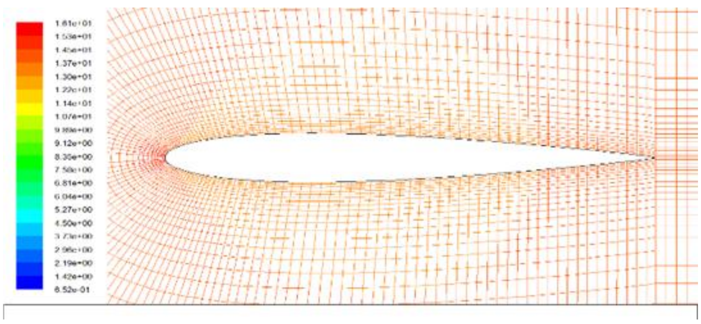

Figure 7. Coefficient pressure of the airfoil without dimples.

The previous pictures detail the evolution of the pressure around the airfoil with the variation of the angle of attack “Fig. 8,”

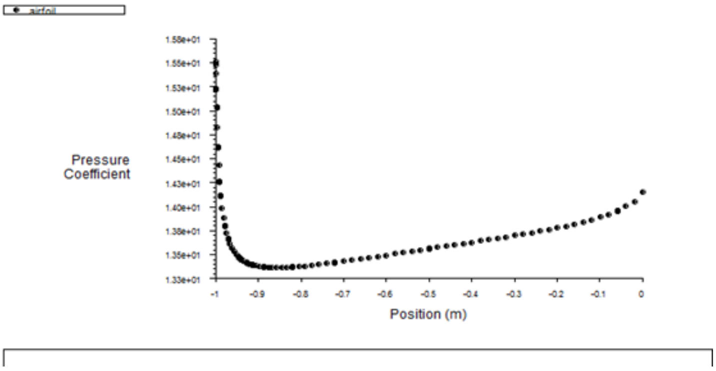

Figure 8. The Pressure distribution on the smooth airfoil

A minimum velocity can be noticed in the same point where the static pressure is maximum "Fig. 9,". At this point (the stagnation point) the velocity should be zero. This bigger result can be due to the mesh is not very accurate (due to the airfoil needs more accuracy.

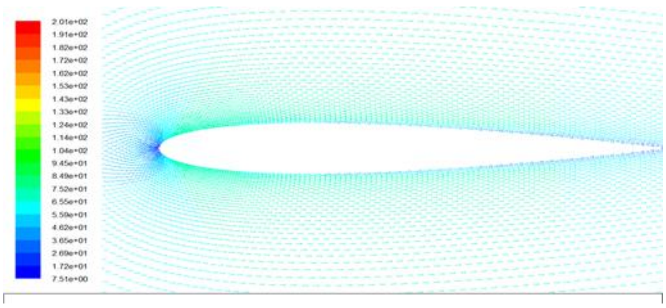

Figure 9. Velocity vectors, airfoil without dimples ($\alpha = 0^0$).

12 Airfoil With Dimple (1) With (Angle Of Attack 4^0)

In this graphic, the contours of static pressure for the airfoil with dimple can be seen "Fig. 10,". It can be compared with the graphic of the airfoil with the same angle of attack, but the differences are going to be more noticed with the numerical results "Fig. 11,".

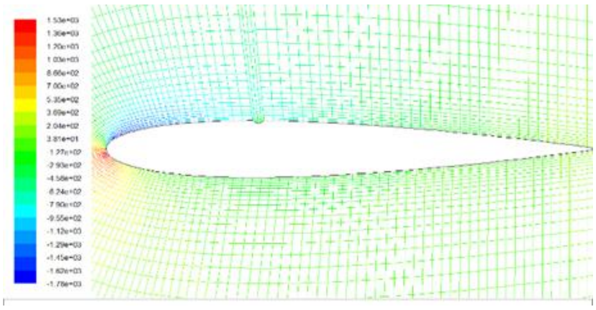

Figure 10. Static pressure of airfoil with dimple (1) angle of attack 4^0

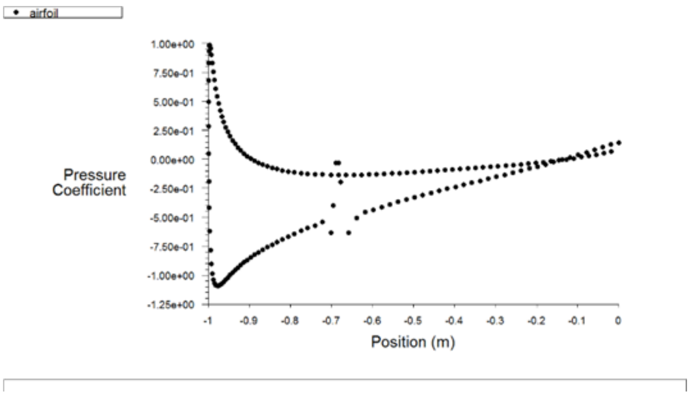

Figure 11.The Pressure distribution on the airfoil with big dimple (1) as a conic for an angle of attack4^0.

13 Numerical Results (Airfoil without Dimples)

The next table shows the results of the lift coefficient, moment coefficient and drag coefficient for different angles of attack obtained in Fluent.

The next table shows "Fig. 12," a plot of the previous values of drag coefficient with regard to angle of attack.

TABLE 1. of drag coefficient with regard to angle of attack

Angle of attack	Coefficient of Drag			
	Smooth	Dimpled 1	Dimpled2	Dimpled 3
0	0,009625	0,012635	0,012049	0,011462
1	0,009811	0,012883	0,012231	0,011614
2	0,010396	0,013489	0,012747	0,012101
3	0,011196	0,014371	0,01355	0,01288
4	0,012207	0,01556	0,014607	0,013885
5	0,012663	0,016428	0,015288	0,014469
8	0,017363	0,021716	0,019039	0,018964
10	0,022686	0,027653	0,025358	0,024119
12	0,031411	0,036932	0,033058	0,031912
14	0,044554	0,055541	0,045374	0,04377
16	0,074409	0,069143	0,071458	0,071096
18	0,10589	0,10584	0,10489	0,10432
20	0,1351	0,13496	0,128522	0,1359

On the above table, all the coefficient of drag for all the airfoil from the improved airfoil dimpled 1 to the dimpled 7 are detailed. As we can see, only the Dimpled 5, 6, and 7 are interested. Indeed, it is interesting to reduce the drag only for the angle of attack before 15 degrees. After, the lift decreases and the flight characteristics are not very common. Then the position 5, 6, and 7 have been kept to carry on the analysis by varying the other parameters at these positions.

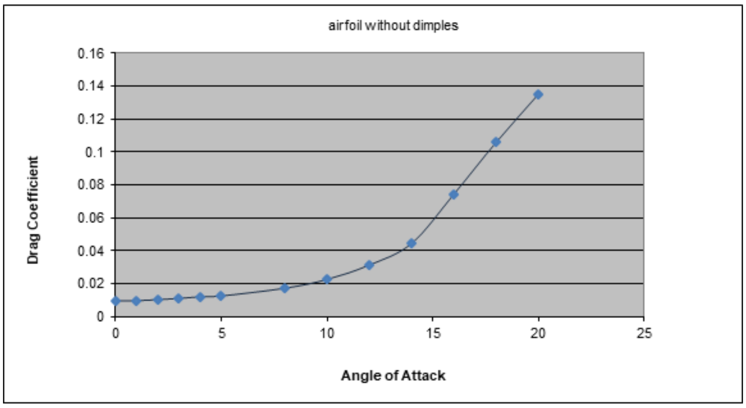

Figure 12. Drag Coefficient vs Angle of Attack for the smooth airfoil

TABLE 2. with the results of lift and dag is shown:

D(N)	L(N)	Angle of attack
14.7382	-1.0412	0^0
18.6919	587.3568	4^0
26.5870	1222.9021	8^0
48.0980	1722.8093	12^0
113.9387	1659.4156	16^0

In these results, it can be observed that the higher angle of incidence, the higher are lift and drag.

14 Conclusion

As it has been commented before, lift and drag depend on the shape of the body and in this investigation a surface with dimples (or similar) has been studied.

To overcome the weight force, airplanes generate an opposing force called lift. Lift is generated by the motion of the airplane through the air and is an aerodynamic force. Lift is directed perpendicular to the flight direction. The magnitude of the lift depends on several factors including the shape, size, and velocity of the aircraft. As with weight, each part of the aircraft contributes to the aircraft lift force. Most of the lift is generated by the wings.

As the airplane moves through the air, there is another aerodynamic force present. The air resists the motion of the aircraft and the resistance force is called drag. Drag is directed along and opposed to the flight direction.

If the values of the drag are compared, a small difference can be observed between them and that a reduction of drag has been got can be said but this small reduction of drag would have as extremely high cost.

15 Recommendations

In this section some recommendations that could have improved the results of this investigation are going to be made.

To be able to obtain a more uniform and accuracy mesh, computers more powerful would have to be used. Thus, the design of wing with dimples like a golf ball could be done and so a more accurate result to be obtained.

The wind tunnel could be used to make the tests with the wing with dimples(like a golf ball). With the computers of the library it has been impossible and with the wind tunnel it would be a very interesting study.

A three dimension model is required to investigate the effect of dimples on airfoil. The effect of the size of the dimples on the three dimension of the airfoil should be studied.

Finally, if Gambit and Fluent are going to be used, many patience is recommended.

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