Optimizing P51d-Mustang Airfoil Using Circular Dimples

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Abstract

In this work, the optimization of the P51d-Mustang airfoil using dimples is studied through computations. The lift to drag ratio is considered in comparisons. Using Creo Parametric, 2D sections of the airfoil are modeled, and the original wing is modeled in 3D. Only circular dimples were chosen for this work. The work has started with the 2D sections to find the optimal positions and size for dimples. This work is translated to the 3D model for different patterns of dimples. Using ANSYS Fluent, after computing different designs at different angles of attack, the resulting optimized airfoil has two rows of dimples on the bottom camber, and closer to the root of the wing. The ratio for the optimized airfoil is higher but only at the original angle of attack 0°, which is similar to other studies.

Keywords: ANSYS Fluent; Creo Parametric; P51d-Mustang; Airfoil; Dimple; Coefficient of Drag; Coefficient of Lift

1 Introduction

Optimizing an airfoil has always been of high importance and significance for both military and civilian uses. The main motive behind this project is to enhance the performance of the aircraft while implementing the knowledge in fluid dynamics and design analysis. The airfoil is optimized through changing its shape, or formation of external or internal dimples on the surface.

According to Nick Nardacci, Titleist's senior manager of product development, dimples are why golf balls fly [3]. Those dimples lead to a delay in the separation of boundary layers (the layer of air sticking to the surface of the ball) due to small turbulences on the surface of the dimples resulting to less drag forces acting on the ball. He adds that the dimples are similar to the wings of an airplane in the sense that they help create lift [3]. Besides the fact that dimples boost golf balls aerodynamically, they also provide a similar result on airfoils. In order to verify the result, a simulation using ANSYS on two NACA 2412 airfoils was performed, one with no dimples the other with a single dimple [2]. The simulations indicated that adding a square dimple throughout the depth of the airfoil slightly increases lift [2]. This means that the optimal airfoil design should depend on the number of dimples, the aspect ratio, and position in order to generate the most lift with the least drag.

The purpose of this report is to validate the results shown in other reports that the optimal airfoil with dimples will be expected to have slightly higher lift and lower drag forces, in other words a slightly better lift to drag ratio. Therefore, a random airfoil will be chosen and a specific shape for the dimple will be chosen and several experiments will be made on that dimple.

The expected outcome of this project is a design of an airfoil for “North American P-51d Mustang”. The chosen dimple shape is circular, similar to the ones on the golf ball. The final product thus reaches elevations higher than our proposed specifications above in order to maximize its lift and minimize drag. Several prototypes are to be tested and each will have different features (internal dimples with different spacings and patterns) and give different results. The optimal prototype will be selected.

2 Methodology

In our design we are going to focus on the surface of the wing only. we will not alter the shape (geometry) of the airfoil neither its material. The only two variables we are going to manipulate and test is the surface roughness of the wing (dimples) and the angle of attack. The flow conditions will be taken into account in our dimensional analysis in which some characteristics that depend on pressure and temperature such as density and viscosity are included in our analysis.

The stability of the aircraft won’t be taken into account, because we need to make sure that the dimples will at first improve the lift to drag ratio. Stresses, strains and thermal loads also won’t be taken into account. The material will remain unchanged in the program, because there will be a comparison between two airfoils (original and with dimples) with the same material.

ANSYS Fluent will be used for the wing’s computational fluid dynamics in 2D and 3D. The testing will focus on the approximate lift and drag generated from this airfoil through finite element methods for steady states conditions. Several tests will be made based on the dimples’ geometry.

The 2D approach focuses on the tip and the root of the Mustang’s wing. 40 points are available to create an accurate section of each airfoil [1] using Creo Parametric. Next, dimples are added on the top and bottom surface to find the optimal position for a dimple to maximize lift.

The 3-D approach focuses on the wing, which is the blend of the tip and the root. The dimples are added closer to the location where there is a bigger pressure gradient. Then the number of dimples is changed that leads to finding the optimal solution for lift and drag (maximize lift and minimize drag). Finally after finding the optimal airfoil, it will be tested for different angles and then compared to the original airfoil.

The equations used to find the coefficients of lift and drag are respectively the following:

$$Cl = \frac{L}{S\rho V^2/2} \tag{1}$$

$$Cd = \frac{D}{A\rho V^2/2} \tag{2}$$

Where:
L: Lift force
D: Drag force
S: Surface area where lift is applied
A: Area where drag is applied
ρ: Density of fluid (air)
V: Relative speed between airfoil and fluid (air)

While the ratio between them is the following:

$$R = \frac{Cl}{Cd} \tag{3}$$

3 Results and Discussions

In this section, the important results will be shown. After testing for different dimple sizes on the tip and the root, the results for the best dimple size will be shown: 0.09m diameter dimple for the tip, and 0.15m diameter dimple for the root.

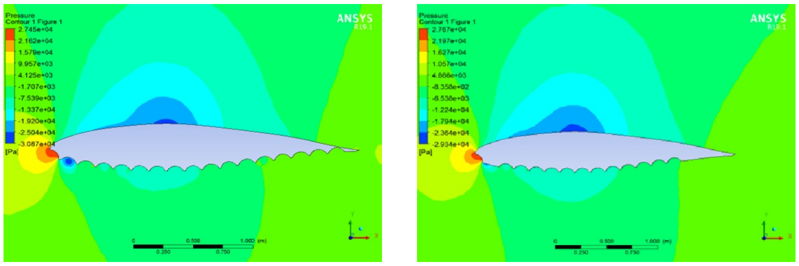
Design Points	Distance On airfoil (m)	Cd	Cl	R
DP 0	0.02	0.013285	0.131201	9.875955
DP 1	0.04	0.013735	0.13274	9.664361
DP 2	0.06	0.014332	0.13527	9.43832
DP 3	0.08	0.014549	0.134623	9.253229
DP 4	0.10	0.014808	0.144493	9.757762
DP 5	0.12	0.015876	0.138028	8.69384
DP 6	0.14	0.015042	0.118498	7.877813
DP 7	0.16	0.015584	0.18188	**11.67087**
DP 8	0.18	0.015467	0.118743	7.677218
DP 9	0.2	0.015749	0.125132	7.945164
Original	–	0.011668	0.183497	**15.72697**

Table 1: coefficients for 2D tip airfoils with one dimple on the top camber

According to table 1, the best value for the ratio R is the best for the airfoil without dimples. In addition, the drag coefficient increased (between 15% and 40%) and the lift coefficient did not get above the original value. Therefore no dimples will be added on the top surface for the rest of the simulations.

Condition	Cd	Cl	R
All Dimples	0.068532	0.80781	11.787
Reduced Dimples	0.068242	0.86773	12.715

Table 2: 2D root airfoil with different dimple conditions



(a) All Dimples

(b) Reduced Dimples

Figure 1: 2D Root with Dimples on the Bottom Camber

According to figure 1(a), on the second dimple from the left there is a very low pressure zone (blue zone), and the right dimples seams to have no offect on the pressure, and it is not feasable to have a very thin ending like shown in the figure. Therefore those dimples are removed (figure 1(b)). The value of the coefficient of drag remained unchanaged, but the coefficient of lift increased by almost 10% (table 2).

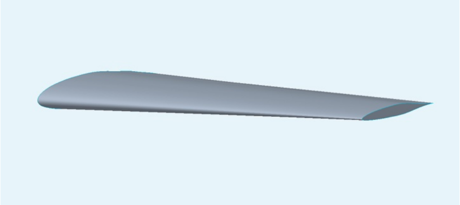


Figure 2: 3D Airfoil

For the 3D part of the results, each side is slightly rotated (2° clockwise at the root and 1° counterclockwise at the tip) and they are both blended with a distance similar to the wing size of the plane, which is almost the same airfoil of the P51d Mustang, as shown in figure 2.

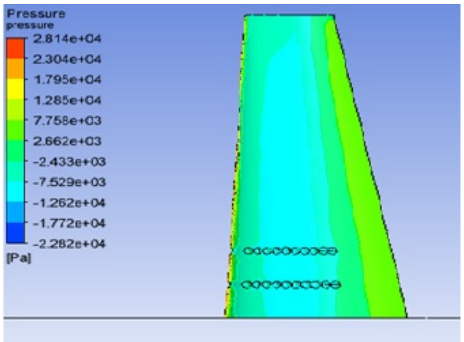


Figure 3: Optimal Airfoil Bottom View

Design	Cd	Cl	R
Original 3D No Dimples	0.18119	2.4864	**13.723**
8 Rows of dimples with 1 row on the leading edge	0.196129	2.523025	12.8641
No rows of dimples on leading edge	0.21474	2.54883	11.86955
4 rows	0.17947	2.517058	14.02492
3 rows closest to tip	0.179774	2.469791	13.7383
2 rows closest to root	0.178089	2.571812	**14.44116**
1 row closest to root	0.175177	2.480568	14.16038

Table 3: 3D airfoil coefficients for different designs

Design	Cd	Cl	R
Original, 0 angle	0.18119	2.4864	13.723
Optimal, 0 angle	0.178089	2.571812	14.44116
Original, 3° angle	0.29636	5.3084	17.912
Optimal, 3° angle	0.43939	7.1488	16.27

Table 4: 3D airfoil coefficients for different designs

After designing different airfoils with different patterns and refering to table 3, the optimal design has a ratio slightly higher than the ratio of the original airfoil, in addition the coefficient of drag is reduced and the coefficient of lift is increased.

According to table 4, the angle with the highest ratio for the airfoil with dimples is at 3°. Comparing it to the value of the original airfoil, the ratio is lower.

4 Conclusion

The enhancement of an airfoil with circular dimples has been studied computationally. Comparing the results to results for other studies [2], it shows that the results for the circular dimples is valid for any airfoil, which is not the best choice to optimize an airfoil. The next step in this study is to do the same computations with different shapes of dimples that will for sure give interesting results that can be compared to other studies.

Bibliography

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