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Numerical Study of Slot Lip Effects on Aerodynamics Performance of a Two-Element Airfoil with the Approach of Decreasing the Landing Distance

Meysam Izadi[1], Arash Shams Taleghani[2], Reza Khaki [3]

[1]Ph.D. Stu., Aerospace Research Institute, Tehran, Iran
[2]Assist. Prof., Aerospace Research Institute, Tehran, Iran
[3]Assoc. Prof., Shahid Sattari Aeronautical University, Tehran, Iran

*Corresponding author: arash.taleghani@gmail.com

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Abstract

The aim of this research is to improve the aerodynamic performance of a NACA-23012 airfoil equipped with a High lift device by changing one of its most important geometric parameters. In this research, Navier-Stokes equations are solved in turbulent and incompressible flow conditions using fluent software. After the airfoil and flap modeling process, at different flap angles (10 to 30 degrees), unstructured meshing was produced in gambit software and the improvement of aerodynamic performance due to change in the geometric parameter of the slot lip was investigated. The flow is assumed to be steady, turbulent, and incompressible, and the algorithm for solving the equations is also selected as pressure-based. The flow Reynolds range is 3.6×10^6 and the turbulence model used is realizable k-epsilon. A comparison of the results and aerodynamic characteristics of the airfoil equipped with a flap after making changes in the geometric parameter shows that with the significant improvement of the aerodynamic coefficients (on average, an increase of 9% in the lift coefficient and also an increase of 6% in the drag coefficient), the landing field of the airplane will be reduced. Also, the investigation of the pressure and velocity gradients at different stages shows that the change is effective and better distributed compared to the reference article.

Keywords: High Lift Devices; Slotted Flaps; Aerodynamic Optimization; Unstructured Grid.

1. Introduction

Nowadays, due to the existing problems surrounding the construction of urban airports as well as the take-off and landing of all types of aircraft on ships and sea runways, the shortness of the landing area is one of the most important variables in the conceptual design [1]. This concern is more in small and light airplanes; because the runways of civil, urban or military, are usually short, and the light aircraft must be able to land on a short runway [2]. So far, a lot of research has been done in the field of flow control in the aerodynamic surfaces of airplanes, but practically, high lift devices are used to reduce the landing area of an aircraft, and until today, no method has been able to provide a suitable industrial alternative for leading and trailing edge high lift devices [3].

Generally, the main task of high lift systems is to provide higher coefficients of lift in take-off and landing conditions, in such a way that this issue has little effect on the performance of the aircraft in cruise mode, but it may also be adapted according to the defined mission [4-5]. For example, in this research, an attempt is made to make the change in line with the reduction of the landing area. This is very valuable from the point of view of research, because it leads to the reduction of construction costs, attention to the landing requirements of military aircraft, attention to the limitations of urban airports, and reduction of landing time, which is very important in many cases [6].

During take-off, a high maximum lift coefficient is required along with a low drag coefficient, which indicates the need for a high lift-to-drag ratio in this phase. While in landing, a high maximum lift coefficient is required as in the take-off phase, with the difference that in this phase, the presence of more drag is important [7].

In this research, first, the geometry of the NACA-23012 airfoil equipped with Clark-y single-slotted flap in different angles of attack and flap was created in the Gambit software, and the domain of flow was defined. By using different tools of Gambit software, meshing has been done successfully and boundary conditions have been defined. Then, the final model, after studying the mesh independency, has been analyzed with the reference article in fluent software for validation, and based on that, finding the appropriate geometry of the slot lip has been followed, which is shown in Figure (1).

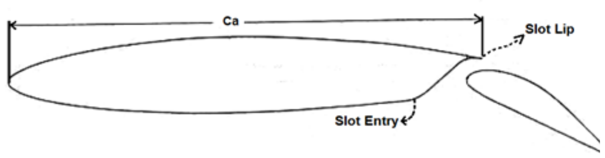

Figure 1. Slot lip parameter

Experimental data were carried out in a wind tunnel of 2x3 meters, maintaining a dynamic pressure of 16.37 pounds per square foot and a speed of 35.8 meters per second.

2. Methodology

As stated in the introduction, the geometric parameter of the slot lip has a great effect on the aerodynamic coefficients, and finding the best size can have a great effect on the optimal design of airplanes. In this research, after validating the results of flow simulation in fluent software with the reference article [8], as well as checking the mesh independency, the aerodynamic coefficients of the NACA-23012 airfoil equipped with a Clark-y single-slotted flap, with different slot lip values (from 0.85c to 0.95c where c is the airfoil chord length) were calculated. Also, the pressure coefficient distribution has been investigated. The size of the slot lip in the reference article is also 0.9 c.

In this research, the simulations are performed at a speed of 35.8 m/s and a Reynolds number of $3.6x10^6$. In all simulations, the discretization of the second-order equations has been taken into account, and for a more accurate solution in the fluent software, a solver with double precision has been used.

The basic principle that is used in fluid mechanics is the principle of conservation of mass, which is expressed by equation 1, which is called the equation of continuity:

$$(\vec{\nabla}.\vec{V})=0 \qquad (1)$$

According to Newton's second law, the result of forces acting on an object is equal to the changes in momentum. Assuming an incompressible flow and a constant viscosity coefficient, the form of Navier-Stokes equation is as follows:

$$\rho\frac{DV}{Dt}=\rho f-\nabla P+\mu\nabla^2 V \qquad (2)$$

Where V is the velocity vector, P is the pressure, f is the volumetric force and μ is the viscosity.

In order to validate the simulations, an article has been used that experimentally tests the performance of the NACA-23012 airfoil equipped with a single-slotted flap, and the comparison of the results shows that the coefficients obtained in different conditions are in acceptable agreement with the data in the reference article and the validation has been done correctly.

Due to the impossibility of using a structured mesh for this geometry, an unstructured mesh has been used. the general simulation conditions are shown in Table (1).

Table 1. Simulation Condition

Flow dimension	2-D
Flow	turbulent
Turbulence Intensity	%1.6
Operating pressure	1 atm
Velocity	35.8 m/s
Precision	double precision
Solver	coupled

3. Discussion and Results

Now, the effect of changing the slot lip value on aerodynamic coefficients will be investigated. Figures (2) and (3) show the comparison of lift and drag coefficients, at a flap angle of 10 degrees and different angles of attack, for the NACA-23013 airfoil equipped with a single-slotted flap with different slot lip values. The blue color shows the data related to the reference article with the slot lip value of 0.9c, the red color shows the data related to the slot lip value of 0.95c, and the green color also shows the data related to the slot lip value of 0.85c. In these figures, it is clear that the aerodynamic coefficients have not improved with the shortening of the slot lip (0.85c), but after increasing the slot lip to 0.05c, the aerodynamic coefficients have improved with the approach of maximizing both lift and drag coefficients.

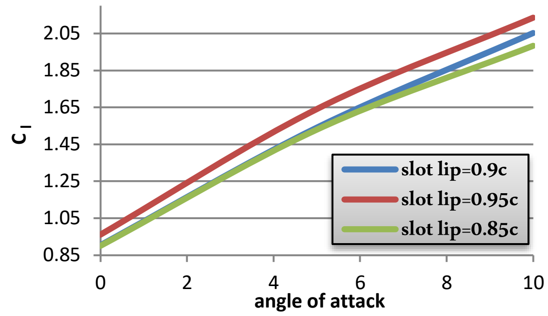

Figure 2. Comparison of lift coefficients for a flap angle of 10 degrees

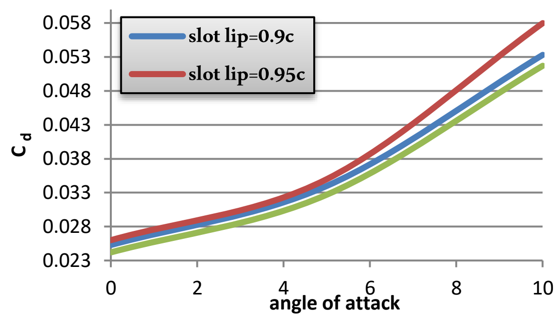

Figure 3. Comparison of drag coefficients for a flap angle of 10 degrees

In flap angles of 20 and 30 degrees (in all attack angles), the conditions are the same. Therefore, referring to these outputs, it should be said that with the amount of changes in the slot lip, which is less than the value of the reference article (0.9c), no positive change has been observed in the lift and drag coefficients, rather, the aerodynamic outputs of the reference article are better. As a result, reducing the slot lip value has not improved the aerodynamic coefficients, but increasing the slot lip improves the aerodynamic coefficients. To be precise, the lift coefficient has increased by 12.8% and the drag coefficient has increased by 8.6%. In general, by increasing the slot lip value to 0.05c, the lift coefficient has increased to 9% on average and the drag coefficient has increased to 6%, which is very effective in reducing the landing area.

The reason for all these differences is the distribution of pressure around the airfoil and flap. The pressure distribution on the main airfoil for two different values of the slot lip, at a flap angle of 10 and an angle of attack of 0 degrees, is shown in Figure (4). In this figure, it can be seen that the area between the pressure distribution curves of the upper surface (suction) and the lower surface (pressure) of the airfoil has increased after increasing the slot lip value to 0.05c, which causes the superiority of the aerodynamic coefficients of the flap with the value of greater than the reference article.

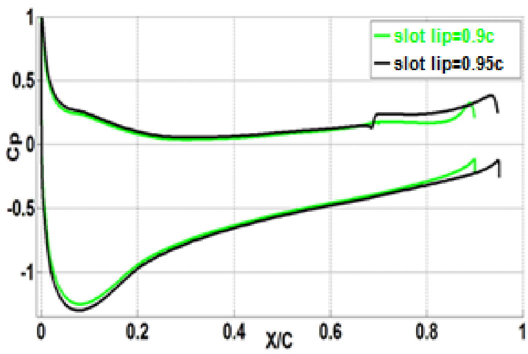

Figure 4. Pressure coefficients at flap angle 10 and angle of attack 0

In the other attack and flap angles, the pressure distribution diagram similarly shows an increase in the area under the pressure distribution around the airfoil. The outputs of the tables and figures and an average increase of about 9% in the lift coefficient and 6% in the drag coefficient show the better performance of the airfoil with the slot lip value of 0.95c compared to its value in the reference article (0.9c), in order to achieve the goal of the research, which was to reduce the landing area.

4. Conclusions

This research was carried out in order to determine the optimal position of the geometric parameter of the wing of a light cylinder-piston airplane (Aria-10 with a weight of about 4 tons) and specifically addressed the slot lip parameter, which is one of the important geometric parameters of an airfoil equipped with a single-slotted flap. The innovation of this research is the optimization of the geometric location of the slot lip parameter in order to increase the lift and drag coefficient simultaneously and in order to reduce the landing area. The NACA-23012 airfoil equipped with a single-slotted flap is selected as the basic geometry and the results of the numerical solution of the flow on it, have been first validated with experimental results. Then by increasing and decreasing the value of the slot lip, its effect on the aerodynamic coefficients was simulated and studied. The results for different geometric modes showed that by reducing the value of the slot lip parameter, not only there was no positive effect on the aerodynamic coefficients in the direction of reducing the landing area, but in several cases, it had an adverse effect on the aerodynamic coefficients. However, under the influence of the increase in the value of the slot lip, the aerodynamic coefficients improved significantly, so that the lift coefficient On average grew up to 9% and the drag coefficient increased by 6%, which is very suitable for reducing the landing area. In general, this research showed that by increasing the value of the slot lip, the area between the two pressure curves of the airfoil's suction and pressure surfaces increased and led to the improvement of aerodynamic conditions.

By optimizing the geometric parameters of the light aircraft and optimal flow control in order to reduce the runway, in addition to taking into account the limitations of urban airports, other benefits such as reducing costs, reducing fuel consumption, reducing noise pollution near airports, etc. will also follow.

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