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Analysis of the Aerodynamic Characteristics of Wing Profiles

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Abstract: Aerodynamics is a fundamental field that studies the laws governing fluid motion, particularly air, around solid objects. Its critical applications span multiple industrial and scientific sectors - from optimizing performance in aircraft, automobiles and wind turbines to designing energy-efficient buildings. The objective of this work is to compare the aerodynamic performance of three wing profiles using a numerical simulation solving the Reynolds-Averaged Navier-Stokes (RANS) equations. Turbulence is modeled with the SST k-ω model, and computations are performed in two dimensions for an incompressible fluid under steady-state conditions. Pressure and velocity fields around the profiles were evaluated for different angles of attack and different velocities. Similarly, key parameters characterizing the aerodynamic performance of the profiles such as lift and drag coefficientswere determined. The results show that theNACA 23012 profile performs better than the NACA 0012 profile at angles of attack between 0° and 15° due to its more streamlined shape, while the NACA 63-430 profile exhibits superior performance at higher angles of attack (20°) owing to its camber. Increased flow velocity results in higher lift coefficients and reduced drag coefficients.

Keywords: Aerodynamic performance, Naca, Numerical simulation, SST k-ω, Ansys fluent.

Introduction

Aerodynamics, a fundamental field, investigates the laws governing the motion of fluids, particularly air, around solid objects. Its critical applications span various industrial and scientific sectors, from optimizing the performance of aircraft, cars, and wind turbines to designing energy-efficient buildings. Advances in aerodynamics have significantly contributed to the understanding and mastery of fluid dynamics, leading to substantial improvements in emerging technologies. In today's industries, a detailed understanding of aerodynamic phenomena is essential for designing optimal structures. The wing, a key component of aircraft, directly influences lift, drag, and flight stability.

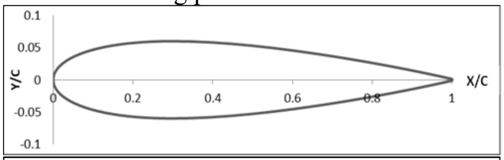
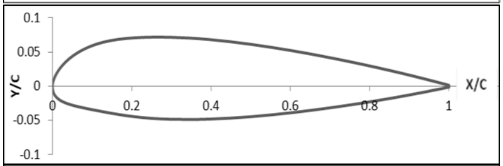
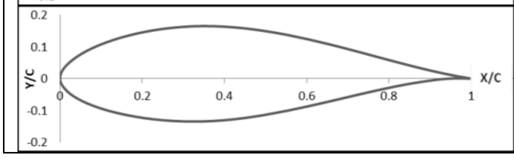
The choice of wing profile, particularly NACA profiles known for their simplicity and efficiency, is of crucial importance in aircraft design, offering optimal performance in lift, drag, and stability. These profiles, developed by NACA in the 1920s and 1930s, remain widely used in the aerospace industry for various types of aircraft. The objective of this study is to compare the aerodynamic performance of different wing profiles using computational fluid dynamics simulations. This study aims to evaluate the advantages and disadvantages of each wing profile and to identify the most effective profile for a given application.

Method

Description of the Physical Problem

In this study, we investigate the steady 2D flow around three NACA wing profiles (Table 1) in an airflow at three different velocities (30 m/s, 60 m/s, 90 m/s) and various angles of attack (0°, 5°, 10°, 15°, 20°). The computational domain consists of a semicircle with a radius of 5 m and a rectangle with a length of 15 m. The chord of the numerical profile, located near the center of the semicircle, is 1 m, as shown in Fig. 1.

Table 1. Characteristics of the three NACA profiles studied

The NACA wing profile	Characteristic
	**NACA 0012** : Asymmetric profile, without maximum camber, with a maximum thickness of 12% of the chord.
	**NACA 23012** : Aerodynamic profile with a maximum thickness of 12%, maximum camber located at 15% of the chord, with an expected lift coefficient of 0.3.
	**NACA63-430 :** Has a minimum pressure zone located at 30% of the chord, an optimal lift coefficient of 0.4, and a maximum thickness of 30% of the chord.

Mathematical Model and Boundary Conditions

The flow through the aerodynamic profile is simulated using the Navier-Stokes equations, with the flow considered two-dimensional. The fluid is Newtonian, incompressible, and steady. The equations governing the airflow are:

Continuity Equation:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad (1)$$

Momentum Equations:

Along the x-direction:

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + \nu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) \qquad (2)$$

Along the y-direction:

$$u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} += -\frac{1}{\rho}\frac{\partial P}{\partial y} + \nu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) \qquad (3)$$

The continuity and momentum equations are solved using the finite volume method with the ANSYS FLUENT computational code. To this end, it is necessary to specify the boundary conditions of the problem, such as inlet, outlet, and wall conditions. For our study, we have chosen to use an inlet condition of the "velocity inlet" type and an outlet condition of the "pressure outlet" type. The upper, lower, and lateral surfaces of the profile have been defined as "wall" boundaries. The fluid considered in our simulation is air with a viscosity of $\mu = 1,7894 . 10^{-5}$ *kg/ m.s* and a density of $\rho = 1,255\ kg/m^3$. The turbulence model adopted for this type of flow is the *SST k-ω*. model. To solve the convective terms, a second-order "Upwind" scheme is used. The "SIMPLE" method is chosen for pressure-velocity coupling.

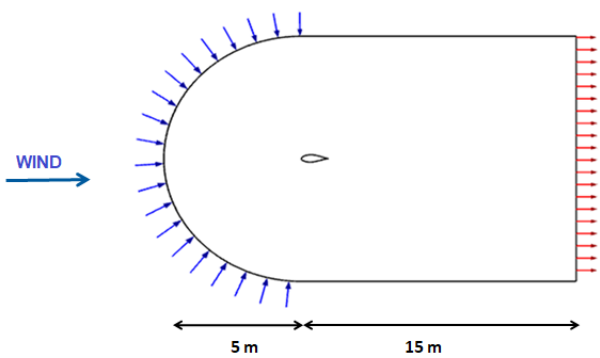


Figure 1. Problem Setup

Results and Discussion

To select the optimal mesh, we conducted tests with three different unstructured meshes, each with distinct numbers of elements (Table 2). The pressure coefficient (Cp) curve was plotted and compared with the experimental results obtained by Mr. Nianxin (Nianxin, 2009). This comparison is presented in Figure 2. It was found that the difference between the results was negligible, and therefore, the first mesh, consisting of 10,140 elements, was chosen for simulating the flow. Table 2 presents the tested meshes.

Table 2. Tested meshes

	Type	Number of Elements
Mesh 1	Tetra	10140
Mesh 2	Tetra	20373
Mesh 3	Tetra	30456

Figure 3 shows the lift-to-drag ratio (C_L/C_D) as a function of the angle of attack for the NACA 0012, NACA 23012, and NACA 63-430 profiles. For the NACA 0012 profile, the lift-to-drag ratio reaches its maximum at an angle of attack of 10°, then decreases progressively. This ratio is generally lower than that of the NACA 23012 profile.

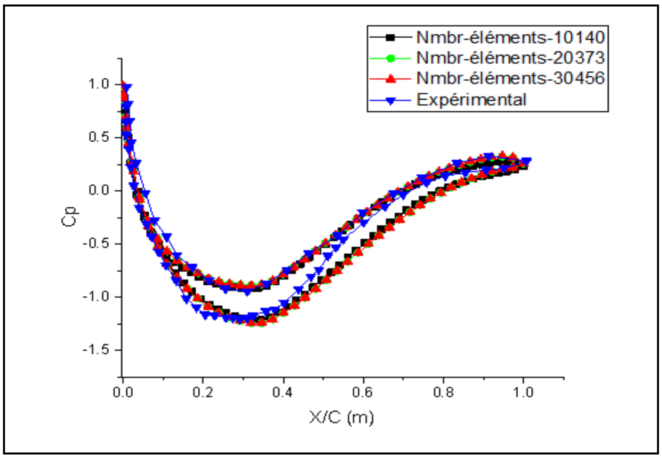


Figure 2. Coefficient de pression pour les trois maillages

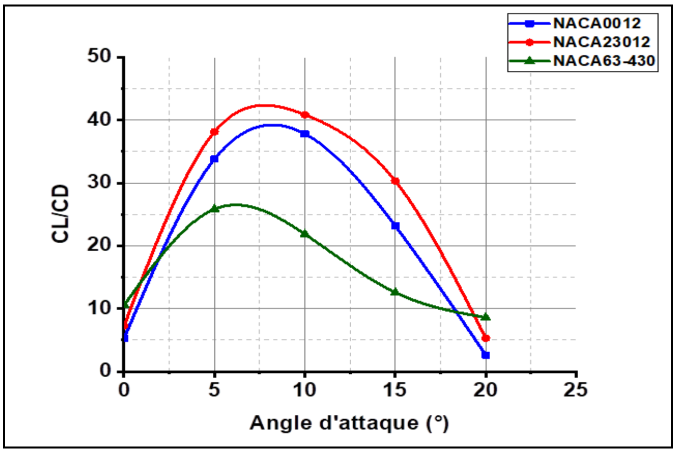


Figure 3. The C_L/C_D Ratio for the three profiles at v=30 m/s.

The NACA 23012 profile generally exhibits a higher CL/CD ratio than the NACA 0012 due to its more streamlined shape at the trailing edge. The more pronounced shape of the rear part of the NACA 23012 profile allows it to generate higher lift relative to drag, resulting in a superior CL/CD ratio. In other words, the NACA 23012 is more efficient in terms of lift generated relative to drag, as reflected by a higher CL/CD ratio. The NACA 63-430 profile shows a high C_L/C_D ratio at high angles of attack due to the specific shape of its camber. This shape is designed to minimize drag at high velocities. The NACA 63-430 can thus generate significant lift with reduced drag, improving its C_L/C_D ratio. The C_L/C_D ratio of the NACA 63-430 typically reaches its maximum at an angle of attack of 5° and then decreases progressively.

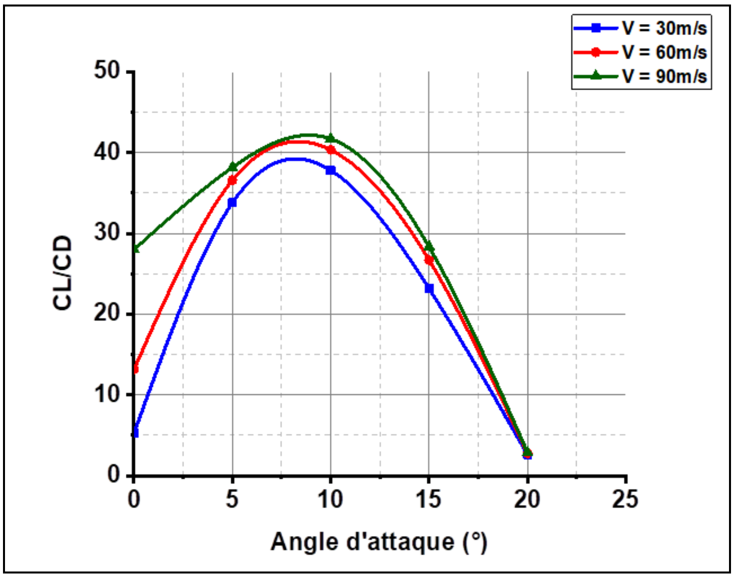


Figure 3. The CL/CD ratio for the NACA 0012 profile at different velocities

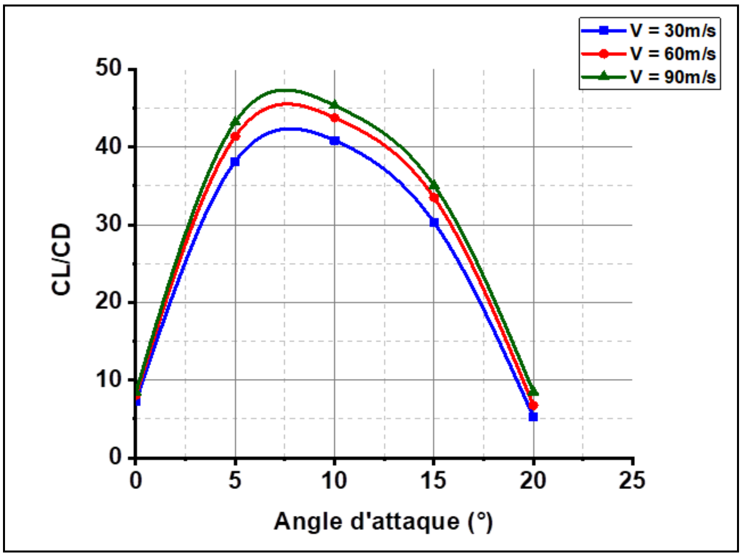


Figure 4. The CL/CD ratio for the NACA23012 profile at different velocities

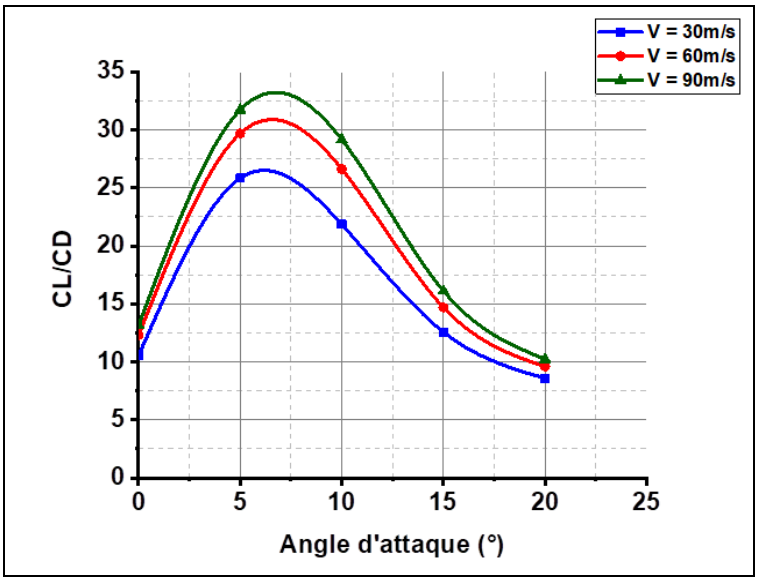


Figure 5. The CL/CD ratio for the NACA63-430 profile at different velocities

Figures 3, 4, and 5 show the C_L/C_D ratio for the NACA 0012, NACA 23012, and NACA 63-430 profiles at different velocities. The effect of velocity on the C_L/C_D ratio depends on the wing profile. Profiles with low camber (NACA 0012) exhibit a less pronounced variation in the C_L/C_D ratio with increasing velocity, whereas profiles with significant camber (NACA 23012 and NACA 63-430) show a more substantial variation in the C_L/C_D ratio with increasing velocity.

Conclusion

A numerical study of the aerodynamic performance of three two-dimensional profiles based on the averaged Navier-Stokes equations is presented. Using the *SST* $k-\omega$ turbulence model, which is particularly suited for flows near and far from the wall, the NACA 0012, NACA 23012, and NACA 63-430 wing profiles exhibit distinct characteristics to meet various aerodynamic requirements. The NACA 0012, a symmetric profile, is widely used due to its balance between lift and drag, making it versatile for many aircraft. The NACA 23012, a cambered profile, offers increased camber for enhanced lift at moderate angles of attack, ideal for maneuverability and turns. In contrast, the NACA 63-430, highly cambered, is suitable for applications requiring high lift at elevated angles of attack, such as aerobatic aircraft, although it may result in increased drag at lower angles of attack.

Scientific Ethics Declaration

* The author declares that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the author.

Conflict of Interest

* The author declares that there is no conflict of interest

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