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MATHEMATICAL SIMULATION OF THE AERODYNAMIC CHARACTERISTICS OF THE NACA 0018 SYMMETRICAL AIRFOIL WITH FLAPS

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Abstract: *This paper studies the airflow around the NACA 0018 symmetric airfoil with hypersuspension system, considered to be an established airfoil, as it is the basis of aerodynamic studies to simulate airflow at different preset conditions. This airfoil has been the basis for aerodynamic developments to increase aerospace performance. The aerodynamic characteristics of an airfoil depend mainly on the flow characteristics, since a wing is actually an airfoil, it generates lift due to its characteristic shape. This study of airfoil performance will have a major impact on aircraft handling. Cross sections of wings, propeller blades, compressor and turbine blades of a jet engine, vertical stabilisers of aircraft, rotary wings and some fixed wings are examples of airfoils. Since a wing is a streamline body, it can have a symmetrical or non-symmetrical shape, characterised by chord length, angle of attack and characteristic length. The drag force and lift force depend significantly on the geometric shape of the airfoil. Correct airfoil design can minimise the drag produced on the airfoil. The purpose of the present study is to focus mainly on the aerodynamic parameters that lead to a significant increase in the lift coefficient, thus in this report the processes of airfoil modelling and simulation at different angles of attack are investigated. The project mainly focuses on the simulation of airflow around the airfoil and their validation through wind tunnel testing.*

Key words: *airflow, airfoil design, aerodynamics, aerospace performance, mathematical simulation*

1. INTRODUCTION

Essentially, an airfoil is a section of a blade or wing. A flap is one such device that is used a tehnique to increase the lift produced by an airfoil. As an airfoil is fitted with a flap system, the curvature (or camber) of the wing increases, resulting in an increase in the lift coefficient of the wing. During take-off, the mandatory lift can`t be arising by the wings alone due to the low speed and therefore flaps are deployed. During flight, when the airflow on the wings starts to separate from the wing surface, there is a separation of the flow and therefore a loss of airspeed of the aircraft. This chapter aims to analyse the numerical analysis of the NACA 0018 profile. Initially, the clean 2D NACA 0018 profile was modelled and simulated to obtain the bearing and strength coefficients. The results were validated by comparison with standard data used in the literature. Based on the previous simulation, a hypersuspension system was added to the airfoil and then the analysis was performed to obtain the lift and drag. The results obtained for both the simple and flapped airfoils were correlated and the adjustment in lift and drag forces were tabulated. This work will be beneficial and will provide a basis for aerodynamics researchers who wish to further investigate and carry out work in the field of symmetrically matched airfoils with hypersuspension system.

2. MATHEMATICAL MODELING OF THE AERODYNAMIC PROPERTIES OF THE SIMETRIC NACA PROFILE ADAPTED FOR HYPERSUSPENSION

For the analysis we continued the studies on the NACA 0018 symmetrical airfoil which was adapted with a hypersuspension system. [1] The

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chord dimension (c) of the profile was 0.385 m. Flap profile geometry is shown in Figure 1.

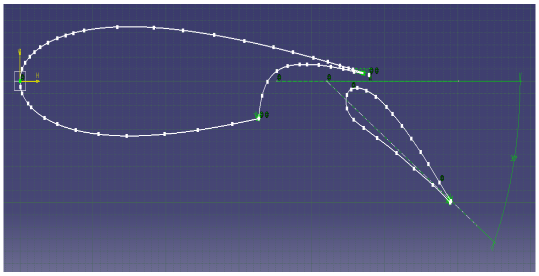

Fig. 1. NACA 0018 profile geometry with flaps

Simple profile coordinates are imported precisely into ANSYS Fluent, and for the flapped profile, coordinates were introduced into CATIA.

A rectangular grid was created for both the simple and flapped profiles.[2] The mesh was made handling ANSYS meshing. Figure 2 shows the NACA 0018 profile grid with flaps.

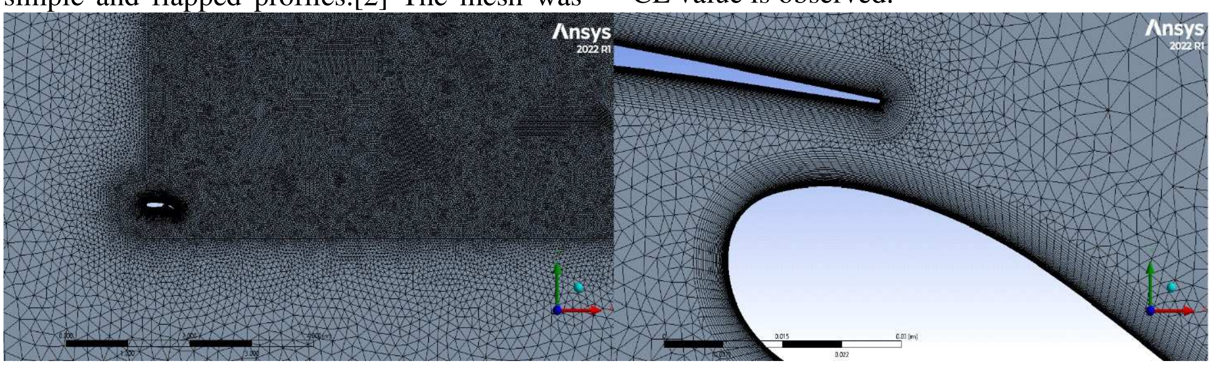

Fig. 2. Point grid for NACA 0018 profile adapted with flaps

The reproduction was performed in FLUENT Solver and the necessary border conditions were entered. The flow specification were as follows: Mach= 0.051 and Re= $3x10^5$. As a result of the low Mach number, density is simulated to be constant. [3]

The lift and strength aspects of the simple and flapped profile were determined by fluctuating the angle of incidence from 0 to 18 degrees. The NACA0018 symmetrical airfoil is used in many applications such as submarine fins, rotary wings and some fixed wings. The ultimate objective is to achieve the lift required to keep an aircraft in the air.

But airfoil construction with proper angle of incidence and implementation has a significant effect on downforce. [4] Insufficient lift force could cause the aircraft to fail to fly, especially at high speeds. Modern technologies use various simulation techniques to avoid costly testing of models, but simulation is based on certain assumptions.

Table 1 displays that by computing flaps to NACA 0018 profile, an boost in the amount of the lift coefficient occurs. In Figure 3, can be identify how the lift coefficient curve for the flapped profile is higher than that for the plain profile. Increasing the lift coefficient by adapting the flaps thus validates the results obtained in this paper.

Simplistic airfoil simulation at 0 and 15 degrees showing that at AOA = 0 degrees, the airflow remains attached to the profile surface, as normal. But from the incidence angle of 10 degrees the flow separation starts and a loss of CL value is observed.

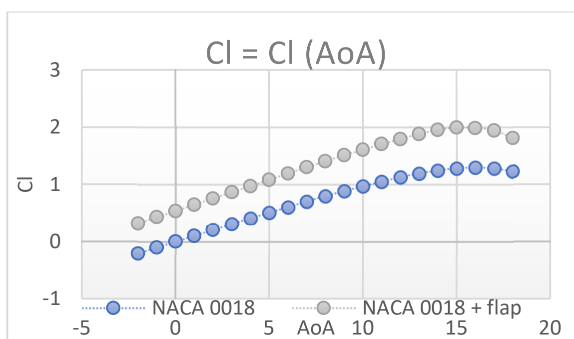

Fig. 3. Representation of the coefficient of lift for the NACA 0018 profile

The flow simulations of the wing profile at 0 and 15 degrees show that the flow remains attached at 0 degrees in the same way as it is attached in the case of a simple profile, as can be seen in Figures 4 and 5. But in the case of the flapped profile, flow separation starts at 15 degrees, unlike the simple profile, where flow separates only at 10 degrees.[5] The existence of flaps grant the flow to continue attached for a longer duration.

Researchers are studying adaptive flaps to be equipped on the wing suction surface near the trailing edge. The aspiration is to establish adaptive flaps that will naturally lift, through the action of gravity and aerodynamic effort, to delay flow partition. The numerical simulation carried out in this paper compares the lift coefficients of clean flaps and flaps with flaps at 30 degrees.

Table 1

Aerodynamic coefficients results from numerical simulations

	ANSYS Fluent			
	NACA 0018		**NACA 0018+FLAPS**	
AoA	**CL**	**CD**	**CL**	**CD**
-2	-0.2056	0.0132	0.3183	0.0391
-1	-0.1014	0.013	0.4274	0.039
0	0	0.0129	0.5365	0.0387
1	0.1014	0.013	0.6456	0.039
2	0.2057	0.0132	0.7547	0.0392
3	0.3094	0.0135	0.8638	0.0394
4	0.4094	0.0139	0.9729	0.0396
5	0.5072	0.0146	1.082	0.04
6	0.6048	0.0153	1.1911	0.0407
7	0.7043	0.0162	1.3022	0.041
8	0.7992	0.0172	1.405	0.0418
9	0.8856	0.0186	1.5102	0.0425
10	0.9685	0.0203	1.6055	0.044
11	1.0504	0.0222	1.705	0.0455
12	1.1276	0.0246	1.7925	0.0479
13	1.1942	0.0276	1.882	0.0525
14	1.2463	0.0318	1.955	0.06
15	1.2836	0.0376	1.995	0.072
16	1.2978	0.0455	1.9872	0.0855
17	1.2815	0.0568	1.945	0.1078
18	1.2291	0.0732	1.8122	0.1522

Fitting the NACA 0018 airfoil with flaps, causes the separation point to move towards the trailing edge.[6] The numerical study carried out in this work found that as the angle of incidence increases from 0 to 18 degrees, the value of the lift coefficient continues to increase with the flap angle set at 30 degrees.

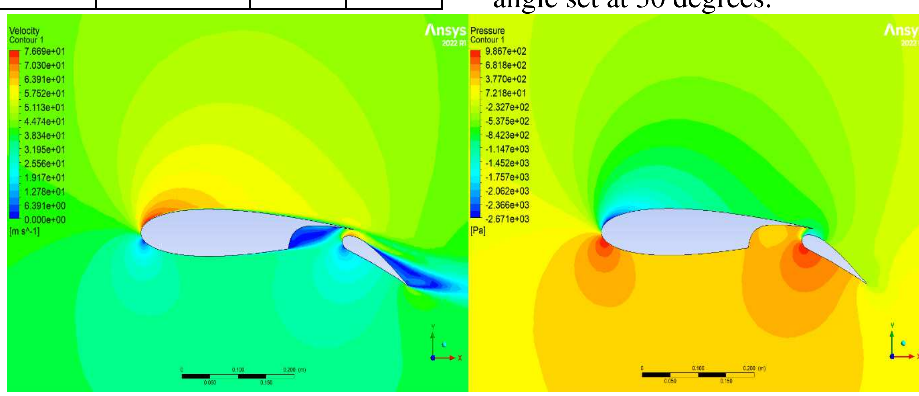

Fig. 4. Speed and pressure contour for NACA 0018 profile with hypersuspension system at 0 degree angle of incidence

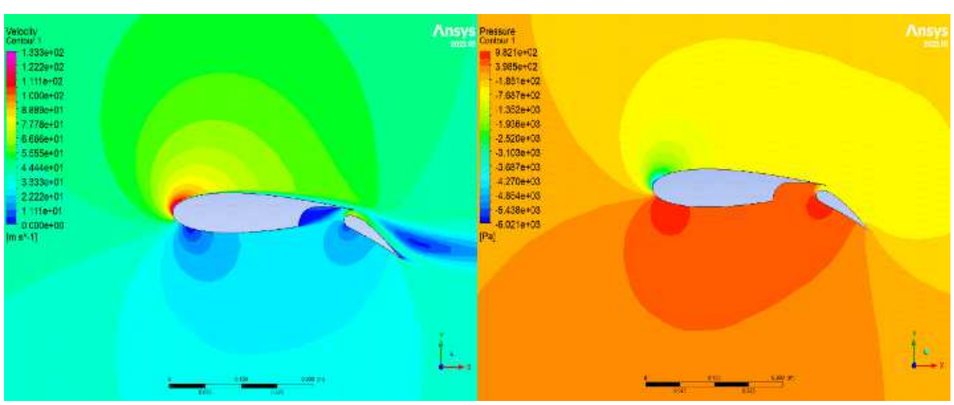

Fig. 5. Speed and pressure contour for NACA 0018 profile with hypersuspension system at 15 degree angle of incidence

The velocity and pressure contours obtained after the numerical simulation are shown in the following figures 5.

The results showed that for the simple profile, the maximum lift coefficient occurred at 16 degrees and was equal to 1.978 and after adding flaps, the lift coefficient value changed to 1.995. The main objective of this chapter is to focus mainly on aerodynamic parameters such as pressure distribution and aerodynamic coefficients.

The whole process of modelling and simulation of the airfoil at different angles of incidence is investigated.[7] This chapter focuses mainly on the simulation of the airflow around the airfoil and in the next chapter we validate the numerical results obtained by the wind tunnel testing.

3. VALIDATION OF NUMERICAL SIMULATIONS OF THE NACA 0018 AIRFOIL ADAPTED WITH HYPERSUSPENSION SYSTEM THROUGH WIND TUNNEL TESTING

In aerodynamics, the wind tunnel test configuration is used for airflow investigation. The wind tunnel section must consistently allow a laminar and uniform flow to produce accurate results when determining flow parameters.[8] Therefore, performing wind tunnel calibration before opening any research experiment is mandatory in a wind tunnel. In the subsonic wind tunnel, dynamic pressure, flow direction, static pressure, total pressure, temperature and degree of turbulence are the parameters that define the flow of air in the subsonic wind tunnel.

During the certification process of an aircraft, flight loads are measured to confirm the designed flight loads. [9] An aircraft designer will also use the data obtained from a flight load study to create a database of loading conditions supported by wind tunnel and CFD computational fluid dynamics results. This database can be used to justify future aircraft design changes or improvements.

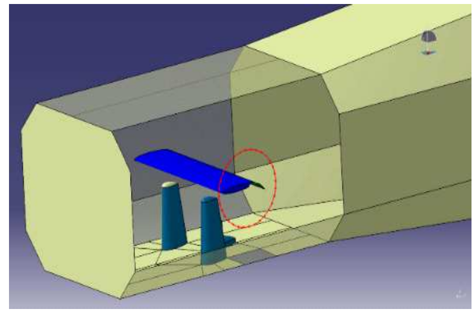

Fig. 6. Simulation of airfoil mounting in subsonic tunnel

The experimental results presented in this chapter cover a area of angles of incidence from 0° to 18°. [10] In this parameter area, both border layer flow regimes are attended: flow separation with consecutive reattachment and flow separation without subsequent reattachment.

Thus, we performed an experimental design carried out in the subsonic tunnel for testing the NACA 0018 symmetric airfoil adapted with hypershear system for validating the numerical simulations presented in the previous chapter. [11] Seven experimental tests were performed at different aerodynamic configurations for the angle of incidence and the following values for the aerodynamic coefficients were obtained.

Table 2

Aerodynamic coefficients resulting from subsonic tunnel profile testing

Experimental results		
AoA	**Cl**	**CD**
5.28	1.1027	0.032589
7.28	1.3271	0.032956
9.28	1.5298	0.03736
11.28	1.7335	0.04158
13.27	1.9153	0.047034
15.28	2.083	0.054485

Figure 7 shows the comparable curves between numerical and experimental data. Thus it can be seen that the coefficient of lift increases with increasing angle of incidence up to a certain limit, then decreases experimentally, but the numerical coefficient of lift remains closer to the value obtained experimentally.

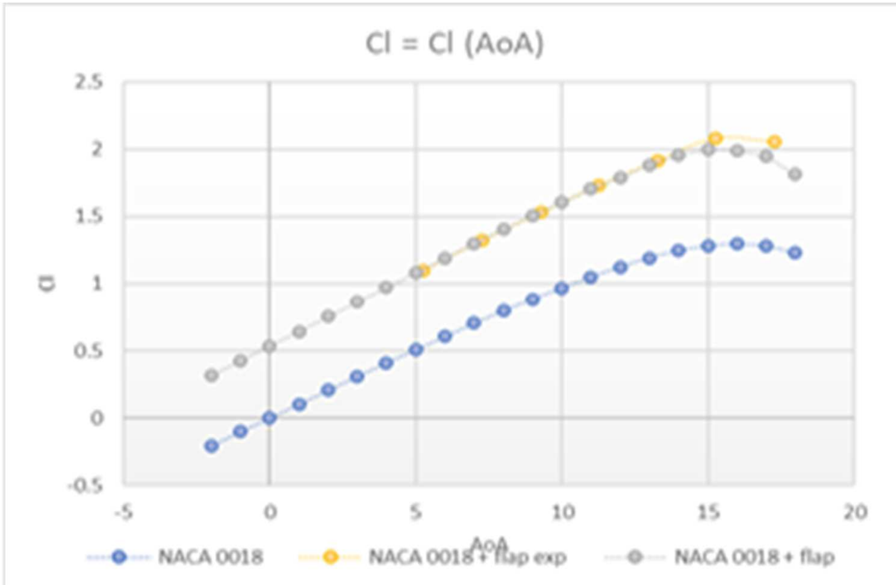

Fig. 7. Comparison of experimental data with numerical data for lift coefficient

The coefficient of drag is plotted in Figure 8 and it can be seen how it increases with increasing angle of incidence experimentally and also the numerical value of the coefficient of drag remains very close. The figure above shows that numerically the coefficient of lift is 1.995 for NACA 0018 at 15 degree angle of incidence and is very close to the experimentally obtained value of 2.083.

The above performance shows that although with increasing angle of incidence, lift boost, but this does not tend to last long. After a few degrees of increasing angle of incidence, lift starts to reduce drastically and this angle of incidence is called the critical angle of incidence. It is also observed that as the angle of incidence increases, the flow boost towards the middle of the aircraft wings. This induces more turbulence in the flow and increases noise.

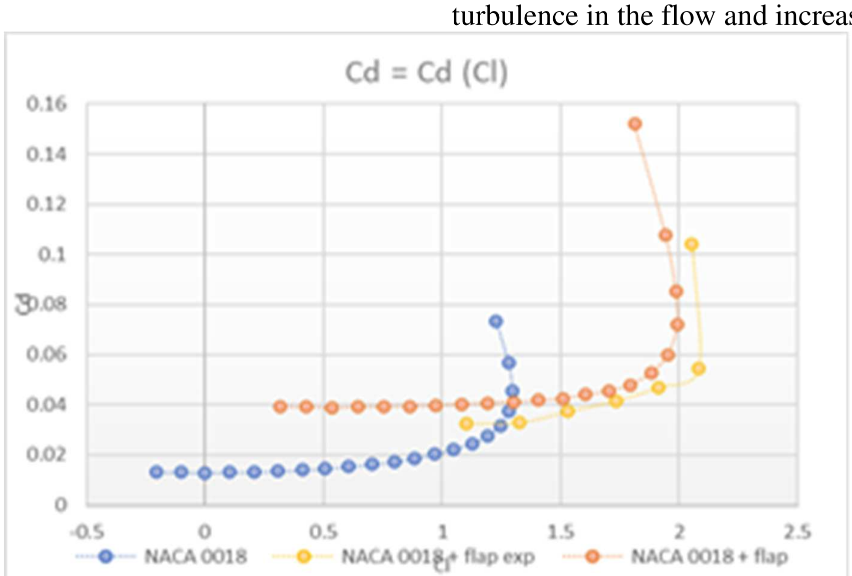

Fig. 8. Comparison of experimental data with numerical data for drag coefficient

For each angle of incidence, the flow around the airfoil varies.[12] The relative velocity (airspeed) on the top and bottom of the aircraft at an angle of incidence of 0 degrees is relatively small. One of the most important objectives is to control flow separation in terms of reducing drag.

Boundary layer separation is associated with high energy losses and, in most applications, adversely affects aerodynamic loads in the form of increased lift and drag. Reducing drag on the wing of an aircraft can reduce fuel consumption and save more energy. Under these conditions, increasing the angle of incidence also boost the drag.

As the angle of incidence boost, the lift coefficient also increases and the pressure on the aircraft influences the aerodynamic characteristics. In this condition, flow separation occurs at the trailing edge and the pressure at the leading edge is higher than at the trailing edge, the resulting pressure being the sum of the positive pressure at the upper surface and the negative pressure at the lower surface of the aircraft. The centre of pressure distribution changes with the angle of incidence.

4. CONCLUSION

In the case of stable product development, 3D modeling, and simulation are powerful and recognized tools for industries such as automotive components [13] or medical devices [14].

However, the numerical simulation of airflow flow around airfoils is still a difficult area for both scientists and engineers to analyse, because during airflow various phenomena occur that require analysis at a very high level of accuracy, and the numerical schemes used must be able to handle these phenomena simultaneously.

For discontinuities such as shock waves, a numerical method should eliminate spurious numerical oscillations by introducing numerical dissipation, which leads to high dissipation near the discontinuity as well as in the smooth regions of the flow field.

Turbulence has been the source of much debate within the aerospace community for some time. Its inherently three-dimensional, chaotic and non-linear nature has in fact turned out to be one of the most difficult problems in physics.

To date, the most effective means of both creating and validating theoretical claims has been through the use of flow visualization and observation. On the experimental side, flow visualization has proven to be an extremely effective technique for both qualitative and quantitative analysis.

Thus, the aim of developing shock capture schemes was to resolve discontinuities without numerical oscillations while maintaining high accuracy.

The expected results of this research report are of national and European interest. This study is intended to support the capabilities that the Romanian aerospace industry has at present but also to support the aerospace capabilities at EU level.

The validation of numerical results or obtaining information on the aerodynamic properties of a model led to the experimental analysis of these models in specially designed aerodynamic tunnels to measure parameters related to the aerodynamics of the model.

This research aims to expand skills for experimental design and analysis as well as advanced design capabilities. On a national level, the existence of these strategic capabilities offers the possibility of exploiting a technological niche in EU and international industry.

In the perspective of industrial collaboration activities with EU and international partners, thanks to this study there is the prospect of developing and studying new concepts and technologies in collaboration with partners from different aerospace organisations (EREA, IFAR, etc.) stimulating collaboration with similar institutes in Europe, Japan and the USA.

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Simularea matematică a caracteristicilor aerodinamice ale profilului simetric NACA 0018 adaptat cu flaps

Rezumat Această lucrare studiază fluxul de aer în jurul profilului aerodinamic simetric NACA 0018 cu sistem de hipersuspensie, considerat a fi un profil aerodinamic consacrat, deoarece stă la baza studiilor aerodinamice pentru a simula fluxul de aer în diferite condiții prestabilite. Acest profil aerodinamic a stat la baza dezvoltărilor aerodinamice pentru a crește performanța aerospațială. Caracteristicile aerodinamice ale unui profil aerodinamic depind în principal de caracteristicile de curgere, deoarece o aripă este de fapt un profil aerodinamic, ea generează portanță datorită formei sale caracteristice. Acest studiu al performanței profilului aerodinamic va avea un impact major asupra manevrării aeronavei. Secțiunile transversale ale aripilor, palelor elicei, palelor compresorului și turbinei unui motor cu reacție, stabilizatorii verticali ai aeronavei, aripile rotative și unele aripi fixe sunt exemple de profiluri aerodinamice. Deoarece o aripă este un corp aerodinamic, poate avea o formă simetrică sau nesimetrică, caracterizată prin lungimea coardei, unghiul de atac și lungimea caracteristică. Forța de frecare și forța de ridicare depind în mod semnificativ de forma geometrică a profilului aerodinamic. Designul corect al profilului aerodinamic poate minimiza rezistența produsă pe profil. Scopul prezentului studiu este de a se concentra în principal asupra parametrilor aerodinamici care conduc la o creștere semnificativă a coeficientului de portanță, astfel în acest raport sunt investigate procesele de modelare și simulare a profilului aerodinamic la diferite unghiuri de atac. Proiectul se concentrează în principal pe simularea fluxului de aer în jurul profilului aerodinamic și validarea acestora prin testarea în tunelul de vânt.

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