Aeroelastic Analysis of an Aircraft Wing Type NACA 4412 with Reduced Scale

Zerrouki Halima and Boutchicha Djilali

***Abstract*—This article addresses the problem of a flutter phenomenon and aeroelastic stability of a typical section airplane wing NACA 4412.**

The flutter is a dangerous phenomenon which finishes in general by the breaking of the plane, it can be determined as a dynamic instability of the structure.

Flutter appears as a result of an interaction of aerodynamic, elastic and inertial forces, it occurs at a determined flight speed which is called the critical speed of the flutter.

The objective of our study is to calculate the critical speed of flutter by a numerical simulation using the computer code ANSYS CFX 14.0 then the results are validated by testing with a slice wing on a subsonic wind tunnel.

The experimental results are similar to those obtained by the numerical approach.

***Index Terms*—Aeroelasticity, aerodynamics, ANSYS, critical speed, flutter.**

I. Introduction

Aeroelasticity phenomena can have a significant influence on the design of flying vehicles. Indeed, these effects can greatly alter the design requirements that are specified for performance disciplines, structural loads, flight stability and control [1]. In addition, aeroelastic phenomena can introduce catastrophic instabilities of structure that are unique to aeroelastic interactions [2].

The taking into account of aeroelastic effects requires the use of numerical methods coupling simulation tools [3], [4] like ANSYS CFX to highlight by the presentation of the study of the real case treated in the experimental part.

The present study is part of a research project that aims to perform aeroelastic analysis of a small scale wing profile and to find and calculate the limits of instability and to design aerodynamic profiles that remain stable in the operating speed range.

II. Digital Simulation

The simulation is made by an ANSYS CFX calculation code in version 14. To carry out this numerical study we used ICEM CFD software to realize our geometry which was a NACA 4412 type wing profile placed in a computational domain that adapts with the test vein of the wind tunnel as shown in Fig. 1, and generated a hexahedron type mesh which is shown in Fig. 2.

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- **The** length **of the rope = 20cm.**
- **The** thickness **= 46cm.**

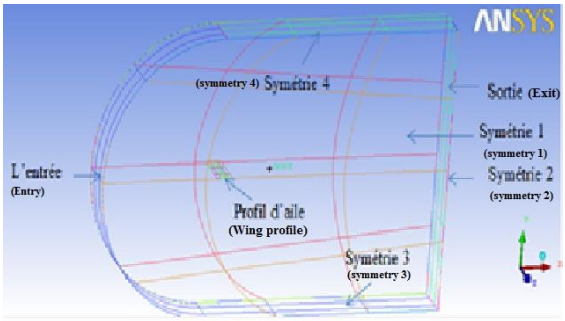

Fig. 1. Field of study.

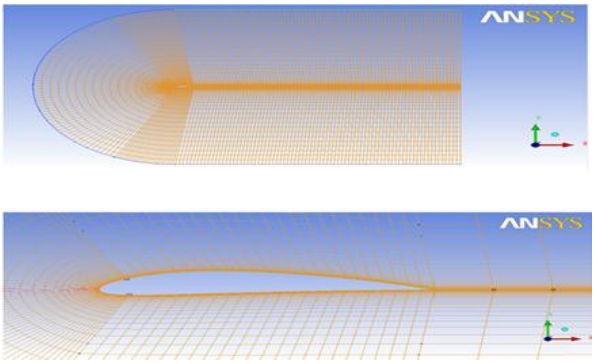

Fig. 2. Meshing of study field and wing.

To perform this simulation (FIG. 3) for a laminar or turbulent flow, the temperature = 25 °C and the pressure = 1.016 bar are introduced as external conditions of study domain, and three values of the input speed 10 m / s, 15 m / s, 20 m / s for different angles of incidence from 0 ° to 20 ° with a pitch of 5 in the form of the equations,

Then we introduced the aerodynamic equations that allow calculating the forces and aerodynamic coefficients as shown in Fig. 4.

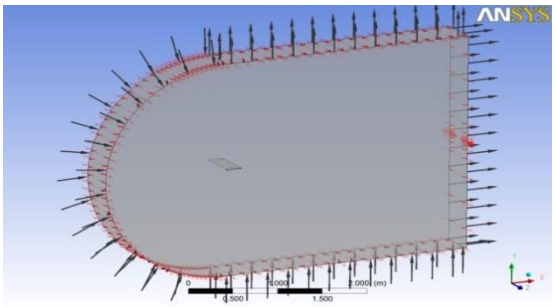

Fig. 3. Geometry of study problem.

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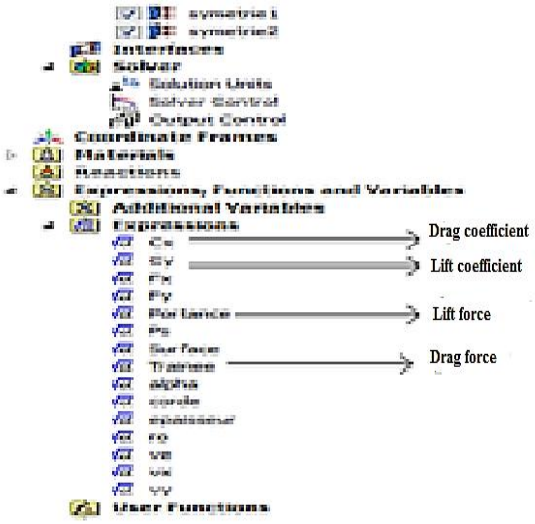


Fig. 4. Equations induce in CFX -pre.

III. Experimental Part

It is from an experiment that the fluid-structure interaction phenomena are studied. For this, we realized a NACA 4412 type aircraft wing made of composite materials on a reduced scale (fig 5).The purpose of this experiment (The aim) is to study the dynamic behavior of a wing profile as a function of the flow velocity for different angles of incidence. The wing profile is elastically fastened at both ends and immersed in an air flow in a subsonic wind tunnel. By varying the angle of incidence with a pitch of five and for each angle the air velocity was varied from zero until the maximum velocity was reached.

We have analyzed with a FFT vibration analyzer the temporal and frequency spectra of the movements produced in a wind tunnel.

To make this series of experiments, we realized the test bench which consists of the aerodynamic profile (wing on a reduced scale), the elastic fixation and the support.

Fig. 5. Final wing.

A. Dynamic Characterization of the Test Bench by Vibration Analysis

To determine the natural frequency of this wing a measurement chain has been composed as shown in (fig 6) [5].

The input and output signals of the structure respectively the excitation force and the acceleration response is processed by the FFT Analyzer and gives, among other things, the FRF (Frequency Response Function) transfer function is presented in Fig. 7 in graph form.

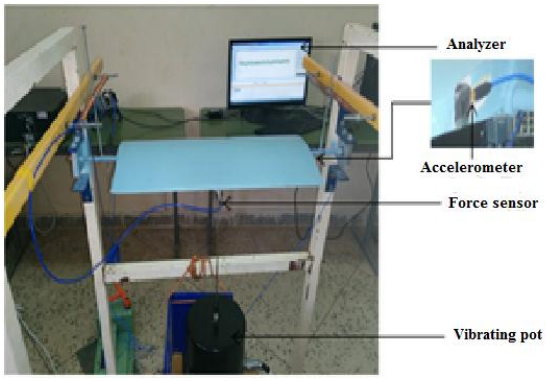


Fig. 6. Experimental setup.

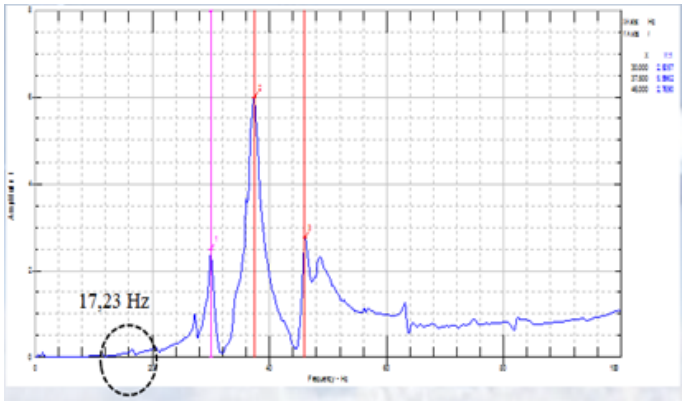


Fig. 7. Frequency response function.

B. Determination of the Natural Frequency of the Analytically Rigid Mode.

Due the complexity of the geometry and the heterogeneity of the materials of manufacture the computation of the different moments of inertia necessary for the analysis and the stiffness of the wing are determined experimentally and are replaced in the equation 1[6].

$$f = \frac{1}{2\pi}\sqrt{\frac{K_t}{I_0}} \quad (1),$$

$$f = 17{,}33\ Hz$$

The evolution of the amplitude of this frequency was followed in the response or excitation by the wind in the wind tunnel.

C. Determination of the Aerodynamic Forces and Dynamic Response of the Structure in the Wind Tunnel

To determine the aerodynamic forces, a measuring chain was composed at the level of the blower as shown in Fig. 8, such that a value of ΔH (3 values) was set each time with a change in the angle of incidence of 0 °to 20 °in a step of 5 ° in order to obtain the values of lift and the drag and one has replaced in the equations (2), (3) to obtain the values of the coefficients of lift and drag successively.

The vibratory response of the structure is measured using a vibration analyzer of the structure by dint of an accelerometer (sensor) and the excitation is made by the wind of the wind tunnel.

To access these results, a test bench was constructed which provided a mounting bracket (frame) on which the wing profile is placed. This structure has four springs placed parallel and two bearings placed at the end on the same direction of flow from a wind tunnel.

In the other end of the structure the sensor was attached in the horizontal position and perpendicular to the flow, the tests were carried out on the wing profile by changing the initial angle of incidence and the speed of the flow as shown in Figure 9.

And since the flow velocity is a function of the pressure difference ΔH (equation 2), we calculated the pressure variation in the Pivot tube ΔH which corresponds to velocities ranging from 5m / s to 25m / s with a step of 5 and varying the angle of incidence [7], [8].

$$C_z = \frac{2.F_z}{\rho.V^2.S} \quad (2)$$

$$C_x = \frac{2.F_x}{\rho.V^2.S} \quad (3)$$

$$V = \sqrt{\frac{2\rho_{eau}.g.\Delta H}{\rho_{air}}} \quad (4)$$

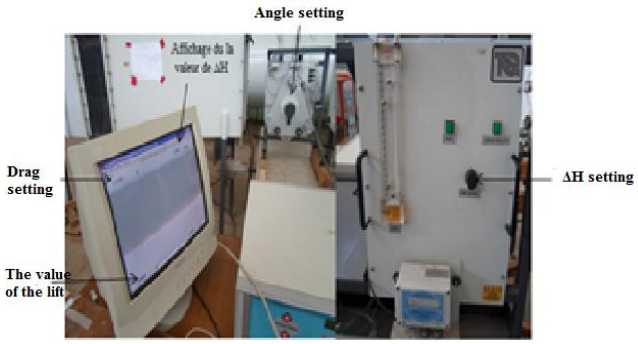


Fig. 8. Determination of aerodynamic forces.

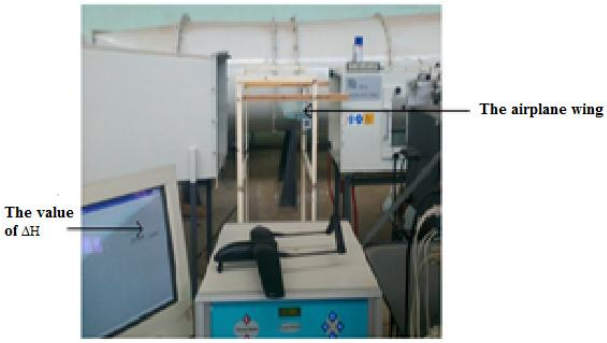
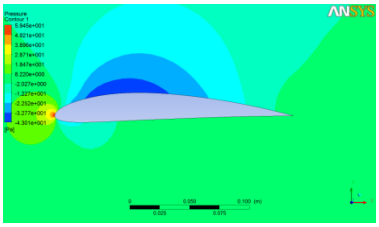


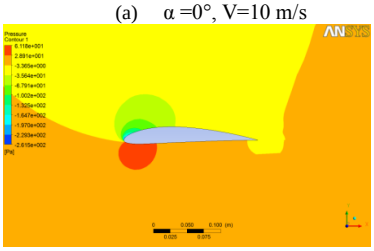
Fig. 9. Experimental setup in the wind tunnel.

IV. Results

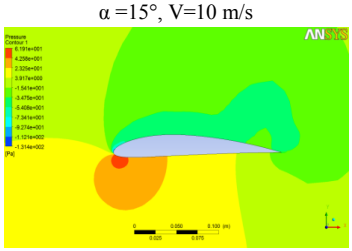
According to the figures (a), (b) and (c) which represent the variation of the pressure field as a function of the variation angle Alpha which are obtained from an ANSYS CFX calculation code, it appears clear that there is a zone of depression on the extrados of the profile for all angles of incidence with a clear increase of the pressure in the vicinity of the leading edge with the increase of the angle of incidence.



(a) α =0°, V=10 m/s



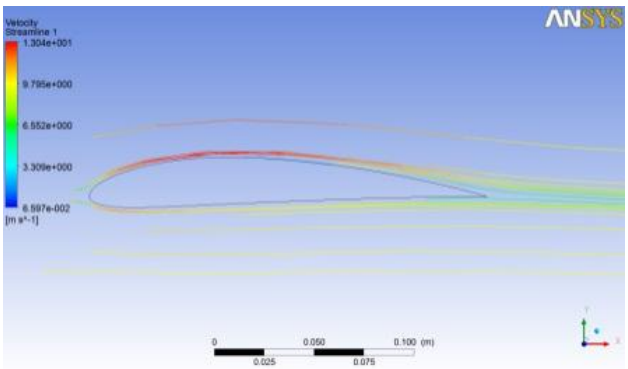
α =15°, V=10 m/s



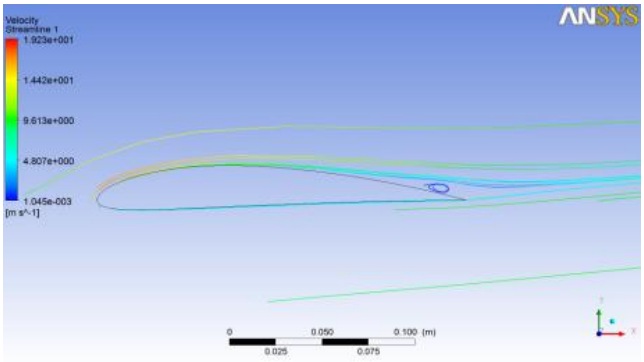
(c) α =20°, V=10 m/s

Fig. 10. Pressure field for different α.

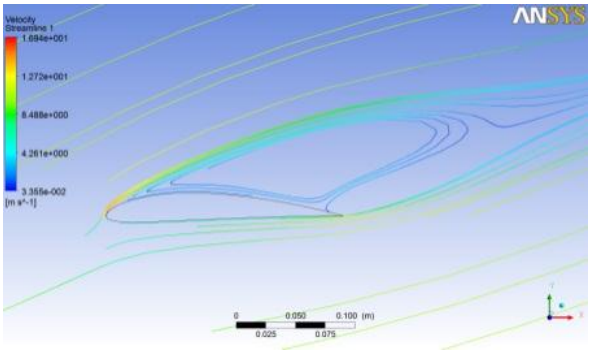
The flow passes around profile symmetrically for the 0 ° angle as shown in Figure 11 (a), and for the other different angles from 5 ° to 20 °, the lines of the currents change its shape that is mean, the trajectory of the flow changes is also their speed, when we increase the angle of attack the speed of the lines of the currents decreases at the surface of the lower surface less than the extrados and we noticed also that there is a recirculation zone in the case of Alpha equals 10.



α =0°



α =10°



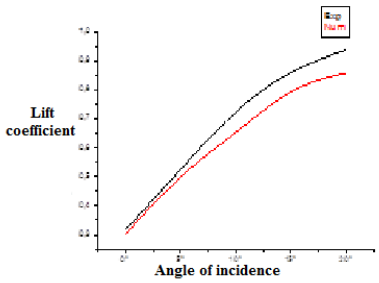
α =20°

Fig. 11. air flow line for different α.

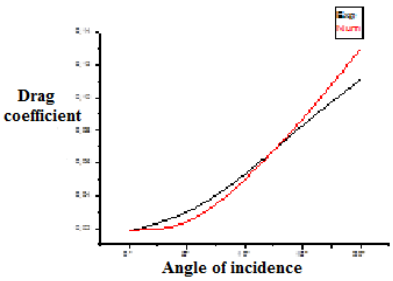
The graphs (a) and (b) of figure (12) represent the graphical interpretation of the numerical and experimental results of the variation of the aerodynamic coefficients (Cz, Cx) as a function of the angle of incidence.

From these graphs, we can note that:

- The coefficient of the drag Cx and the lift Cz increase as the angle of incidence increases.
- The coefficient of friction Cx max reaches its maximum value for the angle 20 °and a minimum value for the angle 0 °.



(a). The curve of lift.



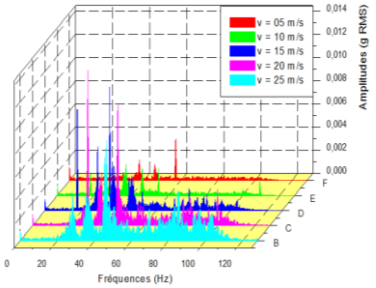
(b). The curve of drag.

Fig.12. Aerodynamic characteristics of the wing profile.

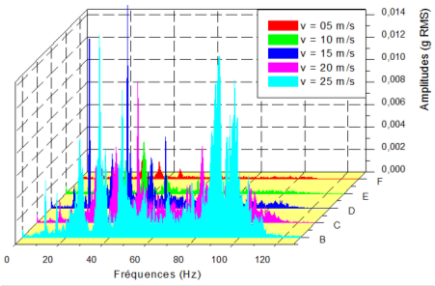
The graphs (a), (b) and (c) of fig. 13 illustrate the variation of the amplitudes as a function of the frequencies for different speeds and for each angle (a), (b) and (c) which are obtained from experience in the wind tunnel.

In this experiment we followed the first three frequencies which are illustrated in Figure 6, as it was noted that the first frequency remains substantially constant for the speed less than 15 m /s but it increases slightly around 20m / s.

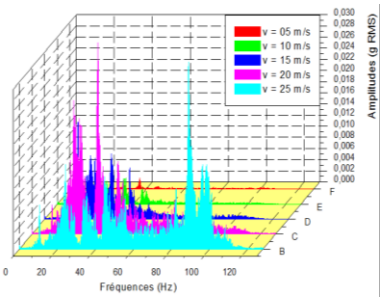
The second frequency decreases to 15m / s then it rises to around 20m / s, while the third frequency remains relatively constant then it drops to around 20m / s the curve is recovering.



(a). α =0°



(b). α =14°

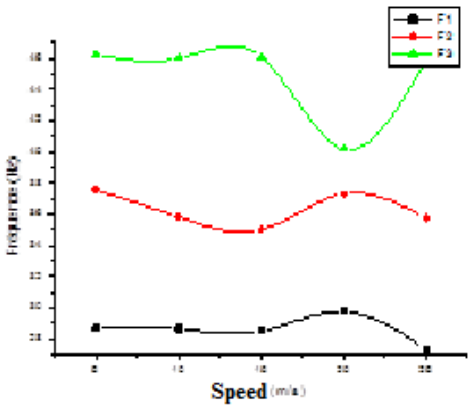


(c). α =25°

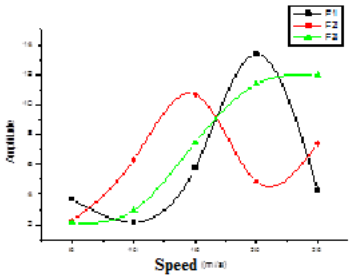
Fig. 13. (a), (b), (c) Evolution of relative amplitudes as a function of frequencies

Due to these last graphs we have extracted the two graphs of the figure 14 which are given an important remark for the two frequencies f1 and f2 such that, they are increased and approached the third frequency which is lowered considerably towards the speed of flow of 20m / s.

According to the aeroelasticity studies of, two modes which approach each other excite each other and give rise to a vibratory instability which causes the aeroelastic phenomenon known under the name of flutter. The speed that corresponds is called the flutter speed.



(a)



(b)

Fig.14. Variation of frequency (a) and amplitude (b) according to the flow velocity

V. Conclusions

The present work shows a good agreement between the numerical and experimental results which show that the modeling of our system is good.

In addition this study allowed us to understand the impact of the angle of incidence on the aerodynamic parameters of the profile and to consider the usual angle of flight, a major change in the pressure distribution around the profile, which generates a variation of the forces acting on this profile.

According to the aeroelasticity studies, we conclude two modes that approach each other excites one to the other and give rise to a vibratory instability that causes the aeroelastic phenomenon known as flutter.

This phenomenon has catastrophic consequences on the structure and safety of passengers.

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References

[1] Laurent STAINER: *Aeroelasticity (aero 016)*, 2007.

[2] D. H. Hodges and A. Pierce, *Introduction to Structural Dynamics Aeroelasticity*, Campridge Aerospace Series, 2001.

[3] Y. C. Fung, “An introduction to the theory of aeroelasticity,” *Dover*, New York, 1993.

[4] F. Blanc, "Numerical methods for the aeroelasticity of aircraft control surfaces,” doctoral thesis of the University of Toulouse 2009.

[5] H. Andrianne, “Identification of the aeroelastic coupling coefficients of a wind tunnel bridge section,” *Engineer's Report*, University of Liège 2005.

[6] V. L. Roudakov, *Aeroelasticity*, edited by the Ministry of Higher Education of the USSR.

[7] H. J. Hasing, “An approximate true damping solution of the flutter equation by determining iteration,” Nov 1979.

[8] *Subsonic Wind Tunnel*, TQ Education and Training LTd 2004.

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