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Experimental and Numerical Methods for Hydrodynamic Profiles Calculation

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ABSTRACT: The calculation of a hydrodynamic profile for a fluid that flows around mainly consists in determining the variation of drag force and lift force. Thus, for NACA 6412 profile, we will calculate and compare the changes of values of the coefficient forces mentioned above. The calculation will be done both experimentally in a naval wind tunnel and with a computational fluid dynamics - CFD (ANSYS 13). These experimental and numerical approaches can be used to study finite scale naval profiles such as the rudder.

1 INTRODUCTION

The main objectives of the paper are: to see how the experimental and numerical calculations of a hydrodynamic profile match, to identify the reasons for which data are not concurring and to also see whether we can use numerical methods for designing or pre-designing purposes.

Calculation of hydrodynamic profile belongs to the engineering field, where we can use three main directions of investigation: an experimental method, a numerical method and an analytical method. In our case, it is very difficult to use the analytical method because the fluid flow as described by Navier-Stokes equations has not been yet solved analytically.

Therefore calculating the forces acting on a hydrodynamic profile can be solved using one of the two methods mentioned above: the experimental and the numerical method. The results in this case are not very precise because in problem statement some simplifying assumptions, specific to our domain, have been considered by default. (OANŢĂ, 2009)

Numerical methods most generally used by computational software are: the finite element method, the finite difference method, the boundary element method and the finite volume method. ANSYS 13 uses finite element and finite volume method.

Since software using numerical methods for solving engineering problems of varying difficulty and providing satisfactory results, have emerged in the past 15 years, most problems have been solved by the experimental method. Therefore the approach proposed in this paper by comparing the two methods try to present more clearly the physical phenomenon investigated and the differences between the two methods.

To study the coefficients C_x (drag coefficient) and C_y (lift coefficient), we must remark at first that in the phenomenon of fluid flow around a wing, one of physical quantities, i.e. the force (lift force or drag force), is a variable size depending on the incidence angle α. Therefore, it can be said that the process under study is a nonlinear one. The Π theorem applies both to linear phenomena and nonlinear phenomena.

Let's analyze the similarity of the simple nonlinear process (one size variable), described by the implicit function (DINU, 1994):

$$f(\rho, v, c, l, R, \Gamma, \tau, p, \alpha) = 0 \tag{1}$$

where the force R, is a function of α :

$$R = f_1(\alpha) \tag{2}$$

In relation (1):

ρ - fluid density;

v - fluid velocity;

Γ - velocity circulation,

p - fluid pressure;

τ - period of swirl separation;

c - chord length;

l - wing span.

Nonlinear dependence expressed by equation (1) is a curve obtained experimentally. Its equation is obtained by putting the condition that the power polynomial has the form:

$$R = k_0 + k_1\alpha + k_2\alpha^2 + ... + k_n\alpha^n \tag{3}$$

and the polynomial should be verified by some experimental points. The experimental points can be determined both experimentally and by using a fluid flow modeling program.

2 WORKING PARAMETERS

We considered a NACA 6412 profile with a relative elongation 6 with the following characteristics:

- the length of the chord equal to 0.080 [m];
- the wing span equal to 0.480[m].

The profile (Fig. 1) is located in an air stream with a velocity of 15 m/s. The Reynolds number calculated with formula (4) has the value of 85.000.

$$\mathrm{Re} = \frac{v \cdot c}{\upsilon} \tag{4}$$

where:

v = fluid velocity m/s;

c = chord length m;

υ = cinematic viscosity m^2/s.

The angles of incidence are (Fig. 1):

- $-10^0 \div 0^0$ step 2^0;
- $+0^0 \div 15^0$ step 3^0;

The forces that are acting upon a hydrodynamic and aerodynamic profile are: the lift force and the friction force or force due to boundary layer detachment. These forces give a resultant force R which decomposes by the direction of velocity at infinity and by a direction perpendicular to it. R_x component is called drag force and R_y component is called lift force.

R force can also be decomposed by the direction of chord (component R_t- called tangential force) and by the direction perpendicular to the chord (R_n component – called normal force). (DINU, 2010)

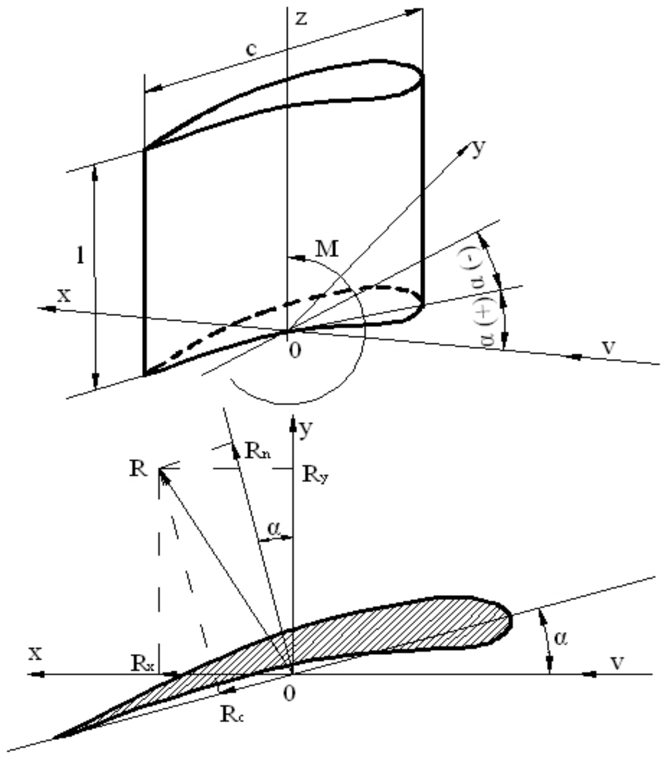

Figure 1. General representation of the profile

3 EXPERIMENTAL DETERMINATION OF THE AERODYNAMIC FORCES

Experiments were made in a naval aerodynamic tunnel. Airflow was uniform on a section of 510 × 580 mm.

A tensometric balance was used to determine the forces acting upon the wing. Results of tests are given in Table 1.

Table 1. Results of experiments

Results / Incidence angles	R_x N	C_x	R_y N	C_y
$\alpha = -10^0$	1.2134	0.2293	-1.80246	-0.3406
$\alpha = -8^0$	0.8567	0.1619	-1.69714	-0.3207
$\alpha = -6^0$	0.6620	0.1251	-1.31877	-0.2492
$\alpha = -4^0$	0.5069	0.0958	-0.95679	-0.1808
$\alpha = -2^0$	0.4212	0.0796	0.16511	0.0312
$\alpha = 0^0$	0.4503	0.0851	2.16284	0.4087
$\alpha = +3^0$	0.6884	0.1301	5.432238	1.0265
$\alpha = +6^0$	0.9679	0.1829	8.198366	1.5492
$\alpha = +9^0$	1.4558	0.2751	10.10931	1.9103
$\alpha = +12^0$	2.0125	0.3803	11.37568	2.1496
$\alpha = +15^0$	2.7528	0.5202	12.2255	2.3102

In Fig. 2 and Fig. 3 we have represented the graphics of the function $C_y(\alpha)$ and $C_x(\alpha)$, respectively.

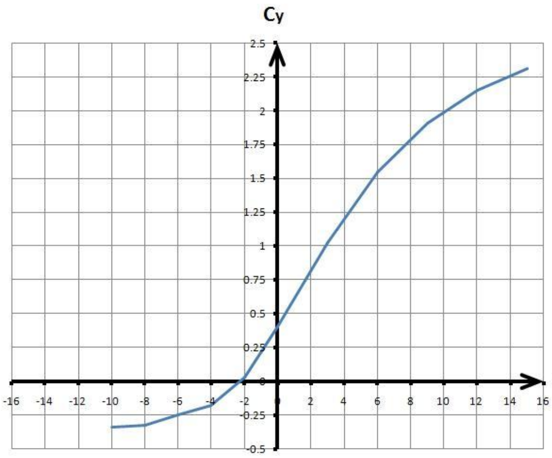

Figure 2. Graphic of C_y experimentally obtained

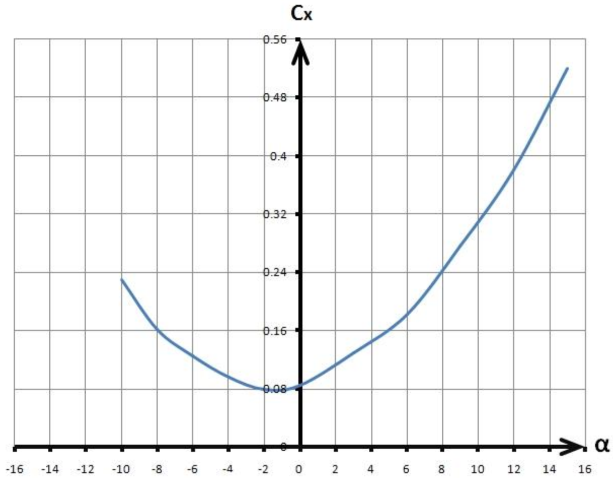

Figure 3. Graphic of C_x experimentally obtained

4 DETERMINATION OF THE AERODYNAMIC FORCES USING CFD

4.1 *NACA 6412 profile*

Using Design Modeler v. 13.0, we were able to accurately reproduce the NACA 6412 profile, as represented in figure 4. Airflow was uniform on a bigger section 980 × 511 mm.

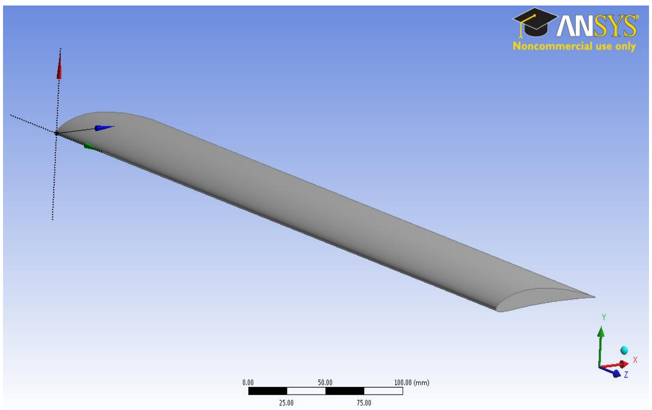

Figure. 4 Geometric representation of the NACA 6412 profile

4.2 *Profile discretization*

After the geometric representation of NACA profile, we went to its discretization, as shown in Fig. 5.

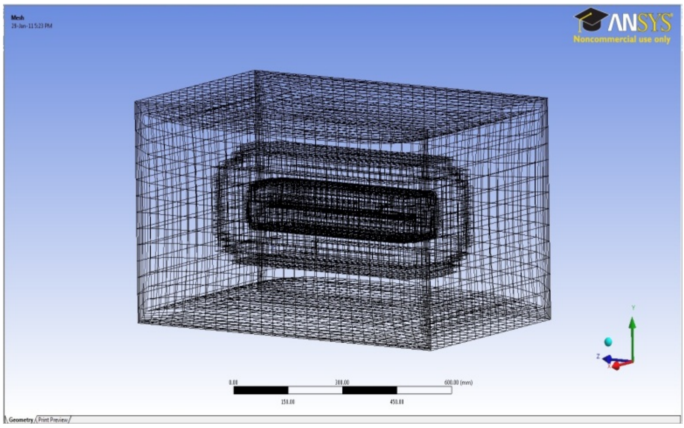

Figure 5. Profile discretization

We discretized the NACA profile in more than 10 million cells, of which 9 million are hexahedrons, 55.000 are wedges, 35.000 are polyhedral, 1500 are pyramids and only 400 are tetrahedrons. The mesh has also over 30 million faces and 11 million knots.

4.3 *Calculation of the aerodynamic forces*

Using Fluent program version 13.0, we set the boundary conditions as follows:

- The profile is attacked with a velocity of 10 m/s, under different angles, namely -10^0, -8^0, -6^0, -4^0, -2^0, 0^0, $+3^0$, $+6^0$, $+9^0$, $+12^0$, $+15^0$;
- Behind the profile, atmospheric pressure is equal to 101325 Pa.
- The fluid motion is turbulent with a Prandtl number equal to 0.667.
- The air density is considered constant and it is equal to 1.225 kg/m^3;
- The air dynamic and cinematic viscosity are also considered constant and are equal to 1.7894×10^{-5} kg/ms, 0.0001460735 m^2/s, respectively;
- The turbulence viscosity ratio is set to 10.

Process has stabilized after 208 iterations allowing us to visualize the values of drag and lift forces and their coefficients, presented in table 2.

Table 2. Results using CFD

Results / Incidence angles	R_x N	C_x	R_y N	C_y
$\alpha = -10^0$	0.4536	0.0857	-1.5145	-0.2862
$\alpha = -8^0$	0.3606	0.0681	-0.8234	-0.1556
$\alpha = -6^0$	0.2819	0.0532	-0.4900	-0.0926
$\alpha = -4^0$	0.2616	0.0494	-0.1756	-0.0332
$\alpha = -2^0$	0.2529	0.0477	0.1582	0.0299
$\alpha = 0^0$	0.2683	0.0506	2.1501	0.4063
$\alpha = +3^0$	0.3402	0.0642	5.3861	1.0178
$\alpha = +6^0$	0.4604	0.0869	8.0507	1.5213
$\alpha = +9^0$	0.6160	0.1164	9.4658	1.7887
$\alpha = +12^0$	0.8447	0.1596	10.4375	1.9723
$\alpha = +15^0$	1.1043	0.2086	11.3418	2.1432

In the Fig. 6 and Fig. 7 we have represented the graphics of the function $C_y(\alpha)$ and $C_x(\alpha)$, respectively.

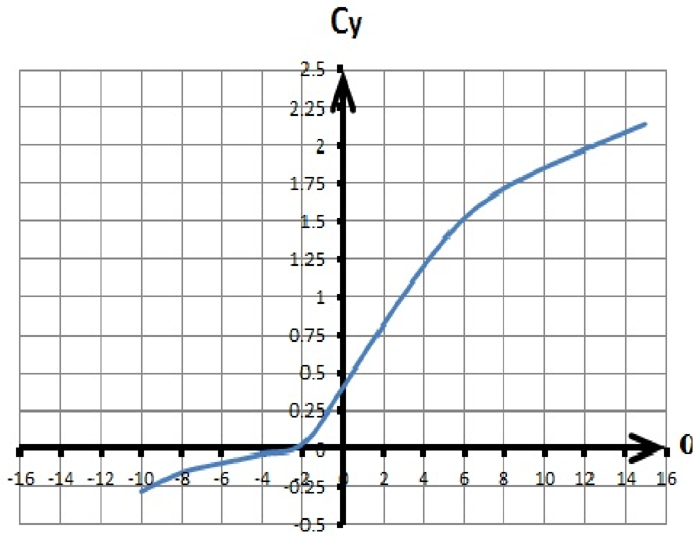

Figure 6. Graphic of C_y obtained using CFD

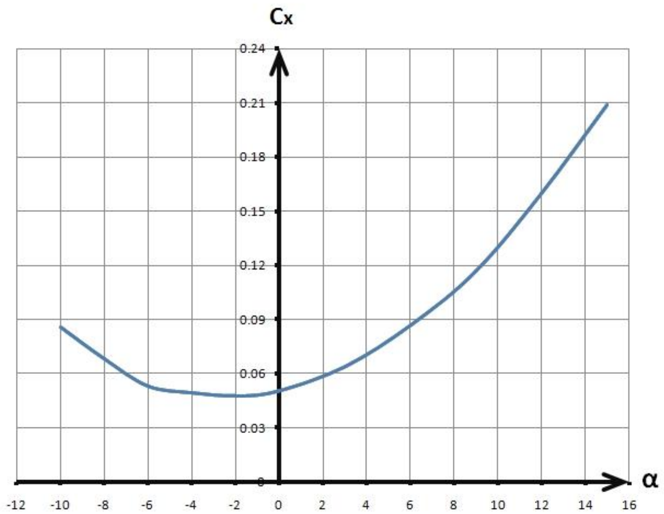

Figure 7. Graphic of C_x obtained using CFD

5 CONCLUSIONS

Comparing the C_y coefficients values obtained by experiment and using CFD, we can make the observation that they are very similar in a the field of the incidence angles [-2^0,6^0]. Also, comparing the C_x graphic, we remark that the graphics are very similar, but between the values there are some differences.

These differences are due to experimental errors (errors of measurement devices), numerical errors (rounding errors), and also discretization errors.

Also, the CFD programme doesn't take into account the induce resistance in the case of finite span wings. As a consequence an induce angle α_i will appear which thus decreases the incidence angle α. The alteration of direction and value of velocity bring about the corresponding alteration of lift force, which is perpendicular on the direction of stream velocity. (DINU, 1999)

In order to reduce these differences, it is recommended that the object of study be discretized into a larger number of cells. It is also advisable to leave out some simplifying conditions, and to impose various other conditions that simulate reality to a better precision (e.g. energy equations, air compressibility).

CFD can replace the experiment within certain limits, being a good method for pre-designing.

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