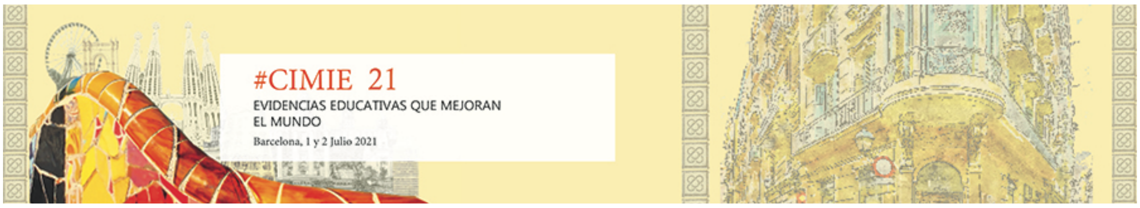

INTERDISCIPLINARY CONNECTION OF MANUFACTURING AND FLUIDS AREAS BY STUDYING OPTIMIZED AIRFOIL SHAPES

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Abstract

This work focuses on practical activities carried out by the students, compromising knowledge and skills developed in two different areas in the curriculum: Manufacturing Technology and Fluid Mechanics. The student focuses on 3D design, modeling and manufacturing using 3D printing techniques of different wing profile models of aeronautical interest and in power generation applications. Second, the subsequent aerodynamic analysis of these geometries is approached from the point of view of Experimental Fluid Mechanics.

Keywords: Airfoil, 3D Priting, Addtive Manufacturing, Wing, Aerodynamics, Fluid Mechanics.

Introduction and objectives:

The purpose of this work is to show the results of the Education Innovation Project that is currently being carried out with the students of the last courses of the Degree in Industrial Organization Engineering, taught at the Defense University Center (CUD) of San Javier. This project focuses on developing practical activities that include knowledge and skills acquired in two different areas in the study plan: Mechanical and Manufacturing Technology, and Fluid Mechanics (Aerodynamics). It is intended to enhance the creativity of the students and their capacity for the association of transversal knowledge between both subjects, by Discovery Learning, and Learning-through-doing methodologies.

In the first place, the student's work focuses on 3D design (García, Juanas, & Hernández, 2014; Horvath, 2014; Joshi & Sheikh, 2015), modeling and manufacturing using 3D printing techniques (Ngo, Kashani, Imbalzano, Nguyen, & Hui, 2018) of different airfoil models of interest for Fluid Mechanics and Aeronautics. Second, an experimental aerodynamic study of the models is carried out.

The proposal focuses on the use of different additive printing technologies, such as stereolithography (SLA) (Chun, 2016; Ma, 2013) and fused deposition modeling (FDM) (Comb, Priedeman, & Turley, 1994; Dudek, 2013; Kozior & Kundera, 2017), through which the students can verify, through their work, the advantages, and disadvantages of each of these techniques from the point of view of the obtained surface finish. Subsequently, experimental characterization of the models is carried out in an experimental aerodynamic installation (a subsonic open wind tunnel). In this way, the effect of different surface finishes on the aerodynamic behavior of the profiles can be analyzed. Additionally, other techniques (surface treatments or polishing) can be used to achieve different surface rugosity, expanding the sampling field and enriching the results of the experimental characterization.

The approach to these technologies by the students, allows them to discover by themselves the results obtained, being the protagonist of their learning, which frames this work in the theory of Discovery Learning.

Additive Manufacturing methodology and results:

The first step consisted of the selection of the aerodynamic profile from the NACA (National Advisory Committee for Aeronautics) series. Once the main families of NACA airfoils had been analyzed, 2 profiles belonging to the 4-digit series were selected: NACA0012 and NACA 2412 (Figure 1). These are well known and have been widely studied, which allowed to previously know the results to obtain in the experiment and thus be able to carry out a validation of the design, manufacturing and experimental tests in the wind tunnel.

With the airfoils selected and points of the profiles obtained using the AirfoilTools.com tool, the 3D models were designed using Autodesk CATIA v5 CAD Software (Figure 2) as a constant chord wing.

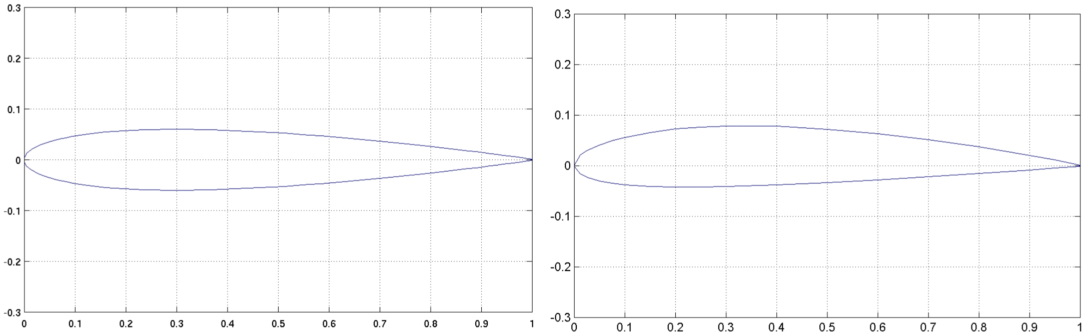

Figure 1: Aerodynamic NACA 0012 (left) and NACA 2412 (right) airfoils.

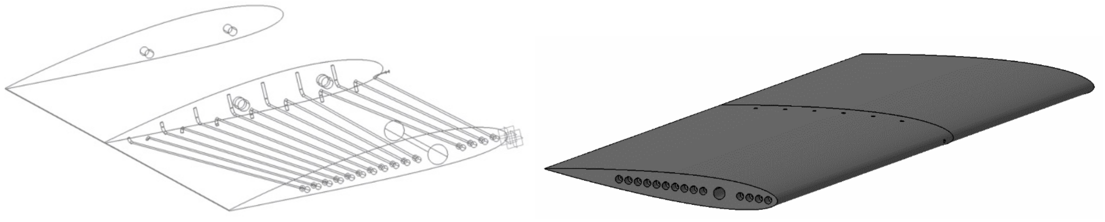

Figure 2: NACA 0012 (left) wireframe and NACA 2412 solid (right) airfoils CAD design.

Nowadays, new component design planning is based primarily on Computer Aided Design (CAD) environments where each curve or surface is approximated by manual or semi-automatic definition of control point networks. Thus, the design of the profiles was carried out taking into account the test section available in the wind tunnel for the experimental tests (1.2 x 0.3 x 0.4 m). The dimensions selected for the model were 100 mm (chord) x 360 mm (length). 15 internal ducts were implemented with access on the same cross section (7 at extrados, 7 at intrados and

1 at leading edge) of 1.5mm internal diameter to allow measurement during the aerodynamic tests in the wind tunnel.

Fused Deposition Modeling (FDM) technology was selected for 3D printing due to the speed of printing, reliability, user-friendly and low product cost. The material used was PLA. Fused deposition modeling is a filament-based rapid prototyping system. FDM allows the components to be built layer by layer by extruding a semi-fused thermoplastic polymer, allowing the manufacture of complex shapes such as curved shell structures as skull bones, turbine blades or marine propellers without the use of special tools. In addition, the process parameters are minimally or not influenced by the final shape of the components (Boschetto & Veniali, 2010).

The 3D printer used was a Prusa i5 mk3s. PrusaSlicer 2.3 software was selected to laminate the models. Nevertheless, print tests were also carried out with SLA technology (Form2 from Formlabs) due to the high quality and accuracy provided by this technology. The tests revealed that, due to the design of the internal ducts (D1.5 mm), they were not capable of dislodging the resin that remained lodged in the internal duct during printing due to the capillarity effect, causing the ducts to be blocked, not being the profile valid for measurements in the wind tunnel.

Due to the printing volume limitations (250 x 210 x 210 mm), it was decided to divide the design into two parts, which would be joined together by means of two pins. In addition, in order to join the profile to the wind tunnel by means of a threaded rod, an M6 hole was added.

During this phase of the project, it was demonstrated that the high complexity and the small dimensions of the internal structures of the profiles posed a challenge when it came to obtaining a profile with total watertightness in all the ducts. Since the material used for 3D printing (PLA) is porous, it was impossible to manufacture a completely watertight profile between all the ducts, affecting the characterization of the profile. After the optimization process of the orientation and the parameters used for printing, it was possible to manufacture suitable profiles to be experimentally tested in the wind tunnel (Figure 3).

Although the necessary tightness is not achieved, the profiles are valid for tests in the field of learning through practice by students. Therefore, the profiles are not valid to measure experimentally, although they are from an educational point of view.

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The main printing parameters for the profiles used were 0.15mm layer thickness, 50% infill (cubic pattern) and 1.2m wall thickness.

Figure 3: NACA 2412 airfoil 3D printing (28h 18’) (left) and assembled (right).

Experimental Aerodynamics results and discussion:

The aerodynamic profile models manufactured as described in the previous section, have been tested in the aerodynamic experimental facility at *CUD San Javier*, at the Spanish Air Force Academy. This installation is an open, subsonic wind tunnel, with a low level of turbulence, optimal for characterizing the aerodynamic behavior of the profiles, from the point of view of incompressible flow. This installation has been successfully tested in different scientific works, among which stands out (Serna-Serrano, López-Belchí, & Sánchez-Velasco, 2015).

The profiles have been assembled in a 1.2 x 0.3 x 0.4 m test section, equipped with a Pitot tube and static source, and a pressure scanner to measure the pressure distribution along the airfoil, as well as a type-K thermocouple, for temperature monitoring in the test section. The airfoil models are mounted vertically in the test section (Figure 4), coupled to a stepper motor that is controlled by a control and data acquisition software based on Matlab and Arduino, with a graphical interface (GUI), previously developed at *CUD San Javier* (Serna-Serrano et al., 2015).

Figure 4. Aerodynamic experimental facility during the testing of the symmetric airfoil.

The control software makes it possible to modify the angle of attack (AoA) of the airfoil during the tests, as well as to adjust different operating frequencies of the wind tunnel drive fan (from 0 to 50 Hz), which translates into different test air speeds. The test procedure is as follows:

1. The airfoil is installed in the tunnel, connected by a threaded rod to the stepper motor.
2. The Scanivalve hardware (equipment that scans the pressures of the different gauges) is started 30 minutes before the tests for heating up. The Pitot pressure acquisition equipment is also started.
3. The Arduino is started, which controls the stepper motor, as well as the PC where the acquisition and control software is installed. The system takes measurements over a 20 s interval and computes the average.
4. Next, the tunnel is started, indicating the fan frequency.
5. When steady flow is achieved (a few seconds), the acquisition is started, and measures are taken. The pressure and temperature values are averaged for 10 s. This corresponds to AoA = 0 (Angle of Attack).
6. The AoA is changed (every two degrees) and the measurement is repeated.
7. When the entire range of positive and negative AoA has been covered, the wind tunnel is stopped. A new fan frequency value is set, and the test is repeated.

This procedure was carried out with the two profiles tested (symmetric and curved) and the dimensionless pressures (pressure coefficients) were plotted against x/c (c being the chord of the profile), as well as c_L versus AoA. The results obtained prove that the behavior of 3D-printed models fits the linear trend predicted by incompressible flow theory (Anderson Jr, 1991), as well as the stall regions for both maximum and minimum AoA.

Main conclusions and future work:

It has been found that, through this Educational Innovation proposal, students acquire in a significant way and from their own experience, and through laboratory work, practical knowledge related to two different areas of the Industrial Organization Engineering degree. Likewise, the project helps them to understand the connection of the knowledge acquired between the subjects studied.

In addition, as an indicator of objectives compliance, a high degree of student satisfaction has been achieved. This will be conveniently evaluated through a survey that will be delivered to students after completing the activity.

It has been shown that, since this proposal is intended for students who have already taken the subjects involved, and who are highly motivated to carry out their Final Degree Project on a subject related to these areas of knowledge, the project schedule does not have to coincide with the academic schedule of these subjects.

The characterization of the profiles was carried out correctly but there are certain differences with the results available in the specialized bibliography of the NACA family, due to the method of manufacturing the aerodynamic profiles (3D printing with FDM technology) and the porosity of the material used (FDM) that caused communication between the internal channels.

Finally, it has been found that the use of additive manufacturing techniques is an option that provides wide possibilities for aerodynamic teaching, and that could be used in the future in multiple education studies. For example, it is proposed to continue this work line through the aerodynamic experimentation of new designs of wingtip devices (*winglets*) manufactured by 3D printing. In this way, the educational innovation proposal does not end with the current activities, but it will be possible to extend it in the long-term future with new generations of students.

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