

## Virtual and experimental aerodynamic study for student's lab

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### Abstract

*This paper presents an aerodynamics study of different flat shapes using a virtual wind tunnel. The results of the simulation using Comsol Multiphysics software consist of a field of air velocity distribution and one of the distributions of dynamic pressure values. Flat surfaces as triangle, rectangle and circle are compared. Drag coefficients are calculated for rectangle and circle. An experimental study is also done in the same conditions, in order to compute the drag coefficients. The values are about the same in the both cases-virtual and experimental. This is an important result concerning the e-learning teaching, in condition of Coronavirus restrictions. This virtual lab is an opportunity for students to understand the aerodynamics principles concerning the effect of wind on turbine blades. Also, it is an economical way to choose the optimal shape for blades to build an efficient turbine.*

**Keywords:** aerodynamic study, virtual lab, e-learning teaching, drag coefficient

### 1. Introduction

Nowadays education requires quick changes and adaptations due to many reasons. First of all, the advances of technology and its inclusion in the daily activities that contributes to the overall awareness of learners' intention to use new educational resources in mixed educational contexts (Lazar et al., 2020) makes the need of specialists in the Sciences' field more acute. Research is a key determinant for education (Lazar, 2019) due to its contribution to understanding the predictors of students' academic performances. According to The Organisation for Economic Co-operation and Development (OECD), we can expect that an average of 35% of the youth from the member countries will graduate a form of higher education until reaching the age of 30 years old (OECD, 2006). The problem stressed by the report is that only a quarter of them would choose a scientific or technological career. It is obvious that this percentage is far from insuring the request of the labour market. On the other hand, the context brought by the COVID 19 crisis has shown that the importance of the e-learning will increase for reasons of health security. An UNESCO study shows that most of European countries choses to close the schools and to provide online classes for the students (<https://unesdoc.unesco.org>). These facts lead to the conclusion that educational tools for a better e-learning of the Science, Technology, Engineering and Mathematics (STEM) topics are needed (Lazar et al., 2020). A lot of studies provide different methods and tools for these purposes (Berlic and Constantinescu, 2004, Marciuc et al., 2016, Ion and Voinea 2018, Marciuc and Miron 2018, Mihalache and Berlic 2018, Danesc and Voinea, 2019, Dinu et al., 2019, Voinea et al. 2019, Chiriacescu et al., 2020).

The aim of this paper is to compare the results of an experimental laboratory and a virtual one, in the study of some physical phenomena, to switch between them, if the educational conditions require it. Thus, we analyzed the behaviour of different geometrical flat shapes (rectangle, triangle, circle), placed in a stream of air both in virtual and experimental labs. We have also calculated and compared the drag coefficient, obtained from the experimental values and with those obtained from computer simulations. The results can be further used to investigate the possibility to build

real models of aerodynamics shapes used as turbine blades (Oukassoua et al., 2019, Chiriacescu et al., 2021).

Moreover, this approach may be developed to create a supply of virtual laboratories that can be complementary used with the actually ones.

## 2 Methods

### 2.1 Virtual study

From the fluid dynamics theory, the motion of the airflow in tunnels can be described by standard  $k-\varepsilon$  turbulence model, utilized in COMSOL Multiphysics. We used a complex model for simulation the turbulent flow model of an incompressible fluid SST (Monter's Shear Stress Transport). This model describes both the condition at a distance from an obstacle ( $k-\varepsilon$  model) and near the studied shapes ( $k-\omega$  model) in the CFDM module (<https://doc.comsol.com/5.4/doc/com.comsol.help.cfd/CFDMModuleUsersGuide.pdf>).

Based on this model, one may study the behaviour of surfaces of different shapes when they are placed in an air stream, being able to make a comparison between their behaviour as function of shape, under the same conditions.

The surfaces were built in FreeCAD (<https://www.freecadweb.org>) and imported into COMSOL. To create the simulation, the aerodynamic tunnel is built (Fig. 1a) in the shape of a parallelepiped (300 mm on  $O_x$ , 200 mm on  $O_y$  and  $O_z$ ). The parallelepiped is centrally aligned, the center of the coordinate system being the geometric center of the parallelepiped.

We defined the surface through which air enters and the initial wind speed along the  $O_x$  axis with the value of 10m/s ("Inlet" command), the surface through which the air exits ("Outlet") and the tunnel walls, the four remaining faces, as well as opaque surfaces ("Symmetry"). To the shape of study, it is assigned the role of obstacle with the command "Wall". It is considered a thin solid body, with a thickness of 1.5mm, with an area of about 1600 mm<sup>2</sup>. The meshes are further defined (Fig. 1b) and there are small tetrahedral figures that establish a network inside and on the surface of the material. In the nodes of the network we calculated the physical quantities of interest. For air, we choose a lower density of knots ("Coarser"), and for the surface of the body a higher density ("Normal" or "Fine"). In addition to the dimensions, we also used other physical quantities, such as wind speed, materials used (air for fluid, iron for body), boundary conditions and the physical model. Figure 2 illustrates the different settings that are made after importing the model to be studied. Once the settings are set, the program is run with the "Compute" command. The results of the calculations consist of a field of air velocity distribution (Fig. 2) and one of the distributions of dynamic pressure values.

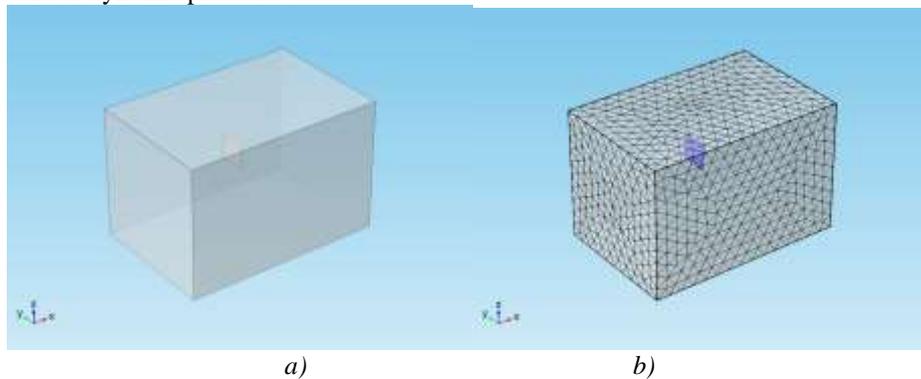


Figure 1.a) The virtual aerodynamic tunnel with the studied shape inside b) Meshes

The Comsol program allows the calculation of the normal pressure force on the contact surface by integrating the forces acting on its infinitesimal areas.

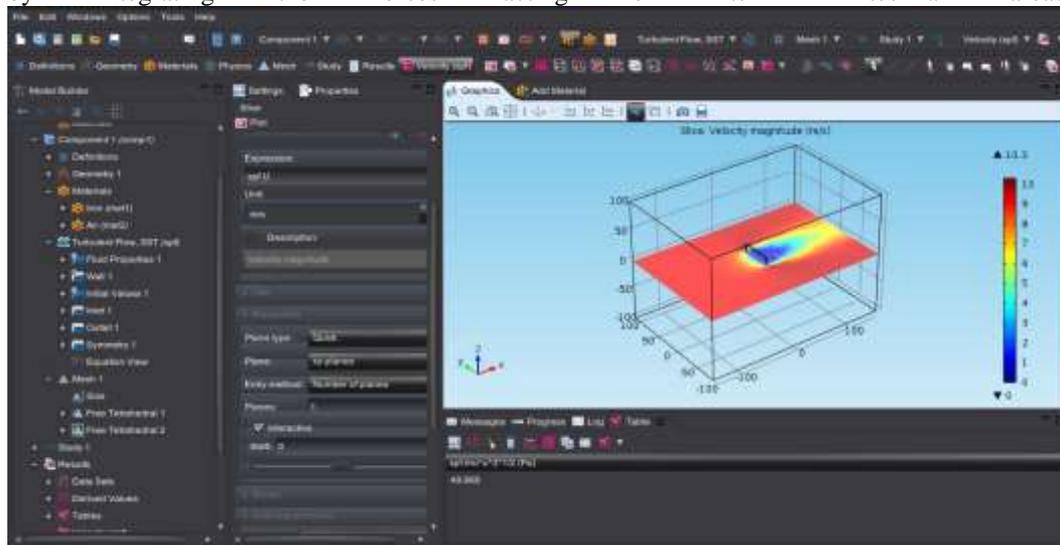


Figure 2. Working panel of COMSOL Multiphysics. In the right window the velocities field for a square plate is shown.

## 2.2 Experimental study

The design of the experimental device is presented in Figure 3 and consists in a dynamometer to measure the normal pressing force on the shape for study (disc or rectangle with the same sizes as in the virtual experiment) and mounted on the stand, the Pitot tube to measure the dynamic pressure and an aerodynamic tunnel. The surfaces of different shapes are placed in front on the aerodynamic tunnel, which can be set to different values of speed. The wind speed is measure with the anemometer.

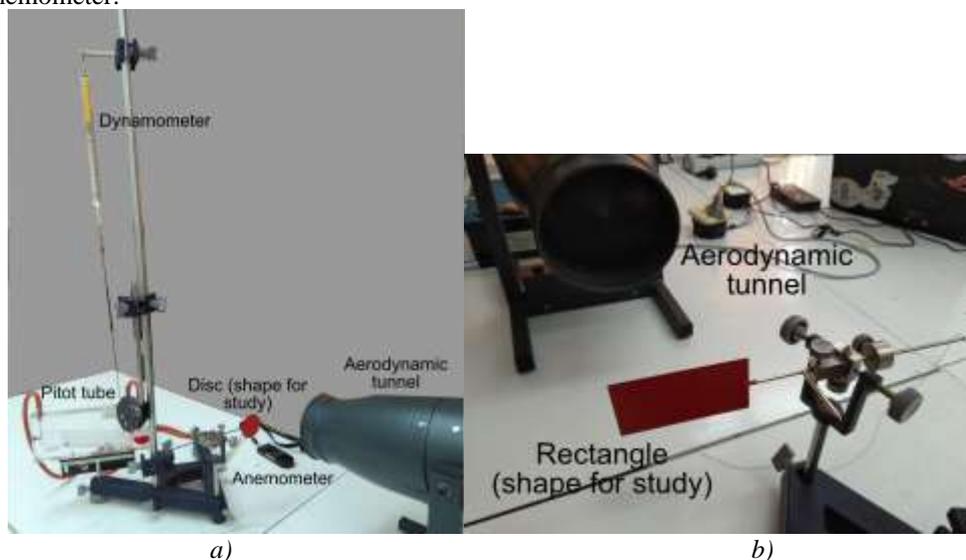


Figure 3. a) Experimental setup – overall view; b) Experimental setup - detail

### 2.3 Drag coefficient

The drag coefficient  $C_d$  is a proportionality constant and describes the „aero-dynamic quality“ of the body: the higher the aerodynamic quality of a body, the lower  $C_d$  and thus the corresponding drag force (Gasch and Twele, 2012).

The dependence of the resistance force on the dynamic pressure from the relationship [1] has been studied.

$$[1] \quad F = C_d \cdot p_d \cdot S$$

For a certain surface  $S$ , the resistance force has a linear dependence on the dynamic pressure. From the slope of the graph, we calculated the coefficient  $C_d$ . The dynamic pressure varied by the values of the wind speed from aerodynamic tunnel.

### 3. Results

#### a) Simulation of aerodynamic of flat shapes placed in virtual wind turbine

The geometric shapes are placed in a virtual wind tunnel built in Comsol, perpendicular to the wind direction. The wind speed is considered to be 10 m/s. The program shows the pressure field and the trajectories of the air particles. As seen in Fig. 4, the dynamic pressure field is visualized by color code, the corresponding values being related to the normal atmospheric pressure - 1atm. The red areas represent higher pressures and the blue ones pressures lower than atmospheric pressure.

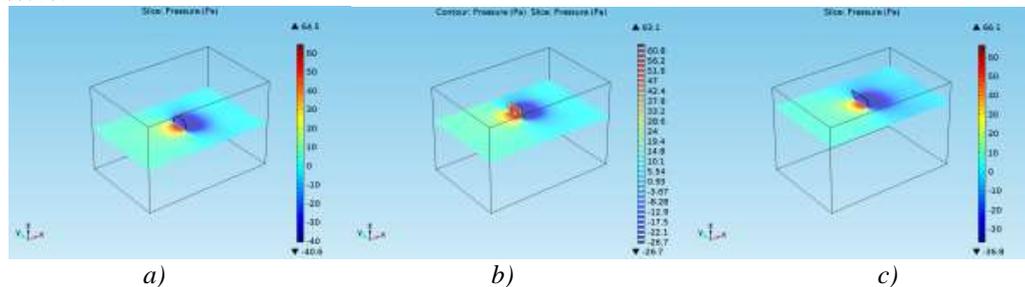


Figure 4. Pressure field for: a) disk shape; b) square; c) triangle; the colors legend shows the pressure difference with respect to the atmospheric pressure in Pa.

A qualitative analysis of the shape influence on the air flow may be performed by the students observing the color according with the dynamic pressure values in the vicinity of the body. The program allows to change the plane of the field, so a more detailed image can be obtained, as in the tomographic imaging. Even though in the central positions the pressure field is almost the same, when we get closer to the border of the shape, certain differences can be observed. A quantitative study may be made, following the values of the dynamic pressure that can be obtained in any space point of the space inside the “tunnel”. It is also possible to analyze how the wind speed changes in different regions in the vicinity of the obstacle (Fig. 5). On the right side of the image the color legend is displayed - each color being assigned to a velocity value. The air particles trajectories are shown in pink color. It can be seen that behind the surfaces, the wind speed significantly decreases, to less than half of the initial value, regardless of the studied shape.

The velocity field distributions behind the obstacle show a significant deviation of the air particle trajectories in the vicinity of the shapes’ outline and higher values of speed than in the middle part, corresponding to the pressure variations.

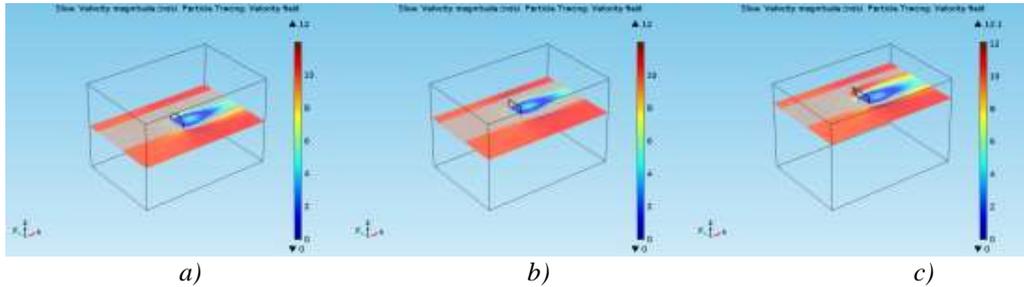


Figure 5. Velocities field for a) disk b) square; c) triangle; the colors legend indicates speed in m/s and pink color is used to show the airflow trajectories.

From the analysis of the velocity field and the trajectories of the air particles, the students can understand how the effect of rotation of a compact surface placed in a stream of air occurs. The analyze of the particles trajectories represents a useful method to understand the aerodynamics of different shapes. For example, we can see in Fig. 5c) that the air trajectories are different close to the sides of the triangle, as this shape has a different behaviour in wind than rectangle and disk.

We calculated the normal drag force on the contact surface for rectangle and disk from the simulated values of the pressure, in order to compare with the experimental ones. The variation of this force on dynamic pressure is shown in Fig. 6. The dependence is linear as in equation [1]. From the statistical analyses, we evaluated the slope of the graph and from equation [1] we computed the drag coefficient. We obtained a value of 0.92 for  $C_d$  in case of the disk shape and 1.09 for the rectangle.

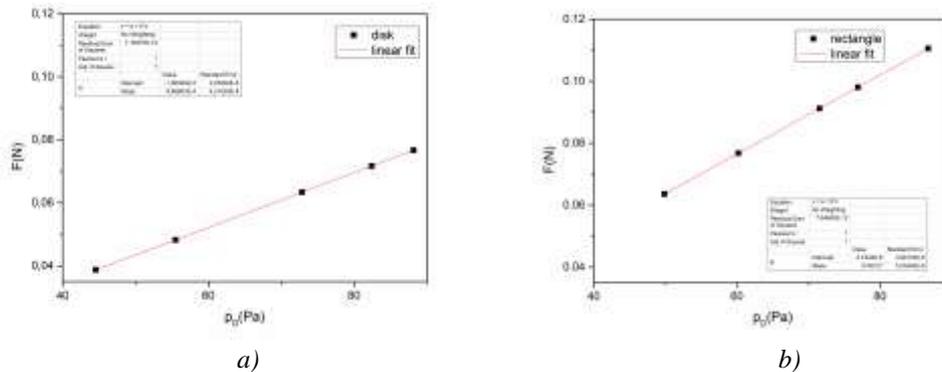


Figure 6. Drag coefficients-simulating values a) Disk ( $C_d=0.92$ ); b) Rectangle ( $C_d=1.09$ )

From experimental results, the linear fit of the data give the values for the drag coefficient: 0.91 for the disk and 1.34 for the rectangle. The experimental values have some errors, as we expected, but the statistical analyses indicated a good linear fit (Fig. 7).

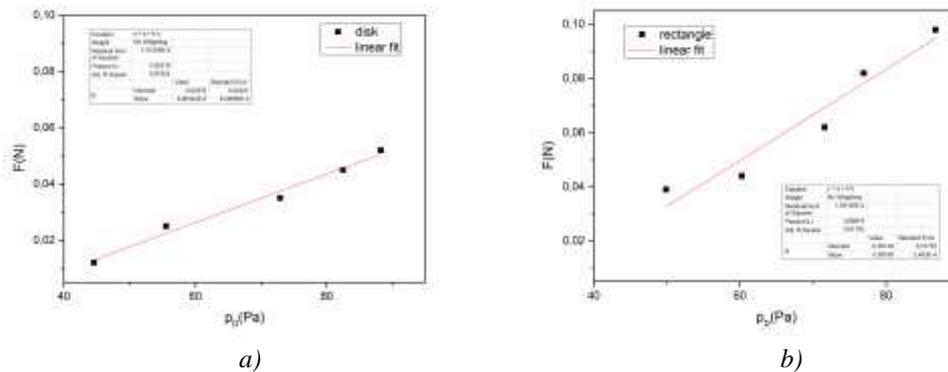


Figure 7. Drag coefficients- experimental values: a) Disc ( $C_d=0.91$ ); b) Rectangle ( $C_d=1.34$ )

The values obtained in literature for the drag coefficients are 1.11 for the circular plate (disk) and 1.10 for the rectangular one (Gasch and Twele, 2012), so the results obtained from both virtual and real experiment are quite close to these values.

#### 4. Conclusions

The analysis of the behaviour of bodies with different geometric shapes in the virtual wind tunnel is a simple method that does not require special resources leading to a better understanding of the physical principles used in fluid mechanics, in our case showing how the turbine blades are working.

We demonstrated that the virtual experiment can be a good complement for the real ones, held in laboratories. Moreover, some more features, as pressure and velocity fields and the trajectories of air particles (like the smoke used in real aerodynamic studies) are very visible in computer simulation. As long as it approximates very well the reality, those images can be used for aerodynamic studies. In this way, depending on the simulation results, different shapes and sizes can be chosen to build real models for blades that can be physically studied in laboratory conditions. On the other hand, it can be a good starting point for further studies and can offer a better image of what can expect to obtain from real experiments. Moreover, due to the widely use of e-learning due to isolation conditions, the virtual laboratory can partially replace the experiment held in lab. As the nowadays youth are very attracted by the new technologies and computer applications, this kind of virtual experiments can be very challenging, attracting them towards STEM studies.

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