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Mechanical engineering with solidwork flow simulation improving and supporting undergraduate student learning in mechanical engineering courses: Fluid dynamic course

Youssef Kassem*, Near East University, Mersin 10, Nicosia 99138, Turkey
Ramzi Asteg Faraj, Near East University, Mersin 10, Nicosia 99138, Turkey
Huseyin Camur, Near East University, Mersin 10, Nicosia 99138, Turkey

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Abstract

The computer-aided design programs such as Solidwork flow simulation (SWFS) provide powerful, engaging, hands-on software to understand and develop designs for the real world. SWFS can be considered as a virtual laboratory. The purpose of this study is to show that using SWFS will help the undergraduate students to understand the concepts of fluid dynamic course in the Mechanical Engineering Department. This paper presents an example of the effect of both the temperature and density on the stream flow characteristics around a vertical axis wind turbine using SWFS. Moreover, the use of the SWFS in engineering education is shown by an important experiment taken from the field of mechanical engineering.

Keywords: Fluid dynamic, mechanical engineering, SWFS, virtual laboratory.

*ADDRESS FOR CORRESPONDENCE: **Youssef Kassem**, Near East University, Mersin 10, Nicosia 99138, Turkey.
E-mail address: yousseuf.kassem@neu.edu.tr / Tel.: +90 (392) 2236464

1. Introduction

The designing process is becoming more demanding and complex. Many empirical studies point out that a structured, goal-oriented design process is mandatory for an innovation success (Leon, 2009). In designing a product, laboratories play the crucial role of testing the product to verify its quality, safety and stability at each stage of the manufacturing process (Signore & Jacobs, 2017). Laboratories are equipped with real working instruments and devices (Zubia & Gomes, 2007) and such equipment has limited lifetimes, thus requiring repair and maintenance (Ibrahim, 2011).

Despite the many real advantages of laboratories, they have some serious disadvantages. One of the biggest disadvantages of engineering laboratories is the cost of setting up a laboratory, the cost of maintaining an existing laboratory and the cost of carrying the experiments (Daineko, Dmitriyev & Ipalakova, 2016; Diwakar, Poojary & Noronha, 2012; Ibrahim, 2011).

As a solution to the problems associated with laboratories, virtual laboratories are used as an alternative or a supplement to the physical or real laboratories (Chien, Tsai, Chen, Chang & Chen, 2015). Computer-aided design (CAD) software is considered as virtual laboratories software. CAD can be defined as the use of a computer system to assist in the creation, modification, analysis or optimisation of the design (Narayan, Rao & Sarcar, 2008). The goal of CAD software is to assist innovators, inventors, designers and process developers in their creative performance, with the expectation of changes in paradigms through the use of CAD software (Cohn, 2010). Some examples of general CAD in mechanical engineering are componential flow dynamic, SolidWork and so on (Leondes, 2001).

This paper describes solidwork flow simulation (SWFS) software that can be used as a virtual engineering laboratory in mechanical engineering courses like fluid dynamic course. The type of simulation and its advantages and disadvantages are described briefly. In addition, the use of the SWFS in mechanical engineering education is shown by an important experiment/simulation results taken from published scientific articles. Moreover, in order to improve understanding of the concepts of the fluid dynamic course, a simple project was given to the students who took this course to study how the ambient temperature and the pressure effect on the result of streamflow characterises around the vertical axis wind turbine, without having to use really expensive components such as wind tunnel, sensors and special camera for showing the flow around the objects.

2. Virtual laboratory

Laboratories are an integral part of any engineering course (Ibrahim, 2011). A virtual laboratory (VL) system is a distributed environment providing remote access to various kinds of scientific equipment and computational resources (Meyer, Davoli & Zappatore, 2010). Computer Aided Designing or VL applications have been applied in the world in order to reduce the number and cost of experiments and obtain more information before designing subjects.

The Computer Aided Designing Programs provide powerful, engaging, hands-on software to understand and develop designs for the real world (Ibrahim, 2011). The integrated 3-D software like Autodesk and SolidWork makes design development easy to learn, easy to teach and exciting to use. The 3-D software is applicable and capable of achieving a part designing, simulation and prototyping.

2.1. Solidwork flow simulation

Solidwork is a mechanical design automation software package used to build parts, assemblies and drawing that takes advantage of the familiar Microsoft Windows graphical user interface (Planchard, 2018). Solidwork is an easy to learn, design and analysis tool (Solidwork simulation Xpress, SolidWorks Motion, SWFS, etc.) which makes it possible for a designer to quickly sketch 2-D and 3-D concepts, create 3-D parts and assemblies and details 2-D drawing (Matsson, 2014).

SWFS is a fluid flow analysis add-in package that is available for SolidWorks in order to obtain the solution to the full Navier–Stokes equation that governs the motion of a fluid (Matsson, 2011).

3. Course description: Fluid mechanics

Fluid mechanics is the branch of science concerned with moving and stationary fluids. Given that the vast majority of the observable mass in the universe exists in the fluid state, whose life as we know it is not possible without fluids and the atmosphere and oceans covering this planet are fluids, fluid mechanics has unquestioned scientific and practical importance. Its allure crosses disciplinary boundaries, in part because it is described by a nonlinear field theory and also because it is readily observed. Mathematician, physicists, scientists, engineers of many types and even artistes have been drawn to study, harness and exploit fluid mechanics to develop and test formal and computational techniques, to better understand the natural world and to attempt to improve the human condition (Douglas, 2011).

Fluid mechanics concerns itself with the mathematical description of the motion of physical bodies, binding together the concepts of force, momentum, velocity and energy to describe the behaviour of macroscopic objects (Gibiansky, 2011).

Due to its consistent success, classical mechanics has been widely studied by physicists and mathematicians alike. Even though it must rely on quantum mechanics for small-scale motion and special relativity for high-velocity travel, it is considered a mostly complete and solved set of theories. However, there is still one problem in classical mechanics that remains unsolved: the solution in fact, whether a solution is guaranteed to exist to the general case of the Navier–Stokes equations for fluid dynamics is unknown.

The Navier–Stokes equations, developed by Claude-Louis Navier and George Gabriel Stokes in 1822, are equations that can be used to determine the velocity vector field that applies to a fluid, given some initial conditions. They arise from the application of Newton’s second law in combination with a fluid stress (due to viscosity) and a pressure term. For almost all real situations, they result in a system of nonlinear partial differential equations; however, with certain simplifications (such as 1-D motion), they can sometimes be reduced to linear differential equations. Usually, however, they remain nonlinear, which makes them difficult or impossible to solve; this is what causes the turbulence and unpredictability in their results.

4. Examples

The basic definition of fluid dynamics is the science of fluid flow, compressible flow, in which both density and temperature changes become significant. Therefore, the fluid dynamic course aims to show the fluid motion and the effect of temperature and density on the characteristics of stream flow around the object. The study of such flows where both density and temperature changes associated with pressure change become appreciable is called gas dynamics. For example, the interaction between the atmospheric boundary layer and the wind turbines needs to be better understood. One of the wind rotors of a vertical axis, Savonius wind rotor was developed by a Finnish engineer, Sigurd Savonius, in 1925. Savonius wind rotor that is composed of two vertical half cylinders is also considered to be a kind of wind rotor. It is simple in structure and a drag-type turbine (Hemami, 2012; Mathew, 2006). Computer-aided designing software have been overwhelmingly used in the study of streamflow characteristics around Savonius wind rotor like ANSYS (Nasef, El-Askary, AbdEL-hamid & Gad, 2013; Wenehenubun, Saputra & Sutanto, 2015) and SWFS (Driss et al., 2015; Driss, Mlayeh, Driss, Maaloul & Abid, 2016; Frikha, Driss, Ayadi, Masmoudi & Abid, 2016;).

An example of mechanical engineering simulation is given in this section given as project for undergraduate students to show the importance of flow simulation and also to show how easily simulation can be carried out using a commercial simulation package such as SWFS.

In this example, the stream flow characteristics in terms of velocity and pressure around a small vertical axis wind turbine farm have been studied. Figure 1 displays a simple Savonius wind turbine, vertical axis, problem as it would appear in a textbook/scientific published article.

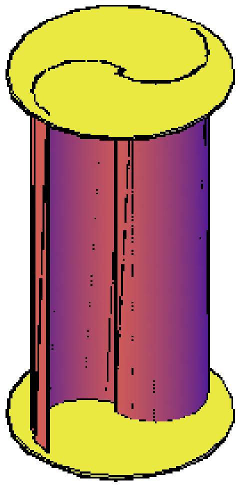

Figure 1. Simple design for Savonius wind turbine

As mentioned before, the main general equations in the fluid dynamic course are called governing equations: continuity equation, Navier–Stokes equation and energy equation. The SWFS focuses exclusively on helping students solve problems (simple and complex problems), observing the streamflow characteristics around of the object, which are one of the main parameters for designing wind turbine, car, airplane and so on.

In general, SWFS is based on the resolution of the Navier–Stokes equations in conjunction with the standard *k*–*ε* turbulence model. The Navier–Stokes equations governing the flow of air are obtained from the continuity equation, the equation of momentum, the transport equation of turbulent kinetic energy (*k*) and the transport equation of dissipation rate of turbulent kinetic energy (*ε*).

The transport equations of the turbulent kinetic energy *k* and the dissipation rate of the turbulent kinetic energy *ε* are written as follows:

The governing equations can be expressed as follows in the Cartesian system. The continuity equation is written as follows:

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u_i)}{\partial x_i}=0 \tag{1}$$

The momentum equation is written as follows:

$$\frac{\partial(\rho u_i)}{\partial t}+\frac{\partial(\rho u_i u_j)}{\partial x_j}=-\frac{\partial P}{\partial x_i}+\frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_j}{\partial x_j}+\frac{\partial u_j}{\partial x_i}-\frac{2}{3}\delta_{ij}\frac{\partial u_i}{\partial x_i}\right)\right]+\frac{\partial\left(-\rho\overline{u_i' u_j'}\right)}{\partial x_j}+F_i \tag{2}$$

The transport equation of the turbulent kinetic energy *k* is written as follows:

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_i}\left(\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right)+\tau_{ij}^{R}\frac{\partial u_i}{\partial x_j}-\rho\varepsilon+\mu_t P_B \tag{3}$$

The transport equation of the dissipation rate of the turbulent kinetic energy *ε* is written as follows:

$$\frac{\partial(\rho\varepsilon)}{\partial t}+\frac{\partial(\rho\varepsilon u_i)}{\partial x_i}=\frac{\partial}{\partial x_i}\left(\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_i}\right)+C_{1\varepsilon}\frac{\varepsilon}{k}\left(f_1\tau_{ij}^{R}\frac{\partial u_i}{\partial x_j}+C_B\mu_t P_B\right)-f_2 C_{2\varepsilon}\frac{\rho\varepsilon^2}{k} \tag{4}$$

As described in previous sections, we studied the effectiveness of the CAD software in helping students to understand the concept/theories of fluid dynamic course. As an example, streamflow characteristics around one and two Savonius wind turbines are shown in Figures 2 and 3, respectively. From these examples, the student observed the velocity, pressure and temperature distribution around the turbine.

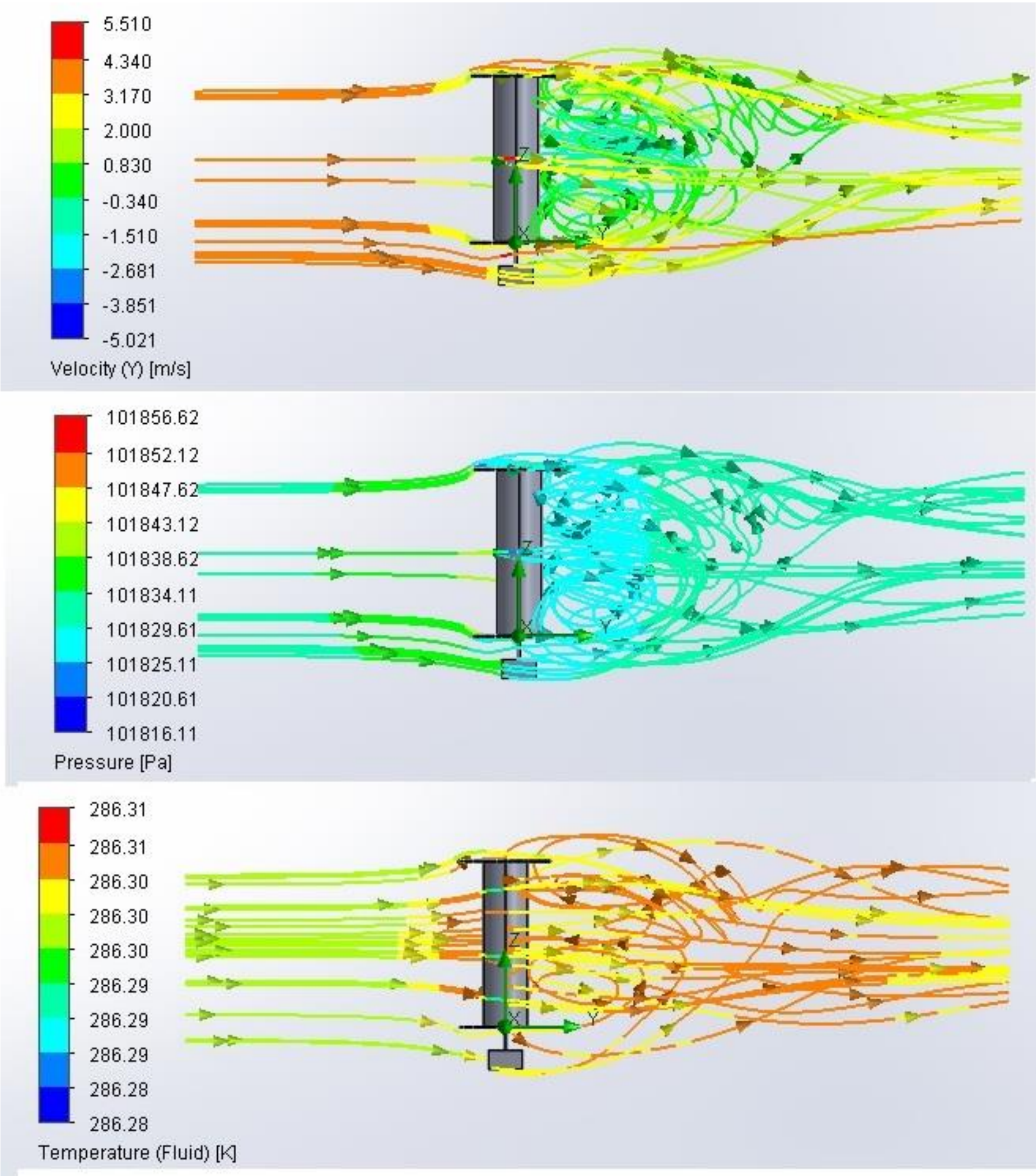

Figure 2. Streamflow distributions output around one Savonius wind turbine (average temperature, pressure and density values are recording in the summer season for Cyprus)

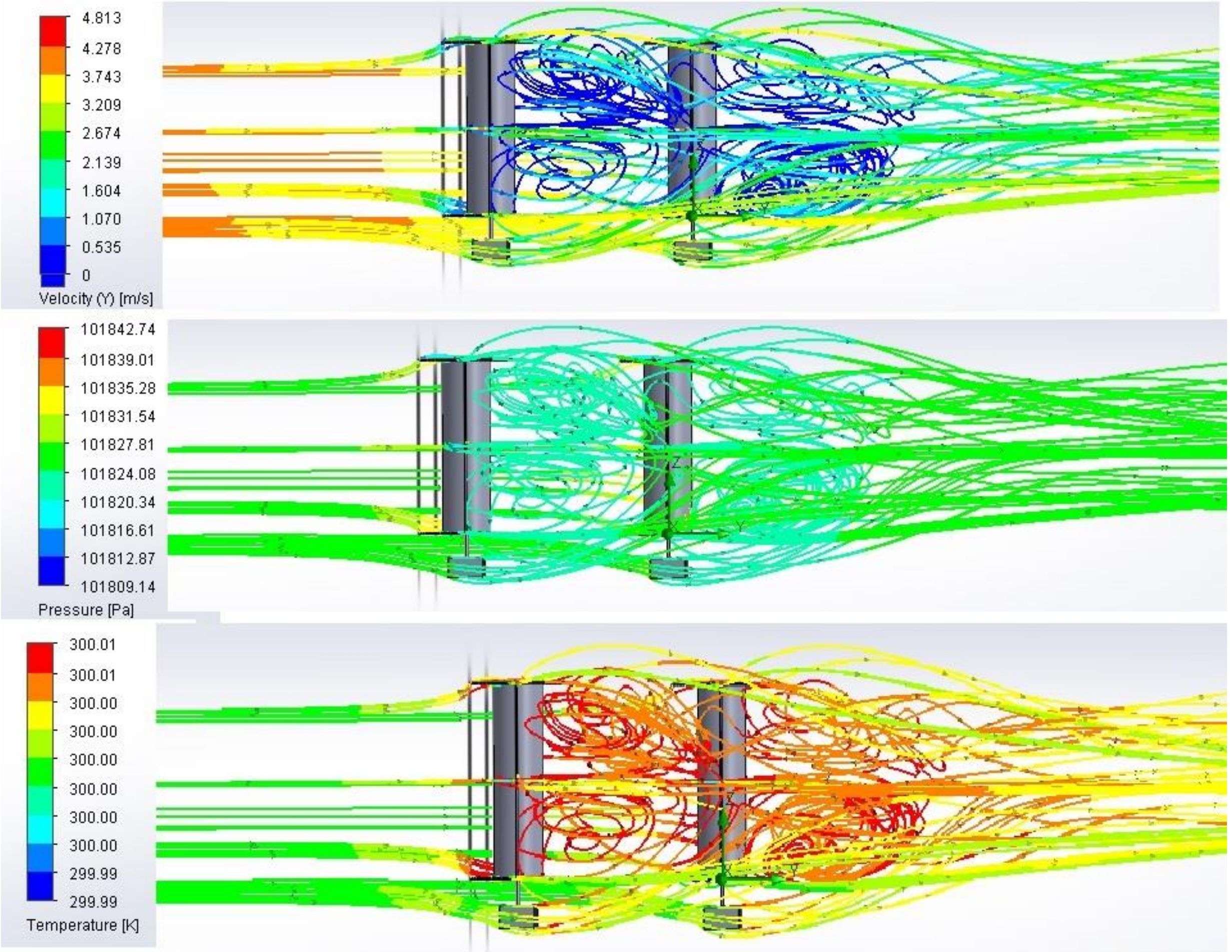

Figure 3. Streamflow distributions output around two Savonius wind turbine (average temperature, pressure and density values are recording in the summer season for Cyprus)

5. Conclusions

In this paper, Computer-Aided Designing software is one of the most important software in the Mechanical Engineering Department. SWFS is one of the commercial software can be suitable for learning and understanding the concept of fluid dynamic course. Also, it can provide students learning to solve complex engineering problems on their efforts. Although SWFS does not replace real physical laboratories, they can be very useful in teaching the working principles of various engineering instruments and devices.

In summary, the SWFS described here has demonstrated that students can be given sufficient feedback, while working without using a replace real physical laboratories, to understand the flow characteristics around objects (like a car and wind turbine) and to test the object under the environmental conditions before designing it.

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