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Augmenting Fluid Dynamics Instruction with 3-D Printers and Wind Tunnel Instrumentation to Improve the Effectiveness and Efficiency of Instruction in Aerodynamics

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Abstract

Wind tunnels are used in engineering technology programs to impart and reinforce instruction in aerodynamics: generally, part of fluid dynamics course. Students learn the key principles of lift, drag, and aerodynamics forces as it pertains to fluid structure interaction. They then setup several geometries and structures in the wind tunnel to evaluate their aerodynamic effectiveness and compare findings of their experimental evaluation to that of theoretical learning.

Strategies were developed where students integrate technology—3D printing and wind tunnel instrumentation—to learn key aerodynamics principles and related energy components in a thermal and fluid systems course. Students learned aerodynamics concepts in the course and how it affects wind turbine energy extraction. In labs, the students subsequently mount a 3D printed wind turbine blade in a wind tunnel to evaluate its aerodynamic effectiveness.

Wind tunnel instrumentation and 3D printer augmented fluid dynamics instruction and labs were examined. It was hypothesized the technology could be used to rapidly generate designs of energy extraction components in laboratory-based fluid dynamics and aerodynamics education. As a result, in addition to ensuring that learning was at least as effective, the instructional process would be more efficient, than the non-augmented instruction. This paper presents the results of student performance and comparisons of the augmented and non-augmented instruction with respect to 3D printing and wind tunnel experimentation.

Introduction

Due to ease of rapid prototyping, 3D printing techniques are increasingly being adopted in academic settings for low cost generation of educational and experimental models. Many 3D printers are available now that can print a variety of shapes and sizes in different materials. Instructors can now use 3D printed replicas of actual shapes for class room teaching and demonstration. Some of these models are also used by instructors for testing and validation of processes and validation of science. Some of the educational experts have used 3D printing to augment learning and have reported their findings.

Ishutov [1] and his colleagues demonstrated how 3D printing was used in geoscience education and research. They remarked that 3D printing of "near-identical rock proxies" helped students learn the "model of terrains, fossils, and crystals. The integration of digital sets with 3D printed geomorphologies supports communication for both societal and technical objectives". Mohammed [2] discussed the benefits of 3D printing in oceanographic studies and reviewed different 3D printing technologies to study "real-life application related to oceanography”. They remarked that 3D printing allowed rapid prototyping of complex ocean environment and organism. The observed that “3D printing technologies offer exciting opportunities for rapid prototyping of complex and customized models at low cost”. Zhang [3] and his colleagues reported the application of 3D printing to enhance military education specifically augmenting military equipment theoretical education.

3D printing has been used to augment learning in the fluid dynamics and aerodynamics using wind tunnel and related experimentation [4,5,6,7]. Matsson [4] and his colleagues incorporated 3D printing in undergraduate engineering student learning process where in a NACA wing section was 3D printed and tested in a wind tunnel and aerodynamic results were compared to CFD results using Ansys. They reported that the project was a good example of merging class room learning with practical example creating an effective learning environment. Linke [5] and his colleagues reported on the development of including 3d printing in an active project based undergraduate curriculum wherein airfoil and nozzle shapes were 3D printed for teaching gas dynamics. They remarked that the tools provided “novel hands-on” interdisciplinary teaching instrument for aerospace and mechanical engineering students. Kroll and Artzi [7] used wind tunnel models to enhance learning of senior year aerospace engineering students. They printed two aircraft models and tested the models in a sub-sonic wind tunnel. They then compared the wind tunnel results to analytic performance. They reported that the models yielded satisfactory results and resulted in cost savings in an environment of tight academic budget constraints. They observed that “conducting real-wind-tunnel testing contributes significantly to the education experience of the students”. They also stated that “research in aerospace techniques can also be served by the rapid prototyping technique of making quick, low-cost wind-tunnel models”.

Wind tunnel and 3D printing has been used to augment learning about wind energy harvesting techniques and efficiency. Chiou [8] and his colleagues incorporated 3D printing in green manufacturing laboratory specifically determining wind turbine efficiency using 3D modeling and printing. They customized blades were experimentally used by the students to determine optimum angles to operate wind turbines. They remarked that “Learning the 3-D printing technology offers students a greater ingenuity of information and promotes students’ interdisciplinary skills in integration of 3-D printing with renewable energy systems”.

In this paper, strategies were developed where students integrate technology—3D printing and wind tunnel instrumentation—to learn key aerodynamics principles and related energy components in a thermal and fluid systems course and student performance with regards to augmented instruction was compared to non-augmented instruction.

Nomenclature

L_s	Lift force (N)
ρ	Density of air (kg/m^3)
U	Wind velocity (m/s)
d	Airfoil chord length for airfoil
CL_A	Non-dimensional lift coefficient per angle of attack
dl	Incremental length of the blade (m)

Model and Method

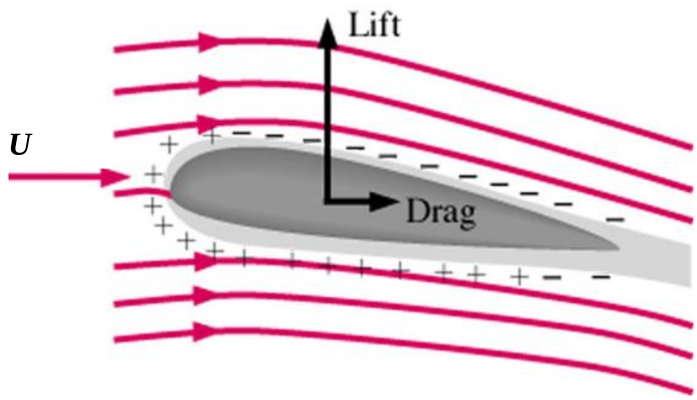

Figure 1: Airfoil cross-section with aerodynamics forces. Courtesy Cengel [9]

Because of geometric differences, the lift force at the aerodynamic centre of any airfoil section (Figure 1) is the result of a pressure difference between the upper and lower surface of the airfoil when the air flows past that airfoil section. The camber of the airfoil produces varying velocities at the top and bottom surface of the airfoil. The pressure difference when multiplied by the area of a section of the blade of length produces the lift force of dL. The lift coefficient is a non-dimensional term that captures the geometry of the airfoil impacted by lift forces.

$$dL = \frac{1}{2}\,\rho * U^2 * d * CL_A * dl \quad (1)$$

The total lift for the main blade is obtained by integrating the lift values for the entire blade length exposed to wind. The lift is dependent on the angle of attack which is the angle that the airfoil chord makes with the chord axis.

A DU-25 airfoil (Figure 2) commonly used in the wind turbine industry was used to as a cross-section of the wind turbine blade which was extruded to model the blade (please see Figure 3). The 3D model of the blade was subsequently 3D printed by the students with device to mount the blade in the wind tunnel (please see Figure 4). A fusion 3D printer (please see Figure 5) was used to 3D print the wind turbine model.

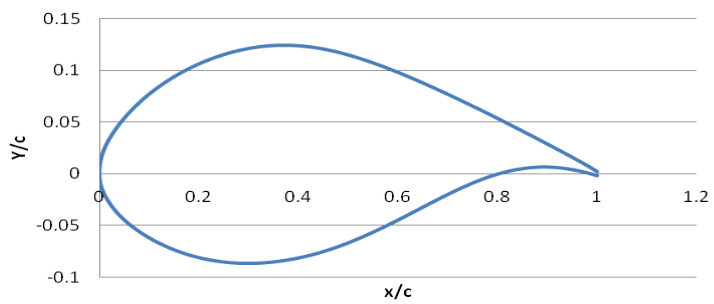

Figure 2: DU airfoil and blade cross-section

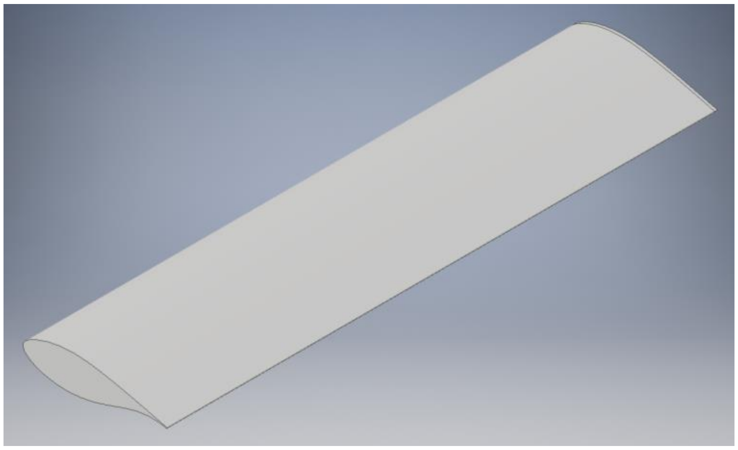

Figure 3: 3D Model of Blade extruded from DU airfoil

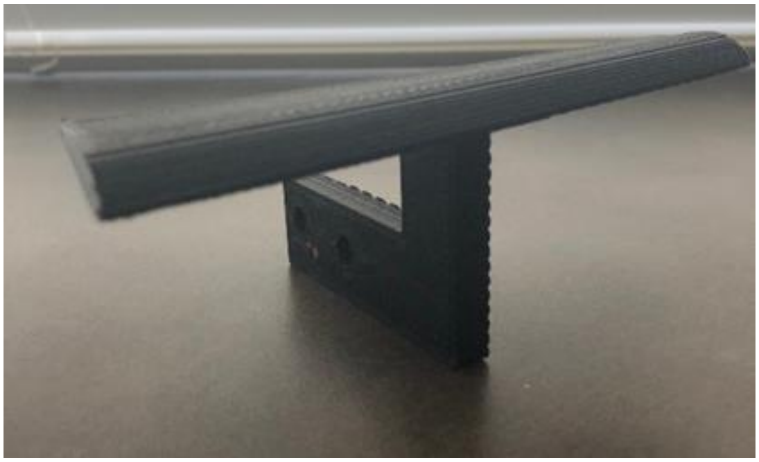

Figure 4: 3D Printed Model of Blade

Figure 5: Fusion 3D printer used to print the 3D Blade. Courtesy fusion 3D printer [10].

Wind Tunnel Experimentation

A wind tunnel was used to mount the 3D printed blade to understand lift and how the angle of attack can be manipulated to change the lift and optimize efficiency. Figures 6 and 7 depict the wind tunnel with air entry, test bed, and air exit. Figure 8 depicts load sensor for measuring the lift forces and device for adjusting the pitch angle settings and the computer interface (LabView) with the wind tunnel for force measurements.

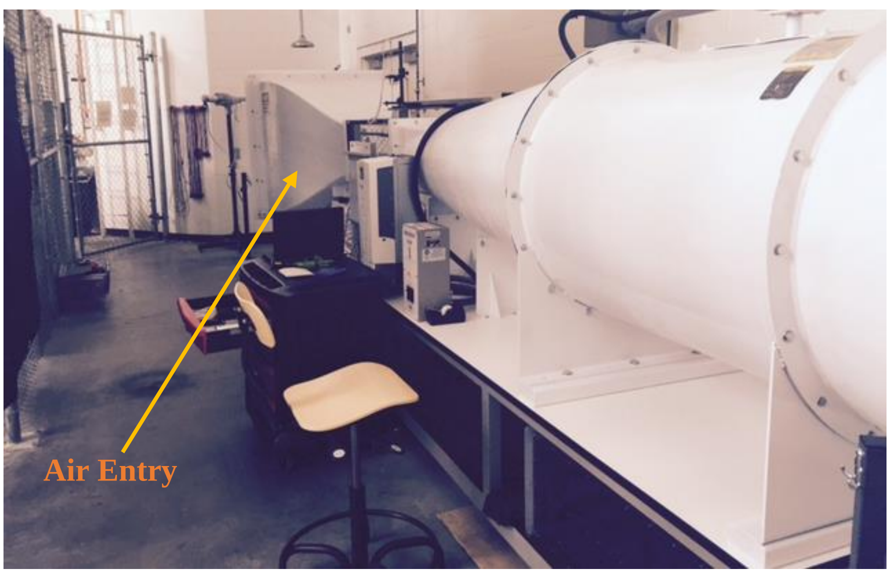

Figure 6:Wind Tunnel showing air entry

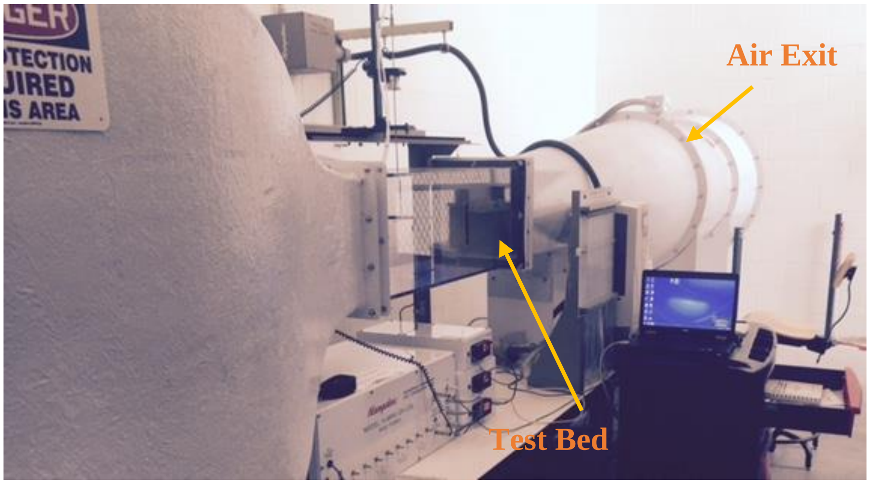

Figure 7 :Wind Tunnel air exit and test bed

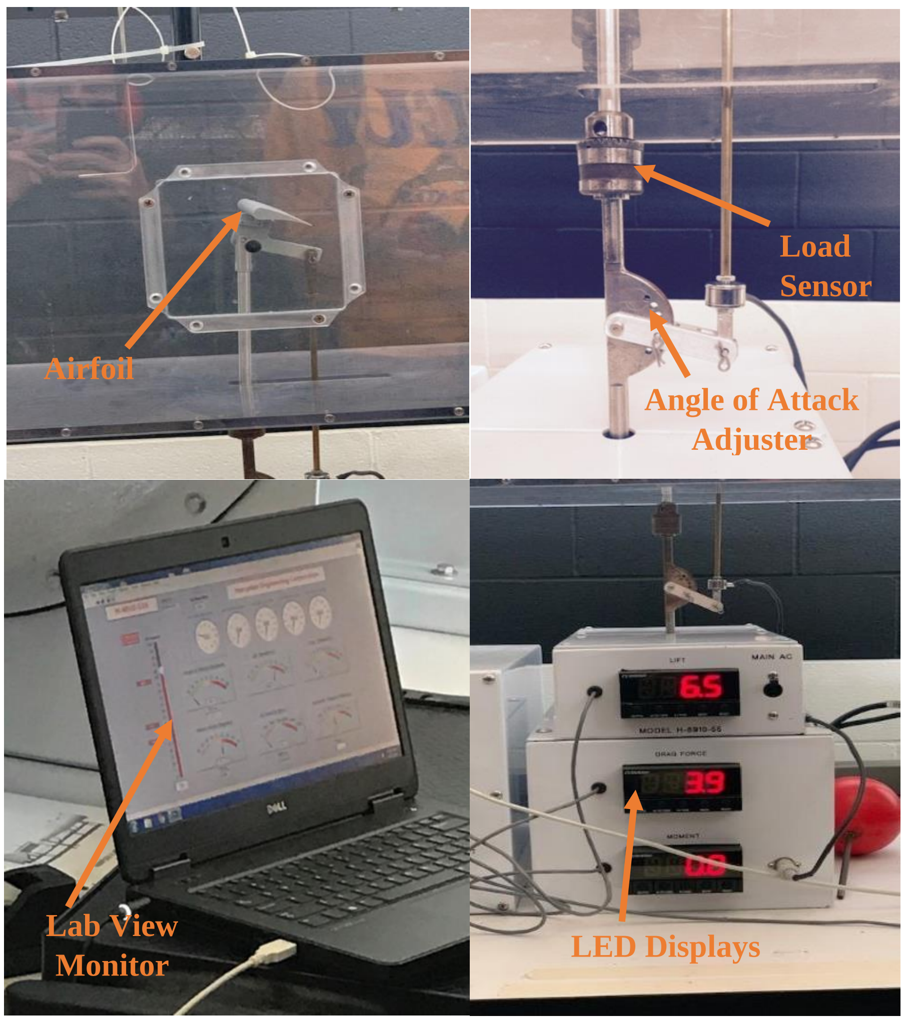

Figure 8: Locking, Pitch Angle adjustor, and load Sensor

Evaluation and Results

The printed model was used by the instructor to augment classroom instruction (Figure 9). Learning was experimentally validated by the students with the printed blade and wind tunnel.

Figure 9: 3D printed blade used for classroom instruction and experimentation

Pretest and posttest (Appendix 1) were administered to the students to gauge the difference in their performance before and after instruction. A set of ten questions covering various areas of aerodynamics was administered. Each true or false question carried ten points each totaling one hundred points.

Figure 10 depicts the average performance of the students whose learning was not augmented. It was observed that the average performance of the students increased moderately after instruction.

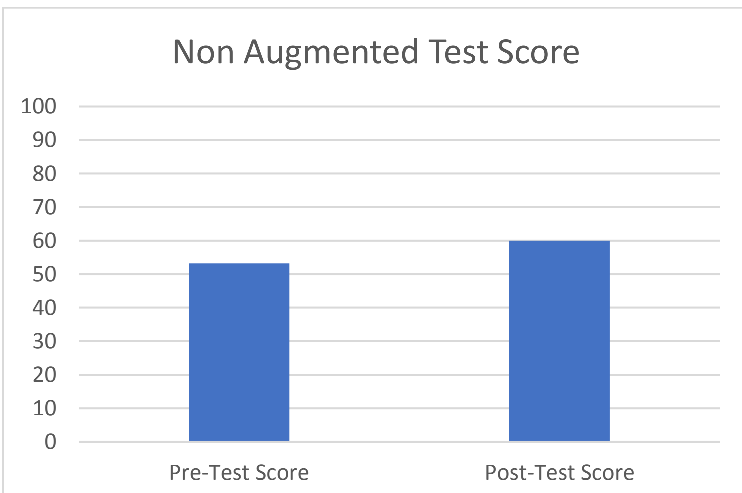

Figure 10: Average of Pre and Post test results for Non-Augmented Instruction

Figure 11 depicts the performance of the students whose learning was augmented. It was observed that the average performance of the students increased greatly after augmented instruction.

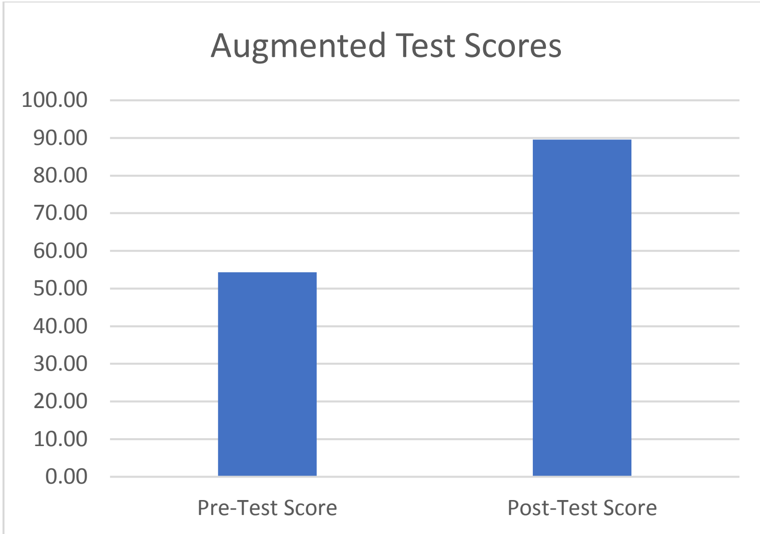

Figure 11: Average of Pre and Post test results for Augmented Instruction

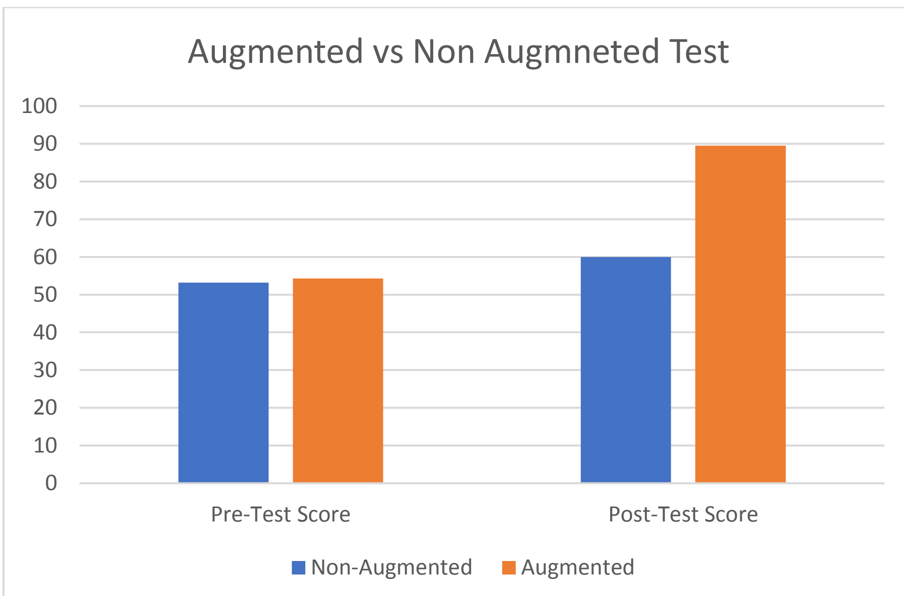

Figure 12: Average of Pre and Post test results for augmented Instruction

Figure 12 depicts the comparison of the performance of the students of non-augmented vs augmented instruction.. Observation of the post test results reveal a substantial improvement in the post test results for the augmented instruction when compared to non-augmented results.

Conclusions

In this paper, a 3D printed model of a wind turbine blade and wind tunnel experimentation was used by the instructor to augment classroom instruction in aerodynamics. Comparison of the performance of the students of non-augmented vs augmented instruction was conducted via pre and post-test comprising of ten questions related to aerodynamics of blade. It was observed that the students score in both the pre-tests prior to both augmented and non-augmented instruction learning was almost similar. Observation of the post-test results revealed a substantial improvement in the post-test results for the augmented instruction when compared to non-augmented results.

Wind tunnel instrumentation and 3D printer augmented instruction can be used to rapidly generate and iterate the aerodynamics and designs of energy extraction components in laboratory-based fluid dynamics education. Instructors can use synergies of these technologies to create a cross learning platform with relative ease in a technology-based laboratory curriculum.

References

[1]. Ishutov, S., Jobe, T. D., Zhang, S., Gonzalez, M., Agar, S. M., Hasiuk, F. J., & Chalaturnyk, R. (2018). Three-dimensional printing for geoscience: Fundamental research, education, and applications for the petroleum industry. AAPG Bulletin, 102(1), 1-26.

[2]. Mohammed, J. S. (2016). Applications of 3D printing technologies in oceanography. Methods in Oceanography, 17, 97-117.

[3]. Zhang, Z., Wu, X., & Zhang, J. (2016, December). Research related to application of 3D printing technique in educational military equipment. In 2016 International Conference on Advances in Management, Arts and Humanities Science (AMAHS 2016). Atlantis Press.

[4]. Matsson, J. E., Voth, J. A., McCain, C. A., & McGraw, C. (2016, June). Aerodynamic Performance of the NACA 2412 Airfoil at Low Reynolds Number. In *2016 ASEE Annual Conference & Exposition*.

[5]. Linke and his colleagues reported on the development of including 3d printing in an active project based undergraduate curriculum wherein airfoil and nozzle shapes were 3D printed for teaching gas dynamics. They remarked that the tools provided "novel hands-on" interdisciplinary teaching instrument for aerospace and mechanical engineering students.

[6]. Spearrin, R. M., & Bendana, F. A. (2018). Design-build-launch: a hybrid project-based laboratory course for aerospace engineering education. Acta Astronautica.

[7]. Kroll, E., & Artzi, D. (2011). Enhancing aerospace engineering students' learning with 3D printing wind-tunnel models. Rapid Prototyping Journal, 17(5), 393-402.

[8]. Chiou, R., Tseng, T. L. B., & Jayadev, S. (2018, June). Enhanced 3-D Printing for Energy Harvesting Project Implementation into Green Energy Manufacturing Laboratory. In 2018 ASEE Annual Conference & Exposition.

[9]. Cengel, Y. A., & Boles, M. A. (2008). Thermodynamics: An Engineering Approach, -PDF. McGraw-Hill.

[10]. Fusin 3D printer Retrieved from https://www.fusion3design.com/

Appendix 1

Pre and Post-Lab Activity Test

Total Points-10. 1 Point for each question.

True or False. Please circle the correct choice

Q1. Lift acts parallel to the fluid flow direction.

True False

Q2. The magnitude of lift force always increases when the angle of attack is increased.

True False

Q3. Aerodynamics of airfoils, wings, and wind turbine blades are based on Newton's principle.

True False

Q4. The curvature of airfoil that produces lift is called camber.

True False

Q5. Drag acts parallel to the fluid flow direction.

True False

Q6. The line connecting the leading edge of the airfoil with the trailing edge is called diameter.

True False

Q7. Density of fluid has direct relationship with drag force (when density goes up the drag goes up).

True False

Q8. Thin airfoils have low drag force.

True False

Q9. Angle of attack is the angle of the chord line of the airfoil and direction of relative wind speed.

True False

Q10. Lift and drag force acts at the center of gravity.

True False