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Establishment of Aerospace Engineering Laboratory to Foster Education and Research

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Abstract

In this paper, establishment of a new Aerospace laboratory at Kennesaw state university is discussed. The lab is founded to enhance the Aerospace engineering minor at the school of engineering. Details of the minor program are discussed. Various equipment related to the discipline are gradually acquired through internal and external funding, endowments and gifts. Additionally, other related equipment already present on campus is gathered at one centralized location. As a result of the establishment of the lab several research, academic and related projects have started and are currently in progress. Some of these projects and their implications are discussed. Vast majority of these projects involve students. Student perspectives on the advantages of the lab and future potentials are also discussed.

Key Words: Minor, Laboratory, Equipment, Projects, Research, Education, Students

1. Introduction

A new AERO (Aerospace Engineering and Research Organization) Laboratory is created at Kennesaw state university. The university currently offers a minor in Aerospace Engineering. Minor is available to students majoring in all disciplines of engineering and sciences. To earn a minor, students are required to take five Aerospace Engineering classes including a senior design capstone project. By the time students finish their minor, they are well versed in Aerospace concepts and are on a path to either pursue graduate degrees in Aerospace engineering or a career in the Aerospace industry. The AE minor has grown in popularity over the past few years. To support this growth, the school established an AERO lab in the summer of 2019. This lab provides a platform for students and faculty to collaborate on hands-on projects, conduct aerospace and related research and use the facilities for educational purposes. Various Aerospace related equipment dispersed in labs around the campus were consolidated and brought into one space and new equipment acquired for the AERO lab. The lab now houses motion actuated flight simulator, several 3D printers including an industrial printer, hot wire cutting machine, and a 5 axis milling machine. Student projects are also showcased in the lab. Additionally, the AE lab is equipped with a low speed wind tunnel, a wind turbine and a gas turbine engine test bench. It is expected that the addition of this lab will boost further interest in the Aerospace program and as a result make it a more attractive engineering school for current and future students. In this paper, the use of this lab for the purpose of conducting various undergraduate research studies is discussed. Topics include but are not limited to wind turbine blade design using wind tunnel; gas turbine engine parametric cycle analysis using an engine test bench; aircraft wing optimization using Computer Aided Design (CAD) software, 3D printing, milling and wind tunnel testing. Additional topics include helicopter swashplate design and fabrication using 3D printing; aircraft winglet optimization using CAD, wind tunnel, hot wire cutting and 3D printing; and model fixed and rotary wing aircraft design and

fabrication for student design competitions. Summaries of various design projects is discussed and student feedback in terms of the efficacy and usefulness of the AERO lab is collected and presented. Usefulness of the lab for the local AIAA student chapter and the Aerial Robotics Team are also discussed.

2. Literature Review

Studies have shown that establishing focused research and academic laboratories help enhance and grow the institutional programs. These labs require resources and support. Lugmayr [2] points out that managing and leading an academic or research laboratory requires many skills, high degree of flexibility, setting visionary goals, and ability to cope with institutional and funding agencies, among other needs. This effort also fosters creativity as more emphasis is given to research development, performance measurement, and reward schemes. Lugmayr also asserts that a creative laboratory requires the support from university, and the administration with providing resources. It also requires personal commitment, motivation and risk taking. The AERO lab houses several computers and provide specialized disciplinary software. Some of these are also available to students remotely. Lee and Mehta [3] discuss the method for establishing a remote lab in which students learn how to develop and deploy computer based applications that connect to database servers. The AERO lab provides opportunities for undergraduate students to engage in research early in their academic careers. Bedell and Bedell [4] argue that engaging students in research is a uniquely rewarding experience for undergraduates. Many publications have highlighted the advantages of getting undergraduate students involved in research outside of the classroom, from developing one-on-one relationships with research mentors to preparing for graduate school. Bendell [4] assert that 'An immersive research experience contributes substantially to a student's personal and academic development, and it helps build highly practical, marketable skills.' To make the lab successful in the long run, sustainability and productivity of its operations has to be of paramount importance. Haynes et al. [5] suggest that a well-functioning lab is a productive lab. They discuss the guiding principles of good lab management. Younis [6] supports the usefulness of engineering laboratory facilities, among others, for ABET (Accreditation Board for Engineering and Technology) accreditation and how they contribute towards satisfying the criteria for obtaining educational learning objectives. Arati et al [7] argue that Laboratory plays a vital role in acquiring technical skills which are needed in professional careers. Traditional learning from theory courses is supplemented by laboratory work for verification and deep conceptual understanding. Sasha et al [8] assert in their work that demonstrators play an important role in teaching practical concepts and skills in engineering. They also outline a training program for laboratory managers that results in improved skills and leads to greater satisfaction. Feldman and Silevitch [9] conducted experiments to show the impact of doing design in a large lecture-oriented course. They also discuss that this approach requires more resources. Santos et al [10] present the results of an experimental undergraduate laboratory that emphasize system level perspectives. Ernst [11] argues the importance of properly maintained equipment and direct involvement of faculty as factors that could enhance student learning in engineering labs. Other similar researchers, in various engineering, science and technology disciplines have shown the efficacy of using laboratories to foster education and research.

3. Aerospace Engineering Minor

The cost and overhead involved in creating in a full degree program can be prohibitive. A new program requires administrative cost, infrastructure including additional classrooms, lab space and the instruction cost. A traditional Aerospace Engineering program has a number of foundation courses that are similar to those in other disciplines for example Mechanical Engineering. From the university's perspective, it is a lot easier to justify the addition of a new minor program that would require minimal additional resources, than to justify a full major program. At the time of this papers publication, a full major in aerospace engineering does not exist at the university. The minor program at the Kennesaw State University was established a few years ago and has continued to gain attraction and attention. The Aerospace Engineering minor is designed to provide students with sufficient knowledge and skills to allow them to operate as a competent practitioner within the field of Aerospace Engineering. Students develop not only technical know-how but also a practical and analytical approach to problem-solving that allows them to address a range of Aerospace Engineering and related challenges.

This program gives an integrated knowledge of engineering that is currently appreciated by most engineering employers. Core modules provide students with a thorough understanding of many of the most important and central subjects in Aerospace Engineering today, from computer modeling to engineering materials. There is considerable focus on gaining practical experience, and lectures by visiting practicing engineers and laboratories. This ensures that students become familiar with current methods and approaches within the industry.

Currently, following courses are offered as part of the Aerospace Engineering minor at the Kennesaw State University:

1. Aerodynamics (Low speed and some aspects of high speed)
2. Aircraft Design and Performance
3. Avionics
4. Aircraft Propulsion
5. Helicopter Theory
6. Aerospace Structures
7. Senior Design Project in Aerospace

A student is required to select five courses in order to earn their minor. Aerodynamics and Senior design and required and others are electives. Aerodynamics is a 3000 level course and is a pre-requisite for all other Aerospace courses. To start the minor, students are required to have finished Calculus II. The minor is open to all engineering and science students. Most of the students who enroll in the minor program major in Mechanical Engineering so the transition is smooth. A few Systems, Electrical and Mechatronics Engineering students have also enrolled in the minor program. A few students majoring in non-engineering disciplines e.g. Mathematics and Physics have also successfully finished the AE minor program. These students may require some additional self-study to bring them up to speed on the basic Aerospace or engineering concepts. Since the AE minor is optional, students that enroll in the program self-select themselves and are therefore naturally motivated to learn the Aerospace concepts. Most students that earn their minor in Aerospace Engineering are excited, motivated and have therefore performed well in all classes.

In the senior design course, students demonstrate their ability to apply the knowledge learned in various AE courses towards a professional society sponsored aerospace design project. This senior design project is a three credit hour class and spans over one semester. Capstone projects are done in groups of three to four students. This capstone class is in addition to the senior capstone project that is required for their major degree. Students are able to finish the minor program by typically taking one extra class in every semester during their last two years on undergraduate degree program. Some students take these classes over the summer and others have delayed their graduation by a semester to earn the minor.

The Aerospace minor program has grown over the years. Following are some of the major milestones and accomplishments:

- [Information Withheld] Endowed Scholarship for Women in Aerospace ($50,000), established 2017
- [Information Withheld] yearly funding for Aerospace scholarships ($15,000 / year) since 2015
- AERO Lab (Aerospace Education and Research Organization), established 2019
- Students graduating with the AE minor are now employed at organizations including Lockheed Martin, Boeing, Pratt & Whitney, Delta, Northrop Grumman and other major Aerospace organizations
- Average number of students enrolled in the AE minor per year is greater than 100

As evident from the above accomplishments, the AE minor program has grown in numbers and strength. A number of large, medium and small Aerospace organizations have been facing a deficit of aerospace engineers [1] for years and this deficit has only increased in the recent years. The AE minor program continues to attract talented students and help fulfil the industry deficit. The AERO lab, established over summer 2019, complements the growth of the minor program. The lab provides a platform for students to apply the concepts learned as part of the minor in the form of class projects, research projects and capstone senior design projects.

4. Aerospace Related Laboratory Equipment

One big challenge with starting the AERO lab was to acquire relevant equipment. Through internal and external grants, gifts and scholarships the author was able to gather funding to gradually acquire relevant equipment. Initially there was no designated space to house the equipment, so it was placed in various laboratories in different buildings across the university. Eventually when the space became available in summer 2019, all the equipment was moved to the AERO lab. Once the lab was established, even more equipment was acquired from donations, gifts and grants. Following is a list of some of the key equipment housed in the AERO lab. Their corresponding uses are also listed in Table 1:

Table 1: List of AERO Lab Equipment and their uses

Equipment	**Uses**
FAA Certified motion actuated flight simulator	Training for students to learn the basic parts of aircraft, their controls and corresponding motions. The simulator is also used for research where students can design their own aircraft and eventually fly it to determine flight characteristics
Wind Turbine	Students can design various wind turbine blades by varying parameters like chord, taper ratio, sweep, twist, span, number of blades, type of airfoil, angle of incidence, wind speed etc. They can optimize the wind turbine blades for given environmental conditions.
Wind Tunnel	With the help of smoke generation machine, wind tunnel is used to visualize vortices generated by various lift producing devices including model aircraft, airfoils and other shapes. Pressure probes mounted on various shapes can also help students visualize the pressure distribution of airfoils, cylinders and other objects. Students design and fabricate models and measure lift and drag at various speeds and angle of attacks.
5-Axis Mill	The 5-axis CNC mill is used to machine metal and wood parts. Models are fabricated for wind tunnel testing. Other parts are machined for creating model aircraft.
3D Printers	The lab is equipped with an industrial 3D printer and two consumer 3D printers. Various types of materials are printed to create parts or assemblies for research, design competitions, wind tunnel tests etc.
CNC Hot Wire Cutter	Hot Wire CNC cutter is used to cut foam. This is used to create different types of airfoils, wings, fuselages, empennages and other parts for flying model aircraft.
Gas Turbine Engine Test Bench	The gas turbine engine test bench is used to simulate the function of a high by-pass ratio gas turbine engine. Students learn the aerodynamics, thermodynamics, controls and sub-system operations of the engine.
Computer Workstations	In addition to the computers connected to various equipment listed in this table, additional computers are provided for students to perform related studies.
Software	Software capabilities available to students include but are not limited to CAD, CFD, FEM, Parametric Design Analysis and other specialized software.

In addition to the equipment listed in Table 1, the AERO lab also provides space for students to meet for design competitions, professional society meetings, lectures, lab sessions, invited lectures, seminars etc. The author's goal is to continue to expand these resources by adding more equipment and engaging more students in hands-on activities.

5. Summary of Research Projects

Following are summaries of some of the research and other projects that students have participated in directly as a result of creating of the AERO lab. Some of these studies are currently in progress and others have produced results that have been published in journal papers and conference proceedings. This effort also enables students to participate in technical research conferences where they present their work.

a) Gas Turbine Engine Parametric Study using Test Bench

In this research, two students that are enrolled in the Aircraft Propulsion class also take part in a research project. The project entails working on gas turbine engine simulator to gather engine performance metrics. The low by-pass ratio engine is designed for light general aviation business or private jet aircraft. Tests are performed at various flight conditions. Input parameters like outside temperature, altitude, velocity etc. are changed one variable at a time. Outputs like thrust, efficiency, fuel consumption etc. are measured for various flight conditions. Temperatures and pressures are also recorded at various stages of the engine. Temperature and pressure are used as inputs for physics based analytical engine cycle analyses. The metrics measured from test bench are then compared with the analytical analyses learned in the class. It was observed that the student participating in this study showed more interest in the class, spent more time in the lab and overall performed better than their counter parts. Test bench used in this study is show in Figure 1.

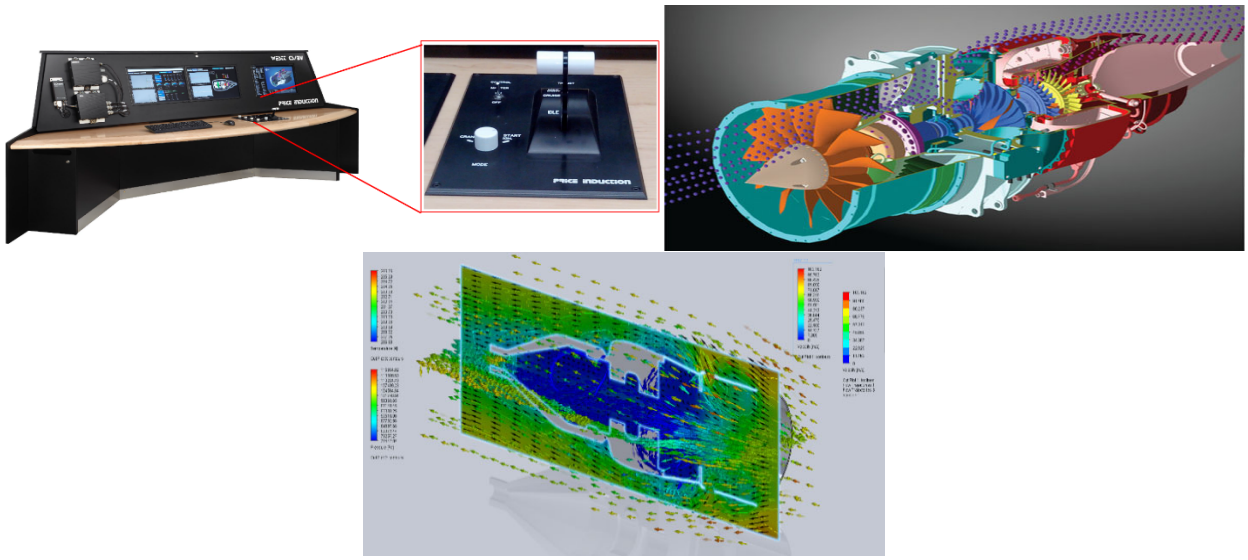

Figure 1: Gas Turbine Engine Test Bench and Flow Simulations

b) Flight Simulator based Case Study

In this study, student learning and retention is assessed using a motion based fixed wing flight simulator. Students are given introduction to the principles of flight. They are presented with written literature to review before the flight. A short presentation is given to them that describes the flight controls, basic instruments and the mission. Then they fly the aircraft flight simulator and are asked to complete a pre-defined mission. Points are given for successfully completing

several legs of the mission. They are graded based on their flight performance and handling and control of the aircraft during the flight. The efficacy of the hands on learning in a laboratory environment is explored. The motion actuated flight simulator used in this study housed in the AERO lab is shown in Figure 2.

Figure 2: Motion based Flight Simulator

c) Helicopter Swashplate Design and Analysis

In this study, students help design, build and test the compliant swash plate for a model helicopter. This mechanism enables the swashplate to tilt in all directions and move vertically as one unit. In this study, the pitch links of the model helicopter are replaced by a semi compliant mechanism. This mechanism is directly connected to the pitch horns to control the pitch of the individual blades. The actuation of the bars can be achieved by using high torque stepper or servo motors. These precise low and high amplitude outputs are specifically required for the cyclic and collective controls of the helicopter swashplate. The compliant swashplate mechanism can be fabricated as a single piece using an injection molding technique or by 3D printing. The mechanism is modeled by two similar vector loops in two different planes. The mathematical model of the plate motion and the forces on the mechanism links are developed and simulated using MATLAB and Simulink. This mechanism will be applied to the helicopter directional control where the plate in the pitch-roll mechanism will serve as the swash plate of the helicopter.

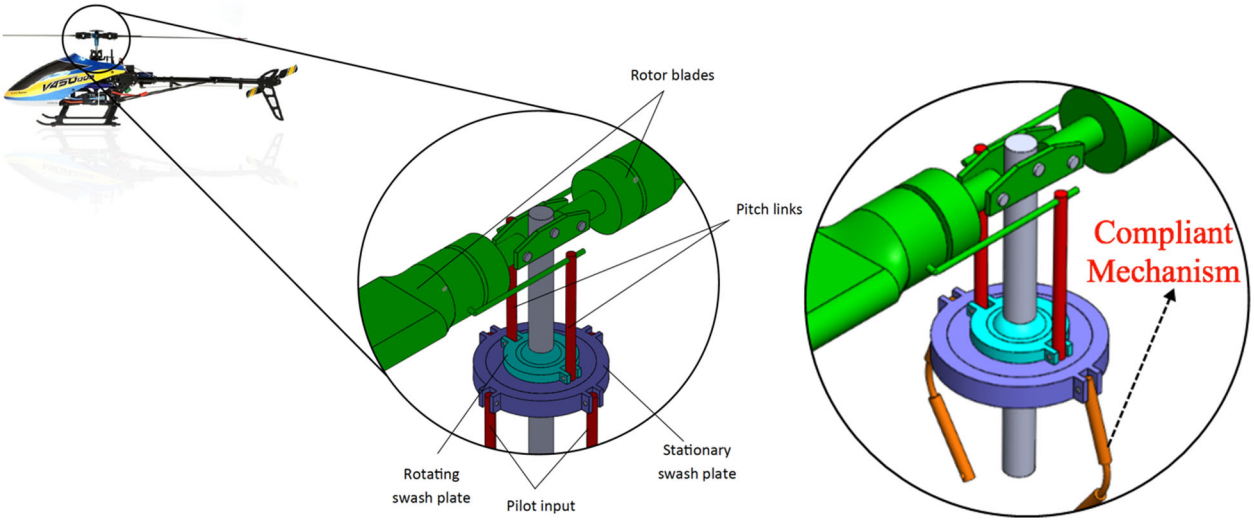

Figure 3: Helicopter Compliant Swashplate Design

d) Aircraft Winglet Design Optimization

In this study, students are working to optimize the winglets of an aircraft to obtain the best flight performance for a given mission. They perform analytical studies, create CAD models, perform CFD analyses, 3D print those models to test them in wind tunnel and compare results. Figure 4 shows some of the tests and simulations performed as part of this on-going study.

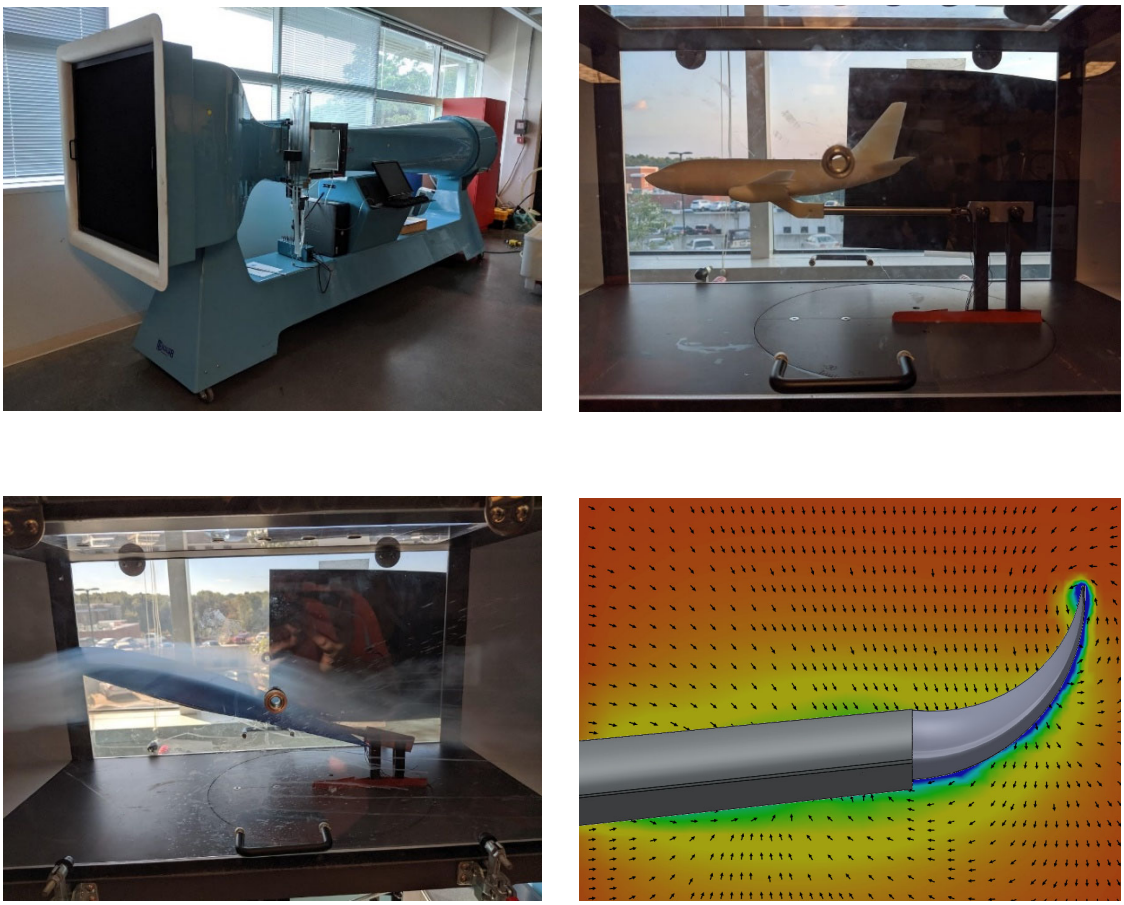

Figure 4: Aircraft and Airfoil Design, Fabrication and Testing

e) Wind Turbine Blade Optimization

In this study, undergraduate students are involved in conducting research project on optimizing wind turbine for low speed environments. A number of design changes are made to the wind turbine blades. These are tested experimentally, analytically and using computer simulations to determine a combination of these variables that maximizes the amount of power that can be extracted from wind by using a small wind turbine. Students gets a chance to explore various research methodologies, gets motivated to work above and beyond what is expected for the degree and excels in their coursework because of the additional motivation. This work has also helped with retention and progression and could motivate other fellow students therefore promoting recruitment in engineering programs. Figure 5 shows the wind turbine apparatus used in this study, CAD models, 3D printed models and CFD analyses performed.

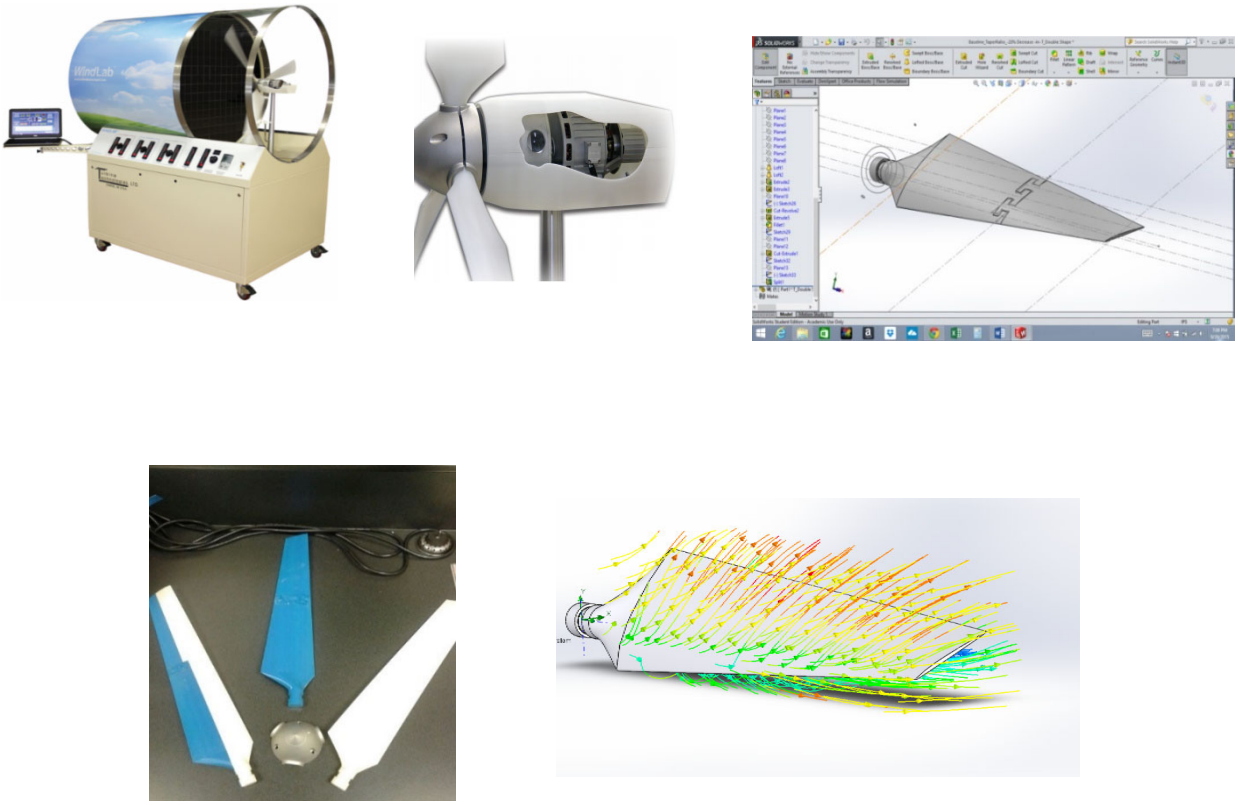

Figure 5: Wind Turbine Blade Design, Simulation, Fabrication and Tests

These are a few examples of a number of research and other academic projects in progress at the AERO lab. Some results obtained from these studies have been presented and published in conference proceedings and journal articles and others are still in progress [12-16]. It is expected that some of these projects will result in securing further external funding. When students are involved in conducting a research study, they also participate in writing the findings in the paper and therefore get a chance to become authors of scholarly research publications.

6. Student Perspectives

Several students that work on various projects in the lab were asked questions about the usability of the lab. Following are some of the questions and their responses.

a) What are the benefits / dis-benefits of having the AERO lab on campus?

"Providing a space for students to meet and have access to computer capable of CAD, a space for more advanced machine(s) to be stored that allow for quick access for students, and finally a good space that is open for public viewing to help generate interest. A dis-benefit, however, is that due to the number of tools/equipment in the lab, actual instruction space or space for larger groups is highly limited."

"I believe the benefits to having to AERO lab on campus include having a centralized location for groups like AIAA and Aerial Robotics to meet and be able to have a space available where we don't need to worry about reserving times or facilities around other departments' schedules. It's very convenient to have our space to base out of, and I don't see a dis-benefit from it."

"With the creation of the aero lab we now have a centralized location for aerospace projects before one had to utilize many of the different lab throughout the collage."

b) 2. For what purposes have you used the AERO lab within the past year?

"In the past year, the AERO lab has mostly been used as a design space for small groups to work on CAD files for competition aircraft."

"I have used the AERO lab this past year for AIAA, such as the presentation to Cobb county stem teachers I helped deliver as well as the preparation for that. As the Aerial team, we use the lab for countless meetings, as well as using the computers to be able to have multiple people work at the same time and allow for easy communication between projects."

"As a prominent member of the aerial robotics competition team we have used the aero lab for making and testing our wing design, utilized the computers for CAD and flow simulation, and lastly used the simulators to train prospective pilots for our aircrafts."

c) 3. How has the AERO lab helped the Aerial Robotics and the AIAA student organizations?

"The AERO lab has been a HUGE help to aerial robotics. It provides a non-manufacturing space for students to meet and work. While the aerial manufacturing shop is a great space, it does not allow for design work to be done as the tables are filled with work-in-progress aircraft and tools. What little space was available for CAD laptops, only gave room for 2-3 students to be working at once. The AERO lab has allowed groups of up to 8 students to be designing at once. We also have advanced tools, such as the CNC foam cutter, that have allowed the team to make multiple and more advanced aircraft."

"For us the lab has helped us immensely with the designing, testing and building of our aircrafts. For instance in part thanks to the equipment found in the lab we are able to build an aircraft in as little as 3 days while last year due to having to run around to different lab I would have taken us 2 weeks to build one plane."

d) 4. What can be done to improve the AERO lab?

"A laser cutter would be a great tool to essentially fully outfit the lab. Other useful improvements could be more storage to "hide" tools/work-in-progress projects, so the lab could

look more clean at first glance. The room looks more messy than it actually is purely due to the amount of stuff in the room."

"There isn't anything I can think of that AERO lab needs to improve in"

"It could be bigger there are some equipment I would recommend for the lab but at the moment space is limited."

As evident from the above comments, several students have been able to take advantage of the AERO lab for research, school projects and design competitions. This has resulted in an overall increase in interest in the Aerospace minor on campus. This fact was recently published by the university newspaper.

7. Conclusions and Future Work

The creation of one centralized AERO laboratory for the Aerospace related experiments, research and education has helped improve and grow the minor program at the Kennesaw State University. It has provided a platform to highlight Aerospace related activities for faculty and students. Several students have taken advantage of the lab by using it for research, professional society work, student competition work and other projects. The long-term goal is to continue to grow the minor program by adding more courses and eventually turning it into a major degree program in Aerospace Engineering. This goal requires several resources including but not limited to having specialized laboratories. Establishment of the AERO lab is a steppingstone towards achieving that long-term goal.

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