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Implementation of Computer Aided Engineering in an Undergraduate Curriculum

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Abstract

It is important to educate and train STEM specialists in order to keep a worldwide presence as a nation with cutting-edge research and leading universities where innovative and technologically up-to-date curricula are provided to educate the next generation of engineers.

This paper outlines the inclusion of a course called Computer Aided Engineering (CAE), which would traditionally be offered at the graduate level, into an undergraduate curriculum as a tool to educate and train students early-on as industry-ready professionals. A junior-level course, CAE consists of Computational Fluid Dynamics (CFD), Finite Element Analysis (FEA), Computer Aided Design (CAD) and optimization. Although students get trained to use CAD software as freshmen, they need additional training on analysis and optimization of engineering systems prior to capstone design series. This course provides an opportunity to teach not only using computational tools but also providing a fundamental understanding of engineering analysis and optimization. Associated with presentation of this course, the paper will also discuss Autodesk Generative Design process and how its innovative approach revolutionizes product design and optimization in engineering education and engineering practice.

Introduction

As globalization becomes a reality with rapidly advancing digital communications and the Internet, education and training within the context of global engineering needs to be revisited. Jobs in the STEM fields are not limited to within certain locales. Thus, job searching in these industries is becoming much more competitive. And, it is essential to educate and train undergraduate students early on with the tools that they need to solve real world problems and to become industry-ready individuals with competitive credentials.

Integration of Computer Aided Design, Finite Element Analysis and Computational Fluid Dynamics in undergraduate courses is common and such work has been published in literature [1-3]. However, inclusion of design processes and engineering analysis under one single course is not a common approach especially at undergraduate level. In fact, FEA and CFD used to require expert knowledge and skills as well as extensive computational resources in the past. However, today's computational resources which include high-power personal computers and cloud-based computing, and associated software developments allow students to easily use such analysis packages at undergraduate levels. This paper discusses an undergraduate course, Computer Aided Engineering, and how it integrates design, analysis and optimization under the same course.

Overview of Computer Aided Engineering in Mechanical Engineering Curriculum

Mechanical Engineering curriculum is based on 120 credits and offers traditional courses as well as various specialties including energy, applied mechanics, aerospace and manufacturing/design in the Department of Mechanical Engineering at Howard University. A recent change to the curriculum included development of a new course, "Computer Aided Engineering", in response to demands of students as well as faculty who expect students to have advanced design (CAD) and analysis (FEA/CFD) knowledge and skills in upper level courses such as Mechanical Design and Capstone Design series.

This course teaches students how to use commercially available Computer Aided Engineering software for multidisciplinary system design and optimization. With the acquired skill, students will be able to conceptualize complex engineering problems in virtual spaces and solve those by using CAE software (i.e., Ansys Workbench, Ansys Fluent, Fusion 360, Autodesk CFD). Structural, generative design, thermal, heat transfer, and fluid dynamics analysis are covered in the course with real-world engineering examples. Some multiphysics analyses are also investigated in the class by coupling different types of analysis to tackle challenging engineering problems. Students learn how to work on a multiphysics design project in a team through offline meetings, synchronous, and asynchronous communication tools (i.e., Slack and Blackboard).

Two third of classes are held in a computer lab of the Department of Mechanical Engineering at Howard University. Some basic concepts/physics and CAE examples are covered during the classes and students follow the examples on their workstations to practice. And one third of the classes are performed based on distance learning class. All the learning materials for each class are provided online (e.g., online articles, online tutorials, lecture notes, etc.) for students' self-learning. After learning by themselves, students learn further by doing assignments and upload the work on the course Blackboard page. Feedback of student assignments are delivered to them using the same platform through evaluation data based on the rubric provided with the assignment.

Computer Aided Engineering: A Combination of CAD, FEA, CFD and Optimization

Computer Aided Engineering (CAE) is divided into four subsections: CAD, FEA, CFD and Optimization by Generative Design. CAD (Computer Aided Design) is a course which is introduced to students as a first-year course. CAE involves CAD at advanced levels for further analysis and design. FEA (Finite Element Analysis) and CFD (Computational Fluid Dynamics) are used for engineering problem solving for stress and flow analyses. Following sections explain CAD, FEA and CFD portions of the course along with optimization which follows a revolutionary design method called Generative Design.

Computer Aided Design

Computer Aided Design is the first step of setting up a FEA or CFD simulation. As mentioned previously, student learn basics of CAD in the Intro to Computer Aided Design during their freshmen year. However, this course exposes students to new drawing tools to widen their CAD knowledge as well as native drawing tools of each FEA and CFD software. Knowing the native 3D modeling tool of each simulation tool is useful when frequent design change is required during optimization process. In addition, students are expected to collaborate via a cloud-based CAD software in preparation for their group project which is assigned in the second half of the course.

Finite Element Analysis

For this topic, students learn how to use FEA simulation software to solve various engineering problems such as static stress analysis, buckling analysis, and shape optimization. Significant emphasis is given on teaching how to choose the right type of FEA simulation and apply correct boundary conditions. By performing multiple case studies on each FEA simulation topics, students learn skills on how to choose a right simulation type to get the desired outcome. Moreover, students learn how to interpret the simulation result in terms of safety factor, stress, and deformation analysis. Through proper interpretation of the analysis result, students also learn how to improve their design. In one of the examples, they learn how to identify stress concentration area and how to alleviate the effect through design change. They also learn how to generate a model based on stress analysis tool in order to find a design which meet the users' input specification (e.g., mass, stiffness, deformation, etc.). Figure 1 shows an example stress analysis.

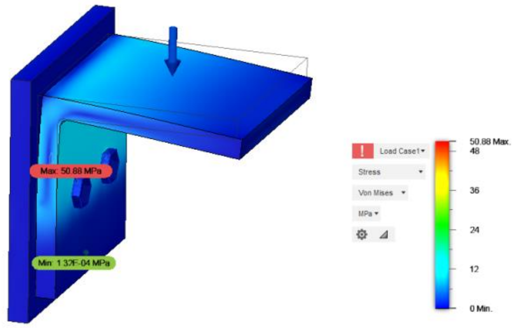
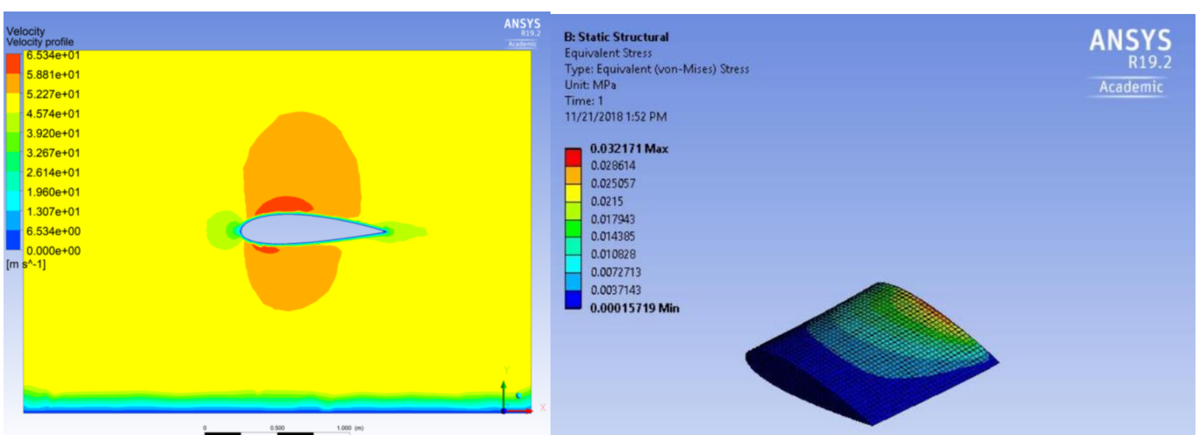


Figure 1. Example stress analysis during class: a bracket mounted on a wall using two bolts

Computational Fluid Dynamics and One-Way Coupling

In this class, simulations of fluid flow in a pipe or around airfoil are covered so students can understand how the numerical analysis can provide various engineering parameters of systems such as velocity, pressure, drag coefficient, etc. Based on the pressure field generated by CFD simulation, structural analysis is performed to investigate the structural integrity due to the load applied from fluid flow as shown in Figure 2. This interdisciplinary example will help students to be equipped to handle various the real-world engineering problems.



(a) (b)

Figure 2. Analysis example of fluid-structure coupled system: static structural analysis of a airfoil under fluid flow

Generative Design (Optimization)

Generative Design is an optimization tool provided by Autodesk Fusion 360. Iterative structural designs of items are generated through statistical method combined with stress analysis on the specifications, machining options, materials, objectives (e.g., light weight, low-cost, or high stiffness) [4-5]. The process of Generative Design is different from regular design and analysis process. Users begin the design with partial or no design model and input necessary boundary conditions (i.e. preserve and obstacle geometries, loads, materials, machining processes, and design objectives). Due to the heavy calculation load, the calculation can only be performed using cloud-based computing. Users can choose best solution considering weight, stiffness, and cost of the design. The promoted designs can be further modified or improved in the modeling space. Figure 3 shows the design process of Generative Design.

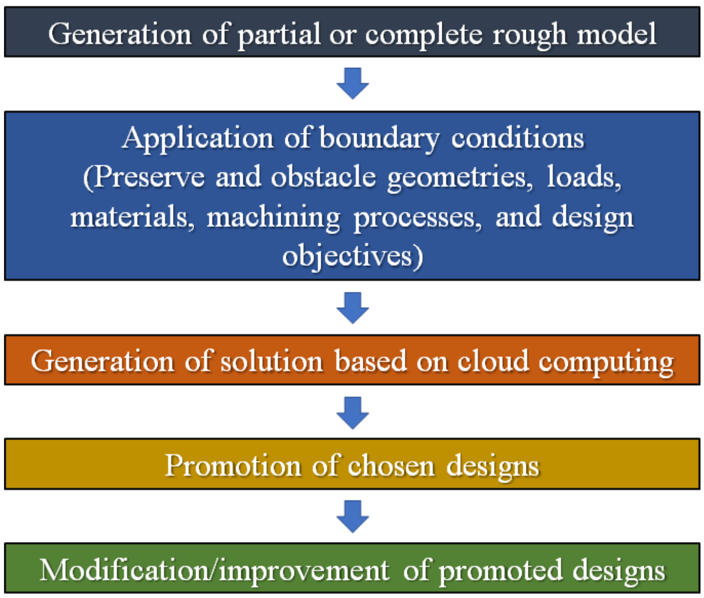


Figure 3. Design process based on Generative Design

Optionally, the design can go through additional analysis. Based on the boundary conditions and design objectives, Generative Design calculates solutions for each material, machining process, and design objective. Due to the expensive calculation, a cloud computing is required for any calculation. This is a new approach of designing engineering parts. Students in the class learn about this tool and understand how to get optimized solutions with various materials, machining processes, and design requirements. Generative design tool helps students to have a new way of designing engineering part which can be much lighter and/or simpler than the counterparts designed by human engineers. And the design based on the tools can give inspiration in optimizing the existing parts. More and more parts can be optimized with generative design tools available on the market combined with the addictive manufacturing and students are prepared to exploit this relatively new technology for their future career. Figure 4 and Figure 5 show two different bracket designs using Generative Design.

Figure 4. Bracket designs by Generative Design (Photo credit: 3D Printing Media Network) - https://www.3dprintingmedia.network/windows-os-frustum-generate-launches-to-further-open-up-generative-design-for-am/

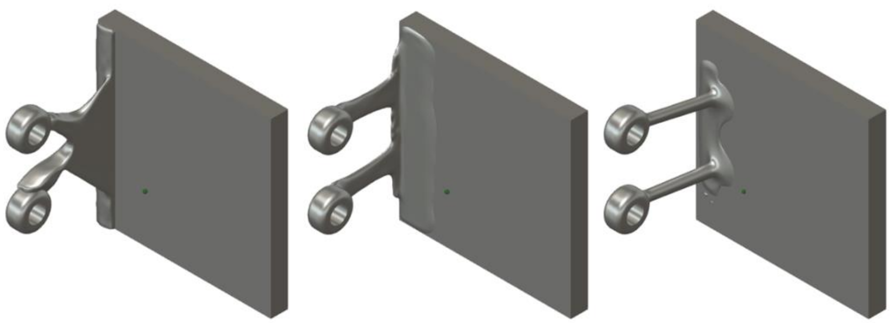


Figure 5. Bracket designs generated by Fusion 360 Generative Design tool

Conclusions

Newly developed course, Computer Aided Engineering, helps to educate and train undergraduate students who learn how to design, analyze and optimize engineering systems using user-friendly commercial software packages including Generative Design which revolutionizes the design approach. While this paper shows the general structure and purpose of the course, it is anticipated to assess student learning outcomes using direct and indirect evaluations in the future. In particular, the impact of CAE on students' performance in capstone design series will be assessed and reported.

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