On augmenting students' learning in beam structures using numerical simulations

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Abstract
Virtual laboratories are seen as an alternative to the delivery of traditional laboratory activities. Additionally, it can be used to supplement or complement traditional teaching practices, especially for engineering topics that are typically assumed by students to be difficult to grasp. In this paper, the use of numerical simulations for a laboratory exercise on a major course in aerospace engineering will be discussed. Moreover, the influence of finite element analysis (FEA) on the learning process of students regarding beam profile and bending performance will be highlighted. SolidWorks program was used for the modeling and structural analysis of beam profiles under predetermined conditions. Numerical model verification and validation were made using established formulae and theories from engineering mechanics. This method was later implemented under the aerospace laboratory course for aerospace engineering students. Fourteen (14) students were asked to report the results of their simulations as well as observations on the structural performance of the beams through a laboratory report. Students' consent to perform content analysis of their reports was secured through Google survey. Applying FEA, students were able to establish connections between beam profile, moment of inertia and bending stiffness, which are often hard to explain in traditional teaching methods. Further, students better appreciate theories associated with beams and their application to aircraft structures. As we navigate a VUCA environment and rapid advancements in computing, numerical simulation programs can supplement or provide alternative avenues where students can learn topics that are conventionally perceived to be challenging.

Keywords: Aerospace engineering, Beams, Computer-aided design, Remote laboratory, Simulation.

Introduction

In engineering education, laboratories are critical as they enhance learning of students in specific topics or fields of expertise. Over the years, the finite element analysis (FEA) has been frequently used in various industries to hasten product development and increase the reliability of machine parts. Rapid advancements in the semi-conductor industry enabled the generation of high-performance computers, enabling the FEA to be more reliable than ever. As educators are challenged to deliver lessons effectively to students, this paper will delve into the use of FEA in teaching, specifically on an I-beam section commonly utilized in aircraft structures. The use of numerical simulations in teaching is not new. Plass et al. (2012) said that computer-based simulations helped improve the learning of students in Chemistry. This is also supported by Pucholt (2020), citing that simulations enhance the performance of students in Physics, and he claimed that computer-based simulations can be an alternative to traditional teaching strategies utilized in Physics. Fluid dynamics and transport phenomena are some of the complex topics in fluid mechanics. Gajbhiye (2020) suggested the use of computer-based simulations in teaching the said topics and later found improvements in the learning process of chemical engineering students. Bishay (2020) found a statistical increase in the performance of engineering students who have acquired the FEA intervention as compared to those coming from traditional approaches.

Moment of inertia is one of the concepts introduced in engineering mechanics when dealing with beams. Yet, according to a survey conducted by Streveler et al. (2006), it is one of the least understood topics in engineering mechanics. In particular, the good bending performance of I-beam structures can be linked to its moment of inertia. Inertia is defined as the object's tendency to resist motion. Meanwhile, moment can be described as the turning effect of a force acting

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on the body. Thus, we can define moment of inertia as a characteristic of a body to resist a turning motion as an effect of a force acting on a body. Contrary to the typical moment of inertia utilized in rotating bodies, the area moment of inertia or second moment of the area describes the ability of a body to resist deformation due to loading (Weisstein, 2012).

The second moment of area can also be referred to as planar or polar moment of inertia, which describes how a body can resist loading by virtue at which the areas are distributed from an axis (Collins, 2018). Polar moment of inertia, which is often used interchangeably with planar moment of inertia, defines the resistance of a body to torsion. Unlike planar moment of inertia, in which the moment is taken at a distance normal to its cross section, the distance utilized for calculation for polar moment of inertia is taken parallel to its cross section. Mass moment of inertia differs from second moment of area by virtue of its units. Collins (2018) noted that the mass moment of inertia is of great importance to angular acceleration and describes how the distribution of mass goes along in an axis, not the areas only.

The behavior of a homogenous material subjected to pure bending can be depicted in Figure 1. The Euler-Bernoulli theory, widely known as the classical or simple beam theory, sets forth the fundamental principles associated with slender and long beams (Bauchau & Craig, 2009), typical of aircraft wings. It can be realized that the highest strains can be located at the top and bottom parts of the beam. Whereas the portion of the beam near the neutral axis, the line that intersects the longitudinal plane of symmetry and neutral surface, experiences little to no stresses. This is further supported by Sun (2006), saying that much of the segments of a beam with rectangular cross section are not utilized for carrying stress, and the use of an I cross section is well justified. The area moment of inertia of an I cross section is also greater than of a rectangular one, enhancing the bending resistance of the beam, which is well clarified from the Flexure formula.

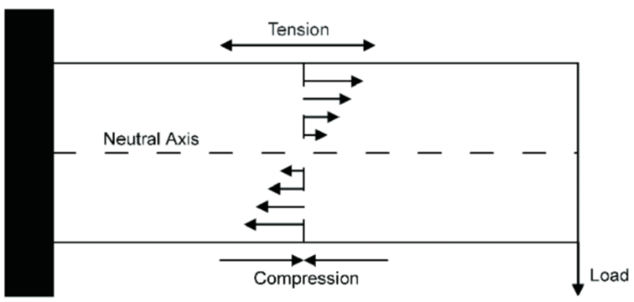

Figure 1. Stress distribution for a simple beam under loading. Adapted from "Feeding Mechanics in Spinosaurid Theropods and Extant Crocodilians" by A. Cuff and E.J. Rayfield, 2013, PloS one, 8(5). Copyright 2013 by PloS one.

A cantilever wing is a wing construction with no external bracing as shown in Figure 2. The design is typically introduced in aircraft to reduce drag and is often employed in high-speed aircraft. Though, the implication of the design is more on the structure. Wing construction requires sound selection of spar length, size, and profile, which can address issues with cantilever wing design. An aircraft wing can be viewed as a long beam fixed in one end that needs to withstand bending as well as torsional loads during flight. The wing structure essentially gets its high bending stiffness from the spar configuration, typically of an I-beam cross section. According to engineering mechanics, the good bending stiffness of the I shaped cross-section can be found from the high magnitude of moment of inertia, specifically, the area moment of inertia, which is dependent on how far the concentrated area is from the neutral axis. The more distant the concentrated area from the neutral axis, the lesser the bending. Sun (2006) told that aircraft wings are typically constructed with high span to depth ratio. Thus, bending stress is more critical than transverse shear. Nonetheless, the latter is generated when bending is induced to a body.

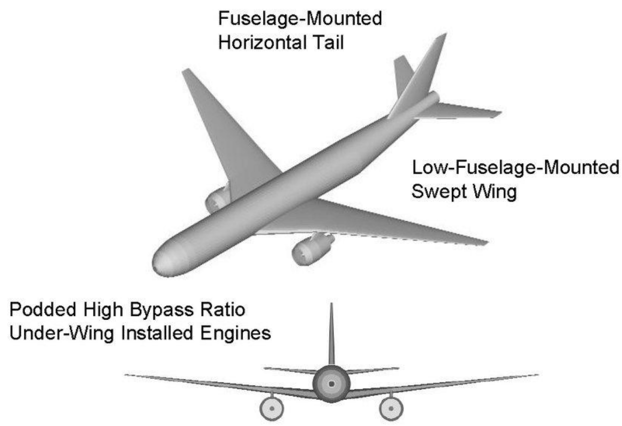

Figure 2. Cantilever wing design utilized in aircraft. Reprinted from "Multidisciplinary Design Optimization of low-noise transport aircraft [Doctoral dissertation]" by L.T. Leifsson, 2005. Copyright 2005 by L.T. Leifsson.

The finite element method (FEM) is one of the utilized algorithms by most numerical simulation programs. The FEM concept can be likened to how we solve an area or perimeter of an irregular shape. Typically, we aim for an exact solution, which is associated with higher degree equations. Meanwhile, an irregular shape can be broken down to a composite of regular shapes, where equations are of lower degree. Therefore, the solution is simpler. Solutions to engineering problems are accompanied by complex differential equations and if the composite shape idea is applied, it can simplify the approach and get an approximation of a problem, regardless of how complex it is. The FEM process starts in pre-processing.

Pre-processing includes setting the boundary conditions (inputs for the simulation), and importantly the size and number of elements (mesh). As FEM is an approximation technique, the accuracy of the solution lies in how we select the elements. A delicate balance between solution accuracy and computational time is desired. In the solution phase, this is where the software resolves the problem defined in the pre-processing. To verify and validate the solution, post-processing is undertaken. This is where the user interrogates the model and qualifies whether the result is acceptable or not. Inputs for the calibration of the model came from post-processing. Until a desired model is obtained, the process is repeated.

Computational software not only offers solutions to complex physics problems of a model being simulated. It can also provide insights into the behavior and response of a model when subjected to a certain input (force, temperature, velocity). This can be done through generation of visual plots that further enhance the understanding of the user. Literatures on student learning have already established the relevance of visual demonstrations and improved learning. Visual demonstrations enable problem analysis to be more operational rather than superficial (Bassok & Holyoak, 1989; Butcher, 2006; Goldstone & Son, 2005; Joseph & Dwyer, 1984; Moreno et al., 2011; Sloutsky et al., 2005). Moreover, Moreno et al. (2011) & Scheiter et al. (2009) said that student learning is at its best when both abstract and concrete visual demonstrations are present. Further, visualizations allow learning to be centered on establishing connections between students' prior knowledge and the information at hand instead of the typical knowledge transfer which is often one way (Bransford et al., 2000; Collins et al., 2018; Donovan & Bransford, 2005; Moreno et al., 2011). With this, it can be noted that one of the scientific foundations for the positive effect of numerical simulations on student learning can be linked to visual representations.

Most of the literature available on the use of numerical simulations for teaching centers on CFD, Mathematics, Material Science, and Magnetism. FEA has been mentioned as well in various sources. However, most of them focus on its implementation as a precursor to a formal FEA course or a tool to check a design or proof of concept. Meanwhile, sources concerning the FEA of beams revolve around its design and development, its industrial applications, and optimization techniques for solving related problems. Little to none was directly conducted on the use of numerical simulations to aid in teaching beam structures among students. It is the objective of this paper to demonstrate how FEA can be utilized to aid in teaching beam structures among aerospace engineering students enrolled in aerospace laboratory 1.

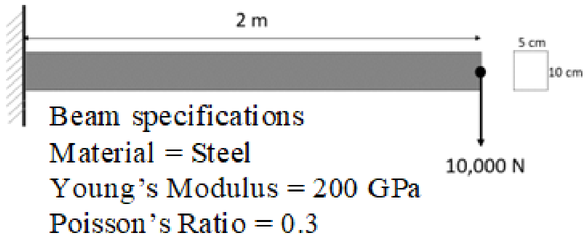

Figure 3. Simulation constraints in relation to the cantilever beam construction

Figure 4. Conceptual framework of the study

Several studies have investigated the use of simulations in teaching engineering concepts. Zapalska (2021) utilized simulations and gamification to teach undergraduate engineering students the essence of business within a manufacturing setting. Anchored in the principles of experiential learning, Zapalska (2021) found that students found the experience both enjoyable and educational. Additionally, students learned to work in teams, which is a primary graduate outcome for engineering programs. Taher and Khan (2014) studied the influence of simulation-based methods in teaching circuit construction within an engineering technology program. The authors found that the simulation-based strategy had a slight effect on student learning compared to a hands-on approach. However, they noted that students still found simulation-based programs lacking in terms of mimicking real-world situations and suggested that a hybrid teaching approach (simulation + hands-on) should be implemented. They argued that simulation-based strategies can complement traditional instruction in undergraduate engineering courses. Negahban (2024) reviewed the literature on the impact of simulations in engineering education, finding that simulation-based learning is often less costly than traditional physical experiments. Moreover, Negahban (2024) noted that simulation-based teaching can enhance student engagement and motivation. Finally, the author argued that future research must address existing gaps in linking simulation-based teaching to learning theories and concretizing simulation-based assessments.

The Aerospace Laboratory 1 subject aims to provide laboratory activities that will reinforce the learning of students on some major courses in the aerospace engineering program, including aircraft structures. Wing structure is one of the topics being discussed in aircraft structures and several subtopics discussed on the subject include beams, wing bending and torsional performance, and stiffeners. This paper determines whether FEA can help achieve the intended learning outcomes for the laboratory activities in the Aerospace Laboratory 1 subject and improve the student learning process. Specifically, this study addresses the following objectives:

1. Collect data on student output regarding the accomplishment of laboratory activity objectives.
2. Gather insights into how students navigate laboratory activities in relation to achieving objectives and reinforcing specific topics.
3. Verify whether students benefited from using numerical modeling to achieve laboratory objectives and the overarching course outcomes.

Reinforced by literature regarding the positive effects of simulation-based activities on the student learning process, this study is anchored in the concepts of simulation-based learning for teaching challenging engineering topics, as illustrated in Figure 4. Beyond simply using simulation programs for laboratory activities, this undertaking aims to enhance student comprehension of complex engineering concepts. To improve the implementation of these interventions, reflection is integrated into the framework represented by the bidirectional arrows connecting each element. This design addresses identified gaps in simulation-based learning strategies, specifically regarding their connection to learning theories and the concretization of associated assessments. These arrows also emphasize the importance of a feedback mechanism that ties simulation-based strategies directly to teaching and learning outcomes.

Method

Prior to the implementation of the FEA based strategy as a laboratory activity in aerospace laboratory 1, modeling and FEA of beams with rectangular and I shaped cross sections were conducted. Results of the numerical simulations were verified using established engineering mechanics formulae. Cantilever wing construction was implemented in the simulations, with one end fixed and the other end applied with a force parallel to the cross section of the beam. The details provided as boundary conditions (see Figure 3) were taken to typical problems encountered by students in engineering mechanics. Principles and concepts associated with beams were utilized to verify and validate the results acquired from the simulations. SolidWorks utilizes a library of materials based on Metals Handbook Desk Edition, ASM International by Davis (1998), ensuring the accuracy of the simulations. This, in a way, ensures that the results of the simulations are with high degree of consistency with experimental results (Genouvrier, 2014). Though, controlling the properties of steel is difficult and the usual characteristics of steel utilized in textbooks reflect the average (Mahendran, 1996). The elastic modulus and Poisson's ratio utilized in this paper are commonly reflected in sources, which often reflect that of mild steel (Mahendran, 1996).

Table 1 shows that the value for maximum deflection acquired by numerical simulation is in good agreement with the result of a mathematical equation. Aside from the deflection value, the shape of the beam deflection generated in the simulations is similar to that of a typical response of an actual beam from a load when Physics validation is made as displayed in Figure 5. This is supported by (Skotny, 2017), noting that the deformation shape is as equally important to the performance values acquired during simulations.

Table 1. A comparison of cantilever rectangular beam performance values from numerical simulations and code verification

Performance value	Mathematical calculation	Numerical simulation
Maximum deflection (mm)	32	32
Maximum bending stress (MPa)	240	245

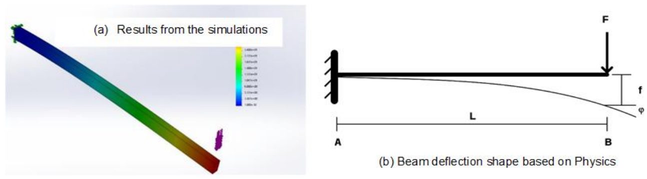

Figure 5. The beam deflection shape acquired in the simulation by students is similar to the deformation shape as prescribed by Physics. The image at the right is created by Pekaje (public domain).

Model validation can be performed by utilizing established simple beam problems with known loadings and boundary conditions as reference (McCaslin, 2021). The output obtained from this undertaking was later used to check the submissions of students. Most students have received lectures on wing structure before the lab activity was given to them. All of them finished engineering mechanics prior to their enrolment in Aerospace Laboratory 1. Prior to the lab exercise, most students find the I-beam topic puzzling or difficult to grasp, consistent with the findings of Streveler et al. (2006). It can be further attested when a recitation on I-beam performance has been asked and none of them convey a clear response and have utilized moments of inertia in their answers. Students were first introduced to the basic principles of FEA, the software SolidWorks and how to do modeling in the program. Students enrolled in the course have little to no previous experience with the use of SolidWorks and a full day session has been dedicated to the matter.

Student permission was obtained to conduct a content analysis of laboratory reports for this study. Each report consists of five sections. The first section contains administrative details, including the student's name and the report title. In the second section, students generate the required plots and perform simulation verifications to assess the soundness of their models using concepts learned prior to the laboratory course. Beyond verification, students must validate their results, an essential step in any simulation activity. While verification confirms the theoretical accuracy of the simulation (the mathematical "correctness"), validation evaluates its physical realism (the "real-world" accuracy). This process instills the importance of post-processing and interrogating simulations to ensure they reflect real-world models accurately. The third section requires students to summarize their learning by connecting prior knowledge with insights gained during the activity. This serves as the reflective component of the assessment, allowing students to narrate their learning process and realizations. Finally, students provide a conclusion based on their findings (Section 4) and offer recommendations for the further enhancement of the intervention (Section 5). Collectively, these sections were designed to concretize learning while enabling students to contribute to the continuous improvement of the laboratory activity.

Students were asked for their consent to include their laboratory reports in this study via a Google Form. This form sought the permission of students enrolled in the laboratory course to use their work for research purposes. Out of 19 students enrolled in the course, 16 responded to no objections and out of 16, 14 managed to submit on time. Only a few universities in the Philippines offer aerospace engineering. Compared to the other engineering and technology programs offered at the university, aerospace engineering is an up-and-coming program. On Mindanao, which is one of the major islands in the Philippines, only Ateneo de Davao University offers aerospace engineering. This can explain the modest size of students in the program. With the establishment of the space agency, the exposure space research is gaining through small satellite development and scholarships made available to the program and the Philippine government and several key industries initiating activities towards the establishment of the aerospace sector (Asian Development Bank, 2021), Aerospace engineering enrolment is estimated to increase in the years to come.

Content analysis has been selected in this paper for the reason of non-rigidity of the approach. Content analysis seeks “messages” on various types of data, visual, aural or textual in nature, to comprehend the information the material tries to convey (Krippendorff, 2018). Also, students' answers come in various forms (textual and pictorial) and the use of highly structured strategies may not capture the needed information from the students. The specifications of beams utilized in the undertaking were pre-determined and were based on usual structures utilized in the aircraft, such as long, slender beams typical of simple beams (Bauchau & Craig, 2009; Sun, 2006).

The first objective of the study was addressed through an analysis of the first and second sections of the students' laboratory reports. These sections were designed to assess student comprehension of the simulation-based intervention introduced prior to the assignment. The second objective was addressed by examining the third and fourth sections, where students narrated their process for handling results and the specific insights they acquired during the activity. Finally, the third objective was met through the analysis of the final section of the report, which gathered student recommendations for enhancing the simulation-based learning intervention.

Results and Discussion

This section discusses the major themes extracted from the analysis of students' work in Aerospace Laboratory 1. Testimonies highlighting the enhanced learning of students regarding beam profile and structure concepts and principles were included. Students’ insights on using numerical simulation for enhanced learning not only of aerospace engineering concepts but also of engineering in general, were captured.

All the student laboratory reports analyzed in this study were able to explain the influence of beam profiles on bending performance when using numerical simulations. Most students were able to show in detail how they did the simulations. Some even managed to do more aspects beyond the expectations for the laboratory report, such as the study of deformation scales (Figure 6) in the post-processing and the influence of the meshing strategy (Figure 7) on the results of the simulations. The activity also makes the learning more participatory, since the students voluntarily explore other aspects necessary for a better understanding of the topics involved. Students were able to connect learning that they acquired from courses they took prior to taking the subject by performing code verification (McCaslin, 2021; Thacker et al., 2004), which is an important step in ensuring that the results generated by the numerical model are consistent and valid. Table 2 presents some of the notable remarks made by students on the positive influence of numerical simulations on their learning of the subject.

Table 2. Numerical simulations enhance the learning of students with beam profiles and structures

Respondent	Remarks
1	*"This activity helped add more skills in analyzing the scenarios involving different materials."*
3	*"The values for maximum deformation between the simulation and the manual computation are more or less identical, with only a small error."*
4	*"This lab experiment highlights how much of a difference just the shape of a material makes in how it counters forces being acted on it"*

Table 3 posits that students have improved their learning about the influence of beam profile on its bending performance after they took the laboratory activity. Due to the interactive nature of the program, it enables students to be more involved with the learning process. Students were able to establish the effects of varying the cross-section of the beam on its bending performance. Numerical simulations reinforced the results acquired by students in performing manual calculations of beams' stress, displacement, and strain. The approach of students was no longer confined to the variables of the equations alone, instead, they questioned them together with the results of the simulations. This confirmed the findings by Moreno et al., 2011 and Scheiter et al., 2009, noting that students learn best when abstract activities (in this case, manual calculations, and theoretical lectures in the classroom) are complemented by visual representations. The activity also enabled them to relate the moment of inertia with the beams' performance, where most of them find the topic difficult when a lecture about it is delivered on a separate course.

Table 3. FEA improves students' comprehension regarding the relation between beam profile and bending performance

Respondent	Remarks
6	*"Comparing the 2 beams, the I-beam when introduced by a load, experiences less bending. This is because of how the area of the beam is shaped thus leading it to be distributed in a way that maximizes its capacity to withstand bending stress."*
8	*"We were able to understand that given the beam dimensions from the exercise, the I-beam indeed performed better. Moreover, another advantage that the I beam has is that it is relatively lighter and much more appropriate to use if drilling holes is necessary."*
9	*"The stress on the rectangular beam has a greater value between the two (rectangular and I profiles) as well. This trend also follows for the strain between the two beams."*
10	*"The I-beam has shown to have a lower amount of stress compared to the reference beam (rectangular beam)"*
14	*"In the straight beam (rectangular) there is a lot of bending stress while the I beam has lesser bending stress. This is due to the different shapes of both beams."*

Streveler et al. (2006) reported that some theories associated with solid mechanics, particularly with a moment of inertia, are taken by students to be difficult to grasp during lectures. With the aid of numerical simulations, students not only relate the moment of inertia with beam profile and bending performance, but also explain the physical meaning of the parameters as exhibited in Table 4. This can be supported by the fact that visual plots generated by numerical simulations can be used for post-processing of data as shown in Figure 8. Also, students have employed the typical method to solve for the maximum deflection of the beam and compare it with the results of the simulation. Even if they have yet to take a formal FEM class, it can be inferred that students have learned to verify and validate the results of their simulations. Students employed the post-processing step, which is critical in any numerical simulation. In the absence of actual lab activity to check the bending performance of the beam through a bending test, they were able to verify and validate their work by interrogating the results of the simulations. Model verification and validation are paramount to identify whether the simulation's results are accurate and conform to the real beam performance (McCaslin, 2021; Skotny, 2017). According to Bishay (2020), the use of FEM in teaching can induce critical thinking and an increased interest in the topic taught to students. Gajbhiye, et al. (2020) also noted that understanding of complex topics/ subjects in engineering can be enhanced with the use of simulations. The explanations made by students on the better performance of I cross section in bending are consistent with those of (Bauchau & Craig, 2009) and (Sun, 2006). The findings by the respondents support the definition made by Collins (2016) and were able to demonstrate comprehension of the concept through the analysis of simulation results.

Table 4. Students learn and appreciate better theories associated with beams and structures through FEA

Respondent	Remarks
1	*"Since both beams have the same cross-sectional area, the advantage of the I beam extends to the force distribution around the area of the I beam, which spreads out more with larger outer dimensions than the more compact rectangular beam, which makes the I beam stiffer."*
2	*"The wide flanges on top and the bottom of the I-beam are located farthest from the neutral axis."*
11	*"A beam's resistance to bending is measured by its moment of inertia"*
13	*"By having more material (planar moment of inertia) further from the neutral axis, the greater the moment of inertia. The I-beam is designed to maximize the bending stress it can withstand while minimizing the weight.".*

Students also reported that the activity can be extended to other courses in the program and can supplement or be an alternative to the delivery of these lessons as displayed in Table 5. Young et al. (2012) mentioned that the FEA allows civil engineering students to comprehend and perform analysis of structures through three dimensional (3D) visualizations. Coyle and Keel (2001) argued that FEA should be introduced early to engineering students to reinforce their learning in basic engineering principles. The visual plots generated by FEA software enable students to have a physical understanding of the model they're studying (Coyle & Keel, 2001; Young et al., 2012).

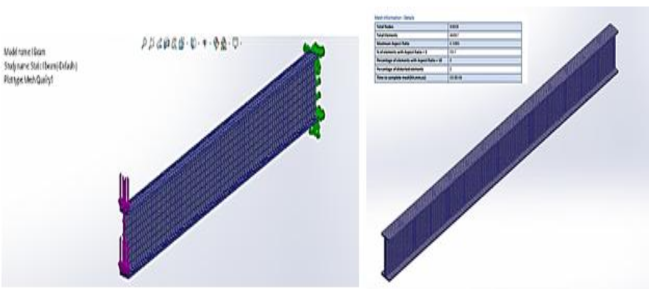

Figure 6. Students inputting the boundary conditions and trying different mesh settings to verify the FEA model

It is also interesting to note that most students have inquired with other sources how the cross section would perform in other conditions such as buckling. This enables them to appreciate the presence of lateral stiffeners and ribs, which is a common subject in aircraft structures. This has affirmed the literature on the effect of visual demonstrations in enabling students to be more operational in their analysis rather than fixed and superficial (Bassok & Holyoak, 1989; Butcher, 2006; Goldstone & Son, 2005; Joseph & Dwyer, 1984; Moreno et al., 2011; Sloutsky et al., 2005).

Table 5. The use of FEA software can be an alternative or supplement to traditional teaching approaches in complex engineering subjects

Respondent	Remarks
1	*"I learned that utilizing this tool would generate more clarity when studying the strength of materials necessary for building and plane construction. I was also able to review the effects of the shape of a material on its structural integrity."*
2	*"This simulation activity taught me the principle between yield strength and stress, the relationship between stress and strain, and the effect of changing cross-section shape to the deflection and bending experienced by a beam."*
12	*"I highly recommend doing this activity while learning about Statics of Rigid Bodies. This is to help learners visualize what really is happening on a body with a given external loads."*

Part of a student's laboratory report is for him/her to provide a summary of his/her learning from the concerned activity. Students must also include recommendations for the improvement of the activity if they find any. Several remarks made by students to improve laboratory exercise can be seen in Table 6. Common responses include the extension of the activity to pre-requisite courses such as Statics of Rigid Bodies and Strength of Materials and the improvement of virtual laboratory access to computers with SolidWorks. Moreover, some students gain more confidence in using numerical simulations and would want to engage in trying other complicated engineering problems to simulate.

Table 6. Students recommendations for the improvement of the laboratory exercise

Respondent	Remarks
5	*"Analyze more complex systems and models to further our understanding on the different forces in play"*
7	*"I recommend simulating models and meshes related to the aerospace field"*

The activity was given in an online setting, and most students do not have the software (SW) in their computers. Remote access has been the option for others, and most of the students that did remote access share the same sentiments when it comes to poor access due to internet connectivity among others. Much of the improvements should be made in remote access to lab software, not only with access to software in lab computers in the university. It is advised that the virtual laboratory is enhanced such as the use of 3D experience and high performance computing (HPC) on demand features of SolidWorks.

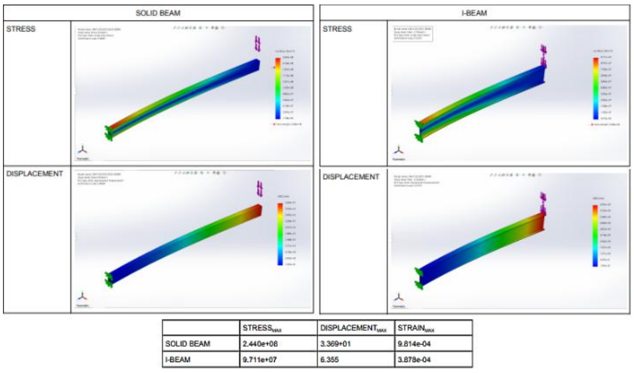

Figure 7. Students generated the goal plots to show the differences in performance between rectangular and I-shaped beam profiles at a certain deformation scale

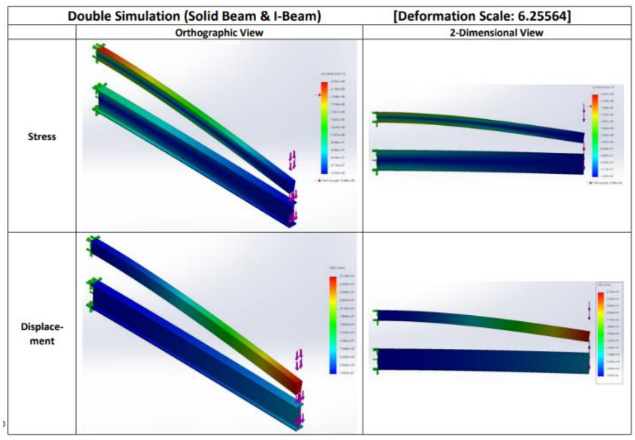

Figure 8. Students have utilized and compared the stress and displacement plots to determine the influence of profile on beam structural performance

There must be a constant and conscious effort to teach not only what and how of numerical simulations. Most importantly, to teach students to interpret the results of numerical simulations through verification and whether it reflects actual results (validation). The exercise not only made the students better appreciate concepts in mechanics and aircraft structures, but as well to recognize the advantages and limitations of the simulations, by interrogating the results of the simulations, which is crucial in engineering, in generating sound and ethical decisions and actions.

Conclusion

The use of numerical simulations can help improve the learning of students in I-beam construction for aircraft structures. Teaching beam profile, moment of inertia and bending stiffness, and how these concepts are related to each other can be augmented with the use of FEA. Moreover, students' appreciation of theories with regards to I-beam structure and its application to aircraft structures is enhanced using numerical simulations. As we navigate a VUCA environment and rapid advancements in computing, numerical simulation programs can supplement or provide alternative avenues where students can learn topics that are conventionally perceived to be challenging.

Suggestions

This study can be extended to other engineering related disciplines to further verify the findings reported in the paper. Despite the advantages of numerical simulations for teaching and learning, educators and school administrators must be cognizant of the financial, technological, and training requirements associated with the use of technology.

Co-Author Contribution

Rodolfo S. Treyes: Validation, Writing – Review & Editing, Supervision
Rogel Mari D. Sese: Supervision, Project Administration

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Conflict of Interest

No conflict of interest.

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