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THE USE OF 3D MODELING SOFTWARE TO ENHANCE ROTORCRAFT MAINTENANCE TRAINING

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In order to obtain an airframe and powerplant (A&P) certificate, students must receive a minimum of 1,900 hours of instruction from an FAA approved 14 CFR Part 147 School. Within Part 147, students are only required to learn about helicopters at a level 1 proficiency, which requires only classroom lectures. In order to fill this possible gap in knowledge, the authors created a training exercise at the sophomore level. A helicopter tail rotor was simulated using CATIA to model common stresses on helicopter components. Additionally, helicopter accident reports were used to increase the understanding of proper maintenance, and how components can affect the failure of the rotary system. Through the exercise, students are expected to improve their knowledge of rotary assemblies, while simultaneously expanding their comprehension of statics. As students progress through their Part 147 training, they can apply their understanding of flight-critical components while making inferences on safety and procedures.

All general aviation (GA) aircraft must recurrently undergo an annual inspection and in some circumstances a 100-hour inspection, depending on the operating conditions, performed by a certified airframe and powerplant (A&P) mechanic. While some inspections require an Inspection Authorization (IA) rating to return these aircraft to service, the A&P certificate is considered the minimum requirement to perform the maintenance for both types of inspection (14 CFR 43, 2019). With 292,002 mechanics practicing in the U.S. 2018, the number of aviation mechanics that have undergone specific Part 147 training to receive their A&P certificate is considerable (FAA, 2018a). However, it is important to note, that students at Part 147 Schools are only required to study about helicopters for 1 hour at the level 1 proficiency in the entire 1,900 hours of instruction for the A&P, thus creating a potential knowledge gap. This gap in knowledge could lead to students not being prepared for future careers in helicopter maintenance (Torrez & Kozak, 2019). Thus, posing a potential threat to the quality of maintenance performed on the 10,500 rotorcraft registered with the FAA in the United States (FAA 2018b).

The potential knowledge gap described in the quality of learning is currently being addressed by helicopter manufactures in the U.S. by providing additional helicopter training specific for their helicopters, however, more needs to be done to standardize the level of learning for all mechanics. While this problem is not exclusive to the U.S, different regions address this issue in different ways. For example, in Europe, the A&P equivalent administered by the European Union Aviation Safety Agency (EASA) is an Aircraft Maintenance License (AML). The AML is then broken down into 3 main groups with several subgroups. In order to perform maintenance

on specific types of aircraft, such as a single turbine engine helicopter, one must have the proper AML license with the appropriate type rating (AMC/GM Part-66, 2012). Adding aircraft type ratings to the A&P might not be feasible at this time, however, the FAA can assist helicopter manufactures in the U.S. by increasing and standardizing the amount of knowledge taught to students through the Part 147 curriculum.

Literature Review

The use of advanced technology in maintenance training in Part 147 classrooms and laboratories has been encouraged for the last 30 years as ways to train students to the highest level of technical skill possible. Computer simulations are often seen as practical supplements to various aspects of learning, such as simulating the operation of a turbine engine, analyzing stresses of structures, or testing the aerodynamics of a design (Johnson & Norton, 1991). Conversely, building or using physical mockups instead of computer simulations can be expensive and time intensive for Part 147 schools (Abshire & Barron, 1998).

Computer Aided Design (CAD) can often optimize a designer's effectiveness when solving intricate models. One of the tools within CAD is the use of Finite Element Analysis (FEA), which models the real-world stresses applied to designs. FEA is expected whenever a designer intends on testing the strength of a structural system and is often one of the first tools taught to engineering students (Novak & Dolšak, 2008). Through FEA, students are exposed to key steps of the structural design process. They are able to make changes to the types of materials and tolerances on the parts to see how it all impacts the related systems (Amoo, 2013).

Within helicopter design and maintenance for both normal category and transport category helicopters, a damage-tolerant concept is used to determine when structural components need to be replaced. Parts that are considered Principal Structural Elements (PSEs) must be analyzed and tested during the design of the component and must be inspected regularly on the helicopter to ensure that they do not cause a complete failure of the helicopter if the part were to fail (14 CFR 27, 2019; 14 CFR 29, 2019). Hess, Stecki and Rudov-Clark bring up the point that using FEA to model possible design weakness in systems is necessary for damage-tolerant maintenance, as it can highlight parts that might require additional maintenance or inspections. Increased knowledge of failures of individual parts will result in an overall increase in reliability of the entire system (Hess, Stecki, & Rudov-Clark, 2008).

In addition to FEA, case studies of helicopter accidents were used to highlight the need for correct maintenance, as it has been proven that students use these case studies to understand human errors in real-world scenarios and their consequences in ways that are more impactful than learning in a classroom (Saleh & Pendley, 2011). The accidents used as case studies for this laboratory exercise were likely caused by maintenance technician errors, and even though technicians performing the maintenance were performing tasks that are taught during their A&P training, the technicians might not have had the familiarity with helicopter systems to anticipate potential problem areas.

Laboratory Project

In order to fill the knowledge gap and increase student understanding of flight critical areas of helicopters, a laboratory project, also referred to as the laboratory activity, was designed around a Schweizer 269A helicopter, such as the one seen in figure 1. The course that this laboratory will be implemented in is a sophomore-level statics course with a bi-weekly, one-hour lecture and a weekly two-hour laboratory. The key concepts taught in the course are statics and forces on aircraft using the 3D modeling software CATIA to simulate the effects on various aircraft components.



Figure 1. Schweizer 269A helicopter located at a Part 147 School

The main part of the project is a helicopter tail rotor, modeled with CATIA software after the Schweizer 269A tail rotor, shown in Figure 2. The finished CATIA modeled tail rotor, and tail rotor under analysis can be seen in Figure 3. In the laboratory activity, students will be simulating the forces felt by the tail rotor through normal operation by applying rotational forces on the CATIA model and observing the areas with greatest stress concentrations.



Figure 2. Schweizer 269A tail rotor used as a guide for the construction of the CATIA model

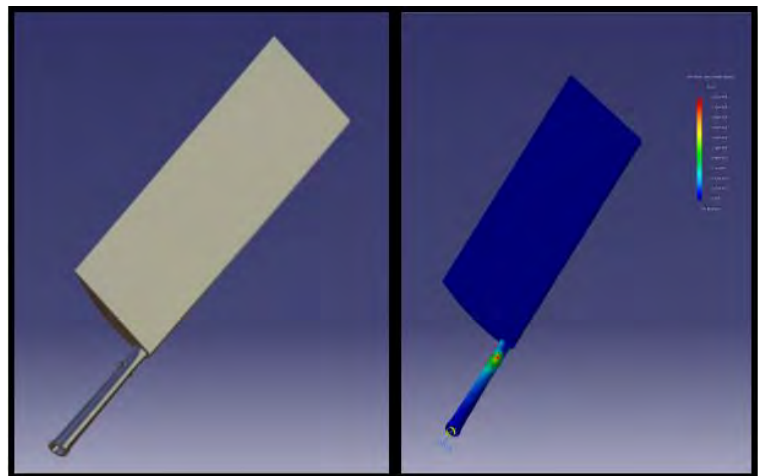


Figure 3. Side by side comparison of Schweizer 269A tail rotor modeled in CATIA with the Von Mises Analysis of the model

To determine the amount of rotational force to apply on the model, students will be asked to obtain the minimum and maximum revolutions per minute (RPM) values for the main rotor for the specific model of helicopter from the Type Certificate Data Sheet (TCDS). Knowing that the tail rotor rotates at a speed ratio of 3:1 to 6:1 when compared to the main rotor, students will be computing the RPMs for the simulations for the following scenarios:

- 1) Speed ratio of 3:1, and minimum rotor RPM
- 2) Speed ratio of 3:1, and maximum rotor RPM
- 3) Speed ratio of 6:1, and minimum rotor RPM
- 4) Speed ratio of 6:1, and maximum rotor RPM

With the information obtained above, students will fill out a table such as the one in Table 1 to complete their laboratory activity:

Table 1. *Schweizer 269A Main and Tail Rotor RPMs*

	3:1 Speed Ratio		6:1 Speed Ratio	
	Minimum Limit (RPM)	Maximum Limit (RPM)	Minimum Limit (RPM)	Maximum Limit (RPM)
Main Rotor				
Tail Rotor				

Using the tail rotor RPMs computed, students will run the four scenarios described above, record the maximum Von Mises stress, and displacement values obtained for each scenario. A typical image of a post-processed tail rotor, displaying the Von Mises can be seen in Figure 3. After recording the required information, students will be answering post-analysis questions to justify and theorize the results they obtained. The analysis questions are shown below in Table 2.

Table 2. *Post Analysis Questions*

Post Analysis Questions	
Question Number	Questions
1	Where was the primary stress found on the tail rotor assembly for each of the increasing RPMs applied to it?
2	If you were to design maintenance based on the analysis, where would you focus your inspection on?
3	What improvements could you make to the tail rotor assembly to increase the strength of the tail rotor?
4	What are the drawbacks/benefits for the solutions you gave in questions 3?
5	What issues with rotorcraft maintenance do you foresee impacting the results that you received?

One of the benefits of using a Schweizer 269A helicopter for the tail rotor model is that an actual Schweizer 269A helicopter is located in a hangar adjacent to the classroom and laboratory. If students have difficulties visualizing the areas of stress, the movement of the forces, or how the tail rotor affects the rest of the helicopter, they can refer to the physical helicopter to answer their questions. Additionally, the hangar also contains the technical documents for the Schweizer 269, so they will be able to look up any maintenance procedures or cut-away diagrams for the helicopter, if necessary. Furthermore, this helicopter may be used as a static maintenance trainer by students in an upper level course depending on aircraft assignments, so students who are already familiar with the flight-critical components and technical documents might find themselves at an advantage.

In order to increase a student’s understanding of the impact of improper maintenance, two National Transportation Safety Board (NTSB) accident case studies involving related accidents in rotorcraft. Students will read these studies, then have to answer a set of questions about them prior to starting the lab. Students will then submit their written answers along with their report at the end of the lab. The case study questions are found in Table 3.

Table 3. *Case Study Questions*

Case Study Questions	
Question Number	Questions
1	What was the probable cause of failure for the accident?
2	What parts of the rotorcraft did the failure(s) affect during flight?
3	What other factors played a role in the failure of the aircraft?
4	Describe some of the key takeaways from the accident that can be applied to maintenance procedures performed in labs.

Limitations and Future Works

There were several limitations regarding the development of the tail rotor model. First, CATIA does not have a default composites material with assigned values regarding the strength of the material. Since we did not have access to accurate data regarding the composition of the tail rotor, we used aluminum to model what the stresses would look like. Doing so allowed students to see a general concept regarding stress. Another restriction regarding the lab is that the hangar does not always possess the appropriate tools to disassemble the physical tail rotor, and even if it did, students would need appropriate permission and supervision from authorized personnel in the hangar. This would limit the amount of analysis the students could do with the physical rotor to tasks that do not require disassembly.

In order to overcome or reduce the impact of these limitations, the authors plan to further refine the laboratory exercise for use during the Fall 2019 semester. By analyzing the tail rotor within CATIA, they can potentially see if variations of materials and sizes and other loads can be used to see when these catastrophic failures happen, and they can further research the properties of the materials. Survey questions will be conducted to gather student’s knowledge and comfort levels for working on helicopters, as well as their perceived workload. The authors plan on dividing Fall 2019 students into two groups where one receives the laboratory instruction about helicopters, and one does not. Through pre and post surveys, the authors will track the effectiveness of the lab activities, both for the case studies and the CATIA exercises.

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