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A Laboratory Project to Enhance Wood Construction and Repair Understanding in a Part 147 School

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American aircraft have always incorporated wood as a primary structural material (FAA, 2018). Although metal has become the leading material in civil aircraft production, approximately 5% of the fleet still uses wood within structural components of the airframe. In order to maintain safe, airworthy aircraft, Airframe and Powerplant (A&P) certificated mechanics must be sufficiently trained in methods and practices approved by the Federal Aviation Administration (FAA). The current 14 CFR 147 training requirements for A&P schools list, at minimum, introductory teaching and understanding of wood building and maintenance concepts, but no hands-on projects or technique evaluation. This lack of hands-on education may leave A&P students unprepared as they enter their careers. Due to this discrepancy in training minimums and experience expectations, a new project was developed that better instructed students in the construction, inspection, and repair of wood structures by providing them hands-on experience. This multi-week project involved students, in groups of four, building a 1/8 scale, Sitka spruce truss fuselage of a light general aviation aircraft. Students were required to use method, techniques, and practices acceptable to the FAA for wood construction and inspection. Upon completion of their build, students were evaluated for the quality of their workmanship and adherence to design data. Finally, students were asked to anonymously self-evaluate their perceived gains in wood building and inspection techniques.

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For many years, wood was used as a main constructional element in the building of aircraft. While the practice is somewhat waning today, there are still a tenable number of these wood structured aircraft flying within the United States today. As these machines age, there is a continual need for qualified technicians to inspect, repair, and maintain them in a way that preserves their functionality and, most importantly, their airworthiness. The Federal Aviation Administration prescribes a set of regulations that must be met for an aircraft to remain airworthy, one of which is the need for Airframe & Powerplant certificated mechanics to perform the necessary maintenance. These A&P mechanics must be well versed in the methodologies surrounding wood inspection and repair, however their training requirements are surprisingly lax in this area. In order to improve A&P understanding of wood construction and repair, an A&P school has developed a new project that goes beyond the required minimum instruction set forth by the FAA. The goal of this new project has been to give students a hands-on active learning opportunity; an opportunity which helps improve their skills and technique with wood structures.

Overview of Wooden Aircraft Construction

Wood was a primary structural material during the beginning decades of aviation because there were few materials that could match its combination of strength, durability, low weight, and low cost (FAA, 2018). There are still a reasonable number of aircraft still flying that incorporate wood into their structures. Table 1 outlines a selection of popular aircraft designs containing wood. These aircraft were chosen based on their use in General Aviation (G.A.) in the U.S. With a United States G.A. fleet of approximately 199,300 fixed wing aircraft (FAA, 2017), these selected aircraft represent 4.96% of those registered within the U.S.

Table 1

Popular aircraft with wood structures registered in the United States as of 2018..

Type	Number Registered with FAA	% of G.A. Fleet
Piper J-3 Cub (and variants)	4,178	2.10%
Aeronca Champ	2,567	1.29%
Bellanca Citabria (and variants)	1,253	0.66%
Bellanca Viking (and variants)	660	0.33%
Pietenpol Air Camper	227	0.11%
EAA Biplane	70	0.04%
Pitts Special (and variants)	851	0.43%
Total of Select Aircraft	9,806	4.96%

*Data obtained from 2018 FAA aircraft registry

The Piper Cub’s original production ran from 1937 through 1947, and saw nearly 20,000 aircraft produced (Smithsonian Institute, 2018). Piper Cubs were used widely in civilian and military flight training as well as serving as military observation aircraft (Smithsonian Institution, 2018). The popularity of the design has since led to modern manufacturers reproducing Cubs and Super Cubs, as well as Cub-inspired original designs that use modern material like carbon fiber (“Carbon Cub SS,” 2018). The original Cub was made with a welded steel tube frame, but most models used a wooden wing spar underneath fabric covering. These aircraft were powered by reciprocating engines ranging from 40 to 65 horsepower (Smithsonian Institute, 2018), which yielded a docile aircraft for training and recreational flight. With their low fuel use, forgiving handling, and simplistic design, Cubs have remained prominent in American aviation.

Another prominent aircraft to be built from wood is the Champion originally produced by Aeronca, which entered production in 1945 ("American Champion 7EC Champ," 2009). The initial production run ended in 1951, but the American Champion company took over the design and resumed production during 1955 ("American Champion 7EC Champ," 2009). The Champ fuselage was constructed of wood stringers and formers, and the aircraft's wing spars were wood, with aluminum ribs and a fabric skin overlay (Davisson, 1997). Champs saw extensive use as flight school aircraft, as well as some models being used by the U.S. military (Visel, 2018). Derived from the Champ's design was the Citabria, an aerobatic rated taildragger ("American Champion Citabria," 2009) that has been in production since 1964. The Citabria design retained the wooden spars and fuselage paneling of its predecessor and has proven to be an inexpensive and enjoyable aircraft to fly ("Aircraft Spotlight," 2016). Bellanca Aircraft produced the Citabria design throughout the 1980s, however they were not Bellanca's first venture into wooden aircraft.

Bellanca produced their Viking model out of Minnesota beginning in 1967 (Cox, 2004), building the most substantial aircraft discussed thus far. The Viking featured a wing made from Sitka spruce and mahogany plywood, which yielded a strong, lightweight, and aerodynamically smooth lifting surface (Cox, 2004). In addition to this, the Vikings were four seat, retractable gear, high performance aircraft, with excellent handling characteristics ("Bellanca Super Viking," 1993). With its clean lines, large carrying capacity, and a 300-horsepower engine, the Viking placed itself in a different class of aircraft from the trainers and aerobatic aircraft previously mentioned. Bellanca's design was far more focused on luxury, receiving favorable reviews on its performance and handling, as well as having a range more suited to cruising instead of sport flying ("Bellanca Super Viking," 1993).

In the world of experimental or *homebuilt* aircraft, wood has remained a relevant material. The Pietenpol Aircamper was conceived and designed by Bernard Pietenpol, and first flew in 1928 (Pietenpol, 1991). The Aircamper design called for a wood structure for both fuselage and wing assembly. The plans specified the use of spruce, mahogany plywood, and white ash woods throughout. Most surfaces, such as fuselage sides and floor, as well as gusset plates, were to be mahogany plywood, while structural items like spars are Sitka spruce (Pietenpol, 1991). The assembly of the Aircamper was almost entirely glue based, with gusset plates added for extra strength. To this point, the Pietenpol plans stated: "There is no point in using a lot of nails. The strength lies in the gusset plate and gluing." (Pietenpol, 1991, p. 8).

A later design in the category of homebuilt aircraft was the EAA biplane. This aircraft was commissioned by Paul Poberezny, the founder of the Experimental Aircraft Association (EAA) ("1960 EAA Biplane," 2018). By 1960, a team of engineers and high school students had developed a design with wooden, fabric covered wings and a tube steel fuselage ("1960 EAA Biplane," 2018). The EAA biplane was sold only as a set of plans which provided the builder all they needed to know to construct their own aircraft. The authors were granted access to an EAA biplane that belongs to a Part 147 certificated mechanic school. This aircraft was donated to the school in a state of partial completion, which allowed students a chance to easily study the wooden construction of its wings. Pictures have been included in Figures 1, 2, and 3 to exemplify wooden structures as discussed in this paper.

Figure 1. A front quartering view of an EAA biplane used for maintenance instruction at a Part 147 Aviation Maintenance Technician School.

Figure 2. Image looking toward the centerline of the EAA biplane, depicting a close-up view of the internal structure of a wooden wing.

Figure 3. Wood structure inside a partially complete wing of the EAA biplane.

The Pitts Special has been another popular homebuilt biplane aircraft, with some of its variants including wood in their construction. Pitts Specials have been known as an aerobatic aircraft, not designed for comfort or travel. Pitts biplanes were described as “tiny, impractical, loud, and demanding” (“Budget Buy: Pitts Special,” 2017); its sole purpose in existence was to provide a fun, thrilling ride to those willing to endure its abuses (“Budget Buys: Pitts Special,” 2017). From decades old home build kits, to mass produced trainers, or the high-speed comfort of the Viking, wooden aircraft remain prevalent in the U.S. As can be seen in table 1, when the totals of these selected aircraft were combined, they represented 4.96% of the U.S. General Aviation fleet.

Aircraft Certification and Maintenance

Within the United States, all aircraft must comply with the requirements of the FAA to remain airworthy. According to the FAA, “An aircraft with a type certificate (TC) is airworthy when it conforms to its U.S. TC and is in a condition for safe operation.” (Department of Transportation [DOT], 2017 p. I-1). Experimental aircraft do not have a Type Certificate and are therefore considered airworthy when in a condition for safe operation. For the aircraft mentioned above, and for many others under 12,500 lbs. gross weight, this determination of conformance and safety is made during detailed inspections every 12 calendar months, or every 100 hours of operation if the aircraft is used for hire (Inspections, 2018). These inspections must be performed by an appropriately rated mechanic (Inspections, 2018), and during these inspections, it is feasible that damaged or degraded wood structures may be found.

If defects are found that necessitate repair, mechanics must use the proper reference data to perform their work. Advisory Circular AC 43.13-1B is an FAA resource that has been considered acceptable data for repairs on non-pressurized, civil aircraft, and contains a wealth of information on wood construction. One difference between metal and wood construction is the wide use of adhesive bonds in wood assemblies. Critical factors like surface preparation, grain orientation, and clamping pressures must be considered during assembly, and approved glues must be used (FAA, 1998). Repairs to spars generally consist of splices with feathered surfaces and reinforcement plates, while skin repairs call for scarf patches, with a myriad of specific requirements (FAA, 1998). The technicians that have been charged with these repairs must possess a specialized skill set to execute proper, safe, and long-lasting repairs, and must also be certificated through the FAA in order to legally release the aircraft for return to service.

These specialized technicians are typically Airframe and Powerplant (A&P) certificated mechanics. Some technicians choose to work without their A&P, and these individuals must be supervised directly by another technician that is a certificated mechanic (FAA, 2013). Without an A&P mechanic directly involved in the maintenance being performed, the work is not allowed (Persons authorized, 2012). In order to sustain an airworthy fleet of wooden aircraft, it is imperative that A&P mechanics be well versed in the complex and demanding repair and maintenance of wood structures, however the training requirements in this aspect have been surprisingly lax. In order to obtain their A&P, mechanics must have had at least 18 months of experience relating to the specific certificate sought (airframe or powerplant) or have a combined 30 months of both (Experience Requirements, 1970). There is a second way of complying with the experience requirements: attending and graduating from an FAA approved aviation maintenance technician school (Experience Requirements, 1970).

For schools to be approved by the FAA, they must comply with 14 C.F.R Part 147, which specifies the organization, operation, and curriculum content of aviation maintenance technician schools. Airframe Curriculum Subjects, Appendix C to 14 C.F.R Part 147 (2018) specifically lists the following requirements related to wood structures as the minimum instruction on wood for A&P certification:

1. Service and repair wood structures.
2. Identify wood defects.
3. Inspect wood structures.

These tasks are held to a teaching Level 1, which requires no practical application or manipulative skill; only general knowledge and instruction by lecture (Airframe Curriculum Subjects, 2018). Of the three teaching levels, Level 1 is the least in-depth level, requiring students to only have general understanding. Many other subjects such as sheet metal, landing gear, and electrical tasks are held to Level 2 or 3, which mandates that students need to have a functional grasp of topics and be able to perform the work they are studying (Airframe Curriculum Subjects, 2018). Levels 2 and 3 require manipulative skill and practical applications of the topic at hand (Curriculum Requirements, 2018). The defining factor that separates Levels 2 and 3 is that Level 3 tasks must be executed to a level that could constitute return to service requirements (Curriculum Subjects, 2018). This means the student’s work should meet manufacturer guidelines for work quality on airworthy machines. The lack of hands on training with wood structures presents the opportunity for a disconnect to develop between skills *taught* and skills *expected* of A&P mechanics.

Upon certification as an A&P mechanic, students who have only had an introductory training in wood structures would be allowed to perform repairs and modifications like those outlined in AC 43.13. According to the findings of research performed by Freeman et. al. (2014) on the subject of active learning, student performance shows a noticeable increase when lecture is coupled with active hands on learning, and that "students in classes with traditional lecturing were 1.5 times more likely to fail than were students in classes with active learning" (Freeman et. al., 2014). Even though Part 147 schools are fulfilling their minimum requirements by solely lecturing on wood structure construction and repair, lecture isn't always enough to teach safe practices.

It should also be noted that 14 C.F.R Part 65.81, General Privileges and Limitations (1980), which deals with mechanic privileges and limitations, states that a mechanic may not perform any work which they have not performed previously, regardless of their certification or ratings. The caveat to this rule is that a properly certificated and experienced mechanic may supervise the work, allowing the new mechanic a chance to perform the task at hand (General Privileges and Limitations, 2018). While it was feasible in decades passed that a fledgling mechanic would be given the chance to work under an experienced mechanic if they were going to maintain wooden aircraft, the number of certificated mechanics with woodworking experience is steadily declining (FAA, 2018).

Project

The use of laboratory-based training has been extensively used to increase student understanding of basic concepts and real-world problems (Lanza, 1984; Sundberg & Moncada, 1994; Mahendran, 1995; Burrowes & Nazario, 2008). Furthermore, hands-on training is a fundamental part of teaching technical topics (Wheway, 1991). To help close this gap in experience, a new project was developed for use in a Part 147 certificated school and has been implemented into the curriculum for two semesters. The project required students to build a simplified version of a wooden aircraft fuselage using FAA approved techniques and practices. The primary learning outcome of the project was to introduce student to the techniques used in wooden aircraft construction. There were some secondary learning outcomes as well, such as reinforcing in the students a sense of responsibility for the quality of their work and encouraging communication when working as a team.

During this four-week project, groups of three students were given ample supplies of aircraft-grade Sitka Spruce, T88 epoxy, tools, and engineering drawings of a truss structure. Multiple views of the expected truss can be seen in Figure 4. A 3D representation of the truss can be seen in Figure 5. This truss was a 1/8th representation of a simplified aircraft fuselage, and students were required to build it according to standard construction practices. By requiring students to adhere to standard practices such as those in AC 43.13, this exercise provided students hands on experience with wooden aircraft structures.

During the construction of the truss, students were expected to follow engineering drawings to measure and cut appropriate lengths and angles from Sitka spruce stock. Once students laid out their parts and prepared the surfaces to be bonded, they mixed and applied T-88 epoxy. This epoxy is a common two-part epoxy resin used by experimental aircraft builders and has been approved by the FAA for repairs on certificated aircraft. T88 was chosen because of its high strength, ease of application, and simple mixing characteristics (System Three, 2018). Once their epoxy was applied, students were expected to devise a clamping arrangement to hold their pieces together and provide ample pressure for curing, as seen in Figure 6.

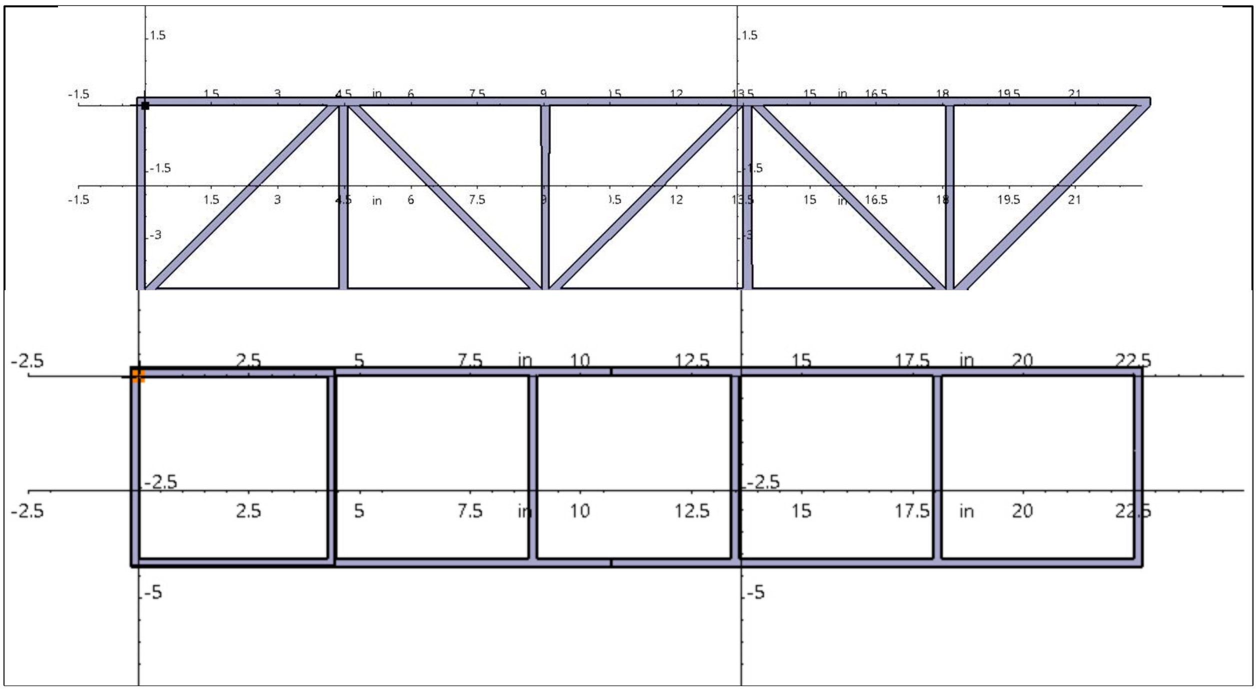

Figure 4. 3D CAD drawings used to create the engineering drawings that students were given to complete their build projects. Views shown: left side and top.

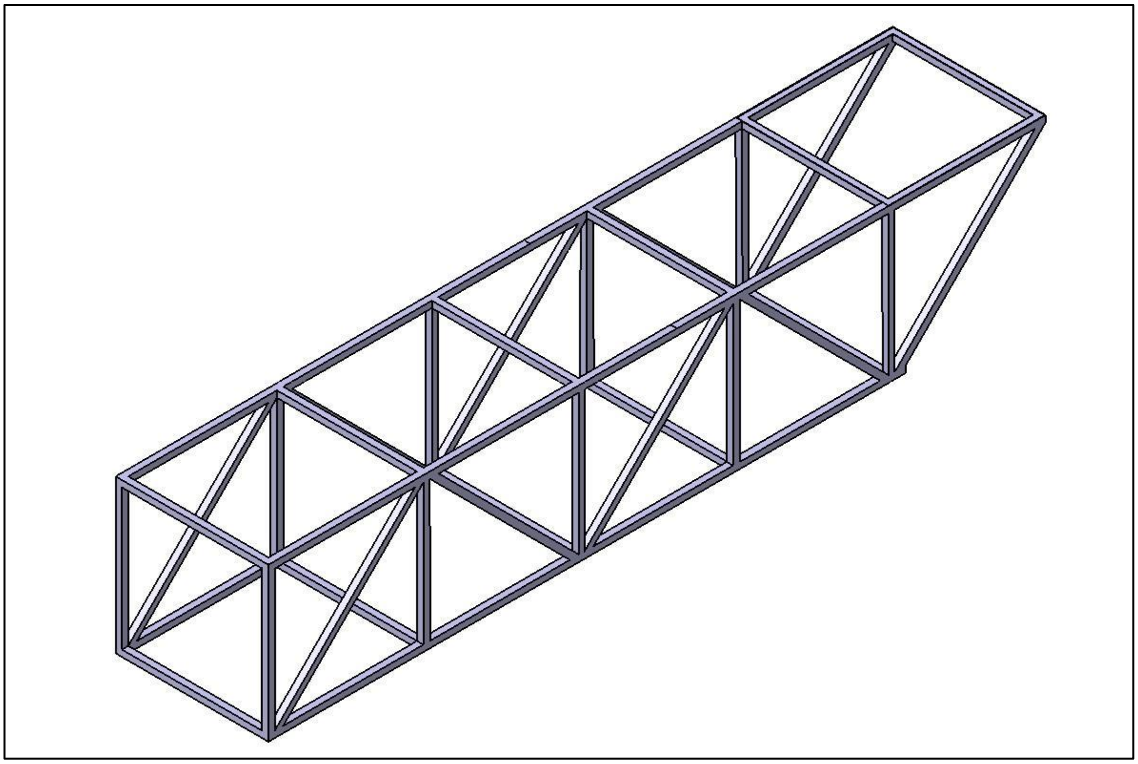

Figure 5. CAD isometric picture of the truss assembly.

Figure 6. Truss structure clamped in place to allow epoxy to cure during student build project.

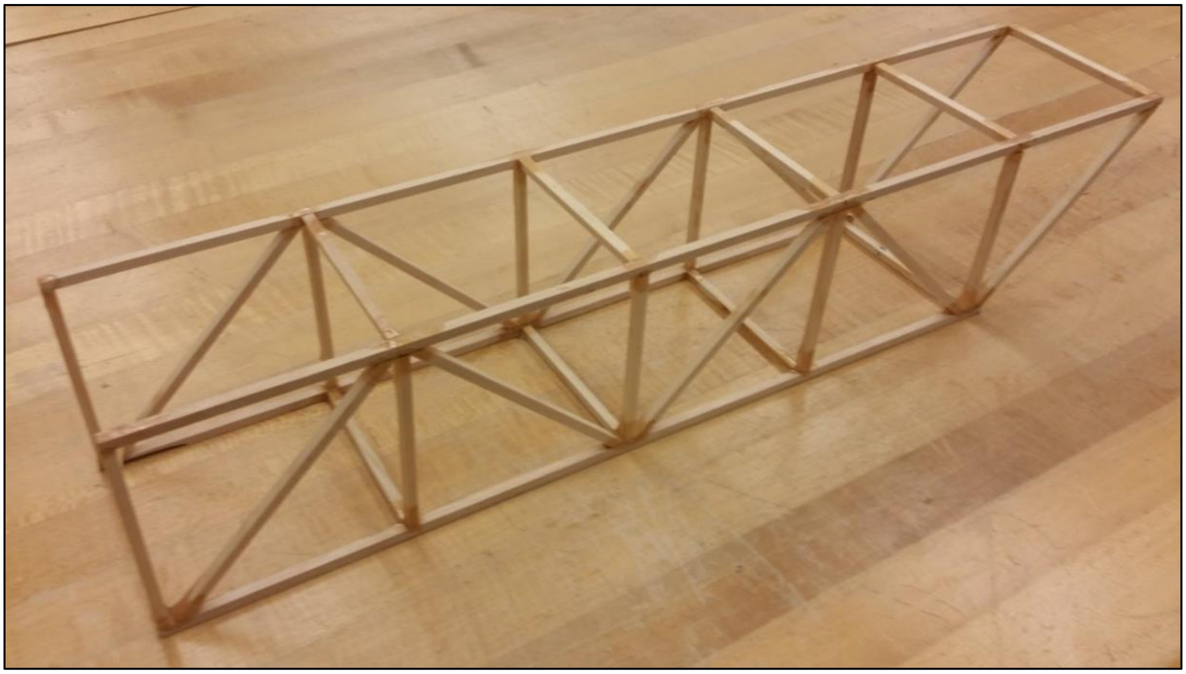

Figure 7. Isometric picture of a completed truss assembly as built by Part 147 students.

Upon finishing their build project, students were evaluated on the quality of their construction. Projects were inspected for clean, straight cuts at the proper angles. Trusses were measured for dimensional adherence to the engineering drawing provided. The structure was also checked for the straightness and symmetry of construction. Finally, students were evaluated on the appearance of their glue joints; excess epoxy was to be removed and gaps in joints were to be kept to a minimum. A finished truss assembly can be seen in Figure 7.

In order to document project outcomes at the end of the semester, the students who participated in the building exercise were asked the following questions, and asked to respond on a 5-point scale: "As a result of your work in this class, what GAINS did you make in the SKILL of building a model of an aircraft fuselage?" Responses can be seen in Table 2.

Table 2

Responses to "building skills" question

Gained a great deal (5)	4	Median	Standard Deviation
Gained a lot (4)	10	-	-
Gained somewhat (3)	4	-	-
Gained a little (2)	0	-	-
Gained nothing at all (1)	0	-	-
Totals-	18	4.0	0.67

"As a result of your work in this class, what GAINS did you make in the SKILL of identifying and explaining the wooden materials used within aircraft construction?" Responses to this question can be seen in Table 3.

Table 3

Responses to "wooden materials" question

Gained a great deal (5)	3	Median	Standard Deviation
Gained a lot (4)	10	-	-
Gained somewhat (3)	3	-	-
Gained a little (2)	2	-	-
Gained nothing at all (1)	0	-	-
Totals-	18	3.9	0.85

This practical, hands-on project was designed to give students an introductory view of working on a wooden structure. By teaching wood builds in this manner, the Part 147 school was able to exceed the Part 147 requirements of solely lecture exposure to wood structure. The goal of their exceedance was to better prepare A&P students to handle the complexities of maintaining America's G.A. fleet.

Conclusion

While wooden aircraft may not be the primary representative of the G.A. fleet, they still represent a relevant portion of aircraft flying. Many designs utilize wood structures. As they age, these aircraft will suffer decay from decades of use, and accidents may happen necessitating repairs. The intricacies of wood structure repair and maintenance require A&P technicians to be well-versed in skills which are not well-taught in current Part 147 schools. By implementing this new construction project into their curriculum, steps are being taken toward better educating the current generation of students.

It should be acknowledged that implementing this project incurs additional burdens for Part 147 schools. The monetary cost for the supplies will exceed the typical budget that is required for a Part 147 curriculum that simply meets minimum requirements. Additionally, as Part 147 curriculum timelines are often densely-scheduled as is, the time commitment to afford students enough work time to complete their project may present a challenge for educators. Despite these challenges, this project should be considered as a supplement to Part 147 operations because of its potential benefits. By providing an opportunity to handle the material, use real-world tools and techniques, and evaluate the finished product, the Part 147 school's new wood project gives students more experience with wood structures than is required by the FAA.

Future Works

In future semesters, the Part 147 instructors involved in this new course exercise plan to incorporate a destructive testing and failure analysis component to the project. It is expected that applying a load to the structure in a controlled and measurable fashion would allow the students to compare their construction techniques and evaluate how quality of workmanship affects the strength of the truss structure. The destructive portion of the project would also include an analysis of how and where their truss structure failed. By studying the appearance of the wood and epoxy joints in the truss, students would be able to better identify failure conditions present on actual airframes.

Another addition to the build project would be to include an assignment for the students to produce a 3D Computer Aided Design (CAD) model in a program that includes structural analysis capabilities. Students would apply the structural properties of the materials used in their build, namely Sitka spruce, then use the structural analysis tools to simulate the same mounting and loading conditions as applied to their physical models. The purpose of this assignment would be for students to compare the differences between CAD results and actual prototyping of structural designs. While CAD can be an extremely helpful tool in the design process, it is not always entirely accurate, and this project would help put a tangible example in front of students to learn from, better preparing them for their careers as technicians.

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