The ATEC JOURNAL

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BETTER RESULTS FOR COUNTERSUNK RIVET REPAIRS

INTEGRATING 3D PRINTING INTO AN AMT PROGRAM

VALID ASSESSMENT OF TRANSVERSAL COMPETENCIES IN AIRCRAFT MAINTENANCE:

INSIGHTS FROM FOCUS GROUPS WITH INDUSTRY STAKEHOLDERS

About the Council

ATEC was founded in 1961. Its mission is to promote and support aviation maintenance technical education.

The council actively engages with regulatory and legislative bodies to advocate on behalf of the community, and provides resources, continuing education, and networking opportunities for our members.

Our membership is made up of employers, vendors, and educational institutions with aviation technical programs. The vast majority of member schools are certificated by the FAA to provide aviation mechanic programs.

- Membership supports the following activities and initiatives—
- Advocating for sound regulatory policy, the development of clear and concise guidance, and consistent enforcement and application
- Participating on industry and agency committees to further aviation technical education and workforce development
- Fostering and supporting career pipeline partnerships between industry and educational institutions
- Facilitating networking opportunities through the annual conference, Washington fly-in, regional outreach meetings, and virtual webinars
- Enhancing aviation technical career awareness through support of ATEC's sister organization, Choose Aerospace

About the Journal

The *ATEC Journal* (ISSN 1068-5901) is a peer-reviewed, biannual electronic publication. The publication provides an opportunity for educators, administrators, students and industry personnel to share teaching techniques and research. Authors are encouraged to submit their articles for publication consideration, whether scholarly, research, application, or opinion, by using the submission form below. Papers supporting the council's regulatory and legislative agenda may be considered for presentation via online webinar and at the annual conference. Suggested topics include:

- Technical and soft-skills curriculum integration
- A history of legislative actions affecting aviation maintenance workforce development
- A study on implementing employer-education partnerships
- Funding implications stemming from Bureau of Labor Statistics occupational outlooks
- Highlighted innovations in the aviation maintenance industry
- A look at successful online teaching methods and subject matter in other technical fields
- Surveying currently used computer-based teaching across aviation maintenance training schools

SUBMISSION DEADLINES

Fall Issue Closing Date: October 1 • Spring Issue Closing Date: May 1

SUBMIT AN ARTICLE FOR REVIEW AT ATEC-AMT.ORG/THE-JOURNAL.HTML

from the EDITOR

This Journal was led by the tireless efforts of Dr. Karen Johnson for the past eight years. As an editorial board member, I had the privilege of working with Karen and seeing firsthand her unparalleled work ethic, pursuit of excellence, and dedication to the aviation maintenance education community. Although she has stepped down as editor, I know she will continue to be a highly contributing member of the aviation maintenance education community.

I am grateful for Karen and Crystal Maguire for offering me this opportunity, and I will strive to ensure that the Journal continues to be a valuable resource. I also want to encourage the ATEC community to share your expertise, research, best practices, and opinions by contributing articles to the Journal.

I understand that submitting your work for peer review can feel daunting. Few, if any, people enjoy being critiqued, especially after you have put forth your best effort in a written product. However, I hope authors will find our peer review process to be collegial, constructive, and beneficial. To that end, I encourage those who are interested in submitting works to the Journal to reach out if you are unsure of how to proceed. I will do my best to help.

I want to thank our authors for contributing timely and practical articles, our editorial board members for reviewing the articles, and the publication team at ATEC. I want to thank Jeff Strong, who continues to offer his expertise and service as our Senior Copy Editor. Lastly, I'm grateful for my School Director, Dr. James Birdsong, who has provided support for me to serve in this role.

Best,

Daniel Siao
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Committee Updates

ATEC committees are comprised of dedicated individuals representing both educational institutions and industry partners. A full list of committees and current participants is available at www.atec-amt.org/committees. The council welcomes new voices and actively encourages member representatives to get involved. If you're interested in contributing to the council's ongoing initiatives, please reach out to learn more about joining a committee.

ATEC ACADEMY

The Academy wrapped its fifth cohort this summer, with graduates representing the Federal Aerospace Institute, Wayne Community College, Tulsa Tech, Cape Cod Community College, and Middle Tennessee State University. Since the program's debut in spring 2024, more than fifty aviation maintenance instructors have enrolled, underscoring ATEC Academy's commitment to addressing the ongoing challenge of recruiting and retaining qualified instructors amid rising workforce demand in the aviation maintenance sector.

ATEC Academy provides a comprehensive professional development pathway tailored for new and emerging instructors in FAA-certificated schools. The program blends two full days of in-person instruction with approximately three months of virtual coursework. Participants explore topics such as active teaching strategies, student behavior management, assessment and evaluation methods, lesson planning, and current trends in technical education. The curriculum places special emphasis on delivering effective hands-on lab instruction and meeting FAA certification requirements.

Another cohort kicked off in October, with additional opportunities launching this spring in Portland and this fall in Tulsa. Registration is now open, and space is limited—early enrollment is encouraged. For program details and upcoming offerings, visit www.atec-amt.org/atec-academy.

MIKE SASSO
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ANNUAL CONFERENCE COMMITTEE

We look forward to welcoming you to Portland this spring for the 2026 ATEC Annual Conference, taking place March 29–April 1. Planning is well underway, and the Alaska Airlines Group is excited to host the aviation education community.

In addition to a full slate of educational sessions featuring regulatory updates, best practices, and opportunities for networking and engagement, attendees can look forward to a welcome reception with fantastic views of the city, dinner under the wings of the Spruce Goose, and tours of the Horizon Air Operations Center along with our host school, Portland Community College.

Explore the agenda, see the exhibitor directory, book your hotel accommodation, and register at www.atec-amt.org/events/2026-annual-conference#attendees.

ARCHIE VEGA
MEETING PLANNING CHAIR
Director of Maintenance and Development,
Horizon Air

REGULATORY COMMITTEE

ATEC is continuing facilitation of a working group to make recommendations to update the Mechanic Airman Certification Standards. Member representatives from across the country are contributing to a comprehensive update, building on prior proposals developed by fellow trade associations. This work is also informing recommended revisions to the FAA's Aviation Maintenance Handbooks, ensuring both documents reflect modern expectations for aviation maintenance training and certification. ATEC encourages members to share feedback on the ACS and handbook materials to help shape these essential resources, and stay tuned for briefings on proposed recommendations at the upcoming Annual Conference.

Beyond the ACS effort, the committee remains focused on reducing barriers to airman testing including increased engagement with the FAA's testing contractor, PSI Services, and assisting programs that are making application for Organization Designation Authorization to provide airman testing services. It continues to push for increased discretion and flexibility for designated mechanic examiners to support a more efficient and responsive certification system. The committee is also working with the FAA to implement congressional directives that will ease the transition for military-trained technicians into civilian careers and allow mechanic candidates to begin the testing process earlier in their training pathway.

For more information about the committee's work, visit www.atec-amt.org/regulatory-priorities.

SEAN GALLAGAN
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CHOOSE AEROSPACE

Since last spring, Choose Aerospace has continued to scale both its impact and visibility in the aviation maintenance pipeline. The organization formally launched the ATEC General Aviation Maintenance Credential, an industry-recognized exam available exclusively to students who complete the Choose Aerospace curriculum, with early success stories like Putnam City Schools—where 9 of 11 students recently earned the credential. The credential is accepted as state-approved in Iowa and Oklahoma, with plans to expand those approvals to other states in the coming year.

Scholarship support has expanded as well: Choose Aerospace announced its 2025 scholarship recipients (more than $50,000 in awards) and is now launching the new Choose Aerospace SkillPointe Scholarship Fund, a national-scale program designed to connect aviation maintenance students with employers and postsecondary opportunities. Look for applications to open next month.

Program enrollment is strong, with 1150 students in 50 active programs across 23 states—a 60% increase over last year. Over 2600 students have participated in Choose Aerospace since its inception. Operationally, Choose Aerospace has transitioned to the SkilRedi learning management system, introduced group discount pricing to keep the curriculum affordable as programs grow, and delivered robust in-person teacher training to support implementation.

This momentum has been recognized nationally: Choose Aerospace was recently selected for Aviation Week Network's 2026 Laureate Award in the MRO category, underscoring the program's role in addressing long-term technician shortages. We couldn't be more proud of what we've accomplished and are looking forward to more successes in 2026.

KELLY FILGO
CHOOSE AEROSPACE DIRECTOR OF OPERATIONS
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LEGISLATIVE COMMITTEE

The Legislative Committee is celebrating a productive Fall Fly-In, where ATEC members gathered in Washington, D.C. for two focused days of meaningful regulatory and legislative engagement. The event once again served as an invaluable forum to connect with elected leaders and gain insight from administration officials on rules, guidance, and priorities affecting aviation technical education.

Key topics included continued work toward revising mechanic Airmen Certification Standards and handbooks and furthering reauthorization-driven tasks such as evaluating early knowledge test eligibility for mechanic applicants and supporting military-trained technicians transitioning to civilian careers. On Capitol Hill, attendees educated congressional leaders and staff on aviation technical workforce challenges and encouraged action to ensure appropriated FAA workforce grant dollars are fully funded.

Building on the discussions and momentum generated during the Fly-In, the Legislative Committee is continuing its work to advance recommendations and move key projects forward. Save the date for next year's Fly-In, taking place Sept. 23–24, 2026.

JARED BRITT
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ATEC ACADEMY

Educator Professional Development Series

UPCOMING DATES

Thu. & Fri. **Apr. 2-3, 2026**	**Portland Community CLIMB Center** 1626 SE Water Ave, Room #306 Portland, OR 97214
Tue. & Wed. **Jun. 9-10, 2026**	**Tulsa Technology Center** 801 E 91st St Tulsa, OK 74132

Struggling to find and keep instructors? Are you hiring instructors with extensive industry experience with little to no teaching experience?

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REGISTER NOW at **atec-amt.org/atec-academy**

Better Results for Countersunk Rivet Repairs

Don Morris

Don Morris earned his MAS in Aviation Education and Management from Embry-Riddle Aeronautical University and his BS in Physics from Illinois State University. He has over 25 years of classroom experience and is an Associate Professor of Aviation at Southern Illinois University, Carbondale.

James Barker

James Barker is an assistant professor of aviation at Southern Illinois University Carbondale. Originally an auto and heavy machinery mechanic James expanded to aviation in 2017. He holds both a bachelor's and master's degree in the field of aviation as well as airframe and powerplant certifications. Specializations were obtained in both the areas of Avionics and Advanced propulsion. The owner of an automotive restoration shop, and faculty advisor of two separate aircraft maintenance RSOs, Mr. Barker is interested in all things' maintenance.

ABSTRACT

Precisely matched drilling holes is an essential part of the sheet metal repair process. It is quite precise when the original holes are made for universal head (AN470) rivets. For repairs made to parts formed with countersunk or dimpled (AN426) rivets, it is much less precise. This paper examines the problem geometrically and explains why this is so. It then details a simple, self-made tool that demonstrably increases precision. It follows our creation of this tool and its use in our sheet metal lab on a live aircraft repair project. It then quantifies the superiority of the results that this technique produces.

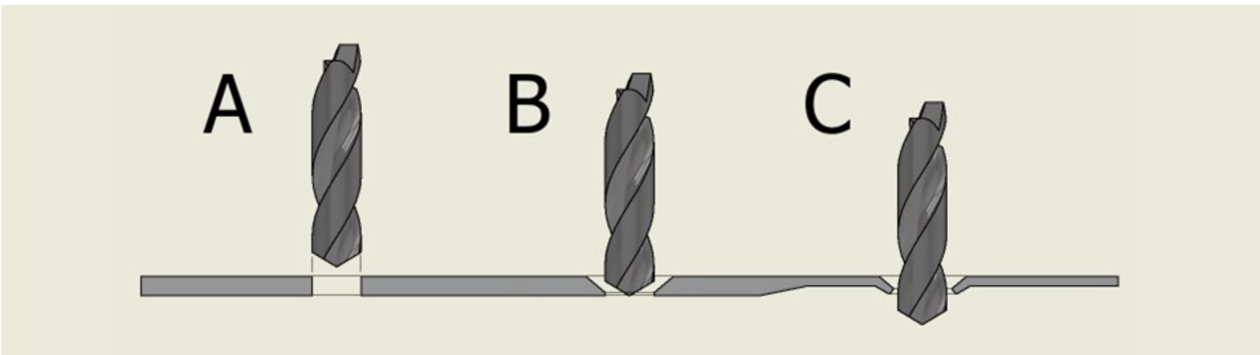
A few years ago, our department asked the local Dassualt-Falcon sheet metal repair department director which single concept was the most important to cover thoroughly in an aircraft sheet metal repair class. Without hesitation, he replied, "how to get your holes." Repairing a metal aircraft almost always involves some degree of riveting new, undrilled parts to existing, already drilled parts. This is one of the reasons that proper rivet removal technique is critical. The repair relies on clean rivet removal and reusable rivet holes on every undamaged part that contacts any newly fabricated or replaced part. It also requires accurate hole transfer from the existing, undamaged part to the new replacement part.

The Federal Aviation Administration's (FAA) mechanic training textbook, Aviation Maintenance Technician Handbook – General, FAA-H-8083-30B (2023), describes the process of hole transfer as follows: "Accomplish transfer of holes from a drilled part to another part by placing the second part over first and using established holes as a guide." This is frequently referred to as "match drilling," and is the go-to technique for most repairs. In our experience, it works well for AN470 (universal head) rivets. We have used it very successfully to repair 100 Series Cessnas and similar aircraft—but when one of our instructors began rebuilding a wrecked Van's RV with its myriads of flush rivets, he was very unhappy with the results.

The Problem

Figure 1 illustrates the problem. As long as a drilled piece of sheet metal (position A) is of sufficient thickness, it forms a good guide for the drill bit, precisely locating the hole in the layer beneath (not shown). It is only necessary that the sheet be of sufficient thickness to allow the flutes into the hole before drilling begins. Using a little trigonometry, we can calculate that for a number 3 rivet and a standard 118-degree drill bit, the sheet must be over 28 thousandths thick to be able to guide the bit. When part of the hole has been countersunk (position B), the entire sheet thickness no longer provides an accurate location. Now the only portion that locates the drill bit is the much thinner "uncountersunk" portion of the hole. In this scale illustration, a 118-degree number 30 drill bit is obviously imperfectly located in the center of the 100-degree countersunk 50 thousandths thick sheet metal. The problem becomes even more severe when considering a dimpled sheet (position C). As the dimple is formed, the "lip" folds away from the hole, resulting in a slightly larger diameter hole than that which was originally intended. We face the angle problem described in B, and the fact that the entire hole is now a larger diameter. The angular data for the illustration was taken from the film "Four Methods of Flush Riveting" (1942) and the MS20426 Spec Sheet (Department of Defense, 1988). This is why match drilling 426 rivets results in low accuracy hole location. It requires painstaking eye-hand coordination to guide the drill bit into the center of holes that do not form accurate physical guides.

Figure 1
Illustration with Drill Bits and Straight, Countersunk, and Dimpled Holes



Note. Source: Authors

A Simple Solution

This past spring, we had some advanced sheet metal students who indicated interest in working on a "live" project. We brought in a Van's RV that needed a wing rib replaced. Figure 2 shows one of the students about to begin drilling on a Van's RV wing in the lab. While explaining the importance of drilling accurately on countersunk holes, the instructor who owned the airplane realized that a small tapered drill bushing could be used to fill up the space and more accurately locate the drill bit. This instructor was certainly not the first person to think of this solution—but we were unable to find any reference to it in any published manuals or handbooks. We did find a similar suggestion on a Van's Aircraft Forum, where the conclusion was to use a "hinge bit" from Home Depot (Burbidge, 2009).

Figure 2
Student Preparing to Repair a Van's RV Wing

Note. Photo used with student's permission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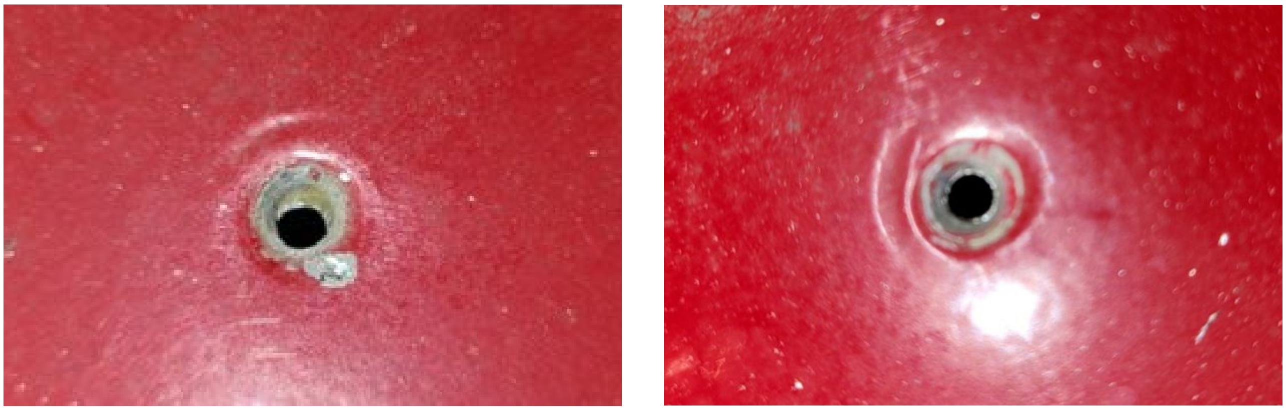
Unconcerned with the novelty of the technique, we were interested in a safe and workable repair. We fabricated a simple bushing from a tiny piece of aluminum tube, gave it to the students, and were pleased with the results. Figure 3 shows the visibly superior concentricity resulting in drilling with a bushing. Figure 4 shows the original tiny piece of tubing along with our more sophisticated brass research prototype.

Figure 3
Unquantified Results



Note. The left hole is drilled without bushing, and the right hole is drilled with bushing.

Figure 4
Original Drill Bushing and the More Sophisticated Test Bushing

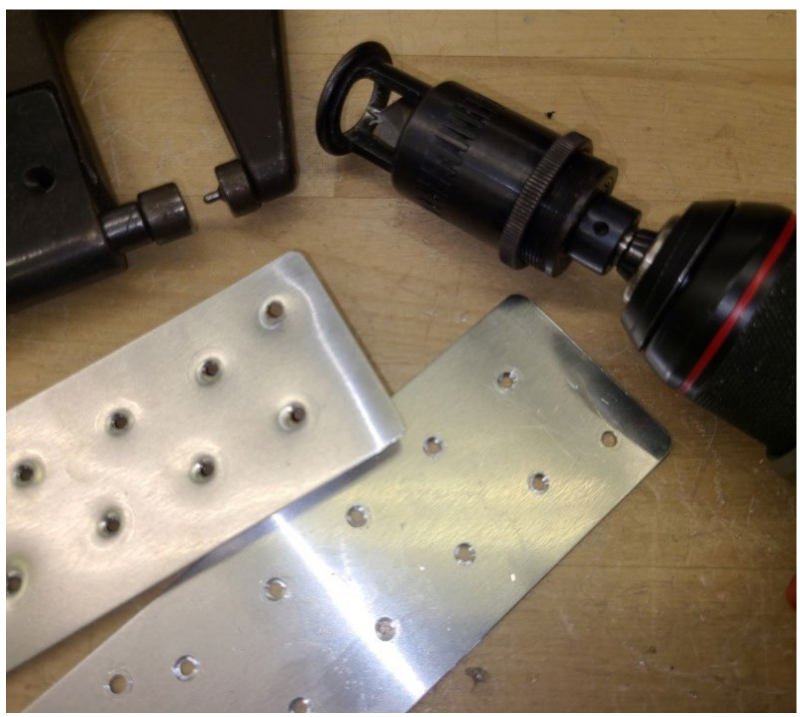
Our students' field report indicated that the aluminum bushing worked well but tended to gall onto the drill bit in use. It also required regular resharpening. We purchased a length of one quarter inch diameter brass rod and used a lathe to bore a number 40 hole down the center. We then tapered one side to a relatively sharp point. We beveled the other side to 100 degrees to match the dimple and countersunk recesses in the sheet metal. The second version of the tool was then used to quantitatively evaluate the effectiveness of the technique. Figure 5 shows the improved tool in actual use after the testing was complete.

Figure 5
Tool in Use

Evaluation

We chose to evaluate our bushing using 32 thousandths thick material. This was chosen because colloquial wisdom indicates that an AN-3 rivet can be secured in this thickness of skin by either countersinking or dimpling. It also did not hurt that we had some left over from class. We prepared four identical pieces of skin, each with 20 separate number 40 holes drilled in it. Two of these pieces of skin were countersunk and two were dimpled (Figure 6). These pieces were then laid over four more undrilled pieces of skin and secured firmly with temporary rivets.

Figure 6
Test Sections Being Prepared



Note. Countersunk and dimpled test sections are shown in the picture.

For our control values, we asked a non-sheet metal specialized airframe & powerplant technician (A&P) to precisely drill the rear holes in one of the sets of countersunk skins and one of the sets of dimpled skin without using the bushing. We then used a calibrated microscope to measure errors in concentricity (Figure 7). We recorded the data and determined the average error for each control value. See Table 1.

For our experimental values, we asked the same non-sheet metal specialized A&P to drill the final two sheets, this time providing the bushing and verbal instructions for its use. Once again, we used the calibrated microscope to measure errors in concentricity. We recorded the data and determined the average error for each experimental value—also recorded in Table 1.

Figure 7
Completed Test Sections with Measurements

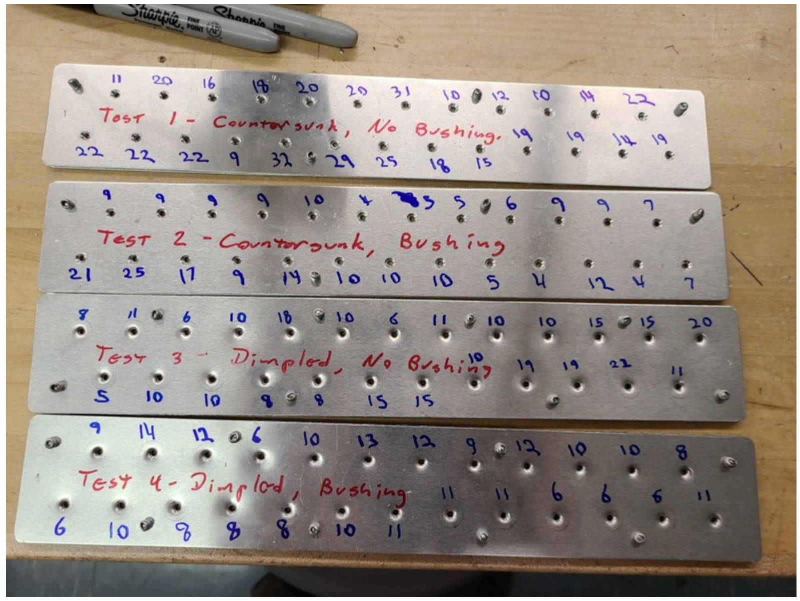


Table 1: Results Using a Control and Experimental Group

Average error (thousandths)	Control (no bushing)	Experimental (bushing)	*p*
Countersunk	12.76	3.92	< .001
Dimpled	7.08	4.48	.014

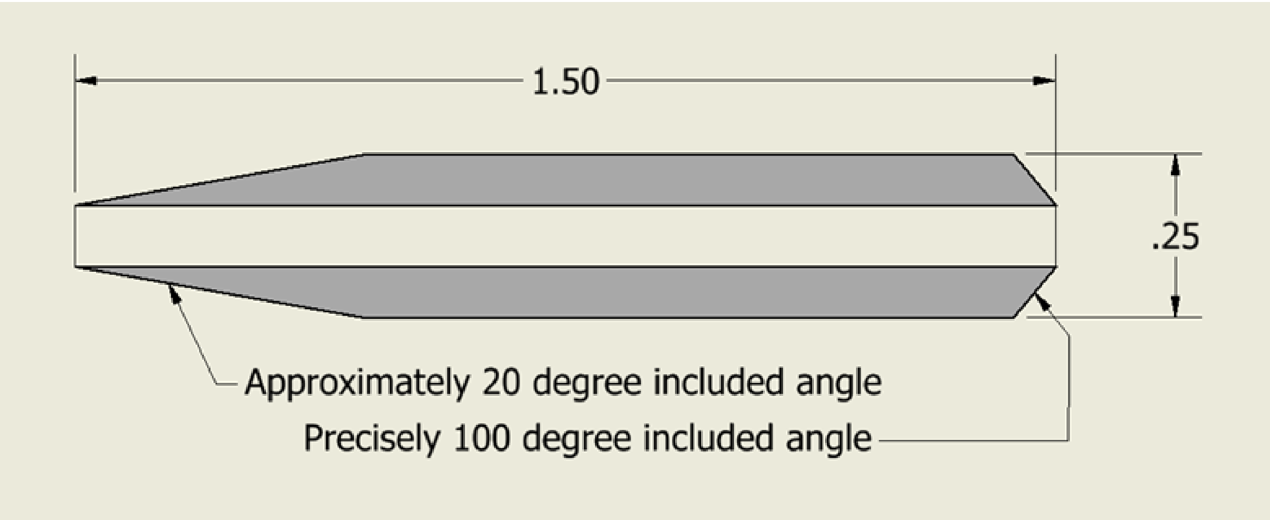
Note. n = 20 for each of the four groups. The likelihood that the bushing led to improvement was 100% for the countersunk group and 98.6% for the experimental group.

To determine statistical significance, a two-tailed unpaired heteroscedastic *t*-test for independent samples was used. This test calculates the probability that the datasets are from the same population—or in our case that the improvements were random and unrelated to the using the bushing. This test is part of Microsoft Excel's Analysis Toolpack (Microsft Support, n.d.). The results of this test are also included in Table 1. The test showed a 98.6% probability that the improvement in accuracy while match drilling the dimpled holes was due to the tool. For the countersunk holes, the probability that the result was not random rose to 100.0%. In other words, there is less than one-tenth of 1 percent chance that the improvement in precision was random.

Details of Improved Bushing

This tool is so simple and inexpensive that it is unlikely we can find anyone to mass produce it. Fortunately, it is easily self-built—especially if you have access to a lathe. A cross-section drawing is in Figure 8. Drill the center axis of the brass rod to the same diameter as the rivet hole in question. Cut the 100-degree end on the lathe after drilling the hole. Next, form the approximately 20-degree angle. In our experience, the easiest way to form this angle is to chuck the tool in a handheld drill and gently sand the bevel with a belt sander while the tool is spinning. Deburr the angle, and the tool is ready to use.

Figure 8
Cross-section of the Improved Tool



Conclusion

This tool is simple, effective, and inexpensive. We recommend that sheet metal mechanics fabricate a set of these for each common size of rivet. We believe that anything that is as inexpensive and effective as this tool is worth sharing.

References

Burbidge, Michael. (2009, November 24th). Mistake installing wing tips (match drilling dimpled holes) [Online forum post]. Van's Air Force. https://vansairforce.net/threads/mistake-installing-wing-tips-match-drilling-dimpled-holes.50943/

Department of Defense. (1988). Military Specifications Sheet, MS20426. Retrieved from https://www.fastenerz.com/specs/ms20426.pdf

Federal Aviation Administration. (2023). FAA-H-8083-30B, Aviation Maintenance Technician Handbook – General. Washington, DC. Retrieved from http://www.faa.gov

Four methods of flush riveting [Film]. 1942. Walt Disney industrial training. Retrieved from https://www.youtube.com/watch?v=WC5BAp2xvDc

Microsoft Support (n.d.). t-test function. https://support.microsoft.com/en-us/office/t-test-function-d4e08ec3-c545-485f-962e-276f7cbed055

Integrating 3D Printing into an AMT Program

James Barker

James Barker is an assistant professor of aviation at Southern Illinois University Carbondale. Originally an auto and heavy machinery mechanic James expanded to aviation in 2017. He holds both a bachelor's and master's degree in the field of aviation as well as airframe and powerplant certifications. Specializations were obtained in both the areas of Avionics and Advanced propulsion. The owner of an automotive restoration shop, and faculty advisor of two separate aircraft maintenance RSOs, Mr. Barker is interested in all things' maintenance.

ABSTRACT

Our aviation maintenance technician (AMT) program strives to educate our students on how to properly maintain aircraft. However, constraints such as lack of funding, aging training aircraft, and lack of parts availability created the need for a new, cost-effective way to keep our equipment operating. Additive manufacturing or three-dimensional (3D) printing has found its way into all corners of manufacturing. From household knickknacks to aerospace components, why not bring this technology to our classrooms? Using a 3D printer, I experiment with introducing printed aircraft parts, training aids, and tools into an AMT training environment.

Advantages of this approach include the ability to quickly and easily replicate a wide range of components out of multiple materials and color options. Parts are easily reproduced because the files used to print them can be saved for future use. Three-dimensional printed parts are often cheaper and quicker to produce than sourcing premanufactured versions from a vendor. This is all available using free design software and an entry-level printer that can be purchased for under $200. Challenges include where and how this tool is used within AMT programs. The potential exists for students to believe the replacement of failed airworthy components with 3D printed versions is acceptable on airworthy aircraft. To combat this, care must be exercised as to when and how 3D printed parts are introduced. Another challenge is the learning curve that exists for those unfamiliar with computer-aided design software (CAD) and how to properly set up a 3D printer. Although many tutorials exist, some trial and error is expected before producing parts that meet expectations. In addition to the learning curve, there is a need to exercise proper health and safety precautions. Three-dimensional printing involves heating different materials, some of which can release toxic fumes that can be harmful. Proper ventilation and personal protective equipment are paramount.

Integrating 3D Printing into an AMT Program

Additive manufacturing, or 3D printing as it is more commonly referred to, has proven its usefulness in countless industries and applications. The process offers the ability to create both simple and complex components in a variety of materials. Once a component has been designed and printed, its file can be saved for future use. This means the part is also reproducible. Once an extremely expensive and exclusive field, it is now becoming increasingly affordable and accessible (Eufy, 2025). With entry-level 3D printers being sold for under $200, we are seeing them become more common among hobbyists (Eufy, 2025).

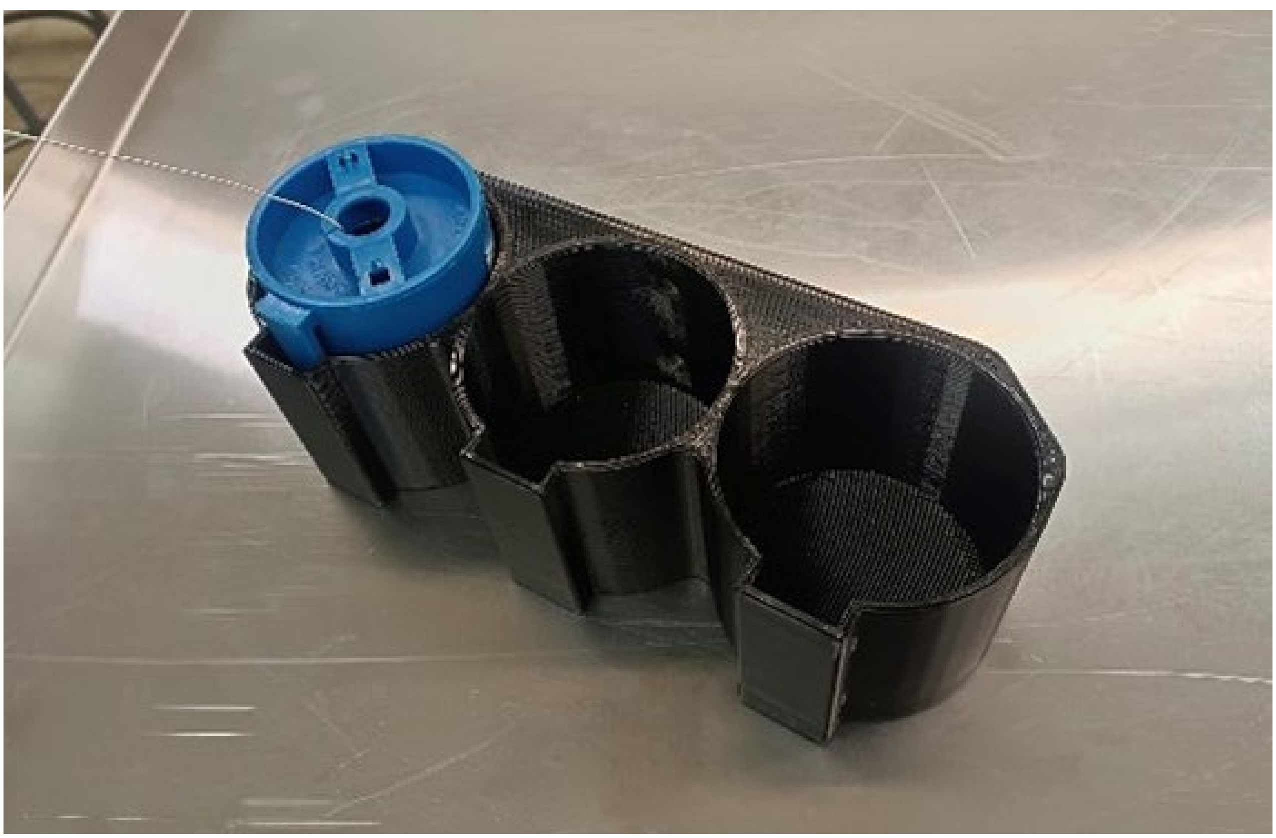
As an aviation maintenance professor, I am constantly searching for replacement parts within my institution's financial reach. Age, repetitive use, and the occasional surprise error-based learning exercise result in the need for continued maintenance and repair on our training aircraft and equipment. While purchasing airworthy replacement parts would be ideal, the cost often becomes prohibitive since the training aircraft themselves will never again be airworthy. The search for cheaper non-airworthy components proved difficult because you are at the mercy of the used parts market, their prices, and availability. So, why not make the needed parts in-house?

Use and Integration

The first attempt was made after discovering an unserviceable landing gear bell crank in a Cessna 310J used for demonstrating gear swings. A gear swing had been attempted with the nose strut completely deflated. This caused the nose gear to contact the airframe as it was retracted, which strained the bell crank to the point of failure. After unsuccessfully searching for the correct replacement part, the aircraft was shelved indefinitely with no repair or replacement plans. After discovering the issue, I decided it would be the perfect opportunity to test my theory. Using the damaged original as a template, I was able to recreate the component out of scrap steel plate and tubing. After bolting the part in and testing it, we found that the landing gear operated as intended. While the installed bell crank is not original, heavy use is not a concern as the gear swing demonstrations are only conducted a few times a year. Of course, producing a part out of steel instead of aluminum would raise serious concerns from an engineering standpoint. It is a general rule that you do not want to make a part any stronger or weaker than it was originally designed. You could be altering how and where stress concentrates or inadvertently eliminating engineered weak points. If the same issue that destroyed the original bell crank were to occur again, it would likely damage or destroy other parts in the system as the new bell crank would no longer be the weakest link. A placard was placed on the aircraft and faculty were advised of the retrofitted component. Although not ideal, for this unairworthy (permanently grounded) aircraft, I viewed this repair as an acceptable solution for the time being.

Several months later, I came across a student installing a rack for safety wire spools on their tool chest. I asked them where they acquired it since I was interested in getting one for myself. They replied they had designed and printed it out themselves on a home 3D printer. The quality and strength of the safety wire spool holder were impressive. This 3D printed spool holder is shown in Figure 1.

Figure 1
3D Printed Safety Wire Spool Holder



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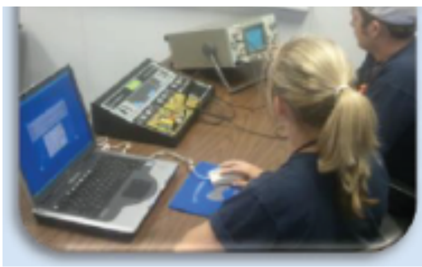

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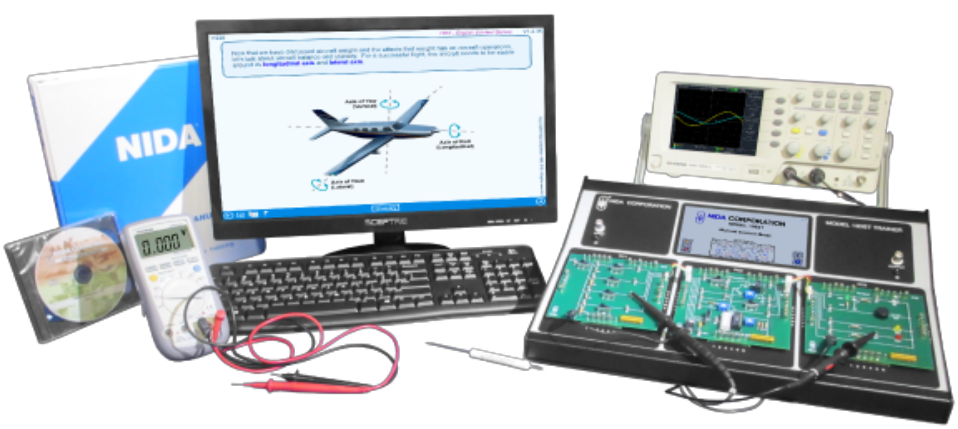

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The fabricated bell crank was proof that I could replicate basic aircraft components for use in a training environment. However, scrap steel and an inexpensive welder can create only so much. In the following months, I purchased a 3D printer and began teaching myself the basics of CAD through online tutorials. Over the next 2 years, 3D printing would be integrated into every course I taught.

Using Fusion 360 as the design software, which is free to educators and students, I began to experiment with creating basic shapes and designs. Those designs were then exported to a program called Cura, where the parameters were set for printing. This program is also free to download. Fusion 360 allowed me to design the parts I wanted, and Cura took that design and added information the printer needed to do its job.

Figure 2 depicts my first attempt at creating a 3D printed part for aviation maintenance technician (AMT) program use. A simple adapter used to retain the factory air cleaner assembly on a lift truck despite the installation of a different fuel metering device.

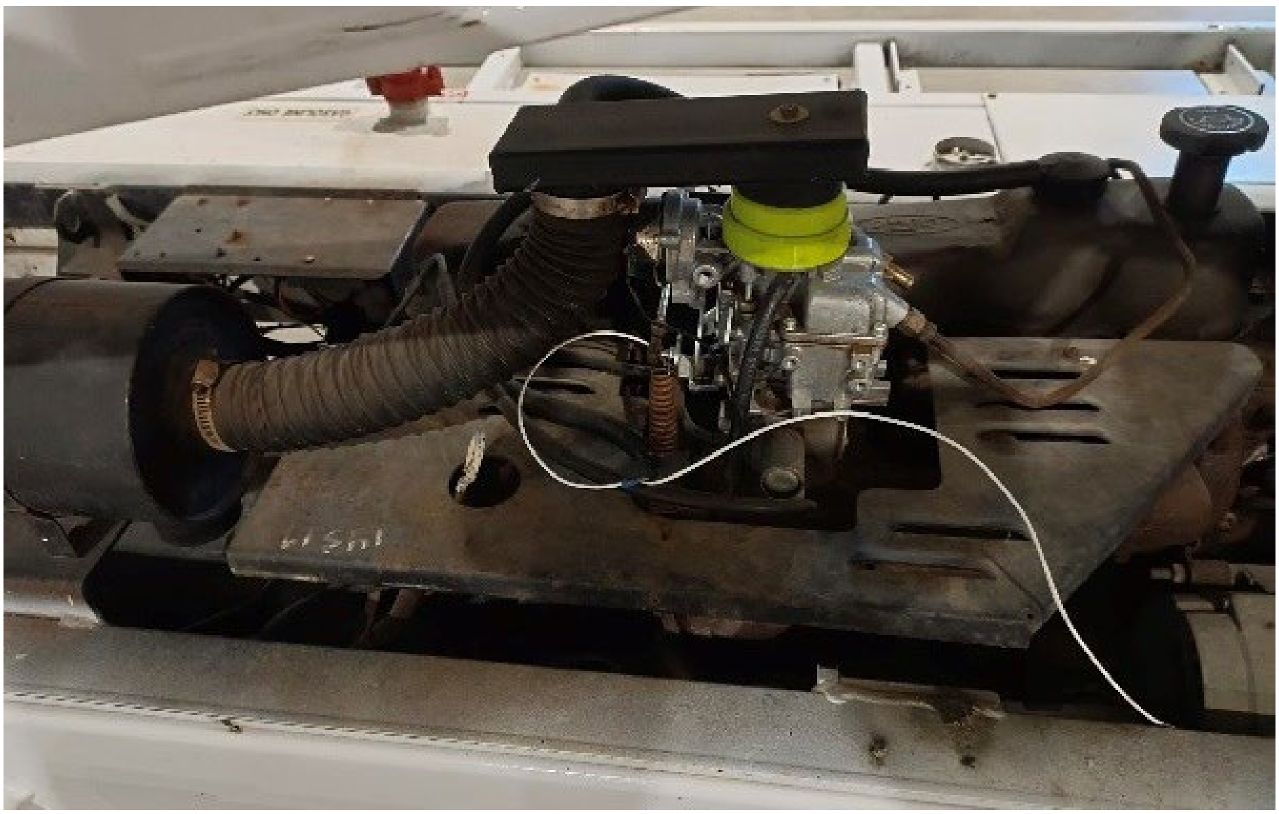


Figure 2
3D Printed Air Filtration Adapter to Carburetor

The lift truck had a float carburetor that was beyond repair. Exact replacements were difficult to locate because this equipment had an obscure industrial variant of the Ford 300 inline six-cylinder engine. Because this same engine was used for years in automotive applications, an automotive variant was easily located and installed for a fraction of the cost. Although a direct bolt-on from the intake manifold side—the air inlet side of the carburetor—did not match the existing air filter setup. Installing a standard automotive setup would have been difficult given the low clearance requirements beneath the lift platform. After half an hour of designing and another hour to print, we had an adapter to make everything work together. This part, like many in this paper, is made of green PLA (polylactic acid), a biodegradable thermoplastic. The advantage of PLA is that it is less expensive and is generally considered less toxic than other alternatives,

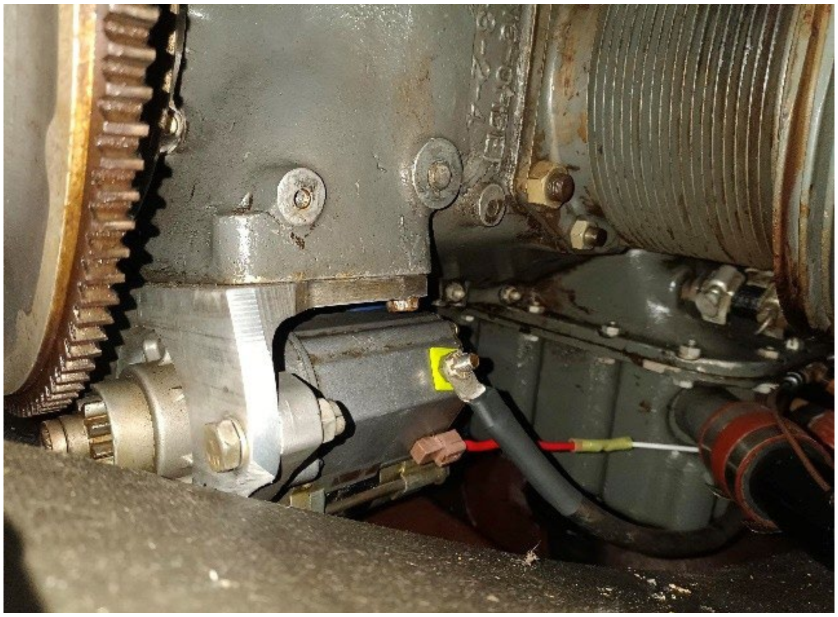
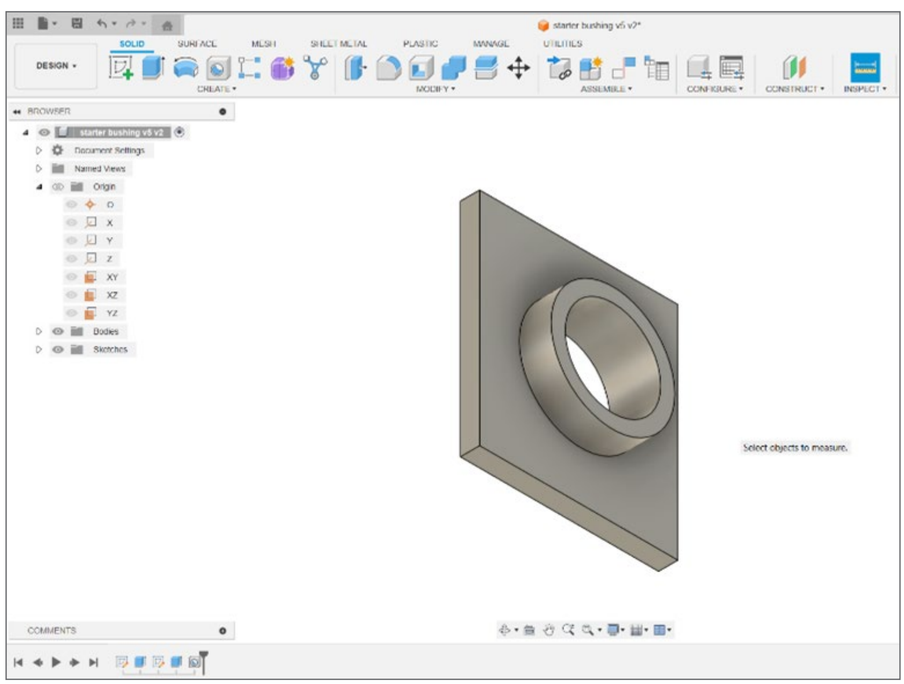


Figure 3
Aircraft Starter Isolator Bushing Created Using 3D Printing

such as ABS plastic (Schendel, 2024). Additionally, its green color helps it stand out, making it perfect for trial components and the photos included in this paper. Despite PLA being generally considered not fuel or oil safe, it currently shows no signs of degradation after 24 months of use. This part was created in less time than it would have taken to drive to and from the nearest parts store. Material costs were low. If the part becomes damaged or otherwise starts to fail, a replacement can be printed using the original file. Figure 3 shows the repair of an experimental aircraft starter using 3D printing.

This starter, like many, has a stud that is used to pass power through the housing of the starter. One end secures the power cable that feeds power from the battery, and the other end feeds power to the electric motor within the starter itself. This stud must be isolated from the body of the starter to avoid shorting out the power supply to ground. The original stud had been damaged by a student cross-threading the starter cable retaining nut. The insulator was damaged when the stud was allowed to spin while attempting to remove the nut. This rotation cracked the aged plastic isolator, allowing the stud to ground against the starter housing and resulting in an inoperative starter. After searching for a suitable replacement, we were again met with the cost and time dilemma. This one component was, to our knowledge, not sold individually. A replacement starter would cost several hundred dollars and take weeks to obtain.

Figure 4
CAD File of Replacement Starter Bushing



I was able to manufacture a replacement stud using a standard bolt, a tap and die set, and a hand file. The stud insulator was replicated using CAD software after transferring the dimensions from the broken original (Figure 4).

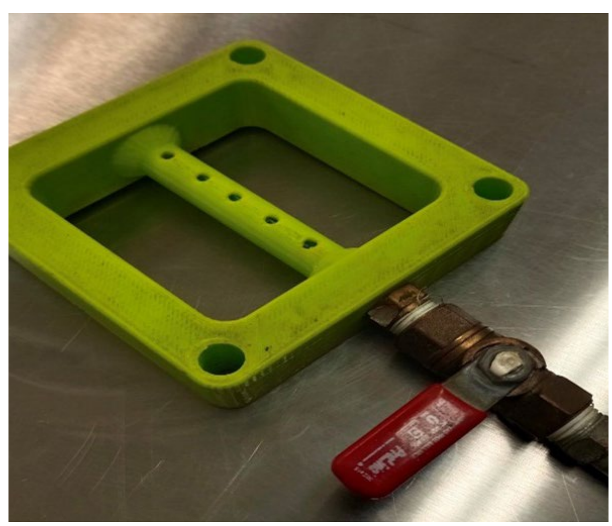
Once the part was designed, several settings were adjusted, including density of the part and level of detail required within Cura before being sent to the printer. In less than two hours from start to finish, we had a functioning starter again, and the students were able to complete their project. Factors such as heat absorption and vibration would be a concern if it were used for anything but maintenance training. Regardless, the performance of this part has already justified the few cents' worth of filament used to produce it. This component has been in use for 11 months at the time of this publication with no sign of deterioration. Additionally, this aircraft has an external solenoid installed between the battery and starter. If the printed part were to fail and ground itself, power would cease flowing when the starter switch is released. The power cable to the starter is not constantly energized.

Yet another example shows that a replacement part can be made without the original for reference. Figure 5 shows a dome light cover of a Piper PA-22 Tri-Pacer printed using clear filament.

Figure 5
3D Printed Dome Light Cover Using Clear Filament

The original light cover had been missing for years. After measuring the distance between mounting tabs and the overall height needed to clear the light bulb, the part was designed and printed. The part shown was finished and installed the same evening. Although not a replica of the original part, it clipped into place and functions as intended. The factory cover is available for purchase for less than $30 from one vendor, which raises the question of whether 3D printing the part is worth the effort. I would argue that it is. Material cost was much less than $30, and I was also able to design, create, and install this 3D printed part in one evening as opposed to waiting a week or more for the factory part to arrive. You could argue that the time spent designing this part would offset its cost savings, and that would only be correct initially. If this part is broken regularly during training activities, the cost and time of acquiring this part from the vendor is compounded. On the contrary, with the 3D printed part, the part can be reprinted as many times as it is needed. Aside from duplicating existing components, access to a 3D printer has allowed me to develop one-off tools, and prototypes. One example is shown in Figure 6.

Figure 6
3D Printed Test Piece Used to Force Air Through an Aircraft Carburetor



This test piece, again printed out of green PLA, allows me to perform a rudimentary test of my students' float carburetors post-rebuild. The test piece bolts to the airbox side of an MA 4-5 carburetor using existing mounting locations and has a threaded port to accept a pneumatic valve. Crossing the center of the test piece is a discharge rake. Compressed air is pumped into the test piece, where it passes through the discharge rake. Discharge ports allow the compressed air to escape upward through the throat of the carburetor. As air rushes through the venturi, it creates a low pressure signal and draws fuel from the bowl. Spraying a mist out of the top or (intake) side of the carburetor. For this test, the carburetor is temporarily fed distilled water from a gravity-fed tank. During this test, the student can see the liquid atomize as it is expelled and a change in overall flow while moving the mixture control lever. The accelerator pump is tested for function and is often followed by surprised laughter when the pump discharge sends a geyser of water towards the ceiling. Regardless of its flaws, it was successful in creating a fun educational tool capable of visualizing some basic carburetor theory. This version as well as the second were both made possible by 3D printing. Without the capability of printing a piece like this, I would have had to start with a solid chunk of material and slowly machine away excess material until I had the same piece shown. This would have required much more time and effort for the person creating the part. With the 3D printed part, I was able to make modifications to the CAD file and reprint the part with the changes I desired. If I were making the part by hand I would have had to start from scratch if the alterations didn't involve removing more material.

This test piece illustrates a major advantage of 3D printing over traditional fabrication methods. The printing process happens in layers as the tool builds up the material over numerous passes, which allows us to design voids and passages within the part. In this case, it was instrumental in creating the discharge rake and internal passageways for airflow within the test piece. This meant no machining and no drilling. To that effect, 3D printers are even capable of printing different thread sizes and pitches, which can create a part that comes out of the printer ready to fasten. Figure 7 shows a 3D printed hex head nut as an example.

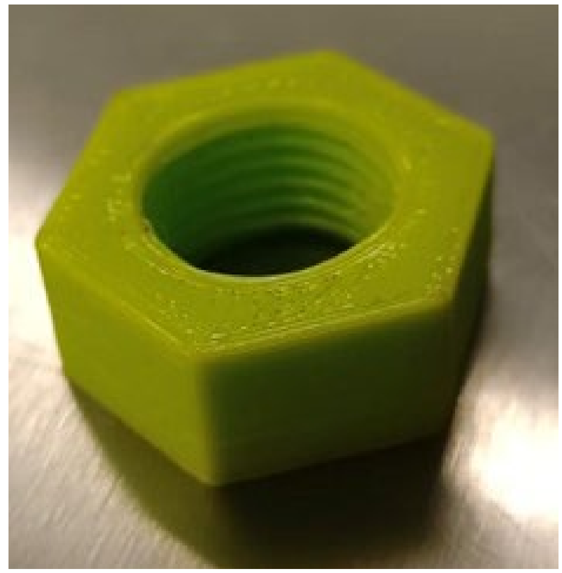


Figure 7
3D Printed Hex Head Nut in Green PLA

Had 3D printing not been available to me when I thought of the idea of the carburetor test piece, it would likely have never been made. Software is mobile. I can access it from my computer wherever I go. That means I can design parts in my office, in the classroom, or even at home. When I return to work, I have a part that is ready to print, whereas traditional machining and fabrication requires you to be hands on start to finish, tethered to your tools and equipment. A few more examples are described below.

Figure 8
3D Printed Hose Adapter in Green PLA

Figure 8 shows a 3D printed part used to replace an obsolete hose adapter on our shop vacuum. Again, this may seem like a small and meaningless part to go through the trouble of producing. However, the savings add up. For every part I produce quicker and cheaper than I could have acquired traditionally, the more I offset the initial cost of the printer and filament. This hose adapter for our shop vacuum saved us an estimated $100. How can a part that costs $1 or $2 at most save you $100? I saved $100 because without this adapter, the vacuum is useless for our needs. If it will not function for its intended use and the part needed to fix it is obsolete, I must purchase a replacement vacuum and endure the downtime associated with that. The cost of which is exponentially greater than the failed part itself.

Figure 9 shows edge protectors designed and printed to cover the sharp metal corners of our lab tables. Again, this is a simple use of this technology. Let us ignore the cost savings argument for a moment. Even if these edge protectors cost the same or even slightly more than store-bought examples, the 3D printed parts are still advantageous. I designed this part to fit and be used in this exact application. A store-bought part is unlikely to do the same in this case. I designed this part to be reproducible, able to be printed in many different colors and materials and easily modified if alterations are deemed necessary. This is all easily done by swapping filament colors and types in the printer and making small edits to the saved design file.

Figure 9
Table Edge Protectors Made from Green PLA

Figure 10 shows an instrument block-off plate. These are used to fill a hole in an instrument panel that is not being used. Online sources list these at prices ranging from $9 to $15 each. I can produce dozens from a single roll of filament that costs $25 dollars to purchase. Even if I were to be extremely conservative and say that an entire roll of filament, which I paid $25 for, only produces ten instrument blanks. It will still cost me $90 dollars to purchase the same quantity online if I choose the cheapest option at $9 each. This translates to 360 percent more if the parts were purchased from a vendor. Although shown here in green PLA, black filament produces a part that is virtually indistinguishable from those purchased online.

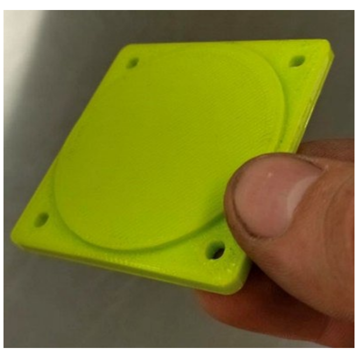
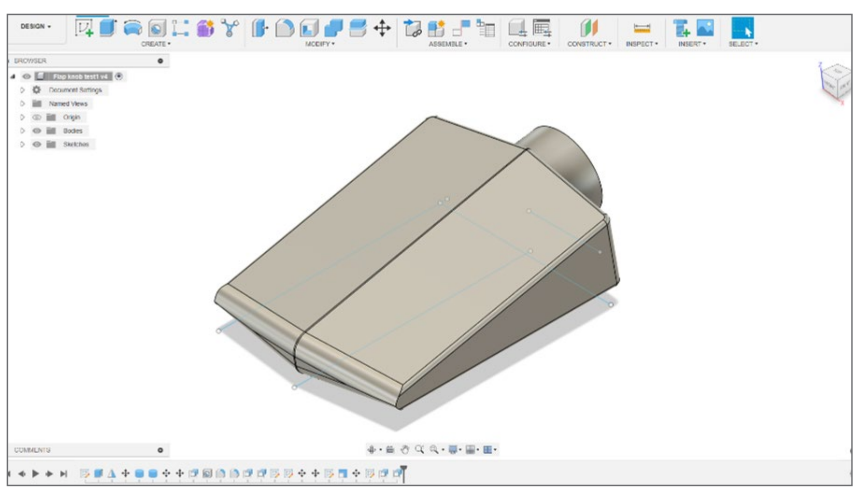


Figure 10
Instrument Panel Blanks in Green PLA

Figure 11 depicts a CAD file of a Cessna flap control knob, another example of a common wear item now inexpensively and easily replaced using 3D printing. Uses are seemingly endless, and the examples depicted here are only a handful of the many parts in use: circuit breaker lockout clips for performing maintenance, novelty key chains for fundraising, or 3D printed inlays for toolbox shadowing. If you need custom parts that can be easily replicated in a variety of materials and colors, additive manufacturing may be an option.

Figure 11
Flap Control Knob CAD Drawing



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Cautions and Restrictions

On another note, the use of 3D printing and other in-house fabrication techniques should be used with caution. Although there are plenty of benefits, there are drawbacks. The first of which is the learning curve involved in manufacturing good-quality parts. With different filaments comes the need to alter print temperatures and feed rates. Different materials vary in their level of toxicity and storage requirements. Certain materials warrant more adequate ventilation to protect yourself and others from the fumes that are off-gassed during the printing process. Storing filaments in humid environments may ruin the material as moisture is absorbed. More complex parts may require temporary support to be printed to keep the part from warping or collapsing during production. The density of the part can be modified, as well as its overall finish. A more detailed and dense part will result in longer print times and more filament use. Time and experience are needed to get the most out of 3D printing.

Second, producing homemade parts in an aviation maintenance training program could prove dangerous if not done carefully. When I make a 3D printed part for one of our aircraft, I do so knowing it is only because of the specific circumstances involved. The airplanes are not airworthy and will never be airworthy. The parts I produce are not installed anywhere that would jeopardize the safety of myself or others. Limited funding, limited parts availability, and delays in acquiring parts made this a viable option for my AMT program. However, just because I understand that does not mean a student who sees me making my own parts will. I must be extremely cautious and go above and beyond to ensure my students understand what is and is not allowed in the field. Numerous discussions have been held, differentiating between what repair techniques are useful for home use and which are acceptable on aircraft. A failure onboard an aircraft jeopardizes the lives and safety of those on it and on the ground. That is not the place for cost-saving measures and unapproved parts.

Conclusion

Additive manufacturing has proven to be extremely useful in cutting costs and downtime within our AMT program and shows promise for further integration. This process allows great flexibility in component design, ranging from the creation of exact replacement parts to one-off designs. Complex parts can be replicated days, months, and even years after the original print with the push of a button. A variety of different colors and materials allows this process to create parts for a wide range of applications. Despite the learning curve and the initial cost of investment, the cost is offset every time a part is created quicker and cheaper than it could be purchased through conventional means.

References

Eufymake. (2025). 3D printing costs: What you should know. Eufymake. https://www.eufymake.com/blogs/buying-guides/how-much-do-3d-prints-cost

Schendel, G. (2024, March 17). 5 reasons why ABS plastic needs to go away. ALL3DP. https://all3dp.com/2/is-abs-plastic-safe-toxic/

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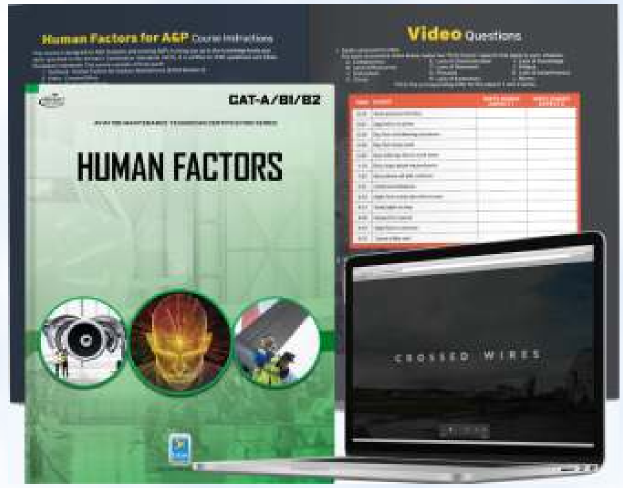

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Valid Assessment of Transversal Competencies a Aircraft Maintenance: Insights from Focus Groups with Industry Stakeholders

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ABSTRACT

Aircraft maintenance training is shifting from time-based and theory-based toward Competency-Based Training and Assessment (CBTA), as promoted by the International Civil Aviation Organization (ICAO). This transition highlights the importance of non-technical, transversal competencies (TVCs), yet their assessments remain challenging. This study explores how TVCs can be assessed effectively in the context of aircraft maintenance by establishing the design requirements and methods using focus groups. Results indicate that programmatic approaches were preferred over traditional methods, particularly the use of personal competency portfolios integrating self, peer, and instructor assessments. Qualitative rubrics defining performance standards were identified as critical to ensure objectivity, supported by instructor training in evaluation and calibration. These findings provide practical guidance for embedding TVCs within aircraft maintenance training and assessment.

Introduction

Over the past few decades, due to technological changes improving aviation operations and safety (Amin et al., 2022; Ichou & Veress, 2023; Karakilic et al., 2023; Papanikou et al., 2021; Pereira et al., 2022; Stamoulis, 2022) aircraft maintenance technicians are operating in increasingly more complex environments which require specific competencies. However, training standards and regulations for aircraft maintenance technicians continue to focus primarily on theoretical multiple choice exams and time-based experience measures (Kearns et al., 2016; Zylawski & Ma, 2023). This approach contrasts with global trends in education, where educational programmes are shifting to CBTA (Catacutan et al., 2023; Chaney & Hodgson, 2021; McGrath & Yamada, 2023; Misko & Circelli, 2022) to address the growing demands of the rapidly changing job market requiring professionals to be flexible, adaptive, and equipped to respond effectively to new challenges. In this context, competencies and their valid assessments, rather than isolated knowledge and skills, are essential (Baartman et al., 2006; Frerejean et al., 2019; Gulikers et al., 2007; Mulder, 2014; Paeßens et al., 2023; Terzieva & Traina, 2015).

Training organizations offering basic training in aircraft maintenance are caught between adhering to traditional aviation regulations and, at the same time, preparing students for a dynamic work environment that demands competencies that are not consistently required in the regulations. These overlooked competencies mainly concern non-technical, transversal competencies (TVCs) that are often strongly related to human factors. TVCs are higher-order, non-subject-specific, and multidimensional competencies (Bray et al., 2020) that emphasize the correct application of both knowledge and skills (Winch, 2013). An example of a crucial TVCs for aircraft maintenance technicians to operate safely in the complex aviation environment is to communicate effectively in various situations (Korba et al., 2023; Newman & Scott, 2023). ICAO (2020) developed a competency framework to address the need for training to be more holistic and competency based, in contrast to the current standards (Airbus, 2022; Johnson, 2023; Zylawski & Ma, 2023) and articulates both technical and transversal competencies.

Our previous research revealed that the aviation industry considers communication as significantly more important than other TVCs from ICAO's competency framework for aircraft maintenance, followed by teamwork (Kes et al., 2025)

A paradigm shift in aircraft maintenance training

Replacing time-based requirements by CBTA would indicate a true paradigm shift for aircraft maintenance: Currently, the focus lies on theoretical multiple choice exams, and time-based practical experience (EASA, 2022; FAA, 2025; ICAO, 2022). In Europe, the theoretical training is hours-based (EASA, 2022). However, using multiple choice exams is less suitable for assessing complex competency development, since they are not very likely to elicit high level competence (Gulikers et al., 2018). They rarely go beyond the level of comprehension in Bloom's taxonomy for learning and do not even require recall but solely recognition of the correct answer (Biggs, 1996; Gulikers et al., 2018; Spencer & Spencer, 1993; Van der Vleuten, 1996a). Instead, competencies can only be assessed through observing one's behavior and performance (Gruppen et al., 2012; Gulikers et al., 2018; ICAO, 2020; McClelland, 1973; Miller, 1990; Spencer & Spencer, 1993).

Aim of this study

In this study, we aim to explore how student mastery regarding TVCs can be assessed effectively in the context of aircraft maintenance training. First, relevant findings from the literature are outlined. Second, these findings are integrated into an aircraft maintenance assessment concept. Third, this concept is validated by industry stakeholders through focus groups. Before detailing these various steps, the background of this study is explained below.

Background of this study

This study builds on prior research that identified the most critical yet difficult-to-assess TVCs and observable behaviors (OBs) from ICAO's aircraft maintenance competency framework through a global expert survey. A subsequent Delphi study refined these by defining performance levels, contexts, knowledge, skills, and attitudes (Kes et al., 2025). Using these standards, we examine in this study how students can be effectively assessed in relation to the following competencies:

- Competency 11 - Communication: "Communicate effectively in all situations and ensure clear and common understanding" with OB 11.4, "Maintains situational awareness when selecting method of communication, speaks clearly, accurately and concisely" and
- Competency 8 – Teamwork: "Operate safely and efficiently as a team member" with OBs 8.1, "Fosters an atmosphere of open communication," and 8.12, "Anticipates and responds appropriately to the needs of others" (ICAO, 2020).

Research questions

To establish a method for assessing communication and teamwork effectively on aircraft maintenance students, we formulated two research questions:

1. What are the design criteria for valid assessment of communication and teamwork?
2. What assessment methods are feasible for all stakeholders to summatively assess the OBs?

Requirements for Assessing Competencies

There is evidence in the literature that as competencies are context-dependent and related to specific tasks in a particular ecosystem, both training and assessment should take place in a relevant holistic environment. Using rubrics to provide detailed criteria with performance indicators for evaluation can assist objective assessments (Griffin et al., 2007; Krause et al., 2015). Evidence from both formative and summative assessments can be collected in a personal (electronic) portfolio for each student (Baartman et al., 2007; Biggs, 1996; Krause et al., 2015; Schuwirth & Van der Vleuten, 2011; Sluijsmans et al., 2008).

When designing holistic assessment methods, both feasibility and acceptability must be addressed, catering for different stakeholders like students, teachers and assessors, industry, and regulators. This could result in additional requirements, for example, when assessment methods should be implementable both in educational and real work settings (Norcini et al., 2011; Prescott et al., 2002). Gulikers et al. (2007) stress the importance of including students in the design process since they may differ from teachers and assessment designers in how they perceive the authenticity and meaningfulness of assessment tasks. Furthermore, relying on one single assessment to predict future performance has been shown to be inadequate (Gulikers et al., 2018; Miller, 1990; Norcini et al., 2011; Terzieva & Traina, 2015; Van der Vleuten, 1996b; Van der Vleuten et al., 2012; Van der Vleuten & Schuwirth, 2005a). Therefore, an effective approach emphasizes the combination of a diverse range of assessment methods to ensure a reliable evaluation of performance (Australian Medical Association, 2022; Holmboe et al., 2010; Miller, 1990; Norcini et al., 2011; Prescott et al., 2002; Terzieva & Traina, 2015; Tikunoff & Ward, 1978; Van der Vleuten, 1996b; Van der Vleuten et al., 2012; Van der Vleuten & Schuwirth, 2005a). Assessors need training for a shared understanding and consensus regarding assessment outcomes to ensure validity and reliability (Terzieva & Traina, 2015).

Reliability, Validity and Acceptability

Choosing the right assessment methodologies implies compromising between reliability, validity, and acceptability, where sampling is more important for test reliability than standardization and objectivity. Especially the assessment of complex TVCs, requires professional judgement and, if appropriately sampled, can be sufficiently reliable without using highly standardized, structured and objective evaluations (Van der Vleuten, 1996a; Van der Vleuten & Schuwirth, 2005b). Consequently, assessment methods for TVCs are mainly based on qualitative, descriptive, and narrative information rather than numeric data (Van der Vleuten & Schuwirth, 2005b).

Another important aspect for choosing an assessment method is acceptability: Many (educational) professionals and organizations are driven by opinions, sentiments, and traditions (Van der Vleuten, 1996a). Given the paradigm shift this study represents in aircraft maintenance training, this is an important point of attention.

Assessing Communication and Teamwork

Regarding the assessment of communication and teamwork specifically, similar guidelines emerge from the literature. Because of its complex behavioral nature, communication should be observed directly in an authentic context over a longer period, and reducing communication skills to checklists assessments should be avoided (Van Den Eertwegh et al., 2014). Gilligan et al. (2024) state that diversity regarding gender, individual capabilities, cultures, and nationalities should be included in the assessment context when assessing communication.

Using anonymized peer assessments emerge as useful in the training and assessment of both communication and teamwork. Using anonymized peer-assessments potentially reveals elements of team dynamics that may not be observable from outside (Jones & Abdallah, 2013; Van Helden et al., 2023) and are considered more reliable since teachers simply cannot oversee all team dynamics and its corresponding interactions (Farland & Beck, 2019; Strom & Strom, 2011).

Designing assessment concept

Using these guidelines, the first two authors, together with a small team of aircraft maintenance instructors, drafted an initial design for assessing teamwork and communication. In this design, various concepts from the literature were elaborated and visualized in a presentation tailored toward the context of aircraft maintenance training. The following elements were included:

- The concept of a personal portfolio containing a collection of assessment data;
- Rubrics for each OB describing the behavior on three different levels: Beginner, In Development, and Competent;
- The principle of holistic assessment; merging technical and transversal competencies;
- Various assessment methods; self-assessment, video assessment, peer assessment, and instructor assessment.

This initial design was then further reiterated and improved through various focus groups with different stakeholders.

Methods

The input from all stakeholders is pivotal to understanding the criteria for assessing TVCs in a valid and feasible way. This section will describe the methods used to answer the research questions.

Data collection

To establish the design criteria and meet the requirements regarding validity, reliability, and feasibility of the design for all stakeholders, several exploratory focus groups were applied. In focus groups, data is collected through group interaction on a topic determined by the researcher (Morgan, 1996). Focus groups are suitable for exploring both new ideas and examining existing ones and therefore useful to reveal understandings, opinions, views, and how these aspects are elaborated in a social group interaction (Wilkinson, 1998). Additionally, focus groups are useful when tacit knowledge is required as evidence (Ryan et al., 2014) or when stakeholders' engagement is required (Gibson & Arnott, 2007; Morcke et al., 2006; Pyrialakou et al., 2019; Tremblay et al., 2010). During a design process, stakeholders focus groups can deliver input to improve and refine the design (exploratory focus groups), and after implementation focus groups can evaluate the efficacy, quality, feasibility, and effectiveness of the design (confirmatory focus groups) (Gibson & Arnott, 2007; Tremblay et al., 2010). Focus groups are typically homogenous groups with six to eight participants but never more than 12, and sessions generally take one to two hours (Ryan et al., 2014; Tremblay et al., 2010; Wilkinson, 1998).

Focus groups formation.

Aircraft maintenance students, Maintenance, Repair and Overhaul (MRO) industry representatives, instructors, assessors, and regulators were recruited using the first author's network and snowball sampling: a recruitment method in which initial participants help identify or invite further participants from their own professional network. Four focus group sessions were conducted in total. One focus group consisted solely of students, while the other three included an international mix of aviation regulators, MRO representatives, instructors, and assessors from the United States of America, the United Kingdom, Greece, Turkey, and The Netherlands. The focus group with students was designed differently from those with other stakeholders to better reflect their perspectives, needs, and experiences. This will be further explained in the section about the study design. A total of 27 stakeholder representatives participated. One participant did not actively contribute and was therefore excluded from the dataset.

Demographic background

To gain a comprehensive understanding of the focus group participants, the demographic background is described where a distinction is made between students and other stakeholders, since their sessions were set up slightly differently.

Students

Students were recruited at MBO College Airport in The Netherlands, where instructors selected students based on their ability to constructively contribute to this study. In total, eight students were selected, and six students showed up at the focus group session. Their age ranged from 18 to 31 (average 25). Their educational background ranged from a bachelor's degree to no educational diploma. All students were enrolled in a full-time aircraft maintenance training program at MBO College Airport, with three students in year two and three in their fourth (final) year.

Other stakeholders

The three stakeholder focus group sessions consisted of six, five, and ten participants. Their age ranged from 30 to 69 (average 48). Figure 1 shows the roles participants held within aviation, excluding those related to training and assessment, which are presented separately in Figure 2.

Figure 1
Experience in Aviation Maintenance Excluding Training and Assessment (n = 20)

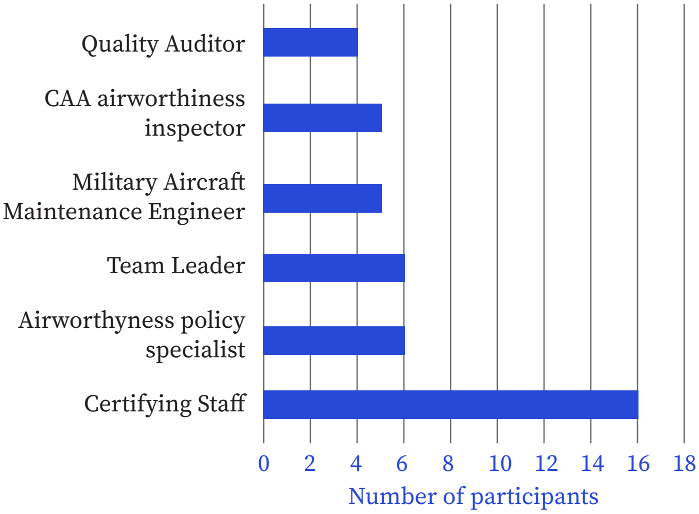
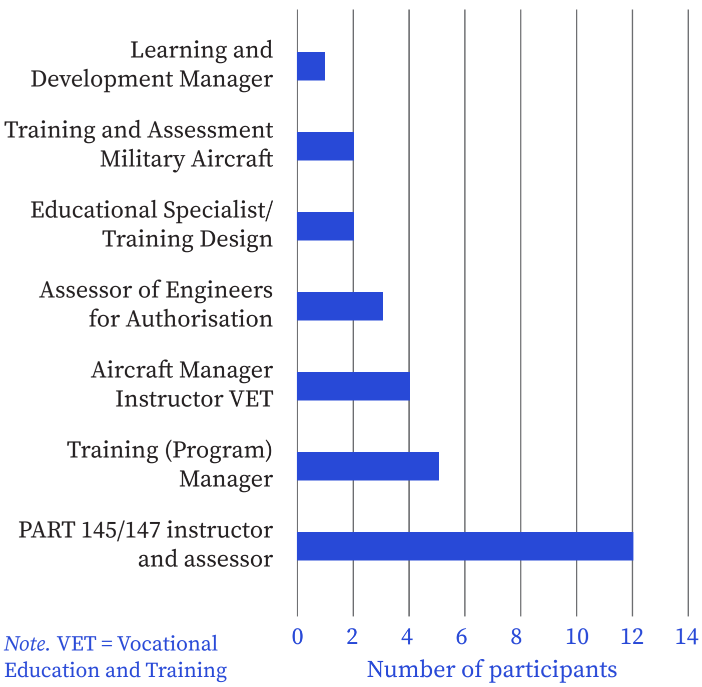


Figure 2
Experience in Aviation Maintenance Training and Assessment (n = 20)



Note. VET = Vocational Education and Training

Table 1 shows the roles the participants held while participating in the focus groups, where some participants held more than one role at the time. Each participant was asked to report their strongest expertise. This is shown in Table 2.

Table 1
Professional Roles of Participants During Focus Group Participation (n = 20)

Current role in Aviation Maintenance	*n*
Manager / Supervisor Technical Training	6
Instructor Aircraft Maintenance PART 145/147	5
Instructor Aircraft Maintenance VET	3
Airworthiness Policy Expert / Specialist	3
Program Manager Innovation, Training & Education	2
Aircraft Maintenance Training Design	1
Director of Regulatory and Technical Operations	1
Human Resources	1

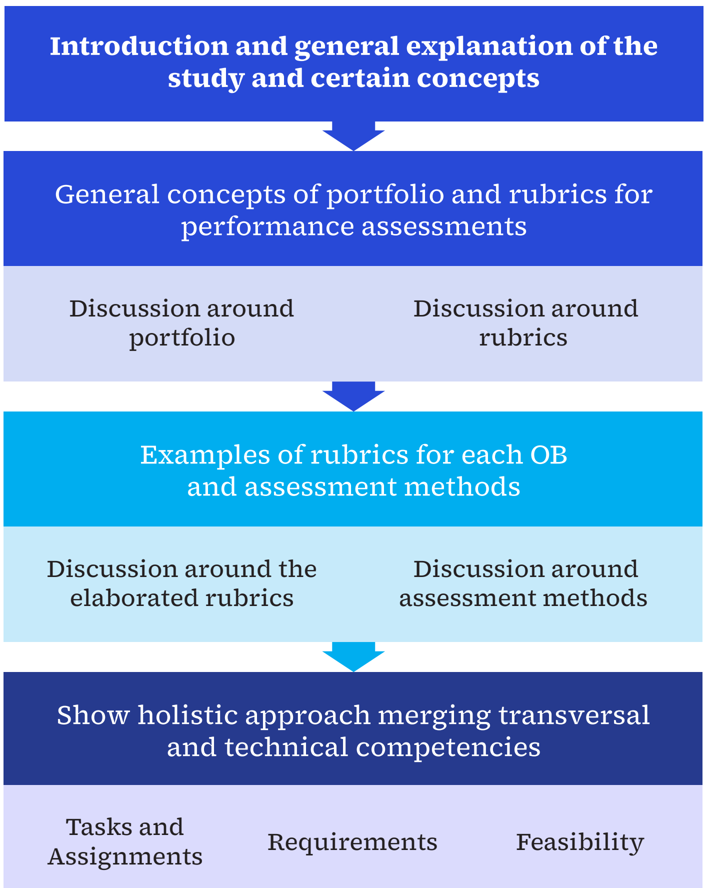
Table 2
Strongest Expertise of Each Participant (n = 20)

Strongest Expertise	*n*
Aircraft Maintenance Training and Assessment	7
Aircraft Maintenance	3
Aircraft Maintenance Training Design & Development	3
Regulation	2
Maintenance Manager	1
Training Management	1
Safety, Compliance, Quality, Regulatory, and Technical	1
Rulemaking, Standardization, and Oversight	1
Human Resources	1

Study design

Figure 3 shows the structure and flow of the focus group sessions. The sessions were guided by concepts and examples presented on slides, along with topic-related questions. Participants received a detailed explanation of the study's background. Additionally, key concepts were explained to ensure common understanding. All participants were encouraged to speak freely and to not feel pressured to conform if their views differed.

Figure 3
Schematic Display of Focus Group Sessions



The student session focused on their opinions, ideas, and needs in relation to the assessment of communication and teamwork. In contrast, the other sessions also examined the feasibility of the assessments within various contexts, including VET organizations, other aviation training organizations (Part 145 and 147), and relevant regulatory oversight requirements.

Practical implementation

All sessions took place in the summer of 2025 and were moderated by the first author. Two sessions were face-to-face, and two were held online. They were recorded and transcribed using Microsoft Teams. The second author attended all sessions to make notes and monitor the recordings and transcriptions. The third author attended the first two sessions to make notes and monitor the flow of the process. Ethical permission was granted by the university's Human Research Ethical Committee, reference number 5465.

The transcripts were checked for accuracy and readability against the original recordings and then anonymized and coded using Atlas.ti, followed by further analysis and categorization to extract the main themes by the first and second author. Any ambiguous areas were jointly reviewed and re-examined using the transcripts for clarification.

Results

The main findings are discussed per category: design requirements and assessment methods. The data represent consensus among the participants unless otherwise reported. For findings that are the product of collective sensemaking, the discussion process is also described.

Design Requirements

Several concepts have been explored during the focus group sessions:

- Multiple assessments documented in a personal portfolio;
- Rubrics describing different performance levels;

The personal portfolio comprises a collection of performance assessment results obtained through various assessment methods, all standardized by rubrics and conducted in authentic contexts. The assessment methods and authentic contexts are discussed below. First, the design requirements of the portfolios themselves, including the rubrics used for the performance assessments, are discussed. When needed, the views of the students and other stakeholders are separated to enhance clarity.

Portfolio with multiple assessments

The students were unanimously in favor of this concept. Collecting several assessment data of performance, rather than one final summative assessment, was associated with both a decrease of pressure and a more objective performance measurement: "This is so much better than just one large final exam. That's just a snapshot. A portfolio will take away so much pressure!" "If you had a bad day and then you have to do your final assessment then you may fail even though the whole year you were doing well and then you don't pass."

There were some concerns regarding the objectivity of the instructors: "If you don't click with your instructor this may affect his objectivity." Another concern was the standardization of the assessments: "You need standards, otherwise instructors will add their own flavor and then it's less objective." Although instructor objectivity was a concern, the students remained ambivalent whether to change instructors regularly to ensure objectivity:

> Having the same instructor for a long time can also really add value. This way he has much more time to understand your progress and he can get to know you better and see things that another instructor probably wouldn't see in a short period.

The other stakeholders also expressed a positive attitude toward personal portfolios documenting multiple assessment datapoints. All participants reported that this method would be feasible in their contexts but listed prerequisites for implementation:

> I think it's really good. I can work with this. I have students who perform so much better than others, you would actually like to get them through sooner, while others need more time. With a portfolio you can do that as long as it is filled properly. You need good rules, good conditions for that.

Another commented, "It should be possible. Companies already have processes with evaluations and performance appraisals." A striking finding was that in all three focus group sessions, the MRO industry representatives expressed their concerns regarding conflict of interest versus objectivity. When a company is short of staff with certain licenses or authorizations, there is a need for candidates to pass assessments, which may bias the assessor. The participants would prefer to outsource the assessments to training organizations only, to avoid bias.

> In your own company there's more pressure to let the guy pass. You know, when there's no pressure, you can assess the guy as it is. But if you're in a team and the boss is knocking on your door, "I need him tomorrow," you know you cannot fail this one.

Another important finding is that when participants were discussing the portfolio requirements from a regulatory perspective, a national NAA representative said: "anything will be an improvement to what regulators do today regarding evidence of performance," to which all participants agreed.

Table 3 shows the overall findings of the stakeholders' views (without the students). When comparing the different requirements mentioned by all stakeholders (students included) most prerequisites mentioned involve standardization and oversight, taking up two thirds of all requirements. The other third is divided into didactical requirements and objectivity issues. Even though some requirements were mentioned more frequently than others, they were treated equally since there were no objections. Figure 4 shows the proportion of the various types of requirements the participants suggested.

Figure 4
Types of Requirements Related to a Portfolio with Multiple Assessments

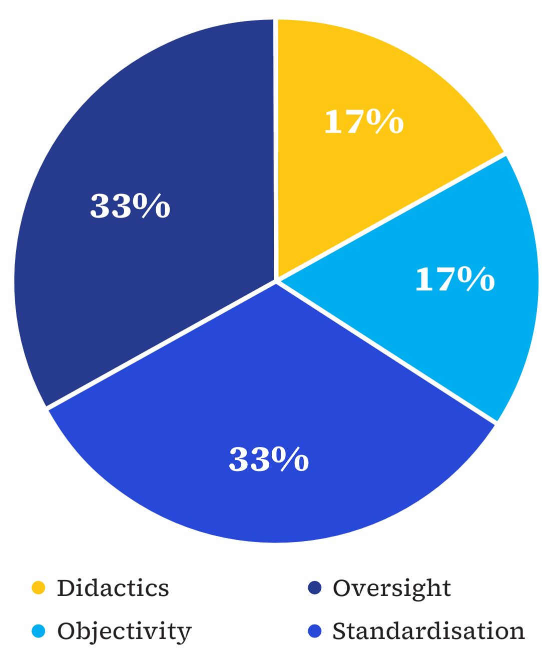


Table 3
Other Stakeholders' Focus Groups Findings on a Portfolio with Multiple Assessments

Opinion	Requirements
Enhances self-paced learning.	Recording evidence properly to avoid fraud.
More reliable due to both frequency and context variation of performance.	Avoid (financial) conflict of interests in maintenance organizations.
Not only enhances transparency on progress but allows to intervene accordingly.	Alignment of assessments in increasing complexity for holistic interpretation.
Enhances ownership for the student and employee and provides context for self-assessment.	Level of assessment should match training stage.
Very useful to continue after licensing when working.	Requirements from regulators regarding evidence - conditions a portfolio must meet.
	The assessment information behind the data should be accessible for audits.
	Solid criteria for portfolios and the assessments they are based on.
	The portfolio needs to be standardized to a level that it facilitates the portability between MROs.
	Regulators will need evidence of consistent performance relative to the standard.
	A data collection methodology to gather, process, and analyze data, enabling the assessment programme to distinguish competent students from those who are not.

Rubrics describing different performance levels

Tables 4, 5, and 6 represent the proposed rubrics discussed, in which two minor suggestions from the participants have been included. All stakeholders viewed the rubrics as very helpful and very clear. A student mentioned: "This is very clear; you understand exactly what behavior is required," and another student added: "This avoids discussion because it is written down exactly what is required." One instructor reacted: "This makes me really happy. This really helps to monitor and evaluate performance. I could easily just put a group of students at work and then monitor where they stand." An industry representative said, "With rubrics like these it is easier to assess, and it will contribute to the acceptance of the students into the organization if we all use this methodology." However, the students were unsure about the rubric of OB 11.4: "When we are working on a task, we are talking all day about everything. So, a lot of unnecessary information will be communicated."

When it was explained that the focus was on communicating key information to a colleague or supervisor—rather than everyday communication—they suggested it would help to create a clear assessment context, such as a role-play element. Role-play will be further discussed in the section about tasks and contexts.

With regard to the rubric of OB 8.12, a participant pointed out that it was difficult to measure whether a student "notices" something since this is an internal cognitive process. For example, the draft rubric described at the "competent" level: "The student/employee always immediately notices from the body language of his/her fellow student/colleague that he/she needs help". The instructor commented: "You don't know what someone notices, only when he acts on it."

Collective Sensemaking on Narrative Rubrics

In one focus group, a discussion emerged regarding the qualitative descriptions of the behaviors. One participant pointed out:

> It is always debatable what is good enough. Does "always" mean 100% of the time or 99%? You could quantify the levels by saying a good assessment is that more than 90% of the cases you have shown that be-

havior and a bad assessment is less than 10%, or any scale like that. I don't like that too much because then it becomes a mathematical exercise and that should not be the case.

After a discussion over "how many, how often" and the ORCA method (Observe, Record, Classify and Assess/Evaluate), the group collectively concluded that quantifying behavior was not their preference when assessing TVCs like communication and teamwork. However, good guidance material for the assessor on how to manage the rubrics used for the assessments becomes necessary.

Authentic Assessment Contexts

When discussing what types of tasks or assignments could operationalize these competencies for assessment purposes, participants proposed various approaches, involving three key elements: environment/context, tasks, and scenarios, which were sometimes combined. All focus groups considered role-play as a suitable approach for both training and assessment, allowing specific scenarios to be practiced. While students acknowledged that role-play might sometimes feel unnatural, they still favored its use. Several instructors reported that they were already using this approach successfully.

Closely related to this, the importance of authenticity was emphasized in various ways, in which a form of simulation

Table 4
Discussed Rubric for Training and Assessment of Observable Behavior 11.4 of ICAO's Competency Framework

Competency	Observable Behavior	Beginner	In development	Competent
Competency 11 – Communication: 'Communicate effectively in all situations and ensure clear and common understanding'	11.4 Maintains situational awareness when selecting method of communication, speaks clearly, accurately and concisely.	When communicating, the student/employee does not distinguish between information that is or is not safety critical. Therefore, a lot of unnecessary information is communicated and/or essential information regarding safety is omitted.	When communicating, the student/employee makes some distinction between information that is or is not safety critical. Some redundant information is still communicated and/or some essential information is still omitted regarding safety.	The student/employee communicates only information that is in the interest of safety. No unnecessary information is communicated.
		The student/employee usually or always automatically assumes that the information they communicate is clear to the recipients, without checking this.	The student/employee sometimes automatically assumes that the information they communicate is clear to the recipients, without checking this, or only checks this with a few recipients.	The student/employee never automatically assumes that the information they communicate is clear to the recipients and therefore always checks this with all recipients.
		When the student/employee receives verbal information, they do not check whether they have understood it correctly.	When the student/employee receives verbal information, they sometimes check whether they have understood it correctly. For example, if they are not completely sure.	When the student/employee receives verbal information, they always check whether they have understood it correctly by repeating it, possibly in different words.
		The student/employee makes many assumptions during their communication, without checking whether those assumptions are correct.	The student/employee makes some assumptions during their communication, which should have been checked.	The student/employee does not make assumptions but always checks first whether they are correct.

predominates. Table 7 summarizes the approaches considered valid for training and assessment by all participants, using their own words as much as possible. Duplicate suggestions have been removed; however, some overlap or similarity between certain methods may still be noted. All suggestions were considered feasible by all stakeholders, although many participants representing the MRO industry recognize that it increases the workload.

> What makes it difficult is that those competencies need to be continuously observed and often they also have to pass for their PART modules and then this comes on top of it. We're almost a training organization rather than a maintenance organization.

On the other hand, several MRO industry representatives shared that some methods are already being explored in their organization for the purpose of Lifelong Learning of personnel.

Assessment Methods

Several methods to measure and document performance of communication and teamwork have been discussed in all focus group sessions: video assessments, self-assessments, peer-assessment, and instructor assessment, using the rubrics as a reference. Although formative assessments were mentioned by some participants, they mainly approached the assessments as summative elements of the assessment data collection of the personal portfolio.

Students Focus Group Results

One interesting finding is that the students were very critical toward video assessments. Not so much because of privacy reasons, but because of its unauthenticity. As one student described: "Making a video of your performance seems forced and unnatural. Then you're more focused on making a good video than on the actual performance that is being measured." Students favored self-assessments and instructor assessments, if the instructor is objective

Table 5
Discussed Rubric for Training and Assessment of Observable Behavior 8.1 of ICAO's Competency Framework

Competency	Observable Behavior	Beginner	In development	Competent
Competency 8 – Teamwork: 'Operate safely and efficiently as a team member'	8.1: Fosters an atmosphere of open communication.	The student/employee shows little to no interest in their fellow students or colleagues.	The student/employee shows some interest in their fellow students or colleagues.	The student/employee shows interest in their fellow students or colleagues.
		The student/employee does not ask any questions, especially if they feel that it concerns something they should know.	The student/employee asks some questions, sometimes even if they feel that it concerns something they should know.	The student/employee asks a lot of questions, even if they feel that it concerns something they should know.
		The student/employee does not discuss it with fellow students/colleagues or teacher/supervisor if they have made a mistake.	The student/employee sometimes discusses it with their fellow students/colleagues or teacher/supervisor if they have made a mistake, or limits this to one or a few team members.	The student/employee always discusses it with their fellow students/colleagues or teacher/supervisor if they have made a mistake and involves all team members in this.
		The student/employee involves few or no team members in their communication, even though it is important for the other team members.	The student/employee involves some team members in their communication, but not all team members for whom it is important.	The student/employee involves all team members for whom this is important in their communication.

and not biased by any previous performance or behavior. Using the rubrics was another requirement to avoid discussions or personal opinions. When discussing the possibility of using technological applications like VR, the students were skeptical: “We have done some things in VR like an inspection, and you walk through an airplane and you can see inside the airplane. It was funny, but it didn’t really add anything. It’s just not realistic enough.” Another student questioned the reliability of using VR in general: “Even if it would be super realistic; you may excel in racing games, but that doesn’t make you a Formula 1 driver.”

Collective Sensemaking on Peer-Assessments

The students unanimously regard peer assessment as both valuable and desirable. Not only were they considered useful to decrease the burden of the instructor but also to decrease stress levels of the students: “It takes away the stressor of having the instructor’s eyes on you. Instead, you’re just working with one of your peers.”

However, opinions were divided on whether such assessments should be anonymous. Some students stated that anonymity is necessary to provide honest feedback, particularly when addressing a peer’s poor performance. Others argued that feedback should be given openly, as this allows

Table 6
Discussed Rubric for Training and Assessment of Observable Behavior 8.12 of ICAO’s Competency Framework

Competency	Observable Behavior	Beginner	In development	Competent
Competency 8 – Teamwork: 'Operate safely and efficiently as a team member'	8.12: Anticipates and responds appropriately to the needs of others	The student/employee does not respond to non-verbal cues such as body language from peers or colleagues indicating a need for help.	The student/employee sometimes responds to non-verbal cues such as body language from peers or colleagues indicating a need for help.	The student/employee usually or always responds to non-verbal cues such as body language from peers or colleagues indicating a need for help.
		The student/employee does not offer support when a peer or colleague has been working on a task for an extended period without progress	The student/employee sometimes offers support when a peer or colleague has been working on a task for an extended period without progress	The student/employee usually or always offers support when a peer or colleague has been working on a task for an extended period without progress
		The student/employee never proactively offers their help.	The student/employee sometimes proactively offers their help.	The student/employee usually or always proactively offers their help.
		When the student/employee offers assistance, they take over the task completely without explaining to the fellow student/colleague what to do, or does so in a hurry/stressed manner.	When the student/employee offers assistance, they take over to some extent, but still involve the fellow student/colleague to some extent in completing the task. They may do this in a hurry/stressed manner.	When the student/employee offers assistance, they calmly guide(s) the fellow student/colleague through the process and in this way they complete the task together.
		The student/employee does not handle the observed information about their fellow student/colleague discreetly and confidentially before, during or after they have helped them.	The student/employee handles the information observed about their fellow student/colleague in a partially discreet and confidential manner before, during or after they have helped them.	The student/employee handles the information observed about their fellow student/colleague discreetly and confidentially before, during and after they have helped them.

Table 7
Main Findings: Training and Assessment Approaches for Communication and Teamwork

Training and Assessment Approaches	Simulation Category
Daily jobs and tasks	Tasks
Troubleshooting, inspection; challenging tasks	Tasks
Create tasks you cannot perform alone	Tasks
Role play	Scenario
In base maintenance you can simulate line maintenance by creating scenarios	Scenario
Increase complexity like AOG with 180 pax and a nervous pilot, or a phone call that another aircraft comes in	Scenario
Simulate that students are in charge	Scenario
Variety in team so you are consistent with your behavior	Environment
Some elements of communication and teamwork don't have to be trained around an aircraft	Environment
Simulate base or line maintenance in a training hangar	Environment
Instructors set the right example - practice what you preach	Environment
Simulate communication and teamwork in the shops when you start building up training. It doesn't have to be around an aircraft.	Environment
Activities that are progressively unstructured by ramping up the number of stressors.	Scenario & Environment
Simulation or real MRO context and tasks	Environment & Tasks
Simulate operational environment where collaboration is imperative. Let them do things they can't do alone.	Scenario & Tasks
Create realistic scenarios using the MEL and ETOPS	Scenario & Tasks
Simulate that they are leading an A-check	Scenario & Tasks
Designate students as team lead and let them do a shift handover when another group of students comes in	Scenario & Tasks
Create scenarios where you have to rely on each other'scommunication because you can't see each other, for example when one is rigging the flight controls and the other student is in the cockpit moving the flight control to place the rigging pin. Or when one is in the fuel tank and the other student has to hand him the tools he needs.	Scenario & Environment & Tasks

Note. AOG = Aircraft On Ground; MEL = Minimum Equipment List; ETOPS = Extended-range Twin-engine Operational Performance Standards.

for constructive dialogue and mutual understanding. They found that, in a way, anonymous feedback can be considered as socially unsafe.

The students acknowledged that in professional settings feedback is rarely anonymous and being open supports the development of a culture of transparent communication. They stressed the importance of introducing peer feedback from the very beginning of the program to help students become comfortable with the process over time. As a compromise, the group agreed that anonymity is not essential if feedback discussions take place in a small, safe setting—ideally with no more than four participants, of which at least one is an instructor.

Other Stakeholders

All participants expressed support for self-assessments, peer assessments, and instructor assessments—particularly favoring a combination of these approaches. The rationale for endorsing specific types of assessments varied, with several participants emphasizing that the purpose of assessment can extend beyond measuring performance. In some cases, the methods were seen as valuable, highlighting their formative potential. For instance, self-assessment was viewed not only as a tool for evaluation but also as a means of fostering reflection—an aspect participants considered essential in a safety-critical environment such as aviation. One instructor explained: "I noticed that students do not always know themselves so well. They tend to overestimate their performance. Comparing their self-assessments with my own observations and discussing with them what they could improve helps them reflect."

Regarding peer-assessments, one participant shared how using peer-assessments in their maintenance organization enhanced mutual recognition within their team, having a positive impact on their teamwork.

Instructor assessments were considered as the most reliable, but not always feasible due to the workload for the instructor. A few participants stated that at least two assessors are needed for objectivity, but this was not a general finding from the discussions.

When it came to the use of digital tools and applications such as AI, only one participant expressed strong enthusiasm, while another saw digital tools as more appropriate for training purposes rather than assessment. The most optimistic participant suggested that recording performance on video and using AI to analyze it could increase the amount of feedback provided. Although many participants acknowledged the time-consuming nature of giving narrative feedback, there was limited support overall for the use of digital tools in assessment. Video-based assessments were also not favored—primarily due to concerns about privacy. However, a few participants did note that such recordings could serve as reliable evidence for audit purposes.

Table 8 outlines the requirements the participants considered essential for each assessment method. Many prerequisites concern thorough training for all stakeholders.

Table 8
Requirements for Different Assessment Methods

Assessment Method	Requirements
Instructor Assessment	• Instructor must be objective and not biased • Clear rubrics must be used • Training is needed for instructors and assessors.
Self-Assessment	• Students need to be trained on doing this; start practicing early in the training program
Peer-Assessment	• Students need to start early to practice being objective and taking it seriously • Clear rubrics must be used • Feedback in a safe, small group setting with at least one instructor present

Discussion

Many elements drawn from the literature were incorporated into the presentation for the focus groups to respond to, such as the concept of a portfolio, rubric examples developed from previously defined performance levels, and proposed assessment methods. Overall, the participants responded positively to these approaches. This indicates that the literature on this subject is highly applicable to CBTA in aircraft maintenance.

Looking more closely at the first set of more detailed ideas—such as the rubrics—it is noteworthy that, through collective sensemaking, one focus group concluded that numerical scoring was not preferred for assessing TVCs, even though the narrative rubrics allowed room for interpretation. This aligns with findings in the literature, which suggest that the assessment of complex TVCs is primarily based on descriptive, narrative information rather than quantitative data. Other focus groups immediately encouraged the descriptive nature of the rubrics.

Another notable outcome from the more directive elements discussed, was the students' final agreement that peer assessments should not be anonymous, as anonymity could itself create a socially unsafe environment. After weighing the pros and cons, they decided through collective sensemaking that anonymity was not needed, but that feedback should be given in a small, safe setting. This stands in contrast to the literature, where anonymized peer assessments are often recommended as effective for training and assessing communication and teamwork competencies. A plausible explanation for this discrepancy could be that aviation students are educated within a "just culture" philosophy, which emphasizes open discussion of mistakes and near-misses without fear of punishment to foster collective learning and improve team safety.

Regarding the rubrics, it was noted that the rubric for OB 8.12 was flagged for including a cognitive process that cannot be directly observed by the instructor and therefore should be revised. Interestingly, the rubric for OB 11.4 also involves a cognitive process, using the term "assume," yet the participants did not comment on this. A possible explanation is that the associated action—checking with the recipients of the communication—is clearly defined and observable, which may have made the cognitive element less problematic.

Limitations

Of the 27 participants, 26 provided valuable input, but the number of student participants was relatively small. Students needed to be available, motivated and capable of contributing constructively, which limited the selection. Additionally, all student participants came from the same college; a more diverse group with varied educational and internship experiences might have influenced the findings.

The current study included four focus group sessions with different stakeholders from five different countries. Although many consistencies were found among the focus group sessions, having more stakeholders available representing the students, regulators and maintenance (training) industry may have impacted the results.

Conclusion

In this study, we aimed to identify valid and feasible methods for assessing OBs 11.4, 8.1 and 8.12 from ICAO's Competency Framework for Aircraft Maintenance.

Design Criteria

The design criteria are addressed by research question 1: What are the design criteria for valid assessment of communication and teamwork? Based on the results, the following criteria are outlined.

Portfolio with multiple assessment datapoints

Using a portfolio with multiple performance assessments is preferred over one final summative assessment. It is deemed more reliable, more transparent, and it enhances self-paced learning. The latter is not only because it reinforces ownership by the student, but also because it supports student-level interventions by the instructor. Finally, it is considered less stressful for students. Furthermore, the attributed value of a portfolio went beyond obtaining a license and was considered a useful tool for documenting lifelong learning and development post-licensing.

Requirements for portfolio implementation

Most of the conditions suggested by the participants concerned standardization and oversight. In essence, it comes down to having solid criteria and a standardized method for collecting, processing, and analyzing assessment data and how this can be used for audits by the regulators. However, standardization was not only emphasized for oversight purposes, but also for (international) transferability among organizations. To a lesser extent, didactic requirements and aspects regarding objectivity are deemed important: The level of assessments should match the training stages applying increasing complexity in a holistic training environment, and instructors and assessors should be objective and unbiased.

Textual Rubrics

The rubrics demonstrated in tables 4, 5, and 6 are considered very clear and useful both for training and assessing the OBs of focus. Although the rubrics are fully narrative and may leave room for interpretation, this approach is preferred over quantitative scoring due to the nature of the competencies. Moreover, the rubrics were seen as an effective way to address concerns about objectivity and standardization. However, clear guidelines for the teacher and assessor are needed to support the correct scoring of performance.

Approaches to operationalize communication and teamwork

To elicit the demonstration of these competencies for assessment purposes, several approaches were deemed both valid and feasible. The approaches all indicate a form of simulation and can be discerned by tasks, scenarios, and environments but were also described by a combination of these aspects.

Tasks

All participants agreed that training and assessment should be done through daily jobs and tasks. For these competencies, tasks involving inspection and troubleshooting were deemed suitable, preferably those that can not be done by one person alone and that challenge students.

Scenarios

All participants considered role-play a strong approach to embed the tasks in meaningful scenarios. More detailed examples to create a realistic context for students are simulating line maintenance events, such as communication scenarios with pilots during AOG, simulating a supervising role for the student leading an A-check, or doing shift handover. Also, scenarios using the MEL and ETOPS are considered useful for assessing communication and teamwork. In general, it was considered essential to combine tasks and scenarios that require collaboration and mutual reliance.

Assessment Methods

The assessment methods are addressed by research question 2: What assessment methods are feasible for all stakeholders to summatively assess the Observable Behaviors? To fill the portfolio, a combination of self-assessments, instructor assessments, and peer-assessments were preferred. For each method, a few conditions were outlined.

For instructor-assessments the objectivity and unbiased attitude of the instructor was stressed, along with using clear rubrics. Additionally, it was required that instructors were properly trained. For self-assessments it was considered essential that students start with practicing this in an early stage to train the reflective nature of this method. For peer-assessments it was also important for students to start practicing this early to avoid bias. Feedback should be provided in a small and safe setting with at least one instructor present.

The next step is to implement these findings in a real training and assessment program to evaluate their effectiveness. As the requirements identified are largely generic, their applicability can be explored across various contexts. Further research is needed to examine the consistency of these requirements when adapted to different aviation maintenance training settings, ideally at an international level.

References

Airbus. (2022). Great Mechanics, Find them, keep them. AIRBUS - FAST Technical Magazine. https://browserclient.twixlmedia.com/0ba7a0848114178ebac91fb18d85d314/root/c437283bb66072fd154ba4f6b74f3deb

Amin, N., Yother, T. L., Johnson, M. E., & Rayz, J. (2022). Exploration of Natural Language Processing (NLP) Applications in Aviation. Collegiate Aviation Review International, 40(1). https://doi.org/10.22488/okstate.22.100211

Australian Medical Association. (2022). Competency Based Medical Education—AMA Position Statement. Australian Medical Association. https://www.ama.com.au/sites/default/files/2022-11/competency-based-medical-education-position-statement-2022.pdf

Baartman, L. K. J., Bastiaens, T. J., Kirschner, P. A., & Van der Vleuten, C. P. M. (2006). The wheel of competency assessment: Presenting quality criteria for competency assessment programs. Studies in Educational Evaluation, 32(2), 153–170. https://doi.org/10.1016/j.stueduc.2006.04.006

Baartman, L. K. J., Bastiaens, T. J., Kirschner, P. A., & Van der Vleuten, C. P. M. (2007). Evaluating assessment quality in competence-based education: A qualitative comparison of two frameworks. Educational Research Review, 2(2), 114–129. https://doi.org/10.1016/j.edurev.2007.06.001

Biggs, J. B. (1996). Enhancing teaching through constructive alignment. Higher Education, 32, 347–364. https://link.springer.com/article/10.1007/bf00138871#Abs1

Bray, A., Byrne, P., & O'Kelly, M. (2020). A Short Instrument for Measuring Students' Confidence with 'Key Skills' (SICKS): Development, Validation and Initial Results. Thinking Skills and Creativity, 37, 100700. https://doi.org/10.1016/j.tsc.2020.100700

Catacutan, A. B., Kilag, O. K. T., Diano, F. M., Tiongzon, B. D., Malbas, M. H., & Abendan, C. F. K. (2023). Competence-based curriculum development in a globalized education landscape. Excellencia: International Multi-Disciplinary Journal of Education (2994-9521), 1(4), 270–282.

Chaney, K. P., & Hodgson, J. L. (2021). Using the Five Core Components of Competency-Based Medical Education to Support Implementation of CBVE. Frontiers in Veterinary Science, 8, 689356. https://doi.org/10.3389/fvets.2021.689356

EASA. (2022). Easy Access Rules for Continuing Airworthiness (Regulation (EU) No 1321/2014). European Union Aviation Safety Agency. https://www.easa.europa.eu/en/document-library/easy-access-rules/easy-access-rules-continuing-airworthiness-0

FAA. (2025). Aeronautics and Space Subchapter D - Airmen. Part 65 Certification Other Than Flight Crewmembers Subpart D - Mechanics. Federal Aviation Administration / Department of Transportation.

Farland, M. Z., & Beck, D. E. (2019). Collaborative Learning Teams to Longitudinally Teach and Assess Teamwork Behaviors and Attitudes. American Journal of Pharmaceutical Education, 83(9), 7255. https://doi.org/10.5688/ajpe7255

Frerejean, J., Van Merriënboer, J. J. G., Kirschner, P. A., Roex, A., Aertgeerts, B., & Marcellis, M. (2019). Designing instruction for complex learning: 4C/ID in higher education. European Journal of Education, 54(4), 513–524. https://doi.org/10.1111/ejed.12363

Gibson, M., & Arnott, D. (2007). The Use of Focus Groups in Design Science Research. ACIS 2007 Proceedings 14, 327–337. http://aisel.aisnet.org/acis2007/14

Griffin, P., Gillis, S., & Calvitto, L. (2007). Standards-Referenced Assessment for Vocational Education and Training in Schools. Australian Journal of Education, 51(1), 19–38. https://doi.org/10.1177/000494410705100103

Gruppen, L. D., Mangrulkar, R. S., & Kolars, J. C. (2012). The promise of competency-based education in the health professions for improving global health. Human Resources for Health, 10(1), Article 1. https://doi.org/10.1186/1478-4491-10-43

Gulikers, J. T. M., Bastiaens, T. J., & Kirschner, P. A. (2007). Defining authentic assessment. Five dimensions of authenticity. In Balancing Dilemmas in Assessment and Learning in Contemporary Education. (pp. 75–88). Routledge. https://doi.org/10.4324/9780203942185

Gulikers, J. T. M., Runhaar, P., & Mulder, M. (2018). An assessment innovation as flywheel for changing teaching and learning. Journal of Vocational Education & Training, 70(2), 212–231. https://doi.org/10.1080/13636820.2017.1394353

Holmboe, E. S., Sherbino, J., Long, D. M., Swing, S. R., & Frank, J. R. (2010). The role of assessment in competency-based medical education. Medical Teacher, 32(8), Article 8. https://doi.org/10.3109/0142159X.2010.500704

ICAO. (2020). ICAO Doc 9868. Procedures for Air Navigation Services. Training.

ICAO. (2022). Annex 1 Personnel Licensing—International Standards and Recommended Practices. International Civil Aviation Organization.

Ichou, S., & Veress, A. (2023). Maintenance 4.0: Automation of Aircraft Maintenance Operational Processes. International Journal of Aviation Science and Technology, vm04(is01), 23–31. https://doi.org/10.23890/IJAST.vm04is01.0103

Johnson, R. L. (2023). Competency-Based Human Factors and Risk Assessment Training in 14 Code of Federal Regulations (CFR) Part 147 Maintenance Schools. The ATEC Journal, 44(2), 16–25.

Jones, D. K., & Abdallah, M. (2013). Assessment of Communication and Teamwork Skills in Engineering Technology Programs. 23–225.

Karakilic, E., Gunaltili, E., Ekici, S., Dalkiran, A., Balli, O., & Karakoc, T. H. (2023). A Comparative Study between Paper and Paperless Aircraft Maintenance: A Case Study. Sustainability, 15(20), 15150. https://doi.org/10.3390/su152015150

Kearns, S. K., Mavin, T. J., & Hodge, S. (2016). Competency-based education in aviation: Exploring alternate training pathways. Ashgate.

Kes, L., Saunders -Smits, G. N., & Specht, M. M. (2025). Towards New Educational Standards for Aircraft Maintenance: Analysing Transversal Competencies on Industry Safety Priorities and Assessment Challenges. In Review. https://doi.org/10.13140/RG.2.2.32434.26561

Kes, L., Van Wesel, F., Saunders -Smits, G. N., & Specht, M.M. (2025). Defining Valid Criteria for Transversal Competency Assessment in Vocational Education and Training for Aircraft Maintenance using the Delphi Method. In Review. https://doi.org/10.21203/rs.3.rs-6429387/v2

Korba, P., Sekelová, I., Mikula, B., & Koščáková, M. (2023). Needs Analysis of Aircraft Mechanics' English Language Skills. Aerospace, 10(2), 189. https://doi.org/10.3390/aerospace10020189

Krause, J., Portolese Dias, L., & Schedler, C. (2015). Competency-Based Education: A Framework for Measuring Quality Courses. Online Journal of Distance Learning Administration, 18, 1–9.

McClelland, D. C. (1973). Testing for competence rather than for 'Intelligence'. American Psychologist, 1–14.

McGrath, S., & Yamada, S. (2023). Skills for development and vocational education and training: Current and emergent trends. International Journal of Educational Development, 102, 102853. https://doi.org/10.1016/j.ijedudev.2023.102853

Miller, G. E. (1990). The assessment of clinical skills/competence/performance. Academic Medicine, 65(9), Article 9.

Misko, J., & Circelli, M. (2022). Adding Value to Competency-Based Training. National Centre for Vocational Education Research Ltd. Adelaide, Australia.

Morcke, A. M., Wichmann-Hansen, G., Nielsen, D. G., & Eika, B. (2006). Complex perspectives on learning objectives: Stakeholders' beliefs about core objectives based on focus group interviews: learning objectives. Medical Education, 40(7), 675–681. https://doi.org/10.1111/j.1365-2929.2006.02509.x

Morgan, D. L. (1996). Focus Groups. Annual Review of Sociology, 22(1), 129–152. https://doi.org/10.1146/annurev.soc.22.1.129

Mulder, M. (2014). Conceptions of Professional Competence. In International Handbook of Research in Professional and Practice-based Learning. (pp. 107–137). Springer. https://www.mmulder.nl/wp-content/uploads/2011/11/2014-Mulder-Conceptions-of-Professional-Competence-in-Billett-et-al1.pdf

Newman, M., & Scott, S. (2023). It Was This Wing Wasn't It? Identifying the Importance of Verbal Communication in Aviation Maintenance. The International Journal of Aerospace Psychology, 33(2), 139–152. https://doi.org/10.1080/24721840.2023.2169146

Norcini, J., Anderson, B., Bollela, V., Burch, V., Costa, M. J., Duvivier, R., Galbraith, R., Hays, R., Kent, A., Perrott, V., & Roberts, T. (2011). Criteria for good assessment: Consensus statement and recommendations from the Ottawa 2010 Conference. Medical Teacher, 33(3), 206–214. https://doi.org/10.3109/0142159X.2011.551559

Paeßens, J., Ma, B., & Winther, E. (2023). Effectiveness of Collaboration in VET: Measuring Skills for Solving Complex Vocational Problems With a Multidimensional Authentic Technology-Based Assessment. International Journal for Research in Vocational Education and Training, 10(1), 46–67. https://doi.org/10.13152/IJRVET.10.1.3

Papanikou, M., Kale, U., Nagy, A., & Stamoulis, K. (2021). Understanding aviation operators' variability in advanced systems. Aircraft Engineering and Aerospace Technology, 93(10), 1691–1698. https://doi.org/10.1108/AEAT-03-2021-0065

Pereira, B. A., Lohmann, G., & Houghton, L. (2022). Technology trajectory in aviation: Innovations leading to value creation (2000–2019). International Journal of Innovation Studies, 6(3), 128–141. https://doi.org/10.1016/j.ijis.2022.05.001

Prescott, L. E., Norcini, J. J., McKinlay, P., & Rennie, J. S. (2002). Facing the challenges of competency-based assessment of postgraduate dental training: Longitudinal Evaluation of Performance (LEP): Facing the challenges of a competency-based assessment system. Medical Education, 36(1), 92–97. https://doi.org/10.1046/j.1365-2923.2002.01099.x

Pyrialakou, V. D., Gkritza, K., & Liu, S. S. (2019). The use of focus groups to foster stakeholder engagement in intercity passenger rail planning. Case Studies on Transport Policy, 7(2), 505–517. https://doi.org/10.1016/j.cstp.2018.12.009

Ryan, K. E., Gandha, T., Culbertson, M. J., & Carlson, C. (2014). Focus Group Evidence: Implications for Design and Analysis. American Journal of Evaluation, 35(3), 328–345. https://doi.org/10.1177/1098214013508300

Schuwirth, L. W. T., & Van der Vleuten, C. P. M. (2011). Programmatic assessment: From assessment of learning to assessment for learning. Medical Teacher, 33(6), 478–485. https://doi.org/10.3109/0142159X.2011.565828

Sluijsmans, D. M. A., Straetmans, G. J. J. M., & Van Merriënboer, J. J. G. (2008). Integrating authentic assessment with competence-based learning in vocational education: The Protocol Portfolio Scoring. Journal of Vocational Education & Training, 60(2), 159–172. https://doi.org/10.1080/13636820802042438

Spencer, L. M., & Spencer, S. M. (1993). Competence at work: Models for superior performance. Wiley.

Stamoulis, K. (2022). Innovations in the Aviation MRO: Adaptive, digital, and sustainable tools for smarter engineering and maintenance. Eburon Academic Publishers.

Strom, P. S., & Strom, R. D. (2011). Teamwork skills assessment for cooperative learning. Educational Research and Evaluation, 17(4), 233–251. https://doi.org/10.1080/13803611.2011.620345

Terzieva, L., & Traina, I. (2015). Transferable/Transversal competences. How to teach and how to assess. International Journal of Science and Research, 8.

Tikunoff, W. J., & Ward, B. A. (1978). Insuring Reliability and Validity in Competency Assessment. Journal of Teacher Education, 29(2), 33–37. https://doi.org/10.1177/002248717802900210

Tremblay, M. C., Hevner, A. R., & Berndt, D. J. (2010). Focus Groups for Artifact Refinement and Evaluation in Design Research. Communications of the Association for Information Systems, 26. https://doi.org/10.17705/1CAIS.02627

Van Den Eertwegh, V., Van Dalen, J., Van Dulmen, S., Van der Vleuten, C. P. M., & Scherpbier, A. (2014). Residents' perceived barriers to communication skills learning: Comparing two medical working contexts in postgraduate training. Patient Education and Counseling, 95(1), 91–97. https://doi.org/10.1016/j.pec.2014.01.002

Van der Vleuten, C. P. M. (1996a). The assessment of professional competence: Developments, research and practical implications. Advances in Health Sciences Education, 1, 41–67.

Van der Vleuten, C. P. M. (1996b). The assessment of professional competence: Developments, research and practical implications. Advances in Health Sciences Education, 1, 41–67.

Van der Vleuten, C. P. M., & Schuwirth, L. W. T. (2005a). Assessing professional competence: From methods to programmes. Medical Education, 39(3), Article 3. https://doi.org/10.1111/j.1365-2929.2005.02094.x

Van der Vleuten, C. P. M., & Schuwirth, L. W. T. (2005b). Assessing professional competence: From methods to programmes. Medical Education, 39(3), 309–317. https://doi.org/10.1111/j.1365-2929.2005.02094.x

Van der Vleuten, C. P. M., Schuwirth, L. W. T., Driessen, E. W., Dijkstra, J., Tigelaar, D., Baartman, L. K. J., & van Tartwijk, J. (2012). A model for programmatic assessment fit for purpose. Medical Teacher, 34(3), Article 3. https://doi.org/10.3109/0142159X.2012.652239

Van Helden, G., Van Der Werf, V., Saunders-Smits, G. N., & Specht, M. M. (2023). The Use of Digital Peer Assessment in Higher Education—An Umbrella Review of Literature. IEEE Access, 11, 22948–22960. https://doi.org/10.1109/ACCESS.2023.3252914

Wilkinson, S. (1998). Focus group methodology: A review. International Journal of Social Research Methodology, 1(3), 181–203. https://doi.org/10.1080/13645579.1998.10846874

Winch, C. (2013). Three Different Conceptions of Know-How and their Relevance to Professional and Vocational Education: Three Different Conceptions of Know-How. Journal of Philosophy of Education, 47(2), Article 2. https://doi.org/10.1111/1467-9752.12025

Zylawski, C., & Ma, M. (2023). CBTA as a Solution to the MTX Talent Crisis. Aviation Voices: Commercial Aviation Safety & Training. https://aviationvoices.com/maintainer-competency-based-training-and-assessment-cbta-learning-from-air-france-industries/

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