**Collegiate Aviation Review International**

Volume 39 | Issue 2 Peer Reviewed Article #5

9-24-2021

# Maintenance of Composite-Based Aircraft Components and Structures through the Perspective of Aviation Maintenance Technicians in the United States

Peng Hao Wang
*Purdue University*

Natalie Zimmermann
*Purdue University*

For the last three decades, the field of aircraft construction and manufacturing has been experiencing a significant change as the material of choice for aircraft construction has been continuously transitioning from metal to composite materials. This underlying change to the way aircraft structures and components are manufactured is propelled by composite materials' intrinsic design and operational advantages. Nevertheless, as new technologies are introduced into the aviation industry, it is crucial to consider how all aspects thereof are affected, most importantly to ensure that safety is not compromised. As a critical part of the aviation industry and a key factor influencing the safety thereof, maintenance activities and certified aviation maintenance technicians (AMTs) need to be considered when evaluating the impact of the introduction of composite materials in the aeronautical field. Consequently, the conducted study specifically focuses on aircraft maintenance activities, especially as it pertains to the interaction of certified AMTs with composite materials. The goal of the study was to highlight and understand the opinions and perceptions of AMTs on composite materials and how, from a front-line perspective, aviation maintenance activities have changed with the introduction of novel materials. The input gathered from AMTs is a tool to understand potential pitfalls, deficiencies in training and resources, and safety threats from a maintenance perspective that may stem from the increased use of composite materials. With this purpose, certified maintenance technicians in the United States were surveyed and their responses were analyzed to identify recurring themes in the topics presented. Responses indicated issues related to formal composite-centered AMT training, knowledge, and resources available for composite maintenance.

Recommended Citation:
Wang, P. H. & Zimmermann N. (2021). Maintenance of composite-based aircraft components and structures through the perspective of aviation maintenance technicians in the United States. *Collegiate Aviation Review International*, 39(2), 94-133. Retrieved from http://ojs.library.okstate.edu/osu/index.php/CARI/article/view/8305/7648

The use of composite materials has continuously increased throughout the last decades, making them now a common material of choice for the construction of commercial aircraft primary structures (Haresceugh et al., 1994). Composite materials are used to manufacture a variety of parts and structures of a wide range of aircraft across manufacturers as they present a collection of advantages when compared to aluminum and other traditional aircraft materials. Among others, composite materials allow for lighter, more fuel-efficient and environmentally friendly aircraft constructions due to their comparative light weight and ability to be shaped into aerodynamically efficient parts, while simultaneously presenting excellent mechanical properties (Gopal, 2016; Hadcock, 1998; Haresceugh et al., 1994; Kassapoglou, 2013). Examples of civil, transport-category aircraft in which composite materials are used for the manufacture of parts and structures include the Boeing B737, B777 and B787 models, as well as the Airbus A220, A320, A350 and A380 models (Airbus, 2019; Gopal, 2016; Hiken, 2017; Kassapoglou, 2013; Soutis, 2005). In each aircraft, the exact composite material application and use are different. On the A320, the control surfaces, vertical and horizontal stabilizers are manufactured out of composite materials (Kassapoglou, 2013; Soutis, 2005). Similarly, composite sandwich materials were used for the manufacture of the horizontal stabilizer of the B737 **(**Kassapoglou, 2013). On the B777, composite materials were originally employed for the construction of the main floor beams, control surfaces and tail assembly (Kassapoglou, 2013). However, on the B777X, similar to the A220, A350 and B787, the use of composite materials is expanded and used for the manufacture of the wings (Airbus, 2019; Hiken, 2017; Kassapoglou, 2013; Soutis, 2005). On the A380, composite materials account for around 25% of the aircraft's weight, as composites are used for the manufacture of fuselage sections floor beams, the center wing box, and the aft pressure bulkhead (Kassapoglou, 2013; Soutis, 2005). On more recently designed aircraft, such as the B787 and A350, the aircraft fuselage is constructed solely out of composite materials. In addition, the center wing box and wings of the B787 and A350, respectively, are built as all-composite structures (Gopal, 2016; Kassapoglou, 2013). On these two aircraft, composite materials account for approximately 50% of the structural weight (Gopal, 2016; Kassapoglou, 2013; Soutis, 2005).

However, with the increased use of composite materials in aircraft structures, it is crucial to consider the maintenance characteristics of these materials and their impact on conventional maintenance activities. As is highlighted in a variety of maintenance-related documentation published by the Federal Aviation Administration (FAA, 1998, 2016, 2018a), the tools and methods used for composite material inspection, maintenance, and repair significantly vary compared to those used for the maintenance of traditional aircraft materials, such as aluminum. These changes and shifts in aviation maintenance practices and their impact on the work of aviation maintenance technicians need to be recognized, especially as the use of composite materials is continuously increasing. Properly performed maintenance activities are critical for the continuing safety of the aviation industry (FAA, 2018b), and thus it is critical to consider all aspects and elements that can impact these activities. Aviation maintenance technicians conducting and performing the maintenance and repair activities are a key element of aviation maintenance, and by extension of the safety thereof. Therefore, it is necessary to analyze and assess how the significant maintenance changes introduced by the increased use of composite materials impacts aviation maintenance technicians.

## Literature Review

### Composite Materials in Aviation Maintenance and Technician Education

Literature suggests that traditional aviation maintenance technician (AMT) education is not sufficient to meet the challenges of modern aviation, which includes the maintenance of composite-based aircraft structures (Haritos & Macchiarella, 2005). The use of composite materials for the manufacture of primary, structural aircraft components has introduced additional obstacles to aircraft maintenance and repair activities. First, the inspection of composite structures is more complex and difficult than the inspection of metallic structures due to the inherent manufacturing intricacy thereof (Kroes & Sterkenburg, 2013). Second, the damage type, failure modes, and damage propagation observed in aircraft composite structures present differences when compared to the damage found on metallic structures, subsequently requiring a different approach to aircraft maintenance, and specifically inspection activities (Hobbs, Brasil, & Kanki, 2009; Sterkenburg & Wang, 2013; Werfelman, 2007). For instance, while the inspection of metallic structures heavily relies on visual inspections, the inspection of composite structures frequently requires the further use of non-destructive testing (NDT) techniques, such as ultrasound, thermography and x-ray, as composite damage may not always be visually identified (Kroes & Sterkenburg, 2013; Ostrom & Wilhelmsen, 2008; Werfelman, 2007). By extension, NDT methods frequently require separate, additional and specific training and certification, which adds further complexity to the process of aircraft composites inspection (Kroes & Sterkenburg, 2013). Similar to the inspection, the repair of damaged or failed aircraft composite-based structures differs from techniques used to repair metallic structures and methods used for non-structural composite repairs. Consequently, further adjustments to standard, existing repair processes and procedures are required (Mitchell, Poudel, Li, Chu, & Mattingly, 2013).

As a crucial part of the aviation industry, the training and education of individuals involved in the maintenance and repair of aircraft need to be re-evaluated and adjusted to meet the novel requirements set by the evolving nature of aircraft construction. However, the training and education requirements in the field of composite maintenance have been vastly criticized as the requirements therefore are not standardized and fail to represent the needs of the industry (Hobbs et al., 2009).

In the United States, the FAA regulates the training requirements for aviation maintenance technician (AMT) certification under the Code of Federal Regulations (C.F.R.). When evaluating the curriculum required to be taught at AMT schools (Title 14 C.F.R. Part 147 Appendix C, 2017) it can be observed that comparatively old and outdated technology – such as wood, dope and fabric inspection, construction and repair – is required to be taught extensively, while novel technology – such as composite inspection and repair – is less prevalent. Even though basic composite education is mandated, extensive courses covering composite repairs and NDT are only optional, with their inclusion left up to the discretion of each AMT school (FAA, 2015). Consequently, standardization issues, as introduced by Hobbs et al. (2009), as well as a workforce not educated to meet the requirements of modern aviation – as hypothesized by Haritos and Macchiarella (2005) – emerge.

To address the above-mentioned, theoretically studied, shortcomings in AMT education as well as to address the potential impact on aviation maintenance activities, a study focused on aviation technicians' perceptions, attitudes, and opinions with regards to composite aircraft maintenance and repair was conducted.

## Surveys in Aviation

In an effort to increase the safety of the maintenance activities themselves and of the aviation industry, aviation maintenance technicians and mechanics are frequently surveyed and interviewed regarding their attitudes and opinions on a variety of issues. Most commonly, these surveys and interviews are focused around the areas of maintenance manuals and technical publications, training, procedures, human factors, safety management systems and safety culture.

Human factors in relation to aviation technical manuals were studied by Chaparro & Groff (2002) and Chaparro, Groff, Chaparro, and Scarlett (2002) as they aimed to identify, through a combination of techniques, human factors issues that are related to aviation maintenance technical manuals. As part of the study, a survey was employed consisting of a questionnaire and interviews to determine the perceptions of maintenance technicians on the quality and usability of the maintenance documentation used, and to compare the maintenance documentation across aircraft manufacturers. Further in the area of technical publications, Zafiharimalala, Robin, and Tricot (2014) explored how maintenance documentation is used by aviation maintenance technicians, employing a survey to understand how and when maintenance technicians use said documentation as well as the reasons for which technicians do not use the maintenance documents. In addition to human factors related to maintenance manuals and the actual use of these manuals, avantgarde approaches to technical publications, such as 3D aircraft maintenance manuals, are also researched and explored. A study conducted by Wang and Leib (2014) investigated the usefulness and acceptance of 3D maintenance manuals, compared to traditional manuals, as seen by front-line aviation technicians.

The relationship and interaction amongst maintenance technicians and pilots, especially in the area of maintenance discrepancy reporting, has been explored and studied by surveying both pilots and maintenance technicians. To understand maintenance discrepancy reporting policies and practices, as well as the opinions of aviation professionals with respect to the effectiveness of said practices and the training in the area, Mattson, Petrin and Young (2001) surveyed a group of pilots and maintenance technicians. Similarly, Munro, Kanki, & Jordan (2008) explored factors that influence logbook entries as well as the impact on these entries if it is known that they may be read by regulatory agencies. In the research, Munro et al. (2008) used a survey to identify factors influencing the level of detail of the description of discrepancies in a logbook and the frequency of direct discussions of these discrepancies between pilots and mechanics. The survey consisted of a combination of yes-no, multiple choice and rank-order questions, and Likert-type scales.

Georgiou (2009) and Hackworth et al. (2007) explored human factors in aviation maintenance activities by surveying, among others, aviation maintenance technicians. While Georgiou (2009) aimed to investigate human factors related to aviation maintenance activities and their impact on safety, Hackworth et al. (2007) focused on the impact and difference between regulatory and voluntary approaches to maintenance human factor programs. Georgiou (2009) employed a survey to identify the human factor types that impact the performance of aviation mechanics and the extent to which these human factors impact the safety of the industry. The survey items from Hackworth et al. (2005) fall in the following categories: demographics, human factor metrics, organizational policies, error management, fatigue management, human factors training, motivation for a human factors program, and proactive human factors support.

Safety is a critical aspect in all areas of the aviation industry, including aviation maintenance organizations. Thus, a vast volume of research is centered around the implementation of safety management systems (SMS) in aviation maintenance activities, the safety culture of aviation maintenance organizations, and risk perception factors. Kearns and Schermer (2017) employed a survey with the aim to determine the attitudes and perceptions of aviation professionals on SMS, and differences therein based on gender and/or nationality. Similarly, McDonald, Corrigan, Daly, and Cromie (2000) explored the relationships between safety culture and SMS aspects through a variety of techniques, including interviews and surveys. Patankar (2003) analyzed an accident-free aviation organization to determine the factors that may have contributed to its positive safety record. Through questionnaires distributed to flight operations personnel, maintenance personnel as well as other employees of the organization, Patankar (2003) aimed to measure the safety attitudes of the employees as well as their opinions on the factors contributing to the exceptional safety record. Kim and Song (2015) focused specifically on the safety culture of a maintenance organization in Korea, with the purpose of using the results to improve further SMS implementations. The survey consisted of a variety of Likert- and nominal-scale elements, as well as free-response questions for safety proposal descriptions. Lastly, safety and risk can, and may, be perceived differently by every individual. For example, Chionis and Karanikas (2018) compared the opinions and attitudes of professional aviation maintenance personnel, engineers, and trainees through a survey. The survey consisted of questions about risk perception factors and scenarios for which the participants had to select a course of action.

As can be seen through the literature described, aviation maintenance technicians are mainly surveyed on procedural, managerial, safety, and human factor related aspects. Conversely, the perceptions, attitudes, and opinions of maintenance technicians in areas related to technical aspects, such as modifications to aircraft, for example through the increased use of composite materials and their impact on the maintenance activities, are not represented in existing literature. Nevertheless, such surveys can be beneficial to properly understand how industry professionals are impacted by considerable changes that impact their activities, as is shown by a variety of studies performed on pilots. With the implementation of glass cockpits and the further automation of flight, pilots have experienced substantial changes to their activities in the last decades. Thus, to understand how these changes impact pilots themselves, aircraft operation and the effect on safety, a variety of studies focusing on pilots' perceptions, opinions, attitudes, performance, and interactions with these systems have been performed.

Studies by Casner (2008), McClumpha, James, Green, and Belyavin (1991), Mosier and Fischer (2012), Sherman, Helmreich, and Merritt (1997), and Weyer (2016) focused on pilots' beliefs, attitudes, and perceptions with respect to automation and glass cockpits. By presenting pilots with a variety of scenarios and asking them to judge automation elements thereof, Mosier and Fischer (2012) studied how variations in automation as well as context and task features impact professional pilots' perceptions regarding workload, task management, situation awareness, automation cross-checking, and automation-related errors. Casner (2008) and McClumpha et al. (1991) focused specifically on pilots' attitudes towards advanced cockpit systems and advanced technology aircraft, respectively. Casner (2008) aimed to assess pilots' advanced cockpit system attitudes and beliefs, identify relationships between experience and attitudes, compare the attitudes of general aviation pilots and airline pilots, and recognize differences in impact perceptions. Similarly, McClumpha et al. (1991) studied pilots' attitudes and impressions on the design, reliability, skills, training, workload, flight management system, output and feedback, as well as crew interaction elements of advanced technology aircraft. With the purpose of identifying obstacles to the efficient human-automation interaction and to understand the distribution of roles in digital cockpits, Weyer (2016) analyzed and assed the confidence of pilots on human-automation interaction and collaboration, as well as the factors that influence this confidence. Furthermore, the impact of nationality, professional culture, and organizational differences on the pilots' attitudes towards automation were assessed and explored by Sherman et al. (1997).

In addition to perceptional and attitude-focused surveys and research, studies on the interaction between pilots and the advanced and automated systems have been performed by Casner (2009) and Sarter and Woods (1992, 1994). Sarter and Woods (1992) studied the impact of flight-deck automation on the performance of pilots by analyzing the interaction between pilots and the Flight Management System (FMS). Specifically, Sarter and Woods (1992) asked pilots to provide descriptions of issues encountered with the FMS, but also observed the transition process of flight crews to glass cockpit aircraft, while focusing on the pilots' interactions with the FMS and communications between the crew and instructors. To further understand pilot-automation interaction and performance, Sarter and Woods (1994) studied pilots' mode awareness and ability to apply flight context knowledge and understanding by observing and analyzing pilot-FMS interaction and pilots' reactions to hypothetical events during simulated flights. Additionally, the effect advanced cockpit systems can have on pilot workload and errors was studied by Casner (2009), who analyzed the effect of navigation equipment, control method, as well as flight and navigation instrumentation on error and workload.

Through these studies, an increased and more comprehensive understanding of the impact that advanced cockpit and automated systems have on pilots is obtained. The results can be used to identify, amongst others, issues, complications and pitfalls in the implementation of the advanced systems, gaps in knowledge and training, the impact on safety, as well as possibilities for further improvement thereof. Due to the lack of similar research with regards to aviation maintenance technicians' knowledge, opinions, attitudes, and perceptions of composite materials, it can be challenging to identify issues and difficulties presented by the maintenance of composite-based airframes and structures, and potentially to devise future improvements in the area. The impact of the scarce literature in the area is further magnified when considering the implications of aircraft maintenance on the safety of the aviation industry.

## Methodology

To understand the practical implications of the introduction of composite-based structures into the lifecycle of aircraft, specifically focusing on potential challenges to maintenance and repair activities, aviation maintenance technicians (AMTs) in the United States were surveyed. Specifically, the purpose of the conducted survey was to answer the following research questions:

1. What are the opinions, attitudes, perceptions, and knowledge of AMTs in the United States regarding composite maintenance and repairs?
2. What are the similarities and differences between composite and metal maintenance and repair activities with regards to the opinions, attitudes, perceptions, and knowledge thereof of AMTs in the United States?

Through the results of the survey, potential shortcomings in mandated AMT education, as well as difficulties and safety issues arising from the introduction of composite materials into aircraft construction were aimed to be identified.

### Survey Design

References from the literature were used to design the survey. Specifically, elements and survey formats from Casner (2008), Chaparro et al. (2002), Hackworth et al. (2007), and Mattson et al. (2001) were included into the survey design developed. Overall, the survey was divided into three main sections: (1) demographic questions, (2) questions related to the opinions and perceptions of AMTs with regards to composite materials, and (3) composite material knowledge questions. While the demographic information is used to categorize the responses and obtain an understanding of the background of the survey respondents, the questions related to opinions/perceptions and composite knowledge are used to gain insight into the relationship between AMTs and composite materials in the United States. Furthermore, the survey elements presented in the second section of the survey – questions related to opinions and perceptions – are divided into two types: (1) Likert-scale ranking and (2) open-ended questions. On one hand, the Likert-type scale is used to allow AMTs to indicate their agreement/disagreement with statements related to composite maintenance activities and repairs. On the other hand, the open-ended questions are used as a tool for AMTs to narrate their personal opinions and perceptions on composite materials in aviation maintenance and repairs. The third section of the survey – composite material knowledge questions – is used to test the composite-related theoretical knowledge AMTs have. Specifically, these questions were retrieved from a test guide (Aviation Supplies & Academics [ASA], 2018) for the FAA airframe and powerplant (A&P) examination – an FAA-regulated exam that is to be passed by AMTs to obtain the mechanics' certificate and perform certain types of maintenance on U.S.-registered aircraft (FAA, 2020). The full survey, outlining the questions, is presented in the *Appendix*.

**Survey Participants and Distribution**

The target population for the surveys included FAA-certified aviation mechanics, with either the airframe rating (referred to as "A") or the combined airframe and powerplant ratings (referred to as "A&P"). As the survey was intentionally kept broad to reflect the diversity of the aviation industry in the United States, the target population was not further narrowed down. Consequently, all AMTs with "A" or "A&P" ratings, regardless of factors such as occupational status, experience, or background, were included in the survey. Related demographic elements were collected via the survey questionnaire (as reflected in the *Appendix*), but were solely used to frame the responses in context rather than to further refine the scope of the survey. Therefore, the only participation pre-requisite was for participants to have either an "A" or "A&P" rating.

To reach the largest number of eligible participants while still representing the diversity of the aviation industry, a Facebook™ group was used for the distribution of the survey per an Institutional Review Board (IRB) approved procedure. The group in question has approximately 27,000 members and is used as a platform for AMTs to discuss aviation-related content, primarily focusing on aviation maintenance/repair topics. The survey was maintained on the group for one month, while group members were introduced, invited, and reminded of the possibility to participate in the survey twice – once per week during the first two weeks. As aforementioned, the group participants were informed of the only pre-requisite to participate – if the pre-requisite was met, group members could voluntarily decide to participate.

## Results

After the one-month period, 92 responses to the survey were recorded. However, not all the responses included complete answers to the questionnaire. Only the survey responses that included complete, full answers to at least the Likert-scale rating section of the questionnaire were considered for the analysis of the opinion/perception element of the study. Similarly, to evaluate the theoretical knowledge of composite materials of AMTs, only responses that included answers to all the knowledge questions were analyzed. Through this filtering, the responses break down as follows (see Figure 1):

- Responses with at least opinions/perceptions Likert-scale rating section complete: 50
- Responses including answers to open-ended questions: 38
- Responses with complete answers to knowledge questions: 18

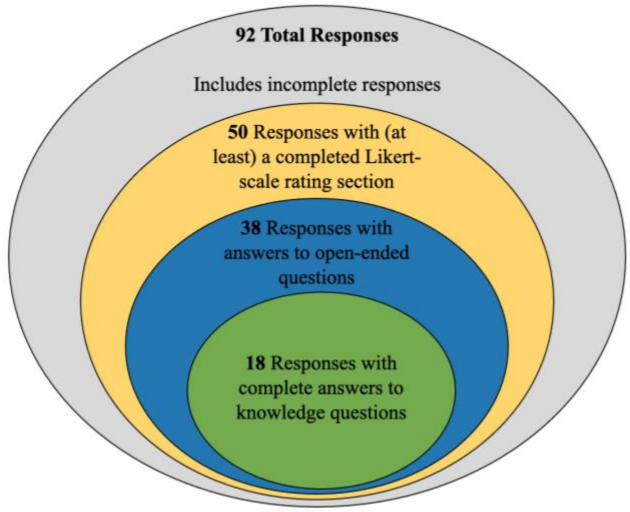


*Figure 1.* Venn Diagram with breakdown and results of response filtering.

During the analysis, each of the above three elements: Likert-scale rating, open-ended questions and knowledge questions, were analyzed separately.

## Demographic Results

For the demographic analysis, the 50 responses which included – at least – a complete Likert-scale rating section were considered. Under the demographic analysis, the following elements are evaluated: employment information, AMT experience, educational background, certification and licenses, age, as well as background/experience with composite materials. Table 1 highlights and summarizes the demographic information obtained.

The majority of the survey respondents are employed at an airline maintenance department, followed second by entire-aircraft repair stations. With regards to positions held, more than half of the respondents indicated that they practice as mechanics/technicians, with the responses reflecting a variety of backgrounds, including – but not limited to – overhaul technicians, structural technicians, and line mechanics. However, there was also representation from the quality control (QC), maintenance control, and managerial positions among the respondents. The participants’ experience as aviation maintenance technicians is approximately evenly distributed among all year categories, with the lowest experience being one (1) year and the highest experience being 45 years – both indicated by one participant, respectively.

Table 1
*Demographic Information*

| Demographic Element | Frequency | Percentage |
|---|---|---|
| ***Employment Organization*** | | |
| Airline Maintenance Department | 18 | 36% |
| General Aviation/Business Aircraft | 4 | 8% |
| Maintenance School/Training Facility | 3 | 6% |
| Manufacturer | 2 | 4% |
| Military/Government | 8 | 16% |
| Repair Station – Entire Aircraft | 12 | 24% |
| Other | 3 | 6% |
| ***Current Employment*** | | |
| Mechanic/Technician/A&P/AMT | 33 | 66% |
| Mechanic/Technician – Lead or Manager | 7 | 14% |
| Maintenance Control | 1 | 2% |
| Instructor | 2 | 4% |
| Inspection/Quality Control | 1 | 2% |
| Other | 6 | 12% |
| ***Years with Experience as Aviation Maintenance Technician*** | | |
| 0 – 5 Years | 13 | 26% |
| +5 – 10 Years | 15 | 30% |
| +10 – 30 Years | 11 | 22% |
| 30+ Years | 11 | 22% |
| ***Highest Level of Education Completed*** | | |
| High School/GED | 2 | 4% |
| Trade School | 11 | 22% |
| Associate’s Degree | 1 | 2% |
| Some College | 17 | 34% |
| Bachelor’s Degree | 17 | 34% |
| Graduate Degree | 2 | 4% |
| ***Certificates Held*** | | |
| Mechanic: Airframe Rating | 1 | - |
| Mechanic: Airframe & Powerplant | 21 | - |
| Inspection Authorization (IA) | 12 | - |
| Mechanic/IA + FCC License | 15 | - |
| Mechanic/IA + Pilot’s License/Certificate | 8 | - |
| IA + Designated Airworthiness Rep. | 1 | - |
| Mechanic + Repairman | 1 | - |

The formal education levels represented in the sample range from High School/General Education Diploma (GED) to Graduate degrees, with both extremes representing four percent of the participants. Some form of college education as well as a Bachelor’s degree are the most frequent educational levels of the survey participants. Trade school education (i.e., vocational school and/or technical school) follows third – a path that allows for formal aviation maintenance technician training. Lastly, to evaluate the licenses and certificates held by the participants – a crucial factor in the field of aviation maintenance – a non-mutually exclusive list was created, as licenses and certificates can be held in any combination. Therefore, Table 1 does not include percentages for this category. As it was a requirement to participate in the survey, all respondents indicated that they have a mechanic's license with the airframe or the airframe and powerplant ratings. However, a large portion of the participants had additional licenses/certificates, including the inspection authorization (IA), a combination of pilot certificates and licenses, as well as licenses from the Federal Communications Commission (FCC). Additionally, the sample included a Designated Airworthiness Representative (DAR) as well as a certified repairman – both FAA-regulated certifications. Furthermore, aviation maintenance technician training as well as composites-specific training were evaluated separately. Table 2 provides an outline of the type – and when applicable, duration – of aviation maintenance and composite training received.

Of the 50 respondents, 45 received their aviation maintenance training at a technical school, such as a four-year college program or trade school. This training was received, on average, for 1.94 years, with extremes of 0.5 and one year (potentially indicating an early termination of the educational programs) to four years (i.e., as observed in most college-level programs). Fifteen participants received aviation maintenance training through a military program, lasting – on average – slightly below five years. A total of 13 participants received aviation maintenance training through another source – potentially through on-the-job (OTJ) training or through experience. However, it is important to note that the three indicated forms of training can be completed in combination. Therefore, specific combinations of the three main types of training were observed among the survey respondents.

Table 2
*Specific Training Information*

| **Aviation Maintenance Training** | | |
|---|---|---|
| **Training Source** | **Number of Responses** | **Average Duration of Training** |
| Technical School | 45 | 1.94 Years |
| Military | 15 | 4.76 Years |
| Other | 13 | 5.54 Years |
| Combination: Tech./Military | 13 | - |
| Combination: Tech./Military/Other | 3 | - |
| **Aircraft Composite Materials Education** | | |
| **Type of Education** | **Source of Education** | **Number of Responses** |
| | Certification Training | 18 |
| Formal | Employer | 6 |
| | Independent/Voluntary | 1 |
| Informal | Experience | 17 |
| No composites training/education | - | 8 |

Observing aircraft composites material training and experience specifically, similar trends can be observed. Half of the respondents indicated that they received formal education in the field of aircraft composite materials, with certification training – as for instance FAA-regulated AMT training – being the most popular form of education. While a few individuals indicated that either a current or a formal employer sponsored/provided composites training, one participant completed specific training in the field on a voluntary basis.

Approximately 80% of the survey respondents – specifically 41 of the 50 respondents – have experience working with composite aircraft/materials. The form of the experience, however, varies, as shown in Table 3. The list provided in Table 3 is non-mutually exclusive, so that each category can be indicated more than once per respondent. The most frequent source of experience is performing maintenance and repairs (or minor field repairs) on composite aircraft, followed by experience gained through education and/or training. A comparatively small number of respondents indicated gaining experience from a manufacturing and/or design engineering environment, while one participant indicated having worked with composite materials on experimental aircraft.

Table 3
*Composites-Specific Experience*

| **Experience Type** | **Number of Responses** |
|---|---|
| Educational/Training Context | 18 |
| Maintenance, repairs, and overhauls | 33 |
| Manufacturing | 7 |
| Others – Minor Field Repairs | 1 |
| Others – Design Engineering | 1 |
| Others – Experimental Aircraft | 1 |

## Perceptions and Opinions Results

The results obtained from the second section of the questionnaire, relating to the opinions and perceptions of AMTs with respect to composite materials, are divided into two sections. First, the results from the Likert-scale rating statements are presented in terms of the frequency of responses. Second, the results from the open-ended questions are analyzed through basic, essential qualitative analysis to identify reoccurring themes among the responses.

## Likert-Scale Results

A total of 25 Likert-scale ranking questions were employed in the survey, with a six-point scale ranging along the strongly disagree (1) to strongly agree (6) spectrum. The detailed ranking statements are found in the complete questionnaire in the *Appendix.* Figures 2 through 5 below visually represent the statements to be ranked and their relative rankings.

Questions 18, 19, and 27 as well as questions 13, 14, 30, and 31 are related to the training and understanding, respectively, of aircraft maintenance technicians in the fields of both, metal and composite aircraft repair/maintenance. The opinions and perceptions of the survey participants in these areas are reflected in Figure 2. With individual exceptions, it can be seen that, overall, technicians believe that their training has prepared them better for the maintenance and repair of metal airframes. Similarly, while 37 respondents agree in some form that their training was adequate for a career focused on metal-based aircraft, only 24 respondents claim the same for a career focused on composite-based aircraft. Moreover, the most frequent rating for the statement “My training and education have adequately prepared me to work with composite aircraft structures” is a 2 on the used Likert-scale, thus reflecting disagreement, while the same statement but for metal aircraft is most frequently rated as a 6 – “Strongly agree”. The differences in metal- and composite-oriented training and education further affect the understanding of the respective disciplines. The distribution of respondents indicating an understanding of the consequences of damages to metal aircraft structures is clearly left-skewed, highlighting that only a few mechanics do not believe that they understand the consequences of metal failures. Evaluating the same statement but focusing on the understanding of composite failures and the consequences thereof, it can be seen that the shape of the distribution changes. The majority of the respondents indicated that they agree with the following statement: “I fully understand the consequences of damages to aircraft composite structures”. However, comparatively, the number of respondents that indicated that they do not agree with the above statement is greater in reference to composite structures than to metal structures. Similarly, most respondents noted that they understand elements related to metal aircraft maintenance. However, a different response pattern was observed in reference to composite aircraft maintenance. Specifically, in reference to composite aircraft maintenance, the responses along the disagree-agree spectrum are more equally distributed.

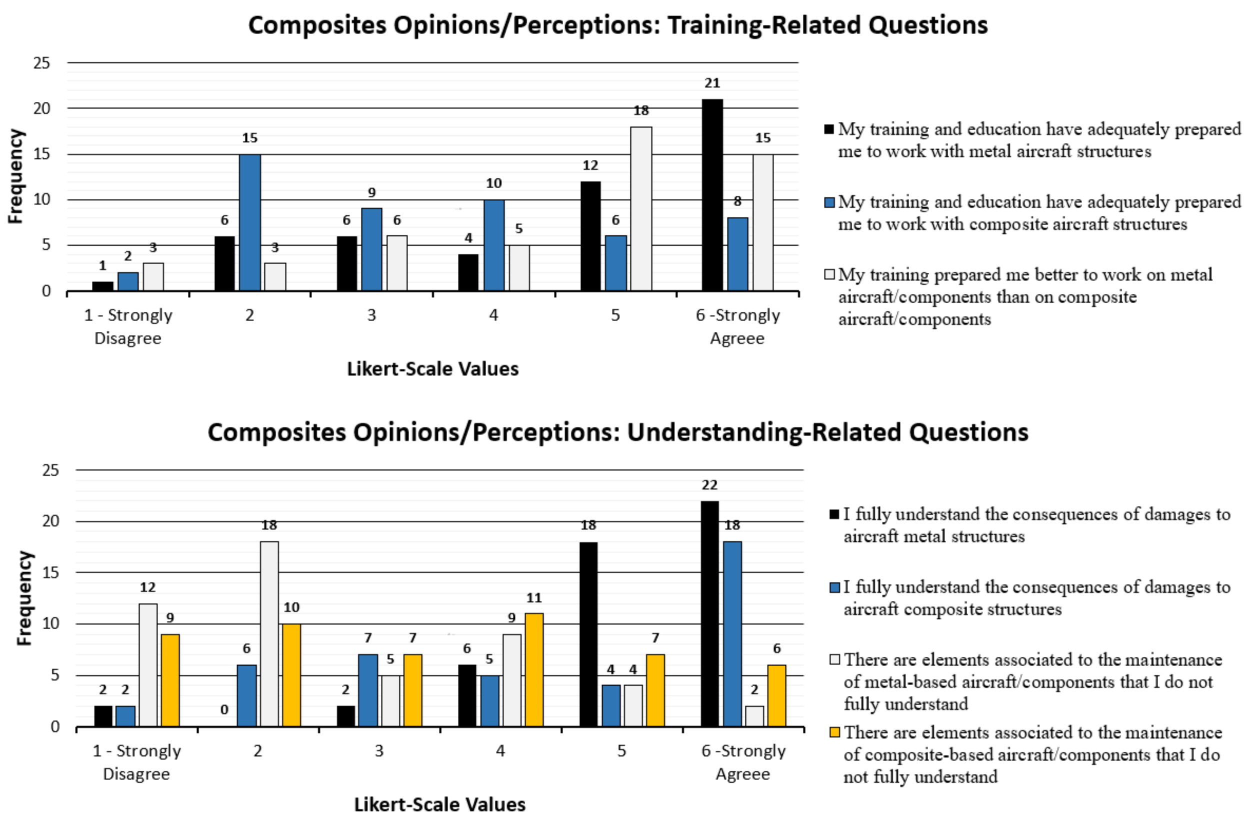


*Figure 2.* Responses on training and understanding of metal/composite aircraft maintenance.

Differences in the responses were also observed when evaluating maintenance-related elements such as time, confidence, and ease. Specifically, questions 13, 20, 21, 22, 23, 24, and 25, as shown in Figure 3, related to the aforementioned topics. The majority of the respondents, specifically 31, indicated that more time is required to perform repair activities on composite aircraft than on metal aircraft, with 18 respondents strongly agreeing that composite repairs are more time consuming than metal repairs. With regards to confidence, similar trends in answers are observed for metal and composite repairs. For both, metal- and composite-based aircraft/components, a left-skewed distribution is observed, indicating that more responses are recorded in the "agree" section of the Likert-scale. Nevertheless, the extremes of both distributions differ. On one hand, for metal aircraft, 22 respondents indicated that they "strongly agree" with the indicated confidence statement. On the other hand, for composite aircraft, a lower number – specifically 10 respondents – indicated a strong agreeance with the statement presented. This trend is similarly highlighted by the blue series on the graph, as six participants indicated that they feel more confident performing maintenance/repairs on metal aircraft.

Considering the actual difficulty of performing maintenance activities on metal- and composite-based aircraft, participants' responses converged toward the center of the Likert-scale range. Combined, 19 participants – 38% of the responses – indicated small agreement and disagreement with metal-based aircraft being easier to work on than composite-based aircraft.

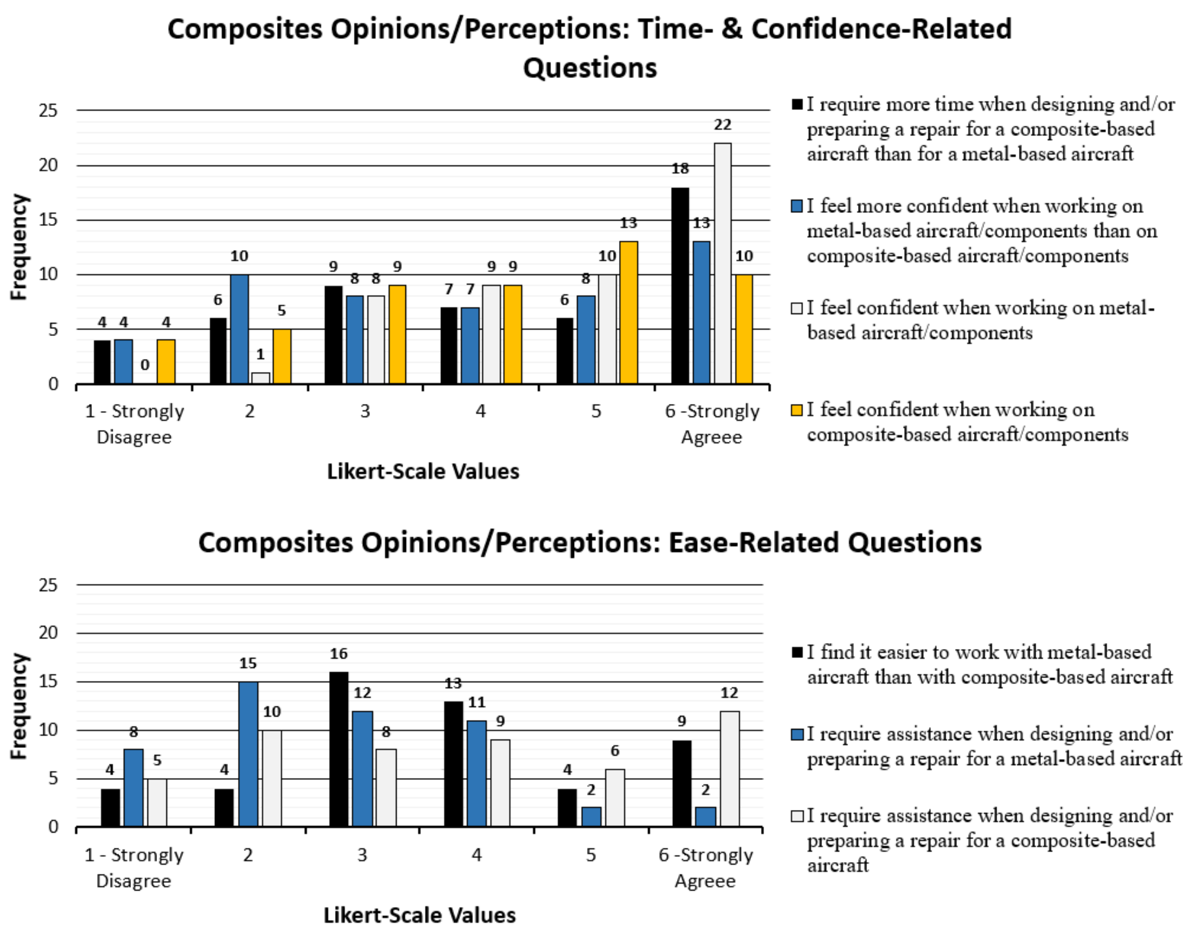


*Figure 3.* Responses on time, confidence and ease of metal/composite aircraft maintenance.

Moreover, the responses are approximately evenly split across the agree-disagree spectrum: 24 responses are on the disagreement side while 26 responses are on the agreement side. However, the responses start differing when focusing on the need/requirement for assistance during the repair process. The majority of the participants indicated a certain degree of disagreement with the following statement: “I require assistance when designing and/or preparing a repair for a metal-based aircraft”, resulting in a right-skewed distribution. However, the same statement in reference to composite-based aircraft yields a more even distribution. Even though the mode is located at the Likert-scale value of “6 – Strongly agree” with 12 responses, the responses are approximately evenly distributed along the spectrum: 23 responses fall along the disagreement spectrum while 27 responses fall along the agreement spectrum.

Challenges encountered, detectability of errors, as well as the errors made when performing maintenance and repair activities on metal- and composite-based aircraft are evaluated under questions 16, 17, 26, 34, 35, 36, and 37. The results obtained from the Likert-scale rating to these questions are visually represented in Figure 4. At a first glance, the distribution of the three challenge-related statements appears to be even, equally distributed on the scale, and similar for metal and composite aircraft. However, small but notable differences can be appreciated. For instance, with regards to the first statement – “I feel challenged when working with/on metal-based aircraft” – the responses are approximately evenly distributed among ratings “1” through “4”, but drastically decrease in the two upper-limit ratings. No participants indicated maximum agreement – “6 – Strongly agree” – to said statement. The distribution of the answers to “I feel challenged when working with/on composite-based aircraft” is similar to the statement for metal-based aircraft, with slight differences towards the extremes of the scale. Specifically, fewer participants selected the two extreme ratings on the “disagree” end of the scale, while more participants selected the two extreme ratings on the “agree” end of the spectrum. These minute differences indicate a slight increase in the level of challenge when performing maintenance/repair activities on composite structures and components. This minute difference is similarly reflected and synthesized in the third statement: “I feel more challenged when working on composite-based aircraft/components than on metal-based aircraft components”. As was observed in previous instances, the answers are approximately evenly distributed on the disagree-agree spectrum. Nevertheless, the “agree” spectrum, indicating more challenges when working on composite-based aircraft components, was selected by 27 participants. More divergence in responses is observed evaluating the rankings for the error-related statements. Participants indicated that errors are more quickly/easily recognizable in metal-based aircraft/components. Specifically, with regards to metals, 43 responses are found on the “agree” spectrum, while only 18 responses are found on the “agree” spectrum for composites. When evaluating the frequency of errors made on metal and composite aircraft, respectively, a different distribution of responses was obtained dependent on the directionality of the statement presented. First, when the statement is phrased indicating more errors being made on metal aircraft – the series in white on the second graph in Figure 4 – the distribution is right-skewed, indicating that most respondents do not believe that more errors are made on metal aircraft. However, when the statement is phrased indicating more errors being made on composite aircraft – the series in yellow on the second graph in Figure 4 – the distribution is approximately symmetrically distributed with a peak around rating “3”. Moreover, 26 of the responses fall on the “disagree” side of the spectrum, conflicting with the previous responses obtained.

Lastly, in Figure 5, statements with regards to the demand experienced by mechanics (corresponding to questions 28, 29, 32, and 33) are evaluated. Three statements (black, blue, and white series) reflect a similarly right-skewed shape, while the last statement – yellow series – is centered and approximately evenly distributed along both sides of the spectrum. For both, metal and composite aircraft maintenance/repairs, answers were more frequent on the “disagree” end of the spectrum. Furthermore, “1 – Strongly disagree” was the most frequently selected ranking for both statements. Combined, these two characteristics indicate that the majority of mechanics do not feel highly overwhelmed while performing maintenance/repair activities on either form of structure. However, it is important to note that, for composite aircraft, 13 participants indicated a certain degree of feeling overwhelmed, while only two participants indicated the same for metal aircraft. With regards to mental demand, a slight right-skew is observed for metal aircraft. For the statement “Working on metal-based aircraft/components is mentally demanding”, 19 participants indicated that they agree therewith, with three indicating that they “strongly agree”. The mode for this statement, with 12 responses, concentrates along the rankings of “2” and “3”, both on the “disagree” end of the spectrum.

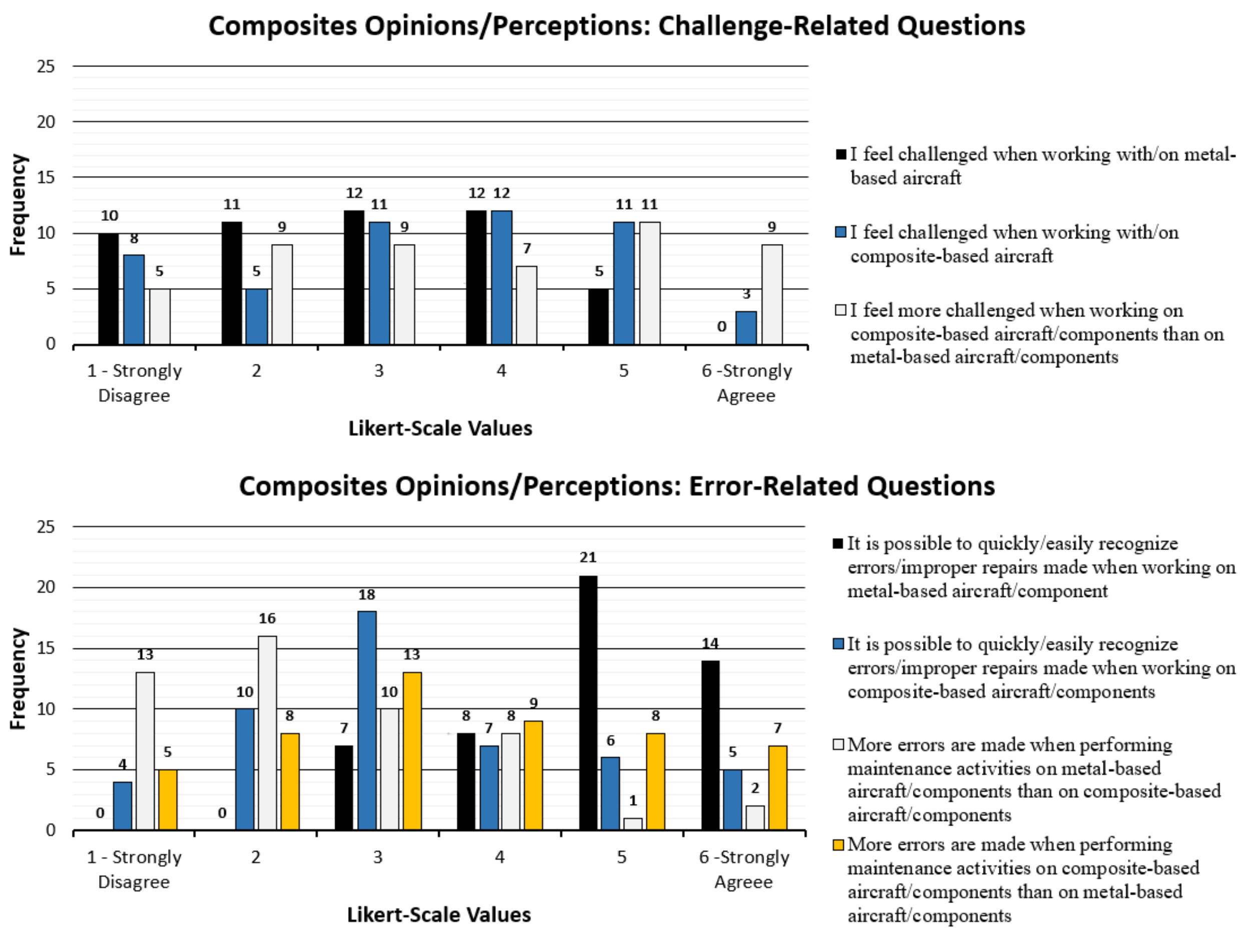


*Figure 4.* Responses on challenges and errors of metal/composite aircraft maintenance.

The same statement but worded for composite aircraft resulted in a distinct shape. The mode thereof, with 13 responses, concentrates along the rankings of “3” and “4”, with a slight majority of the responses (26 specifically) being recorded on the “agree” end of the spectrum. The differences in the distribution of the answers are indicative of higher levels of mental demand being experienced, on average, when performing repair and maintenance activities on composite-based aircraft/components.

## Open-Ended Questions

As mentioned above, the results from the 10 open-ended questions included in the questionnaire are categorized and grouped by reoccurring themes, with the purpose of identifying trends in opinions and perceptions. Table 4 highlights the reoccurring themes categorized as well as the frequency of the respective categories.

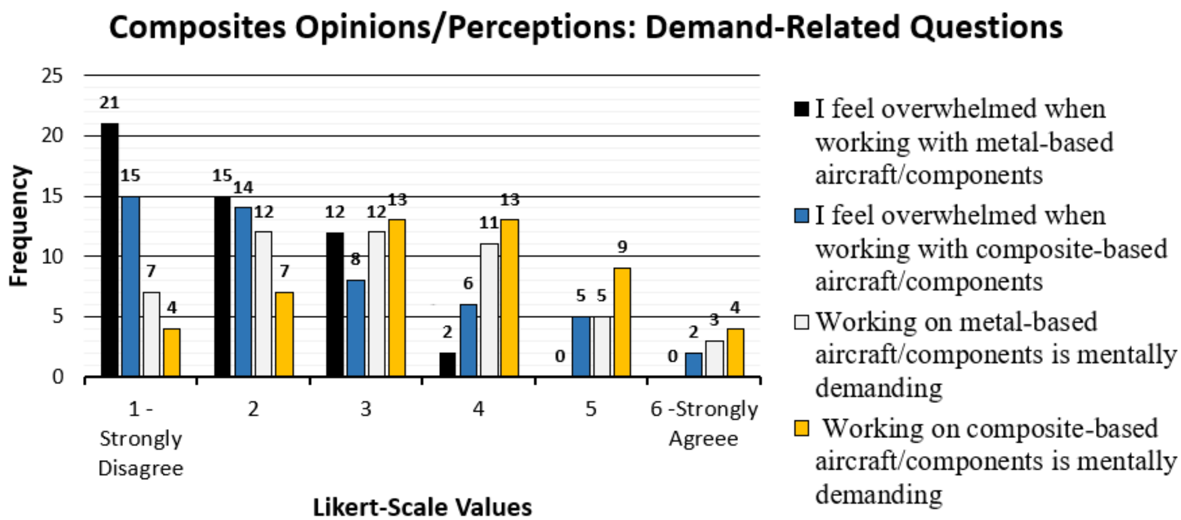


*Figure 5.* Responses on demand of metal/composite aircraft maintenance.

A larger number of participants indicated a preference for working on metal-based aircraft/components than on the composite counterpart. Specifically, two reasons for this difference are explained to be the comparative simplicity and ease of working with metallic-based structures as well as more background knowledge, training, experience, and confidence mechanics have – or have gathered – with regards to metal-based aircraft/component maintenance/repair activities. However – even with the majority of participants indicating a preference for metal-based maintenance/repair activities – some responses highlighted a preference for composite-based maintenance/repair activities, while six participants indicated that they do not have a preference.

To understand the divergence in opinions with regards to the preference, two elements were studied. First, opinions with regards to the likes and dislikes of each, metal- and composite-based maintenance and repair activities were gathered. Second, opinions related to elements that complicate and add difficulty to each material's respective maintenance/repair activities were obtained. For both materials, elements related to the actual repair processes, material characteristics, as well as the knowledge, training, experience of the workforce were frequently quoted as both benefits and drawbacks. However, more nuanced but less frequently-quoted elements present salient differences. For instance, working with composite materials has been quoted by participants to be more flexible, where mechanics enjoy the properties composite materials present, the modern technology used, and the challenges presented. On the other hand, maintenance/repair activities on metal structures are quoted to present benefits in the form of availability of resources as well as reduced time requirements to complete said repairs. Furthermore, when evaluating composite repairs specifically, trends emerge that were not indicated for metal-based repairs. Themes related to identifying damages, setting-up a repair, controlling the variables influencing the repair, and validating the repair were more represented in the responses related to composite structures. However, as aforementioned, these results do not indicate that maintenance and repair activities on metallic structures are not accompanied by challenges or do not present difficulties. Instead, they intend to highlight differences that affect the maintenance/repair activities of composite-based aircraft/components specifically. The following quote from one participant summarizes the responses to the open-ended questions: "Composite maintenance requires greater knowledge of material performance, care, and environmental control. Metal maintenance is so established that it is relatively easy to find expertise and to train others, and is far less nuanced".

Table 4
*Summary of Open-Ended Questions*

| **Question/Topic** | | **Themes** | **Frequency** |
|---|---|---|---|
| Preference: Working with metal- vs. composite-based aircraft/ components? | Preference for *composites* | Experience, training, & background | 2 |
| | | More detailed instructions | 1 |
| | Preference for *metal* | Simplicity/Ease | 5 |
| | | Less chemicals | 1 |
| | | Experience, training, confidence, & background | 8 |
| | | More satisfying to work with | 1 |
| | | Equipment availability and requirements | 2 |
| | No preference | | 6 |
| Working with metal-based aircraft/ components | Likes | Familiarity, simplicity, and ease of use | 11 |
| | | Damage resistance and identification | 5 |
| | | Availability of resources | 2 |
| | | Work/repair/material-related elements | 16 |
| | | Time (quicker to repair) | 2 |
| | Dislikes | Accessibility | 4 |
| | | Work/repair/material-related elements | 11 |
| | | Health and safety aspects | 5 |
| | | Complexity/difficulty in repairs | 2 |
| Working with composite-based aircraft /components | Likes | Work/repair-related elements | 5 |
| | | Manufacturing/repair processes | 6 |
| | | Material characteristics | 7 |
| | | Ease and flexibility | 5 |
| | | Challenge and learning | 3 |
| | Likes | Modern technology | 1 |
| | Dislikes | Maintenance/Repair processes | 9 |
| | | Specialty tools | 2 |

| **Question/Topic** | | **Themes** | **Frequency** |
|---|---|---|---|
| Working with composite-based aircraft /components (ctd') | | Reduced experience/knowledge | 3 |
| | | Airworthiness aspects/Repair validation | 2 |
| | | Messiness | 5 |
| | | Health aspects | 4 |
| Difference: Metal- vs. composite-based aircraft/ components maintenance | Composite maintenance has a higher standard of quality (more knowledge, care, and control) | | 2 |
| | Different forms of deterioration and damage | | 1 |
| | Different tooling and maintenance/repair techniques | | 6 |
| | Different training | | 1 |
| | Metal repairs are more permanent | | 1 |
| | Metal maintenance/repair requires more skill | | 1 |
| | No difference between the two types of maintenance | | 2 |
| Difficulties during maintenance | Metal-based aircraft | Accessibility | 10 |
| | | Fastener-related issues | 5 |
| | | Potential for dents and cracks | 4 |
| | | Metal characteristics (i.e. corrosion) | 5 |
| | | Time and precision requirements | 2 |
| | | Tooling issues | 3 |
| | | Repair requirements (i.e. positioning, sealing) | 2 |
| | | Size/weight of components/tooling | 1 |
| | | Knowledge, experience, confidence, & training | 4 |
| | | Unable to form complex repair shapes in field | 2 |
| | | Maintenance documentation | 1 |
| | Composite-based aircraft | Failed/Improper repairs | 5 |
| | | Need for specific products/materials/tools | 7 |
| | | Environmental control concerns | 5 |
| | | Damage creation and identification | 4 |
| | | Complex lay-ups | 3 |
| | | Hard to identify and correct mistakes | 2 |
| | | Work area set-up | 1 |
| | | Detail orientation | 1 |
| | | Knowledge, experience, confidence & training | 5 |
| | | Health hazards | 1 |
| | | Messiness | 2 |

**Knowledge Question Results**

The results from the knowledge questions are presented in Table 5 and Figures 6 and 7, highlighting the number and percentage of correct responses to the knowledge questions included in the questionnaire (refer to the *Appendix).* As indicated previously, 18 participants provided full responses to the knowledge questions.

Observing the histogram in Figure 6 as well as the results summarized in Table 5, it can be seen that precisely half of the questions were answered correctly by more than 50% of the participants, while the remaining half were answered correctly by less than 50% of the participants. However, no single question was answered correctly – or incorrectly – by all the participants. The mode – with six questions – is a score range from 10% to 20%. The category with the highest score range – 90% to 100% – includes four questions with a correct answer rate of 94.44% (17 correct answers from 18 respondents).

Table 5
*Summary of Knowledge Question Results*

| Question | Correct Answers | Percentage Correct | Question | Correct Answers | Percentage Correct |
|---|---|---|---|---|---|
| **1** | 16 | 18.89% | **15** | 7 | 18.89% |
| **2** | 16 | 18.89% | **16** | 11 | 18.89% |
| **3** | 9 | 50% | **17** | 11 | 50% |
| **4** | 4 | 22.22% | **18** | 14 | 22.22% |
| **5** | 2 | 11.11% | **19** | 11 | 11.11% |
| **6** | 11 | 61.11% | **20** | 15 | 61.11% |
| **7** | 6 | 33.33% | **21** | 11 | 33.33% |
| **8** | 13 | 72.22% | **22** | 12 | 72.22% |
| **9** | 12 | 66.67% | **23** | 14 | 66.67% |
| **10** | 17 | 94.44% | **24** | 16 | 94.44% |
| **11** | 17 | 94.44% | **25** | 16 | 94.44% |
| **12** | 15 | 83.33% | **26** | 13 | 83.33% |
| **13** | 13 | 72.22% | **27** | 15 | 72.22% |
| **14** | 5 | 27.78% | **28** | 14 | 27.78% |

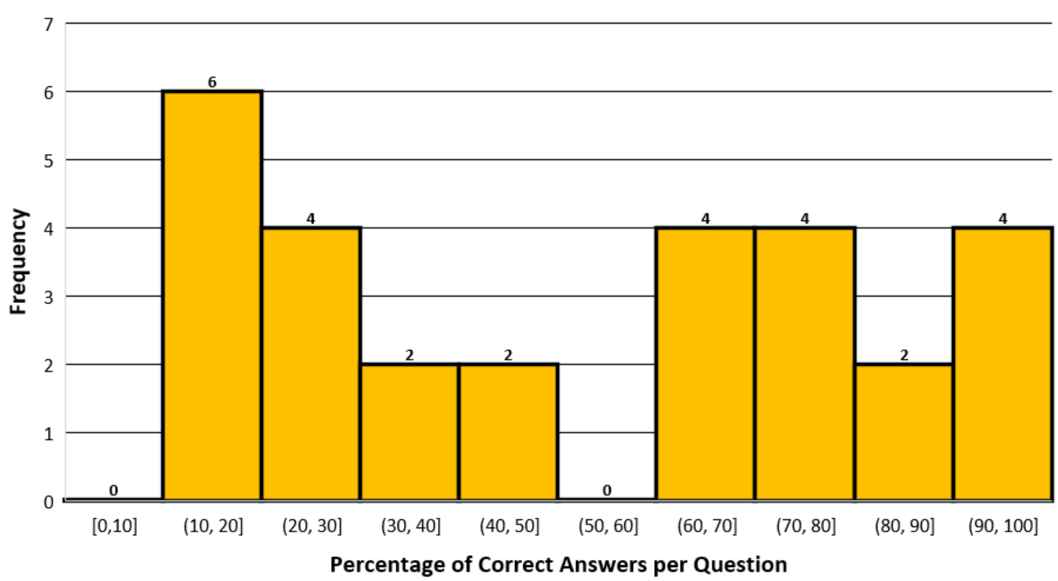


*Figure 6.* A&P knowledge questions results: Correct answers per question.

Figure 7 highlights the distribution of test scores obtained. The lowest score obtained was 42.86%, corresponding to 12 out of 28 questions being answered correctly. The highest score obtained was a 96.43%, corresponding to 27 out of 28 questions being answered correctly. The two most frequent scores were 64.29% (18 out of 28 questions correct) and 78.57% (22 out of 28 questions correct), each occurring three times. The average score equals 66.87%. Adhering to FAA passing scores, where a 70% or higher is required to obtain a passing grade (FAA, 2015) only eight participants (less than half) would have passed the test presented.

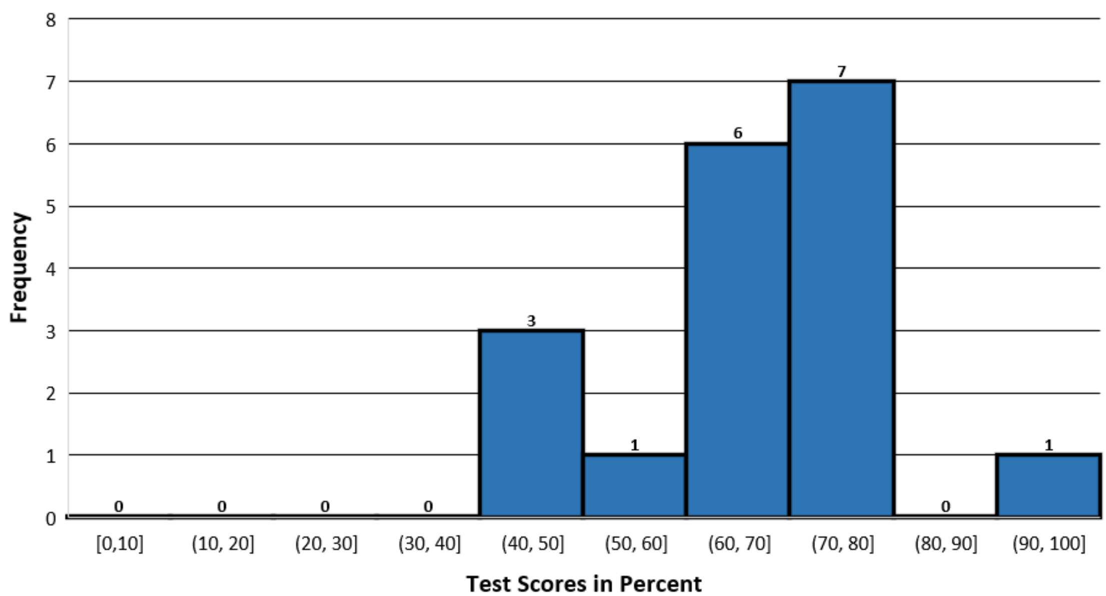


*Figure 7.* A&P knowledge questions results: Test scores.

## Discussion

With developments in technology, it is crucial to adapt and adjust the underlying systems and procedures that support the technological improvements throughout their lifecycle. In the case of composite materials and their application in the aviation industry, activities including maintenance and repair of airframes, structures, and components need to be adjusted to meet the needs of the changing aircraft composition. As a pivotal element of maintenance and repair activities, aircraft mechanics – and more specifically A&P certified technicians – require the appropriate training and resources to upkeep the composite aircraft fleet.

Considering education specifically, even though 41 participants (~80% of the respondents) have experience working with composite materials, only 25 participants (50% of the respondents) received formal education in the field. Further exacerbating these results, the respondents to the survey indicated that there is a gap between the training of composite- and metal-based maintenance/repair activities, where the training received better prepares individuals for a career maintaining a metal-based fleet rather than a composite-based fleet. When evaluating the FAA-mandated curriculum for technician education (Title 14 C.F.R. Part 147 Appendix C, 2017), the context for the discrepancies in training perception can be understood. The curriculum mandated and prescribed by the FAA prioritizes instruction on principles of wood/dope- and metal-based aircraft repair and maintenance, while topics related to composite materials are scarce in content with the individual AMT schools being responsible for further composite in-depth education (Title 14 C.F.R. Part 147 Appendix C, 2017). As introduced by Hobbs et al. (2009) and mirrored by the results of this study, the training requirements do not accurately represent or meet the needs and demands of the aviation industry. Examples of suggested additional composite-related areas of education include, but are not limited to, repair techniques for glass fiber, carbon fiber, Kevlar and boron reinforced composites, introduction to the tooling and equipment required for composite repair activities, as well as composite-specific nondestructive inspection coursework (FAA, 2015).

The repercussion of reduced, or limited, formalized training in the area of aircraft composite materials is further reflected in safety-critical aspects. First, participants indicated a comparatively higher understanding of, and confidence in, maintenance/repair-related aspects for metal-based aircraft than for composite-based aircraft. Second, relating to challenges felt during maintenance activities, a slight but notable skew towards composite maintenance/repairs being perceived as more challenging is observed, as indicated in literature by Kroes and Sterkenburg (2013). Moreover, in terms of error-recognizability, participants indicated that maintenance/repair errors on metal aircraft are easier to identify than on composite aircraft – a further threat to safety. These trends are also reflected in both, the open-ended perception/opinions questions posed as well as the composites knowledge questions. Training, knowledge, confidence, and experience – specifically, the lack thereof – was frequently quoted as a disadvantage, downside, and aspect adding difficulty to composite-based maintenance activities. As above-mentioned, less than half of the participants that provided full answers to the knowledge questions would have met the FAA standard 70% passing score on the knowledge questions – further indicating reduced knowledge in the topical area. These results must be further considered in relation to the demographic data described in Tables 1, 2, and 3. More than half of the respondents (specifically 80%) have experience working on composites, and 90% indicated completing their training at an AMT school. In theory, the education provided should have equipped technicians with the tools and knowledge to be knowledgeable in, and confident with, the materials encountered in the industry. Furthermore, AMTs working with composites are expected to be familiar with the basics thereof. However, the knowledge test results do not reflect these expectations. There are two potential explanations for the results obtained. First, the knowledge questions are not reflective of the composite-related knowledge taught at technical institutions or of the composite-related maintenance activities and repairs performed in the industry. Second, AMTs are not sufficiently familiar with the topic of composite-related maintenance and repair activities. Similarly, the fact that composite maintenance/repairs are perceived to be more challenging was identified by participants as well, even though the challenge was identified as a positive element. Lastly, difficulties identifying damage in composite structures and a more complex repair validation process were indicated by respondents as additional challenges in the open-ended questions, lining up with the results from the Likert-scale rating questions.

Lastly, in addition to downsides pertaining to elements such as composite knowledge, education, and challenges, the maintenance/repair industry appears to not be prepared to perform the required maintenance/repair activities on composite structures. As was indicated by Ostrom and Wilhelmsen (2008), Kroes and Sterkenburg (2013), and Werfelman (2007) composite maintenance and repair activities require a different set of tools, equipment, and resources.

However, per the responses obtained in the open-ended segment of the questionnaire, the required resources, such as specialized tools, are not always available, adding further challenges to the tasks at hand.

## Limitations and Future Work

The main limitation present in the conducted study is the low response rate, specifically to the open-ended questions section. Moreover, the categorization of the qualitative results – specifically the responses to the open-ended question – was based on the knowledge and experience of the authors, potentially adding subjectivity into the study. Therefore, the generalizability of the results obtained needs to be carefully considered. Similarly, even though – as provided by the demographics results – the respondents were from a variety of backgrounds, the sample is only representative of the aircraft maintenance technician workforce in the United States, adding further limitations to the generalizability.

It is suggested for future research to expand the study to aircraft maintenance technicians employed in different countries or that received AMT training and certification from aviation regulatory authorities outside of the United States. Subsequently, different training and certification regulations can be compared and evaluated in the area of composites education, while expanding the generalizability of the results. Moreover, future research efforts should focus on methods to address the shortcomings of composite-related AMT education highlighted in the study. Specifically, a cooperative research approach including representatives from AMT schools, regulatory agencies, as well as technicians performing composite repairs is recommended to meet the needs of the industry and bridge the gap identified by the results obtained in the presented study.

## Conclusion

The study conducted aimed to identify the opinions and perceptions of airframe/airframe & powerplant certified mechanics in the United States on the topic of composite-based aircraft maintenance and repair activities. As the use of composite materials increases in the aviation industry, the related maintenance activities need to be adjusted accordingly. However, antiquated mandated training together with more intrinsically complicated structures and a lack of resources, complicate the maintenance of composite-based aircraft structures.

The results from the performed study indicate that aircraft maintenance technicians' training in the area of composite aircraft maintenance/repair is not adjusted to the current needs of the industry. In turn, the understanding of composite damages and respective repair mechanisms is decreased (as shown through the opinion/perception and knowledge questions), increasing the challenges faced by mechanics and presenting potential safety hazards. Adding thereto is the inability of certain existing maintenance/repair facilities to sustain the maintenance/repair activities of composite-airframes due to a lack of specific resources. Therefore, for composite-based maintenance activities to reach the maturity level of metal-based maintenance activities, changes in the required training are necessary while the respective maintenance/repair facilities need to be overhauled to include the resources to sustain the maintenance/repair activities of composite structures.

## References


Airbus. (2019). *Facts & figures – A22- Family: Purpose built for efficiency.* Retrieved from https://www.airbus.com/aircraft/passenger-aircraft/a220-family.html

Aviation Supplies & Academics [ASA]. (2018). *Airframe test guide* (2019 ed.). Newcastle, WA, United States: Aviation Supplies & Academics [ASA], Inc.

Casner, S. M. (2008). General aviation pilots' attitudes toward advanced cockpit systems. *International Journal of Applied Aviation Studies, 8*(1), 88-112. Retrieved from https://www.researchgate.net/profile/Stephen-Casner/publication/255569860_General_Aviation_Pilots%27_Attitudes_Toward_Advanced_Cockpit_Systems/links/0f31753993ed05bc56000000/General-Aviation-Pilots-Attitudes-Toward-Advanced-Cockpit-Systems.pdf

Casner, S. M. (2009). Perceived vs. measured effects of advanced cockpit systems on pilot workload and error: Are pilots' beliefs misaligned with reality? *Applied Ergonomics, 40*(3), 448-456. doi: 10.1016/j.apergo.2008.10.002

Chaparro, A., & Groff, L. S. (2002). Human factors survey of aviation maintenance technical manuals. *16th Symposium on Human Factors in Aviation Maintenance.* Symposium conducted at the meeting of the Federal Aviation Administration [FAA], Transport Canada, and the Civil Aviation Authority [CAA], San Francisco, CA, United States, Retrieved from https://commons.erau.edu/publication/969

Chaparro, A., Groff, L. S., Chaparro, B. S., & Scarlett, D. (2002). *Survey of aviation technical manuals, phase 2 report: User evaluation of maintenance documents* (DOT/FAA/AR-02/34). United States Department of Transportation, Federal Aviation Administration. Retrieved from https://commons.erau.edu/publication/971

Chionis, D., & Karanikas, N. (2018). Differences in risk perception factors and behaviors amongst and within professionals and trainees in the aviation engineering domain. *Aerospace, 5*(62), 1-23. doi: 10.3390/aerospace5020062

Federal Aviation Administration [FAA]. (1994). *Acceptable methods, techniques, and practices – Aircraft inspection and repair* (Advisory Circular [AC] 43.13-1B). Retrieved from https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_43.13-1B_w-chg1.pdf

Federal Aviation Administration [FAA]. (2015). *Certification and operation of aviation maintenance technician schools* (Advisory Circular [AC] 147-3B). Retrieved from https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_147-3B.pdf

Federal Aviation Administration [FAA]. (2016). *Repairs and alterations to composite and bonded aircraft structure* (Advisory Circular [AC] 43.214A). Retrieved from https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_43-214A.pdf

Federal Aviation Administration [FAA]. (2018a). *Aviation maintenance technician handbook – Airframe* (FAA-H-8083-31A, Vol.1). Oklahoma City, OK, United States: United States Department of Transportation. Retrieved from https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/media/amt_airframe_hb_vol_1.pdf

Federal Aviation Administration [FAA]. (2018b). *Aviation maintenance technician handbook – General* (FAA-H-8083-30A). Oklahoma City, OK, United States: United States Department of Transportation. Retrieved from https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/media/amt_general_handbook.pdf

Federal Aviation Administration [FAA]. (2020, December 17). *Aircraft mechanic oral, practical, and written tests.* Retrieved from https://www.faa.gov/mechanics/become/test_requirements/

Georgiou, A. M. (2009). The effect of human factors in aviation maintenance safety. *2009 International Symposium on Aviation Psychology.* Symposium conducted at the meeting of Wright State University, Dayton, OH, United States. Retrieved from https://corescholar.libraries.wright.edu/isap_2009/76

Gopal, K. V. N. (2016). Product design for advanced composite materials in aerospace engineering. In S. Rana & R. Fangueiro (Eds.), *Advanced composite materials for aerospace engineering – Processing, properties, and applications* (pp. 413-428). Duxford, United Kingdom: Woodhead Publishing. doi: 10.1016/B978-0-08-100037-3.00014-6

Hackworth, C., Holcomb, K., Dennis, M., Goldman, S., Bates, C., Schroeder, D., & Johnson, W. (2007). *An international survey of maintenance human factors programs* (DOT/FAA/AM-7/25). United States Department of Transportation, Federal Aviation Administration. https://apps.dtic.mil/sti/pdfs/ADA475576.pdf

Hadcock, R. N. (1998). Aircraft applications. In S. T. Peters (Ed.), *Handbook of composites* (pp. 1022-1043). Boston, MA, United States: Springer. doi: 10.1007/978-1-4615-6389-1_49

Haresceugh, R. I., Bowen, D. H., Bonfield, W., Hodgson, A. A., Gent, A. N., Livingston, D. I., & Beardmore, P. (1994). Aircraft and aerospace applications of composites. In A. Kelly (Ed.), *Concise encyclopedia of composite materials* (pp. 1-31). Oxford, United Kingdom: Pergamon. doi: 10.1016/B978-0-08-042300-5.50012-1

Haritos, T., & Macchiarella, N. D. (2005). A mobile application of augmented reality for aerospace maintenance training. In *24th Digital Avionics Systems Conference (DASC) Proceedings* (Vol. 2, pp. 5.B.3-1- 5.B.3-9). 24th Digital Avionics Systems Conference. doi: https://doi.org/10.1109/DASC.2005.1563376

Hiken, A. (2017). The evolution of the composite fuselage: A manufacturing perspective. *SAE International Journal of Aerospace, 10*(2), 77-91. doi: 10.4271/2017-01-2154.

Hobbs, A., Brasil, C., & Kanki, B. (2009). The coming paradigm-shift in maintenance: From metals to composites. *2009 International Symposium on Aviation Psychology.* Symposium conducted at the meeting of Wright State University, Dayton, OH, United States. Retrieved from https://corescholar.libraries.wright.edu/isap_2009/77/

Kassapoglou, C. (2013). *Design and analysis of composite structures: With applications to aerospace structures* (2nd ed.). Chichester, United Kingdom: John Wiley & Sons, Ltd. doi: 10.1002/9781118536933

Kearns, S. K., & Schermer, J. A. (2017). Survey of attitudes toward aviation safety management system (SMS) training: Impact of gender and national culture. *Aviation Psychology and Applied Human Factors, 7*(1), 1-6. doi: 10.1027/2192-0923/a000109

Kim, C-Y., & Song, B-Y. (2015). A study on safety culture in aviation maintenance organization. *Advanced Science and Technology Letters*, *120,* 485-490. doi: 10.14257/ASTL.2015.120.95

Kroes, M. J., & Sterkenburg, R. (2013). *Aircraft maintenance & repair* (7th ed.). New York, NY, United States: McGraw-Hill Education.

Mattson, M., Petrin, D. A., & Young, J. P. (2001). Integrating safety in the aviation system: Interdepartmental training for pilots and maintenance technicians. *Journal of Air Transportation World Wide, 6*(1), 37-64. Retrieved from https://core.ac.uk/download/pdf/42698259.pdf#page=45

McClumpha, A. J., James, M., Green, R. G., & Belyavin, A. J. (1991). Pilots' attitudes to cockpit automation. *Proceedings of the Human Factors Society Annual Meeting, 35*(2), 107-111. doi: 10.1518%2F107118191786755698

McDonald, N., Corrigan, S., Daly, C., & Cromie, S. (2000). Safety management systems and safety culture in aircraft maintenance organisations. *Safety Science, 34*(1-3), 151-176. doi: 10.1016/S0925-7535(00)00011-4

Mitchell, K. R., Poudel, A., Li, S., Chu, T. P., & Mattingly, D. (2013). Nondestructive evaluation of composite repairs. *American Society for Nondestructive Testing Annual Conference.* Paper presented at the meeting of American Society of Nondestructive Testing, Las Vegas, NV, United States. Retrieved from https://www.researchgate.net/profile/Shanglei-Li-2/publication/262639579_Nondestructive_Evaluation_of_Composite_Repairs/links/555e157d08ae6f4dcc8dd0a0/Nondestructive-Evaluation-of-Composite-Repairs.pdf

Mosier, K., & Fischer, U. (2012). Impact of automation, task and context features on pilots' perception of human-automation interaction. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 56*(1), 70-74. doi: 10.1177%2F1071181312561035

Ostrom, L. T., & Wilhelmsen, C. A. (2008). Developing risk models for aviation maintenance and inspection. *The International Journal of Aviation Psychology, 18*(1), 30-42. doi: 10.1080/10508410701749407

Patankar, M. S. (2003). A study of safety culture and an aviation organization. *International Journal of Applied Aviation Studies, 3*(2), 243-258. Retrieved from https://www.academy.jccbi.gov/ama-800/Fall_2003.pdf#page=61

Sarter, N. B., & Woods, D. D. (1992). Pilot interaction with cockpit automation: Operational experiences with the flight management system. *The International Journal of Aviation Psychology, 2*(4), 303-321. doi: 10.1207/s15327108ijap0204_5

Sarter, N. B., & Woods, D. D. (1994). Pilot interaction with cockpit automation II: An experimental study of pilots' model and awareness of the flight management system. *The International Journal of Aviation Psychology, 4*(1), 1-28. doi: 10.1207/s15327108ijap0401_1

Sherman, P. J., Helmreich, R. L., & Merritt, A. C. (1997). National culture and flight deck automation: Results of a multination survey. *The International Journal of Aviation Psychology, 7*(4), 311-329. doi: 10.1207/s15327108ijap0704_4

Soutis, C. (2005). Introduction: Engineering requirements for aerospace composite materials. In P. E. Irving & C. Soutis (Eds.), *Polymer composites in the aerospace industry* (pp. 1-18). Duxford, United Kingdom: Woodhead Publishing. doi: 10.1016/B978-0-85709-523-7.12001-8

Sterkenburg, R., & Wang, P. H. (2013). *Structural composites: Advanced composites in aviation.* Weyers Cave, VA, United States: Avotek Information Resources.

Title 14 Code of Federal Regulations [C.F.R.] Part 147 Appendix C. (2017). *Airframe curriculum subjects.*

Wang, Y., & Leib, S. (2014). Understanding the perceptions of Chinese aviation maintenance technicians related to the implementation and use of 3D aircraft maintenance manuals. *The Collegiate Aviation Review International, 32*(2), 66-78. doi: 10.22488/okstate.18.100456

Werfelman, L. (2007). The composite evolution. *AeroSafety World, 2*(3), 17-21. Retrieved from https://flightsafety.org/asw/mar07/asw_mar07_p17-21.pdf

Weyer, J. (2016). Confidence in hybrid collaboration. An empirical investigation of pilots' attitudes towards advanced automated aircraft. *Safety Science, 89*,167-179. doi: 10.1016/j.ssci.2016.05.008

Zafiharimalala, H., Robin, D., & Tricot, A. (2014). Why aircraft maintenance technicians sometimes do not use their maintenance documents: Towards a new qualitative perspective. *The International Journal of Aviation Psychology, 24*(3), 190-209. doi: 10.1080/10508414.2014.918444

## Appendix
## DISTRIBUTED SURVEY

### Demographic Questions

1. Select the type of organization in which you work:

    ____ Airline Maintenance Department

    ____ Repair Station (Entire aircraft)

    ____ Repair Station (Components only)

    ____ Manufacturer

    ____ General Aviation/Business Aircraft Operations

    ____ Military/Government Fixed Base Operator

    ____ Other Military/Government

    ____ Maintenance School/Training Facility

    ___ Other (specify):

2. State your job title:

3. Years in current position:

4. Years with experience as an aviation maintenance technician:

5. Select the highest level of education completed:

    ____ High School graduate/GED

    ____ Trade School

    ____ Some college

    ____ Bachelor's degree

    ____ Graduate degree

    ____ Other (specify):

6. Indicate the type and years (in numerical form) of maintenance training you received. If you did not receive one of the listed types, insert "0" in the respective field:

   ____ Technical School - ____ years

   ____ Military - ____ years

   ____ Other - ____ years

7. FAA certification:

   ____ None

   ____ Yes

8. Licenses or certificates currently held (check all that apply):

   ____ Airframe

   ____ Powerplant

   ____ Inspection Authorization

   ____ Private

   ____ Commercial

   ____ FCC

   ____ Other(s) (specify):

   ____ None

Indicate your age:

   ____ Under 25

   ____ 26 – 35

   ____ 36 – 45

   ____ 46 – 55

   ____ 56 – 65

____ 65 +

9. List up to five of the aircraft you currently work on and indicate the length of time you have worked on them

| Aircraft | Specialty area<br>(i.e. avionics, airframe, engines, ALL, etc.) | Time worked on aircraft |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |

10. Have you received formal education in the area of aircraft composite materials?

____ No

____ No, but gained through experience

____ Yes – As part of/provided by (Select all that apply):

____ Certification training (i.e. Part 147 curriculum)

____ Current or previous employer

____ Independent/Voluntary additional training

____ Other (specify):

11. Do you have experience working with composite aircraft or materials?

____ No

____ Yes - ____ Years - Type of experience (Select all that apply):

____ Educational/Training context
____ Manufacturing
____ Maintenance, repairs, and overhauls
____ Other (specify):

**Opinions and Perceptions**

Ranking Statements

Rate the following statements using the given scale:

12. I find it easier to work with metal-based aircraft than with composite-based aircraft

| | | | | | |
|---|---|---|---|---|---|
| 1<br>Strongly<br>disagree | 2 | 3 | 4 | 5 | 6<br>Strongly<br>agree |

13. I fully understand the consequences of damages to aircraft metal structures

| | | | | | |
|---|---|---|---|---|---|
| 1<br>Strongly<br>disagree | 2 | 3 | 4 | 5 | 6<br>Strongly<br>agree |

14. I fully understand the consequences of damages to aircraft composite structures

| | | | | | |
|---|---|---|---|---|---|
| 1<br>Strongly<br>disagree | 2 | 3 | 4 | 5 | 6<br>Strongly<br>agree |

15. I feel challenged when working with/on metal-based aircraft

| | | | | | |
|---|---|---|---|---|---|
| 1<br>Strongly<br>disagree | 2 | 3 | 4 | 5 | 6<br>Strongly<br>agree |

16. I feel challenged when working with/on composite-based aircraft

| | | | | | |
|---|---|---|---|---|---|
| 1<br>Strongly<br>disagree | 2 | 3 | 4 | 5 | 6<br>Strongly<br>agree |

17. My training and education have adequately prepared me to work with metal aircraft structures

| | | | | | |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |

| | |
|---|---|
| Strongly disagree | Strongly agree |

18. My training and education have adequately prepared me to work with composite aircraft structures

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Strongly disagree | | | | | Strongly agree |

19. I require more time when designing and/or preparing a repair for a composite-based aircraft than for a metal-based aircraft

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Strongly disagree | | | | | Strongly agree |

20. I require assistance when designing and/or preparing a repair for a metal-based aircraft

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Never | | | | | Very frequently |

21. I require assistance when designing and/or preparing a repair for a composite-based aircraft

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Never | | | | | Very frequently |

22. I feel more confident when working on metal-based aircraft/components than on composite-based aircraft/components

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Strongly disagree | | | | | Strongly agree |

23. I feel confident when working on metal-based aircraft/components

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Strongly disagree | | | | | Strongly agree |

24. I feel confident when working on composite-based aircraft/components

| | | | | | |
|---|---|---|---|---|---|
| 1<br>Strongly disagree | 2 | 3 | 4 | 5 | 6<br>Strongly agree |

25. I feel more challenged when working on composite-based aircraft/components than on metal-based aircraft/components

| | | | | | |
|---|---|---|---|---|---|
| 1<br>Strongly disagree | 2 | 3 | 4 | 5 | 6<br>Strongly agree |

26. My training prepared me better to work on metal aircraft/components than on composite aircraft/components

| | | | | | |
|---|---|---|---|---|---|
| 1<br>Strongly disagree | 2 | 3 | 4 | 5 | 6<br>Strongly agree |

27. I feel overwhelmed when working with metal-based aircraft/components

| | | | | | |
|---|---|---|---|---|---|
| 1<br>Never | 2 | 3 | 4 | 5 | 6<br>Very frequently |

28. I feel overwhelmed when working with composite-based aircraft/components

| | | | | | |
|---|---|---|---|---|---|
| 1<br>Never | 2 | 3 | 4 | 5 | 6<br>Very frequently |

29. There are elements associated to the maintenance of metal-based aircraft/components that I do not fully understand

| | | | | | |
|---|---|---|---|---|---|
| 1<br>Strongly disagree | 2 | 3 | 4 | 5 | 6<br>Strongly agree |

30. There are elements associated to the maintenance of composite-based aircraft/components that I do not fully understand

| 1 Strongly disagree | 2 | 3 | 4 | 5 | 6 Strongly agree |
|---|---|---|---|---|---|

31. Working on metal-based aircraft/components is mentally demanding

| 1 Strongly disagree | 2 | 3 | 4 | 5 | 6 Strongly agree |
|---|---|---|---|---|---|

32. Working on composite-based aircraft/components is mentally demanding

| 1 Strongly disagree | 2 | 3 | 4 | 5 | 6 Strongly agree |
|---|---|---|---|---|---|

33. It is possible to quickly/easily recognize errors/improper repairs made when working on metal-based aircraft/component

| 1 Strongly disagree | 2 | 3 | 4 | 5 | 6 Strongly agree |
|---|---|---|---|---|---|

34. It is possible to quickly/easily recognize errors/improper repairs made when working on composite-based aircraft/components

| 1 Strongly disagree | 2 | 3 | 4 | 5 | 6 Strongly agree |
|---|---|---|---|---|---|

35. More errors are made when performing maintenance activities on metal-based aircraft/components than on composite-based aircraft/components

| 1 Strongly disagree | 2 | 3 | 4 | 5 | 6 Strongly agree |
|---|---|---|---|---|---|

36. More errors are made when performing maintenance activities on composite-based aircraft/components than on metal-based aircraft/components

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Strongly disagree | | | | | Strongly agree |

**<u>Open-Ended Questions</u>**

37. Do you prefer working with metal- or composite-based aircraft/components?

    a. Why?

38. What aspects of working with metal-based aircraft/components do you like?

39. What aspects of working with metal-based aircraft/components do you dislike?

40. What aspects of working with composite-based aircraft/components do you like?

41. What aspects of working with composite-based aircraft/components do you dislike?

42. In your opinion, how do maintenance activities of metal- and composite-based aircraft/components differ from each other?

43. List some difficulties you experience/have experienced when performing maintenance activities on metal-based aircraft

44. List some difficulties you experience/have experienced when performing maintenance activities on composite-based aircraft

45. List some factors that, in your opinion, complicate the maintenance of composite-based aircraft

46. List some factors that, in your opinion, complicate the maintenance of metal-based aircraft

## Knowledge Questions

1. Metal fasteners used with carbon/graphite composite structures *(ASA 8053)*
    a. May be constructed of any of the metals used in aircraft fasteners
    b. Must be constructed of materials such as titanium or corrosion resistant steel
    c. Must be constructed of high strength aluminum-lithium alloy

2. Sandwich panels made of metal honeycomb construction are used on modern aircraft because this type of construction *(ASA 8054)*
    a. Has a high strength to weight ratio
    b. May be repaired by gluing replacement skin to the inner core material with thermoplastic resin
    c. Is lighter than single sheet skin of the same strength and is more corrosion resistant

3. (1) When performing a ring (coin tap) test on composite structures, a change in sound may be due to damage or transition to a different internal structure
   (2) The extent of separation damage in composite structures in most accurately measured by a ring (coin tap) test *(ASA 8055)*
    a. Both No. 1 and No. 2 are true
    b. Only No. 1 is true
    c. Only No. 2 is true

4. Which of these methods may be used to inspect fiberglass/honeycomb structures for entrapped water? *(ASA 8056)*
   1. Acoustic emission monitoring
   2. X-Ray
   3. Backlighting
    a. 1 and 2
    b. 1 and 3
    c. 2 and 3

5. When repairing puncture-type damage of a metal faced laminated honeycomb panel, the edges of the doubler should be tapered to *(ASA 8058)*
    a. Two times the thickness of the metal
    b. 100 times the thickness of the metal
    c. Whatever is desired for a neat, clean appearance

6. One of the best ways to assure that a properly prepared batch of matrix resin has been achieved is to *(ASA 8059)*
    a. Perform a chemical composition analysis
    b. Have mixed enough for a test sample
    c. Test the viscosity of the resin immediately after mixing

7. How does acoustic emission testing detect defects in composite materials? *(ASA 8060)*
    a. By picking up the "noise" of any deterioration that may be present

   b. By analyzing the ultrasonic signals transmitted into the parts being inspected
   c. By creating sonogram pictures of the areas being inspected

8. What precaution, if any, should be taken to prevent corrosion inside a repaired metal honeycomb structure? *(ASA 8061)*
   a. Prime the repair with a corrosion inhibitor and seal from the atmosphere
   b. Paint the outside area with several coats of exterior paint
   c. None. Honeycomb is usually made from a manmade or fibrous material which is not susceptible to corrosion

9. One method of inspecting a laminated fiberglass structure that has been subjected to damage is to *(ASA 8062)*
   a. Strip the damaged area of all paint and shine a strong light through the structure
   b. Use dye-penetrant inspection procedures, exposing the entire damaged area to the penetrant solution
   c. Use an eddy current probe on both sides of the damaged area

10. When inspecting a composite panel using the ring test/tapping method, a dull thud may indicate *(ASA 8063)*
   a. Less than full strength curing of the matrix
   b. Separation of the laminates
   c. An area of too much matrix between fiber layers

11. The length of time that a catalyzed resin will remain in a workable state is called the *(ASA 8065)*
   a. Pot life
   b. Shelf life
   c. Service life

12. A category of plastic material that is capable of softening or flowing when reheated is described as *(ASA 8066)*
   a. Thermoplastic
   b. Thermocure
   c. Thermoset

13. Superficial scars, scratches, surface abrasions, or rain erosion on fiberglass laminates can generally be repaired by applying *(ASA 8069)*
   a. A piece of resin-impregnated glass fabric facing
   b. One or more coats of suitable resin (room-temperature catalyzed) to the surface
   c. A sheet of polyethylene over the abraded surface and one or more coats of resin cured with infrared heat lamps

14. Composite fabric material is considered to be the strongest in what direction? *(ASA 8072)*
   a. Fill
   b. Warp
   c. Bias

15. What reference tool is used to determine how the fiber is to be oriented for a particular ply of fabric? *(ASA 8073)*
    a. Fill clock (or compass)
    b. Bias clock (or compass)
    c. Warp clock (or compass)

16. The strength and stiffness of a properly constructed composite buildup depends primarily on *(ASA 8074)*
    a. A 60% matrix to 40% fiber ratio
    b. The orientation of the plies to the load direction
    c. The ability of the fibers to transfer stress to the matrix

17. Which fiber to resin (percent) ratio for advanced composite wet lay-ups is generally considered the best for strength? *(ASA 8075)*
    a. 40:60
    b. 50:50
    c. 60:40

18. What is the material layer used within the vacuum bag pressure system to absorb excess resin during curing called? *(ASA 8076)*
    a. Bleeder
    b. Breather
    c. Release

19. Proper pre-preg composite lay-up curing is generally accomplished by *(ASA 8077)*
    1. Applying external heat
    2. Room temperature exposure
    3. Adding a catalyst or curing agent to the resin
    4. Applying pressure
    a. 2 and 3
    b. 1 and 4
    c. 1, 3, and 4

20. When repairing large, flat surfaces with polyester resins, warping of the surface is likely to occur. One method of reducing the amount of warpage is to *(ASA 8078)*
    a. Add an extra amount of catalyst to the resin
    b. Use short strips of fiberglass in the bonded repair
    c. Use less catalyst than normal so the repair will be more flexible

21. When making repairs to fiberglass, cleaning of the area to be repaired is essential for a good bond. The final cleaning should be made using *(ASA 8079)*
    a. MEK (methyl ethyl ketone)
    b. Soap, water, and scrub brush
    c. A thixotropic agent

22. Fiberglass laminate damage not exceeding the first layer or ply can be repaired by *(ASA 8081)*
    a. Filling with a putty consisting of a compatible resin and clean, short glass fibers
    b. Sanding the damaged area until aerodynamic smoothness is obtained
    c. Trimming the rough edges and sealing with paint

23. Fiberglass damage that extends completely through a laminated sandwich structure *(ASA 8082)*
    a. May be repaired
    b. Must be filled with resin to eliminate dangerous stress concentrations
    c. May be filled with putty which is compatible with resin
24. Fiberglass laminate damage that extends completely through one facing and into the core *(ASA 8083)*
    a. Cannot be repaired
    b. Requires the replacement of the damaged core and facing
    c. Can be repaired by using a typical metal facing patch

25. Repairing advanced composites using materials and techniques traditionally used for fiberglass repairs is likely to result in *(ASA 8084)*
    a. Restored strength and flexibility
    b. Improved wear resistance to the structure
    c. An unairworthy repair

26. The preferred way to make permanent repairs on composites is by *(ASA 8085)*
    a. Bonding on metal or cured composite patches
    b. Riveting on metal or cured composite patches
    c. Laminating on new repair plies

27. The part of a replacement honeycomb core that must line up with the adjacent original is the *(ASA 8087)*
    a. Cell side
    b. Ribbon direction
    c. Cell edge

28. Which of the following are generally characteristics of carbon/graphite fiber composites? *(ASA 8089)*
    1. Flexibility
    2. Stiffness
    3. High compressive strength
    4. Corrosive effect in contact with aluminum
    5. Ability to conduct electricity
        a. 1 and 3
        b. 2, 3, and 4
        c. 1, 3, and 5