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A Comparative Analysis of Maintenance Safety Practices in University and Non-University Part 141 Flight Programs

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Abstract - *This literature review compares Federal Aviation Administration (FAA) Part 141 collegiate and non-collegiate aviation institutions, with a particular focus on maintenance-related safety. A quantitative analysis of instructional flight accidents from 1988 to 2025, using the National Transportation Safety Board [1] Case Analysis and Reporting Online (CAROL) database, applied a comparison of means test to see if there are significant differences in the causal category of maintenance, providing insight into how maintenance standards influence safety outcomes. Beyond statistical findings, the review highlights the role of organizational culture, noting that collegiate Part 141 programs often emphasize Safety Management Systems (SMS) that foster accountability, reporting, and continuous improvement, thereby shaping both flight operations and maintenance practices. Maintenance Resource Management (MRM) is also examined in parallel to Crew Resource Management (CRM), emphasizing communication, coordination, and error mitigation strategies. These include structured shift handoffs and tool control systems, with evidence suggesting that collegiate programs implement these practices more rigorously than non-collegiate counterparts. Finally, the review synthesizes research on human factors affecting compliance, particularly conditions known as the "Dirty Dozen." Collectively, these findings illustrate the interconnected roles of accident analysis, organizational culture, resource management, and human factors in shaping maintenance safety within both collegiate and non-collegiate Part 141 training environments.*

Key Words*: *FAA Part 141, Safety Management Systems, Maintenance Resource Management

1. INTRODUCTION

Aviation safety is a central concern in Federal Aviation Administration (FAA) Part 141 programs, with high maintenance safety standards presupposing the operation of flight schools [2]. This review analyzes instructional flight accidents from 1988 to 2025 using the National Transportation Safety Board's (NTSB) Case Analysis and Reporting Online query system (CAROL) database to compare the causal factor of maintenance across different types of institutions [3]. Beyond accident data, the discussion highlights organizational culture, examining how collegiate programs incorporate Safety Management Systems (SMS), Maintenance Resource Management (MRM), and Crew Resource Management (CRM). Human factors such as the "Dirty Dozen," are also considered to show how compliance challenges intersect with training standards. Together, these themes frame how safety outcomes are shaped across different Part 141 environments.

2. METHODOLOGY

2.1 Quantitative Analysis

Accident frequency data was examined to determine if the number of maintenance-caused accidents from Aviation Accreditation Board International [4] accredited schools is less than non-AABI accredited schools operating under FAR Part 141 at a significant level. Using the NTSB's CAROL system, filters were used to source only relevant data. The CAROL system returned 8,792 accident cases through the use of the parameters shown in Table 1

Table -1: CAROL Query Search Parameters Used to Filter Dataset

Parameter #	Field	Condition	Value
1	Event Date	Is on or after	01/01/1988
2	Event Date	Is on or before	10/19/2025
3	Investigation Mode	Is	Aviation
4	Country	Is	United States
5	Purpose of Flight	Is	Instructional

The January 1st, 1988 (Parameter 1) was chosen as the start year since that is when the AABI organization was created [5]. Given the large number of accidents returned from both AABI and non-AABI accredited Part 141 operators, accidents occurring prior to 1988 were unnecessary to include in the later calculation of accident rates. The latter date of October 19th, 2025 (Parameter 2) was chosen as the quantitative analysis was conducted the parameters of this timeframe, to allow for the most current information to be analyzed. As Part 141 only applies to flight schools operating under the authority of the FAA in the United States [6], it was included as a location constraint (Parameter 4). The "Instructional" query value (Parameter 5) was included to obtain only accidents that were operating within the parameters of Part 141, as without it, many irrelevant events were included.

With the events gathered, a list of AABI accredited flight schools and a list of FAR Part 141 flight schools were added from the AABI and FAA websites. A binary coding system was used to translate the qualitative data in the NTSB reports into analyzable quantitative data by indexing the name of the operator and comparing it to the listed accident one. Indicator columns were added to the dataset, returning "1" if the aircraft operator or primary cause matched a specific column's condition, and "0" if not. In this manner, it was found that there were 140 accidents involving aircraft operated by AABI schools and 635 accidents involving Part 141 operators that were not accredited by AABI. Of the AABI accidents, only one was found to have "maintenance" listed as the primary cause, whereas 22 of the 635 Part 141 accidents were found to have been primarily caused by maintenance practices.

With the dataset cleaned and the specific accident data gathered, a comparison of means hypothesis test could now be developed to determine if the accident rates of the two groups were statistically significantly different. An underlying assumption of this method is that the data follows a Gaussian distribution, also known as the Normal distribution. As the data post-cleaned was binomially distributed, it was necessary to approximate it to the Normal distribution after checking to ensure that this was appropriate [7]. To do this, the number of AABI or Part 141 accidents were made to function as the trials in the sample of interest, (n=775 AABI or Part 141-operated aircraft accidents) and the relative frequency of AABI accidents from all CAROL-sourced accidents as the probability of success. As the product of these two variables was greater than 5, the check was passed and the maintenance accident rates of the two groups was calculated. A null hypothesis was created and stated the accident rate of Part 141 operators was less than or equal to the rate of AABI operators, and the alternative hypothesis claimed that AABI operators had a lower rate. Comparing the standardized Z-score of the 95% confidence interval to that of the alternative hypothesis, evidence was found suggesting that the accident rate of AABI operators was significantly lower than that of Part 141 operators.

3. LITERATURE REVIEW

At the outset of this research, a core investigative focus was established through the guiding question: What differences, if any, exist between Part 141 flight programs and AABI-accredited flight schools? After identifying a statistically significant difference in maintenance-related accident rates between the two groups, the research team initiated a comprehensive review of the relevant literature.

The review was organized around four subtopics: (a) structural differences between university-affiliated and non-university Part 141 flight schools; (b) maintenance resource management; (c) safety culture and maintenance culture within flight training organizations; and (d) human factors influencing maintenance compliance. Academic and governmental sources were obtained from databases such as ScienceDirect, Purdue Libraries, and MDPI, using search terms including, but not limited to, human factors, SMS culture, Dirty Dozen, and maintenance compliance. The collected literature was synthesized, reviewed in consultation with a faculty advisor, and used to inform the final conclusions and results of the study.

3.1 Differences between University and Non-University Part 141. Flight Programs

Flight training in the United States is primarily conducted "through an FAA-certificated (approved) pilot school or through other training providers" [8]. In comparison to other training providers, "pilot schools are regulated in accordance with Title 14 of the Code of Federal Regulations in part 141" [9]. When explaining the other regulatory framework and how it differs, the FAA states that "unlike pilot training conducted under 14 CFR part 61 [training], part 141 schools are required to use a structured training program and syllabus" [10]. Both 61 and 141 pathways lead to the same pilot certificates and ratings as applicable to what the pilot wishes to obtain; however, they differ in structure, regulatory oversight, and minimum training requirements. In addition to syllabi, Part 141 FAA-certificated pilot schools include stage checks at specific points in training, chief instructor oversight of all training, and reduced minimum flight hour requirements to qualify for examinations [11].

Under Part 141 regulations, university-affiliated programs operate distinctly from independent flight schools. University 141 flight programs are embedded within accredited institutions of higher education and learning, combining FAA-approved flight and ground training with academic coursework, official degree requirements to graduate, and the eligibility for the Restricted Airline Transport Pilot (R-ATP) certificate [12]. Independent Part 141 schools, while still subject to some oversight due to being given the label and privileges of being a Part 141, focus on flight training without the academic infrastructure. More FAA-approved Part 141 schools appear each year, but as can be seen in FAA legal documentation regarding reduced aeronautical experience requirements for an Airline

Transport Pilot (ATP) certificate, the FAA provides institutional authority to a small number of 141 flight schools to certify its graduates for permission to apply for an R-ATP upon program completion [13].

These differences between university-based Part 141 programs and non-university-based Part 141 schools have different implications for training capacity, program structure, regulatory and accreditation framework, curriculum, and examining authority. This section of the literature review will examine such differences in detail, providing regulatory documentation, scholarly analyses, and industry studies to demonstrate how the differences shape both pilot training and outcomes and the much larger aviation workforce pipeline.

3.2 Training Capacity

Training capacity is an important part of being a Part 141 school. Research conducted by Thomas and Toole [14] investigated what the training capacity was for flight schools that responded to a survey request. The question that drove this research was "where will these future pilots come from? The United States is the world leader in training pilots but does the country have the capacity to fulfill pilot demand?" [15]. The foundation of their research was FAA data on the number of licenses issued in the year 2018. A question investigated by the authors concerning the numbers proposed was how many of all pilots who received licenses went to a regional or large Part 121 air carrier, such as United Express or United Airlines, in the future. The goal of the research was "to quantify the training capacity at FAA-approved Part 141 Pilot Schools associated with university degree programs." [16]. To simplify the study, "small schools" were defined as having 250 students or less, with "large schools" having 250 or more active students.

Having considered the number of active students enrolled, the next variable was determining what, if anything, restricted the output of graduates. The results showed that "eighty-two percent of schools indicated a lack of CFIs limited their ability to produce pilots. Forty-two percent of respondents suggested that a lack of aircraft adversely impacts their school's ability to train pilots" (Thomas & Toole, 2020, p. 4). Other variables listed but were specific to each individual school included "limitations of local air traffic control, low [student] enrollment, cost of training, lack of Airframe and Powerplant (A&P) mechanics, and ramp space" [17].

Another issue was the time it took for a commercial applicant to receive a Certificated Flight Instructor (CFI) license. Survey responses indicated that a single applicant could take over six months prior to being ready to take and complete the CFI check ride. Given this study was conducted in 2020, the results may not be as accurate since the FAA changed the standards for the CFI check ride from Pilot Testing Standards (PTS) to Airman Certification Standards (ACS) [18]. This change decreased the length and difficulty of the exam, making the certificate more obtainable. However, something more akin to today is "flight training delays due to a lack of FAA Designated Pilot Examiners (DPE's) to conduct check rides" [19]. Having an applicant wait two to three months to be on a DPE's check ride schedule will impact their graduation timeline. The most impactful result, however, was an apparent lack of CFIs. It was discussed that while finding a CFI was difficult, retaining them long enough to see any significant impact to student graduation rates was an additional challenge. It was not discussed whether CFI employees being appropriately rated or not (an instrument or multi-instructor add-ons) impacted the ability to train students.

3.3 Part 141 University Comparative Program Structure

The foundational content for a school wanting to be a Part 141 operator is the Training Course Outline (TCO). One study observes that "Training Course Outlines are governed by 14 Code of Federal Regulations (14 CFR) Part 141" [20]. Without a TCO, a Part 141 operation simply cannot take place at a flight school. Every individual school that desires to function as a Part 141 or needs to maintain their status "must have a TCO approved by the Federal Aviation Administration" before any Part 141 operations can be conducted. As far as the TCOs themselves are concerned, "written TCO guidelines for each Part 141 flight school must meet or exceed the minimum requirements set forth in 14 CFR Part 141" [21]. Only university institutions were used in comparison, not Part 141 schools that were not universities.

Many different universities all over the U.S. offer training at the Part 141 level and have an approved TCO. However, the content, deadlines for stage checks, and end of course check rides may vary. The results from this research showed that although the course may have been at the same level, such as Private Pilot Airplane, the average flight time requirements by students to complete the course varied by the university. Some universities had higher average flight times than others for a student, but it was the same grade of certificate awarded upon completion. Out of all rules governing TCOs, the most important concept is that "fundamental core training guidelines are mandated through the FAA and must be included within the TCO in order for the flight school to conduct operations under 14 CFR Part 141" [22]. If the school does not meet such requirements and implement them, they will not be allowed to operate at the Part 141 level, regardless of what else is or is not put in their TCO.

3.4 Regulatory and Accreditation Framework

For FAA Part 141 flight schools, the difference between an accredited university and a flight school is subtle. The former may bestow an educational degree, among other things, in addition to flight certificates and ratings, as per its charter or legislation. These slight differences are what empower a university to grant an applicant the ability to apply for a

Restricted Airline Transport Pilot (RATP) certificate upon completion of the curriculum and coursework.

As stated in the Code of Federal Regulations, a person with a commercial pilot certificate and an instrument rating may apply for a R-ATP at 1,000 hours if the applicant completed the required ground and flight training "as part of an approved part 141 curriculum at the institution of higher education" [23]. The key phrase being "the institution of higher education". There are many flight schools that are Part 141, however, not all of them are institutions of higher education. To be considered an institution of higher education, regardless of the subject, the school must be accredited by the right agency. Specific to aviation, the highest level of accreditation in the United States is known as the Aviation Accreditation Board International (AABI). AABI takes FAA Part 141 standards a step further and requires even heightened safety standards and procedures to grant accreditation to a university. As said by the AABI, "aviation programs must satisfy the expectations of a wide range of quality criteria" [24]. This statement alone is what sets a Part 141 university apart from a Part 141 program that is not a university. In comparison to a regular Part 141, a Part 141 that is an institution of higher education meet expectations in terms of "strategic management of resources, interactions of faculty and students in the educational process and achievement of degree learning goals" [25]. Accreditation is what allows a pilot to apply for an R-ATP and receive an hour reduction, not just the fact that a school has a TCO and is approved to operate as a Part 141.

To further show the significance of the accreditation, an example of what happens when a university receives initial or reaffirmed accreditation can be seen in a letter from the Southern Association of Colleges and Schools Commission on Colleges (SACSCOC) to Embry- Riddle Aeronautical University (ERAU). As said by SACSCOC, "the Board of Trustees reaffirmed accreditation. No additional report was requested. Your institution's next reaffirmation will take place in 2032 unless notified" [26]. In addition to the written reaffirmation, it was also requested that ERAU provide a "Quality Enhancement Plan" [27]. Thus, in addition to the FAA, ERAU, like many universities, must satisfy more stringent requirements for accreditation. An example of this does not exist for a regular 141 that is solely a flight school. With the accreditation example provided, it must be known that the FAA does have an official published list for institutions authorized to certify graduate pilots for ATP certificates with less hourly requirements [28]. As said in the list, "graduates may be eligible to apply for a restricted privileges airline transport pilot (R-ATP)" [29]. This list comprises colleges and various universities offering associate and bachelor's degrees in flight training. Further rules for specific hour reductions can also be found in the official document.

3.5 Part 141 University Curriculum

In addition to accreditation, another set of requirements which sets a Part 141 institution separate from a regular Part 141 is the curriculum. A regular Part 141 only requires content specific to the certificate or rating sought; however, a Part 141 university requires the pilot to go through a variety of coursework to receive an associate or bachelor's degree. Information can be found on the official website of Embry-Riddle Aeronautical University for their Bachelor of Science in Aeronautical Science. According to ERAU, "the Bachelor of Science in Aeronautical Science degree program blends pilot training with academic study" [30]. Thus, graduates finish with all certificates and ratings and a four-year degree at the same time. Similar information can also be found at another prestigious aviation institution—Purdue University. Purdue, the university "offers a bachelor's degree in professional flight that provides you with a comprehensive perspective of the aviation industry" [31]. It is highlighted that the student will take courses with a focus on "leadership, teamwork, decision-making, communication, resilience, and technical excellence encompassing the many facets of the aviation ecosystem" [32]. Such coursework is essential to be a successful pilot and critical to requirements when earning an aviation degree.

3.6 Self-Examining Authority

Although there are major items that make a university Part 141 flight program different than a Part 141 flight program that is not of higher education, there are Part 141 requirements which apply to both. The most prevalent of these being self-examining authority. Self-examining authority is when the flight program can perform in-house flight examinations instead of requiring an FAA Designated Pilot Examiner to conduct a check ride. As stated in the Code of Federal Regulations for section 141.63, a Part 141 certificated flight school must meet a set of requirements to unlock examining authority [33]. Such requirements include how long the flight school has had the Part 141 authorizations for each specific course, and in addition, "must have trained at least 10 students in the training course for which examining authority is sought [34]. In addition to the course completion, the pass rate is at least ninety percent [35]. Not only must a Part 141 university and Part 141 flight school both follow the same procedures to apply for self-examining authority, but both types of Part 141 program must still follow the same procedures and standards to keep said privilege. This may not seem significant; however, having self-examining authority solves a major issue for large flight schools—check ride delays. Mosey and Rosser observe that "many Part 141 flight schools experience challenges in attaining examining authority" [36]. Prior research mentioned in this study suggested that schools that used an FAA DPE would experience check ride delays due to scheduling and the availability of the examiner [37]. To provide a number for how significant DPE activity is in issuing licenses, it was found in this study that "there were

851 DPEs approved to conduct practical tests in 2021, which accounted for 87% of total practical tests administered with the remaining 13% of practical tests" conducted by a Part 141 with the self-examining authority [38]. Flight programs with self-examining authority have an advantage over other programs as they do not have to wait to schedule with a DPE but, rather schedule the exam with the authorized pilot working for the program. This may be a chief pilot or whomever is authorized by the FAA to conduct the examination at the flight school. Depending on the geographic location, an applicant may have to wait several months to get a check ride on schedule with a DPE, even if they are ready. Thus, self-examination authority is a key factor in a program's success due to the ability to schedule students for tests sooner, rather than having students ready to wait for the test and potentially lose proficiency.

4. QUANTITATIVE ANALYSIS OF ACCIDENT DATA AND HYPOTHESYS TESTING

As described in the methodology, a quantitative analysis of Part 141 and AABI operated aircraft accident data was performed at the beginning of this study. The hypothesis testing process shown below and previously detailed was performed to better lend credence to the merit of this research. Demonstrating a significant difference in the safety outcomes of the two classes of operators can further emphasize the need for high standards of instruction and especially maintenance, as shown in the calculations below. The calculated numbers shown in the subsequent steps were rounded to the fourth decimal place, but their unrounded forms were used in the actual calculations.

Determine the probability of an AABI operated aircraft being involved in an accident:

$$P(AABI) = \frac{\#\ of\ AABI\ Accidents}{Total\ Instructional\ Accidents}$$

$$P\ (AABI) = \frac{140}{8792} = 0.0159 = p$$

Explanation of Terms

$P(AABI)$ – Probability of an accident involving an AABI operator occurring. Calculated from the relative frequency of AABI accidents compared to all other instructional accidents over the time of the study (1988-2025)

$p = P(AABI)$ in subsequent steps

Check to see if sample is sufficiently large enough to be approximated to a Gaussian distribution:

If $n * p \geq 5\ \&\ n * (1-p) \geq 5$ then approximation is appropriate.

$$775 * 0.0159 = 12.3225\ \&\ 775 * (1 - 0.0159) = 762.6775$$

Both are greater than 5 so approximation to a Gaussian distribution is appropriate.

Explanation of Terms

n = Total # of AABI and Non-AABI accidents in the sample.

$n = 775\ accidents.$

Establish hypotheses for testing and choose significance level:

$$H_o{:}\ \mu_A \geq \mu_{141}\ \&\ H_A{:}\ \mu_A < \mu_{141}$$

$$\sigma = \sqrt{n * p * (1-p)} = \sqrt{775 * 0.0159 * (1 - 0.0159)} = 0.4426$$

Significance level of 95%, α = 0.05, 95% p-value = 1.96

Explanation of Terms

$\mu_A = \bar{x}$ – Average rate of AABI accidents due to maintenance from 1988 to 2025

μ_{141} – Average rate of Part 141 accidents due to maintenance

σ – Population standard deviation

Calculate accident rates:

$$\bar{x} = \frac{\#\ of\ AABI\ maintenance\ accidents}{Total\ AABI\ accidents} = \frac{1}{140} = 0.0071$$

$$\mu_{141} = \frac{\#\ of\ Part\ 141\ maintenance\ accidents}{Total\ 141\ maintenance\ accidents} = \frac{22}{635} = 0.0347$$

Calculate alternate hypothesis Z score:

$$Z = \frac{\bar{x} - \mu_{141}}{\frac{\sigma}{\sqrt{n}}} = \frac{0.0071 - 0.035}{\frac{0.4426}{\sqrt{775}}} = (-1.755)$$

Explanation of Terms

Z = Test statistic to be compared to 95% critical value

Determine p-value and compare to alpha p-value (obtained from standardized Z-score table):

$(-1.755) \rightarrow 0.04006$. The Z test statistic translates to a standardized Z-score of 0.04006.

$0.04006 < 0.05$. The test Z-score is compared to the alpha value.

Since the p-value of the test statistic is less than that of the 95% confidence interval, the null hypothesis that the maintenance-caused accident rate of AABI schools is greater than or equal to that of the Part 141 maintenance-caused accident rate is rejected. The research team concludes that there is a statistically significant difference in the maintenance accident rates of the two groups. Specifically, the maintenance accident rates of AABI operators is significantly lower than those of Part 141 flight schools. This indicates that the maintenance practices of AABI operators have a lower chance of resulting in accidents during the operation of an aircraft.

5. HUMAN FACTORS AFFECTING COMPLIANCE

5.1 Dirty Dozen Framework and Its Role

The FAA emphasizes that the greatest influence on future aviation safety will come not from new technology, but from improving human performance, noting that 75-80% of all aviation accidents are caused by human error, and that approximately 12% of those human-error accidents originate in maintenance activities [39]. Because maintenance errors typically remain latent, the FAA [40] highlights the importance of understanding human-factor conditions that shape maintenance performance. According to the FAA [41], a high number of maintenance-related events in the late 1980s and early 1990s led Transport Canada to identify twelve common human factors that degrade people's performance. Later, these twelve factors became known as the "Dirty Dozen" [42]. "Dirty Dozen" items were adopted as a straightforward and practical framework for understanding and discussing human error in maintenance [43]. Transport Canada's report [44] highlights the impact of these conditions through multiple case studies. The FAA Aircraft Maintenance Technician (AMT) Handbook suggests that it is critical to understand the Dirty Dozen, identify its symptoms, and know how to escape failures [45]. For these reasons, the Dirty Dozen provides an appropriate and industry-validated foundation for analyzing the human-factor precursors of maintenance compliance and non-compliance.

5.1.1 Fatigue

Hobbs and Williamson [46] identified fatigue as "mental or physical fatigue, generally related to a lack of adequate nighttime sleep and/or night shift work" (Table 2). It is one of the most frequently reported contributors to procedural non-compliance among maintenance technicians. A study by Santos and Melicio shows that 95.9 percent of surveyed aviation maintenance personnel admitted they had made or knew someone who had made maintenance errors due to stress or fatigue [47]. In an Australian Transport Safety Bureau study of airline and non-airline maintenance organizations, pressure, fatigue, and coordination problems were among the factors contributing to maintenance occurrences [48]. Another quantitative analysis by Hobbs and Williamson [49] showed that memory lapses were 2.4 times more likely when fatigue was present, confirming a connection between inadequate rest and omission-type errors. Although fatigue is associated with one's mental or physical condition, it is intensified by shift scheduling, like working night shifts, and environmental aspects which further may have an influence [50]; [51]. Together, these demonstrate that fatigue consistently ranks among the leading contributors to maintenance errors across diverse operational environments.

5.1.2 Time pressure

Research shows that aviation maintenance and inspection tasks are often carried out in work environments where technicians experience time pressure, limited feedback, and challenging environmental conditions. All of which can increase the likelihood of errors during complex tasks [52]. An international online survey indicates that maintenance personnel may face many task demands at the same time, which can lead to the loss of important information or the unintentional omission of maintenance steps. When several tasks must be completed within a limited time, time pressure increases the chances of errors [53]. Hobbs and Tada [54] highlight that mechanics were asked to hurry a task or complete another urgent one, rush an inspection, or omit to read the documentation before starting a job at least once a month, highlighting how frequently maintenance tasks are performed under time constraints (Table 3). Earlier FAA research suggested when inspectors were given more time to complete inspection, more faults were detected, showing that time can directly affect inspection performance [55]. Recent FAA reports highlighted that attention and memory-related errors are most associated with time pressure, along with fatigue and environmental factors [56]. Together, these findings show that time pressure increases the risk of incomplete tasks and procedural non-compliance.

5.1.3 Stress

Stress consistently shows that psychological and work-related stressors can negatively affect performance in aviation and other technical environments [57]; [58]. This study indicates that stress is caused not only by personal circumstances but also by work-related conditions, including work-life balance problems, difficult work schedules [59]; [60]; [61]. Another study shows that stress, fatigue, and adverse work environments have significant associations with human error, and together with repetition can explain nearly half of the error rates [62]. Together, these findings indicate that stress is affected by both organizational and personal factors, and can cause lower performance and mistakes, which can reduce maintenance compliance [63]; [64]; [65].

5.1.4 Communication

Communication is a key human factor that can either support or undermine compliance. Newman and Scott [66] found that a "lack of communication" was the most frequently described Dirty Dozen category, accounting for about 20% of 746 coded contributory-factor descriptions. Also, Newman and Scott [67] showed that when technicians experienced miscommunication in a team, it led to unclear instructions or incorrect performance (Table 5). Communication between pilots and mechanics is another weak point, Munro et al. [68] found that short turn-around times and crew schedules are often limited face-to-face meetings. Also, the same study suggests that both pilots and mechanics felt dissatisfied with the way discrepancies were communicated, because they lacked accuracy and detailed information [69]. Irwin et al. [70] suggest that communication is one of the main non-technical skills and concluded that this skill is important for safe and effective work performance. Together, findings show that communication problems can result in incorrect or repeated work, making maintenance compliance harder to achieve.

5.1.5 Complacency

Complacency can influence maintenance performance when technicians perform familiar or repetitive tasks. Research identifies complacency as one of the conditions that can reduce technicians' ability to work safely [71]. In a study of maintenance errors at major U.S. air carriers, Harper and Bliss [72] found that complacency and lack of attention were most frequent among considered human factors which cause maintenance errors (Table 3). This study also suggested that repetitive and simple tasks were a contributor to complacency and to the failure to follow instructions [73]. Requests for quick maintenance also contributed to improper service without utilizing required instructions, increasing risk of errors [74]. As a whole, complacency is best understood as a reduction in vigilance and active checking during familiar tasks, and that this reduction increases the likelihood of errors affecting maintenance compliance even among experienced technicians [75].

5.1.6 Lack of Knowledge

Lack of knowledge is another human factor that can influence maintenance compliance, particularly when technicians are faced with unfamiliar procedures, systems, or requirements. A study notes that mechanics can be affected by poorly designed testing, poor instructions and training, and incomplete or incorrect documentation, and that these conditions can combine with other factors to contribute to accidents and incidents [76]. Hobbs and Williamson [77] found that knowledge-based performance was less reliable than rule-based and skill-based performances and concluded that safety interventions should focus on rules and knowledge. This highlights how insufficient technical or procedural knowledge can lead technicians to choose the wrong procedure, misunderstand requirements, or omit required steps.

5.1.7 Distractions

Within the Dirty Dozen framework, distraction is treated as one of the twelve most common preconditions for maintenance error, referring to interruptions that pull one's attention away from primary task and increase the risk of incorrect steps [78]. Mellema et al., [79] found that distraction was rated significantly higher in reactive Maintenance Event Reports (MERs) than in proactive Maintenance Operations Safety Assessment (MOSA) reports, indicating that attentional lapses are more associated with actual maintenance deviations and errors (Table 2). Authors' analysis confirms that distraction is a meaningful human-factor contributor specifically in cases where maintenance tasks did not comply with required procedures.

5.1.8 Lack of Teamwork

Teamwork is essential in aviation maintenance because most tasks require inspectors, technicians, and supervisors to coordinate their work. Samad et al. [80] found that respondents overall agreed that teamwork is a critical part, explaining that supervisors in most cases help their subordinates, and that deadlines make teamwork even more important. Gramopadhye and Drury [81] emphasize the importance of teamwork between inspectors and maintenance personnel as both need to continually cooperate to ensure the work meets organizational standards. Mellema et al. [82] identified Lack of Teamwork factor presents equally in both incident reports (MER) and safety observations (MOSA), showing that teamwork issue increases the likelihood of maintenance deviations and non-compliance occurrences.

5.1.9 Lack of Resources

In aircraft maintenance, lack of resources refers to not having the necessary tools, parts, time, or information needed to complete a task. The FAA's AMT Handbook emphasizes that missing or inadequate resources can interrupt maintenance work and notes that any shortage of essential tools or parts can lead to unsafe conditions and even contribute to accidents [83]. Rashid et al. [84] reported that resources were among potential error triggers, highlighting that inadequate resource provision can directly increase the risk of maintenance errors. Effective utilization of maintenance resources is critical for decreasing aircraft downtime and low aircraft grounded time, reinforcing that resource availability is a key factor [85].

5.1.10 Lack of Assertiveness

In aviation maintenance, assertiveness is understood as the ability of technicians to express their concerns, opinions, and needs rather than remaining silent when something seems wrong [86]. Lam and Chan [87] found that 61.3% of respondents had observed unsafe maintenance practices that they did not report, and technicians referred to organizational culture and management style as key reasons for not speaking up. Under and Gerede [88] noted that employees often remain silent and avoid voluntary reporting, emphasizing that organizations should prominently indicate the importance of reporting.

5.1.11 Lack of Awareness

Within the Dirty Dozen framework, lack of awareness is identified as a failure to understand a situation, and its possible results, which may negatively affect maintenance performance [89]. The Endsley and Robertson [90] study shows that complexity of aircraft systems and multiple technicians working on the same aircraft make it easy for information and tasks to "fall through the cracks". It may create an opportunity that tasks are not completed properly, important information is not communicated, and problems go undetected. This connection is supported by Endsley's [90] Situational Awareness (SA) error taxonomy. SA failures are classified into three different levels. According to Endsley [91], "Level 1 - Failure to correctly perceive the situation; Level 2 - Failure to comprehend the situation; and Level 3 - Failure to project the situation into the future". Oliveira et al. [92] report that common task-level SA failures may lead to complacency. Together, these findings demonstrate that situational awareness increases the risk of procedural non-compliance.

5.1.12 Norms

Within the Dirty Dozen framework, norms refer to the unwritten rules, informal practices that can deviate from approved procedures and become accepted through peer pressure and habit [93]. Hobbs [94] notes that group norms are unspoken rules learned from coworkers, and some of them can become unsafe. In a study of 308 aircraft maintenance workers, Fogarty and Shaw [95] reported that intentions, group norms, and individuals' attitudes accounted for 50% of technicians' self-reported violations. Key et al. [96] describe work norms in aviation maintenance as unspoken rules that can evolve into non-approved procedures, a form of normalization of deviance. Vaughan [97] initially introduced the concept of normalization of deviance when organizations continued to operate despite repeated evidence that something was wrong. Together, these findings show that when unsafe practices become normal within a team, formal procedures can be ignored, even when technicians know the correct requirements.

6. MAINTENANCE PRACTICES AND THEIR IMPACT ON SAFETY

Maintenance practices in aviation can consist of inspection checklists, clear procedures for the periodic downing of aircraft for inspections or discrepancies, and a robust system of double-checking and communication [98]. The inclusion of these elements in a Part 141 program, while part of the minimum requirements for operation according to the FAA, can be elevated to greater levels. Agencies such as the Aviation Accreditation Board International (AABI) certifies that programs meet higher standards for their operations along with the core tenants imposed by the FAA. The scrutiny of the FAA and other agencies, alongside clear communication, provide the basis of accident and hazard mitigation strategies for maintenance resource management (MRM).

6.1 Maintenance Standards for 14 CFR Part 141 Flight Schools

According to Advisory Circular (AC) 141-1B, sections 7.4, 7.5, and 7.6, 14 CFR Part 141 schools are required to meet the regulatory requirements necessary to maintain their aircraft and have additional accountability by the FAA to do so. As per section 7.6, a 14 CFR Part 141 flight school "must have access to equipment and facilities sufficient to maintain its aircraft" [99]. Additionally, sections 7.4 and 7.5 state that maintenance programs and facilities "must be inspected during the initial certification process and during spot checks on a random basis for Quality Control (QC), as well as routine checks for proper documentation and compliance of maintenance records, ADs, and life-limited parts requirements" [100].

6.2 Maintenance Standards for Part 141 AABI Accredited Flight Schools

For those 14 CFR Part 141 university flight schools that are also certified by the AABI, the requirements for these programs are heightened even further. According to AABI, "[approved programs] MUST provide an adequate number of safe, reliable, and appropriately equipped and maintained aircraft to satisfy program goals" [101]. This means that an AABI certified university flight school's maintenance department must uphold this requirement on top of all other necessary FAA maintenance regulations. The institution also "MUST have and use a verifiable formal aviation safety program that demonstrates the involvement of students, faculty, and staff. The institution's aviation safety program MUST incorporate SMS key components appropriate to its national regulators" [102]. On this basis, 14 CFR Part 141 flight schools, and especially those that are AABI certified, distinguish themselves by the additional requirements and accountability placed on them to keep their aircraft safe and reliable. These requirements are important in increasing the standard of these institutions and could help explain the results found in the previous quantitative analysis section of this literature review. More research is needed to understand the exact methods these institutions use to comply with these regulations, however, Maintenance Resource Management may help explain how they do so.

6.3 Maintenance Resource Management (MRM) and Communication in Maintenance

James C. Taylor [103] defines Maintenance Resource Management as "the collaboration and communication for maintenance safety". This is comparable to the pilot equivalent "Crew Resource Management" (CRM), as they are both primarily concerned with communication methods. In fact, many tenants of MRM were derived from the already existing values of CRM during its development [104]. Pilots, however, experience "active" failures while maintenance technicians experience "latent" failures [105]. Jim Reason, the inventor of the "Swiss Cheese" analogy for accident causation, distinguished the two types of failure in how easily these failure's consequences are observed over time [106]. He defined "active errors" resulting in immediate consequences, and "latent errors" impacting operations over longer periods. He also emphasized the importance of organizations recognizing the risks posed by latent consequences in their mitigation strategies [107]. When a maintenance technician's work results in latent consequences, it can be days, months, or years for it to be noticed [108]. Due to the quiescent nature of their mistakes, technicians may be less considerate of their actions since the effects of their errors do not directly impact them, nor will their repercussions be felt immediately.

This reinforces the need for the adoption of a significant pillar of successful Maintenance Resource Management, which is proper communication. According to James C. Taylor [109], MRM is "about open communication and trust" and the FAA [110] states that "MRM requires and supports a very high level of communication among all the people involved in maintaining aircraft" and "is at the heart of any good MRM program". Communication between maintenance technicians on work performed, jobs still in progress during shift changes, and mistakes made is a key component of preventing maintenance-related accidents. In addition, how maintenance technicians log work performed during inspections and from discrepancies reported by pilots is crucial to establishing a safe and trustworthy maintenance operation [111].

MRM-style communication in a maintenance operation can take place in both verbal and non-verbal ways, both by synchronous and asynchronous means [112]. Synchronous may take the form of talking directly to a manager or coworker, while asynchronously may be leaving notes for the next technician [113] Communication during shift changes is especially necessary, as the FAA [114] in their Human Factors Guide to Maintenance and Inspection describes shift-to-shift changes as an "error prone activity [whose success] almost entirely depends on good communication". Leaving a note on job cards or having thorough shift-to-shift meetings between two or more parties is a way of implementing effective MRM [115].

Logging work performed by keeping thorough maintenance records is another form of MRM communication. Records of work performed are essential to a safe operation, especially during a shift change [116]. In this manner, if erroneous work is performed and consequences arise from issues due to poor maintenance, the cause can be traced to the person and procedures responsible. Pertaining to record-keeping, Part 141 schools are held to a high standard with AC 141-1B stating that they must "have procedures in place to ascertain that all discrepancies are corrected and recorded in the aircraft records" [117]. This is specifically called out in the FAA's Procedural Compliance in Aviation Maintenance [118] document as well, that instances of Failure to Follow Procedures (FFP) can be reduced by utilizing a "description of completed tasks, but also a list of potential problems and concerns so that employees can be on the lookout".

Another application of MRM designed to mitigate human error is the utilization of inspection checklists [119]. A thorough, expert-created checklist in the aircraft being inspected can ensure that no component gets overlooked. Checklists for both routine and in-depth inspections can decrease the likelihood of these types of instances from occurring. In addition, checklists for more complex and complicated projects that utilize the FAA approved steps in the maintenance manual, as well as additional feedback from previous work orders, can lead to efficient, safe, and reliable maintenance [120].

A heightened awareness of human error in maintenance may lead a maintenance program, especially those abiding by FAA 14 CFR Part 141 and the strict additional AABI accreditation requirements to adopt many modes of MRM in their operations. Manoj S. Patankar in Chapter 13 of the third edition of Crew Resource Management by Kanki et al. titled "Maintenance Resource Management for Technical Operations" links Maintenance Resource Management adoption and AABI accreditation. He discusses the implication that MRM research efforts led to the adoption of many safety policies currently in place, including the AABI requirement for a "robust safety management program in all AABI-accredited colleges/universities" [121]. Thus, any AABI-accredited institution may adopt aspects of MRM as core values of their maintenance operations.

7. SAFETY CULTURE AT COLLEGIATE PART 141 PROGRAMS AND MAINTENANCE PRACTICES

Culture can impact the overall mission and goals of an organization. In the context of aviation, safety culture in particular plays a crucial role in preventing accidents, mitigating risks, and advancing initiatives to keep a company safe and compliant with regulatory policies. Numerous collegiate Part 141 aviation programs [122]; [123]; [124]; [125]; [126] have implemented Safety Management Systems (SMS) into their operations, creating a culture of safety and continuous improvement. This culture encourages personnel in the program, such as maintenance teams, to choose safety first. A culture of safety can help to encourage thorough maintenance of airplanes to prevent damage in the future.

7.1 Part 141 Collegiate Programs Safety Initiatives

Collegiate aviation programs operate under 14 Code of Federal Regulations (14 CFR) Part 141, a set of regulations that outline strict guidelines for programs to follow to train and certify pilots. Increased structure amongst these programs contribute to the introduction of SMS's at universities to ensure a high level of safety in their operations [127]; [128]; [129]; [130]; [131]. SMS consists of safety policy, safety risk management, safety assurance, and safety promotion. Each chapter helps create an environment where participants can operate and work safely in an industry that is inherently risky. SMS can also improve morale and performance amongst the members of an institution, further enhancing the overall culture students will operate in [132].

7.2 Collegiate Aviation Program Safety Culture

The safety culture of a program is critical for shaping the operations, decisions, and mindsets of personnel. Cox and Flin [133] gives the best insight into what safety culture signifies, "… the product of individual and group values, attitudes, perceptions, competencies, and patterns of behavior that determine the commitment to, and the style and proficiency of, an organization's health and safety management". To cultivate a culture focused on safety, all individuals must be involved in initiatives to not only change their mindsets, but their habits and ways they operate or work. A culture that is resilient and focused on improvements is only as good as the "policies, procedures and principles within an organization" [134]. For an effective culture, all participants must be educated on these principles, so they know how to best enact them in their daily work.

The personnel of a collegiate aviation program must be invested through participation, collaboration, and recognition to create a safety-oriented operation. To lay the foundations necessary for safe learning and work for these individuals, an emphasis on a positive safety culture and an understanding of safety initiatives and procedures begins on day one [135]. Aspiring for excellence and an emphasis on safety from day one, collegiate aviation programs can cultivate an environment conducive to learning and safety. The influence of the actions and perceptions of those around one may help to motivate students and personnel to act in compliance with safety procedures while participating in SMS programs [136]. Positive actions in the interest of safety by fellow students or employees will be recognized by their peers, providing rewards and reinforcement of safe behaviors while discouraging unsafe ones [137]. Participants can help to strengthen the actions of themselves and others towards a positive safety culture to maintain the identity of their program they are members of. However, holding each other accountable starts with the management of an institution.

A safety culture requires a top-down approach. In 2018, Robertson [138] measured the perceptions of collegiate aviators regarding the various major aspects of their programs and overall safety culture with the Collegiate Aviation Program Safety Culture Survey (CAPSCS). The results indicated that there was a positive relationship between involvement by management, such as the Chief Flight Instructor, and successful implementation of an SMS in collegiate aviation programs [139]. From this study, it can be demonstrated that a commitment to safety from a top-level employee will have a trickle-down effect to the students and personnel of an organization to act in the best interests of safety.

Management not only affects the perceptions of safety, but it can also influence the actions of a program's members. One prevalent area can be seen in the effects of submitting safety reports, which is a keystone to identifying weaknesses and vulnerabilities of safety management while giving an organization the ability to proactively learn and adapt before accidents occur [140]. A similar study to Robertson's [141], conducted by Adjekum et al. [142] also using the CAPSCS found respondents felt their programs' safety reporting would benefit greatly from assurance from leadership that their voices were heard. To ensure leadership remains involved and supportive of safety initiatives, numerous collegiate programs have safety commitments or policies. Signed by the Accountable Executive, collegiate aviation programs can maintain a proactive safety culture affirmed by their leaders that gives its members the ability to thrive [143]; [144].

7.3 Aircraft Maintenance Culture

Part 141 Collegiate Aviation Programs have foundational pillars of safety embedded to create an operation that is safe and proactive for both students and personnel. Aviation maintenance technicians are immersed in the same safety culture that pilots are, which positively affects their work. To adhere to the highest standards, AMTs must be supported by the organization for which they work, and that starts with safety practices throughout. In a study of a flight training facility in New Zealand, aircraft maintenance engineers felt that if their employers considered implementing positive safety practices, safety education, and safety procedures, they can increase the safety of their workplace [145]. Safety policy, promotion, and education are all aspects of collegiate Part 141 programs in which AMTs participate in. Furthermore, aspects of collegiate aviation programs, such as the encouragement of safety reporting from peers or leadership, can help to better prepare AMTs for their work. A supportive organization can lay the foundations for continuous improvement and quality work to be accomplished. Human errors can be learned from, reliability can be improved, and an overall greater state of readiness can be achieved [146]. Lessons learned from real-world experiences can benefit the entire organization as improved procedures and practices can be implemented to ensure the highest quality work is completed. However, when external pressures from different sources, which are highly discouraged in SMSs, are introduced, shortcomings can occur in the work being completed. With the backing of an institution for safe practices, AMTs are not pressured to hastily complete work. However, when AMTs are not supported, they may feel compelled to process aircraft expeditiously without a keen eye for thoroughness. Safety norms ingrained during their training may disappear as the organization's pressure catches up to them. A throughput-centered environment may outweigh the legal, moral, and ethical responsibilities of AMTs to conduct work at the highest quality [147]. Even if management expects AMTs to explicitly follow the regulations, the overall goals of a company may cloud those expectations [148]. Perceptions of what they feel is valued by leadership in the organization may force an AMT to cut corners and increase the pressure for work to be completed. AMTs are already subjected to plenty of physiological issues without the external pressures of an organization or leadership, "Aviation maintenance personnel, subjected to fatigue, stress or pressure, presents hazards procedures which might lead to a potential risk" [149]. By subjecting them to a stressful workplace culture, they may begin to physically break down, compromising work that is already being completed without any thoroughness or support from their employer.

The prevention of violations of regulations may stem from the environment in which work is accomplished. A strong error management climate, in which error knowledge is shared and issues addressed, can help to eliminate violations, which usually indicate organizational issues [150]. The proper work environment can help to discourage violations of practices that could compromise safety. A strong error management climate similarly describes how Part 141 collegiate aviation programs operate.

Aviation maintenance technicians and their work greatly benefit from participating in a collegiate Part 141 program. AMTs, and maintenance facilities in general, are not required to have an SMS, per Code of Federal Regulations 14, Part 5 [151]. However, the benefits of working inside a program with safety initiatives and support from leadership can positively influence their work. An organization with a proactive safety culture proves it can mature and become prepared for the next event that may occur in all facets of their operation. AMTs tend to develop a more professional outlook on safety when they are in a professional environment [152]. With all employees focusing on a common goal of safety, hazards and dangerous practices can be identified and stopped before incidents occur. When operating in a collegiate Part 141 program with a positive safety culture, supportive leadership, and proactiveness from all parties, AMTs can work in an environment conducive for quality and safe craftmanship for training aircraft to keep the operation safe.

8. CONCLUSIONS

This literature review concludes that maintenance safety within FAA Part 141 flight training programs is strongly influenced by organizational culture and the allocation of safety-related resources. Collegiate Part 141 institutions demonstrate more consistent and formalized implementation of Safety Management Systems (SMS), Maintenance Resource Management (MRM), and Crew Resource Management (CRM), which collectively enhance oversight, accountability, and systematic error mitigation. Within this category, programs holding additional accreditation from the Aviation Accreditation Board International (AABI) represent a further tier of safety maturity, reflecting more rigorous standards and structured safety governance. Conversely, non-collegiate Part 141 programs tend to exhibit less comprehensive adoption of these frameworks, indicating comparatively weaker institutional emphasis on standardized safety practices. These disparities suggest that variations in organizational culture, regulatory engagement, and compliance rigor play a decisive role in shaping maintenance-related safety outcomes across Part 141 training environments.

9. RECOMMENDATIONS ON FUTURE RESEARCH

The quantitative analysis conducted as a precursor to this study shows a statistically significant difference in the maintenance-caused accident rates of AABI and Part 141 collegiate flight programs, with AABI programs boasting the lower one. As part of future research efforts, further analyses could be conducted on crash rates influenced by other prominent accident causes such as pilot error. While not the focus of this study, the literature examined indicates that the educational aspects of AABI, Part 141, and non-Part 141 flight school programs may be more impactful to the safe operation of an aircraft than previously thought.

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