

Issues That Precipitate Errors in Airline Maintenance

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Human factors in Federal Aviation Regulation Part 121 aircraft maintenance operations as they relate to technician performance are important factors that play a significant role in the public safety of air transportation systems. This paper reports on the results of an analysis of one thousand National Aeronautical and Space Administration "Aviation Safety Reporting System" incident reports for aircraft maintenance related issues. This paper identifies aircraft types, including systems, and compares events that precipitate human errors. Five high profile performance based error categories were selected for this paper. They include: technician qualifications, inspections, parts installation, contract maintenance, and log book documentation issues.

INTRODUCTION

Sociotechnical systems research investigates factors affecting risk, decision making, and performance in high reliability, safety critical organizations. Factor management in high reliability organizations calls for investigating the interactions among diverse working groups to assess the impact of tools, organizational, and individual behaviors toward maintaining safety and reducing risk. High-reliability industries must therefore study their system vulnerabilities to diminish the chance of an incident or accident with a catastrophic outcome. Tracing sources of risk and threats to safety in an organization can prove a daunting task, however, in recent years voluntary, confidential, non-punitive reporting systems have been developed that allow individuals to report events, or near miss incidents, in an attempt to trace vulnerabilities. These anonymous reporting systems aim to identify deficiencies in safety and provide data to propose specific improvements across-the-board (Reynard, 1992). Incidents, or deviations from safe operations, are precursors to accidents that exist in orders of magnitude significantly higher than accidents (Heinrich, 1959). These events indicate the presence of problems in systems that have the potential to result in an accident if they are not monitored and controlled. Incident reporting in aviation, such as the National Aeronautical and Space Administration's (NASA) Aviation Safety Reporting System (ASRS), has provided opportunity to proactively analyze and remedy unsafe conditions before they result in accidents (Chappell, 1997; Connell, 1999; Fitts & Jones, 1947; von Thaden & Wiegmann, 2001). Anonymous incident reporting programs are fundamental features of safety management systems as they often provide information about latent organizational safety hazards that may not emerge in the process of an accident investigation (Connell, 1999).

Technological advancements in aircraft design, materials, and manufacturing processes have significantly reduced the rate of aircraft mechanical incidents and accidents. As technologies improve, mechanical failures have decreased; however, those attributed to human performance have not experienced that same rate of change (Hart, 2004; Wiegmann & Shappell, 2003). This paper identifies and compares types of aircraft, mechanical systems, and/or operational failures that

initiate maintenance errors in this sector. The research approach used to investigate both mechanical as well as human performance issues centered on analyzing 1000 National Aeronautical and Space Administration's (NASA) ASRS reports covering CFR Part 121 commercial air carrier maintenance operations.

This paper presents findings focused on five high profiles of maintenance (operational) performance based human error categories. These categories include: technician qualifications, inspections, parts installation, contract maintenance issues, and log book documentation.

METHOD

ASRS documents provide factual information regarding an event such as day, time, place, aircraft type, aircraft system, component, maintenance factors, and technician assessments. Narratives are written by the event reporters and edited by researchers at NASA for clarity and anonymity purposes. Events are classified for factors such as reporter, hazards, anomalies, primary problems, and deficiencies. It is important to note that ASRS data has limitations. The major limitation is that as a voluntary, confidential, and non-punitive reporting system, ASRS was established to gather safety data from industry practitioners, who can report without fear of retribution or certificate action (FAA, 1997; Connell, 1999). It is neither comprehensive nor complete (Reynard, Billings, Cheaney, & Hardy, 1986) and may be seen as biased since the system offers immunity and it is not a random population sample. The database is not inclusive of all airline incidents, given that each airline may have its own incident reporting system (e.g., ASAP), which is proprietary (FAA, 2002). However, experiential data (e.g., total hours logged, years of experience, etc.) suggest that these reports provide real world insight into operational and airworthiness issues, and as such serve as a rich source of information. The ASRS data provides a window of opportunity for researchers to examine industry occurrences to suggest recommendations for practice.

For this study, we initially downloaded Part 121 air carrier maintenance reports from the ASRS online database for the period covering July 1997 through August 2006, resulting in 3534 maintenance events. A sub set of 1000 reports (August

2004 – July 2006) were extracted for this study. Of the 1000 reports, 320 were deemed not applicable (i.e., human errors were not identified in these reports.). Thus 680 reports were analyzed for maintenance issues and human error outcomes. Examination of the reports revealed the reporter’s job classification identified as: aircraft maintenance technicians (AMTs, 65%), flight crews (19%), lead AMTs (5%), inspectors (5%), maintenance control personnel (3%), foremen (<1%), and other (combined) maintenance and flight personnel (2%).

To analyze the dataset, two independent raters, a subject domain expert with forty years experience in airline maintenance (major legacy carrier), corporate, general aviation, and university teaching/research), and a researcher in aviation human factors, classified and coded mechanical issues, unsafe acts, and contributing factors which may have led to unsafe acts (Reason, 1990; Wiegmann & Shappell, 2003). Unsafe acts consist of skill-based errors (e.g., slips, lapses, and perceptual errors), decision making errors, routine violations (e.g., workarounds, cutting corners), exceptional errors (e.g., blatant violations) and unknown (Reason, 1990). When the research pair could not come to agreement regarding the factors surrounding the case, a third human factors researcher and aviation expert would code the case to break the tie. The raters achieved an acceptable level of reliability: 0.4-0.6 in Cohen’s kappa and 0.8-0.9 in the proportion of agreement.

RESULTS

Overall outcomes. In the 680 ASRS reports coded, five areas emerged as problematic (see Figure 1): Inspection (12%¹), Wrong part installation (10%), Logbook recording (8%), Contractor (7%), and Qualifications (5%).

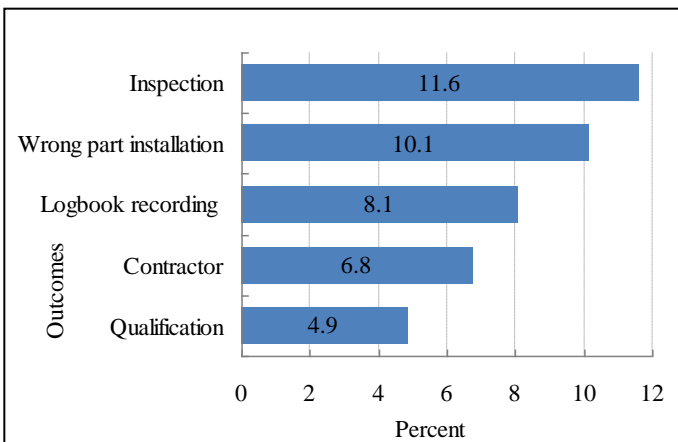


Figure 1. Major event issues from 680 ASRS reports.

The largest profile event concerns improper inspection, identified in approximately 12% of the reports. Examples of inspection issues include: missing or non-completion of required inspection items (RII), incomplete or misunderstood inspection processes, and procedures (i.e., a required inspection item mandated by the Federal Regulation). The prominent systems identified in improper inspection issues are: flight controls (22%), power plants (15%), and landing gear

¹ Items rounded for ease of reporting/reading.

(15%). Most disconcerting is non-completion of required RII inspections, representing inspections that verify whether critical maintenance tasks were appropriately conducted or were omitted on aircraft that were returned to service. Of the aircraft models in this category, Boeing B-737’s were identified in 27 cases (34%), followed by MD80/DC9/DC10 models in 15 cases (19%), and the Embraer Regional Jet (ERJ) series in 10 cases (13%).

Wrong parts installations (10%) pinpoint part number identification errors regardless of standardized procedures for part number applicability and aircraft specificity prior to installation. The prominent systems identified in this category consist of: flightdeck (e.g., navigation, communication instruments, and auto flight, 25%), equipment and furnishings (16%), power plants (13%), and landing gear (13%). Of the aircraft models in this category, Boeing B737’s were identified in 28 cases (41%), followed by Boeing B- 767’s in 9 (13%) and MD80/DC9/DC10 models in 7 cases (10%).

Eight percent of ASRS reports analyzed in this study included logbook-recording problems such as failure to make a logbook/document entry, incomplete log book entries, recording wrong information, Minimum Equipment List (MEL) variance issues, and changing logbook entries without appropriate authorization. Title 14 Code of Federal regulations Part 43.9 states, “Each person who performs maintenance, preventative maintenance, rebuild, or alters an aircraft, airframe, power plant, propeller, appliance or component shall make an entry in the maintenance record of that equipment” (FAA 2007). Since multiple individuals in airline maintenance operations interact with varying aircraft types at multiple sites, log book documentation and record keeping is paramount for operational verification and safety.

Contractor maintenance was identified in approximately 7% of the reports. For example, AMTs and flight crew’s found multiple discrepancies in aircraft, arguing that given tasks were not conducted correctly in outsourced companies. Two prominent systems identified in this category were power plants (22%), followed by equipment and furnishings (11%). Of the aircraft models recorded in this category, Boeing B737’s were identified in 12 cases (26%), followed by the ERJ series in 7 cases (16%), and MD80/DC9/DC10 models in 6 cases (13%).

Technician qualifications represented 5% of the analyzed reports. Qualification report examples consist of; returning aircraft to service in a CAT II operation² with expired sign-off certification, maintenance apprentices working on aircraft components without FAA certification or training, tasks assigned to certified (non-trained and/or inexperienced) technicians who have not been approved for the specific task. The five prominent systems identified in this category were: power plants in 10 cases (30%), followed by landing gear in 5 cases (15%), flightdeck systems in 4 cases (12%), fuel systems in 3 cases (9%), and doors/windows in 3 cases (9%). Of the models recorded in this category, Boeing 737’s were identified

² Cat II aircraft are certified for precision instrument approach and landing with a decision height lower than 61m above the touchdown zone elevation, but not lower than 30m, and includes a runway visual range not less than 350m.

in 12 cases (36%), followed by MD80/DC9/DC10 in 15% of the cases, Boeing B-757's in 6 cases (18%), and the ERJ series in 3 cases (9%).

Overall contributing factors. In the 680 ASRS incidents, 13 areas emerged as problematic contributing factors (see Figure 2). Lack of vigilance (421 cases, 62%) was the most predominant contributing factor observed, followed by time pressure (146 cases, 22%), document and procedure (130 cases, 19%), and coordination (115 cases, 17%).

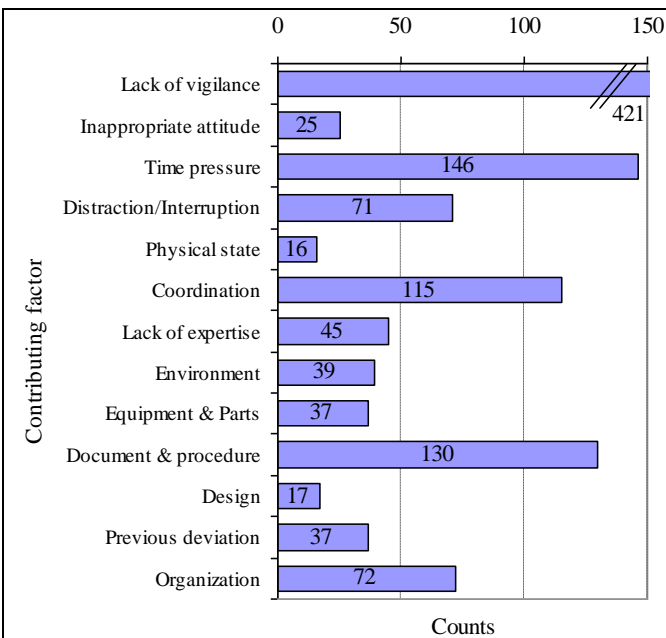


Figure 2. Identified contributing factors in 680 maintenance ASRS reports.

Unsafe acts for each outcome. Figure 3 illustrates the proportion of each unsafe event coded. Skill-based error accounts for the highest proportion of total error at 53%. In particular, logbook recording errors demonstrated a high proportion of skill-based error (67%); illustrating that logbook entry errors generally occur due to inadvertent human errors such as slips and lapses.

Routine violations accounted for 15% of the total contributing factors. Wrong part installation exhibits a distinct distribution of routine violations; 52% of the unsafe acts were identified as routine violation. In these cases, many reporters admitted that they did not verify part numbers, which constituted receiving this categorization.

Decision errors accounted for 9% of the total contributing factors. A considerable proportion of decision errors are present in inspection (14%) and qualification (15%) items. This suggests that decision errors are more frequent in processes related to inspection and technician qualification and that AMTs experience problems with interpreting procedures requiring decisions. Conversely, wrong part installation included relatively few decision errors (3%), which suggests that these tasks may be relatively clear and simple.

Unknown unsafe acts (29% total) represent a high proportion of contractor related issues (35%) as employees in companies that outsourced maintenance tasks found

deficiencies; the contributing factors cannot be determined.

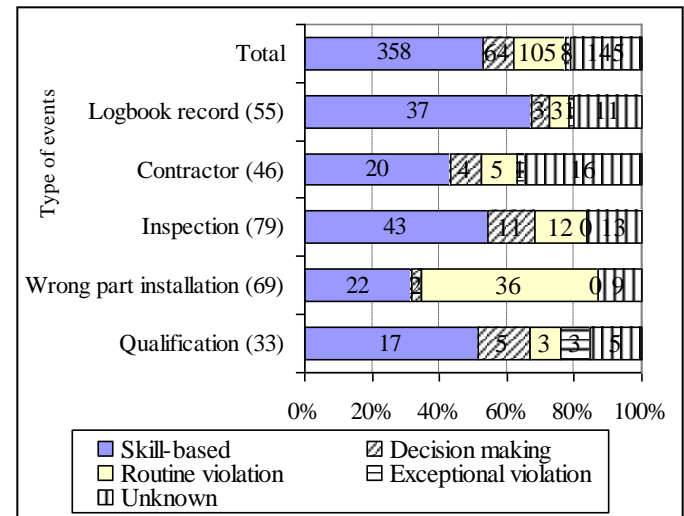


Figure 3. Unsafe acts and type event in 680 ASRS reports.

Contributing factors for each type of outcome. After our initial analysis, 150 reports for which we could not determine a contributing factor were excluded, resulting in 530 remaining reports. These reports were then further analyzed for the specific precipitating issues in advance of the event.

Lack of vigilance contributes to a significant portion of maintenance inspection (71%, see Figure 4), wrong parts installation (85%, see Figure 5) and logbook entry (83%, see Figure 6) errors. These results suggest that reported unawareness of AMTs highly contributed to these undesirable outcomes.

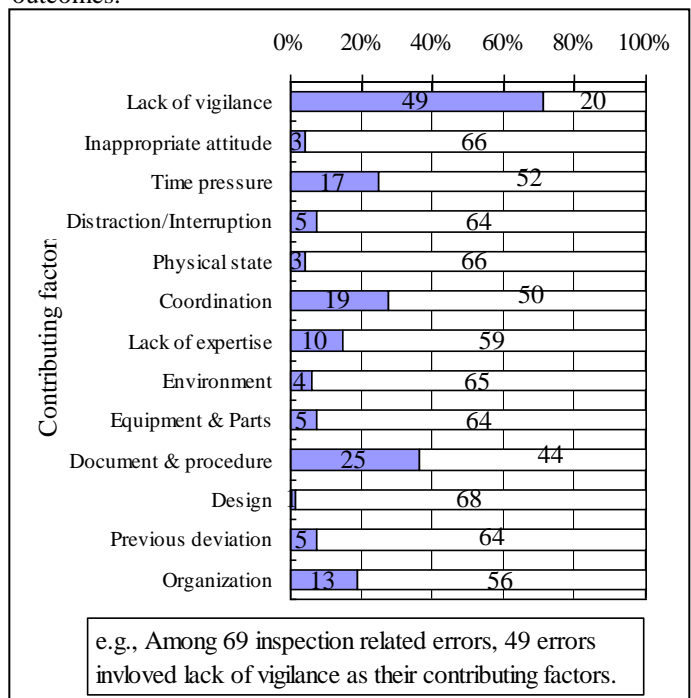


Figure 4. Maintenance inspection items (69 cases).

Document and procedure issues constitute a relatively high proportion of both inspection (36%, see Figure 4) and wrong part installation (34%, see Figure 5) errors. In many

cases, reporters state that documented procedures were poorly articulated and thus misunderstood.

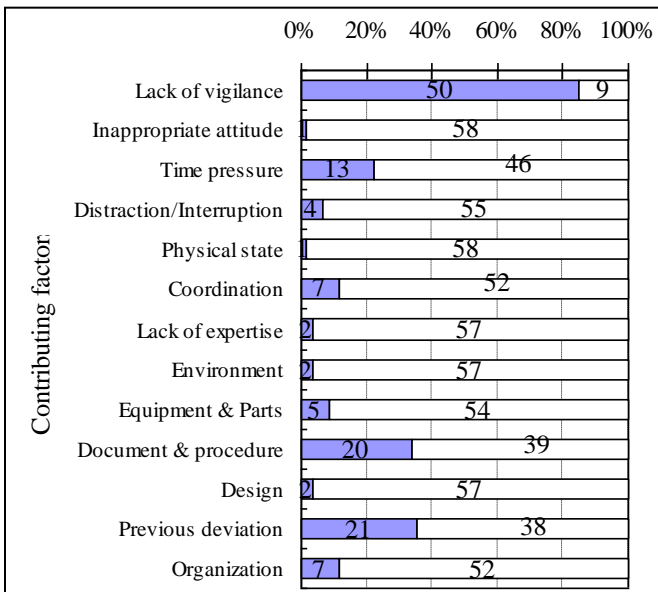


Figure 5. Maintenance wrong parts installation (59 cases).

Previous deviations made by other AMTs also contributed to the proportion of wrong part installation errors (36%, see Figure 5). Although technicians are to verify parts every time they install them, their incident reports illustrate that the attitude of relying on others' assigned tasks spread throughout the maintenance field. This then accounts for a substantial share of the reason for wrong part installation in routine violations.

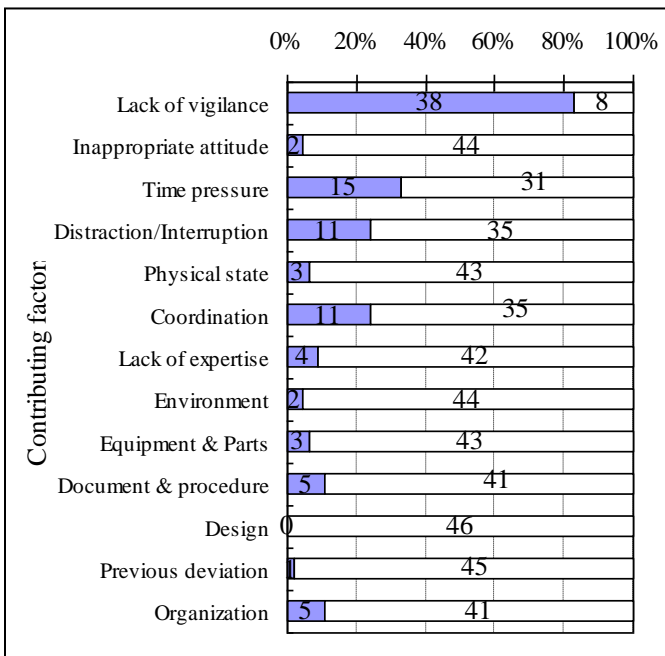


Figure 6. Maintenance logbook recording items (46 cases).

Organizational items constitute a considerable proportion of contractor related issues (38%, see Figure 7). In their reports, technicians argued that their company's existing procedures

did not properly control outsourced contractors.

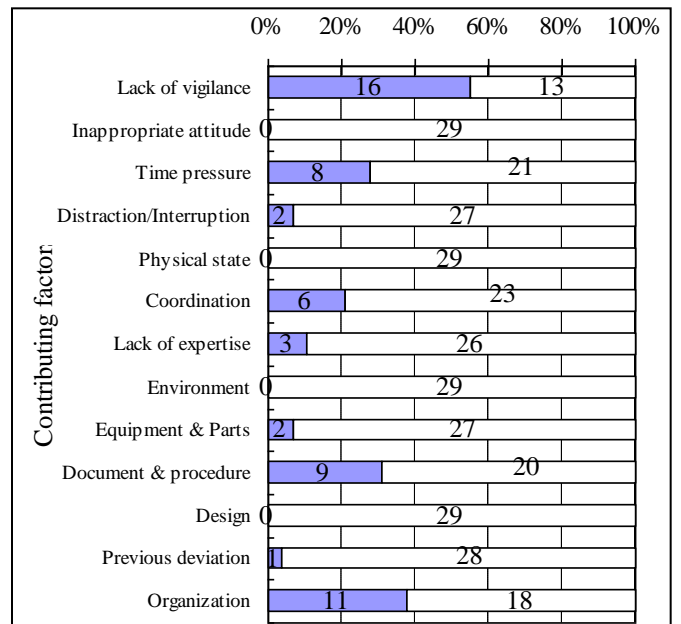


Figure 7. Maintenance contractor items (29 cases).

Lack of expertise (35%) and coordination (46%) items ranked high among the maintenance qualification issues (see Figure 8). Specifically AMTs indicated the need to be more familiar with procedural issues. This is also highly related to organizational factors as supervisors are responsible for assuring that qualified personnel are assigned to the corresponding level of the maintenance tasks.

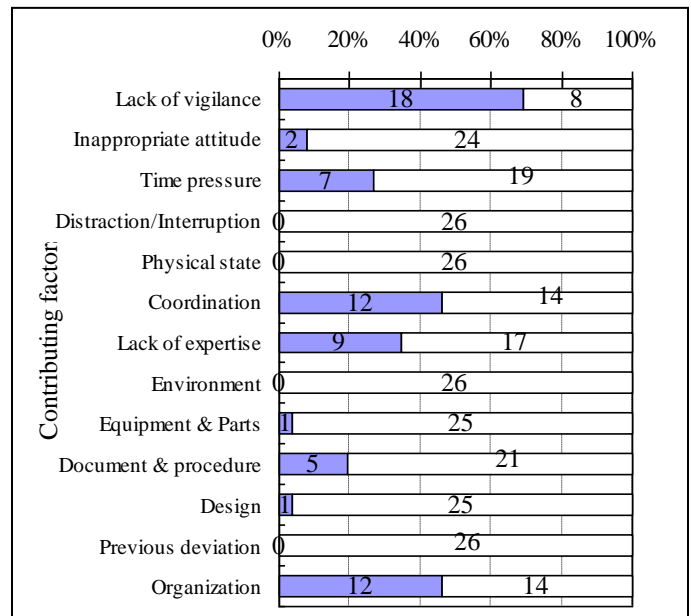


Figure 8. Maintenance qualification items (26 cases).

DISCUSSION

Our results demonstrate that safety systems in aircraft maintenance, such as inspections, parts control, logbook entry, and qualification, are vulnerable to human error even though

they have many checks and balances in place to prevent such errors. Overall, over half (53%) of the undesirable outcomes analyzed in the ASRS data were attributed to skill-based errors, such as slips, lapses, and perceptual errors, followed by routine violations (15%) and decision making errors (9%). In their survey study, Hobbs and Williamson (2003) demonstrated that 37% of aircraft maintenance errors were caused by lapse, slip, and perceptual errors (i.e., equivalent to skill-based errors in our study), 23% were knowledge-based errors and rule-based errors (decision errors), and 17% were violations. In our study, using the data in ASRS, raters coded a higher percentage of routine violations than in the Hobbs and Williamson study. Our study further investigated unsafe acts in each type of undesirable outcome, illustrating different distributions. For instance, logbook entry errors mostly occurred due to “merely” forgetting the process, whereas wrong part installations were often precipitated by workarounds.

In today’s air transportation environment, fleet technological sophistication ranges from aircraft to aircraft; from analog/mechanical designs to advanced composite electronic platforms. These vehicles interact and operate together in a complex dynamic environment. Understanding the diverse vehicle technologies and the types of structures, systems, and component failures that lead to potential airworthiness issues, provides insight into how to address human failings in processes concerning airworthiness. This requires not only a holistic review but also a specific analysis of current error types including contributing factors, and the mechanical nature of the event/incident that precedes that error. The 1000 ASRS reports we analyzed provided an opportunity to focus, examine, and study in greater depth the relationships between error types, error performance classifications, and contributing factors as they apply to real world commercial aircraft maintenance environments. The results suggest potential relationships between performance errors and aircraft systems technologies, reliabilities, and return to service issues.

CONCLUSION

Technological advances in design and materials have changed the aircraft as a vehicle, but have not changed the human/machine interactions of that vehicle in an operating environment under the everyday stress of major air carrier scheduled air service. In-depth research is required in the field of aircraft maintenance human performance, based on the relationship between mechanical issues (e.g., specific systems) and their contributing factors that give rise to human error. Using the rich information from ASRS and other program sources (such as ASAP), researches will continue to study relational data.

With aviation transportation safety as the top priority, airline maintenance procedures must continually insure that vehicles are operationally safe. Maintenance personnel are the prime conduit to attaining safe performance as their work processes play a major role in preserving safe operations. Their human errors can lead to financial as well as catastrophic outcomes. Given the differences in aircraft design, system technologies, technician demographics, technician fleet

experience, and outsourcing, this study provides a framework for looking at issues in maintenance performance errors through the lens of aircraft technology. Further analysis of other aircraft systems is currently underway.

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