Federal Aviation Administration

Procedural Compliance in Aviation Maintenance

Handbook of Best Practices and Recommendations

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Executive Summary

Procedural compliance is essential for aviation safety. Despite the continued training and focus on procedure following, Failure to Follow Procedures (FFP) is one of the most pervasive human factors issues in aviation maintenance, contributing to the majority of all accidents/incidents. These events can have substantial human (e.g., injuries and loss of life) and financial costs, necessitating intervention. The historic response to FFP was a blame cycle of training or disciplinary action, which may appear faster and easier in the short term, but the scientific literature has found not to effectively reduce FFP. This report provides generalizable recommendations for the reduction of FFP based on a review of data from multiple studies, the examination of event investigation tools, and the evaluation of human factors data analysis methods. **This handbook is a compilation of countermeasures that can be used to build a systematic response to FFP where contributors at all levels of the organization are considered and mitigated.** This approach may ultimately reduce the rate of incidents and improve safety in the maintenance workplace. This report and future research could support the human factors needs of personnel who evaluate, approve, and oversee maintenance training, operations, and procedures, including identification and management of relevant FFP risks.

Keywords: failure to follow procedures, compliance, aviation maintenance, human factors, risk management

What is FFP?

Safe behavior is critical in aviation maintenance, where errors and non-compliance with approved procedures can lead to negative safety events like incidents and accidents. Maintenance performers should follow work instructions *exactly as written*, as required by Federal Aviation Regulations (FAR). **The requirement is straightforward, but complying with it in practice is not.** There are still many maintenance-related safety events that are the result of employees not following prescribed procedures for completing a task – known as **Failure to Follow Procedures** (FFP).

FFP in Review: Case Studies

Case #1 In June, 1990, a British Airways BAC-111 climbing through 17,300 feet on departure had the left windscreen blew out, and the commander was partially sucked out the window opening. Upon investigation, it was determined that the bolts used at the windscreen's last maintenance were undersized when compared to the specified bolt. The work was performed by the Shift Maintenance Manager, counter to normal procedure; investigators noted the night shift when the work occurred was understaffed. Additionally, the manager was working his first night shift after several days off, reportedly had 1½ hours of sleep, and was completing the work during his physiological nadir (0300-0500). Investigators found that the specified bolts were out of stock at the storeroom, and that the manager tried to visually match a bolt against the stores supervisor's advice (ultimately selecting the wrong bolt). In addition to the manager's failure to follow procedure, there were additional organizational-level contributing factors.

Investigators further found that the windscreen had been previously replaced with incorrect bolts as well; inspections of other BAC-111 aircraft found two further cases of incorrect bolts used to secure windshields. Investigators also noted that the error could have been caught by a cabin pressurization test, which was not required.[i]

Organizational Level Contributing Factors

- Installation tool out of calibration.
- Improper placement of the safety riser to complete the installation.
- Insufficient number of designated bolts available.
- Unsuitable equipment .
- Manager's work did not require a review.
- Evidence of inadequate monitoring.

Case #2 In January 2003, a Beechcraft 1900D operated by Air Midwest (dba US Airways Express) crashed on takeoff, resulting in the deaths of all passengers and crew. The National Transportation Safety Board (NTSB) reported that the probable cause was a loss of pitch control during takeoff resulting from incorrect rigging of the elevator control system during a maintenance check and compounded by a center of gravity substantially aft of the certified limit.[ii] The rigging of the elevator control system was performed by a newly-hired repair technician mechanic with neither training nor experience in that maintenance check (the organization had a notably high turnover rate among maintenance employees). The inspector indicated that he had other duties and "did not think he needed to closely supervise the mechanic because of his previous flight control rigging experience," allowing the technician to skip steps in the procedure (one of which would have likely identified the incorrect rigging).

The inspection of the work was also compromised since the individual who was providing oversight for the work also provided the follow-on inspection. The findings further revealed that accuracy and completeness improvements were needed for the work cards and maintenance manuals.[iii] Additionally, the high employee turnover rate may have prevented the formation of an effective safety culture.

Case #3 In December 2011, an Eurocopter AS350-B2 helicopter crashed near Las Vegas, Nevada, killing four passengers and destroying the helicopter; the NTSB attributed the accident as maintenance-related. Failures included: a) the improper reuse of a degraded self-locking nut, b) the improper or lack of installation of a split pin, and c) inadequate post-maintenance inspections. However, there were additional contributing factors.[iv]

Contributing Factors

- ☒ Fitness for duty (fatigue): Both the mechanic and quality control inspector had insufficient time to adjust to working an earlier shift than normal.
- ☒ Improper installation and inadequate post-maintenance inspection (organization scheduling practices).
- ☒ Work cards did not have clearly delineated steps to support the installation and post-installation inspection.

How often does FFP occur?

Investigations estimate that FFP is one of the most pervasive human factors issues in aviation maintenance, contributing to between 40.5% and 87% of all maintenance-related events.[v] This rate has remained steady across the last two decades, and FFP is still cited as a top human factors challenge in aviation maintenance today. These events can have substantial human (e.g., injuries and loss of life) and financial costs, necessitating intervention.

As illustrated in these examples, FFP events can occur for many reasons within *and* beyond the control of the front-line employees. The numerous factors that go into FFPs show why it is important to think about the full operational context when preventing FFPs. It is important to not consider just the individuals performing the work, but also factors related to the environmental and working conditions, crew coordination (colleagues and supervision), and the organizational context (culture, resource management).

When considering these broader contextual factors, a much more complex and dynamic view of FFP emerges – lending itself to more robust prevention strategies.[vi] Thus, it is necessary to intervene at multiple levels within the organization and across the industry. **Until systemic mitigations are implemented across the aviation maintenance industry, FFP is likely to remain a high-prevalence challenge with significant costs.**

Why do we need a multi-level approach to FFP mitigation?

What is the historic response? The historic response to FFP was a person-centered, "blame and train" response to errors or mishaps, focusing on the person performing the work.[vii] Organizations commonly instituted further screening, additional training, new policies/procedures and regulations, more enforcement of compliance, and harsher disciplinary action (up to termination).[viii]

A person centered approach is not sufficient for effective safety management.

- ☒ Even experienced workers can make errors, whether willfully or not.
- ☒ Blaming and training prevents learning from the event.
- ☒ Blaming and training can impede Safety Management System (SMS) effectiveness – with unintended consequences of undermining just culture, reducing employees' trust and willingness to report future near-misses (i.e., precursors to incidents) and FFPs.

Why does this response happen? Why doesn't it work? Overreliance on training, procedure writing, and other person-centered mitigations has been the prevailing safety management strategy not only in aviation, but across healthcare, nuclear power, and other safety-critical fields.[ix] These person-centered mitigations look like a quick, financially expedient way of gaining closure and moving forward from the event on a well-trod, but ultimately incorrect path that does not prevent FFPs from happening again.[x]

For example, personality/attitude and physical characteristics (e.g., body size/strength, sensory impairment, health) are commonly touted as contributors to FFP. However, the available research suggests their contributions are minimal,[xi] and there is little research on the practicality and benefits of potential mitigations (e.g., change the person).

Experts in safety management and resilience engineering have learned that adverse events occur in a nonlinear, dynamic way instead of a single failure point (for example, the individual performing the work).[xii] That is why single-point fixes like counseling, disciplinary actions, and other person-centered mitigations are not effective. What is needed is a shift to viewing human error as a symptom of failure, rather than individual faults.[xiii] Thus, a more effective approach to reducing FFP should consider the environmental and other contextual factors that shape human performance.

So what's the solution? Most mechanics already know how to follow a procedure to perform the work, so more technical training or additional procedures to follow are not likely to help prevent FFPs. Instead, what technicians need in the work environment is support like adequate resources like usable work cards, positive peer pressure, enlightened supervision, and adjustments for demands like time pressure and task overload.[xiv]

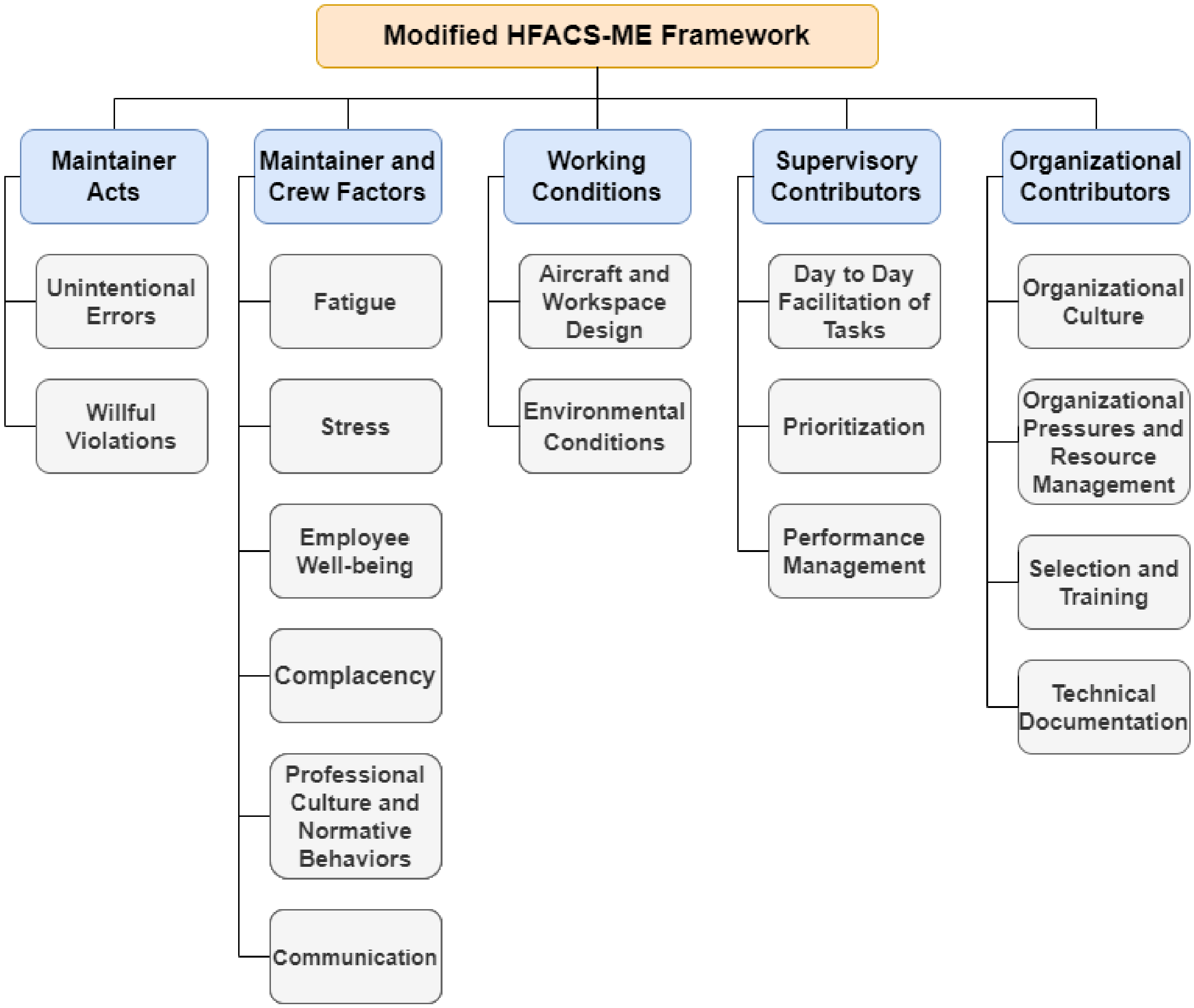
To reduce negative safety events and to break the "blame cycle", it is important to recognize:[1]

- ☑ Human performance is shaped by situational and environmental factors.
- ☑ Simply instructing operators to not make unintentional errors is ineffective.
- ☑ Errors often result from multiple contributing factors, both within and beyond the control of the operators.
- ☑ Situations and environments are usually easier to alter than operators.

Rather than focusing on the individual operators responsible for the specific FFP, it is essential to look at the contributors to FFP from a multi-level perspective when making safety improvements and mitigations targeting FFP.[xv]

Using a Taxonomy for Investigating FFPs: A Bird's Eye View

A multi-level taxonomic framework can provide a structure for understanding the common contributing factors to FFP, how they are interrelated, and how they can inform targeted mitigation strategies. The Human Factors Analysis and Classification System - Maintenance Extension (HFACS-ME) framework excels at classifying the contributing factors - *why* the event occurred.[xvi] We modified the HFACS-ME model so that it that more accurately describes the influence of various contributing factors to FFP and more clearly delineates where the change requirement originates.[xvii]



Ultimately, it is expected that this Modified HFACS-ME Framework will support the shift from the traditional "blame and train" approach to support the utilization of more effective mitigations targeted at addressing the root causes underlying the event.

The remainder of this report reviews the most prominent causal and contributing factors for FFP, along with potential targeted solutions and mitigations. It should be noted that the factors explored in this report are not a comprehensive list of reasons procedures are not followed, but rather an indication that there are numerous intertwined contributing factors to FFPs that can originate from different sources within and beyond the individuals performing the work. These contributing factors to FFP are described serially in this report; however, note that, as the case studies illustrate, these factors rarely occur in isolation and there may be interactive effects. The complexity involved in FFP events underscores the importance of having a multi-level approach to investigation and mitigation.

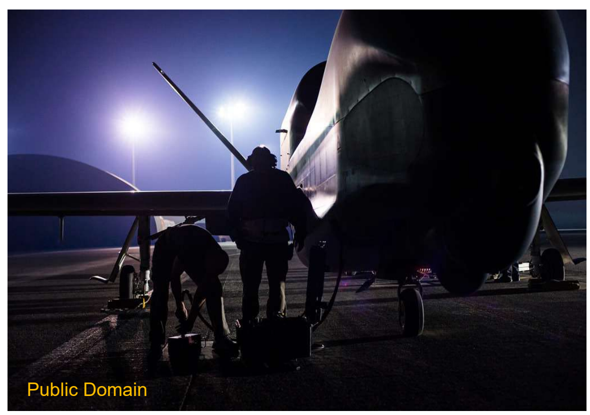
Maintainer Acts

FFP can be classified into two major categories: *unintentional errors* and *willful violations*. **Most FFPs are unintentional errors**, as only 16-34% of FFPs are intentional or willful violations.[xviii] Unintentional errors may be due to misperception, lack of knowledge, decision-making, etc. This distinction between unintentional errors and willful violations is important because research has shown these two types of FFP have different contributing factors and may produce different outcomes.[xix] The following sections provide a multi-level consideration of why these errors and violations may occur, along with corresponding mitigations.

Maintainer and Crew Factors

Maintainers, working either individually or in crews, are the first line of defense for safety in the organization. They ensure safety in the vast majority of normal operations,[xx] and are most aware of the hazards, making their reports a valuable source of information for effective safety management. On the other hand, maintainers occasionally make mistakes and historically they have been blamed for events, with failures being attributed to their capabilities, motivation, or risk-taking behavior.[xxi]

These contributing factors can be mitigated at the individual level but there are times that organizational factors limit or constrain the effectiveness of individual mitigations; thus a **collaborative approach between individuals and organizations is needed**. In most instances, the organization should share responsibility for mitigating FFPs due to their role in generating some of the psychosocial risks that impact aspects of the maintainer and crew factors.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Fatigue

Why Fatigue is Important

Employee fatigue/alertness has been a concern and a focus of research across aviation-related industries, and maintenance has all of the criteria for increased fatigue risk, with long shifts, overtime, and "back of the clock" night operations.[xxii]

How to Mitigate Fatigue

Employees and organizations share a responsibility for mitigating fatigue. Recommendations for employees focus on the integration of the work schedule with family life, gaining adequate nutrition and sleep, taking rest breaks, and the possible use of breaks for naps. Research has shown the benefits of strategic napping, with ideal durations to avoid waking from deep sleep, which would result in greater sleep inertia.

Recommendations for organizations are geared towards reducing fatigue risk. These recommendations are important considerations given previous research showing that tasks requiring greater cognitive effort – those that may be more complex and safety-critical – are at greatest risk for fatigue-related errors.

Fast Facts about Fatigue

- ☒ 96% of Aviation Maintenance Technicians (AMTs) surveyed (or someone they know) had made fatigue related errors.
- ☒ One in seven shifts is operating at elevated fatigue risk levels, increasing the rate of incidents.

To reduce fatigue risk, employees should:

- ☑ Integrate work schedule with family life.
- ☑ Maintain adequate nutrition and sleep.
- ☑ Take rest breaks.
- ☑ Consider using breaks for naps. Naps should be short enough (<45 min.) or long enough (110-120 min.) to avoid waking from deep sleep.

To reduce fatigue risk, organizations should:

- ☑ Use shift scheduling practices to allow more time for rest and recovery between shifts.
- ☑ Use scheduling tools to optimize shift schedules.
- ☑ Ensure frequent rest periods, fatigue education, improved shift turnover procedures, and implementation of a Fatigue Risk Management System (FRMS).

Stress

Why Stress is Important

Studies have shown the negative impact of personal and work-related stressors on well-being and performance. Although much of the stress research focuses on personal sources of stress, newer research points to a number of work-related stressors as well, such as time pressure, workload, distraction/interruption, and organizational structure and climate.

How to Mitigate Stress

One common mitigation is to learn and use stress management techniques. As is discussed in the following sections, there is a large role for managers and supervisors in reducing time pressure, workload, and other work-related stressors.

Employee Well-Being

Why Employee Well-Being is Important

Traditionally, employee wellness has been viewed independently from workplace safety, but recent research has illustrated that the two are intertwined. Specifically, research has linked employee well-being (e.g., health, stress) to organizational safety outcomes. Given this, managerial and supervisor support for well-being concerns is needed.

How to Mitigate Employee Well-Being Issues

Organizations should consider implementing wellness programs, assessment tools, career development guidance, and other interventions, as these efforts may ultimately translate to improved productivity and safety performance.

Guidelines for employee well being efforts are available from:

- The World Health Organisation's *Healthy Workplaces* (Burton, 2010).
- The National Institute for Occupational Safety and Health's *Total Worker Health Program* (n.d.).
- The European Agency for Safety and Health at Work's *Manage Stress* (2013).

Complacency

Why Complacency is Important

Complacency is a sense of calm or safety that can cause a lack of awareness; it can easily lead to mistakes, errors, and accidents. Hazardous attitudes such as complacency have been identified by researchers as one of the top three human error challenges for maintenance.

To reduce complacency:

- ☑ Consistently use safety checklists.
- ☑ Understand procedures.
- ☑ Stop when attention is low.
- ☑ Step away to reassess the situation.
- ☑ Verifying completed work.

How to Mitigate Complacency

Recommendations for reducing complacency involve both supervisors and employees. Low attention to work is a key warning sign of complacency; supervisors and employees should stop when attention is low and reassess their situation. Understanding procedures and using safety checklists can also help to reduce complacency.

Professional Culture and Normative Behavior

Why Professional Culture and Normative Behavior is Important

A professional culture of AMTs strongly committed to safety must negotiate competing demands (i.e., productivity and safety) in an error-prone environment.[xxiii] As a result of these competing demands, employees may develop unauthorized procedures or shortcuts that are viewed as 'unimportant steps'.[xxiv] This shortcutting behavior often becomes culturally normative within the organization (i.e., "because it has always been done that way"), and is often viewed as acceptable by management so long as it helps improve efficiency. However, giving such behavior a pass reinforces the normalization of deviance,[xxv] leading to accidents/incidents in the long run.[xxvi]

How to Mitigate Normative Behavior

Normative behavior can be mitigated by continuous attention, detection of deviance, and clear criteria for unacceptable behavior. To mitigate the use of unauthorized procedures, management can review such procedures to ensure usability and accuracy, and correct deviations from authorized procedures, even if operations are running smoothly.

To support professional culture and reduce normalization of deviance, organizations should:

- ☑ Be aware of the normative behavior phenomenon and implement methods to detect and mitigate normative behaviors, and establish clear criteria for acceptable behavior.
- ☑ Pay consistent attention to normative behaviors to continually ensure compliance. Normative behaviors occur gradually over time and are, to some extent, part of an organization's evolution.
- ☑ Mitigate the use of unauthorized procedures by reviewing procedures to ensure usability and accuracy, and correct any deviations from procedures (such as shortcuts used when under time pressure,) even if operations are running smoothly.
- ☑ Collaboratively review procedures and processes with employees to identify areas where modifications can improve overall performance.

Communication

Why Communication is Important

Verbal and written communication can support situational awareness of what each team member is doing and how they can best work together to complete the tasks.[xxvii] Unfortunately, miscommunications are often a contributor to incidents/accidents and injuries in the workplace.

Not only do AMTs need to communicate within the maintenance department, but they must also communicate well with employees in other departments, such as flight crews. For instance, adequate and complete information from pilots allows maintenance personnel to diagnose and resolve the issues faster; in turn, pilots feel more comfortable with airworthiness when maintenance reports are complete and communications are thorough.

ASRS Database Findings
(Suzuki et al., 2008)

- Poor coordination in 17% of Aviation Safety Reporting System (ASRS) maintenance events.
- Of those events, 79% occurred within a single department.
- Frequent errors involved: not delivering information, sending wrong information, and lack of responsibility.
- In one particular coordination task, shift turnover, was involved in 51% of all maintenance communication errors (Parke & Kanki, 2008).
- When inter-departmental communication errors occur, they frequently involve conflicts about aircraft airworthiness and/or the information provided in logbooks.

How to Mitigate Communication Issues

To mitigate FFP specifically related to shift turnover, communications should include not only a description of completed tasks, but also a list of potential problems and concerns so that employees can be on the lookout. Other best practices are to use a checklist and a combination of face-to-face communication and paper documentation.

Mitigations for improving situational awareness and communication within and across departments include: sharing information and mental models across teams, verbalization of decisions, improved shift meetings and teamwork, improved feedback, and situational awareness training.[xxviii] Another potential mitigation designed to promote effective communications is aviation training on interpersonal communication and coordination, task allocation, conflict resolution, and decision making[xxix]; however, additional research is warranted regarding the effectiveness of that training in the operational maintenance environment.

Working Conditions

The design of the aircraft, environment/workspace, and equipment/tools are commonly associated with accidents and injuries, contributing in up to 67% of all maintenance mishaps in the NTSB's Aviation Accident Database.[xxx]

Aircraft and Workspace Design

Why Aircraft and Workspace Design is Important

Some maintenance events are attributable to design of the workspace and/or aircraft. For instance, the aircraft and surrounding working conditions can be confining, obstructed from view, or inaccessibly beyond reach.[xxxi]

How to Mitigate Aircraft and Workspace Design

Improving the ergonomic design of the workspace has been shown by experts to improve aircraft availability, delivery times, employee morale, and customer satisfaction.[xxxii]

While considerable attention has been focused on cockpit design during the last few decades, this is less true regarding the design of the aircraft for maintainability. Looking to the future, the introduction of new diagnostic tools and technologies will

require new policies, procedures, and training. While many new tools and technologies are designed to improve the diagnostic ability and performance of aircraft systems, they may also introduce new human factors issues. Careful attention will be required to ensure that employees understand and can follow new methods of troubleshooting and performing maintenance on increasingly complex aircraft systems.

Environmental Conditions

Why Environmental Conditions are Important


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FFP can in part result from inadequate or unsafe environmental conditions, such as: poor lighting, extreme temperatures, exposure to weather, uncomfortable noise levels, insufficient housekeeping/ cleanliness, and exposure to hazardous/toxic substances. These factors can make it harder to complete work (such as by impairing cognitive function) and increase the risk of error on highly complex tasks, particularly by accelerating the onset of fatigue.

How to Mitigate Environmental Conditions

Although some environmental and facility conditions are inherent in aviation maintenance, they may still contribute to events and accidents/incidents. Experts recommend that organizations try to minimize the impact of environmental conditions to the extent possible.

Equipment, Tools, Parts, and Consumables

Why Equipment, Tools, Parts, and Consumables are Important

The availability and adequacy of equipment, tools, parts, and consumables are frequently identified as contributing factors to between 11.8 and 27% of all maintenance events.[xxxiii] Specific concerns include the use of materials that are damaged/faulty, unavailable, inappropriate for the task, uncertified, or mis-calibrated.


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How to Mitigate Issues with Equipment, Tools, Parts, and Consumables

Employees should not use materials that are unsuitable for the job and should make supervisors aware of issues related to the resources provided. It is incumbent on the organization to ensure the provision of adequate materials. Supervisors need to ensure that materials are readily available, reinforce their use, and ensure that materials are returned to their proper locations following their use.[xxxiv] Ideally, this would involve a system that prevents work without proper tools being taken from a controlled environment (e.g., tools storage) and systematic training for every new tool and piece of equipment added to the workplace.

Supervisory Contributors

Fast Facts about Workload

- Surveys of maintenance personnel found 75-80% believed they could not complete the job in time if they followed all the procedures.
- Strenuous employee work schedule was one of the top job stressors reported by maintenance workers.

Supervisors can be a major source of support for maintenance employees. They serve as intermediaries in communicating safety policies/procedures and are a key influence on safety outcomes, predicting compliance behavior, and promoting organizational resilience.[xxxv] Yet, supervisors' actions can also contribute to FFP. Studies have found that supervisory conditions were involved in ≈60% of all maintenance related events.

Day to Day Facilitation of Tasks

Why Day to Day Facilitation of Tasks is Important

Among a supervisor's responsibilities are planning and organizing resources: finances, personnel, and physical resources (e.g., equipment and tools, documentation). Failure to do so (such as through inadequate management or supervisory attitude) is one contributor to FFP. Ensuring employees have adequate resources is considered a critical driver of both safety culture and safety performance. Thus, careful attention should be paid to resource allocation.

Supervisors who fail to plan work tasks appropriately can push unachievable workloads onto their maintenance personnel. Industry surveys have found workload is a top contributor to noncompliance and that high workload increases the risk of using unauthorized procedures.

How to Mitigate Issues with Day to Day Facilitation of Tasks

Supervisors should organize personnel resources and delegate tasks carefully to prevent unachievable workload. Part of this is ensuring that tasks are assigned to qualified personnel and that there is an equitable distribution of work across personnel. However, depending on the nature of the tasks and the personnel available, there are limits within which the supervisor can reduce FFP associated with workload.

Finally, supervisors should schedule work with task complexity and employee fatigue in mind, as research has shown task complexity and fatigue lead to impaired cognition, in turn increasing the likelihood for error. Providing a "second set of eyes" or 2-step task verification is a recommended mitigation for FFP, particularly for tasks that are prone to cognitive-related errors.[xxxvi]

Prioritization

Why Prioritization is Important

One of the most commonly cited contributors for FFP is competing demands (e.g., productivity and safety), and organizational emphasis on the bottom line. Often, shortcutting is overlooked by management if no incidents have occurred.

Benefits of increasing supervisors' safety related communications

- ☑ Increased use of PPE.
- ☑ Improved safety culture ratings.
- ☑ Decreased minor injury rates.
- ☑ Higher safety performance.

How to Mitigate Prioritization Issues

To reduce FFPs, supervisors should explicitly communicate to employees the importance of safety over production and correct deviations from procedures. By increasing supervisors' safety-related communication, organizations have seen improvements in use of personal protective equipment (PPE), injury rates, and safety culture ratings. Supervisors may need to be explicitly trained to offer safety-related communication.

Performance Management

Why Performance Management is Important

Supervisors are responsible for setting and enforcing performance expectations. Failure on the part of supervisors to meet these responsibilities (e.g., poor accountability, ineffective disciplinary procedures, and inadequate positive rewards) can lead to FFP among employees.

Benefits of SMBWA

- ☑ Reduced noncompliance.
- ☑ Reduced subjective workload.
- ☑ Increased identification of hazards.
- ☑ Increased safety communications.
- ☑ Increased teamwork.
- ☑ Increased safety audit scores.
- ☑ Improvements in safety climate.
- ☑ Improvements in safety behavior.

How to Mitigate Performance Management Issues

Supervisors should directly engage with employees about their job performance and have informal conversations about safe behaviors. Supervisors should also publicly recognize employees for safe behavior and provide corrective feedback when errors are made.

Supervisors can only provide timely feedback if they frequent the work area; their presence improves not only safety behavior but also safety culture. One method found to be successful in reducing FFP is Safety Management by Walking Around (SMBWA). In this program, managers, supervisors, and peers observed technicians' behaviors and provided feedback: positively reinforced safe behavior, questioned inappropriate behavior, and provided job training on proper task completion.

Organizational Contributors

To detect and mitigate FFPs, organizations must consider the broader context within which FFPs occur. Previous analyses of event reporting databases found organizational problems were a contributing factor in 13.7-26.7% of maintenance-related incidents.[xxxvii]

Organizational Culture

Why Organizational Culture is Important

Organizational culture is the shared beliefs about work practices, values, and expectations within an organization. High-Reliability Organizations (HROs) have fewer adverse events because they recognize humans are fallible and that things can go wrong.[xxxviii]

Features of High Reliability Organizations (HROs) include:

- ☑ Recognizing the multifaceted nature of causal factors.
- ☑ Implementing safety management practices as a means of prevention.
- ☑ Considering safety in terms of making the system robust to human and operational hazards.
- ☑ Anticipating potential risks by equipping themselves to mitigate errors at all levels of the organization.

How to Mitigate Organizational Culture Issues

Recommendations for improving organizational culture are to reduce barriers to reporting (fear of blame), encourage honest reporting, assure management commitment, and stress the importance of the collection, analysis, and sharing of risk-related information within and across organizations/industries.

One primary way to promote a positive organizational culture is to support a voluntary program for reporting hazards, errors, and other mishaps. Example reporting systems sponsored by regulatory authorities include the NASA's Aviation Safety Reporting System (ASRS) and the FAA's Aviation Safety Action Program (ASAP).

Companies need to educate their employees how to file reports, and what types of hazards and events should be reported.[xxxix] The program should be accessible, protected (confidential), and non-punitive.[xl] Companies should have clear criteria for what kinds of reports will be accepted. As part of this, managers and supervisors need to operationally define different types of willful violations, communicate them to employees, and consistently employ appropriate corrective actions.[xli] The boundaries between acceptable and unacceptable behavior and the consequences for willful violations need to be clearly communicated with employees to maximize compliance and to support a just and safety culture.[xlii]

It is essential that employees know that any reported incidents and FFPs will be handled justly[xliii] and that the organization is committed to learning from mistakes rather than simply punishing the individuals who make them.[xliv] To that end, management should respond by analyzing reports to identify areas in need of improvement, and by providing feedback on corrective actions taken. By demonstrating that reporting efforts are not punitive and that outcomes are used to improve the operational environment, the overall culture and SMS will improve. Further guidance on implementing reporting programs is available on the FAA website and the *FAA Practical Guide to Maintenance ASAP Programs*.[xlv]

To improve organizational culture, organizations should:

- ☑ Reduce barriers to reporting (fear of blame).
- ☑ Encourage honest reporting.
- ☑ Assure management commitment.
- ☑ Ensure employee involvement throughout the improvement process.
- ☑ Stress the importance of the collection and analysis of reports.
- ☑ Share risk-related information within and across organizations/industries.

Organizational Pressures and Resource Management

Why Organizational Pressures and Resource Management is Important

Although the term "Safety first" is oft repeated, the ultimate goal of many organizations is something other than safety (e.g., mission and/or finances). This imposes competing demands on the workforce, which include time pressure, workload, conflicting priorities, and other factors.

Time pressure is frequently cited as one of the most critical factors behind FFPs. Increased time pressure generally results in lowered performance and an increase in errors, especially in complex work environments like aviation maintenance. Although pressure is an inherent part of the aviation maintenance environment, all reasonable efforts should be made to reduce pressure among front-line employees.

Another source of organizational pressure is allocation of scarce human resources. The aviation maintenance industry is facing a global shortage of personnel in the next decade, resulting in fewer front-line employees each handling an increased workload.

How to Mitigate Organizational Pressures and Resource Management Issues

As previously noted, supervisors should allocate personnel resources to minimize excess workload pressure.[xlvi] Further, as an industry, education and outreach programs are needed to help recruit the next generation of aviation personnel

Selection and Training

Why Selection and Training is Important

A well-trained workforce will be more efficient and less likely to make errors in the use of new equipment, technology, and procedures. Organizations must have in place a process to first select and hire individuals based on the necessary knowledge, skills, abilities, and other characteristics (KSAOs) to perform the job, and then provide on-the-job (OJT) and recurrent training to ensure that employees can maintain and update the necessary KSAOs.

Roughly 90% of the critical skills for AMTs are acquired through OJT, However, OJT is often unstructured and inconsistent, involving shadowing the lead mechanic or trained AMT. Other issues concern the selection of qualified trainers who possess the technical knowledge and motivational/interpersonal skills to be successful.

How to Mitigate Selection and Training Issues

Efforts should be made to improve OJT by establishing clear selection criteria for trainers,[xlvii] performance criteria for trainees, and objective assessments of trainees' performance.

The workforce of the future will likely require different KSAOs due to a changing workforce, ongoing technological changes, and increasing system complexity.[xlviii] Looking to the future, further consideration is warranted for design-for-maintainability, FAA certification requirements, and identification of high priority training needs.[xlix]

In addition to technical skills, AMTs need human factors education, as this creates awareness among employees of factors that may impact their performance and offers strategies to mitigate FFPs. FAA Advisory Circular 120-72A provides criteria to inform the design and evaluation of human factors in maintenance training. Training courses on human error and noncompliance are also available on the FAA Safety team website.[l]

Advances in technologies such as Augmented Reality (AR) and Virtual Reality (VR) create unique opportunities for improved training. AR/VR allows for hands-on practical exercises to supplement classroom training, and may be more cost effective than traditional methods. AR training has been shown to reduce AMT learning curve for tasks such as troubleshooting an aircraft; however there are ergonomic/comfort and other considerations when implementing this technology. Further work is needed to resolve potential roadblocks to the implementation of AR/VR and to ensure that the applications are dedicated to tasks in a way that maximizes suitability, effectiveness, and safety.

Technical Documentation

Why Technical Documentation is Important

One frequently cited reason for FFPs is the technical documentation itself.[li] Maintenance personnel spend 25-45% of their time using maintenance documentation;[lii] despite this, there are often deficiencies with the manuals.

When questioned whether the maintenance manual describes the easiest way to do a procedure, only 18% agreed, and only 13% agreed that the "manual understands" how they do maintenance.[liii]

Challenges with technical documentation mainly relate to how understandable and accessible the content is for AMTs – it can be confusing, incomplete, inconsistent, inaccurate, and so on.

These challenges with technical documentation may arise due to constraints faced by procedure writers, such as writers not being familiar with the work environment, requirements, and users' needs. Procedure writers also face time pressure,[liv] resulting in a lack of time for proactive usability testing of the documentation, which often leads to writers receiving feedback only after the procedures are implemented into work practice.

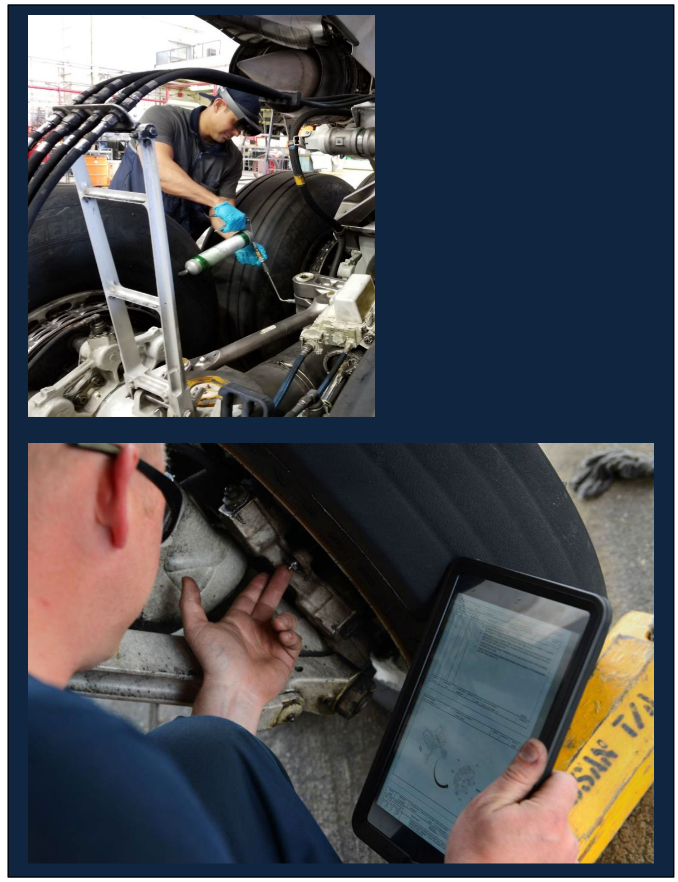
How to Mitigate Technical Documentation Issues

Organizations can help reduce FFPs by working to ensure that technical documentation is written for AMT comprehension and usability.

Best practices in technical documentation writing include:

- ☑ Utilize the Documentation Design Aid to improve comprehension and readability of airline workcards.
- ☑ Validate maintenance procedures against standard human factors techniques.
- ☑ Use best writing practices when documenting procedures, such as clear and consistent language, active tense, concrete vocabulary, clear structure, and connecting words.
- ☑ Conduct usability beta testing to ensure that documentation and materials fit the context in which they will be used.
- ☑ Make user-focused revisions to fix any errors or confusions in the documents.
- ☑ Improve communications between technicians submitting change requests and the technical writers.
- ☑ Ensure prompt feedback of actions taken to improve procedures.
- ☑ Collaborate across industry to identify maintenance procedures that should be systematically validated.
- ☑ Maintain manufacturers' databases containing user-reported errors, feedback to users, and actions taken to mitigate errors.

Technological advances such as portable digital aids, laptops, and wearable computers may also improve the usability of technical documentation. These process-oriented applications ensure the information is available in a way that more directly supports maintenance activities. Therefore, further efforts to reduce FFPs should be directed toward digitizing maintenance documentation that is process oriented, including interconnectivity of maintenance information systems, and incorporating portable support systems so the materials are easily accessible and widely available to technicians. Displays of work instruction in AR/VR may also help, as this technology displays the information in a way that is more accessible to the user. Further research is needed to test realistic use cases and determine how best to integrate these new technologies into the maintenance environment.



Summary

FFP is one of the top human factors challenges in aviation maintenance. These events necessitate action because they can have substantial human and financial costs that can include injuries and loss of life. The historic response to FFP was focused on the employee, which led to a blame cycle of training or disciplinary action. Although blaming-and-training can be faster and easier in the short term, experts have found that person-centered mitigations like "blame-and-train" do not effectively reduce FFP. Instead, a systematic approach is needed, where contributors at all levels of the organization are addressed.

While the discussed mitigations may each seem self-evident, the novel contribution of this operator manual is a compilation of countermeasures that can be used to build a systematic response to FFP, where contributors at all levels of the organization are considered and mitigated.

At the employee and crew level, contributors to FFP pertain to readiness for the job (e.g., fatigue, stress, complacency) as well as crew coordination factors like teamwork and communication. Although front-line employees have partial responsibility to manage factors like getting enough rest/breaks and utilizing stress management techniques, there are also actions the organization can implement to reduce or mitigate the effects of these factors. Organizations can implement fatigue risk management systems, reduce the workload and time pressure that places undue stress on employees, and foster employee well-being programs. Other factors that organizations can address include complacency, professional culture and normative behaviors (i.e., shortcutting). These factors require vigilance on the part of employees, but may also be combatted at the organizational level by reviewing processes to correct deficiencies and employing 2-step task verification to ensure tasks were completed correctly.

Finally, situational awareness and good communication within and across departments can reduce FFP. Tactics to improve situational awareness and communication include sharing information and mental models across teams, verbalization of decisions, improved shift meetings and teamwork, improved feedback, and situational awareness training.[lv]

Environmental conditions that are beyond employee levels of comfort (e.g., noise, lighting), or poorly designed (e.g., confined space, inaccessible) are oft-cited contributors to FFP. Improving the ergonomic design of the workplace and aircraft for maintainability has been shown by experts to improve overall performance.[lvi] Additionally, as system complexity increases, additional design consideration will be needed to support maintainability on increasingly complex aircraft. Other relevant working condition factors pertain to the availability, accessibility, and adequacy of equipment, tools, parts, and consumables. The organization is ultimately responsible with providing adequate resources needed to perform the job.

Supervisors serve as important intermediaries in communicating safety policies/procedures, and are a key influence on safety outcomes. Supervisors should pay careful attention to resource allocation, as this is a critical driver of both safety culture and safety performance. When assigning tasks, supervisors should be cognizant of workload, qualifications of personnel, task complexity, and fatigue. Additionally, supervisors must clearly communicate priorities and emphasize the importance of safety over competing demands (e.g., productivity). Finally, research shows benefits from setting and enforcing performance expectations by providing timely feedback (both positive and corrective).

To mitigate contributors to FFP at the organizational level, a potential solution could be adopting the basic principles of HROs, since the emphasis on learning from negative events can help make systems more robust to human factors hazards.

Organizations should also strive to reduce pressure (e.g., time, workload) and carefully manage resources, in light of constraints like financial viability and an industry shortage of maintenance personnel. Organizations need a robust process for recruitment, selection, and training to ensure that employees can maintain and update the necessary KSAOs to perform the work.

Finally, the organization must ensure the technical documentation is accurate, complete, and usable; else it is unlikely to be followed.

While these recommendations may ultimately reduce the frequency of certain FFPs, they will not prevent all instances, and there is no single *best* way to manage errors.[lvii] Many of the events that occur have more than a single contributing factor; most events involve factors interacting across multiple levels of the organization, including aspects of the work processes.[lviii] The complex nature of FFPs, along with the advances of new technology, tools, and procedures, will require continued human factors research and oversight. Further efforts are needed to enhance the efficiency, safety, and resilience of aviation maintenance operations.

List of Abbreviations

Abbreviation	Definition
AMT	Aviation Maintenance Technician
AR	Augmented Reality
ASAP	Aviation Safety Action Program
ASRS	Aviation Safety Reporting System
CAROL	Case Analysis and Reporting Online
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FFP	Failure to Follow Procedures
FRMS	Fatigue Risk Management System
HFACS-ME	Human Factors Analysis and Classification System - Maintenance Extension
HRO	High-Reliability Organization
KSAOs	Knowledge, Skills, Abilities, and Other Characteristics
NTSB	National Transportation Safety Board
PPE	Personal Protective Equipment
OJT	On the Job Training
SMBWA	Safety Management by Walking Around
SMS	Safety Management System
VR	Virtual Reality

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Suggested Reading

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[xii] Leveson (2011a, 2011b).
[xiii] Dekker (2001a).
[xiv] Hobbs (2008); Schmidt et al. (2012); Suzuki et al. (2008).
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[xvii] See additional discussion in Key et al. (2022).
[xviii] Hobbs and Williamson (2000); McDonald et al. (2000b); Reason and Hobbs (2003).
[xix] Hobbs and Williamson (2003); Reason and Hobbs (2003).
[xx] Dekker (2001c).
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[xxiii] Holden (2009); Reason and Hobbs (2003).
[xxiv] McDonald (2001); McDonald et al. (2002).
[xxv] i.e., what Dekker (2016) refers to as a "drift into failure".
[xxvi] Dekker (2001b, 2001c); McDonald (2001).
[xxvii] Endsley and Robertson (2000); Latorella and Prabhu (2000).
[xxviii] Endsley and Robertson (2000).
[xxix] e.g., Crew Resource Management, Maintenance Resource Management, and Team Resource Management.
[xxx] n.b., the NTSB began the Case Analysis and Reporting Online (CAROL) database for cases since 2008.
[xxxi] Hobbs (2008).
[xxxii] Ward and Gaynor (2009).
[xxxiii] Allen and Rankin (1996); Hobbs and Williamson (2003); Virovac et al. (2017).
[xxxiv] Hobbs and Williamson (2003).
[xxxv] Akselsson et al. (2009); Hofmann et al. (2017); Zohar (2000).
[xxxvi] Barnes and Drury (2019); The Boeing Company (2016).
[xxxvii] Schmidt et al. (2000); Suzuki et al. (2008).
[xxxviii] Reason (2000).
[xxxix] Dekker (2011).
[xl] Barach and Small (2000); Dekker (2011); Ioannou et al. (2017).
[xli] The corrective action likely will depend on the severity of the violation and the consequences of it.
[xlii] Hudson (2003).
[xliii] e.g., punish when boundaries have been clearly/deliberately crossed; do not punish otherwise.
[xliv] Reason and Hobbs (2003).
[xlv] https://www.faa.gov/about/initiatives/maintenance_hf/fatigue; i.e., the Aviation Safety Action Program; FAA (2009).

[xlvi] e.g., some organizations may face frequent turnover in their staffing, which complicates OJT and proper staffing for certain tasks.
[xlvii] i.e., who possess the technical knowledge and motivational/interpersonal skills to be successful.
[xlviii] See Shanmugam and Robert (2015).
[xlix] We refer the reader to Hoffman et al. (2013) for a thorough discussion of training needs and methods for the next generation of personnel who will support increasingly complex and cognitively intense work tasks.
[l] For available courses, see https://www.faasafety.gov/gslac/ALC/course_catalog.aspx
[li] Avers et al. (2015); Dekker (2014).
[lii] Hobbs (2008).
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[liv] Virtaluoto (2013).
[lv] Endsley and Robertson (2000).
[lvi] Ward and Gaynor (2009).
[lvii] Reason and Hobbs (2003).
[lviii] See Leveson (2011a, 2011b).