



## INVITED PAPER

# Latent Failures in the Hangar: Uncovering Organizational Deficiencies in Maintenance Operations

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## **Latent Failures in the Hangar: Uncovering Organizational Deficiencies in Maintenance Operations.**

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### **Introduction**

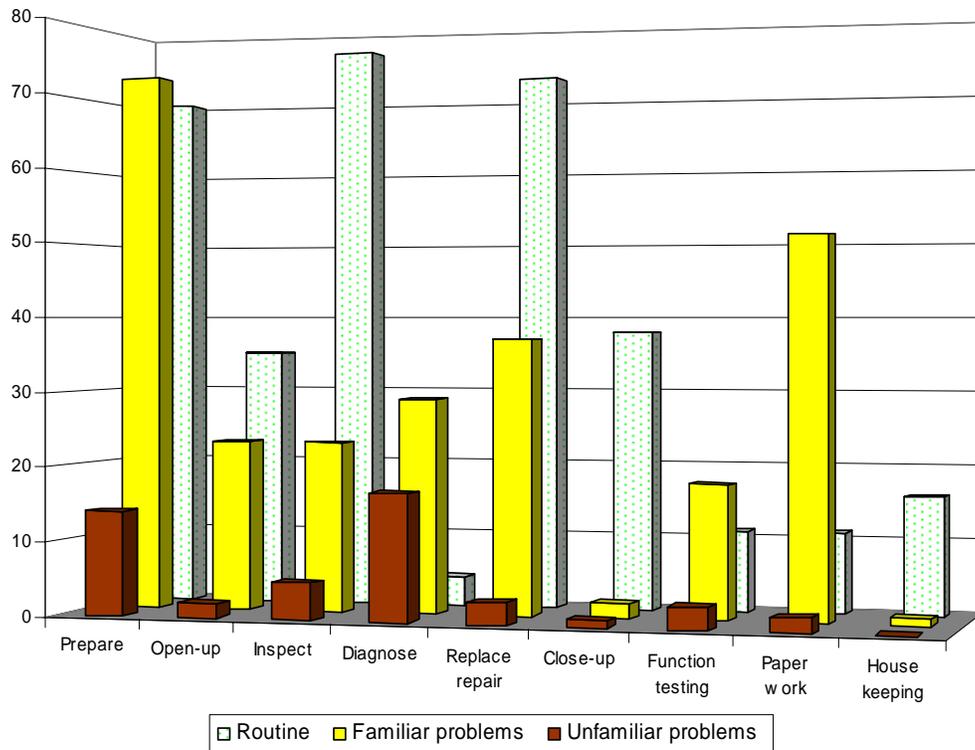
Accident statistics for the worldwide commercial jet transport industry show maintenance as the “primary cause factor” in a relatively low 4% of hull loss accidents, compared with flight crew actions that are implicated as a “primary cause factor” in more than 60% of accidents (1). Yet such statistics may understate the significance of maintenance as a contributing factor in accidents. When safety issues are presented alongside the fatalities that have resulted from them on worldwide airline operations, deficient maintenance and inspection emerges as the second most serious safety threat after controlled flight into terrain (2). According to former NTSB Board member John Goglia, maintenance has been implicated in 7 of 14 recent US airline accidents (3).

While it may be tempting to consider that the lessons learned about human performance in other areas of aviation will translate readily to maintenance, some of the challenges facing maintenance personnel are unique. Maintenance technicians work in an environment that is more hazardous than all but a few other jobs in the labor force. The work may be carried out at heights, in confined spaces, in numbing cold or sweltering heat. Hangars, like hospitals, can be dangerous places. We know from medicine that iatrogenic injury (unwanted consequences of treatment) can be a significant threat to patient health. In maintenance as in surgery, instruments are occasionally left behind, problems are sometimes misdiagnosed, and operations are occasionally performed on the wrong part of the “patient”. Aircraft and human patients also have another common feature in that many systems are not designed for easy access or maintainability.

In order to understand maintenance deficiencies, we need to understand the nature of the work performed by maintenance personnel, and the potential for error that exists in maintenance operations. It is relatively easy to describe the work of maintenance personnel at a physical level. They inspect systems, remove, repair and install components, and deal with documentation. Yet, like virtually every human in the aviation system, maintenance personnel are not employed merely to provide muscle power. They are needed to process information, sometimes in ways that are not immediately apparent. The central thesis of this presentation is that in order to uncover latent failures in aviation

maintenance, we must recognize the invisible cognitive demands and pressures that confront maintenance personnel.

In general, line maintenance tasks progress through a series of stages, much like the stages of a flight. The information-processing demands change as the job progresses. The preparation stage involves interpreting documentation and gathering tools and equipment. The work area must then be accessed, most likely by opening panels or removing components. After core activities such as inspection, diagnosis, and repair, the task concludes with documentation and housekeeping, or clean-up tasks. An analysis was conducted of the activities of 25 aircraft engineers at two international airlines. At 15 minute intervals, participants were asked to describe the nature of the task they were performing at that moment, according to whether it was routine, involved familiar problems or involved unfamiliar problems. A total of 666 observations were made of line maintenance activities. The analysis indicated that the preparation stage was not only the most time-consuming task stage, but was also a stage at which personnel must overcome challenges and solve problems (see figure 1). Between 15 and 20% of their time was spent performing work packages they had never performed before. Diagnosis and functional testing also presented significant problem-solving demands and involved relatively little routine task performance (4).



*Figure 1. Cognitive demands and job stage in line maintenance (N=25).*

## **The nature of maintenance error**

In recent years, analyses of databases of maintenance-related incidents and accidents have revealed some of the more common types of maintenance quality lapses.

In 1992, the UK CAA identified the major varieties of maintenance error as incorrect installation of components, the installation of wrong parts, electrical wiring discrepancies (including cross-connections), and material such as tools left in the aircraft (5). In a recent review of over 3000 maintenance error reports, parts not installed, incomplete installation, wrong locations, and cross connections were the most common error types (6). The most common airworthiness incidents reported in a survey of Australian Licensed Aircraft Maintenance Engineers (LAMEs) were incomplete installations, incorrect assembly or location, vehicles or equipment contacting aircraft, material left in aircraft, wrong part, and part not installed (7).

Applying human error models to maintenance discrepancies reveals that underlying these events are a limited range of cognitive error forms. More than 50% of the maintenance errors reported in the Australian survey could be placed in one of three categories: memory failures, rule violations, or knowledge-based errors (8).

### *Memory failures*

The most common cognitive failures in maintenance incidents are failures of memory. Rather than forgetting something about the past, the engineer forgets to perform an action that he had intended to perform at some time in the future. Examples are forgetting to replace an oil cap or remove a tool. Memory for intentions, also known as prospective memory, does not necessarily correlate with performance on standard measures of memory (9). Prospective memory also appears to show a marked decrease with age, a finding that may have implications for older maintenance personnel.

### *Rule violations*

Common rule violations include not referring to approved maintenance documentation, abbreviating procedures, or referring to informal sources of information such as personal “black books” of technical data.

In a study of the everyday job performance of European aircraft mechanics, McDonald and his colleagues found that 34% acknowledged that their most recent task was performed in a manner that contravened formal procedures (10). McDonald et al. refer to the “double standard of task performance” that confronts maintenance personnel. On the one hand, they are expected to comply with a vast array of requirements and procedures, while also completing tasks quickly and efficiently. The rate at which mechanics report such violations is a predictor of involvement in airworthiness incidents (11). Violations may also set the scene

for an accident by increasing the probability of error, or by reducing the margin of safety should an error occur. For example, the omission of a functional check at the completion of maintenance work may not in itself lead to a problem, but could permit an earlier lapse to go undetected.

The survey of Australian airline maintenance personnel indicated that certain critical rule workarounds occur with sufficient regularity to cause concern (12). Over 30% of LAMEs acknowledged that in the previous 12 months they had decided not to perform a functional check or engine run. Over 30% reported that they had signed off a task before it was completed, and over 90% reported having done a task without the correct tools or equipment. These procedural non-compliances tend to be more common in line maintenance than in base maintenance, possibly reflecting more acute time pressures.

#### *Knowledge-based errors*

Rasmussen (13) introduced the term “knowledge-based error” to refer to mistakes arising from either failed problem-solving or a lack of system knowledge. Such mistakes are particularly likely when a person is feeling their way through an unfamiliar task by trial and error. Most maintenance engineers have had the experience of being unsure that they were performing a task correctly. In particular, ambiguities encountered during the preparation stage of maintenance tasks may set the scene for errors that will emerge later in the task.

### **Errors and violations as symptoms of system issues**

As Jim Reason has made clear, errors and violations such as those described above may be symptomatic of latent failures in the organization (14). As such, they may call for responses at the level of systems rather than interventions directed at individuals. System issues in aircraft maintenance can be divided into two broad classes.

The first class of system issues comprises well-recognized systemic threats to maintenance quality. These issues have been so thoroughly identified that they can hardly be called “latent failures”. They include broad issues such as time pressure, inadequate equipment, poor documentation, night shifts and shift hand-overs. Smart has listed a set of factors that can increase the chance of error, including supervisors performing hands-on work, interruptions, and a “can do” culture (15). Of these factors, time pressure appears to be the most prevalent in maintenance occurrences. Time pressure was referred to in 23% of maintenance incidents reported in the Australian LAME survey (8). Time pressure was also identified as the most common contributing factor in Aviation Safety Reporting System (ASRS) maintenance reports received by NASA (16). This does not necessarily indicate that maintenance workers are constantly under time pressure. However incident reports indicate that time constraints can induce some maintainers to deviate from procedures. Although these system issues are

recognized as threats to work quality, the extent to which they are present will vary from workplace to workplace. Evaluating the threat presented by each factor is an important step towards managing maintenance related risks.

The second class of system issues can be more truly referred to as latent failures. These tend to be task-specific risks that can remain dormant for a considerable time. There are numerous maintenance tasks that are associated with a recurring error, sometimes due to difficult access, ambiguous procedures or other traps. Two well known examples are: static lines to an air data computer on a twin engine jet aircraft that must be disconnected to reach another component, with the result that the lines are sometimes not reconnected; and wheel spacers that routinely stick to a removed wheel, resulting in the new wheel being installed without the spacer.

### **Barriers to uncovering maintenance issues**

Despite the extensive documentation that accompanies maintenance, the activities of maintainers may be less visible to management than the work of pilots. A major challenge is to increase the visibility and openness of maintenance operations.

#### *Time*

While some maintenance errors have consequences as soon as the aircraft returns to service, in other cases months or years may pass before a maintenance error has any effect on operations. The world's worst single aircraft disaster resulted from an improper repair on the rear pressure bulkhead of a short range 747. The aircraft flew for seven years after the repairs were accomplished before the bulkhead eventually failed (17).

The passage of time between an error and its discovery can make it difficult to reconstruct events. Despite the extensive documentation of maintenance work, it is not always possible to determine the actions or even the individuals involved in a maintenance irregularity. In the words of one manager "Most maintenance issues are deep and latent; some items are over 2.5 years old when discovered and the mechanics have forgotten what happened" (18).

#### *Blame culture*

The culture of maintenance has tended to discourage communication about maintenance incidents. This is because the response to errors frequently punitive. At some companies common errors such as leaving oil filler caps unsecured will result in several days without pay, or even instant dismissal. It is hardly surprising that many minor maintenance incidents are never officially reported. When Australian maintenance engineers were surveyed in 1998, over 60% reported having corrected an error made by another engineer without documenting their action (12).

### *Outsourcing*

The trend towards outsourcing places another potential barrier in the way of open disclosure of incident information. Some major airlines in the US are now outsourcing up to 80% of their maintenance work (19). Third party maintenance organizations may be reluctant to draw attention to minor incidents for fear of jeopardizing contract renewals.

### **Recent progress**

In recent years, significant progress has been made in addressing the “not so latent” failures in maintenance operations. Several regulatory authorities now require maintenance error management systems that include human factors training for maintenance personnel and non-punitive reporting systems. For example, the UK Civil Aviation Authority (CAA) has released Notice 71 that encourages operators to introduce maintenance error management programs. A central part of such a program is a reporting system that allows people to report maintenance occurrences without fear of punishment. The CAA states that “unpremeditated or inadvertent lapses” should not incur any punitive action. In the US, maintenance Aviation Safety Action Programs (ASAP) are being introduced, enabling maintainers to report inadvertent regulatory violations without fear of retribution. The success of such programs will depend on recognizing the spectrum of unsafe acts in maintenance, encompassing errors, violations, negligence and recklessness, and defining in advance the types of actions that can be reported without fear of punishment (20). Establishing a clear policy on blame and responsibility should be a high priority for companies and regulators alike.

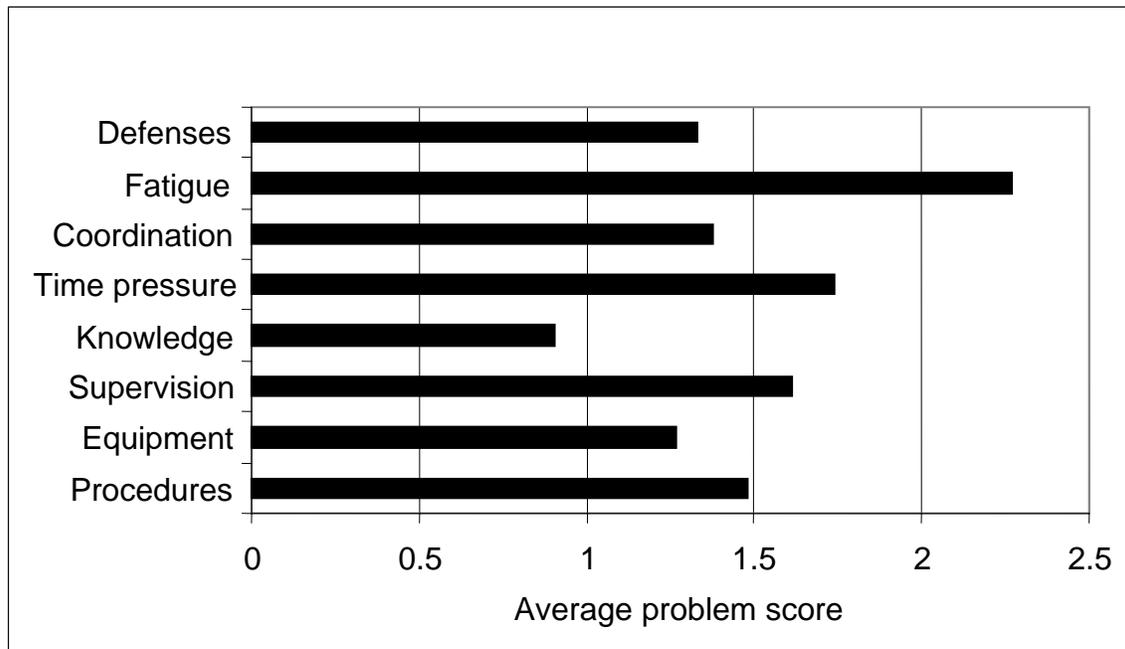
### *Investigation approaches*

Structured investigation approaches are increasingly being introduced within maintenance. Systems include the Aircraft Dispatch and Maintenance Safety (ADAMS) investigation framework (21) and Human Factors Analysis and Classification System – Maintenance Extension (HFACS-ME) (22). The oldest and most widely known system is Boeing’s Maintenance Error Decision Aid (MEDA), now used by approximately 50 airlines worldwide (6). MEDA presents a comprehensive list of error descriptions and then guides the investigator in identifying the contributing factors that led to the error.

### *Monitoring organizational conditions*

In recent years several proactive systems have been developed to measure safety culture in maintenance organizations. These include the Maintenance Climate Assessment Survey (MCAS) (23), Maintenance Resource Management Technical Operations Questionnaire (MRM-TOQ) (24), Managing Engineering Safety Health (MESH) (25) and the Maintenance Environment Questionnaire (MEQ). The Maintenance Environment Questionnaire was developed in Australia

and is based on an earlier checklist administered to over 1200 maintenance engineers (11). The MEQ was designed to evaluate the level of error-provoking conditions in maintenance workplaces. The MEQ evaluates the following seven error-provoking conditions: Procedures, Equipment, Supervision, Knowledge, Time-pressure, Coordination, and Fatigue. In addition, the questionnaire contains items addressing maintenance defenses, or “safety nets” in the system. The eight factor scores are the main output of the survey. Once the questionnaire has been completed by a sample of maintenance personnel, the ratings are combined to create a profile similar to the example shown in figure 2.



*Figure 2. Example of a maintenance environment profile for a line maintenance organization.*

## Conclusion

Advances in technology throughout the last century have enabled the number of flight crew members to be progressively reduced to the standard complement of two on current aircraft. Developments in UAV technology have already led to unmanned combat aircraft. Unmanned civilian cargo aircraft may be in service before long.

Despite continuing advances in vehicle health monitoring and built in test equipment, the work of maintenance personnel is unlikely to be automated in the near future because maintenance activities present challenges that at present, only humans can meet. We may be able to auto-fly but we cannot “auto-maintain”.

In order to understand maintenance deficiencies and the conditions that lead to them, it is necessary to appreciate the demands that maintenance work places on the individual maintenance worker, and the types of errors and violations that occur in response to these demands. Memory lapses, procedural non-compliance and knowledge-based errors are significant classes of unsafe acts in maintenance.

Some of the conditions that promote errors and violations in maintenance have been clearly identified in recent years. For example, fatigue and time pressure are widely recognized hazards. In these cases, policies regulating hours of work, and maintenance resource management (MRM) training are potentially effective countermeasures (26).

Other threats to maintenance quality are harder to identify. These include recurring errors, traps in procedures, and practices that introduce unacceptable iatrogenic risks. The potential for delay between maintenance actions and consequences can present a problem for reactive investigations. The blame culture that pervades much of the industry can make it difficult to proactively identify threats to maintenance quality. One of the most pressing challenges now facing the maintenance sector is not technical in nature, rather it is how to foster a spirit of glasnost to promote incident reporting and the disclosure of incident information.

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