Understanding Real-World Aviation Maintenance Performance Through Scenario Interviews

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SUMMARY

This study explores systemic contributors to maintenance issues using the Human Factors Analysis and Classification System (HFACS) framework. Through scenario-based interviews with experienced maintenance professionals, the research identifies how technicians adapt their practices to overcome design limitations, environmental challenges, and organisational pressures.

The findings indicate that maintenance personnel sustain safety by continually modifying their work practices to address system constraints. This provides valuable insights into how safety in real-world settings arises from everyday adjustments rather than solely from adherence to established procedures. Recognising human adaptability helps aviation stakeholders enhance system resilience by aligning procedures, training, and system design with real work practices, thereby continuously improving safety.

KEYWORDS

Aviation Maintenance, HFACS, SITT, Systemic Factors

Introduction, Rationale and Conceptual Positioning

Recognising the importance of understanding how humans perform has long been a focus of safety research, emphasising systemic factors that shape complex events and how people adapt to meet operational demands (Wears & Hollnagel, 2017). Aviation maintenance is a high-risk, regulated field where human performance affects safety (Kanki & Hobbs, 2022). Aviation maintenance incidents frequently result from interconnected mechanical, organisational, and human factors rather than isolated mistakes. Rashid et al. (2013) emphasised that these incidents stem from conditions embedded in organisational processes. Hobbs (2021) noted that design constraints, environmental pressures, and workload variability shape maintenance work and influence human performance. He also observed that, although maintainers often justify procedural deviations as essential for task completion, such non-compliance underscores the ongoing disparity between formal procedures and real-world practice. Hollnagel (2014) argued that variability in performance is inevitable in complex systems and that resilience depends on the ability of people to adjust effectively under changing conditions. This study examines how aviation maintenance personnel experience and respond to operational challenges, recognising the complexity beyond simple errors. It analyses how unexpected circumstances occur and how personnel adapt, exploring their perceptions of operational challenges and how they adapt to meet complex operational demands while maintaining safety. The aim is to identify the systemic factors that shape performance variability and how these factors interact within complex operational settings.

Design, Participants, and Contextual Boundaries

Fifteen experts—including mechanics, engineers, supervisors, accident investigators, and pilots—from the aviation maintenance sector participated in approximately one-hour semi-structured interviews. A purposive sampling strategy was followed as initial participants were selected to represent a diverse group of experienced aviation operators to ensure a broad spectrum of insights. Then, Snowball sampling was used to increase the number of participants, with initial participants recommending other qualified individuals. The research employed a scenario-based technique, specifically the Scenario Invention Task Technique (SITT) (Pabel & Naweed, 2019), to collect data. Participants, possessing between 6 and 35 years of experience, engaged in discussions regarding the issues presented in each scenario through the use of open-ended questions and prompts that encouraged sharing real-life examples. Two scenarios, based on recent and real U.S. NTSB incident reports involving fastening errors that led to in-flight incidents, served as the foundation.

The questions began with general inquiries about participants' roles, aviation maintenance experience, training, and education to establish expertise. Participants then described each scenario's problem through open-ended questions without prompts. Follow-up questions investigated areas highlighted by participants, ensuring a thorough investigation of potential factors. Additional questions aimed to obtain concrete examples from participants' experiences related to the scenarios. After explaining a specific question, follow-up questions clarified the reasoning. Prompts such as “Could you please explain more?”, “Would/Why do others think similarly?” and “What made you think that?” were used to gather detailed explanations. All participants received similar prompts across both scenarios.

Analytical Pathways

Thematic analysis (Braun & Clarke, 2021) was employed to identify specific themes within the data. Themes were analysed and reported through coding using NVivo software. HFACS by Wiegmann and Shappell (2003) was used as a guiding framework to structure the analysis. Subsequently, the complex interconnected causal factors within different HFACS systemic levels reported by the participants emphasise the value of adopting a systematic approach to understand these novel interrelationships.

Navigation of Interconnected Challenges in Practice

Participants cited challenges in their performance. Table 1 presents the types of challenges participants identified as constraining maintenance performance.

Participants described non-prescribed adaptations used to negotiate these challenges and maintain safety when procedures alone were insufficient. The adaptive behaviours included examples, as shown in Table 2.

In the four systemic levels of HFACS there are 15 possible interconnections of types of factors. Table 3 presents 9 different examples of interconnections between causal factors that were identified.

Table 1: Challenges Faced by Participants and Their Explanation (System Constraints Identified)

Themes of Challenges	Examples of How Participants explained the System Constraints
Design Limitations	
-Poor Manufacturer Modifications. -Complex Design -Over-design of Parts -Ambiguities in Manuals -Lack of Standardised Codes	*M1: …"we've removed a canopy and a washer that needed to be fitted wasn't fitted, so it was a complex hinge mechanism with multiple fasteners and different bolts of different measurements and it was complex. It wasn't as so as simple as you get…this one was a bolt with multiple washers…You needed multiple people to put in it together, essentially to then fasten it, and then it would be torqued wire locked…Every manufacturer, every country designs aircraft in different ways, but some countries may have a certification specification or airworthiness codes…all depends on what system it is and what the risk of that failing or not being completed correctly"*
Inadequate Supply Operations	
-Supply Deviations -Availability of Items -Inaccurate parts details	*M3: … "there's been an issue with packaging or logistics supply system... They put the wrong nut in the bag that had the details.... especially with some of small nuts for example, they could look similar, they could look exactly the same size "*
Operational Challenges Affecting the Task	
-Environmental Challenges -Hard to Detect System Failures -Accessibility Issues -High Levels of Expertise Required	*M2: …"In my experience with ejection seats, there are specific types of springs that need to be fitted. However, the springs often look very similar. The same maintenance team might be working with these parts for years…can lead to confusion and errors…if the part's accessibility is too difficult. For example, during post-flight checks or maintenance checks, it might be hard to identify that there was no wire locking until a deeper maintenance check is done. That would essentially be somewhat of a design issue, but more about accessibility than the mechanical connection…. sometimes, harder-to-access parts become easier to miss during installation"*
Psychological Challenges	
- Time Pressure -Exceeded the Limit of Working Hours -Stress -Peer Pressure	*A6: …"You could name any component in any system and these things happen. If a technician is in a rush to finish a job… a pressured technician might still proceed, even though it's wrong and shouldn't be done "* *M8: …"particularly with ageing aircraft or heavily tasked aircraft or there's a lot of pressure…there was a panel which had a lot of fasteners…regularly some of those fasteners were subject to a deferral…. When you've got a lot of fasteners with potentially a lot of other maintenance paperwork that can sometimes detract from the core principle"*

Table 2: Examples of Non-Prescribed Adaptations Used by Participants to Maintain Safety

Themes of Adaptations	Example of Participants' Adaptations
Professional Judgement in Long-Term Escalation of Systemic Design Issues	*A4: …"an example…like afterburner…A movement panel… happening during flying and we found some of these panels cracked … because of the high vibration… checked all engines we found the same problem …. we raised it to the manufacturer to manufacture a better material….which does work"*
Halting Installation Outside Routine Supply Procedures	*M8: …"It is not until we install the aircraft that we figure it out before we start installation…I think that's happening from the supply that we ordered the bar…when we need to reinstall, we see the serial number is not matching"*
Use of Non-Prescribed Functional Testing to Detect Deviations	*M4: …"when fitting a component… would do a leak check to find that fasteners haven't been done up correctly…we've had experiences with V-band clamps not being torqued up correctly and they have been found on leak checks"*
Application of Extra Safety Precautions Beyond Procedures	*A6: …"most of our things would also be wire-locked…you would put torque marks on a lot of things, so it was probably less prevalent when you've got those additional mechanisms"*
Conducting Extra Post-Task Checks Prior to Release to Service	*A5:…" After I went back to the tool store to return all the tools, I found a spanner missing…looked for the spanner around the aircraft, no spanner…put the engine down again…found the spanner on top of the engine…forgotten it on top of the engine…lucky because the aircraft was still on the ground"*

Table 3: Identified Themes of Interconnected Causal Factors Within the HFACS Taxonomy, Management Conditions (MC), Working Conditions (WC), Human Conditions (HC), Human Acts (HA)

Type of Interaction	Type of levels within HFACS	Example of Interaction in HFACS sub-levels
Single level	WC-WC	Poor design of parts and vibration during service.
	MC-MC	Poor supply and inadequate inspection by the organisation
	HA-HA	Improper installation of aircraft parts by the maintainer and the use of incorrect parts
Two level	HC-HA	State of mind of maintainer and improper installation by the maintainer
	WC-MC	Inadequate maintenance procedure and poor design of parts
	WC-HA	Incorrect part being used by the maintainer and vibration during service
	HA-MC	Lack of quality control in the organisation and improper installation of a part by the maintainer
Three level	HC-WC-MC	Poor design of a part, poor technician experience and availability of spares
	WC-HA-MC	Poor supply and improper installation by a maintainer and dated items fitted

Firstly, the factors that interconnect within a single HFACS level were identified, such as within WCs, MCs, and HAs. This is exemplified by M2, who provided the following account for factors within the HA level:

"*…It was visually easier to identify the difference because the newer type was either bronze or silver. However, given that it's just a part the technician takes off the shelf and how insignificant that part seems to the overall system integrity, it was missed... The incorrect part had been installed on seats for years, and the same technician might have been using the wrong part without realising it due to its insignificance…*"

The evidence from the incident states that the difference between the correct and incorrect parts was visually apparent. However, because the part seemed insignificant and was routinely taken off the shelf in habitual use, the technician did not recognise the error. The repeated practice over time of using the wrong part without realisation points to systemic variability in maintenance practices. If a technician unknowingly installs an incorrect part, the improper installation is a direct consequence of the part being misidentified, which means the two issues are interconnected.

Secondly, factors that interconnect across two HFACS Levels were identified. For example, A7 stated the following account for factors across WC and HA levels:

"...It wasn't solely due to the vibration; it was due to the incorrect parts being fitted..."

Lastly, causal factors that interconnect across three Levels were identified. For example, A1 explained how the HC, WC, and MC interconnect:

"…so it was all these different things coming together that would, even when they would change the design slightly, it still kept happening because they weren't addressing everything… it wasn't one single thing that was causing it; it was the design, the availability of spares, … the technicians around, they didn't always have that experience ….it was all these things that would come together and... you weren't seeing this every day,.., once, twice a year…Because we'd keep getting safety notices about it, so it shows that the mitigations are ineffective. I think that's quite relatable to this one…".

Understanding Adaptive Performance in Aviation Maintenance

Aviation maintenance occurrences in real-world settings stemming from interactions among procedures, working conditions, and frontline maintenance actions, rather than from isolated errors or procedural deviations. Humans adapt their work to navigate systems' constraints, emphasising the importance of adaptation in routine maintenance tasks. Participants showed system awareness by understanding operational realities and considering how organisational and contextual factors influence documentation and practices expectations. They highlight that maintenance is performed by informed practitioners who interpret and adapt to system conditions to ensure safe task completion when procedures do not fully account for operational realities, rather than simply following prescribed procedures. Adaptations were often described as professional judgements made to maintain system integrity under real-world conditions.

Humans in aviation maintenance adapt their practices to systemic challenges and their performance varies depending on the risks encountered. Adaptive strategies were to ensure safety, such as secondary inspections and post-task checks that align with concepts in resilience engineering (Hollnagel, 2014). Rather than deviating from safety, these adaptations help maintain it amid uncertainty. The findings support the view that performance variability is a necessary part of working in complex socio-technical systems, where experience and professionalism of those involved in maintenance are essential to safe performance when procedures alone are insufficient.

While adaptations support safe local outcomes, their informal nature questions organisational learning. Many adaptive practices depend on individual experience rather than systematic documentation or sharing. Without mechanisms to highlight these adaptations within existing regulatory and organisational frameworks, organisations may rely on individual resilience instead of addressing systemic issues. While adaptations are essential, their informal nature can also obscure underlying systemic issues. This highlights the need for a just culture that promotes open reporting, understanding, and learning, enabling organisations to value adaptations.

Key Learning Points for Stakeholders

The research shows that aviation maintenance personnel recognise the importance of their adaptability in maintaining safety during real-world maintenance activities. It provides evidence of systemic interconnections that affect maintenance outcomes. The paper presents insights into how maintenance staff handle operational variability and adapt to circumstances within complex systems. Aviation stakeholders could empower maintenance personnel's adaptive expertise by supporting professional judgement, reducing constraints that inhibit adaptative behaviours, and providing resources to help frontline staff to effectively address emerging challenges. Recognising and supporting adaptive abilities enables stakeholders to strengthen resilience in maintenance system by creating a flexible, learning environment. This approach ensures that system design and training can adapt to maintenance realities, thereby continuously enhancing system safety.

Emergent Insights and Core Contributions

The study provides an in-depth analysis of the complexities faced by aviation maintenance personnel when fastening aircraft parts. It identifies various systemic factors within HFACS levels, such as working conditions and human actions, that contribute to maintenance incidents in aviation, showing how the outcomes, or rather maintenance issues, can emerge from the interaction of these factors. The results highlight that maintenance personnel operate within tightly connected socio-technical systems where they must continuously adjust their performance to maintain safety. The results reveal that human errors in fastening components are rarely isolated acts but rather the result of interconnected systemic factors at different levels. Mapping these findings within HFACS uncovered multiple cross-level interconnections between management conditions (e.g., inadequate quality control), working conditions (e.g., vibration, design issues), human conditions (e.g., fatigue, limited experience), and human acts (e.g., improper installation or inspection lapses). These connections indicate that maintenance problems originate from systemic coupling rather than simple cause-and-effect relationships. Interconnected organisational issues, work conditions, and human performance are closely coupled, such that modifications in one can influence others. For example, a technician might improperly tighten an aircraft component, which on its own might not cause a failure. However, if the component also has a design flaw—such as a tendency to vibrate during flight—the combination of the incorrect tightening and vibration could result in a failure during operation. Interviews with aviation maintenance personnel showed that they acknowledged variations in their performance during routines, interpreting these as the results of systemic factors rather than isolated individual errors. For instance, design limitations and operational challenges like accessibility create practical constraints that can lead to such maintenance incidents. Maintenance staff actively adapt their interactions with systems to cope with challenges in the work environment, demonstrating resilience by adjusting their work practices. This research advocates for incorporating practical experiences to ensure procedures are relevant to real-world conditions. By focusing on how maintainers adapt to system limitations, this study extends HFACS-based systemic models towards a more integrated understanding of performance variability.

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References

Braun, V., & Clarke, V. (2021). Thematic Analysis: A Practical Guide. SAGE Publications. https://books.google.com.sa/books?id=mToqEAAAQBAJ

Hobbs, A. (2021). Aircraft maintenance and inspection.

Hollnagel, E. (2014). Safety-I and Safety-II: The Past and Future of Safety Management (1st ed.). CRC Press.

Kanki, B. G., & Hobbs, A. N. (2022). Maintenance human factors and flight safety. In Human Factors in Aviation and Aerospace, Third Edition (pp. 477–515). Elsevier. https://doi.org/10.1016/B978-0-12-420139-2.00019-8

Pabel, A., & Naweed, A. (2019). Scenario Invention Task Technique (SITT): a practical innovation for qualitative research in a reef tourism study. Travel and Tourism Research Association: Advancing Tourism Research Globally, 89. https://scholarworks.umass.edu/ttra/2019/research_papers/89

Rashid, H. S. J., Place, C. S., & Braithwaite, G. R. (2013). Investigating the investigations: a retrospective study in the aviation maintenance error causation. Cognition, Technology & Work, 15(2), 171–188. https://doi.org/10.1007/s10111-011-0210-7

Wears, R. L., & Hollnagel, E. (2017). Why is Work-as-Imagined Different from Work-as- Done? In Resilient Health Care (1st Edition, Vol. 2). CRC Press. https://doi.org/10.1201/9781315605739

Wiegmann, D. A., & Shappell, S. A. (2003). A Human Error Approach to Aviation Accident Analysis: The Human Factors Analysis and Classification System. CRC Press LLC. http://ebookcentral.proquest.com/lib/nottingham/detail.action?docID=429630