Lesson Learned: the similarities and differences of human factors in Aircraft Maintenance between JL123 and CI611

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SUMMARY

This paper makes use of the human factors analysis and classification system (HFACS) to analyse maintenance-related causal factors of two accidents - Japan Air Lines (JAL) flight 123 (JL123) and China Airlines (CAL) flight 611 (CI611). Furthermore, the pathways that could have resulted in the two accidents were identified by applying the HFACS framework. The study also compares the similarities and differences between these accidents. The findings of this paper lend support to past research on HFACS where higher levels at an organisation have been shown to have directly affected the lower levels. Lessons from these accidents have also been identified in order to prevent recurrences.

KEYWORDS

Active failure, Human Factors Analysis and Classification System, Latent Failure

Introduction

Over the years, there has been a shift in the human factors focus on determining the causes of aviation accidents during investigations. The current focus includes decision-making, supervisory factors and organisational culture among others as compared to the earlier focus on skill deficiencies. The human factors analysis and classification system (HFACS) framework by Shappell and Wiegmann (2001) allows investigators to focus on these factors and it is based on Reason's organisationally based model of human error (Reason, 1990). This framework has four levels which are level 1 (unsafe acts of operators – active failures), level 2 (preconditions for unsafe acts – latent and active failures), level 3 (unsafe supervision – latent failures) and level 4 (organisational influences- latent failures). The relevance of the HFACS framework in human factors can be seen in its modern applications in human reliability assessment for complex space operations (Alexander, 2019). The framework was also recently applied as a proactive prevention in public health during COVID-19 (Bickley & Torgler, 2021) and most relevant to this paper is the adaptation of the framework to aircraft maintenance deviations (Illankoon et al., 2019). The HFACS framework is depicted in Figure 1.

Past research has concluded that there is a relationship between the errors that occur at lower levels and inadequacies at higher levels in an organisation (Li & Harris, 2013). The accident of JL123 saw the rupture of the pressure bulkhead that led to a loss of flight control that subsequently led to the crash of the aircraft (Aircraft Accident Investigation Commission, 1987). The accident of CI611, on the other hand, involved the in-flight break-up of the aircraft as it approached its cruising altitude (Aviation Safety Council, 2002). Problems with maintenance have been considered as having had the most significant impact which allowed these two accidents to occur (Jiang, 2020). Thus, the aim of this paper is to analyse and compare the maintenance-related causal factors of JL123 and CI611 accidents using the HFACS framework in order to learn lessons and prevent recurrences.

Methodology

This is a qualitative study of applying the HFACS framework which consists of 18 categories to analyse the JL123 and CI611 accident reports to determine causal factors related to maintenance. Four aviation human factors researchers formed a subject matter expert focus group and conducted a content analysis based on the accident reports. The analysts had received detailed training on the HFACS framework. The presence (coded 1) or absence (coded 0) of each HFACS category was evaluated from the narrative of each accident report. Where there were discrepancies in the categorisation of an accident, the researchers convened and resolved differences in observations.

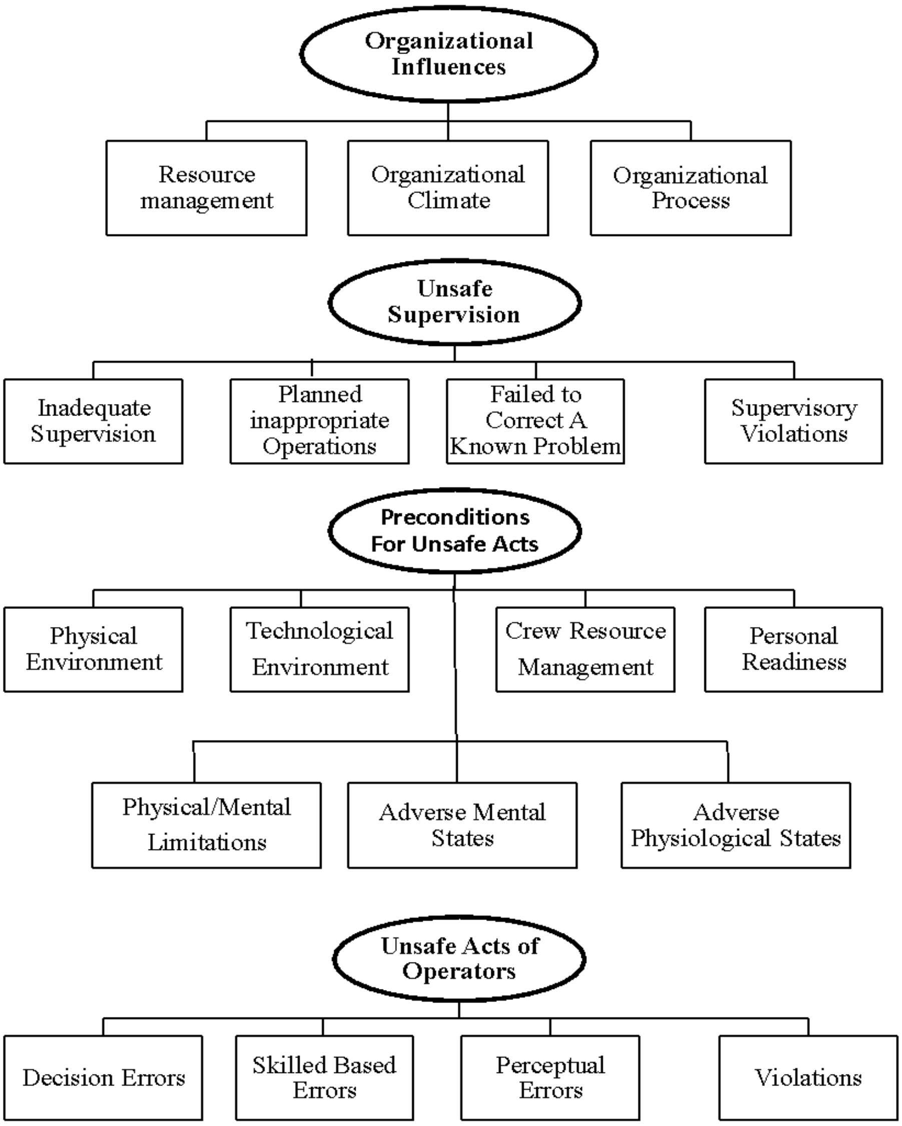

Figure 1: The HFACS framework- Shappell and Wiegmann (2001)

Results and Discussion

The two accidents were analysed and discussed in the focus group and the similarities and differences based on the executive summaries of official accident reports for both aircraft were identified.

Similarities and differences between CI611 and JL123 Accidents

The similarities between the two accidents are straightforward. In both instances, the aircraft involved were Boeing 747 models and the aircraft had suffered a tail strike prior to the actual accidents. Moreover, the maintenance work done after the tail strike was not according to the Boeing Structural Repair Manual (SRM). The lack of quality follow-up-maintenance inspections, post-repairs, was also observed in both instances. This may have resulted in maintenance personnel in both cases not detecting cracks from metal fatigue following the repair works. Furthermore, both airlines during the planning phase had aimed at carrying out proper repair works, however, the actual repair works done were different from the intended corrective measures. Lastly, maintenance records were found to be incomplete in both cases.

The series of aircraft models involved in both accidents were different. In the case of CI611, repair works on the bulkhead after a tail strike incident was conducted internally by CAL Engineering Maintenance Division (EMD). On the other hand, JL123 repair works on the tail were conducted by a Boeing AOG (Aircraft on Ground) repair team dispatched by Boeing and contracted by JAL. The accident of CI611 resulted in the disintegration of the body of the aircraft into different parts, whereas flight JL123 had only lost its tail prior to crashing. Flight radar data indicated that the JL123 bulkhead raptured at about twenty-four thousand feet whilst the complete disintegration of CI611 occurred at a higher altitude of about thirty-four thousand nine hundred feet above mean sea level. Additional information on the comparison can be found in Table 1.

Table 1: Comparison between JL123 and CI611

Flight	JL123	CI611
Type of Aircraft	Boeing 747 SR-100	Boeing 747-200
Manufactured Date	30 January 1974	15 July 1979
Total Flight Hours	25,030	64,810
Prior Tail Strike Incident Date	2 June 1978	7 February 1980
Accident Date	12 August 1985	25 May 2002
Year interval between Tail Strike and Crash	7 years	22 years
Number of Casualties	520	225
Total Number of landings	18,835	21,180

The rupture of the tail bulkhead of JL123 destroyed the hydraulic lines which controlled the pitching and yawing movements of the aircraft; this in turn led to the loss of flight controls. Flight characteristics of JL123 made it difficult for pilots to control. The captain and first officer (FO), however, put in significant efforts by combining available crew resources (use of power levers and aileron controls) to control the aircraft. In spite of all efforts of the flight crew, JL123 eventually crashed (Aircraft Accident Investigation Commission, 1987). Such a demonstration of Crew Resource Management (CRM) needs to be commended given the fact that more than half of events involving loss of flight control result in an accident and half of these accidents result in a catastrophe (Jacobson, 2010). The timely and effective CRM applied moments before the crash of JL123 may have allowed those four individuals to survive such a tragedy.

Analysis using HFACS framework

The focus group also involved categorising each of the causal factors from JL123 (three points) and CI611 (six points) as listed in the executive summary using the HFACS framework. The causal factors were discussed to determine the pathway between the HFACS categories that might have been followed and resulted in the accidents. All pathways for JL123 (in blue) and CI611 (in red) identified in the focus group are in Figure 2. The solid lines represent the direct relation between a high level and their immediate lower level on the HFACS framework. Furthermore, the dotted lines represent a direct relationship between higher levels of HFACS (level 3 and level 4) and lower levels (level 1 and level 2). The dotted lines thus denote that actions at the highest level can directly impact the lowest levels without necessarily interacting with the levels in between. Solid black boxes bring focus to the categories of the HFACS that were found to be relevant for the two accidents. On the other hand, the grey dotted boxes represent categories found to be unrelated to the two accidents.

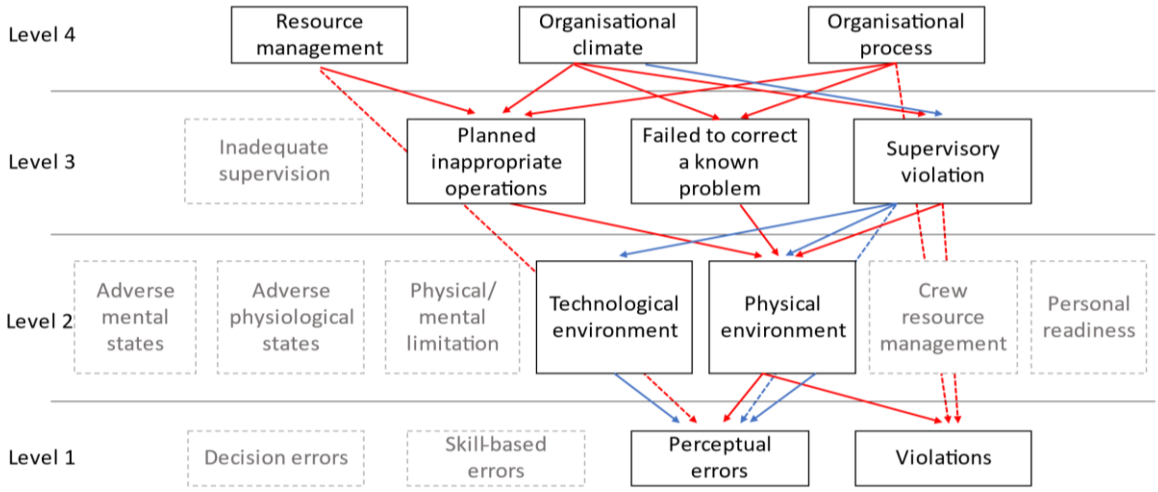

Figure 2: Pathway between the HFACS categories for JL123 (blue) and CI611 (red)

Impact pathway for JL123 accident

The impact pathway for JL123, as determined by the participants, is depicted using the colour blue in figure 2. For JL123, the organisational climate (level 4), such as poor safety culture, could have led to supervisory violations (level 3) during the repair works. Such violations could have resulted in improper repairs being carried out after the tailstrike incident. Additionally, supervisory violations may have also contributed to the lack of proper checks during subsequent inspections in the years following the tailstrike incident. Such supervisory violations during the repair might have led to a deterioration of the technological environment (level 2) during the flight in the form of the loss of primary flight controls.

Moreover, it could have been that failures at the higher levels could have had a direct impact on the failures at the lower levels for the JL123 accident. These pathways are represented by dotted blue lines in figure 2. In the case of JL123, it could have been that supervisory violations (level 3) in the form of improper repair work carried out under the direction of the supervisors might have directly led to perceptual errors (level 1) in the form of the maintenance staff's inability to detect cracks during the inspection.

Impact pathway for CI611 accident

The impact pathway for CI611, as determined by the participants, is depicted using the colour red in figure 2. For CI611, the possible poor organisational climate (level 4) at CAL and its poor resource management (level 4), such as not providing magnifying glasses and lighting during the inspection, could have led to supervisory violation (level 3) in the form of improper maintenance operations which in turn could have impacted the physical environment (level 2) of the maintenance team, for example, poor lighting condition. These findings, therefore, are similar to the findings of Li & Harris (2013) given that in both accidents, factors at lower levels like perceptual errors and physical environment are impacted by higher levels like supervisory violation and poor organisational climate.

Just like for JL123, in the case of CI611, there were also possible situations where failures at higher levels could have directly impacted the lower levels. These pathways are represented by dotted red lines in figure 2. In the case of CI611, it was suspected that violations and perceptual errors (level 1) made by maintenance staff like not carrying out the right repair following the tail strike incident and failing to observe the impact of the wrong repairs during subsequent inspections could have been direct consequences of organisational process and resource management (level 4) respectively. Poor resource management (level 4) could be depicted, for example, by the inability of CAL to provide eddy-current detection tools to conduct a non-destructive test during subsequent inspections.

Participants also deemed that the catastrophic outcome of the CI611 accident could have been avoided had the safety culture at CAL been more positive. Another possible explanation of the impact pathway of the accident can be explained with regards to the safety culture. According to Li and Harris (2006), national culture affects the safety culture of an organisation. The latter, in turn, is heavily dependent on the actions of senior management. The lack of suitable actions from the senior management with regards to safety at CAL has already been previously identified. It is worth noting that the aircraft involved in the accident was allowed to remain in operation even with evident safety issues (following the tailstrike incident) since 1997. This means the organisation had at least five years to make corrections to the improper repairs had inspections been carried out properly. This brings into focus the attitudes of the senior management which could have negatively impacted the safety culture at CAL. Such a safety culture could have impacted resource management, organisational climate, and organisational process (level 4). This, in turn, could have led to failures at level 3 like planned inappropriate operations, failed to correct a known problem, and supervisory violation. All of which could have been a result of the poor or lack of quality supervision from middle-level management. Failures at level 3 could be the failure to carry out the appropriate repairs and delays in carrying out the said repairs. The lack of supervision (another failure at level 3) might have also impacted the physical environment (level 2) for the maintenance team carrying out the supervision in the form of poor lighting and lack of magnifying glasses.

Similarities between the impact pathways of JL123 and CI611 accidents

The maintenance supervisors are responsible to provide their personnel with resources, facilities and a working environment to succeed and ensure repairs are done safely and efficiently (Harris & Li, 2011). It was deemed that for the maintenance supervisors at JAL (Boeing maintenance company) and those at CAL (CAL EMD), these qualities were absent and this was a possible supervisory violation. Such a supervisory violation (level 3) may have affected the performance of the maintenance engineers carrying out the repairs and the maintenance environment generally that could have allowed perceptual errors (level 1) during repair works in the case of JL123 (represented by the blue dotted line) and violations of Boeing SRM in the case of CI611 (represented by red dotted lines).

Interestingly, for both JL123 and CI611 accidents, no pathways connecting adverse mental states, or physical/mental limitations (level 2) were found. This means that the participants did not classify these categories as having contributed to the occurrence of the two accidents. The findings of this analysis are dependent upon the causal factors identified in the official reports. It may have been that the accident reports did not find any such psychological precursors at the management and supervisory level of maintenance as contributing factors to the accidents.

Differences between the impact pathways of JL123 and CI611 accidents

In the case of JL123 only one category, that is, organisational climate from level 4 seems to have played a role in the occurrence of this accident. It could be that the organisational climate at JAL disregarded or did not prioritise safety. This could have been the precursor for supervisory violation (level 3) to take place that allowed improper repairs to be made. Supervisory violation was the only category from level 3 that was identified as part of the HFACS analysis. Subsequent pathways that may have allowed the accident to occur have been described above. On the other hand, in the case of CI611, all of the categories from level 4, which are poor resource management, poor organisational climate, and poor organisational process, seemed to have impacted three of the four categories at level 3, which included supervisory violation, planned inappropriate operations and failure to correct a known problem. It could be that the poor organisational culture may have affected numerous levels within CAL. A lack of appropriate response after the tailstrike from the top management at CAL (failure to correct a known problem) might have resulted in delayed repair works and the planning of inappropriate maintenance works which did not follow the procedures as recommended by Boeing (planned inappropriate operations) both of which could have been a result of poor supervision. Subsequent pathways that may have allowed the accident to occur have been described above.

Additionally, in the case of the CI611 accident, poor resource management (level 4) like not providing the maintenance teams with the appropriate resources (like magnifying glasses and proper lighting) might have directly led to perceptual errors (level 1) by the maintenance teams. Due to the unavailability of proper resources, it could be that the maintenance teams were unable to properly carry out inspections following the tailstrike incident. Furthermore, the organisation process (level 4) perhaps not taking immediate action following the tailstrike incident and delaying repair work could have resulted in violations (level 1) in the form of the incorrect repair being done after the tailstrike incident. This pathway is represented in red dotted lines in figure 2. No impact of level 4 directly on level 1 was observed in the case of the JL123 accident.

Conclusion

The aviation industry can learn lessons from the accidents of JL123 and CI611. Based on the findings of this study, for there to be a significant improvement in the overall safety of aviation maintenance, interventions must primarily focus on level 3 and level 4. This study identified “organisational climate”', “resource management” (level 4) and “supervisory violation” (level 3) that impacted lower levels in both cases. Additionally, the study also highlighted the importance of national culture and its impact on CAL’s organisational safety culture which significantly contributed to the crash of CI611. It is thus possible to conclude that to avoid recurrences, the culture of the country and the airline will need to be one that prioritises safety and takes timely actions. The development of a good safety culture needs to be a top down process. For the safety culture to succeed, it is imperative that all shareholders like the senior management, the middle management, and the lower-level operators within an airline are involved. Continuous monitoring in the form of regular safety inspections and audits must take place. Proper records of these inspections must be maintained for future reference. Findings of these inspections and audits must be used to continuously improve the safety standards within an airline. Lastly, the regulators must work towards improving the safety standards by providing airlines with proper inspection training and by keeping a watchful eye on the operations carried out by the airlines, especially those that raise safety-related concerns.

This study lends support to the theoretical basis of the HFACS framework and past research. Future accidents can be avoided by targeting changes in the areas identified above. Effective human factor interventions need to be introduced to prevent the recurrence of such accidents.

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