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The Intellectual Insights in Forensic Investigations of Airplane Accidents

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Abstract:

Forensic evidence plays a critical role in determining the cause of an airplane crash. Such evidence can range from individual problems with materials and sub-systems that lead to catastrophic failure, to performance anomalies, design issues and flawed regulations. The goal of this essay is to explore the role of forensic evidence in a series of aviation accidents with the purpose of de-emphasizing notions of culpability and competences of the crew as the primary causes of crashes. It suggests a wider application of forensic science also to structures and systems surrounding the aircraft, and hence a more multidisciplinary response to the issues of contemporary aviation safety. The improvement in the latter and the prevention of future incidents ought to be the common goal of the aviation industry, regulatory bodies, passengers and general public. The discussion is structured around the basic principles of the inquiry conducted by the forensic investigator. The main focus is on the three types of evidential consideration in a typical forensic account: physical (deconstructive analysis, expert examination of the airframe wreckage, aircraft systems and engines), environmental (consideration of the wider airline operation, strategic aspects of company policy, weather, air traffic control), and systemic causes (structural and organizational issues at the level of airline management, regulatory bodies, government, procedures and standards in the sphere of air travel). There is a potential discussion of the wider types of evidence within each of these categories that becomes the context of an exposition, in real-life detail, of the various contributing factors within the aforementioned planes dynamics.

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INTRODUCTION

Research in aviation safety has led to important developments in the aviation industry. Broadly defined, aviation encompasses the activities associated with mechanical flight and the airline industry (Johnson, 2021). The importance of investigating aviation accidents has surged with the increase in the number of aircrafts (Okine *et al.,* 2024). The aviation industry is one of the most heavily regulated sectors in the world, and the globalization of the industry has significantly increased the amount of regulation established by national, regional, and international bodies (Sun *et al.,* 2024). Similarly, aviation accident investigations follow a broad regulatory framework (Bills *et al.,* 2023). Overall, due to the international nature of the industry, aviation accident investigations are more structured than any other type of accident investigation worldwide (Garcia, 2023).

On May 25, 1979, an American Airlines DC-10 experienced a crash immediately after takeoff from Chicago's O'Hare Airport, prompting an investigation that lasted six months—longer than any prior crash investigation (E. 1980- Vatz, 2004). This incident highlighted the intricate nature of forensic investigations in aviation accidents (Wigger, 2023). In an average year, the United States sees approximately 2,000 reported aviation incidents, a number that pales in comparison to the significantly higher frequency of truck and automobile accidents (Tozer, 2022). A meaningful comparison can be drawn between airline incidents and more prevalent vehicular collisions (Balcerzak *et al.,* 2024). Typically, when a trucking accident occurs, local police respond to the scene within minutes, often being the first emergency responders (Wright and Uchneat, 2021). Soon after, state troopers arrive, followed by insurance investigators, who document the scene by measuring skid marks and attempting to reconstruct the events leading to the accident (Smith, 2021). In stark contrast, airline accidents remain at the crash site for an extended period without immediate removal (Wang, 2022). Generally, the crash location is preserved for thorough examination, with investigative teams scrutinizing everything from the fuel lines of an engine to the eventual position of the aircraft's tail (Knezevic, 2021). In many air accident scenarios, the initial responders are often media crews, with camera operators arriving before print journalists, who then sift through personal effects for opportunities to interview grieving families (Vasigh and Azadian, 2022).

Importance of Forensic Studies in Airplane Accidents

A top priority of any civilized society is the safety and security of its citizens (Chukwu *et al.,* 2024). Therefore, strong regulations and processes have been established to ensure that human lives, particularly during day-to-day activities, are as secure as possible, and that victims of harm or their families are justly compensated (Munkasu, 2024). The aviation sector exemplifies an area where government, corporate, and civil safety regulations are of utmost importance (Balasundharam *et al.,* 2021; Stroeve *et al.,* 2022). In addition to the essential requirement for insurance coverage, security checks, and the presence of aviation officials both on board and at strategic locations, airports and airlines undergo thorough and regular scrutiny by individuals, agencies, and organizations (Sese, 2023). For example, airlines are periodically audited for safety, performance, financial integrity, and related aspects (Zieba and Johansson, 2022). Despite this seemingly impenetrable safety net, incidents of air-carried killings continue to occur (Garcia, 2023).

After the customers and revenue of an air-carrier, losses by an air-crash will be the most severe on the Airlines management (Sarin and Pruitt, 2024). This Management value of an aircraft consists of two things, the real and the used price of a destroyed aircraft (Ćosić *et al.,* 2024). The second factor is the earnings-

balance of the destroyed aircraft (Walków and Niemczyk, 2021). The depreciation of an aircraft starts mainly after one year of usage and depends on two things, the total running of an aircraft and of course the model of the aircraft (Alcaide *et al.,* 2022). In the actual price it would mean that after one year of service, only 80 % of the original buying value would be left (Taher and Chan, 2023). Another factor to consider, in regard to the real price, is the technological progress (Cao *et al.,* 2024). It is very fast in aviation, especially in the field of consumables, like fuel-saving engines, materials to decrease the aircraft weight, engines examination techniques, electronic equipment and so on, that could produce smaller and more efficient planes with more kilometres to fly (Sudarshan *et al.,* 2022; Bor *et al.,* 2024).

Types of Forensic Evidence

Crashes, near crashes, and collisions involving airplanes can result in large amounts of forensic evidence. Such cases can easily involve multiple sub-categories of evidence, both physical and non-physical types of data (Nechyporuk *et al.,* 2021). Good attorneys and accident analysts, working on behalf of both victims and airlines involved in airplane accidents, need to be familiar with the basics of how forensic evidence is collected and analyzed after U.S. airplane mishaps (Wang *et al.,* 2023). Any semblance of a forensic investigation into yields solid, concrete evidence that what was or was not done right (Sarin and Pruitt, 2024). This clear evidence can help courts to justly assign liability (Vermeij *et al.,* 2022). Wreckage and debris can help reconstruct the paths aircraft took during the event(s). Damage to individual pieces of wreckage can be analyzed to get a general sense of the forces acting upon that object at the time of an impact or explosion (Clavandier, 2023). Similarly, tool marks can be analyzed to determine the type of tool used and the direction of the force that created the mark (Lee, 2023). Examples of craneical cases in which it is highly likely that more than one category of forensic evidence will be present include fueling accidents that cause fires or explosions and engine failures that result in detachments of engine components from the aircraft (Saleem *et al.,* 2014). There are many types of evidence that are not tangible, which means they cannot be physically touched. This category often includes paper-only items, like maintenance records or pilot data. Although not physical, this type of evidence can still be vital to forensic investigations (Lee, 2023).

Physical Evidence

The necessity for physical evidence in forensic investigations is unequivocal (Owen and Lynch, 2016). It is through physical evidence that an aircraft accident can be forensically analyzed to ascertain the reasons for any malfunction, the aircraft's operational status leading up to the accident, and to reconstruct the events that occurred before and after the incident (Chen *et al.,* 2022). The physical evidence relevant to an aircraft accident primarily includes material objects such as wreckage, components, system parts, instruments, engines, and environmental conditions (including weather, lighting, and aerodrome surfaces) (Abdollahi and Pradhan, 2023). Although witness statements are extremely valuable, they do not qualify as physical evidence (Mentis *et al.,* 2021). Gathering and preserving material objects post-accident is crucial to ensure that balanced evidence is available for investigators and involved parties (Khattak *et al.,* 2021).

Forensic Techniques and Technologies

The advancement of methodologies and technology can transform the role of forensic scientists in accident investigations. These advancements provide opportunities to reveal the sequence of events that can improve accuracy and enhance accepted analysis methods (Mantas and Patsakis, 2021). This paper reviews current and advanced forensic engineering, accident reconstruction, and analysis methods used to investigate airplane accidents. It also analyzes how forensic techniques and technology are advancing (Pulumati *et al.,* 2023). The fusion of laser scanning, UAV photogrammetry, computer simulations and data analytics explain the adoption of a forensic approach (Madeira *et al.,*

2021). An interdisciplinary approach, involving aviation experts, engineering analysis, and forensic consideration, can produce a greater transparency of the sequence of events. Further advances in technology and analysis can expect to enhance the insight that an accident investigation can offer (Gao *et al.,* 2021). Tragic events are often studied, not just to understand why they happened, but how to prevent them from occurring again (Olugbade *et al.,* 2022). Methods of improving safety become integral to that purpose. Furthermore, technological advancement not only extends its use to new fields of applications but also broadens capabilities and generates, potentially, a new approach to how the analysis is conducted (Eyre *et al.,* 2017). Such a context is a chance to understand forensic processes, their challenges and benefits, reflecting on how the quality of investigation depends on the quality of accessible evidence. Due to political, military, and economic interests, the access to the place of crash is limited. Restrictions concern the presence on situs, gathering and analysis of data (Soori *et al.,* 2023). Time is the crucial element of the analysis. Following first hours after the crash, digital media edit the world's subject awareness (Ahmed *et al.,* 2022).

Black Box Analysis

Airplane accidents are catastrophic events that may result in severe consequences in terms of life and material damages (Zhang and Mahadevan, 2021). Each year civil aviation accidents cause losses including fatalities, serious injuries, destroyed equipment, and massive financial losses around the world (Midtfjord *et al.,* 2022). Therefore, detailed analysis of airplane accidents is very important and this task is of great research interest (Yu *et al.,* 2017). Analysis of the flight parameters prior to the accident, gathered during the last moments of the flight, as well as the last conversation in the cockpit, is a great tool to investigate airplane accidents and to provide safety recommendations (Falco *et al.,* 2021). The increased possibilities of the data recorders are of greater importance in understanding and explaining some accidents, since they provide exact information of the various airplane parameters on the last moments of the flight (Padovan *et al.,* 2023). Black boxes, which are generally called flight data recorders (FDR) and cockpit voice recorders (CVR), are the primary source of data in investigating the airplane accidents (Naseer *et al.,* 2024).

Despite the expectations from the airline companies, the most detailed information about the accidents is provided by the black boxes prepared and installed on the airplanes (Matalgah and Alqodah, 2023). The black boxes must be able to record the selected flight data and the sounds and conversations in the cockpits at least for thirty minutes during the flight (Jacob, 2023). There are two micro devices to locate the black boxes; underwater locator beacon (ULB), and ground locator beacon (GLB) (David-Cooper, 2022). ULB, when it comes into contact with water, starts to run and keeps working for at least 30 days depending on its battery life (Konoval, 2023). The latest improvements in technology are such that the black boxes are located in a short period of time and it is possible to obtain and interpret the recordings stored in them (Causse *et al.,* 2022). Because of this reason, the data within the black boxes are able to provide detailed information as the basis of the accident's investigation (Passarella *et al.,* 2023).

Legal and Ethical Considerations

There are many things to consider when conducting a comprehensive investigation of airplane accidents from a forensic viewpoint (Stemn and Joe-Asare, 2021). In addition to following strict scientific protocols, investigators must also remain aware of legal and ethical aspects connected to their work (Friedman and Ladinsky, 2021). If carried out correctly, accident investigations help to maintain public trust in the aviation safety system (Lee and Wong, 2021). Practices that undermine this trust relationship must be addressed (Yadav *et al.,* 2023). A sense of responsibility to each other as well as to the community they serve is noted. The growth of ambiguity with respect to the boundary between criminal justice and administrative safety functions is shown (Falco *et al.,* 2021). Thus, accidents investigations may also have

legal ramifications as well. Points for establishing a more secure investigative future are derived (Ramírez *et al.,* 2023). Certification requirements and regulation on aviation security could have an impact on airlines operational safety and on forensic possibilities in case of accidents, e.g. by hampering a forensic examination of wreckage right on the airfield (Martinho *et al.,* 2021). Concerning toxicological examinations, it is indicated that the availability of reference values is still deficient (Raji *et al.,* 2022). Incremental aspects of forensic investigations may be recognized only in retrospect, as is the case with a 20-year-old Douglas DC-4 accident that crashed on an inbound approach path during a hit-and-run-border crossing maneuver at a defined pattern altitude after the pilot had seen runway environs in sight (Dahlmann Rosa, 2018). Despite attempts by industry to ensure tighter security, headsets can still be found on the open market and wired with adapters for personal stereos (Ramírez *et al.,* 2023). Therefore, it is recommended that all forensic earphones be capable of being used with airline seats and click-lock from the plug, with a unique plug or prong configuration (Martinho *et al.,* 2021). Although crew member headsets may “not be used for non-authorized purposes,” it is noted that even if they end up in pawn shops or thrift stores, they are for exactly the same type of equipment as supplied to public safety organizations and can then be re-wired for those types of receivers (Raji *et al.,* 2022). On the base of those military reports on bullet hole damage, for the continued employment of the electronic equipment or their components in future aircraft types, a fundamental rigorous proof of the electromagnetic compatibility has to be furnished in the context of safety assessment (Falco *et al.,* 2021; Lee and Wong, 2021). Preceding a forensic linguistic analysis of these texts, some legal and systemic considerations are outlined (Yadav *et al.,* 2023).

Case Studies

For this part of the research, the objective is to highlight some accidents through case studies that elaborate on the theories and principles looked at in the earlier sections (Nechyporuk *et al.,* 2021). The objectives are to examine the cases for important forensic findings and to describe what was learned (Wang *et al.,* 2023). Accidents are used as an analytical framework, as empirical data on how theories are applied (Polk, 2022). Accidents have been always happened ever since the airplane was first flown (Dinh-Zarr *et al.,* 2024). This section will also show how, once the aviation sector has occurred and resolved how questions in accidents can be instructively analyzed (Nechyporuk *et al.,* 2021).

Except for relatively minor and relatively innocuous occurrences, usually these events are looked at thoroughly, if not always immediately or properly (Stemn and Joe-Asare, 2021). A second reason is to use what is learned, positively, to try to increase the maximum safety of an aviation system (Hashmi *et al.,* 2024). Design, manufacture, and operate aircraft safety is a common aim, but scrutinizing accidents provides opportunities to look for additional, less immediately obvious things that might further improve safety (Kong *et al.,* 2024). It is expected that, by looking through the recounted cases, an insight can be gained into the scope and nature of the examination and the issues commonly thought about (Rane *et al.,* 2023). The intent of this effort is to help experts in this field to avoid typical blind alleys and oversights and to assist in the evolution of their techniques and methodologies (Ghasemi *et al.,* 2023). This point is to highlight some recurrence and lasting challenges following accidents, often hard discerned from the data, but a take-home point (Lee *et al.,* 2023).

TWA Flight 800

On the 17th of July, twenty years ago, Flight 800 from Trans-World Airlines (TWA) exploded off the coast of New York (Elumalai *et al.,* 2022). This stimulated an unparalleled forensic analysis encompassing electronic components possibly causing sparks, and components of the fuel tanks that exploded (Dhurandher *et al.,* 2023). The latter analysis found residues matching soot inside the tanks (Jayabal, 2024). However, the soot might originally stem from molecules fed polluted from an aircraft's engines leaking fuel (Brown *et al.,* 2023). Conversely, instrumental

analyses showed an entry of neither after-burner fumes nor exhausts inside the right tank, and the presence of patterns also at concomitantly inspected other aircraft from the identical production batch confirms their common, entirely factory-like provenance (Fang *et al.,* 2023). Hence further investigations focusing on the residues' chemical composition are envisaged, aiming at devising emission tests capable to discriminate between different pollution sources (Jiao *et al.,* 2024).

Conclusion

In conclusion, it is found that the implementation of forensic science in airplane accidents contributes to the comprehension of the accidents. A number of evidence is attracted to find out the cause of the accidents. The recovery process of the evidence is consulted to produce a report. It can therefore be concluded that a crash worthy seat is an important safety factor in civil aircraft to protect both passenger and crew from fatal injury, and to survive in an airplane accident. Overall, this research while involving detailed experimental and analytical program and numerous individual studies yielded important scientific and technical conclusions, and practical findings on the crash worthiness of passenger aviation seats. The findings of the research will have far-reaching implications for policy and rule-making on crash worthy seats. It identifies significant benefits and advantages to passengers, improved protection and reduced injury severity in survivable accidents. There are also excellent opportunities for broader-based research supported by the industry, universities, and government to address the most fundamentally and complex effects of seat. Given that individuals have access from all over the world, aircraft insecurity is a severe issue that is rapidly getting worse. Attacks might be systematic, involve airport bombings, aircraft hijackings, or midair shootings. However, serial bombing in aircrafts is a common issue.

CONFLICT OF INTEREST

Author hereby declares that he has no conflict of interest.

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