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Abstract

Aircraft accident investigation plays a pivotal role in advancing global aviation safety by identifying the technical, operational, environmental, and human factors responsible for catastrophic flight events. Among the various sources of forensic evidence, Flight Data Recorders (FDRs) and Cockpit Voice Recorders (CVRs), collectively known as aircraft black boxes, provide the most reliable and objective information for reconstructing accident sequences and determining root causes. This chapter presents a comprehensive case study analysis of major aircraft accidents based on recovered black box data, emphasizing the integration of flight parameters, cockpit communications, maintenance records, radar observations, and environmental information to achieve accurate accident reconstruction. Comparative analyses of representative accidents highlight recurring failure mechanisms, human–automation interaction challenges, software anomalies, operational deficiencies, and organizational influences that have shaped modern aviation safety practices. The chapter further examines emerging technologies, including artificial intelligence, machine learning, digital forensics, digital twin modeling, and multi-source data fusion, which significantly enhance black box data interpretation and evidence-driven decision-making. Current challenges associated with underwater recovery, large-scale data processing, and next-generation flight recording systems are also discussed to identify future research opportunities. The presented framework offers a multidisciplinary perspective that supports investigators, aerospace engineers, regulatory authorities, and researchers in developing intelligent accident investigation methodologies and strengthening proactive aviation safety management for increasingly complex aircraft systems.

Keywords: Aircraft Accident Investigation; Flight Data Recorder (FDR); Cockpit Voice Recorder (CVR); Black Box Data Analytics; Digital Forensics; Aviation Safety.

Introduction

Aircraft transportation has become one of the most reliable and indispensable modes of global mobility, supporting economic development, international trade, tourism, humanitarian operations, and rapid movement of passengers and cargo across continents [1]. Continuous advancements in aerospace engineering, digital avionics, satellite navigation, intelligent flight management systems, and automated control technologies have substantially enhanced the safety and efficiency of modern aviation [2]. Commercial aircraft currently operate within highly integrated technological environments that combine advanced sensors, communication networks, real-time monitoring systems, and sophisticated onboard computing platforms capable of managing thousands of operational parameters throughout every phase of flight [3]. Although these technological developments have significantly reduced accident rates over recent decades, aviation accidents continue to occur because of complex interactions among technical failures, environmental disturbances, operational limitations, software anomalies, organizational deficiencies, and human performance factors [4]. Every major accident presents valuable opportunities to improve engineering practices, operational procedures, regulatory policies, and safety management systems. Consequently, systematic investigation of aircraft accidents remains an essential scientific discipline dedicated to identifying causal mechanisms, preventing recurrence, and strengthening the long-term safety and reliability of global aviation systems [5].

Aircraft accident investigations have evolved from conventional examinations of physical wreckage into multidisciplinary forensic processes supported by digital technologies, computational analytics, and evidence-based engineering methodologies [6]. Modern investigations incorporate expertise from aerospace engineering, structural mechanics, human factors, meteorology, materials science, electronics, software engineering, digital forensics, and aviation psychology to reconstruct accident sequences with exceptional precision [7]. Central to these investigations are the Flight Data Recorder (FDR) and Cockpit Voice Recorder (CVR), commonly referred to as aircraft black boxes. These recording systems continuously capture synchronized operational information describing aircraft performance, engine behavior, flight control movements, navigation status, system warnings, cockpit communications, and pilot interactions throughout flight operations [8]. The objective nature of recorded flight data enables investigators to accurately determine the chronological sequence of operational events while minimizing uncertainties associated with eyewitness accounts or incomplete physical evidence [9]. As aircraft technologies continue to advance, black box systems remain the most authoritative source of information for understanding accident causation and evaluating aircraft performance under critical operational conditions [10].