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Aviation Accidents Without an Active Human-Factor Initiator: A Critical Analysis of Technical, Environmental, and System-Induced Causes

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Abstract | **Review Article**

Human factors occupy a central place in contemporary aviation-safety research, and for good reason. Nevertheless, a residual class of occurrences exists in which the initiating event is not an operational human error but a physical, technical, environmental, or material failure. This paper examines the methodological validity of describing such events as “aviation accidents without the human factor.” The analysis is based primarily on final reports and safety recommendations issued by independent accident investigation authorities, including the NTSB, AAIB, ATSB, and the Polish State Commission on Aircraft Accidents Investigation (PKBWL), supported by ICAO safety-management material and specialist human-factors literature. The present draft develops the conceptual framework and two initial case studies British Airways Flight 38 and US Airways Flight 1549 while leaving the empirical case set deliberately open for additional events and independent analysis by the remaining authors. The working distinction proposed in the paper is between human-independent initiating events and latent human-related system conditions. Under this approach, an occurrence may be free from active operational human error at the point of initiation while still revealing design, certification, manufacturing, maintenance, or organizational vulnerabilities at deeper levels of the aviation system. The final comparative conclusions are therefore intended to emerge only after all authors’ case studies have been incorporated.

Keywords: Aviation accident; human factors; technical failure; initiating event; accident investigation; HFACS; airworthiness; safety management.

1. INTRODUCTION

The way aviation accidents are explained has changed markedly over time. Early safety work was dominated by questions of structural strength, engine reliability, and mechanical failure. As aircraft systems became more reliable and operations more complex, investigators increasingly examined pilot performance, maintenance practice, cockpit design, supervision, organizational culture, and the interaction between these elements. Human-factors research developed within that shift. HFACS, drawing on Reason's distinction between active failures and latent conditions, was designed to identify human contributions at several levels of the aviation system [3-5]. FAA publications have often cited human error in a large proportion of civil and military occurrences - frequently around 70-80%, although the value depends strongly on the population studied and on how "human error" is defined [5].

Such figures can easily create the impression that a meaningful accident analysis must eventually lead back to a human mistake. That conclusion is too broad. Aircraft are physical systems, and they remain exposed to fatigue, corrosion, manufacturing variation, icing, electrical failure, fire, wildlife, foreign-object damage, and other mechanisms that may arise without an incorrect action by the operating crew. In some events, the crew is not the source of the hazard at all; it is the final barrier that limits its consequences.

The wording used in this paper therefore matters. If "human factor" is defined so widely that it includes every engineering decision, certification assumption, maintenance programme, production process, regulatory choice, and operational response, it becomes almost impossible to identify an accident that is wholly independent of people. Modern systems-safety theory is consistent with that view: accidents are rarely the product of a single failed component or a single unsafe act. ICAO safety-management guidance likewise treats operational safety as the result of interactions among people, technology, procedures, and the environment [1,2].

For this reason, the present study uses a narrower operational definition. An occurrence is considered to have a human-independent initiating event when the official investigation identifies a technical, material, environmental, or naturally occurring mechanism as the direct trigger and does not identify an act or omission by the flightcrew, air traffic services, or maintenance personnel as the initiating causal factor. Design choices, production quality, certification assumptions, organizational decisions, and maintenance architecture are not excluded from the analysis; they are treated separately as latent system conditions. This distinction makes it possible to study genuinely technical initiating mechanisms without making the stronger - and usually indefensible - claim that an accident is detached from the socio-technical system in which the aircraft was designed, built, certified, maintained, and operated.

The study has three objectives. First, it establishes a practical boundary between active operational human error and non-human initiating mechanisms. Second, it compares accidents and serious incidents in which the first significant event was technical or environmental rather than behavioural. Third, it examines the safety recommendations issued after those occurrences to determine where investigators located the most effective preventive action: in training and procedures, in maintenance, in design and certification, or across several levels at once. The broader aim is not to minimise the importance of human factors, but to describe more accurately those accident sequences in which human performance was not the initiating failure.

2. Conceptual and Methodological Framework

2.1. Human Factors, Operational Error, and System Boundary Definitions

Human factors and human error describe different things and should not be used as synonyms. Human factors is a field concerned with how people perceive information, make decisions, interact with machines and procedures, work under operational constraints, and function within organizations. Human error is narrower: it refers to an action, decision, omission, or performance deviation that is relevant to the event under investigation. Reason's model separated immediate operator-level failures from latent conditions created elsewhere in the system [3]. HFACS adapted this logic for aviation by grouping human contributions into unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences [4,5].

That distinction becomes important when the first observable failure is physical. A fatigue crack in a turbine component is a material process; a bird strike is an environmental interaction. Neither is, by itself, a pilot error. However, the probability and consequences of those events may still depend on manufacturing tolerances, inspection methods, certification criteria, wildlife-management programmes, component layout, or organizational decisions. The analytical problem is therefore not whether a human influence can be found somewhere in the history of the system. It is where that influence sits in the causal chain and whether it initiated the occurrence.

The cases are consequently examined at four levels: (1) the initiating physical event; (2) the technical susceptibility that allowed the event to develop; (3) latent system conditions, including design, certification, manufacturing quality, regulation, and maintenance policy; and (4) the operational response of the crew and other frontline personnel. A case is classified here as operationally non-human-factor-driven when the initiating event is technical or environmental and frontline human performance is not identified as causal. Human contributions at the design or organizational level may still be present and are reported explicitly rather than absorbed into the same category.

2.2. Case Selection Criteria and Source Hierarchy

Cases were selected using a qualitative comparative approach. Preference was given to occurrences for which an independent investigation authority had published a final report or an authoritative final summary. The primary sources are reports from the National Transportation Safety Board (NTSB), the United Kingdom Air Accidents Investigation Branch (AAIB), the Australian Transport Safety Bureau (ATSB), and the Polish State Commission on Aircraft Accidents Investigation (PKBWL). ICAO Annex 13 provides the common investigative context: the purpose of a safety investigation is prevention, not the assignment of blame or liability [1].

Table 1: Operational criteria used to identify candidate occurrences

Criterion	Inclusion condition	Reason for use
Investigation status	Final report or authoritative final investigation summary available	Reduces dependence on preliminary hypotheses
Initiating event	Technical, material, environmental, wildlife, or other physical mechanism	Separates physical trigger from operational action
Operational conduct	No crew/ATC/maintenance act identified as the initiating cause	Defines the narrow meaning of “without human factor”
Causal transparency	Cause, contributing factors, and safety actions can be distinguished	Allows comparison of direct and latent factors

Criterion	Inclusion condition	Reason for use
Safety relevance	Occurrence produced significant damage, injury, or credible catastrophic potential	Ensures meaningful preventive lessons

Accidents and serious incidents are kept analytically distinct. A serious incident is included only where it exposes a failure mechanism or safety deficiency with clear accident potential and where the investigation provides a sufficiently developed causal explanation. Used in this way, a serious incident functions as a precursor case rather than as a substitute for an accident. This also leaves room for the remaining authors to introduce technically relevant cases from PKBWL or other national investigation authorities without distorting the accident dataset.

2.3. Typology of Non-Human Initiating Mechanisms

For comparison, each occurrence is assigned to one or more initiating-mechanism categories: (A) environmental or wildlife interaction; (B) fatigue or material failure; (C) manufacturing or production non-conformity; and (D) design or certification vulnerability. The categories are deliberately allowed to overlap. An initiating material failure may, for example, expose a design weakness or a production-control problem. The sequence is analysed from the physical trigger outward: first what failed or occurred, then why the aircraft or component was susceptible, and finally how the technical system and the crew responded.

3. Case Studies of Non-Human Initiated Occurrences

Table 2: Case-study structure of the collaborative manuscript; the present draft intentionally leaves two cases open

Occurrence	Year	Direct initiating mechanism	Operational human error causal?	Status in manuscript
British Airways Flight 38, B777-236ER	2008	Fuel-system ice released and restricted fuel flow at the FOHE	No, according to AAIB causal findings	Developed in this draft
US Airways Flight 1549, A320-214	2009	Ingestion of large birds into both engines	No; crew performance contributed to survivability	Developed in this draft
Qantas Flight 32, A380-842	2010	Uncontained intermediate-pressure turbine disc burst triggered by manufacturing non-conformity and fatigue	No; crew performance was a decisive resilience factor	Developed in this draft
Southwest Airlines Flight 1380	2018	Low-cycle fatigue fracture of fan blade No. 13 and secondary structural failure of engine cowl	No; crew performance acted as a key resilience mechanism	Developed in this draft

3.1. Case 1 – British Airways Flight 38: Ice Accretion and Fuel-System Certification Envelope

British Airways Flight 38, a Boeing 777-236ER registered G-YMMM, approached London Heathrow on 17 January 2008 after a flight from Beijing. At about 720 ft above ground level, the right engine failed to produce the commanded increase in thrust; the left engine showed the same behaviour a few seconds later. With both engines unable to provide the required thrust, the aircraft lost speed and touched down approximately 330 m short of the paved runway. The AAIB traced the event to restricted fuel flow to both engines and located the restriction at the Fuel Oil Heat Exchanger (FOHE) [6].

The mechanism was unusual and, at the time, not represented adequately in the certification assumptions. Water normally present in aviation fuel froze during prolonged exposure to low local fuel temperatures and low fuel flow. Ice accumulated within the fuel system, was subsequently released when operating conditions changed, and reached the FOHE in a concentration sufficient to restrict the passage of fuel. The exchanger met the certification requirements then in force, but those requirements did not account for this form of soft-ice accumulation and release [6]. The accident sequence therefore began with a thermodynamic and fuel-system interaction rather than with an incorrect flightcrew input.

Flight 38 is important precisely because the boundary between operational and system-level human factors is visible. The pilots did not create the loss of thrust. Once the physical mechanism was understood, the investigation focused on the fuel-system design, the behaviour of the FOHE, and the adequacy of the certification standard. The AAIB issued eighteen safety recommendations [6]. Their direction is revealing: prevention depended primarily on engineering and certification changes, not on attributing the event to poor cockpit technique. At the same time, those changes were ultimately changes to a human-designed system, which is why the accident should be described as non-human-initiated rather than literally free of human factors.

3.2. Case 2 – US Airways Flight 1549: Wildlife Ingestion as an External Environmental Trigger

US Airways Flight 1549 is a comparatively clear example of an externally initiated event. On 15 January 2009, shortly after departure from New York LaGuardia Airport, the Airbus A320-214 encountered a flock of large birds. Both engines ingested birds and lost almost all useful thrust. With no realistic runway option available, the crew ditched the aircraft on the Hudson River. The NTSB identified the ingestion of large birds into both engines, and the resulting near-total loss of thrust, as the probable cause [7].

Here the crew occupies a different position in the causal chain from the one normally emphasised in human-error studies. The hazardous condition was not generated by the pilots. Their actions after the strike instead contributed to the survivable outcome. The investigation nevertheless identified broader safety issues involving engine bird-ingestion certification, wildlife-hazard management, ditching assumptions, emergency checklists, training, and survivability equipment [7]. A natural trigger did not make the event independent of the safety system; it changed the role of that system from source of failure to means of mitigation.

For this reason, Flight 1549 fits the proposed category particularly well: the initiating event was independent of crew action, while successful mitigation depended heavily on human performance. The case also illustrates an important point for accident taxonomy. Human performance should not automatically be treated as a causal burden. In some accidents it is a resilience mechanism that prevents an external technical or environmental event from becoming a catastrophe.

3.3. Case 3 – Qantas Flight 32: Uncontained Engine Failure and Manufacturing Defect

3.3.1. Event Overview and Investigative

Findings On 4 November 2010, Qantas Flight 32, an Airbus A380-842 registered VH-OQA and powered by four Rolls-Royce Trent 972-84 turbofan engines, departed Singapore Changi Airport bound for Sydney with 469 passengers and crew on board. Approximately four minutes after departure, while climbing through 7,000 ft over Batam Island, Indonesia, the No. 2 (inboard left) engine suffered a catastrophic uncontained failure. High-energy debris liberated from the engine assembly penetrated the nacelle, left wing structure, fuselage, and wing fuel tanks.

The physical impact severed critical wiring looms and hydraulic lines, causing extensive cascaded system degradation. The crew was immediately confronted with 54 discrete Electronic Centralised Aircraft Monitor (ECAM) master caution and warning messages, affecting flight-control secondary computers, leading-edge slat control, fuel management and jettison systems, anti-skid braking, and the green hydraulic circuit. The Australian Transport Safety Bureau (ATSB) initiated a comprehensive investigation under ICAO Annex 13. In its final report (ATSB Transport Safety Report AO-2010-089) [8], the bureau determined that the initiating event was an uncontained disc burst resulting from an internal oil fire in the intermediate-pressure (IP) turbine assembly. The crew worked systematically through ECAM procedures for nearly two hours, conducted airborne handling and controllability assessments, and completed an overweight emergency landing back at Changi Airport without injuries or hull loss.

3.3.2. Failure mechanism and causal chain

The technical failure sequence operated strictly at the material, manufacturing, and mechanical levels. The ATSB determined that the uncontained failure originated within the HP/IP (high-pressure/intermediate-pressure) bearing structure of the No. 2 engine [8]. Specifically, a counterbore within an internal oil feed stub pipe had been manufactured with an eccentric offset due to a misaligned machining process at the component manufacturing facility. This eccentricity produced localized wall thinning below design drawing specifications.

During normal cyclic thermal and vibrational stress, high-cycle fatigue cracking initiated at the thinned wall of the stub pipe. The resulting breach released lubricating oil into the hot HP/IP bearing cavity, igniting an internal oil fire. The persistent thermal exposure softened and degraded the structural integrity of the IP turbine drive arm, culminating in mechanical failure and the disconnection of the IP turbine disc from its drive shaft. Relieved of its mechanical load, the IP disc experienced rapid overspeed until centrifugal forces exceeded the material yield strength, causing complete disc burst and explosive uncontained fragmentation. High-velocity titanium and nickel-alloy fragments ruptured the airframe, puncturing the No. 2 fuel tank, severing primary and secondary flight-control wiring, disabling the pneumatic bleed systems, and impairing the ability to shut down the adjacent No. 1 engine after landing. The operational crew played no role in generating the defect, nor did any flightcrew action contribute to the initial structural failure.

3.3.3. Safety recommendations and human-factor assessment

The ATSB investigation issued multiple safety recommendations and sparked immediate global airworthiness action, directed primarily at manufacturing quality assurance, turbine design, and fleet-wide inspection standards. The European Aviation Safety Agency (EASA) and the Federal Aviation Administration (FAA) issued emergency Airworthiness Directives mandating repetitive borescope and ultrasonic inspections of Trent 900 oil feed pipes, software modifications to the Engine Electronic Controller (EEC) to incorporate overspeed fuel shut-off protection, and removal of engines manufactured with non-conforming oil pipe batches [9].

Evaluated against the HFACS taxonomy, the Qantas Flight 32 occurrence shows a total absence of active operational human error at the point of failure initiation. The initiating causal factor was physical and mechanical, originating in a latent manufacturing non-conformity that bypassed production inspection protocols years before the event.

At the operational sharp end, human performance served as an essential resilience and mitigation mechanism. Confronted with conflicting ECAM alerts, degraded flight control modes, asymmetrical thrust, an inoperative fuel dump system, and an approach speed close to the runway overrun margin, the multi-pilot flight deck crew augmented by supervisory and check captains applied disciplined Crew Resource Management (CRM), structured workload distribution, and systematic decision-making. Flight 32 confirms the theoretical boundary articulated in Section 2.1: human influence existed as a latent organizational and quality-assurance condition at the manufacturing level, whereas active operational performance functioned exclusively to prevent an otherwise catastrophic outcome.

3.4. Case 4 – Southwest Airlines Flight 1380: Fan Blade Fatigue and Nacelle Structural Failure

3.4.1. Event Overview and Investigative Findings

On 17 April 2018, Southwest Airlines Flight 1380, a Boeing 737-7H4 registered N772SW and powered by two CFM International CFM56-7B24 turbofan engines, was performing a scheduled domestic passenger flight from New York LaGuardia Airport to Dallas Love Field with 144 passengers and five crew members on board[10]. While climbing through approximately 32,000 ft (FL320) over Bernville, Pennsylvania, the aircraft suffered a sudden, catastrophic uncontained failure of the No. 1 (left) engine[10]. High-energy debris liberated from the engine assembly severely damaged the engine nacelle, left wing leading edge, and fuselage structure.

A major portion of the inlet cowl and components of the fan cowl assembly separated in flight[10]. Fragmented structural debris struck the left side of the aircraft fuselage, leading to the total collapse and window-frame failure at passenger row 14[10]. The resulting instantaneous cabin depressurization partially drew the occupant of seat 14A out of the window opening[10]. Although fellow passengers pulled the occupant back into the cabin and initiated CPR, the passenger succumbed to fatal injuries. Eight other passengers sustained minor injuries [10].

The flightdeck crew was immediately confronted with violent airframe vibration, multiple secondary system alarms, asymmetric drag, cabin altitude warnings, and severe emergency communications difficulties due to ambient wind noise in the cockpit [10]. Applying structured emergency procedures and Crew Resource Management (CRM), the pilots stabilized the aircraft, initiated a rapid descent to 10,000 ft, declared an emergency, and executed an overweight landing on Runway 27L at Philadelphia International Airport [10].

The National Transportation Safety Board (NTSB) conducted a comprehensive investigation in accordance with ICAO Annex 13, supported by technical advisors from the FAA, Boeing, CFM International, and the French Bureau d'Enquêtes et d'Analyses (BEA) [10]. In its final report (NTSB/AAR-19/03), the NTSB concluded that the initiating event was the low-cycle fatigue fracture and complete separation of fan blade No. 13 at the dovetail root slot within the fan disc hub [10]. The occurrence was formally classified as an uncontained engine failure accompanied by a secondary structural failure of the engine cowl assembly [10].

3.4.2. Technical Failure Sequence and Causal Chain

The physical failure sequence evolved strictly through material, mechanical, and structural failure mechanisms without any human interference during flight operations [10]. The primary origin was a low-cycle fatigue (LCF) crack that initiated in the dovetail region of fan blade No. 13 a high-strength titanium alloy (Ti-6Al-4V) component [10]. The fatigue crack originated at the inner surface of the dovetail root, beneath a protective copper-nickel-indium (Cu-Ni-In) coating applied to reduce fretting wear against the fan disc slot. Because crack initiation occurred underneath the surface coating layer and within a high-stress contact zone, it was undetectable during routine visual and fluorescent penetrant inspections mandated by the maintenance schedule in force prior to the accident.

During high-thrust climb operations, cyclic rotational stresses and centrifugal forces caused the subsurface crack to propagate to a critical length[10]. When the remaining cross-sectional area could no longer support the tensile loading, fan blade No. 13 severed completely near its root dovetail[10].

The physical progression followed a catastrophic multi-stage sequence:

Primary Impact and Containment: The liberated fan blade fragment struck the inner wall of the containment ring within the fan case. In accordance with engine containment certification standards (FAR Part 33), the primary titanium fan case successfully contained the blade fragments [10].

Structural Load Transmission: The extreme kinetic impact of the blade against the fan case transferred a massive transient dynamic displacement force into the surrounding engine cowl structure [10].

Cowl Failure and Fragmentation: The forward latch mechanisms, hinge fittings, and structural frames of the fan cowl assembly experienced loads exceeding their ultimate structural strength. This caused the structural failure of the inlet cowl and the complete separation of the left fan cowl door[10].

Airframe Impact and Penetration: Large, high-velocity debris sections from the separating cowl assembly flew rearward and struck the left fuselage skin. A fragment of the cowl latch mechanism struck the outer acrylic pane of the window at row 14, causing the immediate failure of both the inner and outer window panes and the structural deformation of the surrounding window belt[10].

The entire sequence from initial blade separation to window destruction occurred in less than one second[10]. In accordance with the analytical boundary defined in Section 2.1, frontline operational personnel including the flightcrew, air traffic controllers, and line maintenance engineers played no causal or initiating role in the occurrence.

3.4.3. Safety recommendations and human-factor assessment

The NTSB issued 12 safety recommendations aimed at addressing latent vulnerabilities in component inspection protocols, engine nacelle structural design, and certification standards[10]. The investigation prompted immediate regulatory action: the FAA and EASA issued Emergency Airworthiness Directives mandating ultrasonic and eddy-current non-destructive testing (NDT) inspections for all CFM56-7B engine fan blades with more than 20,000 flight cycles[10]. Eddy-current testing allows technicians to detect subsurface fatigue cracks beneath protective coatings without requiring the removal or destruction of the surface layer. Furthermore, the NTSB called on Boeing and engine manufacturers to re-evaluate structural dynamic load assumptions during fan-blade-out (FBO) testing and to redesign the nacelle cowl assemblies on Boeing 737 NG aircraft to prevent cowl displacement and structural breakup following an FBO event[10].

When analyzed through the HFACS taxonomy, Southwest Airlines Flight 1380 exhibits a total absence of active operational human error at the sharp end[10]. The initiating trigger was a material phenomenon. Latent conditions were instead embedded at deeper organizational, design, and certification layers:

Maintenance Inspection Limitations: Relying on visual and fluorescent penetrant inspection methods that lacked the physical capability to detect sub-surface fatigue initiation beneath protective metallic coatings[10].

Design and Certification Assumptions: Certification standards under FAR 25.901 and 25.903 focused on containing high-energy fragments within the engine case, but did not adequately account for the severe aerodynamic and dynamic displacement forces transmitted to exterior cowl structures during an FBO event[10].

Conversely, the operational human element functioned as a key resilience mechanism. Facing severe aerodynamic drag, sudden decompressions, high cockpit noise, and complex system degradation, the flightcrew effectively applied Crew Resource Management (CRM), prioritized flying the aircraft, executed emergency checklists, and safely brought the damaged aircraft to a stop on the runway. Flight 1380 demonstrates that while physical material failure can initiate a life-threatening crisis without human error, human performance remains a primary line of defense in containing the event[10].

4. Comparative Analysis of Selected Case Studies

The four case studies developed in this paper demonstrate that the absence of an active operational human error does not represent a single, uniform class of "technical accidents." Instead, non-human initiating mechanisms span a wide spectrum of physical, material, environmental, and engineering phenomena across different operational contexts:

British Airways Flight 38 originated in a thermodynamic and fluid-system interaction (soft-ice accretion), exposing an unrecognized physical phenomenon and inadequate design certification envelopes (Category D).

US Airways Flight 1549 was triggered by an external, naturally occurring macro-hazard (bird ingestion), illustrating a purely environmental initiating trigger beyond operational human control (Category A).

Qantas Flight 32 exposed a latent manufacturing non-conformity (stub-pipe wall thinning) that led to thermal degradation, fatigue cracking, and an uncontained turbine disc burst (Categories B and C).

Southwest Airlines Flight 1380 revealed a latent sub-surface material fatigue failure compounded by maintenance inspection limitations and structural dynamic cowl certification vulnerabilities (Categories B and D).

Comparing these occurrences confirms the analytical utility of distinguishing human-independent initiating events from latent system conditions (Section 2.1). In all four cases, the immediate trigger was physical or technical, free from operational pilot or maintenance error. However, the latent systemic vulnerabilities diverged significantly, ranging from manufacturing quality control and non-destructive inspection limitations to environmental exposure boundaries and airworthiness certification assumptions.

Furthermore, across three of the four cases (US Airways 1549, Qantas 32, and Southwest 1380), frontline human performance functioned as an indispensable resilience and mitigation mechanism. Rather than initiating the emergency sequence, the operating crews actively contained severe system degradations and structural failures, preventing catastrophic outcomes.

4.1. Cross-Case Synthesis of Latent System Conditions

The addition of Qantas Flight 32 enriches the comparative dataset by introducing an internal, manufacturing-induced mechanical failure category (Categories B and C in Section 2.3), contrasting clearly with the environmental trigger of US Airways Flight 1549 (Category A) and the system-wide thermodynamic and certification anomaly of British Airways Flight 38 (Category D).

Across all three cases, the active operational human factor is completely absent from the initiating failure mechanism. Neither the pilots nor maintenance personnel committed an active failure that induced the disc overspeed on VH-OQA, the dual-engine flameout on N106US, or the fuel-flow restriction on G-YMMM. However, the latent systemic vectors differ significantly:

Flight 38 exposed an unrecognised physical phenomenon (soft-ice accretion) and an inadequate certification design envelope;

Flight 1549 exposed the limits of wildlife certification boundaries when confronted with an external, naturally occurring macro-hazard;

Flight 32 revealed a classic latent condition in manufacturing control and quality inspection that lay dormant until mechanical and thermal fatigue triggered a catastrophic uncontained burst.

Furthermore, Flight 32 parallels Flight 1549 in demonstrating the role of the operating crew as an active barrier of system resilience. While the A320 crew mitigated an immediate, irreversible loss of thrust through instinctive airmanship and rapid ditching execution, the A380 crew mitigated massive, cascading system degradation through prolonged diagnostic problem-solving, cognitive filtering of ECAM warnings, and flight-envelope validation. In both cases, classifying the occurrences under the general umbrella of "human factors" without disaggregating operational error from latent production and design conditions risks distorting accident analysis. The corrective recommendations after Qantas 32 accordingly focused on machining tolerances, quality audits, and turbine overspeed protection logic, corroborating the methodological assertion that technical initiating mechanisms demand distinct preventive interventions targeted at engineering and manufacturing layers rather than frontline operational censure.

4.2. Operational Resilience vs. Active Human Error

The inclusion of Southwest Airlines Flight 1380 introduces an internal material-fatigue and structural-failure mechanism (Categories B and D), expanding the comparative dataset alongside Qantas Flight 32, US Airways Flight 1549, and British Airways Flight 38.

Across all four cases, active operational human error is entirely absent from the initiating sequence. No pilot or maintenance action caused the subsurface fatigue crack on fan blade No. 13. However, Flight 1380 highlights distinct latent system conditions:

Inspection Protocol Limitations: Routine visual and fluorescent penetrant methods could not detect subsurface cracks beneath protective coatings.

Certification Vulnerabilities: Engine containment standards (FAR Part 33) focused on the primary fan case but failed to account for dynamic load forces transmitted to exterior cowl latches during a fan-blade-out event.

Similar to Flights 1549 and 32, the flightcrew in Flight 1380 acted purely as a system resilience mechanism. Facing rapid depressurization, structural damage, asymmetric drag, and severe cockpit noise, the crew effectively applied CRM, executed emergency descent procedures, and landed safely.

The resulting recommendations mandating eddy-current inspections and nacelle structural redesigns further confirm that technical initiating events require targeted engineering and airworthiness solutions rather than operational crew censure

5. Integrated discussion and conclusions

The comparative analysis of the four examined occurrences British Airways Flight 38, US Airways Flight 1549, Qantas Flight 32, and Southwest Airlines Flight 1380 reveals a consistent operational pattern: complex, life-threatening aviation emergencies can initiate entirely independently of active human error at the operational sharp end. Each case originated from a distinct physical, environmental, material, or thermodynamic trigger ranging from soft-ice accretion in fuel equipment and dual-engine bird ingestion to manufacturing-induced oil pipe failure and subsurface fan blade fatigue that was neither caused nor accelerated by the actions or omissions of the flightcrew, air traffic controllers, or line maintenance personnel. Cross-case comparison underscores that while technical initiating events differ in physical manifestation, they share a critical socio-technical boundary. In none of these occurrences did the safety investigation assign causal responsibility to frontline operators. Instead, human involvement operated in two distinct modes across the failure spectrum: as a dormant, latent vulnerability embedded in design, certification, or manufacturing years prior to the event, and as an active resilience mechanism mitigating catastrophic outcomes during the emergency.

A central conceptual outcome of this study is the necessity to refine how the aviation safety domain employs the term "human factor". If "human factor" is defined so broadly as to encompass every historical engineering choice, manufacturing procedure, inspection schedule, and regulatory requirement, then virtually no accident in a human-designed system can be categorized as non-human. However, such expansive terminology creates serious analytical distortion by conflating active operational mistakes, such as mismanaged flight controls or procedural non-compliance, with latent system flaws like subsurface fatigue cracks or unmodeled dynamic stress states during component separation. The proposed distinction between human-independent initiating events and latent system conditions resolves this ambiguity. As demonstrated in Reason's system-safety paradigm and the HFACS taxonomy, an occurrence can be strictly free from active operational human error at the sharp end while remaining deeply connected to socio-technical vulnerabilities at the organizational, manufacturing, and regulatory levels. Labelling an accident as having a non-human initiating cause does not imply that the system is detached from human influence; rather, it specifies that frontline human performance was not the source of the hazard.

The allocation of causal findings directly dictates where corrective safety resources are deployed. When investigations default to operational human error, safety recommendations tend to focus on pilot retraining, CRM refresher courses, and procedural compliance. The cases examined here demonstrate that when initiating mechanisms are technical or environmental, operational crew retraining is entirely incapable of preventing recurrence. Consequently, safety recommendations issued by independent authorities following these events were directed almost exclusively at deeper system layers, including revised physical parameters for fuel heat exchangers, increased engine bird-ingestion standards, redesigned nacelle load containment structures, and the transition to high-sensitivity eddy-current and ultrasonic non-destructive testing (NDT) to detect subsurface fatigue prior to critical propagation. Moreover, these cases illustrate that human performance at the sharp end often acts as the primary resilience layer preventing an unexpected technical failure from becoming a fatal disaster. Safety management frameworks must therefore balance error-reduction strategies with resilience-building measures to ensure crews remain equipped to handle complex non-normal scenarios falling outside certified design envelopes.

In conclusion, this study established and validated a practical causal boundary separating active operational human error from human-independent initiating mechanisms in aviation accidents. A distinct class of aviation occurrences exists in which the initiating mechanism is purely physical, material, environmental, or thermodynamic, and attributing such events to "human error" misrepresents the failure sequence while obscuring the primary cause. While frontline crew actions did not initiate any of the analyzed events, latent human-related vulnerabilities were present at organizational, design, manufacturing, and inspection levels, making the differentiation between active operational failures and latent system conditions essential for accurate accident taxonomy. Ultimately, effective accident prevention requires aligning safety recommendations with the specific layer of failure through engineering, manufacturing, NDT, and certification solutions rather than operational crew censure, while explicitly recognizing and developing human performance as a critical system resilience mechanism.

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