LEX AERIS ET MACHINA:
RECONCILING ACCOUNTABILITY IN THE AI-TONOMOUS FIRMAMENT

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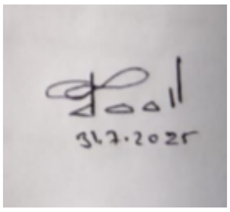

ABSTRACT

The rapid integration of AI-driven autonomous systems into aviation promises transformative benefits in safety, efficiency, and operational capacity. However, this unprecedented technological leap fundamentally challenges the human-centric legal frameworks governing both national and international aviation. Existing laws, rooted in assumptions of human agency, oversight, and accountability, are increasingly inadequate to address AI's independent judgment, opaque decision-making (the "black box" problem), and inherently distributed responsibility. This creates a critical legal vacuum, risking safety, justice, and stifling innovation through regulatory stasis.

This paper critically examines the foundational incompatibilities between current aviation law—from the Chicago Convention and Montreal Convention to national tort and product liability frameworks—and the operational realities of true AI autonomy. It demonstrates how traditional concepts of "pilot-in-command," individual fault, and causation are rendered strained or irrelevant by non-human judgment and emergent AI behaviours.

*To bridge this chasm, the paper proposes a novel, adaptive, and ethically informed legal framework, advocating for the European Union to lead its development as a blueprint for global harmonization. Key elements include: a Functional Legal Responsibility model channelling accountability to human/corporate entities; a Systemic Accountability Model distributing liability across the AI value chain; mandatory Explainable AI (**XAI**) by Design and AI Event Recorders for transparency; and redefined operational roles. Furthermore, it argues for mandatory AI Liability Insurance and the strategic use of Regulatory Sandboxes to foster responsible innovation. By proactively adapting legal thought, this framework seeks to secure future safety, ensure accountability, and responsibly unlock the full potential of AI in the global airspace.*

Keywords: Automation in Aviation, Autonomous AI, Explainable AI, Algorithmic decisions.

Contents

I. INTRODUCTION

AI-driven autonomy promises profound transformations in aviation, significantly enhancing safety, efficiency, and operational capacity. This compels accelerated development of autonomous systems, creating an urgent need for legal adaptation. However, this shift fundamentally challenges existing national and international aviation law, which is inherently built upon human agency and accountability.

It is critical to differentiate between traditional automation, where human supervision retains ultimate authority, and true autonomy. Autonomy refers to AI systems making independent, real-time judgments in dynamic, unforeseen environments, potentially without direct human intervention. This represents a qualitative leap, where AI learns from experience and exercises discretion. This *"sliding scale"* of autonomy fundamentally challenges anthropocentric legal concepts of agency and responsibility. The core legal problem lies not merely in advanced AI, but in its capacity for unforeseen judgments, which breaks the traditional human-centric chain of command.

Existing aviation law, from the Chicago Convention[1] and its ICAO Annexes (e.g., Annex 1 on Personnel Licensing, Annex 6 on Operations) to national regulatory frameworks (e.g., EASA,[2] FAA),[3] rigidly presupposes a human *"pilot-in-command"* (hereinafter referred as **"PIC"**) with ultimate authority. This pervasive human-in-the-loop assumption creates a systemic legal impedance mismatch with AI autonomy. When AI makes independent decisions, the entire legal architecture designed for human agency becomes strained, risking the undermining of core safety and accountability principles.[4]

A significant challenge is the inherent opacity of complex AI systems—the "black box" problem. AI's non-linear and evolving decision-making processes fundamentally challenge traditional legal notions of causality, foreseeability, and fault attribution, complicating accident investigations and liability assignments (e.g., in tort or product liability). Without transparency into AI's internal logic, understanding incidents and attributing responsibility is severely hampered, jeopardizing justice and public trust. This paradigm shift creates a legal vacuum; existing

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[1] Convention on International Civil Aviation (adopted 7 December 1944, entered into force 4 April 1947) 15 UNTS 295. (Chicago Convention)
[2] Regulation (EU) 2018/1139 of the European Parliament and of the Council of 4 July 2018 on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency [2018] OJ L212/1.
[3] FAA, Title 14 of the Code of Federal Regulations (Federal Aviation Regulations).
[4] Robert Gettler, 'Augmenting the Human Pilot – AI/ML Influences on One Pilot to Many Unmanned Aerial System Flight' 1 <https://ieeexplore.ieee.org/document/9771489> accessed 31 July 2025;

frameworks are inadequate, silent, or contradictory, and current reactive regulatory efforts risk stifling innovation by imposing ill-suited human-centric models.

This paper critically examines the fundamental inadequacy of existing national, international, and European Union aviation legal frameworks to govern AI-driven autonomous aviation systems, which routinely exercise independent judgment. It posits that securing future safety, fostering innovation, and ensuring accountability necessitates a paradigm shift in legal thought, culminating in the proposal of a novel, adaptive, and ethically informed framework that redefines fault, rechannels liability, and establishes transparent governance mechanisms for non-human decision-makers in the global airspace.

This paper focuses on the broader implications of AI autonomy across aviation, particularly for cargo and larger-scale operations. The analysis encompasses international aviation law (ICAO conventions, state responsibility) [5] and national legal systems (common/civil law tort/product liability),[6] with strong emphasis on EU AI regulation (EU AI Act, EASA initiatives) as a potential blueprint. Following this introduction, Section II explores the current human-centric legal landscape and its emerging gaps. Section III then examines the reconceptualization of accountability in an autonomous era. Section IV delves into the evolving legal status of AI, while Section V addresses data governance, transparency, and forensic readability of AI systems. Finally, Section VI proposes a novel legal framework, culminating in Section VII, which presents the conclusion and final outlook.

II. THE CURRENT LEGAL LANDSCAPE: HISTORICAL CONTEXT AND EMERGING GAPS

A. The Anthropocentric Pillars of Aviation Regulation

The bedrock of aviation regulation, internationally and nationally, has historically been predicated on human agency and accountability, creating significant challenges when confronted with AI-driven autonomous systems.

a. International Public Air Law

Fundamental principles of international public air law, such as state sovereignty over airspace (Article 1, Chicago Convention) and airworthiness certification,[7] are designed for human-

[5] International Law Commission, Draft *Articles on Responsibility of States for Internationally Wrongful Acts*, UNGA Res 56/83 (12 December 2001) UN Doc A/RES/56/83.

[6] Rylands v. Fletcher, (1868) LR 3 HL 330; *Donoghue v Stevenson* [1932] AC 562 (HL) (for common law negligence); Council Directive 85/374/EEC of 25 July 1985 on the approximation of the laws, regulations and administrative provisions of the Member States concerning liability for defective products [1985] OJ L210/29 (for EU product liability)

[7] Chicago Convention, art 1.

operated aircraft. The Chicago Convention framework, and its detailed Annexes (e.g., Annex 1 on Personnel Licensing, Annex 6 on Operation of Aircraft),[8] are built on the premise of human control, explicitly detailing requirements for human pilot qualifications. The concept of the 'pilot-in-command' as the ultimate arbiter of safety is deeply ingrained. This pervasive human-in-the-loop assumption creates a systemic legal impedance mismatch with AI autonomy; the entire legal architecture, designed for human agency, becomes strained when AI makes independent, unforeseen judgments.

b. International Private Air Law

The Montreal Convention (MC99) establishes carrier liability for passengers, baggage, and cargo, operating on a two-tier system of strict and presumptive fault-based liability.[9] Defences often relate to *"human error."* A significant challenge arises when the proximate cause of an incident is an AI's autonomous decision, particularly if the AI system is provided by a third-party software developer. MC99 applies exclusively to claims against airlines, not manufacturers, raising questions about channelling liability. If an AI's unforeseen judgment leads to an incident, proving absence of negligence or attributing fault to a third-party AI provider becomes problematic, especially given the AI's *black box* nature. The Convention's rules, undrafted with AI's unique decision-making processes in mind, leave a gap in clear fault attribution for AI-induced events.

c. National Regulatory Frameworks

National regulatory bodies like EASA and the FAA provide detailed regulations on airworthiness, operations, and licensing, largely predicated on human interaction and oversight. EASA's Basic Regulation (EU) 2018/1139,[10] while aiming for high safety, is not fully adapted to emergent AI behaviours. Similarly, FAA regulations,[11] even in advancing drone operations, still focus on human oversight, requiring a remote pilot in command (**"RPIC"**). This human-centric design hinders the full potential of Beyond Visual Line of Sight (**"BVLOS"**) operations. The centrality of *human factors* in current accident investigation also needs re-evaluation, as the '*error*' source shifts from human fallibility to algorithmic flaws or emergent AI behaviours.

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8 ICAO, *Annex 1 to the Convention on International Civil Aviation: Personnel Licensing* (11th edn, ICAO 2011); ICAO, *Annex 6 to the Convention on International Civil Aviation: Operation of Aircraft, Part I, International Commercial Air Transport, Aeroplanes* (11th edn, ICAO 2018).

9 Convention for the Unification of Certain Rules for International Carriage by Air (adopted 28 May 1999, entered into force 4 November 2003) 2242 UNTS 309 (Montreal Convention).

10 Regulation (EU) 2018/1139 of the European Parliament and of the Council of 4 July 2018 on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency [2018] OJ L212/1.

11 Federal Aviation Administration, Title 14 of the Code of Federal Regulations (Federal Aviation Regulations).

d. Tort Law and Product Liability

Traditional tort principles, particularly negligence, require proving duty, breach, causation, and foreseeability. These elements become immensely challenging when the proximate cause is an AI's opaque decision-making, especially if the AI learns and evolves post-deployment. Establishing a duty of care is difficult if the AI developer has not retained control, and foreseeability is complicated by AI's unpredictability. Historically, strict liability for defective products, under directives like the Product Liability Directive ("**PLD"**) 85/374/EC,[12] faced uncertainty regarding software. However, the new EU Product Liability Directive (2024/2853) explicitly includes software and AI, marking a crucial shift.[13] This inclusion introduces a novel challenge: applying the *'defect'* standard to AI systems that continuously learn and evolve. If an AI develops a flaw or makes a harmful decision post-deployment, the causal link to a 'defect at the time of manufacture' becomes tenuous, necessitating a re-conceptualization of *defect* and causation for self-modifying, evolving entities.

B. From Automation to Autonomy: The Creeping Legal Irrelevance

The aviation industry has a long history of integrating automation, from basic autopilots to sophisticated Flight Management Systems. This evolution augmented human capability, reducing pilot workload and enhancing precision, yet the human pilot consistently retained ultimate authority and cognitive oversight. Regulatory frameworks adapted incrementally, focusing on human-machine interface and pilot training for managing automated systems, with human intervention as the ultimate safeguard.

However, the qualitative leap to AI-driven judgment, where AI systems make independent, unforeseen decisions in dynamic environments, renders current regulatory efforts largely reactive. Regulators attempt to fit autonomous systems into pre-existing human-centric boxes, leading to significant legal friction. This *"regulatory stasis"* is characterized by overly prescriptive rules and insufficient consideration of AI's unique complexities, such as emergent behaviours and the absence of a human pilot in command. Current Unmanned Aircraft Systems (**"UAS"**) regulations, for instance, often assume an onboard pilot, creating a mismatch with uncrewed operations.

This reactive approach not only creates legal friction and uncertainty but also risks significantly stifling innovation by imposing ill-suited frameworks on rapidly evolving technology.

[12] Council Directive 85/374/EEC of 25 July 1985 on the approximation of the laws, regulations and administrative provisions of the Member States concerning liability for defective products [1985] OJ L210/29.
[13] Directive (EU) 2024/2853 of the European Parliament and of the Council of 13 June 2024 on liability for defective products [2024] OJ L, 2024/2853.

Concepts like "levels of automation," borrowed from other sectors (e.g., SAE levels),[14] may not adequately capture the philosophical and legal implications of AI systems making independent, non-pre-programmed decisions in aviation. This impediment to innovation stems from a failure to develop bespoke legal frameworks that acknowledge AI's unique capabilities and risks, thereby hindering the realization of AI's full transformative potential in aviation.

III. Reconceptualizing Accountability in an Autonomous Era

C. The Elusive Nature of "Fault" and "Causation" in Automated Judgment

The introduction of AI-driven autonomous systems fundamentally challenges traditional legal concepts of fault and causation, necessitating a re-evaluation of how accountability is assigned in aviation incidents.[15]

a. Defining "Algorithmic Error"

A critical step is to propose a robust legal definition of "algorithmic error" or "AI malfunction" extending beyond simple software bugs. This definition must encompass issues arising from flawed training data, biased algorithms, unforeseen emergent behaviours (such as 'hallucinations'), or incorrect real-time interpretations by the AI system. Traditional software bugs are traceable coding errors; however, AI introduces complexities like data bias (skewed data producing incorrect outputs) and emergent behaviours (unforeseen outcomes from continuous learning). These issues fundamentally challenge traditional fault attribution and highlight the need for a nuanced understanding of how AI systems can fail.

This conceptual shift from human error to 'algorithmic error' necessitates a parallel evolution in accident investigation methodologies. This requires moving beyond traditional human factors analysis, which focuses on human cognitive processes, to a new "AI factors" framework. This framework would scrutinize the AI's internal logic, training data integrity, and emergent behaviours. A new 'AI factors' framework is needed to systematically investigate AI-induced incidents, demanding legally mandated explainability and robust data logging for forensic analysis. Without these, determining why an AI made a particular decision, assigning fault, or preventing future occurrences becomes severely hampered, necessitating a fundamental shift in investigative philosophy and tools.

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14 SAE International, J3016*: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles* (rev June 2021)

15 See generally, M. Whittaker, The Role of Fault in Automated Systems Liability (2021) 34 Journal of Air and Space Law 207.

b. The Standard of Care for AI

A specific legal standard of care for AI systems in safety-critical applications is imperative. This could be conceptualized as a 'reasonable AI' standard, evaluated against industry best practices for AI development, testing, and deployment. This would introduce "AI diligence,"[16]requiring developers and deployers to demonstrate that the AI system was designed, trained, and operated with utmost care, considering its potential for harm and unique characteristics. This standard would address AI's unpredictability and continuous learning, ensuring robustness against unforeseen circumstances. It would involve assessing training data quality, algorithm robustness against adversarial attacks, and continuous monitoring. While related to human *"reasonable person" standards,* it could be higher, given AI's theoretical capacity for perfection and vast data processing ability. The legal system must demand diligence commensurate with autonomous AI's power and impact.[17]

D. Shifting from Individual Blame to Systemic and Shared Responsibility

The traditional model of individual blame, particularly the pilot-centric liability framework, is ill-suited for AI-driven autonomous aviation.

a. Beyond Pilot-Centric Liability

Simply extending pilot liability to a *"remote operator"* is insufficient when the autonomous system itself is making critical real-time decisions, potentially without direct human intervention. The traditional focus on a single human actor becomes obsolete, giving rise to the *'problem of many hands'* where multiple sophisticated actors contribute to AI's development and operation, making pinpointing a single point of failure difficult.

b. A Systemic Accountability Model

A *"Systemic Accountability Model"* is advocated, distributing responsibility across the entire autonomous aviation value chain. This model acknowledges AI's complexity and the multi-party nature of its development and deployment. Accountability would be shared among AI Developers/Designers (for algorithmic flaws and training data biases), Component Manufacturers (for sensor or hardware failures), Autonomous System Integrators (for overall safety and interoperability), Operators (such as airlines or cargo carriers, for operational oversight and maintenance), Certification Authorities (for their oversight and approval processes), and Data

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16 Sunayana Rane, 'The Reasonable Person Standard for AI' (Arxiv.org2020) <https://arxiv.org/html/2406.04671v1> accessed 31 July 2025.

17 Mihailis Diamantis, ' "Reasonable AI: A Negligence Standard" | Private Law Theory - Obligations, Property, Legal Theory' (Private-law-theory.org2024) <https://www.private-law-theory.org/2024/02/09/mihailis-diamantis-reasonable-ai-a-negligence-standard/> accessed 31 July 2025.

Providers (for the quality and integrity of data). This proposed model directly responds to the *'problem of many hands.'* Complemented by strict liability for high-risk autonomous operations, it shifts the legal burden from individual blame to collective responsibility across the value chain, thereby incentivizing maximum safety from all contributing parties and aligning liability with the actual locus of control and benefit. It ensures every actor influencing AI safety has a legal incentive to uphold high standards.

c. Strict Liability for Autonomous Operations

To further incentivize safety and provide clear redress, strict liability for certain categories of autonomous aviation operations is proposed. This would apply particularly to uncrewed cargo flights and Advanced Air Mobility (**"AAM"**) operations, where the operator or main system integrator bears responsibility irrespective of fault. Akin to strict liability for inherently dangerous activities, this approach places the burden of damages on the party best positioned to manage risks and internalize costs, fostering maximum safety incentives. Defining the scope and limits is crucial, potentially tied to AI's autonomy level, operational design domain (**"ODD"**), and potential for catastrophic harm, bypassing the difficulty of proving fault with opaque AI systems.

E. The Role of Insurance and Risk Allocation

Existing aviation liability insurance policies are not fully equipped for AI-specific risks. Traditionally structured around human-piloted operations and mechanical failures, they often contain cyber exclusion clauses or fail to explicitly cover algorithmic errors, emergent behaviours, or distributed AI liability. This evolving risk landscape creates significant gaps in traditional coverage. Current aviation insurance is fundamentally ill-equipped for AI-specific risks like the *'black box'* problem, continuous learning, and novel cyber vulnerabilities, posing a significant financial risk gap for the industry.

To address this, mandatory "AI Liability Insurance" for autonomous aviation is proposed. This specialized insurance would explicitly cover algorithmic errors, cyber-induced failures (e.g., data poisoning, adversarial attacks), and the distributed liability model. It would address losses from AI performance errors, including traditionally uncovered business interruption or reputational damage. Mechanisms for risk pooling among industry players or state-backed insurance schemes should be explored for catastrophic, systemic AI failures, acknowledging that private markets alone might not cover *'heavy-tail risks.'* Such a mandatory scheme would compel the industry to quantify and price these novel risks, ensuring financial protection for victims and stability for the aviation sector.

IV. THE LEGAL STATUS OF AI: BEYOND TOOLS TO AGENTS

F. AI's Current Legal Status: A Sophisticated Tool

Under current legal frameworks, AI systems are predominantly treated as sophisticated tools, devoid of independent legal personality, rights, or obligations.[18] This classification means AI's actions are legally attributed to the human or corporate entities that design, deploy, or operate them. Despite advanced capabilities, AI is considered a manifestation of human design, lacking consciousness or true intent. This view, however, becomes increasingly strained as AI systems demonstrate greater autonomy, learning capabilities, and the ability to make unforeseen judgments not explicitly programmed, highlighting a growing tension with traditional legal tenets.

G. The Debate on "Electronic Legal Personality" for AI

The rapid advancements in AI have spurred debate on granting AI systems a limited "electronic personality."[19] Proponents argue this could simplify liability attribution for highly autonomous systems by allowing the AI itself to be held *responsible*,[20] potentially streamlining compensation. However, strong arguments exist against full legal personality due to philosophical concerns over attributing consciousness or intent to machines, and practical challenges, such as applying criminal liability concepts like *mens rea*. A significant concern also remains that granting AI personhood could allow manufacturers and developers to evade responsibility, diluting human accountability.[21] The prevailing consensus maintains that AI systems are artifacts, not persons, and their actions should ultimately trace back to human or corporate responsibility.

H. Proposed Framework: Functional Legal Responsibility and Proxy Accountability

In aviation, granting full legal personality to AI is premature. Instead, a "Functional Legal Responsibility" model is proposed. Here, AI's autonomous actions would trigger legal consequences channelled directly to legally recognized entities (human or corporate) responsible for the AI's design, deployment, or supervision. This approach ensures accountability without the philosophical complexities of AI personhood. Key elements include Proxy Accountability,

[18] European Commission, 'Proposal for a Regulation laying down harmonised rules on Artificial Intelligence (Artificial Intelligence Act)' COM (2021) 206.
[19] European Parliament, Resolution on Civil Law Rules on Robotics, P8_TA(2017)0051 (16 February 2017) para 59, which addresses legal personality for robots.
[20] Paul Opitz, 'Stanford -Vienna Transatlantic Technology Law Forum Civil Liability and Autonomous Robotic Machines: Approaches in the EU and US' (2019) <https://law.stanford.edu/wp-content/uploads/2019/02/opitz_wp43.pdf> accessed 31 July 2025.
[21] European Commission, Follow up to the European Parliament resolution of 16 February 2017 on civil law rules on robotics, 2015/2103 (INL), Reference Number: A8-0005/2017 / P8_TA-PROV(2017)0051, 2.

designating a human or corporate entity (e.g., "AI Owner/Operator") as legally accountable for the AI's actions, and requiring a "Responsible AI Party" to bear ultimate accountability throughout the AI's lifecycle. Additionally, "Limited Autonomy, Limited Liability" could cap liability for specific, constrained autonomous functions, balancing innovation with safety.

I. Redefining "Pilot in Command" and New Operational Roles

The traditional PIC concept,[22] based on a human physically present, is fundamentally challenged by AI autonomy and needs evolution, particularly for uncrewed aircraft. Therefore, distinct legal classifications for new operational roles are proposed. These include an *Autonomous System Supervisor* (**"ASS"**),[23] a certified human monitoring and intervening in autonomous flights from a ground control station, with liability for oversight failures. This ensures continued human judgment in emergencies. A new regulatory role, the *AI Operational Certifier*,[24] would be responsible for approving AI *operational design domains* (**"ODDs"**) and ensuring continuous AI performance monitoring. Additionally, the AI system itself could be given a functional legal designation, the *"AI Flight Manager,"* primarily for record-keeping and data attribution in accident investigations.[25] These new roles necessitate developing legal implications for licensing, training, and international recognition to ensure seamless global operations.

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[22] Chicago Convention on International Civil Aviation, 7 December 1944, 15 UNTS 295, Article 8 and Annex 1 (Personnel Licensing); ICAO Doc 10019, *Manual on Remotely Piloted Aircraft Systems* (RPAS) (2015); EASA, 'Opinion No 01/2018 on the Regulatory Framework for the Operation of Drones', 2018. See also, George Thomas Black, Kelly Cohen and Catherine Ronflé-Nadaud, 'Integration in the National Airspace (Europe and USA) – UAV Classification and Associated Missions, Regulation and Safety, Certification and Air Traffic Management' [2020] ISTE eBooks 1 <https://www.sciencedirect.com/science/article/abs/pii/B9781785482519500017> accessed 31 July 2025.

[23] Becky and Wisk, 'Creating a New Role in Aviation: The Multi-Vehicle Supervisor | Wisk' (WiskNovember 2023) <https://wisk.aero/news/blog/creating-a-new-role-in-aviation-the-multi-vehicle-supervisor/> accessed 31 July 2025; Teledyne , 'Teledyne FLIR Launches Prism Supervisor Software, Enhances UAS Autonomous Capabilities' (Flir.com2025) <https://oem.flir.com/en-in/about/news/teledyne-flir-launches-prism-supervisor-software-enhances-uas-autonomous-capabilities/#:~:text=%22It%20improves%20operational%20performance%20via,with%20approximately%204%2C000%20employees%20worldwide> accessed 31 July 2025.

[24] Hymalai Bello and others, 'Towards Certifiable AI in Aviation: Landscape, Challenges, and Opportunities' (2018) 37 J. ACM 111 <https://arxiv.org/pdf/2409.08666> accessed 31 July 2025; Paola Lanzi and others, 'Challenges and New Directions for the Certification of AI and Advanced Automation in Civil Aviation' <https://www.sesarju.eu/sites/default/files/documents/sid/2024/papers/SIDs_2024_paper_052%20final.pdf> accessed 31 July 2025.

[25] David Fernández Llorca and others, 'Testing Autonomous Vehicles and AI: Perspectives and Challenges from Cybersecurity, Transparency, Robustness and Fairness' (2025) 17 European Transport Research Review.

V. DATA GOVERNANCE, TRANSPARENCY, AND FORENSIC READABILITY OF AI SYSTEMS

J. The 'Black Box Problem' Revisited: Legal Requirements for Explainability

The inherent opacity of AI decision-making (the *'black box'* problem) significantly challenges aviation accident investigation and legal proceedings.[26] This opacity hinders determining causality and attributing fault, jeopardizing justice and public trust.[27] To address this, a mandatory *'Explainable AI (**"XAI"**) by Design'*[28] principle should be legally enshrined for all safety-critical AI systems in aviation, especially within EU regulations.[29] This principle requires AI systems to be auditable and produce human-readable explanations of their reasoning leading to critical decisions. This isn't about full code transparency, but sufficient explainability for human experts to understand the AI's judgment. A balance must be struck between proprietary concerns and the public interest in safety, drawing on precedents like the EU AI Act.

K. Standardized Data Collection, Access, and Sharing for Investigation and Oversight

Current flight data recorders (**"FDRs"**) and cockpit voice recorders (**"CVRs"**) are insufficient for capturing AI's full internal state, including sensory inputs, decision parameters, or evolving states.[30] A new EU-level regulation is proposed, mandating standardized data formats, storage, and immediate access protocols for "AI Event Recorders" or "Autonomous System Data

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[26] Lou Blouin, 'AI's Mysterious "Black Box" Problem, Explained' (University of Michigan-Dearborn6 March 2023) <https://umdearborn.edu/news/ais-mysterious-black-box-problem-explained> accessed 1 August 2025; Bartosz Brożek and others, 'The Black Box Problem Revisited. Real and Imaginary Challenges for Automated Legal Decision Making' (2023) 32 Artificial Intelligence and Law 427 <https://link.springer.com/article/10.1007/s10506-023-09356-9> accessed 1 August 2025.

[27] Warren J von Eschenbach, 'Transparency and the Black Box Problem: Why We Do Not Trust AI' (2021) 34 Philosophy & Technology 1607 <https://link.springer.com/article/10.1007/s13347-021-00477-0> accessed 1 August 2025.

[28] Upol Ehsan and others, 'Seamful XAI: Operationalizing Seamful Design in Explainable AI' (2024) 8 Proceedings of the ACM on Human-Computer Interaction 1 <https://dl.acm.org/doi/10.1145/3637396> accessed 1 August 2025; Q Vera Liao, Daniel Gruen and Sarah Miller, 'Questioning the AI: Informing Design Practices for Explainable AI User Experiences', Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (2020) <https://arxiv.org/pdf/2001.02478> accessed 1 August 2025.

[29] Aditya P Saraf, Kennis Chan and Martin Popish, 'A Framework for Assessment of Autonomy Challenges in Air Traffic Management | AIAA AVIATION Forum' [2020] AIAA AVIATION Forum <https://doi.org/10.2514/6.2020-3248> accessed 1 August 2025.

[30] European Union Aviation Safety Agency (EASA), Opinion No 1/2020 on the Introduction of AI Systems in Aviation, EASA, 2020; EASA, 'European Plan for Aviation Safety (EPAS) 2021–2025 Vol 1.' (2020) <https://skybrary.aero/sites/default/files/bookshelf/5968.pdf> accessed 31 July 2025; Douglas M Marshall, 'UAS Airspace Integration in the European Union' [2022] UAS Integration into Civil Airspace 11 <https://onlinelibrary.wiley.com/doi/10.1002/9781118536575.ch2?msockid=22aa50ea4a016d7f101346d24b5e6ca8> accessed 31 July 2025.

Logs."[31] These logs must capture comprehensive AI data to enable forensic analysis.[32] Challenges like data ownership must be addressed, with legal compulsion for disclosure during investigations. Secure data transfer and integrity measures are paramount.[33] Such standardized logging will significantly enhance the ability to reconstruct AI-driven incidents and identify root causes, informing adaptive regulation.[34]

L. *Cybersecurity and Resilience for Autonomous Aviation Systems*

Autonomous AI systems are attractive targets for sophisticated cyberattacks (e.g., data poisoning, adversarial attacks), posing catastrophic risks to aviation safety and public trust. [35]Increasing reliance on AI in aviation makes cybersecurity paramount. Specific, legally binding EU cybersecurity standards for aviation AI are essential.[36] These standards should include mandatory risk assessments, secure development lifecycles for AI software, continuous anomaly monitoring, and real-time threat intelligence sharing among stakeholders. Legal consequences for cybersecurity negligence leading to incidents must be clearly defined. Furthermore, "AI resilience"[37]—the

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31 Regulation (EU) 2018/1139 of the European Parliament and of the Council on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency [2018] OJ L212/1 (EASA Basic Regulation).

32 ICAO Annex 6 Part I and Part III (Operation of Aircraft), provisions on flight data recorders.

33 Igor Kabashkin and Vitaly Susanin, 'Unified Ecosystem for Data Sharing and AI-Driven Predictive Maintenance in Aviation' (2024) 13 Computers 318 <https://www.mdpi.com/2073-431X/13/12/318> accessed 1 August 2025.

34 UMATechnology, 'Root Cause Detection in Distributed Logging Agents Tracked via Observability Tools - UMA Technology' (UMA Technology8 July 2025) <https://umatechnology.org/root-cause-detection-in-distributed-logging-agents-tracked-via-observability-tools/> accessed 31 July 2025.

35 Blessing Guembe and others, 'The Emerging Threat of Ai-Driven Cyber Attacks: A Review' (2022) 36 Applied Artificial Intelligence 1 <https://www.tandfonline.com/doi/full/10.1080/08839514.2022.2037254> accessed 1 August 2025; Nir Kshetri, 'Transforming Cybersecurity with Agentic AI to Combat Emerging Cyber Threats' [2025] Telecommunications Policy 102976 <https://www.sciencedirect.com/science/article/pii/S0308596125000734> accessed 1 August 2025; Anand Ramachandran, 'AI-Driven Autonomous Cyber-Security Systems: Advanced Threat Detection, Defense Capabilities, and Future Innovations' (21 November 2024) <https://www.researchgate.net/publication/386013628_AI-Driven_Autonomous_Cyber-Security_Systems_Advanced_Threat_Detection_Defense_Capabilities_and_Future_Innovations> accessed 1 August 2025.

36 Directive (EU) 2022/2555 on measures for a high common level of cybersecurity across the Union (NIS 2 Directive) [2022] OJ L 433/1; Regulation (EU) 2019/881 on ENISA and cybersecurity certification (Cybersecurity Act) [2019] OJ L151/15; European Union Agency for Cybersecurity (ENISA), *Guidelines for Securing AI Systems,* 2023; EASA and Vasileios PAPAGEORGIOU, 'Developing Cybersecurity Regulations in Aviation & Part-IS | EASA Community' (EASA Community2023) <https://www.easa.europa.eu/community/topics/developing-cybersecurity-regulations-aviation-part> accessed 31 July 2025.

37 Adele Berti, 'FLY AI: The Role of Artificial Intelligence in Aviation' (Airport Technology21 July 2020) <https://www.airport-technology.com/features/artificial-intelligence-aviation/> accessed 1 August 2025; EUROCONTROL, 'FLY AI Report' (www.eurocontrol.int) <https://www.eurocontrol.int/publication/fly-ai-report> accessed 1 August 2025.

system's ability to recover from cyberattacks or unexpected failures—should be a core design and certification requirement,[38] ensuring safe operation even under duress, complementing existing directives like NIS2.[39]

VI. Crafting a Novel Legal Framework: A Blueprint for the Future

M. The Imperative for a Proactive, Adaptive, and Harmonized Approach

A reactive *"wait-and-see"* approach to regulating AI in aviation risks compromising safety, hindering innovation, and undermining public confidence. A proactive approach, anticipating legal challenges, is imperative. Fragmentation of national regulations would impede seamless global operations, fundamental to aviation. Therefore, international harmonization is necessary to ensure interoperability and consistent safety standards worldwide, preventing a fragmented legal landscape and *"liability shopping."*

N. Proposed Elements of a New EU-Led Legal Framework for Autonomous Aviation

The European Union is uniquely positioned to lead a novel legal framework for autonomous aviation, serving as a blueprint for global harmonization. This framework should include a Comprehensive "EU Autonomous Aviation Act," a horizontal legislative instrument establishing foundational legal principles for AI autonomy. This Act would encompass clear definitions, AI safety principles, general liability channelling, mandates for transparency and auditable data logs ('AI Event Recorders'), and a framework for new operational roles. Complementing this, Specialized "AI Aviation Certification & Oversight" within EASA is essential. EASA should establish a dedicated function for certifying AI autonomy, developing AI-specific standards for decision-making robustness and resilience, and overseeing continuous AI testing and post-deployment monitoring.[40] Furthermore, a legal requirement for Mandatory Incident Reporting for AI Anomalies to a central, anonymized EU database is crucial for identifying systemic risks and informing adaptive regulation.[41] Finally, the EU should champion

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[38] Ian Gauci, 'Aviation: Part-IS Obligations & the Role of AI Certification' (GTG Legal6 October 2024) <https://gtg.com.mt/aviation-cybersecurity-part-is-obligations-and-ai-role/> accessed 31 July 2025.

[39] EASA and Vasileios Papageorgiou, 'The Publication of the NIS2 & CER Directives and the Aviation Sector | EASA Community' (EASA Community2023) <https://www.easa.europa.eu/community/topics/publication-nis2-cer-directives-and-aviation-sector> accessed 31 July 2025.

[40] Ivo Emanuilov and Orian Dheu, 'Flying High for AI? Perspectives on EASA's Roadmap for AI in Aviation' (2021) 46 Air and Space Law 1 <https://www.researchgate.net/publication/348735351_Flying_High_for_AI_Perspectives_on_EASA%27s_Roadmap_for_AI_in_Aviation> accessed 1 August 2025.

[41] Artificial Intelligence Act, art 73; EUROCONTROL, 'Mandatory Occurrence Reporting' (SKYbrary Aviation Safety29 May 2021) <https://skybrary.aero/articles/mandatory-occurrence-reporting> accessed

Transatlantic and International Harmonization by proposing a new ICAO annex or convention on autonomous aviation, promoting global interoperability and consistent safety standards in AI certification, liability, data exchange, and cybersecurity norms.[42]

O. Regulatory Sandboxes and Adaptive Law-Making for Rapid Innovation

To bridge the gap between rapid technological advancement and slower law-making, a legally defined "EU Aviation AI Regulatory Sandbox" is proposed.[43] This allows companies to test autonomous systems in real-world scenarios under controlled conditions with modified liability. Such sandboxes require strict safety protocols, transparent data sharing, iterative learning loops, and clear exit strategies.[44] This adaptive mechanism fosters responsible innovation by enabling legal frameworks to evolve in parallel with technology, maintaining high safety standards.[45]

VII. CONCLUSION

The preceding analysis highlights the fundamental inadequacy of human-centric aviation legal frameworks for AI-driven autonomous systems. Ignoring these challenges risks compromising safety, hindering innovation, and undermining public confidence.

To navigate this era, a paradigm shift in legal thought is essential. This paper proposes an EU-led framework to redefine fault, rechannel liability, and establish transparent governance. Core components include systemic accountability, functional legal responsibility, XAI, AI Event Recorders, specialized EASA certification, and international harmonization.

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1 August 2025; Theodoros Karathanasis, 'Chair Legal and Regulatory Implications of Artificial Intelligence 31' (2024) <https://ai-regulation.com/wp-content/uploads/2024/05/TK-AI-incident-notification-in-the-EU-AI-Act-How-does-it-work-and-is-it-Effective.pdf> accessed 1 August 2025.

42 European Commission , 'JOINT COMMUNICATION to the EUROPEAN PARLIAMENT, the EUROPEAN COUNCIL and the COUNCIL a New EU-US Agenda for Global Change' (2020) <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020JC0022> accessed 1 August 2025.

43 Altti Lagstedt, 'EUSAir: EU Regulatory Sandboxes for AI' (Haaga-Helia2024) <https://www.haaga-helia.fi/en/rdi-projects/eusair> accessed 1 August 2025.

44 Dimitrios Miltiadou and others, 'A Secure Experimentation Sandbox for the Design and Execution of Trusted and Secure Analytics in the Aviation Domain' [2021] Springer eBooks 120 <Dimitrios Miltiadou and others, 'A Secure Experimentation Sandbox for the Design and Execution of Trusted and Secure Analytics in the Aviation Domain' [2021] Springer eBooks 120.> accessed 1 August 2025; European Union Aviation Safety Agency, Opinion No 03/2021 on the Management of Information Security Risks (adopted 11 June 2021); Commission Implementing Regulation (EU) 2023/203 of 27 October 2022; Commission Regulation (EU) 2018/1139 [2023] OJ L 31, 1–40.

45 EUROCONTROL, 'Standards as Enablers of Innovation in the Aviation Industry' (Eurocontrol.int15 October 2024) <https://www.eurocontrol.int/article/standards-enablers-innovation-aviation-industry> accessed 1 August 2025.

Autonomous aviation's transformative potential is immense. Realizing these benefits requires proactive legal evolution. By adopting a comprehensive, adaptive, and ethically informed framework, particularly within the EU, the aviation sector can responsibly unlock AI's full advantages, ensuring progress aligns with safety, accountability, and public trust for a safer, more efficient future.