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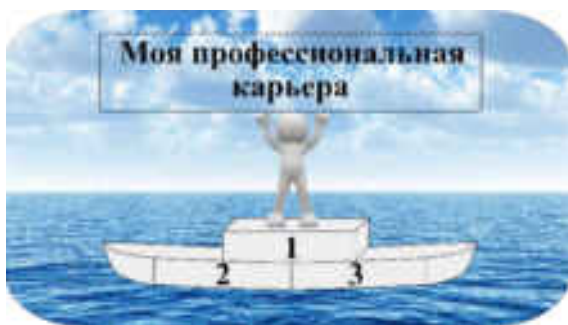


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**Международный научно-образовательный электронный журнал
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Название публикации: «AN INTEGRATED MODEL OF COMPOSITE MATERIALS, AUTOMATED DESIGN, AND PREDICTIVE MAINTENANCE FOR IMPROVING THE RELIABILITY OF AVIATION SYSTEMS»

Abstract. Ensuring the reliability of an aviation system can no longer be treated as the task of a single life-cycle stage. This study addresses the fragmentation between materials selection, structural design, manufacturing technology, operational monitoring, and maintenance, which weakens the overall reliability of complex objects such as unmanned aerial vehicles (UAVs) and gas-turbine aero-engines. The aim is to analyse a group of related engineering studies as a single concept and to propose an integrated model for improving the structural, technological, and operational reliability of aviation hardware. The work is theoretical and analytical: it applies a systematic comparison of existing engineering results and synthesises them around the concept of a reliability chain. Five thematic directions are examined: the mechanical behaviour of V95P aluminium-alloy fasteners after high-temperature treatment; automated CAD/CAE shaping of UAV external geometry; heat-transfer effects during the curing of epoxy-based composite parts; the combination of vacuum infusion, computational fluid dynamics, and intelligent energy management; and predictive-maintenance modelling for aero-engines. The principal result is an integrated model that links material quality, design, manufacturing stability, aerodynamic and energy efficiency, and predictive maintenance into one conceptual reliability function. The model is intended as an analytical framework rather than an empirical formula. Its significance lies in supporting integrated engineering education, stage-by-stage technical control

for UAV development teams, and the gradual introduction of predictive-maintenance practices in civil aviation.

Keywords: automated design, aviation reliability, composite materials, predictive maintenance, unmanned aerial vehicle, gas-turbine engine.

1. Introduction

In modern aviation engineering, reliability is not secured solely by testing the finished product or by scheduled maintenance. The safe operation of an aircraft depends on the interaction of material selection, structural design, manufacturing technology, in-service monitoring, and data-driven maintenance. For complex objects such as unmanned aerial vehicles (UAVs) and civil-aviation engines, structural lightness, aerodynamic efficiency, energy economy, and early fault detection should be treated as one coupled system rather than as separate problems.

The mechanical properties of the materials used in aircraft structures are among the primary determinants of technical safety. Abdujabarov et al. (2022) studied the mechanical properties of wire made from the V95P aluminium alloy after high-temperature annealing and showed that the technological plasticity of fastening elements for aircraft structures can be improved. This indicates that reliability begins to form at the stage of preparing the material and semi-finished product, not only during operation. Recent work on Al–Zn–Mg–Cu fastener wire, to which V95P belongs, confirms that the annealing and cold-working route governs the strength–ductility balance and the cracking resistance of the finished fastener (Gao et al., 2026).

For UAV structures, material choice is accompanied by the external shape, aerodynamic configuration, and automated design. Shokirov et al. (2022) analysed the shaping of UAV external geometry using computer-aided design (CAD) and computer-aided engineering (CAE) systems. This approach allows several structural variants to be developed, evaluated, and optimised in parallel from the earliest design stage.

Polymer-matrix composites are now widely used in UAV structures. Khusnutdinova et al. (2025) examined the influence of heat-transfer mechanisms on the curing of thick-walled UAV parts made from epoxy-based composites. Takhirov et al. (2025) proposed an approach for a multifunctional composite UAV that combines

vacuum infusion, computational fluid dynamics (CFD), and intelligent energy management. For civil-aviation engines, Umarov (2025) considered the use of a predictive-maintenance model to improve engine reliability and flight safety under the conditions of Uzbekistan.

The aim of this paper is to analyse these results as a single engineering concept and to propose an integrated model for improving the structural, technological, and operational reliability of aviation hardware.

2. Materials and Methods

This paper is theoretical and analytical. No new laboratory experiments or flight tests were performed. The main method is a systematic analysis of existing engineering studies, a comparison of their technical content, and their synthesis into a coherent concept. The analysis was carried out along five directions: (i) the mechanical properties of aluminium alloys and fastening elements for aircraft structures; (ii) automated design of UAV external geometry; (iii) heat-transfer mechanisms during the curing of epoxy-based composite parts; (iv) the effect of vacuum infusion, CFD analysis, and intelligent energy management on the UAV structure; and (v) predictive-maintenance models for aero-engines.

The study adopts the concept of a reliability chain. Under this view, the reliability of aviation hardware is formed not at one isolated stage but across a sequence of linked stages: material selection → structural design → manufacturing → verification of aerodynamic and energy efficiency → operational monitoring → predictive maintenance.

3. Results

3.1. Material properties and structural reliability

Fastening elements are small but critical parts of the overall safety system of an aircraft structure. The study of the V95P alloy shows that high-temperature annealing can raise the technological plasticity of the wire and enable the manufacture of fastening details for aircraft structures (Abdujabarov et al., 2022). Such treatment can reduce local stress concentrations, technological defects, and the risk of fatigue in service. A recent comparative study of Al–Zn–Mg–Cu wire reaches a consistent

conclusion: the cooling regime after intermediate annealing controls precipitation and texture, and a more uniform, ductile state markedly improves cold-heading formability and resistance to cracking (Gao et al., 2026).

This is also relevant to UAV and light-aircraft structures. While composites reduce weight and improve aerodynamic efficiency, they are sensitive to metal fasteners, joints, load-transfer zones, and manufacturing defects. It is therefore appropriate to assess the composite structure and its metal fastening elements as one structural system rather than separately.

3.2. Automated design and aerodynamic efficiency

Traditional drawing- and experience-based methods are insufficient for shaping UAV geometry. CAD and CAE systems make it possible, from the first design stage, to compare several variants, check the aerodynamic shape, and evaluate structural constraints (Shokirov et al., 2022). This matters for UAVs in particular, because a small structural change can noticeably affect lift, drag, energy consumption, and endurance. Coupled CFD and finite-element studies of composite UAV airframes confirm that aerodynamic and structural performance are best evaluated together rather than in isolation (Vijayalakshmi et al., 2023).

The multifunctional composite UAV proposed by Takhirov et al. (2025) is notable because it integrates composite materials, vacuum infusion, CFD analysis, and intelligent energy management into one design framework. In this approach the structure is treated not as a fixed geometric shape but as a balance between material, technology, aerodynamics, and energy use.

3.3. Composite curing and manufacturing quality

For thick-walled composite parts, curing is a critical technological stage. Uneven curing of the epoxy binder can cause internal stresses, microvoids, delamination, and reduced mechanical properties. Khusnutdinova et al. (2025) analysed the role of heat-transfer mechanisms during curing and drew attention to the problem of low thermal conductivity. Numerical modelling of vacuum-infusion processes likewise shows that controlling pressure and the thermal field is decisive for the final quality of thin- and thick-walled composite parts (Shevtsov et al., 2024).

This has direct practical importance for UAVs, whose wings, fuselage, skins, and load-bearing parts often combine thin- and thick-walled zones. Temperature non-uniformity during curing can later promote hidden defects under the vibration, fatigue, and impact loads of flight. Controlling the thermal regime during manufacturing is therefore a precondition for operational reliability.

3.4. Energy management and operational stability

Because a UAV has limited energy resources, structural lightness, reduced aerodynamic drag, and rational distribution of electrical energy directly affect endurance. An intelligent energy-management system improves operational stability by monitoring on-board voltage, current, battery state, and load regimes in real time (Takhirov et al., 2025).

The key point is that energy management is not only an electrical-system issue. It is connected to aerodynamic drag, structural mass, payload, flight profile, and control algorithms. The chain of material, aerodynamics, energy, and reliability should therefore be evaluated jointly during UAV design.

3.5. Predictive maintenance and engine reliability

Predictive maintenance (PdM) assesses the condition of aviation hardware from sensor data, operational parameters, and machine-learning algorithms. The model proposed by Umarov (2025) targets the near-term failure risk of turbofan engines in civil aviation and treats thermal and vibration indicators as important diagnostic signals. Broader work on aircraft-engine prognostics confirms the value of interpretable, ensemble machine-learning models for remaining-useful-life estimation and maintenance scheduling (Özcan, 2025).

This approach can be adapted to UAV systems, where the technical condition can be assessed from data collected at the engine or electric drive, the battery, the control module, the navigation block, and the structural load zones. The goal is not repair after a failure but early detection of failure probability and a maintenance decision taken in advance.

3.6. The integrated model

On the basis of the analysis, the following integrated model is proposed for improving the reliability of aviation hardware. Stage 1, material and joint selection, evaluates aluminium alloys, composites, fastening elements, and their processing regimes; studies of the V95P alloy illustrate how material properties influence operational reliability (Abdujabarov et al., 2022; Gao et al., 2026). Stage 2, digital design, uses CAD and CAE tools to analyse UAV geometry, load-bearing parts, aerodynamic shape, and structural constraints together (Shokirov et al., 2022; Vijayalakshmi et al., 2023). Stage 3, manufacturing, controls temperature, pressure, binder distribution, and microvoid risk during vacuum infusion, lay-up, and curing (Khusnutdinova et al., 2025; Shevtsov et al., 2024; Takhirov et al., 2025). Stage 4, aerodynamic and energy optimisation, uses CFD analysis, an energy-consumption model, and intelligent energy management to assess endurance, stability, and payload capacity (Takhirov et al., 2025). Stage 5, operational monitoring and predictive maintenance, tracks changes in engine, energy, vibration, temperature, and load parameters and estimates failure probability in advance (Umarov, 2025; Özcan, 2025).

Table 1. Analysed sources and their functional role in the integrated model

Source	Main research focus	Function within the integrated model
Abdujabarov et al. (2022)	V95P aluminium alloy; high-temperature treatment; mechanical properties of fastener wire	Assessing the reliability of materials and fastening elements (Stage 1)
Khusnutdinova et al. (2025)	Curing of composite parts; heat transfer; epoxy binder	Controlling manufacturing quality and reducing internal-defect risk (Stage 3)

Source	Main research focus	Function within the integrated model
Shokirov et al. (2022)	Automated design of UAV external geometry (CAD/CAE)	Digital design and selection of structural variants (Stage 2)
Takhirov et al. (2025)	Composite UAV; vacuum infusion; CFD; intelligent energy management	Linking material, aerodynamic, and energy efficiency (Stages 3–4)
Umarov (2025)	Aero-engines; predictive maintenance; reliability and safety	Operational monitoring and early failure prognosis (Stage 5)

In the proposed model, reliability is treated as an integral quantity that can be expressed conceptually as:

$$I = f(M, L, T, A, E, P)$$

where I is the overall reliability of the aviation system; M is the quality of the material and its mechanical properties; L is the quality of the design and structural solutions; T is the stability of the manufacturing process; A is aerodynamic efficiency; E is the efficiency of energy management; and P is the effectiveness of the predictive-maintenance system. This expression is a conceptual basis for engineering analysis rather than an empirical computation. In future work, measurable indicators can be developed for each factor, and their weighting coefficients can be determined from experimental data. The structure of the model and the operational-data feedback loop are summarised in Figure 1.

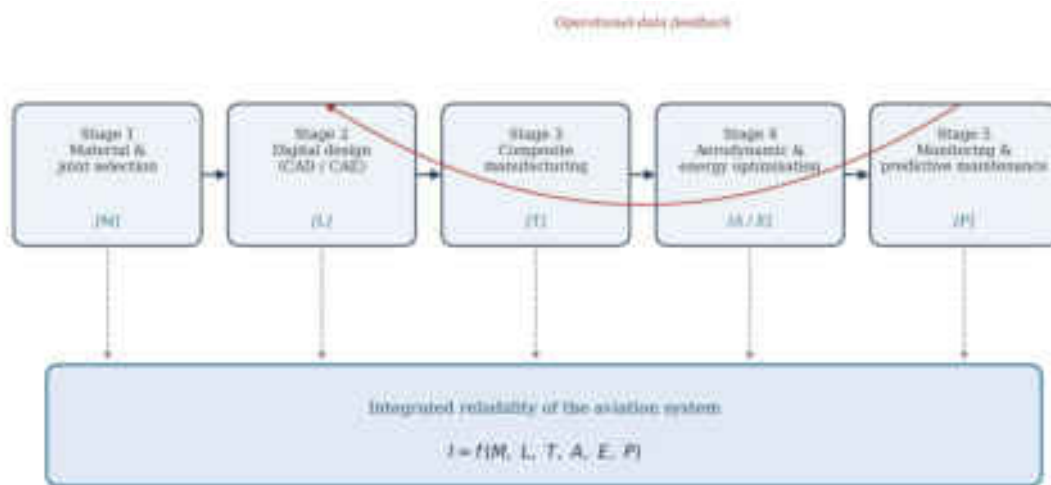


Figure 1. Conceptual structure of the integrated reliability model, showing the five processing stages, their contribution to the overall reliability function $I = f(M, L, T, A, E, P)$, and the feedback of operational data into the design stage.

Alt text: A horizontal flow of five linked boxes — material and joint selection, digital design, composite manufacturing, aerodynamic and energy optimisation, and monitoring and predictive maintenance — each feeding downward into a wide box representing integrated system reliability, with a curved feedback arrow returning from the monitoring stage to the design stage.

4. Discussion

The analysis indicates that the reliability of aviation hardware is improved more effectively by integrating material selection, structural design, manufacturing technology, and operational maintenance into one engineering system than by refining each of them separately. Each link in the chain constrains the others: a well-chosen alloy can still fail at a poorly cured joint, and an aerodynamically efficient shape can still be unreliable if its energy budget or its in-service condition is not monitored. The value of the integrated model is that it makes these dependencies explicit and connects the design and maintenance stages through a feedback of operational data.

The proposed approach has several practical implications for aviation education, UAV technology, and civil-aviation maintenance in Uzbekistan. First, it supports teaching materials science, aerodynamics, structures, manufacturing technology, and technical operation as connected subjects rather than isolated courses. Second, it offers

UAV development teams a stage-by-stage technical-control procedure. Third, it allows predictive-maintenance elements to be introduced gradually when monitoring the condition of engines and on-board systems in civil aviation.

Several limitations should be acknowledged. Implementing the model in practice requires sufficient sensor data, stable quality control of composite manufacturing, skilled use of CAD/CAE/CFD software, trained technical staff, and alignment with regulatory documents. The reliability function is conceptual: the indicators and weighting coefficients for each factor have not yet been determined experimentally, and the model has not been validated on a physical platform.

5. Conclusion

The analysis shows that the reliability of aviation hardware is best improved by combining material selection, structural design, manufacturing technology, and operational maintenance into a single engineering system. Studies of the V95P alloy show the importance of the technological plasticity and mechanical properties of fastening elements. Automated design with CAD and CAE tools allows structural variants to be selected systematically. Controlling heat-transfer mechanisms during composite curing is necessary to reduce internal defects and stabilise mechanical properties. The integration of vacuum infusion, CFD analysis, and intelligent energy management improves the aerodynamic and operational efficiency of UAVs. Predictive maintenance supports the early detection of faults in aero-engines and other complex systems.

The proposed integrated model can serve as a conceptual basis for the combined assessment of structural, technological, and operational reliability. Future work should validate the model using operational data from a real UAV platform or aero-engine, develop a system of indicators, and formulate a method for the quantitative assessment of reliability.

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Use of artificial intelligence. The author used Claude AI for language editing and structural improvement of the manuscript. The author takes full responsibility for the accuracy, originality, integrity, and final content of the article.

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