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PERFORMANCE-BASED CERTIFICATION AS A DRIVER OF INNOVATION IN AIRCRAFT DESIGN

The transition from CS-23 Amendment 4 to CS-23 Amendment 5 introduced a fundamental change in the philosophy of airworthiness certification, replacing a prescriptive framework based on predefined technical solutions with a performance-based approach centered on high-level safety objectives. This transformation reduced reliance on prescriptive regulatory requirements and increased flexibility for integrating emerging technologies, including electric propulsion systems, fly-by-wire architectures, distributed propulsion concepts, and digital engineering methods. At the same time, the burden of demonstrating means of compliance shifted significantly from regulatory authorities to applicants. The study analyzes the key principles introduced by CS-23 Amendment 5, including the separation of safety objectives from technical implementation methods, the integration of industry consensus standards, aircraft-level safety assessment, risk-based certification approaches, and the Level of Involvement (LOI) framework. Particular attention is paid to the challenges faced by design organizations with limited certification heritage. The paper examines the Ukrainian context, where intensive development of unmanned aerial systems has generated practical experience in rapid design cycles, digital engineering tools, autonomous systems, and advanced aircraft technologies. The transfer of this experience to future civil general aviation projects may create additional certification challenges, as newly established organizations are frequently assigned conservative DOA performance assessments, leading to increased regulatory involvement. The potential application of Knowledge-Based Engineering (KBE) as a supporting digital methodology is investigated. KBE enables the formalization of engineering knowledge, the automation of design procedures, the generation of structured compliance evidence, and improved traceability throughout the development process. The study demonstrates that integrating KBE principles with model-based engineering approaches may support organizational maturity and reduce certification complexity in a risk-based regulatory environment.

Keywords: *performance-based certification, airworthiness, aircraft design, design automation, aircraft, UAV, knowledge-based engineering, strength.*

Introduction

The regulatory framework for aircraft certification preceding the implementation of CS-23 (Amendment 5) [1] was characterized by pronounced conservatism and a prescriptive nature. These regulations were rooted in engineering concepts and technologies dominant in the aviation industry of the mid-20th century. Consequently, airworthiness standards focused on the detailed regulation of specific design configurations, manufacturing technologies, materials, and systems. While sufficient for the technological landscape of that era, this approach eventually became a significant barrier to the integration of modern innovations.

The rapid emergence of transformative technologies at the dawn of the 21st century is most notable within the light aircraft and general aviation sectors. It exposed the growing obsolescence of traditional airworthiness standards. The integration of electric and hybrid propulsion systems, the implementation of sophisticated fly-by-wire flight control architectures, the adoption of additive manufacturing processes, and the advancement of design methodologies, including generative design, knowledge-based engineering, high-fidelity simulations, AI and surrogate models collectively expanded the technological frontier beyond the scope of existing regulatory provisions. Ultimately, these modern engineering advancements were fundamentally incompatible with the rigid requirements of the existing regulatory framework.

Regulatory authorities, most notably the FAA, were compelled to rely increasingly on Special Conditions to bridge the gap between existing requirements and emerging technologies. The growing frequency of such interventions indicated that the prevailing regulatory framework had reached its operational limits. This prompted a structural reform process, initiated through the FAA's CPS initiative in 2008 [2] and developed by the Aviation Rulemaking Committee between 2011 and 2013. The legislative mandate followed with the Small Airplane Revitalization Act in 2013, culminating in the synchronised introduction of updated requirements by the FAA in December 2016 and EASA in March 2017[3].

However, while this synchronization marked a milestone in regulatory theory, the practical transition from a prescriptive to a performance-based environment has revealed a new set of structural, economic, and institutional frictions that challenge the initial promise of a “simplified” certification landscape.

Formulation of the problem

The transition from the prescriptive framework of CS-23 Amendment 4 [4] to the performance-based model introduced by Amendment 5 [1] fundamentally changed the philosophy of airworthiness certification. The previous approach relied on detailed technical requirements and predefined design solutions, while the current framework establishes high-level safety objectives and allows applicants to define appropriate Means of Compliance. This transition increased flexibility and simplified the integration of emerging technologies, but also transferred a substantial portion of responsibility for compliance justification from regulatory authorities to applicants.

Such a regulatory approach creates additional challenges for organizations with limited certification experience. Within the EASA risk-based framework, the Level of Involvement (LOI) [5] depends not only on technological novelty and system complexity, but also on the demonstrated performance of the Design Organization Approval (DOA). Newly established organizations are commonly assigned an unknown performance level, resulting in increased regulatory oversight and more conservative certification processes.

For Ukraine, this issue has particular relevance. Rapid development of unmanned aerial systems (UAS) during recent years has generated significant practical experience in areas including digital design methods, electric propulsion systems, autonomous control, and short development cycles. A portion of this experience may subsequently be transferred into the development of future civil general aviation aircraft. However, organizations originating from the UAS sector may face additional certification barriers due to limited experience with civil airworthiness procedures and the resulting higher levels of regulatory involvement.

Under these shifting regulatory conditions, digital engineering methods that enhance process transparency and mitigate the risk of late-stage non-compliance are increasingly vital. Knowledge-Based Engineering (KBE) [6] emerges as a promising methodology in this context; by formalizing engineering logic and automating design workflows, it offers versatile mechanisms that can be extended to support the systematic generation of structured compliance evidence.

The aim of the paper is to identify the challenges associated with implementing the modern CS-23 performance-based framework for Ukrainian design organizations and to investigate the potential of advanced digital prototyping approaches, such as KBE, for improving organizational maturity, reusing validated best practices, supporting compliance activities, and eventually reducing certification complexity within a risk-based regulatory environment.

Key Principles of CS-23 Amendment 5

CS-23 Amendment 5 introduced a fundamental shift from prescriptive regulation to a performance-based certification framework. The previous approach mandated predefined design solutions and standardised analytical methods. Whilst this simplified compliance verification through checklist-based assessment, it also acted as a technological constraint. Any deviation from established design practices required lengthy Special Conditions approval, rendering innovation financially prohibitive for most applicants.

The core transformation replaces detailed prescriptive rules with technology-neutral, high-level safety objectives. A representative example is CS 23.333 "Flight envelope", which previously mandated the V-n diagram methodology through an exhaustive regulatory structure tied to conventional aerodynamic configurations. Under CS-23 Amendment 5, the equivalent requirement states only that structure must withstand foreseeable operating loads without detrimental permanent deformation or failure. Specific analytical procedures are delegated to Acceptable Means of Compliance (AMC), Guidance Material (GM), and industry consensus standards.

This produces a two-level regulatory architecture. The primary level (§23.2000–§23.2635) defines technology-neutral airworthiness objectives. The secondary level contains engineering methodologies, testing procedures, and verification techniques. Because detailed technical content is excluded from the codified CS-23 text, AMC and GM documents can be revised without initiating a full rulemaking process, directly reducing regulatory inertia. A structurally analogous approach appears in the European Military Airworthiness Certification Criteria (EMACC) [7], derived from MIL-HDBK-516B, where high-level airworthiness objectives remain fixed whilst technical standards integrated into the Type Certification Basis (TCB) are tailored to the operational context.

The second transformational cluster in CS-23 Amendment 5 is the replacement of the traditional aircraft categories: normal, utility, aerobatic, and commuter with a level-based classification. Levels 1 and 2 cover low-speed aircraft (V ≤ 250 KCAS); Levels 3 and 4 cover high-speed aircraft (V > 250 KCAS), with engine count as a secondary differentiator [1]. This structure scales certification requirements to aircraft complexity and operational risk. A further simplification followed from integrating the former CS-VLA [7] specification into the unified CS-23 framework, eliminating a parallel certification structure for light aircraft. The legal basis for industry consensus standards is established in CS 23.2010(a): "The applicant must provide a means to determine compliance with this part acceptable to the Agency." By 2020, ASTM Committee F44 (General Aviation Aircraft) had published 38 standards, with 29 further documents under development [9]. Because ASTM procedures include periodic review cycles, new technologies can be incorporated into certification practice without revising the core regulatory text, which is substantially faster than conventional governmental rulemaking. CS-23 Amendment 5 also formally recognises in-service experience as valid compliance evidence, permitting verified operational data to support certification demonstrations where appropriate.

The third transformational cluster directly determines the regulatory burden placed on applicants. CS 23.2000(b) defines continued safe flight and landing as the capability to maintain controlled flight and complete a landing after system failures without requiring exceptional pilot skill. This reorients safety analysis from individual component reliability towards aircraft-level performance under failure conditions, enabling more flexible distribution of redundancy and focusing testing resources on the most safety-critical scenarios.

This risk-based philosophy is institutionally reinforced through integration with the Level of Involvement (LOI) [5]. LOI defines four regulatory involvement classes based on technological novelty, system complexity, Design Organisation Approval (DOA) performance, and safety criticality. Routine projects may proceed under limited oversight (LOI Class 1); novel or safety-critical technologies require extensive EASA involvement (LOI Class 4). Together, Amendment 5 and the LOI framework form an adaptive, risk-proportional certification system with efficient allocation of regulatory resources.

This combined framework substantially increases demands on applicants (Fig.1). Under prescriptive rules, compliance was demonstrated through standardised solutions requiring minimal independent justification. The new framework requires applicants to select and justify their chosen means of compliance, establish traceability between requirements and design decisions, and produce a comprehensive body of compliance evidence. For newly established organisations, the absence of a DOA performance history results in assignment to higher LOI classes, increasing the proportion of Compliance Demonstration Items (CDI) subject to direct EASA review [5].

Certification therefore, becomes an integrated engineering process rather than a concluding project stage. This creates a structural demand for methodologies such as KBE. It is capable of formalising engineering knowledge, automating compliance evidence generation, and reducing certification effort without compromising safety objectives.

Application Perspectives

CS-23 Amendment 5 opens the certification pathway to a broader range of design organisations. In the Ukrainian context, this is particularly significant because the scale and intensity of UAV development activity over recent years has produced a substantial industrial and engineering base, and a rapid growth in the number of organisations seeking to transition from UAV manufacturing toward general aviation aircraft is anticipated. However, this openness brings a challenge for newly established design organisations. Under the LOI framework [5], EASA assigns regulatory oversight proportionally to four factors: technological novelty, system complexity, safety criticality, and demonstrated DOA performance. Organisations without a certification track record are assigned an "unknown" DOA performance level. This directly triggers a higher LOI class, typically Class 3 or 4, which means that EASA takes on a larger share of direct compliance verification activity, reviewing individual CDIs rather than delegating findings to the applicant.

The practical consequence is significant. Organizations without proven compliance histories must justify every selected means of compliance, establish traceability between requirements and design decisions, and produce a complete body of compliance evidence largely under active regulatory scrutiny. Under a performance-based framework, this is not a final documentation step. It is an integrated engineering process. Without well-established procedures and proven methodologies, the certification process can become a major factor affecting the costs and timelines of the entire aircraft development programme.

This challenge is particularly relevant for organisations whose engineering experience was developed in the UAS domain. Ukraine has accumulated substantial practical knowledge in UAV development over recent years. However, the regulatory environment for UAS differs considerably from EASA Part 21 civil aviation certification [10]. Transitioning from UAS development to general aviation under CS-23 requires not only new technical competencies but also demonstrable organisational process maturity.KBE is a methodology in which domain-specific expert knowledge, design intent, engineering constraints, and decision rules are formalised and embedded directly into software algorithms [6, 11, 12]. KBE originated in the 1980s from early rule-based expert systems and has since evolved into integrated components of modern Product Lifecycle Management (PLM) and CAD systems.

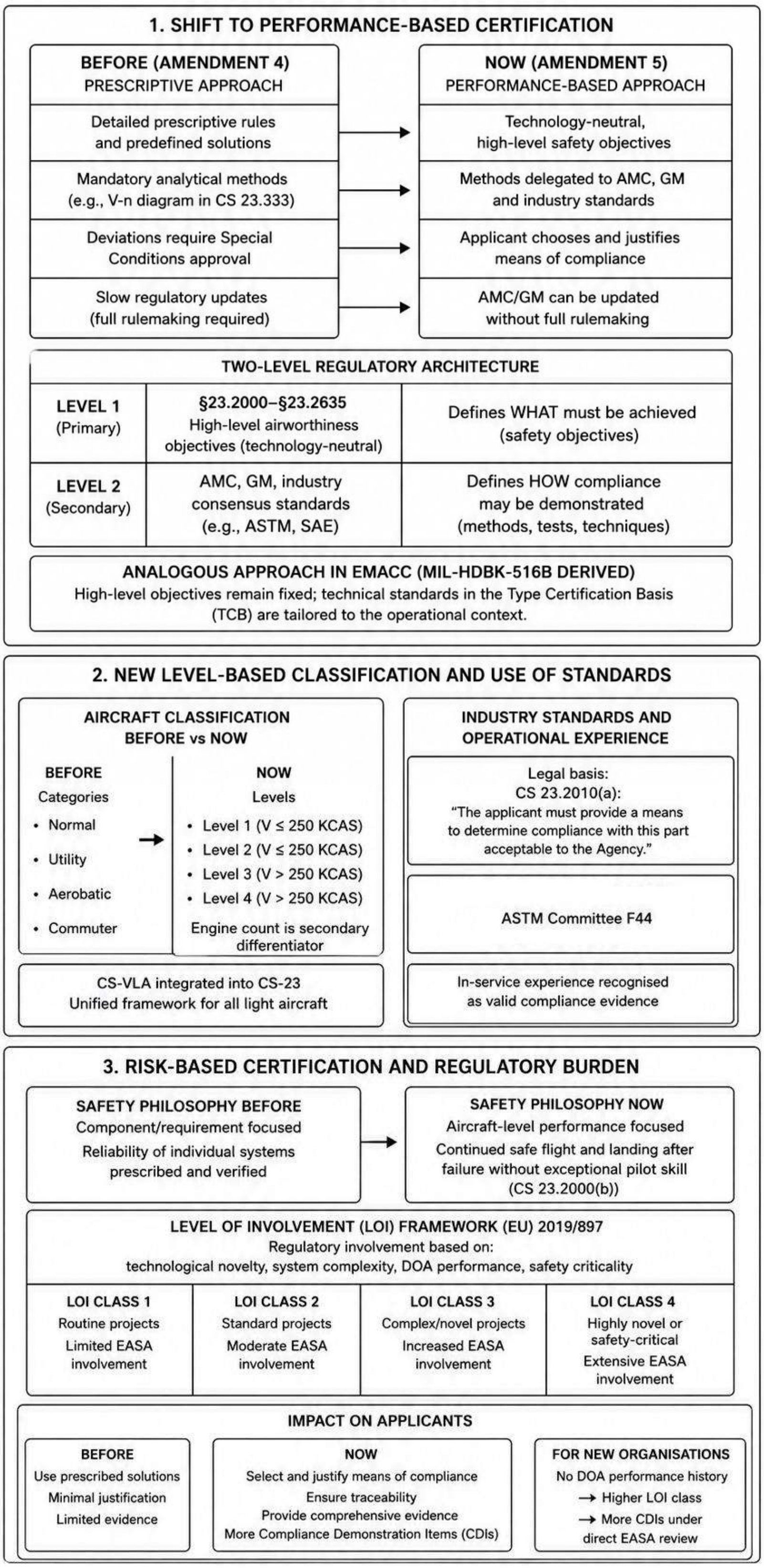

Fig.1. Key changes of CS-23 and their impact on DOA

KBE is distinct from conventional CAD and CAE workflows. In a standard CAD or CAE environment, most engineering decisions are made manually by the user: geometry is drawn interactively, analysis inputs are entered by hand, and compliance checks are performed separately by an engineer reviewing the results.

KBE replaces this manual chain with a structured computational framework in which geometry generation, analytical models, and design constraints are coupled and executed algorithmically. The engineer defines the rules, and the system applies them consistently across every design variant.

KBE is also distinct from Artificial Intelligence in its contemporary form. AI and machine learning models, including surrogate models and neural networks, are data-driven. They learn patterns from datasets and produce predictions within a trained domain. Their internal logic is not directly readable, which historically made them difficult to accept in a regulatory context. KBE, by contrast, is deterministic and rule-based. Every output is the result of an explicit, auditable sequence of encoded engineering logic (Fig.2). This transparency is precisely the property that makes KBE relevant to airworthiness compliance [6].

Regulatory and industry consensus standards, including ASTM and SAE specifications, can be encoded directly into KBE algorithms. When the system generates a structural sizing output, it can simultaneously tag that output with a reference to the specific ASTM, SAE or other standards clause that governed the calculation. This creates a continuous digital thread from requirement to design decision to compliance evidence, which is the traceability that EASA expects from a compliant certification process.

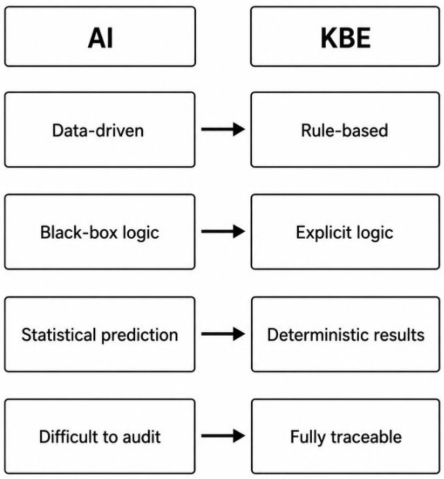

Fig.2. Artificial Intelligence vs Knowledge-Based Engineering

Let's illustrate this approach through a surrogate-informed KBE application for structural sizing of an aircraft wing spar for a CS-23 aircraft, in which three automated modules operate sequentially along a continuous digital thread.

The first module is an aerodynamic surrogate model, trained offline on 5000 wing configurations evaluated via high-fidelity CFD simulation. This model provides spanwise aerodynamic load distributions for any given combination of chord length, aspect ratio, taper ratio, and sweep angle. As shown in [13], such KBE application can generate design solutions in under 20 seconds on a standard laptop computer. Without the surrogate models, an equivalent full CFD analysis would require hours or days of computation on dedicated hardware.

The second module of such an application manages geometric constraints. For each design iteration, the system automatically generates internal wing geometry, including spar dimensions, using parametric CAD rules that ensure compatibility with the selected aerofoil profile and skin thickness at every spanwise station.

The third module performs structural sizing and compliance checking. The system automatically applies an ultimate factor of safety of 1,5 in accordance with ASTM F3116 (Standard Specification for Design Loads and Conditions) [14]. Material properties are extracted from a verified database aligned with SAE AMS specifications. The spar cap cross-section is sized against tension and compression using closed-form equations derived from ASTM F3115 [15]. If shear buckling limits are exceeded in the web panel, the system enters an internal optimisation loop, adjusting thickness or adding stiffeners until a positive Margin of Safety is achieved across all failure modes.

The output of such an application typically should have two components: a fully optimised 3D CAD model of the wing structure, and an automatically generated compliance report in which every dimension, thickness, and material selection is cross-referenced directly to the governing ASTM and SAE clause. The design rationale is fully traceable. EASA can audit not only the result but the decision logic that produced it.

This kind of automated traceability directly addresses the principal difficulty faced by new organisations. Rather than relying on manual, error-prone compliance documentation, the applicant provides the regulatory authority with a structured, self-documenting output produced by a formalized and auditable framework.

Tool Trustworthiness

The use of KBE tools, and particularly surrogate models embedded within them, raises a legitimate question about software trustworthiness. EASA does not assess individual engineering software tools directly. However, it does assess the methods and processes by which compliance is demonstrated. A KBE system that produces automated compliance outputs must therefore be qualified in a way that gives the authority confidence in its results.

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The applicable framework is DO-330 Software Tool Qualification Considerations [16]. DO-330 classifies engineering software tools into qualification criteria based on the degree to which their outputs are used directly in compliance demonstrations. A KBE system that automates structural sizing or generates compliance reports typically falls under Tool Criteria 2 or 3 [17]. Qualification under DO-330 requires the applicant to produce a Tool Operational Requirements document mapping the system's internal logic to the underlying regulatory standards, to execute a defined Tool Qualification Plan, and to validate outputs against independent physical or numerical test results across the operational parameter domain.

Once qualified, the KBE system transitions from an internal design tool into a formally approved source of compliance evidence. The regulatory consequences are substantial. Because the decision logic has been audited and approved at the tool level, EASA's review of subsequent project outputs can focus on verifying that inputs remain within the validated operational boundaries, rather than re-examining individual engineering decisions. This is the mechanism by which a qualified KBE system can reduce LOI from Class 3 or 4 toward Class 1 or 2 for projects using that system.

For AI components within a KBE framework, specifically surrogate models that would otherwise be considered opaque black boxes, EASA's Artificial Intelligence Roadmap 2.0 [18] and Notice of Proposed Amendment 2025-07 [19] provide a developing qualification pathway. NPA 2025-07 prescribes explicit criteria across seven dimensions of trustworthiness, including technical robustness, explainability, data lineage, and operational domain boundaries. These criteria are aligned with the requirements of the EU AI Act (Regulation (EU) 2024/1689) [20]. Under this framework, a surrogate model that meets the defined trustworthiness criteria within its validated input domain can be accepted as a compliant analytical tool rather than treated as an uncertifiable risk. Combined with DO-330 tool qualification, this creates a coherent path for integrating data-driven models into a formally approved KBE environment that simplifies DOA certification activity (Fig.3).

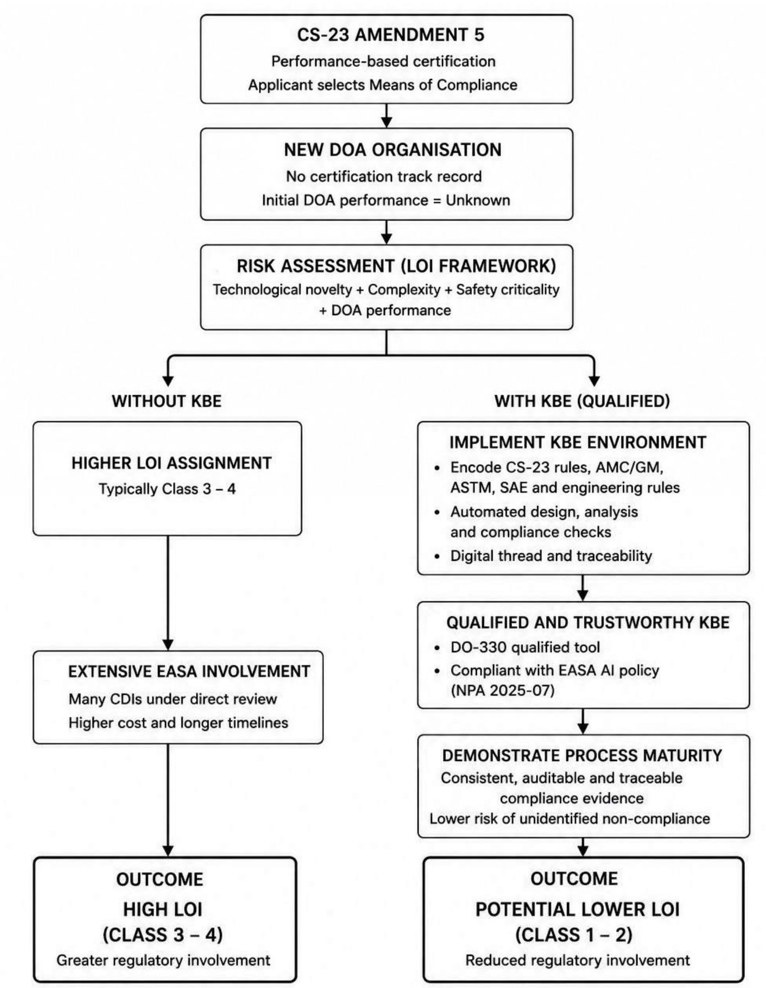

Fig. 3. KBE for compliance demonstration in new DOA

One platform that enables the surrogate-informed architecture of future KBE systems in practice may be SplineCloud [13], a cloud-based environment for creating, storing, and managing surrogate models built on B-spline approximations and multidimensional response surfaces. SplineCloud allows surrogate models to be stored independently from the KBE application code. A KBE system queries the platform via API using a unique model identifier. When the tag with validated status is assigned to the specific model version, any authorised system querying that identifier from the platform immediately inherits the approved, verified physics prediction. This decoupled architecture allows different engineering teams to update and re-validate aerodynamic or structural models independently, without disrupting downstream KBE applications. It also protects intellectual property: a manufacturer can grant a supplier access to a certified aerodynamic loading model through the platform interface without exposing the underlying training data or source geometry.

Conclusions

CS-23 Amendment 5 creates genuine technical and commercial opportunities for organisations developing general aviation aircraft. The performance-based framework is deliberately designed to accommodate innovation, new technologies, and non-traditional configurations.

At the same time, the shift toward applicant-led compliance demonstration increases the burden on organisations without established certification experience. For teams transitioning from UAS development, particularly those whose engineering base grew from practical work in demanding operational environments, this regulatory maturity gap is a real constraint.

KBE can be seen as a practical response to this constraint. It does not replace engineering expertise. It codifies and preserves it in a reusable, auditable, and traceable form. When qualified under DO-330 and, where applicable, aligned with the EASA AI trustworthiness criteria, a KBE system constitutes institutional engineering memory. It reduces dependence on individual specialists, mitigates compliance risk arising from staff turnover or subjective interpretation of standards, and produces structured compliance evidence that a regulator can verify efficiently.

For a newly established organisation, a qualified KBE system effectively substitutes accumulated certification experience with documented, audited process maturity. In a framework where LOI is directly tied to demonstrated organisational performance, this matters. The new regulatory environment does not eliminate the difficulty of the first certification. However, it provides the conditions under which a well-structured engineering methodology, supported by appropriately qualified digital tools, can meaningfully reduce that difficulty.

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Conflict of Interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has no associated data.

Use of Artificial Intelligence

AI-assisted tools were used to facilitate literature search, information summarization, and translation. Final analysis, interpretation, and conclusions were performed by the authors.

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СЕРТИФІКАЦІЯ, ОРІЄНТОВАНА НА ПОКАЗНИКИ ЕФЕКТИВНОСТІ, ЯК РУШІЙ ІННОВАЦІЙ У ПРОЄКТУВАННІ ЛІТАКІВ

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Предметом дослідження в статті є трансформація підходів до сертифікації льотної придатності літаків авіації загального призначення внаслідок переходу від CS-23 (Поправка 4) до CS-23 (Поправка 5), а також можливості застосування інженерії на основі знань (Knowledge-BasedEngineering, KBE) для підтримки процесів сертифікації, яка базується на показниках ефективності. **Метою** роботи є аналіз ключових змін, запроваджених CS-23 (Поправка 5), та оцінка потенціалу KBE для підвищення зрілості організацій-розробників і формування доказової бази відповідності. **Завдання дослідження:** проаналізувати особливості переходу від прескриптивної до моделі сертифікації, що базується на показниках ефективності; дослідити принципи використання консенсусних стандартів та ризик-орієнтованого нагляду; оцінити вплив концепції

LevelofInvolvement (LOI) на новостворені організації; визначити можливості застосування KBE у процесах проєктування та сертифікації авіаційної техніки. Використано **методи** системного аналізу нормативної документації EASA, порівняльного аналізу сертифікаційних підходів, а також концептуального моделювання цифрових інженерних процесів. Отримано такі **результати**. Визначено основні напрями трансформації сертифікаційної системи CS-23, що включають перехід до високорівневих цілей безпеки, впровадження консенсусних стандартів як методів відповідності, оцінювання безпеки на рівні повітряного судна та інтеграцію ризик-орієнтованого механізму LOI. Показано, що підвищення відповідальності заявника за вибір і обґрунтування методів відповідності збільшує вимоги до сертифікаційної експертизи організацій-розробників. Проаналізовано перспективи використання KBE для формалізації інженерних знань, автоматизації проєктних процедур, забезпечення трасованості між вимогами та результатами аналізу, а також формування структурованої доказової бази відповідності. Розглянуто можливість інтеграції KBE з сучасними підхорнутьпанельдами цифрової інженерії, включаючи модельно-орієнтовану системну інженерію та кваліфікацію інструментальних засобів відповідно до вимог DO-330. **Висновки**. Показано, що перехід до сертифікації, що базується на показниках ефективності, створює нові можливості для впровадження інноваційних технологій, але одночасно підвищує вимоги до компетентності організацій-розробників. Наукова новизна роботи полягає в узагальненні взаємозв'язку між концепціями CS-23 (Поправка 5), LOI та KBE, а також в обґрунтуванні можливості використання KBE як інструменту накопичення сертифікаційної експертизи, підвищення зрілості організації та підтримки процесів доведення відповідності в умовах ризик-орієнтованого регуляторного середовища.

Ключові слова: сертифікація на основі експлуатаційних характеристик, льотна придатність, конструкція літака, автоматизація проектування, літаки, БпЛА, інженерія на основі знань, міцність.

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