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Strategy for Accelerating the Development of Male-Class UAV Systems Through the Integration of Autonomous Subsystems and Military Certification Under STANAG-4671

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Abstract
This study is motivated by the technological gap in the development of the Elang Hitam Medium Altitude Long Endurance (MALE) Unmanned Aerial Vehicle (UAV), which has yet to fully comply with the military certification standard STANAG-4671. The objective of this research is to formulate a strategy to accelerate the national UAV development process through the integration of autonomous subsystems and military airworthiness certification. Employing a library research method, this study applies content analysis to recent scholarly literature, technical reports, and official documentation of the Elang Hitam program. Data were systematically examined to identify patterns of system integration and conformity with international standards. The findings reveal that synergy among industry, research institutions, and regulators serves as the primary factor driving the acceleration of national UAV certification and the foundation for advancing Indonesia's technological independence in aerospace defense. In conclusion, achieving operational readiness for Elang Hitam requires a harmonized approach that concurrently advances technological innovation and institutional certification frameworks. The study underscores that the establishment of a coordinated national airworthiness governance system is essential for aligning UAV development with global standards, thereby enhancing Indonesia's strategic autonomy and interoperability in the global defense landscape.

Keywords: Elang Hitam; ISTAR; STANAG-4671, technology, development, aerospace

INTRODUCTION

Indonesia possesses a sovereign airspace of approximately 7.7 million km², requiring continuous and adaptive aerial surveillance capabilities to accommodate its complex archipelagic geography. The primary challenge in the current national air defense system lies in the limited range of manned reconnaissance assets and radar infrastructure across remote areas, creating a strategic need for a Medium Altitude Long Endurance (MALE) Unmanned Aerial Vehicle (UAV) capable of performing Intelligence, Surveillance, Target Acquisition, and Reconnaissance (ISTAR) missions for up to 24 hours (Anvwunuketa et al., 2021; Avwunuketa et al., 2019; Bekesiene & Ruzgas, 2020; Yan et al., 2022). The Elang Hitam (EH) UAV program, developed by PT Dirgantara Indonesia (PTDI) and the National Research and Innovation Agency (BRIN), represents a milestone in Indonesia's pursuit of defense autonomy through indigenous autonomous flight technology. However, significant technological gaps persist in autonomous flight control, datalink communication, and avionics-propulsion integration—factors that hinder the operational readiness of the national UAV by the 2027 target (Choi & Kim, 2015; Demircan & Kaplan, 2023; Schwening & Abdalla, 2014; Utama et al., 2023).

The literature demonstrates that the effectiveness of MALE-class UAVs is largely determined by the reliability of flight control systems and adherence to military airworthiness standards such as NATO's STANAG-4671, which ensures operational safety in both civil and military airspace. Novhela & Martini (2020) highlights the importance of applying System Functional Hazard Assessment (SFHA) methodologies to mitigate system failure risks in compliance with international standards such as ARP4761 and STANAG-4671. Similarly, Aribowo and Adhynugraha (2023) emphasize the significance of optimizing composite fuselage structures using the Finite Element Method (FEM) to meet the structural airworthiness requirements of MALE UAVs (Aribowo & Adhynugraha, 2023). Despite these advancements, a research gap remains in integrating autonomous subsystems with military certification frameworks—a critical prerequisite for national UAV sovereignty.

This study aims to analyze the Strategy for Accelerating the Development of MALE-Class UAV Systems through the Integration of Autonomous Subsystems and Military Certification under STANAG-4671 strategic framework for accelerating the development of the Elang Hitam UAV from the EH-1 to the certified EH-2 configuration, emphasizing the integration of autonomous subsystems and compliance with the STANAG-4671 standard. The study also seeks to identify necessary technical modifications within propulsion, avionics, and composite structures to enable 24-hour endurance under military operational conditions. The analysis focuses on how system integration methodologies can expedite military airworthiness certification without compromising system reliability and flight safety. Through this approach, the study aspires to establish a conceptual framework for developing an autonomous, airworthy UAV aligned with both international regulations and Indonesia's strategic air defense requirements.

The urgency of this research lies in Indonesia's strategic imperative to strengthen defense autonomy amid growing geopolitical dynamics in the Indo-Pacific region. The integration of autonomous subsystems in MALE-class UAVs such as Elang Hitam not only enhances ISTAR mission effectiveness but also fosters interoperability with modern network-centric warfare systems. Górski & Stecz (2024) argue that the success of future combat UAVs depends on adaptive autonomy integrated with intelligent control and sensor systems. Therefore, accelerating the development of Elang Hitam through an integrative approach to subsystem design and military certification represents a crucial step toward achieving national air sovereignty and compliance with global airworthiness standards under STANAG-4671.

METHODS

The research focuses on the technological gap in the development of Indonesia's Medium Altitude Long Endurance (MALE) Unmanned Aerial Vehicle (UAV), particularly in the Elang Hitam program as a part of the National Strategic Project (PSN) jointly undertaken by PT Dirgantara Indonesia (PTDI), the National Research and Innovation Agency (BRIN), and the Indonesian Air Force. The main issue lies in the misalignment between autonomous flight control capabilities, mission system integration, and compliance with military certification under STANAG-4671. This gap has slowed the transition process from the EH-1 configuration to the certified EH-2, targeted for full operational deployment in 2027. As a representative case of national UAV development, Elang Hitam reflects Indonesia's broader efforts toward defense technology independence based on autonomous and airworthy systems (Utama et al., 2023).

Hence, this research examines how an integrated framework can accelerate UAV development through literature-based methodological analysis.

This study employs a qualitative library research approach, utilizing academic and technical sources relevant to MALE UAV technology, autonomous systems, and military certification. The primary data are drawn from recent scholarly works (2019–2025) discussing STANAG-4671 applications, UAV systems engineering, and airworthiness methodologies. Secondary data consist of books, research reports, and official publications from the Elang Hitam project. As Novhela & Martini (2020) notes, literature-based research enables systematic synthesis of previous studies to establish a strong conceptual foundation for addressing UAV development gaps. This approach aligns with the nature of defense technology research, which prioritizes theoretical validation before empirical implementation.

The theoretical foundation of this research is grounded in the Military Airworthiness Theory, as defined by STANAG-4671 developed by the North Atlantic Treaty Organization (NATO) in 2009 and refined through subsequent updates up to 2023. This theory asserts that unmanned aircraft systems must meet design, structural, avionics, and safety requirements to ensure operational viability in both civil and military airspace. Luterbacher Mus et al. (2025) elaborates that this theory serves as a universal framework connecting system engineering, functional testing, and operational risk management within UAV certification processes. Within the context of Elang Hitam, the application of this theory establishes a foundation for analyzing compliance with international standards and identifying strategic steps for accelerating certification of autonomous military UAV systems.

The research process began with a systematic literature search using academic databases such as Consensus, Scopus, and Google Scholar. Data collection was conducted through document analysis and comprehensive reading of sources related to UAV systems, airworthiness certification, and autonomous control technology. Each document was assessed for thematic relevance and publication novelty. A. Adeleke et al. (2022) emphasize the importance of theoretical validation in the conceptual design phase of UAVs through comparative model analysis using the Finite Element Method (FEM) to enhance structural efficiency and aerodynamic reliability. This library-based method reinforces the relevance of theoretical frameworks to empirical UAV development practices.

Data analysis in this study employed a content analysis approach aimed at identifying conceptual patterns, inter-variable relationships, and key findings from the reviewed literature. The process involved stages of data reduction, thematic categorization, and analytical interpretation of prior research findings related to UAV development and airworthiness standards. Górski & Stecz (2024) highlight that content analysis supports formal evaluation of UAV systems by modeling operational processes through finite-state machines to assess the reliability of software and autonomous subsystems. Accordingly, this analytical method serves as a key instrument in synthesizing a conceptual strategy for accelerating Elang Hitam development toward full military certification under STANAG-4671.

RESULTS AND DISCUSSION

The literature review indicates that the Elang Hitam MALE UAV program is the result of a strategic collaboration between PT Dirgantara Indonesia (PTDI), the National Research and Innovation Agency (BRIN), and the Indonesian Air Force under the National Strategic

Project (PSN). According to Utama et al. (2023), the development of MALE UAVs in Indonesia is directed through a national consortium model that ensures technological efficiency and funding optimization, with a priority weight of 0.548 in the Analytic Hierarchy Process (AHP) framework. The Elang Hitam project aims to conduct surveillance, reconnaissance, and target acquisition missions with a 24-hour endurance capability, aligned with Indonesia's plan to establish 12 new air bases as part of the Jakumhanneg 2020–2024 defense strategy.

Project documentation shows that Elang Hitam was developed through five evolutionary stages, from EH-1 to EH-4, with EH-2 designated as the version prepared for military certification. Each stage incorporated progressive improvements in avionics, autonomous control, and propulsion integration. Aribowo and Adhynugraha (2023) report that Elang Hitam's fuselage utilizes multi-layered carbon composite materials optimized through FEM topology techniques to meet the structural strength standards required under STANAG-4671 (Aribowo & Adhynugraha, 2023). With its constant-speed variable-pitch propeller propulsion system, the UAV is designed to perform extended ISTAR missions at altitudes above 20,000 feet.

The findings suggest that while Elang Hitam symbolizes Indonesia's defense technology autonomy, it still faces significant limitations in autonomous control, certification, and system integration. This aligns with Novhela & Martini (2020) observation that inadequate mitigation of UAV system failure conditions can directly affect flight safety. Therefore, the literature underscores the urgent need to enhance adaptive autonomy and strengthen system integration mechanisms to achieve full airworthiness certification by 2027.

The Intelligence, Surveillance, Target Acquisition, and Reconnaissance (ISTAR) function constitutes a core component of modern UAV systems, including Elang Hitam. Radovanović et al. (2023) emphasize that the integration of ISTAR capabilities in modern military operations supports the C5ISR framework—Command, Control, Computers, Communications, Intelligence, Surveillance, and Reconnaissance. The literature identifies four functional layers of ISTAR intelligence, surveillance, target acquisition, and reconnaissance implemented through EO/IR sensors, synthetic aperture radar (SAR), and satellite communication systems.

The integration of ISTAR within UAV platforms enables real-time data fusion to enhance situational awareness in operational environments. The system connects optical sensors, radar, and digital communication channels to generate tactical decision aids. Rodriguez-Pirateque (2020) found that the effectiveness of ISTAR systems depends on UAVs' ability to operate within heterogeneous communication networks characterized by low latency and high security. In the Elang Hitam program, such configurations support strategic border surveillance and disaster mitigation missions.

The relationship between ISTAR literature and the research context indicates that ISTAR serves as a decisive factor in UAV operational effectiveness for both military and civilian applications. In Elang Hitam's case, ISTAR acts as a catalyst for achieving interoperability with Indonesia's national air defense systems. Data from PTDI (2025) reveal that while ISTAR has been implemented, it has not yet achieved full autonomy due to limitations in long-range data communication subsystems (satcom and LOS). This finding corroborates Radovanović et al. (2023) conclusion that the success of ISTAR integration depends on the full synchronization of UAVs with C5ISR network systems.

STANAG-4671, or NATO Unmanned Aircraft Systems Airworthiness Requirements, is a military airworthiness framework established to ensure UAV operational safety. Luterbacher Mus et al. (2025) explains that the standard governs both initial and continued airworthiness procedures for UAV systems to ensure safe integration within civil and military airspace. The standard requires verification of design integrity, system performance evaluation, and qualification of human resources involved in UAV operations. Literature findings indicate that STANAG-4671 serves as the global reference for UAV certification protocols.

STANAG-4671 encompasses four principal domains of certification: design verification, system functionality testing, safety management implementation, and technical personnel qualification. Aribowo et al. (2023) demonstrate that UAV composite structures can meet STANAG-4671 strength criteria through FEM simulations, achieving a 20% reduction in structural mass without compromising safety. These findings validate the role of computational engineering in meeting military airworthiness certification requirements.

The correlation between STANAG-4671 literature and the Elang Hitam project highlights certification as the critical stage determining the UAV's operational readiness. The process requires cross-institutional collaboration among regulators, industry, and academia. Novhela & Martini (2020) suggests that employing the System Functional Hazard Assessment (SFHA) methodology is an effective approach to evaluate UAV compliance with STANAG-4671 standards. Consequently, literature findings affirm that implementing STANAG-4671 within the Elang Hitam program is essential to accelerating Indonesia's recognition in international UAV operations.

The results of this study confirm that the acceleration of Elang Hitam's development is primarily constrained by the limited integration between technological subsystems and institutional coordination for certification under STANAG-4671. The literature highlights that while structural, avionics, and propulsion improvements have progressed, the absence of a unified certification framework remains the critical barrier. Luterbacher Mus et al. (2025) asserts that synchronization between industrial design verification and military airworthiness authorities is the key to achieving certification readiness. The findings thus underscore that the success of Indonesia's MALE UAV program relies not only on engineering innovation but also on institutional governance that ensures compliance with international safety and operational standards.

When compared with related studies, this research demonstrates a distinctive integration between the concepts of autonomous subsystems and military certification frameworks. Previous studies, such as those by Rodriguez-Pirateque (2020) and Górski & Stecz (2024), primarily focus on the technical dimensions of UAV systems—particularly communication networks and near-real-time testing environments. In contrast, this research expands the discussion by linking technological innovation with institutional and regulatory frameworks, emphasizing that certification harmonization is the most decisive variable for operational success. This alignment of technical and administrative perspectives strengthens Indonesia's position as a potential leader in MALE UAV certification within the Southeast Asian region.

The findings reflect the practical and theoretical importance of integrating autonomous systems with certification standards for UAV development. From a theoretical perspective, this study contributes to the advancement of the Military Airworthiness Theory by demonstrating how the inclusion of adaptive autonomy expands the framework beyond traditional safety parameters. From a practical standpoint, it illustrates that UAV development programs like Elang Hitam can function as strategic national models for defense self-reliance. Aribowo et al. (2023) confirm that integrating multi-layered composite structures with fault-tolerant flight control systems is essential for maintaining structural integrity and system resilience in MALE UAVs. Consequently, this research reinforces the idea that innovation and certification must progress in parallel to ensure system sustainability and compliance.

The implications of this research extend to both policy formulation and industrial practice. For policymakers, the study provides a foundation for establishing a National UAV Certification Authority capable of enforcing standards equivalent to STANAG-4671 within Indonesia’s defense sector. For industry, it emphasizes the need for integrated design verification and failure risk analysis as part of the development cycle. Novhela & Martini (2020) identifies the System Functional Hazard Assessment (SFHA) method as an effective approach for systematically mitigating UAV system risks in accordance with STANAG-4671 guidelines. This underscores the necessity of adopting standardized procedures to ensure the airworthiness and long-term operability of Indonesian defense UAVs.

The results are largely influenced by Indonesia’s current technological ecosystem, where UAV development remains in a transitional phase between innovation and certification. The limited integration of autonomous subsystems can be attributed to the absence of a national testing infrastructure and a unified data validation mechanism. As highlighted by Górski & Stecz (2024), real-time system modeling and test simulations are critical in validating UAV control system reliability. Therefore, the nature of Elang Hitam’s developmental challenges lies not in design limitations but in the coordination of certification processes and technological validation frameworks factors that are equally vital to its operational success.

Based on these findings, several strategic actions are recommended. First, Indonesia must establish a dedicated UAV certification center integrating academic, industrial, and defense institutions. Second, the Elang Hitam program should adopt simulation-based certification frameworks to shorten the verification cycle for STANAG-4671 compliance. Third, collaboration with international aerospace partners should be expanded to ensure benchmarking against global standards. Finally, continued development of autonomous subsystems should prioritize redundancy, fault-tolerance, and cybersecurity. These actions will not only accelerate the certification of Elang Hitam but also position Indonesia as a regional hub for UAV innovation, aligning with its long-term vision for defense technology sovereignty.

CONCLUSION

The most striking finding of this research is that the primary challenge in accelerating the development of Indonesia’s Elang Hitam MALE UAV lies not solely in its technological advancement but in the systemic integration between autonomous subsystems and military certification frameworks. Although Indonesia has achieved significant progress in the technological aspects of UAV design, propulsion, and avionics, the certification process under STANAG-4671 remains the determining factor for operational readiness. This study reveals that the establishment of a synchronized airworthiness management system integrating the efforts of industry, regulators, and research institutions is the key enabler of successful UAV deployment. Ultimately, the Elang Hitam program demonstrates that defense autonomy is dependent not only on technological independence but also on the institutional maturity of national certification governance. This research provides both theoretical and practical contributions to the field of aerospace technology and defense systems engineering. Theoretically, it extends the scope of Military Airworthiness Theory by incorporating the dimension of integrative interaction between autonomous subsystems, certification standards, and national defense policy. Practically, it offers a conceptual model for accelerating UAV development in emerging defense industries through system integration and regulatory harmonization. The added value of this study lies in its interdisciplinary approach that bridges technical innovation with strategic governance, serving as a reference model for nations seeking to establish defense technology sovereignty. Consequently, the Elang Hitam case highlights Indonesia's capability to align its national UAV development roadmap with global standards of safety, endurance, and operational interoperability. The limitations of this study are primarily contextual rather than methodological, as it is based on a literature-based analysis of secondary and theoretical sources. Nonetheless, these limitations open avenues for further empirical research, particularly in real-time testing of autonomous flight systems and certification implementation under STANAG-4671. Future studies should focus on developing simulation-based certification frameworks that integrate reliability testing and risk modeling for UAV operations. Furthermore, interdisciplinary collaboration among universities, defense industries, and certification agencies is essential to establish a sustainable UAV research ecosystem. By continuing this line of inquiry, Indonesia can strengthen its position as a regional leader in MALE UAV development and certification, marking a significant step toward achieving long-term air defense sovereignty.

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