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Systemic Innovation Failure in High-RCD Aerospace Projects a Chain-Linked Analysis of Indonesia's N-250 Program

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ABSTRACT
This qualitative case study analyzes systemic innovation chain failures in Indonesia's N-250 aerospace program to reposition its collapse as a systemic disruption rather than a mere economic casualty. Using Kline and Rosenberg's Chain-Linked Model, the research examines concepts including market validation, design-production iteration, and research connectivity within *Industri Pesawat Terbang Nusantara* (IPTN). Data were gathered through a purposive review of academic journals, policy documents, and industry reports conducted from November 2025 to May 2026. Findings indicate that pre-existing structural weaknesses in the innovation chain, accelerated by the 1997-1998 financial crisis, led to the project's failure. Finally, the study implies that aerospace success depends on ecosystem resilience and interconnected innovation chains rather than isolated technological ambition or funding alone.

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INTRODUCTION

The defense industry plays a strategic role in strengthening national sovereignty, technological independence, and economic resilience. In developing countries, defense-related innovation projects often symbolize national prestige and technological ambition while simultaneously serving as instruments for technological catch-up and industrial upgrading (Anderson & Luiz, 2025). However, large investment in Research, Concept, and Development (RCD) does not automatically guarantee innovation success because technological capability depends on broader institutional and ecosystem support (Rao, 2019).

One of the most ambitious aerospace innovation initiatives in Southeast Asia is Indonesia's N-250 aircraft project. Developed by *Industri Pesawat Terbang Nusantara* (IPTN) using fly-by-wire (FBW) technology, the aircraft is designed as an advanced regional turboprop. The project ultimately failed to reach the commercial production and certification stages, even though it had successfully reached the prototype testing phase (Amir, 2007).

The failure of the N-250 project is often attributed to the Asian financial crisis and IMF intervention, as noted in previous studies. However, such explanations tend to oversimplify the innovation process by focusing only on external economic shocks. Systemic disconnection among research, production, market adaptation, and organizational learning processes, is often the cause of innovation failure in complex industries (Malerba, 2002). Contemporary scholarship on innovation systems argues that failure often emerges from cumulative mismatches among industrial learning, institutional coordination, market validation, and knowledge integration, rarely from a single external shock (Caliari et al., 2023).

While previous studies frequently attribute the collapse of the N-250 program primarily to the 1997–1998 Asian financial crisis and IMF intervention, such interpretations may understate deeper structural weaknesses within the innovation ecosystem. Contemporary literature on innovation systems argues that failure often stems from cumulative mismatches between industrial learning, institutional coordination, market validation, and knowledge integration processes; conversely, large-scale technology projects rarely fail due to a single external shock. Therefore, a national innovation capability depends on the resilience of interconnected production and learning systems, not merely on technological ambition (Caliari et al., 2023).

This paper argues that the Chain-Linked Model (Kline & Rosenberg, 1986) provides a more comprehensive explanation of the N-250 failure because it emphasizes iterative feedback loops among innovation actors rather than linear technological progression. Existing studies on the N-250 program predominantly emphasize macroeconomic disruption and political intervention as the primary causes of project failure. However, attention to structural weaknesses within the innovation ecosystem itself remains limited. This creates an analytical gap because large-scale aerospace innovation failure often emerges from disconnected feedback mechanisms among market validation, production capability, research integration, and technological learning processes rather than external shocks alone (Rao, 2019).

Therefore, this study contributes analytically by repositioning the N-250 failure as a systemic innovation-chain disruption rather than merely an economic casualty of the Asian Financial Crisis. This study found that innovation failure refers to the inability of the innovation system to sustain certification, commercialization, mass production, and long-term ecosystem sustainability, rather than merely technological limitations.

LITERATURE REVIEW

Innovation in High-Technology Defense Industry

Innovation refers to new products that create value for organizations and society, including the implementation of ideas, technologies, and processes. Innovation in the defense industry is characterized by long development cycles, high uncertainty, technological complexity, and high capital intensity.

Unlike consumer industries, defense innovation requires continuous interaction among government institutions, research organizations, manufacturers, suppliers, and end users. Recent literature on innovation indicates that technological capabilities in the defense and aerospace sectors are increasingly dependent on participation in global innovation ecosystems, collaborative industry platforms, and cross-border knowledge networks. Consequently, firms operating in relative technological isolation face substantial disadvantages in certification capability, subsystem integration, and adaptive learning capacity (Jovanovic et al., 2021).

Chain-Linked Model of Innovation

Kline and Rosenberg (1986) developed a Chain-Linked model that views innovation not as a linear process, but as the result of a dynamic and ongoing interaction between the stages of research, design, manufacturing, and market response. The model does not view innovation as a linear path from invention to market, but rather emphasizes: (1) problem-solving mechanisms; (2) redesign processes; (3) knowledge integration; (4) iterative feedback loops; and (5) interaction between market needs and technological development. This model is particularly relevant to the defense and aerospace industries, where learning by doing, subsystem integration, and rapid prototyping are essential (Micaëlli et al., 2014). Figure 1 illustrates the chain-linked model proposed by Kline and Rosenberg.

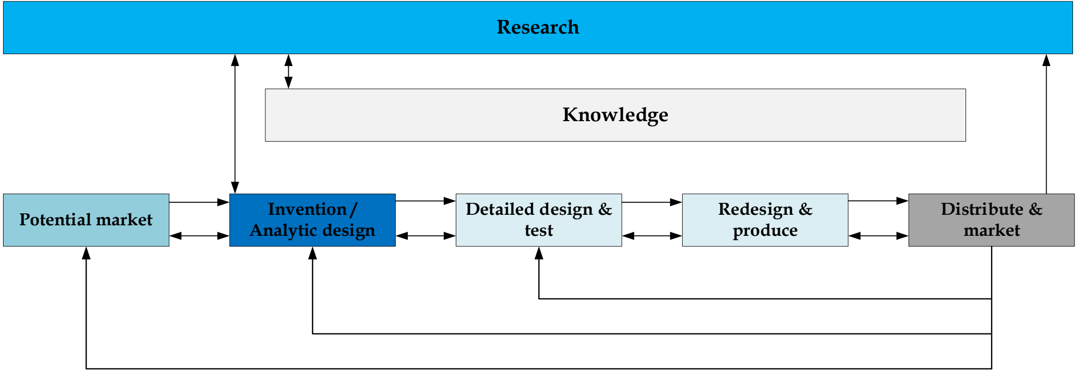

Figure 1. Chain-linked Model
Source: (Ho et al., 2025)

Innovation Failure in Aerospace Industry

Aerospace innovation projects often fail due to market misalignment, excessive technological ambition, weak industrial ecosystems, and inadequate production scalability (Malerba, 2002). A robust iterative learning system, supported by international collaboration and operational feedback mechanisms, underpins the success of global aerospace companies such as Embraer and Airbus. On the other hand, even if a system's technological capabilities are adequate, an innovation system that lacks an adaptive feedback structure remains vulnerable to failure (Jacobsson & Bergek, 2011).

Theoretically, the chain-linked model conceptualizes innovation as an interactive, non-linear system driven by continuous feedback loops across market demand, design, manufacturing, and research. Far from a sequential progression, it advances through iterative problem-solving, meaning that any breakdown within these feedback channels can destabilize the entire innovation system (Kline & Rosenberg, 1986). This systemic view aligns with the sectoral innovation system perspective, which emphasizes that innovation performance depends on the co-evolution of firms, institutions, and knowledge networks within an industry (Malerba, 2002).

As shown in Figure 2, innovation success in aerospace industries depends on the continuity of interconnected feedback loops among market validation, design iteration, research integration, and production capability. The external shocks did not independently generate innovation failure but accelerated pre-existing structural weaknesses within the innovation ecosystem. External shocks become critical only when the innovation ecosystem lacks systemic resilience (Fiorini et al., 2024).

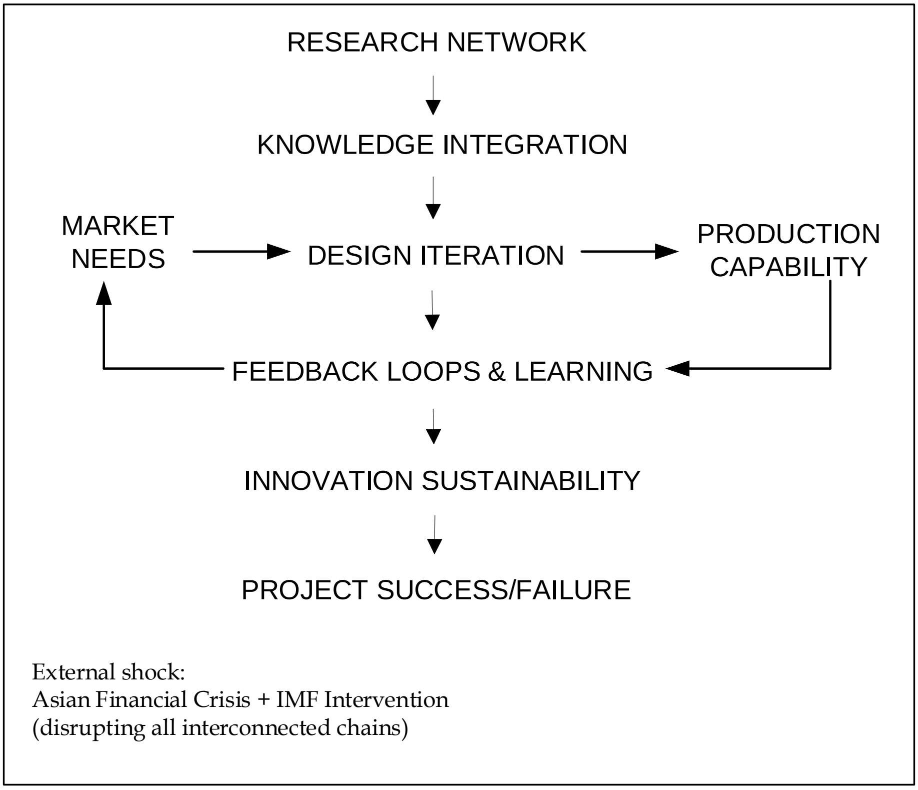

Figure 2. Innovation success in aerospace industries

Source: (Amir, 2012)

METHODOLOGY

This study employs a qualitative analytical case-study approach to investigate systemic innovation failure within high-technology aerospace development. The qualitative case-study approach was selected because the N-250 program represents a historically bounded and institutionally complex innovation process involving interactions among government policy, industrial capability, technological learning, and international collaboration. When systemic innovation failures involve nonlinear cause-and-effect relationships that are embedded in organizational and institutional contexts, the case study methodology serves as a tool for investigating such failures.

The geographical and institutional scope of this study focuses on Indonesia's aerospace sector, with a particular emphasis on the state-led industrial ecosystem, namely *Industri Pesawat Terbang Nusantara* (IPTN). As the epicenter of national aerospace ambitions in Southeast Asia during the 1990s, this context provides a relevant empirical framework for examining institutional interactions among domestic state-owned enterprises, research networks, and global technology providers.

This study focuses on the N-250 aircraft program initiated by IPTN in the 1990s. Using the purposive document selection method, this study specifically examines sources that discuss innovation systems, the dynamics of the aerospace industry, certification procedures, and the direction of defense industry policy in Indonesia. Documents were selected based on three criteria: (1) relevance to innovation failure mechanisms; (2) empirical discussion of aerospace industry capability; and (3) direct relation to IPTN/N-250 development.

Data were collected from: (1) academic journal articles; (2) historical policy documents; (3) aerospace industry reports; (4) innovation management literature; and (5) previous studies on Indonesian aerospace development. A comprehensive review of the literature, mapping of historical developments, and systematic organization of these secondary data sources were carried out in a structured manner over a designated six-month period, from November 2025 to May 2026.

The analytical framework is based on the Chain-Linked Model of innovation proposed by Kline and Rosenberg (1986). This model is used to identify systemic weaknesses in several areas, including production cycles, market design integration, research connectivity, knowledge accessibility, and operational feedback mechanisms. To minimize interpretive bias, a data triangulation process was applied by comparing academic literature, historical records, and relevant policy documents (Creswell & Poth, 2018).

The Chain-Linked Model was chosen as the primary analytical framework because it conceptualizes innovation as an iterative and interactive system rather than a linear sequence from research to commercialization. As previous studies have shown, this model is particularly well-suited for analyzing high-tech industries characterized by subsystem integration, intensive feedback loops, and learning-by-doing processes (Figueiredo, 2022). In addition, the study applies interpretive comparative analysis by contrasting the N-250 experience with the CN-235 and Embraer programs in order to identify differences in innovation governance, industrial learning patterns, and international collaboration structures.

RESEARCH RESULTS

Weak Market Validation

The lack of robust market validation before large-scale development began was one of the main weaknesses of the N-250 program. The N-250 program was largely driven by state-led technological ambition instead of demand-oriented market dynamics. In this study, weak market validation refers to limited evidence of export confidence, limited ongoing customer commitment, and insufficient recognition of international certifications prior to reaching the stage of large-scale production.

The Chain-Linked Model emphasizes that market needs should continuously influence design and production decisions. However, IPTN lacked strong launching customers and failed to establish sufficient international market confidence. Evidence of this market weakness is clearly illustrated by the CN-235 precedent: (1) Customer Rejection: many potential customers preferred to purchase aircraft from CASA (Spain) rather than IPTN, even for an identical product; (2) The 'Backward' Image: this preference was explicitly linked to the perceived 'backward image of developing countries' associated with IPTN, which hampered its ability to compete on equal footing despite having a technically comparable product (Amir, 2007). Unlike Airbus, which conducted extensive iterative testing and pilot feedback integration during FBW development, IPTN had limited market interaction mechanisms (Edquist & Zabala Iturriagagoitia, 2012).

Limited Design-Production Iteration

Although IPTN successfully developed prototypes, the organization lacked opportunities for large-scale serial production. If only IPTN had a sustainable manufacturing cycle, they could produce: (1) operational learning; (2) cost optimization; (3) reliability improvement; and (4) production efficiency refinement. As a result, technological maturity remained incomplete, and the iterative redesign loop (a key element of the Chain-Linked Model) was never fully activated. Comparative evidence from Embraer demonstrates that firms achieving global aerospace competitiveness do so through continuous iterative production, not prototype-stage development alone (Figueiredo, 2022).

Restricted Access to Global Knowledge Networks

Compared with global aerospace firms, IPTN operated with limited access to advanced avionics, aerodynamics, and certification expertise. Several empirical indicators document this restriction:

First, Certification Dependency. While IPTN's Spanish partner (CASA) received FAA certification for the CN235 prototype, the Indonesian-made version was rejected because Indonesia lacked a Bilateral Aviation Safety Agreement (BASA) with the United States at the time (Amir, 2007). This forced IPTN to hire expensive British (CAA/JAA) consultants to guide the certification process. In the 1990s, global avionics and certification typically accounted for 30%

of total aircraft development costs (Vértesy, 2007), constituting a structural barrier that incumbents like Embraer had bypassed through earlier bilateral integrations.

Second, High Foreign Dependency Ratios. The Rockwell Collins Pro Line 4 avionics suite and the Allison AE2100 (U.S.) engine are key to the reliability of the N-250 aircraft (Vértesy, 2007). While IPTN could manufacture the airframe, the flight control laws and avionics integration remained proprietary to Western suppliers, creating a 'technological ceiling' where IPTN functioned as a system integrator rather than an original technology creator (Maharani & Matthews, 2022). Subsequent analysis confirms that the Indonesian aerospace industry remains dependent on foreign providers for engines, propellers, and composite materials even decades later (Riswandi & Yudoko, 2023).

Third, Reputation Gap and Market Access. International customers explicitly preferred to purchase the identical CN-235 aircraft from CASA (Spain) over IPTN (Indonesia) due to the perceived 'backward image' of developing nations. Established competitors such as Saab, BAE, and Embraer maintained after-sales networks and brand loyalty that IPTN, as a new entrant, could not replicate (DTIC ADA306863, 1995).

Fourth, Triple Helix Fragmentation. The IMF's 1998 Letter of Intent forced the termination of state funding for the N-250 after US$900 million had already been spent (Suryana, 2024). Subsequently, many of the 16,000 engineers trained at IPTN migrated to overseas competitors including Boeing and Airbus, liquidating the knowledge capital the government had spent approximately US$2 billion to build (Matthews et al., 2025). International collaboration was confined to the component procurement level rather than strategic technological co-development.

Fragmented Research-Innovation Connectivity

The innovation chain between research institutions and industrial production was insufficiently developed. Technical problems encountered during aircraft development were not supported by a mature national aerospace research infrastructure capable of rapid iterative problem-solving. The program's capacity for iterative technological problem-solving has been diminished due to the limited responsiveness of the domestic research network, a critical deficiency from the Chain-Linked Model perspective, which posits research connectivity as a prerequisite for innovation resilience (Jacobsson & Bergek, 2011).

External Shock as Chain Disruption

The Asian financial crisis of 1997–1998 and IMF intervention accelerated the collapse of the innovation system by simultaneously disrupting: (1) RCD funding; (2) supplier confidence; (3) market trust; (4) production continuity; and (5) human resource retention. The crisis actually served as a catalyst rather than the sole cause of the failure, given that structural vulnerabilities had already weakened the resilience of the innovation chain long before the crisis struck. This finding is consistent with Calieri et al. (2023), who demonstrate that large-scale technology projects rarely fail due to a single external shock alone.

Comparison of Aerospace Innovation Pathways: CN-235, N-250, and Embraer

While the N-250 program failed to reach operational status, the CN-235 project achieved operational deployment because it relied on international collaboration between IPTN and CASA Spain. The partnership enabled: (a) knowledge transfer; (b) risk sharing; (c) gradual capability building; and (d) sustained production learning. Table 1 presents a structured comparison of the three innovation pathways.

Table 1. Comparison between CN-235, N-250, and Embraer

Aspect	**IPTN-CASA (CN-235)**	**IPTN (N-250)**	**Embraer**
Innovation Strategy	Collaborative innovation through joint development with CASA Spain	Indigenous technological leap through state-led development	Incremental innovation through gradual capability accumulation
Fly-by-Wire (FBW) Adoption	Conventional flight control system (no advanced FBW emphasis)	Direct early implementation of advanced FBW	Gradual integration after industrial capability maturation
Market Validation	Existing demand in military and transport sectors	Weak commercial commitment and limited international confidence	Strong alignment with regional aircraft market demand
International Partnership	Extensive (CASA Spain partnership)	Limited strategic co-development, dependence on suppliers	Extensive global industrial and commercial collaboration
Production Learning	Continuous learning through serial production and joint manufacturing	Minimal serial production due to prototype limitation	Continuous iterative production
Certification Readiness	Supported by international partner certification ecosystem	Incomplete, dependence on external certification institutions	Progressive certification capability development

Aspect	IPTN-CASA (CN-235)	IPTN (N-250)	Embraer
Financial Sustainability	Shared development risk and bilateral support	State-dependent	Commercial diversification and export-oriented revenue model
Innovation Ecosystem	Integrated bilateral innovation ecosystem	Fragmented national innovation ecosystem	Mature and Integrated innovation ecosystem
Outcome	Sustained production and operational deployment	Program termination before commercialization	Global aerospace competitiveness and market expansion

Source: Amir (2008), Figueiredo (2022), Maharani & Matthews (2022), and Vértesy (2007)

DISCUSSION

Analysis and Interpretation of Findings

The findings presented in the Results section demonstrate that the N-250 program's failure cannot be attributed to a single external shock. Instead, the evidence reveals a pattern of pre-existing systemic weaknesses across all five dimensions of the Chain-Linked Model: market validation, design-production iteration, knowledge network access, research connectivity, and feedback loop continuity. The simultaneous fragmentation of these interconnected chains created a brittle innovation ecosystem that was unable to withstand the pressure of the 1997–1998 financial crisis.

An alternative interpretation suggests that the program might have succeeded if the Asian financial crisis had not interrupted financial support. The technological achievements demonstrated during prototype testing indicate that IPTN possessed substantial engineering capability. However, the present study argues that the financial crisis acted primarily as an accelerative shock rather than the sole origin of failure. Innovation-system scholars emphasize that resilient technological ecosystems maintain adaptive continuity even under severe macroeconomic pressure through diversified partnerships, iterative production learning, and institutional flexibility (Caliari et al., 2023). The N-250 ecosystem lacked these resilience mechanisms before the crisis occurred.

Comparison with Theories and Previous Literature

The comparative data in Table 1 demonstrates three distinct aerospace innovation pathways within late-industrializing sectors. The CN-235 program relied on collaborative capability development through international partnership, reducing certification and market-entry risks. The N-250 pursued accelerated indigenous technological advancement despite limited ecosystem maturity and incomplete institutional support. Embraer has taken a more gradual approach, focusing on: learning through serial production, emphasizing market adaptation, and progressively building capabilities. This distinction underscores that sustainable aerospace innovation can be achieved through alignment between innovation strategy and ecosystem readiness, rather than relying solely on technological ambition (Lundvall, 1992; Mazzucato, 2018).

Practices in countries with late-stage economic industrialization demonstrate the importance of gradually building up capabilities, as illustrated by Embraer's experience. From the outset, Embraer focused on gradual market penetration, international partnerships, and continuous production learning before expanding into more advanced areas. Embraer took this approach rather than pursuing direct technological parity with leading aerospace companies. This adaptive strategy reduced systemic vulnerability and enabled stronger integration into global aerospace value chains (Anderson & Luiz, 2025). However, the Embraer comparison should be interpreted as an analytical contrast rather than a deterministic benchmark, as Brazil and Indonesia operated under different geopolitical, financial, and industrial conditions.

IPTN's attempt at a rapid technological leap through direct FBW implementation is consistent with leapfrogging theory. Such strategies may accelerate technological visibility but simultaneously increase institutional and production risk when innovation ecosystems remain insufficiently consolidated (Choi, 2008). The comparative study of Airbus and Embraer suggests that sustained innovation in the aerospace sector does not rely on isolated technological breakthroughs. Rather, it is largely determined by the continuous incorporation of operational feedback and the gradual accumulation of technological capabilities (Rao, 2019).

Research Implications

The findings contribute theoretically to the understanding of systemic innovation failure by extending the Chain-Linked Model into the context of defense aerospace development in emerging economies. The study repositions the N-250 failure as an innovation-chain disruption rather than merely an economic casualty of the Asian Financial Crisis. This theoretical repositioning has implications for how scholars conceptualize technology project failure in late-industrializing states.

Practically, the findings suggest that technological sovereignty policies should prioritize ecosystem resilience, industrial learning continuity, and international knowledge integration alongside national technological ambition. Governments and industrial policymakers in developing economies designing high-technology aerospace programs should ensure that certification infrastructure, bilateral agreements, iterative production systems, and research connectivity are established before committing to advanced technological leapfrogging strategies (Priyono et al., 2023).

Research Limitations and Directions for Future Research

The limitations of this study lie in its reliance on historical secondary data and policy documents, which limits the depth of its institutional analysis. Furthermore, the absence of primary data from direct participants (including former IPTN engineers, policymakers, and program managers) prevents a comprehensive exploration of the organization's internal dynamics and decision-making processes. Future studies could include interviews with policymakers, aerospace engineers, and former IPTN executives to provide deeper institutional insights into the mechanisms of innovation failure.

In addition, future studies should conduct a comparative analysis of failures in aerospace innovation in several developing countries, including Brazil, South Korea, and Turkey. This step is essential for developing a more comprehensive framework for evaluating the resilience of innovation ecosystems in the defense industry. Such comparative studies would strengthen the generalizability of the Chain-Linked Model's application to defense aerospace contexts and provide a more comprehensive understanding of how institutional ecosystems influence technological catch-up trajectories (Figueiredo, 2022).

CONCLUSIONS AND RECOMMENDATIONS

The failure of the N-250 program demonstrates that high RCD investment alone is insufficient to ensure innovation success in high-technology defense industries. Using the Chain-Linked Model, this study identifies that systemic innovation failure emerged from: (1) weak market integration; (2) limited production iteration; (3) fragmented research connectivity; (4) restricted knowledge access; and (5) absence of operational feedback mechanisms.

This study also contributes theoretically by extending the application of the Chain-Linked Model into the context of defense aerospace innovation failure within developing economies. The findings suggest that technological sovereignty policies should prioritize ecosystem resilience, industrial learning continuity, and international knowledge integration alongside national technological ambition.

The innovation ecosystem, which had been fragile from the start, collapsed even more rapidly due to the Asian financial crisis. The findings challenge the assumption that large RCD expenditure automatically produces innovation success. Sustained innovation in the complex aerospace industry is, in fact, driven not so much by technological ambition alone, but rather by institutional capacity. It is this capacity that sustains a comprehensive adaptive learning cycle, encompassing market uptake, production processes, and even research systems at the earliest stages.

This study is limited by its reliance on secondary historical and policy data. For future research, a deeper institutional understanding of the mechanisms underlying innovation failures can be gained through interviews with policymakers, aerospace engineers, and former IPTN executives. In addition, future studies should conduct a comparative analysis of cases of aerospace innovation failures in several developing countries. This comparative approach aims to formulate a broader framework for evaluating the resilience of the innovation ecosystem in the defense industry sector.

ADVANCED RESEARCH

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