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THE USE OF F-35 FLIGHT SIMULATORS IN THE PROCESS OF PREPARING PILOTS FOR OPERATIONS IN A MULTI-DOMAIN ENVIRONMENT AS A CRUCIAL PART OF THE NATIONAL SECURITY

Abstract

The implementation of the Lockheed Martin F-35A Lightning II by the Polish Air Force marks a game-changing moment in Poland's defense modernization and constitutes a qualitative leap in national security architecture. This article examines the role of advanced flight simulation technology – the F-35 Full Mission Simulator (FMS) and the Autonomic Logistics Information System/Operational Data Integrated Network (ALIS/ODIN) – in preparing Polish pilots for operations across multiple domains: air, land, maritime, space, and cyberspace. Drawing on the theory of multi-domain operations (MDO), NATO transformation doctrine, and Polish strategic defense documents, the article argues that the systematic integration of high-fidelity simulation into the F-35 training pipeline is not merely a pedagogical instrument but a strategic enabler of Poland's deterrence posture and alliance interoperability. The study traces the evolution of simulation-based training from Cold War-era procedural trainers to contemporary immersive environments, analyses the unique technical characteristics of the F-35 simulator ecosystem, and evaluates the implications for Polish air power development within the broader framework

of national security transformation. The article concludes that effective exploitation of F-35 simulation capabilities will be decisive for Poland's ability to fulfil collective defense commitments on NATO's eastern flank.

Keywords

F-35 Lightning II, flight simulator, multi-domain operations, Polish Air Force, national security, NATO, pilot training, air power transformation, deterrence, eastern flank

Introduction

The security environment on NATO's eastern flank has been fundamentally transformed by Russia's full-scale invasion of Ukraine in February 2022. Poland, sharing borders with both the Kaliningrad Oblast and Belarus, faces a qualitatively new threat landscape characterized by integrated conventional and hybrid warfare, the simultaneous contestation of multiple operational domains, and the deployment of advanced anti-access/area denial (A2/AD) systems that challenge classical conceptions of air superiority.[1] Against this backdrop, Poland signed a contract in January 2020 for the acquisition of 32 F-35A Lightning II aircraft, valued at approximately USD 4.6 billion. This decision represents not simply the replacement of ageing Warsaw Pact-era platforms but a fundamental repositioning of the Polish Air Force (Siły Powietrzne Rzeczypospolitej Polskiej) within NATO's collective defense architecture.[2]

The concept of multi-domain operations (MDO), formalized in U.S. Army doctrine as early as 2018 and increasingly adopted across NATO, posits that future high-intensity conflicts will be decided not in any single domain but at the convergence points between air, land, maritime, space, and cyberspace. In this operational context, the F-35's unique sensor fusion capabilities, its role as a node in a broader battle network, and its capacity to operate across all five domains render simulator-based training qualitatively different – and far more complex – than that required by previous aircraft generations.[3]

The F-35A, as a fifth-generation multirole combat aircraft, embodies a doctrinal shift from platform-centric to network-centric warfare, and its operational effectiveness is inseparable from the training ecosystem (including advanced simulation infrastructure) that underpins it. Central to that ecosystem is a hierarchy of flight simulation devices designed to prepare pilots not merely to fly the aircraft but to exploit its role as a node in a multi-domain joint force.[4] This article analyses that ecosystem,

1 Koziej S., *Bezpieczeństwo Polski w świetle wojny na wschodzie*, Warszawa 2022, Rozdział 3.

2 https://www.gov.pl/web/obrona-narodowa/f-35-dla-polski

3 The U.S. Army in Multi-Domain Operations 2028, 6 December 2018.

4 https://www.af.mil/About-Us/Fact-Sheets/Display/Article/478441/f-35a-lightning-ii/

situates it within the doctrine of multi-domain operations, and draws out its implications for Poland's national security in the context of the ongoing transformation of the Polish Air Force.

Multi-Domain Operations: Theoretical Framework and Air Power Applications

The doctrine of multi-domain operations represents a conceptual response to the recognition that potential adversaries have deliberately developed capabilities designed to contest U.S. and NATO dominance in the air, maritime, space, and cyber domains simultaneously. The U.S. Army's *Multi-Domain Operations 2028* concept document, describes MDO as operations designed to "compete, penetrate, dis-integrate, and exploit" adversary systems across all domains and the electromagnetic spectrum, culminating in the convergence of capabilities to achieve strategic effects.[5]

For air power doctrine, the MDO paradigm has profound implications. Air forces are no longer conceived primarily as forces for achieving and exploiting air superiority in the traditional sense, but as integrating nodes that can simultaneously contribute to – and draw upon – land, maritime, space, and cyber effects. The F-35 platform operationalizes this vision through its Distributed Aperture System (DAS), Active Electronically Scanned Array (AESA) radar, and the sensor fusion capability embedded in the AN/APG-81 and related systems, which allow the pilot to operate as a data aggregator and distributor for the broader joint force.

The MDO paradigm imposes qualitatively new cognitive demands on combat pilots. In legacy aircraft, the pilot's primary cognitive task was to fly the aircraft safely while employing weapons against a relatively discrete set of threats. In the F-35, the pilot operates as a systems manager within a network, processing fused sensor data from multiple domains, making decisions that affect joint effects across the battlespace, and managing information flows that previous generations of pilots never encountered.[6]

Cognitive load theory, as applied to pilot training research, suggests that the working memory limitations of human operators are a critical bottleneck in complex decision-making environments. Simulation-based training is uniquely suited to address this challenge because it permits the progressive and controlled introduction of complexity, enabling pilots to develop automated responses to routine tasks (thereby freeing working memory for higher-order decision-making) before they encounter the full operational environment. This is the core pedagogical rationale for the sophisticated simulation infrastructure associated with the F-35 program.[7]

5 The U.S. Army in Multi-Domain Operations 2028, 2018.

6 Bronk J., *Maximum Value from the F-35: Harnessing Transformational Fifth-Generation Capabilities for the UK Military, Royal United Services Institute for Defence and Security Studies*, London 2016.

7 Salas E., Bowers C.A., Rhodenizer L., *It is not How much you have but you use it: toward a rational use of simulation to support aviation training*, The International Journal of Aviation Psychology, 1998.

NATO's Allied Command Transformation has been instrumental in developing the conceptual framework for MDO at the alliance level. The 2022 Strategic Concept, adopted at the Madrid Summit, explicitly recognizes the need for the alliance to operate across all domains, and subsequent guidance documents have emphasized the importance of simulation-based collective training for maintaining interoperability.[8] Poland's defense planning documents, including the *Development Strategy for the National Security System of the Republic of Poland 2022* (Strategia rozwoju systemu bezpieczeństwa narodowego Rzeczypospolitej Polskiej 2022) and the *Defining the Main Directions of Development of the Armed Forces of the Republic of Poland and Their Preparations for the Defense of the State for the years 2025-2039* (Określenie głównych kierunków rozwoju Sił Zbrojnych Rzeczypospolitej Polskiej oraz ich przygotowań do obrony państwa na lata 2025–2039), align closely with NATO MDO doctrine and assign a central role to the F-35 acquisition in achieving the capability goals mandated by the NATO Defence Planning Process (NDPP).

The Historical Evolution of Flight Simulation as a Training Instrument

Flight crew training is a continuous process involving the development of theoretical knowledge and practical skills throughout a pilot's entire service career. In order to improve flight safety, flight simulators have been developed since the beginning of the 20th century, enabling training in controlled conditions.

The first simulator was the Antoinette Trainer, created in 1909. The entire simulator was mounted on a barrel. In order to operate the controls, two crew members manually moved the cockpit with the pilot inside in the desired direction. a breakthrough came in 1927 with the development of the Link Trainer ("Blue Box"), which replicated the operation of onboard instruments and the aircraft's response to control movements. After World War II, the rapid development of aviation and increasingly complex cockpits led to the creation of more advanced simulators that accurately reproduced flight conditions and crew cooperation. From the 1950s onward, motion and visualization systems were developed, initially based on films and physical models, and later on computer graphics. Modern technologies such as HUDs, helmet-mounted displays, and virtual reality made it possible to achieve a very high level of training realism – up to 98% similarity to real flight conditions.

Today, simulators range from simple computer programs to advanced full-scale cockpit replicas equipped with motion platforms. Modern aviation training is based on comprehensive training systems whose primary goal is to improve flight safety and the situational awareness of flight personnel.[9]

8 NATO 2022 Strategic Concept, Madrid 2022.

9 Madowicz A., *Analiza wymagań stawianych symulatorom klasy Basic Instrument Training Device w szkoleniu lotniczym na przykładzie symulatora ELITE*, Wyższa szkoła Oficerska Sił Powietrznych, Dęblin 2015.

Transfer of Training and Simulator Fidelity

A central question in the research literature on simulation-based training concerns the relationship between simulator fidelity and the transfer of training to the operational environment. Early assumptions that higher physical fidelity necessarily produced greater positive transfer have been substantially complicated by subsequent empirical research. Studies conducted in the context of both civil and military aviation training have demonstrated that psychological fidelity (the degree to which the simulator replicates the cognitive and perceptual conditions of actual flight) is a more reliable predictor of training transfer than physical or engineering fidelity.[10]

This finding has important implications for the design of F-35 simulator training. The F-35's operational environment is defined not primarily by its aerodynamic handling qualities (which, while advanced, are not fundamentally different from those of earlier fourth-generation aircraft) but by the information environment it presents to the pilot. Achieving high psychological fidelity in F-35 simulation therefore requires, above all, faithful replication of the sensor fusion display, the mission systems interface, and the communications architecture of the actual aircraft.[11]

The F-35 Program and Polish Air Force Transformation

Poland's decision to acquire the F-35A was embedded within a broader strategic recalibration that accelerated following the 2014 Ukraine crisis. The Polish national security strategy identifies Russia as the principal security threat and establishes the strengthening of territorial defense and collective security as the primary goals of defense policy.[12] The 2022 Act on Defense of the Homeland (Ustawa o Obronie Ojczyzny), which restructured the legal framework for Polish defense, explicitly set the target of increasing the minimum defense expenditure to 3 percent of GDP increased to 4,8 percent in 2026 (the highest commitment among NATO members) and mandated a comprehensive modernization of all branches of the armed forces, with air power as a priority area.[13]

The F-35A program sits at the intersection of three strategic imperatives: the enhancement of Poland's own territorial air defense capability; the deepening of the U.S. – Polish defense partnership, including the permanent stationing of U.S. military forces in Poland; and Poland's integration into NATO's fifth-generation air power community alongside F-35 partner nations.[14]

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10 Bogusz D., *Flight Simulators in the Research Units of the Polish Armed Forces and Polish Air Force Universitys*, Polish Air Force University, Dęblin 2025.

11 https://www.lockheedmartin.com/en-us/news/features/2022/f-35-training-systems-keep-pilots-mission-ready.html

12 National Security Strategy of the Republic of Poland, 2020.

13 Act of 11 March 2022 on the Defence of the Homeland (Journal of Laws 2022, item 655).

14 https://www.gov.pl/web/national-defence/the-first-polish-f-35-fighter-unveiled

The Polish Air Force currently operates the F-16C/D Block 52+ (47 aircraft, acquired 2006–2008), the MiG-29 (in declining numbers, progressively transferred to Ukraine since 2022) and FA-50GF (12 aircraft, acquired 2023). The transition from these platforms to the F-35A represents a generational shift not only in aircraft capability but in the entire concept of air power employment. Fourth-generation fighters, even in the advanced F-16 variant, are fundamentally platform-centric: their effectiveness is primarily a function of the aircraft's own sensors, weapons, and aerodynamic performance.[15]

The F-35A, by contrast, derives a substantial proportion of its operational effectiveness from its role as a networked node: its ability to aggregate, fuse, and distribute sensor data across the joint force multiplies the effectiveness of not only the aircraft itself but of other platforms and systems that receive its data products. This fundamental difference in operational concept makes the transition from F-16 to F-35 a more complex undertaking than a simple platform replacement, and renders simulator-based preparation for the mission systems environment critically important.

The Technical Architecture of the Polish F-35 Simulator Ecosystem

The F-35 training system is one of the most complex and expensive simulation infrastructure programs ever developed for a single aircraft platform. It encompasses multiple categories of training device, arranged in a hierarchy of fidelity and cost, and is administered through the Autonomic Logistics Information System (ALIS). Recently transitioning to the Operational Data Integrated Network (ODIN) which integrates training records, maintenance data, and mission planning across all partner nations.[16]

Under the terms of the F-35 procurement agreement and the associated Government-to-Government arrangements with the United States, Poland is committed to establishing a comprehensive F-35 training infrastructure at its designated Main Operating Base (MOB), which has been identified as Łask Air Base (32nd Tactical Air Base). The planned infrastructure includes eight linked Full Mission Simulators with associated mission planning and debriefing systems, to be operational in advance of the delivery of the first aircraft.[17]

The Full Mission Simulator (FMS) is the highest-fidelity training device in the F-35 ecosystem. It consists of a motion platform (typically a six-degrees-of-freedom hexapod), a high-resolution visual system with a wide field of view of approximately 360 degrees by 135 degrees, and a fully representative cockpit incorporating the Panoramic Cockpit Display (PCD) and all mission systems interfaces. The FMS is

15 https://www.gazetaprawna.pl/wiadomosci/artykuly/9443802,polskie-sily-powietrzne-czym-dysponuja.html

16 https://www.lockheedmartin.com/content/dam/lockheed-martin/rms/documents/f35-training/F-35-Lightning-II-PC-bifold-Blue_2015.pdf

17 https://www.gov.pl/web/obrona-narodowa/f-35-dla-polski

capable of replicating all phases of flight, including combat operations in contested environments, with a high degree of psychological fidelity.[18] [19]

The most technically demanding aspect of F-35 simulator design is the faithful replication of the aircraft's sensor fusion capability. The F-35's mission systems integrate data from the AN/APG-81 AESA radar, the AN/AAQ-37 Distributed Aperture System (DAS), the AN/AAQ-40 Electro-Optical Targeting System (EOTS), the AN/ASQ-239 electronic warfare suite, and communications datalinks including Link 16 and the Multi-function Advanced Data Link (MADL). The pilot interacts with this fused data through the Panoramic Cockpit Display and the Helmet Mounted Display System (HMDS).[20]

Replicating this sensor environment in simulation requires not only accurate modelling of individual sensor phenomenology but also the simulation of the electronic environment in which the aircraft operates: radar emissions and jamming, infrared signatures, datalink communications, and electronic warfare effects. The Joint Simulation Environment (JSE) program, developed by Lockheed Martin and BAE Systems under U.S. Air Force contract, addresses this challenge through high-fidelity physics-based sensor modelling and a reconfigurable threat environment database that can replicate the most capable known and projected adversary integrated air defense systems (IADS).[21]

The establishment of the F-35 training center at Łask creates the possibility of a Polish contribution to broader NATO F-35 simulation activities. The alliance's F-35 partner nations have invested in networked simulation infrastructure that will eventually enable multi-national, multi-base synthetic training exercises (analogous to the live exercise series such as *Baltic Operations (BALTOPS)* and *Ramstein Alloy*) in which Polish crews can train alongside Dutch, Norwegian, Danish, and other allied F-35 operators in a shared synthetic environment.

National Security Implications: Simulation as a Strategic Enabler

The national security value of F-35 simulation infrastructure extends well beyond its immediate function as a training tool. In the framework of NATO deterrence theory, the credibility of extended deterrence on the eastern flank depends not only on the physical presence of capable forces but on the demonstrable readiness of those forces to conduct high-intensity operations against sophisticated adversaries.[22] Simulation-based training is a key enabler of operational readiness: it allows Polish F-35 pilots to maintain proficiency in mission profiles (including suppression of enemy air

18 https://www.airandspaceforces.com/firstf-35full-missionsimulatorarrivesateglin/

19 https://www.f35.com/f35/news-and-features/Advancing-F-35-Pilot-Training.html

20 https://www.aivon.com/blog/aerospace-electronics/f-35-multisensor-fusion-and-avionics-overview/

21 https://www.navair.navy.mil/nawcad/jse

22 Ciastoń R., Gruszczyński J., Lipka R., Radomyski A., Smura T., *Przyszłość Sił Powietrznych i jednostek obrony powietrznej w Siłach Zbrojnych RP*, Pułaski dla obronności Polski, Warszawa 2015.

defenses, deep strike, and electronic attack) that cannot safely or affordably be practiced in live flight at the required frequency.

The significance of this point should not be underestimated. The Russian A2/AD system deployed in Kaliningrad Oblast (centered on the S-400 surface-to-air missile system, the Bastion coastal defense system, and a dense integrated electronic warfare architecture) represents arguably the most sophisticated localized A2/AD complex next to the NATO territory. The ability of Polish F-35 pilots to operate effectively within and against this system is a core requirement of Poland's deterrence posture, and it can only be developed – at a strategic level – through repeated, high-fidelity simulation of the relevant threat environment.[23] The linked F-35 Full Mission Simulators, with its reconfigurable threat database and sensor-fidelity electronic warfare environment, is the instrument that makes this preparation possible without the operational risks and diplomatic sensitivities of live rehearsal.[24]

The F-35's role as a networked data node means that its effective employment in MDO requires not only national training but the rehearsal of interoperability with allied F-35 operators and with the broader NATO C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance) architecture. The Multi-function Advanced Data Link (MADL), which is unique to the F-35 community, creates a dedicated high-bandwidth, low-probability-of-intercept communications network among F-35 aircraft that is inaccessible to legacy platforms.

The implications for Polish security are significant. As Poland's F-35 community matures, Polish aircraft will become integral nodes in the F-35 coalition network operating on NATO's eastern flank, sharing sensor data and contributing to a Common Operational Picture (COP) that enhances the situational awareness of the entire joint force. Simulation-based training, is the primary vehicle for developing the tactics, techniques, and procedures (TTPs) required for effective multi-national F-35 networking.[25]

The F-35's ALIS/ODIN logistics and mission data management system introduces an innovative cybersecurity dimension to Polish air power operations. The system aggregates maintenance and operational data from all F-35 aircraft globally and transmits it to Lockheed Martin servers, raising questions about data sovereignty and the potential for adversary exploitation of this information architecture. Poland's General Staff and the Agencja Bezpieczeństwa Wewnętrznego (ABW – Internal Security Agency) have a legitimate national security interest in the cybersecurity architecture surrounding F-35 data flows, and the simulation infrastructure (which also interfaces with ALIS/ODIN) must be evaluated from this perspective.[26] [27]

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23 Koziej S., *Bezpieczeństwo Polski w świetle wojny na wschodzie*, Warszawa 2022, Rozdział 3.

24 https://www.f35.com/f35/news-and-features/Advancing-F-35-Pilot-Training.html

25 Sztobryn M., *Diagnoza użycia samolotów F-35 w Siłach Powietrznych RP. Zarys problematyki*, Lotnicza Akademia Wojskowa, Dęblin 2023.

26 https://www.lockheedmartin.com/content/dam/lockheed-martin/rms/documents/f35-training/F-35-Lightning-II-PC-bifold-Blue_2015.pdf

27 Cwojdziński L., *Cyberbezpieczeństwo systemów uzbrojenia sił powietrznych Stanów Zjednoczonych – zapewnienie bezpieczeństwa misji*, Przegląd Komunikacyjny 2023.

At the same time, the cyber domain presents an opportunity as well as a vulnerability. The F-35's electronic attack capabilities, which can be rehearsed in simulation, include the ability to conduct cyber effects through the electromagnetic spectrum (jamming, deception, and intrusion) that may constitute a significant contribution to NATO's emerging cyber operations posture. The rehearsal of these capabilities in simulation, in coordination with allied cyber command structures, is a growing component of F-35 training globally and represents an area in which Poland's F-35 program can contribute to collective alliance capability.

Human Capital and the Long-Term Development of Polish Air Power

The successful exploitation of the F-35's capabilities – and of the simulation infrastructure designed to develop those capabilities – is ultimately dependent on the quality and continuity of the human capital base of the Polish Air Force. Poland faces challenges common to many NATO air forces: competition with the civil aviation sector for qualified pilots and technical staff, the long lead times required to train F-35 qualified pilots from initial flight screening to combat-ready status (typically 4–5 years), and the organizational and cultural adjustments required by the transition from Warsaw Pact legacy procedures to NATO standards.[28] [29]

Simulation-based training addresses several of these challenges directly. One of the most consequential – and frequently underappreciated – security benefits of advanced flight simulation is economics. The cost of operating a modern combat aircraft is staggering. An F-35A costs approximately USD 34,000 – 40,000 per flight hour, against simulator costs of approximately USD 1,000 – 2,000 per hour. This difference significantly expands the training capacity available within a given budget. Simulation also mitigates the risk of prolonging during the conversion training phase and quality decrease of the training. It also protects the investment in trained pilots and accelerating the development of operational capability.[30]

Conclusions

This article has argued that the F-35 flight simulator ecosystem occupies a central and strategic role in the transformation of the Polish Air Force and, by extension, in the architecture of Polish national security. The analysis has demonstrated that simulation-based training is not a peripheral support function but a core operational requirement, particularly in the context of multi-domain operations where the cognitive and technical demands placed on F-35 pilots exceed those of any previous aircraft generation.

28 Bogusz D., *Szkolenie selekcyjne kandydatów na pilotów wojskowych w Siłach Zbrojnych Rzeczypospolitej Polskiej*, Lotnicza Akademia Wojskowa, Dęblin 2020.

29 https://www.altair.com.pl/pierwszy-etap-szkolenia-polakow-na-f-35

30 https://www.ultidefense.com/f-35-pilot-training-cost-pipeline/

Several conclusions emerge from the foregoing analysis:

- the Full Mission Simulator of the F-35 training ecosystem are essential enablers of Poland's deterrence posture, providing the only safe and affordable means of preparing Polish pilots for operations in the Kaliningrad A2/AD environment;
- the networked simulation infrastructure is a critical instrument for developing the interoperability required for effective MDO on NATO's eastern flank;
- the cybersecurity dimensions of the F-35 ALIS/ODIN architecture require dedicated attention from Polish national security institutions, both to protect operational data and to ensure the integrity of the simulation training environment;
- the human capital dimension of the F-35 program – the development and retention of a qualified pool of F-35 pilots, simulator instructors, and mission systems engineers – is a long-term national security investment that requires sustained political commitment and resource allocation beyond the initial procurement phase.

On the basis of these conclusions, the following policy recommendations are advanced:

- the Polish Air Force should establish a program of regular multi-national networked simulation exercises with allied F-35 partner nations;
- Polish relevant authorities should conduct a comprehensive assessment of the cybersecurity architecture surrounding F-35 ALIS/ODIN data flows and simulation system connectivity;
- the War Studies University and the Polish Air Force Academy should develop dedicated academic curricula for MDO doctrine and F-35 mission systems employment, integrating simulation-based training at the tactical, operational, and strategic levels.

The F-35 program represents Poland's most significant investment in national security since NATO accession in 1999. The flight simulator ecosystem (unglamorous in comparison to the aircraft itself) is the indispensable instrument through which that investment will be translated into genuine operational capability and deterrent credibility on NATO's eastern flank. The strategic importance of getting simulation right cannot be overstated.

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