Rebalancing Combat Aviation Training

Integrating Synthetic Environments for Multi-Domain Mission Readiness

By Lieutenant Colonel Antonio Gutierrez, ESP Air Force, JAPCC

Combat pilots have always preferred to fly, and that preference has shaped how militaries train. However, in recent decades, simulator training has increasingly supplemented live flight hours. As the synthetic training environment evolves in sophistication and scope, the question is no longer whether live flying matters. It is whether a training model built around it can produce the volume, variety, and readiness that modern combat demands. Many Allies reference a benchmark of 180 live flying hours per pilot per year, of which only 40 may be accomplished in a full-mission simulator.[1] Meanwhile, operational requirements are evolving: fighter aircraft inventories are decreasing, and sustainment costs for fifth-generation aircraft such as the F-35 are higher than anticipated.[2] Simultaneously, advances in simulated training through live, virtual, and constructive (LVC) environments create opportunities for NATO members to adopt a next-generation approach to mission readiness.

High-performance professions have long used simulation to compress learning cycles and supplement live training time. Formula 1 teams, for example, rehearse procedures and refine decision-making in high-fidelity simulators before the car ever reaches the circuit. The difference is the operating environment: a Formula 1 driver optimises performance on a known track with relatively stable parameters, whereas a combat pilot must prepare for changing theatres, adaptive threats, and unpredictable mission conditions. Networked, high-fidelity LVC environments can expose aircrews to scenarios and threat densities that live flying in peacetime cannot reliably replicate.

NATO air forces face compounding pressures: the battlespace has expanded into cyber and space domains, while the airspace available for training has become increasingly restricted.[3] Consequently, Allied air training must undergo a fundamental transformation to enable Multi-Domain Operations (MDO) and the integration of fifth- and sixth-generation platforms. Operators must integrate multi-domain effects with advanced threat replication to win in a future near-peer, large-scale conflict. NATO should develop and adopt LVC training as an essential and complementary training environment for preparing aircrews for MDO. It can improve mission-ready proficiency and integration at scale, delivering a repetition rate and variability that live flying alone cannot match.

The Requirement for Complexity

NATO's Joint Air Power Strategy, issued in 2018 and revised in 2025, identifies MDO as the linchpin of operational success, requiring the orchestration and convergence of effects across all five domains.[4] The ability of NATO combat air power to perform MDO depends on advanced sensors, weapons, and integration capabilities. Fifth- and sixth-generation aircraft and autonomous collaborative platforms (ACP) increasingly provide these capabilities, acting not only as shooters but also as sensor and data-fusion nodes within a broader system of systems. These systems are redefining the tactical training requirements for air power employment. Against this backdrop, two primary drivers are reshaping how NATO must train its aircrews.

Data Density and the Shift to Mission Management: Pilots must adapt to increasingly complex battle management interfaces. In fourth-generation aircraft, pilots processed fragmented sensor inputs and translated them into aircraft manoeuvre and weapons employment. In fifth-generation aircraft, advanced automation aids in basic flight control, data fusion, and system-driven effects, enabling the pilot to concentrate on battlespace awareness, effects management, and broader tactical decision-making.

Supporting this evolution, modern simulators can replicate multi-domain threats that the live-fly environment cannot as easily generate: cyber effects, electronic warfare, and a saturated information environment that increases cognitive load. Future air combat will depend on superior package-level situational awareness, battle management, multi-domain effects application, and prioritisation, rather than stick-and-rudder skill.

Preparing for Autonomy: ACPs are uncrewed platforms that use artificial intelligence (AI) to translate human intent, ranging from specific commands to broader objectives, into autonomous actions.[5] The Uncrewed Combat Air Vehicle (UCAV), **also known as Collaborative Combat Aircraft (CCA),** is one such type. Crewed aircraft will likely supply the human intent behind ACP employment, transforming a single platform into a human-machine team across missions ranging from offensive and defensive counter-air to airlift and aerial refuelling. This development demands that aviators shift from traditional cockpit skills toward the competencies required to manage distributed, multi-effector teams. These include task delegation, supervisory control, cognitive offloading, and the integration of autonomous agents into dynamic mission environments.

Aircrews will likely develop, rehearse, and validate human-machine teaming (HMT) competencies in synthetic environments before executing them safely in the physical domain. Within the virtual space, pilots and mission aircrew can explore, discuss, and test the boundaries of AI responsibility and the scope of human oversight.

The Operational Imperative: Advanced Training in a Constrained World

Realising full capability requires an advanced and realistic training environment. Three constraints prevent NATO from achieving this complexity through live-fly training alone.

Airspace Geometry: Modern beyond-visual-range air-to-air missile systems, such as the AIM 424 Long Range Air to Air Missile (LRAAM), are projected to reach up to 460 km (250 NM), while the AGM-158B Joint Air-to-Surface Standoff Munition-Extended Range (JASSM-ER) can strike land targets beyond 500 NM.[6]

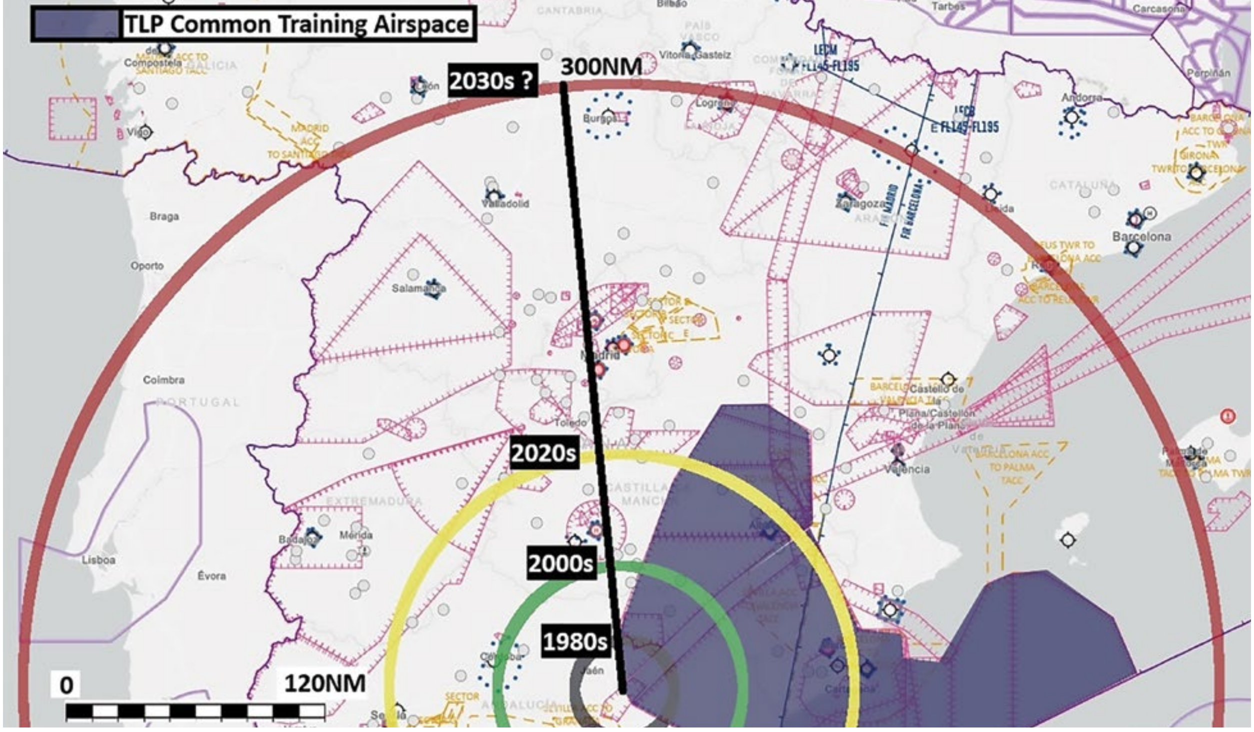

***Figure A:** Baseline Air-to-Air Weapons Ranges overlayed with Spanish Tactical Leadership Programme (TLP) training areas. The above graphic is derived from open-source, historical data to provide a perspective by which the baseline for air-to-air weaponry has shifted from the 1980s to the 2020s (2030s range is notional).*

Emerging capabilities such as hypersonic air-launched weapons promise even greater range. Similarly, the range and capabilities of adversary systems continue to increase. The Russian S-400 surface-to-air missile system can threaten targets at up to 400 km (216 NM).[7] Expanded engagement ranges require live-fly airspace that can replicate realistic engagement geometries.

This technological leap has expanded the airspace volume required for realistic training (Figure A), creating a direct conflict with civil aviation. European airspace is among the most saturated in the world, and nations remain reluctant to constrain economically beneficial air traffic.[8] Efforts such as the Single European Sky and Flexible Use of Airspace improve coordination but cannot increase the amount of available training airspace.[9]

Electromagnetic Spectrum (EMS) Replication: Replicating multi-domain convergence in live training is not feasible, even under optimal conditions. To prepare for high-end conflicts, NATO must familiarise operators with a broad range of multi-domain effects, EMS degradation, and the resulting impact on aircraft systems and weapons performance. However, containing these effects within training-airspace boundaries is impractical, particularly in the space and cyber domains, given the risk of spillover into civil navigation and communications signals.[10]

Force Design and Cost Requirements: To date, 13 NATO nations have committed to purchasing the F-35 Lightning II, adopting it as an advanced but costly capability upgrade over their ageing fourth-generation fighters. Approximately 650 European-owned F-35s are expected to be operational by 2030, comprising roughly 20 percent of the Alliance's fighter aircraft inventory of 3,300.[11] This increase in capability is predicated on proficient pilots who understand what fifth-generation aircraft can do and how to employ them. However, rising sustainment costs and finite airframe life render flying hours an increasingly constrained resource.[12] The Alliance must adopt an LVC model and establish the infrastructure to realise the promised benefits of this fifth-generation fleet.

Operationalising the Synthetic Roadmap

An LVC training model integrates live and synthetic technologies to create a scalable training environment.[13] The train-how-we-fight concept now depends heavily on the ability to replicate a multi-domain environment while overcoming spatial, EMS, and economic constraints. While traditional live-flight training and standalone simulators will remain indispensable, they cannot integrate multi-domain effects at the scale the modern combat environment demands. Therefore, NATO should develop and normalise LVC training while preserving the essential competencies that only live flight can provide, including critical airmanship and somatosensory training. LVC comprises three distinct elements.

Live (L): Involves real people operating real systems. This remains essential for the aerodynamic and physiological effects of flight, including g-loading and somatosensory feedback.

Virtual (V): Involves real people operating simulated systems. This supports mission-management training, allowing operators to master platform interfaces and HMT in a high-repetition environment without airframe wear.

Constructive (C): Involves simulated people and systems driven by computer models. 'Constructive' forces provide the necessary mass and complexity, generating large-scale, reactive, and AI-driven threats that cannot be replicated with live assets.

By blending these environments, a pilot in live flight can train alongside a wingman in a simulator, while engaging a system-generated and numerically superior force package of enemy air and land systems in a manner that is repeatable and scalable. Organisations and nations across the Alliance have pursued initiatives that address this requirement:

- In 2020, the US Air Force (USAF) launched the Rebuilding the Forge (REFORGE) concept, using advanced simulators to support basic pilot training.[14] Major exercises such as Red Flag (USAF integration exercise) and Valiant Shield 24 (US Pacific Command joint exercise) also use LVC components, integrating virtual and constructive assets.
- The Netherlands Aerospace Centre, in collaboration with the Royal Netherlands Air and Space Force, focuses on user-oriented LVC concepts in air-domain training.[15]
- The French Armed Forces have pursued the Massive Network Simulation project, *Simulation Massive en*

Airmen participate in the LVC portion of Red Flag (2015) at the Combined Air Operations Center at Nellis Air Force Base. Red Flag 15-2 was the first Red Flag exercise that included hundreds of virtual and constructive participants in simulators at their home stations or the Distributed Mission Operations Center at Kirtland Air Force Base, US.

Réseau, and the Jeannette system, making significant efforts to interconnect simulators.[16]

- Within the Tactical Leadership Programme (TLP) in Albacete, Spain, the Modern Air Combat Environment (MACE) provides a high-fidelity simulation system used to generate realistic air combat scenarios.[17]
- The International Flight Training School at Decimomannu Air Base in Sardinia, Italy, uses the Embedded Tactical Training System (ETTS) to enable pilots to interact in real time through LVC modes within its closed environment.[18]

While these efforts illustrate substantial progress, they also highlight the need for a unified, Alliance-wide framework capable of integrating and scaling such developments. The NATO Distributed Synthetic Training (DST) initiative provides a framework for such integration. As one of NATO's 31 high-visibility projects to boost operational effectiveness, economies of scale, and Allied connectivity, DST prepares forces for complex operational environments.[19] DST envisions a comprehensive federation of national synthetic training capabilities to support mission readiness and high-fidelity operational training.[20] Launched in October 2024, DST gained rapid momentum with 13 Allies signing a Memorandum of Understanding in October 2025, establishing the strategic framework upon which technical execution must now build.[21]

Recommendations for Implementation

Establish the Foundation: Transitioning to an LVC model requires clear doctrine and standardised architecture.[22] Before procuring hardware, NATO should enforce common standards, such as the High-Level Architecture (HLA) and Distributed Interactive Simulation (DIS) protocols. This will ensure that nations develop systems aligned with NATO reference architectures rather than in isolation. National procurement agencies should mandate compliance with these standards for all future simulation acquisitions. Nations should still maintain the ability to operate national-only simulators for sensitive national training purposes, while a standardised architecture permits integrated coalition training when required. NATO should treat any simulator that cannot connect to the coalition network as operationally limited.

Solve the Multi-Level Security Paradox: Classification and releasability constraints further impede coalition training. NATO should accelerate standardised cross-domain solutions to enable real-time, classification-aware data exchange and prioritise secure federation over default isolation. Acquisition requirements must define both operational and training modes, allowing systems to filter data by classification and connect to coalition simulation networks while preserving the option to isolate from network risks. In practice, some operators will access the system's full data picture while others receive data only authorised for their classification or national caveats. Embedding this dual-mode architecture as a core interoperability requirement will ensure future systems support both operational employment and coalition synthetic training from the outset.

Professionalise the Synthetic Workforce: Running complex LVC scenarios requires embedded simulation structures within Combat Wings and Air Operations Centres, supported by permanent, specialised staff to manage the technical and doctrinal requirements. Yet current manning structures treat simulation support as a secondary function across most Allied organisations. Allies should grow the training and support for personnel who facilitate the LVC environment, and foster either an organic military or a contract workforce to evolve and sustain synthetic training capabilities.

Rebalance the Investment Portfolio: High initial capital costs deter nations from committing to LVC infrastructure, but operations and maintenance costs for the synthetic environment are low in comparison to those of an aircraft fleet. NATO nations should shift the metric of value from 'unit cost' to 'training value', measured, for example, in repetitions or integration density (the total number of systems or platforms participating). LVC preserves airframe life and enables scenarios not feasible in peacetime live training, and this value should be weighed against the acquisition cost of LVC systems.

Conclusion

Addressing these challenges is not merely a technical undertaking but a strategic imperative requiring a fundamental transformation of NATO's internal processes and culture. Live flight remains indispensable for validating aerodynamic performance, physiological stress, and mission integration in the physical domain. However, LVC must carry the burden of scale, repetition, and multi-domain integration required for future combat readiness. Without this recalibration, the Alliance risks fielding fifth- and sixth-generation aircraft within a fourth-generation training construct. ●

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ABOUT THE AUTHOR

Lieutenant Colonel Antonio Gutierrez
ESP Air Force, JAPCC

Lieutenant Colonel Antonio Gutierrez graduated from the Spanish Air Force Academy in 2001 as a fighter pilot and holds a Bachelor's degree in Industrial Organisation Engineering. He served at Ala 14 in Albacete and later as a flight instructor at the Air Force Academy, additionally flying with the Patrulla Águila aerobatic team. After completing the Staff Course and a Master's degree in Security and Defence, he worked in the Spanish Air Operations Centre and subsequently at the Joint Operations Command. He has participated in Baltic Air Policing and EUNAVFOR Atalanta operations. In the field of simulation, he led the 'Joint Vignettes' Focus Area during CWIX 2016 and directed the simulation team responsible for the recurrent Mazar-e-Sharif HQ JOC training under Resolute Support. He also headed the ITC team during the Spanish exercise DRAGON 21. He is currently assigned to the JAPCC Combat Air Branch as a fixed-wing subject matter expert.