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Military Innovation and Defence Acquisition: Lessons from the F-35 Programme

by Niccolò Petrelli

ABSTRACT

The F-35 was originally conceived as a multirole air superiority/strike aircraft capable of operating in self-contained formations, or alone, into hostile airspace. As its development proceeded, however, it proved extremely difficult to overcome the trade-off between low observability, and range and weapons payload. This had a significant impact on the evolution of debates on concepts of operations, leading to a consensus over employing the aircraft as a decentralised node for command & control rather than as originally envisioned. Consequently, requirements for its integration into existing force structures among the programme's partners have not only changed, but have become more demanding and complex, prompting the need to rethink existing defence acquisition organisation and models.

F-35 | Italy | Defence industry | Procurement | Italy's military policy

keywords

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Introduction

What concept has driven development of the Lockheed Martin F-35 Lightning II, and how has this concept affected its capabilities? How have debates about concepts of operations (ConOps) evolved? What are the adoption requirements that the aircraft generates?

The study of the F-35's capabilities, employment and requirements is not only relevant in and of itself but has also implications for scholarship in security and strategic studies and defence policy more broadly. The literature claims that military innovation, a process consisting of interrelated changes in hardware (technology) and software (organisation and tactics/operational art), leading to a reconfiguration of some segment of military operations,[1] generally takes place in a largely linear and sequential way. The introduction of a family of new technologies or a new weapon system may prompt a re-conceptualisation of patterns of operation and generate related organisational changes or, vice versa, innovation may start with speculation, with an aspirational vision of how some segment of military operations could be implemented in the future to guide the development or procurement of related hardware.[2] While to a certain extent interrelated, in such an understanding changes in software and hardware are conceived of as taking place linearly and sequentially.

[1] Andrew L. Ross, "On Military Innovation: Toward an Analytical Framework", in *SITC Policy Briefs*, No. 1 (September 2010), https://escholarship.org/uc/item/3d0795p8; Colin S. Gray, "Technology as a Dynamic of Defence Transformation", in *Defence Studies*, Vol. 6, No. 1 (March 2006), p. 26-51.

[2] Peter Dombrowski and Eugene Gholz, *Buying Military Transformation. Technological Innovation and the Defense Industry*, New York, Columbia University Press, 2006; Dima Adamsky, *The Culture of Military Innovation. The Impact of Cultural Factors on the Revolution in Military Affairs in Russia, the US, and Israel*, Stanford, Stanford University Press, 2010; Matthew Evangelista, *Innovation and the Arms Race: How the United States and the Soviet Union Develop New Military Technologies*, Ithaca, Cornell University Press, 1988, p. 6-14.

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Has modern military technology changed this pattern? If so, what are the implications for approaches to defence acquisition? This paper helps answer these questions by employing an idiographic theory-guided research design aimed at describing, explaining and interpreting the case of the F-35 through process-tracing informed by the prevailing theoretical perspective on military innovation outlined above.[3]

1. Evolution of the F-35 capabilities

The F-35 is the outcome of the Joint Strike Fighter (JSF) development and acquisition programme. This emerged in late 1995 from the Joint Advanced Strike Technology (JAST) programme and aimed at delivering an aircraft capable of: operating in small formations or as single aircraft with minimum or no close escort or penetrating support elements in high threat areas, and providing high lethality against a variety of targets.[4] The JSF "development logic" was similar to that of the F-16: producing a versatile, multipurpose fighter capable of fulfilling a number of roles in the air-to-air and air-to-ground arenas, but not fully specialised in any of them.[5] The most comprehensive study published to date on the JSF programme as well as a comprehensive review of the studies conducted by the US Congressional Research Service (CRS) confirm that so far the programme has indeed been implemented according to this logic.[6]

The main feature of the F-35 architecture is the interactivity among the combat systems whereby functional outcomes, and therefore capabilities, are generated synergistically rather than by stove-piped functions. Five interactive systems, linked by a high-speed fibre optic data bus, make up the aircraft's "sensing apparatus": AN/ASQ-242 Communications, Navigation, and Identification avionics suite, the APG-81 Active Electronically Scanned Array (AESA) radar, the AN/AAQ-37 Distributed Aperture System, the AN/AAQ-40 Electro-Optical Targeting System and the AN/ASQ-239 electronic-warfare system.[7] Data from these on-board sensors as well as

[3] Jack S. Levy, "Case Studies: Types, Designs, and Logics of Inference", in *Conflict Management and Peace Science*, Vol. 25, No. 1 (March 2008), p. 3-4; Andrew Bennett and Jeffrey T. Checkel, "Process Tracing: From Philosophical Roots to Best Practices", in Andrew Bennett and Jeffrey T. Checkel (eds), *Process-Tracing. From Metaphor to Analytic Tool*, Cambridge, Cambridge University Press, 2015, p. 3-10, https://assets.cambridge.org/97811070/44524/excerpt/9781107044524_excerpt.pdf.

[4] Defense Science Board (DSB), *Report of the Defense Science Board Task Force on Joint Advanced Strike Technology (JAST) Program*, Washington, Office of the Undersecretary of Defense for Acquisition & Technology, September 1994, p. ES-3, https://apps.dtic.mil/docs/citations/ADA292094.

[5] Aaron Mehta, "Boeing Positions F-15 as F-22 Supplement", in *Defense News*, 15 September 2015, https://www.defensenews.com/digital-show-dailies/afa-air-space/2015/09/15/boeing-positions-f-15-as-f-22-supplement.

[6] Bert Chapman, *Global Defense Procurement and the F-35 Joint Strike Fighter*, Cham, Palgrave Macmillan, 2019, p. 89-137. For an overview of studies conducted by the CRS see: *F-35 Joint Strike Fighter (JSF) Program*, https://www.everycrsreport.com/reports/RL30563.html.

[7] Information about these systems can be found in BAE Systems website: *AN/ASQ-239 F-35 EW countermeasure system*, https://www.baesystems.com/en-us/product/an-asq-239-f-35-ew-

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from off-board sources is fused by the F-35's central computer into an integrated interpretation of the surrounding tactical situation. The fusion functionality processes incoming data about objects in the environment and performs association against existing tracks. It detects further information needs, prioritises them and issues new commands to the sensors considered most appropriate to satisfy these needs. Identification and tracking continue automatically in a closed-loop fashion as new data from on-board or off-board sensors is acquired. These, in turn, can be either relayed to other platforms in "open transmit" mode or, subject to data bring-back memory capability, manually recorded and stored. The results of the fusion process are provided to the pilot/vehicle interface for display, fire control for weapon support, and electronic warfare for countermeasures support.[8]

Widespread agreement exists that, with regard to systems integration and data fusion, the F-35 represents a quantum leap in comparison to the additive architecture of 4th generation systems. In the F-35 the interactivity among the combat systems allows the aircraft to respond synergistically to threats, leveraging each sensor's strengths as well as making up for each of the sensor's weaknesses. This, in turn, enables the creation of new tactical options on a continuous basis.

With regard to low observability (LO), also known as "stealth", from the beginning of the programme the goal was to achieve an acceptable level while securing appropriate levels of manoeuvrability and containing production and maintenance costs; some capabilities were therefore sacrificed. Indeed, compared to the F-22 Raptor (another aircraft with advanced stealth capability), the F-35 has a less disciplined shape, with very low radar cross section (RCS) primarily in the X and Ku band.[9] Additional RCS reduction was secured through application of radar-absorbing material. First of all, as in any other US stealth aircraft since the B-2, the F-35 displays an "edge treatment" in the form of a different-coloured triangularly wedged band around the perimeter of the airframe filled with glass-fibre honeycomb loaded with carbon. By absorbing currents and incident radar waves, as well as slowing surface current transitions, this contributes to RCS reduction. Moreover, the F-35 features a new LO substance called fibre mat, carbon nanotube-infused fibres that can absorb or reflect radar, which has been built into the composite "skin" of the aircraft. The use of fibre mat ensures that electro-

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countermeasure-system; and Northrop Grumman website: *AN/APG-81 AESA Radar*, https://www.northropgrumman.com/Capabilities/ANAPG81AESARadar/Pages/default.aspx; *F-35 Lightning II*, https://www.northropgrumman.com/Capabilities/F35Lightning/Pages/default.aspx; *AN/AAQ-37 Distributed Aperture System (DAS) for the F-35*, https://www.northropgrumman.com/Capabilities/ANAAQ37F35/Pages/default.aspx.

[8] Greg Lemons et al., *F-35 Mission Systems Design, Development, and Verification*, paper presented at the 2018 Aviation Technology, Integration, and Operations Conference, Atlanta, 25-29 June 2018, p. 11; Thomas L. Frey et al., *F-35 Information Fusion*, paper presented at the 2018 Aviation Technology, Integration, and Operations Conference, Atlanta, 25-29 June 2018.

[9] Konstantinos Zikidis, Alexios Skondras and Charisios Tokas, "Low Observable Principles, Stealth Aircraft and Anti-Stealth Technologies", in *Journal of Computations & Modelling*, Vol. 4, No. 1 (2014), p. 141, 144, https://www.scienpress.com/download.asp?ID=1040.

magnetic properties do not vary with angle.[10]

Unclassified studies of the F-35 stealth capabilities demonstrated that the aircraft's RCS is comparatively very low, at least as far as the fuselage is concerned, with very low detection range especially in the X-band.[11] It can therefore be agreed that the F-35 is a truly "stealth" platform, to the extent that a tactical multirole fighter can be. Detection is not impossible, much less engagement, as the logic of LO is not to prevent detection, but to "break the kill chain".

With regard to payload, in stealth configuration, that is without external armaments, the F-35 has a capacity of about 2,585 kilograms (kg) of ordnance. The F-35 disposes also of two internal weapon bays (two smaller and two bigger except for the B variant) with two hardpoints each; these are shorter but deeper than those of the F-22, making it capable of carrying four missiles, two apiece in each of the two racks depending on combat configuration, as well as non-strategic nuclear weapons.[12] On the other hand, the internal fuel tank has a capacity of between 6,000 and 9,000 kg (depending on the aircraft's variant), giving it a combat radius ranging from 1,600 for the B version to 2,200 kilometres (km) for the A version (which can be in any case extended through aerial refuelling).[13]

The F-35 can expand payload up to more than 9,900 kg of internally and externally carried ordnance by taking advantage of 12 stations on the strike fighter's wings for weapons pylons – yet, at the cost of sacrificing stealth. Underwing hardpoints allow the F-35 to carry up to a maximum of 14 missiles or, alternatively, six Joint Direct Attack Munition bombs and four missiles.[14] Moreover, the two wing stations closest to the fuselage can hold external tanks containing approximately 3,500 kg of fuel, giving the F-35 a combat radius of approximately 2,800 km.[15] Whether

[10] Dan Katz, "The 'Magic' Behind Radar-Absorbing Materials for Stealthy Aircraft", in *Aviation Week & Space Technology*, 28 October 2016; Second Line of Defense (SLD), "The F-35's Low Observability: Lifelong Sustainability", in *"Re-Norming" Air Operations*, Arlington, SLD, 2012, p. 66-71, https://www.sldinfo.com/wp-content/uploads/2011/02/Re-Norming-Air-Operations.pdf.

[11] Konstantinos Zikidis, Alexios Skondras and Charisios Tokas, "Low Observable Principles", cit., p. 147-148. See also: Carlo Kopp, "Assessing Joint Strike Fighter Defence Penetration Capabilities", in *Air Power Australia Analyses*, No. 2009-01 (7 January 2009), https://www.ausairpower.net/APA-2009-01.html.

[12] Michael Peck, "The F-35 Just Became a Missile Carrier", in *The Buzz*, 7 May 2019, https://nationalinterest.org/node/56267. For official data on standard payload capabilities see: Lockheed Martin, *F-35 Lightning II Program Status and Fast Facts*, 17 April 2019, https://www.lockheedmartin.com/content/dam/lockheed-martin/aero/documents/F-35/F-35%20Fast%20Facts%20April%202019.pdf.

[13] Garrett Reim, "Analysis: F-35's Next Engine to Reach for More Range", in *FlightGlobal*, 6 August 2019, https://www.flightglobal.com/analysis/analysis-f-35s-next-engine-to-reach-for-more-range/133651.article.

[14] Mark Episkopos, "Watching an F-35 Go into Beast Mode Is Terrifying", in *The Buzz*, 14 May 2019, https://nationalinterest.org/node/57392; see also F-35 Lightning II website: F-35 Weaponry, https://www.f35.com/about/carrytheload/weaponry.

[15] Brian W. Everstine, "Lockheed Looking at Extending the F-35's Range, Weapons Suite", in *Air Force Magazine*, 17 June 2019, https://www.airforcemag.com/?p=7929.

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the Lightning II weapons and fuel payload are truly adequate to meet expected operational requirements remains a moot point. In fact, even though the F-35A's range and loiter time in stealth configuration are greater than most existing 4th generation aircraft, a maximum combat radius of 2,200 km seems inadequate to perform long-range combat missions with reduced tanker support, or to conduct persistent operations over permissible environments as envisioned in the original operational concept.[16] Secondly, the F-35's highly limited weapons payload of just four missiles "leaves it at a severe disadvantage at a time when fighters carrying more than ten missiles are increasingly the norm". If outfitted for short-range combat, for instance, the JSF would only be able to fire a single round of beyond visual range (BVR) missiles as they usually fired in pairs to increase chances of interception.[17]

In sum, the application of a multirole development logic has not, predictably perhaps, led to a perfectly balanced system. The F-35's formidable situational-awareness and information-processing capabilities and LO design came in fact with trade-offs in terms of limited range and weapons payload capacity. True, the aircraft's open modular systems architecture allows for continuous product improvement exploiting the latest advances in tactics and technologies. Nevertheless, the examination of its current capabilities – in terms of combat systems, stealth and payload – stresses trade-offs whose existence calls into question the effective possibility of employing the aircraft as envisioned in the original guiding concept. This, in turn, has significantly influenced the evolution of debates on ConOps.

2. The evolving debate on concepts of operations

As mentioned above, the original "proto-concept of operations" driving the development of what would become the F-35 focused to a considerable extent on the system's ability to operate in a sort of "stand-alone" mode. In fact, it envisioned the future JSF as operating alone or in small formations in a rather independent fashion in hostile territory by virtue of combining low-observability features, highly integrated avionics and sensor fusion, and precision targeting.[18]

The early consensus on ConOps reflected this understanding. The F-35's sensor fusion engine could provide a degree of integrated tactical situational awareness previously achievable only by linking aircraft to a large support infrastructure

[16] This is especially true for the F-35B, which has a smaller internal fuel capacity than the F-35A by roughly 30 per cent.

[17] "New 'Sidekick' Missile Upgrade a Potential Game Changer for F-35's Air to Air Capability - 50% Payload Increase Expected", in *Military Watch Magazine*, 8 May 2019, https://militarywatchmagazine.com/article/new-sidekick-missile-upgrade-a-potential-game-changer-for-f-35-s-air-to-air-capability-50-payload-expansion-expected.

[18] F-35 Lightning II website: *Multi-Mission Capability for Emerging Global Threats*, https://www.f35.com/about/capabilities.

comprising assets such as the Joint Surveillance Target Attack Radar System (Joint Stars or JSTARS), the Airborne Warning and Control System (AWACS), and ground-based intelligence reach-back and targeting infrastructures. Moreover, thanks to its stealth capabilities a force of F-35s could penetrate defended adversary air space undetected. The combination of these two capabilities was thus believed to allow the F-35 to execute air superiority and strike missions virtually simultaneously, rather than sequentially, with beyond visual range surprise engagements of hostile aircraft from unexpected directions, as well as long-range strikes against fixed and moving targets on sea and land.[19] The fact that the JSF was a multirole platform capable of missions traditionally performed by specialised aircraft made any air formation composed of F-35s inherently self-contained and highly flexible, with each platform able to switch from one role to another on a continuous basis.[20]

Around 2009 the original vision for the employment of the JSF came to be increasingly questioned and a new operational paradigm emerged, which consolidated into a new consensus around 2015, as the F-35 approached the final stages of the Systems Development and Demonstration phase and professional debates started to devote more attention to operational issues.[21] This was heavily influenced by the broader debates on the future security environment and joint ConOps taking place in the countries participating in the programme. Such debates implied new notions of non-sequential cross or multi-domain patterns of operations; foreshadowed tighter integration in both planning and execution of intelligence and operations and posed particular emphasis on deception, stealth and ambiguity;[22] and last but not least, they envisioned dramatically increased modularity and flexibility in military systems as well as across the functions these systems perform on the battlefield.[23] Moreover, the new paradigm was affected by two trends characterising air force structuring in Western countries: the steady decrease in the number of manned platforms developed and procured, and the increasing salience of robotic systems.[24]

[19] Peter Layton, "Fifth-Generation Air Warfare", in *Australian Defence Force Journal*, No. 204 (2018), p. 25, https://defence.gov.au/ADC/ADFJ/Documents/issue_204/ADFJournal204_web.pdf.

[20] Robbin F. Laird, "Embrace the Air-Power Revolution", in *Defense News*, 21 February 2011, https://sldinfo.com/2011/02/embrace-the-air-power-revolution; Robbin F. Laird, "A 21st-Century Concept of Air and Military Operations", in *Defense Horizons*, No. 66 (March 2009), p. 3, https://ndupress.ndu.edu/Media/News/Article/1006309.

[21] Jeremiah Gertler, "F-35 Joint Strike Fighter (JSF) Program", in *CRS Reports for Congress*, No. RL30563 (23 April 2018), https://fas.org/sgp/crs/weapons/RL30563.pdf; US Secretary of Defense, *Selected Acquisition Report (SAR): F-35 Lightning II Joint Strike Fighter (JSF) Program (F-35)*, December 2018, https://www.esd.whs.mil/Portals/54/Documents/FOID/Reading%20Room/Selected_Acquisition_Reports/19-F-1098_DOC_33_F-35_SAR_Dec_2018.pdf.

[22] David A. Deptula, *The Combat Cloud: A Vision of 21st Century Warfare*, keynote address at Association of Old Crows, Washington, 1 December 2015, http://media.wix.com/ugd/a2dd91_1550c5f873934b068afa8be3ad4ddd54.pdf; VeraLinn Jamieson and Maurizio Calabrese, "An ISR Perspective on Fusion Warfare", in *The Mitchell Forum*, No. 1 (October 2015), p. 2, http://www.mitchellaerospacepower.org/single-post/2015/10/22/An-ISR-Perspective-on-Fusion-Warfare.

[23] George M. Gross, "The New Generation of Operational Concepts", in *Small Wars Journal*, 8 January 2016, https://smallwarsjournal.com/node/36753.

[24] Martin van Creveld, "Approaching the End?", in John Andreas Olsen (ed.), *European Air Power*.

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Fundamentally, such a broader paradigm sees the F-35 as a potential enabler of automated data gathering, fusion and exchange processes at the base of disaggregated air and joint operations.[25] Regarding air operations, in contrast with a traditional Combined Air Operations Centres (CAOCs)/AWACS-based hub-and-spoke system, with the AWACS acting as the central hub pushing out targeting and warning data, in an F-35-based system the JSFs would become dispersed stealth extensions of the CAOC, disseminating information and generating horizontal communications to air assets, making the system function as a truly decentralised network.[26]

With regard to joint operations, the integration of the F-35 into air force structures is seen as heralding a shift from what might be called an "air support template" to a different air-enabled one, centred on the non-kinetic use of this 5th generation aircraft.[27] Thanks to its sensor and communications packages and its fusion capabilities, the JSF can evolve from a "sub-element operator" role to a partial command and control (C2) node in a distributed battle management system, supporting decision-making of air, ground and maritime command elements, and reshaping in this way the entire C2 architecture. Indeed, not only C2, but command, con¬trol, communications, computers (C4) and intelligence surveillance and reconnaissance (ISR) could, through the integration of the F-35, be reshaped into C4 and ISRD, with decision-making (D) actually shared across the battlespace.[28] This without any prejudice to the possibility of having the Lightning II available over target areas to "shoot last", striking residual targets on the battlespace.

The debate on F-35 ConOps thus evolved through two schools of thought. The initial "minimalist" thinking stayed very close to the original concept driving the JSF programme, seeing the F-35 as an extremely advanced tactical fighter, a "tip of the spear" able to generate a quantum leap in the conduct of air operations

Challenges and Opportunities, Lincoln, Potomac Books, 2014, p. 201-215; Michael W. Wynne, "'Re-norming' the Asymmetric Advantage in Air Dominance: Going to War with the Air Force You Have", in *Second Line of Defense Special Reports*, October 2010, https://sldinfo.com/wp-content/uploads/2010/11/Wynne-Special-Report.pdf.

[25] David A. Deptula, "Evolving Technologies and Warfare in the 21st Century: Introducing the 'Combat Cloud'", in *Mitchell Policy Papers*, Vol. 4 (September 2016), p. 7, http://www.mitchellaerospacepower.org/single-post/2018/08/20/Evolving-Technologies-and-Warfare-in-the-21st-Century-Introducing-the-"Combat-Cloud".

[26] Robbin F. Laird and Edward T. Timperlake, "The F-35 and the Future of Power Projection", in *Joint Force Quarterly*, No. 66 (July 2012), p. 85-93, https://ndupress.ndu.edu/Portals/68/Documents/jfq/jfq-66/jfq-66_85-93_Laird-Timperlake.pdf; Gilmary Michael Hostage and Larry R. Broadwell, "Resilient Command and Control: The Need for Distributed Control", in *Joint Force Quarterly*, No. 74 (July 2014), p. 38-43, https://ndupress.ndu.edu/JFQ/Joint-Force-Quarterly-74/Article/577526.

[27] Jeff Harrigian and Max Marosko, "Fifth Generation Air Combat: Maintaining the Joint Force Advantage", in *The Mitchell Forum*, No. 6 (July 2016), p. 6, http://www.mitchellaerospacepower.org/single-post/2016/06/07/Fifth-Generation-Air-Combat-Maintaining-the-Joint-Force-Advantage.

[28] Robbin F. Laird et al., "Enabling Three Dimensional Warriors", in *Three Dimensional Warriors. The Roles of the Osprey and the F-35B*, Arlington, SLD, 2009, p. 36-49; Robbin F. Laird, "A Key Foundational Element for 'Re-Norming': The F-35 Combat System Enterprise", in Second Line of Defense, *"Re-Norming" Air Operations*, Arlington, SLD, 2012, p. 60-62, https://www.sldinfo.com/wp-content/uploads/2011/02/Re-Norming-Air-Operations.pdf.

primarily by operating in small self-contained formations. Later, a "maximalist" school of thought emerged, which envisioned the F-35 as a dispersed C2 and situational awareness node enabling network-centric, distributed and cross-function air and joint operations. This latter school of thought has been gaining widespread support among the armed forces of the programme's partners and will most likely drive the present and future decisions about the aircraft's integration.

3. Integrating the F-35: technology and weapon systems requirements

Adoption of military technological innovations generates infrastructural requirements in terms of: logistics, communication and weapon systems.[29]

In term of logistics, integrating the F-35 would be highly demanding. On the one hand, as mentioned above, the conceptual origins of the Lightning II date back decades, before extensive integrated air defence systems put a premium on the need to expand aircraft's reach in contested environments, as well as before a decade of counterterrorism and counterinsurgency pointed to the importance of "persistence" in finding, fixing, tracking, targeting and engaging targets in permissive air space.[30] The limitations of the F-35 fuel payload in comparison to similarly sized strike aircraft, particularly in stealth configuration, therefore generate significant requirements in terms of both range and persistence. These, in turn, are further compounded by requirements brought about by employment of the aircraft as a C2 node as envisioned by emerging ConOps.[31]

As a consequence, integration of the Lightning II will entail the provision of multiple (and possibly mobile) forward arming and refuelling points to provide strategic depth and operational persistence.[32] For NATO countries participating in the programme,[33] this does not represent a problem in terms of naval and ground facilities; yet, it will put heavy stress on the tanker force. According to a Joint Air Power Competence Centre study, the Alliance is already characterised by an imbalance between the number of receiving aircraft versus tankers, caused by the constantly decreasing number of tankers provided by member states. Although

[29] Andrea Gilli and Mauro Gilli, "The Diffusion of Drone Warfare? Industrial, Organizational, and Infrastructural Constraints", in *Security Studies*, Vol. 25, No. 1 (2016), p. 50-84.

[30] Gregory D. Knepper, "Access Assured: Addressing Air Power Reach, Persistence and Fueling Limitations for Contested and Permissive Air Operations", in *Brookings Reports*, September 2014, p. 1, http://brook.gs/2bk4COv.

[31] Mark Gunzinger et al., *Air Force for an Era of Great Power Competition*, Washington, Center for Strategic and Budgetary Assessments (CSBA), 2019, https://csbaonline.org/research/publications/an-air-force-for-an-era-of-great-power-competition/publication/1.

[32] Robert C. Owen, "Distributed STOVL Operations and Air-Mobility Support: Addressing the Mismatch between Requirements and Capabilities", in *Naval War College Review*, Vol. 69, No. 4 (Autumn 2016), p. 31-48, https://digital-commons.usnwc.edu/nwc-review/vol69/iss4/6.

[33] These are, beside the US and Italy: Canada, Denmark, the Netherlands, Norway, Turkey and the UK.

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the introduction of 5th generation aircraft will prompt a decrease in the overall number of fighters capable of air-to-air refuelling, their employment for longer range/endurance missions will generate more fuel requirements, and therefore more need for air-to-air refuelling support. This will further increase in light of the expected higher sortie rate per aircraft of all three variants of the F-35.[34]

Taking advantage of the F-35 Lightning II's unparalleled "sensing" capabilities, and assigning it as a C2 node as the aircraft enters service in the 2020s, entails the ability to share its fused sensor multi-domain situational awareness with legacy aircrafts (as well as with land-based and maritime assets). For NATO countries, this in turn will require considerable improvements in data exchange processes through the various datalink architectures, primarily that of the Eurofighter Typhoon and the MQ-9 Reaper, the most diffused unmanned aerial vehicles among the European partners of the F-35 programme.[35]

F-35s have been designed to cooperate primarily with one another (up to four) through the stealthy, highly automated and integrated Multifunction Advanced Data Link (MADL) tactical communications network. The Lightning II is also equipped with the current NATO standard for 4th generation fighter aircrafts, including the Typhoon, the Joint Tactical Information Distribution System/Tactical Information Data Link, commonly referred to as Link 16.[36] There are, however, two problems with employing Link 16 for communications between the F-35 and the Typhoon: Link 16 is limited in terms of both bandwidth and detectability.[37] Excluding the unlikely eventuality of the US exporting MADL technology for use on foreign-built platforms, this connectivity requirement can be satisfied in two ways. The first, rather expensive, way is to equip the Typhoon with a gateway enabling interoperability of aerial platforms operating on incompatible data link networks. This would be the Battlefield Airborne Communications Node, a high-altitude airborne gateway operational since 2008 that translates among tactical data link networks, enables joint range extension, beyond-line-of sight connectivity and IP-based data exchange.[38] The second is tactical rather than technical. F-35s operating in stealth mode would pass information over MADL's directional "daisy chain" and

[34] Joint Air Power Competence Centre (JAPCC), *Air-to-Air Refuelling Flight Plan: An Assessment*, Kalkar, JAPCC, February 2011, p. 12-13, https://www.japcc.org/portfolio/air-to-air-refuelling-flight-plan.

[35] JAPCC, *Air Warfare Communications in a Networked Environment: An Interdisciplinary Analysis*, Kalkar, JAPCC, July 2017, p. 8, https://www.japcc.org/portfolio/air-warfare-communication-in-a-networked-environment.

[36] Daniel Akers (ed.), *Understanding Voice and Data Link Networking. Northrop Grumman's Guide to Secure Tactical Data Links*, San Diego, Northrop Grumman Corporation, December 2014, p. 2-3, https://www.northropgrumman.com/Capabilities/DataLinkProcessingAndManagement/Documents/Understanding_Voice+Data_Link_Networking.pdf.

[37] Nick Zazulia, "F-35: Is the Trillion-Dollar Fighter Finally Worth It?", in *Avionics International*, August-September 2018, http://interactive.aviationtoday.com/avionicsmagazine/august-september-2018/f-35-is-the-trillion-dollar-fighter-finally-worth-it.

[38] Justin Bronk, "Maximum Value from the F-35. Harnessing Transformational Fifth-Generation Capabilities for the UK Military", in *Whitehall Reports*, No. 1-16 (February 2016), p. 5, https://rusi.org/node/15481.

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the JSF farthest from the leading edge of combat would rebroadcast the data in Link 16 waveform to legacy platforms.

It has been emphasised how the F-35's limits in terms of lethality in conjunction with the "shoot last" approach envisioned by emerging ConOps require the ability to employ 4th generation aircraft or unmanned aerial vehicles as functional firepower "throw weight".[39] In the case of NATO countries this equates with relying on the Eurofighter for the core of their combat power until at least 2030.

The Typhoon combines range and heavy weapons payload, with a maximum strike load of four bombs, six missiles and three external fuel tanks, and also has a high sortie-generation rate; it currently suffers however from a significant gap that might impact adversely on the F-35 integration. As Bronk has stressed, it remains crucial to equip the aircraft with the CAPTOR-E AESA or "E-Scan" radar. The current CAPTOR-M in fact performs rather poorly in long-range non-cooperative threat recognition and is unable to positively identify aircraft detected at long range (approximately 65 km). This means that without information on targets fed across Link 16, the Eurofighter cannot use BVR missiles such as the AMRAAM and Meteor that use radar to track targets.[40] In November 2014 Typhoon's partners agreed on the integration on the platform of the CAPTOR-E as a priority. At the time of writing, however, despite its availability none of the four Eurofighter partner nations (Germany, Italy, Spain and the United Kingdom) has yet decided to order it.[41] This is particularly problematic in light of the considerable standoff range that on-stealth strike aircraft such as the Typhoon should maintain in relation to Integrated Air Defence Systems areas for prospective NATO operations against Russia.[42]

As for unmanned aerial vehicles, while technologically feasible and relatively affordable in permissive operating environment, their use in contested and highly contested environments generates overly demanding requirements. In fact, the considerable weapons and defensive systems payload requirements associated with their employment would dramatically increase their size and unit cost.[43]

This brief examination thus makes clear not only that the requirements for adopting the F-35 have changed considerably in light of the new emerging operational paradigm, but also that, as a consequence, they have become much more compelling.

[39] John D.W. Corley, "A Conversation with General Corley About the Future of Air Power", in *Second Line of Defense Special Reports*, September 2010, https://www.sldinfo.com/wp-content/uploads/2010/09/Conversation-with-General-Corley-Special-Report.pdf.

[40] Justin Bronk, "Maximising European Combat Air Power. Unlocking the Eurofighter's Full Potential", in *Whitehall Reports*, No. 1-15 (April 2015), p. 7, 9, https://rusi.org/node/14907.

[41] Giovanni de Briganti, "Eurofighter Looks to Future Improvements But AESA Radar Lags", in *Defense & Aerospace*, 20 June 2019, https://www.defense-aerospace.com/articles-view/feature/5/203668/aesa-radar-still-lacking-as-eurofighter-looks-to-future-improvements.html.

[42] Mark Gunzinger et al., *Air Force for an Era of Great Power Competition*, cit., p. 42, 63.

[43] Ibid., p. 85-86.

Conclusion: The integration of the F-35 into Italy's Armed Forces

The examination of the F-35 technologies, the emerging debates on ConOps, and the prospective requirements of integrating the aircraft into 4th generation air force structures, suggests that modern military innovation involves a much less linear and sequential process than often portrayed – a process in which material and ideational factors continuously affect each other through complex feedback relationships. Reflecting the increasing complexity of weapon systems and the growing importance of software,[44] modern military innovation is therefore best understood in a systems perspective: ideas shape material goals and choices, setting the technological trajectory of weapon systems; and material conditions and technological requirements in turn shape ideas, tactics and procedures. Relating this conclusion to the broader findings of the recent literature on military innovation suggests that such a dynamic will increasingly represent the norm, something which has, in turn, significant implications for the present and future of defence acquisition processes, prompting the need for more "agility".[45]

Despite the budgetary constraints and the short time frame characterising Italy's defence planning process,[46] the armed forces have, in general, successfully handled the challenges of integrating the F-35. Italy was the second programme partner, after the US, to declare Initial Operational Capability for the aircraft; it started early on to think through the operational implications of its introduction, and successfully addressed many of the requirements deriving from integration of Lightning II into the force structure. More specifically, Italy has made progress with the Typhoon software, sensor fusion and weapons-integration programmes, through the 2018 P1Eb upgrade, as well as by starting to integrate Paveway IV bombs and Storm Shadow missiles.[47] And yet, according to the available sources the defence acquisition processes related to the integration of the F-35 have been rather piecemeal, sometimes slow, and apparently have also had a rather narrow technical focus. This seems, at least to a certain extent, ascribable to the organisation and functioning of the defence acquisition process, which in Italy is particularly complex, with multiple overlapping lines of procurement (bilateral, multilateral and EU).[48]

[44] J. Michael McQuade and Richard M. Murray (eds), *Software Is Never Done. Refactoring the Acquisition Code for Competitive Advantage*, Washington, Defense Innovation Board, 3 May 2019, https://innovation.defense.gov/software.

[45] Andrew D. James, "Emerging Technologies and Military Capability", in Richard A. Bitzinger (ed.), *Emerging Critical Technologies and Security in the Asia-Pacific*, Basingstoke/New York, Palgrave Macmillan, 2016, p. 11.

[46] Vincenzo Camporini, "Come pianifica la Difesa", in *Informazioni della Difesa*, No. 6 (2008), p. 8-12, http://www.difesa.it/InformazioniDellaDifesa/periodico/IlPeriodico_AnniPrecedenti/Documents/Come_pianifica_la_Difesa.pdf.

[47] Justin Bronk, "Maximising European Combat Air Power", cit., 7, 13, 19, 20.

[48] Guido Tatone, *La recente evoluzione del settore del Defence Procurement: i vantaggi della costituzione di un Mercato unico europeo nel settore degli armamenti*, Rome, Centro Militare di Studi Strategici (CeMiSS), 2018, p. 117-119, http://www.difesa.it/SMD_/CASD/IM/CeMiSS/Pubblicazioni/ricerche/Pagine/Ricerca_Tatone.aspx.

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The Secretariat General of Defence/National Armaments Directorate (SGD/NAD) is the organisation tasked with guiding and managing the process of procuring weapons systems and developing and/or acquiring related equipment and technologies. It is characterised by a considerable degree of organisational specialisation, with the 3rd Department in charge of relations with private firms operating the defence sector, the 4th Department supervising and monitoring multinational programmes, while coordinating them with national ones to avoid overlap, and the 5th Department developing the defence knowledge base to ensure the feasibility of current and future programmes.[49] The activities of the three departments are coordinated at the top by the Deputy Director for National Armaments, but there are no stable interdepartmental entities at lower levels bringing together the various segments of the acquisition process. Also lacking is a structured coordination mechanism between the SGD/NAD and Centre for Defence Innovation, the main organisation within the general staff tasked with conceptual innovations in the armed forces.[50] The special directorates created to supervise highly complex procurement programmes, such as the Forza NEC and the JSF, seem for their part to be almost exclusively concerned with technical issues. Last but not least, the standard defence procurement model is an incremental "single step to full capability" one wherein a single, very long effort is undertaken to achieve an early-defined set of capabilities on the basis of systems and technologies identified at the beginning of the programme.[51]

This acquisition model provides for stability and a certain degree of technical flexibility, and yet the dynamics of the modern military innovation process identified in this paper warrant a different, more agile approach. What is required is to design structures and processes able to ensure stability and flexibility from both the technical and conceptual standpoint. These in turn would enable the defence establishment to rapidly deliver a basic "threshold" capability, which is operationally useful, and subsequently build on this to provide more capability, getting closer to the full objective originally envisioned, while simultaneously keeping track of possible alternative evolutionary trajectories in the operational employment of a weapon systems, and the relative technological requirements.

This can be achieved through two types of change in the Italian defence procurement model. First and foremost, a structural change is needed. In light of the continuous feedback between hardware and software characterising the innovation process, the creation of a permanent structured joint mechanism between the SGD/NAD and Centre for Defence Innovation, entrusted with analysing the evolution of

[49] See the Italian Ministry of Defence website: *The Defence General Staff*, https://www.difesa.it/EN/SMD/Pagine/The_Defence_General_Staff.aspx.

[50] See the Italian Ministry of Defence website: *Centro Innovazione della Difesa*, https://www.difesa.it/SMD_/Staff/Reparti/III/CID/Pagine/Centro_Innovazione_Difesa.aspx.

[51] See Chapter 5 in Italian Ministry of Defence, *Rapporto annuale SGD/DNA 2007 / SGD/NAD Annual Report 2007*, Rome, Ministry of Defence, January 2008, p. 50-65, http://web.archive.org/web/20170621224706/https://www.difesa.it/Content/Pubblicistica/Documents/8377_art5.pdf.

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defence programmes in terms of hardware in conjunction with debates about ConOps, tactics and procedures, is advisable.

A second change that might improve the acquisition process would concern the more extensive employment of evolutionary acquisition models such as the "spiral" approach originally introduced at the beginning of the Forza NEC programme some years ago.[52] Resembling a collection of parallel overlapping but closely interconnected subprogrammes, each in a different phase of the acquisition process, the spiral model assumes that the major technological and conceptual features of a programme emerge and are defined through experimentation. Such an approach aims at proof-testing technologies, reducing technological risks, incorporating iterative feedback from users and, most importantly, reducing the time between the identification of new operational needs and the fielding of operationally useful equipment to begin to meet those needs. When appropriately implemented, the spiral model better fits the dynamics of contemporary military innovation.[53]

In the current operational environment, agility in procurement will be the prerequisite for timely innovation.

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[53] Mark A. Lorell, Julia F. Lowell and Obaid Younossi, *Evolutionary Acquisition Implementation Challenges for Defense Space Programs*, Santa Monica, RAND, 2006, https://www.rand.org/pubs/monographs/MG431.html.

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