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Leveraging capability: A study of the interoperability of fourth- and fifth-generation NATO fighter aircraft

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In many respects, the Lockheed Martin F-35 Lightning II is the future of NATO airpower. The United States Military plans to procure 2,456 aircraft.[1] Seven additional NATO allies plan to purchase a combined total of 478, and it is likely that other members will add to this tally.[2] As only the second fifth-generation type to enter service, the F-35 provides a step change in capability over existing fourth-generation "legacy' aircraft.

[1] For reference, the US Military currently operates approximately 3,100 fighter and attack aircraft and the European NATO allies operate approximately 2,030.
"World Air Forces 2018," in *FlightGlobal* (Reed Business Information Limited, December 2017). https://www.flightglobal.com/asset/21905/waf/; Justin Bronk, *Maximizing European Combat Air Power: Unlocking the Eurofighter's Full Potential*, Royal United Services Institute for Defence and Security Studies (London, UK, 2015), https://rusi.org/sites/default/files/whr_1-15_maximising_european_combat_air_power_0.pdf.
[2] These nations are – the United Kingdom, Italy, Turkey, Norway, the Netherlands, Belgium and Denmark. See Lara Seligman, "The Countries Where F-35 Sales Are Taking Off," *Foreign Policy* (2018), https://foreignpolicy.com/2018/06/22/the-countries-where-f-35-sales-are-taking-off/.; Philip Blenkinsop, "Belgium chooses Lockheed's F-35 over Eurofighter: Belga," *Reuters* (22 October 2018), https://www.reuters.com/article/us-aerospace-belgium-idUSKCN1MW1J7.

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The F-35, however, has been a long time coming, and is *still* coming slowly. Though the type entered service with the US Air Force in July 2016, rigorous development and training programs, ongoing production capacity issues and lengthy delivery timelines will result in the new fighter being fielded in relatively small numbers in the coming decade. This is especially true for European customers, which have ordered fewer aircraft. For example, the UK plans to purchase 138 F-35s and is the program's largest export customer. However, it is expected that only a maximum of 37 will be in service with the Royal Navy (RN) and Royal Air Force (RAF) at any given time before 2030. Fewer still will be deployable.[3] F-35s will operate alongside older types for the foreseeable future. Across the alliance, technology and tactics must be refined to leverage the capability of what F-35s are available.

Fighter aircraft interoperability must be scrutinized. In this research paper, I will address the question: with the advent of the F-35 in NATO service, to what extent can alliance fighter aircraft be made interoperable? I suggest that technical and tactical interoperability of fourth- and fifth-generation NATO fighter aircraft can be achieved, and is the most efficient way to leverage the F-35's fifth-generation capability.

I start by providing a definition and brief discussion of interoperability, before considering the state of tactical information sharing between fourth-generation aircraft. I then evaluate the F-35's networked capacity, and discuss how technology and tactics can be refined to enable intergenerational interoperability. I set out three obstacles to great integration of air fleets, and present solutions.

Interoperability: broad definitions and a lukewarm embrace

The US Department of Defense Joint Staff defines interoperability as "[the] ability of systems, units, or forces to provide and accept services from other systems, units, or forces, and to use the services so exchanged to enable them to operate effectively together."[4] Terry Moon, Suzanne Fewell and Hayley Reynolds categorize issues of interoperability into two groups: technical interoperability between systems and

[3] Bronk, *Maximizing European Combat Air Power: Unlocking the Eurofighter's Full Potential*, p. 2.

[4] "Department of Defense (DOD) Dictionary of Military Related Terms (Joint Staff, Department of Defense, Washington, 1999), p. 229.

transactional interoperability between organizations.[5] Due to this paper's overriding focus on fighter aircraft, the scope has been narrowed to discussion of technical interoperability – which includes the technological compatibility of systems, and tactical interoperability. At both levels, interoperability entails an active, mutually beneficial transfer. Fighter aircraft frequently transfer data to other fighter aircraft over compatible data links. They also possess the capability to conduct complimentary actions. For example, one aircraft uses its radar to jam the radar of an enemy interceptor – transferring a service, so that another aircraft may attack a target more freely – receiving the first service and then providing a second service. Interoperability is instrumental; interoperable platforms can cooperate to achieve an objective.

Contemporary Western force planning is keen to embrace interoperability. NATO has long sought to achieve broad (multi-level) interoperability among members to enhance operational effectiveness and efficiency.[6] In 2013, the Interoperability Standards and Profiles directive was put in place to categorize consultation and command and control standards employed within the alliance.[7] The Royal Australian Air Force has adopted Plan Jericho, an organizational strategy to achieve what it calls the world's first "fifth-generation air force." This is described as a "fully-networked force that exploits the combat-multiplier effects of a readily available, integrated and shared battlespace picture to deliver lethal and non-lethal air power." It will prevail "against the increasingly complex and lethal threats of warfare in the Information Age."[8] Here, information networks are prioritized over individual platforms and capabilities. The 2018 US National Defense Strategy reads that "interoperability is a priority for operational concepts, modular force elements, communications, information sharing, and equipment."[9] Though these efforts signal that the topic of interoperability is now a focus of high-level strategic planning, each lacks more specific discussion of how it is achieved.

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[5] Terry Moon, Suzanne Fewell, and Hayley Reynolds, "The What, Why, When and How of Interoperability," *Defense & Security Analysis* 24, 1 (2008): p. 5.

[6] Ibid., p. 7.

[7] *NATO Interoperability Standards and Profiles (NISP)*, North Atlantic Treaty Organization (Brussels, Belgium, 2013), https://standards.globalspec.com/std/1639362/stanag-5524.

[8] Royal Australian Air Force, Force of the Future: Toward's the World's First 5th Generation Air Force, (Canberra, Australia: 2015).

[9] United States, Department of Defense, *National Defense Strategy* (2018), p. 9.

Despite broad consensus within policy establishments that interoperability is an important goal, there is a paucity of academic literature on it. The topic was a focus of study following Operation Desert Storm, but relatively less has been done recently.[10] Writing in 2008, Moon, Fewell and Reynolds reference two works from the turn of the century as “the literature.”[11] Their piece, along with a RAND Corporation report written in 2000, illustrates the challenges of studying the subject. Military interoperability is complex and conceptually nebulous. We can see this in the highly inclusive American definition and the broad groupings quoted above. Issues of interoperability can concern one country or several. There is no single model that can be applied to assess the full spectrum of the topic. Moreover, because technological details of military platforms are often classified, it is unclear how precise civilian study of interoperability through the three models favoured by Moon, Fewell and Reynolds can be.[12] Still, the entry into service of the fifth-generation F-35 is a unique opportunity to consider how NATO fighter aircraft can cooperate.

Technical interoperability today

Tactical information sharing is central to technical interoperability. The current NATO standard for fourth-generation fighter aircraft is the Joint Tactical Information Distribution System/Tactical Information Data Link, commonly referred to as Link 16. Development of Link 16 as a secure communications system for flights of aircraft operating within the line of sight began in the late 1970s, and the data link was first fielded by the US Military in the late 1980s.[13] Broader NATO Link 16 compatibility is a product of the Multifunction Information Distribution program, funded by the US,

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[10] See Hura, Myron, Gary W. McLeod, Eric V. Larson, James Schneider, Dan Gonzales, Daniel M. Norton, Jody Jacobs, Kevin M. O'Connell, William Little, Richard Mesic, and Lewis Jamison, *Interoperability: A Continuing Challenge in Coalition Air Operations* (Santa Monica, Calif.: RAND Corporation, MR-1235-AF, 2000). As of 20 November 2018: https://www.rand.org/pubs/monograph_reports/MR1235.html, pp. 19-21.

[11] Moon, Fewell, and Reynolds, "The What, Why, When and How of Interoperability," p. 5.

[12] Ibid., 16.

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

France, Germany, Italy and Spain. The program's objective was to create a secure communications network encompassing all critical NATO airborne assets involved in aerial combat. It resulted in the signature of NATO Standardization Agreement 5516: General Systems Characteristics – Link 16 in January 2003. This document provided specifications for data exchange between compatible NATO systems via Link 16.[14] Today, the Boeing F-15 Eagle, Lockheed Martin F-16 Falcon, Boeing F/A-18 Hornet, Dassault Rafale, Eurofighter Typhoon, Saab Gripen and Panavia Tornado are all Link 16 compatible. In addition, air- and space-based relay platforms enable Link 16 to connect these assets to a variety of airborne controllers and surveillance platforms, and to ground-based Command and Control (C2), Information Systems Research, and Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR) assets.[15] A Northrop Grumman publication estimates that as of 2015, approximately 5000 individual platforms are Link 16-equipped.[16]

Moon, Fewell and Reynolds identify nine layers of coalition interoperability. Link 16 enabled information sharing satisfies the first three. These are physical interoperability, protocol interoperability and data/object model interoperability.[17] To illustrate this point, let us consider the technical interoperability of a Link 16 equipped 'evolved' fourth-generation fighter, the Eurofighter Typhoon. Through Link 16, the Typhoon receives tactical information in real time from C2 and ISTAR assets, as well as other combat aircraft. Encrypted data is transmitted between Link 16 radio terminals on one of 51 different frequencies. The transmission frequency changes every 13 microseconds based on a predetermined pseudo-random pattern contained within 128 stacked "nets."[18] The form of data exchanged is standardized, and can be read by all compatible platforms within range. Data transmitted concerns friendly and hostile aircraft locations, general situational awareness, air and ground targets, and air defence

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[14] *General Systems Characteristics - Link 16*, North Atlantic Treaty Organization (Brussels, Belgium, 2003), https://standards.globalspec.com/std/489498/nato-stanag-5516.
[15] Hura, McLeod, Larson, Schneider, Gonzales, Norton, Jacobs, O'Connell, Little, Mesic, and Jamison, *Interoperability: A Continuing Challenge in Coalition Air Operations*, p. 108.
[16] Akers, *Understanding Voice and Data Link Networking: Northrop Grumman's Guide to Secure Tactical Data Links*, pp. 2-2.
[17] Moon, Fewell, and Reynolds, "The What, Why, When and How of Interoperability," p. 13.
[18] Charlie Cruz, "Netwars Based Study of a Joint Stars Link 16 Network" (Master of Science Air Force Institute of Technology, 2004), https://apps.dtic.mil/dtic/tr/fulltext/u2/a423871.pdf (AFIT/GCS/ENG/04-06).

threats. This is processed by the Typhoon's Attack and Identification System (AIS) before being presented to the pilot. Though the type is equipped with advanced sensors – namely the CAPTOR-M radar, passive PIRATE Infrared Scan and Track (IRST) and Defensive Aids Sub-System (DASS), its systems architecture is federated. The pilot must frequently act as tactician and systems operator, interpreting and synthesizing data while flying the aircraft. The process to disseminate data from the aircraft's own sensors involves numerous manual inputs.[19]

The F-35: networked life within a walled garden

According to the United States Congressional Research Service, fifth-generation aircraft "incorporate the most modern technology," combining "new developments such as thrust vectoring, composite materials, stealth technology, advanced radar and sensors, and integrated avionics to greatly improve situational awareness."[20] Indeed, in the modern information-centric battlespace, the F-35 has unparalleled sensory capabilities. The jet's core systems include an AN/APG-81 active electronically scanned array (AESA) radar, a passive AN/AAQ-37 Distributed Aperture System (DAS), the Electro-Optical Targeting System (EOTS) and an integrated Communications, Navigation and Identification (CNI) avionics suite. AESA type radars are a recent innovation on fighter aircraft and surpass older mechanically scanned sets in the categories of multiple simultaneous target tracking, high resolution air and ground mapping, low probability of detection and electronic attack.[21] The DAS is the only 360 degree, spherical awareness system in service today. It sends infrared imagery to the pilot's helmet-visor and permits them to see the space around the aircraft at day and night, in real time. The DAS fuses data from other sensors to identify, categorize, rank and recommend responses to potential threats. This information is transmitted to the pilot's helmet-visor. EOTS is the first forward looking infrared system with infrared search and track capability. This enhances situational awareness and allows the pilot to target air and ground threats with greater stealth and precision. The F-35's CNI suite

[19] Bronk, *Maximizing European Combat Air Power: Unlocking the Eurofighter's Full Potential*, p. 21.
[20] Jeremiah Gertler, F-35 Joint Strike Fighter (JSF) Program, Congressional Research Service, 23 April 2018, 1.
[21] Ibid., p. 6.

uses Software-Defined Radio (SDR) technology to carry out many of its 27 distinct functions simultaneously.[22] SDRs combine reconfigurable radio frequency hardware with computer processors to run software that produces a desired waveform.[23] A corporate publication from 2012 indicates that the CNI suite in the F-35 operates over 10 radio channels and more than 40 separate waveforms. Data is harvested from at least 30 conformal antennas built into the aircraft.[24] The systems described here generate significantly more data than those mounted to existing NATO fighter platforms. Computers on board the F-35 analyze this data closely. The aircraft's systems can assess and make value judgments, fusing together pieces of data into useful tactical information. The result of fused systems architecture is a tactical picture of unparalleled detail.[25]

F-35s have been designed to cooperate with one another rather than with existing NATO fighter aircraft. Though the platform is equipped with Link 16 and can regulate the sensory data that it transmits over this system, certain highly sensitive data cannot be transmitted.[26] Moreover, use of Link 16 when operating within denied or contested airspace adversely affects the aircraft's Very Low Observable (VLO) characteristics. Link 16 transmissions are readily detectible, and as a fifth-generation fighter, the F-35 is designed for maximum stealth. Instead, the aircraft employs the new Multifunction Advanced Data Link (MADL) as its primary tactical communications network. Compared to Link 16, MADL is stealthier, transmits data at a higher rate, and has far superior automation and integration with aircraft systems. Greg Lemons, a missions systems expert at Lockheed Martin, argues that we can "best think of [MADL] as a way

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[22] Justin Bronk, *Maximum Value for the F-35: Harnessing Transformational Fifth-Generation Capabilities for the UK Military*, Royal United Services Institute for Defence and Security Studies (London, UK: 2016), https://rusi.org/sites/default/files/20160201_whp_maximum_value_from_the_f-35_web.pdf, 4.
[23] *Communications, Navigation and Identification (CNI) Avionics for the F-35 Lightning II: New Dimensions for the warfighter in digital battlespace*, Northrop Grumman Information Systems (San Diego, CA: Northrop Grumman Corporation, 2012), http://www.northropgrumman.com/Capabilities/SDRs/Documents/F35-CNI_datasht.pdf.
[24] Ibid.
[25] "Mission Systems and Sensor Fusion | F-35 Lightning II," Lockheed Martin Corporation, 2018, accessed 22 November 2018, https://www.f35.com/about/capabilities/missionsystems.
[26] Gareth Jennings, "RAF demos F-35B and Typhoon interoperability," *Jane's Defence Weekly* (2017), https://janes-ihs-com.proxy.library.carleton.ca/DefenceWeekly/DisplayFile/jdw64684?edition=2017.

to extend one avionics system into multiple aircraft."[27] This implies a level of technical and tactical interoperability not seen before. Indeed, the F-35 satisfies two additional layers of Moon, Fewell and Reynolds' coalition interoperability scale. These are information interoperability and knowledge/awareness.[28] MADL currently enables a flight of up to four F-35s to seamlessly and securely exchange highly classified sensory data and preprocessed tactical information in real time. F-35 pilots need not be tacticians and systems operators. Instead, they fly the aircraft while it automatically gathers and fuses data, before presenting it as dynamic information. With their sensors in constant communication, a flight of F-35s shares one Common Operational Picture. We can start to consider such formations not as made up of individual platforms, but as a singular systems network, with each aircraft fulfilling and trading functions and ultimately contributing to the effectiveness of the whole. In a 2008 interview with *Defense Daily*, USAF Major General Charles Davis, then head of the F-35 Program Office, highlighted this point. He said, "we talk a lot about international operations, coalition operations. What [the F-35] basically means is that you have a netted airborne network that spans all those…countries."[29]

The F-35's reliance on MADL and stealth more generally set it apart from existing, non-stealthy NATO warplanes. The only other type equipped with MADL today is the Northrop Grumman B-2 Spirit stealth bomber, of which the USAF only operates 20.[30] Plans to upgrade the stealthy Lockheed Martin F-22 Raptor, also exclusively in USAF service, were abandoned due to cost. Industry sources have indicated that the F-22's closed-off sensor architecture precluded it from participating in coalition operations in Libya in 2011.[31] Though the US Department of Defense has publically discussed the potential to upgrade other aircraft types to MADL, the data

[27] Nick Zazulia, "F-35: Is the Trillion-Dollar Fighter Finally Worth It?," *Avionics International*, no. (August/September 2018): http://interactive.aviationtoday.com/avionicsmagazine/august-september-2018/f-35-is-the-trillion-dollar-fighter-finally-worth-it/.

[28] Moon, Fewell, and Reynolds, "The What, Why, When and How of Interoperability," p. 13.

[29] "Interoperability Seen As Key To Future Fighter Platforms.". *Defense Daily International* 9, 34 (29 August 2008). Retrieved from http://go.galegroup.com.proxy.library.carleton.ca/ps/i.do?p=AONE&u=ocul_carleton&id=GALE%7CA184192806&v=2.1&it=r&sid=AONE&asid=b6997040#.

[30] "World Air Forces 2018."

[31] Amy Butler, "5th-To-4th Gen Fighter Comms Competition Eyed in Fiscal 2015," *Aviation Week Network* (2014), http://aviationweek.com/defense/5th-4th-gen-fighter-comms-competition-eyed-fiscal-2015.

link would ultimately provide less utility and inferior information security in platforms of lesser sensory capability.[32] While it is possible that US types be so-equipped in the future, it is unclear that the US will export the technology for use on foreign-built platforms. It is therefore unlikely that fourth-generation types in NATO services, with their federated sensor architectures and relative lack of processing power, will receive MADL and obtain similar heights of technical interoperability. However, beyond the fact that legacy fighter types will remain in service for the foreseeable future with F-35 operators, the same countries must also consider systems interoperability with NATO allies that do not currently have formal plans to purchase the F-35 – including Germany, Canada and Spain.

Breaking down barriers to intergenerational information sharing

The challenge then is to enable legacy assets to benefit from the F-35's sensor suite and fusion engine. The F-22 has recently achieved stealthy inflight data connectivity with networked air, ground- and space-based assets using the Talon HATE pod, which can be mounted to an F-15 for operations.[33] US and UK development of F-35 technical interoperability is ongoing. In February 2017, an RAF F-35B successfully communicated with an RAF Eurofighter Typhoon in a trial over the Nevada Desert dubbed 'Babel Fish III.' Information was broadcast stealthily over the F-35's MADL, and the Typhoon's Link 16 system successfully received and read it with the help of a Northrop Grumman Airborne Gateway equipped with a Freedom 550 SDR. A press release from Northrop Grumman indicates that the Freedom 550 is derived from the F-35's CNI suite.[34] The data transfer-rate achieved in the trial and the distance at which it took place was not made public; it is also unclear whether the Airborne Gateway was

[32] Zazulia, "F-35: Is the Trillion-Dollar Fighter Finally Worth It?"
[33] Srivari Aishwarya, "USAF and Boeing demonstrate Talon HATE airborne networking system's capabilities," *Air Force Technology* (2017-05-11 2017), https://www.airforce-technology.com/news/newsusaf-boeing-demonstrate-talon-hate-airborne-networking-systems-capabilities-5812573/.
[34] "Northrop Grumman and Royal Air Force Demonstrate Enhanced Airborne Communications Interoperability Between 5th and 4th Generation Fast-Jet Aircraft," news release, 2017, https://news.northropgrumman.com/news/releases/northrop-grumman-and-royal-air-force-demonstrate-enhanced-airborne-communications-interoperability-between-5th-and-4th-generation-fast-jet-aircraft.

mounted to the Typhoon or hosted on a third platform. In any case, Air Commodore Linc Taylor, Senior Responsible Officer for the UK's F-35 program, called it a "great step forward in interoperability between our fourth- and fifth-generation aircraft." Andrew Tyler, Chief Executive of Northrop Grumman Europe, called the capability to "network sensor data between fifth-generation and fourth-generation fast-jets and other battlespace assets in a stealthy manner…critically important to enabling the full capability offered by fifth-generation aircraft."[35]

The US Military currently fields a communications gateway that enables technical interoperability of aerial platforms equipped with incompatible data link networks. Northrop Grumman has served as Prime Contractor for the Battlefield Airborne Communications Node (BACN) since 2005. The network entered operational service in 2008; the Airborne Gateway and Freedom 550 are related systems. According to a manufacturer press release, BACN is a high-altitude airborne gateway that "translates and distributes voice communications, video, imagery and other battlespace information among numerous sources."[36] The system "translates among tactical data link networks, enables joint range extension, beyond-line-of sight connectivity for disadvantaged users, and IP-based data exchange among dissimilar users."[37] BACN was first test-deployed in Southwestern Asia in 2008 in one heavily modified Martin WB-57 electronic warfare aircraft. This was soon replaced by four modified USAF Bombardier E-11 executive jets. More recently, three USAF Northrop Grumman EQ-4B Global Hawk Unmanned Aerial Vehicles (UAVs) have augmented the force. The EQ-4B operates at high altitude and can remain on-station for more than 34 hours at a time.[38] Overseas BACN field support sites have been jointly constructed by Northrop Grumman and the US Military to support operations. In 2016, BACN platforms supported approximately 7,000 combat strikes in Southwestern Asia. The system has

[35] Ibid.

[36] "Northrop Grumman's BACN Completes 10,000 Combat Missions," news release, 2017, https://news.northropgrumman.com/news/releases/northrop-grummans-bacn-completes-10-000-combat-missions.

[37] "Battlefield Airborne Communications Node (BACN)," Capabilities, Northrop Grumman Corporation, 2018, accessed 21 November 2018, http://www.northropgrumman.com/Capabilities/BACN/Pages/default.aspx.

[38] John Keller, "EQ-4B UAV to provide battlefield networking and situational awareness," *Military & Aerospace Electronics*, C4ISR (2017), https://www.militaryaerospace.com/articles/print/volume-28/issue-6/news/news/eq-4b-uav-to-provide-battlefield-networking-and-situational-awareness.html.

been praised by pilots and tactical air controllers for its ability to bring a wide variety of aerial assets into operations.[39] In an August 2017 interview with *The Drive*, BACN program Executive Officer Lieutenant Colonel Timothy Helfrich said that while "BACN doesn't have the right type of radios to communicate, or the data link terminals, to communicate with the fifth-gen aircraft…there would be a lot of synergy there by having a fifth-generation to fourth-generation gateway on BACN."[40] Though a requirement had not been set for such a capability at the time, BACN testing and development is ongoing. It seems plausible that such a capability will be developed in the future.

Tactical interoperability and the best use of the F-35

So far, our discussion has focused almost exclusively on the technological compatibility and technical interoperability of fourth- and fifth-generation NATO fighter aircraft. Technical interoperability underpins the tactical interoperability of such types. It is in the tactical advantages afforded by the F-35 to combined NATO air forces that the platform's capability can be realized. In a report authored for the Royal United Services Institute in 2016, Justin Bronk envisages two Concepts of Operation (CONOPS) for the F-35. First, the type makes for a highly potent tactical strike fighter. Because of its unprecedented situational awareness, the F-35 need not rely on traditional airborne support enablers and ground-based intelligence and targeting facilities to nearly the same extent as legacy fighter aircraft. As Bronk writes, the platform simply requires less "reach-back."[41] Instead, a flight of F-35s operating within denied airspace can rely on the type's VLO capability and advanced sensors and communications systems to conduct operations. Bronk draws on interviews with senior United States Marine Corps (USMC) officers to argue that this is the CONOPS envisaged for the F-35 by the USMC.[42] The USMC plans to gradually replace its entire active fast-jet and electronic

[39] Tyler Rogoway, "We Chew The Fat About BACN With Program Boss And Airman Who Used It In Combat," *The Drive*, The War Zone (2017), http://www.thedrive.com/the-war-zone/13562/we-chew-the-fat-about-bacn-with-program-boss-and-airman-who-used-it-in-combat.
[40] Ibid.
[41] Bronk, *Maximum Value for the F-35: Harnessing Transformational Fifth-Generation Capabilities for the UK Military*, p. 4.
[42] Ibid., p. 2.

warfare fleets – a total of 270 aircraft, with the F-35. It will take delivery of 353 Short Takeoff and Vertical Landing (VTOL) F-35Bs and 67 carrier-optimized F-35Cs.[43] Given the planned force composition, as well the USMC's traditional prioritization of operational self-sufficiency, it follows logically that tactical interoperability with other air assets may be a lower priority. Though the European NATO allies could hypothetically field a sizeable combined force of F-35s in the future, this CONOPS is less compatible with smaller forces of F-35s operating in tandem with fourth-generation aircraft and does not advance intergenerational interoperability.

The United States Navy (USN) is set to implement a CONOPS that leverages the capabilities of a mixed-generation fast-jet fleet. The current USN fast-jet fleet is the youngest of the three US armed services. The USN operates 512 Boeing F/A-18E/F Super Hornet strike fighters and plans to purchase an additional 110 through to 2023.[44] This 'evolved' fourth-generation fleet is large, capable and relatively new; Boeing continues to produce and upgrade the platform. 369 F-35Cs are being purchased to replace the remaining 267 legacy-model F/A-18s in active service.[45] USN F-35Cs will operate alongside F/A-18E/Fs until at least 2040. In a commentary written in 2015, Vice Admiral Mike Shoemaker, then-commander of Naval Air Forces, described the complimentary roles that each will play in a Carrier Strike Group's "integrated warfighting package."[46] The F-35 will "penetrate threat envelopes" and gather and fuse tactical information before sharing it among networked platforms. Because the type is limited to carrying munitions and fuel internally when operating as a VLO platform, the F/A-18E/F's large and diverse payload capability must be leveraged for "lethality and flexibility."[47] Here, we can treat the F-35 as an Intelligence, Surveillance and Reconnaissance (ISR) asset

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[43] *Marine Aviation Plan 2015*, United States Marine Corps (Washington D.C.: United States Military, 2015), https://www.aviation.marines.mil/Portals/11/2015%20Marine%20Aviation%20Plan%20Final_%2010%20Oct%202014_1110%20EDT.pdf, 2.3.2.

[44] Joseph Trevithick, "Here is Boeing's Master Plan for the F/A-18E/F Super Hornet's Future," *The Drive*, The War Zone (2018), http://www.thedrive.com/the-war-zone/21045/here-is-boeings-master-plan-for-the-f-a-18e-f-super-hornets-future.

[45] James Drew, "US Navy considers reduced annual F-35C buy," *FlightGlobal* (13 August, 2015), https://www.flightglobal.com/news/articles/us-navy-considers-reduced-annual-f-35c-buy-415654/.

[46] "Admiral's View: The Case for Aircraft Carriers and Air Wings," DoD Buzz, Military.com, updated 2015-08-11, accessed 24 November 2018, https://www.military.com/dodbuzz/2015/08/11/admirals-view-the-case-for-aircraft-carriers-and-air-wings.

[47] Ibid.

first, and as a weapons-platform second. The F/A-18E/F is the force's 'bomb-truck.' F-35s operating inside contested airspace could scramble air-defence radars and stealthily relay sensitive reconnaissance and targeting information via SDR relay platform to F/A-18E/Fs operating just outside of detection range. F/A-18E/Fs could then venture closer to the target and launch stand-off weapons against it. In this scenario, the F-35 allows the F/A-18E/F to remain undetected or at least further away from the target than it would otherwise need to be, and the F/A-18E/F provides the force that the F-35 cannot. Closer in to the carrier strike group, F/A-18E/Fs can also use their superior kinematic performance to defend the local airspace. The USN warfighting package is made stronger through integrated capability and tactics.

Bronk writes that multinational "Red Flag" exercises hosted regularly by the USAF demonstrate that air combat is decided by situational awareness and persistence in terms of kinematic energy, fuel and payload.[48] A mixed-generation force package provides this combination. In simulated air combat, RAF and German Luftwaffe Eurofighter Typhoons have proven far more effective when operating alongside USAF F-22s. The F-22s maintain higher speeds and altitudes than the Typhoons, using their stealth and sensors to direct the engagement and defeat advanced threats. The increased situational awareness and battlefield management afforded to the Typhoons allows them to contribute their superior kinematic energy and weapons payloads with greater decisiveness and lower risk. RAF pilots interviewed after one such simulation maintained that the increased combat performance afforded to four Eurofighters is similar whether the flight is supported by two, four or six F-22s.[49] This CONOPS is an efficient use of fifth-generation platforms. They make for effective 'force multipliers.'

Obstacles to interoperability

Three obstacles to achieving interoperability of fourth- and fifth-generation NATO fighter aircraft warrant further consideration. First, air force organizational structures were not designed to facilitate technical or tactical interoperability. Air forces around the world are made up of air wings, air groups and air squadrons. This has been

[48] Bronk, *Maximizing European Combat Air Power: Unlocking the Eurofighter's Full Potential*, p. 14.
[49] Ibid., p. 14.

the reality since the advent of the warplane during the First World War. A squadron is almost always equipped with one aircraft type – and the unit trains to maximize the capability of that platform. Regardless of mission-effectiveness achieved, the conceptualization of the squadron as the standard organizational unit of air forces places inherent limitations on how aerial capability is envisaged and produced. Even today, as the NATO allies participate with increasing regularity in a variety of joint-training exercises, many Western air forces remain focused on capability development and operational planning for individual platforms. Bronk writes that the RAF continues to seriously undervalue information sharing and force-wide capability.[50] Antiquated thinking persists within the alliance.

The second obstacle to NATO interoperability is the ongoing capability development program for the F-35. Indeed, the type may never be fully 'mature' in the traditional sense of the term. While future upgrades to the F-35's modular systems architecture could enable the type to facilitate still-greater integration of networked assets, they will be costly for operators and may risk allied fleets 'falling out of step' with one another. The F-35 has entered service at the Block 3F level of capability, which allows for an expanded flight envelope and full use of the type's weapons-suite.[51] Development of Block 4 capability, otherwise known as Continuous Capability Development and Delivery (C2D2), is well underway. The US Government Accountability Office maintains that these upgrades will be carried out in four increments. Blocks 4.1 and 4.3 will mostly consist of software updates, with the former addressing nine existing systems deficiencies. Blocks 4.2 and 4.4 will involve more significant hardware changes.[52] The US Congressional Research Service projects that the Block 4/C2D2 program will cost $10.8 billion through FY2024. The US will pay $7.1 billion, while international partners pay the remaining $3.7 billion.[53] For reference, an F-

[50] Bronk, *Maximum Value for the F-35: Harnessing Transformational Fifth-Generation Capabilities for the UK Military*, pp. 6-7.
[51] Valerie Insinna, "F-35 program office floats new 'agile acquisition' strategy," *Defense News* (September 6, 2017 2017), https://www.defensenews.com/smr/defense-news-conference/2017/09/06/f-35-program-office-floats-new-agile-acquisition-strategy/.
[52] Pat Host, "Pentagon faces major cost increase on F-35 Block 4 modernisation | Jane's 360," *Jane's Defence Weekly* (2018), https://www.janes.com/article/78443/pentagon-faces-major-cost-increase-on-f-35-block-4-modernisation.
[53] Gertler, F-35 Joint Strike Fighter (JSF) Program, p. 9.

35A in Lot 10 of Low-Run Initial Production costs approximately $95 million.[54] Such follow-on costs are significant and arrive shortly after type acquisition. As the United States Military pursues its Third Offset Strategy, they are set to continue apace – over the next decade, Lockheed Martin plans to implement more than 60 major software and hardware upgrades on the type (including those related to Block 4/C2D2).[55] NATO F-35 operators planning to maintain full technical interoperability with US networked assets must commit to buying into successive upgrade packages. Allies will also have to consider financing corresponding upgrades for communications suites on existing fourth-generation platforms. Failure to keep pace will result in reduced levels of interoperability.

The third obstacle to interoperability of allied aircraft is the tension that is likely to arise between national sovereignty and operational effectiveness as a result of enhanced information sharing. F-35s from multiple operators can share classified tactical information seamlessly over MADL. Through SDR gateways, it is likely that they will also be able to share a significant portion of this picture with fourth-generation networked assets. However, allied operators may be hesitant to freely exchange high-value ISR information. The US in particular has a sophisticated national intelligence apparatus and has demonstrated a historical tendency to protect intelligence closely. There is a risk that sharing such data in the name of force integration will reduce information security.[56] In his interview with *Defense Daily*, Major General Davis warned that "the US will have to come to grips with what data it shares with its coalition partners." He continued, "There is a lot of data that, for a lot of good reasons and a lot of not-so-good reasons we just mark, 'this is U.S. only and I'm not going to share." He concluded, "We've built these things that can share a wide variety of data with a lot of folks…so if we don't find a way to do that as smoothly as possible...that will be a big challenge."[57]

[54] Ibid., 16; "Agreement Reached on Lowest Priced F-35s in Program History | F-35 Lightning II," news release, 2017, https://www.f35.com/news/detail/agreement-reached-on-lowest-priced-f-35s-in-program-history.
[55] Zazulia, "F-35: Is the Trillion-Dollar Fighter Finally Worth It?."
[56] Hura, McLeod, Larson, Schneider, Gonzales, Norton, Jacobs, O'Connell, Little, Mesic, and Jamison, *Interoperability: A Continuing Challenge in Coalition Air Operations*, p. 19.
[57] "Interoperability Seen As Key To Future Fighter Platforms."

In addition to this consideration, the Autonomic Logistics Information System (ALIS) has elicited concerns from F-35 operators – namely Australia, Norway and Italy. ALIS serves as the data access point to each F-35. It has 65 applications. These include download and installment of manufacturer software patches, pre-flight download and storage of packaged operational data, and systems and airframe monitoring to identify maintenance needs.[58] ALIS data, including detailed operational data, is downloaded post-flight from individual aircraft and then uploaded to Lockheed Martin servers in Fort Worth, Texas for storage and analysis. Operator concerns here centre primarily on the sensitivity of the information being given up to Lockheed Martin.

Solutions: towards enhanced interoperability

A shift in thinking on information sharing – manifest in a handful of concrete initiatives, can address many of these issues. The NATO allies should adopt a standard communications gateway to allow networked platforms and units to communicate with ease. Though developing and fielding such a capability will be costly – achievement of theatre-wide BACN coverage in Afghanistan cost the US Military around $1 billion, it has been highly effective in American use.[59] Moreover, in 2015, a Northrop Grumman spokesman claimed that the "family of potential [gateway] solutions" is broad, with physical platforms varying in size and cost.[60] To complement this capability, the allies should also agree to a basic networked capacity for new aerial platforms. This cost could be built into program budgets. The US Military has already demonstrated similar thinking by requiring that all current and future US air power platforms be compliant with the Distributed Common Ground System (DCGS), a military intelligence system.[61] The Through Life Interoperability Process (TULIP) computer model, designed to assess and manage the technological compatibility of systems equipped with tactical data links throughout their services lives, is already in use with the US Military, UK Military and

[58] "ALIS: Keeping the F-35 Mission Ready | F-35 Lightning II," Lockheed Martin Corporation, 2018, accessed 25 November 2018, https://www.f35.com/media/videos-detail/alis-keeping-the-f-35-mission-ready.
[59] Bronk, *Maximum Value for the F-35: Harnessing Transformational Fifth-Generation Capabilities for the UK Military*, p. 7.
[60] Ibid., p. 7.
[61] Ibid., pp. 6-7.

those of several NATO allies.[62] TULIP could be scaled-up for application across the alliance. Its existing widespread adoption would facilitate this process. By mitigating against the practice of applying different networked capabilities to select types, these measures would guarantee baseline technical interoperability for all NATO air platforms and facilitate consideration of enhanced tactical interoperability.

As the F-35 enters service with international operators, a new NATO standard for classified information sharing is needed. There is little current publically available information on this topic. However, an industry analyst has suggested recently that no agreement currently exists.[63] This hypothetical framework would need to balance concerns of national security and operational efficiency. Further to Major General Davis' point, it would entail F-35 operators re-assessing their criteria for sharing or withholding information. Information sharing protocols employed by the Fives Eyes (FVEY) intelligence alliance could be considered in this process. FVEY F-35 operators could even agree to share greater amounts of sensitive information, if such an arrangement is not already planned. F-35s operated by Turkey, whose relations with the West have grown increasingly strained of late, could also require special consideration under such an agreement.[64]

Two solutions to ALIS-related operator concerns have been devised. At the behest of Australia, Norway and Italy, Lockheed Martin has recently been contracted to develop sovereign data controls for the F-35, which will allow international operators to restrict transmission of certain types of information through ALIS. At the same time, the three aforementioned countries have opened data centres in the US designed to manage sensitive mission files.[65] This solution could work in tandem with the proposed NATO information sharing agreement to systematize the transformational information sharing capability promised by the F-35.

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[62] Moon, Fewell, and Reynolds, "The What, Why, When and How of Interoperability," p. 11.
[63] Operations Analyst Michael Hannay, Lockheed Martin, Phone Interview on F-35 Systems, interview by William Richardson, *Telephone*, November 2018.
[64] Lara Seligman and Robbie Gramer, "Fighter Sale to Turkey Could Pit Trump Against Congress," *Foreign Policy* (2018), https://foreignpolicy.com/2018/06/22/fighter-sale-to-turkey-could-pit-trump-against-congress-f-35-military-pentagon-russia-s-400-national-defense-authorization-act/.
[65] Leigh Giangreco, "DUBAI: Foreign F-35 partners work up interim solution for ALIS sovereignty concerns," *FlightGlobal* (12 November 2017), https://www.flightglobal.com/news/articles/dubai-foreign-f-35-partners-work-up-interim-soluti-443146/.

Conclusion

The F-35 should be viewed by the NATO allies as an opportunity to advance the fighter capability of the entire alliance. Though it can transmit tactical data between networked assets in real time, data sharing over the Link 16 network is not stealthy, is limited by transfer-rates, and cannot transmit the same variety or quality of information as MADL. When harnessed in conjunction with the F-35's sensory capacities, MADL constitutes a step change for technical and tactical interoperability of allied fighter aircraft. The F-35's modular systems architecture also has the potential to integrate forces further in the future. Adoption of a standardized gateway platform, combined with the development of CONOPS tactics that leverage the strengths of the F-35 as well as the frequent kinematic and weapons-load advantages of legacy platforms, will permit members of the alliance to develop a highly integrated, full-spectrum aerial fighter capability. Interoperability of fourth- and fifth-generation aircraft at the technical and tactical levels should be a first-order NATO focus.

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