MAXIMISING EUROPEAN COMBAT AIR POWER

Unlocking the Eurofighter's Full Potential

Justin Bronk

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Contents

Erratum

1 May 2015: On page 1, an error of fact in the first paragraph has been corrected.

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Acronyms and Abbreviations

AARGM	Advanced Anti-Radiation Guided Missile
AESA	Active electronically scanned array
AIS	Attack and identification system
ALARM	Air Launched Anti-Radiation Missile
ALCM	Air-launched cruise missile
AoA	Angle of attack
AWACS	Airborne Warning and Control System
BACN	Battlefield Airborne Communications Node
BVR	Beyond visual range
BVRAAM	Beyond-visual-range air-to-air missile
C2	Command and control
CFTs	Conformal fuel tanks
CONOPS	Concept of operations
DASS	Defensive aids sub-system
ECM	Electronic countermeasures
ESM	Electronic support measures
EW	Electronic warfare
FCAS	Future Combat Air System
FE@R	Force elements at readiness
FLIR	Forward-looking infrared
FOC	Full operating capability
HARM	High-Speed Anti-Radiation Missile
HMI	Human-machine interface
HMSS	Helmet Mounted Symbology System
IADS	Integrated air-defence system
IDS	Interdictor/strike
IOC	Initial operating capability
IR	Infrared
IRST	Infrared scan and track
LERX	Leading-edge root extensions
LO	Low-observable
MIDS	Multifunction information distribution system
NCTR	Non cooperative threat recognition
OSD	Out-of-service date
RAM	Radar-absorbent materials
RCS	Radar cross section
ROE	Rules of engagement
SAM	Surface-to-air missile
SEAD	Suppression of enemy air defences
Tac/R	Tactical reconnaissance
VLO	Very low-observable
WVR	Within visual range

Executive Summary

The limited remaining lifespan of legacy aircraft such as the Tornado and F-16A/B in European air forces, coupled with the cost and timescales associated with the F-35 programme, mean that the Eurofighter Typhoon, along with the French Rafale, will by necessity provide the backbone of Europe's combat air power for at least a decade from 2020. With sensor, weapon and network upgrades scheduled for integration, the Eurofighter could remain combat effective in most likely operational scenarios beyond 2030.

The Eurofighter's combination of high thrust-to-weight ratio, manoeuvrability at all speeds, 65,000-foot service ceiling, supercruise capability, powerful radar and large missile load ensures that it outclasses any currently operational fighter aircraft in the world with the exception of the US F-22 Raptor.

In terms of air-to-ground capability, the Eurofighter is relatively immature compared to many legacy aircraft and even to the Dassault Rafale and Saab Gripen. In RAF service, Paveway II and enhanced Paveway II bombs are available for Tranche 1 aircraft whilst the P1Eb software upgrade for Tranche 2 and 3 aircraft has enabled Paveway IV delivery. At present, only the RAF and Royal Saudi Air Force operate their Typhoons as multirole aircraft. In Spain, Germany and Italy, the Eurofighter is purely an air-to-air fighter at present. However, strike and interdiction capabilities are planned for introduction in Italian and German service over the next decade.

There is no reason why the Eurofighter cannot be made at least as effective in the strike role as the Tornado, F-16, Rafale or other comparable aircraft. The performance and load-carrying capabilities of the jet mean that it can be made substantially more capable in the strike role than legacy designs. However, this will require continued investment in the integration of weapons such as the Brimstone II and Storm Shadow missiles, which are on contract for integration with the RAF's Typhoon fleet in the P3E upgrade by 2018.

Given the Eurofighter's current performance, and the weapons and sensor upgrades already on contract – such as CAPTOR-E and the Meteor beyond-visual-range air-to-air missile (BVRAAM) – it is likely to remain more than a match for any aerial threat it is likely to meet at least until 2025 and be able to hold any enemy aircraft at threat well beyond 2030.

Following a British-led defensive aids sub-system (DASS) upgrade, Eurofighter's passive electronic warfare (EW) and detection capabilities – through the electronic support measures (ESM) component – are considered highly capable by pilots. However, the active EW component of the DASS – the electronic countermeasures (ECM) – is still in need of improvement if it is to reach the same level of capability achieved by other partner states such

as France's SPECTRA system on the Rafale. Currently, upgrades to the DASS in this area are scheduled for the universal P4E software block, which is due in service around 2020.

There are significant performance gains to be found relatively cheaply through fixing subsystem deficiencies in areas such as communications, as well as by maximising sensor fusion between the upcoming active electronically scanned array (AESA) CAPTOR-E radar, PIRATE infrared scan and track (IRST) and DASS. Pilots from all Eurofighter states interviewed for this Whitehall Report want the CAPTOR-E radar, better sensor fusion and small subsystem fixes prioritised over any other potential upgrades. Options such as leading-edge root extensions (LERX), conformal fuel tanks (CFTs), up-rated engines and thrust vectoring would all enhance the performance of the jet. However, since the aerodynamic performance is already superb, the cost-benefit ratio would be less favourable than the radar and subsystem fixes.

If the DB-110 RAPTOR Tac/R pod is not integrated onto Typhoon before the out-of-service date (OSD) for Tornado (2019), the RAF will lose an extremely important and internationally valued capability currently performed by its fast-jet fleet as part of coalition operations.

Developing maximum network, systems and tactical interoperability between the Eurofighter and the initially small numbers of F-35s, which will enter service throughout the 2020s, offers significantly increased combat effectiveness for both types. Each is capable of offering strengths where the other is comparatively weak. The Eurofighter offers exceptional performance, heavy- and diverse-ordnance capacity, long-range and combat mass, whilst the F-35 will bring unmatched situational awareness, low-observable survivability in defended airspace and powerful electronic warfare capabilities.

Due to repeated successes whilst operating with US F-22s at Red Flag exercises, the Eurofighter's capability is held in high regard by the elite of the USAF's air-dominance community and has shown it can offer significant combat advantages to a high-end US strike package.

Continued investment in the Eurofighter platform is needed to unlock the full potential of the jet. It will require a relatively modest level of sustained funding to complete the Eurofighter's maturation into a fully functional multirole asset with capabilities to outmatch any operational fighter outside the US. Conversely, failing to fix performance bottlenecks in subsystems, complete full multirole weapons integration and modernise the ECM electronic warfare suite would be an inefficient defence-investment decision.

Given the number of capability enhancements which are on the cusp of being delivered, any new operators would benefit greatly from the investment in the Eurofighter's journey to maturity made by existing partner states as they would be buying a 'finished product' – and one with the potential for significant future enhancements.

Introduction

This report aims to address a perceived lack of understanding, in political, media and some military circles, of the Eurofighter Typhoon multirole combat aircraft, its capabilities and level of maturity. It is currently operated by the UK, Germany, Italy, Spain, Austria and Saudi Arabia, and is soon to enter service in Oman. The Eurofighter will provide the core of four of the five most powerful European air forces for at least a decade between the late 2010s and around 2030. A thorough understanding of the platform is, therefore, important in an era where air power is the cornerstone of modern defence capabilities, and defence budgets are under constant pressure. The fiercely competitive and high-value international fighter export market means that all manufacturers claim their aircraft offer superlative performance, reliability and flexibility in combat. Therefore, this study draws extensively on interviews with Eurofighter pilots and capability managers in the British Royal Air Force (RAF), German Luftwaffe and Italian Aeronautica Militare to gain an operator's perspective on the Eurofighter that goes beyond corporate literature and statistics.

Europe's NATO member states collectively possess just over 2,030 fast-jet aircraft. On paper the alliance boasts formidable combat air power even without the US. However, there is a legacy-aircraft problem within NATO, especially within Europe. The majority of Europe's fast jets are aging third- and fourth-generation types such as the AV-8B Harrier, Panavia Tornado and F-16 Fighting Falcon. Though undeniably impressive aircraft for their day, these are unlikely to remain operationally credible against near-peer opponents, let alone peer opponents such as Russia's Su-35S, for long enough to be replaced en masse by fifth-generation platforms. The problem for European air forces is that replacing these legacy platforms with capabilities to match the projected threat environment in the next 10–20 years is an expensive undertaking.

Europe currently produces arguably the two most-capable multirole fighter aircraft available for purchase by air forces around the world. The Eurofighter Typhoon and Dassault Rafale are both potent air-superiority and strike platforms which were designed specifically to replace the legacy fighter fleets in Europe. However, significant parts of the political, media and, in some cases, military circles see the stealthy US F-35 as the future of Europe's combat air fleets.

If the common political and media narrative is to be believed, the F-35 has already made all previous fighter aircraft designs obsolete and will soon revolutionise Western air power. Its combination of stealth, sensor-fusion-enabled situational awareness, open-software architecture and electronic warfare capabilities promise capabilities which are, to varying

degrees, impossible to deliver on more traditional platforms such as the Eurofighter, Rafale and Gripen. However, serious delays and cost increases in the F-35 programme, coupled with shrinking budgets in the wake of the global economic crisis, are likely to result in small European fleet sizes if purchased early. Novel maintenance procedures and early-production bugs will further drive down force elements at readiness (FE@R) numbers available to European air forces. No matter how advanced a fast jet is, it can only be in one place at any given moment. There is a risk that European air forces could price themselves into operational irrelevance.

Current UK plans for the F-35 envisage an initial order of forty-eight aircraft spaced across production lots such that a maximum of thirty-seven F-35Bs will be in service at any given time until at least 2030 with the RAF/Royal Navy. Due to the needs of the training cycle, maintenance and readiness, a maximum effort during a crisis might deliver up to twenty F-35Bs to be forward deployed, whether on land or carrier. This would yield between twelve and fifteen aircraft serviceable at any given time. The UK is one of the largest potential F-35 customers in Europe, with states such as the Netherlands, Norway and Italy aiming to field even fewer aircraft within a ten-to-fifteen-year timeframe. The F-35 is a potentially huge force multiplier for other networked assets on the ground and in the air. However, unless NATO is prepared to accept a crippling reduction in combat mass in the air domain, the F-35 alone cannot fulfil Europe's combat-air requirements within the timeframe envisaged by this study. Therefore, measures which could obtain the best combat capability and flexibility out of the Eurofighter, given the limited defence funds available, must be considered.

As of early 2015, the Rafale can be considered a more-mature platform than the Eurofighter; its active electronically scanned array (AESA) radar, whilst significantly smaller than the CAPTOR-E – on contract for integration in the Eurofighter from 2018 – is operational and is already capable of delivering almost all the air-launched weaponry in France's arsenal. The Eurofighter is yet to reach its full potential. However, given the performance of the basic airframe – and the significant capabilities on contract for operational deployment by 2020 – that potential should surpass that of the Rafale in many respects. The longer development timescale of the Eurofighter is partly due to the differing operational requirements and priorities of the four main partner nations. In the past, these have led to a lack of consensus on the scale and focus of investment in the platform within the consortium framework.

As the RAF and Italian air force finally retire the Tornado GR.4 and IDS (interdictor/strike) by 2019 and 2020 respectively, and the Luftwaffe starts to transfer some interdiction duties from Tornado to Typhoon post 2016, the Eurofighter will have to provide the backbone of the front-line air power for four of the five most powerful European NATO air forces – the British RAF,

German Luftwaffe, Italian Aeronautica Militare and Spanish Ejército del Aire. Due to the delays and continuing uncertainty over pricing and timescales within the multinational F-35 programme, these air forces will have to rely on the Eurofighter for the core of their combat power until at least 2030. For Germany, which does not currently intend to purchase the F-35, the Eurofighter is 'all there is' beyond Tornado. Therefore, it is important to work out how to get the most out of this extremely capable platform in a future operating environment in which the US may increasingly see fifth-generation aircraft as theatre-entry standard. This report will examine how operators currently view the Eurofighter's capabilities against high-level threats today, how they perceive the aircraft's capability to operate within the projected future operating environment and what needs to be done to best operate the Eurofighter alongside fifth-generation assets such as the F-35.

Whilst already very capable in many respects, the aircraft has not yet received many upgrades which Eurofighter GmbH originally intended for mid-life introduction such as up-rated engines with thrust vectoring, advanced electronic attack capability and true sensor fusion, especially between the PIRATE infrared scan and track (IRST), the defensive aids sub-system (DASS) and radar. Plans to integrate advanced weapons such as the Meteor beyond-visual-range air-to-air missile (BVRAAM) and Storm Shadow air-launched cruise missile (ALCM) are running behind the initial schedule although they are now on contract for integration by 2018 in RAF service, prior to the British out-of-service date for the Tornado. The question is whether such upgrade programmes represent good value for money in capability terms. Another crucial upgrade of the aircraft is the CAPTOR-E AESA or 'E-Scan' radar. The funding to integrate this upgrade was only recently confirmed by partner nations but appears to now be a priority. The upgrade can be retrofitted to any Tranche 2 or 3 aircraft.[1]

Before the major upgrade and weapon-integration programmes are considered in any depth, however, this report briefly examines where the Eurofighter platform currently sits in capability terms.

1. Justin Bronk, Elizabeth Quintana and Trevor Taylor, 'UK Funding for "Captor-E" AESA Radar Announced – Better Late than Never', RUSI.org, 15 July 2014, <https://www.rusi.org/analysis/commentary/ref:C53C54C0115349/#.VM-bUi64yuo>, accessed 2 February 2015.

I. Current Capability

The Eurofighter was designed for air superiority – the most aerodynamically demanding role for a jet fighter. Thanks to powerful engines and generous use of light composite materials, it has a positive thrust-to-weight ratio which allows it to accelerate even in a vertical climb and maintain energy during combat manoeuvres. The distinctive delta-wing shape with large, aerodynamically decoupled canard control surfaces mounted on the nose is optimised for maximum manoeuvrability at supersonic speeds, lift at low speeds or high altitudes, and the ability to sustain high-G turns. An intended effect of this aerodynamic configuration is very high airframe strength and a large wing area for under-wing stores. The Eurofighter can operate at extremely high altitudes of up to 65,000 feet and speeds of up to Mach 2.[1] This performance, coupled with powerful radar and up to eight long- and medium/short-range missiles, is designed to allow the aircraft to outperform and destroy any opposing aircraft at beyond visual range (BVR) or within visual range (WVR) if necessary. Operating at extreme altitudes at supersonic cruise speeds without needing to use thirsty afterburners allows the Eurofighter pilots to not only maintain an energy advantage over opponents in BVR combat, but also extends the effective range of their missiles by up to 50 per cent.[2] In terms of design philosophy, its closest antecedent is the formidable US F-15C Eagle. As with the F-15, the drawbacks of this approach are high procurement and operating costs compared to lighter designs such as the F-16 and Saab Gripen. If total programme cost is divided by the number of aircraft procured then the RAF's Typhoons cost somewhere in the region of £110 million each at current prices.[3] Although expensive, partner nations receive an air-superiority fighter capable of outmatching all currently operational fighter aircraft in the world with the exception of the stealthy and even more expensive US F-22 Raptor. The Eurofighter's exceptional BVR performance comes from the powerful and wide field-of-regard radar, brute aerodynamic performance and large missile load-out. Within visual range, the new Helmet Mounted Symbology System (HMSS) allows extreme off-boresight missile shots which, coupled with the high thrust-to-weight ratio and agility of the platform, make it a very dangerous opponent even against the most-modern super-manoeuvrable Russian and Chinese Su-27 'Flanker' derivatives.

One of the standout features of the Eurofighter is the Eurojet EJ-200 engines which offer supercruise capability and are the most reliable military jet engines in the world.[4] During seven months of intensive operations over

1. Ministry of Defence, 'Royal Air Force Aircraft and Weapons', 2nd ed., 2013.
2. Personal interviews with front-line RAF Typhoon pilots, RAF Leuchars, 1 April 2014.
3. National Audit Office Report, *Management of the Typhoon Project*, Report HC 755 (London: The Stationery Office, 2011), p. 8.
4. *Defence Turkey*, 'EJ200: Unbeatable Reliability', 25 November 2014.

Libya on Operation *Ellamy* in 2011, RAF Typhoons flew more than 3,000 hours. During that time RAF maintenance crews performed only a single EJ-200 engine change which was conducted as a practice to maintain ground-crew proficiency rather than due to any failure.[5] The engines are software managed to allow 'care-free' operation for the pilot at all speeds and angles of attack, significantly decreasing pilot workload and thereby increasing performance in more advanced tasks. In the early years of the Eurofighter programme, software bugs would often complicate start-up procedures and aircraft availability. However, especially during the last five years, these issues have largely been solved and the jet has earned a reputation amongst pilots and maintenance crews for excellent reliability 'on the ground', helping deliver greater serviceability and operational output per airframe and pilot.[6]

In terms of sensors, the CAPTOR-M radar currently mounted on the Eurofighter is widely recognised as one of the most powerful and precise of its kind. It can be used to detect and track targets at ranges of over 100 nautical miles. However, AESA types outclass it in terms of multiple simultaneous target tracking, high resolution SAR mapping, low probability of hostile intercept and electronic-attack capabilities. Therefore, the CAPTOR-E AESA radar is being integrated into the platform as a priority agreed by all partner states in November 2014.[7] This new radar offers a very wide field of regard compared to standard fixed-plate arrays and will offer improvements in range, tracking resolution and fidelity, stealth, tactical options, electronic attack and ground mapping over the current CAPTOR-M. Since almost all modern combat aircraft carry radar warning receivers to detect hostile radar signals, passive operation is an important capability for the Eurofighter. To this end, and to provide a limited stealth-detection capability, the Eurofighter is equipped with a powerful IRST scanner called PIRATE, except in Luftwaffe service. This is entirely passive in operation, producing no emissions which could be detected by hostile threats. Due to the fact that PIRATE works by detecting the heat generated on an aircraft's skin by air friction – rather than radar returns – it also offers significant potential capabilities against low-observable (LO) aircraft.[8] However, due to funding priorities and the fact that the Luftwaffe does not use it, it is only in the past two years that the sensor has started to move towards an operationally useful level of capability. Prior to this, shortages of spare parts and immature software – which was

5. Personal interview with senior RAF officer involved in Operation *Ellamy*, RUSI, London, 5 December 2014.
6. Personal interviews with front-line Aeronautica Militare Eurofighter pilots and commanders, Grosseto Airbase, Italy, 16 January 2015.
7. Nicholas de Larrinaga, 'Eurofighter Nations Sign EUR1 Billion AESA Integration Contract', *IHS Jane's Defence Weekly*, 19 November 2014.
8. Personal interview with capability managers at Eurofighter GmbH, Munich, 23 October 2014, and front-line Aeronautica Militare Eurofighter pilots and commanders, Grosseto Airbase, Italy, 16 January 2015

incapable of dealing with the sheer number of false positives inherently generated by such a sensitive sensor – hampered its operational use. Since PIRATE operates in the infrared (IR) region, it must be used in conjunction with other sensors to allow kinetic engagements of targets substantially BVR using missiles such as the AMRAAM and Meteor that use radar to track targets.[9] Italy has made some progress with PIRATE/CAPTOR sensor fusion, but this is still a work in progress. The UK's version of CAPTOR-E (Radar 2 Extended Assessment Phase) is being developed to take advantage of some of this work and build on it to incorporate inputs from PIRATE and the DASS much more than the current sensor suite centred on CAPTOR-M.[10] BVR armament is the AIM-120C AMRAAM radar-guided missile and this will soon be boosted by the much longer-ranged Meteor with full two-way datalink allowing midcourse guidance updates. The two-way datalink (not available for the Rafale due to platform limitations) is crucial for realising the full performance of the missile, in particular for expanding the no-escape zone given the long flight time and potential for significant target course changes at long range.

At close range, the Eurofighter nations field one of two different missiles in addition to the internal 27-mm Mauser cannon. Germany, Italy, Spain and Austria use the IRIS-T heat-seeking missile which offers extreme off-boresight capability, enabling successful engagements of targets behind the aircraft itself in conjunction with the HMSS helmet.[11] The RAF uses the AIM-132 ASRAAM which is faster and has a significantly longer range exceeding 25 km. This comes at the cost of pure manoeuvrability.[12] ASRAAM also has lock-on-after-launch capability which allows high off-boresight shooting as well as the potential for longer-range engagements cued through PIRATE. Both missiles have IR seekers with high resistance to countermeasures.

Real strike capabilities currently exist only in the British and Saudi Typhoon fleets, with the Italian, Spanish and German Eurofighters currently exclusively tasked in the air-to-air role. The CP-193 Austere air-to-ground software package for Tranche 1 Typhoons in RAF service enabled Litening III targeting pods and Paveway II and enhanced Paveway II laser-guided bombs to be used from 2008 but outside the standardised consortium software-development

9. Personal interview with front-line Aeronautica Militare Eurofighter pilots and commanders, Grosseto Airbase, Italy, 16 January 2015; see also Bundesheer, 'Der Eurofighter "Typhoon" (VII)', 2008, <http://www.bundesheer.at/truppendienst/ausgaben/artikel.php?id=807>, accessed 4 March 2015.
10. Personal interview with RAF staff officer in the Typhoon programme, High Wycombe, 20 February 2015.
11. Personal interview with Luftwaffe officers including operational pilots, operational test and evaluation pilots and capability development staff, Cologne, 11 February 2015.
12. MBDA Missile Systems, 'ASRAAM; Within Visual Range Air Dominance Weapon', January 2015, <http://www.mbda-systems.com/mediagallery/files/asraam_datasheet-1424427241.pdf>, accessed 4 March 2015.

plan. The P1Eb software upgrades currently being applied to RAF Tranche 2 Typhoons provide genuine multirole capability with the ability to switch between air-to-air and air-to-ground modes in flight, as well as Paveway IV bombs and many other enhancements.[13]

As a result of the British-led upgrade work, the DASS – which includes threat detection, early warning and countermeasures systems – now includes a thoroughly effective electronic support measures (ESM) package. This enables the recognition and tracking of hostile threat signals (including those from 'low probability of intercept' AESA radars), as well as various other classified functions. However, the active electronic countermeasures (ECM) components of the DASS, whilst sophisticated, still lag behind the latest French and US capabilities on platforms such as the Rafale, EA-18G and F-22. This is an area where operators suggested that further priority investment could yield significant increases in survivability, especially against ground-based air defences.[14] However, given the highly classified nature of these capabilities, further details of these and possible upgrades are beyond the scope of this study.

From an operator's perspective, the most limiting factor of the Eurofighter platform at present is not the slow pace of upgrades for weapons systems or sensors. Whilst the major systems such as the engines are extremely reliable, there are persistent problems with many of the smaller subsystems such as the radios and even the digital altimeter.[15] These issues are longstanding and in the past have not been treated as priority investment areas because they are by nature small and unassuming from a programme-management point of view. However, in practice small subsystems which do not function properly act as serious performance bottlenecks for the system as a whole. There are fixes for some issues in upcoming software blocks, and new production aircraft are less prone to many of them already. However, at squadron level – especially in German and Italian service – problems remain and should be fixed as a priority. Currently, pilots are forced to spend mental capacity coping with minor errors and trying to work around them. This limits their ability to use some of the more advanced capabilities of the platform. Furthermore, certain relatively minor deficiencies can seriously constrain the capability of the system as a whole to function as intended.

13. BAE Systems Newsroom, 'First Multiple Release of Paveway IV from an RAF Typhoon is a Success', 4 November 2014, <http://www.baesystems.com/article/BAES_177708/first-multiple-release-of-paveway-iv-from-an-raf-typhoon-is-a-success>, accessed 4 March 15.
14. Personal interviews with senior RAF officer involved in Operation *Ellamy*, RUSI, London, 5 December 2014, front-line RAF Typhoon pilots, RAF Leuchars, 1 April 2014, and front-line Aeronautica Militare Eurofighter pilots and commanders, Grosseto Airbase, Italy, 16 January 2015.
15. Personal interviews with front-line Aeronautica Militare Eurofighter pilots and commanders, Grosseto Airbase, Italy, 16 January 2015.

An obvious example of such a deficiency is the poor long-range non-cooperative threat recognition (NCTR) capabilities using the current CAPTOR-M radar. NCTR in this case refers to the capability to positively identify aircraft which have been detected at long range (more than 40 miles) – where optical means are useless – using either high-definition radar ranging or jet-engine modulation identification. Whilst platforms such as the E-3D Airborne Warning and Control System (AWACS) and some advanced US fighter platforms can use these methods to positively identify potential threats at long range, the Eurofighter currently lags behind in this capability and is likely to do so for some years under current plans.[16] This means that without information on target identification being fed to them across Link 16 from other allied assets, Eurofighter pilots cannot use their most powerful BVR capabilities and tactics under most rules of engagement (ROE), since they cannot positively identify potential targets until almost WVR.[17] This is not necessarily a huge operational drawback since in every likely operational scenario Eurofighters would be operating with AWACS assistance and alongside coalition assets able to co-ordinate on target identification. However, it is an example of how small subsystem deficiencies can significantly impair the capability of other crucial – and independently reliable – systems to the detriment of overall combat effectiveness. The proposed CAPTOR-E radar which is planned for operational service by 2022 in the RAF and other partner nations slightly later does include greatly enhanced NCTR capabilities as a priority.[18] Until then, changes in radar software and waveforms, coupled with new operational tactics, could partially alleviate the problem for aircraft equipped with CAPTOR-M aircraft by altering the radar resource allocation of individual aircraft in a flight to have a better chance of jet-engine modulation identification. This would come at the cost of temporarily diminished wide-area scanning and multiple target tracking.[19]

16. Personal interviews with Luftwaffe officers including operational pilots, operational test and evaluation pilots and capability development staff, Cologne, 11 February 2015, and front-line Aeronautica Militare Eurofighter pilots and commanders, Grosseto Airbase, Italy, 16 January 2015.
17. Personal interviews with front-line Aeronautica Militare Eurofighter pilots and commanders, Grosseto Airbase, Italy, 16 January 2015.
18. Personal interview with RAF staff officer in the Typhoon programme, High Wycombe, 20 February 2015.
19. Personal interview with RAF staff officer in the Typhoon programme, High Wycombe, 20 February 2015.

II. Air-to-Air Threat Environment

As already outlined, the Eurofighter is at its core an air-superiority fighter. As such, it is optimised for air-to-air combat against extremely fast and agile opponents such as the Su-27/35 'Flanker' family. In order to offer a credible conventional deterrent on NATO's eastern flank, Europe arguably requires fighter aircraft capable of engaging the latest and best Russian aircraft on at least equal terms. The baseline training standard for NATO air-combat exercises is against simulated maximum-threat Russian air-superiority platforms.[1] The logic behind such a threat-environment assumption is to ensure that NATO airmen are prepared for a worst-case scenario and in real combat should find any lesser opponents easy to handle.

Live training exercises with Indian Air Force Su-30MKI fighters in 2007 and 2011 were an unusual opportunity to test the Eurofighter's WVR combat capabilities against the most advanced 'Flanker' then in service. The RAF Typhoons involved in the exercises were able to reliably beat the Su-30MKIs by countering the latter's advantage in horizontal turning and high-alpha[2] manoeuvres through superior acceleration and vertical manoeuvres, coupled with helmet-cued missile targeting.[3] This experience emphasises the importance of a high thrust-to-weight ratio and G-sustainment capability even in WVR situations, demonstrated by the phenomenal 104 kills to zero losses in air-to-air combat achieved by the similarly large, high-thrust/weight F-15. The core of the Eurofighter's strength in the air-to-air domain rests on its aerodynamic design and engine combination which gives a superb thrust-to-weight ratio and high manoeuvrability at supersonic speeds, as well as the airframe's ability to mount powerful radars such as the CAPTOR-M and CAPTOR-E.

Whilst the capabilities described above are very important for maintaining air superiority, they are not sufficient in themselves. A huge part of NATO's ability to maintain an advantage in the air-to-air domain is its extensive co-operative training programmes. Large-scale live-flying exercises such as Red Flag provide Western and Allied air-force personnel with an invaluable opportunity to experience and train for high-intensity warfare. This not only builds the personal competence of aircrew but allows air forces to experiment with new and innovative tactics to best use the various strengths

1. Personal interview with senior Aeronautica Militare officer, London, 24 November 2014 .
2. 'Alpha' or angle of attack (AoA) specifies the angle between the chord line of the wing of a fixed-wing aircraft and the vector representing the relative motion between the aircraft and the atmosphere. In layman's terms it can be loosely understood as the difference in angle between the direction of forward movement and where the nose of the aircraft is pointing.
3. Personal interview with ex-RAF Typhoon pilot involved in 2011 exercise, Munich, 23 October 2014.

and capabilities of different platforms. An obvious example of this is experimenting on how best to integrate stealthy fifth- generation fighters into large, mixed and usually multinational strike packages to achieve maximum safety and combat effectiveness. Eurofighters flown by RAF and Luftwaffe pilots have already proven that the platform is significantly more effective when operated in tactical formations with fifth-generation assets. During Red Flag exercises, USAF F-22 Raptors operate in relatively small numbers at extremely high altitude and speed, using their powerful radar, stealth and situational awareness to direct Eurofighters from a 'god's-eye view'. The Raptors can observe engagements as they develop, intervening at will to destroy any particularly high-threat targets where the Eurofighter force risks being overwhelmed.[4] The Eurofighter also significantly improves the combat effectiveness of the overall combat package by bringing combat mass, hefty missile loads, swing-role capability and impressive BVR and WVR combat performance to the mix. Combining two F-22s with four Eurofighters has proved a superlative combination at successive Red Flags, delivering combat power 'greater than the sum of its parts'.[5] Whilst not able to offer the same aerodynamic performance as the F-22, even limited numbers of F-35s should be able to greatly increase the Eurofighter's combat effectiveness through superior situational awareness and battlespace management.

At present, the latest 'Flanker' variants represent the peak of the air-to-air threat which Eurofighter operators might face in any conflict. However, both Russia and China have extant fifth-generation stealth-fighter development programmes. The Russian T-50 can best be described as a less-stealthy but more-manoeuvrable, better-armed and longer-ranged version of the US F-22 Raptor. A handful of prototype T-50s are currently in flight testing but there have been substantial problems including engine fires, wing-surface modifications and patching, and delayed weapons trials. It currently resembles the F-22 programme between its first flight in 1997 and initial operating capability (IOC) in 2005. With substantially fewer resources and experience in building stealth aircraft, it will probably take Russia at least as long to attain full operating capability (FOC) with their T-50s as it took the US to iron the problems out of the F-22 (low-observable aircraft present uniquely complex design challenges). This would suggest small numbers of genuinely combat-capable T-50s might enter Russian service by around 2025 and export variants such as the Indian PAK-FA derivative somewhere closer to 2030.

China's J-20 is another story. Whilst it appears to be at a similar stage in development to the T-50, with six prototypes in flight testing as of January

4. Personal interviews with Red Flag-experienced RAF Typhoon pilots, RAF Leuchars, 1 April 2014, and Luftwaffe Eurofighter pilot, London, 3 December 2014.
5. Personal interviews with Red Flag-experienced RAF Typhoon pilots, RAF Leuchars, 1 April 2014, and Luftwaffe Eurofighter pilot, London, 3 December 2014.

2015, the Chinese programme has none of the resource constraints of its Russian cousin.[6] The J-20 should properly be classed as LO rather than very low-observable (VLO) since it lacks the all-aspect stealth of the F-22 in its current form and forward canards are inherently un-stealthy. However, it will be a formidable and hard-to-detect long-range strike aircraft with air-to-air capabilities. Crucially, it will most likely be produced in increasingly large numbers throughout the 2020s with an IOC in 2017–18 on current projections. Against LO designs such as the T-50, J-20 and export-focused FC-31, the Eurofighter will struggle in the air-superiority role without CAPTOR-E, since CAPTOR-M cannot reliably detect and target such designs. Some sources have suggested the CAPTOR-E will be capable of detecting LO designs such as the F-35 out to around 60 km and PIRATE IRST has great potential for detecting stealth designs which are, by nature, large and hot with a correspondingly strong infrared (IR) signature.[7] Progressive enhancements to PIRATE and the accuracy of passive location and electronic warfare capabilities through the DASS, coupled with the radar 2 CAPTOR-E being developed for the RAF, together offer a boost to situational awareness and detection capabilities, which should make RAF Typhoons formidable opponents against even LO designs from the early 2020s.[8] Other partner states are not yet signed up to such a comprehensive sensor-suite upgrade, although Italy has showed interest, particularly in the radar 2 version of CAPTOR-E. Spain and Germany are currently committed to the radar 1+ version of CAPTOR-E, which offers standard air-to-air AESA capability as well as limited air-to-ground search functions including high-definition SAR mapping. However, it does not imply the same level of commitment to develop the sensor-fusion, electronic warfare and communications potential of the CAPTOR-E architecture.

Furthermore, Russia and China lack both the knowledge of how to incorporate LO and VLO assets into a larger strike or air-dominance package. At present, they also lack opportunities for their pilots to train in large-scale, high-fidelity joint exercises such as Red Flag, which give Western air forces and pilots much of their asymmetric advantage. Eurofighter pilots must continue to benefit from these exercises if they are to best use the strengths of their aircraft and integrate with allied VLO and LO assets in the face of slowly increasing and proliferating numbers of high-threat fifth-generation opponents. The Eurofighter will most likely retain at least a self-escort capability against the most serious peer-opponent assets beyond around 2025 but will remain highly competitive against all non-stealthy fighter

6. Jeffrey Lin and Peter W Singer, '6th J-20 Stealth Fighter Rolls Out, More to Soon Follow', *Popular Science*, 23 December 2014.
7. Lee Tae-hoon, 'F-35: A Game Changer in Modern Warfare', *Korea Times*, 24 October 2011.
8. Personal interview with RAF staff officer in the Typhoon programme, High Wycombe, 20 February 2015.

aircraft, which will continue to dominate adversary forces until well beyond 2030. The Eurofighter will also continue to be a powerful force multiplier as a multirole asset within larger strike packages alongside F-35s and other coalition assets even once eclipsed in the air-superiority role.

Large-scale combat exercises such as Red Flag suggest that modern air combat is decided primarily by two factors: the best networked situational-awareness picture; and combat persistence of assets in terms of kinetic energy, fuel and missile stores.[9] Small numbers of fifth-generation F-35s providing situational awareness to a 'backbone' of Eurofighters which excel in combat persistence has the potential to transform European air-superiority capabilities. In the case of Red Flag, it was notable that the increase in combat performance afforded to four-ships of Eurofighters working with F-22s was similar whether it was two, four or six F-22s.[10] Significantly, German sources report that USAF F-22 pilots have allegedly expressed a preference for operating alongside Eurofighters over the USAF's own F-15Cs in a hypothetical high-intensity conflict.[11] In a period of austerity and capability gaps, where powerful voices in the US openly question Europe's contributions to collective NATO defence, having an air-superiority asset which is held in high regard by the air-dominance elite of the USAF is valuable.

9. Personal interview with RAF pilots with experience in the Typhoon and F-35 programmes, London, 28 January 2015.
10. Personal interview with RAF pilots with experience in the Typhoon and F-35 programmes, London, 28 January 2015.
11. Personal interview with Red Flag-experienced Luftwaffe Eurofighter pilot, London, 3 December 2014.

III. Ground-Based Air-Defence Threat Environment

Whilst the Eurofighter is optimised to combat other advanced fighter aircraft, the latest air-defence networks incorporating triple-digit surface-to-air missile (SAM) systems such as the S-400 and S-300PMU2/HQ-9 fed by multiband fire-control and detection radars are an equally serious threat to modern fighter aircraft over or near hostile territory. Countering such threats requires distinct weaponry, tactics and capabilities from those optimised for air-to-air combat.

The traditional approach to penetrating an integrated air-defence system (IADS) involves both defensive techniques such as jamming, countermeasures, threat avoidance and evasive manoeuvres and also offensive 'hard-kill' approaches such as anti-radiation missiles to destroy radar and SAM sites and cruise missiles to destroy enemy command and control (C2) nodes. Suppression of enemy air defences (SEAD) is the role designation for aircraft specifically tasked with granting access to areas protected by ground-based air defences. The Eurofighter is not optimised for jamming or the SEAD role, and neither are the Rafale or Gripen. The British Air Launched Anti-Radiation Missile (ALARM) could provide RAF Typhoons with a significant self-escort capability against SAM sites. The advantage of ALARM, in particular, is that it requires no specialist sensor inputs from the launch aircraft and so can grant a limited SEAD capability to platforms without requiring large-scale modifications. Tornado GR.1, GR.4 and F.3 variants all carried ALARM and Typhoon could be adapted to launch the weapon, at least from a technical standpoint.

In the absence of a dedicated anti-radiation weapon, the Eurofighter would currently require support from dedicated electronic warfare and SEAD assets in order to penetrate an IADS boasting current generation radar and triple-digit SAM networks at a feasible level of risk. European air forces can currently call on limited quantities of F-18, F-16 and Tornado ECM aircraft for this role. However, these are highly unlikely to be viable as the primary SEAD assets against a near-peer, let alone a peer opponent in the present day. There will be an even larger gap in fifteen years' time. The Italian and Spanish air forces use the US High-Speed Anti-Radiation Missile (HARM) and Italy is a partner of the US Navy in the latest ARM-88E Advanced Anti-Radiation Guided Missile (AARGM) version. However, there are no current plans to incorporate the weapon onto Italian Eurofighters at this time. As the older F-18s, F-16s and Tornado ECMs reach the end of their viable front-line service lives, the Eurofighter will potentially have to take over the 'hard-kill' SEAD role, together with initially small numbers of F-35s as they enter service. The Eurofighter and F-35 match offers a potentially

formidable anti-IADS combination if the necessary weapons-integration and software-upgrade work is funded and implemented across NATO – although sufficient combat mass will still be required to create and then exploit temporary breaches in IADS coverage.

The US approach to the IADS problem, embodied in aircraft such as the F-35, F-22 and B-2, is to reduce the aircraft's radar cross section (RCS) using stealth shaping and materials in its core design. The goal is to allow the aircraft to approach close enough to radar-dependent enemy air defences to either inflict 'hard kills' using ordnance or 'soft kills' using electronic warfare (cyber-attacks). If they are not aiming to open a temporary window for non-stealthy aircraft, these assets can often simply bypass radar-dependent defences. This approach proved extremely effective over Iraq in 1991 and 2003, Libya in 2011 and Syria in 2014. Whilst the Eurofighter has some RCS-reducing features such as an angled radar array to reduce hostile returns and extensive structural use of composites and radar-absorbent materials (RAM) in key areas such as wing and canard leading edges, it cannot be made low-observable.[1] However, it is important to remember that 'stealth' simply makes an aircraft more difficult to detect, not invisible. Stealth also only works from certain angles and against particular radar wavelength bands. Low-observable (LO) or very low-observable (VLO) design makes an aircraft hard to detect using certain radar types, but does not offer a comprehensive answer to air superiority or the suppression of enemy air defences.

Many policy-makers and operators in the combat air sector subscribe to the mainstream view that within 10–15 years, VLO will be the theatre-entry standard for top-tier strike and air-superiority platforms. In this view of the future threat environment, aircraft without stealth will simply be unable to enter the airspace of peer or even near-peer adversaries. Therefore, they will be relegated to at least the second wave of any coalition operation.[2] On the other hand, the Eurofighter is capable of carrying a significantly heavier and more varied air-to-air and air-to-ground payload on up to thirteen external hardpoints than is currently projected for fifth-generation fighters, which must carry their payload internally in order to remain stealthy. For comparison, the F-35B variant of the Joint Strike Fighter – which the UK will operate initially – can carry two AIM-120 AMRAAMs and two 1000-lb precision-guided bombs internally in strike configuration whereas a typical strike load for Typhoon in RAF service might consist of four Paveway IV bombs or twelve Brimstone II missiles, four AIM-120 AMRAAMs, two AIM-132 ASRAAMs and twin supersonic auxiliary fuel tanks to extend range. This

1. Paul Smith, 'Radar Love', *Eurofighter World (*February 2015), pp. 18–21; Paul S Owen, 'Structural Design', *TyphoonStarstreak.net,* <http://typhoon.starstreak.net/Eurofighter/structure.html>, accessed 1 April 2015.
2. Personal interview ex-Royal Air Force Typhoon force commander, RUSI, London, 5 December 2014.

will be improved if the new common launcher for Brimstone II, Spear 3 and Paveway IV is incorporated as planned by 2018.[3] Therefore, in a 'night one' scenario where stealth is a 'first-wave' requirement, the Eurofighter force will still be required to deliver the follow-on bulk of European firepower in co-ordination with the initial stealthy strike package.

The Eurofighter's significant payload including the Storm Shadow ALCM would complement smaller numbers of F-35s in the SEAD role. Since weapons such as the upgraded ARM-88E and MBDA SPEAR 3 are highly unlikely to be integrated into the F-35's software before at least the mid-2020s, in stealth configuration it will lack kinetic punch against air-defence assets in small numbers. However, with its superb sensor suite and networked capabilities, small numbers of F-35s could designate targets for the Eurofighter, Rafale and Gripen assets employing advanced stand off ALCMs such as Storm Shadow. This would allow these non-stealthy assets to hold even S-400-class SAMs with extreme ranges of up to 400 km at risk without having to get close enough to be targeted in retaliation. However, the subsonic nature of even advanced ALCMs means that at maximum ranges they could take up to thirty minutes to strike their targets.[4] This is a problem when those targets – such as modern Russian and Chinese radar and SAM systems – are highly mobile. The issue is that without passive homing anti-radiation missiles like AARGM and ALARM, stand-off munitions in an SEAD role require a target location to be designated before launch, since they cannot seek out radar-emitting defences themselves.

However, others suggest there may be greater potential longevity in alternative approaches to penetrating modern integrated air defences.[5] These might make use of RCS-reducing features but mainly rely on electronic jamming, whole-force networking, defensive-aids suites and offensive capabilities. In fact, there is a growing conviction to be found amongst German operators that 'stealth as we currently understand it will not be a dominant issue in 15–20 years time because it is only optimised to defeat detection within certain radar bands. By developing radars which operate across multiple wavelengths and frequency bands, as well as IRST technology improvements, stealth designs have already been somewhat compromised and will likely be completely overcome within 20 years.'[6] This may be a slightly over-simplified view in that a reduced RCS will likely remain useful in many scenarios. However, in the face of significant improvements

3. Personal interview with ex-RAF Typhoon weapons instructor, London, 17 March 2015.
4. Royal Air Force, 'Storm Shadow', *raf.mod.uk,* <http://www.raf.mod.uk/equipment/stormshadow.cfm> accessed 13 January 2015.
5. Personal interview with serving Luftwaffe officer with operational experience as an F-4 Phantom, Tornado and Typhoon pilot, London, 3 December 2014.
6. Personal interview with serving Luftwaffe officer with operational experience as an F-4 Phantom, Tornado and Typhoon pilot, London, 3 December 2014.

and diversification of detection technologies, the aerodynamic, size and cost compromises required to 'build-in' VLO capabilities into platforms could end up outweighing the benefits derived in many situations. This is because in order to maintain a stealthy shape in the x-band, aircraft must be physically larger for a given level of aerodynamic performance. They must carry their weaponry internally – limiting fuel load and payload and creating overall size penalties. They must also be maintained in near-perfect physical condition which makes maintenance extremely costly and intensive. The German air-to-air-focused outlook on the future of air-combat capability is that the advantage will be found in greater network integration to create a true 'system of systems', rather than extremely costly and, therefore, scarce x-band stealthy fighter designs.

Against modern IADS or multiple enemy aircraft, the Eurofighter will show up on radar at long range. It must therefore detect threats first and use its long-range missiles and stand-off munitions to out-range them, as well as active and passive electronic warfare capabilities. However, when employed as part of a combined strike package with specialised SEAD assets and small numbers of fifth-generation aircraft to deal with particularly dangerous threats and provide a situational-awareness advantage, the Eurofighter's combination of long-range hitting power, raw performance and high sortie-generation rate make it a formidable asset. Against sub-peer opponents lacking triple-digit SAMs and fifth-generation fighters, the Eurofighter offers the potential to significantly improve performance over all legacy types whilst being available in significantly larger numbers than multirole stealth fighters until the late 2020s.

IV. Upgrades

Part of the problem surrounding the Eurofighter's development following its introduction into service in 2004–06 has been the substantially differing mission priorities of the four development nations. Under the original consortium arrangements, upgrades were supposed to be jointly funded and developed. This has proved a predominantly unworkable model given the significantly different operational imperatives and doctrinal role for the Eurofighter in British, German, Italian and Spanish service.[1] The Luftwaffe and RAF, the two largest operators of the aircraft, do not even fly aircraft with the same technical specifications – the Luftwaffe's Typhoons lack the prominent nose-mounted PIRATE IRST sensor. The Luftwaffe does not intend to integrate the PIRATE system – instead, it is considering a fourth-generation laser-designator pod for forward-looking infrared (FLIR) capability. Currently, only the RAF and Royal Saudi Air Force possess what can credibly be described as multirole Typhoons with the P1Eb software-equipped FGR4s. However, Italy will soon benefit from the RAF's software and weapons-integration programmes, after having signed up as the second European user to receive the P1Eb upgrade. However, this contract only covers the software and the Italian air force is still examining exactly when its Eurofighter fleet will be transitioning to full multirole operations.[2] The Luftwaffe is also looking to transfer some air interdiction and close air-support tasks to its Eurofighter fleet in the 2020–25 timeframe. Similarly, it will receive the P1Eb upgrade in due course through the NETMA four-state development path, a requirement due to airworthiness certification restrictions in German law.[3] In the past, frustrated by lack of four-state commitment to actually push forward multirole capabilities for the Eurofighter, the RAF and BAE Systems have developed the air-to-ground functionality for Typhoon outside the NETMA process. For example, whilst the P1Eb software blocks currently being integrated into the RAF Typhoon fleet is theoretically transferable to any Eurofighter partner nation, it has not been developed to accommodate particular national certification requirements. This is has caused some delays in integration outside the UK, especially in Germany.[4]

Due to Italy's fiscal situation, the Aeronautica Militare is unlikely to receive significant quantities of the 100 F-35s Italy officially plans to order before

1. National Audit Office Report, *Management of the Typhoon Project*, Report HC 755 (London: The Stationery Office, 2011), p. 8.
2. Personal interview with senior officer, Aeronautica Militare, London, 24 November 2014.
3. Personal interview with Luftwaffe officers including operational pilots, operational test and evaluation pilots and capability-development staff, Cologne, 11 February 2015.
4. Personal interview with Luftwaffe officers including operational pilots, operational test and evaluation pilots and capability-development staff, Cologne, 11 February 2015.

at least 2030. Meanwhile, Italy's Tornado fleet is facing the same service limitations as those of the RAF. Aging airframes are leading to expensive and intensive maintenance requirements, declining serviceability rates and life limitations due to fatigue. These necessitate either retirement or costly life-extension programmes within the next 5–10 years. The unusual Italian A-11 Ghibli light attack jet, which has complemented Tornado operations over Afghanistan and Libya, will also be retired by 2017–18.[5] This is well before F-35s will be available in quantities and at a level of maturity to replace them in the air-to-ground role. Therefore, one avenue being explored by the Aeronautica Militare is to follow the British lead with Paveway IV and Storm Shadow integration. This would give their Eurofighter squadrons the capability to fill the strike-role gap between Tornado's drawdown and eventual F-35 FOC.

In order to complement, and eventually take over from, Tornado in the strike and interdiction role in the RAF, Aeronautica Militare and later Luftwaffe service, the Eurofighter requires not only fleet-wide software upgrades to P1Eb standard (or equivalent), but also integration of the Storm Shadow stand-off air-launched cruise missile and the dual-mode Brimstone or Brimstone II anti-armour missile which has proved so successful in Libya and more recently over Iraq. The integration of these weapons is planned and early test flights are underway on instrumented production (test) aircraft in the UK. However, the flight trials and software integration of these important capabilities have been far slower than they might have been because only one of the four core partner nations is actively pursuing them at present. Another issue is the extremely extensive airworthiness and air-safety regime put in place following the damning 2009 Haddon-Cave report into the crash of the Nimrod XV230 in Afghanistan in 2006.[6] This requires extensive flight testing, modelling and training before any new weapons can be certified for carriage by RAF aircraft. This is a financial disincentive and delaying factor in expanding the Eurofighter's payload flexibility. However, it is important to remember that these airworthiness requirements are not platform specific. As a European multirole platform going forward, much of the work required to clear the aircraft for different payloads and integrate software to enable advanced air-ground functionality has already been done by the RAF and BAE Systems Air in the UK. In the coming decades, genuine multirole capability for the Eurofighter fleets of the Italian air force and possibly the German and Spanish air forces could be achieved at much lower cost and significantly faster than for the RAF on the back of shared British progress in this area.

5. Personal interview with Aeronautica Militare General Staff officer, Rome, 15 January 2015.
6. Charles Haddon-Cave, *The Nimrod Review*, House of Commons Report (London: The Stationery Office, 2009).

Another key mission for the Tornado, especially in RAF service, is tactical reconnaissance (Tac/R), which was the main output for up to 90 per cent of RAF sorties over Libya in 2011 and against Daesh (also known as the Islamic State of Iraq and Syria) in Iraq. The Litening III laser-targeting and reconnaissance pod has already been integrated onto the Typhoon in RAF service, which allows limited tactical reconnaissance in addition to its core targeting role for PGMs. However, the Tornado's premier Tac/R asset is the wide-area surveillance RAPTOR multispectral imaging pod. Its DB-110 sensor suite, derived from those carried by the iconic American U2 spy-plane, enables long-range oblique imaging and scanning of very large areas in a single sortie or high-resolution, multi-spectrum video capture of specific areas and targets of interest in real time. It is one of the most-valued capabilities which European states bring to US-led coalitions. The RAPTOR pod in RAF service is very large and would require substantial aerodynamic testing before being mounted on the Typhoon. It would also require a new interface since in the Tornado the weapons-systems operator, rather than the pilot, controls the pod which is obviously not an option in the single-seat Typhoon. However, single-seat Polish F-16s now carry the pod which is a proof of concept. Given the value placed on RAF Tac/R capabilities by coalition partners and the pool of experience within the RAF aircrew and intelligence branches in operating RAPTOR, incorporating this sensor pod into the Typhoon fleet should be looked at as a priority upgrade before the Tornado force is finally phased out in 2019.

To ensure that the Eurofighter can maintain the capabilities which the Tornado, F-18 and Harrier currently provide to European air forces once the latter types are retired is only part of the challenge. Whilst armament, software and sensor-payload upgrades required to accomplish this are known quantities, the longer-term challenge is to ensure maximum interoperability with the F-35 as it enters front-line service in the 2020s. This challenge comprises issues including datalink security and bandwidth, communications, and sensor fusion. During Red Flag, F-22s and Eurofighters could only communicate through a Battlefield Airborne Communications Node (BACN) due to the unique communications equipment on the F-22. Through Link 16, the Eurofighter can receive information in real time from networked ground and air assets. Whilst it does not employ the sort of centralised sensor-fusion architecture found on the F-35, and to a lesser extent the F-22, the Eurofighter's attack and identification system (AIS) presents a combined picture to the pilot via the multifunction information distribution system (MIDS). AIS also integrates data from the Eurofighter's own radar, PIRATE, DASS and navigational aids to present the pilot with the best possible situational awareness from an otherwise federated sensor architecture. However, this still requires a significant amount of data

management on the part of the pilot and could be significantly streamlined.[7] One of the most impressive features of the F-35 off board and onboard systems is the capability to process and share information between a staggering variety of airborne, land-based and maritime assets. Ensuring that the Eurofighter's sometimes-troubled communications systems are seamlessly interoperable with the F-35 is crucial in obtaining the maximum combat capability from Europe's fast-jet fleets as well as maximising the Eurofighter's value as a contribution to US-led coalitions. For example, if the RAF were to integrate the RAPTOR pod onto its Typhoons, feeding real-time information from this unparalleled stand-off sensor into the combined situational-awareness picture would grant F-35 pilots and their mission co-ordinators increased situational awareness within denied airspace without carrying non-stealthy external reconnaissance pods. Eurofighter GmbH has suggested incorporating improvements to the bandwidth capabilities of the MIDS datalink, AIS-driven sensor fusion and the human-machine interface (HMI), into upgrade schedules in the early 2020s. These offer very significant boosts to the platform's capability to thrive in the information-centric battlespace out to 2030 and beyond.[8]

A variety of airframe and engine upgrades have been suggested such as thrust-vectoring engines and leading-edge root extensions (LERX) to improve the aircraft's already formidable WVR performance, and conformal fuel tanks (CFTs) to increase range without significant drag penalties. The CFTs can theoretically be mounted on all Tranche 3 aircraft if certified and would certainly give a boost to the aircraft's ability to mount long-range interdiction missions. However, the RAF has a very capable tanker fleet in the A330 MRTT and extensive experience operating with other NATO-member tankers. This means that the Typhoon's range is more than adequate without CFTs, except in situations where aerial tanking is in critically short supply.[9] Even without aerial refuelling, a large wing and fuselage and the ability to carry up to three supersonic external fuel tanks give the Eurofighter an impressive range. Eurojet's offers of more powerful or more efficient variants of the EJ-200 engines have likewise met with lukewarm responses, since the platform already boasts formidable performance.[10] Whilst pilots would welcome the performance enhancements such upgrades would bring, all those interviewed agreed that they should not be viewed as a priority and that scarce funding could be much better spent on other aspects of the Eurofighter system.

7. Personal interviews with frontline Aeronautica Militare Eurofighter pilots and commanders, Grosseto Airbase, Italy, 16 January 2015.
8. Personal interview with ex-RAF Typhoon pilot and Eurofighter capability manager, London, 17 March 2015.
9. Tim Ripley, 'UK Downplays Conformal Fuel Tanks for Eurofighter Typhoon', *IHS Jane's Defence Weekly*, 4 December 2014.
10. Personal interviews with Aeronautica Militare staff officers, Rome, 15 January 2015, and front-line Aeronautica Militare Eurofighter pilots and commanders, Grosseto Airbase, Italy, 16 January 2015.

There is no fundamental reason why the Eurofighter platform should not be at least the equal of any other European multirole aircraft. The aircraft has suffered from deeply unflattering public comparisons in the strike role to both the Tornado and French Rafale due to the delayed implementation of weapons integration, software upgrades and DASS improvements. The Rafale is a similar design in many respects, having a similar delta-canard aerodynamic configuration and emerging from common programme roots. Pending the entry into service of Storm Shadow and Brimstone II, on contract for the RAF by 2018, Rafale is possibly a more mature multirole platform due to full integration of the most advanced French air-to-ground weaponry and operational AESA radar. This should be seen as indicative of a failure on the part of the Eurofighter nations to invest properly in the potential of the platform following its initial introduction into service. With a significantly better thrust-to-weight ratio, coupled with a larger radar aperture allowing a more powerful and high-resolution AESA array, the Eurofighter has the potential to be an even more-capable multirole platform than the Rafale. However, the Eurofighter upgrade programmes have been consistently underfunded and priorities have been repeatedly changed at short notice. The result has been a widespread view held by politicians and the media that the platform itself is inflexible and unsuitable for modern requirements.

V. Conclusions

Europe's major air forces face serious challenges in the fifteen years up to 2030 and in all likelihood well beyond. Shrinking budgets come at a time when aging legacy fleets require replacement, fifth-generation platforms are extremely expensive and late, and high-end ground- and air-based threats are proliferating. This combination threatens to erode Europe's significance as a combat-air provider. However, in the Eurofighter, European states have the most-formidable non-stealth air-superiority platform in the world. Once the CAPTOR-E AESA radar and Meteor BVRAAM are integrated, European air forces will have a fighter capable of deterring and, if necessary, defeating any opposing air threats they may meet until the mid-2020s and any non-peer threats substantially beyond that. It should not be forgotten that the primary mission of any air force is to defend its state's airspace and in this the Eurofighter is formidably capable. With radar and armament upgrades funded and on schedule, it will only become more so until the mid-2020s even once potential opponents begin to field small numbers of stealth fighter and bomber aircraft. The RAF's P1Eb software already enables its Typhoon force to conduct true multirole sorties with Paveway IV PGMs whilst also retaining formidable air-to-air capability. The integration of Storm Shadow ALCMs and Brimstone II remain a priority for the RAF, with both planned for integration by 2018. These will be increasingly attractive for the Italian air force as their Tornado IDS fleet is drawn down around 2020. With these capabilities, the Eurofighter will represent a mature and extremely potent strike platform with much greater multirole and self-escort capabilities than the Tornado and AMX types it replaces. However, an important priority for the RAF, in particular, should be the integration of the superb RAPTOR reconnaissance pod onto the Typhoon force. This would allow the UK to continue its contribution of high-quality Tac/R capabilities to US-led coalitions after the Tornado is retired. With the significant reductions in UK combat-air mass in the past decade, it is vital that the RAF retains its Tac/R function, which is under provided by European air forces and is a niche capability highly valued by the US.

In terms of upgrades to the platform itself, operators' preferences are clear. Airframe and engine upgrades such as LERX to increase high-alpha performance, thrust vectoring and conformal fuel tanks would all improve the aircraft's performance. However, these should not be viewed as urgent. The Eurofighter's kinematic performance is already superior to any other currently operational fighter aircraft with the exception of the F-22 Raptor. Instead, pilots across the RAF, Luftwaffe and Aeronautica Militare want the small-scale problems with subsystems fixed as a priority. Whilst huge progress has been made in eradicating the majority of software and equipment bugs since the aircraft first entered service in 2003, there are still noticeable deficiencies with some subsystems such as the radios. Fixing

these issues should not be nearly as capital-intensive as major modifications such as CFTs or the CAPTOR-E radar. However, they offer very significant performance gains through removing performance bottlenecks in both system architecture and pilot workload.

Ensuring carefree communications and data sharing between Eurofighters and other assets is essential not only to unlock the full potential of the platform in its current role but also to ensure full interoperability with the information-centric F-35. The combat potential of both aircraft could be greatly increased if they were operated together using concepts of operations (CONOPS) which plays to their specific strengths. The F-35B possesses formidable situational-awareness and information-processing capabilities as well as an LO design which allows it to approach substantially closer to advanced threats. However, these come with trade-offs in terms of limited range, kinematic performance and stealth-payload capacity.[1] The Eurofighter offers excellent range, kinematic performance and payload. Once Storm Shadow and the German Taurus KEPD 350 ALCMs are integrated, along with the Meteor, the Eurofighter will be able to offer long-range stand-off precision strike and air-to-air capabilities to support the F-35 from a safer distance and altitude. At the same time, the F-35 offers the potential to greatly improve the Eurofighter's situational awareness, clear temporary windows into advanced enemy air defences for the larger Eurofighter force and provide control of the air, in terms of the C2 and traditional senses.

Whilst the Eurofighter has had a troubled development history, this should not obscure the fact that its operators now possess one of the world's finest air-superiority aircraft with growing and potentially superb multirole strike and reconnaissance capabilities. Whilst the future of European combat air may indeed belong to the F-35 and its Future Combat Air System (FCAS) successor, the RAF, Luftwaffe, Aeronautica Militare and Ejército del Aire cannot afford to neglect investment in the Eurofighter in the near term. The platform will continue to provide the backbone of Europe's air power until at least 2030 and, as such, essential subsystem fixes, weapon and software integration, FOC for CAPTOR-E and enhanced sensor fusion should be prioritised. These will ensure that the Eurofighter can fill the gap left by diminishing combat mass, aging legacy fleets and the late arrival of next-generation aircraft. If investment is sustained in the mid to long term, the significant systems growth potential on top of the formidable basic airframe/engine combination, as well as upgrades to weapons systems, radar, PIRATE and the DASS, mean that the Eurofighter is capable of remaining a valuable and potent multirole asset for air forces well beyond 2030.

1. The F-35B range is limited in comparison to similarly sized strike aircraft due to demands of short take-off and vertical landing operations and the inability to carry external under-wing fuel tanks in operational environments where its stealth attributes are required.

About the Author

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