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Acronyms and Abbreviations

ABM	Air battle management
ABM&S	Air battle management and surveillance
AESA	Active electronically scanned array
AEW	Airborne early warning
ATAR	Air-to-air refuelling
AWACS	Airborne warning and control system
BLOS	Beyond line of sight (communications or datalink)
C2	Command and control
CSP	Capability sustainment programme
ELINT	Electronic intelligence
E-3D	ABM&S aircraft operated by the RAF
E-3F	Modernised ABM&S aircraft operated by the French Air Force
E-3G	Modernised ABM&S aircraft operated by the United States Air Force
EO	Electro-optical
ESM	Electronic Surveillance Measures
FAF	French air force (L'armée de l'air)
HAPS	High altitude pseudo-satellite
IADS	Integrated air defence system
IFF	Identification Friend or Foe
IRST	Infrared scan and track
ISR	Intelligence, surveillance and reconnaissance
ISTAR	Information, surveillance, target acquisition and reconnaissance
LOS	Line of sight (communications or datalink)
LPI	Low probability of intercept
MADL	Multifunction advanced data link
MEZ	Missile engagement zone
MoD	Ministry of Defence
NIFC-CA	Navy Integrated Fire Control-Counter Air (a United States Navy programme)
PED	Processing, exploitation and dissemination
PESA	Passive electronically scanned array
P_K	Probability of kill
PLAAF	People's Liberation Army Air Force
RCS	Radar cross section
SAM	Surface-to-air missile
SDSR	Strategic Defence and Security Review
SEAD	Suppression of enemy air defences
SIGINT	Signals intelligence
UHF	Ultra-high frequency
USAF	United States Air Force
VLRAAM	Very long-range air-to-air missile

Executive Summary

THE RAF'S SIX E-3D Sentry Air Battle Management and Surveillance (ABM&S), or AWACS, aircraft perform a large number of functions.[1] Within these, their three primary missions are to provide early warning and classification of approaching aerial threats in an operational area, to provide airborne command and control (C2) functions for complex air operations, and to selectively relay communications from a multitude of assets in the joint environment. Of the three tasks, the air C2 mission is probably the most crucial since it is an absolute requirement for complex air operations in both permissive and non-permissive environments.

However, much-needed modernisation and upgrades to the RAF's E-3D fleet have not been carried out, which has resulted in it lagging behind the French and US E-3 fleets in terms of both reliability and mission system capacity. This issue was recognised in the 2015 National Security Strategy and Strategic Defence and Security Review (SDSR), which committed the UK government to upgrade and extend the service life of the E-3D fleet until 2035.

In order to extend the aircraft to meet this stated ambition, the RAF began a capability sustainment programme (CSP) for its E-3D Sentry in 2016, with the aim of bringing the RAF's six remaining airframes up to at least the current modernised standard of the E-3 fleets operated by the US Air Force (USAF) and French Armée de l'air (FAF). The programme is estimated to cost at least £2 billion and is intended to have the whole fleet upgraded by 2025 to enable the fleet to operate until 2035.

However, it is unclear that a capability sustainment programme of the E-3D based on the mid-life upgrade made by the USAF and FAF during the 2000s, which extended their E-3 fleets to 2035, is still the optimal path for the RAF to take today. First, recent technological developments – such as missiles and aircraft employing radar cross section (RCS) reduction features or hypersonic speeds – have cast doubt on the ability of the E-3D fleet to detect some potential threats. Second, fifth and 4.5th-generation fighters are increasingly capable of generating higher fidelity situational awareness in their operating areas than an E-3, thus undermining its role for the first of the primary missions outlined above. Finally, the proliferation of threat technologies – in particular very long range air defence systems and very long range air-to-air 'AWACS-killer' missiles, as well as the introduction of non-Western fifth-generation fighters – will force large support enabler platforms such as E-3s and tankers to operate at much greater standoff ranges from the main battlespace than in previous conflicts. This is likely to degrade the usefulness of the E-3's primary sensor suite due to range limitations.

1. The RAF took delivery of seven E-3 airframes but only six are operational, with the seventh airframe used for training only. Since the RAF refers to a fleet of six aircraft when discussing E-3D, that number will be used for this paper.

This suggests that it may be worth exploring other options for providing air C2 for the RAF in the next two decades and beyond. Indeed, there are multiple options for potential ABM&S based on modern commercial airframes which could provide much greater mission availability, cheaper operating costs and better spares availability than E-3. They would also have more inherent electrical power and cooling capacity to provide more capable communications suites, mission systems and sensors. Procuring a new ABM&S platform solution would incur significant upfront acquisition, training and introduction to service costs. As a comparative example, the RAF's nine new P-8 Poseidon maritime patrol aircraft, featuring cutting edge sensors, mission system and an airframe based on a commercial airliner (Boeing 737-800) are being procured off the shelf from the US at an estimated cost of £2.47 billion, which includes infrastructure set up costs and training. Part of the deal is a demanding timeframe with the first aircraft due for delivery in 2019/20 from a deal agreed in July 2016.[2] While the P-8 is obviously not an ABM&S platform, it shares many similarities in terms of being an airliner-derived, long endurance platform designed around an advanced sensor suite, mission system and signal processing capabilities, and a large mission system crew. Therefore, it seems reasonable to assume that an off-the-shelf ABM&S replacement for the RAF's six E-3Ds based on a commercial derivative with a modern AESA radar and mission system would not cost dramatically more than the current £2 billion plan for the E-3D CSP, and could be delivered in a similar timeframe (by the mid-2020s).[3]

The paper explores the trends and emerging capabilities that may well shape the final form of the post-2035 replacement for the E-3 across NATO, since it is obviously desirable to synchronise the RAF's ABM&S capability with the US and NATO E-3 replacement timetable. One potential option for the US is a distributed network of multirole sensor and shooter platforms with ground-based remote C2 provision – especially if the US Navy's Integrated Fire Control-Counter Air (NIFC-CA) programme proves successful when fully fielded through the 2020s.[4] Chinese and other rival powers starting from more of a clean slate in terms of air C2 and wide-area surveillance capabilities may even end up showing the US and its allies the way in this field.

Finally, this paper assesses the different options that are potentially available to the RAF in continuing to meet the government's SDSR-mandated objective to extend the crucial air C2 capability provided by the E-3D out to at least 2035. Even assuming that the solution chosen to replace the E-3 for the USAF is available on time in 2035, it will take time to procure and make available to allies like the UK, so whatever the RAF is relying on for air C2 and AEW will

2. RAF, 'MOD Seals the Deal on Nine New Maritime Patrol Aircraft to Keep UK Safe', press release, 11 July 2016.
3. Figure of £2.47 billion is taken from the Pentagon's Foreign Military Sales announcement figure of $3.2 billion calculated using the exchange rate on 18 May 2017. Defense Security Cooperation Agency, 'United Kingdom – P-8A Aircraft and Associated Support', 16–26, press release, 25 March 2016.
4. NIFC-CA is an ongoing US Navy project which aims to link sensor and shooter platforms into a unified weapons system construct that will enable weapons employment to be conducted at the maximum kinetic range of each missile, rather than being limited by the sensor capabilities of the launch platform. For information on some of the latest developments in NIFC-CA, see Lockheed Martin, 'F-35 and Aegis Combat System Successfully Demonstrate Integration Potential in First Live Missile Test', press release, 13 September 2016.

almost certainly have to last beyond 2035 before being replaced. With state-on-state conflict seemingly a growing possibility and new threat technologies already posing challenges for even the modernised E-3 fleets of the USAF and FAF, the RAF should not be reluctant to consider a more unconventional solution for its ABM&S requirements over the next 20 or so years, instead of simply patching up the E-3D Sentry fleet through a capability sustainment programme in the hope that ‘it will do’ until the US provides a NATO-wide E-3 replacement.

Introduction

IT IS WELL known in UK defence circles that the RAF's E-3D Sentry Air Battle Management and Surveillance (ABM&S) fleet, more commonly known as AWACS, is facing significant reliability and obsolescence issues as a result of difficult investment decisions required by the Ministry of Defence (MoD) since the mid-2000s. This is in spite of the fact that in terms of airframe hours flown, the RAF's E-3Ds are among the youngest military Boeing 707 derivatives flying. Much-needed modernisation and upgrades, most notably a planned mid-life upgrade called Project Eagle – postponed indefinitely in 2009[1] – have not been funded and this has resulted in an E-3D fleet that lags behind the French and US fleets in terms of both reliability and mission system capacity. Nevertheless, the airborne command and control (air C2) function which the E-3D fulfils for the RAF is a critical mission set in both permissive and potential high-threat environments. Therefore, recognising the need to maintain air C2 capabilities over the next twenty years, the National Security Strategy and Strategic Defence and Security Review (SDSR) in 2015 committed the government to upgrading and extending the service life of 'Sentry and Rivet Joint until 2035'.[2]

In order to extend the aircraft to meet this stated ambition, the RAF began a capability sustainment programme (CSP) for its E-3D Sentry fleet in 2016. The aim of this CSP is to bring the RAF's six remaining E-3D airframes up to at least the modernised standard of the E-3 fleets operated by the United States Air Force (USAF) and French Armée de l'air (FAF). The programme is estimated to cost at least £2 billion and is intended to have the whole fleet upgraded by 2025.[3] While the government has committed to Sentry capability sustainment until 2035, the precise sustainment solution has not yet been finalised. It is worth remembering that this RAF effort to bring the E-3D to rough parity with the USAF/FAF E-3G/F Block 40/45 standard will not solve most of its inherent limitations with regards to its mechanically scanned radar, low-observable and hypersonic target detection and tracking, mechanical complexity and lack of LPI scanning capabilities for the next decade and a half.[4] This is, instead, a long overdue process to bring the ageing RAF E-3D fleet back up to the standard that was intended had the MoD been able make different investment decisions over the past decade. As will be seen, however, Block 40/45 standard – while providing a substantial mission system capability increase over the RAF's current E-3D standard – should not be assumed in itself to be sufficient to make Sentry the most

1. Urmee Khan, 'Troops' Lives Being Put at Risk after MoD Cuts Five New Equipment Programmes', *The Telegraph*, 1 June 2009.
2. HM Government, *National Security Strategy and Strategic Defence and Security Review 2015: A Secure and Prosperous United Kingdom*, Cm 9161 (London: The Stationery Office, November 2015), p. 32.
3. Howard Wheeldon, 'UK Defence (254) – RAF Waddington Prepares For Exciting Future', CMSStrategic.com, 6 June 2016.
4. For details on Block 40/45 upgraded standard, see Darren D Heusel, 'E-3 Block 40/45 Deploys to Combat Theater.. The Wait is Over', US Air Force Air Combat Command, 20 November 2015.

efficient possible solution to the UK's air battle management (ABM) and air C2 needs out to its proposed renewal date of 2035.

The aim of this paper is certainly not to criticise the personnel who man the RAF's E-3D force and who undertake near-constant operations with assets facing reliability and availability challenges. Rather, it is to examine the crucial questions surrounding the identification of the most efficient way to deliver the RAF's ABM and air C2 needs out to 2035, whether there are alternative options available in terms of platforms or systems and what they might look like both in the next two decades and post-2035. The RAF in particular is at a crossroads, having committed to the first stages of an expensive CSP that is required to make sure the E-3D fleet is fit for purpose not only in 2025, but also to ensure it can last until its post-CSP target out-of-service date of 2035. However, this process is still at a sufficiently early stage where it is still constructive to examine whether this is indeed the MoD's most efficient course of action. In exploring these issues, this paper examines a range of constraints being placed on traditional ABM&S and considers major trends in emerging approaches to future ABM&S systems, which together may well shape the procurement decisions of the UK in particular and of the US and NATO more broadly.

The study was conducted via a combination of desk research, interviews with serving personnel, site visits and a roundtable discussion held at RUSI in late February 2017, during which current and former RAF ISTAR (information, surveillance, target acquisition and reconnaissance) force members as well as subject matter experts from Airbus, Boeing, Saab and Northrop Grumman were invited to critique a draft of the paper in open discussion with the author. However, the analysis and conclusions presented here remain those of the author alone and are not intended to speak for the RAF or the various defence firms that have kindly cooperated with the research process.

I. E-3D and the Core Air C2 Mission

EVER SINCE THE E-3 Sentry was accepted into USAF service in 1977, it has set the standard for airborne early warning (AEW) and C2 in Western air operations. AWACS aircraft blend a medium-large airframe with a powerful radar for wide-area surveillance, communications arrays and a significant number of aircrew to operate the systems and provide air C2 to friendly forces. The system's performance in the 1991 Gulf War made the advantages of integrated AWACS capabilities abundantly clear. The ability to orbit outside the range of threat aircraft and surface-to-air missiles (SAMs) while providing ABM, threat detection, tracking and identification data to friendly aircraft up to 555 km (300 nm) away has repeatedly proved a critical force multiplier for NATO air operations. Without delving too deeply into doctrinal definitions, this study will use the term 'air C2' to refer to the provision of command and control functions from the air, including ensuring coordination and communications in a joint environment, as opposed to the more air-centric ABM mission, which for this study will be considered a subset of the wider air C2 mission set.

Due to the size and general complexity of the E-3 system, as well as its aircrew complement of eighteen including ten mission system operators, these aircraft are a significant drain on funding and manpower for air forces struggling with inadequate combat mass, personnel numbers and funding. In 2012, for example, the MoD estimated that an RAF E-3D squadron with six aircraft required 308 personnel on average and cost £99 million annually to run under normal conditions.[1] This figure will certainly be higher in 2017 after five years of constant operations and well-publicised mechanical issues and fleet groundings.[2] This compares with approximately 150 personnel who make up V (AC) Squadron, which operates five smaller Sentinel R1 ground-mapping radar aircraft and which, even with an inefficient, unplanned service extension model, is estimated to cost less than £50 million annually until 2018.[3] The relatively high operating costs of the E-3D fleet are compounded by poor reliability: half the fleet was in sustainment or deep maintenance in early 2015 – comparing badly with all other RAF fixed-wing assets – while in late 2016 to early 2017 the entire fleet was grounded due to wiring problems which have subsequently been fixed.[4]

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1. House of Commons Defence Committee, *Future Maritime Surveillance*, Fifth Report of Session 2012–13, HC 110 [incorporating HC 1918-i of Session 2010–12] (London: The Stationery Office, 2012), p. 103.
2. See, for example, Ben Farmer, 'RAF Fleet of Sentry Early Warning Planes Grounded after Wiring Fault', *The Telegraph*, 7 November 2016.
3. The Sentry force was reported to cost £198m in total to run from 201418. See Beth Stevenson, 'NATO Summit: MoD Discusses Sentinel Maritime Upgrades with Raytheon', *FlightGlobal.com*, 4 September 2014; RAF Waddington, Number V (Army Cooperation) Squadron, <http://www.raf.mod.uk/rafwaddington/aboutus/5acsquadron.cfm>, accessed 17 May 2017.
4. *Hansard*, House of Commons, 'Military Aircraft', Written Answers, 4 March 2015.

The E-3D (like other AWACS platforms) performs a large number of functions, but its three primary missions are:

- To provide early warning and classification of approaching aerial threats in an operational area.
- To provide airborne C2 functions for complex air operations.
- To selectively relay communications from a multitude of assets in the joint environment.

The E-3D can perform communications relay functions automatically, but this ties up limited and high-demand radio channels, denying their use for other functions and so this is generally not a priority task as it saps mission capacity.

Of the three tasks, the air C2 mission is probably the most crucial and most likely to remain a relatively unchanged operational requirement out to 2035. For offensive operations against a near-peer opponent, the task of coordinating the activities of the large number of assets required to execute the suppression of enemy air defences (SEAD), offensive counter air patrols, strike missions, air-to-air refuelling (ATAR) support and battle damage assessment requires significant human capacity and communications link bandwidth. E-3 is the main UK asset for this task, and operates as a capacity multiplier for the force commander – greatly increasing the number of missions that can be coordinated effectively at any given time. E-3 orbits must maintain standoff distance from enemy threats, and so they remain as close to the battlespace as is safe, along with tanker aircraft and other standoff intelligence, surveillance and reconnaissance (ISR) assets, such as Rivet Joint and Sentinel aircraft. As a campaign progresses and (hopefully) enemy air defences are increasingly degraded or destroyed, the E-3s and tankers can operate further and further forward, enabling a corresponding growth in their mission effectiveness. In the permissive air environments of Afghanistan, Iraq and Syria, where the UK has become used to operating over the past fifteen years, the RAF's E-3D has been able to operate almost at will in the heart of the battlespace, where its own radar coverage is most useful. It has also been able to conduct its air C2 role predominantly through ultra-high frequency radio channels (UHF) and other line-of-sight (LOS) communications and data links without significant disruption.

During this same period, however, several technological developments have conspired to alter the character of the often unsung but critical mission set performed by large AWACS platforms such as the E-3 in modern air operations. The first of these is the steady increase in the sensor capabilities and data processing power carried by modern fighter aircraft, which are often capable of generating higher fidelity situational awareness for individual pilots in their immediate operational areas than the E-3's own sensors. This is true for conventional air threats in many circumstances, but it is especially true for threat technologies which require extremely modern radar technology to track reliably. The proliferation of missiles and aircraft employing radar cross section (RCS) reduction features or hypersonic speeds has introduced a growing range of potential threats which even modernised USAF-standard E-3G Block 40/45s have great difficulty detecting and tracking with their AN/APY-1/2 mechanically scanned radar system.

Sensor Trends and Limitations

In terms of radar coverage, a traditional fighter's radar array which is limited in size and scanning arcs by being mounted in a streamlined nose fairing can be likened to a person using a powerful but narrow beam torch in a large darkened room. They can see whatever they point their radar at often in extremely impressive detail, but are largely blind to the rest of their surroundings. An E-3's AN/APY-1/2 or indeed any other AWACS-class array can be thought of in this analogy as turning on a light bulb on the ceiling: while it might not illuminate everything in every corner, it provides 'big picture' awareness that is very hard to achieve with even large numbers of fighter radar arrays networked together. However, active radar-scanning is no longer the only effective means of building situational awareness available to aircraft in the modern battlespace. The E-3D carries Electronic Surveillance Measures (ESM) pods to passively track and identify electronic emissions without relying on the AN/APY-1/2 active scanning mode. Advanced defensive aids suites on modern fighters also allow aircraft such as the RAF's Typhoon and F-35 to passively track hostile electromagnetic emissions and can give distance, track and bearing information for multiple threats simultaneously. Furthermore, many modern fighter aircraft are also equipped with either electro-optical or infrared tracking systems that can provide a high-fidelity picture of threats such as enemy aircraft or missile launches, as well as keeping tabs on friendly assets without emitting any detectable radiation themselves, albeit at shorter ranges than active radar and subject to environmental disruption.

The F-22 Raptor is an example of where fifth-generation situational awareness has made a subset of the fighter community less dependent on AWACS support. It has granted F-22 pilots a higher fidelity threat picture within their own frontal radar-hemisphere coverage than the E-3, even if they are not yet able to transfer that situational awareness in full to other, less advanced friendly platforms.[5] F-22 pilots operationally fulfil an active battlespace management role in their interactions with friendly fourth-generation jets according to USAF fighter integration doctrine (3-1), although individual pilot workload remains a bottleneck in that respect. As such, not only is the fifth-generation community already able to see the tactical situation in equivalent or higher fidelity than E-3 operators, but the F-35 will improve on, and extend, those capabilities to a host of air forces outside the small USAF F-22 community over the coming decade. Furthermore, from Block 4 standard onwards,[6] the F-35 is expected to be able to share this situational awareness with legacy assets much more easily than at present – a trend which will almost certainly accelerate through the 2020s, driven by the need to maintain the combat effectiveness of legacy assets against increasingly dangerous threats.[7] The more that fourth-generation aircraft rely on their fifth-generation colleagues for situational awareness,

5. Author conversation with currently operational USAF F-22 pilots, London, May 2016.
6. F-35 software development is grouped into Block X standards which progressively 'unlock' more advanced and flexible capabilities for the jet. The US Marine Corps declared IOC with Block 2B in August 2015, and US Air Force declared IOC with Block 3i software in August 2016. Block 3F is currently in final testing and evaluation and full operating capability will be achieved with Block 4 at some point in the early 2020s.
7. For more information, see Justin Bronk, 'Maximum Value from the F-35: Harnessing Transformational Fifth-Generation Capabilities for the UK Military', *Whitehall Report*, 1-16 (February 2016).

threat warning and targeting information, the less critical the surveillance role of a traditional AWACS will be for a high-end air combat mission against a state opponent.

This trend, however, should be balanced against the likely continued importance of the primary air C2 function that AWACS assets are performing at present over more permissive operating areas, such as Syria and Iraq. Here, the presence of low-observable assets actually complicates the already difficult but essential task of deconflicting the often very large numbers of sorties being undertaken in close proximity by a number of states often listening to different frequencies, on different and sometimes dynamically tasked missions and sometimes unaware of each other's presence. This mission is made doubly difficult by the need to coordinate with a host of ground forces, some of which may often be irregular or at least non-NATO and which fast jets in particular often have no means of directly contacting securely. In this regard, the RAF's E-3D still performs well: with its large complement of ten mission system operators, the E-3D is able to provide high levels of capacity to commanders and aircrew alike for mission tasking, airspace deconfliction and communications relay functions in spite of sensor limitations.

The air C2 mission will remain crucial for Western air operations in permissive and non-permissive environments both in the years up to 2035 and beyond, not least due to the proliferation of more unmanned and even autonomous air vehicles alongside low-observable and legacy manned aircraft. Therefore, when considering what comes after the E-3D and the broader future of the current ABM&S mission set, the question is not whether the air C2 component will be required. It is whether this air C2 function is best carried out by people operating a mission system in a medium-large airliner airframe at a safe distance behind the battlespace or by people on the ground in the UK or elsewhere.

In an ideal world, one would want the redundancy, extra capacity and electromagnetic and cyber resilience that could be achieved by operating both ground-based, remote air C2 and on-station C2 and deconfliction services from an airborne asset. However, with defence continuing to be asked to do more with less, a continuing mismatch between funding and political ambition and so many competing priorities in the Equipment Plan,[8] the cost for such duplication may be too great. Therefore, it is worth taking a look at the operational constraints that are likely to be placed on the E-3D, or, indeed, any large airliner-based enabling asset, up to and beyond 2035 in order to compare the risks to operational effectiveness of the airborne asset versus a remote ABM and network-based situational awareness approach. With this in mind, the next section will examine the projected operational vulnerability of, and consequent operational constraints likely to be placed on, the E-3 Sentry platform in its current upgraded US (E-3G) and French (E-3F) Block 40/45-standard out to 2035, its proposed out-of-service date.

Threat-Based Constraints on AWACS Operations

The second major factor which is already affecting the operational character of the ABM&S mission set except in permissive environments are long-range SAMs and very long-range

8. National Audit Office, *The Equipment Plan 2016 to 2026*, HC 914 (London: The Stationery Office, 2017).

air-to-air missiles (VLRAAMs). Until neutralised, these threats effectively force AWACS aircraft to operate so far back from defended airspace that the usefulness of their on-board radar arrays is greatly reduced. This standoff distance also forces them to rely on beyond-line-of-sight (BLOS) links for at least some of their air C2 role, with strike and offensive counter air assets further forward. Protecting large AWACS aircraft from such threats inside missile engagement zones (MEZs) is an increasingly complex and difficult task even for the USAF with its unparalleled number of high-end SEAD and air dominance assets. Essentially, an E-3 is an airliner airframe whose g-tolerance for defensive manoeuvring is further reduced by the structural strains of mounting a large, heavy radar array on the dorsal spine of the aircraft. All AWACS aircraft have large radar cross sections. They also broadcast very high-powered radar signals in order to perform their AEW role. This makes it easy to passively track them from at least as far as the radar horizon unless they employ active electronically scanned array (AESA) radars with low probability of intercept (LPI) and frequency agile technology, which E-3s does not but more modern AWACS types do.

In the unclassified domain at least, the USAF lists the E-3G Sentry Block 40/45, which uses the same AN/APY-1/2 mechanically scanned radar as the RAF's E-3D, as capable of tracking aerial targets with its active radar scan out to at least 400 km (source states at least 250 miles), which fits with the distance to the horizon when flying at around 35,000 ft.[9] The AN/APY-1/2 does have a pulse mode for scanning beyond the horizon but in general, consistent target-grade tracking and identification of non-cooperative threats (those not broadcasting Identification Friend Or Foe [IFF] or civilian transponder codes) is limited to inside the radar horizon. This gives us, as a rule, a range limitation of around 370–400 km for the standoff AEW capabilities of the E-3 or indeed any single-aircraft AWACS system for low-flying level threats, although for those flying at medium and higher altitudes the radar horizon is significantly less restrictive and RAF sources quote a figure of about 555 km (300 nm).

The problem with the range limitations imposed on any radar system by the curvature of the earth is that existing mobile SAM systems, such as the Russian S-300V4 and S-400, are already being tested with missiles that are designed to destroy large targets such as AWACS aircraft at ranges of up to 400 km, for example the 40N6 and 9M82MD.[10] They too suffer from the radar-horizon limitation, but their missiles can be cued in by air defence radars further forward than the launch vehicles themselves. What these very long-range SAM systems already mean is that an E-3 or any other AWACS aircraft cannot tweak its flight path to 'out-range' and avoid the MEZs of a modern Integrated Air Defence System (IADS) without staying several hundred kilometres behind the battlespace. This would leave friendly aircraft without the benefit of full coverage from their AEW, threat identification and IFF interrogation capabilities inside

9. US Air Force, 'E-3 Sentry (AWACS)', 22 September 2015, <http://www.af.mil/AboutUs/FactSheets/Display/tabid/224/Article/104504/e-3-sentry-awacs.aspx>, accessed 18 May 2017. The distance to the horizon increases with altitude above the earth's surface and at 35,000 ft the distance is roughly 370 km.
10. For example, see *GlobalSecurity.org*, 'S-400 SA-21 Triumf – Missiles'; Guy Plopsky, 'Are Russia's Lethal S-400 SAMs Equipped with the Latest Long-Range Missiles?', *National Interest*, 19 January 2017.

defended airspace. The E-3 can still perform battlespace management functions through LOS and BLOS links and provide a communications relay capability while remaining further back from the battlespace. However, the usefulness of its own radar systems, except in a defensive scenario, is significantly degraded by this imposed standoff range.

Very long-range 'AWACS killer'-class SAMs and even air-launched missiles are not, strictly speaking, a new development. The Russian S-200 SAM system, first deployed in 1967, was capable of striking large, non-manoeuvrable targets at up to 300 km under ideal conditions, but the 5N62 Square Pair radar used to scan for targets and guide the missile after launch was limited to 270 km and was relatively straightforward to jam by modern standards. Furthermore, the S-200 launchers were static, took a long time to load and prepare, and required large sites which were easy to identify and map via space-based reconnaissance, as well as using specialised air defence radar-triangulating aircraft such as the RC-135U Combat Sent. Likewise, air-launched anti-AWACS missiles that were developed during the late Cold War, such as the Russian R-37 Vympel, remained extremely large, heavy and still required a launch aircraft to get within around 150 km of an AWACS for a direct shot. If not, these older types had to rely on a blind shot at the area when an AWACS was thought to be operating using inertial navigation system-guidance in the hopes that the missile would get close enough to find the target itself. Terminal homing was achieved in this mode by the missile's own seeker if it managed to get close enough to acquire the target and the whole approach resulted in a low probability of kill (P_k).

The current generation of very long-range SAM systems, such as the Russian S-400 and the Chinese HQ-9, are different. These systems are highly mobile and carry many more missiles, while the radars, which find targets at very long range and provide missile guidance data, are likewise much smaller, more numerous, harder to jam and give more accurate target information. It is therefore much harder to put ground-based air defence radars out of action, much harder to jam them, and the missiles they guide are increasingly resistant to jamming and carry dual-mode seekers. These systems pose a serious danger even to modern fourth- and 4.5th-generation fighter aircraft that have potent defensive aids suites, extreme aerodynamic agility for evasive manoeuvres and can accelerate rapidly to well above the speed of sound. An AWACS, such as the E-3, has no such advantages and must avoid such threats, relying on jamming as a last-ditch defensive option. Passive defensive countermeasures such as chaff and flares are not carried as they are unlikely to be an effective decoy to modern missile threats for such a large aircraft with a huge RCS and emissions signature. Jamming at high-power levels, even with modern Digital Radio Frequency Memory techniques for spoofing enemy radar and the capability to rapidly adjust to frequency changes by threat systems, cannot reliably guarantee survivability except for short periods against modern SAMs. Even specialised electronic warfare assets that also possess fighter-class performance, such as the US Navy's EA-18G Growler, have seen their survivability within high-end IADS severely restricted by advances in SAM and air defence radar technology over the past decade. AWACS, along with other large electronic intelligence (ELINT) and signals intelligence (SIGINT) platforms, are well understood as critical enablers for Western air power; it is little surprise then that various adversary nations have worked hard since the 1990s to develop countermeasures to keep them away from their airspace. Furthermore, Russian and Chinese aggressive deployments in Eastern Europe and the

South China Sea respectively are greatly increasing the number and size of 'no-go areas' for AWACS aircraft in the event of a conflict.[11]

Even more worryingly, high-end air defence systems, such as the S-300V4 and HQ-9, are inexpensive compared to Western combat aircraft and are being bought enthusiastically by 'near peer' rival countries, including Iran, which would previously have been considered relatively manageable threats for Western air power.[12] This proliferation trend will almost certainly be strengthened by a more unstable, multipolar geopolitical landscape, which appears the most likely outlook based on current trends.

It is, therefore, necessary to ask the question: how will the ABM/air C2 mission and the E-3 specifically be affected by being forced to stay much further back from the battle zone than in previous operations such as Kosovo and Iraq in 1990–91 and 2003 even against near peer opponents between now and 2035 when the USAF and NATO as a whole plan to procure a replacement? Given the proliferation of high-end threat systems today, and the trajectory of Chinese military spending in particular in comparison to the US and its allies, it seems fair to assume that the current threat picture where the E-3s are operating at significant risk within the radar horizon of modern SAM threats is only going to get worse. It is not only the case that the E-3 and future AWACS types will have to remain outside the increasingly large MEZs of advanced SAM systems. In many parts of the world, threats may actively come hunting large critical enabler aircraft such as the E-3 and tankers far inside what has until recently been assumed as the controlled airspace behind the battle zone.

China, for example, is actively flight-testing a 320 km-plus range VLRAAM which is 20 ft long and has been launched from Shenyang J-16 fighters. This missile reportedly follows a loft-cruise flight profile at up to 100,000 ft to make it harder to detect and improve energy retention in the cruise. It also is designed to use satellite uplinks and other BLOS data links for mid-course corrections and carries active radar, anti-radiation (to home in on transmitting radar systems) and infrared multi-mode seeker capabilities, all of which combine to give a much improved P_k compared to previous generations of long-range air-to-air missiles. The missile is specifically designed to allow anti-AWACS engagements by Chinese fighter aircraft using sensor data from other platforms, and if fired in large numbers would be a very dangerous threat for even upgraded US E-3 and E-2 Hawkeye AWACS, as well as tankers and other ELINT aircraft.

The maturation of non-Western stealth aircraft is also likely to increase the vulnerability of large, subsonic, non-stealthy support aircraft in the future operating environment. Aircraft such as the J-20A being developed by Chengdu Aerospace Corporation, with multiple low-rate production examples already in service with the People's Liberation Army Air Force (PLAAF), will be hard for existing E-3 Sentry aircraft to track. The US Navy's E-2D Hawkeye and AESA-equipped

11. For example, *ImageSatIntel (ISI)*, 'New Deployment of HQ-9 in the South of Hainan May Create a No-Fly Zone in the South China Sea', 11 May 2017; *BBC News*, 'Kaliningrad: New Russian Missile Deployment Angers Nato', 22 November 2016.
12. Christopher Harmer, 'The Strategic Impact of the S-300 in Iran', American Enterprise Institute, August 2016.

AWACS types, such as the Royal Australian Air Force's E-7 Wedgetail and Saab's Erieye-based solutions, are more capable in this regard. However, even with these more modern systems, low-observable fighters represent a serious emerging threat to Western enabler aircraft operating even hundreds of kilometres behind the assumed front lines, especially in a cluttered and heavily jammed battlespace.

These threats are not simply a problem for the survivability of the E-3 Sentry in a contested air environment; they pose a significant danger to all large Western support aircraft, including the RC-135 reconnaissance family, ATAR aircraft and other AWACS platforms. However, the AEW and wide-area surveillance aspects of the AWACS mission set are particularly affected as a result of the standoff range imposed by the threats detailed here. There are other, less obvious, ramifications for the air C2 mission set. Short-range tactical fighters, which make up the vast majority of Western combat airpower, depend on ATAR aircraft, which will also be forced to stay potentially many hundreds of kilometres behind the main area of operations. This will further increase the requirement for assured air C2 since strike assets will be penetrating further from their ATAR support into enemy territory. Tactical fighters will therefore need to have their mission timings and tanker rendezvous slots even better coordinated than at present. This will be especially pertinent in a contested environment where tankers and strike aircraft will frequently have to dynamically adapt to enemy activity and environmental changes while keeping their own emissions to an absolute minimum to avoid being tracked.

In sum, what these factors suggest is that the air C2 mission will remain critical in both permissive and high-threat environments, but that in the latter (which may well become much more common) support assets such as E-3 and ATAR aircraft will be forced to operate much further back from the immediate battlespace than in any previous conflict. This will degrade the usefulness of the E-3 (and all AWACS types') primary sensor suite due to range limitations, but if anything will increase the critical nature of the air C2 mission, whether that is conducted by airborne personnel with a mission system or by ground-based personnel through BLOS communications links. There are other, less conventional options available in meeting this challenge. For example, due to the short range of tactical fighters, ATAR aircraft will have to be in the area of operations anyway. Therefore, it may be worth considering whether they should be equipped with sufficient communications payloads to act as communications relay nodes. In theory, ATAR assets with the correct communications payload could, along with other assets further forwards, provide sufficiently assured access to connectivity to allow air C2 to be conducted remotely from the ground. This would eliminate the need to put people in harm's way on board a dedicated AWACS type, and eliminate the need to provide costly airborne capabilities. Given what has been discussed here about the changing nature of the vital air C2 mission and the AEW aspects of the current ABM&S mission set, it is important to consider what trends are currently visible that will frame the options for Western air forces going forwards.

II. Future Airborne C2 and AEW Approaches

Four major trends are apparent in emerging approaches to future ABM&S systems:

- Advances in radar-scanning technology.
- Growth in the capability of passive sensors.
- Increases in the signal post-processing power of mission systems that enable higher quality situational awareness to be gained from sensor suites.
- The emergence of new surveillance architectures based on distributed nodes rather than single platforms.

AWACS technology itself has moved on significantly since the AN/APY-1/2 radar was selected for the E-3 system. Most AWACS systems being procured around the world today take advantage of advances in electronically scanned radar and mount either active or passive electronically scanned arrays (AESA or PESA). These can simultaneously scan for and track hundreds of threats and are frequency agile and LPI-capable, meaning that they are harder to for adversaries to detect, passively track and jam reliably than traditional mechanically scanned arrays. In practical terms, what AESA technology in particular means for AWACS-type aircraft is that much smaller and more efficient business jet or medium-sized airliners can mount arrays that offer superior range and detection capabilities compared with the AN/APY-1/2 mounted on the large Boeing 707 airframe of the E-3. AESA arrays are more reliable than mechanically scanned arrays due to using far fewer moving and load-bearing components, and having significant levels of redundancy in the case of failure of some transmit and receive modules.

Future wide-area surveillance is also likely to involve much heavier use of passive sensors compared with traditional AWACS platforms. Passive sensors based on tracking of enemy emissions via electronic or infrared scan and track (IRST) methods offer significant advantages over traditional radars in certain situations, as does the wide-area electro-optical (EO) tracking being developed for the F-35, with its 360-degree coverage EO targeting system. There are limitations on optics-based detection range imposed by atmospheric conditions, false-positive rates and most obviously, the requirement for line of sight that keep the effective range of EO and infrared (IR) tracking significantly shorter than possible with active radar scanning. However, there are also advantages: sensors based on EO or IRST technology offer the capability to track aircraft, missile launches and other items of interest without any detectable emissions at all and with far greater resistance to jamming. A future E-3 replacement in the 2030s timeframe will almost certainly have to take advantage of such technology, in order to keep its own radar emissions requirements to a minimum and to give operational flexibility. The explosion in very large micro- and nano-satellite constellations heralded by developments such as OneWeb also point to future AEW systems being able to draw on a completely revolutionary level of space-based EO,[1] IR and even radar coverage from military and potentially commercial networks for military purposes. It is, therefore, becoming harder to hide hot, fast aircraft in a world where mutlispectral sensors are being linked with, and enhanced by, ever more capable signal post-processing computer power.

Over the past 15 years, signal processing hardware and software have become orders of magnitude more potent, much less demanding of space and cooling capacity, and able to reduce mission system crew requirements for ABM&S mission sets through increased automation. However, some tasks, notably combat identification of unknown contacts, remain problematic and are likely to require significant human capacity for at least another decade. It is still an advantage to have a large mission system crew complement for any air C2 or ISTAR platform, but the trade-offs in terms of required aircraft size, cost, weight and complexity have altered since the 1970s and 1980s when the E-3 took shape. Modern AWACS designs, such as the Boeing E-7 Wedgetail and Saab Erieye, as well as the Chinese KJ-200, KJ-500 and KJ-2000, combine powerful AESA radars, ELINT-gathering capabilities and mission systems with smaller crews than the E-3. They also have much greater signal post-processing capabilities to enable better detection, identification and tracking of low-observable and hypersonic threats. The E-7 Wedgetail is also notable for being designed around a commercially mass-produced airframe (the Boeing 737-700ER), while the Erieye radar and mission system are designed to be platform-agnostic and have been successfully mounted on a variety of commercial-derivative airframes. This approach significantly enhances inherent reliability and reduces maintenance challenges compared to military-specific airframes through the use of modern, mass-produced and commercially proven and readily-available components, engines and avionics, even though military certification issues often prevent military aircraft from drawing directly on civilian parts stores.

Distributed sensors as opposed to a single large radar on a single large aircraft is another potential long term trend. Alongside several variants on the traditional AWACS airframe/radar/mission system combination, China is also developing a more radical AEW system in an attempt to counter Western low-observable airframe designs. China's Divine Eagle drone is a high-altitude, long-endurance UAV, which appears to mount large long-wavelength radar arrays.[2] The concept behind the Divine Eagle is to create multiple overlapping coverage orbits generating data that can be cross-referenced and analysed by ground stations. This will give the PLAAF a better chance of 'joining the dots' and tracking low-observable aircraft such as the B-2 Spirit and F-22 Raptor. However, it is also one of the first ever attempts to develop an operational AEW network based on UAV-borne sensor nodes distributed across multiple platforms and ground-station processing, exploitation and dissemination (PED). The US Navy's NIFC-CA concept also envisages the creation of a resilient network of sensors and shooter platforms which automatically share data and coordinate. This is intended to ensure that the best situational awareness picture is generated for all participating assets and that each kinetic shot is taken by the optimal launch platform. However, full implementation of the NIFC-CA architecture for the US Navy remains

1. Peter B de Selding, 'One Year after Kickoff, OneWeb Says Its 700-Satellite Constellation is on Schedule', *Space News*, 6 July 2016.
2. Jeffrey Lin and P W Singer, 'A Closer Look at China's Divine Eagle Drone', *Popular Science*, 10 July 2015.

an aspiration rather than a unified development programme and is currently at the stage of undergoing component trials, such as allowing Aegis Baseline 9-equipped vessels to fire SM-6 interceptors at targets identified and designated by F-35s over the horizon.[3]

NIFC-CA and the Divine Eagle programmes point the way towards a scenario in the mid- to late 2020s and certainly by the 2030s where sensor-data sharing through LPI, directional, jam-resistant data links such as the F-35's multifunction advanced data link (MADL) allow such high-fidelity situational awareness for all linked force components that traditional, dedicated AEW and wide-area surveillance assets such as the E-3 are unnecessary. While technological progress in terms of the airframes themselves has remained relatively predictable since the end of the Cold War, the growth in data link capabilities and variety has been explosive, as has the increase in means to disrupt them. The latter phenomenon has been driven mainly by Russia and China. It is a relatively safe bet, therefore, that the next decade will see further rapid evolution in software-driven data link technology and also a similar increase in BLOS options for currently LOS-limited links, such as MADL, in a similar fashion to the historical and ongoing evolution of Link 16 well beyond its initial design applications. On the flip side, the proliferation and further development of already impressive Chinese and Russian electromagnetic spectrum-denial technologies to other anti-Western states and potentially non-state actors will mean that, in the future, the electromagnetic spectrum will be a heavily contested environment.[4]

These four trends of advances in radar technology, growth in passive sensor tracking capabilities, ever more powerful signal post-processing driven by modern computer capacity, and distributed sensor architectures will all have important implications for ABM&S going forwards. However, what they mean for each air force will depend on their ability to bring them into service as operational capabilities.

In terms of technological possibilities, there are likely to be ever more effective means for legacy and new assets to share situational awareness and targeting data in the future operating environment. However, converting these advances into operationally useful capabilities will require conscious investment decisions by the RAF (as with other air forces). It takes coordinated planning and sustained investment of limited funding to ensure that new data link technologies are incorporated into the force and standardised to ensure assets can take advantage of them. Furthermore, it is unlikely that ethical considerations will allow all threat identification, prioritisation and targeting to be automated, at least in the West, so people will have to remain in the loop with all the design implications that come with them. The air C2 role, currently fulfilled by the E-3, will remain important, even if situational awareness between allied aircraft is radically improved for deconfliction purposes. The most important question, therefore, given that the future operating environment will likely be marked by a heavily contested electromagnetic spectrum and the proliferation of long-range kinetic threats,

3. US Navy, 'Navy Conducts First Live Fire NIFC-CA Test with F-35', NNS160913-15, press release, 13 September 2016.
4. For an example of US thinking on the electromagnetic spectrum and warfare, see the statement of US Department of Defense CIO Terry Halvorsen in Sydney J Freedberg, 'DoD CIO Says Spectrum May Become Warfighting Domain', *Breaking Defense*, 9 December 2015.

is which option will involve greater operational risks in a non-permissive environment: reliance on a single airborne platform with air C2 and PED capabilities onboard or the use of networks to conduct PED and air C2 remotely while keeping operators out of harm's way?

There are many factors to be considered. A large-medium, airliner-based asset acting as a communications, networking and C2 hub several hundred kilometres behind the main battle area in the manner of the E-3 but relying less on its own sensors could certainly be a very valuable asset to any high-end air force and in more permissive environments could conduct the same role as the E-3 does today. However, it would represent a critical node that is an obvious target for any peer or near peer opposing forces in possession of long-range missiles or low-observable fighters, as discussed in the previous section. However, in a heavily contested communications environment, these kinetic risks against state opponents might be outweighed by the value of not relying on BLOS data links to ground stations for C2. On the other hand, an airborne C2 platform would still rely on being able to offboard data to other assets in order to execute its mission, and so would also be vulnerable to denial of communications to a lesser extent.

At this stage, it is important to stress that in general, the RAF (as with all European air forces) has a pressing need to invest more heavily in communications and data link technology regardless of the specific questions relating to the E-3D. This includes not only increasing the diversity of available data links and communications channels to improve electromagnetic resilience, but also investing in communications relay and waveform translation capabilities for every airframe with the spare weight and power to mount them. Ensuring that as many manned and unmanned assets as possible can act as communications relays in addition to their primary missions is essential for realising the RAF's goal of creating an information-enabled next generation force. It would also increase cost-effectiveness in the long run by ensuring that every asset put into the air, regardless of its primary task, is utilised to the maximum possible extent. Whether the E-3D or any other solution provides the core air C2 requirement, it will be of very limited use in contested environments if it cannot communicate with other force elements. These communications links will not miraculously appear; they require coordinated investment and planning, as well as exercises to develop operational tactics to use them efficiently. The F-35 in particular is seen as key to improving the future situational awareness, combat capabilities and survivability of a host of legacy assets through sharing real-time situation awareness data that it gathers inside defended airspace. However, for the UK, this will be possible only with significant investment in both the diversity, resilience and bandwidth of LOS and BLOS data links and the provision of sufficient relay platforms to translate F-35 data from MADL or other LPI waveforms into Link 16 or whatever else is needed in order to pass it back to Typhoons, Type 45 destroyers and other assets that might require access to that data.[5]

In contrast to a traditional airliner-derived E-3 replacement, a solution based on multiple situational awareness and targeting data exchange links between distributed strike assets, loitering High Altitude Pseudo-Satellites (HAPS), unmanned combat aerial vehicles and other multirole platforms might be less vulnerable to kinetic or electronic warfare-based attacks against single points of vulnerability. Projects such as the MoD's recently acquired prototype

5. For more information, see Bronk, 'Maximum Value from the F-35'.

solar-powered HAPS, called Zephyr, are already on course to reach a level of technological maturity by the early 2020s. These assets will be able to carry compact radar arrays or communications suites, while their solar cells and lightweight construction already allow them to fly for months at a time.[6] They also have very small radar cross sections and heat signatures, making them hard to target. Such technology could certainly point the way towards a version of the Divine Eagle concept, whereby data from multiple airborne sensors from UAVs and/or HAPS can be relayed to ground stations for signal-processing and PED, offering increased resilience and cost effectiveness, as well as greater coverage than a traditional AWACS design. However, this distributed sensor approach would still rely on being able to assure transmission of the situational awareness generated by each individual asset both to a remote ground station for PED and back to combat assets, therefore increasing vulnerability to disruption of the electromagnetic spectrum.

6. Airbus, 'Zephyr, the High Altitude Pseudo-Satellite', <https://airbusdefenceandspace.com/our-portfolio/military-aircraft/uav/zephyr/>, accessed 18 May 2017.

III. RAF E-3D Choices and the Core Air C2 Requirement

THERE ARE TWO main policy questions that emerge for the RAF from the above discussion on the E-3D and broader AWACS-related technologies, both now and looking towards the future. The first is how best to continue to meet the government's SDSR-mandated objective to extend the crucial air C2 capability which E-3D provides out to at least 2035. The second and related question is what form the eventual replacement for the E-3 in wider NATO service is likely to take after 2035, since there is an obvious desire to synchronise the RAF's ABM&S capability with the US and NATO E-3 replacement timetable.

This second question of what is likely to be available in terms of solutions for the air C2 and wide-area surveillance requirements of a post-2035 RAF is certainly important, since development and procurement processes for such a capability would have to begin by around 2025 to meet a 2035 in-service date. However, the increasingly pressing nature of this deadline should not mean that issues relating to current AWACS capabilities should be overlooked, not least because the RAF is almost certain to be heavily tasked with challenging operations repeatedly over the next 20 years or so. The current state of the E-3D fleet, which did not receive the intended mid-life upgrade in the 2000s, poses significant challenges in terms of mechanical reliability, obsolescence and system capacity. Therefore, the question of greatest immediate importance is whether the decision to extend the life of the E-3D Sentry, set out in the 2015 SDSR, is the most efficient course of action to ensure the RAF's air C2 requirements are met between 2017 and 2035. It is worth remembering at this juncture that even if a US E-3G replacement is fully combat-ready in 2035, it will still take time to replace the USAF's own E-3 fleet, let alone that of the UK and other operators in NATO and the Gulf. It is likely, therefore, that either the E-3D or an interim replacement would be required to operate significantly beyond 2035, whatever the current official programme out-of-service date.

As discussed earlier in this paper, the importance of the onboard active radar surveillance capabilities of the E-3D is diminishing due to continual growth in the sensor-suite capabilities on a host of fast jet, unmanned and multirole aircraft. Two other factors are the growing importance of passive tracking to limit friendly electromagnetic emissions and the increasing proliferation of long-range SAM, VLRAAM and nascent low-observable fighter threats among peer and near peer rival powers. However, the requirement for air C2 in both contested and uncontested airspace will continue to be critical, and the importance of creating resilient networks of LPI, directional, high-bandwidth data links through which to share situational awareness and enable C2 from airborne platforms or ground stations will only increase. Therefore, the RAF's air C2 requirement for the next two decades should be looked at by policymakers in these terms, rather than simply asking, 'How do we replace or extend E-3D?' The RAF needs a way to maximise the resilient connectivity between its combat and support assets, especially if it is to take advantage of the potential offered by the F-35 when it enters service from 2018. Sharing and building on mutual situational awareness is crucial to realising the RAF's goal of becoming a next-generation air force. It is also crucial to ensuring that the legacy assets that will still make up the bulk of RAF strength in 2035 can survive and remain effective in ever more heavily electromagnetically and kinetically contested operating environments.

Limitations in combat mass, in terms of platform numbers, personnel and funding available to support readiness and training, mean that the RAF must make maximum use of every flying platform. Since tactical fighter range limitations mean that the Airbus A330 MRTT will always need to be operating as close to the battlespace as threats will allow, it would seem logical to undertake the moderate investment required to equip these ATAR aircraft with a secondary capability to act as automatic communications relay and waveform translation nodes. The E-3D, based on the Boeing 707 airframe which first flew in 1957 and which has not been in production since the late 1970s, will always incur higher operating costs and experience more issues relating to spares availability, in particular electrical systems, than a modern airframe. Since the key requirement for the RAF is to provide resilience for air C2, whether using the E-3D, another airborne asset or doing so remotely, the question must be asked whether a CSP based on the upgrade undertaken by the USAF and FAF of its E-3 forces during the 2000s is still the optimal path for the RAF to take in 2017.

There are multiple options for potential ABM&S based on modern commercial airframes which could provide much greater mission availability, cheaper operating costs and better spares availability than the E-3 while also having more inherent electrical power and cooling capacity to provide more capable communications suites, mission systems and sensors. Since the RAF already operates the tried and tested A330 as the Voyager tanker transport, and will soon operate the P-8 Poseidon based on the ubiquitous Boeing B737-300, these two airframes make obvious potential choices as an alternative to E-3D extension – to be a potential interim capability until the USAF has a proven E-3G replacement in the late 2030s. A new ABM&S platform solution would, of course, incur significant upfront acquisition, training and introduction-to-service costs and represent a certain level of programmatic risk. As a comparative example, the RAF's nine new P-8 Poseidon maritime patrol aircraft – featuring cutting-edge sensors and mission system, and an airframe based on a commercial airliner (Boeing 737-800) – are being procured off the shelf from the US at an estimated cost of £2.47 billion, which includes infrastructure set-up costs and training. Part of the deal is a demanding timeframe with the first aircraft due for delivery in 2019/20 from a deal agreed in July 2016.[1] While the P-8 is obviously not an ABM&S platform, it shares many similarities in terms of being an airliner-derived, long-endurance platform designed around an advanced sensor suite, mission system and signal processing capabilities, and a large mission system crew. Therefore, it seems reasonable to assume that an off-the-shelf ABM&S replacement for the RAF's six E-3Ds based on a commercial derivative with a modern AESA radar and mission system would not cost dramatically more than the current £2 billion plan for the E-3D CSP and could be delivered in a similar timeframe (by the mid-2020s).[2]

1. RAF, 'MOD Seals the Deal on Nine New Maritime Patrol Aircraft to Keep UK Safe'.
2. The figure of £2.47 billion is taken from the Pentagon's Foreign Military Sales announcement figure of $3.2 billion, with the figure in sterling calculated using the exchange rate on 18 May 2017. See

Conclusion

THE RAF, AS with all European NATO air forces, is struggling to provide adequate combat mass from small fleets of highly capable fast jets with insufficient provision of key enablers such as AWACS aircraft and airborne communications nodes. As such, it is not enough to simply 'go with the plan' for ABM&S in general and air C2 in particular if there is a more efficient solution to be had by thinking outside the box.

The RAF's E-3Ds need a £2-billion CSP both to bring them to rough parity with current US and French standards by the mid-2020s and to stretch the fleet out to 2035 in the process. However, the E-3, even in modernised form, is no longer a cutting-edge ABM&S system in a world where proliferating long-range missile systems and emerging non-Western low-observable fighters can force it to stay hundreds of kilometres from contested airspace, placing a higher premium on BLOS communications capacity rather than onboard sensors. Even when it is able to operate closer to the battlespace, the AN/APY-1/2 mechanically scanned radar array common to all E-3s has significant inherent limitations in terms of its ability to detect low-observable, very slow moving and hypersonic threats, unlike more modern AESA-equipped AWACS types already in service with the US Navy and various air forces around the world. An AESA-equipped ABM&S platform with improved communications node capabilities, based on a commercial-derivative airframe, seems a logical alternative option which could provide the RAF with a more capable and efficient alternative to extending the life of the E-3D over the next 20 years. Such an approach would incur programmatic risk and acquisition and integration costs, but the MoD should examine and weigh these against the expensive work required to extend the E-3D with a view to ensuring the RAF has the best capability possible for the next two decades.

In terms of replacing the E-3 across NATO after 2035, a distributed network of multirole sensor and shooter platforms with ground-based remote C2 provision might well be the option chosen by the US – in particular if the US Navy's NIFC-CA programme proves successful when fully fielded through the 2020s. Alternatively, Chinese and other rival powers starting from more of a clean slate in terms of air C2 and wide-area surveillance capabilities may even end up showing the US and its allies the way in this field. However, regardless of the choice made by the US when replacing the E-3, whether it opts for a similar airliner-based AWACS type or a distributed sensor solution with ground-based PED, post-Cold War procurement experience suggests that it will be many years before the chosen solution is brought into service and combat-ready, and will therefore be available to allies. This has significant implications for the RAF as it seeks to fulfil its air C2 and AEW requirements in the intervening period: whatever platform or configuration of capabilities it chooses will have to serve well beyond 2035 before being replaced.

Defense Security Cooperation Agency, 'United Kingdom – P-8A Aircraft and Associated Support', news release, 25 March 2016.

As such, with state-on-state conflict seemingly a growing possibility and new threat technologies already posing challenges for even the modernised E-3s fleets of the USAF and FAF, the RAF should not be reluctant to consider a more unconventional solution for its ABM&S requirements over the next 20 or so years, instead of simply patching up the E-3D Sentry fleet through a capability sustainment programme in the hope that 'it will do' until the US provides a NATO-wide E-3 replacement.