Defence Research Paper

An Analysis of the Value of Air-to-Air Refuelling to Modern Air Operations

(Defence Research Paper - Advanced Command & Staff Course No 21 2018-2019)

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Abstract: Although the potential of air-to-air refuelling has been repeatedly demonstrated, it has nevertheless evolved to be an area of marginal interest for many Western nations. With recent operations exposing critical shortfalls in this capability, this paper seeks to re-examine the value of air-to-air refuelling to modern warfighting. In order to do so, it first explores current doctrine, before analysing the historical development of air-to-air refuelling and its recent contribution to operations. Subsequently, the likely future challenges facing the capability are considered. This paper concludes that air-to-air refuelling is a highly versatile and valuable capability within modern operations, and notes that underappreciation and underinvestment in this area may be sufficient to limit Western war fighting capacity in future conflict.

Introduction

> The more I see of war, the more I realise how it all depends on administration and transportation…It takes little skill or imagination to see where you would like your forces to be and when; it takes much more knowledge and hard work to know where you can place your forces and whether you can maintain them there.[1]
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> - Field Marshal Earl Wavell

The perspective of World War II General Field Marshal Earl Wavell speaks to an inconvenient truth: too often in post-operation analyses, and particularly in victory, the underpinning hand of logistics is an assumed more than an acknowledged contribution. Lamentably, developments following World War II, notably the increasing role for airborne logistics and aerial refuelling within it, do not appear to have altogether shaken this trend. It is certainly not without a degree of justification that air-to-air refuelling (AAR) crews of the United States Air Force (USAF) at times regard themselves as 'invisible men in invisible airplanes'.[2]

Perhaps a focus on combat elements beyond that applied to supporting enablers is unsurprising: after all, what use is a force multiplier absent the force itself? However, even if accepted, it must be recognised that such logic will shape the concepts and capabilities of a given actor. Unfortunately, these forces are all too evident in the evolution of aerial refuelling. Early post-World War II assessments within Britain's Air Ministry that 'flight refuelling on future types of aircraft [would not represent] a paying proposition' epitomise a wider trend that has seen AAR struggle to gain adequate recognition and investment in many nations.[3] Thus, despite positive salients in history, it is a capability that has been dominated by the US within Western air orders of battle.

Again, it is not necessarily remarkable that the US would possess a preponderance of power amongst Western actors in a given capability area. What is increasingly notable, however, is the unsustainability of this position in a climate of prolonged expeditionary commitments, profound resource constraints and a growing threat from rising and resurgent powers. Recent coalition performance has only served to emphasise that, beyond the US, Western AAR capabilities are ill-matched to the full spectrum demands of contemporary conflict. In consequence, there is merit in re-examining the value of this capability to modern air operations.

In order to achieve this, this paper will first explore current air power doctrine, seeking to define key terms and to identify common themes amongst leading nations. With limited published material available outwith Western powers, both this and the ensuing analysis will centre on the concepts and capabilities pertinent to these actors. From here, the origins of AAR will be considered, highlighting the early factors that shaped subsequent US dominance in this area. The role of the Vietnam War in the assimilation of AAR into wider US operational concepts will then be assessed. Subsequently, the parallel evolution of British AAR capabilities,

and the impact of differing operational and political imperatives upon capability development, will be analysed. The preparedness and performance of British AAR during the 1982 Falklands War will then be used to demonstrate both the value of the capability and the potential operational impact of underinvestment in AAR.

Having investigated the evolution of aerial refuelling, its value in more recent operations will then be explored. Initially, the impact of this capability upon high-intensity warfighting in the 1990-91 Gulf War will be considered, alongside the contribution of coalition partners. The role of AAR in Western-led operations in the following decades will then be briefly examined, highlighting the mounting centrality of AAR within operational concepts, and increasing US reluctance to mitigate the shortcomings of partner nations. Finally, the future challenges to AAR will be investigated. Here, the UK will be used as a case study to demonstrate the difficulties faced by non-US actors in maintaining an affordable and relevant AAR-enabled force. The issues facing the wider AAR community will then be evaluated, centring on the complexities and importance of coalition operations in light of a mooted return to high-intensity warfighting. Overall, it will be argued that AAR is a highly versatile and valuable capability that is demonstrably and increasingly central to modern operations. However, in so doing, it will be recognised that beyond the US, underappreciation and underinvestment in this area may be sufficient to limit Western war fighting capacity in future conflict.

Concepts

At the outset, it is useful to examine how AAR is framed within modern doctrine, utilising both North Atlantic Treaty Organisation (NATO) publications and national concepts from four members of the five-eyes community: Australia, Canada, the United States (US) and the United Kingdom (UK). Here, strong standardisation is evident at the highest level, with all national concepts placing AAR as a sub-component of air mobility. Within this, national terminology is closely aligned, with all definitions for air mobility coherent with that of NATO, which establishes it as '[those capabilities enabling] the deployment, sustainment and recovery of military and civilian personnel and material by air'.[4] Such similarity is also evident for definitions of AAR, which is broadly presented by all as 'the in-flight transfer of fuel between tanker and suitable receiver aircraft [in order to increase] the range, endurance, payload and flexibility of… capable receiver aircraft'.[5]

Beyond standardisation at this basic level, however, divergence in the doctrinal treatment of this capability is increasingly apparent. Reduced attention and focus is particularly evident in non-US doctrine, with neither the UK nor Australian exploration of AAR exceeding 100 words within documents of 122 and 253 pages respectively; similarly short treatment in the Canadian capstone doctrine is somewhat offset by more detailed treatment within its sub-ordinate *Move* keystone doctrine.[6] In light of this, the USAF digital framework offers valuable conceptual consideration of what would otherwise appear to be an area of peripheral doctrinal emphasis.[7]

Despite such limitations, sufficient detail exists to identify recognised mechanisms through which AAR can contribute to joint operations, notably including the ability of AAR to enhance the key air power strengths of *speed* and *reach*. Through this approach, receiving aircraft may be flown greatly beyond their normal range, reducing the impact of Access, Basing and Overflight frictions, and minimising time lost to en-route maintenance and weather vulnerabilities. AAR can therefore be seen to enable the projection of air power capabilities both further and faster than would be feasible without this capability. Identified with Canadian and USAF doctrine as a *force enabling* contribution, this has evident utility for the projection of fast-jet air power.[8] However, the potential to reach globally from a domestic base also carries significant consequences for stand-off strategic strike, including nuclear munitions in the case of the US, and rapid deployment, particularly in the case of Special Forces.[9]

In addition to enhancing air power strengths, AAR is also offered in partial alleviation to the inherent weaknesses of air power, specifically *limited payload*, *impermanence*, and the *basing* sub-element of *fragility*.[10] In this sense, AAR may reduce the requirement to trade between mission payload and mission fuel, offering the airborne replenishment of fuel in cases where runway or aircraft design constraints would otherwise preclude or limit mission feasibility. Beyond payload, AAR may also enable receiving aircraft to remain on-station far in excess of their routine endurance, potentially allowing the same degree of operational coverage to be achieved with fewer aircraft. Both this latter point, and the ability to reduce the weighting of geographic necessity in basing selection, are presented as *force multiplying* benefits of AAR within the consulted doctrine.[11]

Origins

With much potential for AAR implied within doctrine, it is useful to now consider the inception of this capability, with particular emphasis on how early perceptions and attitudes shaped its development and distribution among nations. In this regard, the earliest concepts emerged amongst aviators in the First World War, with the first, albeit crude, AAR attempts completed in the US in 1921. Within two years, the US Army Air Service was conducting more significant trials, such that by 1924, this service had demonstrated the ability to triple the range of a receiving aircraft during a flight from the Canadian border to Tijuana, Mexico.[12]

Despite this early success, it was not until 1927 that further development activity began in earnest, with the Army Air Service successfully completing a continuous flight in excess of 150 hours. The pace of development then accelerated quickly, with further record flight lengths achieved within months, culminating in a near month-long flight of 647 hours. However, notwithstanding the Mexican demonstration flight, many such attempts had been conducted while remaining in the vicinity of the aviators' bases, and had therefore offered only limited insight into how this might be used to extend the range of an aircraft. Ultimately, the military potential of this capability failed to gain traction with the US prior to World War II, amidst apparent concern that the reduction in payload required to accommodate refuelling equipment would negate any benefit of extended range strike.[13]

Nevertheless, successes in the US did serve to reinvigorate parallel efforts in Europe, with early Royal Air Force (RAF) interest principally centred on the potential to extend the range of aircraft that had taken off at light weight. Such logic was based variously on reducing fatigue in sea plane hulls, limiting damage to grass strips and as a means of circumventing weight restrictions being considered by the League of Nations for bomber aircraft. However, as in the US, early interest did not translate into operational capability, resigning the leading legacy of AAR prior to World War II to an experimental mail service between Southampton and New York.[14]

Developments in AAR during World War II fared little better. US interest re-emerged in 1942 within concepts to strike Japan, but became marginalised by lengthy lead-in times for both equipment and training. Similar British ambitions in 1944 underpinned interest in an AAR capability for its Tiger Force, with AAR intended to offset a lack of Allied basing in the region. However, extended development timelines again undermined its necessity following the capture of airfields closer to Japan.[15] Lacking a clear operational driver, British commitment to the concept therefore remained markedly hesitant in the early the post-World War II period; rising Cold War urgency to have Moscow within range of US bombers would ultimately provide the catalyst to develop the AAR concept militarily. In consequence, the first employment of AAR in support of combat operations was completed by a limited pool of nine US KB-29 aircraft during the 1950-53 Korean War.[16]

The Vietnam War

> I don't believe many foresaw that air refueling would become a basic part of the scheme of employment of fighter forces over North Vietnam. Yet, early operations indicated that it would be most difficult to sustain any significant [tactical] air effort unless air refueling were used…with any substantial armament load, there was no way an F-105 or F-4 could fly [against Hanoi] without air refueling.[17]
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> - General William W. Momyer
> US Commander Seventh Air Force (1966-68)

Following the limited operational employment of AAR in support of the Korean War, the Vietnam War would see the US utilise AAR at an unprecedented scale in support of combat activity. The intensity of the war, and its supporting AAR requirements, were such that many of the operational advantages and concepts identified in modern refuelling doctrine would be exposed and developed during the course of the conflict. Such an evolution is firmly evident in General Momyer's above assertion and in consequence, the contribution of AAR to the Vietnam War will now be used as a case study to explore this development.

In focussing on this conflict, it is important to recognise that as war in Vietnam approached, AAR concepts remained closely coupled to strategic bombing and nuclear deterrence within US attitudes. In consequence, the first aircraft capable of refuelling fighters close to their intended operating speeds and altitudes, the KC-135, was allocated to US Strategic

Air Command (SAC), limiting the development of tactical concepts. The employment of AAR aircraft in support of fighters pre-war was therefore largely confined to the facilitation of extended-range deployments; the first exercise activity in which such aircraft supported fighters in the *strike* phase did not take place until 1964, less than six months prior to the deployment of KC-135s to South East Asia.[18]

Given such limited pre-war exposure, the role of AAR in shaping the employment and operational capabilities of fast-jet aircraft in Vietnam will first be considered. In this regard, AAR enabled fighter aircraft to operate against North Vietnam from the relative security of Thailand, reducing the ground threat to both aircraft and their support crews. It also allowed these aircraft to operate with reduced compromise to their payload, while the ability to dynamically re-schedule AAR brought enhanced in-mission flexibility, enabling combat aircraft to be re-tasked as necessary.[19] Beyond basic force multiplying, AAR was also able to yield more nuanced contributions to the fast-jet force. Here, limitations on airfield handling capacity, particularly arming, threatened to limit the amount of combat aircraft that could be generated in support of a single mission. Thus, by refuelling the earliest aircraft to launch, AAR was able to increase the force concentration available to combat planners, with attendant consequences for high-intensity operations against North Vietnam.[20]

Fast-jet AAR in Vietnam would also expose the concept of '*saves*': the practise of refuelling an aircraft that had otherwise insufficient fuel to complete its flight to base. Inherently connected to the advent of AAR in combat operations, this is a prominent term in US literature on the topic, with 53 'saves' officially recognised in 1966 alone.[21] Given the striking risk of such operations, one may question whether AAR in fact encouraged operationally-focussed risk-taking beyond levels that would have been considered without it. Nevertheless, records reflect that this mechanism enabled a number of aircraft to provide extended support to critical operations, and also facilitated the recovery of aircraft with battle damaged fuel systems. Thus, while not an uncontroversial concept, the ability of AAR to enable the recovery of aircraft and airmen that would otherwise have failed to return is a capability that is not readily dismissed.[22]

Beyond supporting fast-jet aircraft, the contribution of AAR remained significant, with force enabling contributions coming to the fore. AAR directly facilitated B-52 operations from the US base at Guam, offering the immediate benefit of reducing the strain on airfields closer to Vietnam, while also providing secure basing for a strategic asset. As a result, B-52s from Guam were heavily involved in the Arc Light raids against North Vietnam, in addition to the politically-significant Linebacker raids of 1972. More broadly, both carrier-based AAR and the airborne refuelling of helicopters were first fielded in major combat operations in this theatre, while AAR aircraft had also been adapted to meet the novel fuel requirements of the SR-71 reconnaissance aircraft. Such indirect support to reconnaissance efforts was further augmented by installing collection and communications rebroadcasting equipment onto AAR aircraft themselves, thereby maximising returns on their significant loiter times.[23]

With significant benefits of AAR identified in this campaign, a number of shortfalls were also exposed. AAR aircraft were swiftly recognised as both highly vulnerable and highly valuable, restricting their ability to meet refuelling requirements in the contested airspace of North Vietnam. Moreover, the increasing centrality of AAR to operations in Vietnam rendered demand such that by 1972, 30 per cent of SAC's total refuelling fleet were committed to the theatre, testing even the significant resources of the US.[24] Limits to the ability of AAR to alleviate wider pressures would also be recognised, with the use of AAR to create large strike packages offering North Vietnam substantial warning of impending strikes. Separately, the enormous logistic demands of aerial refuelling had exposed the dependency of AAR basing on upstream logistic capacity.[25]

Viewed holistically, Vietnam can readily be seen as an important point in the development of AAR both conceptually, and as an operational capability. Notwithstanding fuel provided by carrier-based naval assets during the war, AAR aircraft of the USAF ultimately offloaded almost nine billion pounds of fuel in the course of nearly 200,000 operational sorties.[26] Such statistics suggest that by the end of the war, AAR had become an integral component of US expeditionary war fighting capacity; the parallel evolution of British concepts between World War II and the 1982 Falklands Conflict will now be considered.

British AAR and the Falklands Experience

Pre-War Evolution

The evolution of AAR within British concepts offers valuable insight into how differing national strategic and financial contexts shape the development of operational capabilities. Here, the 1947 Air Ministry assertion that AAR did not represent 'a paying proposition' had established inauspicious foundations, from which the difficulty of attracting resource to AAR soon became apparent.[27] Not for the last time, the force multiplying potential of AAR would prove insufficient to justify reductions in basic force mass, with Fighter Command expressing concern at the impact of the cost of this capability on overall fighter force sizes.[28]

Nevertheless, by 1954, attitudes had begun to soften, with initial British interest mirroring early US perceptions of AAR as a mechanism to augment strategic bombing capabilities. Within such visions, all 'V-class aircraft [were to have] fixed fittings to enable them to be operated as either tankers or receivers', placing AAR of significant status within the V-bomber concept.[29] Critically, however, such developments were not intended to generate a dedicated tanker force. Rather, existing aircraft would be required to provide this capability without compromising the strategic bomber footprint. Recognition of the need for a dedicated AAR force, both for V-bomber aircraft, and increasingly also for transport and fighter aircraft, would finally come in 1959. Indeed, the latter held particular significance in light of the limited unrefuelled range and endurance of the English Electric Lightning air defence aircraft. However, Treasury concern remained readily apparent regarding entry-ism and the affordability of providing AAR to a 'large part of the total frontline strength of the RAF'.[30]

Financial hesitance despite the increasing utility of AAR likely reflects the reality of the wider political climate. The legacy of World War II and intervention in Suez had significantly strained the British economy, with marked consequences for defence expenditure, initially epitomised in the publication of the 1957 *Sandys White Paper*. While the most severe outcomes envisioned for manned combat air power by this paper did not materialise, both this and subsequent defence reviews would increasingly focus Britain's defence posture toward collective self-defence in Europe. Trends to erode expeditionary capabilities and extra-European commitments would culminate in the 1974 *Mason Review*, which limited Britain's strategic priorities to four areas: NATO in Europe; defence of the eastern Atlantic; defence of the UK and the strategic nuclear deterrent.[31]

Despite such trends, the exact impact of iterative defence reviews between 1957 and 1974 upon Britain's overall AAR capabilities is difficult to quantify. Certainly they were not fatally undermined: the challenging procurement environment created by these reviews did not preclude the approval of two replacement AAR platforms in the period, nor did it prevent the capability from becoming closely associated with UK air defence and fast-jet deployments. Nevertheless, the anti-expeditionary climate that Conservative Prime Minister Margaret Thatcher would subsequently ascribe to 'Suez syndrome' ensured that extended-range capabilities were not at the fore of the RAF's procurement activities.[32] In consequence, by 1982, Britain operated an aging and modestly-sized tanker force with AAR receiver capabilities absent in a number of key aircraft.

AAR in the Falklands

In light of the above, the Argentinian invasion of the Falkland Islands presented UK politicians and strategists with a considerable challenge: Britain's declining expeditionary posture had ensured that no large-scale out-of-area contingency plans were available, yet the islands were located more than 8,000 miles from the UK. Furthermore, given the diplomatic difficulties of operating from the South American mainland, the nearest overt staging post available was at Ascension Island, approximately 4,000 miles from the Falkland Islands. The resulting Access, Basing and Overflight challenges were rapidly recognised as placing AAR to the fore in any candidate RAF response plans.[33]

Both the operational benefits of AAR, and the impact of non-expeditionary posturing upon the capability, are evident across the RAF contribution to this campaign, not least in the case of the Harrier GR.3. Here, the vertical landing capability of this aircraft rendered it the only RAF fast-jet aircraft with any prospect of operating from Royal Navy carriers, and it was duly identified by planning staff as a potential attrition replacement for the Sea Harrier. However, the air-to-air mission set of the Sea Harrier represented a significant change of role for the GR.3, requiring both aircraft modification and aircrew training. In consequence, AAR-augmented deployment was used to buy No. 1(F) Squadron vital pre-deployment preparation time, enabling them to meet their onward transport, *SS Atlantic Conveyor*, at Ascension Island, without further delay to their arrival in-theatre. This action utilised the only RAF Harrier squadron qualified in AAR at the time.[34]

Beyond facilitating GR.3 theatre entry, AAR's most direct contribution to kinetic elements of the campaign came in the form of supporting the Vulcan Black Buck operations. In this regard, AAR-extended Vulcan sorties were offered alongside a number of candidate options as a means to initiate offensive action against Argentine positions on the islands. This option presented no small technical complication to the Vulcan force, whose AAR capability had atrophied significantly: crew training had ceased in 1962 and much of the refuelling equipment had fallen into disrepair. Nevertheless, between the options, AAR-extended Vulcan strikes appeared to minimise both the risk of collateral damage, and the risk to the Sea Harrier force that was deemed vital to the defence of the naval task group. With AAR deemed a surmountable development requirement, the Vulcan option was duly selected.[35]

The first Vulcan sortie against Port Stanley was successfully mounted on 1 May 1982, establishing a new record for the longest-range air attack. In the course of the next 42 days, a further six Black Buck sorties would be planned, of which four resulted in bombing or anti-radiation missile strikes against the islands. The direct operational impact of these strikes appears limited; however, they are also ascribed deterrent significance, drawing Argentine fighter aircraft toward defence of the homeland and away from offensive operations against the task force. Given such strikes were simply unfeasible without AAR, the capability can therefore justifiably claim a significant contribution within this action.[36]

Beyond direct action, AAR also contributed fundamentally to non-kinetic efforts by RAF aircraft during the campaign, including Maritime Radar Reconnaissance by Nimrod MR.2 aircraft and long-range re-supply by C-130K aircraft. Critically, preparation for such operations would highlight fundamental shortfalls in AAR receiving capabilities on both platforms, with highly expedited modifications underpinning their subsequent operational contribution. Indeed, the pace of industry response was such that both aircraft types would complete AAR-assisted missions within a month of the instructions to proceed with industry. For the Nimrod, this newly-installed capability was integral to enabling maritime reconnaissance close to the Argentinian coast, providing vital information on the location of the Argentine fleet in missions lasting up to 19 hours. Separately, AAR was central to C-130K missions in the vicinity of the Falkland Islands, including Special Forces support flights to dispatch stores and paratroopers. Twelve such missions, each lasting a minimum of 20 hours, had been completed at the point of the Argentinian surrender.[37] The C-130K aircraft would also be swiftly modified to provide an AAR donor capability, albeit this was not fielded until shortly after the conflict.[38]

Central to all the above contributions was the Victor K.2 tanker aircraft. During ten weeks of conflict, Victor tankers are estimated to have completed 600 AAR missions while transferring in excess of five million tonnes of fuel from a fleet of only 23 aircraft. Furthermore, the Victor contribution was not solely in the AAR donor role. Prior to the arrival of the Nimrod MR.2 in-theatre, AAR-extended Victor aircraft were also used to conduct limited Maritime Radar Reconnaissance, providing intelligence to the Royal Navy Task Force on shipping and ice floe locations.[39]

In recognising the contribution of AAR, it is necessary to identify a key limitation of the capability in this campaign, namely efficiency. In this regard, extreme-range AAR operations were highly asset intensive, requiring a large number of tanker aircraft solely to refuel other tankers. By way of example, almost three times as much fuel was transferred to supporting Victors than was provided to the Vulcan during the first Black Buck operation.[40] Indeed, demand was such that the number of Victor aircraft required to achieve this mission consumed almost all of the operational capacity of the airfield at Ascension Island. In consequence, limitations in both tanker fleet efficiency and airfield capacity often necessitated a choice between the generation of Hercules re-supply, Nimrod reconnaissance or Vulcan strike sorties.[41]

When considering the utility of AAR to this campaign, brief mention of the impact of Argentinian AAR capabilities is also valuable. Here, two KC-130H tanker aircraft were able to contribute significantly to the results achieved by Argentina, with more than 100 refuelling serials completed during the hostilities. Most prominently, this capability enabled Argentine Super Etendard and A-4 aircraft to strike against the British task force from mainland Argentina, mitigating the unsuitability of Falkland Island runways for such aircraft. Moreover, this capability was integral to allowing these aircraft to operate in the fuel-intensive environment of ultra-low-level, and thereby to the ability of Argentinian strike aircraft to penetrate British defences.[42] More broadly, this capability was also sufficient to generate perceptions of threat at Ascension Island, resulting in the positioning of a number of Harrier GR.3 and latterly Phantom aircraft in a deterrent role at the airfield. Thus, both directly and indirectly, Argentina also benefited appreciably from the capabilities of AAR.[43]

Lessons

The contribution of AAR to the Falklands campaign, and the capability shortfalls that had been exposed therein, provided significant momentum for change in the aftermath of the conflict. Reflecting on the lessons of the campaign, the UK Ministry of Defence (MOD) ceded that by 1982, the RAF had become 'essentially a short-range or medium-range air force', focussed towards NATO and the defence of Europe.[44] Within this context, AAR had come to be regarded as 'a means of increasing time on task, not of extending range'.[45] In consequence, the Falklands conflict had forced the RAF 'to turn into a long-range air force', which in the eyes of the MOD had resulted in 'a significant change in the outlook and capability' of the RAF.[46] This transformation had included the pre-planned introduction of the VC-10 tanker role, in addition to the new purchase of nine wide-bodied Tristar AAR aircraft. Notably, the latter aircraft was listed first amongst a number of required post-conflict capability enhancements across the armed forces.[47] In light of the above, the performance of AAR in the Falklands campaign can be seen as closely coupled to a significant transformation in the operational perspective of the RAF, albeit AAR fleet sizes would ultimately remain modest.

However, with key lessons regarding AAR seemingly learned in the aftermath of this campaign, it is worth noting one area of tension, namely the exceptional performance of industry. Here, the viewpoint of Air Vice-Marshal George Chesworth is informative:

> At Northwood we understood that the installation of a completely new system in the Nimrod, resurrection of the Vulcan system and providing longer legs for the Hercules was a mammoth task. But such was our confidence in the ability of MOD, industry… and the Service…in this war situation…we took for granted the improved capability of the air assets.[48]

Air Vice-Marshal Chesworth's trust is similarly reflected in the lessons identified by the Secretary of State for Defence in the immediate aftermath of the campaign. For him, the campaign was deemed to have demonstrated 'the value of a broadly based national defence industry, and the benefits of an in-house research capability'.[49] In light of such perspectives, the ever-increasing trend towards privatisation, enhanced safety regulation, multi-national procurement and aircraft complexity in the years following this conflict must be viewed as weakening the relevance of this lesson. Certainly, it is difficult to foresee the exceptional modification timelines demonstrated in this campaign being repeated at scale, even factoring for the impact of operational imperative upon risk taking. Such logic implies a significant risk to future operations in the event deficiencies in contingent AAR capabilities become established.

AAR in the Post-Cold War Environment

Gulf War I

With the majority of the fundamental benefits of AAR both demonstrated and understood by Western powers during the Cold War, the return to expeditionary operations at the end of this period provides useful further insight into the value and limitations of the capability. Within this, the 1990-91 Gulf War represents a particularly valuable case study, with the largely dormant capabilities of air power dramatically re-emphasised in large-scale and high-tempo expeditionary warfare. Here, AAR would prove fundamental to the conduct and success of the operation, with US Chief of Staff General Merrill McPeak asserting that 'the tanker contribution to Desert Storm is what made [the air campaign] work'; 'no tankers, no airlift, no Desert Storm'. [50]

The force enabling capacity of AAR was reasserted from the outset under Operation Desert Shield, with in excess of 1,000 aircraft deploying directly to the operational theatre from bases in the US. The contribution of this action to deterrence posturing is epitomised by the deployment of armed F-15C fighter aircraft, which were able to assume an alert posture in Saudi Arabia within a day of being notified to deploy. Beyond such rapid deployment, AAR also reprised the lessons of Vietnam, enabling vulnerable aircraft to operate from secure and suitable locations beyond their unrefuelled radius of action. Notably, this approach underpinned F-117 stealth strikes in the opening days of the conflict, in addition to B-52 cruise missile sorties conducted round-trip from the US.[51]

In addition to force enabling, AAR also offered force multiplying contributions to combat operations against Iraq. In this regard, favourable access and basing conditions supported the generation of AAR missions close to Iraqi airspace, maximising the offensive reach available to combat elements. This was coupled with robust *Counter-Air* and *Suppression of Enemy Air*

Defence capabilities to ensure that such high-value, high-vulnerability assets could do so at tolerable operational risk, while also denying enemy forces the ability to exploit their own AAR capabilities. The overall contribution of AAR is evident within post-war statistics: during the course of combat operations, on average 18 per cent of aircraft in the air were tanker aircraft; more than 60 per cent of attack sorties were dependent upon AAR, with AAR aircraft refuelling more than 1,400 aircraft per day.[52]

The above statistics add significant weight to AAR's centrality to coalition operations, with AAR-contributing nations comprising the US, the UK, Saudi Arabia, France and Canada. However, despite improvements in partner capability, not least the UK, the vast majority of the AAR task was met by the US; wider nations conducted approximately 10 per cent of AAR sorties flown. This figure is substantially below the equivalent across all mission sets, in which non-US aircraft provided approximately 15 per cent of total sorties generated. Accordingly, AAR can be seen as a disproportionately US-centric undertaking in this campaign, the scale of which demanded almost half of the USAF tanker force. Such demand is likely to have held consequences for the US airborne strategic deterrent capability, albeit at a time of improved US-Russia relations.[53]

In addition to evident restrictions in the ability of coalition partners to contribute to the AAR effort, further limitations were also exposed by the campaign. Despite the prevalence of tankers in the force mix, this capability at times remained a limiting factor, constraining both the combat sortie rate and the maximum force size of a given strike package. Here, the saturation of suitable air bases, and more pressingly, the operational airspace itself exacerbated issues of capacity, emphasising the importance of efficiency within operational planning. In light of this, pessimistic pre-mission fuel requests proved a particular frustration, with 85 per cent of AAR aircraft transferring less than 50 per cent of their available offload during operations, resulting in the airborne 'dumping' of fuel on numerous occasions.[54]

Post-First Gulf War: Mounting US Strain

In the aftermath of the Gulf War, AAR continued to demonstrate its status as an established and central supporting capability, with little let up in the demand for expeditionary combat operations. AAR remained a coalition effort in this period: by way of example, the RAF had provided AAR support to deterrence and containment operations over Northern and Southern Iraq, in addition to supporting combat operations over Bosnia and Kosovo by the turn of the millennium. Indeed, the latter campaign would see more than 200 NATO AAR aircraft dedicated to the operation. Nevertheless, US assets continued to meet the majority of demand, with growing evidence that the limits of US capacity were being approached.[55]

Strain upon the US AAR capability was exacerbated by the response to the terror attacks of 2001. This aircraft-based attack had introduced a further task for USAF AAR aircraft, with airborne tanker coverage required to support combat air patrols over key US sites. Furthermore, the ensuing transition to retaliatory operations against landlocked Afghanistan

had created a parallel AAR requirement, without which both carrier and land-based operations could not be effectively brought to bear. Indeed, demand was such that the ratio of AAR missions to strike sorties had at times approached 1:1.[56] This challenge was further emphasised by the return to combat operations against Iraq under Operation Iraqi Freedom, where the number of committed USAF AAR aircraft peaked at 319 aircraft from a mission capable pool of 379 and a total fleet of 539. Such heavy AAR demand carried particular concern for wider US warfighting: a 2004 US report noted that despite the evident strain, the overall weight of effort of this campaign was likely some way below US ambitions for future high-intensity conflict. This report also highlighted a further change in the usage of AAR in the Afghanistan and Iraq campaigns, whereby a more permissive air environment had been exploited to routinely provide AAR directly over the battlefield. Through this technique, AAR was enabling the footprint of ground forces and firepower to be offset by loitering combat aircraft, again at increasing commitment to AAR assets.[57]

Against the backdrop of mounting pressure on US resource, coalition efforts against Libya in 2011 can be seen as a significant cautionary indicator. Here, it is critical to note that the strongest overt pressure to intervene came not from the US, but rather the UK and France. In consequence, while the campaign ultimately transferred to NATO leadership, the performance of non-US nations in this operation offers particularly valuable insight into wider Western AAR capabilities.[58] In this regard, non-US nations were able to provide between 12-15 AAR aircraft over the course of the campaign, with France dominating this contribution. Britain was able to offer limited support in the face of concurrent operational demand, while broader coalition contributions came from Italy, the Netherlands and non-NATO Sweden; Turkey limited the provision of AAR to its own forces.[59]

Overall, the non-US contribution equated to approximately 23 per cent of AAR missions flown, representing a comparable if not favourable ratio to that of previous campaigns. However, serious shortfalls remain apparent, with non-US AAR aircraft capable of supporting a force ratio of only 1:10 between AAR and offensive air power elements, hugely below the near 1:1 peak observed in Afghanistan. This ratio undoubtedly constrained the offensive capabilities of the coalition: even when improved to a ratio of 1:4 by US efforts, post-operation analysis identified that 'tanker availability was the main limiting factor for the pace of air operations'. [60]

The significance of this shortfall is amplified by the declared impact upon the US. Post-operational assessments would conclude that 'Libyan air operations placed [US] refueler units under stress and would have been beyond the capacity of the Air Force to produce, had [reservist] volunteers not saved the day'.[61] Such strain suggested observable limits in the ability of the US to underwrite coalition shortfalls, particularly in discretionary interventions. US politicians were similarly scathing. For US Secretary of Defense Robert Gates, the campaign exposed 'shortcomings – in capability and will – [that had] the potential to jeopardize the alliance's ability to conduct an integrated, effective and sustained air-sea campaign'. He further warned of 'dwindling appetite and patience in [US politics]…to expend increasingly precious

funds on behalf of nations…[that were themselves]…apparently unwilling to devote the necessary resources'. [62] AAR deficiencies thus formed an important component within public US frustrations at the capabilities of its alliance partners.

Given the starkness of the US message, it is perhaps encouraging to note indicators of change. Then NATO Secretary-General Anders Fogh Rasmussen was swift to recognise the scale of non-US dependency upon US capabilities such as refuelling, ceding that 'more Allies should be willing to obtain them'. [63] There is also evidence of action to underpin the narrative: by 2018, the UK, France, Germany, Norway, the Netherlands, Belgium and Luxembourg were all amongst nations to refresh or to seek to renew their refuelling fleets.[64] With little sign of alleviation to the operational demand, there appear cautious grounds for optimism regarding NATO and coalition AAR.

AAR: The Challenge for Future Operations

With US ability and willingness to meet the AAR requirements of coalition operations seemingly in decline, and little evidence of abatement in the associated demand, the AAR capabilities of Western–oriented powers would appear to be approaching an important crossroads. However, such an assessment has thus far been made with little reference to trends in future conflict, despite evidently rapid evolution in both the political and operational domains. In consequence, this paper will now explore the challenge facing future AAR operations.

Case Study: The UK

Initially, the UK will be used as a case study to expose the difficulties facing non-US nations. Here, UK AAR capability for the foreseeable future is provided by the RAF through a private finance initiative that employs a core pool of nine Voyager aircraft, with the contractual potential to utilise a further five aircraft under surge conditions. Notably, this fleet represents both the sole AAR donor capability, and also the sole strategic passenger transport capability, approved within the UK inventory. Thus, it is necessary to recognise that the day-to-day-demands placed upon this fleet are substantial even before considering emerging threats to the capability. Specifically, Voyager aircraft provide 24/7 standby support to the UK air defence deterrence posture, with a further aircraft supporting a similar requirement in an enduring deployment in the Falkland Islands. Beyond air defence, the UK is also currently maintaining a deployed AAR presence supporting operations in Iraq and Syria, thus committing at least one third of all core aircraft to priority AAR operations. Even in the absence of further operational tasking, the remainder are required to accommodate the separate demands of passenger and fast-jet deployments, in addition to AAR training and periods of aircraft maintenance. Thus, while the surge pool remained largely unused as at 2016, it is readily apparent that surplus core capacity is likely to be limited even at current scales of operation.[65]

Recognising a degree of strain on current capabilities, two key emerging areas of tension will now be considered, the first of which concerns Voyager compatibility with wider UK military

aircraft. In this regard, a critical impact derives from the UK adoption of the *probe and drogue* method of refuelling at the expense of the alternative *boom* method favoured by the USAF. This incompatibility is most evident within the UK's large aircraft fleet: the C-17 transport, P-8 maritime reconnaissance and RC-135 intelligence aircraft fleets are all optimised to utilise the USAF system despite the lack of a UK capability. Critically, this suggests a particular limitation for UK airborne intelligence collection, especially when considered alongside runway limitations that ensure UK RC-135 crews 'require a tanker for every mission' from their home base, according to USAF Colonel Thomas Torkelson.[66] Notwithstanding wider developments in aircraft range and endurance, this limitation therefore appears to risk a return to the limited expeditionary posture at the time of the Falklands campaign for large aircraft. Beyond such aircraft, the UK also lacks a helicopter airborne refuelling capability, with particular impact upon the timely deployment of Special Forces.[67]

The introduction of the F-35 aircraft carries further consequences for UK AAR, with the lack of a boom capability complicating the mooted procurement of F-35A aircraft given the latter's lack of a refuelling probe. In itself, this is not unconcerning given the F-35A's lower unit cost and higher combat radius compared to the carrier-adapted F-35B variant. Indeed, there is evident potential for this incompatibility to threaten overall UK F-35 force capacity, if unit cost is assumed to correlate closely with affordable fleet size. However, more fundamental impacts can also be seen, most significantly in the ratio of sovereign AAR assets to strike aircraft. In this regard, the intended UK purchase of 138 F-35 aircraft would at best represent a ratio in excess of 1:9, predicated on the unrealistic assumptions of maximum Voyager surge and no wider calls on the platform. When such a ratio is considered with regard to force ratios desired in preceding campaigns, this would suggest that UK maximum offensive capability would likely only be available with international AAR support. High-intensity sovereign operations may be unlikely; nevertheless, placing a dependency upon a wider capability pool that is recognised as being under-resourced would appear to suggest a degree of imbalance in current UK force plans.[68]

Wider Challenges

Given the likelihood of enduring coalition dependencies, the wider challenges facing Western nations in future conflicts will now be explored. Here, beyond ceding sovereign capability, two significant frictions are apparent. At a basic level, approval for receiver aircraft to refuel from coalition partners remains underdeveloped: in 2014, 40 per cent of the potential donor-receiver combinations within the European inventory were not cleared for use, risking delay to operational reaction times even in the event of latent equipment compatibility.[69] Beyond clearances, a further issue is presented in the implicit connection between AAR and the mission conducted by the receiving aircraft, potentially staking the offensive actions of one actor to the enabling activities of another. This latter friction risks substantially complicating mission co-ordination and strike planning.[70]

With challenges evident, the necessity of coalition action has nevertheless been enhanced given the rising interest in warfighting at scale associated with Russian resurgence.

However, despite European procurement messaging, a NATO-led air power review in support of the 2016 Warsaw Summit continued to emphasise the urgent shortfalls in coalition AAR capability previously identified in the after-action analysis of Libya. Again, European capability deficits were particularly stressed, with such nations reportedly contributing less than 10 per cent of the 709 AAR aircraft available to the alliance.[71] Thus, should future escalatory posturing or action be required, NATO's ability to maintain a credible air power stance appears to remain somewhat staked to US AAR; the intended US pivot towards Asia can only exacerbate this issue.[72]

Compounding this problem, not least among European nations, are the spiralling costs of equipment programmes when set against profound budgetary constraints. Thus, having previously identified renewed commitment amongst a number of European partners to re-invest in AAR capabilities, it useful to examine the detail of planned procurement. Here, the overall uplift in European AAR aircraft in the 2020-25 timeframe is estimated to be approximately 22 aircraft, potentially representing a 40 per cent improvement from the 2014 position.[73] However, much of this uplift reflects the optional use of A400M in the refuelling role, with issues of capacity and off-role utilisation potentially limiting the realisation of much of this benefit. In consequence, the absolute impact of this activity is likely to remain modest despite encouraging headline figures. Moreover, mounting unit costs for both modern fighter and AAR platforms are likely to do little to encourage the adoption of an AAR capability amongst the 40 per cent of European nations who possess AAR receiver capabilities but no organic tanker aircraft; the notable absence of Hungary and Poland from current European procurement efforts despite apparent initial interest may well speak to such difficulties.[74]

Beyond evident issues with capacity, it is also important to recognise that warfighting at scale significantly complicates the conduct of AAR. At the heart of this issue are the Anti-Access and Area Denial (A2AD) capabilities fielded by an increasing array of actors, not least Russia and China. Such measures drastically increase the range at which static, high-value or vulnerable assets can be placed under threat, with attendant impact on both basing and airborne AAR operations. Paradoxically, therefore, effective A2AD can be seen to both increase the necessity for AAR while decreasing the feasibility of completing it.[75]

The A2AD threat carries particular consequences for the interdependency between AAR and future Western carrier operations given the limited unrefuelled combat radius of the F-35B. Estimated to be 450 nautical miles, this radius risks drawing the carrier group perilously close to the anti-surface capabilities of developed states, even if employed against targets close to hostile borders.[76] This logic adds a degree of weight to suggestions that AAR might be essential to extend the range of carrier strike aircraft. It is therefore significant that current carrier-based AAR capabilities are at best limited, and are entirely absent in the case of the UK. In consequence, without further development, UK carrier operations requiring AAR will either be dependent on land-based assets, which may be impracticable given the A2AD environment, or reliant on US carrier-based AAR with little guarantee of availability. Thus, given

the limitations inherent in either dependency, there would appear significant utility in pursuing a carrier-based AAR platform with at least some ability to operate within a contested environment. Here, the buddy refuelling capability of the F-35, the V-22, or the autonomous capability in development under the MQ-25 programme, would all appear credible candidate options.[77]

Consideration of autonomous capabilities provides a useful final focus regarding future challenges. Such developments may in fact reduce the otherwise mounting burden: current capabilities in this area, including the MQ-9A Reaper, already possess unrefuelled loiter capabilities in excess of 12 hours, with concepts such as the solar-powered Zephyr aircraft seeking to vastly extend this.[78] Indeed, given the additional system weight and complexity of incorporating AAR, there appears little incentive to reverse such developments, particularly for roles such as reconnaissance. However, factoring for the above-mentioned A2AD threats, it remains more likely that future autonomous combat systems will share the AAR dependencies of current piloted platforms, given the greater manoeuvrability and overall system complexity required by such aircraft. In consequence, the US Navy's 2015 demonstration of remotely-piloted AAR may offer early insight into an important next-generation capability.[79]

Conclusion

The above analysis has sought to present AAR as a critical yet underappreciated capability within Western air inventories. In light of this, a review of contemporary doctrine has been shown to support both aspects to this contention: beyond the US, there is at best limited exploration of this capability but nevertheless, the potential for AAR to emphasise the strengths of air power, while alleviating key weaknesses, is evident when considered holistically. Beyond doctrine, divergence between the US and wider actors has been identified even in the early development of AAR, with slow progress limiting the ability of AAR to demonstrate operational utility during World War II. Thus, post-war forces have been shown to have accelerated US interest while frustrating early UK efforts, rendering Korea and Vietnam important proving grounds for the military potential of aerial refuelling. Indeed, the latter conflict has been presented as holding particular significance for the integration of AAR with tactical forces, while also serving to expedite and enhance the development of wider AAR principles. Early evidence of the ability for AAR demand to stretch supply capacity has also been highlighted in this campaign.

Turning to the parallel evolution of Britain's AAR capability, it has been argued that political and financial strictures were important in limiting the growth and centrality of AAR within UK air power concepts. Viewed in this context, shortfalls in UK AAR capability at the outbreak of the Falklands conflict can be seen to have epitomised a wider lack of expeditionary focus. From here, the performance of AAR during this conflict has been demonstrated to have yielded important benefits for both sides. For the UK, AAR enabled strategic strikes against Argentine positions on the islands, in addition to supporting reconnaissance and re-supply missions, while also enhancing the flexibility of force deployment. Separately, this capability

underpinned Argentine operational tactics and created a wider deterrent effect on UK forces at Ascension Island. Overall, the performance of AAR in this conflict has been shown to have re-emphasised the importance of such expeditionary capabilities within the strategic mind-set of the RAF.

The ensuing analysis of AAR in more recent operations has underscored the potential and centrality of AAR previously identified. Here, force multiplying and force enabling contributions rendered the capability fundamental to the air power campaign of the First Gulf War in the eyes of senior military officials, despite mounting evidence of capacity limitations. This campaign has also been used to offer tangible evidence of the deepening capability divide between the US and wider coalition partners. The increasing challenge presented by this division to coalition cohesion in post-First Gulf War operations has also been demonstrated, particularly in light of the diverse and sustained commitments faced by the US post-2001; AAR shortfalls in the 2011 Libya conflict epitomised such deficiencies. The attendant threat to Western high-intensity warfighting potential has also been shown, with recent European procurement behaviours offering some evidence of improvement.

With significant complexity facing current AAR operations, the additional challenges of future conflict have also been considered. Here, the RAF has been used to exemplify these difficulties, most notably the inherent tension between standing commitments, expeditionary demands and firmly finite resources. The RAF has also been used to highlight the potential for equipment compatibility to shape the operational capabilities of a nation, in addition to exposing an apparent imbalance within its intended future force construct. Beyond the RAF, the enhanced complexity and necessity of coalition AAR operations has also been demonstrated, particularly in light of the threat from rising and resurgent actors. A2AD has been shown to be a particular threat to vulnerable AAR assets, with even greater risk to carrier force projection. With automation likely to offer at best partial alleviation, the future of AAR therefore appears unlikely to be less demanding than the contemporary challenge. In consequence, efforts to improve doctrinal and physical investment in AAR amongst Western nations are likely to be of firm significance to the wider warfighting capacity of such actors in future conflict.

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Text includes both UK and Americanised text spelling of Refuelling and Refueling throughout this article.