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Evolving Aerial Refuelling for Contested Airspace

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Modern air campaigns are inherently dependent on the operational reach of tanker fleets. For decades, the Alliance designed an air operating model around the assumption that High Value Airborne Assets (HVAAs) could operate within safe sanctuaries in the rear echelon. Today, the proliferation of sophisticated Anti-Access/Area Denial (A2/AD) strategies, long-range interceptors, low-cost one-way effectors, and uncrewed systems has shattered the illusion of sanctuary.[1] It is now essential to explore alternative methods of air refuelling. These could include a hybrid fleet of large-capacity and smaller tankers capable of operating in higher-threat environments, or the integration of uncrewed assets to reduce overall mission risk. Consequently, Allied nations must fundamentally reassess their approach to aerial refuelling design by pivoting towards a combined approach that retains heavy volumetric capacity while introducing innovative, survivable options to deliver fuel inside contested environments.

Strategic Path Dependency

To understand the vulnerabilities of the current fleet, we must briefly examine how early technical choices shaped its development. The foundations of modern aerial refuelling were built upon military experimentation that pushed the boundaries of aviation endurance and range. Examples include the 1929 test flight that remained aloft for over 150 hours and the 1949 non-stop flight that circumnavigated the globe.[2] Modern aerial refuelling operations developed during the 1950s, driven by then US Strategic Air Command (SAC) and its requirement for global reach to achieve

A KC-135 refuels a stealth bomber. Even the B-21 Raider's range, persistence, and combat effectiveness depend on tanker support reaching it.

strategic deterrence. Ultimately, the immense fuel requirements of nuclear bombers forced the US Air Force (USAF) down a divergent path from its European Allies, a choice that permanently shaped the architecture of its aerial refuelling capability.

Early engineering choices reflected rational design trade-offs based on distinct operational necessities. The USAF designed the refuelling boom to satisfy the high-volume and high-speed fuel delivery demands of its massive strategic bomber fleet. The refuelling boom is hydraulically operated to transfer approximately 4,000 litres of pressurised aviation fuel per minute to a single receiver. The boom design prioritised offload velocity above all, while budgetary constraints required the USAF to standardise across its fighter and support fleets.[3,4] Meanwhile, the probe-and-drogue system remains prominent among many Allied nations and US naval aviation, as its flexible hose and drogue design allows a single heavy tanker to simultaneously refuel a two-ship fighter formation. Despite a slower offload rate of roughly 1,100 to 1,500 litres per minute, it also offers greater flexibility and lower acquisition costs.[5] As refuelling methods continued to evolve on both sides of the Atlantic, aerial refuelling became increasingly associated with particular platforms rather than the operational effect itself.

These design choices yielded the current tanker fleet, dominated by large commercial-derivative aircraft such as the Boeing KC-135 and Airbus Multi-Role Tanker Transport (MRTT).[6] Although efficient in terms of raw fuel payload and flight hour costs, these platforms feature massive radar cross-section and sluggish flight characteristics, leaving them uniquely vulnerable to threats.

The Evolving Operational Environment

While the refuelling tanker design paradigm has not drastically changed since the 1950s, the same cannot be said for the modern battlespace. Advanced A2/AD postures and long-range effectors have transformed the operating environment. Contemporary threats to refuelling tankers are no longer confined to localised surface-to-air missile engagement zones. Peer adversaries have developed a web of overlapping kinetic and non-kinetic threat layers that threaten every element of an airborne strike package, including command, control, and logistics nodes. Chief among these threats are ultra-long-range active radar-guided air-to-air missiles, such as the Russian R-37M and the Chinese PL-15. These 'HVAA killers' are designed to bypass fighter screens entirely, targeting low-manoeuvrability platforms from ranges exceeding 200 kilometres.[7]

New threat vectors, such as hybrid warfare and proliferation of drone technology, have also eroded safe sanctuary. Even remote main operating bases across

An A330 Voyager simultaneously refuels a Eurofighter Typhoon and a Tornado using the probe-and-drogue system, highlighting the flexibility and efficiency of multi-aircraft refuelling.

Europe and the Middle East are now vulnerable to low-cost, long-range one-way effectors, subversion, and sabotage. Tankers are forced to operate from further rear orbits because of advanced long-range threats, often at the expense of on-station time and offload capacity. The usable fuel offload, absent meaningful force extension plans, diminishes rapidly at the forward edge, constraining Allied combat persistence and making an air campaign more costly and more difficult to plan.

True Strategic Cost

The evolving peer threat environment has led modern acquisition programmes to heavily favour fifth-generation fighters and low-observable bombers designed to penetrate hostile territory.[8] However, this creates a dangerous imbalance by modernising the combat platform while neglecting the total strike package. This force design strategy only succeeds if the tanker can manoeuvre to the precise location required to accomplish its mission. If an adversary's threat networks prevent refuelling assets from accessing the battlespace, this further jeopardises the mission by increasing the risk to strike assets. As the evolving threat landscape pushes required stand-off distances even further out, this capability mismatch between tankers and receivers becomes a critical vulnerability. Today, the most pressing constraint on Allied air power is no longer the performance of the fighter or bomber fleet, but the availability, reach, and range of the refuelling tanker. The true cost of delivering a strategic effect must be calculated as the sum of all systems required to achieve it. Allied nations must recognise that the survivability of the aerial refuelling fleet is functionally inseparable from the lethality of the strike force.

Future Adaptations and Creative Solutions

Aerial refuelling is not a platform; it is a capability. The evolving operational landscape requires that NATO nations reassess their legacy approach of using large, refitted commercial platforms as the standard. NATO Aerial Refuelling Doctrine classifies tanker aircraft as HVAAs, a justified but overly general classification that limits creative solutions for future air-to-air refuelling (AAR).[9] While broadly accurate for heavy tankers like the Boeing KC-46 and MRTT, the HVAA classification creates the false perception that all tanker aircraft are converted from large commercial variants and constrains discussions of novel solutions to the paradigm of large, high-volume assets. Additionally, technological advances in uncrewed systems and autonomous collaborative platforms (ACP) offer future options. Decoupling tankers from HVAA provides nations with more scalable AAR alternatives, beyond the handful of costly and vulnerable platforms, and creates a more resilient, distributed logistics network.

An A-10 Thunderbolt II receives fuel using the probe-and-drogue method during an AAR exercise over a desert landscape.

Other types of aircraft, such as the Lockheed C-130, Embraer C-390, and even the Boeing F/A-18, can be configured with aerial refuelling capability. They either have dedicated variants or offer ground-configurable solutions that add tanker capacity without new acquisition programmes and logistics support pipelines, and give commanders mission optionality outside of a single, dedicated role. For instance, the HC-130 is a modified USAF special mission platform that uses an established system to provide dedicated aerial refuelling support to Joint Personnel Recovery (JPR) missions. It has different performance characteristics than traditional heavy tankers, brings with it an additional suite of communications and troop transport capability, and can operate in higher-risk environments than other heavy tankers. Although these aircraft offer refuelling capability to the battlespace, their limited fuel capacity and high-risk mission complexity have largely kept them away from steady-state mission profiles as prescribed by Air Refuelling Doctrine.

Allied nations should explore expanding non-traditional aerial refuelling capability, such as configuring existing combat aircraft to conduct AAR on demand. An improved version could include advance fourth- or fifth-generation fighter aircraft, or even legacy assets modified with internal and external fuel storage and offload capability. Although tactical aircraft have limited fuel offload capacity, the ability to provide even limited range and endurance extension to combat aircraft could result in a significant operational difference. In sufficient quantity, these aircraft could execute a distributed AAR concept of employment, working a pre-planned or dynamic hub-and-spoke system to deliver fuel closer to the target area.

Another means of granting more flexibility for forward AAR is dual-mode optionality for current and future receiver aircraft. Most receivers are configured for either boom or probe-and-drogue AAR, not both. Aircraft like the HC-130 and the re-configured F/A-18 buddy tanker can only offer probe-and-drogue refuelling. Therefore, if the receiver requires boom tanking but the only available tanker is limited to probe-and-drogue, the aircraft cannot be made compatible in the air. For example, the USAF recently developed a modular refuelling probe for the Fairchild A-10 to support US Central Command operations. The device can be installed and removed by aircraft maintenance personnel, effectively converting a boom receiver into a probe-and-drogue receiver when required by the mission.[10] This pragmatic adaptation enables A-10s to receive fuel from low-flying tactical tanker fleets such as the HC-130s, and allows combat aircraft to refuel closer to the fight and reducing demand for heavy tankers.

Early ACP development has focused on Collaborative Combat Aircraft (CCA), and USAF leadership has

A US Marine Corps CH-53 and USAF HH-60 conduct aerial refuelling with an MC-130 assigned to Combined Joint Task Force – Horn of Africa, demonstrating that refuelling capability exists beyond the rear echelon.

indicated an interest in aerial refuelling capability for future increments.[11] The US Navy's Boeing MQ-25, an uncrewed refuelling platform, is now in low-rate production. It was developed to extend range for the carrier air wing and reduce the burden of buddy tanking on the F/A-18 fleet.[12] The aircraft also offers an early example of distributed, low-volume aerial refuelling. The MQ-25 meets Modular Open System Architecture (MOSA) design standards, allowing major components to be incrementally replaced without major system redesign.[13,14] This allows faster adaptation to meet future system requirements or to expand existing capability. For example, future integration of a refuelling receptacle could allow the MQ-25 to operate as an AAR 'worker bee', receiving fuel from traditional tankers at-range, and then delivering mission-critical fuel deep into contested airspace without increasing the risk to traditional HVAA tankers. If incorporated across NATO nations at scale, uncrewed platforms could help close the reach-survivability gap for Allied AAR.

While a distributed refuelling model in a resource-limited context seems counter-intuitive, these challenges must be weighed against operational realities. To be clear, non-traditional refuelling methods do not render traditional heavy tankers obsolete. Large HVAAs remain relevant by serving as high-volume foundational 'hubs' that move massive quantities of fuel within the theatre and the battlespace. The objective is simply to introduce flexibility through smaller, more survivable 'spokes' capable of pushing that fuel further inside the threat ring. Admittedly, utilising existing strike aircraft as buddy tankers assumes excess capacity within the current fleet. However, this trade-off is often necessary to stage fuel closer to the target, significantly increasing the time-on-station and overall effectiveness of the remaining strike package. Lastly, smaller platforms offer limited offload quantity compared to heavy tankers, extending the range of only a few combat aircraft.[15] But at the tactical edge, that marginal extension is often the determining factor between successfully servicing a critical target and accepting unacceptable mission risk. As ACPs enter the battlespace, pairing traditional crewed buddy tankers with small, low-volume uncrewed systems will allow commanders to project power deep into the Missile Engagement Zones of A2/AD environments while mitigating risk to crewed platforms. NATO's future investment decisions must weigh these trade-offs.

Conclusion

The luxury of operating heavy, vulnerable tanker fleets in permissive environments is rapidly becoming a relic of a bygone era. In an A2/AD environment, relying solely on vulnerable HVAAs to bridge the tyranny of distance is a strategic gamble that NATO and its Partners can no longer afford. Nations must pursue a two-pronged approach: procuring larger, more survivable heavy tankers to sustain bulk fuel requirements, while developing smaller, repurposed, and uncrewed platforms. These include the MQ-25, converted combat aircraft, and future ACP variants, to push fuel closer to the contested edge. This shifts the focus from sheer offload capacity to survivability, agility, and tactical innovation, ensuring the total strike package maintains its required range and lethality without assuming unacceptable operational risk. Ultimately, aerial refuelling is not merely a logistical support function that can be confined to the rear area. Acknowledging this reality requires a commensurate commitment in survivability, research, development, and procurement to keep refuelling capability effective, even in the most hostile environments. ●

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Major Eric Yuan is currently a student at the USAF Expeditionary Center's School of Advanced Study of Air Mobility (ASAM). He recently completed an assignment as the Air Refuelling Subject Matter Expert at the JAPCC. In this role, he managed the air mobility portfolio, leading the Global Air-to-Air Refuelling interoperability and compatibility efforts, supporting AIRCOM's Specialized Heavy Air Refuelling Course (SHARC), and acting as Chairman of the Military Committee's Joint Standardisation Board-Air Air-to-Air Refuelling Working Group (AARWG). Major Yuan commissioned from the United States Air Force Academy in 2014 and received his 'Wings' from Laughlin Air Force Base, Texas. He has flown the KC-10A, KC-135, and KC-46A, and has served in a variety of operational and support positions throughout his career, flying air refuelling, airlift, and training missions worldwide. Maj Yuan has approximately 3,000 flight hours, with more than 1,500 combat hours.