The Bridge to Air Power - Aviation Engineering on the Western Front 1914 - 1918

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The development of the British air weapon on the Western Front during the First World War represented a radical and unprecedented change in the way that national resources were employed in exploiting a technological opportunity to achieve tactical and operational advantage. Logistic competence was the precondition for air superiority and the 'modern style of warfare' – indirect, predicted artillery fire. The Royal Flying Corps' logistic staffs, led by Brigadier-General Robert Brooke-Popham, demonstrated considerable agility in meeting the demands of three-dimensional warfare. Sustaining adequate numbers of frontline aircraft required substantial numbers of skilled and semi-skilled personnel, located largely beyond the battle zone, operating at a continuously high tempo while coping with rapid technological change and high wastage. These elements formed a complex, dynamic and integrated network that was also partly self-sustaining, in the form of salvage and repair, with the ability to compensate for shortfalls in aircraft and aero-engine production as well as unpredictable demand. The logistic principles developed on the Western Front provided the foundation for Royal Air Force success in the Second World War and anticipated the management practices that underpin today's global supply chain – as well as demonstrating the enduring interdependence of logistics and air power.

This article has been drawn from the author's PhD, undertaken as a Portal Fellow. The full PhD can be accessed via Birmingham University's eTheses Repository and the British Museum's EThOS.

Introduction

We take for granted the existence of a global economy underpinned by a complex supply chain connecting distributed manufacturing, via an extensive international transportation network, to worldwide markets. Engineering lies at the heart of these activities, creating and supporting products while responding to rapidly changing customer requirements. This is not just a one way process, but increasingly involves recycling to meet 'green' as well as financial imperatives. Operating at a tempo determined by the marketplace, where fashion is sometimes as important as technological advances, the regular introduction of new products is critical to commercial success.

Although we may believe that this picture is a recent one, I would argue that its essential characteristics can be found in the maelstrom that was the First World War. The 'Great War' has long been recognised as an industrial war that consumed vast amounts of materiel, and where logistic superiority gave the Allies an overwhelming advantage.[1] The outbreak of war in 1914 has been described as marking the end of the first phase of globalisation, but it is equally possible to see it as the culmination of a process triggered by the Industrial Revolution that only came to an end with the Great Depression.[2] In sustaining military operations in the face of high attrition and rapidly evolving technology, processes and systems were developed that underpin today's global economy. This was best exemplified in the conduct of the air war where air superiority could only be achieved through a relentless struggle that pitted machine against machine in a seesaw process that saw neither side achieve an overwhelming technical or tactical advantage.

To explore this idea further, I will look in particular at the arrangements created to support the Royal Flying Corps (RFC) on the Western Front and how a huge engineering and supply network provided a war-winning capability – in the form of three dimensional warfare – that underpinned Allied success.[3]

The involvement of engineering in the war zone is hardly a recent development. Vegetius records that engineers and craftsmen were integral to the Roman Legion and that their presence in camp was essential in the fabrication and repair of weapons and armour - as well as in the construction of buildings and the undertaking of siege works.[4] What was unprecedented in the British Air Services, and the RFC in particular, was the scale of the engineering effort - such that over 90% of the total strength of the RFC on the Western Front comprised logistic (engineering and supply) personnel and only a very small proportion (some 8%) were assigned combat roles.[5] This was in sharp contrast to the BEF where 60% of personnel were assigned to the teeth arms.[6]

As the intensity and extent of the air war grew, the RFC developed operations management techniques that anticipated best practice in contemporary supply chains.[7] Demand forecasting, rough-cut planning, postponement, mass customisation, lean manufacturing, distributed production, reverse logistics, integrated supply chain management and disruptive innovation

all found their place on the Western Front. Although unprecedented, these techniques drew partly on the advances in advanced manufacturing and mass production achieved over the previous century, including standardisation, interchangeability and the employment of scientific management.

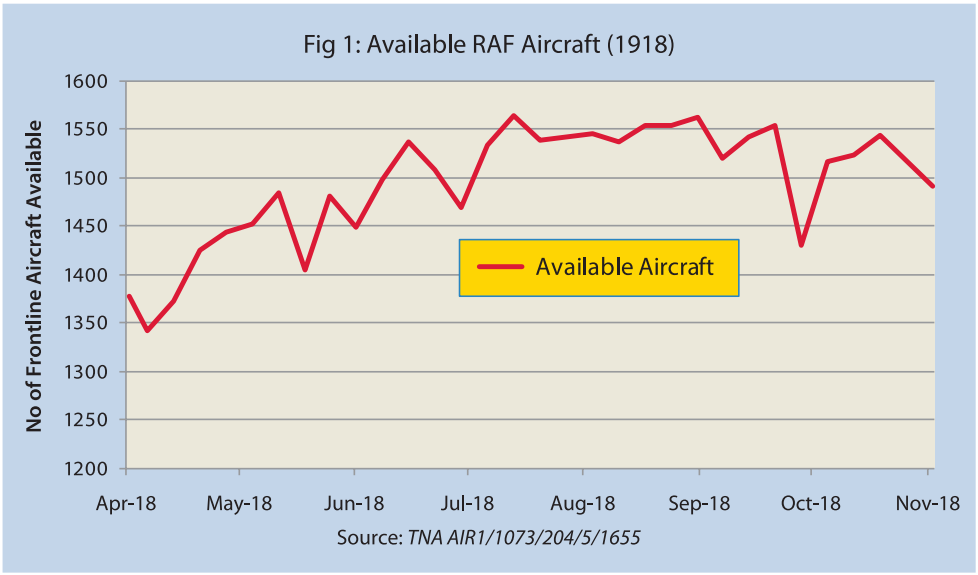
Scientific management is concerned with the organisation of work and the management of the worker. It is closely associated with 'Taylorism' and the measurement of performance, but in its broadest sense comprises the planning of industrial activity and the setting of standards of efficiency.[8] These ideas emerged in the USA at the turn of the century and are credited with transforming manufacturing. It has been suggested that scientific management made little progress in the UK prior to the First World War but the picture is less straightforward.[9] Admittedly, scientific management did not advance rapidly or uniformly across all industries, but the management of mechanisation advanced rapidly in the years immediately prior to the First Word War. Alongside this development was the tentative introduction of commercial methods in military affairs. The impetus for these changes stemmed from the South African War and major failures in the procurement and distribution of supplies by the War Office.[10] The solution was the creation of the 'soldier business man', to facilitate the manipulation of material resources through cost accounting.[11] One of the more visible results was a training programme for logistic officers overseen by the London School of Economics, under the leadership of Sir Halford Mackinder. Starting in 1907, this initiative paved the way for the employment of business experience in the management of logistics during the First World War.[12] The techniques and processes employed by the RFC to manage an increasingly complex and extensive supply chain should be seen, therefore, against this background and the reforms in Army administration introduced by Haldane in the decade prior to the outbreak of war.

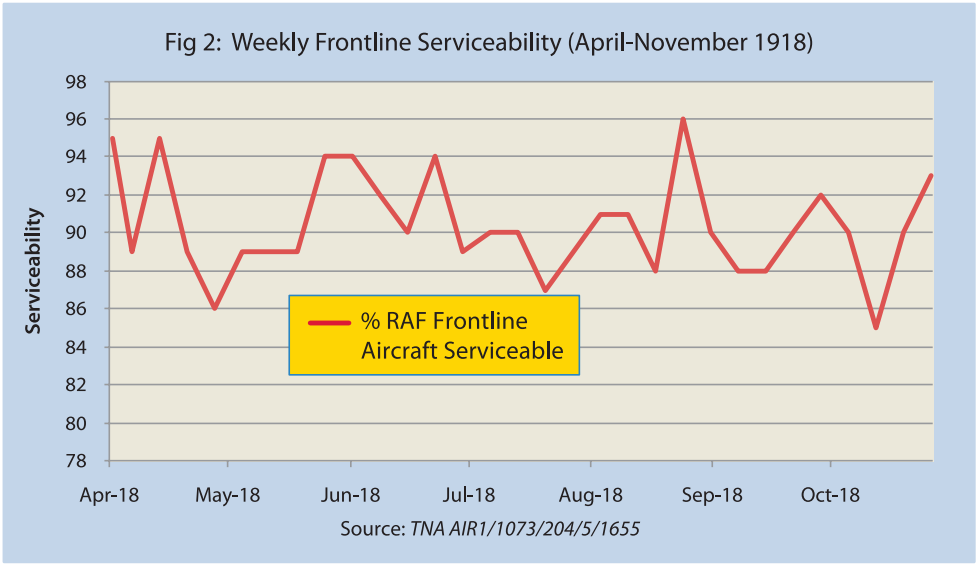
The RFC's achievements on the Western Front have sometimes been regarded as an interesting experiment that contributed little of direct military value to the war's outcome but offered some pointers to the role of air power in the Second World War.[13] This rather simplistic view overlooks two important points. Firstly, that aviation was both the precondition and precipitant for the advent of three-dimensional warfare on the Western Front; the integration of air and ground forces to deliver accurate, predicted, indirect fire at distance.[14] Without the RFC's ability to achieve air superiority this simply could not have happened and it is quite possible that the stalemate of trench warfare would have endured. Secondly, although the RFC's contribution to the advent of modern warfare was undoubtedly significant, indeed essential, the means of achieving this outcome was unprecedented, if not revolutionary. One of the most interesting aspects of early military aviation was how much its organisation owed to contemporary business practice and the way that it developed as a national endeavour rather than as a distinct activity - outside mainstream society or civilian experience.

RFC Operations on the Western Front

The RFC (and RAF)'s achievements on the Western Front were substantial and a key factor in the BEF's ultimate success. The metrics for 1918 are undoubtedly impressive.[15] In the last ten

months of the war the RAF: flew 484,000 hours; engaged 12,000 hostile batteries for destruction; destroyed 1,150 gun pits and damaged 3,500; took 256,000 photographs; dropped 321,000 bombs and fired 321,000 rounds. In delivering these outputs, over 7,000 aircraft were struck off charge – lost to enemy action, crashes or simply worn-out.[16] Even so, aircraft availability (the number of aircraft available to the frontline squadrons to undertake operational tasks), remained largely constant through 1918 (**Fig. 1**). Serviceability also remained high, at over 80% (**Fig. 2**), reflecting excellent technical skills and ready access to tools, equipment **and** spares.[17]





The RFC Logistic System

The RFC's logistic system on the Western Front was part of a global system that acquired, handled, distributed and maintained large quantities of technically advanced equipment across four continents. This was not simply a supply chain but incorporated engineering and repair activities that modified, reconstructed and configured aircraft and engines to meet the frontline's changing needs. The entire system was motorised, indeed, the RFC was the first organisation in the British Army to be fully motorised, and drew on an extensive transportation network, including sea, rail and inland waterways, to deliver equipment, spares and consumables to airfields and depots.[18] Although the RFC was a small proportion of the BEF, it had to manage an unprecedented inventory against a highly volatile and unpredictable demand.

By 1918, and the formation of the Royal Air Force (RAF), the RFC's inventory on the Western Front was substantial,[19] comprising: 1,500 frontline aircraft; 3,000 aircraft and 5,000 engines on charge; 12 aircraft and 16 engine types; and 40,000 separate line items (stock control units). This highlights a key challenge faced by the RFC. To sustain a single squadron on the frontline the supply chain had to hold as many aircraft again and three times as many engines. Although engine wastage was lower than aircraft wastage, there were many more arisings (from wear, defects or damage) meaning that at any one time there were as many engines under repair as fitted to frontline aircraft.

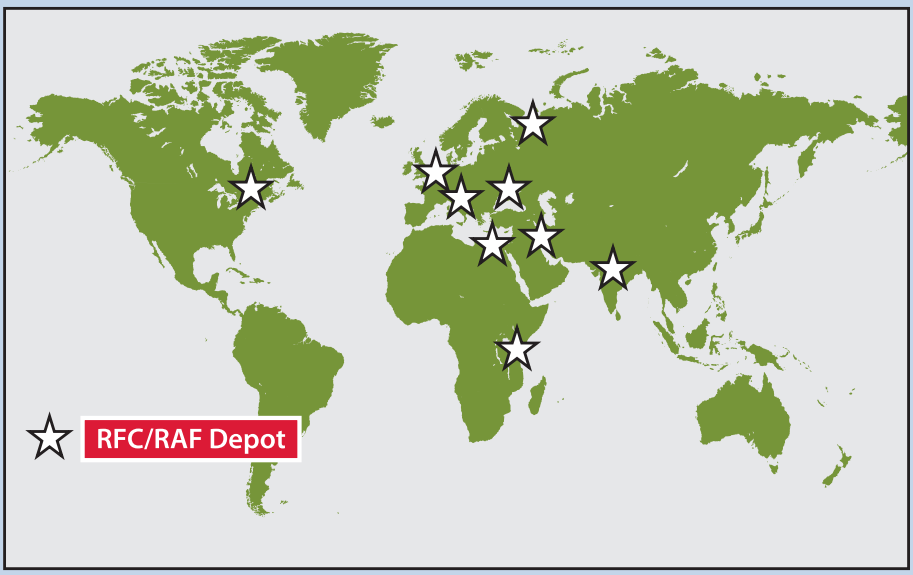
The range and quantity of the RFC's inventory was unprecedented for its time. The largest inventory previously seen was probably that managed by Sears Roebuck, who pioneered mail order and introduced the concept of central warehousing and integrated order control in Chicago at the end of the nineteenth century. The RFC's inventory on the Western Front comprised twice as many line items as the Sears-Roebuck Catalogue (20,000) and anticipated the immense range of spares required by the RAF during the Second World War (813,000). Even today, the RAF's inventory (although below its peak of 1.4 million line items at the end of the Cold War) remains impressive – reflecting the inherent complexity of military air systems. In fact, the inventory range managed by the RFC compares favourably with a modern supermarket chain, albeit without the advantages of automated data processing or the internet, that holds around 50,000 line items.[20]

The efficient and effective handling of a large and complex inventory should not be taken for granted. The problems faced by the Tank Corps in implementing robust stores handling practices and sustaining adequate levels of availability underscore the RFC's relative proficiency in coping with both the mass and detail of industrial warfare.[21] The RFC's inventory was largely held by depots located up to 30 miles from the front line, supported by a range of smaller forward issuing units closer to the operational squadrons. The depots' role was to: hold and issue inventory; erect aircraft; repair aircraft and aero-engines; install special to type equipment; modify equipment; salvage aircraft and aero-engines. Supplying the depots was very much a global business. Although the special steels and forgings came from the UK, as did some of the wood (such as ash), most of the raw materials required in the manufacture of aircraft and

engines had to be imported. This was also true of aluminium, fabric, dope, petroleum products and castor oil – all essential to the industry. Such was the demand for aircraft that licensed production was also required – either British designs built by foreign manufacturers (in France and the USA) or foreign designs built by British manufacturers. This still proved inadequate and substantial numbers of aircraft and engines had to be purchased overseas – primarily from France. Indeed, in 1916 the British Government funded an entire aero-engine plant in France to mass produce the Hispano-Suiza design for both countries.[22] Much of the work of the depots involved the preparation, modification, standardisation and reconstruction of aircraft and engines. Some of this was pre-planned, to avoid disruption to production lines, but the majority of work was in response to operational experience or to repair aircraft and engines damaged in combat or through accidents.

The RFC was active in every theatre of the First World War, from France to Italy and the Middle East. Flying aircraft at any distance from the home base represented a major logistic challenge, especially under climatic extremes. Supply and repair depots were established around the world to support and sustain air operations (**Fig. 3**). The bulk of the RFC's overseas effort was focussed on the Western Front where the frontline required a constant supply of aircraft, engines, stores and consumables (including fuel, oil, bombs and ammunition). By 1918, the scale and tempo of this operation was considerable,[23] and involved: 50,000 personnel (3% BEF); 7,000 vehicles (12% BEF); 79 airfields, and six depots that received 1,000 ton stores and 1,500,000 gal fuel each month while issuing 900 aircraft.

Fig 3: Global Distribution of Depots 1914 - 1919



The high number of vehicles employed by the RFC gave its supply chain substantial 'velocity' – the speed at which items could move within the logistic system. Motorisation, that is the use of motor vehicles in support of operational functions, permeated every part of the RFC organisation from the depots to the frontline squadrons. Additional vehicles were allocated to specialist tasks (such as carrying ammunition) while others were held as a strategic reserve to deploy as required. This sophisticated transportation system, allied to a substantial inventory, allowed the front line's needs to be met quickly and effectively under a wide range of conditions.

Modern Supply Chain

The parallels between the challenges faced by the RFC on the Western Front and modern supply chains are significant. Today's global market is characterised by: uncertainty; rapid obsolescence; volatile demand; and complexity.[24]

Uncertainty characterised the supply of aircraft and engines on the Western Front throughout the entire war. Wastage varied greatly from month to month - driven not only by operational tempo and enemy action but also by the weather, landing accidents, unreliability and obsolescence. The pace of aeronautical development during the First World War, the 'constant tactical factor',[25] was so rapid that obsolescence became a major problem. Failure to provide aircraft and engines with adequate performance to match continuing improvements in the German Air Service's fighting abilities compromised the RFC's ability to achieve air superiority and led to a substantial increase in wastage. The 'Fokker Scourge' in 1915/1916 and 'Bloody April' in 1917 are the most obvious examples of why quality mattered as much as quantity. The regular replacement of older aircraft types or time-expired machines was an important feature of the RFC's logistic system on the Western Front, although many of these could, and were, recycled for employment on the Home Front in training or air defence duties.

Demand volatility forced the RFC to postpone product configuration – to respond more rapidly to changing customer needs. This required the creation of a generic inventory (or strategic reserve) that could be readily modified to meet demand. Postponement saved time and allowed production to be optimised as well as reducing overall stock levels. By creating an in-theatre repair facility – in the form of the RFC's engine and aircraft depots – equipment could be held forward close to the squadrons awaiting final configuration. The depots' reconstruction programmes were planned in advance but amended in light of the actual supply position and real demand. Without the depots and their ability to create additional aircraft and engines (beyond new supply from England) more aircraft would have had to be held in reserve to maintain the same levels of availability.

The complexity of the RFC's supply chain arose because of the need to balance mass-production (and the standardisation of design) with technical development.[26] Complexity within the supply chain creates unpredictable effects and uncertain demand. There are two broad categories of complexity: sources of network complexity (the number of squadrons, aircraft

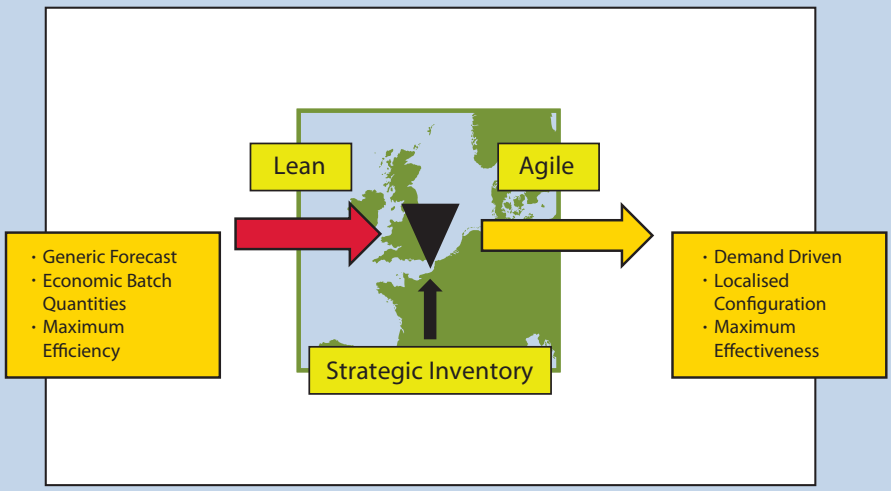
firms, engine firms and logistic units); and sources of information complexity (lead times, aircraft types, inventory range and operational roles).[27] By 1918, sources of network complexity on the Western Front were 25 times greater than 1914, while sources of information complexity were more than 400 times greater.[28]

The Effectiveness of the RFC Logistic System

The key challenge in any supply chain is to meet customer demand. However, since production generally takes longer than the customer is prepared to wait it is necessary to hold inventory. During the First World War it generally took an average of 34 weeks to take a new aircraft from design to mass production and some 64 weeks for an engine.[29] Once a particular type was in production, contracts had to be set some 25-30 weeks ahead of the required delivery. In other words, the Western Front's supply needs (in aircraft and aero-engines) had to be estimated somewhere between 9-12 months ahead of actual demand. These lead times grew during the course of the war.

The relationship between supply (in the form of production capacity and inventory) and demand can be represented as a fulcrum – demand is balanced by a combination of capacity and inventory. If the fulcrum can be moved closer to the customer, demand can be satisfied by a smaller inventory and/or less capacity. This can be achieved either by increasing product velocity or by improving the demand horizon. In fact, this is exactly what the RFC implemented in France. By creating a network of depots and forward supply parks, the frontline's demands were rapidly met – either from the immediate strategic reserve or by erecting cased aircraft. At the same time, the repair and reconstruction programme

Fig 4: RFC Decoupling Point



focused on making good the shortfall. The RFC's depots represented what is now known as the 'decoupling point' – the point in the supply chain where supply meets demand.[30] Upstream of this point, the Ministry of Munitions was able to manage the production of new aircraft as efficiently as possible; while downstream the emphasis was on effectiveness rather than efficiency. In effect, the depots marked the transition from a lean to an agile system (Fig 4, see page 17). This is known as a 'hybrid' system and is now recognised as 'best practice' in supply chain management.

Logistic Innovation

To achieve these outcomes and sustain the frontline, the RFC had to create a system based on little previous experience and no existing model. This demanded flexibility, intellectual honesty and a willingness to innovate. The RFC's senior leadership, in the form of Major-Generals Hugh Trenchard and Geoffrey Salmond, provided the necessary strategic direction but day to day responsibility for sustaining front line availability and serviceability fell to Brigadier-General Robert Brooke-Popham who managed the RFC's logistic arrangements in France for most of the First World War.[31] At his direction, the RFC introduced a wide range of techniques and processes that still find their place in modern supply chains, including: demand forecasting; rough-cut planning; strategic inventory; postponing configuration; mass customisation; hybrid (lean/agile) approach; distributed production; reverse logistics; integrated supply chain management; and disruptive innovation.

At the heart of the RFC's logistic system was the process of predicting future demand. This was based on calculated wastage (determined by a combination of experience, seasonal variation and operational tempo), the planned size of the frontline and the required level of reserves. These routine forecasts were used to set long-term production contracts, allocate shipping space and plan the level of in-theatre repair. A key step in the planning process was the creation of a monthly forward plan defining the quantity and type of future aircraft deliveries up to three months ahead. This allowed the War Office and HQ RFC to adjust in-theatre plans to match actual, as opposed to planned, production. The difficulty of determining detail demand (as opposed to global demand) was resolved by holding a stock of ready to repair aircraft that could be rebuilt quickly to meet shortfalls in deliveries or higher than anticipated wastage rates. By creating a strategic reserve and placing it at the decoupling point, the RFC was able to switch production or alter products at short notice. The effectiveness of these arrangements depended heavily on the efficient recycling of aircraft and engines. Salvage parties ensured that almost every crashed aircraft on the Allied side of the frontline (more than 95%) was retrieved either for rebuilding or breaking down into individual spares.

In addition to rebuilding aircraft, the RFC's depots were also responsible for the final configuration of all aircraft prior to frontline delivery. This included installing wireless and photographic equipment and completing urgent modifications, such as the fitting of bomb racks to fighters during the German spring offensive, and the embodiment of routine modifications not undertaken during manufacture to avoid slowing production rates. By focussing on the

manufacture of standard designs, and outsourcing the airframe to non-aviation companies, skilled in wood-working and piece metal working, the Ministry of Munitions was able to accelerate production rates. Final assembly was undertaken at home-based Aircraft Acceptance Parks where separately sourced high-value components (such as engines and instruments) were installed and the completed aircraft test flown. The depots represented the supply chain fulcrum – the point where supply meets demand and where 'lean' meets 'agile'. Downstream of the depots the frontline units 'pulled' aircraft and aero-engines, whereas upstream the Ministry of Munitions 'pushed' aircraft and aero-engines.

HQ RFC demonstrated considerable skill in managing the supply chain as a single entity, balancing new production and repair to meet the frontline's daily needs in aircraft, engines and spares. This involved a number of techniques, including varying the balance between air and sea delivery (to meet volatile demand volumes) while altering the detail of in-theatre repair and salvage programmes to meet changing demand by aircraft type. The agility of the entire organisation was such that new units could be rapidly created to meet the needs of mobile warfare (such as the deployment of advanced stores distributing sections during the Hundred Days Campaign) or existing processes altered to meet operational circumstances (such as the decision to move from a 'pull' to a 'push' system in delivering stores during the German spring offensive).

The RFC waged a continuous battle, in the form of sustaining innovation, to counter the enemy's technological and tactical advances, such as modifying artillery observation aircraft to lay smokescreens or drop small arms ammunition. It also engaged in disruptive innovation, such as the decision in 1917 to transfer the two-seat F.E.2 from daylight operations – where it was increasingly struggling against improved German fighters – to the night-bombing role. This required a whole series of changes, including the creation of dedicated night-flying training units in the UK (together with specially modified dual-control machines) and an extensive modification programme – navigation lights, night-flying instruments, new multiple bomb-racks and structural changes to carry larger bombs – to reconfigure the aircraft for its new role. As a result, rather than being withdrawn, the F.E.2 remained an important part of the frontline until the end of the war, providing an invaluable tactical bombing capability. In essence, the RFC created an entirely new 'market' for a mature product that would otherwise have been discarded – together with the associated production capabilities, infrastructure, spares, aero-engines and operational knowledge.

Conclusions

The contribution of the RFC's logistic system in supporting air operations on the Western Front was significant and, in many ways, revolutionary. Air power demanded very different logistic arrangements compared to previous military requirements. Sustaining the frontline required substantial numbers of skilled and semi-skilled personnel, located largely beyond the battle zone, capable of functioning at a continuously high tempo while coping with rapid technological change and substantial wastage. These support elements formed part

of a complex, dynamic and integrated network with the capacity to handle uncertainty while responding rapidly to unexpected demands. It was also partly self-sustaining, in that salvage and repair made a significant contribution to maintaining a continuous supply of aircraft and aero-engines. Van Creveld's assertion that the First World War was the first time in warfare that it was logistically easier to stay put than to move is an interesting observation but obscures a more important point.[32] The scale and intensity of fighting on the Western Front required all combatants to create complex networks capable of rapidly distributing large volumes of material that flowed both ways. What was significant about the First World War was that, whether the armies moved or not, their supplies were always on the move and none more so than the resources needed to sustain air power.

The RFC's logistic system was modern both in its needs and in the processes developed to meet these needs. In this effort, a variety of logistic techniques were pioneered (supply chain integration, strategic warehousing, velocity management, postponement and make-to-order, new product introduction, international sourcing, hybrid and reverse logistics) that now provide the basis for global supply chain logistics management. The RFC, led by a new breed of soldier-technocrat, who combined military values, managerial competence and business skills, was the epitome of an 'entrepreneurial military organisation', characterised by intellectual honesty, imagination and the courage to exploit historical failure.[33] The outcome was a new style of warfare that wove together 'industrial mobilization, national resources, morale and operational art'.[34] The RFC's logistic system on the Western Front was the bedrock for this achievement, delivering strategic success, facilitating 'modern warfare' and anticipating the management practices that now form the global supply chain – an immense legacy for a small military organisation that flourished for just five years at the beginning of the last century. In providing the foundation for air operations, and sustaining the RFC's efforts to achieve air superiority, logistics was the bridge between the nation's economy and air power.[35] It is a relationship that continues to this day.

Notes

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[16] *TNA AIR1/926/204/5/915* – Aeroplane and Engine Casualties, *TNA AIR1/998/204/5/1242-1243* – Duplicate Returns. The 1917 total was inflated to some extent by the front-line replacement programme that saw most squadrons re-equip with new types.
[17] *TNA AIR1/1073/204/5/1655* – Weekly Returns.
[18] Employing Liddell Hart's definition of 'motorization', as distinct from 'mechanization' – the employment of armoured fighting vehicles. B. Liddell Hart, *Thoughts on War* (London: Faber & Faber, 1944), p. 160.
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