We now know the dominant weapons on the battlefield are the ones that can be mass-produced, operated by motivated fighters, kept in action with spares and supplies, and used in concert with other weapons. In the words of General George S. Patton, "How easily people can fool themselves into believing wars can be won by some wonderful invention rather than by hard-fighting and superior leadership."

Rewind

Readings in Logistics

From Production to Operations: The US Aircraft Industry, 1916-1918
Logistics Lessons from the Past—Deployed Operations
German Wonder Weapons: Degraded Production and Effectiveness
A Historical Perspective on the Future of Military Logistics
The Logistics Constant Throughout the Ages

In this edition of the *Air Force Journal of Logistics* we begin a new feature—"Rewind: Readings in Logistics." This continuing feature will present articles and essays previously published in an edition of the *Air Force Journal of Logistics* or one of the Journal-produced books or monographs. The feature will include articles that encompass three areas: historical perspectives, contemporary thought, and studies and analyses. Both the current and future content of the feature were selected for two basic reasons—to represent the diversity of ideas and to stimulate thinking. That's what we hope you do as you read the material. Think about challenges. Think about the lessons history offers. Think about why some things work and others do not. Think about problems. Think about organizations. Think about the nature of logistics. Think about fundamental or necessary logistics relationships. Think about the past, present, and future.

The feature also provides a convenient source of material for mentoring and discussing logistics and logistics issues with new Air Force logisticians.

All of the articles and essays for "Rewind" in this edition were published in *Thinking About Logistics 2009,* Air Force Logistics Management Agency, Maxwell Air Force Base, Gunter Annex, July 2009. Copies of *Thinking About Logistics 2009* may be obtained free of charge from the Journal staff.

Lieutenant Colonel Andrew W. Hunt, USAF

From Production to Operations: The US Aircraft Industry, 1916-1918

Introduction

It may be difficult to believe, but America's air force has not always been the best in the world. In fact, before American involvement in World War I, the aviation industry in this country was, for all intents and purposes, nonexistent. This is astounding, given that only a decade before, the Wright brothers had made their famous flight. Shortly thereafter (in 1908), they pitched the idea of using their new flying machine for military purposes to Army officials at Fort Meyer, Virginia. Momentum was strong. But after that meeting, where the brothers' idea was met with skepticism, subsequent efforts to increase the use of the airplane in a military role were minimal, at best. The outbreak of the war in 1914 did little to rekindle a fire that had, for the last 6 years, barely flickered. No one was sure how America would get involved in the conflict. As American intervention in the war became more and more likely, politicians and military leaders alike sought to determine where the United States could help the most—and the fastest. Everyone knew that the US Army would send troops, tanks, and other equipment to the front, but an opinion gaining momentum in Washington was that America might prove a more effective ally if it were to provide a combat air force to the European theater.

The role of the airplane in war had evolved quickly, from simple scouting and artillery spotting to aerial troop support and bombing missions. No longer was the airplane a novelty, it was now a military necessity. In an impassioned statement to the US Government in the spring of 1917, French Premier Alexandre Ribot urged the United States to make a sizable contribution to the production and deployment of aircraft in the European theater.[1] Seeing an opportunity to have a greater impact in the war, not only on the battlefield but also above it, the government began a renewed effort to establish a legitimate aircraft production base in the United States.

The apathy pervasive in the industry meant that serious obstacles existed. Little had been done to advance the technology of the American airplane to the same level as that of the airplanes flown by other combatants.

Unfortunately, the apathy pervasive in the industry meant that serious obstacles existed. Little had been done to advance the technology of the American airplane to the same level as that of the airplanes flown by other combatants. A limited production base initially proved completely inadequate to the challenge of contributing anything meaningful (in terms of aircraft production) to the war. There was no significant information base from which to draw technical expertise in the construction of these new, military-specific airplanes. And there was no prior experience available to direct and guide those in charge of managing this Herculean task. This was extremely evident in the arena of logistics. Never before had the United States had to plan for a production and movement of this size (especially for a new battlefield instrument), and there had never been an obstacle the size of the Atlantic Ocean to hinder the efforts of planners to sustain such an operation. Nevertheless, failure was not an option. The United States *had* to provide a sufficient (in both capacity and capability) air arm if the Allies were to have any increased chance of winning the war above the trenches. As a member of the newly formed Aircraft Production Board said, "The eagle must win this war."[2] Each area of logistics, from production to repair, presented relatively new challenges to the individuals in Washington and on the Western Front. In as little time as possible (roughly 14 months), an intricate system was established to deploy airplanes and then provide the battlefield logistics support necessary for the Air Service to keep the Allied skies clear.

This article examines the state of the aircraft industry (and the associated logistics issues) before and during American involvement in the First World War. The article is divided into three separate sections. First, there is a discussion of the state of the industry in late 1915 and early 1916, to include existing aircraft, facilities, and production centers. A second section examines the logistics methods used and hurdles faced in attempting an unprecedented rapid mobilization. In this section, the formation of the organizations responsible for forming the Air Service is mentioned briefly. The majority of this section, however, focuses on the trials and tribulations of actual aircraft production, specifically the American version of the British De Haviland (DH)-4. From raw materials to finished goods, the generation process of a satisfactory aerial platform was expensive, untested, and time-consuming. As aircraft were needed in large numbers in minimum time, this process is worth investigating. The lack of an existing infrastructure in the airplane industry meant the production process had no prior model. The third section of the article focuses on the planning and construction of the Liberty engine. Like the DH-4, the production of this powerhouse required logistics efforts unseen prior to 1917.

The *Air Service* Before the Americans Entered the War (1915-1917)

While the aircraft situation before the United States entered the war was dire, few options were available to correct this problem.

While the war raged in Europe, the US *air force* lay dormant. In 1915, the entire inventory consisted of 55 airplanes, all trainers. Of this astoundingly low number, General John Pershing, commanding officer of the Army, commented that "51 are obsolete, and the other 4 are obsolescent."[3] Even though the primary need for airplanes was for trainers, it was surprising that the inventory did not include a single combat (bomber or pursuit) plane.[4] (While there were aerial operations in the Mexican campaigns, none was considered a combat mission; airplanes flew observation missions in support of the soldiers on the ground.)

Additionally, the military possessed and operated only two dedicated flying fields: one in Texas and one in New York.[5] In terms of personnel, the Air Corps was just as lacking. Of the 131 officers in this branch of service, only 26 were considered *fully trained,* and not a single member of the US military "had actual combat flying experience."[6]

While the aircraft situation before the United States entered the war was dire, few options were available to correct this problem. In 1915 and 1916, the Curtiss Company was the lone company capable of contributing anything substantial in terms of airplane output. Curtiss was already producing 100 training planes per month for the British.[7] Within a year, the number of contractors the government employed to build airplanes increased to nine companies, tasked to produce 366 planes (of which only 64 were ever delivered).[8]

American Aviation Prepares for War

In late 1916, it was apparent that the United States would soon be a major participant in the war in Europe. As such, it would send its army to fight alongside the British, Italians, and French. But its contribution would not be limited to the role of the foot soldier. With louder and louder voices, the Allies embroiled in the conflict across the ocean urged the United States to contribute a sizable air arm. As the United States was the pioneering nation in the frontier of flight, this was hardly unreasonable. However, as mentioned earlier (and a statement that will be a recurring theme), the apathy in American aviation made this request a difficult one. Before 1917, US civil aviation activities were not at a level that could be considered significant.[9] "America, with the apathy of peace, had been outdistanced by the billigerents in the science of aviation."[10]

Formation of National Committee on Aeronautics and the Aircraft Production Board

The first signs of life in the military aviation sector surfaced in late winter of 1917. On 5 February, officials in the air arm of the army decided to prepare an initial estimate on the aviation requirements needed to support an organization of regulars, volunteers, and the National Guard. Initial dollar amounts neared a staggering $49M.[11] Again, the capacity of the industrial sector to handle these requests was unknown. In the first few months of 1917, the number of contractors employed by the government stood at 11, and nearly 300 planes were on order.[12] For the first time, thought was given to managing the production and acquisition of these materials. The National Committee on Aeronautics was established in

March 1917; its mission was to bring together the manufacturing sector and the government since there was a noted "lack of cohesion."[13] This organization was designed to prevent duplication of efforts and keep costs under control. The committee, headed by noted paleontologist Dr Charles D. Walcott, recognized the absolute lack of airplane manufacturing capability and suggested, to speed up production and mobilization, a standardized training plane for use by both the Army and the Navy be adopted as soon as possible.[14]

In April 1917, the government formed the Aircraft Production Board (APB) to oversee the production plans and projections for the Army aviation sector. This organization was the focal point for all military aircraft production and was solely responsible for ensuring that the United States could field a viable air contingent. Headed by Howard E. Coffin, an automobile manufacturer from Detroit, the APB began its crusade on 12 April (6 days after America formally entered the war), with the announcement of a 3-year production plan: 3,700 aircraft in 1918, 6,000 aircraft in 1919, and from 9,000 to 10,000 aircraft for 1920.[15] Initially, the main focus of the Board was the production of trainers. The rationale behind this decision was that there was little or no knowledge of battle planes in this country and that the gathering of information over the next 6 months (April-October 1917) from the Allies would slow production to the extent that the output realized by manufacturers would be of little use in the war effort.[16]

Since the airplane production sector was so far behind, the APB proposed a deal with the French that would allow the military to make a more immediate impact in the air war in Europe. In May 1917, the United States proposed a 16,500-ton shipment of men and materials to France in exchange for airplanes, motors, and land for airfields.[17] In August of the same year, the deal was revised to read that France would send 5,000 planes and 8,500 engines in return for tools and materials.[18] This deal seemed feasible, as the United States had greater quantities of human and materiel resources, while the Allies had a greater capability to produce combat-ready aircraft.[19] This early reliance on the French would be a pervasive theme throughout the war.

American Intervention Requested

In the summer of 1917, the French and British governments applied the most direct pressure to the American aviation sector. In a meeting between French Premier Rene Viviani and Britain's Lord Arthur Balfour, the common sentiment was that the United States could do more to help the Allied effort by "sending a powerful air force to the Western Front in time to participate in the 1918 campaign."[20] Soon after that meeting, a statement issued by Premier Ribot on 26 May urged the United States to furnish a flying corps of 4,500 aircraft, 5,000 pilots, and 50, 000 mechanics. After this initial requirement, Ribot requested that there be 2,000 planes and 4,000 motors built in the American factories each month until early 1918.[21] Ribot's request may have had some extreme outside influence. It is rumored that the impetus for this proposed plan may have come from Lieutenant Colonel William "Billy" Mitchell.[22] Amazingly, these requests were deemed by the Aircraft Production Board to be attainable.

Since the airplane production sector was so far behind, the APB proposed a deal with the French that would allow the military to make a more immediate impact in the air war in Europe.

Many people echoed the sentiments for American air involvement. Secretary of War Newton Baker said that the formation of an air arm "seems …the most effective way in which to exert America's forces at once in telling fashion."[23] Orville Wright, still an active participant in the aircraft industry, commented that if the Allies have a sufficient number of airplanes to keep the enemy planes back, and their "eyes can be put out—it will be possible to end this war."[24]

Now that a crude production schedule was in place, the military began to tackle the immense logistics effort required to support this massive mobilization. Not only were the engineers and manufacturers under a severe time constraint, but there was also no experience in the production of combat planes to make this process any easier. Unfortunately, for the United States, the Army had not sent observers to Europe to get the necessary technical information for the construction of these aircraft.[25] "Much of it [the project] had to be drafted in the dark," and there was a "supreme need for haste."[26]

The journey of aircraft production began on 24 July 1917, with the passing of the *Aviation Act* in Washington. This legislation provided $640M (although this number would decrease dramatically in the coming year) for research and design, supplies and manufacturing, and procurement of airplanes.[27] The initial projections for having 2,500 operational, domestically built aircraft by 1 January 1918 available for training were deemed "totally within reach … and immediate efforts were taken to build 500 training machines."[28]

Obstacles to Initial Production—Inexperience and Raw Materials

The ability of a nation to produce and procure materiel is key to supporting military operations. General Carter Magruder, a prominent army logistician, noted that, for a nation to be successful in a military campaign, its domestic production must be equal to the expected consumption in all theaters.[29] James Huston, a noted military historian, added that, in the realm of production and fielding of new weapons of war, there are concerns in the production sector. He observed that a new weapon (or piece of equipment) may incur "delay(s) in production," and experience supply difficulties. Put these two thoughts together, and it's clear that building an air force from scratch was going to be extremely difficult.

Perhaps one of the biggest obstacles facing the military in the pursuit of airplane production was the lack of experience in the logistics arena. No one involved had any appreciable expertise in this area, and the events that transpired in late summer of 1917 brought this fact to light. The lack of experience nearly derailed the initial efforts of the Army to field a viable air arm before it even began. Other American industries had benefited from the early years of the war. The Allies had turned to the United States for assistance in the supply of ammunition (among other things), but they never asked for help in producing airplanes.[30] As a result, the airplane industry was nowhere near capable of responding to the initial requests, and even the work done since America entered the war had been "wholly inadequate."[31] The procurement of raw materials for aircraft production was a huge roadblock that faced the men responsible for building these machines. This issue would prove costly and difficult.

Perhaps one of the biggest obstacles facing the military in the pursuit of airplane production was the lack of experience in the logistics arena.

Raw Materials

Raw materials are the first key to production and, therefore to any logistics operation. Huston notes that the availability of raw materials for an item (and the subsequent ease of production for that item) is as important as the battlefield performance of that item.[32] Little thought was given to the fact that the lack of any material, whether major or minor, could lead to the grounding of any production process. As one observer noted, "no one ever thought that the production programme … could be held up by the lack of small items, such as acetate lime for aircraft doping."[33] To ensure the availability of these necessary materials, the government decided that intervention was necessary. The government decided that it must manage and finance these different industries.

The WWI airplane was constructed mainly of wood and linen held together by a series of wires, stitches, and adhesives. The wood used in the production of the airplane had to be lightweight, as the power of the available engines was not sufficient to lift much weight. At the same time, the wood had to be flexible and durable to withstand the poundings administered by both the wind and the ground (landings could be quite rough). Engineers determined that spruce would be the best wood, as it was the "toughest of the softwood."[34] The difficulty facing the government was the collection and processing of this raw material and its delivery to the necessary production plants. The spruce reserves were located in the remote forests of the Pacific Northwest. Access to that area was limited as the roads were often impassable. The government embarked on a large lumberjacking operation, sending approximately 15,000 troops to harvest the valuable wood in the forests of Oregon. This was an unplanned deployment, as no one could have predicted that troops would be used to collect raw materials.

Since spruce was deemed perfect for aircraft production, the government sought to keep it out of the hands of the Central Powers, and the APB announced that "all spruce would be bought by the government."[35] Here, the government exercised its right to act in the interest of national security by basically monopolizing the spruce industry, setting the price that the loggers and lumberjacks could charge per long ton of wood. The spruce was milled (using roughly 4.5 percent of each tree cut—try getting away with that today) and sent by truck to the production plants for further refinement to make it suitable for airplane usage.

Obviously, wood was a main concern, but the availability of linens (for wings and fuselages) and dopes (a material used to coat the wings to render them flame-resistant, waterproof, and tight) was also in question. The need for these two materials was immense. In 1918 alone, the Air Service requested nearly 10 million yards of linen and 204,000 gallons of aircraft dope. The production of these materials was already at the maximum levels available. "Supply could not be increased by existing plants nor by building new plants" due to the lack of precious wood.[36] Another example of the shortage of raw materials was the

lack of castor oil, a lubricant used in aircraft systems. To combat this problem, the United States actually imported castor beans from Asia to seed farmland in this country, thereby creating raw materials.[37] The process of collecting, transporting, and processing these resources was an important hurdle facing the government in 1917. Even with the active participation of the government, many asserted that "satisfactory aviation material would not be available until 1918."[38]

Aircraft Production

Raw materials are the first key to production and, therefore to any logistics operation.

As mentioned earlier, when the United States entered the war, the initial need for domestic aircraft production was solely to fill the requirement for training aircraft. The Curtiss Company and the Standard Aero Company, with the production of the JN-4 *Jenny* and the SJ-1, respectively, adequately fulfilled this need. However, the real challenge rested in the ability of the American industry to produce combat-specific aircraft in time to make them available for the 1918 campaign. At the time, there were four major problems facing the United States in this venture. First, there was no existing knowledge of battle planes or their construction. As noted earlier, the US inventory did not have a single battle plane at the time the United States entered the war. Arthur Sweetser said, "At the outbreak of the war, no one in this country had any knowledge of what a battle plane was." Second (again a prevalent theme), there was a shortage of any appreciable manufacturing and engineering facilities, and capacity prohibited the advancement of airplane technology. Third, the United States was geographically removed from the fighting, which prevented both timely communications and the expedient flow of information with the combatants on front. Finally, no one in the industry was prepared to handle the intricate nature of the problems that would undoubtedly surface with the employment of these new machines.

Specifically addressing the first area of concern, the government sent observers to Europe to obtain the necessary technical data to begin construction of the airplanes. The representatives, led by Major R. C. Bolling, arrived in Europe nearly 3 months after the United States entered the war. As a result, combat aircraft production efforts could not begin until early summer of 1917.[39] Still, the entire production process would be trial and error, with most improvements made after "bitter experience and disappointments."[40] The lack of manufacturing, distance from the front, and inability to solve technical problems all surfaced in the determination of what planes the United States would actually produce.

Originally, the military decided that the construction of combat planes would focus on an American redesign of the immensely capable and extremely popular Spad fighter. However, the life of the single-place (single seat) plane produced in the United States was short-lived. On 15 December 1917, Pershing ordered that production focus on a two-seat variety of airplane and that the production of the single seat planes be left to the Europeans. Subsequently, the reproduction of the Spad was canceled.[42] The military then decided that the British DH-4, a daytime reconnaissance and bomber platform, was to be the focal point of the American Air Service and its production efforts.

The production of the DH-4 was delayed until August 1917, since a model had not yet reached the United States. The model arrived in Dayton, Ohio, on the 26th of the month, and was available for use as a basis for production.[42] The production facilities housing the DH-4 operations were literally built as the plane was constructed. In 2 months, the first DH-4 was rolled off the assembly line and made its first test flight on 28 October 1917. Powered by a Liberty engine, the plane passed all initial tests and was now ready for mass production.

After the successful test flight of the DH-4, the APB awarded a contract for 2,000 aircraft to the Dayton-Wright Company. Initial projections for aircraft production showed that 1,475 aircraft would be ready by 3 January 1918. However, nearly 3 weeks after that projected completion date, the DH-4's production life had just started. The problems of production were not due to a lack of raw materials, as government assistance ensured the requirements were met, but to the continued lack of experience and technical knowledge in the area of production. (The manufacturing processes used in the United States were markedly different than those used in Europe. The United States mastered the assembly line technique, best suited for items that could be made the same way over and over again. In Europe, the production process was highly specialized, where each item was manufactured in whole, one item at a time.)

It was not until 5 February 1918 that the first operational DH-4 aircraft left the Wright plant and arrived in Hoboken, New Jersey. On 15 March, the aircraft was packed aboard a steamer destined for France.[43] On 8 April, the first US-built DH-4 arrived in France. Nearly a month later, the aircraft flew its maiden voyage, armed as a combat plane should be. Although the results of the test flight were deemed satisfactory, certain changes had to be

made to the airframe, which further slowed production and deployment. Specifically, the munitions stations on the aircraft were of British design and were not capable of holding US ammunition. New bomb racks were needed. These were easy corrections, and by the end of 1918, the DH-4 was in "appreciable production."[44] A fully-armed DH-4 consisted of two .30-caliber Marlin machine guns in the nose and two .30-caliber Lewis machine guns in the rear, plus 220 pounds of bombs. By the spring of 1919, it was a viable aerial addition to the Allied efforts. The production rate of the DH-4 was unrivaled for the time period. Said Secretary Ryan, "We built more airplanes from month to month from the time we began than any other nation in the war built from the time it began."[45]

While mass production of the DH-4 was ultimately successful, aircraft production in the United States included other efforts. The government redesigned both the Italian-designed Caproni heavy bomber and the British Handley-Page bomber. Three Capronis were ultimately assembled, while the Handley-Page never progressed past the prototype stage until after the war.

The Liberty Engine

Although the DH-4 is a remarkable example of time-constrained manufacturing of an unproven commodity, the simple fact is that a plane will not fly without a powerplant. In fact, the size of an air force is contingent upon how many quality motors it can acquire or produce.[46] Coinciding with the development of the combat airplane was the aggressive production of the Liberty engine. So named to represent the principle by which it was constructed, the Liberty engine was the shining achievement of American industry during World War I. The Liberty's road was not smooth, as the same pitfalls that slowed production of the DH-4 were also present in the engine-manufacturing sector. At the time of American intervention, four separate manufacturers were capable of building and had built airplane engines. However, since there were no combat planes in the US arsenal, all engines previously constructed were used for training planes only. Therefore, they lacked the power and lightweight characteristics required for use in bombers and pursuit planes. The major challenge, then, was to accomplish two goals: (1) enable the existing manufacturers to increase their capacity to a sufficient level that would allow them to continue producing these engines to meet the growing need of the aviation training program and (2) require the manufacturers to design and build an engine capable of supplying the necessary power to lift the heavier aircraft. By the end of 1917, the first part of the challenge was met. The Curtiss OX5 and the Hall-Scott A7A were produced in sufficient numbers to meet all training requirements. The second part of the challenge would be more difficult to accomplish.

Since an engine takes nearly twice as long to roll through production as an airplane, it is no surprise that brainstorming designs for a new engine occurred shortly after the United States entered the war. In May, designers and engineers met in Washington, DC, determined to leave with the plans for a new, standardized motor. Unlike their decision to redesign the DH-4, the government decided that this engine should be domestically designed and produced, as the design differences among engines would not be easily reconcilable. The goal for this new motor was to remedy all repair problems overseas by using a set of standardized, interchangeable parts, while allowing for a marked increase in horsepower over models already available. After only 4 days in Washington, the plans for the Liberty motor were completed. The motor was to be an 8-cylinder, capable of producing 400 horsepower. Of utmost importance was that the Liberty would have a single stream of spare parts to facilitate the inevitable repair needs overseas.[47]

The real challenge rested in the ability of the American industry to produce combat-specific aircraft in time to make them available for the 1918 campaign.

In determining who would build the motor, the government turned to the automobile industry, which had the existing technology base to begin the task. Lincoln, Packard, and Nordyke and Marmon were selected for the contract, which was awarded on a cost-plus basis; the contractor would be reimbursed for their costs, plus some portion for incentives.[48] The first engine was assembled at the Packard Plant in Detroit and sent to Washington for testing on 3 July 1917. Shortly thereafter, the development and testing of a 12-cylinder version of the engine, designed to better fit the DH-4 aircraft on the production lines, were completed.

As promising as the future of this new engine was, there were still major problems in the production process. As with the DH-4, the projections on production for 1918 were overly optimistic, and the production dates were pushed back repeatedly. The plan was to have more than 9,400 motors produced by the beginning of June 1918. In actuality, the number available by the end of May 1918 was a little more than 1,100.[49] These problems in production resulted from (as in the aircraft industry) the total inexperience in the manufacturing of this type of machine in both large numbers and in a short time. Those in Europe believed

the American method of standardized production could not be applied to the construction of a precise instrument such as an airplane engine.[50] Interestingly, the construction of the airplane engine placed more demands on the manufacturers than did the automobile engine. Manufacturers were forced to expand their capacity (facilities and so forth) to handle these demands.

Manufacturers had to design new machines and tools to build the engines. This took time. In addition, obtaining materials for the production of this engine was not easy. The Liberty 12 was roughly 25 percent lighter than a 12-cylinder automobile engine, so the materials needed for construction of the Liberty were different than those found in the typical automobile of the day.

Despite these roadblocks, production of the Liberty engine reached 15,572 engines by the end of the war, with production reaching an astounding rate of 150 engines per working day at the height of production.[51] The engine was popular with the Allies, as it possessed more power than any other aircraft engine available in the theater. As such, the demand for Liberty engines was "far greater than the Air Service's demands alone."[52] Italy ordered 3,000, the British ordered 300, and France requested a number of engines as well. In terms of raw numbers at the time of the armistice, the production of the Liberty engine has "never been remotely touched in the production of any like complex mechanism."[53]

Coinciding with the development of the combat airplane was the aggressive production of the Liberty engine. So named to represent the principle by which it was constructed, the Liberty engine was the shining achievement of American industry during World War I. The Liberty's road was not smooth, as the same pitfalls that slowed production of the DH-4 were also present in the engine-manufacturing sector.

Transportation

While the production developments of the DH-4 and the Liberty engine were of paramount importance, logistically speaking, nothing can lose a war faster than inadequate transportation. Without the means to get the raw materials from the source to the manufacturers and likewise the finished product overseas, all the efforts by the industrial sector would not matter. It is likely that the transportation infrastructure of the United States was never tested as it was from 1917 to 1918.

The government realized quickly that transportation must be made available and that those resources were scarce in the country already. As the production tempo increased throughout 1917, the means of transporting aircraft, engines, men, and materiel had to be made accessible. Therefore, in December 1917, the War Department established the Inland Traffic Service. This organization immediately seized the existing railroads and designated them for war use only. [54]

Domestic transportation was only half the challenge facing both the airplane and engine manufacturers and the military. Timely delivery of the planes and the materiel to support them was still unproven. Ocean transportation was the lone option, and in a resurfacing common theme, the United States lacked the capacity for this logistics area. Also, the United States had never attempted to ship instruments as complex and delicate as these new planes and motors. Whether or not they would stand up to the rigors of transoceanic shipping was unanswered.

In 1916, the United States accounted for less than 6 percent of the world's 35 million tons of shipping (in terms of vessels).[55] Efforts were made to charter merchant marine ships to increase the shipping capacity of the United States. It was not until 3 years into the war that the United States chartered seven ships in the fleet dedicated to the movement of materiel. By the end of the war, the maritime transport fleet was capable of shipping 2,310 deadweight tons.[56] The initial lack of tonnage not only hindered the delivery of aircraft and engines to the European theater but also complicated domestic port operations. The major ports of embarkation (Hoboken, Brooklyn, and Newport News) were choked with materiel waiting to be shipped, often with no ship to haul it. As a result, US reliance on foreign shipping was prevalent throughout the war. These port facilities ran at or near peak capacity throughout the war. From August 1917 to the cessation of hostilities, nearly 2,000 tons of various materials left American ports daily in support of the war effort.[55] Tonnage shipped to support the aviation corps in Europe totaled 61,000 short tons. Not included in this total are the quartermaster and engineer supplies used by the aviation corps (to include clothes, food, rail improvements, and others).

Summary

The prewar environment seriously hindered the initial mobilization of the aircraft and engine production industries. According to established logistics principles, the initial industrial capacity of a nation is one key to conducting successful operations. At no time before the

war did the United States possess the required reserves needed to supply an air arm until the production in this country reached adequate levels. This lack of reserves prohibited more timely entry into the conflict, as there were no means from which to fill "unforecasted theater requirements." In addition, the initial planning for production was far too idealistic to be feasible, given that there was little or no prior experience in this field of manufacturing. From a planning standpoint, the ability to determine what equipment was needed to fill existing (or planned) requirements was immature, as the planning for such operations was late in coming. Even as the production of both aircraft and engines improved, the level of production reached the level of consumption only at the tail end of the conflict.[58]

The domestic transportation system was vital to the success of the US mobilization and deployment of the Air Service in an efficient manner. In 1917, the domestic transportation system in the United States was entirely adequate for supporting the mobilization effort. A nation's transportation system is key in determining the ability of a nation to conduct efficient operations. If the transportation system can be developed, or is in place to support the necessary force requirements, then the rest of the logistics system can be brought in line in time to be of value.[59] While the logging operations in the Pacific Northwest encountered problems in road conditions and weather, the ability of manufacturers to send the finished goods to the ports was, on the whole, satisfactory. The government's involvement in railroad

The government realized quickly that transportation must be made available and that those resources were scarce in the country already. As the production tempo increased throughout 1917, the means of transporting aircraft, engines, men, and materiel had to be made accessible.

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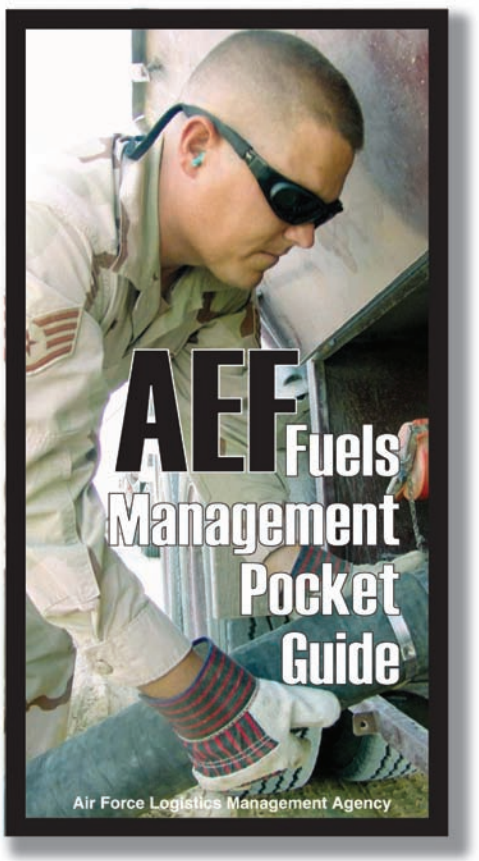

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operations (the Inland Traffic Service) provided the military with the means to transport large amounts of men and materiel in a timely manner. Overseas shipping capabilities lacked, initially, but were soon made sufficient through appropriation of a larger fleet and international cooperation. By the end of the war, the techniques used to deliver troops and cargo were among the best available.

Notes

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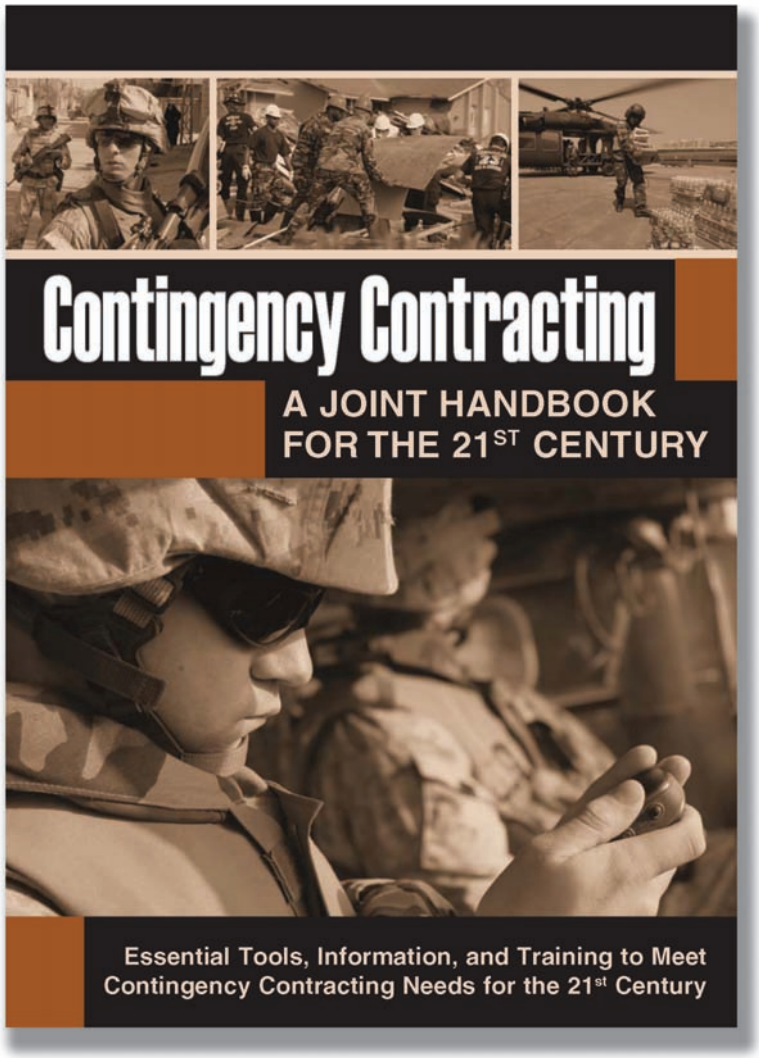

Contingency contracting support has evolved from purchases under the simplified acquisition threshold to major defense procurement and interagency support of commodities, services, and construction for military operations and other emergency relief. Today, this support includes unprecedented reliance on support contractors in both traditional and new roles. Keeping up with these dramatic changes, while fighting the Global War on Terror, is an ongoing challenge.

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AFLMA

Generating Transformational Solutions Today; Shaping the Logistics Enterprise of the Future

Air Vice-Marshal Peter J. Dye, RAF

Logistics Lessons from the Past—Deployed Operations

Wot makes the soldier's 'eart to penk, wot makes 'im to perspire? It isn't standin' up to charge nor lyin' down to fire; But it's everlastin' waitin' on a everlastin' road; For he commissariat camel an' is commissariat load.

Northern India Transport Train—Barracks-Room Ballads
—Rudyard Kipling

Logistics is not so much a science as an art and yet, under the pressure of tighter budgets and downsizing, there is great temptation to adopt the view that sophisticated resource modeling and realistic simulation (including wargaming), together with careful staff work, are sufficient in themselves to provide for effective support of deployed operations. But anyone who has had to maintain aircraft or other complex weapons systems, whether at home or overseas, will know how the unexpected can rapidly degrade effectiveness, notwithstanding the resources available, or the depth and detail of the advance planning.

I am not suggesting we cannot continue to use the techniques mentioned above (and others) to control costs and improve our logistics support. However, much of our recent experience relates to a scenario that increasingly appears to have been driven by an exceptional period in world affairs. Whether we like it or not, our current methods of doing business largely reflect the lessons learned in the Cold War and are tailored to supporting the main base concept. Of course, we cannot simply abandon tried and tested procedures, but we are entering a period of radical change and a concept of operations that owes more to the Royal Air Force's (RAF) experience up to 1945 than the subsequent 50 years of *peace*. Recent studies have addressed the RAF's conceptual framework for developing its capabilities to deal with new realities. Nevertheless, it is very much new territory, with few examples and little practical experience to draw upon. That being so, I would suggest there is considerable merit in looking at how the RAF supported deployed operations in the first half of this century, as part of the ongoing process to develop our post-Cold War logistics strategy.

Anyone who has had to maintain aircraft or other complex weapons systems, whether at home or overseas, will know how the unexpected can rapidly degrade effectiveness, notwithstanding the resources available, or the depth and detail of the advance planning.

To those who suspect my thesis implies things were done better in the past—that there was a sort of logistics golden age—note the deployment in 1916 of the No. 29 Squadron to join the Expeditionary Force. No. 29 Squadron had been formed at Gosport from the No. 23 Squadron in November 1915. Towards the end of January 1916, 20 DH-2 Scouts were allotted to the new squadron. It was decided (somewhat rashly as events proved) to deploy the ground crew and support personnel, together with the squadron transport, ahead of the aircraft move. The former proceeded overseas on 14 March. Ten days later, the aircraft set off for Dover, but mechanical problems (exacerbated by inexperience with the new aircraft, the fact that the squadron had been largely without ground crew for nearly 2 weeks, whilst most of those remaining had contacted measles), poor weather, and accidents en route meant that by the second week of April only 12 machines had actually reached France. The overall attrition was even worse than one might suppose, since the original allocation of 20 aircraft had been supplemented by further deliveries direct from the manufacturer (but none with compasses fitted, which raised some concerns amongst those pilots, who had managed to reach Dover, as to the wisdom of a Channel crossing).

Headquarters Royal Flying Corps (HQ RFC) subsequently calculated that, "the total number of machines consumed, in order to deliver at St Omer 12 serviceable, was 27."[1] The majority of these were scattered around Southern England, some written-off, whilst others ditched in the Channel or crashed on landing in France. The pilots involved fared little better, suffering their fair share of injuries, as well as measles, such that the last arrived in France over 2 weeks later. All in all, it was not one of the RFC's finest hours.

Whilst this catalogue of disasters may be entertaining at this distance, I doubt there are any fundamental lessons to be learnt. However, there are aspects of RAF deployed operations in the Second World War that are actually quite instructive.[2] One example is the logistic support for the RAF elements involved in Operation TORCH, the North African landings that took place in December 1942. Some 450 aircraft were involved in the Eastern operation, centred on Algiers, tasked with providing air cover for the shipping and ground forces, and, once ashore, to protect against air attack and to support the subsequent land advance. Immense difficulties were encountered as this was the first large-scale amphibious landing to be undertaken by the Allies. It was also the first real test of Anglo-American cooperation, the conduct of joint operations and, most importantly, of joint planning. As far as the air element was concerned, it was agreed that the Army would provide fuel and weapons, whilst the RAF would furnish all support vehicles, ground equipment, and technical stores. The relevant equipment was packed at maintenance units in the UK to schedules prepared by the Air Ministry, but the sponsoring branches had no visibility of what was actually provided. It was subsequently reported by the units making up the packs that there were 72 percent inabilities. All *pack-ups* were allocated, in the interests of security, field unit serial numbers. The code for these numbers was given a very limited distribution and not included in the administrative instructions. All stores were then loaded at UK ports for travel by convoy directly to join the Eastern Task Force at Gibraltar.

The actual landings met little opposition and the advance RAF ground parties were able to reach their designated airfields and receive the first Allied aircraft by 1030 on the morning of D Day. Thereafter matters got more difficult. Enemy air attacks commenced in earnest, fuel was in extremely short supply, and essential equipment either did not arrive at the beachhead or was lost on landing (this problem was exacerbated by the limited attention that had been paid to the loading of the ships in the UK such that in some cases it took 2 days to unload priority equipment). It would be wrong to suggest the planners had not anticipated the difficulties likely to be faced in landing large quantities The variety of aircraft and engine types vastly increased the difficulty of supply and repair at the school. More significantly, however, the RAF embarkation staff of 26 personnel of all ranks was quite incapable of sorting the mountains of equipment being discharged. The result was not only were the docks swamped with piles of stores which in fact would not be needed for many weeks, but there was also no means of distinguishing between cases. A great deal of unnecessary equipment found its way to the forward areas in place of items that were urgently required. To make matters worse, although the consumption of ordnance was far less than had been anticipated, the early consignments of bombs arrived with the wrong components or without components at all; this included fusing links. By the end of January the process of marrying up bombs with tails had still not been completed satisfactorily (without wishing to exaggerate, there are echoes of our own experience during Operation GRANBY). There was also the usual share of unexpected, and hence unplanned, maintenance problems. For example, the soft state of the airfields following heavy rain resulted in a large number of aircraft ground looping and breaking their propellers, therefore stocks were rapidly exhausted.

The variety of aircraft and engine types vastly increased the difficulty of supply and repair at the school. More significantly, however, the RAF embarkation staff of 26 personnel of all ranks was quite incapable of sorting the mountains of equipment being discharged.

Logistic problems did not end here. The numbers of RAF movements staff were totally inadequate to the task and thus had to rely upon Army movements personnel. But without the key to unit serial numbers, the latter could only surmise for whom the equipment was intended. This generally ended in it being sent to the wrong unit, who, knowing only its own serial number, could not dispose of the equipment to its proper destination. As a result, much of the equipment off-loaded from the first convoy into Algiers did not reach the correct units until many weeks had elapsed. Finally, when the pack-ups were opened it was often found the items required were either missing or present only in reduced quantities.

Those involved in the handling of stores at Al Jubayl during Operation GRANBY nearly 50 years later many have noticed some similarities between their experiences and the problems encountered in Operation TORCH. In neither event was there effective enemy action to interrupt the supply chain and yet immense difficulties were encountered simply as a result of the scale and pace of the buildup, the sheer volume of stores and the almost impossible

task of locating specific equipment amongst the countless crates and International Standards Organisation (ISO) containers on the dockside. One is forced to conclude that moving thousands of tons of stores across a continent has always been the simplest (but not necessarily the easiest) part of any logistic operation. My personal experience during Operation GRANBY would suggest, however, that even this statement has to be qualified. I recall on one occasion a serviceable aeroengine, urgently required at Muharraq, returning from Lyneham on the same lorry that had rushed it down there—much to the distress of the driver. More importantly, the original inbound unserviceable engine was at that very moment winging its way back to the Gulf in the back of a Hercules! To be blunt, delivering the required item, to the right hands, at the right place and at the right time, remains the overriding challenge for any logistic organisation. It is also true that forging the last link in the support chain can be as difficult as assembling the remainder. It is a task made all the more challenging in a joint multinational environment, subject to the vagaries of host-nation support and the inevitability of unplanned (and hence inadequately provisioned) unserviceabilities. The way ahead must surely lie in both improving asset tracking and also providing greater visibility of the supply chain to all parties, including the consumer as well as the supplier.

One of the unique aspects of the RAF's logistic planning for Operation TORCH was the creation and employment of servicing commandos. These units comprised up to 150 RAF tradesmen, with intensive combat training, who were to be landed during the assault phase and would be capable of defending themselves (and their aircraft), whilst also undertaking the daily servicing, refueling and rearming of aircraft operating from advance landing grounds and captured airfields until such time as the main squadron servicing parties arrived. In theory, the servicing commandos—although entirely comprised of Trade Group 1 (technical) personnel—could only provide rudimentary support as their tools and equipment would be necessarily limited. However, the two servicing commandos employed during Operation TORCH had to undertake the maintenance of many more squadrons, of several aircraft types, and for a considerably longer period than originally intended owing to the difficulties outlined above as well as problems in assembling and moving the appropriate technical personnel forward. In fact, instead of being relieved after a few days, they were employed continuously for 5 weeks without rest.[3] Notwithstanding the servicing commandos' efforts, the lack of maintenance facilities and skilled personnel soon began to make itself felt in the form of reduced aircraft serviceability. This is not to say the logistic planning had failed to make provision for the sustained support of aircraft operations, but it had been envisaged that the majority of squadrons once ashore would be rapidly joined by their assigned maintenance personnel, as well as air stores parks (with sufficient equipment to support 30 days' maintenance) and repair and salvage units. Quite deliberately there had been no provision for major repair (beyond what the repair and salvage units could undertake) in the anticipation of a relatively brief campaign. In the event, the operational commanders decided to accelerate the aircraft deployment plan and this, coupled with the supply chain difficulties already outlined, meant squadrons were compelled to operate for some time without support equipment, adequate servicing and repair arrangements, or even transport and signals support. Typical of these difficulties was the plight of the two Beaufighter night fighter squadrons called forward 3 weeks early. On arrival they had to be maintained by members of the aircrew, co-opted ground personnel from a collocated Hudson squadron, and mechanics from a repair and salvage unit. To compound these problems, the Beaufighters' radar equipment had been removed for security reasons and sent by sea with the ground personnel. Therefore, an emergency supply of radar equipment had to be flown out direct from the UK before night fighter operations could commence. But, not surprisingly, the hastily assembled maintenance team found the radar extremely difficult to install without any specialist knowledge or the appropriate support equipment and tools.

This is not to say the logistic planning had failed to make provision for the sustained support of aircraft operations, but it had been envisaged that the majority of squadrons once ashore would be rapidly joined by their assigned maintenance personnel, as well as air stores parks (with sufficient equipment to support 30 days' maintenance) and repair and salvage units.

Eventually, the second line maintenance units were able to come into action, but this did not immediately resolve every problem. The repair and salvage units found they faced an immense backlog of repairs because of the delays and were effectively immobilised whilst the stores parks discovered the storage space provided by the Army was but a fraction of their actual requirements. Eventually some additional space was found in local farm buildings. Strenuous efforts were made to recover this situation as the campaign developed by improving both the support arrangements as well as the mobility of the squadrons. Maintenance personnel in the forward area were reduced to a minimum to enable the squadrons to be placed on a mobile basis capable of movement at short notice utilising

their own motor transport. The remaining maintenance personnel were withdrawn to the rear echelons. The forward stores parks were also reduced to *immediate issue* stocks only (and the personnel reduced accordingly), whilst the repair and salvage units were totally withdrawn, other than small mobile sections to work with the squadrons. In general, these new arrangements worked well and would provide the pattern for all subsequent campaigns.

Amongst the many other lessons learnt from Operation TORCH was the need to schedule carefully the arrival of equipment and stores, whilst ensuring the necessary personnel and repair facilities were in place as early as possible to permit effective air operations. That said, it was also clear too large a forward support organisation would take a disproportionate share of the available shipping and assault craft, whilst also serving to hinder subsequent mobility. Exercises undertaken in the UK during 1943, in preparation for the Normandy landings, confirmed the overriding importance of reducing what might today be referred to as the *deployment footprint*. In fact, how best to organise the maintenance support for squadrons whilst enhancing their mobility, was a question which group and command staffs had been struggling with since 1940. Prior to the expansion of the RAF, fighter squadrons were largely self-sufficient, each flight having the capability to undertake in-depth repair, as well as the normal servicing functions. It was soon evident this system could not cope with the increased flying rate and greater technical complexity that accompanied the expansion programme. As a result, maintenance support was reorganised on a squadron basis; two flights being responsible for servicing tasks, whilst the third flight undertook major repair work and the deeper inspections. This system, which today we would probably describe as an *autonomous* maintenance organisation, remained in force for the first year of the war. However, during the Battle of Britain it was discovered that the mobility of squadrons was adversely affected and the frequent squadron moves resulted in the maintenance personnel being increasingly detached from their units, sometimes being spread over at least three different stations.

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In an endeavor to improve the mobility of the squadrons and avoid the need to transport large ground parties and redundant bulky equipment from station to station, it was decided to reexamine the maintenance system. After toying with a proposal to do away with all maintenance personnel and rely entirely upon station support (the *centralised* approach), it was agreed a *semiautonomous* organisation should be adopted, whereby the bulk of the repair responsibility, associated tradesmen and ground equipment would be transferred to the station *maintenance party*, leaving only sufficient squadron maintenance personnel to conduct daily servicing and minor inspection tasks. The squadron engineer officer would remain in the squadron but the station maintenance party would provide echelons attached to each squadron, albeit under the command of the station engineer officer. These echelons could also provide a mobile unit to accompany the squadron for *bare-base* moves.

Over the next few years this organisation was further developed to become almost fully centralised; the supporting technical personnel were in effect entirely divorced from the flying squadrons. A three-tier structure was introduced comprising: (1) the *Advanced Landing Ground*, where quick turnaround servicing would be carried out by servicing commandos (as already described); (2) the *Airfield Area*, capable of supporting three squadrons where servicing was fully centralised under the station maintenance party; and (3) the *Base Area* that undertook maintenance beyond the station maintenance party's capability or capacity to complete in under 48 hours. The Airfield Area was in essence a mobile station, but to achieve this it was necessary to create additional support units, including repair and salvage units and forward stores parks. This system was extremely successful in providing effective support to the RAF's flying squadrons, both through the North African and Italian campaigns as well as during and after the Normandy landings. It should be noted that, notwithstanding the centralised maintenance organisation, particular efforts were made to sustain squadron identity by affiliating Airfield Area echelons to specific squadrons under a squadron technical officer. This also served to improve the welfare and management of the technical personnel concerned. That said, such pragmatism was not allowed to detract from the overall policy of centralisation.

As a footnote, the sort of problems experienced by the No. 29 Squadron in 1916 were resolved by making temporary provision at the base airfields in Southern England for maintenance support, while the squadron servicing personnel established themselves in Normandy. In the event, the maintenance arrangements worked extremely well. The first servicing commandos landed on D+1 and received their initial aircraft on D+2 (on a temporary basis, for refueling and rearming). By the afternoon of D+3 some 3,500 RAF

personnel and 815 vehicles had been landed. The permanent move of fighter squadrons to airfields in Normandy commenced on D+4, once the Airfield Areas were ready to receive them. Thereafter the pace of deployment accelerated such that, by the end of June, one wing was arriving every 5 days. Once again, the servicing commandos had proved invaluable, not only enabling damaged aircraft to return back to base, but also ensuring an extremely high availability rate. Nevertheless, once the bridgehead was established and the Airfield Areas in theatre, their importance rapidly declined and they were withdrawn at the end of July.

As in Operation TORCH, a number of environmental maintenance problems arose. Rather than wet airfields, the cause in this instance was dust. The soil on which the landing grounds were constructed contained a very high proportion of silica which lessened the life of engines, particularly those not fitted with air-cleaning devices (such as the Typhoon's Sabre). Unserviceabilities rapidly rose and it was only by pumping oil and water onto the airfield surface and minimising warm-up times that the problem could be contained (but not before 66 engines had been damaged beyond repair). There are echoes again here of the RAF's experience in Operation GRANBY. I would only add that maintaining sophisticated aircraft and weapons systems outside of their normal operating environment is something that has to be practised. Careful planning, experience, and foresight are not a substitute for the real thing!

Following the Normandy breakout, the primary problem facing the maintenance organisation was the ever lengthening lines of supply. Transport aircraft were used to supplement the supply chain and, in particular, to deliver aviation fuel to help support the momentum of the advance. This was successful, and at no stage were operational units ever prevented from carrying out sorties for lack of supplies. In order to avoid bottlenecks and minimise forward storage requirements, the provisioning system was based upon a *call-forward* principle, rather than the base organisation sending supplies into the theatre at will. This has clear parallels to today's concept of *just-in-time* supply and express chain management.

Turning to the lessons we might draw today, I would first observe that the RAF's organisational structure to support deployed and mobile aircraft operations in the Second World War took some four years to perfect. The result was a lean, efficient system that: sustained high availability; enhanced squadron mobility, flexibility and economy in manpower and equipment; and enabled squadron commanders and airmen to concentrate on their operational responsibilities.

Turning to the lessons we might draw today, I would first observe that the RAF's organisational structure to support deployed and mobile aircraft operations in the Second World War took some 4 years to perfect. The result was a lean, efficient system that: sustained high availability; enhanced squadron mobility, flexibility and economy in manpower and equipment; and enabled squadron commanders and airmen to concentrate on their operational responsibilities.[4] It may well be the servicing commando concept—given the remote possibility we will again be required to participate in an amphibious assault on a hostile shore—will remain simply an historical curiosity. Nevertheless, and notwithstanding the passage of time and subsequent technological development, the lessons of 1939-1945 provide much food for thought in deciding how best to develop logistics support. Do we really have the right maintenance organisation to cope with the post-Cold War era? To date, studies have focused largely on the mechanics of deployment support and the resourcing implications rather than the organisational aspects and how this might be developed to enhance mobility and reduce the forward support requirements, particularly the deployment footprint. I have always been an enthusiastic proponent of the semiautonomous maintenance organisation, believing the enhanced squadron *esprit de corps* brings very real benefits. But, this should not blind us to the very real issue of whether such a system is the best or indeed the only way to support deployed operations in the future. Is there not a very real danger that we are solving tomorrow's problems with today's solutions? At the very least the question should be debated.

Notes

1. AIR 1/127/15/40/152, Public Records Office, Kew, London, UK.
2. Much of the source material comes from the Air Historical Branch, *Official History on The Development of RAF Maintenance 1939-1945*, published in 1954.
3. Davies and Kellett, *A History of the RAF Servicing Commandos*, 1989.
4. Report on the Air and Administrative Organisation of the 2d Tactical Air Force, Air Ministry, 1947, 89. Pact with Germany and Italy on 27 September 1940, a pact that was aimed directly against the United States, further exacerbated US-Japanese relations.

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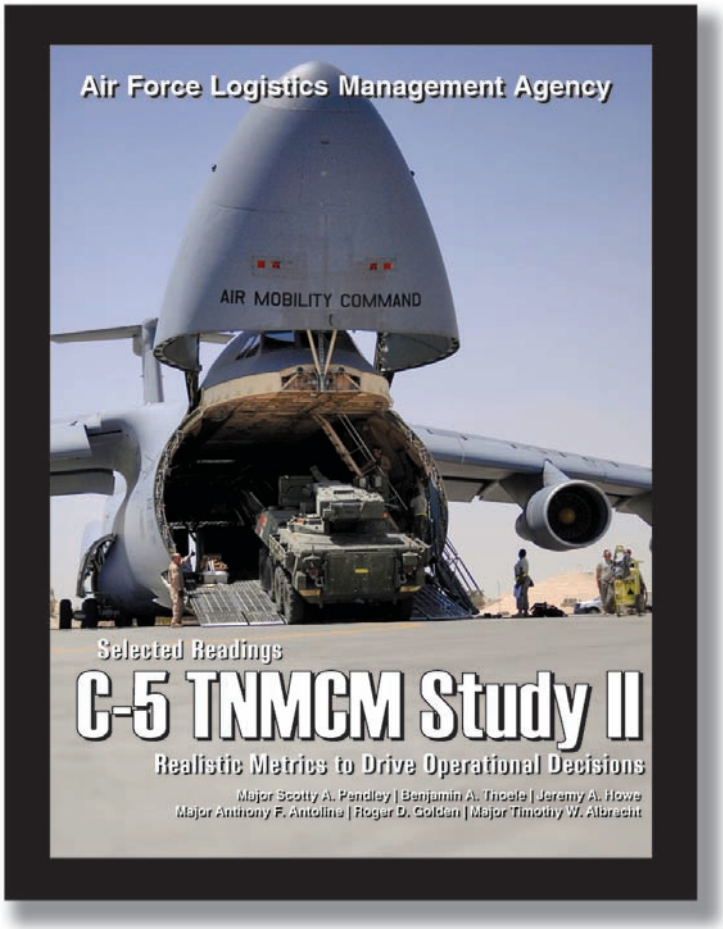

The *C-5 TNMCM Study II* proved to be a stern test of AFLMA's abilities and perseverance. Considering the numerous potential factors that impact TNMCM rates as well as the C-5's historical challenges in the areas of availability and achieving established performance standards, the study team was determined to apply new thinking to an old problem. The research addressed areas of concern including maintaining a historically challenged aircraft, fleet restructuring, shrinking resources, and the need for accurate and useful metrics to drive desired enterprise results. The team applied fresh perspectives, ideas and transformational thinking. As a result, the study team developed a new detailed methodology to attack similar research problems, formulated a new personnel capacity equation that goes beyond the traditional authorized versus assigned method, and analyzed the overall process of setting maintenance metric standards. AFLMA also formed a strategic partnership with the Office of Aerospace Studies at Kirtland AFB in order to accomplish an analysis of the return on investment of previous C-5 modifications and improvement initiatives. A series of articles was produced that describes various portions of the research and accompanying results. Those articles are consolidated in this book.

AFLMA

Generating Transformational Solutions Today; Focusing the Logistics Enterprise of the Future

Lieutenant Colonel Todd J. Schollars, USAF

German Wonder Weapons: Degraded Production and Effectiveness

Introduction

World War II was the greatest conflagration this planet has ever known. It started as a few hegemonic nations annexing territory for economic reasons, then became an ideological battle between right and wrong, and finally ended in a battle of survival for Germany. Facing the Allies' unconditional surrender demands, the Germans combined fervent ideology, a powerful industrial base, and cutting-edge technology to produce weapons to stave off the Allied tide. The effort was mostly concentrated in developing air weapons, where Germany tried, and ultimately failed, to meet the dual and competing needs of strike and air defense. Germany developed several *wonder weapons* to overcome Allied quantitative superiority. Some of these weapons were obviously flights of fancy, while others served as the basis for many US and Soviet weapon systems in the Cold War. German wonder weapons were a cut above anything the Allies had, yet they were not able to change the tide of war because there were not enough of them on operational status. This fact generates two questions. First, why couldn't the Germans produce and deploy their advanced technology in any effective numbers? Second, if German wonder weapons had reached the front in quantity, would they have made a difference in the war's outcome?

The Wonder Weapons

Germany produced a large number of high-technology weapons during World War II. However, unlike the Allies' atomic bomb, electronic warfare, or Norden bombsight, the Germans were unable to reap benefits from their investment.

Germany produced a large number of high-technology weapons during World War II. However, unlike the Allies' atomic bomb, electronic warfare, or Norden bombsight, the Germans were unable to reap benefits from their investment.

The Messerschmitt Me 262 is, along with the V1 and V2, the best known of Germany's wonder weapons. It could fly at more than 540 miles per hour (compared to the P-51's 437 miles per hour); had an operational ceiling of 37,000 feet; and packed a punch with its four heavy, fast-firing 30-millimeter MK 108 cannon concentrated in the nose.[1] It was so far advanced beyond other fighters that General Adolf Galland, commander of Luftwaffe fighters, declared on his first flight, "It felt as if an angel was pushing."[2] The technology behind this superb aircraft was the turbojet engine, which produced more power than piston engines and created less drag than a propeller. The amazing performance of the turbojets shocked Allied aircrews when they first saw the Me 262. It could easily outrun escort fighters, allowing Luftwaffe pilots to dictate the terms of combat. This was especially important for overcoming the Allies' quantitative advantage. Once they were in close, they could deliver devastating fire from their cannon and rocket armament; only a few hits could bring down a heavy bomber.[3] The Me 262 clearly made Allied air leaders nervous because it represented the potential for Germany to regain air superiority. However, the aircraft was not without problems.

The turbojets of the 1940s were still in their infant stage and required delicate care from pilots and maintenance personnel alike. Any sudden throttle movements could cause an engine flameout, resulting in deceleration and a lengthy engine restart—not ideal when a pilot was in combat. The high speeds made formation flying difficult, complicating the concentrated attacks essential to breaking up bomber formations.[4] Both these limitations required highly experienced pilots, something Germany would find in short supply late in

the war. Additionally, maintaining the Junkers Jumo 004 engine was time-consuming and needed considerable skill, also in short supply. Each engine had a life of about 15 to 25 hours before needing replacement,[5] creating both maintenance and logistics supply headaches. Rarely did an Me 262 geschwader (wing with 60 to 90 aircraft) have more than 16 serviceable aircraft for a mission.[6] Even with these problems, the Me 262 was still a potential *war winner*, if not for production and operational obstacles.

Germany was an early pioneer of air-to-air and air-to-ground rockets and missiles. One of the simplest, yet most effective was the R4M unguided rocket. The Me 262 could carry 24 of these small, simple, easy-to-produce weapons. Their size belied their strength: fired from outside the range of American .50 caliber defensive guns, one R4M had "indescribable efficiency—firing a salvo would hit several bombers—one rocket would kill them."[7] The attacks had the added benefit of breaking up bomber formations, making them more vulnerable to other Luftwaffe fighters. R4Ms also had the same ballistic characteristics as the MK 108 cannon, meaning the Me 262 could use the same sight for both weapons.[8] A more advanced weapon was the X-4, a fin-stabilized, liquid propellant, air-to-air missile, having a speed of 600 miles per hour and a range of 3.7 miles. After firing it from an Me 262 or Focke-Wulf Fw 190, the pilot would guide it to the bomber target via a wire connecting the missile and launching aircraft. Then the missile would detonate on impact or with an acoustic fuze.[9] The guidance system had the major disadvantage that the pilot could not maneuver his airplane while guiding the X-4, a serious problem considering Allied escort fighters. Germany was developing an acoustically guided version, using a type of sonar to reach the target and explode, but the war ended before it was ready. Had the Germans deployed the R4M or X-4 in significant numbers, it could have dented the Allied bomber offensive. Moreover, since the Luftwaffe was primarily a striking force, German scientists did not confine themselves to air-to-air missiles.

The Germans also used rockets to propel their fighters.

Germany developed two air-to-ground guided weapons during World War II, both used primarily to stem the tide of Allied shipping crossing the Atlantic Ocean. The first was the Henschel Hs 293—a 1,100-pound bomb with 10-foot wings, a tail, and a liquid rocket engine. The launching aircraft would fire the Hs 293 from outside the target ship's antiaircraft range (possible with the bomb's rocket), then remote control it via radio during its terminal glide to impact. The Hs 293 only impacted at 450 miles per hour, so it had less penetrating power than conventional bombs and was effective only against merchant ships.[10] The Germans overcame the penetration problem with the Fritz X guided bomb. This weapon did not have any propulsion. Rather, the aircraft dropped it as a normal bomb, then the bombardier guided its steep descent by radio remote control.[11] Both the Fritz X and Hs 293 had spectacular success, but Allied defenses overcame these weapons because of limitations cited later. Interestingly, the primary carrier of both weapons was the Heinkel He 177, a bomber whose serviceability greatly limited the bombs' employment, indicating Germany's integration problems.

The Germans also used rockets to propel their fighters. Two specific rocket fighters stand out as examples of what Germany was first able to design, then what shortages drove them to implement. First, the Me 163 was a high-performance interceptor. It relied on its flying wing design and single Walter R II-203 rocket engine to produce astonishing performance. It could reach more than 620 miles per hour and climb to 20,000 feet in a little more than 2 minutes. Allied fighters could not touch it, and it presented bomber gunners with a near impossible leading aim calculation. Like the Me 262, however, its propulsion system was not perfect. The fuels were hard to manufacture, extremely corrosive, and would explode if not properly mixed.[12] Further, two of the fuel tanks were beside the cockpit; any vapor or liquid leaks were life-threatening to the single pilot. The rocket burned more than 18 pounds of fuel per second, giving it not much more than 100 seconds of total burn time before the Me 163 became a vulnerable glider. Therefore, while it was a good basic design, lack of further development made the Me 163 operationally ineffective.

The second German rocket fighter was driven purely by economic and pilot shortages. The Bachem (Ba) 349 Natter launched vertically, climbed at more than 15,000 feet per minute, then flew at 600 miles per hour into the Allied formations, where it released its noseful of unguided rockets. Once its fuel was spent, the Natter glided back to base where the pilot ejected himself and the rocket engine—both then parachuted to earth.[13] The reason for this event was threefold. First, the aircraft structure was cheap and made of noncritical materials, so it could be disposed of. Second, the rocket was difficult to manufacture, so it needed to be saved. German engineers also knew that the shock of landing was likely to detonate any

residual fuel, with dire results for the engine and pilot. Finally, the Natter was designed for inexperienced aviators. Since the vertical takeoff required no skills and landings were not attempted, pilot training could concentrate on intercepting the enemy.[14] This was clearly an extreme circumstance brought on by Germany's desperate situation late in the war.

The final wonder weapons of note were the V1 and V2 rockets, likely the best known of any German weapons. The V1 or Vergeltungswaffe (vengeance weapon) 1 was the world's first cruise missile. It employed a novel pulse jet engine (which made a distinctive sound, hence the name buzz bomb) and short wings to carry its 1,874-pound warhead to targets up to 150 miles.[15] While the overall idea was advanced, the V1 was actually unguided and flew a straight course until its primitive range-setting device locked the controls and crashed the missile into whatever was below, detonating the V1's warhead. This obviously was not a precision-strike weapon, but it did kill 6,184 people in and around London. This is still a record number of cruise missile deaths, impressive considering the number the United States has launched in the last 13 years.[16] The V2 was a prewar project designed to attack targets beyond the range of artillery. It was an unguided ballistic missile and the forerunner of today's intercontinental ballistic missiles and tactical ballistic missiles (the Scud is a direct descendent). The 28,500-pound missile lifted its 2,200-pound warhead[17] in a ballistic trajectory, then plummeted to earth at more than 2,200 miles per hour.[18] V2s were unstoppable after launch; the only way to halt them was bombing the factories or launch sites. V2s inflicted 2,754 deaths in London, Amsterdam, and Antwerp, a record that stood until the immense Scud exchanges of the Iran-Iraq wars.[19] The V1 and V2 were the only mass-produced and employed wonder weapons. As we will see later, there were several reasons why they were not able to produce the effects Germany needed to turn the tide of war.

It is evident the Germans developed air weapons without equal. However, their failure to mass-produce and deploy these weapons is a monument to *what could have been*. It is important to remember that while the air effort received the most attention, the Germans also developed land and submarine wonder weapons, all theoretically capable of providing the push Germany needed to overcome the Allies.

Production Problems: Why Germany Could Not Deploy the Wonder Weapons

Germany arose from the ashes of Versailles to become a huge economic power. Its industry, technology, and mass-production capacity led Europe and most of the world in the 1930s. So why could Germany not produce its wonder weapons in significant numbers? The problem was not capability. Rather, it was the restrictions and obstacles Germany placed on its industry that affected the production time line of extremely sensitive weapons. Four reasons behind Germany's lack of production are discussed here: political and military interference; the difficulty of mass producing advanced weapons; a lack of strategic vision; and finally, damage and dispersion resulting from the Allies' Combined Bomber Offensive. Any one of the reasons was enough to hamper generating high-technology arms; all four in concert were absolutely crippling.

The final wonder weapons of note were the V1 and V2 rockets, likely the best known of any German weapons.

Political interference was a great obstacle to producing weapon systems and was particularly fatal to advanced systems that required long development times. The political obstruction started early and at the top of the Nazi hierarchy. On 11 February 1940, Hitler canceled all development work that could not get aircraft to the front within 1 year.[20] Work stopped on a half dozen major projects, from jets to long-range bombers, all of which would have made the Luftwaffe more capable of fighting a lengthy war. When Germany became desperate for advanced weapons, its hurried response would produce aircraft that had not benefited from full development processes. So confident in early victory were Germany's leaders that they cut the legs out from under the Luftwaffe before the major war really started, denying it any chance of victory in a drawn-out conflict.

High-level conflicts marked the Nazi regime, as Hitler dueled with his advisors for control of the German military's strategic direction. Hitler cut through many of these disagreements by removing dissenters and consolidating power to himself. For example, he already had taken command of military operations when he took control of critical production programs. Although Hitler had a weak technical knowledge of aviation,[21] he realized the importance of jet engines and personally controlled jet engine allocation after June 1944.[22] His tight control took allocation away from production experts. The result was haphazard distribution to manufacturers and operational units, with a corresponding drop in production and aircraft in-service rates. Compounding Hitler's central control was his top officials' fear of or refusal

to confront him on decisions they knew were wrong. At best, dissenters received Hitler's extreme verbal abuse, at worst, removal from office. By 1943, Hitler distrusted the Luftwaffe, and there were many cases of Hermann Goering's passively watching Hitler sow the seeds of his air force's destruction.[23] Even the outspoken Erhard Milch, chief of Luftwaffe production, took orders without objection. When Hitler *uncanceled* the Me 209 program in August 1943, Milch said, "But I have my orders. I am a soldier and must obey them."[24] He knew the restart would split Messerschmitt's production between an obsolescent fighter that would never see operational service (the 209) and a potential war winner (the 262). The best and most damaging example of this phenomenon is seen in the saga to produce the Me 262.

The Me 262 jet started development as a fighter and had capabilities far beyond contemporary piston engine aircraft. It was the top priority for production after Galland's first flight and subsequent endorsement. Milch canceled the Me 209 program to devote full attention to the new jet. However, Hitler interfered and restarted Me 209 production, largely out of fear of another failed advanced aircraft (such as the He 177) and its associated risk. There were already several problems with getting the Me 262 into production. Milch knew Hitler's decision to continue the Me 209 would take up space on Messerschmitt's assembly lines and delay operational employment of the Me 262 but went along, happy the Me 262 was still a fighter.[25] Unfortunately, Hitler's interference in the program had only started.

Political interference was a great obstacle to producing weapon systems and was particularly fatal to advanced systems that required long development times.

Hitler observed Me 262 demonstrations in December 1943 with several staff members, including Goering, Milch, and Galland. After seeing the Me 262, Hitler remarked, "I see the Blitz bomber at last! Of course, none of you thought of that!" Galland, referring to the plane's obvious fighter characteristics, remarked in his autobiography, "Of course, none of us had."[26] Milch actually went behind Hitler's back and continued developing the Me 262 as a fighter. When Hitler found out and confronted him at a meeting on 24 May 1944, Milch responded that the plane required extensive modifications and delays to become a bomber. Hitler exploded. "You don't need any guns. The plane is so fast it doesn't need any armorplate either. You can take it all out!" He then turned to the Luftwaffe's director of research, who responded that Messerschmitt could make the modifications without difficulty (actually, removing the guns and armor to make way for bombs would have changed the center of gravity so much Messerschmitt would have had to move the wings). Goering and Galland were so browbeaten, they remained silent, but Milch finally had enough, saying, "Even an infant could see it was a fighter."[27] Hitler fired him 2 weeks later. Thus, Hitler's meddling and his highest advisors' ineffectiveness at objecting caused significant delays in a potential war-winning aircraft and led to the dismissal of his best aircraft production coordinator. The Me 262 would eventually become a fighter but too late to be produced in numbers sufficient to wrest air superiority from the Allies. There were other systemic problems with producing the jet fighter, but Hitler's interference made it impossible for Messerschmitt to stick with a firm production schedule. This was only one of several obstacles that kept the wonder weapons out of the air.

High-level interference and bickering were not the only impediments to production. The Luftwaffe's officers contributed as well. Galland remembers rival fanatical groups within the officer corps, some more dedicated to Nazi idealism than actually producing an effective air force. This led to a crisis of trust and leadership, two elements on which depends the fighting strength of any unit.[28] Its result was no single voice speaking for the operational and strategic needs of the Luftwaffe; it also made it difficult for the Luftwaffe to present a united front to deflect high-level interference in weapons programs. Furthermore, we often remember the Luftwaffe as an honorable band of eagles. However, several pilots accepted checks from aircraft companies to endorse their products—planes that were often inferior.[29] This, combined with Goering's financial interest in several aviation factories, meant Germany based production choices on personal profit, rather than capabilities. Making inferior planes not only put the Luftwaffe further behind but also took assembly line space away from advanced projects. Military interference also played on a grander scale before the war even started by creating a war industry that could not meet the demands of mass production.

Germany's advanced technology production problems lay both in the character of the industry and pervasive military interference from project inception through delivery. First, German industry was craftsman-based to deliver very complicated weapons.[30] This was ideal for creating wonder weapons but made it nearly impossible to mass-produce them. Second, the armaments industry spread its capacity over several different specialized designs. Instead of a core of proven aircraft, German industry had 425 types,[31] once again hindering mass production and limiting the number of advanced aircraft produced. The reason behind this structure was military fastidiousness—the Wehrmacht liked working with specialized

craftsmen because they could respond to the field's demands for weapon changes.[32] These changes did make the weapons more effective, but the constantly changing specifications made mass production impossible. No engineers or industrialists were consulted before making changes,[33] creating inefficiencies that further limited production. Finally, the Luftwaffe's first transformation came during the 1930s, when it could upgrade its equipment in peacetime. Conversely, the Allies had to transform early in the war; then stuck with late 1930s technology pushed to its limits, a huge production capacity overcame any qualitative shortfalls. However, Germany tried to transform to wonder weapons late in the war. Transitioning to a superior model in war actually can cause substandard combat readiness and degraded logistics as operators and maintainers learn to deal with new technology.[34] The result was German industry produced too little, too late, and actually decreased the Luftwaffe's capability.

Political obstacles, military interference, and an industry ill-equipped to make advanced weapons combined to hinder the wonder weapons' deployment. The cause of these problems was a complete lack of strategic vision, which prevented effective campaign planning and long-term weapons production. The lack of vision began at the highest levels and set a tone of short-range thinking that permeated the Luftwaffe, ultimately crippling its ability to prosecute any kind of strategic warfare. Goering was an extremely able fighter pilot. During World War I, he took command of Manfred von Richthofen's Jasta when the *Red Baron* died in action. However, Goering never gained the technical and logistical perspective needed to command an entire air force.[35] Before the war, he abandoned the 10-year prewar plan for a well-staffed and exercised strategic air force in order to attain short-term goals quickly.[36] The discarded plan included high-tech weapons, long-range strike aircraft, and the ability to put the German economy on a war basis before hostilities began. Even in early 1941, Goering could have pursued an aggressive program to increase German production but failed to do so. Luftwaffe military leaders also were more interested in active operations than preparing for the long term, because they desired tactical superiority at the expense of strategic readiness. This resulted from the massive catchup game Luftwaffe personnel played between the wars and made the officers technocrats and operations experts with limited vision. They could not relate airpower to national strategy, and the resulting defects were fatal.[37] When losses outstripped production in 1942, the Luftwaffe finally demanded construction increases. By the time the numbers caught up, there were not enough aircrews to fly them.[38] The only vision Germany had was a fanatical desire for a technological breakthrough to turn the tide of war,[39] relying on a belief in German superiority rather than reasoned strategic planning. Their fanatical desires not only diverted resources from realistic weapons programs but also gave the Allies targets for the Combined Bomber Offensive—the final impediment to German wonder weapons production.

Any discussion of German weapons manufacturing difficulties is incomplete without considering the Allied bombing campaign. Basically, the Combined Bomber Offensive made an already bad situation untenable for manufacturing wonder weapons.

Any discussion of German weapons manufacturing difficulties is incomplete without considering the Allied bombing campaign. Basically, the Combined Bomber Offensive made an already bad situation untenable for manufacturing wonder weapons. The reader must understand the Combined Bomber Offensive did not stop aircraft production—in fact, more aircraft rolled off the lines in 1944 (39,807) than in any previous year (15,904 in 1942, 24,807 in 1943).[40] However, it caused many operational problems for the Luftwaffe, as we will see in the next section. The Combined Bomber Offensive did cause two major problems with production, negating the impact of increased numbers. First, the bombing forced German industry to disperse, a measure contradictory to mass production.[41] Unlike America's huge aircraft plants like Willow Run, Germany had small factories in many places. While this made Allied targeting more difficult, it also hindered component integration. Different manufacturers also used different tolerances, meaning parts often did not fit together when assembled in the field.[42] Second, as soon as the Allies saw German wonder weapons in action, they were quick to find and strike the factories. After seeing Me 262s successfully attack a US bomber formation at 100 to 1 odds, General James H. Doolittle told Air Marshal Arthur Tedder, "Something must be done, and done quickly."[43] The result was dedicated, systematic attacks on wonder weapon facilities. It is very difficult to mass-produce sensitive, technically advanced weapons with dispersed industry subject to intense bombing. Increased Allied pressure also caused heavy operational losses with which replacements could not keep pace. This attrition was the final explanation for why the Germans could not produce their wonder weapons in significant quantities and turn the war in their favor.

Operational Difficulties: Would the Wonder Weapons Have Made a Difference?

This article has shown the obstacles Germany faced that made wonder weapon mass production and deployment nearly impossible. Even so, it did get limited numbers of its advanced hardware into service. This section will examine whether or not additional weapons would have attained Germany's goals. We must consider both the equipment and other factors such as available crews, training, and the operational constraints imposed by the Luftwaffe's ineptitude and the Allies' air superiority actions.

The first questions we must ask are, were the wonder weapons really that advanced, and if so, were they practical? In many individual cases they were advanced beyond the Allies' equipment, but they were incomplete packages lacking systems integration to other technology. For example, the Me 262 had the devastating 30-millimeter cannon. However, it never reached its full potential because the world's best optics industry could not design a good gyro gunsight that would fit in the jet.[44] A few experienced pilots learned to overcome the deficiency, but increasing numbers of rookies could not, leading to poor combat performance of an otherwise devastating weapon system. Further, the advanced Me 163 quickly ran short of fuel, then glided back to base. Similarly, the Me 262 flew slowly in the landing pattern, and its sensitive jets precluded any sudden power increases. US fighter pilots knew this and, thus, overcame the rocket and jet menace by orbiting their airfields, waiting to bounce the vulnerable fighters returning to base. This, in turn, forced the Germans to use Fw 190Ds for combat air patrols over their fields,[45] further exacerbating the fuel shortage. The air-to-ground weapons likewise had their faults. After releasing the Fritz X or Hs 293, the bomber had to fly a predictable course at only 165 miles per hour until bomb impact,[46] making the lightly armed bombers easy prey for naval fighters. Therefore, while the German wonder weapons were sophisticated, the failure to integrate them into total weapon systems presented vulnerabilities easy for the Allies to exploit.

The advanced technology also presented maintenance headaches for Luftwaffe ground crews.

The advanced technology also presented maintenance headaches for Luftwaffe ground crews. The previous section showed how production problems led to limited spares fabrication and parts incompatibility. Additionally, the emphasis on producing great numbers of new aircraft meant manufacturers were unwilling to *waste* production line space on spare parts, including jet engines.[47] The result was lower in-service rates for aircraft, because without spare parts, damaged aircraft were not repaired. Instead, ground crews cannibalized what they needed to keep other planes in service.[48] Cannibalism invariably led to fewer and fewer operational aircraft. The following story shows the effect of these maintenance troubles. Galland visited JG-7 (Kommando Nowotny) to see the Me 262 in action. The wing's leader, 250-kill ace Major Walter Nowotny, wanted a maximum effort to show why the Luftwaffe needed more Me 262s. This maximum effort consisted of 4 planes out of a unit of 80 aircraft; 2 of the 4 subsequently broke before takeoff. US pilots, having overwhelming numbers, then shot down one of the two remaining aircraft when Nowotny's engines malfunctioned during the dogfight.[49] Germany thus had lost one of its best fighter leaders, who was flying the best aircraft of his career but was let down by a system that could not integrate and maintain it.

Resource shortages forced Germany to use lower technology to gain increased performance. Fuel scarcity led Messerschmitt to experiment with simple steam turbine engines that used 65 percent coal and 35 percent petrol to deliver 6,000 horsepower.[50] They used the Me 264 long-range bomber as a test bed but were not able to produce and integrate the efficient engines before the war ended. Junkers also developed the long-range Ju 390 and worked on a refueling version to take Ju 290 bombers across the Atlantic. Even if the rumored Ju 390 flight to within 12 miles of New York is true,[51] this wonder weapon still could not hit America where it hurt—the industrial areas of the upper midwest. The same would hold true had the airplane used the coal and petrol engines. Similarly, the He 162 jet fighter was another step back: its wooden construction used noncritical materials and unskilled labor.[52] Hitler Youth were the intended pilots, problematic considering the plane's tricky handling. Hitler considered the aircraft and pilots expendable to stop the Combined Bomber Offensive. Fortunately for the young crews, they never flew in combat. While these wonder weapons allowed Germany to concentrate more materiel and fuel on other projects, they contributed no real capabilities to the Luftwaffe.

The most salient reason the wonder weapons would not have given Germany any advantage was the decreasing skill and experience of Luftwaffe pilots by the time the advanced systems arrived. There were two main reasons for waning crew proficiency. First,

many of the best pilots had been killed in action or rendered unfit for duty. Operational losses meant there were few *experten* left in service. In fall 1944 alone, the Luftwaffe lost 12 pilots with 1,146 kills among them.[53] This not only decreased Germany's combat capability but also meant there were few *old hands* left to pass on hard-won knowledge to the new pilots. Most had been flying since 1939-1940 (some even had Spanish Civil War experience), giving them unmatched combat experience. However, the lengthy combat time placed a tremendous physical and psychological stress on them. Indeed, Galland noticed the lack of fighting spirit, even in 1943, when he saw several fighters fire on bombers from too far away to be effective, then leave for home.[54] However, there were some pilots ready to fight, and the limited wonder weapons gave them the spirit to return to duty. When assembling his Me 262 wing, Jagdverband 44, Galland rounded up the most raffish, battle-hardened veterans, several from the pilots rest home. "Many reported without consent or transfer orders. Most had been in action since the first day of the war, and all had been wounded. The Knights Cross, so to speak, was the badge of our unit. Now after a long period of technical and numerical inferiority, they wanted once more to experience the feeling of air superiority. For this, they were ready once more to chance sacrificing their lives."[55] Unfortunately for them, there were far too few pilots and even fewer superior weapons, those being not advanced enough to matter. Germany had again failed those who served her so well.

The second reason for the decreasing pilot skill was the poor state of the replacement program. Starting early in the war, the Luftwaffe's faith in early victory kept it from increasing the front-line force, so there was no pressure to raise training output.[56] When heavy losses set in, there was no reserve from which the Luftwaffe could draw. Later, when it realized it needed replacements quickly, the Luftwaffe lowered training time to only 112 hours, with 84 percent of the time spent in basic aircraft instead of high-performance combat types.[57] This was half the time Allied pilots received. The Luftwaffe also converted bomber crews to fighters, but the 20 hours' training they received was not enough to prepare them for the rigors of outnumbered fighter combat. Hitler even ordered all fighter groups on the Eastern Front to send two of their best pilots to the Reich's defense forces,[58] making the German lack of air superiority in Russia even worse. Finally, the Combined Bomber Offensive created a fuel shortage, leading to training curtailment as early as 1942.[59] Lack of fuel decreased instruction flights, further reducing new pilot skill and experience. All the above meant pilots arriving at the front were not skilled enough to handle basic aircraft, much less employ the highly sensitive wonder weapons (Galland relates how even his veteran pilots had trouble lining up for kill shots in the very fast Me 262).[60] This happened at the time Allied pilots were becoming more numerous and better trained as a result of combat veterans rotating home to instruct new pilots. Allied pilots also were becoming more experienced because of lower combat losses and were flying more aircraft of the same caliber as most German fighters. As the Luftwaffe's losses mounted, it closed the advanced schools, then the basic schools, moving the pilots and aircraft to operational units.[61] Replacements stopped just when the wonder weapons were arriving in numbers. Therefore, even with larger numbers of advanced aircraft, the Luftwaffe did not have the crews to fly them, negating their potential effect on the war's outcome.

The most salient reason the wonder weapons would not have given Germany any advantage was the decreasing skill and experience of Luftwaffe pilots by the time the advanced systems arrived.

Several operational reasons kept the wonder weapons, even in greater numbers, from changing the course of the war. Most of these explanations arose from Allied air superiority and the Combined Bomber Offensive's incessant attacks on German industry and transportation. The struggle for air superiority in 1944 made the Luftwaffe commit 82 percent of its manpower and aircraft to defending the Reich.[62] While this estimate seems high, it does reveal how Germany had to retain forces to protect itself. Further, several wonder weapons, such as the Me 163, were point defense weapons. They were effective defenders but were incapable of extending air superiority over Allied territory or protecting the German Army from Allied close air support and interdiction. Lack of air superiority also meant the Luftwaffe could not conduct offensive operations. This left Germany with no route to victory, as the Allies' goal of unconditional surrender meant Germany could not play a defensive waiting game. Last, defending Germany used many weapons that would have been useful for ground defense and offense. For example, the Luftwaffe employed 10,000 88-millimeter guns as antiaircraft artillery; these guns were also the most effective antitank cannons of the war. Moreover, 500,000 people manned the air defense system, depriving Germany of needed ground troops and factory workers.[63] Hence, wonder weapons in sufficient quantity would provide adequate defense but would not have enabled Germany to go on the offensive and push the Allies away from its borders. As it was, Allied close air support

and interdiction left Germany no avenue to overcome the numerical superiority of US and British ground forces.

Allied interdiction and the ground offensive also kept the wonder weapons from making a meaningful contribution. Allied armies overran many of the Luftwaffe's front-line airfields after the D-day invasion, forcing the Germans farther to the rear. Their subsequent operations from unprepared fields caused lower serviceability, so the Luftwaffe could not meet Allied quantitative superiority with higher intensity operations.[64] Relatedly, Ultra intelligence revealed German movement plans and allowed the Allies to attack Luftwaffe ground units en route to their new airbases.[65] This prevented supplies, parts, and mechanics from arriving to service their airplanes. Finally, the Allies' dedicated attacks on German transportation, especially the railroads, kept new aircraft components from reaching their assembly points (necessary because of the dispersed factories discussed previously). They also destroyed completed aircraft before they could reach combat units.[66] The wonder weapons were no exception—the Allies knew their value and were intent on killing the airplanes on the ground instead of facing them in the air. Consequently, wonder weapons in greater numbers would not have had the chance to become operational. If they had, they would be starved for gas; lacking pilots; operating from bases with no ground support; and thus, incapable of making a difference.

The struggle for air superiority in 1944 made the Luftwaffe commit 82 percent of its manpower and aircraft to defending the Reich.

History shows that superior aircraft did reach operational units. However, there were employment problems that would have increased had Germany deployed more of the advanced aircraft. First, Hitler was overtly hostile to any defensive measures. This, combined with his control of advanced production, meant fighter and antiaircraft deployments were piecemeal. Hitler believed a more effective defense was to meet terror with terror, causing him to deploy his new weapons in less than optimal ways.[67] Once airborne, the defenders did have the benefit of aircraft acting as airborne command posts to coordinate attacks.[68] However, it was only a local measure and did not affect the overall defense of Germany because it could not provide theater-wide situational awareness. Galland sums it up best: "We not only battled against technical, tactical, and supply difficulties, we also lacked a clear picture of the air situation, of the floods coming from the west—absolutely necessary for the success of an operation."[69] More wonder weapons inefficiently employed would not have improved the situation. They likely would have caused more confusion for the limited C2 system coordinating attacks on the bomber forces.

The final reason for the ineffectiveness of the wonder weapons comes from their secretive development and combat employment. Except for Goering and Milch, the Luftwaffe did not know about the Me 262's development until it was already in advanced testing.[70] There was no way for the units to develop training or tactics for the new aircraft if the operators did not know the planes were coming. Often a pilot's first experience with the aircraft would be in combat, with less than optimal results. Additionally, when Galland set up his JV-44 jet fighter unit, it was not subordinate to anyone—many felt it had finally shaken the micromanagement that had ruined the program. However, Hitler would not allow JV-44 to have contact with other units, fearing their defensive mindset would contaminate strike units.[71] This isolation was an effective quarantine, meaning the best pilots could not share their skill and experience with other units, especially those trying to employ complex equipment with rookie crews. The new pilots then had little chance to improve except in one-sided combats with Allied fighters. Lack of tactics for the advanced aircraft and the moratorium on sharing expertise would have made more wonder weapons just as ineffective and would have given the Allied fighter pilots easier targets.

The Luftwaffe was unable to prove what it could have done with more wonder weapons, as production difficulties kept it from reaching the operational numbers that could have made a difference. Incompletely integrated technology, decreasing crew skill and experience, a deficient training program, and Allied attacks kept the advanced aircraft in service from effective operations. These problems would have handicapped greater numbers as well. Galland's comment at the war's end concludes it well. When his unit finally received Me 262s, he said:

> But this was 1945! In the middle of our breakup, at the beginning of our collapse! It does not bear thinking what we could've done with jet fighters, 30-millimeter quick-firing cannons, and 50-millimeter rockets years ago, before our war potential had been smashed, before indescribable misery had come over the German people through the raids.[72]

Fortunately for the Allies, the wonder weapons did not arrive on the scene until it was too late to make their mark.

The V1 and V2 Case

So far, we have seen several reasons why the wonder weapons would not have made a difference, even if Germany had deployed them in significant numbers. However, there is a case showing two wonder weapons Germany managed to develop, produce, and use in large quantities: the V1 cruise missile and V2 ballistic missile. This section will further prove the point that greater numbers of advanced armaments would not have made a difference by demonstrating how 35,000 V1s[73] and 10,000 V2s[74] could not change the war's outcome. The primary reasons were the missiles' technology, the theory behind their combat employment, and production interference. It is logical to assume the other wonder weapons would experience similar problems had Germany mass-produced them.

The first topic is numbers. As we saw earlier, Germany built 35,000 V1s and fired 9,200 of them, killing 6,184 people in England.[75] Likewise, 1,300 V2s hit England between October 1944 and March 1945, killing more than 2,700 and wounding 19,000. V2s had some success degrading Allied logistics with attacks on Antwerp but, on the whole, were another futile effort to turn the war in Germany's favor. Why couldn't huge numbers of these weapons make a difference, especially considering the V2 was unstoppable?

No other countries developed cruise or ballistic missiles during World War II. In fact, the United States and Soviet Union used both the V1 and V2 to create their own systems after the war. However, closer examination reveals the missiles had several of the other wonder weapons' problems: relatively low technology, little systems integration, and minimal reliability. To start, Allied fighters could easily catch the slow (400 miles per hour) V1s and shoot them down. If they were out of ammunition, a few pilots dared to tip the V1s over by placing their wing under the V1's wing and then flicking it up, causing the missile to spin out of control.[76] The British set up dedicated warning nets to detect the incoming V1s and then sent out interceptors. Royal Air Force (RAF) action thus dispatched 4,000 of the 9,000 V1s fired.[77] Interestingly, the British kept all their new Meteor jet fighters in England to deal with the missile threat.[78] However, this was not a victory for the wonder weapons, as the Meteors did not have the range to escort bombers and were not ground attack aircraft either (the Allies already had plenty of aircraft to cover those missions). Vulnerability to interception was not the V1's only problem. A greater fault afflicted it and the V2: lack of accuracy.

While the English could not shoot down the V2s, they and the V1s that penetrated the defenses were extremely inaccurate: V1s had a 12-kilometer circular error of probable (CEP), while V2s had a 6-kilometer CEP,[79] meaning only half the rounds fired fell in a circle with the CEP's radius. The reason was neither *advanced* system had a guidance computer. The V1 flew straight at a constant speed (the engine actually lost efficiency as it burned, keeping the missile at the same speed even though it was getting lighter as it burned fuel),[80] then plunged to earth after the primitive air log propeller in its nose had counted the appropriate number of rotations. Once the air log reached the preset number, it locked the V1's controls so it would dive into whatever was below.[81] The Army's V2 was designed as long-range artillery[82] and essentially lobbed its warhead beyond gunfire's range. Considering the problems of ballistics, high-speed reentry, and rocket efficiency variations from poor fabrication, it was lucky any V2s hit their targets. Even a simple guidance system would have made the missiles more accurate and, certainly, more a threat to Allied targets. These limitations point to the fact that the V weapons were not that technologically advanced—an issue that reduced their effectiveness.

The V weapons caused relatively few deaths or damage, especially compared to the Combined Bomber Offensive.

The V weapons caused relatively few deaths or damage, especially compared to the Combined Bomber Offensive. Three reasons caused the lack of destruction. First, the horrendous accuracy made pinpoint attacks impossible. The Germans did develop a missile-mounted transmitter that stopped signaling when the V1 hit the ground, allowing corrections for the next shot.[83] The ever-resourceful British electronic-warfare teams countered this tactic, spoofing the signal to make the weapons miss by even more.[84] Second, both missiles had very short range: the V1 required launch sites in Holland, with the V2s not much farther back. Even that close to England, the missiles could not reach the heavy industrial areas. Once the Allies liberated Holland, then the rest of Western Europe, the missiles had no way to reach their targets. The only exception was He 111-launched V1s (the first air-launched cruise missiles), which were impractical because of Allied air superiority.[85] Third, the Allies knew well the capabilities of the V1 and V2, capabilities that would increase if Germany could improve the missiles' guidance. The RAF and the US Army Air Forces also knew where the Germans built and launched the weapons and subjected the installations to

unrelenting attack. Once again, the Combined Bomber Offensive created a final obstacle for wonder weapons and made a system that was not making a difference completely useless. With their inherent problems, why then did Germany focus so many resources on building and launching the V weapons? The answer lies in the unique political and military views of the Nazi party.

The lack of accuracy did not bother the Nazis, as the weapons' main purpose was terror, a goal that denied the Germans any chance of effectiveness. Hitler believed they were the *decisive weapons* that would bring him ultimate victory by destroying England and the Allies' will to fight.[86] Had Hitler looked at his own people, he would have seen the Combined Bomber Offensive's tremendous destruction had not broken their spirit,[87] even under daily attacks that dwarfed the entire V1 and V2 campaigns. In addition, he should have learned a lesson from the Battle of Britain, where his extreme efforts could not touch the English spirit. While the V weapons did cause psychological strain,[88] the V1 counter campaign actually had a solidifying effect on British morale. The population eagerly tracked the operation's progress, hailing each interceptor's kill, especially the *tippers*.[89] England had no counter for the V2, but the people soon realized the low threat from the inaccurate missile, seeing it could only strike populated areas. They had dealt with terror raids before, and with the war going the Allies' way, they saw the V2s for what they were: weapons that could terrorize but not effectively hurt the Allies. Therefore, Hitler's purpose for employing the V1 and V2 actually helped the Allies' cause. At the same time, the weapons hurt Germany's chances for developing other wonder weapons.

The V weapons programs impaired other advanced projects by consuming vast resources and manpower that Germany could have used to make effective armaments.

The V weapons programs impaired other advanced projects by consuming vast resources and manpower that Germany could have used to make effective armaments. When Hitler saw a V2 demonstration film on 7 July 1943, he directed that the program receive whatever labor and materials it needed. The program cost more than 5 billion reichsmarks and absorbed tens of thousands of workers (many of them slaves, an additional factor in the poor workmanship)—enough to have produced 24,000 aircraft.[90] The effort compromised the rest of Germany's war economy and prevented programs from having real strategic worth. One such weapon was the Hs-117 radio-controlled surface-to-air missile,[91] something the Germans needed to counter the Combined Bomber Offensive. The resource expenditure did not stop with the basic missile. Germany pursued two extreme measures to improve the weapons. First, it developed a manned V1 much like the Japanese Ohka kamikaze rocket plane. Unlike the Japanese, the Germans found few volunteers to man the aircraft, even after a test program led by famous pilot Hannah Reitsch.[92] One can predict the program would have improved accuracy but would have resulted in many deaths from Allied interception before the missiles reached their targets. The second scheme involved a Type XXI submarine (another wonder weapon) towing a V2 that rode in an underwater launch center to its liftoff point near the US east coast.[93] Although the designers knew it would have minimal accuracy, they justified the expenditure by saying the weapon's harassing effect would have strategic and political results. Germany produced one of these weapons in the 5 months preceding the war's end but never used it. These problems highlight Germany's complete lack of strategic vision and judgment of what made a successful weapon. The same problems would have affected the other wonder weapons had they reached mass production and deployment.

The V weapons were the only wonder weapons that saw mass production and employment yet had insignificant effect on the war's outcome. The basic problems of integration, poor accuracy, futilely striking morale, and wrongly prioritized expenditures made these wonder weapons, at best, useless, and, at worst, a war loser for Germany. We can see the same problems affecting the other advanced projects as well, showing again what little effect they would have, even in large numbers. In the final analysis, the wonder weapons only promoted the fantasy of the next technological breakthrough that would change the war.[94] This fantasy was at the expense of practical weapons that could have given the Luftwaffe and Germany a real chance at victory.

Relevance for Today: The US Defense Transformation

Examining the past for historical interest is fine, but it has true value when one applies it to similar events happening today or that could happen in the near future. Adapting a common phrase, one can see that those who do not learn from the past are doomed to repeat it or, at least, will miss opportunities. World War II Germany attempted to transform its war effort with technology but did not have the strategic vision, operational integration, or production capacity to pull it off. One can easily draw a parallel between Germany's efforts and the

current US transformation employment. This section will examine the ongoing US military transformation with respect to producing technology, integrating it with other innovations and current weapon systems, then using it to execute national security strategy in a challenging world. Additionally, it will compare German efforts to do the same, showing the pitfalls on the way toward dominance in all phases of warfare.

Producing high technology has been America's trademark since World War II. During the Cold War, the United States counted on quality to defeat the Warsaw Pact's quantity. Whereas the Germans canceled all programs that could not be completed within 1 year, Secretary of Defense Donald Rumsfeld wants to cancel all projects that do not take the military to the next level.[95] This is a result of the US strategic orientation toward the long term, rather than focusing on near-term issues. However, the Department of Defense (DoD) must avoid going to the other extreme, because putting all its hope in next-generation weapons will be to the detriment of current and proven technology. Two reasons support this point. First, advanced technology is very expensive, making it difficult to replace combat losses.[96] The Luftwaffe demonstrated this lesson, and the DoD would be wise to learn it. Second, wars are now *come as you are*, leaving little time to develop new weapons to meet current threats—it could be disastrous to get caught between technological advancements. The key for producing technology is how the United States spends money. Germany could not control its wonder weapons' escalating costs, and it skewed the entire war economy. If the DoD cannot control the exponential cost growth in next-generation weapons, it could price itself out of the defense business altogether. The United States needs to make astute decisions regarding successor weapon systems, in some cases making ruthless choices to ensure it spends money in the right places to produce effective forces within a reasonable time.[97] Producing technology is important; more crucial is how the military integrates that technology into operations.

Germany failed to integrate its world-leading technology into effective weapon systems, leading to arms that were not as effective as they could have been. Component shortcomings, lack of aircrews, and maintenance problems contributed as well. The current DoD transformation has a better focus. According to Rumsfeld, transformation is more than building high-tech weapons. It is about finding new ways of thinking and fighting. The goal is not to transform within 1 year or even 10 years—it is an ongoing process.[98] While DoD works the process, it cannot assume new is always better, because integration will always limit high technology[99] until all weapon components are at the same development level. Additionally, a smaller force of less sophisticated weapons leaves more money for maintenance and upgrades.[100] A good example of this is the recent reduction in the B-1 force, allowing the Air Force to upgrade the remaining bombers to be more effective against moving and time-critical targets. Relatedly, buying versatile weapons can bring down costs, improve integration, and increase effectiveness. The new push for an F/A-22 (vice an F-22) shows the Air Force is moving toward versatile platforms.[101] Integrating the technology is vital; equally crucial is taking care of the people who run the weapons. It would be a mistake for DoD to neglect training, retention, and services to pay for new weapons. Germany was unable to use its advanced aircraft for want of experienced aircrews. Current weapons are even more advanced and require the best people to make them effective when the military uses them.

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Developing, producing, and integrating technology does no good unless the United States uses its transformed power in an effective way. There are four ways it can employ power to make the fullest use of the transformation. First, the Services need clear concepts of operations (CONOPS) to guide both using the technology today and as a roadmap to the future.[102] Without thoroughly developed CONOPS describing how to employ new weapon systems to meet long-term goals, the DoD runs the risk of short-term thinking. The Air Force is pursuing eight CONOPS, covering everything from space to global strike and mobility, to realize its vision.[103] Second, the military must use a combination of old and new technology to get the job done. For example, Global Positioning System-guided munitions are superior high-accuracy weapons. However, they are much less effective without a man in the field using simple sighting equipment to find and pass target coordinates to orbiting aircraft. This supports the idea of not placing all hope in fantastic equipment. Third, while fighting the war on terror, the United States cannot become stuck in a defensive mindset like Germany did and lose its capability to strike its enemies. The Secretary of Defense and many other high-level government officials have stated the best defense against terror is a good offense,[104] an appropriate attitude that the United States has so far followed. Moreover,

America should be realistic in planning to employ its power. The DoD has finally moved away from the two major wars scenario to a more realistic approach of fighting one major conflict while holding ground in other contingencies.[105] The DoD is doing this by replacing its Cold War threat-based approach with a capabilities-based view. This concept looks beyond current uncertain needs in order to maintain strategic flexibility and resistance to asymmetric surprise.[106] Thus, the capability-based approach directs readiness for the most likely military needs instead of preparing to counter threats that do not pose a realistic danger. Finally, the United States is strongly advocating effects-based operations (EBO).[107] These operations concentrate on achieving effects that will force the enemy to do our will, instead of just destroying targets that produce arbitrary effects. This requires the military to integrate all systems to find, target, and attack those centers of gravity that will make maintaining the status quo impossible for our adversaries. Attacks requiring pinpoint accuracy to eliminate collateral damage are tailormade for advanced technology, but the United States must ensure it is hitting the right things. Germany squandered its ballistic and cruise missiles trying to attack British morale and ultimately did not attain its goal. The same fate awaits the United States if it does not do its homework to find those things that truly hurt its enemies.

Developing technology while not becoming over reliant on it, integrating advanced weapons to get full use out of all systems, and using the systems most effectively will allow the United States to avoid Germany's problems. Building a transformation to keep America ahead lets it fight on its terms and keeps enemies off balance and struggling to catch up. The United States must be ready for asymmetric threats and let other countries fantasize about finding their own wonder weapons to change their fortunes. If the DoD transforms correctly, it will not only be ready for them but also may even deter adversaries from using counter technologies against America.

Conclusion

We now know the dominant weapons on the battlefield are the ones that can be mass-produced, operated by motivated fighters, kept in action with spares and supplies, and used in concert with other weapons.[108] Ignoring the above advice in pursuit of superior weaponry courts disaster. In the words of General George S. Patton, "How easily people can fool themselves into believing wars can be won by some wonderful invention rather than by hard-fighting and superior leadership."[109] Nazi Germany possessed the technical prowess and industry to produce several wonder weapons during World War II. Its jet and rocket fighters, guided missiles, and cruise and ballistic missiles were all ahead of their time and superior to Allied armament. However, Germany could not transform its military into an effective force to stem the rising Allied tide for several reasons.

Nazi Germany possessed the technical prowess and industry to produce several wonder weapons during World War II. Its jet and rocket fighters, guided missiles, and cruise and ballistic missiles were all ahead of their time and superior to Allied armament. However, Germany could not transform its military into an effective force to stem the rising Allied tide for several reasons.

Germany's first significant problem was producing and deploying its wonder weapons. Many times, Nazi politicians interfered in projects, creating obstacles to efficient production. Further, the military itself played too large a role in design and production specifications, with changing demands making any kind of mass production nearly impossible. Corruption also played a role in keeping incompetent designs afloat, taking valuable production capacity away from truly useful projects. All this boiled down to a lack of strategic vision rising from the Germans' overconfidence in quick victory, a problem that plagued both weapons production and military operations. Finally, the Combined Bomber Offensive made an already horrible system untenable and was the straw that broke Germany's wonder weapons capacity.

Weapons are no good if a country cannot use them. Had Germany actually mass-produced its wonder weapons, it is doubtful they would have done any good. First, the weapons were not that advanced as systems because of German industry's failure to integrate them into total packages. Second, long-term pilot losses led to decreasing crew experience. This, combined with an inadequate training system, meant there were insufficient pilots to fly the wonder weapons. The Luftwaffe compounded the problem late in the war when it completely stripped its training units, sending all pilots and planes to fight. Third, Germany's focus on defense left it little capability to conduct offensive operations to truly hurt the Allies. When it did attack with its only mass-produced wonder weapons, the V1 and V2, it sought only terror effects. Its targeting mistake made the V missiles even more ineffective than their inherent inaccuracy dictated. Additionally, the missile program diverted enormous resources from other projects that could have dented the Allies' progress. In the end, the blade that cut through Poland, France, and the rest of Europe could not be sharpened by the wonder weapons and was ultimately too brittle to survive the exhausting conflict.[110] It dulled against the Allies' steel and concrete and was shattered in its turn, ending any chance of German victory.

The lesson Germany failed to learn is relevant today, as the United States moves to transform its military. We must heed the lesson that it is not enough to produce high technology with a short-term strategy. Instead, the United States must make careful choices on what to develop in the budget-constrained economy and fully integrate new weapons with the support systems and people on which they depend. Then it must effectively and realistically employ its transformed military to keep adversaries off balance. Producing, integrating, and employing new wonder weapons to strike targets for effects rather than brute destruction will bend adversaries to US will and allow the United States to attain its national security objectives. Germany lost the opportunity to become and remain a truly advanced power. America is totally dominant in many factors but must continue its ongoing transformation process to stay ahead and provide unmatched military effectiveness.

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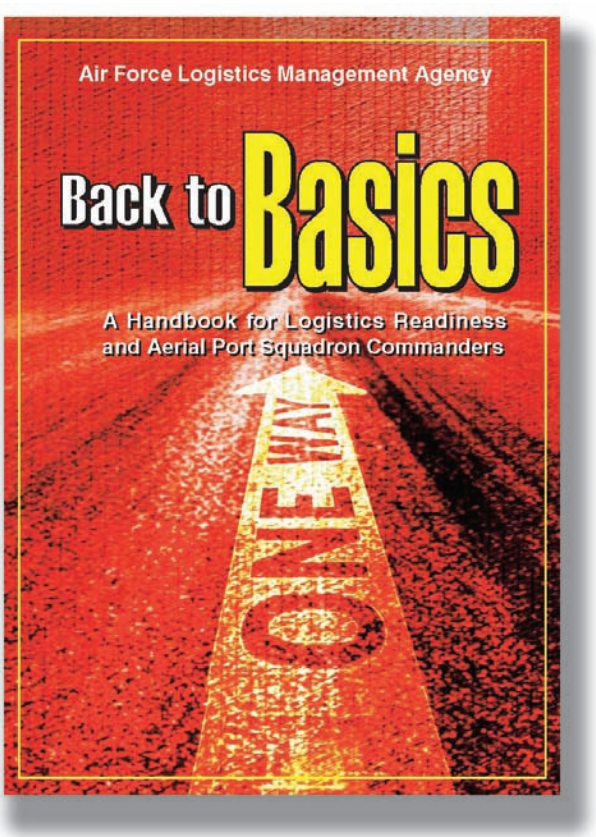

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Colonel Karen S. Wilhelm, USAF, Retired

A Historical Perspective on the Future of Military Logistics

The battle is fought and decided by the quartermasters before the shooting begins.[1]

—Field Marshall Erwin Rommel

No matter their nationality or specific service, military logisticians throughout history have understood the absolute truth represented in the above quote. Whether they were charged with supplying food for soldiers, fodder for horses or the sinews of modern war—petroleum, oil and lubricants (POL), they have understood that victory is impossible without them—even if, sometimes, it seemed their vital contributions were forgotten or ignored. None of the great military captains of history were ignorant of logistics. From Frederick the Great to Napoleon to Patton, they all understood the link between their operations and logistics. The great captains also have all understood that history had much to teach them about the nature of the military profession. Yet, military logisticians do not often spend time studying the history of military logistics.

This article is an attempt by one military logistician to derive relevant general lessons from history that might prove of some use in understanding how best to prepare for the future. There are at least three such general lessons. The first of these is the best case operationally is often the worst case logistically. The second is promises to eliminate friction and uncertainty have never come to fruition. And the third is technological change must be accompanied by organizational and intellectual change to take full advantage of new capabilities. While these lessons are not exclusive to logistics, when applied to the understanding and practice of military logistics, they provide a framework for understanding the past and planning for the future.

Such a framework is vital, now more than ever. Documents such as *Joint Vision 2010*[2] and the follow-on work supporting it are designed to set the course for the US military for the next 15-25 years. Logisticians must not only be proactive in helping set that course, they must use all resources available to ensure it is the right course. A thorough understanding of these three lessons will be of use in this regard.

The German troops marched farther and faster than the peacetime planners had calculated. Since other logistics calculations were predicated on the estimated rate of advance, they were also in error. As a result, the railheads could not be kept within supporting distance of the advancing armies, and heavy transport companies were totally inadequate.

The Lesson of the Best Case

The truth of the sentiment expressed by Field Marshall Rommel was no more apparent than on 2 September 1944 when General George S. Patton's Third Army ground to a halt from lack of fuel. The subsequent pause by Allied forces after their breathtaking race across France allowed the Germans to regroup and reconstitute their defenses and contributed to the extension of the war by another 8 months. Given the logistical riches of the Allies, one is forced to ask why they allowed this to happen. The answer is their failure to plan for the *best case*.

The historical record shows that September 1944 was not the only instance of logistical failure in spite of logistical riches. Logistics planning for *best case* possibilities is just as important as planning for the worst case in supporting military operations. In fact, the best case operationally is often the *worst case* logistically, and the following historical examples support this assertion.

The first historical example is provided by the German invasion of France through Belgium in 1914. The German troops marched farther and faster than the peacetime planners had calculated. Since other logistics calculations were predicated on the estimated rate of

advance, they were also in error. As a result, the railheads could not be kept within supporting distance of the advancing armies, and heavy transport companies were totally inadequate. The failure to plan for the operational best case—a quick breakthrough and advance—could have had a serious impact on the capabilities of the combat forces. In this particular case, it did not because the French halted the German advance before logistics difficulties could. Be that as it may, the evidence indicates the Germans would have had to halt due to logistics problems, and they got as far as they did only through *furious improvisation*.[3]

The second example of failure to plan for the best case is from the North African campaigns of World War II. Both Rommel and the Allies succeeded in putting their operational best case into motion, but ultimately failed because these proved to be the logistical worst case. On at least two occasions, Rommel's offensives achieved massive breakthroughs against the British in the east. He was, however, unable to translate these tactical successes into lasting operational or strategic success because he had completely outstripped his logistics system. Given the distances involved, the primitive transportation infrastructure, the lack of coastal transport capabilities, British air superiority and the lack of effort in correcting these deficiencies, his actions were logistically unsupportable.[4]

Allied efforts in the west after the landings of Operation TORCH were similarly hindered. The failure to effectively plan for the best case was even more egregious in this instance, however, since they were operating from a position of abundance rather than scarcity. The key objective after the landings was to occupy Tunis before the Germans. The best case operationally was no resistance from French forces and a lightning advance to the east. In order to support this logistically, the Allies would have had to reconstitute and augment the existing rail system and bring enough trucks to fully exploit the limited road network. Yet, they did not allocate enough resources to accomplish the task and support the advance. The number of vehicles transported with each convoy was successively reduced with each iteration of the plan. The focus was on the mere accumulation of supplies—to the point that by the time the plan was executed, the port capacity was approximately two and a half times the combined rail and road capacity.[5]

The third example of the best case planning error, and perhaps the most inexcusable from the standpoint of not having learned from experience, is the Allied advance across France. On 25 July 1944, the Allies were 44 days behind schedule. On 31 August, Patton was 150 miles and 5 months ahead of schedule. The 6,000 trucks of the *Red Ball Express* were using 300,000 gallons of gasoline daily to bring him the 350,000 gallons a day that he needed. By 2 September, he had to stop when the entire improvised system collapsed.[6]

Logistics planning for the breakout from the Normandy beachheads was based on the assumption of a slow, deliberate advance in the face of an orderly German withdrawal. The supply sequence entailed arrival at beach, port or harbor and then transport by rail and truck to supply dumps within tactical distance of the advancing forces. The worst case planning of the logisticians involved the possibility of higher consumption rates than projected. Consequently, the actions taken to preclude the worst case were focused on the accumulation of supplies. As noted above, the actual worst case logistically resulted from the best case operationally. The advance far outstripped the schedule, and transportation capability became the limiting factor. By the time Patton had to halt, POL and ammunition stocks were increasing on a daily basis at the beaches and ports but could not be brought forward.[7]

The lesson of these three examples can be summarized as follows. World War I marked a turning point for military logistics. Prior to this time, a moving army was easier to supply than a stationary one because food (for men and animals) was the critical element, and the means to obtain it was through foraging. After 1914, the moving army was much more difficult to supply because the critical element was ammunition (and subsequently, POL), for which foraging is not a viable option.[8] The logisticians learned this lesson almost too well. Their focus became the accumulation of supplies before the beginning of operations and their *worst case* became the point when consumption outstripped accumulation. These examples show, however, that accumulation is only half the equation; the other half is transportation. And in modern mobile warfare, the best case for the tactical forces, for example, the greatest rate of advance, is often the worst case for the logisticians supporting them because of limited transportation capability.

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The Lesson of Friction and Uncertainty

The second historical lesson for logisticians involves the nature of friction and uncertainty. Throughout history, military planners have sought to reduce and even eliminate these two

facts of life. The side that has made the greatest strides toward doing so, or at least made greater strides than its enemy, has also taken great strides towards winning. It has become increasingly tempting with our modern technologies to claim proximity to the *Holy Grail* of their actual elimination. *Joint Vision 2010* uses phrases such as *dominant battlespace awareness*, the *uninterrupted flow of information*, and *full dimensional protection*.[9] An even more insidious problem occurs when friction and uncertainty are assumed away without even a cursory reference. Logisticians must be aware of and avoid the pitfalls inherent in this approach.

In *On War*, Carl von Clausewitz first applied the concept of friction to the analysis of war. A series of quotes will serve to illustrate his meaning.

> Friction … is the force that makes the apparently easy so difficult … friction … is everywhere in contact with chance, and brings about effects that cannot be measured…. The good general must know friction in order to overcome it whenever possible, and **in order not to expect a standard of achievement in his operations which this very friction makes impossible**.[10] [emphasis added]

Friction, in other words, is a rather more elegant expression of Murphy's Law. Clausewitz was trying to tell us that military operations exist in the realm of Murphy's Law, and good commanders adjust their plans accordingly, rather than trying to eliminate it.

Logisticians are subject to the effects of friction and uncertainty almost every day, and yet, often forget their effects when planning—or, conversely, try to anticipate and plan around every possible contingency. The earlier discussion of *the best case-worst case* dichotomy serves to illustrate this point as well. Another example occurred during British operations against the Argentines in the Falklands. The ship *Atlantic Conveyor* was sunk by the Argentine Air Force before she was able to unload her cargo of helicopters, airfield construction equipment, and tents. The British plan was predicated on concluding operations as quickly as possible—primarily because of the long lines of communication and the weather. The cargo sunk with *Atlantic Conveyor* constituted a large part of their capability to do so. "Her loss, while removing the means to speed up the operation, made an early termination even more imperative."[11] One is forced to ask why all such vital cargo was loaded on one ship; apparently no one anticipated the effects of such a loss.

The converse *sin* of trying to eliminate friction by anticipating and planning for all possible contingencies can lead to such rigidity that an unanticipated event or last-minute change is completely disastrous. The most obvious example of such a circumstance is the German mobilization for World War I. German logisticians had planned their two-front war in impeccable detail—right down to the number of trains over each bridge in a given time. And when the Kaiser asked Von Moltke to fight only to the east, against the Russians, Von Moltke answered, "it cannot be done … if Your Majesty insists … [the army] will not be an army ready for battle but a disorganized mob … with no arrangements for supply. Those arrangements took a whole year of intricate labor to complete."[12]

Friction, in other words, is a rather more elegant expression of Murphy's Law. Clausewitz was trying to tell us that military operations exist in the realm of Murphy's Law, and good commanders adjust their plans accordingly, rather than trying to eliminate it.

It is tempting to think that we would never do such things. It is tempting to think that it is a different age, that such rigidity is unnecessary now. It is tempting to think that Murphy's Law is *not as bad as it used to be* because we have such wonderful technology. It is tempting, but we would be wrong to draw such conclusions. Friction and uncertainty will remain with us because of three immutable factors.

First, human beings are still an integral part of the logistics system—and human beings make mistakes, and sometimes they act irrationally. They get bored and enter data into their computers incorrectly. They work for 4 or 5 days with minimum sleep and then fail to secure a load properly—and it falls off the truck and is lost. They feel the pressure of ongoing operations where mistakes can cost lives and make even more mistakes. Our friend Clausewitz pointed out that the military machine "is composed of individuals, every one of whom retains his potential of friction."[13]

The second reason that friction and uncertainty will remain with us is that the military is a complex system, in the scientific use of the term. According to Charles Perrow, complex systems are those systems with multiple interactions among parts, procedures and operators. These systems are subject to interactive failures because their designers and users cannot anticipate all the possible interactions and are, therefore, unable to predict all the possible outcomes of any given decision.[14] Such complexity produces surprise. Unforeseen outcomes result when minor variations lead to some unpredictable total. Organizations typically react to these unpredictable results by adding more complexity, thereby exacerbating the problem

rather than solving it.[15] One needs only examine the examples discussed earlier, or the surprise achieved by the Japanese at Pearl Harbor, in light of this definition, to see how it holds true for military organizations.

The final reason military logisticians cannot escape friction and uncertainty is that the ultimate *consumer* of military logistics is an enemy who has a vested interest in ensuring the logistics system fails. Again, Clausewitz has captured the fundamental idea: "The whole of military activity must . . . relate directly or indirectly to the engagement. The end for which a soldier is recruited, clothed, armed, and trained, the whole object of his sleeping, eating, drinking, and marching is simply that he should fight at the right place and the right time."[16] The whole object of the logistics system is the same, and the *leaner* we make the system, the scarcer the resources become, the more dependent we are on critical information nodes, the more lucrative a target we have created. The *Atlantic Conveyor* is an example of such a target.

The Lesson of Change and Innovation

The third historical lesson for logisticians is organizational and intellectual change must accompany technological change in order to take full advantage of new capabilities. Innovations do not necessarily result from new technologies. New technologies may simply be used to do existing missions better. Innovations occur when new procedures are built around changes in the way organizations relate to each other and to the enemy.[17]

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Again, the best case-worst case dichotomy discussed previously is applicable. For example, the problems experienced by Allied logisticians in supporting the breakout and pursuit across France were as much a failure to adapt intellectually and organizationally as anything else. The planners had already experienced the logistical problems of North Africa, but failed to adapt.

The foundation of that failure to adapt was the failure to recognize that a change in operational concept warranted a change in logistical support concept. The mobile tank warfare pioneered by the Germans highlighted the fact that not only had tactical mobility been restored to the battlefield, but it had increased by an order of magnitude. These operations focused on the application of combat power through combined arms and the shock inherent in high-tempo operations. The necessary logistic change was in supporting the high tempo of operations—not just movement, but speed of movement. This was the primary failure of the logisticians—the failure to recognize the need to support the tempo change—an intellectual and organizational change.

The Germans also failed in this regard. Although not apparent in the early campaigns, it was highlighted once they attacked into the wide-open spaces of the Soviet Union. Although the logistics failure was not the sole or perhaps even the primary cause of the German defeat on the steppes of Russia, it was a major contributor.

The Germans had only partially motorized their combat forces and only a small proportion of their logistics support was moved by truck. The remainder was tied to the use of railroads and animal transport. This weakness was masked in the campaigns in Poland and France by the relatively short distances and the rapid collapse of enemy forces. The vast distances encountered on the Russian Front, coupled with the resilience of the Soviet forces, served to expose this problem and caused the German soldiers to suffer horribly.[18]

The noted military historian, Williamson Murray explains that:

> Relations among technological innovations, fundamentals of military operations, and changes in concepts, doctrine and organization that drive innovation are essentially nonlinear. Changes in inputs . . . may not yield proportionate changes in outputs or combat dynamics.[19]

During periods of transition, in particular, there are significant intellectual, organizational and technological changes. The key change, however, must be intellectual change, for without intellectual change, technological change is essentially meaningless, and organizational change is impossible. Logisticians who grasp at technological change without making the necessary organizational and, more importantly, intellectual changes to fully understand and make best use of new technologies, are doomed to failure. Intellectual change is the requirement to make all others meaningful.

Implications for the Future

In order to examine the implications these lessons hold for the future of military logistics, one must first examine current views regarding the future of military operations. The US

military has entered a period of rapid change. Orders of magnitude improvements in technology have resulted in recent attempts to devise long-range plans to incorporate those improvements into new weapon systems and operational concepts. *Joint Vision 2010* and the documents supporting its implementation provide the guidance for thinking about these new concepts.

In the logistics arena, *Joint Vision 2010* explains the concept of Focused Logistics—defined as

> the fusion of information, logistics, and transportation technologies to provide rapid crisis response, to track and shift assets even while en route, and to deliver tailored logistics packages and sustainment directly at the strategic, operational, and tactical levels of operations.[20]

The vision of Focused Logistics includes enhanced mobility and versatility of combat forces anywhere in the world through the elimination of vertical logistics organizations and the use of tailored combat service support packages and pinpoint delivery systems.[21]

Joint Vision 2010 heralds the creation of two other key concepts—dominant maneuver and full dimensional protection, the latter being simply the complete protection of forces and lines of communication *from fort to foxhole*. Dominant maneuver is envisioned as combat forces operating from dispersed locations in sustained all-weather, day or night operations at a decisive speed and tempo. It is "a prescription for more agile, faster moving Joint operations."[22]

The underpinning for all these concepts is the idea of information superiority—"the capability to collect, process, and disseminate an uninterrupted flow of information while exploiting or denying an adversary's ability to do the same."[23] The *Concept for Future Joint Operations* explains further that the view of operations in *Joint Vision 2010* is predicated on the reduction of friction through greater battlespace awareness. This greater battlespace awareness is conceived as a comprehensive and complete view in space and time; using assured, secure and responsive information; and resulting in the capability to predict enemy intentions and actions.[24]

Given the nature of this vision of the future, the three historical lessons that are the subject of this analysis are clearly applicable. In general terms, these documents discuss the need for organizational change and they constitute at least an attempt at intellectual change. It is too early in the process of change to expect specific suggestions for modifications to existing military organizations. The intellectual change exhibited is part of the current debate regarding an ongoing *Revolution in Military Affairs*. A discussion of whether this revolution actually exists or not is beyond the scope of this article, but the authors of the Joint vision documents clearly believe it does.

Innovations do not necessarily result from new technologies. New technologies may simply be used to do existing missions better. Innovations occur when new procedures are built around changes in the way organizations relate to each other and to the enemy.

With regard to the best case-worst case lesson, it would seem the logisticians of the future would still be susceptible to the effects of this dichotomy. The concept of dominant maneuver is focused on speed, tempo and agility of operations—from dispersed locations. The logisticians' tasks would seemingly be made even more difficult than today. Those who compose this vision of the future would answer that the concept of focused logistics would enhance the mobility and versatility of the logistics forces to the point that they matched that of the combat forces. This is entirely possible, but given that history shows that combat forces are typically ahead of support forces in gaining improved capabilities, it is also entirely possible that logisticians will again find themselves in the position of their worst case being the best case operationally.

It is in the arena of friction and uncertainty that the US military's vision of the future would seem to be most lacking. Combat forces are visualized as smaller and more capable, supported by smaller and more capable logistics forces. The system of forces and support requirements is highly complex and interdependent with little or no slack or excess capability. These forces are to sustain operations around the clock, and success is dependent upon a continuous supply of vast quantities of absolutely accurate information. Although there are occasional disclaimers in the documents to the effect that fog and friction will remain, the concept belies these words—there is no discussion of how the system will cope with or overcome friction and uncertainty.

The only conclusion to be drawn is that the visionaries attempting to set the course for the future of the US military have failed to learn this lesson from the past. They are designing a tightly coupled system of systems. Within that system will exist interdependencies and implicit assumptions that will defy ready understanding and, therefore, result in unexpected outcomes. They are designing a system that is still subject to the vagaries and weaknesses

inherent in human beings, but without taking those vagaries and weaknesses into account. They are designing a system which makes the logistics portion such a lucrative target that a potential enemy can have a greater impact by striking against logistics capability than by striking at combat capability. The failure to appreciate the effects of friction and uncertainty has had grave consequences in the past, and we are creating the potential for the same grave consequences.

These three lessons hold meaning for the future of military logistics. History has shown logisticians can fail if they do not understand the best case-worst case dichotomy, if they do not appreciate the need for intellectual and organizational change and if they do not take into account the effects of friction and uncertainty. While no one should expect history to repeat itself, logisticians can benefit from the study of history with a view toward understanding the errors of the past and the applicable lessons for the future.

Notes

1. *The Rommel Papers* as quoted in Martin van Creveld, *Supplying War: Logistics from Wallenstein to Patton*, Cambridge: Cambridge University Press, 1977, 200.
2. Chairman, Joint Chiefs of Staff, *Joint Vision 2010*, Washington, DC: Pentagon, 1996, 138-140, 199-210.
3. *Ibid*.
4. *Ibid*.
5. Julian Thompson, *The Lifeblood of War: Logistics in Armed Conflict*, Oxford, UK: Brassey's, 1991, 56, 61-67.
6. *Supplying War: Logistics from Wallenstein to Patton*, 213.
7. *Supplying War: Logistics from Wallenstein to Patton*, 212-213, 220-221.
8. *The Lifeblood of War: Logistics in Armed Conflict*, 50.
9. *Joint Vision 2010*, 13, 16, 22.
10. Carl Von Clausewitz, *On War*, trans and ed Michael Howard and Peter Paret, Princeton, New Jersey: Princeton University Press, 1976, 120-121.
11. *The Lifeblood of War: Logistics in Armed Conflict*, 278-279.
12. Barbara W. Tuchman, *The Guns of August*, New York, New York: MacMillan Publishing Company, 1962, 74-75, 79.
13. *On War*, 119.
14. Charles Perrow, *Normal Accidents: Living with High-Risk Technologies*, New York, New York: Basic Books, 1984, 4, 11-12.
15. Chris C. Demchak, *Military Organizations, Complex Machines: Modernization in the US Armed Services*, Ithaca, New York: Cornell University Press, 1991, 3-5.
16. *On War*, 95.
17. Stephen P. Rosen, *Winning the Next War: Innovation and the Modern Military*, Ithaca, New York: Cornell University Press, 1991, 134. See also Williamson Murray and Allan R. Millett, *Military Innovation in the Interwar Period*, New York, New York: Cambridge University Press, 1996, for a book-length treatment of this subject.
18. Matthew Cooper, *The German Army 1933-1945*, Lanham, Maryland: Scarborough House, 1978, 311-312, 331.
19. Williamson Murray, "Innovation: Past and Future," *Joint Forces Quarterly*, Summer 1996, 52.
20. *Joint Vision 2010*, 24.
21. *Ibid*.
22. *Joint Vision 2010*, 20-21.
23. *Joint Vision 2010*, 16.
24. *Concept for Future Joint Operations* (Preliminary Draft Version 4.0), Fort Monroe,Virginia: Joint Warfighting Center, 21 Mar 1997.

The US military has entered a period of rapid change. Orders of magnitude improvements in technology have resulted in recent attempts to devise long-range plans to incorporate those improvements into new weapon systems and operational concepts.

Successful operations depend on the entire wing organization working as a team with but one purpose in mind. The purpose, of course, is to make certain of the destruction of the selected target at exactly the right time and place. All of the years of planning and training, and the great financial and personal costs and sacrifice, will be vindicated by the successful execution of the mission; likewise, all will be wasted by failure, regardless of its cause.

—Air Force Manual 51-44, 1953

Forces that cannot win will not deter.

—Gen Nathan F. Twining, USAF

Daniel McConnell
Richard A. Hardemon
Senior Master Sergeant Larry C. Ransburgh, USAF, Retired

The Logistics Constant Throughout the Ages

War often conjures pictures of combat and large armies moving to the field inspired by a clash of political ideologies or ambitions. Indeed, the intriguing twists and nuances of the strong political current sweeping every conflict forward or the intricate strategy and battlefield tactics that vie for positional dominance can hold one's attention to the exclusion of all other aspects of war. Yet the bulk of a commander's considerations involve the logistical limitations that drive changes to strategy and tactics in order to keep forces supplied and moving. All manner of logistical supplies are necessary to carry on military operations. However, fuel (fodder for animals or petroleum, oil, and lubricants [POL]) holds a special importance in that its supply has influenced and often dominated strategy as long as nations or states have fielded armies.

Transportation of supplies and materiel preceding modern day machines relied on some form of pack animal, principally horses. The horse's need for fodder dictated to the commander the terrain through which he could campaign as well as the campaign seasons.

Following World War I, new modes of warfare made the use of pack animals obsolete; however, armies still employed them on a much smaller scale to move supplies. Technology—manifested in aircraft and mechanized vehicles birthed in the First World War and nurtured during the interwar period—required a new type of fuel in the form of POL. During World War II, in the European theater, massive armies raced across battlefields, and mechanized equipment greatly increased the spectrum of strategic possibilities. However, commanders still had to account for logistical considerations that would influence their tactics. Increasingly, POL dominated their strategy and tactics. Further, POL products accounted for the majority of supplies shipped into theater during the war.

Regardless of its modern connotation, POL's intrinsic equivalent throughout history has been fodder.

Military Campaigns, Strategy, and the Need for Fodder

Regardless of its modern connotation, POL's intrinsic equivalent throughout history has been fodder.

Most great commanders in ancient times, such as Alexander the Great, attempted to limit the number of horses on the campaign by ordering the troops and their attendants to carry many of their own supplies.[1] Yet, historian Donald Engels notes that pack animals were still necessary to carry "the army's noncomestible supplies, such as tents, hammocks, medical supplies, the ambulance, siege machinery, firewood, booty, and perhaps some of the women and children."[2] Though Alexander managed to significantly reduce the number of pack animals, Engels estimates that his army probably had about 6,000 cavalry horses and 1,300 baggage animals. Under the most favorable conditions, where the army campaigned in areas abundant in fodder and only needed to carry 1 day's supply of grain, they still needed approximately 1,100 pack animals to carry 269,000 pounds of grain, if each horse carried 250 pounds.[3] Engels notes that if an army traveled through an area devoid of fodder the number of pack animals needed to transport the grain and fodder requirements for 1 day would jump to 8,400 carrying approximately 1,260,000 pounds.[4] Noted historian Martin van Crevald, in *Supplying War*, similarly describes a generic premechanized army in which "the 40,000 animals accompanying an army would, therefore, require 800 acres per day."[5] Horses were imperative in a campaign, yet their subsistence greatly strained an army's resources.

Prior to the 18th century, few improvements were made to ease the fodder supply problem in Europe. In fact, the French made the problem worse by bringing extra men on the campaign to forage for fodder in the army's immediate vicinity. Historian John A. Lynn estimates between "4,000 and 10,000 men [were] necessary to mow forage for an army of 60,000"—each day a horse required approximately 24 pounds of dry fodder.[6] Interestingly, the French did maintain a magazine system to store troop provisions; however, the need to keep moving to find more fodder tended to cause the army to move too far and too fast away from this system of supply.[7] The ever present need to forage for more fodder forced the French Army to constantly move even when strategy dictated that it should not.

Strategy had to be adapted to account for horses' needs. Most historians agree the challenge of providing for the pack animals overshadowed the troops' provisions. Accordingly, the fodder requirement restricted an army's area of operations to regions that could sustain a high fodder intake. During the winter months when cold weather made fodder impossible to secure, armies were unable to campaign, and military operations necessarily became a seasonal activity.[8] Notably, in the 13th century, the Mongols possessed horses that could find food under the snow, so their time frame for waging war was greatly increased.[9] Early conquerors bypassed cities and only occasionally conducted sieges, as fodder in the immediate area quickly ran out.[10] Intuitively, the massive effort required to forage dictated strict precautions to prevent being surprised while gathering fodder. Though other factors also influenced strategy, the need for fodder dominated both strategic planning and military operations.

As long as armies required horses for cavalry and carrying supplies, the need to find fodder restricted flexibility and operations.

Throughout the first millennium AD, the Muslims were adamant about incorporating knowledge of terrain and vegetation when planning raids. Muslim planners devised contingency plans dependent on the seasons in that, during February and early March, their raids only lasted 20 days so they could get the horses back to Muslim territory to graze. Spring campaigns could only last 30 days, while summer ones were to last 60 because of the availability of fodder.[11] However, the Muslims were also sufficiently organized to set up a series of warehouses near their eastern frontiers over which they campaigned. Reports of these warehouses came in the 7th century and again in the 10th century relating the existence of ready supplies, "including grain and fodder [and] located where defensive or offensive action tended to repeat itself."[12] Despite the Muslims' successes, by the 18th century, few countries, except for the French and Prussians, had adopted a suitable fodder magazine system.[13] The French and Prussian magazine system, as well as the earlier Muslim warehouses, gave their respective forces the advantage of surprise and a greater measure of flexibility by allowing them to mobilize and attack more quickly.

As mentioned earlier, Alexander the Great grappled with the fodder problem throughout his far-flung exploits across Europe. Alexander realized the problems posed by bringing along numerous horses and pack animals, so he attempted to minimize their numbers by requiring his men to carry packs.[14] He also understood that excessive work and not enough food would wear out his cavalry and pack animals and he would not be able to nurse them back to health.[15] Welfare for the horses dictated that he slow his army's pace so the horses and pack animals could graze. The need to move faster, therefore, motivated Alexander to look for new ways to reduce his dependency on horses. His massive fleet helped alleviate this problem by transporting large fodder supplies from port to port, though this locked him into a dependency on the Mediterranean coastline or large navigable rivers, especially during winter.[16] The need to provide fodder for his horses forced Alexander to work within increasingly narrow boundaries as he moved farther away from Macedonia. Alexander's campaigns provide one of the earliest recorded examples of logistical handicaps.

As long as armies required horses for cavalry and carrying supplies, the need to find fodder restricted flexibility and operations. In 1775, during the American Revolutionary War, American forces under General Philip Schuyler planned an invasion of Canada. However, lack of rain made for a hot, dry summer, and General Schuyler could not move up enough fodder to feed the horses needed for a full invasion. Instead, the lack of fodder forced him to wait until late summer when adequate rain nourished the grass enough to supply the invasions.[17] Winter quickly set in after Schuyler experienced early successes and cut him off from all resupply. The "inadequate forage in June and July was not the only reason for the failure of the Canadian campaign, but it surely was one of them."[18]

Fodder further affected flexibility during the American Revolution when free fodder became hard to obtain and the Colonial Army had to compensate farmers for using their land. Wartime prices steadily rose as good pastureland became less available. However, like

Alexander, the American commanders understood that without adequate fodder their limited supply of horses would dwindle. Colonial commanders could send the cavalry away from the army to find cheaper fodder, but they needed the pack animals to stay close and often paid high prices for their nourishment."[19] Without the pack animals, the army could not transport its supplies and conduct operations for very long.

The US Civil War (1861 to 1865) demonstrated the importance of using a rail system to increase strategic flexibility by more efficiently supplying armies. Trains and rail lines came under attack as both sides sought to cripple the other's access to them and prevent valuable supplies from reaching their intended forces. Armies still required cavalry and pack animals to move their food and supplies while in the field and, therefore, continued to need fodder. However, with the locomotive's introduction into warfare, fodder and other supplies could be loaded onto trains and brought to depots within the army's proximity. Established supply lines could then be used to retrieve the materiel. The Civil War became the first conflict in which armies used the new technological innovation to improve logistics, especially resupplying fodder, and to alleviate the need to constantly change camps to find more fodder.[20] In fact, historian James A. Huston, in *The Sinews of War: Army Logistics 1775-1953*, relates that shipments of forage during the winter months averaged $1M. He goes on to say that fodder continued to dominate supply considerations, in that "for tonnage and bulk the item of daily supply that was even more important than food for the men was food for the animals."[21] Trains permitted armies to receive more fodder while maintaining their positions and simultaneously allowed an army to keep more horses.

The period between the Civil War and World War I was filled with advances in technology, which were not fully taken advantage of by the European powers. Further, the dominant powers in Europe (France, Prussia, England, and Russia) failed to truly understand the lessons that could have been learned from the Civil War. Cavalry charges and long baggage trains of horse-drawn wagons persisted, and with that returned the age-old need to feed the livestock. In many ways, the First World War resembled all past wars. However, its rapid consumption of supplies, especially ammunition, dictated that the times and ways of war were changing. But for the moment, it was remarkably similar to the past, in that during the war, Great Britain shipped 5,253,538 tons of ammunition to France as well as the greatest single item shipped, which was 5,438,602 tons of oats and hay.[22] Fuel for horses continued to be a dominant factor.

Regardless of the lessons the Germans should have learned from the past, during World War I, they placed a huge emphasis on cavalry and did not prepare for their maintenance in the field. The German high command ordered commanders to feed their horses off the land as a result of the army's sheer numbers of horses. Van Crevald relates that any attempt to supply the army from home bases would have been impossible.[23] As the Germans moved into France early in the war, luck appeared to be with them as the land was rich and the grain had just been harvested. However, much of the grain was still green, causing many of the horses to become sick and die very early in the campaign. A critical shortage in fodder resulted, and by the time of the Battle of the Marne, where French and British forces engaged and halted the German advance, most of the horses were too weak to keep up the pace.

The Civil War became the first conflict in which armies used the new technological innovation to improve logistics, especially resupplying fodder, and to alleviate the need to constantly change camps to find more fodder.

The German invasion plan, known as the Schlieffen Plan, depended on the speed of the invasion, yet the horses employed in reconnaissance and pulling the heavy artillery were so poorly fed that they could not keep up the pace. Many died before the Germans crossed the border into Belgium. By 11 August 1914, preceding the Battle of the Marne, cavalry forces ordered a 4-day halt to find food for the mounts.[24] By the Battle of the Marne, the starved horses pulling the German artillery, which was the only arm that had a distinct advantage over French forces, could not keep up the pace. "By this time, too, one German army at least was finding that the state of the cavalry seriously interfered with operations."[25] The German high command's severe lack of oversight of properly feeding the horses proved to be a decisive factor in the failure of the Schlieffen Plan.

Following the offensive stall after the Battle of the Marne, the consumption of supplies reached proportions unmatched by any previous war. However, this consumption rate could not have been maintained if the front had not stalled and remained stationary throughout the war.[26] Supply movement via horses would have been inadequate given the war's immense scale. Toward the end of the war, both sides began to introduce motorized transport on a very small scale and began to argue that "complete motorization of local transportation and the widespread use of combat vehicles would restore mobility to the battlefield."[27] Petroleum products, then, came into demand, and by the war's end, more than

759,000 tons of gas and oil had been shipped onto the Continent. War planners deemed the horse obsolete in favor of the more economical and faster moving petroleum-based machines.

Military Campaigns, Strategy, and the Need for POL

Following the First World War, armies began nurturing the technological innovations employed at the end of the war and subsequently developed a strong dependency on petroleum products by the beginning of World War II. POL significantly differed from fodder in that POL had to be manufactured away from the battlefield and then shipped to the battle area.[28] For the most part, fodder as a source of fuel for horses quickly became a thing of the past as armies became fully mechanized. The new machines could be worked harder and go farther and faster, and most important, the time of the year and the route taken by the army did not affect its fuel supply. Commanders could expand their range of strategic operations immensely and do more with less.

However, challenges quickly attached themselves to the new machines and their fuel supply. If army quartermasters did not constantly provide the machines with enough fuel, operators could not normally forage for it. In this respect, commanders lost a measure of flexibility, and the situation forced them to further employ technology to devise ways to overcome the new problems. The result involved underground pipelines and the Red Ball Express, in which a constant stream of trucks traveled distances of up to 400 miles to supply Patton's Third Army.

The German invasion plan, known as the Schlieffen Plan, depended on the speed of the invasion, yet the horses employed in reconnaissance and pulling the heavy artillery were so poorly fed that they could not keep up the pace.

The beginning of World War II saw the German Army still reliant on horse-drawn transport. Hitler neglected to fully mechanize his transport vehicles, though he dramatically increased the number toward the end of the war.[29] Historian Julian Thompson relates that the Germans only possessed three motor transport regiments, for the whole army, capable of carrying 19,500 tons. In 1944, the Allies in northwest Europe could transport 69,400 tons to support 47 divisions. Thompson goes on to state, "Hitler's failure to build up the necessary capacity to provide the transport essential for mobile warfare was one of the principal reasons for the failure of the German invasion of the Soviet Union (Operation Barbarossa)."[30] Regardless of the German Army's deficit in mechanized transport, the Second World War became the pioneering conflict to be predominantly affected by fuel in the form of POL.

Following Germany's invasions of Poland and France, POL's role became readily apparent, and Allied strategists sought to cripple the Axis' ability to effectively employ fuel with US entrance into the war. Plans got under way to target the Ploesti oilfields in Rumania as strategists estimated that the fields had the capacity to produce 9 million tons of refined oil per year, though it only produced 4 million. Allied strategists understood well the Germans' primitive transportation system and the fact their small fleet of motorized transport vehicles had become extremely overburdened by the war's rapid geographic expansion.[31] Accordingly, the Allies did not attack Ploesti in the hopes of crippling the Axis refining capacity. Instead, they were more interested in destroying Ploesti's refining capability so Germany's limited transportation system would have to move the crude oil from the Ploesti area to other refining sites in Germany or France. The war had already severely taxed the Axis transportation system, and the Allies believed the extra strain would cause supply to other areas to fall apart.

The Allies launched the first Ploesti raid on 1 August 1943 and estimated that the Axis oil supply had been reduced by 3 or 4 percent.[32] It was originally believed the raid had destroyed about 40 percent of 6 months of Rumanian refining capacity or a loss of 1.8 million tons of refining capacity as a result of closing the refining facilities from about 1 week to several months.[33] However, the raid's after-action analysis indicated that Rumanian oilfields possessed twice their estimated production capacity, so subsequent raids would have had to destroy about 3 million more tons of refining capacity to begin really limiting Ploesti's actual refining capacity.[34] Though the mission proved to be successful, the Army Air Forces sustained a 30 percent loss, making a follow-up raid impractical.[35] The Allies moved on to other targets, and the Germans managed to quickly rebuild the facilities.

Evolving into a strategy to attack the entire Axis oil industry, the raid, despite its heavy losses, fueled an intense bombing campaign that managed to strike every major oil refinery in German-controlled territory. Ambitiously, the United States and Great Britain set out to severely damage the German oil industry and keep it subdued. Like Ploesti, the Allies' goal was to reduce the German refining capacity as well as the number of refineries available to cannibalize in order to rebuild larger, more productive refineries.[36] They wanted to present Germany with only two options: transport the crude oil to old unattacked refineries near

Marseilles, France, where they were highly vulnerable, or stay in their present locations and attempt to rebuild between raids.[37] The Germans chose the second option, and the Allies timed return missions to prevent refineries from going back on line.[38] As German oil production suffered, so did its armed forces as lack of aviation grade fuel kept the Luftwaffe on the ground and forced the army to heavily dip into rapidly dwindling reserves.

The Germans failed to completely think the entire war effort through and suffered from inadequate fuel reserves. The German Oil Association advised the government that the oil reserves would only last for 5 months given the high rate of consumption. Germany made the reserves last longer by robbing from the civilian sector, but the effects of the Allied bombing after 1943 made the situation critical. Germany's aggressions in 1939 and 1940 were rewarded with its victims' oil reserves. A US investigation following the war relates, "In January 1941, aviation gasoline stocks were approximately 500,000 tons. When Germany conquered the Netherlands, Belgium, and France, about 1 million tons were secured."[39] However, by January 1944, aviation gas had been reduced to 240,000 tons, and by January 1945, it was almost nonexistent.[40] By May 1944, fuel shortages resulted in a drastic reduction in training hours, and operational time was limited strictly to air defenses.[41] The situation had become so critical that the Luftwaffe could provide little opposition to the Allied invasion on 7 June 1944. By 1945, it could not support German ground forces in the Battle of the Bulge after a successful ground offensive.

Germany's lack of fuel reserves also manifested itself in ground operations as the Combined Bomber Offensive and the Allied advance prevented German recuperation. Following victory in North Africa and a successful invasion of Sicily, the Allies drove up the Italian peninsula until stiff German opposition along the Gustav Line halted their advance. The Allies initiated Operation Strangle from 19 March to 10 May 1944 to cut the Germans off from resupply and deplete their fuel reserves. Generally successful, Strangle did not dislodge the Germans, and Operation Diadem got underway on 11 May 1944 to increase German fuel consumption while reducing their resupply through interdiction.[42] Strategically, the Allies planned to dislodge the Germans while strategic bombing would prevent resupply in hopes they would run out of fuel.

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Operation Diadem went according to plan, and by mid-May, 14 fuel depots had been critically depleted, and "the mobility of the entire army had been called into question."[43] German fuel was adequate to compensate for the defensive maneuvers necessitated by the Allied advance at the beginning of the operation. Yet, by early June, the effects of the campaign presented a very hard reality. The German armies had been in retreat for a week, and the American Fifth Army presented a constant threat.[44] Though this defense suited the mountainous terrain and the situation, it required a lot of fuel that the army did not possess. "By June 6, the army was making its moves piecemeal—a unit would move, exhaust its fuel, and wait for resupply."[45] Defensive maneuvers, the mountainous terrain, and movement at night saved the German Army from total defeat, but fuel's use in strategy and its subsequent effect on German strategy was enormous.

On 6 June 1944, the Allies launched Operation Overlord, and the invasion of Eastern Europe began. Original plans called for the Allies to steadily push the German Army toward the Rhine and then force surrender. However, after a massive aerial bombardment on 25 July, the Allies forced a gap in the German lines and then exploited it by pouring through armored divisions.[46] New tactical opportunities to quickly defeat the Germans presented themselves instead of the originally planned methodical push to the Rhine."[47] Patton's Third Army raced through southern France consuming an average of 350,000 gallons of fuel each day.[48] By 7 August, the Third Army had exhausted its fuel reserves, though it managed to maintain the rapid advance for another 3 weeks. Fuel supply reached critical levels from 20 to 26 August when both the First and Third Armies, pursuing the retreating German Army, consumed an average of more than 800,000 gallons of gas a day.[49] However, the supply lines had not yet become so long as to be unmanageable by theater logisticians, and the Allies had enough fuel to enter Paris on 24 August.

Pre-invasion planning called for the Allies to halt and wait for the logistical network of communications and food pipelines. However, their shipping successes and rapid advances into Paris with little German resistance called for a reevaluation of the plan. General Bradley, commanding the First Army, was quoted as saying, "Armies will go as far as practical and then wait until the supply system in [the] rear will permit further advance."[50] Basically, he proposed to move forward, taking as much ground as possible, until they ran out of gas. Once again, fuel requirements dominated strategic decisions and operational action.

Since World War II, POL has become increasingly important to keep an army going in the field. The past 50 years of technological advance have only optimized modes of transportation, not lessened the impact of fuel on strategy, tactics, and operations. While technological advances may reduce the amount of support equipment required for military operations and the size, lethality, or amount of munitions—all of which will further reduce lift requirements—similar advance is seen as unlikely for fuel. Arguably, fuel will remain the dominant logistics factor that limits strategic and tactical planning as well as actual operations for the foreseeable future.

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