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Linking Logistics and Operations:
A Case Study of World War II Air Power

J. A. Stockfisch

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PREFACE

This Note describes the interdependence between logistics and air force wartime operations as illustrated by World War II experience. This experience makes a compelling case for designing military organizations to be flexible, rather than trying to predict behavior to meet the demands for specialized logistic support of technically advanced weapons. Examples of desirable organizational flexibility that arose during the war are presented.

Official histories and secondary sources on the Allied use of air power are the information sources. Although most attention is given to American air forces, selected examination of British and German experience is also presented.

This Note was produced under the Project AIR FORCE Resource Management and System Acquisition Program in the project "Combat Support C3 Needs and Design Concepts." It should interest those concerned with the relationship between logistics and operations.

SUMMARY

Providing wartime air force logistics support is difficult because of uncertainty. Even in peacetime, the variation of the demand for support services and spares consumption relative to average demand required to operate military aircraft is such that mathematical logistics models based on peacetime spares consumption and maintenance workload data suggest either unacceptable system performance or excessive costs. The predictive power of these models is so poor as to provide little useful policy guidance.

Wartime use presents an even more somber picture. This condition argues that rather than try to forecast wartime demands on the basis of irrelevant peacetime data and questionable models, attention should concentrate on creating a logistics system that can more effectively cope with wartime uncertainty. During recent years, through its Logistics Concept of Operations (LOGCONOPS), the Air Force has recognized this need, and that the uncertainty of wartime operations generates unpredictable support demands. This condition calls for linking operations and logistics support by management and command.

This Note distills from a survey of World War II literature two kinds of information that makes a compelling case for LOGCONOPS and provides insight on how to implement it. The first describes the linkage between operations and logistics that tacticians and logisticians faced and how it was permeated by uncertainty. The second describes how management initiatives met the resulting problems. Three World War II uses of American and British airpower are recounted: the tactical air support in the European ground war; the tactical air support in the Pacific amphibious war; and the strategic air offensives against Germany and Japan. Aspects of enemy strategy and air force behavior that motivated friendly initiatives are also described.

THE ROOT CAUSES OF UNCERTAINTY

That war and military operations are permeated by uncertainty is not news. However, major technology shifts between wars greatly stress the logistics system and increase the uncertainty that logisticians and tacticians must face.

Strategic-political uncertainty results from the fact that military operations are undertaken and shaped in response to adversaries' unexpected actions, the ad hoc formation of military coalitions, and the effort to influence neutral countries' behavior and implement other political goals. These often require friendly forces to operate in places and be subject to physical and political constraints planners did not anticipate. Coalition warfare provides

potential host nation support that can mitigate logistic constraints, but it usually also requires compensation to host nations that presents new logistics demands and constraints.

Technological change permits designing and developing new weapons that promise improved physical performance such as higher speed or service ceiling, greater payload, higher accuracy as measured by tightness of shot group. New weapons both permit and call for new tactics, different crew training, and even new organizational arrangements. With long periods between wars, there is little realistic testing and hence useful knowledge of what a new weapon might actually accomplish in war and little opportunity to discover the best tactics that should govern its operational use. Wartime operations, however, quickly shatter most prewar expectations about weapon effectiveness and the applicability of tactics derived from favored doctrine, but combat survival creates strong incentives to discover better tactics to carry out an intended mission, to cope with new enemy tactics, to meet some new mission requirement, and to find a new use for systems that fail to accomplish any of these. These changes greatly stress the logistics system.

THE IMMEDIATE IMPACT OF UNCERTAINTY

The kinds of uncertain events to which logistics managers had to adapt can be categorized as follows:

1. Undertaking operations in a geographic area or a type of operation not planned for.
2. Surface transportation or special support constraints and failures.
3. Adapting to allies in a context of coalition war and host nation support.
4. New or unexpected enemy tactics.
5. Changed friendly tactics in carrying out an established mission.
6. Use of a system for a new or different mission other than what it was originally designed for.
7. Changed mission mix.
8. Changed ordnance expenditure rates.
9. Technical modifications and introduction of new subsystems.
10. Attacks on air bases that damage facilities and aircraft.

How most of these were coped with by management initiatives is summarized in the "Overview" Sections in each of Parts II—IV that treat the three major uses of airpower covered in this Note.

CONCLUSIONS AND POLICY IMPLICATIONS

Use of aircraft and technically advanced weapons in widely different environments to meet diverse threats strongly argues that prewar and even pre-campaign logistics planning can only be based on coarse and highly problematic planning factors and estimates. Actual combat operations will reveal many of these estimates to be off the mark. Prewar tactical concepts will also be sharply revised, to create new support demands. These shifts immediately provide new and more relevant information. A responsive logistics system will quickly acquire and use this information, and the wartime logistics management initiatives described in this survey can be measured in these terms. It follows that design of a support system should concentrate on how managers throughout the system can acquire, disseminate, and use new information more quickly. Most of the management initiatives and logistics innovations implemented by American and British air forces accomplished this in a variety of ways.

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I. INTRODUCTION

THE PROBLEM MOTIVATING THIS STUDY

Much effort has been spent building mathematical models to study Air Force logistics, and much data about spare parts consumption and maintenance workloads during peacetime operations have been collected in attempts to validate the models. Unfortunately, the models poorly predict demand. This failure reflects the fact that the supported systems generate extremely erratic demands. What wartime operations will reveal is even more uncertain, as this study of World War II experience with aircraft demonstrates.

How does one cope with such uncertainty? The answer is to design the logistics system to be more responsive to demands as they are revealed, rather than try to forecast them. During recent years, in recognition of this problem, the Air Force has evolved a Logistics Concept of Operations (LOGCONOPS) (Trainor, 1988, pp. 1–4). This concept requires creating organizational procedures that explicitly couple logistics support and *wartime* operations. These procedures are designed so that they will satisfy the wartime logistics demands as they are generated, without previous knowledge of what these demands will be. This approach implicitly and properly rejects the former Air Force practice of trying to endow individual tactical units with sufficient resources to operate independently of outside support for as long as 30 days. It assumes that peacetime planners have adequate knowledge and information to predict *wartime* spares and munitions demands, and maintenance workloads, for such a period. But planners do not have this kind of information. Only actual combat operations provide it. This fact forces both operators and logistics managers to adapt to previously unknown constraints they jointly face. For operators, this usually means changing tactics, which generates unexpected logistics demands; for logistics managers, it means devising and adopting management initiatives.

This Note examines the use of airpower in World War II to learn two lessons applicable to weapons that have not been thoroughly tested and used in war. The first lesson is that in war these systems will be used in different ways than planners expected and will therefore generate unanticipated logistics demands. Simultaneously, the logistics system will experience shocks, such as attacks on air bases or the transport system. The second lesson is that meeting these problems requires logistics management initiatives that effectively couple logistics and operations that meet the unanticipated logistics demands. The study describes many management initiatives that World War II logisticians and managers took, and distills from them several policy recommendations.

Official histories and secondary writings were the information sources. Few of these studies were devoted to logistics, let alone the relationship between logistics and operations. Several excellent studies indicate, however, that the archives contain much information that would provide additional detail and insight (e.g., Craven and Cate, 1951, pp. 107–139, 547–594; Ruppenthal, 1953, 1959; Matloff and Snell, 1953; Weapon System Evaluation Group, 1951).

BACKGROUND AND CONCEPTS

Logistical Support of Combat Air Forces

It is useful to define logistics as it was defined during World War II, when it had a somewhat broader meaning than in today's usage. An important part of World War II logistic support was major end-items, including combat aircraft themselves, of which the United States alone produced nearly 200,000. Sea and land transportation, including the linking port and dockage facilities (and often their absence), were major constraining elements of the support system. Construction and maintenance of countless airfields was necessary to sustain the operation of short-legged aircraft during campaigns spanning great distances. Spare parts, munitions, fuel, and depot and air base maintenance (and modification) of aircraft and equipment were, of course, obvious elements of the system just as they are today.

In World War II, an air force's logistics system had a two-tier structure. One tier was a set of operating bases. The other was a depot system from which operating bases replenished supplies and obtained periodic inspection and major overhaul of equipment. This structure should not be obscured by whether the logistics resources at an air base belong to a separate air base organization or to tactical units located there. What is relevant is that some resources were immediately available to support a combat unit's operations for a limited time period. Beyond that period, however, a unit had to turn to an outside organization for supplies and specialized services.[1] This World War II model roughly corresponded with the present Air Force system and its air base support, with its flight-line and base-provided support on the one hand, and the support provided by the Air Logistics Centers on the other hand.

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[1]This two-tier logistics concept can be related to the World War II Army Air Force four-echelon maintenance and supply structure where the first and second echelons constituted what was performed in the tactical unit by its air and ground echelons, respectively; the third echelon was performed by a sub-depot, or air base group, colocated with the tactical units it was assigned to support; and the fourth echelon was performed by a depot. Under most conditions, the first three echelons tended to merge or blend together. In World War II organizational design, the distinction between these was mobility: The first and second echelons, including their tools and equipment, were air-transportable; the third echelon could be moved by truck. For a further description, see Craven and Cate, 1955, pp. 370–371, 384n, and 388n.

UNCERTAINTY AFFECTING LOGISTICS

The concept of "uncertainty" covers much territory, so it helps to describe how it affects logistics planning and execution. Stochastic models and parametric statistics do not adequately deal with it. This is because the transition from peace to war presents an entirely different situation, the statistical qualities of which can be revealed only by future experience. This shift can be likened to a dice game in which the shooter is handed a new pair of dice that are "loaded," but with none of the players knowing just how they are loaded. How should military planners play this game? An immediate answer is to better understand the nature of the uncertainty, particularly how it is affected by complicated technical systems that have not been thoroughly tested in war. Experience with recent wars suggests two major causes of uncertainty.

Strategic-Political Uncertainty. Those who make foreign and military policy must often adapt it to influence adversary behavior, to respond to the behavior or needs of allies in coalition war, to buttress domestic political support for the war effort, and to combinations of these. Enemy action can dictate an unanticipated strategy, in terms of the kind of military operation, its location, or both. To bolster an ally or to induce a neutral country not to join the enemy can require either a reallocation of resources, as illustrated by U.S. provision of weapons to allies during World War II at the expense of its own force buildup, or a newly conceived military operation, as illustrated by the unsuccessful allied Gallipoli campaign in World War I. The detail of operations may also be constrained, sometimes to signal restraint or the opposite, as illustrated by air operations during the Korean and Vietnam wars. The amount and kind of host nation support in a coalition war (the only kind of war the United States has engaged in during the present century) directly affects guest nation logistics support and imposes demands for compensating assistance to the host nation.

For military planners, an important result of strategic and political uncertainty is that it calls for commitment of military forces to some unexpected effort in size, kind, or geographic area. World War II presented many such instances. Such shifts stress the transportation and distribution systems and change priorities with respect to what gets transported and distributed. In war the transportation system itself can be attacked, and its capacity becomes problematic.

After America entered World War II American and British planners were agreed on the broad strategy of defeating Germany first, there was much real uncertainty and disagreement as to details. Anxiety about whether the Soviet Union could hang on helped sustain cohesion between the British and Americans during the early period of the coalition. But beyond this obvious and compelling agreement, policy advisors widely diverged in their views about implementation. Each group's view usually reflected the proponent's national interest or military service bias.

Much of the disagreement over World War II strategy was resolved by resource constraints and their subsequent relaxation, an obvious need to respond to enemy action, or combinations of these. Thus although it is legitimate to identify something called "strategic uncertainty," an actual war strategy turns out to be the result of ad hoc adaptation to logistics and resource constraints and the resolution of technical and tactical uncertainties that affect the feasibility of proposed alternative strategies.

Tactical and Technical Uncertainty. It usually turns out that new weapons and their crews are unable to perform missions as planners and weapon designers expected. Although technical change permits new weapons capable of improved physical performance—e.g., better range-payload, faster speed, improved accuracy—how a new system performs in war remains to be seen. In some instances a system designed for one purpose turns out to perform some other mission brilliantly after modest design changes suggested by combat experience or new information about enemy systems.

Occasionally, new systems and perhaps some older system are combined in a new organizational context to have major or revolutionary consequences. Indeed, the history of military aviation has been one of coping with the unexpected by improvisation. The interaction of these uncertainties with the political-strategic kind presents a mixture that is subtle and perplexing indeed. As we shall show, these interactions shape operations and stress the logistics system in unexpected ways.

ORGANIZATION

Overy (1980) claims that there were several distinctly different air wars during World War II. Following sections discuss three major airpower applications: Section II discusses support of European ground fighting; Sec. III describes the use of land- and carrier-based aviation in the Pacific war against Japan; and Sec. IV describes the strategic bombing offensives against Germany and Japan. Section V presents the lessons learned and their implications for the design of a logistic system.

II. TACTICAL AIRPOWER AGAINST GERMANY

The war against Germany had three major phases. This section first considers the German Luftwaffe in the Battles of France and Britain and in its early operations in Russia. Aspects of the logistics management of French, British, and German air forces during this time are also presented. Attention is next directed to the Mediterranean, where the Army Air Forces (AAF) first teamed up with the Royal Air Force (RAF) in the Western Desert and later took part in the Tunisian, Sicilian, and Italian campaigns. Finally, the U.S. force buildup in Britain (Operation Bolero) and pre- and post-invasion tactical air operations are examined.

THE EARLY CAMPAIGNS AND THE LUFTWAFFE

The Battle of France

On May 10, 1940, when the Germans attacked, only 16 of France's 28 bomber groups, or about 140 aircraft, were available for combat. The remaining groups were converting to new types, including American Martin and Douglas bombers. Between May 10 and June 12, French bombers flew 1198 sorties with losses of 88 aircraft. The Germans destroyed 240 French aircraft on the ground with attacks on 47 airfields (Chapman, 1968, p. 352). Airbase attacks immediately link logistics and operations: Runways and damaged aircraft must be repaired when base support capability is reduced due to damage and casualties.

In the meantime the French air force had grave logistics, distribution, and organization problems. About the time of the attack, production of new aircraft was increasing. Unarmed aircraft piled up at depot and school airfields, but armaments were not made available. Newly equipped units were not employed, and offers of their service to the Army and Army Group Headquarters were frequently turned down (Chapman, 1968, p. 352).

The Battle of Britain

After the Battle of France the Luftwaffe quickly positioned two air forces of 2600 aircraft on the Channel coast. Through late July until August 13, small-scale probing operations and antishipping strikes, including mine laying, were carried out. On 13 August, 485 bomber and 1000 fighter sorties were carried out against Channel ports and RAF fields in Hampshire and Kent (Price, 1969, pp. 54–55). The Germans attempted to destroy the RAF Fighter Command initially by attacking RAF airbases and elements of the radar early warning system. Later they shifted to attacks on London. Some critics argue that the Germans should have stuck to bombing Fighter Command airfields, or the radar net, or both

(Bekker, 1964, p. 258). But Luftwaffe high altitude bombing—carried out by He 111s and Do 17s—was poor. Nor did it have clustered fragmentation bombs designed for airfield attacks. Stuka (Ju 87) dive bombing was used early in the campaign, but attrition was very high because escorting fighters could not protect diving bombers. Hence the Stukas dropped their meager loads inaccurately from high altitude, level bomb runs.

The Luftwaffe had two problems. First its bombers could not carry sizable loads nor accurately aim them from the high altitudes they flew. Second, bombers required fighter escort, which was thin because of the limited range of the single-engine Bf 109 fighter. An unexpected consequence of the Luftwaffe's excellent ground mobility, which was designed to move units to advance airfields to keep up with fast moving ground forces, was to neglect improving fighter combat range by means of droppable fuel tanks, a practice the Germans were familiar with, having used them in Spain (Galland, 1978, p. 26). Its twin-engine, heavily armed and long range Bf 110 fighter, designed to escort bombers, proved incapable of handling agile single-engine British fighters, an early example of a weapon failing to perform the mission for which it was designed.

As the battle unfolded, Fighter Command experienced heavy losses and aircraft battle damage. Losses were made good, however, by increasing new production and extensive and rapid repair of damaged aircraft. Both aircraft procurement and major repair responsibility had been taken away from the Air Ministry and placed in a newly created Ministry of Aircraft Production headed by the controversial Lord Beaverbrook. Meanwhile, a Civilian Repair Organization had been created shortly after the Munich crisis to repair damaged aircraft. It sponsored the design and production of a low-loading trailer that could transport a fighter aircraft (with wings detached and stowed alongside) by road. This organization became part of Beaverbrook's Ministry.

Damaged aircraft were ruthlessly cannibalized through manufacturing facilities. In addition to major engine and airframe manufacturers, numerous small business firms were engaged to carry out the repair work, and the resulting organization continued throughout the war to provide major air base and depot level maintenance (Postan, 1952, pp. 316–322). To expedite the repair process, Aircraft Production Ministry officials often "raided" RAF squadrons for spare parts and engines. As Beaverbrook explained "better a stringency of spares and a bountiful supply of aircraft than a surplus of spares and a shortage of aircraft." These expedients and rising production eliminated aircraft as a Fighter Command constraint (Deighton, 1978, pp. 169–172); capable fighter pilot attrition became the chief worry. This integration of aircraft production, damaged aircraft repair, and inventories at operating bases controlled by the same agency provides an example of linking logistics to operations by management. Close proximity of air bases to the manufacturers probably permitted this particular linkage. Modern communication and transport could permit a similar result between air bases and depots despite distance.

The First Fighting Season in Russia

The attack against Russia on June 22 opened with surprise attacks against airfields, destroying nearly 1500 aircraft on the ground. On that same day, flak and air combat destroyed another 322 Soviet aircraft. The toll of aircraft destroyed by ground attacks rose to around 2000 during the first two weeks of the campaign (Bekker, 1964, p. 317). This high loss of aircraft from ground attacks was actually fortunate for the Russians, because most of the destroyed aircraft were obsolete and decidedly inferior to the Bf 109. Many Russian pilots therefore lived to fly modern aircraft that became available from new production and military assistance.

To the Germans' dismay, the campaign turned into a war of attrition that they were poorly prepared to support. Unlike previous campaigns with a brief but high attrition fighting period, Luftwaffe operations in Russia had low attrition rates and high steady state sortie rates. Most missions were ground support and reconnaissance. Campaigns in the West presented narrow frontal distance and high troop densities; in Russia there was a large frontal distance with many sectors very sparsely held. Aircraft could apply force quickly in such sparsely defended sectors, but continual air reconnaissance was essential to detect enemy buildups intended to make penetrations. Unfortunately for the Germans, the more deeply they penetrated the wider the frontal distance became because of western Russia's funnel-like shape. As troop density fell in defended sectors, the demand for air support to help fill gaps became greater. But the deeper the advance into Russia, the more difficult it became to provide logistic support because of a long line of communication and the Luftwaffe logistic organization.

Logistics and operations were poorly connected in the Luftwaffe. Its logistics system was a highly decentralized regional organization. Each territorial air force contained all tactical aircraft types—fighters, bombers, and so on—and was essentially an independent air force (Control Commission for Germany, 1946, p. 21). An air force, in turn, was divided into operational and ground support components. The ground organization was responsible for supply, repair, airfield construction and maintenance, and general administration. When an air force was assigned to operations outside of Germany, the home ground organization dispatched a field headquarters to the designated area and usually adopted the name of the country or area it administered, "Sicily," "Kiev," and so on (Control Commission for Germany, 1946, p. 53).

Officers with operational experience but detached from combat because of injury, old age, or other reasons usually commanded and staffed ground organizations, and few of these men had logistics experience. In the German system, "supply" was a "nonmilitary" activity, and a large proportion of the administrative staff were civil servants. As a result, military professionals regarded ground organizations in Germany as "civilian" establishments. The cultural split between these two groups discouraged interaction and communication.

This separation between administration and operations copied the German Army practice that aimed to free commanders from administrative detail. The system worked in the West with its good communications and dense transportation nets, especially if the campaign was short, but it broke down with territorial expansion, great distances, and interdiction of supply routes by guerrillas and air attacks. Thus as the war dragged on, large numbers of aircraft at distant bases were not operational for lack of spares (Cooper, 1981, pp. 247, 263).

U.S. ARMY AIR FORCES AND THE MEDITERRANEAN

The Western Desert and Middle East

The Desert Air Force. When Italy entered the war in June 1940, large Italian forces in Libya and East Africa directed British attention to the Middle East Command centered in Egypt. The RAF command located there, whose major component was the Desert Air Force (DAF), was second rate, "possessing some 29 squadrons, chiefly of assorted antiques" (Terraine, 1985, p. 304). (Fortunately for the British, the much larger Italian Air Force was third rate). The closing of the Mediterranean to shipping placed the British under a virtual siege, which had been foreseen and for which a 90-day stockpile had been acquired. For the RAF component this was mainly fuel and munitions and a reserve of aircraft equal to 140 percent of first-line strength. Modern aircraft were planned to arrive after a 70-day sea voyage via the Cape and the Red Sea, with no reserves for a long time and much uncertainty about ability to support new aircraft types. To mitigate this transportation constraint, the RAF set up a facility at Takoradi on the African Gold Coast (now Ghana) to implement a trans-Africa ferry route capable of handling 120 aircraft a month. The skeleton of this route already existed to support a weekly British Airways mail and passenger service from the Gold Coast to Khartoum, but considerable work was necessary to handle the expected military traffic. Takoradi to Khartoum was nearly 2700 miles in five or six legs plus another 1000 miles to Egyptian air bases. Work started on this route in July, and on 20 September the first flight of one Blenheim bomber and six Hurricane fighters left Takoradi. By October 1943 over 5000 aircraft had arrived in Egypt by this route.[1]

Flying the Takoradi route and desert operations increased maintenance workloads because of extreme heat, sand, and dust. Lack of adequate spares intensified maintenance problems. For example, Blenheim air cleaners had to be serviced every five hours, a job requiring three hours. Simple replacement of the part required only 15 minutes, but in January 1941 there were only six spares in the Command.

Despite these terrible logistics constraints, the ineptness of the Italian enemy culminated with the fall of Benghazi in February 1941 at the end of a campaign that yielded 130,000 prisoners, 400 tanks, and some 1100 damaged aircraft. During the early months of 1941, Italian forces lost some 325 aircraft in East Africa. Another fiasco was the October 1940 Italian attack on Greece. Both the Germans and the British reacted to these developments for reasons of foreign policy rather than military merit. The British dispatched forces to Greece and Crete mostly from its Middle East Command. The Germans felt obliged to avert another Italian disaster, and Luftwaffe elements appeared in Sicily during January 1941 to attack the British Fleet and convoys to Malta and Greece. Rommel arrived in Africa to initiate an offensive on March 30. The Germans attacked Greece with 1000 aircraft in early April, expelling the British and inflicting heavy naval losses on them. Rommel recaptured Benghazi, laid siege to Tobruk, and crossed the Egyptian frontier. Fortunately for the British, Rommel's Luftwaffe support was only some 50 Ju 87 dive bombers and 25 Bf 110 fighters (Terraine, 1985, p. 335). The DAF fighters strafed German supply columns, and Blenheim bombers dropped small fragmentation bombs on the forces at Tobruk only; these departures from RAF doctrine prevented a total rout of the British Army in the Western Desert.

These events induced command changes in the Middle East, and reorganization of air force logistics. Up to that time, maintenance and logistics of RAF overseas commands were casual at best, falling under the control of the Air Officer in charge of all administration. As a result of Churchill's dissatisfaction with aircraft serviceability in the Middle East Command, Air Vice Marshall Dawson, an engineer specialist previously assigned to the Ministry of Aircraft Production, arrived in June and proposed a major organizational change. He would set up a separate Maintenance Group with himself as Chief to report directly to the Commander rather than the Air Officer in charge of administration. Air Marshal Tedder,

[1]During 1941, the Americans established a South Atlantic aircraft ferry route by way of the Antillies, Brazil, Ascension Island, and Liberia, which fed into the British system.

who was shortly to take command of the Middle East Air Forces, supported the recommendation. At first the Air Staff back in England resisted the proposed change but relented when the Chief of Air Staff indicated his support of Tedder's request (Tedder, 1966, pp. 108–109). Marked improvements followed. Maintenance units were expanded, local resources and civilian labor were exploited, some 34 mobile salvage and repair sections gridded the desert, and an engine overhaul depot was created. Neither the German nor Italian air forces maintained aircraft serviceability as well as did the DAF, and as a result they seldom enjoyed air superiority, although they usually owned more aircraft (Owen, 1948, pp. 58–59, 67–68).

During 1941, the Desert Air Force component of the Middle East Command under the command of Air Vice Marshal Coningham developed innovative doctrine with respect to the use of aircraft in conjunction with army operations. Although an air officer was to command aircraft, an issue that Churchill had to settle, it was an Air Force responsibility to support the Army in the ground fighting to the fullest extent and with all available resources. Both commanders were to agree upon ground and air operations with regard to Air Force targets, the possible acquisition of forward air bases and protection of existing bases by the ground forces, and the potential of using friendly ground forces to bait enemy air attacks to attain air superiority. Air Force and Army headquarters were located beside each other, Air Force liaison officers were assigned to divisions and brigades where they and Army counterparts processed requests for air support, transmitted by a communications net dedicated solely to air-ground coordination. An important function of this system was to provide up-to-date information to air crews about the location of friendly ground force elements involved in highly mobile and fast-moving operations (Terraine, 1985, pp. 345–351).

The most important tactical innovation developed by the DAF was the transformation of fighter aircraft into fighter-bombers. Initially, these were Hurricanes (dubbed "Hurribombers"), which were deployed to the Middle East after the Battle of Britain because they could not survive against Bf 109s in northern Europe. American P-40s acquired by the RAF were also assigned to "Army Cooperation" for the same reason. (However, the Bf 109 required a somewhat larger radiator when used in the desert, which reduced its performance edge over the P-40 somewhat.) The fighter-bomber in ground support and battlefield interdiction—especially that of the rugged P-40—proved decisive (Vader, 1970, pp. 96–114). An important advantage of the fighter-bomber over light or medium bombers for ground support and battlefield interdiction was that providing fighter escort for bombers called for coordination and planning lead time, which reduced mission time-responsiveness. The disadvantage of the fighter-bomber was its short combat radius, which was offset by unit ground mobility and rapid construction of new forward airfields by the Army. This innovative use of the fighter-bomber was to appear elsewhere, and as one of the most decisive applications of airpower in World War II was a prime example of tactical-technical uncertainty whereby a weapon turns out to perform unplanned but vital missions.

Entry of the U.S. Army Air Forces. An unexpected commitment of AAF units to the Middle East and Egypt that took place in the summer of 1942 provides an example of how strategic-political uncertainty permeated World War II strategy. Rommel's 1942 successes provided an alarming threat to the Anglo-American alliance. The shaky British position threatened communication lines to the Far East. This menace affected American plans because the Japanese conquest of the East Indies severed a line of communication between Australia and southern Asia and China. During 1941, through an initial base in Liberia, the AAF used the British aircraft ferry route across central Africa to dispatch aircraft either to Egypt or to the Far East. Both Americans and British therefore had an immediate interest in turning back the Axis offensive (Craven and Cate, 1949, p. 7).

At that early date, AAF logistic support was thin, with most of it supporting a massive air crew training program. Also, shipping space was at a premium. However, the many American-made aircraft in the RAF Middle East Command (Owen, 1948) provided a logistics system, including manufacturer's technical representatives, capable of supporting AAF aircraft. At that time the British intended to expand the Middle East Command mainly from their quota of lend-lease aircraft. But if the AAF were willing to man these additional units, the British would modify their scheduled receipt of lend-lease aircraft to make them immediately available to the AAF. AAF aircrew production exceeded available aircraft, so in June 1942 the AAF agreed to commit nine combat groups, eight service groups, and two air depot groups to the Middle East by early 1943 (Craven and Cate, 1949, p. 14).

The first American combat units to arrive in June came from an unexpected source, the so-called "Halverson Detachment" (named after its commander) of B-24 bombers secretly trained to bomb Japan from Chinese bases. But the situation in Burma had so worsened as to make the operation logistically unfeasible. General Brereton, ordered from India with instructions to bring with him as many heavy bombers as he could muster, arrived in Cairo with nine nondescript B-17s and a party of 225 men on June 28. Together with the Halverson Detachment plus the air element of the American North African military mission, these later combined to form the U.S. Middle East Air Force (Craven and Cate, 1948, pp. 16–17).

During late June and July these B-17s and B-24s operated against Rommel's supply lines. By early August the air echelon of a new group of B-24s arrived with a small stock of spare parts, and its ground echelon arrived later. On July 1 the carrier *Ranger* launched P-40s of the 57th Fighter Group 100 miles off the west coast of central Africa, to be flown to their eventual destination in Palestine. Ground crew maintenance personnel in air transports accompanied and readied the aircraft at night for the next day's flight leg. By mid-August the air-echelon of the 12th Bombardment Group, B-25s, arrived in the Nile Delta from Florida by way of the Antilles, Brazil, Ascension Island, Liberia, and central Africa. The P-40s and B-25s were initially assigned to the Desert Air Force where they acquired experience with combined ground-air operations. Here was another example where strategy was formulated ad hoc as a result of enemy action and available resources to present operators and logisticians unexpected assignments.

North Africa and Tunisia

Strategic planning to land in North Africa (Operation Torch) began on July 31, 1942. The first Draft Outline Plan (Partial) of the Combined Planning Staff was available on August 9; it called for simultaneous landings inside and outside the Mediterranean on November 5 (Howe, 1957, pp. 25–27). (American planners insisted on capturing an Atlantic port.) The forces and supporting shipping were hastily cobbled together because of limited planning lead time and little experience. The meager planning lead time resulted because American and British military staffs were debating whether to undertake the operation. President Roosevelt, in overruling his staff's opposition to the British-favored strategy, required time and the information that time provided to make his decision.

The Landings and Movement to Tunisia. On November 8, an American force landed on the Atlantic coast near Casablanca. Another American force transported and supported by the Royal Navy landed on the Mediterranean coast near Oran, and an allied force also supported by the Royal Navy landed near Algiers. Carrier aircraft, including those of U.S.S. *Ranger* and the escort carrier *Santee* at the Casablanca landing, furnished air support. The Casablanca force also contained the escort carrier *Chanengo* with 77 P-40s aboard, to be catapulted either to make emergency strikes or to land at a valuable airfield with a well-surfaced runway at Port Lyautey. Unfortunately, the runway had been damaged by shellfire and bombing, which caused 17 of the aircraft to be damaged in landing (Craven and Cate, 1949, pp. 59, 77) and generated a surge demand for landing gear and other spare parts.

After these ports and nearby airfields were secure, AAF units quickly followed. Britain-based heavy bomber units moved to North Africa to be used in tactical interdiction missions. Some units scheduled to go to England from the United States ended up in North

Africa instead. Two American fighter groups, initially trained to fly P-39s but retrained to fly Spitfires when they got to England, and two P-38 fighter groups arrived in Algeria from England by way of Gibraltar by D+11. Also arriving in Morocco from England were elements of B-25 and A-20 groups. These were followed by three B-26 groups.

The purpose of seizing these lodgements was to provide ports and bases for a drive to northern Tunisia and link up with Montgomery's westward-bound 8th Army. (No landing was made in Tunisia because of its close proximity to Axis airfields in Sicily and Sardinia.) The distances were great: Algiers was 380 miles from Bizerte or Tunis, and Casablanca was 700 miles from Algiers. The Germans reacted quickly to build up forces in Tunisia, and some 5000 airlifted troops arrived from Sicily by November 17 (Craven and Cate, 1949, p. 81). By the end of January 1943 over 81,000 German and nearly 32,000 Italian troops were in Tunisia (Howe, 1957, p. 368), most of whom were airlifted and supplied by some 400 transport aircraft. Meanwhile, the British 8th Army chased Rommel to the west, to arrive at the Tunisian frontier with 30,000 German and 48,000 Italian troops by early February (Howe, 1957, p. 371). The Western Desert and the allied North African forces merged, to confront the augmented Axis ground and air forces in Tunisia who also enjoyed considerable air support by 390 aircraft on bases in Sicily and Sardinia. By the end of December the Germans in Tunisia had a small air defense and close-support force of single-engine aircraft—about 40 Ju 87s and 35 fighter-bombers, including some FW 190s, probably the best fighter in the theater at the time (Cooper, 1981, p. 215).

Ground forces and AAF units in Morocco and Algeria tried to move quickly to eastern Algeria and Tunisia. Algiers was the major port that immediately supported these operations by means of a railroad with limited capacity, a small amount of coastal shipping, and motor transport. Initially, neither ground nor air force units had their full complement of trucks because of shipping space constraints, and French civilian vehicles were requisitioned to help. Eventually this condition was alleviated by convoys bringing 2000 trucks a month plus a special convoy that brought 4500 trucks to Casablanca and Oran in early March. But motor traffic was hampered by road deterioration from heavy use and much one-way movement caused by narrow bridges and roads (Howe, 1957, pp. 293, 499).

The AAF forward deployment also lagged because of inadequate equipment and materials to construct airfields. Airfield construction and maintenance were difficult because most of Tunisia turned into mud during the rainy season (Craven and Cate, 1949, p. 116). When it did not rain, dust created a high demand for air filters. Dust also increased engine wear and oil consumption. Many vehicles assigned to AAF units were pooled to support ground forces. Resupply was meager, including ordnance and spare parts. At no time during the campaign did AAF units have a normal or full complement of ground personnel. As a result, aircraft in-commission rates were poor. For example, B-17s averaged around 50 percent (Craven and Cate, 1949, p. 131). Since the archaic French telephone system was the major means of communication (because radio communication was unreliable), there was little ability to manage logistics support coherently. This communications weakness evoked even greater dismay since it was also the only way of providing early warning of enemy air attacks.

Fighting in Tunisia. General Eisenhower's Command in Tunisia was handicapped by the condition that its American and British air components initially did not talk to each other (or with the ground forces they were supposed to support), nor was there communication with either the Desert Air Force or the Malta-based Air Command. (There were also touchy problems regarding the command of naval forces.) By early February 1943 a new air forces command, under Eisenhower as "Supreme Commander," was established under Tedder's overall command. It consisted of a "Strategic Air Force" commanded by General Spaatz and a "Tactical Air Force" commanded by Coningham, which included components of American units newly arrived in North Africa and much of the established Desert Air Force. The label "Tactical Air Force" was Tedder's choice because of its functional connotation (Tedder, 1966, p. 397) and was apparently the first time it was used.

The combined Axis forces in Tunisia needed a minimum 60,000 tons of supply a month (Howe, 1957, p. 365), and interdiction of the Axis sea line of communication obviously became an important Air Force mission. (Naval surface and submarine forces also participated, but mines constrained their effectiveness.) As an example of changed tactics, medium bomber crews were trained to use modified gunsights to skip-bomb ships from less than 200 feet altitude at high speed, with 500 lb bombs having 4-second delay fuses. Missions were carried out by six bombers, accompanied by a squadron of P-38s providing high cover and spotting ship targets for the bombers below. The squadron-sized escort was necessary for the fighters' protection. These missions were handicapped by lack of information about possible targets. Single reconnaissance flights were unsafe because of enemy fighters and effective enemy radar on both sides of the channel (Craven and Cate, 1949, p. 148). British Coastal Bomber Command Bristol twin-engine Beaufighters were also used as torpedo-bombers in the antishipping mission. By April, Axis shipping losses between Italy and Tunisia rose to 75 percent (Cooper, 1981, p. 217.) Despite additional shipping the Axis obtained from seizing French ports, at no time was the minimal monthly supply objective of 60,000 tons met. From November through April, total tonnage delivered by air and sea was 188,000, which was slightly over half the requirement. During April, tonnage transported by sea was down to 23,000; that by air, 4300 (Howe, 1957, p. 682).

Meanwhile, the Axis forces were being worn down. Although the Luftwaffe adeptly dispersed and shifted ground support aircraft between numerous airfields, or hid them in orchards, its strength in Tunisia fell, and there was less air support for ground troops. Rather abruptly, the interdiction effort and a major Allied ground attack produced a general collapse in the Axis defense, and the enemy forces surrendered.

Sicily and Italy

Allied leaders decided in January 1943 that victory in Tunisia should be followed as quickly as possible by conquest of Sicily to eliminate enemy air bases that could attack merchant shipping in the Sicilian narrows, use Sicily as a base from which to land forces in Italy, knock Italy out of the war, and establish air bases in southern Italy from which to carry out strategic bombing.

Sicily. The prelude to the Sicilian campaign was a concentrated bombing of the islands of Pantelleria and Lampedusa in the narrows between Tunisia and Sicily. Both were well fortified and possessed radars. Pantelleria had an airfield with a 5000 foot runway. Both garrisons succumbed to bombing. An American P-40 fighter group was quickly installed on Pantelleria, which increased Allied ability to maintain air cover in the forthcoming Sicilian landings.

One useful lesson about bombing effects and ordnance selection was that coastal defense guns were not easy to knock out, and the ability to do so was sensitive to local terrain. On the rocky terrain of these islands, high-explosive bombs with quick fuzes dispensing fragments inflicted few casualties on gun crews. Semiarmor-piercing bombs with delayed fuzes, however, caused ground shocks that damaged fire-control equipment and rendered guns ineffective.

The Sicilian landings were preceded by a vigorous bombing effort from June 15 to July 9 against airfields in Sicily, southern Italy, and Sardinia. The ports of Naples, Salerno, Palermo, and the ferry facilities of Messina and Reggio di Calabria astride the strait between Italy and Sicily were also hit. Most effective against dispersed aircraft on airfields were 20 lb fragmentation bombs in 120 lb clusters and 100 lb demolitions, and 500 lb demolitions against hangars and runways. During the early part of the antiairfield operation, most effort was directed to destroying aircraft; as D-day approached more attention was given to runways and facilities. The assault against airfields forced the enemy to move his air units from Sicily to Italy. Nearly 1000 abandoned and destroyed enemy aircraft were counted in

Sicily (Craven and Cate, 1949, pp. 438–440), reflecting the poor logistics systems of the German and Italian air forces.

Italy and Operation Strangle. Soon after the landings in Italy and the capture of Naples, Allied tactical air units moved from North African and Sicilian bases. B-26 units were based in southern Sardinia. Most B-25 and some fighter groups were based on the narrow east coastal plain of Corsica. These locations permitted reserving the Naples port capacity mainly to support the ground forces and allowed tactical aircraft to operate over southern France and northern Italy, as well as most of central Italy and the fighting front. Desert Air Force units, located in the Foggia area served by the Adriatic port of Bari, worked the east side of Italy and provided night fighter and intruder capability from bases in the Naples area. By late November, AAF medium bombers were hitting bridges on the Florence–Rome rail line and the line along the Italian west coast (Headquarters, 12th AAF, February, 1945, p. 21) for the purpose of constraining logistic support of German ground forces.

In Tunisia and Sicily these units mainly bombed area targets, such as airfields and rail yards. In southern Italy, bombing rail yards achieved modest results, but central Italy differed from the south. The main rail yards were in Florence and Rome, and there was concern about possible collateral damage to cultural treasures in these cities (the Rome and Florence rail yards were nevertheless successfully attacked on several occasions by B-26s with no collateral damage). There was also the question of whether, because rail yards could be repaired quickly, bombing them was effective. Bridges and viaducts, which were plentiful in the Italian mountains, seemed to offer better prospects; but these were small targets, and the inaccuracies that could be overlooked in the bombing of area targets would not do. It was obvious that bombing accuracy and tactics had to be improved.

Improved bombing accuracy was achieved by retraining bombardiers and developing new tactics. Some 18 to 24 light and medium bombers at medium altitude (8000 to 12,000 feet) were usually employed on a bridge attack mission. Smaller flights of three, four, or six aircraft dropped bombs upon the release of a leader. The lead bombardier's skill therefore determined the bombing accuracy of all the aircraft dropping off his signal. As illustrated by the example of the 319th Bomb Group (Cory, 1945, p. 49), a program of screening was begun. Extensive training and a practice program were undertaken simultaneously with accurate evaluation of each bombardier's miss-distances on missions, which required photo coverage of strikes. Although cameras and photographers were initially lacking, cameras were obtained by "devious means" and some aerial gunners were trained to use them. It was then possible to identify the more capable bombardiers, who were given additional training to function as leaders. Accuracy and combat effectiveness improved greatly as the record of the 42nd Bomb

Wing (B-26) testified. During August through September 1943, they carried out 31 railroad bridge attacks, dropping a total of 1610 tons of bombs. In ten of these attacks, either one or more spans of a bridge was destroyed or traffic over it was halted for at least 36 hours, for an average bomb expenditure of 161 tons per successful attack. During March through May, the 42d Wing made 151 Operation Strangle rail bridge attacks, of which 77 were successful, for an average expenditure of 59 tons per attack (Headquarters 12th Air Force, 1945, pp. 18–20).

Essential skills for lead bombardiers in combat at medium altitude were, first, to locate the target visually while directing evasive action immediately before initiating the bomb run when approaching the target area, and, next, to "set up" the bomb run, by verbal instructions to the pilot, so as to begin a smooth and level run within 50 to 60 seconds of the bomb-release point, during which the Norden bombsight was engaged to make the precise calculations that determined the exact course and bomb drop-angle. These maneuvers were constrained by the need to maintain a tight flight formation, which required smooth aircraft handling by lead pilots, even when subject to intense flak or fighter attack. Since enemy gunners observed flak bursts and made corrections, a bomb run longer than 50 or 60 seconds presented increasing and unnecessary hazard; shorter runs and intensive evasive action meant sharply reduced accuracy and zero mission effectiveness. Searching for and developing these skills took place entirely in combat theaters, since bombardiers and pilots were not even made aware of their need during training in the United States, at least through 1943. In this case the tactical-technical uncertainty that affected operations sprang from the fact that training commands seemed to have no knowledge about how to bomb from medium altitude under actual combat conditions. Fortunately, the same condition afflicted enemy air forces throughout the entire war.

Although 12th Air Force medium bombers carried the main load of Operation Strangle, fighter-bombers (particularly recently arrived P-47s), elements of the British Coastal Bomber Command, and U.S. 15th Air Force heavy bombers also took part. The P-47s, armed with eight 0.50 inch machine guns, were initially charged with cutting tracks and shooting up trains and motor trucks. However, its 2000 horsepower R-2800 engine enabled it to haul two 1000 lb bombs, which made the P-47 the champion bridge buster, obtaining one hit per 19 sorties compared with one in 31 for medium bombers (Craven and Cate, 1951, p. 378). Here is an example of tactical-technical uncertainty that provides the pleasant surprise of performing a new mission brilliantly, since the P-47 was designed to be a high flyer escort for heavy bombers. Undertaking such a new mission, however, creates a different support workload than planned.

TACTICAL AIRPOWER IN NORTHWEST EUROPE

The Logistics Buildup in Britain and Host Nation Support

Although the tactical 9th Air Force was reassigned from North Africa to Britain in October 1943, its initial assets and organization of its logistic and support system came from the 8th Air Force, which had been in Britain since February 1942. The 8th's establishment also provided many of the combat units initially deployed to Africa and often was an immediate source of logistics support for the air forces in the Mediterranean. How its support capability was developed was important to Britain-based AAF tactical and strategic air forces.

The buildup of American air and ground forces in Britain (Operation Bolero) was determined by the logistics constraints the British-American coalition faced before the Normandy invasion. During the first year or so of its operational status from August 1942, 8th Air Force's buildup was greatly helped by Britain's industrialization and the RAF's maturity. The 8th availed itself of RAF intelligence, weather, and communications services (Craven and Cate, 1948, pp. 624–626). Since the RAF had operated a small number of American aircraft, such as the B-17 and B-24, during 1941 (Craven and Cate, 1948, pp. 600–603), Britain contained a core of civilian workers with maintenance and supply management skills. During the Bolero buildup of 1942–43 the severe merchant shipping shortage dominating Allied strategy caused numerous supply shortages for arriving American units. Most of these were made good by the RAF, and included flying clothes, tools, vehicles, dinghies, radio and electrical equipment, and many other items (Craven and Cate, 1948, pp. 650–651).

A major airfield construction program had to be undertaken for which the British furnished almost all of the materials and most of the effort (Ruppenthal, 1953, pp. 109–110). Of 129 airfields required by the Americans, the British provided 91, and American aviation engineers constructed 38 (Beck et al., 1984, pp. 52–53). From June 1942 to July 1943, the British provided U.S. forces in the United Kingdom half or more of their quartermaster, engineer, Air Corps, medical, and chemical warfare service supplies (Craven and Cate, 1949, p. 611).

To implement logistics support the AAF created the Air Service Command in the United States in October 1941. In Britain this concept was somewhat at odds with the U.S. Army's Services of Supply, European Theater of Operations, which was copied from its World War I counterpart and was motivated in both instances to control the diverse Army technical services (e.g., Quartermaster, Ordnance, Signal) that had logistics functions. (The Army Air Corps, which was the major component of the AAF, also had a technical service responsibility for aviation materiel.) The AAF was part of the Army and looked to it for common item support, but it also got much support from the British. For example, the British dispensed all the petroleum, oil, and lubricants (POL) in Britain, even though most of it came from the United States under lend-lease (Craven and Cate, 1949, pp. 602, 617).

The VIII Air Force Service Command's function was to provide supply and maintenance services beyond those a combat unit could provide for itself. Under the Army's "four-echelon" structure, this was the third and fourth echelon support performed by service and air depot groups, respectively. A service group, which provided roughly what is today called "intermediate repair," was designed to do third echelon maintenance for two combat groups, possibly with the squadrons dispersed. However, in Europe an entire combat group and sometimes two groups usually operated at a single airfield. Accordingly, air service group elements were collocated with an air combat group. Although it was originally contemplated that the Air Service Command was to control both the air service (third echelon) and depot groups (fourth echelon) and did so in the United States, it quickly became the practice in overseas theaters for the overseas air forces to have the air service groups under the command of the combat units they were designated to support. As a result, the first three *echelons of maintenance* blended together.

The air depot group performed fourth echelon maintenance and supply, which is roughly comparable to what Air Logistics Centers do today. Its maintenance work required machines and layouts that were not readily truck-mobile. The general plan was for one air depot group to support two air service groups and four combat groups, roughly one depot group per combat wing. In Britain (and Australia) there were also very large installations, like Burtonwood near Liverpool, that did highly specialized work on a large scale, such as making major modifications.

Through most of 1943 the 8th Air Force's logistics system was restrained by the shipping shortage, and it functioned as a supply source for the AAF units in North Africa. Shortages of spare parts for such items as superchargers, bombsights, and trucks (which themselves were in short supply) were frequent. A truck shortage adversely affected distribution, although it was mitigated by Britain's fine transportation system. During early 1943 spare parts for 50-caliber aircraft machine guns became so scarce that the total supply was pooled in a single depot with telephone requests being doled out by special truck delivery (Craven and Cate, 1949, p. 621). Here is an example of the kind of central visibility and management control that implementing the LOGCONOPS would require.

Maintenance presented many special problems, including those caused by spare parts shortages. As operations got underway, workloads turned out to be greater than expected because of battle damage resulting from vigorous German resistance. Combat experience also induced technical changes and modifications. At this stage the depot system was immature because of inexperienced personnel, equipment shortages, and rapid growth. During the five-month period ending March 31, 1943, over 20 percent of the aircraft dispatched on 34 missions, or 588 aircraft, received battle damage. This workload and related spares shortages created the predictable complaints between the combat units and the service and depot units. Nearly 90 percent of aircraft were repaired at the bases because combat units did not want to relinquish aircraft to the depots where it seemed to take too long to make repairs. Lack of spares induced much cannibalization and increased workloads at bases. This problem was considerably relieved by the advent of mobile repair units operated by the Service Command depots and consisting of 16 or so specialists with tools and supplies in a truck and trailer. Their job was to make sufficient repairs on a crash-landed aircraft that it could be flown to a depot rather than be disassembled and trucked. These units proved also to be very helpful in many other ways at the bases they visited. After experience with the first such unit, 50 additional ones were created, to repair more aircraft than could the depots from which they came (Craven and Cate, 1949, p. 625). Here is an example of an ad hoc organizational change responding to an obvious need.

A major concern of the cross-Channel invasion planners was that tactical air forces should be ground-mobile and how to implement the capability. After the 9th Air Force was established in Britain, the 8th Air Force handed over its four medium bombardment and three troop carrier groups, plus service support units. The 9th's remaining units were to arrive from the United States. By the spring of 1944, it had 12 air depot groups paired into six tactical air depots. Each pair consisted of an experienced and an inexperienced group. The reason for pairing these was to provide continuity of service when the time came to move to the continent. Service groups, which were stationed with tactical units, were split into two equal teams, designated A and B, totaling about 500 men each. This arrangement was to facilitate ground mobility whereby one team maintained service when the other moved to a forward base. The 9th's Service Command also eventually acquired two truck regiments and an engineer command consisting of 16 aviation engineer battalions (Craven and Cate, 1951, pp. 115–119).

Logistic Support After the Invasion

It was intended to move the 9th Air Force to the continent as ground operations progressed and airfields became available (Craven and Cate, 1951, 547–548). Movement of combat groups was accomplished by one of the air base group teams closely following aviation engineer units preparing an airstrip and setting up facilities to receive a unit's flight echelon. The air base group team would also service aircraft operations until the unit's ground echelon arrived from England, at which time it would move on to repeat the cycle at another airstrip. By the end of July some 19 fighter groups had arrived in France (Craven and Cate, 1951, p. 550), as well as the headquarters of the two tactical air commands. The IX Air Force Bomber command followed during August and September, and by the end of September most of the IX Air Force Service Command was in France as well.

The notable feature of the 9th's operations on the continent was its organization and use of fighter-bombers to support ground operations and an unexpected absence of enemy air opposition. Before the invasion fighter-bombers were divided into the IX and XIX Tactical Air Commands (TACs) to support, respectively, the U.S. 1st and 3d Armies. On September 1, the XXIX TAC was established to support the newly created U.S. 9th Army. The size of these tactical commands varied as combat groups were shifted between them to correspond to the needs of the supported armies.

When American ground forces broke out of the Normandy beachhead at St.-Lô and began their sweep across France at the end of July, fighter-bomber units kept pace. Engineer and transportation resources limited airfield availability, however. Because fighter-bombers were used almost solely for bombing, it became desirable to lengthen runways from 3600 to 5000 feet so the aircraft could better handle bomb loads. From Normandy, tactical groups moved to clusters of airfields, first, in the Chartres-LeMans area and then to the Paris area in September. This clustering of airfields—usually four or five in a "clutch"—increased logistics efficiency by permitting easier communication and transportation between bases to facilitate mutual support. In Northwest Europe, IX Engineer Command and its 17,000 troops built or rehabilitated 241 airfields. By the end of the war, the engineers employed some 10,000 French and Belgian civilians in construction and maintenance tasks (Craven and Cate, 1951, pp. 562–573). Considerable host nation support also resulted from using French and Belgian manufacturing firms and machine shops to manufacture and repair many items and effectively providing compensation for these efforts in the form of badly needed assistance to the war-battered civilian sectors of those countries.

Operations on the continent presented greater maintenance and supply burdens, as well as different supply and maintenance demands. Higher aircraft losses resulted from more intensive aircraft use. Fighters averaged three to four sorties per day. Poor runways suffered from dust or mud, with dust increasing engine wear and oil consumption and mud befouling the aircraft's underside, which increased drag. Rough airfields also increased crackups on takeoff with full bomb loads. High maintenance quality levels were difficult to meet in field conditions with no hangars and other permanent facilities. During most of the campaign, fighter groups were under authorized strength (Craven and Cate, 1951, p. 579).

Mobile service teams from the air depot groups helped considerably to alleviate these difficult conditions. Air depots themselves shifted workloads to aircraft modification, manufacturing critically short spare parts, and engine overhaul. This reassignment of air depot resources and the simultaneous "clutching" of airfields provides an example of restructuring of the support system in response to combat needs.

Supply difficulties were of two kinds. Particular spare parts—dust filters, wings, propeller blades, and so on—were often in short supply because of either increased demand or inability of the supply system to keep up with the movement of the tactical units. There were also ordnance shortages, both of preferred kinds and of total supply. This condition followed from increased activity and sortie rates. Fighter-bombers were used more intensively for bombing in the absence of enemy air opposition, and the excellent ground mobility made possible by ample aviation engineer support made higher than expected sortie rates feasible. Local ordnance shortages occurred frequently because of distribution problems within the theater that were compounded by the overland transportation shortages. At certain times there were also fuel shortages.

OVERVIEW: COUPLING OF LOGISTICS AND OPERATIONS

The dispatch of AAF units to the Western Desert and North Africa followed from strategic decisions that provided little logistics planning lead time. The necessity to change tactics, and numerous supply and transportation constraints, complicated the logistic support of tactical airpower in Europe. The major tactical changes for medium bombers were their use at medium rather than low altitudes against ground targets and the use of skip bombing against Axis shipping in the Mediterranean. In the Western Desert the British initially converted its fighters that were least effective in the air superiority mission to fighter-bombers. The AAF also quickly adopted this shift, and it was greatly enhanced by adapting the powerful P-47 to the mission. The combination of the fighter-bomber and ground mobility afforded by rapid construction or repair of airfields and truck transportation was the major tactical airpower innovation of the war. A responsive and adaptive logistic system was responsible for its implementation.

The most notable logistic management and organizational initiatives displayed were:

- The British integration of damaged fighter repair with manufacturing of new aircraft and the employment of many small business firms, with the Ministry of

Aircraft Production simultaneously controlling spare parts inventories possessed by tactical squadrons during the Battle of Britain, an example of extreme centralized management and off-base support.

- The RAF creation of a separate Maintenance and Supply Command in the Middle East, to include depot engine repair and the use of local civilian resources, under the command of an officer who reported directly to the theater air commander. Churchill's prodding initiated this organizational shift , and the Chief of Air Staff responded to the Middle East Air Commander's request.
- The use of host nation support in the Western Desert, North Africa, Britain, and on the Continent helped directly to meet extraordinary and unexpected workloads, helped indirectly by freeing military maintenance resources to concentrate on highly specialized needs, and allowed depots to create additional mobile repair teams.
- In Britain and Northwest Europe the AAF logistic organization was modified in several important ways. An expanded number of mobile repair teams was organized and dispatched from depots to air bases in Britain during late 1943. Britain-based tactical air depot groups were organized into pairs during early 1944 to facilitate ground movement whereby one group provided support while the other moved as tactical units to France. This use of pairs was continued in France as air units moved to keep up with advancing ground forces.
- TAC airfields were clustered in France for mutual logistic support.

III. TACTICAL AIR FORCES AGAINST JAPAN

American tactical air power was used against Japan in two strategies. One was in the Southwest Pacific, beginning at Guadalcanal in the Solomon Island chain and the Papuan Peninsula of New Guinea, to block enemy advances and to initiate an offensive to the northwest along the East Indian island chain. The other was across the Central Pacific. What follows describes the distinctive logistics problems these strategies presented and how they were resolved.

GUADALCANAL AND PAPUA

With the startling Japanese conquest of Southeast Asia, the Allies were constrained to deploy forces to the Southwest Pacific and Australia. No Allied military planners anticipated such a contingency because none imagined that the British bastion at Singapore would fall. By May 1942 two AAF B-17 heavy bombardment groups arrived in Australia and absorbed remnants of the 7th Bombardment Group from the Philippines by way of Java, two medium bomb groups (one B-26 and one B-25), one light bomb group (A-20s), and remnants of a light bomb group that escaped from the Philippines. Three "pursuit" groups (the designation for fighters at that time) had also arrived, possessing 33 P-39s, 92 P-40s, and 52 P-400s. The P-400 was an inferior export version of the P-39, equipped with a 20mm cannon in its propeller shaft instead of the 37mm cannon of the P-39. Many of these aircraft were originally shipped to the Dutch and Australians or intended for the Philippines after war broke out but were redirected to Australia with the Allied collapses in those places. Only one of the pursuit groups was ready for combat. When one group arrived in Australia, 89 of its 105 pilots had no flying time in fighter aircraft! Some crews that fought in Java were demoralized from the experience (Craven and Cate, 1948, pp. 411–412). The ground echelons of these units and their equipment were skimpy and confused because of the shipping situation. Some units had airplanes but no ground echelon; others had their ground echelon but no airplanes. The published histories do not record how this mess was straightened out, but the distances from Hawaii and the United States obviously dictated a local reshuffling of assets and personnel.

By mid-February Rabaul-based Japanese bombers were hitting Port Moresby on the south coast of New Guinea opposite Australia. Darwin, Australia, was raided from bases in the East Indies. American fighters and light and medium bombers moved to Darwin to join Royal Australian Air Force elements. Heavy bombers moved to Townsville at the northeast end of Australia, almost due south of Port Moresby and Rabaul; some fighters moved to Cape

York, a short distance from the bottom of New Guinea. These places were primitive and undeveloped.

These ill-prepared units had to turn to Australian host nation support for service and administration. However, Australia, northern Australia in particular, was not well developed. The large area made the squadron rather than the group the most important tactical unit. Tactical control of the force had to be split between Darwin and Townsville. Forward air base groups were established at Darwin, Townsville, and other locations further south. Each was obliged to service all types of aircraft. Help was obtained from Australian agencies, including the country's domestic airline. Logistics support was constrained by the fact that supplies, including aviation gas, arrived at Melbourne at the south of the continent, to be shipped by a rail system with multiple gauges and, in the case of fuel, transshipped by water in metal drums to extreme northern bases (Craven and Cate, 1948, pp. 421–423).

The AAF initially established a large depot at Tocumwal, about 100 miles north of Melbourne, which was 800 miles south of MacArthur's headquarters at Brisbane. Brisbane, in turn, was another 1500 or more miles from the northern tactical air bases in the vicinity of Townsville, Darwin, and New Guinea. Before August 1942 more aircraft than not at the northern bases were out of commission for lack of parts—for example, 18 out of 32 B-17s at one base for lack of engines and tail wheels. One reason for this condition was that a requisition from units went through three headquarters before arriving at the Tocumwal depot, at which point it was often returned for not being properly filled out (Kenney, 1987, pp. 42–43). When General George C. Kenney arrived in August to command the the air forces in MacArthur's Command, he promptly ordered logistics managers to expedite filling requests from the field, whether they be written, oral, or telephoned. He then reorganized the logistics system by thinning headquarters staffs and initiated movement of the Tocumwal depot first to Brisbane and eventually to Townsville, which became the main supply and overhaul facility for Australia (Kenney, 1987, pp. 77–80).

In May 1942 the Japanese established a seaplane base on Tulagi Island in the Solomons chain about 40 miles north of Guadalcanal. By the end of the first week of July the Japanese were observed building an airstrip on the northern coastal plain of Guadalcanal. Meanwhile, the Allies had planned to seize Tulagi during early August. However, it was obvious that Guadalcanal would have to be taken as well.

Guadalcanal

The only available troops to take Guadalcanal were two regiments of the First Marine Division that had arrived in New Zealand during June and early July (Hough, n.d., pp. 239–

240). A naval task force of three carriers with 250 aircraft, eight cruisers (three Australian and five U.S.), 15 destroyers, and two new battleships was organized to support and cover amphibious landings at Tulagi and Guadalcanal on August 7. Two Marine air squadrons, 95 Army planes, and 30 planes of the Royal New Zealand Air Force were also available to the Navy command. These latter aircraft were based beyond range of the target area, however, and would remain so until construction of an airfield was completed on the island of Espiritu Santo, in the New Hebrides islands 500 miles southeast of Guadalcanal. A Navy construction battalion (Seabees) and the engineers of the Army's 25th Infantry Division worked to complete an airstrip that would soon be ready.

One week before the August 7 landings a squadron of B-17s based at Espiritu and Efate (200 miles south of Espiritu) began attacking suspected enemy positions on the target islands. When equipped with bomb bay fuel tanks they carried out long photographic reconnaissance missions for which the Navy provided the cameras, and the Marines provided the photographers (Craven and Cate, 1950, pp. 28–29). The squadron's aircraft were divided between these two fields because taxiways and dispersal areas were lacking. For bombing operations, the airplanes based at Efate refueled at Espiritu to deliver a full bomb load. B-26s and New Zealand Hudsons based at New Caledonia were also used for reconnaissance. This use of Army aircraft under Navy operational control for search and reconnaissance continued throughout the campaign because the Navy's patrol aircraft were slow and vulnerable to enemy fighters. The B-17s turned out to have a comparative advantage for performing this valuable mission because they seemed unable to hit ships. Here is another example of a system that does not excel at what it was originally designed to do but proves valuable for some other mission.

The August 7 landing of some 10,000 marines on Guadalcanal and Tulagi was successful, and the enemy construction personnel on Guadalcanal vanished into the jungle. This initial success was quickly counterbalanced by Japanese reaction on the night of August 8–9 when seven Japanese cruisers and one destroyer encountered an Allied force of eight destroyers and eight cruisers (three of which were Australian) in the Battle of Savo Island. Three U.S. heavy cruisers were sunk, and another cruiser and a destroyer were damaged. A burning Australian heavy cruiser had to be sunk the following day.

On the previous day, U.S. carriers departed the area to avoid risk. It therefore became essential to quickly complete the airfield to receive friendly aircraft. On August 9, the transports departed because of the absence of carrier air cover, having unloaded only half of the Marines' supplies and none of their heavy construction equipment. During the night of the 15th, however, four destroyer-transports arrived with drums of aviation gasoline and lubricants, 282 bombs, belted ammunition, spares and tools, and 123 Navy construction personnel to assist division engineers to ready the airstrip and to serve as ground crews for the airplanes that were to arrive in a few days. Throughout the period of runway construction, work was interrupted by air attacks, some of which cratered the runway.

On August 20 an escort carrier launched 19 F4Fs (the top-line Navy fighter at that time) and 12 Douglas scout bombers (SBDs) of a Marine Corps Air Group. Two days later the first five Army P-400s landed, to be joined by nine more five days later. On August 24, 11 Navy dive bombers from the damaged *Enterprise* landed (Hough, n.d., p. 280). The ad hoc collection was dubbed the "Cactus Air Force" after the codename of the Guadalcanal operation, and the air field was christened "Henderson."

The Japanese moved quickly to land troops to recapture the airfield and destroy the bridgehead. The primary mission of friendly air forces was to locate and interdict ships attempting to land and support enemy troops. This effort caused the Japanese to use fast combat ships, usually destroyers, to transport troops and supplies from Rabaul to Guadalcanal, timing the trip to minimize daytime exposure to unfriendly aircraft. After unloading their cargo during the small hours of the morning, these ships would often swing by Henderson Field to bombard it before returning to Rabaul. Occasionally the air field received intense naval gunfire from heavy ships, in one instance over 1000 16-inch shells.

Henderson was continually attacked by airplanes based in Rabaul, some 600 miles northwest. The defenders usually had at least two hours warning from Australian and native "coast watchers," however, which provided ample time for the F4Fs to reach a high enough altitude to be able to bounce the attackers from above. Although enemy bombing was usually inaccurate, attacks were frequent enough to inflict damage. B-17s based at Espiritu supported the defenders. Although they proved ineffective in interdicting enemy ships, they were invaluable for reconnaissance because of their long range (when using bomb-bay tanks) and ability to defend themselves from interceptors. But the longer flying hours resulted in greater engine wear. On occasion, when fuel was available, B-17s staged through Henderson Field to bomb Rabaul, which was also frequently bombed by General Kenney's bombers.

Army P-400 fighters were incapable of intercepting and engaging high-flying Japanese bombers and could not handle enemy fighters. However, their heavy armament made them a good close support aircraft, often dropping bombs and Navy depth charges on enemy troops hiding in ravines. Many of these were later replaced by better-armed P-39s, which had a higher service ceiling for use as interceptors.

Conditions on the island were miserable. "Henderson Field was a bowl of black dust which fouled airplane engines or . . . a quagmire of black mud" (Sherrod, 1952, p. 82). When the field was muddy, Navy fighters could not take off, although the Army P-400s could, which was of no help in defense against air attacks. Initially there were no bomb hoists for the SBDs. Aircraft refueling was by hand pumps from 55-gallon drums, first directly from the drums and later from tank trucks filled from the drums. Conditions were similar for the B-17s operating from Espiritu where drummed fuel was delivered over the side from freighters in the channel to be towed ashore in a net from where they were manhandled (Craven and Cate, 1950, pp. 37–38). On Henderson Field, the early SBDs were equipped with a hard-rubber tail-wheel satisfactory for carrier decks, which "chewed up the runway like a plowshare" (Sherrod, 1952, p. 82).

The Guadalcanal Campaign vividly illustrated the unexpected ways aircraft might be used that create new and different logistics demands.

- The primitive conditions and incessant enemy attacks of the airfield presented the ground echelon and the engineers a continual challenge. An inferior export version of the least-preferred Army fighter—the P-400—provided close air support for Marines, in some instances using Navy depth bombs for ordnance. Army B-17s performed reconnaissance that Navy patrol planes could not handle because they could not consistently hit small targets like ships from high altitudes, the mission the aircraft and its Norden bombsight were optimized to do. Increased and unplanned-for engine wear resulted from the greater flying hours that the reconnaissance missions required. Aircraft from three sunk or damaged carriers reenforced the Cactus Air Force during the campaign and operated from Henderson Field for varying periods.
- The battle illustrated the problems—especially for fuel, munitions, and spare parts—due to remoteness and distance from higher echelon support.

The Papuan Campaign and the Battle of the Bismarck Sea

This campaign roughly coincided with that of Guadalcanal, beginning on July 21, 1942 with a Japanese regimental landing at Buna on the northern side of the Papuan Peninsula. As with Guadalcanal, the Japanese effort was staged and supported from Rabaul. Allied resistance was supported from Australia under General MacArthur's command. (On September 3, AAF elements in his command were organized into the 5th Air Force commanded by General Kenney, who also commanded the Allied Air Forces including elements of the Royal Australian Air Force and the U.S. 5th Air Force). As of August, the 5th Air Force had 258 fighters, 82 medium bombers, 36 light bombers, and 74 heavy bombers. That its fighters were all P-40s and P-39s caused concern about their poor service ceilings relative to the Japanese Zero (Craven and Cate, 1950, p. 101).

By July 1942 the 5th Air Force's operations were supported by two air depot groups and five air service groups. Three of the latter were located in New Guinea. The Townsville installation, 600 miles from Port Moresby, was being built up to be a major air depot. An Air Depot Group at Brisbane (which later moved north) undertook aircraft modifications to implement experimental tactical changes. Among these was modification of the A-20 light bomber to add four 0.5 caliber machine guns to its nose armament, and the addition of bomb-bay tanks to increase range. Low altitude bomb release was restricted because bombs could not be dropped without endangering the airplane. This problem was met by attaching a small parachute to a 23-lb fragmentation bomb with an instantaneous fuze. Forty or more of these could be carried in a honeycomb-like rack, which was designed and fabricated in the Command, and could be scattered over an airfield (Craven and Cate, 1950, p. 106).

Extensive experiments were undertaken at General Kenney's direction with ordnance leading to producing air bursts with demolition bombs by means of long-delayed fuzes that were activated with bomb-release and rendering demolition bombs more lethal against personnel and parked aircraft by wrapping heavy wire around them (Kenney, 1987, pp. 106–108). The incentive to attain air bursts came from the fact the Japanese often parked aircraft in revetments, which provided protection against nearby ground bursts. Since the bomb's fuze-timing was preset, its release had to be made at a precise altitude above the target if an effective air burst was to be accomplished, requiring exact barometric pressure information on the ground in the target area. This information was obtained by one aircraft flying at sea level and radioing the information to the bombers.

At that time a squadron seldom had in commission the nine airplanes that AAF doctrine called for to achieve a desired bombing pattern. Moreover, random cloud formations at low altitudes made high-altitude bombing difficult. Since the principal interdiction target was shipping, hits from high altitude were infrequent even without visibility problems, and attention was directed to bombing at "masthead" level. Experiments were undertaken with skip-bombing and direct aiming at the ship, which also required delayed fuzing of the bomb, determination of how long the delay should be, and how to accomplish it. Modification of a standard U.S. tail fuze with a new detonator housing and RAAF detonators served this end (Craven and Cate, 1950, p. 107).

Masthead-level bombing by B-25Cs allowed dispensing with a bombardier. Instead, the pilot or copilot released bombs by means of an improvised bombsight. Dispensing with a bombardier permitted installing four 0.5-inch machine guns in the nose. Four additional guns were added to the sides in blisters (Craven and Cate, 1950, p. 141). These modifications plus two guns in the top turret provided a fierce air-defense suppression capability when approaching a target. These changes paid off in the Battle of the Bismarck Sea in March 1943 in which the AAF and RAAF units destroyed seven Japanese transports carrying 10,000 troops to reenforce the Lae garrison on the north-central New Guinea coast.

INNOVATION OF THE NAVY'S FAST CARRIER TASK FORCE

The airplane revolutionized naval surface warfare by replacing the big-gun, heavily armored capital ship. This shift was a wartime innovation that combined several technical developments and an organizational change that provided logistic support. The essence of an innovation rather than a technical invention or improvement is that an innovation is a more subtle and more profound transformation, usually requiring combining technical developments with new procedures (new tactics in the military case) and organizational if not social changes. The fast carrier task force was a military innovation of the first rank that had a logistics counterpart.

The Innovation

Before the war, the idea that carrier forces conduct deep-water operations independently of battle lines composed of big-gun ships was not part of any navy's doctrine. Carriers were highly vulnerable, as the Battle of Midway demonstrated. Navy airmen, however, advanced the idea that if task forces were composed of several carriers, they could protect each other. Fast speed and mobility would reduce the likelihood of being located and fixed by the enemy. Radar (one recent invention) was used to maintain defensive formations in night and foul weather. Radar and VHF radio (another recent invention) that permitted multiple channels provided, respectively, early warning of enemy aircraft and control of defending combat air patrols. Beefed up antiaircraft defenses, mainly European-designed Bofors and Oerlikon quick-firing guns, and the proximity fuse (another recent invention) adapted to 5-inch guns improved air defenses. Fast new battleships bristling with antiaircraft guns and new light cruisers whose sole armament was antiaircraft guns bolstered air defense.[1] Mobile sea trains consisting of oilers and ammunition ships, escort carriers bearing replacement aircraft, hospital ships, and ships providing other services permitted replenishment of combat ships at sea. They also made temporary repairs and provided personnel services while a force rested at sparse forward fleet anchorages, such as Ulithi, which eliminated time-consuming trips to and from Pearl Harbor.

[1]For additional discussion of these changes, see Reynolds, 1968, pp. 22–78.

Table 1 describes the combat ship composition of carrier task forces. The operations through August 1943 were either hit-and-run raids or reactions to enemy operations and were of small scale because only two or three fleet carriers were available during that period. By the summer of 1943 a large number of newly commissioned *Essex* class fleet carriers and fast light carriers built up from cruiser hulls became available. How to use them had been the object of considerable thought and debate. The large task force, composed of several task groups that would directly challenge enemy land-based aircraft while supporting an amphibious operation, was first undertaken as an experiment in the Gilberts Island campaign. The ability of the force to stand up to and defeat enemy air forces exceeded expectations.

Table 1

Combat Ships in Fast Carrier Force on First Day of Selected Actions or Campaigns in World War II

			Ships in Force						
		Task	Carriers			Support Ships			
Date	Operation	Groups	CV	CVL	Total	BB	CA	CL	DD
1942									
1 Feb	Marshalls raid	2	2	0	2	0	5	0	10
10 Mar	Lae-Salamaua	1	2	0	2	0	7	0	14
2 May	Coral Sea	1	2	0	2	0	4	4	10
4 June	Battle of Midway	2	3	0	3	0	7	1	14
7 Aug	Guadalcanal landing	1	3	0	3	1	5	1	15
26 Oct	Battle of Santa Cruz	2	2	0	2	1	3	3	14
1943									
31 Aug	Marcus Island raid	1	2	1	3	1	0	1	10
19 Nov	Gilberts campaign	4	6	5	11	6	3	3	21
1944									
30 Jan	Marshalls campaign	4	6	6	12	8	3	3	35
30 Mar	W. Caroline raid	3	5	6	11	6	3	3	35
11 June	Marianas campaign	4	7	8	15	7	4	17	60
9 Sept	Palau-Morotai	4	8	8	16	6	4	8	60
10 Oct	Leyte campaign	4	9	8	17	6	4	10	58
1945									
3 Jan	Lingayen campaign	4	8	5	13	6	3	10	52
16 Feb	Iwo Jima campaign	4	11	5	16	9	5	10	74
18 Mar	Okinawa campaign	4	10	6	16	10	3	11	64
10 July	Assault on Japan	3	8	6	14	9	2	14	60

SOURCE: Weapon System Evaluation Group, 1951, Table II; Coral Sea data from Bradley, 1984, p. 272.

NOTE: CV=fleet carrier; CVL=light carrier; BB=battleship; CA=heavy cruiser; CL=light cruiser; DD=destroyer.

Logistics Support

The logistics support necessary to operate the 1943–1945 task forces was made possible by the Navy's concept of "Service Squadrons," which were administrative subdivisions of the "Service Force." At the height of its activity Service Squadron Ten controlled 609 vessels, from floating drydocks capable of holding a battleship, to barges. It operated at advanced bases and Pearl Harbor, where its ships and barges distributed fuel and supplies. At advanced bases, as in the South Pacific, its specialized ships rendered many other services that would ordinarily be performed in permanent land-based docks and depots. (For a detailed description of these organizations and their operation, see Carter, 1952.)

For any given task force, Squadron Ten provided a mobile support group. Table 2 presents an example for Task Force 58 during the Okinawa campaign. Groups like these made the fast carrier task force feasible. They had two important resource management implications. They reduced the need for constructing temporary shore facilities, and they enabled the combat elements to remain operating at sea for extended periods, to increase the available carrier days. For example, various task forces were able to remain 77, 62, and 47 days off Okinawa (Weapon System Evaluation Group, 1951, p. 30). The logistic innovation greatly extended the time that combat ships could remain on station and increased the fleet's effective combat strength correspondingly, accomplishing a complete linkage between operations and logistics.

Table 2

Composition of Squadron 10 Support of Navy Task Force 58, Okinawa Campaign, 1945

Ship	Number
Merchant tankers	12
Gasoline tankers	6
Ammunition ships	8
Fleet tugs	7
Hospital ship	1
Store ships	6
Destroyer tenders	3
Barrack ships	3
Total	46

SOURCE: Weapon System Evaluation Group, 1951, p. 30

Operations and Demand Shifts

Carrier operations also produced an unforeseen pattern of logisitics support requirements for munitions and aircraft maintenance. Tables 3 and 4 provide ordnance use information. The decline in the use of 1000- and 2000-lb bombs after 1942–43 reflects the sharp decline of enemy ships as targets, and the increase in 100- and 500-lb bombs, napalm, and fragmentation bombs reflects a shift in both the aircraft mix toward fighters and attacks against land targets. The introduction of aircraft-launched rockets was well-received by the carrier forces. Against ship targets, eight 5-inch rockets launched by a fighter had the hitting power of a destroyer's salvo. Table 4 shows this sharp increase in rocket expenditure from 1944 to 1945.

For some purposes operations can be categorized in two phases: before and after Japanese suicide attacks. Fleet combat air patrols for protection against such attacks motivated an increase in the number of fighters in an air group at the expense of bombers. This shift did not adversely affect attack bombing capability, however, because higher performance fighters—the F6F and F4U, like the Army's P-47, were powered by the 2000 horsepower R-2800 engine—functioned effectively as fighter-bombers, and fighter-launched

Table 3

Annual Ordnance Expenditures by Carrier-Based Aircraft, By Type of Ordnance, 1942–1945

Type	Tonnage				Percentage of Total[a]		
	1942	1943	1944	945	1942–43	1944	1945
100-lb GP	40	115	2,036	3,598	6.5	9.7	16.7
250-lb GP	0	0	1,281	927	0.0	6.1	4.3
500-lb GP	192	639	7,914	12,878	34.9	37.6	59.6
1000-lb GP	279	426	3,944	1,336	29.6	18.8	6.2
2000-lb GP	0	223	1,119	558	9.4	5.3	2.6
500-lb SAP	0	0	624	160	0.0	3.0	0.7
1000-lb SAP	0	113	1,401	209	4.8	6.6	1.0
Napalm (Tank)	0	0	118	560	0.0	0.6	2.6
Armor-Piercing	0	10	264	29	0.4	1.3	0.1
Incendiary	2	26	480	68	1.2	2.3	0.3
Fragmentation	8	2	335	957	0.4	1.6	4.4
Depth Bombs	8	50	668	36	2.4	3.2	0.2
Torpedos	131	116	772	292	10.4	3.7	1.3
Mines	0	0	50	0	0.0	0.2	0.0
Unknown[a]	52	0	46	0	—	—	—
Total	712	1,720	21,052	21,052	100.0	100.0	100.0

SOURCE: Weapon System Evaluation Group, 1951, p. 60.
NOTE: GP=general purpose; SAP=semi-armor-piercing.
[a]Percentages are based on totals of ordnance of known types only.

Table 4

Shift of Ordnance Expenditure by Carrier Aircraft, 1944–1945

Year	Bombs (tons)		Rockets (number)	
	Fighters	Bombers	Fighters	Bombers
1944	1,864	17,146	14,584	3,856
1945	4,313	12,171	66,825	9,799

SOURCE: Weapon System Evaluation Group, 1951, p. 59.

rockets could be substituted for bombs as well. Table 5 shows this shift. Table 6 describes carrier force aircraft activity rates by periods. The large difference between "flights" and "action sorties" reflects the fact that an "action sortie" is a flight in which there is contact with the enemy or over enemy territory. Apart from flights for administrative and training purposes, many carrier flights were patrols or searches in which no enemy contact took place.

Summary

The innovation of the fast carrier task force required an entirely new logistic support concept. It also created an entirely different set of aircraft missions and demands for logistics services. The enemy's reaction of suicide air attacks to these highly successful

Table 5

Fighter and Bomber Aircraft Mix of U.S. Navy Fleet Carriers, 1942–1945

Date	Fighters	Bombers
February 1942	18	54
November 1943	36	54
October 1944	55	42
April 1945	73	30

SOURCE: Weapon System Evaluation Group, 1951, p. 12

Table 6

Total and Average Flights and Sorties Per Aircraft from Carriers, 1942–1945

Period	Total Monthly Flights		Monthly Action Sorties	
	Number	Average	Number	Average
1942–43	N/A	N/A	7,381	N/A
1944	137,978	13.8	58,064	5.8
1945	140,447	16.0	52,283	6.2

SOURCE: Weapon System Evaluation Group, 1951, Table IV.

operations evoked a major shift in the carrier air group mix from bombers toward fighters. All these changes created major shifts in the demand for ordnance, part of which was met by the availability of newly developed air-launched rockets.

OVERVIEW: COUPLING OF LOGISTICS AND OPERATIONS

The operations in the South and Southwest Pacific illustrate the combined effects of having to set up business in places that no prewar planners anticipated. Severe distance and physical obstacles resulted in many aircraft types being used in ways that designers and planners did not expect—e.g., carrier aircraft operating from a crude air base. It is difficult to imagine how any sophisticated logistics model (had it existed in the prewar period) fed by peacetime flying data could have helped planners to estimate spare parts consumption and support workloads for these events. An important requirement that was entirely overlooked by prewar planners was the necessity for Army and Marine Corps combat engineers to prepare and maintain air fields.

- Local initiatives were necessary to meet unfolding needs. These ranged from using combat engineers from Marine Corps and Army divisions to prepare air fields, to *the Navy providing* much of the logistics support for AAF units operating in the Guadalcanal and adjacent area, and to General Kenney's movement of the AAF Australia depot system as close to the combat area as possible.
- The great distance from the United States and the prompt recognition that better ways had to be found to attack enemy ships and airfields moved General Kenney to undertake and encourage field experiments to discover better tactics, and to modify aircraft and ordnance to implement those tactics. Kenney's command also made much use of host nation support. These initiatives should not have been surprising since much of Kenney's prewar service was in engineering during which he invented the parachute bomb and conducted experiments. He was one of those valuable officers who possessed both technical and tactical skills.
- The innovation of the Navy's independent carrier task force resulted from *combining* several technical developments and placing the combination in a new organizational context that extended to the provision of logistics support. The logistics support concept was not entirely new. Before the war the Navy had established destroyer, submarine, and seaplane tenders and had experimented with refueling ships at sea. However, extending these concepts to all elements of support—including replacement aircraft by means of escort carriers—for an entire fleet while underway was a major logistics innovation.

IV. THE STRATEGIC BOMBING OFFENSIVES

Before World War II the concept of strategic air war was one of fantasy and prophecy (Sherry, 1987, pp. 1–46). The limited World War I air raids on London and other European cities profoundly affected civilian policymakers and the press. This, plus the popular appeal of flying, sustained postwar airpower advocates. Britain, France, Italy, and Germany created air forces organizationally independent of their armies and navies, in the expectation that aircraft could do much more than merely complement army and navy operations. Advocates of an independent air force obviously believed it should carry out independent operations. What else could these be other than attacks against targets within enemy territory? Advocates claimed and policymakers in Britain hoped that aircraft could achieve decisive military results quickly, avoiding the heavy ground troop casualties of World War I. Air forces became instruments of intimidation and foreign policy as a result of these hopes.

In the United States, the mood of isolation during the interwar period did not provide a similar rationale for an independent air force. There was, however, keen rivalry between the Navy and the Army over military budgets and a latent rivalry between the Army's combat branches over the Army's budget. The Navy and the Army shared the mission of continental defense against approaching hostile naval forces. The Army Air Corps' claim for a share of that mission rationalized its interest in long-range daylight bombardment, for which in 1935 the four-engine B-17 became the selected instrument.

Uncertainty about how to implement the concept of strategic airpower was enormous, however, in two respects. First, there was the question of how, exactly, should a strategic air campaign be carried out with respect to target systems, how they should be attacked, in what sequence, how frequently, and so on. Second, there were the tactical-technical uncertainties about bomber performance characteristics, kinds and size of bombs, navigation, target identification and bomb-aiming, countering air defense, and so on.

This section describes how these uncertainties were met and resolved ad hoc in three separate strategic air operations: the RAF Bomber Command's effort against Germany and the AAF's campaigns against Germany and Japan. In each, strategy was determined by discovering tactical-technical possibilities in a context where new technical devices and countermeasures were continually and experimentally introduced, increasing the logistic burden and the uncertainty logistics managers had to meet.

RAF BOMBER COMMAND AND AREA BOMBING

Before the war, Bomber Command favored daylight precision bombing, but after the war's outbreak that was quickly discovered to be difficult and costly. Indeed, even before the war it was evident that training navigators to find target areas and bomb-aimers to identify and hit targets under conditions remotely resembling reality was not being accomplished even in daytime clear weather. Tests of what could be done at night or in cloudy weather were hardly attempted (Webster and Franklin, 1961a, p. 117).

Bomber Command crews learned by a process that was costly in lost aircraft and crews. The lessons were that in daytime unescorted bombers were easy prey for fighters, medium and high altitude bombing was inaccurate, and low altitude bombing resulted in high losses from flak. Bomber Command then turned to night bombing. But night navigation and target location were especially difficult and restricted to seven or eight moonlight nights of the month if any precision was to be possible. By February 1941, Bomber Command gave up on night precision bombing and turned to area bombing.

During the period November 1941 to December 1942, Bomber Command developed tactics to implement a nighttime area bombing campaign against targets deep in Germany. As its new commander Arthur Harris saw it: If a strategic air offensive were to be carried out, area bombing at night was the only tactically feasible way to implement it. Once this point was settled, attention could concentrate on refining tactics and making technical changes to improve navigation, target identification, and other aspects of operations. These changes presented numerous logistics problems: new and unknown demands for spares, requirements to train ground personnel to maintain new installations, and greater workloads to install new items on aircraft or to make modifications.

Navigation and Target Location

Navigation and locating targets at night was the number one problem in the beginning. A technical assistance for navigation was *Gee*, which was originally developed as a blind weather landing system. All bomber bases in Britain had a long runway along one of the *Gee* signal lines. Its use as a navigation device came after it was discovered that the signal could be read over Germany. *Gee* consisted of a master and slave radio station, transmitting signals simultaneously. By measuring the time difference in receiving these signals and keeping that difference constant, an aircraft could stay on a predetermined line. By means of a second slave station in a different location, an exact point on the line could be determined. Special maps were made to plot these points (Air Ministry, 1963, p. xiv). *Gee* had a range of 300 miles. It was first employed on a 211-aircraft raid on Essen, March 8–9,

1942. The results were disappointing because *Gee* could indicate only the general area of the target, although this was an improvement over earlier performance. It was obvious that attention had to be given to bombing aids.

One bombing aid was *Oboe*. It consisted of two radar devices carried by the aircraft. They retransmitted signals from each of two ground stations, which were able to plot the aircraft's position, one station for course and the other for distance and groundspeed. On a signal from a station the aircraft released its bombs. If all went well an aiming error of 300 yards could be achieved. A disadvantage of the system was that its range was limited by line of sight, which was about 300 miles with Bomber Command's standard aircraft. Another was that a pair of stations could handle only six aircraft per hour and the maximum of three sets of stations only 18 per hour.

Thus pathfinder squadrons were created to employ *Oboe* and *Gee*. The first pathfinder aircraft was the Wellington, a twin-engine bomber for which the newly assigned pathfinder mission must have generated new logistics requirements. However, a new light bomber, the twin-engine de Haviland Mosquito, had an operational ceiling of 30,000 feet or more, and very high speed.[1] The high service ceiling greatly extended the operational range of *Oboe* to cover the entire Ruhr area. The Mosquito's high speed reduced vulnerability on the bomb run and ability of night fighters to intercept it. Thus Mosquitos became Bomber Command's pathfinders. When they were not used for that mission they were sent on bombing missions of their own. Although their bomb loads were small, their accuracy with *Oboe* accomplished many successful missions. The Germans, incidentally, never managed to jam *Oboe*, although they often succeeded in jamming *Gee* from the North Sea onward.

Oboe was nevertheless range-limited. To cover the rest of Germany, an airborne radar, H2S, was first installed in pathfinders in January 1943. By early 1944 every bomber had an H2S set. It was also a valuable navigational aid, enabling the operator to pick out coastlines, rivers, and occasionally a large city's outline. But it was at best a crude bomb-aiming device.

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[1]The Mosquito was one of the most remarkable airplanes of World War II. It was created by private firm initiative in the absence of any Air Ministry "requirement." Its construction was of plywood in the interest of saving metal and utilizing the skills of woodworkers who otherwise would have been in surplus supply during war. Its design was based on the idea that a streamlined, high-speed light bomber devoid of defensive armament and armor could evade enemy fighters, although the RAF initially procured it for photoreconnaissance. Because of its two-man aircrew and revealed low attrition rate, the bombing offensive would have been much better served with a force built around the Mosquito rather than the lumbering heavier aircraft with their six to eight man crews and attrition rates that produced over 47,000 air crew casualties on operations. The Mosquito also turned out to be an excellent night fighter, reconnaissance, and antisubmarine patrol aircraft.

Air Defense and Countermeasures

Before and during the early part of the war the Germans emphasized a ground-based air defense of heavy concentrations of guns and searchlights around important target areas. They sought a high volume of fire rather than accuracy, although by the end of 1940 they had gun-laying radars. By 1941 it was driven home that such a system was not adequate against large-scale raids and that an active defense system had to be organized. As the British turned to night bombing, the Germans organized Bf 110s into night fighter organizations. Recall that the Bf 110 was designed to be a bomber-escort, for which purpose it had long range and heavy armament, but it could not handle maneuverable single-engine fighters like the Spitfire or Hurricane. However, its heavy armament and long loiter time made it an excellent night fighter. Initially night fighters were directed to the vicinity of the bomber stream by ground controllers using both radar and ground-observer information, whence the fighter (which had a two-man crew) would search for attacking aircraft, utilizing moonlight or cloud reflection from friendly searchlights. For the latter purpose the air defense system had a gigantic searchlight belt along the German-Dutch border and into France and Belgium, with searchlights five to six thousand yards apart for a depth of 20 miles in pl[illegible] 1946, pp. 229–232).

As the British attacks increased, so did German air defense. By the end of 1942, 10,000 flak guns were deployed. Ju 88 bombers were equipped with nose guns to augment the Bf 110s as night fighters. A contest of tactical and technical changes between attackers and defenders followed. One of these was the British use of "window," thin strips of aluminum first used in 1943 in the Battle of Hamburg, which when dropped from the air confounded the defender's gun-laying radar. Bomber Command reduced the time of its bomber streams over a target so as to lessen the opportunity for defending fighters to acquire targets. Air defense and especially night fighter techniques improved, largely as a result of equipping night fighters with airborne radar that could detect a bomber within a range of two and a half miles. Thus cycles of technical measures and countermeasures, usually with associated tactical changes, became a dominant feature of operations. Such shifts created unexpected logistics demands and pressure for a more responsive system.

AAF STRATEGIC BOMBING OF GERMANY

The U.S. 8th Air Force was established in Britain during February 1942 to implement a major offensive against Germany that was to precede the planned cross-Channel invasion. Its growth in Britain before the invasion was part of a massive ground and air force buildup that presented a monumental logistics challenge. This section examines the tactical-technical uncertainties of the 8th Air Force's operations and aspects of its operational tempo.

Learning How to Carry Out Daytime Bombing

From August 1942 until the early summer of 1943 American heavy bomber missions from England concentrated on targets along the French coast from St. Nazaire to German North Sea coastal targets, including submarine construction yards.[2] The spring and early summer attacks against the small number of German targets brought strong opposition, especially the one of June 13 against the Bremen submarine yards, when 26 out of 152 dispatched aircraft were lost (Craven and Cate, 1949, pp. 484–487). During this period the use of "lead bombardiers," the experimental development of improved formations and defensive tactics against enemy fighters, and other procedures were conceived, particularly by then-Colonel Curtis LeMay (Freeman, 1970, pp. 22–23). The French coastal targets allowed RAF Fighter Command to furnish most of the fighter escort. Through the summer of 1943 the tempo of operations increased to some nine or ten missions per month of between 200 and 400 aircraft per mission.

On August 17 the first attack deep into Germany was made by 376 aircraft against industrial targets at Schweinfurt and Regensburg. Sixty bombers were lost, mostly to fighters. On October 14 a 320 aircraft mission against Schweinfurt lost 60 more aircraft, again mostly to fighters. Earlier October raids on Bremen and Munster (in the Ruhr) each cost 30 aircraft.

What dismayed bomber crews was the ferocity, tenacity, and varied tactics of attacking aircraft. Ju 88s dropped small bombs on the bomber formations from above. Others lobbed heavy rockets into the formations. But most of the damage was done by single-engine fighters attacking from all angles, particularly head-on. The latter turned out to be very effective because the bombers' frontal defensive armament was thin. (Prewar bomber designers and fighter tacticians assumed that fighters would attack bombers from the rear, as borne out by the fact that Air Corps prewar fighter organizations were designated "pursuit.")

To counter these tactics, bomber defensive armament and protection were improved by advanced gunsights and a mechanical front gun-turret containing two 50-caliber machineguns. An experiment was tried with a modified B-17, designated the YB-40, that was upgunned and intended only to provide defensive firepower; but this idea of an "escort"

[2]For an account of this and other 8th Air Force operations, see Freeman, 1970.

gunship was discarded because its flight characteristics did not match those of the bombers after the latter released their bombs (Air University, 1951, pp. 109–112). The Germans made many modifications as well. One was to increase fighter armament, but the added weight so reduced ability to deal with escorting fighters that more conventionally armed fighters had to be assigned to protect the heavily armed fighters. No prewar scenario writer could have dreamed up such a sequence of coping with tactical-technical uncertainty.

The losses experienced drove home the lesson that the distance range of daytime raids had to be limited to that of fighter escorts, which shattered the prewar argument that bomber formations could fight their way through an active air defense. Prewar Air Corps planners also believed that an effective long-range fighter was not feasible since a size necessary to carry enough fuel for long range would make it too clumsy to deal with agile defensive fighters. The German Bf 110 illustrated this point, and in Europe the American P-38 did not consistently do well against German fighters. Meanwhile, the U.S. Air Corps had adopted the P-47 with a supercharged radial engine to be a high-flying fighter, and with droppable fuel tanks its combat radius could be stretched to 340 miles. (The twin-engine P-38, which was highly regarded in the Pacific and first used in North Africa, had a 520 mile radius with two 75-gallon wing tanks.) Although these capabilities helped, they did not match the bombers' range (Craven and Cate, 1951, pp. 9–10).

The complete solution to the bomber escort problem came from an unexpected source in the form of the North American P-51 (Mustang) fighter. The P-51 was originally designed and produced for the British as an alternative to the P-40. Before the United States entered the war the British purchased 620 of them. Its performance was unsatisfactory for Fighter Command, so they were turned over to the RAF's Army Co-operation Command for low-level ground attack. The Army Air Corps showed little interest in the P-51, although it did procure a version equipped with air brakes to be a dive bomber, designated the A-36, which saw service in Sicily and Italy. The original Mustang was powered by the American liquid-cooled Allison engine, which also powered the Army's P-38, P-39, and P-40 fighters. None of the single-engine fighters in the above group were "high flyers" and in the same class as the top British or German fighters because the Allison's performance could not match the high altitude performance of the British Merlin or the German Daimler-Benz fuel injection engine that powered the Bf 109. Hence it was decided to mate the P-51 with the British Rolls-Royce Merlin engine, of which there was an American-built version.[3] The result was that the

[3]The reason for this condition was complicated and interwined with the subject of engine superchargers. The design of the P-51 equipped with the Allison engine was such that it could not conveniently accommodate a turbo-supercharger that was designed for high altitude and was installed on bombers and the Allison-powered P-38

Merlin-powered Mustang could outrun and outturn the best German fighters at all altitudes (above 28,000 feet it was 70 miles per hour faster than the FW-190). With two 75-gallon wing tanks it had a 600-mile combat radius, and addition of a fuselage tank increased its radius to over 800 miles (Webster and Frankland, 1961b, pp. 80–81). The American-made Merlin engine had some bugs that had to be worked out, and the Mustang itself—which had previously operated at lower altitudes—presented new maintenance and mechanical problems at 30,000 feet (Freeman, 1970, pp. 119–120). Even so, pilots were eager to use it, and the 8th Air Force coveted and eventually obtained most of the P-51s owned by the 9th Air Force, which happily accepted P-47s in exchange.

On March 4, the first American daylight bombing of Berlin took place, during which P-51 fighters appeared over the city. During three subsequent Berlin missions during March, nearly 1800 aircraft attacked the city. On Berlin missions of March 6 and 8, German fighter opposition was strong. Over half were twin-engine night fighters, which had recently been inactive because Bomber Command deep penetrations had ceased. The use of night fighters for day defense was induced by the attrition that day fighters had suffered.

The most important effect of these missions was the destruction of the Luftwaffe's fighter forces from aircraft and pilot losses in their defense against the AAF attacks. By the middle of February, 8th Air Force owned two groups of P-38s, 416 P-47s, and 329 P-51s (Murray, 1986, p. 180). In the spring escorting fighters were released from sticking close to the bombers they escorted to pursue enemy fighters, even to strafe them at their bases. On returning from escort missions, fighters would also carry out strafing attacks against airfields and other targets. Here was a major shift in tactics that necessitated a different and more varied flight profile, presented battle damage from flak, and introduced related logistics demands. When at low altitude over enemy territory, fighter pilots usually managed to expend all their machine gun ammunition before returning to base, increasing gun-barrel erosion and armorers' work loads.

During January through May 1944 the Luftwaffe lost almost 2300 fighter pilots, nearly 100 percent of its authorized strength. Accidents from flying in foul weather contributed importantly to these losses. As time went on, experienced pilots were killed off (Murray, 1986, pp. 182–183). The flying skill of replacements fell as training flying hours were curtailed because of fuel shortages. Increased aircraft production, despite the bombing

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fighter. For single-engine fighters the Allison had a two-stage, gear-driven supercharger designed for medium altitude. European designed superchargers were highly advanced, particularly the gear-driven ones with which the Merlin was equipped. It was simpler to adapt the P-51 to the Merlin than to a turbo-supercharged Allison. (For further information about the development of both engines, see Schlaifer, 1950, pp. 310ff.)

of manufacturing facilities, proved to be of little value, given the ease with which planes could be shot down or destroyed on the ground.

Selected 8th Air Force Operational Data

Table 7 shows the growth of VIII Bomber Command, its operational pace, and its losses. Notice the high attrition rate per sortie during 1943, and how it fell during 1944. By the end of April 1944 flak instead of fighters became the major cause of losses and battle damage. Loss rates per sortie are not the only way of evaluating combat resource use, however. It is instructive to relate total losses per period to available aircraft, or the "operational aircraft" and "aircraft lost" figures. This ratio indicates a logistics workload, as does the number of sorties per aircraft. From mid-1944 onward the ratio of aircraft lost to aircraft available held up, while sortie attrition rates fell as a result of a higher activity rate sustained by increased replacement aircraft (and crews). This situation could reduce the

Table 7

Operational Heavy Bombers, Sorties, and Aircraft Lost, by Month, U.S. 8th Air Force, June 1943-December 1944

Date	Operational Aircraft[a]	Aircraft Lost[b]	Sorties[b]	Sorties/AC	Loss Rate (% of sorties)
1943					
Jun	275	95	2,107	7.1	4.5
Jul	350	118	2,829	8.1	4.2
Aug	390	137	2,265	5.8	6.0
Sep	450	111	3,259	7.2	3.4
Oct	500	215	2,831	5.7	7.6
Nov	650	112	4,157	6.4	2.6
Dec	800	207	5,937	7.4	3.5
1944					
Jan	900	267	6,367	7.1	4.2
Feb	1,000	315	9,884	9.9	3.2
Mar	1,100	325	11,590	10.5	2.8
Apr	1,300	469	14,464	11.1	3.2
May	1,600	417	19,825	12.4	2.1
Jun	2,050	425	28,925	14.1	1.5
Jul	2,000	391	23,917	12.0	1.6
Aug	1,950	340	22,967	11.8	1.5
Sep	2,000	408	18,268	9.1	2.2
Oct	2,100	221	19,082	9.1	1.2
Nov	2,020	247	17,003	8.4	1.5
Dec	1,950	196	18,252	9.4	1.1

[a]Greene, 1966, p. 44.
[b]Office of Statistical Control, *Army Air Forces Statistical Digest: World War II*, 1945, pp. 221, 188–191.

workload per aircraft at bases and depots because there are fewer war-weary ones to keep repaired.

Tables 8–10 show relationships between operations, and aircraft loss and damage for the 8th Fighter Command.

Table 8 indicates that damaged aircraft were roughly double the number lost. This ratio is sensitive to the relative importance of flak and enemy fighters. During the period the table treats, enemy fighter opposition had passed its peak. As German forces withdrew into Germany, flak density increased. It is obvious from Table 8 that the ratio of kills to damage from fighter aircraft fire is more than four times higher than the similar ratio with respect to flak. Thus the logistics planner should be able to project that if his side is winning the air war and if fighters are used on ground sweeps or attacks he should expect lower aircraft loss rates per sortie but sharply increased battle damage rates and hence higher repair workloads. Spare parts demand will increase, but so will supply to the extent that seriously damaged aircraft that manage to return to base provide salvageable parts. A lower loss rate also provides a local spare parts supply from scrapping damaged and worn-down aircraft more quickly with a given flow of new replacement aircraft.

Table 9 shows loss rates by type of mission during March–May 1944. During March the 8th Fighter Command escorted bombers on deep penetrations. During April and May the 8th Air Force came under General Eisenhower's control and flew many tactical and

Table 8

8th Air Force Fighter Aircraft: Damage and Loss According to Cause, European Theater (August 24, 1944 to May 31, 1945)

Cause	A/C Damaged		AC/Lost	
	Number	Percent	Number	Percent
Flak	841	63.2	178	27.0
Enemy aircraft fire	288	21.6	257	39.0
Composite or unknown	84	6.3	79	12.0
Collision with ground objects	44	3.3	14	2.1
Pieces of enemy aircraft	35	2.6	1	0.2
Mechanical failure	11	0.8	80	12.1
Collision with friendly aircraft	9	0.7	20	3.0
Empty shell cases	9	0.7	—	—
Lack of fuel	6	0.5	23	3.5
Friendly aircraft fire	2	0.2	3	0.5
Collision with enemy aircraft	1	0.1	4	0.6
Total	1330	100.0	659	100.0

SOURCE: Greene, 1966, p. 55.

interdiction missions. Notice the differing ratios of damage to loss between the different kinds of missions. Notice also the higher damage and loss rates per sortie when ground strafing, a reflection of the high flak-gun density of German ground forces. Conversely, the high ratio of loss to damage on bomber support missions reflects the higher incidence of encounters with enemy aircraft and the fact that the chance of a damaged fighter aircraft returning from a mission is a decreasing function of mission length and time over enemy territory.

Table 10 shows damage and loss rate by type of fighter. Time length of mission is the obvious explanatory variable of the loss rate by type of aircraft. The sharp difference between the P-47 and the other aircraft types reflects the P-47's air-cooled engine, which did not lose engine coolant as did the P-38 and P-51 engines. It may seem puzzling that the P-38's loss rate was as high as it was relative to that of the Mustang given the fact the P-38 had two engines. In the Pacific (and Mediterranean) the P-38 was valued for this reason, as many pilots returned to base on one engine during a long over-water flight. But over Europe on deep penetration missions a P-38 with one engine out was easy prey for enemy fighters;

Table 9

8th Air Force Fighter Aircraft Damage and Loss According to Mission, European Theater (March–May 1944)

Mission	Sorties	A/C per 1000 Sorties Damaged	A/C per 1000 Sorties Lost
Bomber support	31,688	23	20
Sweep	1,999	35	13
Ground strafing	1,723	80	36
Fighter bombing	1,722	49	9

SOURCE: Greene, 1966, p. 55

Table 10

Damage and Loss Rates for Fighter Aircraft, U.S. 8th Air Force Fighter Command (European Theater)[a]

Type	Average Sortie Length (hr)	Aircraft per 1000 Sorties Damaged	Aircraft per 1000 Sorties Lost	Ratio of Lost to Damaged and Lost
P-47	3.2	18	6	0.25
P-38	4.2	22	17	0.44
P-51	4.4	27	19	0.41
All	3.4	20	10	0.33

SOURCE: Greene, 1966, p. 55.
[a]Data pertinent for August 24, 1943 –May 31, 1944.

moreover, enemy fighter pilots preferred to tangle with the P-38 rather than the more agile single-engine fighters. This condition was not helped by the fact that the P-38's highly idiosyncratic shape made it the most easily and quickly identifiable airplane of World War II.

These data illustrate that even casual examination of operational data and a little thought can help anticipate aspects of logistics workloads and other relevant conditions such as salvageable spare parts from badly damaged aircraft. But such insights and knowledge cannot be exploited if logistics managers are not fully informed about planned operations.

U.S. STRATEGIC BOMBING OF JAPAN

The B-29 was conceived shortly after the outbreak of war in Europe for the mission of Western Hemisphere defense. It was to have a 2000-mile operating radius, to enable it to strike enemy lodgements (Craven and Cate, 1953, pp. 8–9). By the standards of the time it was a huge airplane: Its maximum gross weight was 140,000 lb compared with something over 40,000 lb for the B-17. In operations from the Marianas against Japan, its average bomb load per sortie was slightly over six tons, and B-17s and B-24s in Europe had less than half that. Achieving this capability challenged both engine and airframe designers. Development problems with its turbo supercharged, 2200-horsepower engine delayed operational availability because of a high failure rate. Where and how to use the B-29 provides a classic example of ad hoc strategy and tactical formulation in the face of extreme technical uncertainty.

Where and When To Use the B-29

When the first B-29s became available for operations, it had to be decided where their bases should be located. In a general sense there were three regions: China; somewhere in the Southwest Pacific, depending on MacArthur's progress; and somewhere in the Central Pacific if and when island bases near enough to Japan were captured. As of the middle of 1943, Air Staff plans indicated that ten B-29 groups would be available by October 1944. Since the Navy's fast carrier task force concept was unproved as of the middle of 1943, there was no planned Central Pacific Strategy and no hint that any Pacific islands within B-29 range of Japan's main island would be in American hands by 1944. President Roosevelt, who felt a strong commitment to China, selected the China option because it rationalized providing China additional support to confront the Japanese. The AAF—specifically, General Arnold—went along with this choice because it seemed at the time the only place from which strategic bombardment against Japan could be implemented, despite its obviously high logistics support cost.

Meanwhile the AAF created the 20th Air Force, of which XX Bomber Command was to be a component. The rationale for this organization was to assign the new B-29 units to XX Bomber Command as a component of a Strategic Air Force, which could also be under the personal command of the most senior Army Air Forces officer, General Arnold. Formally, the Joint Chiefs of Staff were to control the force, with General Arnold acting as executive agent. Arnold strongly desired and promoted this arrangement to avoid control of strategic bombers by a theater commander, as was practiced on occasion in Europe (Hansell, 1982, pp. 17–24). Given the Navy command in most of the Pacific, the possibility of a theater command evoked greater dismay.

Thus Operation Matterhorn was undertaken. Air bases were constructed in south-central China from which the B-29s could reach a small part of Japan. Matterhorn's accomplishments were modest. A force of around 150 aircraft flew 49 missions of 3058 sorties and dropped 11,477 tons of bombs (Craven and Cate, 1953, p. 170). About half of these missions were flown from the China bases and the remainder from India and Ceylon. Most missions were against targets in southeast Asia, Formosa, and Manchuria; a small number were against Japan. The impressive thing about the operation was the formidable logistics problems it confronted and the amount of resources expended to produce its combat results. These ranged from the construction of the airfields by tens of thousands of Chinese (Dod, 1966, pp. 439–442), through the air-supply of fuel and bombs over the "Hump" from India, utilizing both transport aircraft and part of the B-29 force, to coping with the teething problems of a new airplane and its troublesome engine. In performing this fuel-transport role, the B-29s flew seven trips over the Himalayas for every sortie against Japan (LeMay, 1988, p. 83). A large number of air transports were used to support the operation as well.

Opportunity to end the resulting frustrations presented itself when the Navy's Central Pacific campaign yielded the Marianas for B-29 air bases. Their capture by the end of July 1944 was followed by an intense period of airfield construction providing five large airfields on three of the islands. The first B-29 wing arrived on Saipan in August 1944. By April 1945 the total was five wings (Craven and Cate, 1953, p. 522).

Organizing Logistics Support for B-29s in the Marianas

Shortly after General LeMay took command of the Marianas-based B-29 operation in late January, the logistics organization was consolidated and centrally managed by combining service group and tactical unit maintenance resources. Assignment of a crew chief to each airplane was eliminated because experienced crew chiefs were scarce and the skills of capable ones could be better utilized under the centralized management arrangement.

Assembly line techniques were instituted for engine changes. Before LeMay's arrival, steps had been taken to bypass the normal sea-transport supply system that operated through Hawaii. By a process obscure to both LeMay and his predecessor, General Hansel, the command's supply officer managed to get hold of some half-dozen C-54 transports that provided a private air service to the Sacramento Air Materiel Command depot, which responded to radio requests for parts. These expedients (some of which, like the acquisition of the C-54s, were "illegal") enabled the command to fly each aircraft an average of 120 hours a month (LeMay, 1988, pp. 113–114).

New Tactics and Shifting Ordnance Demand

At the beginning of the Marianas operations, B-29s followed the same tactics used by AAF heavy bombers in Europe, and also promised to be unsuccessful. Accuracy was poor, often because jet-stream winds were encountered. Long missions and climbs to high altitude strained engines and required extra fuel, which reduced payload and increased engine wear and failures. Daylight operations were also subject to fighter interception, although enemy air defense was not vigorous.

In facing this situation and prodding from Washington, General LeMay implemented radically different tactics. Night area bombing from 6000 to 8000 feet, with incendiary bomb loads, was instituted. Since the Japanese had no night-fighter capability, some defensive guns were trimmed from the bombers. A larger bomb load was permitted by this weight-saving, and less fuel was consumed from flying at lower altitude. On the first such mission, with Tokyo as the target, crews were apprehensive about flak, but it turned out that the Japanese had a weak ground-based air defense. The first 325-aircraft mission of March 9 was a huge success, resulting in a fire storm and thousands of casualties. Over the next nine days Nagoya, Kobe, and Osaka were hit with maximum effort incendiary raids. During the rest of March and all of April, only three incendiary raids were carried out because ordnance was in limited supply. All other missions were mostly against airfields and aircraft factories with high explosives (LeMay, 1988, 191–193). Meanwhile the Navy scurried to increase shipment of incendiaries, Seabees and Marines were pressed into unloading ships, and the bombs were brought directly from ships to aircraft hardstands, bypassing the bomb dumps (LeMay, 1988, p. 127). It was then possible to add the remaining 25 largest cities to the target list. Bombing these sharply reduced Japan's war-making potential.

Table 11 shows the mission profile shift in terms of aircraft bombing altitude. The data for the XX Bomber Command bombing are for those missions dispatched from China and south Asia. The XXI Bomber Command represents operations from the Marianas. The drastic change in tactics beginning in March is evident. Table 12 shows the allocation of bomb loads as between high-explosive and incendiary delivered by the B-29s over time. The shift to incendiary bombs as of March is obvious. The shift back to high explosives in April was due to the shortage of incendiaries. These data as well as the profile and targets of missions (LeMay, 1988, pp. 189–201) show clearly that munitions availability both limited operations and shaped the structure of the bombing campaign.

Extremely damaging to Japan's ability to make war was the merchant-shipping campaign and blockade conducted by U.S. Navy submarines, and Navy and Army air attacks. Like the Luftwaffe, Japanese air forces suffered a sharp decline in pilot skill due to lower flying training hours from the fuel shortage. Unlike the Germans, however, the Japanese had access to ample crude oil and refinery capacity in the former Dutch East Indies. But the sinking of tankers sharply reduced fuel supplies. With respect to maintaining a shipping blockade, the Sea of Japan between Japan's main islands and the Asian mainland lent itself to mining. A B-29 Wing (equivalent to three present-day wings) was assigned to this task since the Navy had no suitable aircraft. From April through August 1945, the 313th Wing produced 1528 sorties to lay 12,053 mines, which sank over 800 thousand tons of shipping and seriously constrained ship movement (Craven and Cate, 1953, pp. 673–674).

Table 11

B-29s Bombing By Altitude, June 1944 – August 1945

Date	Below 8,000 (ft)	8,000-15,000 (ft)	15,000-25,000 (ft)	Over 25,000 (ft)	Average Altitude (ft)
20th Bomber Command					
June 44 – Mar 45	104	225	1,696	269	19,398
21st Bomber Command					
1944 Nov			23	24	23,500
Dec		23		341	24,786
1945 Jan				207	27,000
Feb				360	27,000
Mar	1,855		288		9,364
Apr	288	1,189	1,291		17,079
May	339	1,043	2,497		16,731
Jun	715	1,025	3,048		15,123
Jul	292	4,282	1,120		12,577
Aug	56	873	1,937		15,889
Total	3,545	8,435	10,204		15,866

SOURCE: Office of Statistical Control, *Army Air Forces Statistical Digest: World War II*, 1945, p. 287.

Table 12

Bomb Tonnage Dropped by High Explosive and Incendiary Bombs, 1944–1945

Date	Total	High Explosive	Incendiary
1944	9,064	7,247	1,817
1945			
Jan	3,410	2,511	899
Feb	4,020	2,401	1,619
Mar	15,283	4,105	11,178
Apr	17,492	13,209	4,283
May	24,285	6,937	17,348
Jun	32,542	9,954	22,588
Jul	43,091	9,766	33,325
Aug	21,873	8,641	13,232
Total	171,060	64,771	106,289

SOURCE: Office of Statistical Control, *Army Air Forces Statistical Digest: World War II*, 1945, p. 227.

OVERVIEW: COUPLING OF LOGISTICS AND OPERATIONS

Each of the three strategic air campaigns presented logistics problems peculiar to its location. Compared with the RAF Bomber Command, the American strategic air forces had the problem of quickly creating a support system a great distance from the homeland source of materiel. In both cases, management adopted ad hoc expedients.

- In Britain, host nation support was a major contributor to the early buildup of the 8th Air Force and continued to provide major depot capacity that was used to implement the many aircraft modifications called for by the on-going contest of technical measures and countermeasures.
- With the B-29 Marianas-based operation, both local centralized management of maintenance resources was implemented and special communication and air transport capability was provided to connect base support with the Sacramento supply depot.

Each of the strategic air campaigns had to resolve extensive tactical-technical uncertainties that created new and unexpected logistics demands and workloads. The most dramatic changes were:

- Bomber Command's shift to night area bombing.
- The use of B-29s to deliver incendiary bombs at medium altitude at night.
- The 8th Air Force's development of new bombing and defensive formation tactics and use of long-range fighters to solve the deep penetration problem.

V. CONCLUSIONS: UNCERTAINTY AND LOGISTICS SYSTEM DESIGN

THE PERVASIVENESS OF UNCERTAINTY

The immediate sources of uncertainty that stressed World War II air force logistics systems can be placed in the following categories.

1. Undertaking operations in a geographic area or a type of operation not planned for.
2. Surface transportation or special support constraints and failures.
3. Adapting to allies in a context of coalition war and host nation support.
4. New or unexpected enemy tactics.
5. Changed friendly tactics in carrying out an established mission.
6. Use of a system for a mission other than what it was originally designed for.
7. Changed mission mix.
8. Changed ordnance expenditure rates.
9. Technical modifications and introduction of new subsystems.
10. Attacks on air bases that damage facilities and aircraft.

These causes of stress usually occur in close sequence, with one change evoking another. For example, the development of skip-bombing by General Kenney's 5th Air Force called for delayed fuzing of bombs and permitted the aircraft modification of placing additional machineguns in the bombardier's compartment to improve ability to suppress air defense when approaching the target. Another example was provided by the RAF Bomber Command's shifting to nighttime area bombing, which in turn stimulated technical changes to aid navigation and the new tactic of using pathfinder aircraft. Perhaps the most important *unanticipated* shift in aircraft employment of the war was the transformation of the fighter to a fighter-bomber, the feasibility and effectiveness of which was greatly aided by rapid airfield construction and the innovation of American earth-moving equipment. Although fighters dropped small bombs in World War I and most World War II fighters were designed to carry them, their effectiveness as fighter-bombers was enhanced by more powerful engines and the ground mobility afforded by motor vehicles and rapid construction of forward air bases.

The following lessons should be learned from the many examples described in the above narrative.

- Whenever there has been a long period of time between wars during which technology undergoes major change, prewar tactical and doctrinal concepts will be sharply revised.
- Such changes necessarily require flexible logistics support, and an organization that cannot receive it will probably not survive.
- Host nation support, or whatever resources happen to be in the place one fights, can contribute greatly to a logistics system's capability.

IMPLICATIONS FOR THE DESIGN OF A LOGISTICS SYSTEM

Wartime strategy, operations, and logistics are inseparable. Operators must revise tactics and doctrine in a process of responding to enemy behavior and learning how to make the best use of untested weapons and doctrine as their flaws become apparent. Managers of the logistics system must be flexible and able to adjust their procedures quickly as experience and circumstances indicate. This includes willingness to change and modify decision rules experimentally. Flexibility and responsiveness are not attained by a rigid adherence to rules, for example, when a depot system meets field demands on a first come, first served basis. In the past, depot system managers seldom had any choice but to employ such a rule because they had little knowledge of planned operations. It was not until late 1943 that the Director of the Logistics Plans Division of the Chief of Naval Operations staff was given access to the "Top Secret" dispatch board of the fleet's Commander in Chief (who was also Chief of Naval Operations—Ballantine, 1949, p. 289). Obviously, the several independent Navy Bureaus that carried out procurement and operated the logistic system had to guess about future operations. Conversely, Navy planners during World War II were unsure whether the Bureaus were legally obligated to respond to detailed planning guidance from the Chief of Naval Operations.

Responsive and flexible logistics support requires a management system that consciously links operations and logistics. This could mean not trying to make each operating base dependent only on the depot system but to design a system whereby the logistics support capabilities of a set of bases would be *mutually supporting*. This might involve, for example, sending reparable components from a hard-pressed or damaged base or wing to other bases with available capacity, or transferring spares from one base to another. It means temporarily shifting teams of specialized maintenance personnel, or perhaps having selected mobile teams (with test equipment) available to go where the required work is, as was practiced by the DAF and the U.S. 9th Air Force (Craven and Cate, 1951, p. 130; 1955, pp. 391–392). It may also mean landing a battle-damaged aircraft at a base that has unused repair capacity, with the pilot returning to his home base in a borrowed aircraft. Such a system of air bases laterally supporting each other and specialized depot personnel servicing air bases requires high-level command and control. Instead of individual wings and operating bases being quasi-autonomous with respect to logistic management, they would lose some control over the allocation of the capability they "own." But any single tactical organization should be able to maintain a higher overall operational state or a higher surge ability by virtue of the gains provided by effective pooling under centralized allocation.

As for depot management, particularly for components not reparable at operating bases, priority attention should be given to those that exhibit extraordinary or unexpected need for repair, so as to be able to head off system-wide shortage. Advance and prompt information from the field must be forthcoming if depots are effectively to employ such a policy as an alternative to first come, first served. Modern data processing, communications, and rapid transportation provide the means of implementing such a concept. Hence depot management can be linked to an integrated logistic management of operating bases coupled in turn with operations.

- Ways to assure that prompt information is made available to the depots supporting a system should be considered and evaluated by field experimentation. One approach might be to assign an officer to each combat wing whose sole job is to observe its operations and base repair workloads and to report weekly everything that goes on that can be relevant to logistics. Or mobile repair teams from depots like those used in Britain and France may be a suitable mechanism. Headquarters operations analysis staffs, by frequent visits to field users, may also be of great help. Since prewar peacetime logistics data are of little use to predict wartime demands, information from wartime operations must be the primary wartime management tool. It should therefore be promptly transmitted to managers throughout the system.
- As experience shows, we usually end up getting a great deal of host nation support and compensating the host in some way or other. This capability could be more fully and quickly exploited if usable inventories of resources were taken for areas in which we have contingency plans.

Recognition of the fact that military operations and logistics are inseparable supports the idea that the concept of military command and control should be extended to the wartime logistics support of forces in the field. Vivid examples of the failure to establish any coherent linkage between logistics and operations were those of the French, Italian, and German air forces. In Britain, the Air Ministry's Civilian Repair Organization linked aircraft manufacturing facilities to operating bases. In overseas commands like the Desert Air Force, and the U.S. 5th, 8th, and 9th Air Forces, depot facilities were either moved as close to combat organizations as possible, or mobile repair teams were created and dispatched to assist air bases where and when needed. In the case of the 20th Air Force, unit maintenance resources were rationalized and a half-dozen air transports were committed to provide responsive resupply from the Sacramento Depot to the Marianas bases. The Navy's mobile support squadrons literally brought the depot system to the fleet while at forward fleet anchorages or by means of manila rope used to transfer materiel from supply to combat ships while at sea. These widely different methods that accomplished a close linkage between operations and logistics provide compelling evidence of its feasibility.

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