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A NEW SPHERE

Air Power, 1903–2013

Development in aircraft design and construction is rapid in these days.

—*British Ministerial Committee on Disarmament dealing with Air Defence, 1934*

BEFORE THE FIRST WORLD WAR

Air power is a key area of discussion when considering military technology. It provides examples of dramatic changes in capability and also links past and present with consideration of the future of warfare. Moreover, the nature, impact, and limitations of air power and warfare have been the subject of extensive analysis.[1] Manned heavier-than-air flight, first officially achieved by the American Wright brothers in 1903, was a key instance of the enhancement of fighting capability through totally new technology. Flight, or at least the use of the air, had had an earlier role in warfare with balloons, which were used by the French for reconnaissance in the 1790s, but its capability was now transformed. Imaginative literature, such as that of the novelist H. G. Wells, had prepared commentators for the impact of powered, controlled flight. Science fiction possibly gave some inspiration as to how airships could be used, as in *John Carter of Mars* (1912). In 1908, Count Zeppelin's LZ-4 airship had flown over 240 miles in 12 hours, leading to a marked revival of interest in airships, and in Britain in 1909 there was a scare about a possible attack by German airships.

However, from 1909, when Blériot made the first aeroplane flight across the English Channel, the focus switched to aircraft. A British report on changes in foreign forces during 1910 noted:

> Great activity has been displayed in the development of aircraft during the year, particularly in France and Germany. The main feature in the movement has been the increased importance of the aeroplane, which in 1909 was considered to be of minor military value. This importance was due partly to the surprising success of the aeroplane reconnaissances at the French manoeuvres, and partly to the successive disasters of the Zeppelin dirigibles [gas-filled airships].... Aviation schools have been started in almost every country.[2]

Aviation rapidly became a matter for international competition and therefore anxiety. As Lord Northcliffe, the influential British press baron, remarked, "England is no longer an island." In contrast to the naval race with Germany, but drawing on similar worries, there was concern in Britain about the bombing of its defenseless strategic targets and cities in any war with Germany; although, in 1909, when the chief of the British Imperial General Staff sought views on the likely effectiveness of airships and planes, he met with a skeptical response from General Ian Hamilton, who was unimpressed about the possibilities of bombing. Hamilton wrote, "the difficulty of carrying sufficient explosive, and of making a good shot, will probably result in a greater moral than material effect."[3] Similarly, General Ferdinand Foch, director of the French *École Supérieure de la Guerre,* argued in 1910 that air power would only be a peripheral adjunct to the conduct of war. Nevertheless, the French Directorate of Military Aeronautics was created in 1914.

New developments were frequent and rapid in the early 1910s. In the United States, the first aircraft takeoff from a ship occurred in November 1910 and the first landing on a ship in January 1911.[4] In 1911, Britain, which rapidly integrated air power into army maneuvers, established an air battalion and, in 1912, the Royal Flying Corps.[5] Aircraft were first employed in conflict during the Italian-Turkish War in 1911 and the Balkan Wars of 1912–1913. Grenades were dropped from the air on a Turkish army camp on October 23, 1911, and Turkish-held Edirne (Adrianople), besieged by the Bulgarians in 1913, was the first town on which bombs were dropped from an airplane. However, the use of aircraft had scant impact on operations in any of these conflicts, although the Italians benefited from the development of aerial photography, using it to correct their maps.[6]

By 1914, the European powers had a total of over 1,000 airplanes in their armed forces: Russia had 244, Germany 230, France 120, Britain 113, and Austria about 55. Most of these machines were little more than flying boxes, as they were slow, underpowered, and unarmed. The issue of armament did not really arise until after the outbreak of the First World War in 1914.

THE FIRST WORLD WAR

Aircraft were first used at any scale in the First World War (1914–1918), in which they played an important role, not only in fighting other aircraft but also in influencing combat on the ground (and at sea). The value of aircraft reconnaissance was quickly appreciated, not least because in 1914 aircraft provided intelligence on the moves of armies in the opening campaign on the western front, particularly the crucial change of direction of the German advance near Paris. By creating both an exposed flank for one German army and a gap between two of them, this change opened the way for a successful French counterattack in the Battle of the Marne.[7] The significance of reconnaissance was indicated by the fighter evolving as an armed reconnaissance plane protector, followed by as an armed aircraft for shooting down opposing spotters.

At the tactical level, reconnaissance aircraft proved especially valuable in helping direct artillery fire. In 1915, General Sir Charles Callwell, critical of the initial Allied plan for the attack on Gallipoli as a purely naval operation, remarked, "As a land gunner I have no belief in that long range firing except when there are aeroplanes to mark the effect."[8] Thus, in a classic instance of combined operations, artillery accuracy was believed to rest on reports from air spotters. Moreover, aircraft had an operational effect, as when the Turkish columns advancing across the Sinai Peninsula toward the Suez Canal in 1915 were spotted by British planes.

"Seeing over the hill" altered the parameters of conflict, but, despite capabilities including strafing troops and tanks, aircraft were not yet a tactically decisive nor operationally predictable tool. Their role had been grasped, but execution was limited.

The ability of airplanes to act in aerial combat, nevertheless, was enhanced during the war as specifications changed rapidly with increases in aircraft speed, maneuverability, and ceiling making it easier to attack other planes. Engine power rose and size fell, while the rate of climb of aircraft increased. The need to shoot down reconnaissance aircraft resulted in the development of the fighter, which led to the interrupter gear. This synchronizing gear was developed by a Dutchman, Anthony Fokker, but Fokker was sued for patent infringement by Franz Schneider, a Swiss engineer, and the case continued until 1933 despite the courts finding in favor of Schneider every time. Schneider, who worked for *Luftverkehrs Gesellschaft,* had patented a synchronizing gear in 1913. In addition, Raymond Saulnier, a French aircraft designer, patented a practical synchronizing gear in April 1914. But neither his nor Schneider's was reliable enough for use in combat, partly because of inconsistencies with the propellants used in the machine-gun ammunition, which led to misfires.

Fokker's synchronizing gear was utilized by the Germans from April 1915 and copied by the British, showing once again how war accelerated technological development but, with equal speed, resulted in another stalemate of sorts. This gear enabled airplanes to fire forward without damaging their propellers, and thus to fire in the direction of flight. The Fokker Eindekker aircraft, which the Germans deployed from mid-1915, gave them a distinct advantage and enabled them to seek the aerial advantage over Verdun in the key battle on the western front in early 1916. Vulnerability to German fighters was swiftly demonstrated. Harold Wyllie, a squadron commander in the British Royal Flying Corps, wrote in 1916, "sending out F.E.'s [F.E. 26s] in formation with Martinsydes for protection is murder and nothing else."[9]

The eventually successful French attempt to contest the German advantage reflected their deployment of large groups of aircraft and the fact that they now also had planes with synchronized forward-firing machine guns, both of which allowed them to drive off German reconnaissance airplanes. In turn, in the winter of 1916–1917, the Germans gained the advantage, thanks in part to their Albatross D-1, only to lose it from mid-1917 as more and better Allied planes arrived.

The superior synchronizing gear (the CC Gear) invented by the Romanian engineer George Constantinescu employed no mechanical linkages but a column of fluid in which sonic pulses were transmitted. This was not a hydraulic system because of the use of the pulses. It was more reliable than mechanical systems and allowed for a faster rate of fire. The CC Gear was fitted to British machines from March 1917, notably the Gloster Gladiator. Moreover, because Constantinescu's theory of sonics was kept secret, the Germans failed to copy the gear from shot-down aircraft because they wrongly assumed the device to be purely hydraulic and could not make it work.

Despite significant Allied advantages, notably in 1918, the Germans did not lose in the air as they were to do in the Second World War, and this contrast, in large part, indicated the relatively more limited capability of First World War aircraft, including in range, speed, altitude, acceleration, maneuverability, armament, and payload.

There were also developments in tactics during the First World War. Aircraft came to fly in groups and formation tactics developed. Aircraft also became the dominant aerial weapon: their ability to destroy balloons and airships with incendiary bullets spelled doom for the latter. The German Zeppelin airship had impressed contemporaries as a bomber, but its vulnerability to aircraft swiftly became apparent.

The British Royal Naval Air Service conducted the first effective bombing raids of the war in 1914 when planes carrying 20-pound bombs flew from Antwerp, then still in Allied hands, to strike Zeppelin shells at Düsseldorf and destroyed an airship. As with any munition, the key element was not the bomb but the fuse, and fuses had to be developed specifically for aerial bombs. Bombing became more frequent, and ambitions about its effect increased. The Germans launched bomber attacks on London in 1917 because they believed, possibly due to reports by Dutch intelligence, that the British were on the edge of rebellion. As a result, the attacks were intended not so much to serve attritional goals but rather to be a decisive war-winning tool.

The use of bombers, notably the German *Gotha*, reflected the rapid improvement of capability during the war, as science and technology were applied in the light of experience. The *Gotha* Mark Four could fly for 6 hours at an altitude of 21,000 feet (4 miles or 6,400 meters), which made interception difficult, had an effective range of 520 miles, and could carry 1,100 pounds (or 500 kilograms) of bombs. Furthermore, the crews were supplied with oxygen and with electric power to heat the flying suits.

The first (and deadliest) raid on London, a daylight one on June 13, 1917, in which fourteen planes killed 162 people and injured 432, not least as a result of a direct hit on a school that killed 16 children, led to a public outcry. This slaughter was met—in the rapid action-reaction cycle that characterized advances during the war—by the speedy development of a British defensive system involving high-altitude fighters based on airfields linked by telephones to observers, an instance of the combination of new technologies. The effectiveness of this system led to heavy casualties among the *Gothas* and to the abandonment of daylight raids. More seriously, the rationale of the German campaign was misplaced because, far from hitting British morale, the bombing led to a markedly hostile popular response, and at a time when relative war-weariness was becoming increasingly significant. This response remained the case even in the winter of 1917–1918, when the Germans unleashed four-engine *Zeppelin-Staaken* R-series bombers, able to fly for 10 hours and to drop 4,400 pounds (or 2,000 kilograms) of bombs.[10] The German bombing did not have strategic effect. It did not break British morale and was not capable of inflicting significant economic damage. As a consequence, bombing lacked the potential of submarine warfare.

By the close of the war, the extent and role of air power had dramatically expanded. By the armistice in November 1918, the British had a western front force of 2,600 airplanes as well as many in service elsewhere, and, that September, a combined Franco-American-British force of 1,481 was launched against the Germans in the Saint-Mihiel Salient,

the largest deployment thus far. In 1917, German airplanes destroyed moving French tanks in Champagne. Supply links came under regular attack from the air, inhibiting German and Austrian advances in 1918 and affecting the Turks in the Middle East that year.

Airplane production had risen swiftly. In 1914, the British Royal Aircraft Factory at Farnborough could produce only two air-frames per month, but their artisanal methods were swiftly swept aside by mass production. Air power also exemplified the growing role of scientific research in military capability: wind tunnels were constructed for the purpose of research. Strutless wings and airplanes made entirely from metal were developed. Huge improvements in design, construction, engines, and armaments turned the unsophisticated machine of 1914 into a potent weapon during the course of the war.[11]

THE INTERWAR YEARS

The alarm raised in sections of British society by German air attacks encouraged postwar theorists to emphasize the potential of air power, not least as a progressive and necessary alternative to the slaughter and delay of trench warfare.[12] During the war itself, the consequences of strategic bombing—either to disrupt industrial life or to cause civilian casualties—were, in fact, limited. Indeed, despite the First World War, the impact on war of aircraft was largely untried, so that commentators of the 1920s and 1930s had little practical knowledge on which to base their theories. At the same time, they were able to sustain prewar assumptions about the potential of air power, assumptions that drew on a strong sense of elitism.[13]

Air-power theorists emphasized the bomber. For 1919, the British had planned long-range bombing raids on German cities, including Berlin, with large Handley Page VI 500 bombers, although the war ended before their likely impact could be assessed. Nevertheless, in one of the episodes that repeatedly grabbed attention for air power enthusiasts, one of the planes successfully flew the Atlantic in 1919. Moreover, in 1925, Brigadier-General William (Billy) Mitchell, a key and vocal figure in the early propagation of American air power, told the presidential inquiry on air power that the United States could use Alaska to launch effective air attacks on Japan, which was already seen as a major and growing threat to American interests in the Pacific and the Far East.[14] This aerial capability appeared to offer an alternative to naval power, although the effectiveness of the latter was enhanced with the development of aircraft carriers and carrier doctrine and tactics. In the 1930s, naval aviation came to play a significant role in American naval exercises.[15]

Drawing on prewar ideas about air power, including the apparent potential of the airship,[16] aircraft were used extensively after the First World War for military tasks within and beyond the boundaries of empire. The British Royal Air Force (RAF) bombed Jalalabad and Kabul during the Third Afghan War in 1919, tribesmen in Central Iraq in 1920,[17] Wahabi tribesmen from Arabia who threatened Iraq and Kuwait in the 1920s, and many other targets.[18] In Somaliland, the twelve DH-9s of the RAF's Unit Z brought the necessary combination of force and mobility, and the Dervish stronghold at Taleh was bombed in 1920, greatly affecting Somali morale. In the Far East, the French used aircraft to help overcome opponents and maintain order in Morocco, Syria, and Vietnam. Air power had become a vital ingredient for imperial control. Bombing suggested that artillery could be replaced, increasing the mobility of ground troops.

There were also advances in technique and technology, as in the mid-1920s, when Arthur Harris, later a key figure in the British bombing of Germany but then commander of a squadron in Iraq, rigged up improvised bomb racks and bomb-aimer sights in slow-flying transport planes, as their slowness was conducive to accuracy.[19] Gasoline, incendiary, and delayed-action bombs were all employed in the 1920s. Planes were developed or adapted for imperial policing duties, for example, the Westland Wapiti, a British day-bomber in service from 1928 to 1939 that was used for army coordination, especially on the North-West Frontier of India. In 1922, the Vickers Vernon, the first of the RAF's troop carriers, entered service. It was based in Iraq.

However, in 1922, the General Staff of the British Forces in Iraq observed, in a military report on part of Mesopotamia, "Aeroplanes by themselves are unable to compel the surrender or defeat of hostile tribes,"[20] a lesson that repeatedly needs to be relearned. Moreover, opponents on the ground soon learned not to be overawed but, rather, to take cover, return fire, and adopt tactics that lessened the impact of air attack. This process affected the British[21] and French, and also the Americans in their operations against the nationalist Sandinista guerrilla movement in Nicaragua. This point was not only true for Western powers. Amanullah, king of Afghanistan, used planes he had obtained from the Soviet Union against tribal opponents, but the latter prevailed in 1929 and he was overthrown.[22]

In the 1920s and 1930s, major advances in aircraft technology, including improved engines and fuels and variable pitch propellers, provided opportunities to enhance military aircraft. This was particularly so for fighters in the mid- and late 1930s, as wooden-based biplanes were replaced by all-metal cantilever-wing monoplanes with high-performance engines capable of far greater speeds, for example, the American P-36 Hawk, German Bf 109,[23] and (less good) Soviet I-16 Rata. The British developed two effective and nimble monoplane fighters, the Hawker Hurricane and Supermarine Spitfire. Alongside early warning radar, they were to help Britain resist the German air onslaught in 1940. In the 1930s, the range and armament of fighters, and the range, payload, and armament of bombers, all increased, notably with the introduction of the American B-17 bomber. Major advances in technology included all-metal monocoque construction and retractable undercarriages.

It was necessary to keep up with the advances made by other powers, and a failure to do so could have dire consequences. Although only a few years of development separated them, the Polish air force was outdated and no match for the German *Luftwaffe* (air force) when the latter attacked in 1939, and the French *Armée de l'Air* suffered from a lack of good aircraft, a shortage of pilots, and poor liaison with the army when the Germans attacked in 1940. The Soviet air force, which had been advanced in some respects in the early 1930s, not least in the development of long-range bombers able to attack Japan, was outclassed by the *Luftwaffe* when Germany invaded in 1941. As a key instance of the diffusion of Western techniques, Japan also developed a modern air force. In 1933, the British Chiefs of Staff Sub-Committee referred to the Japanese air force as having "air equipment and a standard of training fast approaching that of the major European Powers" and presented it as "the predominant factor in the air situation of the Far East."[24]

The likely effectiveness of the new aircraft caused much discussion, a key instance of the way in which technology affected the political and public mood. A report from a British diplomat in Spain during the Civil War circulated to the cabinet in 1937 claimed "the Nationalist air forces that smashed the iron ring of defenses round Bilbao were almost entirely made up of German machines piloted by Germans. The final attack was launched by eighty of these bombers in the air at one time, and they created havoc."[25] The adherents of the new theory of the effects of hostile air power on societies played on the fear of stalemate, or at best attrition, on the front line in any future war, and the belief that only devastating air attacks on civilians would end this impasse.

In Britain, there was strong concern about the likely impact of the German bombing of civilian targets. The Chiefs of Staff Sub-Committee reported in September 1938 on the dangers of war with Germany, focusing on the bombing threat: "there is some reason to believe that the German air-striking force *if concentrated against this country alone,* might be able to maintain a scale of attack amounting possibly to as much as 500–600 tons per day for the first two months of war."[26]

The major impact on public morale of German raids on London in the First World War seemed a menacing augury. It was believed, in the words of the ex- and future prime minister Stanley Baldwin in 1932, that "the bomber will always get through." Air Commodore L. E. O. Charlton developed these themes in *War from the Air: Past-Present-Future* (1935), *War over England* (1936), and *The Menace of the Clouds* (1937).[27] Publications and films emphasized the threat from bombing. In the event, the German air assault in 1940–1941, the Battle of Britain and the Blitz, proved less deadly than had been anticipated.

The speed of aircraft posed great problems for anti-aircraft fire, not least by challenging the processes used in ballistics. It was necessary to track rapid paths in three dimensions and to aim accordingly. Research in the United States was directed accordingly at making effective what in effect was an analogue computer. This research looked toward the development in the 1940s of cybernetics and the idea of systems that were human-machine hybrids.[28]

Even more dramatic ideas were also advanced. In his presidential address to the American Rocket Society in 1931, David Lasser discussed the potential of rocket shells, which could carry their own fuel, and of rocket planes flying at over 3,000 miles per hour and threatening "an avalanche of death."[29] These ideas looked toward German ideas during the Second World War, including for long-range bombers, multi-stage rockets, space bombers, or submarine-launched missiles, which, it was planned, were to be used for attacks on New York City and Washington.[30] Such technology appeared to offer an alternative to a German naval power projection that Allied naval strength precluded, and it also seemed to be a way to hit the American home front and American industrial capability.

THE SECOND WORLD WAR

In the event, conventional air attack was important to the German offensives of the early stages of the Second World War. Air support was important to their success. Despite the vulnerability of the German Ju-87 or Stuka to modern fighters, ground-support dive-bombing proved valuable, especially in Poland (1939), Norway (1940), France (1940), and Greece (1941). Furthermore, the terror bombing of cities—for example, Warsaw in 1939, Rotterdam in 1940, and Belgrade in 1941—was seen as a way to break the will of opponents and certainly helped lead to a sense of total vulnerability, encouraging surrender, although the bombing of London in 1940–1941 did not bring Britain to terms. Pursuing air dominance and air-land integration,[31] the *Luftwaffe* was designed to further operational warfare with a limited scope and range, which made it deadly in 1939 and 1940 against Poland and France. However, the *Luftwaffe* was unsuccessful in strategic warfare, such as the Battle of Britain in 1940, or war with the Soviet Union, or the ability to project itself into the Atlantic.

The inadequately prepared and poorly planned Germans were outfought in the sky when they attacked Britain in 1940 in the Battle of Britain. The RAF had this potential because it possessed aircraft that were the equal to those in the *Luftwaffe,*[32] while the Germans never deployed their full strength at any one time.[33] Moreover, the British outproduced the Germans so that losses in fighters were quickly made good because of more efficient manufacture. The British outproduced the Germans with replacement fighters during the Battle of Britain because German manufacture was not maximized for war, while Britain quickly developed an efficient system that drew on superior British engineering and management. In addition, Britain benefited from an integrated air-defense system. Alongside the good fighters, there were effective sensors, notably radar, and the appropriate command and control mechanisms for controlling the firepower. The *Luftwaffe* was also primarily intended to act in concert with German ground forces, something that was not possible in this self-contained aerial battle.

The *Luftwaffe* was unable to defeat the RAF and thus failed to gain the air superiority over the English Channel and southern England necessary for *Operation Sealion*, the invasion that was projected although with inadequate planning, preparation, and resources. The viability of *Sealion* was dubious even had the Germans achieved air superiority over southern England. There were other fighters farther north and west, as well as the potent threat posed by the Royal Navy. Moreover, the Germans had no experience or understanding of amphibious operations. They lacked proper landing craft. The towed Rhine barges they proposed to rely on could only manage a speed of 3 knots and would have failed to land a significant number of troops had any of them managed to reach the south coast.[34]

Similarly, German air power had serious deficiencies in affecting the war at sea, not least because coordination with the navy was very poor. Despite having acquired bases in Brittany in 1940 from which long-range planes could threaten shipping routes in British home waters, a potential lacking in the First World War, the *Luftwaffe* failed to devote sufficient resources to the Battle of the Atlantic against Allied shipping.

Instead, air power greatly helped the Allies in the struggle against German submarines. The Allies had long-range aircraft capable of sinking submarines, such as the British Sunderland and the American Liberator. Coming to the surface in order to attack or refuel, submarines were vulnerable to air attack. The provision of long-range patrol planes and escort aircraft carriers and the acquisition of air bases in the neutral (Portuguese) Azores proved crucial to Allied victory, notably in closing the "Air Gap" over the mid-Atlantic. Submarines were also visible when they were below the surface if they were at insufficient depth. The snorkel enabled submarines to run their diesels and remain submerged, but not at sufficient depth to avoid detection from the air. A submarine just below the surface was perfectly visible from the air so that submarines operating in waters within range of the anti-submarine patrols had to be either on the surface to enable aircraft watches to be continuously maintained or far enough below the surface to prevent detection from the air. The development of a series of devices, including improved radar and more effective searchlights, was important in the struggle against submarines. From 1943, ASVIII radar (a version of H25) combined with the Leigh light were highly effective at detecting and targeting submarines. Doctrinal and tactical changes were also significant, for example, different patterns of firing depth charges. Communications intelligence in the shape of the timely decryption of U-boat radio messages proved very important in thwarting attacks and in hunting for submarines.[35]

Against the Soviet Union on the eastern front from 1941, German air power was of tactical value, but it lacked the capability to achieve operational and strategic goals. In part, this lack reflected the specifications of the German planes, notably the absence of long-range bombers, but there were more serious problems arising from the space-force ratio, with the Germans not having the number of planes necessary in order to have an impact across the very extensive range of the battle zone. There were also the problems posed by the rapid Soviet revival of their air force, which had been devastated in the initial German attack. The extent to which, despite serious losses in this attack, much Soviet industry remained beyond the range of German power proved important to this revival. In order to provide protection for their forces on the ground, the Germans had to devote large numbers of planes to destroying Soviet aircraft.

Moreover, notably from 1943, the Allied air assault on Germany led to the diversion of German planes from the eastern front to western Europe, principally in order to provide fighter-interceptors but also to make retaliatory bombing raids on Britain, the so-called Baby Blitz. The Germans devoted much of their war industry to the manufacture of fighters and anti-aircraft guns designed to protect Germany, which was an important strategic consequence of the Allied Combined Air Offensive.

Far more German industrial capacity was used for these goals than for the manufacture of tanks. As with many counterfactuals (what ifs), this point raises questions about the likely consequences had priorities been different. It is important not to assume that the transfer of resources, including manufacturing plant and skilled labor, to other priorities was (is) easy, but it is a significant issue, not least because priorities were debated at the time.

During the Second World War, alongside failures in execution, there were also major advances in air capability. In part, these advances were a matter of better aircraft, although there was also an improvement in such spheres as the doctrine and practice of ground support and anti-submarine warfare, at least for the British and Americans. Moreover, the training of large numbers of aircrew was a formidable undertaking, although it paid off, particularly for the Allies. For example, in the Pacific, there was a growing disparity in quality between American and Japanese pilots, a matter of numbers, training, and flying experience. The loss of trained pilots at the Battle of Midway in 1942 proved particularly damaging for the Japanese. By 1944, they had a new carrier fleet replacing the carriers sunk by American dive-bombers at Midway, but it had a crucial lack of experienced pilots.[36]

At the same time, it would be foolish in stressing training to neglect the extent to which the Americans by 1943 and, even more, 1944 benefited in the Pacific and over Europe from better aircraft, as part of a more general improvement in Allied capability, as the potential of the industrial base was deployed in a way that the United States had not been able to do in the early stages of the war. Whereas the Japanese had not introduced new classes of planes, the Americans had done so, enabling them to challenge the Zero fighter that had made such an impact in the initial Japanese advances. Entering service in 1940, the Zero was superior in performance to available American planes, notably the Wildcat; at this stage of the war, the Zero was more maneuverable than most planes. However, aside from American improvements thanks to training in new dog-fighting tactics, the introduction of the new Corsair (entered service 1942) and Hellcat (1943) ensured that the Americans had planes that outperformed the Zero, while, as their specifications included better protection, they were able to take more punishment than Japanese

planes. The Japanese had designed the Zero with insufficient range, and also with the safety of their pilots as a low priority. It lacked armor and self-sealing fuel tanks.

The role of air power in the Pacific War underlined its more general effectiveness at sea where the number of units, and therefore targets, was limited, unlike on land. Aircraft carriers proved particularly prominent targets, as with the major American victories over the Japanese at Midway in 1942 and Leyte Gulf in 1944. Neither Germany nor Italy had aircraft carriers.

The provision of improved aircraft was also important to the British and later Anglo-American air offensive against Germany. In August 1941, a British strategic review noted, "Bombing on a vast scale is the weapon upon which we principally depend for the destruction of German life and morale."[37] On May 19, 1943, Winston Churchill commented, in an address to a joint session of the U.S. Congress, that opinion was "divided as to whether the use of air power could, by itself, bring about a collapse of Germany or Italy. The experiment is well worth trying, so long as other measures are not excluded."[38]

Precision daylight bombing, however, was never as successful as prewar advocates claimed it would be, although problems were not appreciated until experience made them clear. The major problems with bombers were the bombsight and navigation systems. Accurate bombing was a technical issue. Not only was bombing highly inaccurate much of the time, but it was also very costly in aircrew and aircraft. When ground-mapping radar was fitted to British heavy bombers, accuracy increased, but there were still problems with identifying the target, even in daylight and without anti-aircraft guns or enemy fighters; and accuracy remained heavily dependent upon the skill of the pathfinder aircraft that preceded the bombers in order to identify targets. The technology to make precision daylight bombing possible did not really exist. Indeed, until the advent of the smart bomb, which was used from the Vietnam War, precision bombing is a largely misapplied term. There were some notable exceptions, such as the bombing of Amiens prison in 1944 by Mosquitoes of the RAF, but that was down to precision flying and experience rather than technology, although it is hard to see many other aircraft of that time achieving the same outcome.

Despite the limited precision of bombing by high-flying planes dropping free-fall bombs, strategic bombing was, in the event, crucial to the disruption of German logistics and communications, largely because the less precise area bombing that was used as an alternative to precision bombing was eventually on such a massive scale. An article in the *Times* of May 1, 1945, significantly entitled "Air Power Road to Victory . . . 1939 Policy Vindicated," claimed that reductions in oil output due to air attack had affected German war potential in all spheres, and that "neither his air force nor his army was mobile." Indeed, the German oil system had been deliberately and successfully targeted in the bomber offensive.

More generally, area (rather than precision) bombing disrupted the German war economy, although it also caused heavy civilian casualties, notably, but not only, at Hamburg in 1943 and Dresden in 1945. Moreover, by 1943, Anglo-American bombing had wrecked 60 percent of Italy's industrial capacity and badly undermined Italian morale, encouraging the sense that Mussolini had failed. This belief contributed greatly to his overthrow that year, although the Allied invasion of Italy was more significant.

The air attack on Germany also led to the Germans diverting much of their air force and anti-aircraft capacity to home defense, rather than supporting front-line units, and also to an emphasis on the production of anti-aircraft guns rather than other pieces of artillery. For example, the success of the British Dambusters raid in breaching German dams near the Ruhr in 1943, and thus in hitting the production of the hydroelectric power that helped industrial production, led to a major commitment of anti-aircraft guns, labor, concrete, and other resources to enhancing the defenses of these and other dams. This commitment resulted in a reduction in the availability of concrete and workers for work on the defenses of the Atlantic Wall against Allied invasion.

The casualties inflicted by bombing have since become a matter of great controversy, notably in Germany but also in Britain, but too little attention has been devoted to the expectations, from both domestic opinion and the Soviet Union, that major blows would be struck against Germany prior to the opening of the "Second Front" by means of an Anglo-American invasion of France. The delay of this invasion, from first 1942 and then, far more, 1943, led to great pressure for alternative action. As such, it matched the pressure on the Western Allies in the First World War to mount attacks in 1915 and 1916, in order to reduce the strain on Russia, pressure that led both to the Gallipoli operation of 1915 and to offensives on the western front. In 1942–1943, the comparable pressure was encouraged by Allied concern about a possible separate peace between Germany and the Soviet Union. There were, indeed, tentative soundings. As far as the domestic mood in Britain was concerned, the Germans had not only begun the bombing of civilian targets during the Second World War but, with the coming of the V-1s and V-2s in 1944, also launched missiles against British cities, again causing heavy civilian casualties.

However, especially prior to the introduction of long-range fighters, bombers were very vulnerable. The American B-17 was heavily armed in the belief that the aircraft could defend itself, but reality proved otherwise. German day-fighters learned to attack head-on because the B-17's top turret could not fire forward. As a result, in a classic instance of the action-reaction cycle, a forward-firing chin turret with two remotely operated.50-caliber Brownings was added with the B-17G. There were also tactical issues. B-17s were supposed to fly in box formations of four, designed to provide mutual fire support, but once the box was broken, the aircraft became easy targets. Diving steeply onto the formations, or attacking from above and behind, gave the German fighters the edge.[39]

Cripplingly heavy casualty rates occurred in some raids, for example, those of the American Eighth Air Force against the German ball-bearing factory at Schweinfurt in August and October 1943. Nineteen percent of the planes on the August 17 raid were lost. The majority of the bombers were lost to German fighters, with anti-aircraft fire and accidents accounting for the rest. The target of these raids reflected the belief that advanced manufacturing was important to the war economy and an important target. Conversely, the Soviets benefited because much of their industrial plant was beyond the range of the *Luftwaffe*. So also was all of that of the United States.

The absence of a need to defend American industrial capacity was a contributory factor to the ability there to focus so many resources on production for overseas operations, including the application of new advances in the mass production of improved weaponry. There was also a labor dimension. The American emphasis on a mechanized and relatively high-tech military entailed (by relative standards) a stress on machines, not manpower, in the American army. As a consequence, a larger percentage of the national labor force worked in manufacturing than in the case of Germany or Japan. Cultural factors also played an important role, as the Americans (like the Soviets and British) were far readier to use women in manufacturing than either the Germans or the Japanese. American agriculture was also more mechanized than its German and Japanese counterparts. Furthermore, the speedy expansion of the fiscal strength of the American federal government played a significant role in encouraging an unprecedented surge in war production.

The Allies aimed strategic bombing against aircraft factories, industry, transport, political targets, and civil society. However, it proved difficult to produce an effective offensive system, let alone vindicate the hopes of prewar theorists eager to see air attack as a swift means to victory. British night attacks on Berlin from November 18, 1943, until March 31, 1944, which, it had been promised, would undermine German morale, led instead to the loss of 492 bombers, a rate of losses that could not be sustained. In the British raid on Nuremberg of March 30–31, 1944, 106 out of the 782 bombers were lost, with only limited damage to the city and few German fighters shot down. This failure resulted in the end of the bomber-stream technique of approaching the target.

Strategic bombing, however, was made more feasible by four-engine bombers, such as the British Lancaster and the American B-29, as well as by heavier bombs and developments in navigational aids and training. British night bombing was improved by much electronic and radar equipment, which the Germans countered with developments of their own. The Lancaster had a very advanced communications system for its time, and British-built Lancasters were fitted with the R1155 receiver and T1154 transmitter, ensuring radio direction-finding. As an instance of action-reaction cycle, the Lancaster's H2S ground-looking navigation radar system, however, could eventually be homed in on by the German night-fighters' NAXOS receiver and had to be used with discretion. The H2S was supplemented by Fishpond, which provided additional coverage of aircraft attacking from beneath and displayed it on an auxiliary screen in the radio operator's position. Fishpond was designed

to counter German night-fighters with upward firing cannon fitted in the fuselage so that they could fly parallel with the bomber but under it before shooting it down. Monica, rearward-looking radar designed to warn of night-fighter approaches, served, however, as a homing beacon for suitably equipped night-fighters and was therefore removed. Similarly, the ABC radar-jamming equipment could be tracked by the Germans, leading to heavy casualties. The development of radar was shown with the Village Inn, a radar-aimed rear turret fitted to some Lancasters in 1944. Moreover, with Oboe and Gee-H, the British developed very accurate navigation systems.

There was also an improvement in the bombs themselves. Thus, the British attempts to sink the German battleship *Tirpitz* were finally successful thanks to the development of the 12,000-pound Tallboy bomb, two of which hit the ship in November 1944.

Because heavily armed bomber formations lacking fighter escorts proved less effective in defending themselves than had been anticipated, the introduction of long-range fighter escorts for the bombers was important, especially the American P-38s (Lightnings), P-47s (Thunderbolts), and P-51s (Mustangs). Both of the latter used drop fuel tanks, which enabled fighters to reach German airspace and still engage in dogfights. The Mustangs, of which fourteen thousand were built, were able not only to provide necessary escorts for the bombers but also, in 1944, to seek out German fighters and thus win the air war above Germany. This success contrasted with the *Luftwaffe*'s failed offensive on Britain in 1940–1941, an offensive that had been less well supported. The drop fuel tanks were key to the ability of the Mustangs and Thunderbolts to hunt German fighters over Germany.

The Mustangs' superiority to German interceptors was demonstrated in late February and March 1944, when, especially in "Big Week," major American raids in clear weather on German sites producing aircraft and oil led to large-scale battles with German interceptors. Many American bombers were shot down, but the *Luftwaffe* also lost large numbers of planes and pilots. The latter were very difficult to replace, in large part because German training programs had not been increased in 1940–1942, as was necessary given the scale and length of the war, and this problem helped to ensure that, irrespective of aircraft construction figures, the Germans would be far weaker. The large number of German pilots shot down in 1943–1944 ensured a decline in German quality, not least because there was insufficient training time (and fuel) for the new generation of pilots. The key element of skill was demonstrated by Erich Hartmann, the highest-scoring German ace, whose achievement was not so much due to the superiority of his Bf109 over Soviet fighters (or even Mustangs, of which he shot down four in one sortie in June 1944) but his skill in using the machine at his disposal.

Toward the end, the Germans, suffering from their loss of control over Romanian oil production in 1944 as a result of the Soviet advance, could not spare the fuel for training, while a lack of training time was also a consequence of the shortage of pilots. In 1943, the Allies did not yet have sufficient air dominance to seek to isolate an invasion zone, but, by the time of the Normandy landings on June 6, 1944, the Germans had lost the air war.[40] This contrast with the earlier situation, like that in the Battle of the Atlantic against German submarines, was one of the reasons why the Allies were wise to delay the opening of a second front by invading France until 1944. The shortage of fuel encouraged the process by which members of the *Luftwaffe* were used for ground warfare.

The Allied invasion of Normandy in 1944 also displayed other advantages of air power in the shape of delivering troops by parachute and glider landings. These troops proved important in securing the flanks of the Allied landings, notably by dropping American parachutists behind Utah Beach and by British glider-borne troops seizing Pegasus Bridge to the east of the British landings. The botched American air-drop was not helped by the planes being flown by crews who had no night drop experience and an unexpected bank of cloud that made the pilots disperse wildly for fear of collision. What was remarkable about the dispersed troops on the ground was that the vast majority went about trying to fulfill their tasks even though they were often with men they did not know.

However, the effectiveness of the parachutists owed much to the rapid advance of troops from the landing sites, as the former lacked the necessary armaments to resist armored attack. As yet, there had not been the development of helicopters, which were to provide the basis for new capabilities in vertical envelopment, ground support, and resupply.

On D-Day, much of the supporting firepower for the invasion force was provided by British and American warships, whereas bombers proved unable to deliver the promised quantities of ordnance on target on time. The targeting of the Atlantic Wall fortifications by warships and bombers was not as good as it should have been so that many of the casemates and bunkers were not hit, while the Allies overestimated how effective shells and bombs would be against concrete. Most gun emplacements that were put out of action by warships or bombers along the Atlantic Wall had their guns badly damaged rather than their concrete casements or bunkers destroyed in the action. However, the Normandy campaign also saw the successful use of close-air support for Allied land forces, notably with the cab-rank system provided by the 2nd Tactical Air Force.[41]

At a strategic level, the transport capabilities of aircraft were seen in the Anglo-American delivery of nearly 650,000 tons of *matériel* from India over the "Hump," the eastern Himalayas, to the Nationalist forces fighting the Japanese in China in 1942–1945. This achievement represented an enormous development in air transport.[42] Another key capability was provided by aerial intelligence, which became crucial to Anglo-American operational planning.[43]

By late 1944, the American air assault on Japan itself was gathering pace. Initially, the American raids were long distance and unsupported by fighter cover, as fighter range was less than that of bombers. This situation led to attacks from a high altitude, which reduced their effectiveness. The raids that were launched were hindered by poor weather, especially strong tailwinds, and by difficulties with the B-29's reliability, as well as the general problems of precision bombing within the technology of the period.

From February 1945, there was a switch to low-altitude night-time area bombing of Japanese cities. The impact was devastating, not least because many Japanese dwellings were made of timber and paper and burned readily when bombarded with incendiaries, and also because population density in the cities was high. Fighters based on the recently conquered island of Iwo Jima (3 air hours from Tokyo) from April 7, 1945, could provide cover for the B-29s, which had been bombing Japan from bases on the more distant island of Saipan since November 1944. Carriers could not provide a base for planes of this size and air attacks of this scale. Thus, the dependence of technology on operations was abundantly shown, in the shape of the hard-fought American conquest of island bases: Saipan had been captured in the summer of 1944. Japan's overrunning in 1942 and 1944 of air bases in China that the Americans had hoped to use as an alternative was significant in shaping American strategy and the geopolitics of conflict that provided a context for the application of technology.

Weaknesses in Japanese anti-aircraft defenses, both planes and guns, eased the American task and made it possible to increase the payload of the B-29s by removing their guns. Although the Japanese had developed some impressive interceptor fighters, especially the Mitsubishi AbM5 and the Shiden, they were unable to produce many due to the impact of Allied air raids and of submarine attacks on supply routes, and they were also very short of pilots. In 1944–1945, American bombers destroyed over 30 percent of the buildings in Japan, including over half of the cities of Tokyo and Kobe. The deadliness of bombing was amply demonstrated.[44]

JET AIRCRAFT

In 1930, Frank Whittle, a British air force officer, patented the principles that led to the first gas turbine jet engine, which he first ran under control in 1937. His innovation was rapidly copied, and the Germans in 1939 and the Italians in 1940 beat the British jet into the air. The jet fighter, however, arrived in service too late to affect the course of the Second World War.

A similar point could be made about guided bombs and rockets, on both the Allied and Axis sides. Accuracy was a major problem for the guided weapons developed by both sides.[45] The Germans used Fritz-X radio-guided bombs against ships in the Mediterranean in 1943. Some were sunk, notably the Italian battleship *Roma* on the way to surrender to the Allies, while others suffered severe damage, but some bombs missed. The Germans also used the Henschel Hs293 radio-guided glider bomb quite successfully and sank up to seven ships with it. The Germans also employed these bombs against bridges in Normandy in August 1944, but less successfully.

In 1944, jets entered service: the British Meteor capable of 490 miles per hour/788 kilometers per hour, and the German Messerschmitt (Me) 262. The Allies found that the speed of the latter (540 mph/870 km) made it difficult to tackle. The tactics of the Me-262 posed serious problems for the Allies. It could seize the initiative effectively, diving at high speed through the Allied fighter screen and continuing under the bombers prior to climbing up in order to attack the bombers from behind. If, however, the Me-262 was involved in a dogfight, it was vulnerable, as it had a poor rate of turn. There were also efforts to catch it when even more vulnerable, on takeoff and particularly as it was coming in to land. The plane had slow acceleration.

Moreover, the Germans had insufficient numbers of the Me-262 to transform the course of the war, as they hoped they could do till near the war's close;[46] and the plane's late entry into the war was also significant, as was a shortage of trained pilots. The Germans had only focused production on the Me-262 after considerable delay, in part because Professor Messerschmitt was also keen to continue work on his projected Me-209, a conventional piston-engine plane. There was also separate work on other jet planes, the Arado Ar-234, which was designed as a jet bomber and reconnaissance aircraft, the Ju-287, a four-engine jet bomber, the Me-163 rocket plane, and the He-162.

Allied air raids also caused delays and problems, not least a shortage of fuel, exacerbating the serious difficulties in the German economy arising from poor organization and the mismatch of goals, systems, and resources. This mismatch was seen, for example, in the shortage of raw materials that led to problems with blade fractures in the turbine rotors and of fuel that limited the number of planes that could be put into service. Hence technology was dependent upon resources and fuel sources. This situation was a more serious problem than Hitler's views on the use of the plane, although these were significant. Only 564 Me-262s were built in 1944. Furthermore, the plane had problems, both with the engines and due to its inadequate rate of turn. Many were lost in accidents, in part due to poor reliability.

A problem with the early jets was the lack of thrust from the engines at low speeds, which made dog-fighting difficult. And if the throttle was applied too quickly at slow speed, there was a danger of flameout. This instance demonstrates the importance of engine technology (and materials technology) in the evolution of air power.

To a degree, Hitler squandered the German lead in jet-powered aircraft because of this preference that the Me-262 should not be used as an interceptor of Allied bombers, despite its effectiveness in the role, but rather as a high-speed bomber. Indeed, in June 1944, he ordered its name changed to *Blitzbomber*.[47] Interest in the use of the plane as a bomber led to delay. By the end of the war, 1,430 Me-262s had been built. The plane was subsequently manufactured in Czechoslovakia, where it served in the air force as the Avia S-92 until 1957.[48]

Jet aircraft developed rapidly after the Second World War. The first successful carrier landing of a jet aircraft took place on HMS *Ocean* in December 1945, while the Korean War (1950–1953) saw the first dogfights between jet aircraft. The Communist Chinese intervened in the war in 1950 in support of the North Koreans and against the American-led UN forces backing the South Koreans. The Communist Chinese had only created an air force in November 1949, and their Soviet-trained pilots lacked adequate experience and were equipped with out-of-date Soviet planes. However, the Communist forces were supported by the advanced MiG-15 fighters of the Manchurian-based Soviet "Group 64." Soviet aircraft operated over the Yalu River on the North Korea–China frontier from November 1, 1950.[49] The Soviets initially fought American Shooting Stars, Starfires, and others, and they were no match for the MiG-15, but the introduction of the American F-86 Sabre provided a slightly superior plane. The newer jets turned the balance one way and back again.

Organizational factors were important to American success over Korea, as the rotation system employed by the Soviet pilots greatly undermined their continuity of experience and thus effectiveness. The tactics of dog-fighting had to change because of the higher speeds of jets, which prevented the sort of dog-fighting seen in the Second World War. What had worked with piston engines could not be made to work with jets because of the higher speeds and g-forces when turning, although all the aircraft still used guns, not missiles. The Americans inflicted far heavier casualties in the air and were able to dominate the skies, with serious consequences for respective ground support, although the absence of adequate command integration limited the American exploitation of this advantage.

At the same time, the value of air support did not diminish the heavy American reliance on ground firepower in order to blunt Chinese attacks, and understandably so given the damage that could be inflicted by artillery as well as the problems bad weather created for aircraft. When James Van Fleet became commander of the American Eighth Army in Korea in 1951, he insisted on a greatly increased rate of artillery fire, including 300 rounds per day per 105 mm howitzer. In resisting the Chinese offensive from May 17 to 23, 1951, the twenty-one artillery battalions assigned to the Tenth Corps fired 309,958 rounds.[50]

The Chinese dictator Mao Zedong had been encouraged by success in the Chinese Civil War (1946–1949) to believe that the technological advantages, especially in air power, which the Americans enjoyed, could be countered, not least by determination. However, as had been the case with the Japanese in the Second World War, American resilience, resources, and fighting quality were underestimated by the Chinese. In the sole war between great powers since the Second World War, the Chinese advance, initially successful in driving the Americans from what became North Korea, was then repeatedly checked.

It was not until the introduction of reheat (the afterburner) in the early 1950s that supersonic flight became feasible. The afterburner adds fuel to the air that has already passed through the turbine and adds a huge amount of thrust very quickly. The afterburner can be switched on by the pilot when he needs extra thrust, a process known as running wet.

In the 1950s, jet fighter-bombers, such as the American F-84 Thunderjet, made their first appearance, and they came to play a major role, replacing more vulnerable Second World War period planes. The Americans also deployed long-range jet bombers (B-47s and B-52s), as well as jet tankers (KC-135s). Doctrine was molded by institutional need and politics as much as technology, notably with the emphasis on strategic nuclear bombing rather than close air support, a preference that suited the American air force.

The greater capability of jet aircraft, the extent of the area of operations, and the extent to which the United States did not wish to commit ground troops in much of it led to the enhanced use of air power in the Vietnam War, compared to that over Korea. Over half the $200 billion spent on the war, a sum far greater than that expended by other Western powers on decolonization struggles, went on air operations, and nearly eight million tons of bombs were dropped on Vietnam, Laos, and Cambodia. Indeed, South Vietnam, where the Americans were helping the South Vietnamese resist North Vietnamese and Viet Cong attacks, became the most heavily bombed country in the history of warfare. There were also major American bombing offensives against North Vietnam, which were designed to fulfill both operational and strategic goals: to limit Northern support for the war in the South, and to affect policy in the North by driving the North Vietnamese to negotiate. These goals were not fulfilled to the extent anticipated. In part, this failure may have been due to the limits placed on the bombing of the North, especially, in 1965–1968, the harbors, notably Haiphong, through which Soviet military assistance arrived; but the air war also raised more general questions about the effectiveness of bombing.

However, as in other conflicts, there was a learning curve, with increased effectiveness in the delivery of air power reflecting improved technique as well as weaponry. This was seen in 1972, both in the Linebacker bombing offensives against the North and in opposing the North Vietnamese Easter Offensive in the South. Greater effectiveness in 1972 owed something to bombing the North Vietnamese harbors but was also due to a marked improvement in American air capability that reflected both the displacement of earlier doctrine, in response to the varied needs of the Vietnam War, and the use of laser-guided bombs. The latter compensated for earlier limitations of accuracy in bombing caused by flying at high altitudes above deadly anti-aircraft fire.[51]

As with the tank, the bomber did not come into its own until the advent of smart munitions. When the Americans tried to hit bridges in Vietnam, they largely failed despite many raids. A single bomb, a Paveway I laser-guided bomb dropped by an F-4 Phantom on the mighty Thanh Hoa Bridge, a key link on the supply route from China, on April 27, 1972, achieved an effect that numerous sorties and tons of ordnance had failed to achieve earlier during Operation Rolling Thunder. The bridge was subsequently hit twice more with Paveways. Thus, irrespec-

nance. However, precision-guided munitions are much more expensive than unguided iron bombs.

As an instance of the competitive advance of technology, the Americans had used electronic jamming in order to limit attacks on their planes by missiles and radar-controlled guns, only for the North Vietnamese to aim at the jamming signals.[52] As a result, countermeasures aircraft were an essential element of any attacking force. The United States also benefited in 1972 from advances in ground-based radar technology, which helped in the direction of B-52 strikes.

The range of capabilities offered by technological advances and also of specifications required was further demonstrated by the greatly increased use of helicopters. They were important in supplying positions and in applying the doctrine of air mobility: airlifted troops, including the new 1st Cavalry Division Airmobile, brought mobility and helped take the war to the enemy. The Americans flew about 36,125,000 helicopter sorties during the war, including 7,547,000 assault sorties, in which machine guns and rockets were used, plus 3,932,000 attack sorties. Over 2,000 helicopters were lost to hostile causes (and many others to accidents), but heavier losses had been anticipated. Helicopters had become more reliable, more powerful, and faster than in the 1950s, and their use helped to overcome guerrilla challenges to land supply and communication routes.[53]

Air power became increasingly significant in the Vietnam War as unwillingness to suffer casualties and then a wish to limit and, finally, end the ground commitment led to an increase in efforts and research into means of removing the soldier from the battlefield. Alongside air power came developments such as scatter mines, submunitions, and camouflaged listening devices, as well as body armor and specialized munitions, such as flechettes. Air power did not lead to American victory, but it played a major role in preventing defeat in the 1960s and early 1970s. Moreover, air power provided the context in which a compromise peace could be negotiated. The absence of American air assistance in 1975 when a new North Vietnamese offensive conquered South Vietnam indicated the importance of air support, although the conquest also reflected the contrasts in fighting quality and determination between the combatants, as well as more specific flaws on the part of much of the

Air power was also very important, and increasingly so, in the Arab-Israeli wars. This importance was clearly displayed in the Six Days War in 1967 when Israel mounted a preemptive attack on Egypt in order to deal with the growing aggression of its unpredictable ruler, Colonel Gamal Abdul Nasser. The Israeli assault began on June 5 with a surprise attack on the Egyptian air bases, launched by planes coming in over the Mediterranean from the west, in other words not the direction of Israel. The Egyptians, who had failed to take the most basic precautions in protecting their planes on the ground, lost 286 planes in just one morning. In addition, their runways were heavily bombed, which reduced their value to Egypt's remaining planes and also reduced the usefulness of these planes. Nasser falsely claimed that the Americans and British had been responsible for the air assault.

Gaining air superiority rapidly proved crucial to the subsequent land conflict, as Egyptian ground forces were badly affected by Israeli ground-support attacks. Jordan joined in that day on the Egyptian side, only to have its air force destroyed by the Israelis, and the West Bank was subsequently overrun by them, their ground forces benefiting greatly from air superiority. The same fate affected Syria, with the Golan Heights overrun. The Israelis benefited greatly from the sequential nature of their campaigning, notably being able to focus first on Egypt.[54]

Air power proved important anew when large-scale conflict resumed in 1973 in the Yom Kippur War. In 1968, the United States had decided to provide Israel with F-4 Phantom jets, an important step in the definition of the Arab-Israeli struggle in terms of the Cold War. Nevertheless, in 1973, Israel's air power was badly affected by the Egyptian use of effective Soviet anti-aircraft missiles. However, once the Egyptian armor had advanced beyond the range and cover of supporting fire, it was badly mauled, and the Israelis eventually prevailed both in the air and on the ground.

In 1978, Israel advanced into southern Lebanon in an attack on the Palestine Liberation Organization. In this operation, the Israeli advance benefited from close air support. In 1982, Lebanon was invaded anew, the Israelis gaining the advantage over the rival Syrians who were established there. Again, air power proved important. The Syrians initially fought well, but, once their missile batteries in Lebanon had been

with American Sidewinder missiles and supported by electronic countermeasures, the Syrians proved vulnerable to Israeli attack, now bolstered by clear mastery in the air.[55] The enhanced capabilities of anti-aircraft weapons ironically also made them more vulnerable to such electronic countermeasures, which was an instance of the limitations of more sophisticated weaponry.

The Sidewinder illustrated the development of weapon types. The AIM-9L was the first "all-aspects" variant of the Sidewinder. It could be fired head-on, which opponents were unprepared for. Previous variants had to chase the target, and therefore had to be fired from behind it. All-aspects capability was a considerable technological advantage in aerial combat. First used in combat by the Americans against two Libyan-flown Soviet-made SU-22s in 1981, this version was employed in the Falklands War of 1982, where it had an approximately 80 percent kill rate and was responsible for shooting down seventeen Argentine planes. Previous variants had a kill rate of only 10–15 percent.

Israeli air (and tank) power proved less effective in Lebanon in 2006 than in 1982. Air operations were unable to end rocket attacks on Israel, including on the major city of Haifa, attacks that led many Israeli civilians to move south temporarily. About five thousand rockets were fired by Hezbollah, dramatically confounding Israel's capacity for deterrence, a capacity that was an intended consequence of military superiority. However, a large percentage of the long-range Hezbollah rocket systems were destroyed in 2006. In a wider strategic perspective, Iran appears to see Hezbollah's strength in Lebanon as a deterrent to Israeli air action against Iran's nuclear program, which is a reminder of the potentially interacting character of different military capabilities, and notably so in the case of deterrence.[56]

Jet aircraft also enhanced the auxiliary functions of air power, supply, and reinforcement. Air power could be used to move large numbers of troops overseas more rapidly than ships. In response to disorder in the Dominican Republic in the West Indies in the spring of 1965, the United States airlifted 23,000 troops in less than 2 weeks. Considerable Soviet airlift capacity, in turn, was demonstrated in resupplying Egypt and Syria during the Yom Kippur War, and in Angola in 1975, helping to thwart a takeover by pro-Western forces. Airlift was very significant in pia, and elsewhere. Indeed, the Caribbean island of Grenada acquired strategic significance as a result of the development of its airport by the Cubans as an airlift base, and concern about this capability helped explain American invasion in 1983. Soviet airlift capacity increased in the 1970s, with the development of long-range heavy-lift transport aircraft and an increase in the number of transport planes to 600 by 1984.[57]

Due in part to airlift, airports became key points of operational importance, and seizing control of them became a crucial goal in coup attempts. Soviet troops were flown into Czech airports on the night of August 20–21, 1968, when the Czech government was overthrown thanks to a Soviet-led invasion, most of which was mounted by land. The Antonov transport aircraft that were used in 1968 were able to move tanks as well as troops.

The effectiveness of air power, however, was a matter of contention. The defeats of Iraq in 1991 and 2003 were seen as, in large part, triumphs for American air power and concepts of air power. Iraqi air defenses were rapidly overcome and effective support was then provided for ground operations. Stealth and precision were characteristics of air attacks that overcame the entire Iraqi air-defense system. Technology played a major role, both with enhanced weaponry and with the use of precision-guided munitions. Thermal-imaging laser-designation systems guided bombs to their targets, and pilots launched bombs into the "cone" of the laser beam in order to score a direct hit.[58]

However, in 1999, the effectiveness of the major NATO (North Atlantic Treaty Organization) air assault on Serbia that was designed to achieve a Serbian withdrawal from Kosovo was called into question. This assault suffered the loss of only two aircraft, but the subsequent Serbian withdrawal from Kosovo revealed that NATO estimates of the damage inflicted by air attack, for example, to Serb tanks, had been considerably exaggerated. Benefiting from the limitations of Allied intelligence information and its serious consequences for Allied targeting, and from the severe impact of the weather on air operations (a large number cancelled or affected), the Serbs, employing simple and inexpensive camouflage techniques that took advantage of terrain and wooded cover, preserved most of their equipment, despite ten thousand NATO strike sorties.

The NATO operations in Serbia highlighted several serious problems with sophisticated technological weapon systems. Not the least of these is the unrealistic expectation among the public, and also among part of the military, for every operation to be conducted "clinically" and with near 100 percent success. Aside from the point that nothing is 100 percent reliable, there is the issue of the decline of reliability with complexity. Human error, the weather, and the actions of the enemy, the last a major factor often ignored by the press, the public, and even the military, all affect outcomes. Moreover, there is the problem that failure is not always understood in terms of the decisive cause of it. In addition, unfulfilled expectations lead to false conclusions. As far as 1999 was concerned, the Serbs were very canny, while NATO was often deprived of that most essential ingredient for success, good intelligence. The lack of success in hitting Serb tanks showed the importance of having special forces on the ground to light up targets with lasers, although bad weather would still have been a factor.

The air assault in 1999 also revealed the contrast between output (bomb and missile damage) and outcome: the air offensive did not prevent the large-scale expulsion of Kosovar civilians from their homes by the Serbs, and this expulsion actually increased as the air attack mounted. The eventual Serb withdrawal may have been due more to a conviction, based in part on Russian information, that a NATO land attack was imminent. The crisis indeed suggested that air power would be most effective as part of a joint strategy, as with the NATO intervention in Libya in 2011, although in Libya the situation on the ground was more propitious than in Kosovo in 1999. Although the damage to the Serbian army from air attack was limited, the devastation of Serbia's infrastructure, in the shape of bridges, factories, and electrical power plants, was important, not least because it affected the financial interests of the elite as well as their morale and the functioning of the economy. Thus, there was a marked contrast between the limited tactical, and possibly more effective strategic, impact of air power.[59] Success lay in hitting the infrastructure rather than the military.

American air power also played a major role in Afghanistan in the overthrow of the Taliban regime in 2001. The air attack helped switch the local political balance within Afghanistan. Impact analysis, however, revealed that bombing was subsequently less effective in support of the ground operations near Tora Bora in December 2001 and in Operation Anaconda, east of Gardez the following March. This decline in effectiveness was attributed to the Taliban ability by the time of the Tora Bora campaign to grasp the relevant parameters of air power and to respond by taking advantage of terrain features that could be used for camouflage and cover. The differences between effort, output, and outcome were amply demonstrated in Afghanistan,[60] although the Americans had greater air effectiveness than the Soviets had done in Afghanistan after the introduction of Stinger mobile surface-to-air missiles in 1996. These missiles limited the freedom of the Soviet Mi-24 helicopter gunships.[61]

In 2003, against Iraq, the Americans made particular use of JDAMs (joint direct attack munitions), which used GPSs (global positioning systems) to convert dumb bombs into smart munitions. This bolt-on guidance package is superior to infrared and laser guidance systems, which can be disrupted by poor weather conditions. JDAMs are not affected by poor visibility or bad weather. An upgrade that included a terminal laser guidance system enabled the bomb to hit a moving target. This system was first used on operations over Iraq in 2008.

Air power is seen as having a clear role in counterinsurgency (COIN) warfare. It constrains opponents' freedom of maneuver and options, and thus plays a part in shaping the battle space.[62] In 1994, the Mexican Armed Forces used helicopter gunships and rocket-equipped aircraft to support their successful attempt to retake the towns seized in the Zapatista guerrilla uprising in the province of Chiapas.[63]

ATOMIC BOMBS

The Second World War was brought to a rapid close in 1945 when the dropping of two atomic bombs by the Americans demonstrated that Japanese forces could not protect the homeland. At the Potsdam Conference, the Allies had issued the Potsdam Declaration, on the evening of July 26, demanding unconditional surrender as well as the occupation of Japan, Japan's loss of its extensive overseas possessions, and the establishment of democracy in the country. The alternative threatened

was "prompt and utter destruction," but, on July 27, the Japanese government decided to ignore the declaration. Atom bombs were dropped on Hiroshima and Nagasaki on August 6 and 9, respectively. This devastation and the revelation of total vulnerability transformed the situation, leading the Japanese, on August 14, to agree to surrender unconditionally, although that decision also owed something to Soviet entry into the war on August 8, invading Japanese-occupied Manchuria, which removed any chance that the Soviets would act as mediators for a peace on more generous terms.

The creation of the atomic bomb was the culmination of an intense period of rivalry between the powers in conception and application. That the atomic bomb was created in the United States was indicative not only of the intellectual resources available to it but also of the nature and scale of activity possible for an advanced industrial society. It was the product not only of the application of science but also of the powerful industrial and technological capability of the United States and the willingness to spend about $1.9 billion in rapidly creating a large new industry, a sum that is far larger in current values.[64] The electromagnets needed for isotope separation were particularly expensive and required 13,500 tons of silver. Major industrial concerns were able to apply their expertise, resources, and manufacturing techniques to participate in the Manhattan Project to make the bombs, the chemical company DuPont producing the necessary plutonium. The American belief in the certainty of improvement through technological progress played a significant cultural role in encouraging support.[65]

The Germans and Japanese were both interested in developing an atomic bomb, but neither made comparable progress. The *Uranverein*, the German plan to acquire nuclear capability, was not adequately pursued, in part because the Germans thought it would take too long to develop. The German conviction that the war would, or could, be finished long before the bomb would be ready was encouraged by their numerous military successes in 1939–1941, but it was an instance of overconfidence adversely affecting the development of new technologies. The Germans were also affected by hostility to what the Nazis termed "Jewish physics," as well as the consequences of overestimating the amount of U-235 required to manufacture a bomb.[66]

In some respects, the use of atomic weaponry suggested the obsolescence, and indeed limitations, of recent military practices. More people were killed in the American conventional bombing of Japan earlier in 1945—the firebombing of Tokyo alone on March 10, the first major low-level raid on the city, killing more than 83,000 people in one night—but that campaign required far more planes and raids: on March 10, 334 B-29s were sent, of which 14 were lost.[67] Indeed, the use of atom bombs, like, at a far more modest level, that of jet aircraft by the Germans in the closing stages of the war in Europe, pointed the way toward a capability for war in which far fewer units were able to wield far more power. This situation is especially relevant for symmetrical warfare.

At the same time, the new use of atomic weaponry in 1945 reflected not the limited capacity of preexisting forms of warfare but the extent to which they had created a military environment in which, in the event of determined conflict between major powers, success was almost too costly, while failure definitely was. In short, a form of total warfare existed that would, it was hoped, now be short-circuited by modern warfare in the shape of the atomic bomb, the latter a logical consequence of strategic bombing doctrine. The heavy Japanese and American losses suffered from campaigning in Iwo Jima, Okinawa, and Luzon earlier in 1945 suggested that an Allied invasion of Japan, in the face of a suicidal determination to fight on, would be very costly. The Japanese homeland army was poorly trained and equipped and lacked mobility and air support, but, fighting on the defensive, it would have the capacity to cause heavy casualties, particularly as it was unclear how to obtain the unconditional surrender that was an Allied war goal. General Douglas MacArthur remarked in April 1945 that his troops had not yet met the Japanese army properly, and that, when they did, they were going to take heavy casualties.[68]

A rapid and complete victory seemed essential in order to force Japan to accept terms that would neutralize its threat to its neighbors. In addition, it was necessary to secure the surrender of the large Japanese forces in China and Southeast Asia. The dropping of the atom bombs showed that the Japanese armed forces could not protect the nation, and it was therefore a major public blow to Japanese militarists. A statement issued

on behalf of President Harry Truman shortly after the first atomic bomb was dropped on Hiroshima declared,

> Hardly less marvelous has been the capacity of industry to design, and of labor to operate, the machines and methods to do things never done before, so that the brain child of many minds came forth in physical shape and performed as it was supposed to do. . . . It was to spare the Japanese people from utter destruction that the ultimatum was issued at Potsdam. Their leaders promptly rejected that ultimatum. If they do not now accept our terms they may expect a rain of ruin from the air. . . . We are now prepared to obliterate more rapidly and completely every productive enterprise the Japanese have above ground in any city. We shall destroy their docks, their factories, and their communications. Let there be no mistake; we shall completely destroy Japan's power to make war.

Critics of American policy claim that the dropping of the bombs represented an early stage in the Cold War, with their use designed to obtain peace on American terms and both to show the Soviet Union the extent of American strength—in particular a vital counter to Soviet numbers on land—and to ensure that Japan could be defeated without the Soviets playing a major role. These goals may have been factors, but there seems little doubt that the prime use of the bombs was to avoid a costly invasion. Truman wrote on August 9, "My object is to save as many American lives as possible, but I also have a human feeling for the women and children of Japan."[69]

Had the war lasted until 1946, the destruction of the rail system by American bombing would have led to famine, as it would have been impossible to move food supplies. There were already systematic American bombing attacks on Japanese marshalling yards and bridges. One important technological advance of the nineteenth century, the railway, was now newly vulnerable to a weapons system that was not conceived of then. There would also have been more deliberate large-scale bombing attacks on the cities. Aside from the raid on Tokyo on March 10, 1945, there had been heavy raids on April 13 and 19 and May 23 and 25.[70] Similarly, there were heavy raids on Nagoya on March 12 and 20 and May 14 and 16. The Japanese anticipated the loss of twenty million citizens if an invasion was mounted. The dropping of the second atomic bomb suggested that such losses could be inflicted without the Americans taking any casualties themselves. The apparently inexorable process of destruction seen with the dropping of this bomb on Nagasaki had a greater impact on Japanese opinion than the use of the first atomic bomb. The limited American ability to deploy more bombs speedily was not appreciated.[71]

Beliefs in inevitable security, inherent exceptionalism, and technological utopianism all underlay the Americans' sense that they alone should have the bomb.[72] In January 1946, Major-General Leslie Groves, the head of the atomic bomb project, warned, "Either we must have a hard-boiled, realistic, enforceable, world-agreement ensuring the outlawing of atomic weapons or we and our dependable allies must have an exclusive supremacy in the field, which means that no other nation can be permitted to have atomic weapons."[73] However, America's nuclear monopoly, which appeared to offer a means to coerce the Soviet Union without being fully mobilized, lasted only until 1949.

Then, thanks in part to successful spying on Western nuclear technology, the Soviet Union revealed its development of an effective bomb that was very similar to the American one. This development had required a formidable effort, as the Soviet Union was devastated by the impact of the Second World War, and it was pursued because Joseph Stalin, the Soviet dictator, believed that only a position of nuclear equivalence would permit the Soviet Union to protect and advance its interests. Nevertheless, such a policy was seriously harmful to the Soviet economy, as it led to the distortion of research and investment choices, and militarily questionable, as resources were used that might otherwise have been employed to develop conventional capability.

Even when the United States alone had the bomb, however, the value of the weapon was limited, as it was insufficiently flexible (in terms of military and political application or acceptance of its use) to meet challenges other than that of full-scale war. Thus, the United States did not use the atom bomb (of which they then indeed had very few) to help their Nationalist Chinese allies in the Chinese Civil War (1946–1949), and their allies lost. Similarly, American possession of the bomb did not deter the Soviets from intimidating the West during the Berlin Crisis of 1948–1949.

Nevertheless, the availability of the bomb in the late 1940s encouraged American reliance on a nuclear deterrent, which made it possible to hasten demobilization after the Second World War and to focus on the U.S. Air Force (which was created in 1947), leaving the United States more vulnerable when the Korean War (1950–1953) broke out.[74] For example, there was a grave shortage of artillery units in 1950, while Strafford Barff, the director of British Information Services in Chicago, noted on July 31, 1950, "The inadequacy of American arms and reported inefficiency of some officers and men have come as a great shock."[75]

In this conflict, the American government decided in 1950 not to drop atomic bombs. Instead, the war was fought with a strengthened conventional military, although, in 1953, the use of the atom bomb was threatened by the United States in order to secure an end to the conflict, which indeed occurred.[76]

This outcome encouraged the view that nuclear strategy had a major role to play in future confrontations, as indeed did the cost of fighting the Korean War, in which the advance of Chinese forces had inflicted considerable damage on American forces in early 1951, and the extent to which the conflict had revealed deficiencies in the American military. The war caused a revival in the American army but also led to its growing concern with readiness. Meanwhile, as the NATO countries were unable to match the build-up their military planners called for, there was a greater emphasis, especially from 1952, on the possibilities of nuclear weaponry, both as a deterrent and, in the event of war, as a counterweight to Soviet conventional superiority. The extent to which British and French forces were committed to resisting decolonization struggles, notably the French in Indo-China (and, from 1954, Algeria) and the British in Malaya, contributed to NATO's weakness in western Europe.

The need to respond to Soviet conventional superiority on land and in the air also encouraged an interest both in tactical nuclear weaponry and in the atom bomb as a weapon of first resort. The tactical nuclear weapons that were developed, such as the recoilless Davy Crockett spigot gun, which had a range of 1.25 miles (120 mm M28) and 2.5 miles (155 mm M29), were treated as a form of field artillery. Ground-launched nuclear missiles were intended for a range of targets, including bringing down Soviet bombers.[77] The British followed the Americans, with the army establishing in 1957 its first surface-to-surface missile regiment. This was equipped with Corporal missiles, a tactical nuclear delivery system capable of delivering a 20-kiloton nuclear warhead over a range of 50–80 miles. Its guidance system, however, proved unreliable.

The need to deal with Soviet numerical superiority also led to the development of non-nuclear weapon systems. These included multiple targeting with air-to-air missiles, high first-shot capabilities with tanks, and the sort of munitions that there is now pressure to ban. Although these technological approaches were not initially very successful, the systems became much more effective, but at huge cost.

The use of the atomic arsenal as weapons of first-strike or resort (in other words without prior opposing use) was pushed by Dwight Eisenhower, NATO's first Supreme Allied Commander from 1950 until 1952 and U.S. president from 1953 until 1961. Aware of NATO's vulnerability, he felt that strength must underpin diplomacy for it to be credible. As president, Eisenhower's New Look emphasized strategic air power and downgraded conventional ground forces, much to the anger of the generals.[78] The number of divisions in the army fell from eighteen in June 1956 to fourteen by that December. In December 1955, the NATO Council authorized the employment of atomic weaponry against the Warsaw Pact, even if the latter did not use such weaponry. The American nuclear stockpile rose from 369 weapons in 1950 to over 27,000 by 1962.

Planning the use of such weapons, and how to respond to that by the Soviets, encouraged a modeling of military options, not least employing the new laboratory and computer systems of MIT (the Massachusetts Institute of Technology) and RAND. This modeling, employing calculations that could not be made by the brain, was an important instance of the impact of technological development on the context within which new weapons were assessed. The manufacturing and use of weapons had to be discussed in terms of such systems. Quantitative analysis came to play a major role, both in assessing effectiveness and in seeking to control the all-important issue of financial costs.[79] The revolutionary prospect of Armageddon held out by nuclear warfare[80] encouraged planning and prediction through modeling.

The Cold War following so speedily on the Second World War helped

which began in the First World War and was very prominent in the Second, was sustained. The institutionalization of government direction of, and support for, scientific research encouraged this process, which, in turn, contributed to a conviction of continual technological change.[81] Research, and even more its use, was scarcely value-free. For example, there was an emphasis on the need for unlimited testing of nuclear weaponry and on the difficulties of implementing any test ban.[82]

More generally, technological advances changed the nature of the skill-base. Thanks to weaponry in which machinery played a major role—for example, complex automatic systems for sighting—skill, rather than physical strength, became even more important for soldiering. Moreover, the industrial-age mass production that had been so significant in the world wars was replaced by technological superiority as a central factor in weaponry, and therefore in the economic capability of military powers.

As a key instance of the application of new knowledge, computers, from the 1960s, transformed operational horizons and command and control options. The American Defense Advanced Research Projects Agency took major steps to enhance computing, contributing in the process to the eventual creation of the internet. It also developed a Strategic Computing Initiative that was responsible for advances in technologies such as computer vision and recognition and the parallel processing useful for code-breaking. Code-breaking required the capacity rapidly to test very large numbers of possible combinations.[83] Such technological advances were more effective because they were grounded in earlier organizational developments.[84] The British military was also important in the development of computing. Wartime code-breaking was followed in the United States and Britain by the use of computers in fire-control systems, for example, naval defense against air attack.[85] Military institutions and research were important to other branches of the economy, being central, for example, to technological developments and application in communications.

Effective in heavy industry, although the many tanks produced had pretty crude driving mechanisms by Western standards, the Soviet Union failed to match such advances in electronics. Moreover, the shift in weaponry from traditional engineering to electronics, alongside the develop-between technology, industrial capacity, and military capability. The Soviet Union fell behind militarily, and notably in the 1980s in response to what has been seen as an "information technology revolution."[86] This growing gap with American capability contributed to a Soviet sense of failure that led to pressure for a new politico-economic system, pressure that unwittingly contributed to the unraveling of the Soviet Union by Mikhail Gorbachev, who came to power there in 1985.

Meanwhile, as a reminder of the variety of uses of technology, nuclear power was developed not only as a form of ordnance but also as a means of propulsion. Indeed, it became the key means for powering large aircraft carriers, from the USS *Enterprise,* and submarines. Only nuclear-powered submarines can remain submerged indefinitely. Diesel submarines have to surface to recharge their batteries.

BALLISTIC MISSILES

Dropped from planes in 1945, the potential of atomic weaponry was swiftly to be transformed by the development of ballistic missiles. In 1957, the Soviet Union launched Sputnik I, the first satellite to go into orbit. The launch revealed a capability for intercontinental rockets that brought the entire world within rapid striking range, and thus made the United States vulnerable to Soviet attack, both from first-strike and from counterstrike. Missiles created a vulnerability that had been far weaker in the case of manned bombers. Satellites also offered other capabilities, being used for reconnaissance from 1961 and for communications from 1965.

The development of ablative shields, made from composites, some of them similar to those used in armor, was important to the success of intercontinental ballistic rockets. Many test firings of the German V-2 had proved unsuccessful because the rocket broke up on reentry, and, although the cause was never conclusively determined, it was probably a combination of instability, vibration, pressure, and heat. It was not until the 1950s that the ablative heat shield was devised because of the need to protect a nuclear warhead from burning up in the atmosphere when it reentered. Such a shield works in a complex way; part of the process makes use of the high temperatures on reentry so that the resin in the

In strategic terms, rockets threatened to give effect to the doctrine of air power as a war-winning tool advanced in the 1920s and 1930s, at the same time as their greater speed and range, and lower vulnerability, rendered obsolescent the nuclear capability of the bombers of the American Strategic Air Command, particularly the B-52s deployed in 1955. Thus, the American lead had been leapfrogged,[87] rather as French shell guns and ironclads had threatened to do to the British Royal Navy in the 1830s—1850s (see chapter 3). The development of intercontinental missiles altered the parameters of vulnerability for civil society and ensured that space was more than ever seen in terms of straight lines between launching site and target. Nikita Khrushchev, the Soviet leader, declared in August 1961 that as the Soviet Union had placed Gagarin and Titov in space, they could be replaced with bombs that could be diverted to any place on Earth.

The threat to the United States from Soviet attack was highlighted by the November 1957 secret report from the American Gaither Committee. On January 18, 1960, Allen Dulles, the director of the CIA, told the Senate Foreign Relations Committee that "one of the key facts behind Soviet diplomacy lies in their view of their increasing power in the military field, particularly missiles."[88] The strategic possibilities offered by nuclear-tipped long-range ballistic missiles made investment in expensive rocket technology seem an essential course of action, since they could go so much faster than airplanes and, unlike them, could not be shot down.[89] Sputnik also appeared to prove Soviet claims that they were overtaking the Americans in technological capability, which contributed to a sense of crisis in the United States in the late 1950s.

The United States had also been developing long-range ballistic missiles, using captured German V-2 scientists, particularly Wernher von Braun and many of his team from the research and testing station at Peenemünde, and the Americans fired their first intercontinental ballistic missile (ICBM) in 1958. The attempt to give force to the notion of massive nuclear retaliation entailed replacing vulnerable manned bombers with less vulnerable submarines equipped with ballistic missiles and also with land rockets based in reinforced silos. In July 1960, off Cape Canaveral (subsequently Cape Kennedy), the American submarine USS *George Washington* was responsible for the first successful underwater lowed suit. Meanwhile, in 1961, the Americans commissioned the USS *Ethan Allen,* the first true fleet missile submarine.

Submarines could be based near the coast of target states and were highly mobile and hard to detect. They represented a major shift in force structure, away from the U.S. Air Force and toward the Navy, which argued that its invulnerable submarines could launch carefully controlled strikes, permitting a more sophisticated management of deterrence and retaliation, an argument that was also to be made by the British navy.

Other states followed the United States into submarine-launched ballistic missiles. In 1962, in what became known as the Nassau Agreement, John F. Kennedy, the American president, and Harold Macmillan, the British prime minister, decided that the Americans would provide Polaris missiles for a class of four large nuclear-powered British submarines that were to be built, although American agreement was dependent on the British force being primarily allocated for NATO duties. In 1968, the first British Polaris test missile was fired from HMS *Resolution,* the British navy's first nuclear-powered ballistic missile submarine, which had been laid down in 1964. Polaris remained in service until 1995, being succeeded by Trident. Also benefiting from the transfer of American nuclear technology, the French commissioned their first ballistic missile submarine in 1969.[90]

The effect of the destructive potential of intercontinental nuclear weaponry was unclear, which increased the significance of this weaponry. It served to enhance the possibility of a nuclear war, by increasing interest both in defining a sphere for tactical nuclear weapons and in planning an effective strategic nuclear first-strike. However, there was also an inhibiting effect, lessening the chance of a great power war, or increasing the probability that such a conflict would be essentially conventional. The risk of nuclear destructiveness made it important to prevent escalation to full-scale war and thus encouraged interest in defining forms of warfare that could exist short of such escalation.

In the early 1960s, U.S. concern about the nuclear balance increased. Kennedy had fought the 1960 presidential election in part on the platform that the Republican administration under Eisenhower had failed to maintain America's defenses. Eisenhower's vice president, Richard Nixon, was the Republicans' unsuccessful candidate. Kennedy aimed

for a strategic superiority over the Soviet Union and increased defense spending accordingly.

Concern about missiles rose to a peak during the Cuba crisis of 1962, when the Soviet Union deployed them in Cuba. These missiles had a range of 1,040 nautical miles, which made Washington a potential target. The Soviet intention was to guarantee Cuba from American attack and thus protect a newly significant protégé, but the deployment of missiles also shifted the balance of terror between the United States and the Soviet Union in the Soviets' favor. In October, the United States imposed an air and naval quarantine to prevent the shipping of further Soviet supplies, prepared for an attack on Cuba, and threatened a full retaliatory nuclear strike. The Cuban leaders, Fidel Castro and Che Guevara, wanted a nuclear war, which they saw as a way to forward world socialism. However, the Soviet Union climbed down, withdrawing its missiles, while the United States withdrew its Jupiter missiles (which carried nuclear warheads) from Turkey and agreed not to invade Cuba. Possibly the threat of nuclear war encouraged the United States and the Soviets to caution, although both sides had come close to hostilities.[91]

In the 1960s, both the United States and the Soviet Union built up their missile forces. However, in 1965, Robert McNamara, the U.S. secretary of defense, felt able to state that the United States could rely on the threat of "assured destruction" to deter a Soviet assault. Thanks in part to submarines, a dispersed weapons system, there would be enough missiles to provide an American counterstrike in the event of the Soviets launching a surprise first-strike and inflicting considerable damage on the American mainland. Nuclear warfare appeared to promise mutually assured destruction (MAD), as submarines could not be found easily and the missiles from each side would theoretically cross in flight.

The logic of deterrence, however, required matching any advances in the techniques of nuclear weaponry, and this was one of the most intense aspects of the Cold War. The evolution of missiles involved developments in detection and countermeasures, but there was also the evolution of rocket motors, of the materials from which the motor casing is made—wire-wound composites, and of the composition and use of the fuel. For example, in 1970, the United States deployed Minuteman III missiles equipped with multiple independently targeted reentry vehicles (MIRVs), thus ensuring that the strike capacity of an individual rocket was greatly enhanced. This meant that any American strike or counterstrike would be more effective. The United States also cut the response time of their land-based intercontinental missiles by developing the Titan II, which had storable liquid propellants enabling in-silo launches, which reduced the launch time.[92] The precision of guidance systems moreover was increased as was information for targeting.

Meanwhile, the destructive power of nuclear weapons had increased when the atomic bomb was followed by the hydrogen bomb. The latter employed a nuclear explosion to fuse atoms together, a transformation that released an enormous amount of destructive energy. Work on this bomb had been carried on unsuccessfully during the Second World War but was stepped up after the Soviet atomic test of August 1949, as the Americans sought to reconfirm their nuclear superiority. The American hydrogen device was first tested on November 1, 1952, producing an explosive yield of 10 megatons. As this device had not been weaponized, it was not really a bomb or what was soon called a superbomb, but this development followed swiftly. In less than a decade, the destructive force released in 1945 had been made to seem limited. Whereas the bomb dropped on Hiroshima had 13.5 kilotons of TNT equivalent, the United States in 1954 tested one with 15 megatons of TNT equivalent, over a thousand times more powerful.

Alongside a level of lethality that proved difficult to comprehend came a rapid closure of the capability gap, and one that was speedier than in the case of the atom bomb. The Soviet Union tested an intermediate type of hydrogen bomb in August 1953, and in November 1955 conducted a test showing it possessed the knowledge to build a hydrogen bomb. Britain followed in 1957, China in 1967, and France in 1968.[93] These weapons, however, were not followed by the cobalt bomb, mentioned in 1950 by Leo Szilard, a prominent nuclear physicist. This was to bring life on Earth to an end by covering the planet with radioactive particles.

The American nuclear position in the 1970s was challenged by the Soviet response, part of the action-reaction cycle that was so important to the missile race. The Soviets made major advances in the development of land-based intercontinental missiles, producing a situation in which

war was seen as likely to lead to MAD, as both sides appeared to have a secure second-strike capability. Since the end of the Cold War, declassified Warsaw Pact documents have revealed that in the 1970s the Soviets planned a large-scale use of nuclear and chemical weapons at the outset of any attack on western Europe. In 1977, the Soviets deployed SS-20 missiles. Mobile, accurate, and armed with nuclear warheads, they were designed to be used in conjunction with conventional forces in an invasion of western Europe. Moreover, in an interview published in the *New York Times* of February 25, 1998, Kanatjan Alibekov, an official in the program, revealed that the Soviet Union had prepared anthrax, smallpox, and plague virus cultures for delivery by intercontinental ballistic missiles.[94]

Concern about attack by ballistic missiles led to American interest in a "Star Wars" program, the Strategic Defense Initiative (SDI). Outlined by President Reagan in a speech on March 23, 1983, this program was designed to enable the Americans to dominate space, using space-mounted weapons to destroy Soviet satellites and missiles, and thus overthrow the balance of terror between the United States and the Soviet Union. Subsequently, these ideas were to be applied in considering how best to challenge other states with long-range missiles, particularly North Korea. The ability to use such weaponry effectively was (and is), however, unclear. This was especially so because of the possible use by opponents of devices and techniques to confuse interceptor missiles.

The rise to power in the Soviet Union in March 1985 of Mikhail Gorbachev, a leader committed to reform at home and good relations abroad, greatly defused tension. Although he supported the army in claiming that the American SDI could somehow be countered,[95] Gorbachev was willing to challenge the confrontational worldview outlined in KGB reports. For example, he was convinced that American policy on arms control was not motivated by a hidden agenda of weakening the Soviet Union, and this conviction encouraged him to negotiate. Moreover, the cost of the Soviet military was a heavy burden on the economy, lessening the possibilities of growth and of winning popular support. The arms race reflected the advantage the West enjoyed in electronic engineering, as well as higher economic growth rates and more flexible economic and organizational processes than those in the Soviet Union. The

Western prohibition on the export of advanced technology was also significant, and in 1974 the United States banned the export of powerful computers to the Soviet Union and its allies.

For long, the Soviet belief in the apparently inevitably insoluble contradictions of Western capitalism ensured that they failed to appreciate the mounting crises their economy, society, and political system were facing. However, the situation changed under Gorbachev. In December 1987, the Soviet government signed the Intermediate Nuclear Forces Treaty, which, in ending intermediate land-based missiles, forced heavier cuts on the Soviets, while also setting up a system of verification through on-site inspection. As a reminder of the political consequences of weaponry, this agreement helped push the German question to the fore as West Germany was the base and target for short-range missiles. In July 1991, START 1 led to a major fall in the number of American and Soviet strategic nuclear warheads.[96]

At the same time, existing missiles were enhanced. The American Trident II D-5 sea-launched missile, deployed from 1990, was more accurate than earlier missiles, while the ability to use the W-88 warhead with the missile increased explosive yield.[97] Alongside developments in "conventional" nuclear warheads, there was also investigation of the prospect for different warheads. One pursued by the Americans, largely in a theoretical fashion, was the hafnium bomb, which was seen as a way to produce a flood of high-energy gamma radiation. As the release of energy from the nuclei does not involve nuclear fission or fusion, such a bomb would not be defined as a nuclear weapon. So far, however, such research has not led to practical applications.

More generally, understandably concerned about the acquisition of weapons of mass destruction by "rogue states" such as North Korea[98] and Iran, the Americans seek a technological means to ensure security, a difficult goal at the best of times. Research is encouraged by particular tasks. Thus, the construction of underground plants for manufacturing and storing weaponry and related material, notably uranium-enrichment plants in Iran, led to the development of bunker-busting bombs, although the likely effectiveness of the latter remained unclear, not least because of advanced Iranian research on stronger concrete. Sensitivity to the

use of atomic weaponry resulted in a commitment to more lethal non-nuclear weaponry.

CRUISE MISSILES

Cruise missiles provided a key gain in military capability from the 1980s and were important to military planning in the last stage of the Cold War and to post—Cold War warfare. These unmanned missiles were valuable because they could deliver precise firepower without the risks, costs, and limitations associated with air power. In their planning for conflict with the Soviet Union in the 1980s, the United States intended to respond to any attack by using cruise missiles to inflict heavy damage on Soviet armor advancing across West Germany. These missiles can carry conventional warheads or use tactical nuclear weaponry. They can be fired in all weathers and can be launched from a variety of platforms. The Soviet Union also developed such weaponry.

Tactical nuclear warheads were not used, but, in the Gulf War of 1991, cruise missiles and precision-guided bombs were employed by the United States to provide precise bombardment. At that stage, cruise weaponry had a crucial advantage over air power due to the extent to which American planes still did not use precision-guided munitions: 9,300 precision-guided munitions were dropped in that war, but most of their aircraft were not equipped, nor their pilots trained, for their use and, instead, employed unguided munitions, which made up 90 percent of the aerial munitions used. Earlier, in the Linebacker I and II campaigns in Vietnam in 1972, there had been extensive and effective use of precision-guided munitions, but the focus was still on iron bombs. The flexibility of cruise missiles was such that they could be launched from land, sea, and air. Thus, the battleship USS *Wisconsin* was converted to ensure that it could launch missiles as well as fire guns when operating against Iraqi forces in 1991.

Subsequently, the United States fired seventy-nine sea-launched cruise missiles at terrorist targets in Afghanistan and Sudan in 1998, an impressive display of force but not one that stopped the terrorists. Indeed, Osama bin Laden was able to raise funds by selling missiles that did not detonate to the Chinese, who were interested in cutting-edge American military technology. Cruise missiles were also used against Serbia in 1999 as part of a combined NATO air and missile assault designed to ensure that Serb forces withdrew from Kosovo. In 1998, the submarine HMS *Splendid* achieved Britain's first firing of a cruise missile, which had been bought from the United States. The following year, *Splendid* fired these missiles at Serb targets in Kosovo as part of NATO operations there. During the successful attack on the Taliban regime in Afghanistan in 2001, cruise missiles were fired from Allied warships in the Arabian Sea. By then, air attack had also improved as the availability of dual-mode laser and GPS guidance for bombs increased the range of precision available.

In the attack on Iraq in 2003, the precision of the American cruise missiles and their attacks on Baghdad were presented as the cutting edge of a "shock and awe" campaign that ushered in a new age of warfare. This account, however, was seriously overstated and it proved necessary to defeat Iraqi forces on the ground. The following year, there was speculation that any Chinese invasion of Taiwan would be countered by a Taiwanese cruise missile attack on the Three Gorges Dam in the Yangzi Valley, exploiting a key point of economic and environmental vulnerability.

Other states also developed cruise missile capacity. In 2004, Australia announced it would spend up to $450 million on buying air-launched cruise missiles with a range of at least 250 kilometers. Chinese nuclear-powered attack submarines are designed to deploy land-attack cruise missiles as well as anti-ship ones. In 2011, Taiwan claimed that its missile capability would counter any hostile activities by the aircraft carrier China had acquired and was making operational.

The key to effective cruise missiles is guidance and targeting systems that allow precise targets to be hit at long range. Otherwise, they are no better than the German V-1 rocket of the Second World War. Information in the form of precise positioning is crucial to the effectiveness of cruise missiles. They exploit the precise prior mapping of target and traverse by satellites using a global positioning system, in order to follow predetermined courses at a set height to targets that are actualized for the weapons as grid references. The digital terrain models of

the intended flight path facilitate precise long-distance firepower, while the TERCOM guidance system enables course corrections to be made while in flight.

Such methods reflect the importance of complex automatic systems in advanced modern weaponry. The force multiplier characteristics of weaponry have been greatly enhanced and have become more varied. Industrial-age mass production has been replaced by technological superiority as a key factor in weaponry, not least because of the transformation of operational and tactical horizons by computers. This capability has also encouraged a premium on skill, which leads to greater military concern about the quality of both troops and training. This concern encouraged pronounced military support for a professional volunteer force, rather than conscripts.

DRONES

A good instance of this skill was the expertise required to direct UAVs (unmanned aerial vehicles) and RPVs (remotely piloted vehicles). These platforms are designed to take the advantage of missiles further by providing mobile platforms from which they can be fired or bombs dropped. Platforms do not require on-site crew and thus can be used without risk to the life or liberty of personnel. As a consequence, they can be low flying, as the risk of losses of pilots to anti-aircraft fire has been removed. This is important given the extent to which the fate of captured pilots has—since that of Gary Powers, the pilot of an American U-2 reconnaissance plane shot down by the Soviets in 1960, and, more consistently, of American pilots in the Vietnam War—become a major propaganda issue.

In addition, at least in theory, the logistical burden of air power is reduced by the use of unmanned platforms. So also is the cost, as they are less expensive than manned counterparts, and there are big savings on pilot training. No matter how complex they become, drones will always be cheaper than manned aircraft. Unmanned platforms are also more compact and "stealthy" (i.e., less easy to detect), while the acceleration and maneuverability of such platforms are no longer limited by g-forces that would render a pilot unconscious.[99] The lack of a crew means that drones offer an alternative to planes greater than that provided by helicopters. The potential offered by the latter has arguably not been sustained,[100] which further increases the potential for drones.

The Vietnam War saw the development of drones. From August 1964 until their last combat flight on April 30, 1975, the USAF Strategic Reconnaissance Wing flew 3,435 Ryan 147B reconnaissance drones over North Vietnam and surrounding areas. About 354 were lost to all causes. Experiments were also carried out to develop drones for combat operations. In 1999, unarmed American drones were used extensively for surveillance over Kosovo in order to send information on bomb damage and refugee columns; and, in Afghanistan from 2001, Iraq from 2003, Pakistan, and Yemen, armed American drones were employed as firing platforms. The 26-foot American Predator with its operating radius of 500 miles, flight duration of up to 40 hours, cruising speed of 80 miles per hour, and normal operating altitude of 15,000 feet is designed to destroy air-defense batteries and command centers. It can be used in areas contaminated by chemical or germ warfare. The Predator has been supplemented by a range of other drones with different ranges and functions. Drone attacks increased greatly under President Obama, from nine in Pakistan in 2004–2007 to 205 in 2008–2010.[101] Having peaked in 2010, with 117 strikes killing over 800 insurgents, the number of attacks fell in 2011–2012, in part due to disagreement with Pakistan, but drone attacks increased against targets in Yemen. In the 2010s, moreover, Britain and France began joint development of drones.

The increasing use of ever more sophisticated drones suggests that they will come to play an ever bigger role on future battlefields. By the early 2010s, researchers were trying to teach drones to follow human gestures so that they would be able to follow the directions of deck handlers and thus use aircraft carriers. It is likely that anti-drone drones will swiftly develop, repeating the process seen with aircraft in the 1910s.

In the clash between Israel and Hezbollah in Lebanon in 2006, both sides used drones, with the Israelis making particularly marked use of them as an aspect of their aerial dominance and attack capacity. Iranian-supplied drones were used not only by Hezbollah but also by Sudan, where one was allegedly shot down in March 2012 over the rebel province of Southern Kordofan. The difficulties encountered by Israel in

Lebanon in 2006 indicated the contrast between force projection and military output, which missiles have greatly enhanced, and, on the other hand, predictable outcomes, in the shape of a successful resolution of the crisis. More generally, this is a problem with all weaponry. At the same time, even if air power cannot end insurrections, it can be important in helping counter them.[102]

ARMS RACES

A major expansion in the advanced weaponry held by a number of states from the late 1990s proved an important change. This expansion was particularly acute in South India. First India and then Pakistan tested nuclear weapons in 1998. That year, Pakistan also test-fired its new *Ghauri* intermediate-range missile, while India fired its new long-range Agni 2 missile the following year: its range is 2,000–3,000 kilometers, extending to Tehran and covering most of China and Southeast Asia. In March 2003, both states test-fired short-range surface-to-surface missiles that could have been used to carry nuclear warheads.[103] Pakistan, in turn, sold weapons technology to other states, including North Korea, Iraq, Iran, Libya, and, probably, Egypt and Syria. Saudi Arabia probably funded the Pakistani nuclear-weapons program and in the late 1980s purchased long-range Chinese missiles. From 1998, Iran tested its *Shahabz* missile. With a range of 1,300 kilometers (812 miles), this missile is able to reach both Israel and American forces located in the region.

Atomic proliferation faces serious practical difficulties.[104] Nevertheless, weapons programs were (and are) designed to provide regimes with the ability to counter the military superiority or plans of other states. Thus, North Korea saw atomic weaponry as a counter to American power, while Syria sought to develop chemical and biological weapons as well as an atomic capability, in response to Israeli conventional superiority. Japan, in turn, felt threatened by North Korea's rocketry, leading, as a result, to Japanese interest in anti-missile defenses and in satellite surveillance, while Israel built up a substantial stockpile of nuclear bombs in response to the chemical weapons of its Arab neighbors. In 2003, Libya abandoned its nuclear program, but Iran proved unwilling to follow suit even after its violations of nuclear safeguards were exposed.

From 2006, this issue caused a serious crisis in relations between Iran and the West, with Iran unwilling to back down in the face of international pressure and in 2011–2012 threatening to close the Strait of Hormuz to international trade. In these and other cases, the advantages apparently offered the Americans by cruise missiles and other advanced military technologies did not lead to the policy outcomes they had sought in the case of the Iranian response. On the other hand, it was better to have these capabilities than not to do so. Moreover, the Iranian threat to close the strait proved redundant in January 2012 when the American aircraft carrier *Abraham Lincoln,* supported by five other warships, sailed through in order to underline the right of passage under international law.

THE CASE OF THE F-35

Meanwhile, air power was developing and using new capabilities, including stealth technology. Whereas only about 10 percent of the aerial munitions employed against Iraq in 1991 were "smart" or guided, the percentage in 2003 was about 70. In 2006, moreover, the Americans conducted tests in which aircraft employed synthetic fuel as part of their jet fuel. However, the rise of cruise missiles and drones led to serious questions about the future value of manned flight.

This issue was to play a role in the response to the biggest military program in history, the American F-35 Joint Strike Fighter. This is the latest in a series of projects for a single plane for that function; for example, the TFX of the 1960s, which became the F-111 built by General Dynamics while the carrier variant, the F-111B, was cancelled. The contract for what became known as the F-35 was awarded to Lockheed Martin in 2001, and, at that time, it appeared to have a lot to offer and to be value for money. The F-35 was designed as a comparatively inexpensive tactical aircraft intended to achieve air superiority and as a ground-attack tool. The F-35 was also seen as at the cutting-edge in technology, as it was planned with the stealth capability that defeats radar recognition as well as with advanced software and sensors. Designed to replace at least four other types in service, the F-35 was intended as the central

American fighter for the next half century as well as the basis for allied air forces.

It was planned that the United States would purchase 2,443 F-35s ensuring that, alongside orders from allies, at least 3,000 could be ordered from the outset. This bulk order was intended to produce major efficiencies of scale, both in procurement and in subsequent maintenance and support. In doing so, it was planned to counter the great expense of producing and delivering a new aircraft. These costs were such that the economic viability of air power had diminished, notably as measured in the number of firms and countries able to manufacture aircraft and the number of countries capable of supporting a significant state-of-the-art air force. As a result, coalitions of interest between a number of purchasers were required, as with the F-35 or the Eurofighter Typhoon fighter.

These coalitions of interest underline the extent to which political decisions played, and play, a key role in purchasing weapons. For example, in 1963, India bought MiG-21 fighters from the Soviet Union, rather than British Lightnings, in order to demonstrate India's distance from the West. Subsequently, American support for Pakistan encouraged the Indians to stick with the Soviet Union and, then, Russia. In turn, improved relations with the United States from the mid-2000s led India to show greater interest in purchasing American fighters and helped lead Japan to settle on the F-35 in 2011. In 2012, India preferred French to British fighters. Read back, this factor of political preference, which appears so obvious in the modern world, suggests the need for caution when criticizing what appears to be the acquisition, and therefore use, of suboptimal technology in the past.

Deliveries of the F-35 to the United States military were supposed to start in 2010, but, by the summer of 2011, the date for entering service had been postponed to 2016. Moreover, the average price of each plane had nearly doubled, from $81 million to $156 million, and program costs had risen to $382 billion. The cost of operating and sustaining the aircraft has also risen significantly, ensuring that the F-35 would be more expensive than the planes it was intended to replace. The scale of America's fiscal crisis, which, in part, is due to expensive wars in the 2000s, made this unacceptable.

Moreover, changes in the strategic environment and the nature of weaponry make the value of the F-35 increasingly questionable. There is doubt about its stealth capacity and its related ability to cope with the most modern air-defense system that it may have to face. Range is also an issue. Whereas the United States had nearby bases from which to confront the Soviet Union, Iraq, and Iran—for example, in Abu Dhabi—the range of about 600 miles is less helpful in opposing China, whose deployment of new planes, including Su-30 MK2 fighters and JH-7A fighter bombers, increases its challenge at sea.[105] However, the development of anti-ship missiles by China able to challenge American aircraft carriers, notably the DF-21F intermediate-range ballistic missile fitted with a maneuvering reentry head containing an anti-ship seeker, poses a major problem. As a result, the carriers may have to operate well to the east of Taiwan, in other words beyond the range of the American navy's F-35s. The new anti-carrier technology has led to a call for doctrinal flexibility in defining the role of carriers as they cease to be the clear supreme arbiter of (American) naval power.[106] Obsolescence for the F-35 was further underlined by planned developments for rival weapon systems, both drones and hypersonic cruise missiles.

In addition, the F-35 indicated classic problems that need to be borne in mind when discussing effectiveness. The F-35's costs and performance were compromised by the plane being expected to fulfill many roles, which, in turn, led to an overly complicated design. In particular, the F-35 was intended for the American air force, replacing its F-16s and A-10s, as well as for the navy, providing a conventional takeoff and landing version (the F-35B) to replace its F-18s, and, also, for the marines, to replace their AV-8B jump jets with a short takeoff and vertical landing version (the F-35C). Aside from its much more limited range and payload, the last caused particular problems, both with structure and propulsion, and it was placed on "probation" in 2011 (although it subsequently came out of it). The F-35C caused problems with the location of its arrester hook, based on the plane's radar-avoiding stealth "design," proving inadequate for catching the wire on landing. That was not the sole issue for there are also difficulties in integrating and testing the complex software that runs the F-35's electronics and sensors. In August 2011, test flights were stopped when a defective valve in the power system was discovered. This was part of a crisis of system failures that saw the F-22 Raptor grounded after a defect was found with its oxygen system. Indeed, the F-22 has been beset by problems since it began to enter service in 2006.

CONCLUSIONS

The F-35 may prove to be an expense too far and an entirely unnecessary system. Indeed, the loss of all or part of the program was mentioned in late 2011 as a possible outcome of defense cuts.[107] At any rate, the fate of the F-35 reflects the rapid rise of obsolescence but also the abiding issues of confusion in goals, limitations in function, and changing tactical, operational, and strategic parameters. These factors will remain important. At the same time, it would be mistaken to treat air power simply as a lesson in failure. The hopes of its advocates were frequently misplaced, notably in terms of outcomes or political consequences, but air power has dramatically changed equations of firepower and mobility. Both in its own right and as part of combined arms operations, air power has made maneuver warfare a more central part of conflict and thus increased the tempo of war.