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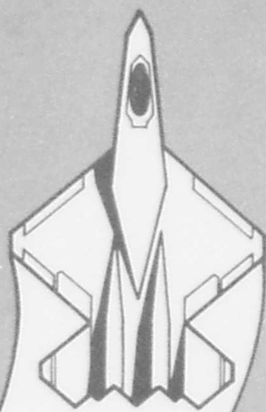

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THE FUTURE OF THE AIR FORCE

CENTER for AEROSPACE DOCTRINE, RESEARCH and EDUCATION

## Checking Six Is Not Enough

### *The Evolution and Future of Air Superiority Armament*

DAVID R. METS

CADRE

CENTER FOR AEROSPACE DOCTRINE, RESEARCH, AND EDUCATION

Report No. AU-ARI-CPSS-91-14

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## *The Evolution and Future of Air Superiority Armament*

*by*

DAVID R. METS
*School of Advanced Airpower Studies*

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## Foreword

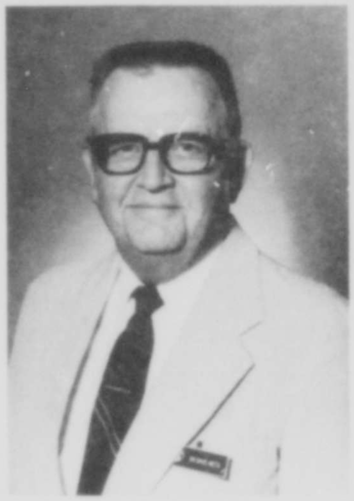
The stunning changes in the complexion of international politics that began late in the decade of the 1980s and continue today will profoundly affect the American military establishment as a whole, and the US Air Force in particular. Decisions about the future course of the military will be made in the early part of the 1990s which will essentially determine the course of the US Air Force well into the next century. Decisions of such importance require thoughtful consideration of all points of view.

This report is one in a special series of CADRE Papers which address many of the issues that decision makers must consider when undertaking such momentous decisions. The list of subjects addressed in this special series is by no means exhaustive, and the treatment of each subject is certainly not definitive. However, the Papers do treat topics of considerable importance to the future of the US Air Force, treat them with care and originality, and provide valuable insights.

We believe this special series of CADRE Papers can be of considerable value to policymakers at all levels as they plan for the US Air Force and its role in the so-called postcontainment environment.

DENNIS M. DREW, Col, USAF
Director
Airpower Research Institute

## About the Author



Dr David R. Mets

Dr David R. Mets earned his BS from the US Naval Academy, his MA from Columbia University, and his PhD from the University of Denver. He completed a 30-year career in the US Navy and Air Force in 1979. During his career, he taught diplomatic and military history at both the USAF Academy and West Point and served as editor of the *Air University Review*, the professional journal of the Air Force. He holds both navigator and pilot ratings and his service included two flying tours in Southeast Asia, the latter as commander of an AC-130 gunship squadron. He is now Professor of Technology and Innovation at Air University's School of Advanced Airpower Studies. His published books include *NATO: Alliance for Peace* (1981); *Land-Based Air Power in Third World Crises* (1986); and *Master of Airpower: General Carl A. Spaatz* (1988).

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## Executive Summary

This essay takes a historical approach to examining the nonnuclear armament acquisition process through the case of air superiority weapons. It deals first with the marriage of armament technology with aviation technology to produce military air power in the age of gun weapons. It argues that it was mainly an adaptive, evolutionary process until the 1950s. In part, that was because ammunition and gun technology were well matured, but airframe and engine technologies were still on the steep parts of their developmental curves.

With the appearance of practical air-to-air missiles, there were predictions that guns were obsolete and defensive counterair tactics were on the verge of a revolution—from the conventional short-range stern chase of the gun era to a time of all-aspect threats at ranges much greater than before. In Vietnam, those predictions were proven premature, and the aircrew community became firmly committed to the requirement for an internal gun in all new fighters.

In the 1970s and 1980s, the infrared missiles did acquire an all-aspect capability at short ranges, and the new radar missiles with a beyond-visual-range multiple launch-and-leave capability were on the horizon. Some were predicting that the new era was finally at hand, but the effectiveness of electronic warfare along with the performance of stealth aircraft in Operation Desert Storm made the predictions uncertain. Too, the potential of air-to-air antiradiation missiles and uncertainties about the feasibility of fully reliable means of target identification further complicated the problem.

Meanwhile, potentially revolutionary improvements were being made in gunsight and gun ammunition technology and were not much noticed. All of this was taking place in a turbulent international and political climate introducing additional imponderables. Finally, in a 1990 reorganization of defense research and development, the Army laboratories were assigned the lead service responsibility for conventional guns—reducing the USAF role in the advanced gun and ammunition development business. This raised the possibility that the service would be lacking a gun advocacy group in its ranks and lead to a neglect of that technology in an austere budget climate.

The study concludes that the USAF leadership would be well advised to enhance the inherent flexibility of air power by providing flexible weapon suites for future fighters. This would include medium-range radar missiles and short-range infrared missiles as well as guns. In the absence of a clear and present danger of general war against a first-class enemy, the leadership probably is able to postpone a commitment to a major and expensive change entailed in the adoption of radically new ammunition and guns. This may be justifiable on technical as well as economic grounds. Notwithstanding the great gain achieved in the development of telescoped ammunition, still greater gains may not be too far in the future if it proves practical to add a caseless feature. Substantial

improvements can nevertheless be made with updated versions of present guns, ammunition, and sights while keeping options open for future, more revolutionary changes. As the Air Force now has a reduced responsibility for exploratory research and advanced development in conventional guns and ammunition, it is recommended that the leadership be alert to assure that such research and development be kept alive and healthy in the US Army laboratories.

# Checking Six Is Not Enough

## *The Evolution and Future of Air Superiority Armament*

MELVIN KRANZBERG, speaking at the US Air Force Academy's Third Military History Symposium, noted that a bias had been introduced to the study of the history of science and technology because writers preferred the glamorous issues. He added that sometimes the unglamorous (but often important) issues had a pervasive effect that went unnoticed because they simply had not attracted the attention of scholars. Kranzberg's remarks, made well before the "lessons" of the air war in Vietnam had been digested, were perceptive. The history of nonnuclear aircraft armament certainly seems to bear them out.[1]

The romance of aviation guarantees that the history of airframe and engine development will get full attention. The obvious importance of nuclear weapons attracts the attention of a parade of scholars. Space and its promise for the future is a magnet for any number of writers. But the history of nonnuclear aircraft armament development, especially aircraft guns and bombs, remains an untilled field. I suppose this is so because the armament part of the system has never been clearly decisive in air superiority battles and campaigns. Though nonnuclear aircraft missiles are an exception, the technology of conventional aircraft armament is far less exotic than those of strategic missiles, nuclear weapons, and aircraft. Also, aircraft bombs and guns were long organizational orphans while careers could prosper or fall with the fortunes of engine, airframe, intercontinental ballistic missile (ICBM), ship, submarine, or tank programs. The time may have come to fill this gap in the history of air power. Clearly, air superiority is as important as it has ever been and crucial nonnuclear armament choices for arming twenty-first century fighters are in the offing.[2]

According to Richard E. Neustadt's and Ernest R. May's *Thinking in Time*, when such choices are to be made one should found them on the study of three histories.[3] First, the personal histories of the main actors have to be considered. Second, the organizational records of the units engaged should be understood. Finally, the past of the issue itself must be comprehended. This essay is planned as a contribution to the latter history. What has been the record of the nonnuclear aircraft air superiority weapons since 1914? What factors made it evolve in the way that it did? How did these factors interact at each stage? The related twenty-first century issue would be: shall the air superiority fighter be armed with missiles only, or should it also include a gun?

This essay is organized chronologically. It is a work of synthesis reliant largely on secondary sources. It begins with the era of air-to-air gunnery from 1914 to the end of the Korean War. The false dawn of the missile era will be discussed, post-Vietnam air-to-air weapons developments examined, and the paper will conclude with some speculations on the nature of nonnuclear weapons development and ideas on future choices. It is clear that there is or should be a close relationship between doctrine and weapons. However, this study concentrates on the armament and deals with doctrine only when it had a direct impact on the arms themselves. It recognizes that the Soviets have a strong record in aircraft gun development, but they have generally trailed the West in air-to-air missile development. Consequently, most of the emphasis in this essay is on the US part of the story. Finally, there is an interdependence between fire control equipment and weapons, but this study will concentrate on the guns and missiles.

## The Era of Air-to-Air Gunnery

IT IS commonly thought that the demand for air superiority or command of the air was a pragmatic reaction to the annoyance of aerial reconnaissance of the early months of World War I. However, Lee Kennett's recent *The First Air War* makes it clear that the notion existed before that.[4] Great air wars were envisioned in the speculative literature long before the Wright brothers' first flight, and the speculation boomed during the decade after 1903. As Kennett shows, practically all of the current roles and missions of air power had been conceived before the "Guns of August" first spoke. Even air-to-air guided missiles had been anticipated. One author speculated that the way to meet the zeppelin threat might be the fashioning of a miniairship containing an explosive warhead and a spool of wire. Directions were to be sent to the miniairship from the defending zeppelin by means of the unreeling wire until the missile collided with the invader. The notion must have seemed farfetched at the time, but it is very similar to one German response to the Allies' jamming of the data-link on the Fritz-guided bomb during World War II. It is even more similar to the current wire-guided missiles used against tanks all over the world.[5]

America's Lt Col Isaac Newton Lewis demonstrated his light, gas-operated machine gun from an Army aircraft at College Park, Maryland, as early as 1911.[6] But it was not at all clear that it would become the weapon of choice in the anticipated battles for command of the air when war broke out three years later. The legends regarding ignorant senior officers prohibiting the wise junior officers from carrying aloft machine guns have been exaggerated. In 1913, the British had a program designed to adapt the use of the Lewis to an airplane, but there were serious problems associated with it. For example, in the absence of a synchronizer, the use of a machine gun demanded a second crew member. Given the limitations of engine power, this gun and additional crew member guaranteed the airplane would not have a speed or climbing advantage over its adversary reconnaissance aircraft, which could therefore refuse combat at will—a disqualifying defect for an air superiority fighter.[7]

It was more than the appearance of the machine gun that put an end to the heyday of the Napoleonic offensive. Airplanes and many other factors had an influence. Such offensive tactics had been suicidal by the minié ball in the American Civil War before either Sir Hiram Maxim or Richard Gatling had perfected their rapid fire weapons. Even in World War I, only 30 percent of the casualties were caused by small caliber wounds—60 percent were inflicted by artillery.[8]

Soon after the onset of World War I the ground generals recognized that aerial reconnaissance was a major contributor to the stalemate. The concentration and surprise necessary for a successful offensive could not be achieved as easily in the presence of aerial observers. The ground leaders demanded the development of a capability to deny the enemy the ability to spot a buildup for an offensive from the air—and to preserve such an ability for their own forces.[9]

## The Original Attempts to Achieve Command of the Air

IN THE period after the American Civil War, the gun technology in the navies of the world had advanced much more rapidly than the associated fire control systems. The ranges were longer, the firing platform less stable, and probably the target movement was greater than with land warfare. After many decades of development the sea services produced a solution, just before the Great War. However, in aerial combat the speeds were higher for both target and firing platform. Moreover, aircraft movements were not confined to a single plane, and weight was a more important consideration than it was at sea. Finally, the fields of fire were more constrained with aircraft than they were with ships. The consequence was the onset of a more or less pragmatic search for weapons and fire control systems that could achieve command of the air—a search that has been going on for three-quarters of a century and which is still far from complete.

Some of the methods tried in the first two years of the First World War seem farfetched to modern readers. One of these was the towing of a grappling hook into an aerial target below. Perhaps that was not all that outlandish when pursuing a slow-moving, unsuspecting zeppelin from above. The Russians actually achieved a kill on a German airplane with such a hook.[10]

Another method that was seriously considered for decades also may not have been as bizarre as it now seems: bombing enemy aircraft from above. The initial threat was the zeppelin, for only it could carry the bomb loads that seemed to be sufficient for real damage at long ranges. As the target was hundreds of feet long, filled with highly flammable hydrogen, and moving slowly along a straight path, getting into a proper position to drop an incendiary dart from an airplane does not seem to pose a problem more difficult than ordinary formation flying. However, staying out of the way of the exploding hydrogen might be more challenging.[11] Nor did the idea die with the Great War. The US Army Air Corps (USAAC) practiced such tactics against shadows of aircraft on our western deserts in the 1930s, and the Luftwaffe tried bombing our B-17 and B-24 formations over Europe in World War II. (They were frustrated by the difficulty of setting the bomb fuzes to detonate at the proper moment.)[12]

Brave attempts were made to fight with side arms and rifles, but the multiple accelerations involved were too much for such low rate-of-fire weapons. Early in the war, the French used rockets successfully—but only against balloons. However, fired from the outboard struts of Nieuport scouts, unguided and few as they were, they could hardly be effective against anything but huge stationary targets. Even at that, it was dangerous work because the pilot had to make a close approach to a balloon to ensure a kill, and the enemy often used "gas bags" as bait for antiaircraft artillery (AAA) traps. In that context, the sky was successfully mined at least once when the Allies provided a dummy balloonist and loaded the basket with high explosives. When a German aircraft approached the explosives were detonated by wire from the ground to get the kill.[13] Notwithstanding some spectacular successes, none of these methods had a sufficiently high "probability of kill" ($P_k$) to serve as an instrument to achieve command of the air.

Early on, Lewis and Parabellum machine guns were mounted in the rear cockpits of two-seaters on flexible mountings. Their virtue was a theoretical possibility of hitting a pursuing enemy without one's own airplane necessarily being at any given point, but the multiplicity of accelerations were such that deadly hits were seldom achieved. In any event, the second crew member and gun usually meant that the plane had no hope of overtaking lighter aircraft and single-seaters. But the idea of flying an airplane with one hand and firing the Lewis gun effectively with the other from a flexible mounting was preposterous. The high rate of fire of a machine gun was essential, but it would have to be mounted rigidly to the airplane if it was to be used in a single-seater with any hope of retaining a performance edge needed to achieve command of the air. Even before the war, it was understood that the greatest hope of achieving the required hits would be to remove the effect of multiple accelerations by attacking on a parallel course to that of the quarry. This meant usually firing straight ahead while flying immediately behind the target as closely as possible.[14]

Early attempts were made to configure fighting aircraft with the engine facing aft—a pusher—that would allow a free field of fire forward. Unhappily that could not work well because the configuration was not as efficient as a tractor arrangement with the propeller in front pulling. The pusher could not usually overtake a tractor, all other things being equal, and could not therefore bring its gun to bear.[15]

While these other methods were being explored in the early days of World War I, an effort continued to make practical the forward firing of a fixed gun on a tractor aircraft. It was difficult to contemplate mounting the machine guns rigidly to the airframe so they would fire outside the propeller arc. An advantage of the current externally powered Gatling guns on US fighters is that a misfire does not stop the gun. But neither the guns nor the ammunition of the Great War were as reliable as they have since become. As the energy for their automatic features came from each detonating round in both gas- and recoil-operated machine guns, a misfire meant a gun stoppage. It was necessary to keep the guns within the reach of the pilot so he could do in-flight maintenance (usually with a ball peen hammer) to get his weapon going again.

One of the main Allied guns—the Lewis machine gun—was often used in fixed installations mounted aboard the top wing above the propeller arc. The aerial version of this gun had a 96-round magazine that could not be adapted to belt feed but had to be changed by hand frequently.[16] That meant that the pilot had to release his seat belt, stand up in the cockpit and fly the aircraft by grasping the stick with his knees, and change the magazine for reloading—this in the presence of an enemy made irate by the first 96 rounds! Alternatively, the gun was mounted in a sliding mount so that the whole gun could be brought down to the cockpit for reloading. That had the additional benefit of permitting upward fire in case it was possible to approach an unsuspecting enemy from behind and below. It is hard to envision bore sighting a weapon in such a movable mount, but the ranges were so short that it was not critical. Reloading was still a cumbersome procedure for use in the midst of air combat. One variation was to put the gun on an inboard strut where it would clear the propeller when in its firing position parallel to the line of flight. When necessary, the breech end could be swung inboard for reloading or maintenance, but that still was too cumbersome for a single-seater. An even less satisfactory arrangement was to mount the gun on the cowl and accept whatever happened to the wooden propeller. The propellers were tightly wrapped in linen to discourage shattering when they were hit. But given the prevailing westerly winds, the German defensive strategy, and the offensive spirit of Sir Hugh Trenchard, in the long run the ensuing forced landings could only help the Kaiser. Even before the war, more than one attempt was being made to solve the problem by firmly mounting the gun on the cowl immediately in front of the pilot and making it fire between the rotating propeller blades.[17]

France's Roland Garros used deflector plates on his prop, became an ace, was shot down and captured by the Germans, and lost his device to them. His design inspired Anthony Fokker to go a step further to create a mechanical synchronizer to interrupt the gun fire at the propeller blades.[18]

Garros went down in early 1915, and the Germans had a workable synchronizer by midsummer. The synchronizer and gun were mounted aboard the Fokker *Eindecker* that had a performance somewhat inferior to contemporary Allied fighters. But for a short time the advantage was more than enough to overcome the performance inferiority. As German tactics were to do their air fighting over their own territory, it was several months before the Allies captured the Fokker apparatus that enabled them to develop synchronizers that removed the advantage and permitted their superior numbers to count for more.[19]

The struggle for air superiority swung to-and-fro throughout the First World War, but never again because of the quality of aircraft armament. The rest of the war was fought with rifle-caliber machine guns mounted on the cowlings of single-seaters and controlled by synchronizers. The subsequent changes were quantitative, adding to the number of guns carried aloft as permitted by increasing engine power. Also, the caliber in some installations was increased, but that was usually to enable the use of incendiary rounds against observation balloons, which did not figure in air superiority campaigns.

The use of the synchronizer, though acceptable for the time, was not a perfect solution. It inevitably had the effect of reducing the gun's rate of fire, which was a crucial factor. The weight of the synchronizer subtracted from the number of guns or amount of ammunition that could be brought aloft—or reduced the performance of the airplane. Fokker's mechanical contrivance was difficult to keep in adjustment and to adapt to new engine installations. The ultimate Allied version was similar but depended upon the transmission of the synchronizing signal via hydraulic fluid rather than mechanical rods. This made operation more reliable and adaptation to new installations a simpler process. There was some interesting gun research and development going on in Germany, but the war ended before further improvement could be made to armament systems.[20]

There was little aircraft weapons development prior to the Armistice. Most of the work was merely the adaptation of weapons designed for ground warfare to work in the air. The cooling problem was easier in the context of the slipstream, and the only change was the removal of the gun's water jacket. But neither Hiram Maxim nor Colonel Lewis could ever have anticipated that their guns would have to operate upside down or under three times the normal force of gravity. Nor could they have foreseen that their weapons would have to work effectively when transported from summertime temperatures on the ground to the subfreezing climes near 20,000 feet in relatively short spells. None of that posed insuperable problems—gun heaters, for example, were developed in short order.

The campaign for air superiority depends on more than just air-to-air combat. During the First World War, the ground defenses took a serious toll—

some say that even the Red Baron (Baron Manfred von Richthofen) fell to gunfire from the ground.

After the Armistice, the war-weary world turned to repairing the damage without much interest in armament development. It was clear that airframe and engine technology were still on the steep parts of their development curves, but there was little worry whether mere adaptation of ground weapons would continue to suffice for the future.[21]

During the First World War, many ideas were tried to give aircraft the weapons to assert air superiority. The method that worked was to adapt ground weapons to use on airplanes. Though cannons were tried, rifle-caliber machine guns came to be the standard; and as engine power heightened, the number of guns on each airplane was increased. That helped compensate for the primitive sights in use by multiplying the rate of fire to improve the $P_k$ by increasing the odds that hits would be achieved in the short time available. Deflection shots were usually a matter of luck, and most kills in dogfights were made from directly behind at short range. Even in those early days, though, many more victories were achieved by surprise on the first pass than there were in dogfights after the enemy had become aware of the danger.

## Interwar Stagnation in Aerial Weapons Development

MILITARY technology underwent huge changes between the wars, but improvements in air-to-air weaponry were not conspicuous among them. Given the parsimony of the conservative American governments before 1929 and the Great Depression thereafter, it was not remarkable that the funds for development were scarce. Further, after the wartime stocks of Liberty engines were used up, there were dramatic advances in engine and fuel technologies. During those years also, airframe technology transitioned from wood framing and fabric surfaces through metal framework to all metal construction and monoplanes with monocoque fuselages—airplanes that had made a quantum jump in both performance and robustness. All these developments had to be funded somehow. Moreover, military aviation had to compete for funds with a Navy that was transitioning from battleships to aircraft carriers and an Army that would have liked to move from horses to trucks. Little wonder that the new aircraft that would fight World War II would come equipped with but a few of the same Browning machine guns that had been tested outside Washington in May 1917. They had, however, begun to move up from the rifle caliber of the First World War to the .50-caliber size that was the mainstay of the Second.

Though the strategic bombing idea had its genesis in World War I and before, the US Army Air Service (USAAS), later the Army Air Corps, emerged from the conflict with a firm commitment that the paramount mission was air superiority and air-to-air battle was essential to its success. Pursuit aviation, then, was an (if not the) elite part of the USAAS. In a day when the liberals thought that the League of Nations might make war obsolete and the conservatives were firmly committed to a balanced budget and lowering taxes, Congress would only authorize one fighter organization, stationed first at Ellington Field, Texas, and after 1922 at Selfridge Field, Michigan. Its initial equipment was a collection of World War I leftovers—SPADs, SE-5s, and a few DH-4s. As the US armaments industries were just hitting their stride when the war ended unexpectedly, the USAAS was blessed with a huge inventory of Liberty engines and brand new Browning machine guns and enormous stocks of .30-caliber ammunition.[22]

The airmen could see that the higher performance and robustness of new generations of airplanes would ultimately demand more potent weapons and that they would require the high rate of fire enjoyed in the past war. Though the Air Service's Materiel Division had responsibility for both airframe and engine development, the Army's Ordnance Department was in charge of all gun programs—including aircraft guns. The airmen thought the .50-caliber gun would be essential in war, but they knew the expense of the ammunition would inhibit its use in peacetime. Farsighted designers provided mountings for both the .30-caliber and the .50-caliber Brownings on all new pursuits. The former were to be used for peacetime practice, but with the mountings already in place it would be a simple matter to quickly put the larger guns aboard once war appeared imminent. Finally, as gun and ammunition technology was more mature than aviation technology, the USAAS had yet another reason for not pushing hard for gun and ammunition programs.[23]

In the US there was not much change in fighter armament between the wars. Though all the guns that were used in Mitchell's First Provisional Brigade were leftovers from the war, the readily available .30-caliber Brownings could have been used in the 1921 operations against the *Ostfriesland*. The air version of the .50-caliber Browning was available very soon afterwards. The ammunition for these two guns had been redesigned and was more reliable than previous rounds. Still, the Army did not move to put the guns out on the wings of fighters to avoid using synchronizers until the mid-1930s. Though some P-35s and P-36s had some guns in the wings, they retained some on the engine cowling, and even the first version of the P-51 Mustang had two of its guns firing through the propeller.[24]

World War I experience proved that the manipulation of guns in open cockpits on bomber aircraft was tough; change came slowly there, too. The bombers used the same .30-caliber guns universally and little was done to give the gunners protection from the slipstream nor a power assist to move the guns smoothly against the rapidly increasing airspeeds. One of the first of the "modern" bombers was the Martin B-10 coming on line in the early 1930s. It did have its forward gunner in an enclosed position, at least, but he still fired .30-caliber guns without power assistance. When the first model of the B-17 appeared a couple of years later, it only had five guns. All of them were enclosed positions. They were .30-caliber weapons in flexible mountings with no power assistance, though the airplane came equipped with mountings that would also accept the .50-caliber gun.[25]

The gunnery problem on bombers did not seem that urgent until 1940. Most of the theorists of the Air Corps Tactical School, along with many others with thoughts on the matter, agreed that the bomber would always get through. For protection it could count on the immensity of space and the difficulty of finding a small speck of bomber in that vastness in time to reach its altitude and position before the defender ran out of gas. Guns would not be needed at all aboard that speck if the defender could not find it—and to all but a few, the notion of the development of a radar was as preposterous as a death ray.

The story elsewhere was similar. Nothing in the Japanese combats with China and the Soviet Union in the 1930s drove them to serious work on their aircraft guns. Though they did some original work in aircraft design, their gun designs were taken from foreign prototypes and made of inferior materials so that their performance was less than that of the originals—a situation that more or less persisted down to Hiroshima.[26]

In Germany, the Soviet Union, Italy, France, and Britain more emphasis was placed on airframes, engines, and fuels than on air superiority weapons. The development in Germany before Hitler was constrained by the Versailles Treaty and the Allied Control Commission. Though Germany was soon allowed back into commercial airframe and engine development, military work remained difficult. Germany's lag in airplane and especially power-plant technology further inhibited specialized work on aircraft guns. Some development was done covertly in the Soviet Union. At the onset of the Spanish Civil War, Soviet forces there achieved a measure of air superiority over the Germans and Italians. Though their aircraft had more and larger caliber guns, one cannot assert that the advantage was due to superior weapons. Until 1937, the Soviet airplanes were better, and the Loyalist side in Spain also had the advantage of numbers. The Soviet fighters generally had two rifle-caliber and two 11-millimeter (mm) (roughly the same as .50-caliber) machine guns at a time when most of the German and Italian planes had but two of the former (as did the contemporary US P-26). However, the Germans deployed a new generation of aircraft to Spain in 1937 and soon had air superiority for the Rebel side. The mainstays of their Condor Legion were the Messerschmitt Bf-109, the Ju-87 Stuka, and the Heinkel He-111H. As all of them started with rifle-caliber weapons, it cannot be asserted that gun quality caused the turn of the tide, rather, it was tactics, numbers, and aircraft performance. The Germans had, however, seen the desirability of a 20-mm cannon and so designed the Bf-109 to mount one firing through the propeller hub. Some of the Soviet I-16s also were carrying 20-mm weapons before the end of the conflict.[27]

All of the European great powers had matured gun industries (including the Soviet Union and Italy). There was little inhibition against adopting foreign ideas even though it was an age of rabid nationalism. For the most part, the advances in ammunition involved quality control and standardization. One of the reasons the US lagged in moving up to the 20-mm level was that it had led the rest to the .50-caliber region and had developed superior ammunition—including a viable armor-piercing incendiary (API) round. This improved ammunition in the M-2 yielded not only a higher rate of fire than the 20 mm but also superior ballistics. The changing of caliber is serious business, for the sunk costs (inventory) are usually enormous. Even before World War II, the Germans had contrived a round with electric ignition, but the rest of the world remained with percussion ignition beyond 1945.[28]

The reason the European powers were going to higher calibers was to get ammunition that would be hot enough (at the increasing ranges) to ignite aircraft fuel. Additionally, it was to get a round with enough mass and velocity to penetrate the armor then coming into use in aircraft. Also, going to a larger bore would permit the use of high explosive rounds and up to a point, increasing the caliber might result in a flatter trajectory. The fire control solution in aerial combat is exceedingly complex, but if the trajectory is made flat enough it reduces the effect of range errors. Since flat trajectory arises in part from higher muzzle velocity, it means that the target has less time to get out of the line of fire. The Europeans probably envisioned their targets as armored bombers more often than did the Americans. To some extent that drove them to leap directly from the .30-caliber region directly to the 20-mm level. However, increasing the caliber usually has the effect of lowering the rate of fire and decreasing the ammunition load one can carry aloft—both undesirable in terms of the probability of hitting enemy aircraft.[29] The larger caliber guns were more useful in air-to-ground operations than the smaller. Their lower rate of fire was not as large a handicap there because the targets were less fleeting than were other fighters. The ground targets were generally less fragile than an airplane; the larger warhead helped.

Though the British led the way in turret development for bombers, all their turrets (through the end of World War II) contained the .303-caliber Browning guns. Their initial approach when they moved to meet the Nazi threat against the British Isles in the mid-thirties was to mount many small caliber, high rate-of-fire guns on the wings of their new Spitfires and Hurricanes. As the potential targets were thought more fleeting even than they had been in World War I, the notion was that the higher the rate of fire, the better the probability of getting a hit. However, before the Battle of Britain (BOB), the Royal Air Force (RAF) had moved to follow the Luftwaffe and the Red Air Force into the 20-mm regions. Some Spitfires and Hurricanes were fitted with experimental 20-mm gun suites in time for combat testing in the summer of 1940.[30]

Just before the onset of the Second World War, the US started to follow the British lead, first with the experimental installation of a power turret on a Douglas B-18 and then with standard turret installations atop the fuselages of the B-25 and B-26 medium bombers.[31]

Though the US was committed to the .50-caliber machine gun for both bombers and fighters, it nonetheless was aware of the prospects and problems of going to a higher caliber. Gen Carl A. Spaatz had been sent to Europe in 1940 to serve as Gen Henry H. Arnold's combat observer. Arnold was at that time the chief of the Air Corps and responsible for preparing it for war. Spaatz reported back that though the acquisition program for the .50-caliber gun should be pushed as hard as possible, some manufacturing capability for a 20-mm air-to-air weapon should be sought. The Army's Ordnance Department had previously acquired both a license to build and some samples of the Hispano-Suiza that were aboard the British fighters. Some were manufactured in the US during World War II, but were mostly used on Navy aircraft. The concept behind building the P-39 around a 37-mm cannon was centered on an air-to-air mission. However, aircraft performance limitations disqualified it for that role, and it came to be used mainly in close air support (CAS) against ground targets. Experimental work mounting 20-mm guns on P-36s and 75-mm cannons on B-18s with a view to air-to-air use was done at Eglin Field, Florida, before Pearl Harbor, but none of it led to operational weapons. The sights of the day were inadequate for the ranges of the weapons and the rates of fire were far too low to compensate for poor sighting.[32]

Before Pearl Harbor little thought was given to developing weapons other than guns for air-to-air combat. But some things were done in other arenas on components that were similar to some that were to be used in missiles after World War II. For example, the systems used in the Kettering Bug, a kind of flying bomb, during and just after World War I may have been distant ancestors of some mid-course guidance systems developed after World War II. In the late 1930s infrared (IR) sensing was conceived as a possible aid in bombing through the clouds. After the war it was to become central to the development of air-to-air missiles. But none of those things came near to being incorporated into operational weapons.[33]

On the eve of World War II, air-to-air weapons had changed more in degree than in nature. Some nations, like the

US, were increasing gun sizes to the .50-caliber level. Others, like the British, were increasing the numbers of guns on fighters and bombers, while generally remaining with the rifle-caliber weapons. The reliability of the guns and ammunition had increased enough that they were often put out on the fighters' wings—outside the propeller arc, thus saving the weight of the synchronizing mechanism. By and large, during the interwar period the weapons were only guns, usually scaled-up versions of World War I weapons. Attacks on enemy aircraft were envisioned as being best carried out by surprise from behind, or out of the sun. The idea of radar was incomprehensible, and locating such an enemy in the vastness of space still seemed like a very serious problem.

## Air-to-Air Weapons and Doctrinal Flaws in World War II

ONLY THE US and the British entered World War II with well-developed ideas on strategic bombing and, as noted, they did not infer that upgraded bomber weapons would be needed for the air-to-air fight. All the other powers were more or less oriented toward tactical aviation—air power in support of the ground battle as opposed to independent operations against enemy economic resources or civilian morale. All the continental powers also understood that winning air superiority was vital to both surface and other air operations. But generally, they agreed with Giulio Douhet that the best way to achieve that was by air-to-ground attack against the enemy air forces at their bases. Consequently, there was more emphasis on bombs and the problems of delivering them on small targets than on new ways of air-to-air combat. Combat soon uncovered defects at both ends of the doctrinal spectrum, and spurred advances in air-to-air weaponry.

The German approach worked in its attack on Poland where some of the enemy's combat power was destroyed on the ground. The rest was technologically dated and could not put up much of a fight. The Germans repeated their success against the French and the British in 1940. After Dunkirk, the Battle of Britain campaign began with an attack on the RAF's infrastructure. It was imperfectly executed, but there is room to doubt that the Luftwaffe could have won through better ground target selection given the geographical and technological constraints on their operation. Still, there was some relief in the RAF when the Germans switched to an attack on London in early September, for it reduced the pressure on the ground structure and simultaneously the losses in British pilots began to diminish.[34]

Insofar as single-engine air combat is concerned, it is difficult to draw any firm inferences from the Battle of Britain. In general the British fighters were about equal in performance to the Germans. Their armament, however, was usually of a smaller caliber and a higher rate of fire than that of their enemy. The British fighters also carried more guns. But the outcome of fighter-on-fighter engagements did not emit any signals strong enough to interrupt the trend toward higher calibers on both sides. Nor did it stimulate a search for weapons other than guns for the air superiority battle.[35]

As for combat between fighter and bomber, the German attackers suffered heavily to little purpose. But the Luftwaffe guns, or lack thereof, cannot be identified as the decisive factor. Their small caliber and scarcity is often cited as one of many factors in the outcomes. Typically, the twin-engine bombers employed would have three guns aboard in flexible mountings, all enclosed, but never in power turrets. All of the guns were rifle caliber (7.9 mm—slightly larger than .30 caliber).[36]

The Luftwaffe itself soon decided that the bomber armament was too light. The contemporary experience of the RAF bomber command, still flying twin-engine bombers, armed only with a few rifle-caliber guns usually not in power turrets, was similar. In 1940, the daylight bomber losses were so heavy that the RAF, like the Luftwaffe, went over to the night attack. Without airborne intercept (AI) radars, losses were reduced for a time—but German and British bombing accuracy severely declined.[37]

Soon after the Battle of Britain, the US provided the RAF with a small number of its latest heavy bombers, the B-17C. They were still lightly armed and lacked power turrets. The RAF used them in daylight high-altitude raids against continental targets without much success, but the feedback led to some design changes in later models of the Fortress—including the introduction of two power turrets and tail guns. About a year later, the US deployed the Eighth Air Force to Britain and commenced raids against the Continent. The initial results (against targets on the periphery of Fortress Europe) were not too discouraging, and the Americans persisted in the daylight attack notwithstanding British skepticism.[38]

## Wartime Expedients

THE RAF responded to the early experiences of the war by continuing its development of larger caliber guns for its air-to-air fighters (which also increased the effectiveness of ground attack). In 1939 most British fighters and all their bombers were carrying rifle-caliber guns and they had a strong incentive to adopt bigger weapons; the US was already on the way up to .50 caliber, a round much larger than the British .303. The US Army Air Force (USAAF) responded by increasing the number of guns on its fighters and placing them all on the wings and retaining the .50-caliber Browning to the end of the war (and beyond).

After the tide turned, the Germans gave more and more attention, though belatedly, to the air defense of their homeland. That led them, in the days of the unescorted heavy bombers, to increase the numbers of guns and their caliber on many of their fighters. This permitted them to await the time when the US escort fighters had to turn around because of fuel and then to trail the bomber formations and take leisurely potshots at the Americans—with fragmenting warheads that caused damage without getting direct hits. It also permitted them to employ high-drag expedients such as mounting large caliber rockets on racks beneath the wings, enabling them to fire larger warheads than was possible with guns into the middle of the US formations. Free from an escort threat, it also permitted them to sling high-drag bombs beneath their fighters, fly well above the range of the B-17s' .50-caliber guns, and leisurely drop the bombs down onto the American formations. For a short time, the large caliber guns and the rockets worked well; the bombs did not.[39] From the beginning, it was too difficult to fuze the bombs correctly.

Those fighters armed with large caliber guns and rockets, and equipped with weighty armor, gradually became heavier and more cumbersome. Finally, when Eighth Air Force escort fighters were able to close the sanctuary for the German fighters at the far end of the bombing trips, the laden Luftwaffe defenders could no longer safely operate. The P-51s covered the bombers at the far end of the trip and the P-47s the nearer segments. Both were armed with .50-caliber Brownings. They generally got the better of all the German fighters—those armed for interception work against the bombers as well as those with lighter armament for the purpose of providing high cover to the interceptors. As practically all fighter-on-fighter attacks were stern shots, the guns of a pair of engaged single-engine planes were almost never firing simultaneously. Though the American guns were smaller, they were sufficient for the tasks—as were those of the Germans whenever they managed to get on the tails of US pilots. The latter events occurred less and less frequently in 1944. That had little to do with the quality of guns, but rather was a result of an ever-increasing disparity in both operational numbers and pilot experience level. The low experience level of the German pilots was a result of the collapsing training program caused by the drying up of the sources of aviation fuel. Even at that, the ME-262 jet with four good 30-mm cannons might have upset the Allied solution but for bad policy choices that kept it from getting on the line in numbers soon enough.[40]

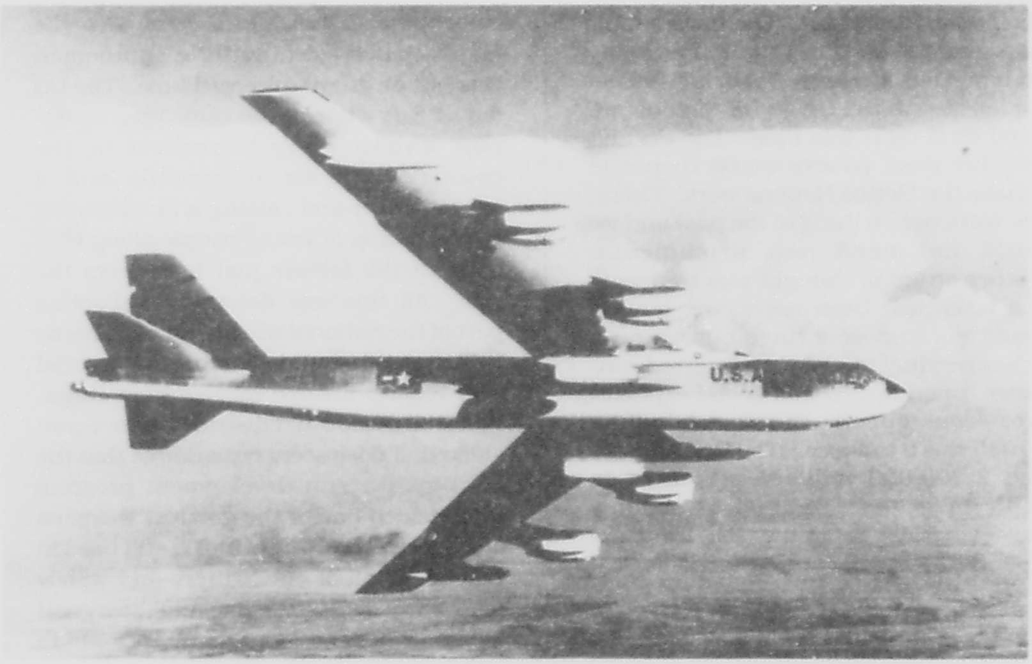
In the Pacific, the Japanese were outnumbered and outclassed in both airplanes and engines. And the longer the war went on, the greater the difference became. The same generalization applied to the pilots. Their pilot production was far lower than that of the US and in the desperate attempt to keep their numbers up, quality declined in the training program leading to disastrous results in combat. The same generalizations applied also to aircraft armament development. Materials were poor, and little research and development was done after the war began. American guns were better at the outset, and though not much improvement was done on them, fighters mounted more guns as the war went on. The difference in the quality and numbers of guns, however, was not a major factor in the defeat of Japanese air power. Numbers of airplanes and pilots; quality of both; and better organization, standardization, and doctrine on the Allied side were all far more significant.[41]

The Japanese, like the British and the Germans, did attempt to move up from rifle caliber to the 20-mm range during the war, while the USAAF and US Navy (USN) remained with the .50 caliber. The Japanese were much more threatened than the Americans. They therefore had a greater incentive to change their armament. But for the most part, they tried to import the technology from the Germans for their economy was not up to the requirements of a long war and could not sustain an extensive aircraft armament research and development program. The Japanese were not devoid of original ideas, however, one being a clever notion for a caseless round for 40-mm weapons. It had actually been worked out before the end of the war so that it was effective against bombers, though its muzzle velocity was too low for fleeting targets.[42]

As noted, the Americans added guns and turrets to their Liberators and Fortresses before Pearl Harbor. But they did not get the Boeing B-29 ready for the European war, so all of them were used against Japan. Its fire control system was a substantial step beyond those in earlier bombers—the guns could be controlled from one centralized station, or some in an alternate mode from the individual gun positions. However, the guns themselves remained the .50-caliber weapons except for one 20 mm in the tail. That might have helped against the Luftwaffe, but the heart was gone from the Japanese air forces by the time the B-29 got there in numbers. Moreover, the Superfortress was moved from daylight to night attack where the guns would be of limited use, so the 20-mm weapons were often removed to save weight. Though the B-36 did not come soon enough for combat, it was designed on the assumption that Britain might succumb. Its design incorporated 16 20-mm guns, remotely controlled from a central station.[43]

We have seen that the notion of an air-to-air guided missile had existed before World War I. But during World War II more work was done on air-to-ground guided weapons than on air-to-air missiles. However, many of the ideas that contributed in one area were (and are) applicable to the other. The Germans and the Americans had developed usable radio-command guided weapons and used them in combat in the Second World War. The US got a number of hits on naval vessels with radar-guided bombs before V-J Day, and was working on television and IR guidance too. Rockets had long been in use in air combat by the Germans. They had a host of imaginative programs in research and development, too many perhaps. Fortunately, the US absorbed many of the ideas, and scientists and engineers as well, during the final collapse of Germany.[44] It was a harvest of huge proportions. The diversity of the harvest was so great that it would permit the new combination of many ideas into new means of war fighting that would have enormous implications for strategy, operations, and tactics, and in turn for international relations.

Insofar as armament is concerned, air-to-air combat was not much different



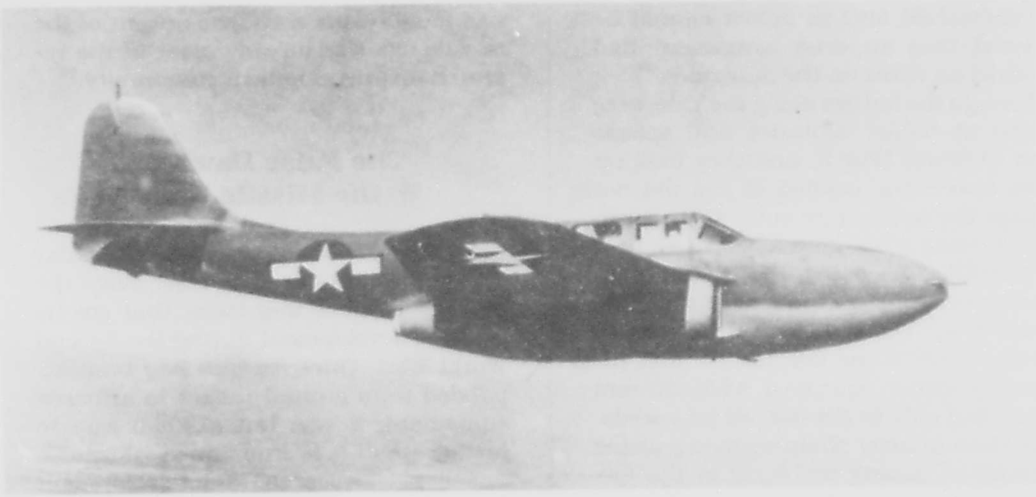
After the B-36, the requirement for turrets and guns to defend all aspects was deleted from bomber designs. The USAF B-52, shown here, came with tail guns only, in the 20-mm size. The theory was that speeds were such that most intercepts would result in stern chases. The B-52s in Linebacker II did achieve two MiG kills with tail guns.

from what it had been in World War I—stern attack with gun weapons. The emergence of practical guided missiles for air-to-air fighting seemed to promise more radical changes in air combat than had been seen before.[45] Another change, beyond the scope of this study, was fire control technology employing radar and improved gyroscopic sights.

## Postwar Stagnation in Nonnuclear Armament Development

NOTWITHSTANDING the harvest of technology from Germany and a backlog of good, but not fully developed, technological ideas that had been generated in wartime America, there was little serious development of nonnuclear aircraft armament in the first decade and a half after Hiroshima. There were multiple reasons for this Initially, many thought that though Woodrow Wilson had failed with the League of Nations, we would do it right this time. The US and the other great powers would cooperate to make the United Nations work. Therefore, wars were a thing of the past and we would not need new armaments. Another strain of thought was that wartime taxes had been necessary, but we should not impose a huge burden on a society needing to make up deferred consumer consumption and social expenditures—consequently the demobilization in 1945 was a collapse. (The USAAF went from 2,300,000 military personnel to hardly more than 300,000 in about a year—generally retaining the least experienced.) Finally, three technological revolutions were under way to absorb all the available developmental funding—jets, ballistic missiles, and nuclear weapons. The Korean War temporarily seemed to reemphasize the need for conventional weapons in an air superiority role, but the emergence of the massive retaliation doctrine, the Soviet detonation of a nuclear device, and the orbiting of Sputnik turned the flow of funds back in the other direction.[46] Within the USAF, the massive retaliation doctrine strengthened the hand of the strategic bombing advocates and limited the attention paid to tactical and conventional air operations.

The US achieved some marvelous things in strategic technology during the period, which benefit us still. It carried out the transition of its bomber fleet to jets and built a huge tanker fleet to support it. The US expanded the power and at the same time miniaturized its nuclear warhead inventory while multiplying its numbers. It led the world in the development of nuclear submarines and the submarine launched ballistic missile (SLBM). The US ICBM programs of the period come close to being in a class with the Manhattan Project, and the Minuteman was put on guard in record time. The US did all this while at the same time equipping almost every household in the country with an automobile and a television set and raising and educating a record crop of young people along with their GI-Bill fathers just back from the war. All this was done while shooting part of the national wealth out of cannons in Korea and sending another substantial part to help Europe recover from Hitler. When all those other distractions are considered, it does seem remarkable that the US began a gun development program that yielded one of the greatest weapons of all time—the 20-mm M-61, still used in practically all of our fighters and widely used abroad. At the same time, two great air-to-air missiles got their start and are still in wide use in Western air forces though they did not revolutionize air fighting as rapidly as had been predicted.[47]



Bell P-59 was the first US jet. One of the reasons for the apparently slow development of nonnuclear aircraft armament in the first two decades after Hiroshima was alleged to be the distracting presence of several contemporary technological revolutions. They included the transition to jets, nuclear weapons, ICBMs avionics, and nuclear submarines.

## The Korean Experience

SOME OF the guided bombs that had been developed during and since World War II were used experimentally in Korea. They were visually tracked and guided over a radio command link quite similar to one of the German World War II bombs and one of its air-to-air missiles (the Nazis had gotten the former into combat, but not the latter). The results were fair, but the technology was not tried on air-to-air weapons.[48] The period between the wars had been but five years, and it was not to be expected that new weapons suites would have been developed and deployed in that time.

During World War II, a new version of the M-2 Browning .50-caliber machine gun had been perfected, but its deployment was only just beginning as the war ended. The principal change was in providing a new liner for the barrel that had great benefits in logistical efficiency and in gun performance. The new weapon, known as the M-3, equipped the air-to-air fighters of the Korean War. The Air Force had transitioned to jets, but the guns were basically the same as in the previous conflict. The main air superiority fighter was the F-86 Sabre and the models used in combat were all armed with six M-3 weapons. The main adversary was the MiG-15. It had one 37-mm and two 23-mm cannons. While the MiG-15 was being designed, the Soviet Union had to consider a long-range heavy bomber threat against the homeland. The US faced a smaller threat and therefore had less incentive to go to big guns on the F-86. (However, the interceptor version of the Sabre did have unguided rockets in the 2.75-inch caliber.) But the cannons did not help the Soviets. The larger caliber resulted in a lower rate of fire and, though the airplane had a better altitude capability than the Sabre, the MiGs suffered greatly throughout. It seems that the superior training and greater combat experience of the American pilots helped overcome the limitations of their airplane. As the high rate of fire of their six .50-caliber M-3 Brownings may have been more significant than the heavy weight of the individual MiG round, it cannot be claimed that superior armament had much of an effect on the outcomes.[49]

Though the battles along the Yalu were fought at higher altitudes and speeds than in World War II, and they took up more space, the coming of jets did not change the basic approach—still a stern attack using guns from as close a range as possible. As noted, the transition to 20-mm weapons in bombers was already under way. The B-47 and B-52 were in development in the late forties, and ultimately came equipped with 20-mm guns—but only in the tail. At jet speeds, only stern quarter shots seemed feasible because of aiming problems in the forward hemisphere. All American fighters engaged in Korea came with .50-caliber weapons, but the F-86F Sabre entered the USAF inventory with 20-mm weapons just as the Korean fighting was ending. The guns were the new M-39s, developed from German technology since the end of World War II. Though the Korean War was fought with guns, the advent of the missile age was already afoot in the research and development community.[50]

## The False Dawn of the Missile Era

THE NOTIONS of infrared and radar detection had existed at least since the 1930s.[51] But it was radar that got its greatest development during the Second World War. Once the idea had been expanded from ground radars to airborne equipment, it was but a small leap to further push it to unmanned vehicles—missiles. Research and development (R&D) on air-to-air missiles, both radar and infrared, commenced in the immediate postwar period and by the mid-1950s, such missiles were coming on the line.

The chief image of conflict in the late 1940s was a transpolar attack carried out by large airplanes laden with nuclear weapons. While the guided missile re-


USAF F-86 Sabre with six .50-caliber M-3 Brownings. Most air combat in the Korean War was done with the M-3. It was, except for the barrel, essentially the same gun that had been demonstrated in 1917 and used in US Navy and Army aircraft in World War II almost universally.

search was being implemented, an initial tack was to employ a shotgun approach by firing a volley of small, unguided rockets. That seemed feasible against an unmaneuvering, relatively slow target (large bomber) and the interceptor version of the F-86 Sabre and the F-89 Scorpion were equipped to fire such volleys. Both aircraft fired 2.75-inch folding-fin aircraft rockets that were in service for many years afterward (26 in the F-86D and 52 [in the pods] in the F-89D).[52] At that point, rocket velocities were lower than the muzzle velocities of aircraft guns, and the unguided solution could not be more than an interim measure.

The research on US guided air-to-air missiles began in the late 1940s. The first missile to reach operational status was the Hughes AIM-4 Falcon, in 1956. It was built with both IR and semiactive radar homing (SARH), and a variety of warheads.[53] The Falcon remained in service for the next quarter century. In those pre-Sputnik days, it was not clear that the Soviets would leapfrog the strategic bomber phase into the ICBM age. All the air-to-air missiles introduced in the 1950s were designed against large-bomber, nonmaneuvering targets.

Two Navy missiles were designed and developed later and remained in service even longer. One was the IR AIM-9 Sidewinder, and the other the SARH AIM-7 Sparrow. The AIM-9 was the first air-to-air missile to score a combat kill in October 1958 when Chinese Nationalist F-86s claimed 14 victories in a single day (over the Chinese Communist air forces). R&D on the Sidewinder had begun in 1950, went through many models, and was produced in tens of thousands by several corporations in the US and by a consortium in Europe. It was still in production in the 1990s. Most of the models had IR seekers, but at least one radar version was tried without much success.[54]

Early IR missiles were limited to stern-quarter shots and their performance was degraded by clouds and rain. They were short-range weapons. As a complement,


USAF F-86D. In the aftermath of World War II, some fighters, like the F-86D, were designed without any guns. This plane had a retractable magazine under the nose that could be extended to fire volleys of unguided air-to-air rockets.

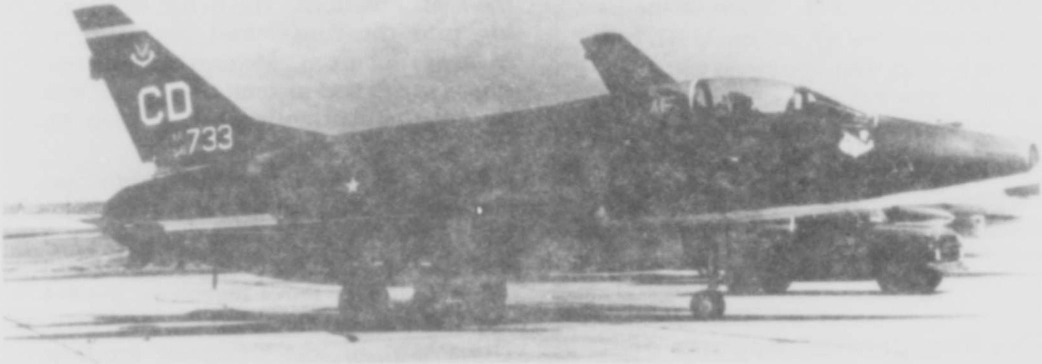
the AIM-7 Sparrow was developed with radar guidance in several variants. The R&D began under Navy auspices in 1946, and the first version of the missile entered service in 1956. The initial version operated on beam-rider principles, but soon a semiactive radar homer was developed. The Sparrow was also built in thousands of copies by several corporations in surface-to-air missile (SAM) and antiradiation missile (ARM) Shrike variants. It was also still in production in the 1990s. The Sparrow is substantially larger and more expensive than the Sidewinder, but it is also propelled by a solid rocket motor that gives it a longer range than the IR missile. The Sparrow is not limited to stern-aspect shots. It requires that the attacking aircraft remain roughly on course with its radar antenna painting the target after launch and until impact. That is not a requirement for the Sidewinder, for the pilot can go on to other business (like escape) as soon as the AIM-9 is separated from the aircraft.[55]

## Postwar Aircraft Gun Development

APPARENTLY little thought was given to the improvement of aircraft guns in the immediate postwar period. However, 1946 initiatives of the Army's Ordnance Department started developments on two trails that had their fruition only after the Korean War was over. One arose from the technology harvested from defeated Germany, and the other from a much older strain of gun development. Many thought that gun technology was so well matured that research would yield only diminishing returns—that investments were better made in missiles. Others thought that the increased speed of jets made imperative higher rates of fire and muzzle velocities and lower weights—and that could not be extracted from a technology already so mature. However, the Germans had been working on a revolver gun that was well along in development by 1945. It had a radical new action that promised significant improvements in rate of fire with high reliability and low weight—but limited still by the pressure and temperature tolerances of a single barrel. The idea for the other track arose in the Ordnance Department itself. It looked toward multiple barrels to spread out the stress and to save weight by using a single action to serve them all—building upon the Gatling gun technology of the nineteenth century.[56]

During the summer of 1946 the Army's Ordnance Department contracted for R&D on a gun envisioning a 20-mm weapon and a revolver action as with the German Mauser MG213C. The technology developed in the next few years was brought into a production program by Ford Motor Company and it resulted in a weapon known as the M-39E. The Mauser technology also led to development of revolver guns in Europe. The American version was ready during the Korean War and actually got into action aboard the F-86F achieving six kills just before the truce. The M-39 is a good gun; it achieves a rate of fire higher than that of the M-3 .50-caliber gun and yet does it with a substantially larger round and a comparable muzzle velocity with a much heavier projectile. The M-39 first went operational in the later F-86s and was standard equipment in the F-100. At this writing, it is still in production and used aboard F-5s.[57]

General Electric of Burlington, Vermont, survived the early phases of the Gatling gun developmental process as the prime contractor. The gun, which was to become the M-61, trailed the development of the M-39, but was ready for operations by 1956. This was at the time



USAF F-100 developed in the late fifties with M-39 20-mm guns. Those weapons were substantial improvements over the Korean War–era M-3 Brownings, but they were quickly superseded by the M-61 20-mm Gatling gun, now standard in most western fighters. The M-39 was a derivative of a German World War II developmental program based on the revolver principle.

that the first generation air-to-air missiles were becoming prominent and when the massive retaliation strategy was diverting funds and talent away from conventional programs. The M-39 represented a substantial improvement over the M-3 Brownings, but probably should be described as an incremental advance. The M-61, however, was a larger advance in a variety of ways though still perhaps not revolutionary in its impact.[58]

The weight of the M-39 is about three times that of the M-3; that of the M-61 Gatling gun is about four times that of the Browning. The M-39 delivers half again more rate of fire than the .50-caliber but the M-61 delivers four times the number of rounds in a given time. Like the M-39, it uses 20-mm ammunition. That is done with a substantially higher muzzle velocity (M-39 = 2,850 feet per second [fps]/M-61 = 3,400 fps), close to a 20 percent increase with the same size round having an exploding capability. Both of those qualities are highly significant in air-to-air applications. Probably equally important, the old machine guns and the M-39 use a reciprocating motion in their actions. The M-61 is characterized by a rotary motion with fewer sudden starts and stops. The result has been a quantum jump in the reliability of the system.[59]

The Air Force and Navy developed several fighters in the middle and late 1950s. The only one that came close to being optimized for the air superiority role in conventional warfare was the F-100 that came along too soon for the M-61, and it was equipped with four M-39s. The F-104 and F-105 were the first two planes equipped with the Gatling gun. The former was built in many variants, including a day fighter version, but the initial lot of production went to the Air Defense Command as interceptors with a gun and Sidewinder missiles. Many others have been built by and for our NATO allies usually with important modifications for ground attack. The F-105 was built as a high-speed penetrator for nuclear attack. It had a bomb bay and came with an M-61 installed. The F-101 and F-102 were envisioned as interceptors also, but the former came in reconnaissance and ground attack variants. Some of the F-101s had guns, though not the M-61, but all of the F-102s were equipped with missiles only. The F-4 was a Navy development designed as a fleet defense fighter—a mission similar to the interceptor role of the Air Defense Command of that day. It, too, was designed with only missiles for air-to-air fighting.[60]

## The Exaggerated Reports of the Death of the Aircraft Gun

BY THE presidential election of 1960, gun technology had made a substantial advance but it was little noticed coming in the shadow of the new air-to-air missile technology. The Kennedy administration with its Flexible Response, seemed to be a move away from the use of guns in the air-to-air role. Practically all of the new fighters were equipped with the AIM-9 Sidewinder, and many, those that could bear the necessary radar, were being built to carry the AIM-7 Sparrow. The two fighters that were to be the USAF mainstays in the air war over North Vietnam were the F-105 Thunderchief and the F-4C Phantom. The F-105 was coming into the units, and Secretary of Defense Robert S. McNamara was enthusiastic to find aircraft that would suit the requirements of both Navy and Air Force.

The F-111 TFX (tactical fighter experimental) program was one manifestation of McNamara's policy, and the F-4 was another. Though the F-111 made it only into the Air Force inventory, the F-4 was put into the fleet and the Air Force. The Phantom was designed for fleet defense, and that role resembles the Air Force's interceptor mission area more than its battlefield air superiority function. Enthusiasm for missiles was not confined to the Navy, though the Air Force (especially in the Tactical Air Command [TAC]) insisted on the need for a gun in an air superiority fighter.[61] The result was that the F-4 was brought into the Air Force inventory for the air superiority role without a gun. However, there was enough sentiment for a gun that development was immediately begun to create a gun pod to be carried externally beneath the airplane. By the onset of the Vietnam


The USAF F-104 of the late 1950s shown here (along with the F-105) was the first aircraft equipped with the General Electric M-61 20-mm Gatling gun. This gun is still standard in most US and many NATO fighters. An improved version of the M-61 is currently in the advanced tactical fighter (ATF).


The F-105 is shown here configured as a conventional fighter-bomber. In Vietnam it was used primarily for bombing while the F-4 covered it against air-to-air attack from MiGs. Though the F-105 had been designed for high-speed nuclear attack, it included an internal Gatling gun from the outset. During the Vietnam War, the F-105 achieved some kills with guns and some with IR missiles, but it could not fire radar weapons.

War, such a pod was on the line as the SUU-16 containing the M-61 Gatling gun.[62]

In Vietnam both of the Air Force's mainstays were applied to combat roles for which they had not been designed. The F-105 with its internal gun came to be the conventional bomber instead of the supersonic nuclear, penetrating strike fighter. The F-4C was at first the air superiority fighter instead of the fleet defense interceptor. (Later, it replaced the F-105 in the bombing role, too.) It did not have a gun, but was equipped with AIM-9 heat-seeking Sidewinders and AIM-7 radar Sparrows. The Thunderchief had a gun and the Sidewinder, but not the Sparrow. The supersonic strike role had demanded a high-speed wing with high wing loading on the F-105. That meant that all of the communist fighters could outturn it by a wide margin, a serious handicap in dogfighting. The F-4 had a lower wing loading. Combined with its high thrust-to-weight ratio, it had an excellent climb rate that was also important and it could come closer to staying with the North Vietnamese fighters in a hard turn. But when the gun pod was hung below its fuselage, it lost some of its performance advantages. Furthermore, the gun so carried was not as accurate as it was in internally carried configurations.[63]

## The Defects of Air-to-Air Doctrine Revealed in Vietnam

THOUGH there seems to have been substantial technological advance in air-to-air weapons during the Eisenhower years, not much thought was given to air superiority doctrine. Michael Howard has written that all doctrine is wrong. He asserted that the peacetime soldier's task is to strive to keep the doctrine from being too far wrong. He argued that when combat comes, it inevitably exposes the doctrinal errors. Then the task becomes to adapt to correct the errors more rapidly than does one's enemies.[64]

The errors in the air-to-air doctrine on the US side were not all that great. But combat soon exposed them, and adaptations were undertaken. The kill ratio was still favorable to the American side, but it was far less favorable than it had been during the Korean War. Aircraft armament was seen to be a more significant factor in the air-to-air fight than in previous conflicts. The IR and the radar missiles had a lower success ratio than their enthusiasts had expected. The communists were able to get better use out of their aerial guns than had been anticipated.[65]

The Americans adapted rapidly; so did the Vietnamese—with significant assistance from abroad. There were important advances in electronic countermeasures (ECM) capabilities for the self-protection of bombers and fighters, and specialized units for the suppression of the ground defenses were built. The combat experience lent force to an already existing program to provide an internal gun for the F-4, and the first E model was put into operations in the fall of 1967. Innovative tactics, as in Operation Bolo early in 1967, yielded some temporary advantages. But the ratio and the performance of the air-to-air missiles remained disappointing.[66]

There was more to this disappointment than just the nature and quality of the air-to-air weapons. The state of air combat training was one. The US peacetime training emphasized achieving air superiority largely through offensive counterair attacks on enemy air assets on the ground. As conducted, air-to-air defensive counterair training was between small units carefully constrained to maintain strict safety standards. This seriously underemphasized the complexity of the air environment in Vietnam and limited the effectiveness of the training. Further, the US policy of rotating its

USAF F-4E. Earlier versions of the F-4 did not have the internal M-61 20-mm cannon seen here (under nose). They were at a disadvantage without a gun in combat against the MiGs. A podded 20-mm gun was developed for external carriage, but that entailed a performance penalty.

pilot force through the combat billets spread the fighting experience through the force but guaranteed that the experience level on the line in Vietnam would be low.

Even with the weapons themselves, some nontechnical factors reduced their effectiveness. The strong point of the AIM-7 was that it could be fired from any aspect, not just behind the target. Also, it had a longer range than either the guns or the IR missiles. Had the AIM-7 been employed in an interceptor role against a strategic nuclear attack as designed, identification of the target would not have become a problem. But in the crowded airspace of Vietnam, it was necessary to insist that the attacker visually confirm the identification of the quarry before firing at a target. Unhappily, by the time a pilot could do so he was usually close enough to use the IR missiles or guns instead—losing both the range and aspect advantages of a key weapon. Additionally, the Sparrow sometimes remained on the pylons through many landings and takeoffs (especially rough on aircraft carriers) and the wear and tear made it unreliable in its functioning. Its operation was more complex than either IR or gun weapons and required a second crew member (given the state of technology). Too, the cockpit control arrangements were less apt than optimum. The SARH configuration required that the fighter remain on a fairly predictable course for the several seconds of the missile's flight and sometimes that was too dangerous to do in the midst of an air fight.

The air-to-air training had inadequately emphasized the dimensions and nature of the firing parameters. Sometimes Sparrows were deliberately fired out of parameters to so threaten an enemy pilot that he would discontinue an attack or take some evasive action that would permit our fighter to close within the range of the remaining weapons. Sometimes the missiles were unknowingly launched when they had no chance of properly guiding on the target. Only about one out of 10 Sparrows launched achieved a kill.[67]

The Sidewinder also had limitations that caused it to fall somewhat below expectations. First, the versions in use in the Vietnam era required stern shots at the exhaust pipes of adversary jets. They were rather easily decoyed by flares. They sometimes homed on the sun or on its reflection from the clouds below. Their maximum range was less than that of the AIM-7, and like the Sparrow, they had a minimum range that offered a kind of sanctuary—one yielding an advantage to enemy aircraft with guns that could be effective inside that range. The Sidewinder was more reliable than the Sparrow because it was less complex, but it was not as reliable as it might have been. As the early marks of the Sparrow and the Sidewinder had been designed for nonmaneuvering bombers, many fighters could outturn them. This was especially effective against the Sidewinder because it not only forced a sharp turn on the missile but also tended to mask the tail pipe heat source from the seeker. The Sidewinder, too, was sometimes fired out of parameters to impress an enemy. Like the Sparrow, the shape of the envelope in which a shot was permissible changed with changing speed and direction. It was difficult for pilots to keep its limits in mind in the heat of combat. The F-4's engines left a trail of smoke even when not in afterburner. That was a serious handicap in the air battle for it allowed the enemy pilots to spot the Americans too quickly. Similarly, the Sidewinder (and the Sparrow) had rocket motors that left a highly visible trail of smoke. This was serious in that their aerodynamic design and top speed was such that if the enemy spotted an inbound missile soon enough, he could usually turn faster than it could and escape. In the end, the ratio of kills per missile was better than that of the Sparrow, but still below 20 percent.[68]

In air-to-air combat, the F-105, F-4, C, D, and E models, and the Navy's F-8 Crusader got significant numbers of kills with their weapons. The Navy F-8s did significantly better than its F-4s. In part, the reason was that the mere presence of internal Mk-12 20-mm cannons built into the Crusader was conducive to more air combat training than was the practice in USN Phantom units. The USAF F-105 did not have as many opportunities as the others because it was usually in a bomber or defense suppression role. However, once its bombs were expended, it could and did fight with its guns and Sidewinders. During the Linebacker operations, for example, in a period of about seven months, the USAF forces got 10 kills with Sidewinders, and seven with the M-61 cannon—though they had made many more attempts with the missiles.[69] Still, most kills during the whole war were achieved with missiles. Though the new weapons achieved most of the kills, the reliability of the AIM-7 and the rules of engagement that inhibited employing it at long range limited the number of kills it made from the forward hemisphere. The Sidewinders of the time were limited to stern shots. Consequently, firing on the enemy from behind at fairly close range was the most frequent approach. The new weapons, in that sense, had not yet revolutionized tactical air doctrine.

## Post-Vietnam Development of Air-to-Air Weapons

THE participants in the Vietnam battles came away with many and varied ideas for the improvement of missiles, but an almost unanimous conviction that a gun would be required on air superiority fighters well into the twenty-first century.[70] In the aftermath, substantial efforts have been made to improve missiles and guns and to develop altogether new weapons in both categories. All USAF and USN fighters acquired since Vietnam have included a gun—all except the AV-8 and the A-10 have used the same M-61 Gatling gun installed in the F-105 and the F-4E. Many foreign air forces use the M-61, too, and almost all of their air superiority fighters and interceptors have also carried guns.[71]

## Recent Combat Experiences

ON THE other side of the world, the Israeli Air Force (IAF) was also an influence on the direction of air superiority doctrine and technology. Its 1967 campaign serves as a classical model of the potential for the achievement of air superiority through offensive counterair (OCA), a surprise attack on the enemy air forces on the ground. However, as the enemy was largely eliminated before it got into the air, that war did not offer much instruction on the subject of defensive counterair (DCA), air-to-air weapons. For a time, the Yom Kippur War seemed to suggest that air superiority might be achieved, or at least contested, by ground-based air defenses, but it, too, offered little instruction in DCA. The few air-to-air kills that were achieved in 1967 were scored with guns; many in the 1973 war were accomplished with missiles.[72]

In the "October War," as in Vietnam, the gun-missile combination seemed most effective. The IAF went into large-scale combat again in 1982 against the Syrian Air Force over the Bekaa Valley. That time, the experience was most instructive in the realm of the balance between air forces and ground defenses for the IAF overcame the latter handily with few losses. The air combat was extensive.

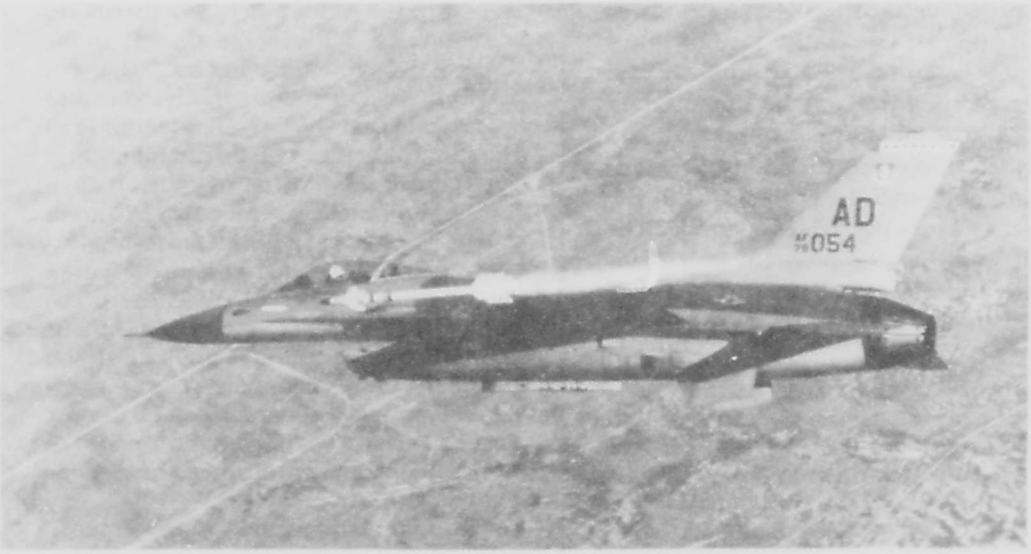
The IAF had it all its own way, but many factors (in addition to superior aircraft armament) contributed to that result—most prominently superior aircrew training. Only 7 percent of the Syrian losses were to guns. By that time the IAF was equipped with F-15s and F-16s. The former had Sparrows and Sidewinders while the latter carried only IR missiles (both aircraft had the M-61 20-mm cannon). The missile success ratio seems to have been higher than in Vietnam, but it was a different enemy and improved versions of the AIM-7 and AIM-9 were operational.[73]

In the Falklands War of 1982, the British prevailed in limited air-to-air fighting. All engagements were the Harrier defenders versus Argentinian jets on bombing missions. Little can be inferred from the fighting beyond noting that most of the British air-to-air kills were achieved using the Sidewinder, but it was a much improved version compared with the ones used in Vietnam.[74]

At this writing (March 1991), the war against Iraq is barely completed. There was not enough of an air superiority battle to establish any clear trends. The media suggests that the short air-to-air jet battle was one sided in favor of the coalition forces, and all of the kills achieved were done with missiles, not guns.[75]

## Product Improvements of the Guns, Sidewinder, and Sparrow

MAJOR reforms arising from the air fighting over North Vietnam included new and more realistic USAF and USN training programs for air combat (Red Flag and Top Gun).[76] As for technology, one result was the design of two new USAF fighters which were optimized for air-to-air combat: the F-15 and F-16. Both designs included space for a gun and for missiles.[77]




USAF F-16 launching an AIM-9 Sidewinder air-to-air missile. The Sidewinder is an IR missile and is lighter and cheaper than radar missiles. It is a short-range weapon. Current Sidewinders are much improved over their Vietnam-era ancestors. They are more reliable and no longer have to be fired from behind the target. Sidewinders got most of the kills in the Falklands War and Bekaa Valley fighting of 1982.

During the 1970s, the USAF had a major R&D program aimed at providing an advanced gun for the F-15, with additional applications to many other aircraft. Known as the GAU-7, it used 25-mm ammunition. Since the beginning, gun design and ammunition design have been interdependent—usually a revolutionary development in ammunition leading to a similar radical improvement in guns. Such an ammunition advance was to have been the foundation for the GAU-7: caseless, telescoped ammunition. The idea was that the projectile was to be telescoped back into the propellant, and the outer layer of the propellant was to serve as its own casing—and be consumed in the barrel on detonation. Not only was this to yield a substantially improved muzzle velocity but also to result in a symmetrical right cylinder round. That simplified the feed system and eliminated an extraction system altogether—with benefits in rate of fire and increased reliability through fewer moving parts. The GAU-7 Gatling gun's design posed no particular problem, and the telescoped part of the ammunition design did produce higher muzzle velocities. However, durability, environmental, and shelf life problems with the caseless feature proved insuperable. The result was that the program was abandoned and the M-16 20 mm was installed in the F-15, F-16, F/A-18, and F-14.[78]

Component technology has advanced dramatically since the Sidewinder and the Sparrow were first developed in the 1950s. The miniaturization of electronic parts, the appearance of small computers, the development of solid-state electronic technology, the advance in propellant technology, and refinements in warhead design have all contributed to substantial product improvements in both missiles. These changes have caused performance and reliability gains for each of them.

The later models of the Sparrow and the Sidewinder are proven more reliable in part because the wear and tear of long carriage on aircraft pylons has less impact on the new solid-state electronics. In later combats there have been fewer failures to eject from their rails, to ignite the propellant, to guide on the target, to properly detonate near the target, and to do sufficient damage to bring the enemy down. Both missiles enjoy improved propellants and aerodynamic design that give them a higher speed and a capacity to make harder turns than their Vietnam-era ancestors—both of which make it harder for an enemy to evade them if he knows he is under attack. The rocket motors have been so improved that they leave less smoke and thus lessen the odds that the enemy will ever discover he is under attack.[79]

All improvements notwithstanding, the Sparrow still is well over double the weight of the Sidewinder. Furthermore, it requires a fairly sophisticated radar aboard the launching fighter. Being a SARH missile, it retains the handicap of mandating that the launcher continue in the same direction with its radar emitting until impact—both of which are dangerous practices. As only one target can be managed at a time (sometimes two AIM-7s were launched at a single target at the same time to increase the probability that at least one would hit), it prevents the mounting of another attack before the first is complete. The Sparrow cannot be used aboard most of the Air Force's F-16s, and it limits the amount of fuel and other munitions that other fighters can carry.[80]

Though substantial improvements were made in the Sparrow by 1980, probably even greater gains were obtained in the IR Sidewinder. It shared almost all of the component advances of

Sparrow (AIM-7) radar missile being fired from USAF F-15. The current Sparrows are much improved over their Vietnam-era ancestors and achieved many of the coalition's kills in Operation Desert Storm. However, they are heavier and larger than the newer radar weapons and they are semiactive systems that require guidance from the launching aircraft until impact. They are all-aspect missiles and are less expensive than the advanced medium-range air-to-air missile.

the Sparrow, but in addition it overcame one of the greatest handicaps of the early model AIM-9s. They had to be fired from a rather thin cone behind the tail of the enemy. By the time of the Falklands and Bekaa Valley fighting, through better cooling, new materials for sensors, enhanced aerodynamic design, and improved optics, the Sidewinders had greatly expanded their envelope so that they were approaching an all-aspect status. They could be fired at the enemy from almost any direction. It was no longer necessary that the sensor have a direct line of sight on the enemy jet's exhaust pipe. It had become so sensitive that it could home in on the parts of the airfoils that had been warmed by air friction entailed in high-speed flight. Head-on shots with Sidewinders became possible. The Vietnam-era IR missiles (including enemy ground-launched portable missiles) could be rather easily spoofed by dropping flares. The later marks of the Sidewinder overcame this by giving the sensors the capability of discriminating between flares and the target heat sources. Even the newest IR AIM-9s were limited in performance by fog, clouds, and rain; and in any event they were short-range weapons.[81]

In the aftermath of the Vietnam War, the Navy also turned to the development of a new fighter—the Grumman F-14. Like its ancestor, the F-4 Phantom, it was optimized for fleet defense—long-range interception of relatively nonmaneuvering targets. Because of the limited deck space of aircraft carriers, it was highly desirable that each F-14 be capable of multiple kills, even simultaneous attacks as far away from the task force as possible. With the coming of standoff missiles in the Soviet airplanes, this characteristic was all the more desirable. The F-14 is capable of carrying the Sparrow (along with its M-61 cannon and Sidewinder missiles). However, the

AIM-7 has a limited range and only one can be directed at a target at any given time. The Navy, therefore, developed a new missile and a sophisticated radar system to overcome the limitations of the AIM-7.[82]

The Navy's AIM-54 Phoenix is used only aboard the F-14. An attack can be managed against six targets at a time while the airplane's radar maintains a watch on as many as 24 targets simultaneously. The Phoenix is launched in a SARH mode against targets as much as 100 miles away. It has its own radar set and can complete the latter part of its trajectory independently while the aircrew initiates additional attacks or begins its escape. In 1981 the Phoenix was close to double the weight and 10 times the price of the AIM-7F and required the use of a very expensive radar system and a second crew member.[83] Consequently it was not used to replace the Sidewinders and Sparrows but rather to complement them.

An examination of the literature on air-to-air weapons seems to support Kranzberg's notion that the glamorous subjects get disproportionate attention. Since the end of the Vietnam War, there have been at least 100 articles on aircraft missiles for every one on gun development. Most of this work was in the print media, and little serious history has been published on either. As it stood at the onset of the 1980s, it was clear that in the West at least air-to-air missile technology had advanced rapidly since Vietnam and many of the limitations had been eliminated or lessened. However, the gun technology, on the surface of things, had not moved ahead. The same gun that was used in the F-105 in 1958 was also used in all of the United States' latest fighters. Though a large majority of the people with operational experience were firmly convinced that future air superiority fighters would nonetheless require a gun, the missile advances were bound to revive the notion that it might be better to eliminate the gun and use the weight (and money) savings for additional missiles or fuel.

## The Horizons of Air-to-Air Weapons Technology

IN THE United States, two air-to-air R&D efforts were started in the 1970s that are now nearing maturation—one for a missile and one for a gun. The missile envisioned was to have many of the advantages of the Phoenix, but smaller and cheaper. The gun was to build on the technology of the GAU-7 to use a quantum jump in muzzle velocity combined with a new sight to achieve an all-aspect capability and a substantially higher $P_k$ than the M-61 Vulcan while retaining all of the advantages of that gun.

## AMRAAM: The Mother of All Missiles

THE ADVANCED medium-range air-to-air missile (AMRAAM) program was generated in 1976 to go beyond the product improvements feasible within the constraints of the Sparrow airframe. After the advanced development phases had been completed, Hughes was selected for the full-scale development program in the early 1980s. The new weapon was seen as a follow-on for all of the radar-guided medium-range missiles in Western inventories. The United States signed a memorandum of understanding (MOU) with some of its principal NATO allies in 1980. The MOU provided that the US would develop the AMRAAM and a combination of its European allies would create a follow-on to the Sidewinder—the advanced short-range air-to-air missile (ASRAAM). There were

Advanced medium-range air-to-air missile (AMRAAM) test shot from the F-15. The AMRAAM is an important advance over other medium-range radar missiles for several reasons. It is smaller and lighter, jam resistant, and is a fire-and-forget weapon. It will be used also on a large part of the F-16 fleet that does not yet have a radar missile capability.

to be coproduction arrangements for both missiles. The US agreed to avoid duplicating short-range missile programs while the NATO allies were to stay away from medium-range radar missile programs for the life of the understanding.[84]

If not revolutionary, the AMRAAM went beyond the usual incremental improvements in weapon systems. It was to incorporate all of the many improvements described above for the post-Vietnam models of the Sparrow and Sidewinders. But, in addition, it was to have an active radar homing mode—to be able to direct itself at its target without assistance from the launching aircraft. That would enable friendly fighters to begin their escapes immediately after launch, to shut down their radars to frustrate enemy targeting, or to manage multiple simultaneous attacks. It was also to enjoy a "home-on-jamming" mode. The missile was designed with inertial midcourse guidance that would keep it on track until its own radar came within range of the victim—without help from the launcher.

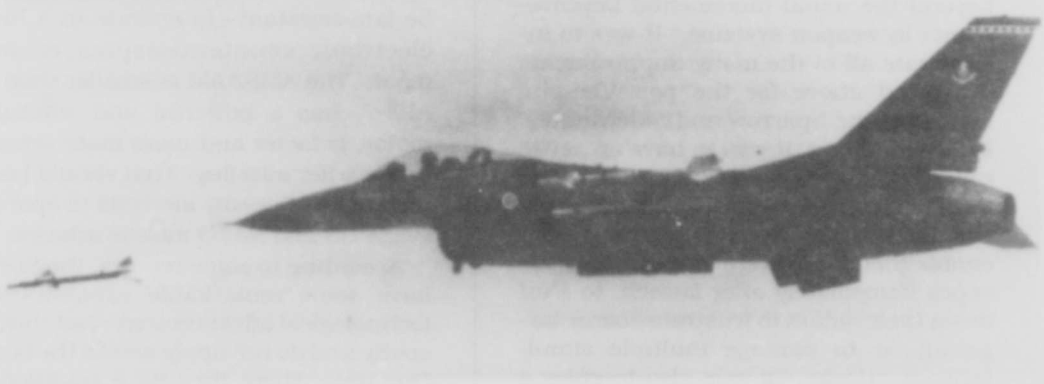
Additionally, the AMRAAM was designed to be 60 percent of the weight of the Sparrow so that more of them could be carried, or that the same number would cause less drag than the equivalent Sparrow load. Its seeker was designed to be jam-resistant—to operate in a heavy electronic countermeasures environment. The AMRAAM is smaller than the AIM-7, has a powerful and smokeless motor, is faster and more maneuverable than earlier missiles. That should lessen the ability of enemy aircrews to spot and evade US and NATO missile attacks.

According to some reports, the Soviets have some remarkable capabilities in technological advancement—but they are spotty and do not apply across the board. One area where they have traditionally lagged behind the West, and seem to lag still, is in the realm of air-to-air missiles. According to those reports, it will be many years before the Soviets have the component technologies to duplicate AMRAAM, and the new missile therefore might go a long way toward compensating for a numerical imbalance.[85]

The AMRAAM program was not without its challenges. It ran into various testing difficulties during the middle eighties, and holding down the costs was very difficult. Even though costs had been brought down substantially by 1990, the unit cost still stood at $600,000 per missile. In May of that year, however, a full-scale test was held over the Eglin Gulf Test Range. One F-15 fired four missiles at four different jet targets in a heavy ECM environment. The AMRAAMs got direct hits on three of the jets and the fourth missile passed close enough to its target that its proximity fuze would have detonated and fragments would have destroyed it. That test, coming after many others proving various aspects of the weapon's functioning, seemed to build substantial confidence in the program. The schedule had called for an initial operational capability (IOC) in the mid-1980s, but it was not achieved until 25 September 1991. Though some AMRAAMs were deployed to the Middle East for the war against Iraq, the air-to-air fighting was over too soon for them to get a combat evaluation.[86]

Though the combat test was not feasible, the range testing and the improvements in the older missiles seemed to offer the basis for speculations that the nature of the defensive counterair battle was on the verge of great change. The F-16 was present in large numbers in the USAF inventory. It had neither the radar nor the weight-carrying capability to handle the Sparrow. It would be able to use the AMRAAM which was a major change for the US and its allies. All their F-16s had been confined to short-range fighting before AMRAAM, now they would all acquire a beyond-visual-range (BVR) capability with the new missile. That meant that for the enemy pilots, at least, "checking six" was no longer enough, for after 1990, danger might come from any direction.[87]

Though the modernity and romance of missile warfare kept the advance of the technology for such weapons in a prominent place in the pages of the media, there was still room to wonder whether the future belonged wholly to the missile. Kranzberg's thesis seemed to be



USAF F-16 firing an AMRAAM. Most US and allied F-16s cannot handle the Sparrow and are therefore equipped only for short-range air combat. AMRAAM will give them an important longer range, all-aspect radar capability for the first time.

borne out in that some important advances in the more mundane gun technology went relatively unnoticed. Ever since it proved impossible to overcome the challenges with the caseless round in the GAU-7 program of the 1970s, a desire continued to use its proven technological advances to develop a weapon that would have a more than incremental effect on the air superiority battle.

Since 1976, the Air Force Armament Development Test Center at Eglin AFB had exploratory and advanced development programs in gun and ammunition technology. By the late 1980s, they had resulted in a tested telescoped round in 20-mm caliber that had achieved around 5,000 fps. General Electric had survived the advanced development phase and produced and tested a flight-weight Gatling gun with fewer than half the parts of the M-61 and about one-third the number of moving parts. As gun sights make their predictions based on the past track and speed of the target, the shorter the time of flight, the less the error arising from changes in the target's path of travel. Consequently, the roughly 50 percent gain in muzzle velocity (over the M-61) would greatly expand the firing envelope of the attacker's gun—again making checking six insufficient for the enemy pilot.[88]

During the late 1950s, the enthusiasm for air-to-air missiles waxed strong. When their kill ratios in Vietnam turned out to be less than expected, the shortcomings of missile technology were typically blamed. But perhaps there was more than that to it. Many of the predictions were based on an assumption, tacit perhaps, that air-to-air gun technology remained stagnant in the 1950s—that the missiles in the future would compete with the .50-caliber Brownings used through World War II and in Korea. That assumption was not true, and it may be valid to say that a part of the outcome in Vietnam arose from the fact that the missiles were not as good as expected, and part from the fact that the guns were better than expected. In 1991, the improvements in the Sidewinders and Sparrows and especially the advances in the AMRAAM seemed spectacular. But the earlier experience stimulates one to ask whether the drama of the missile successes in the Yom Kippur, Falklands, Bekaa Valley, and Iraq fighting may be masking less romantic but also important improvements in ammunition and aircraft gun technology.

## Speculations on the Future of Air Superiority Weapons

MICHAEL HOWARD, as noted previously, has asserted that all doctrine (and consequently technology choices) is inevitably wrong. The choices are affected by thousands of interdependent factors some of which are unknowns that must be covered by assumptions. The goal, said Howard, must be to keep one's doctrine from being too far wrong and to build one's system to be more able to adapt quicker than the enemy's when the combat experience reveals that assumptions are wrong. What follows, therefore, is a group of speculations about the future of air superiority weapons with the hope to improve the odds that the intuitive judgments that must be made will be correct, or not as wrong as those of future adversaries.

Three of the major technical variables that will affect air superiority outcomes in the future are: the AMRAAM, gun technology, and advanced tactical fighter (ATF) programs. Clearly they are interdependent. All three programs were conceived in the immediate aftermath of the fall of Saigon, at a time when Soviet foreign and military policies seemed strong and aggressive. It was also a time when stealth technology was not as widely recognized as an important factor, and when the implications of microcircuitry technology were not nearly so well defined as they have become. It was also a time when instability in the third world was seen as a serious problem, but when military technology had not yet been widely transported thence. It was a time when the notion was popular that the ground-based air defenses could command the air over the battlefield with relative ease. In short, at the time that the requirements for AMRAAM, the ATF, and advanced gun and ammunition technology programs were established, the problem was significantly different from what it is in the 1990s.

The new problem in some ways is more complex than that of the mid-1970s. Though the likelihood of global nuclear war seems to have subsided, the possibility remains; a few more states may have the nuclear capability to start such a war. The threat of a massive conventional general war on the northern European plain seems much diminished, but the possibility remains. We are likely to get more strategic warning of such a thing than might have been the case in the 1970s. The third world introduces additional imponderables. Though the local stimulants of instability remain, or are worsened, the external support from the communist world is no longer as great a factor. Nonetheless, military technology has spread far and wide in the less-developed world since 1975. In sum, the problem seems more diffused and less well defined than it was after the fall of Saigon. As air power's strongest suit is its flexibility, the challenges of the 1990s could increase the premium put on it and the complexity of the choices to be made by the leaders. The challenge may also be air power's opportunity. It's inherent flexibility, if cultivated, may enable it to fulfill Howard's requirement to make our system more adaptable to the lessons of future combat experience than are those of our adversaries.

There are hundreds of possible solutions facing the US leaders charged with cultivating that adaptability. It is recognized that the discussion that follows cannot be definitive in the absence of consideration of political, economic, and platform factors that are interrelated. The discussion nonetheless confines itself to an examination of some of the pros and cons of solutions including high-tech radar missiles like AMRAAM and of those including an advanced gun and gunsight. Even limiting the discussion to those two general areas is somewhat artificial since it leaves out a host of possible product improvement programs that would enhance the value of current air-to-air weapons in substantial ways. Much depends, also, on the technology, tactics, numbers, terrain, and training of the adversary—all of which are less "knowable" then they have been heretofore.

## Solutions Including Multimode Radar Missiles

THE TESTIMONY of any number of authorities asserts that the capability of getting in the first shot will be a substantial, perhaps decisive, advantage in future air battle.[89] The champions of putting the high technology into the weapons instead of the platform and of medium-range missiles argue that the coming of AMRAAM tends to be revolutionary—not evolutionary. Danger can threaten enemy pilots from any direction, at much higher speeds than before, from far greater distances, and with less rocket motor smoke to tip them off. Whether on standard fighters of the 1990s or future fighters, such missiles will magnify the flexibility already inherent in superior platforms. The launch-and-leave capability of AMRAAM will enable multiple attacks and immediate evasion after missile launch. It also enhances the situational awareness edge arising from

US and NATO airborne warning and control system (AWACS) by expanding the sphere that the enemy pilot needs to survey. In combination with the stealth and new radars of the advanced tactical fighter, for example, the AMRAAM further multiplies the first shot opportunities.

The improvement in air power adaptability that could arise from AMRAAM might well be compounded by the nature of the current USAAF force structure and declining defense budgets. A very large part of the fighter force is made up of swing-role F-16s. The airframe seems to be excellent in the air-to-air role at short ranges. It is young in years and has long service ahead. However, it does not have any BVR capability at all since it is equipped only with 20-mm guns and the AIM-9 Sidewinder IR missile. From the beginning AMRAAM was designed to be compatible with the F-16 in size and weight, as well as in its electronics. The addition of such a weapon would greatly expand the numbers of fighters available for the full range of the air superiority battle at a cost much lower than purchasing additional F-15s or ATFs.

Missiles like the AMRAAM, however, are inevitably complex. They are made possible only by the dramatic and recent advances in microcircuitry. The individual components are more reliable than they were in the Vietnam days, but complexity still tends to breed unreliability. It also tends to breed high cost and small inventories. The unit cost of AMRAAM runs well over a half million dollars.[90] Notwithstanding that the new weapon has a multimode seeker, it is dependent upon electromagnetic radiation. This could conceivably diminish its effectiveness in two ways. If the stealth being designed into new US aircraft spreads to other nations, then the range capability of the AMRAAM could be degraded. Further, the advance in electronic warfare (EW) technology and tactics might make it too dangerous for the launching fighter to turn on its radar, or the emissions coming from the missile itself may serve to alert the enemy to an imminent attack (admittedly a short warning because of AMRAAM's speed). The technology for airborne antiradiation missiles already exists, which may serve to weaken all airborne radar-based systems. Finally, the AMRAAM launch-and-leave capability has a defect to go along with that virtue. Once it is separated from the aircraft and locked on to a target, the aircrew has no further role in the operation of the missile. In a confused situation, that weapon may not discriminate between foe and an accidentally intervening friend. That fratricide problem exists also with current Sidewinders; but those are short range weapons and the longer range of the AMRAAM may seriously complicate the problem.

The possible difficulties with acquiring and tracking targets may not be the most serious inhibitors of BVR air-to-air fighting. Throughout the Vietnam War, the potential of radar missiles was never fully exploited because of the requirement to get a positive visual identification of the target before firing. According to Benjamin Lambeth and others, this problem would be even worse today because the latest and best two Soviet fighters both have twin vertical stabilizers. That makes them both similar in appearance to the F-15. Yet many authors (Lambeth being a prominent one) cite the absence of an effective means of electronic identification of a noncooperative target as a serious fault in the US scheme of things. On top of that, the target set is getting tougher because of the increasing use of remotely piloted vehicles and cruise missiles—small targets flying at low levels that are difficult to acquire with a radar. As with gun projectiles, the shorter the time of flight, the greater the chances of a hit. But, as missile speeds get higher, radome heating becomes an increasingly serious problem. The high unit costs usually mean a peacetime inventory too small to fight a sudden but extended war. High costs also mean that live-fire training cannot be done and that simulators will have to be used. Simulators are expensive and, though very realistic, they can never be quite as close to the real thing as live-fire training.

The original concept for the AMRAAM was that it would be complemented by a European-developed short-range missile, ASRAAM, with a new IR seeker and rocket motor. The ASRAAM program has fallen on hard times and according to many reports the actual creation of a production missile is unlikely.[91] The same sources suggest that were the ASRAAM program frustrated, then the US could further develop the Sidewinder to provide many of the same capabilities in a fairly short time. The later marks of the Sidewinder have an all-aspect capability and a good combat record. Either ASRAAM, or Sidewinder would help moderate the unit cost problem of AMRAAM, and both would supply a passive launch-and-leave feature to complement that of the radar missile at the shorter ranges. Both, like AMRAAM, can pose a threat from any direction (at the shorter ranges) that helps to bring about a radical change in the terms of engagement. Also, the IR missiles are lighter and less complex than radar missiles and that yields benefits in terms of expense, reliability, and weapons load per sortie.

## Solutions Including Advanced Guns and Ammunition

THERE IS hardly any suggestion at all among the current crop of aviation writers that future fighters could do without a gun. Almost all of them advocate its inclusion, especially for the sake of flexibility. Some might say that unanimity ought to stimulate the USAF decision maker to wonder whether the idea has become the conventional wisdom worthy of questioning.

It seems certain that a gun is worth consideration for the sake of adaptability alone. None of the air-to-air missiles can be used against surface targets, whereas even the current M-61 Gatling gun is proven effective against a wide variety of ground targets—and economical against most of them.

The issue of including an advanced technology gun is another question. It would have an even greater flexibility against surface targets because of its radically increased muzzle velocity. Though the current developmental weapon is in the same caliber as the M-61, the 50-percent increase in velocity has a disproportionate effect on all vehicle targets except tanks. The penetration ability of the round varies with the square of the speed at impact. Further, the accuracy is improved because the trajectory is flatter and the target has less time to get out of the line of fire. Whether fired against an air or ground target, a gun projectile is not vulnerable to countermeasures once it leaves the barrel. But as noted, in air-to-air combat the increased muzzle velocity combined with a new sight makes feasible beam and head-on shots with guns. That capability turns guns into all-aspect weapons, contributing to new terms of engagement along with the new IR and radar missiles. That, in combination with the all-aspect Sidewinders, means that violent maneuver in the close-in battle no longer means finding an avenue of escape outside our weapons envelope. Running out of ammunition or fuel in a close-in battle then would be catastrophic. All missiles have an inner limit to their firing envelope, but there is no minimum range for a gun—no close-in sanctuary. To the extent that stealth and electronic warfare degrades the capability of radar missiles, they will increase the relative utility of guns. As the advanced gun will remain a visual-range weapon notwithstanding its longer range, the want of an effective identification, friend or foe (IFF) does not degrade its operation as much as that of a radar missile.

The advanced gun technology is a General Electric program. Its M-61 has an enviable record of reliability, and the new weapon has far fewer parts, as noted previously, and still fewer of them are moving parts. That seems to promise an even greater reliability in a new weapon.[92]

The combination of a modified M-61 with a new, but conventional 20-mm round can yield about half the gain of an advanced technology gun. But the new gun would come at a substantial price. The US and its allies have a considerable sunk cost in M-61 guns and standard 20-mm ammunition. The maintenance of another noninterchangeable line of guns and ammunition in the supply accounts would seriously complicate logistical arrangements and interoperability. The parts of the modified M-61 (and its improved ammunition) are interchangeable with older stocks. It would take a long time to replace all the M-61s and their ammunition in the inventory as the older guns wear out and the ammunition is used up. Shortening that time would entail enormous expense. The current gunsight is subject to error because it bases its direction only on the accelerations of the shooter and not the target. The new sight envisioned for the advanced technology gun uses inputs from the target, which involve measurements taken by radar—making it subject to electronic countermeasures. Post-World War II research, as noted, has revealed that a great majority of kills have been achieved on the first pass when the victim has been unaware of the threat. As a short-range weapon, the gun would not usually enjoy the first-shot advantage.

A further inhibitor of going over to an advanced technology gun in the 1990s is that there is a possibility of buying into the technology too soon. Though the caseless principle was found wanting in the 1970s and many experts still believe it to be impractical, caseless rounds have already proven feasible in small arms. Traditionally an inhibitor of technology application has been the feeling in the R&D community that even more advanced technology is just around the corner. Adding a caseless feature to the advanced ammunition would yield enormous benefits in simpler gun and feed mechanisms. We have seen that the M-61 was conceived in the late 1940s, and it is still the first-line air superiority gun in US and many allied forces. Any decisions made now on advanced gun technology would likely affect us for an even longer time.

Other improvements that may be just around the corner make the challenge all the more difficult. For 50 years, at least, some have longed for a trainable capability in fighter guns. Fixed guns cannot be pointed at a turning target if the attacker wishes to close the distance—the attacker must lead the prey by more than the lead required by the gun to reduce the range. If the shooter could train his guns, even by a limited amount, he could have his guns lead the target by a lesser angle than the one he is using with his aircraft to close the distance. He could therefore shoot even while shortening the range—an immense advantage. Were he able to use this "off-boresight" capability with a helmet-mounted sight, it would be all the more effective.[93]

## Recommendations

THERE ARE so many interdependent variables and imponderables affecting future air superiority weapons choices, firm recommendations would be acts of supreme arrogance. A traditional lament in Air Research and Development Command and then in Air Force Systems Command has been that conventional weapons being the responsibility of the Army and Navy were lacking advocacy groups inside the Air Force. Therefore, the story goes, when Vietnam came, the USAF was insufficiently prepared with its bomb inventory. Whatever the merits of the case, this study suggests that it did not apply to guns. The M-61 was ready well before the beginning of the war, and it was more than adequate to the task. The fact that it was not in the F-4C had nothing to do with the want of an advocacy group within the Air Force. However, a recent reorganization of science and technology responsibilities among the services assigns the lead service role of the conventional gun work to the Army.[94] It may therefore behoove the Air Force policymakers to assure that continuing support is given to conventional gun research and technology programs in the Army laboratories. This is to guarantee that when and if new guns and ammunition are decided upon, the technology base will indeed be available.

Meanwhile, if air power is to be flexible, it must have flexible platforms—multipurpose airplanes is the usual answer. The flexibility of the platforms can be enhanced by a flexible set of weapons—the full potential of the F-16 cannot be exploited because it does not now have a BVR missile capability. Consequently, it does seem that Michael Howard's prescription for adaptability of doctrines (and force structure and weapons) can be best fulfilled by assuring the availability of medium-range missiles and guns, complemented by short-range missiles. The decision as to which gun is shrouded in imponderables. An intuitive judgment must be made. The attractiveness of a quantum jump in muzzle velocity and a simpler, more reliable gun than the one in current fighters is substantial. Yet the experience with the Browning M-2/M-3 and the General Electric M-61s suggest that such choices tend to be forever. It is therefore this author's intuitive judgment that the new missiles be complemented with the improved M-61 and improved but conventional 20-mm ammunition. This would avoid a premature and practically irreversible commitment to advanced gun technology and ammunition when even greater gains may indeed be just around the corner—and when the threat remains diffuse, not well defined, and seemingly not immediate. Such a choice entails a continuing press for continued R&D in science and technology programs related to conventional aircraft guns. Since those programs now fall under the Army leadership, the Air Force must assure that they receive continuous support.

## Summary

THE HISTORY of armament for air combat is less well known than that for infantry or naval fighting. At the dawn of military aviation, gun and ammunition technology was already well matured; the aircraft arming process was largely a matter of adapting ground weapons to aerial combat. Therefore the developmental curve was rather flat for the first 40 years of the history of air power. The curve made a rather sharp turn just after World War II that was little noticed because it was masked by enormous and simultaneous changes in other technologies more romantic than nonnuclear aircraft armament: nuclear weapons, ICBMs, transition to jets, nuclear submarines, and space flight. For a time early in the air-to-air missile age, it did not seem that air fighting would really be revolutionized—though the speeds were higher and the space used greater. Most combats still boiled down to a stern chase firing from a range as short as possible. Jet speeds made that necessary for the guns, and seeker limitations made it necessary for the early IR missiles. The radar missiles of the 1960s theoretically could fire from elsewhere, but in Vietnam the visual identification requirements were such that too often the attackers were already too close to use the Sparrow before they had fulfilled them. The small wars since Vietnam amply demonstrated that the newer IR models had expanded their capabilities so that they had become all-aspect weapons. New sight and gun technology may already be at hand that will do the same for the guns. When the fire-and-forget and multiple attack capabilities of the new radar missiles are added to that equation, it can be seen that the environment of the air battle may have become more lethal than it was even in the days of the Vietnam War. That change might even be described as revolutionary, but one that is little noted because many other more romantic developments have usually attracted the attention of journalists and historians alike.

**Notes**

1. Melvin Kranzberg, "Science Technology and Warfare; Action, Reaction, and Interaction in the Post-World War II Era," in *Science, Technology, and Warfare: Proceedings of the Third Military History Symposium, United States Air Force Academy, 8–9 May 1969*, Monte D. Wright and Lawrence J. Paszek, eds. (Washington, D.C.: Office of Air Force History, Headquarters USAF, 1970), 153. Kranzberg's notion was alive and well in 1991 as demonstrated in Jeffrey Record, "AF's Future Bright After Stellar Gulf Showing," *Air Force Times*, 11 March 1991, 32. Record remarks that Operation Desert Storm may buttress the arguments of those in Congress who say that the services have concentrated on the "big ticket," glamorous platforms like sophisticated aircraft and aircraft carriers but neglecting to build up the unglamorous munitions stocks enough for any sort of prolonged conflict.

2. This paper is built upon an earlier monograph covering the history of the development of aircraft guns from 1914–1945 in greater detail and will form a part of a longer study that will be a futures research paper on nonnuclear aircraft armament in general.

3. Richard E. Neustadt and Ernest R. May, *Thinking in Time* (New York: Free Press, 1986), 91–110. It is recognized throughout that the air-to-air battle is only a small part of the whole struggle for air superiority. It is not even the preferred method, for as the Israelis showed in 1967 an offensive counterair strike with bombs against enemy airfields can be utterly decisive with a relatively small effort. The drying up of German and Japanese fuel sources through bombing and submarine interdiction so hampered their pilot training programs that it was a major factor in achieving air superiority in World War II. The German ground defenses imposed more losses on Eighth Air Force in the last year of World War II, and such defenses have become an even greater factor in a complex air superiority equation ever since.

4. Lee B. Kennett, *The First Air War, 1914–1918* (New York: Free Press, 1991), 63.

5. Ibid. Research is continuing to use fiber-optic cable in similar applications.

6. Maurer Maurer, *The U.S. Air Service in World War I*, vol. 2, *Early Concepts of Military Aviation* (Washington, D.C.: Government Printing Office, 1978), 10.

7. Mike Spick, *The Ace Factor: Air Combat and the Role of Situational Awareness* (Annapolis, Md.: Naval Institute Press, 1988), 32.

8. George Raudzens, "War-Winning Weapons: The Measurement of Technological Determinism in Military History," *The Journal of Military History* 54 (October 1990), 417–21.

9. Kennett, 64; Air Vice-Marshal John R. Walker, *Air Superiority Operations* (London: Brassey's Defence Publishers, 1989), 8. Such "screening" from enemy eyes had been a major function of cavalry in bygone wars, as were many of the other roles of aviation.

10. Spick, 33. As a former tanker pilot, the successful grappling of another airplane seems to me miraculous given the difficulties often encountered in placing a refueling boom into a bomber's receptacle when the bomber is actively cooperating in the operation.

11. Zeppelin combat provides an interesting sample of Kranzberg's complaint. It has attracted the wide attention of historians and others, yet its significance was less than many other dimensions of aerial warfare that are not nearly so well understood. One interesting account of such combat is Raymond H. Fredette, *The Sky on Fire: The First Battle of Britain* (New York: Holt, Rinehart and Winston, 1966).

12. United Kingdom, Air Ministry, *The Rise and Fall of the German Air Force, 1933–1945* (New York: Saint Martin's Press, 1983), 291. When it is remembered that the proximity fuze was indeed invented during World War II, the German effort does not seem so farfetched for such fuzes would have solved their timing problems. The huge and relatively slow-flying bomber formations were so cumbersome that dropping a fragmentation bomb through them

was not all that difficult and that could be done well above the reach of the US .50-caliber guns in the bomber turrets—as long as the bombers were not escorted.

13. Kennett, 27.

14. Henri Hegener, *Fokker—The Man and the Aircraft* (Letchworth, Herts, United Kingdom: Harleyford, 1961), 23-24; Walter Raleigh, *The War in the Air*, vol. 1 (3 vols., Oxford: Clarendon Press, 1922, 1969), 262. In most cases, not only was it necessary to get directly behind the quarry, but also to do it unobserved for the target had to be flying a straight path. Once it started a turn, then the shooter had to lead the target which with a fixed gun meant he could not stay on the tail of his quarry. This lead was practically impossible to maintain on a turning target except for the most fleeting instants. The glamour of the dogfight has caused it to seem otherwise in the literature. Most authors have been preoccupied with the romance of the one-on-one combat between a pair of chivalrous aerial knights. However, from the days of Richthofen onwards many more kills were achieved on targets not knowing of the presence of a threat than on those who had been alerted to the danger. See Walker, 99–103, for an explanation of the geometry of the problem and Lon O. Nordeen, *Air Warfare in the Missile Age* (Washington, D.C.: Smithsonian Institution Press, 1985), 32, 46, for descriptions as to how the generalization that the probabilities of a kill on the first pass far exceeded those accomplished after a dogfight had been started was still valid in the Vietnam War and the combats of the 1970s and 1980s. See Spick, 6, for the reasons why dogfighting has been overemphasized in the literature and the degree to which the $P_k$ on the first pass was far superior even in the First World War. As for the virtues of a flexible mount, there was but one point and direction in all of space from which a fixed-gun fighter could hit any given target. In the flexible installation, since the gunner could point the weapon, there were innumerable such points—and often the gunner could shoot at a pursuing enemy while that enemy's guns were pointing elsewhere.

15. Richard P. Hallion, *Rise of Fighter Aircraft, 1914–1918* (Annapolis, Md.: Nautical and Aviation Publishing Co. of America, 1984), 34; Tre Tryckare, *The Lore of Flight* (Gethenburg, Sweden: Cagner, 1970), 361. In the very early days of the war, British DH-2s were not too far behind the German Eindeckers in performance, but the gap widened as engine power was increased in the biplane tractors.

16. Hallion, 34–38; Tryckare, 157; George W. Chinn, *The Machine Gun*, vol. 1 (Washington, D.C.: Government Printing Office, 1951), 314–15; Sidney F. Wise, *The Official History of the Royal Canadian Air Force*, vol. 1, *Canadian Airmen and the First World War* (Toronto, Canada: University of Toronto, 1980), 361.

17. Hallion, 6; Chinn, 284; Adrian O. Van Wyen, *Naval Aviation in World War One* (Washington, D.C.: Government Printing Office, 1969), 68; Benedict Crowell [assistant secretary of war, director of munitions, World War I], *America's Munitions, 1917–1918* (Washington, D.C.: Government Printing Office, 1919), 296.

18. Hallion, 8; Hegener, 25; John H. Morrow, *German Air Power in World War I* (Lincoln, Nebr.: University of Nebraska Press, 1982), 40–45; Chinn, 346–47; Anthony H. G. Fokker and Bruce Gould, *Flying Dutchman: The Life of Anthony Fokker* (New York: H. Holt and Co., 1931), 23, 123–38, are all sources of information.

19. Kennett, 70; John W. R. Taylor, *Combat Aircraft of the World from 1909 to the Present* (New York: Paragon, 1969), 154–55; John R. Cuneo, *Winged Wars*, vol. 2, *The Air Weapon, 1914–1916* (Harrisburg, Pa.: Military Service Publishing Co., 1947), 233; Chinn, 313.

20. Tryckare, 158; Chinn, 202–3; Fokker and Gould, 180. One of the programs, according to Chinn, was a two-barrelled gun that had a single action that reciprocated to extract and reload one barrel as the other was firing. It was a simple, and thus reliable, mechanism that is the underlying technology for one of the main weapons of the Soviet air forces, their two-barrelled 23-mm gun.

21. Wise, 515.

22. In response to the coming of armor late in World War I, General Pershing had suggested that machine guns be developed in the .50 caliber. Soon afterwards, a new and effective round was so developed and the Browning .30-caliber gun was merely scaled upward with very little change. 1st Lt R. C. Zettel, Army Air Corps, chief, Armament Branch, Experimental Engineering Section, Materiel Division, McCook Field, Dayton, Ohio, "Notes on .50 Caliber Machine Gun," 20 January 1927, Report no. 248.6282-4, copy at USAF Historical Research Center, Maxwell AFB, Ala. [hereinafter cited as USAFHRC]; Robert Frank Futrell, *Ideas, Concepts, Doctrine*, vol. 1, *Basic Thinking in the United States Air Force 1907–1960* (Maxwell AFB, Ala.: Air University Press, December 1989), 61.

23. Pamphlet, US Army Air Service, Air Service Tactical School, Langley Field, Va., Armament Course, 1924–25, 1–23, file no. 248.101-45, USAFHRC; Maurer Maurer, *Aviation in the U.S. Army, 1919–1939* (Washington, D.C.: Office of Air Force History, 1987), 224–25, 381.

24. Report, First Provisional Air Brigade, Langley Field, Va., "Armament Used in Maneuvers," 8 August 1921, file no. 248.222-69, USAFHRC; Taylor, 478–79, 536–37, 554; Merle Olmstead, *Aircraft Armament* (New York: Crown, 1970), 39–40.

25. I. B. Holley, Jr., "Development of Aircraft Gun Turrets in the AAF, 1917–1944," Army Air Forces Historical Study 54, file no. M-27218-54, Air University Library [hereafter cited as AUL], 1–25.

26. R. J. Overy, *The Air War, 1939–1945* (New York: Stein and Day, 1980), 89–95, 211; Wesley F. Craven and James L. Cate, *The Army Air Forces in World War II*, vol. 1, *Plans and Early Operations* (Chicago, Ill.: University of Chicago Press, 1948), 81; United States Strategic Bombing Survey [hereinafter cited as USSBS], "Japanese Air Weapons," Report no. 63 (Washington, D.C., 1947), 1–7; Chinn, 353; Martin Caidin, *Zero Fighter* (New

York: Ballantine, 1956), 158–59; Lt Col H. R. Oldfield, US Army Air Corps, assistant chief of staff, G-2, to assistant chief of staff, G-2, War Department, Washington, D.C., letter, subject: Information from American Flyers Returning from China Service, 20 June 1938, file no. 2009.256, USAFHRC.

27. John F. Guilmartin, Jr., "Aspects of Airpower in the Spanish Civil War," *Air Power Historian* 9 (April 1962): 83–85; Chinn, 423–24, 662–63; Kenneth R. Whiting, *The Development of the Soviet Armed Forces, 1917–1972* (Maxwell AFB, Ala.: Air University, 1977), 31–33; Peter Elstob, Condor Legion (New York: Ballantine, 1973), 96, 100; US Air Force, "Soviet Aircraft Armament," *Air Intelligence Digest* (November 1948), 37–43, file no. 142.0371, USAFHRC; Kenneth R. Whiting, *Soviet Air Power* (Maxwell AFB, Ala.: Air University, 1979), 15–20.

28. See note 27, especially Chinn, 555.

29. See Walker, 45–49, for a clear explanation of some of the problems of air-to-air gunnery

30. Derek Wood and Derek Dempster, *The Narrow Margin* (New York: McGraw-Hill, 1961), 283, 420, on the presence of 20-mm Spits and Hurris in BOB; Carl A. Spaatz, Diary of Brig Gen Carl Spaatz on tour of duty in England, Box 7, Spaatz Papers, Manuscripts Division, Library of Congress [hereinafter cited as Spaatz Papers]; Carl Spaatz to Gen Henry H. Arnold, letters, 27 August 1940 and 31 July 1940, Spaatz Papers, Box 7.

31. Holley, 20–25. The problem was a tougher one than might appear at first glance. While moving up from the .30 to the .50 caliber in flexible mountings was not that tough a problem, the space clearances in a turret were much tighter and the British had designed all their aircraft to carry the .303 Browning, sometimes with four guns in a turret. As the US was planning to use the .50 caliber, it was much more than merely sending a set of blueprints across the Atlantic.

32. See note 31; US Army Air Corps, Army Air Corps Board, Report, "Test of 75-Millimeter Aircraft Gun and Mount T-1, in B-18 Airplane," 21 June 1941, file no. 2053, Eglin AFB Technical Library; memorandum, US Army Air Corps, 23d Composite Group, Eglin Field, Fla., subject: Memorandum Report on Firing Tests of XP-36F, 29 November 1940, file no. 1393, Eglin AFB Technical Library; Andrew W. Waters, *All the U.S. Air Force Airplanes, 1907–1983* (New York: Hippocrene Books, 1983), 256–57; Report, US Army Air Corps, "United States Army Air Corps Armament Conference," Munitions Building, Washington, D.C., December 1939, file no. 167.66-8, USAFHRC.

33. Kenneth P. Werrell, *The Evolution of the Cruise Missile* (Maxwell AFB, Ala.: Air University Press, 1985), 12–17, on the Kettering Bug; US Army Air Forces, Air Proving Ground Command, "Personal Narratives of Key Personnel, to 31 March 1946," no date, on file, History Office, Air Force Development Test Center, Eglin AFB, Fla., 1–7; US Army Air Forces, AAF Board, Orlando, Fla., "Controlled Missiles," 29 October 1943, file no. 2416, Eglin Technical Library; Maj Gen Grandison Gardner, "Recollections of Wartime Eglin Field," on file, History Office, Air Force Development Test Center, Eglin AFB, Fla.

34. Thomas E. Griess, ed., *Atlas of the Second World War: Europe and the Mediterranean* (Wayne, N.J.: Avery Publishing Group, 1984), 55–86; D. J. Goodspeed, *The German Wars, 1914–1945* (Boston, Mass.: Houghton Mifflin, 1977), 325–36.

35. Richard Hough and Denis Richards, *The Battle of Britain* (New York: Norton, 1989), 36–37 156, 307–34; Diary, Spaatz Papers; Adolf Galland, "Defeat of the Luftwaffe: Fundamental Causes," *Air University Review* 6 (Maxwell AFB, Ala., Spring 1953): 18–36.

36. Taylor, 144, 166–67, 179.

37. Anthony Verrier, *The Bomber Offensive* (New York: Macmillan, 1968); David Irving, *The Rise and Fall of the Luftwaffe: The Life of Field Marshal Erhard Milch* (Boston, Mass.: Little, Brown, 1973), 104–8.

38. Taylor, 554–55; James Parton, *Air Force Spoken Here* (Washington, D.C.: Adler and Adler, 1986), 216–31; Williamson Murray, *Strategy for Defeat* (Maxwell AFB, Ala.: Air University Press, 1983), 55–56.

39. USSBS, European War, Report no. 59, *Defeat of the German Air Force*, 1945, 1947, 12–18. According to news reports, an F-15E actually hit an airborne Iraqi helicopter with a laser-guided bomb in the Desert Storm fighting, "Eglin's AMRAAMs Join War," *Northwest Florida Daily News*, 22 February 1991, 3.

40. USSBS, *Defeat of the German Air Force*, 19–43.

41. USSBS, Pacific War, Report no. 62, *Japanese Air Power*, 1–3; USSBS, Pacific War, Report no. 63, *Japanese Air Weapons*, 1–7, shows that both the Japanese army and navy had separate programs to copy the US M-2 Browning in the .50-caliber size. Both programs resulted in a usable weapon, but the parts of the two weapons and their ammunition were *not* interchangeable. The zero fighter was superior at first, but was outclassed later on by new US aircraft.

42. USSBS, *Japanese Air Weapons*, 33–41.

43. Taylor, 455, 465.

44. Ronald W. Clark, *War Winners* (London: Sedgwick & Jackson, 1979), 106.

45. Frederick I. Ordway III and Ronald C. Wakeford, *International Missile and Spacecraft Guide* (New York: McGraw-Hill, 1960), 117–18, 125–29, 133–35.

46. US Air Force, Air Force Systems Command, Research and Technology Division, Ad Hoc Study Group, Bolling AFB, D.C., Report, January 1964, copy, on file, History Office, Air Force Development Test Center, Eglin AFB, Fla., 1–2.

47. Eric H. Biass, *Aircraft Armament* (Cointrin, Switzerland: Interavia, 1984), 79–98; Dale M. Davis, "Airborne Guns and Rockets," *Ordnance*, March–April 1973, 388–91; Col D. J. Alberts, "New Technology and Tactical Aircraft," *Military Technology*, June 1986, 92–99.

48. See Ordway and Wakeford, 133–34, on wartime German missiles.

49. Robert F. Futrell, *The United States Air Force in Korea 1950–1953*, revised ed. (Washington, D.C.: Office of Air Force History, 1983), 244–53, 696–98; Air Commodore P. D. L. Gover, RAF, "Air Supremacy—The Enduring Principle," in *War in the Third Dimension*, Air Vice-Marshal R. A. Mason, ed. (London: Brassey's Defence Publishers, 1986), 67–68.

50. See Ordway and Wakeford, 32–33, for information on the Falcon—which came in several versions including both semiactive radar and infrared guidance; Futrell, *The USAF in Korea*, 244–53; Taylor, 456–57, 540–41; Lt Col Ralph L. Kuster, Jr., "Air-to-Air Missiles," *USAF Fighter Weapons Review*, Spring 1974, 15–17.

51. Guy Hartcup, *The Challenge of War: Britain's Scientific and Engineering Contributions to World War Two* (New York: Taplinger Publishing Co., 1970), 254.

52. Ordway and Wakeford, 127–28; Taylor, 540–41, 547–48; Bill Gunston, *The Illustrated Encyclopedia of Aircraft Armament* (New York: Orion Books, 1988), 43.

53. Bill Gunston, *An Illustrated Guide to Modern Airborne Missiles* (New York: Arco Publishing, Inc., 1983), 31; Edward L. Korb, ed., *The World's Missile Systems* (Pomona, Calif.: General Dynamics, 1982), 57–58; Gunston, *Aircraft Armament*, 43–44.

54. Gunston, *Aircraft Armament*, 55; Ordway and Wakeford, 34–35.

55. Ordway and Wakeford, 35–37; Gunston, *Modern Airborne Missiles*, 59. The beam rider's antenna is pointed backwards to receive directive signals from the attacking aircraft based on data the aircraft gathers from its radar pointing at the target; the antenna of the SARH missile faces forward to receive reflected energy that the attacker's radar has bounced off the target. It automatically uses that energy to home on the target. The homing energy generally gets stronger as that missile closes on the object.

56. Maj Dennis C. Carel, "The History of the Aerial Gatling Gun," Research Report No. 87-0415 (Maxwell AFB, Ala.: Air Command and Staff College, 1987), 1–7; Gunston, *Aircraft Armament*, 36–37.

57. Carel, 7; Taylor, 540–41, 543; Gunston, *Aircraft Armament*, 202–3.

58. Carel, 9–21; Blass, *Aircraft Armament*, 79–98; Davis, 388–91.

59. Davis, 388–91; Carel, 9–17; Gunston, *Aircraft Armament*, 187, 194–95, 202–3.

60. Taylor, 466, 543–44, 517–19, 552–53; Carel, 18–21.

61. That the thought that guns would be needed persisted is demonstrated by the fact that the USAF had moved to provide a gun in a pod for the F-4C, which came without one well before the crisis in Vietnam as described in Capt Gary L. Broadway, "Have Gun Will Travel," *Fighter Weapons Newsletter*, December 1965, 4–9; Though Capt Robert Thor in "GAR-8," *Fighter Weapons Newsletter*, June 1958, 29–30, one of the earliest articles on the Sidewinder in the tactical air community's official organ, made the obligatory comment on the necessity for a gun he was enthusiastic for missiles. He remarked that the missile would require establishing new (more difficult) standards for entering the ace category and that "it may come to a point where if you claim a gun kill you will be admitting that you goofed (by not getting it sooner with a missile)"; on McNamara's approach, Frederick H. Hartmann and Robert L. Wendzel, *Defending America's Security*, 2d ed. (Washington, D.C.: Pergamon-Brassey's International Defense Publishers, 1990), 148–51.

62. Broadway, 4–9; Gunston, *Aircraft Armament*, 195; Carel, 21.

63. Taylor, 524–25, 552–53; Nordeen, 213–17.

64. Michael Howard, "Military Science in an Age of Peace," Chesney Memorial Gold Medal Lecture, 3 October 1973, reprinted in *Journal of the Royal United Services Institute for Defence Studies* 119 (March 1974): 3–11.

65. Gen William W. Momyer, *Airpower in Three Wars* (Washington, D.C.: Government Printing Office, 1978), 155–58; Nordeen, 16–78.

66. See note above; Spick, 144–52; Tom Wilson, "The Wild Weasel Legacy—The Early Days," *Defense Electronics*, September 1988, 52–61, suggests that the Soviet Union recognized the importance of EW before the US did but that rapid adaptation was done after 1965 in the heat of Vietnam combat; see also Maj Ronald L. Hanson, "Evolution of the Modern Dogfight," Research Report No. 87-1110 (Maxwell AFB, Ala.: Air Command and Staff College, 1987).

67. Momyer, 155–61; Nordeen, 45–47, 74–78, 216–18.

68. Momyer, 155–57; Gunston, *Aircraft Armament*, 170.

69. Momyer, 157. By then the F-4E with its internal gun was on the line, and the F-105s were no longer in use as bombers though they remained engaged in defense suppression until the end; Barrett Tillman, *MiG Master: The Story of the F-8 Crusaders*, 2d ed. (Annapolis, Md.: Naval Institute Press, 1990), 62–71.

70. Samples are: Alberts; Hanson; Capt Michael B. Larkin, "F-15 Gun Employment," *USAF Fighter Weapons Review*, Spring 1981, 28–31; Capt Thomas K. Mascot, "Aerial Gunner, Eagle Style," *USAF Fighter Weapons Review*, Summer 1986, 2–7; Walker, 45.

71. The A-10 has the GAU-8 that is built by General Electric as in the M-61. It is a ground-attack gun similar in its operating principles but firing 30-mm ammunition optimized against tanks. The big change came in the ammunition that incorporated aluminum casings with substantial weight savings, plastic rotating bands with important effects on barrel wear, and warheads with heavy metal cores yielding important armor penetration benefits. Dale Davis, "Historical Development Summary of Automatic Cannon Caliber Ammunition," Technical Report, file no. AFATL-TR-84-03, Eglin AFB Technical Library, 34–43, 71–77, 88–101. The AV-8B Harrier in USMC service carries a General Electric gun in pods—the GAU-12 in the 25-mm size. The gun

is similar to all other GE Gatling guns, but the feed system is unique coming in a separate pod of its own. Gunston, *Aircraft Armament*, 191. Neither the A-10 nor the AV-8B is optimized for air combat though the British version of the Harrier did get several air-to-air kills with its Sidewinders in the Falklands fighting in 1982.

72. According to Nordeen, 121-23, 168-72, the IAF claimed 58 air combat kills in the Six-Day War, reportedly all of them with guns—most often with 30-mm cannons. In the Yom Kippur War, the IAF claimed 370 aircraft killed in air combat (while losing four). Nordeen says that IAF IR missiles (updated versions since Vietnam) killed 200 enemy fighters with close to a 50 percent success ratio—and cites Israeli sources as saying that the lopsided success was in part due to superior weapons. The Egyptian IR missiles had difficulty getting a lock on and the gunsights in the MiG-21 tended to tumble under the stress of relatively low G-forces; Lawrence Whetten and Michael Johnson, "Military Lessons of the Yom Kippur War," *The World Today*, March 1974, 101-9; Nadav Safran, "Trial by Ordeal: The Yom Kippur War, October 1973," *International Security* 2 (Fall 1977): 133-70, is an excellent short overview of the whole war.

73. Nordeen, 184-85; Benjamin S. Lambeth, "Moscow's Lessons from the 1982 Lebanon Air War," in *War in the Third Dimension*, Air Vice-Marshal R. A. Mason, ed. (London: Brassey's Defence Publishers, 1986), 127-48; Marshall Lee Miller, "The Soviet Air Force View of the Bekaa Valley Debacle," *Armed Forces Journal International*, June 1987, 54-56; Ze'ev Schiff and Ehud Ya'ari, *Israeli's Lebanon War* (New York: Simon and Schuster, 1984), 166-68; Paul S. Cutter, "Lt Gen Rafael Eitan: 'We Learned Both Tactical and Technical Lessons in Lebanon'," *Military Electronics/Countermeasures* 9 (February 1983): 94-102.

74. Capt John O. Coote, Royal Navy (Ret), "Send Her Victorious. . . ," U.S. Naval Institute *Proceedings* 109 (January 1983): 34-42; Adm Stansfield Turner, USN (Ret), "The Unobvious Lessons of the Falklands War," U.S. Naval Institute *Proceedings* 109 (April 1983): 50-57; Dr Robert Scheina, "The Malvinas Campaign," U.S. Naval Institute *Proceedings*, May 1983, 98-117.

75. Jeffrey M. Lenorovitz, "Allied Air Supremacy Keeps Air-to-Air Engagements Limited," *Aviation Week & Space Technology*, 18 February 1991, 45-46, cites only AIM-7 and AIM-9 kills though all the American aircraft were equipped with M-61 cannons. The new USAF advanced medium-range air-to-air missile was deployed to Saudi Arabia with 33d TFW F-15s, but it seems that it did not get there in time for the air combat. "Eglin's AMRAAMs Join War," 3.

76. Nordeen, 44, 75; Walker, 41, 156; Maj Gerald R. Volloy, "Red Flag in Perspective," *USAF Fighter Weapons Review*, Spring 1979, 3-5.

77. Spick, 154-56; Air Vice-Marshal R. A. Mason, *Air Power: An Overview of Roles* (London: Brassey's Defence Publishers, 1987), 39-42.

78. Davis, "Ammunition," 34-43, 71-77, 88-101.

79. Gunston, *Aircraft Armament*, 144-45, 170-71, 172-73; Korb, 255-62, 271-76.

80. See note above; Capt Mark R. Brightman, "Air-to-air Missile Capabilities," *USAF Fighter Weapons Review*, Fall 1985, 15-16; Edward Cobleigh, "Time and Tactics: Key to Aerial Combat," *Jane's Defence Weekly* 8 (14 November 1987): 1138-43.

81. Brightman, 15-16; Gover, 59-80.

82. Korb, 169-70.

83. Ibid., 273-74. The initial model of the Phoenix became operational in 1974, and the AIM-7F came on line in 1980.

84. Gp Capt Duncan Lennox, "Air-to-Air Missiles," *NATO's Sixteen Nations* 30 (October 1985): 82-86.

85. Ibid.; Steven Zaloga, "Soviet Air Combat Capabilities," *Armed Forces Journal International*, 29 September 1989, 44.

86. "Eglin's AMRAAMs Join War," 3; Gunston, *Aircraft Armament*, 164-65; Mark Hewish, Anthony Robinson, and Gerarde Turbe, "Air-to-Air Missiles," *International Defense Review*, August 1990, 871-77; James W. Rawles, "AMRAAM: Better Late than Never," *Defense Electronics* 20 (November 1988): 42-49; Doug Richardson, "Future Air-to-Air Missiles," *Military Technology*, July 1988, 92-96.

87. "Checking six" is flyers' jargon for keeping an eye out for enemies directly behind one's own aircraft—traditionally by far the most likely sector from which danger would come.

88. Roger Frost, "GE's Aircraft Gun Strategy," *International Defense Review*, June 1990, 691-92; Bill Sweetman, "Killer Beer Cans for the 1990s," *International Defense Review* 21 (September 1988): 1127; Bill Sweetman, "US Emphasis on External Power," *International Defense Review* 19 (January 1986): 50.

89. Benjamin S. Lambeth, *The Outlook for Tactical Airpower in the Decade Ahead*, Rand study no. P-7620, Santa Monica, Calif., 1986, 25; Lambeth, "Pitfalls in Force Planning: Structuring America's Tactical Air Arm," *International Security* 10 (Fall 1985): 89; Spick, 6, suggests that this has always been so, and the entire book posits that it has become ever more important.

90. Marvin Leibstone, "AMRAAM: The Missile that Won't Quit," *Military Technology* 14, September 1990, 90.

91. Eric H. Biass, "Air-to-Air Missiles: High-G Turn in Sight," *Armada International* 14 (December/January 1990/91): 50-57.

92. Frost, 691-92.

93. Maj Gary Morgan, Tactical Air Warfare Center, Eglin AFB, Fla., interview with author, 13 May 1991.

94. Lanny Burdge, Wright Aeronautical Laboratories, Eglin AFB, Fla., interview with author, 13 May 1991.