under the belly) as well as racks under the conformal tanks and launcher rails for air-to-air missiles (up to eight can be carried). Low Altitude Navigation and Targeting Infrared Night (LANTIRN) pods mounted under the engine ntakes add IR navigation and targeting capabilities, allowing for night low-evel navigation and attack tactics. The Strike Eagle can deliver a full range of lumb bombs as well as guided munitions (Maverick and laser-guided oombs).[78] It is also armed with a 20 mm Gatling gun.

The only major problem faced by the F-15E was expense. The aircraft per-ormed well in its assigned role and encountered few developmental problems, out the "E" cost about 50 percent more to acquire and operate than the "C." This helps explain why the USAF cut the original procurement plan of 392 back to 209. More recently, improved versions of the F-15 are regarded by ome as threats to the Air Force's next proposed fighter aircraft, the F-22.[79]

It is clear that the F-15 has been an outstanding success. It overcame en-ine problems to give the Air Force greatly enhanced air-to-air combat capa-ility and later almost unprecedented air-to-ground capabilities. The aircraft's xcellence was seen early on and then demonstrated decisively in combat. Cru-ial to this success was good cooperation between the USAF and McDonnell-Douglas. Many in government and industry deserve credit for this accom-lishment, perhaps none more than the project managers who provided strong eadership: General Benjamin Bellis (USAF) and Donald Malvern (McDon-ell-Douglas).[80]

The reformers played a major role and made critical contributions to the -15. The result was neither the lean, mean, austere fighter favored by the re-ormers, nor the big, sophisticated aircraft they opposed. In many respects it pped both schools of thought and melded them into a superb air superiority ghter that after twenty years is arguably the finest in the world. Nevertheless, here were those who had serious reservations about how the Eagle had turned ut. The reformers saw it as a prime example of what the U.S. fighter devel-opment system produced, that is, how a good design became needlessly bur-ened with equipment that was heavy, expensive, and of questionable re-ability and utility. Thus, some of those that pushed hardest for the F-15 egan to advocate another machine that was closer to the reformers' vision of proper (or pure) air superiority fighter.[81]

4

The F-16

Lightweight to Multipurpose Fighter

Along with the F-15, the F-16 maintains its place as one of the best air-to-air fighters flying in the world today. It certainly is a great commercial success, with 4,000 being built and serving in about twenty countries. As notable as these accomplishments is its unusual development, wherein a number of diverse events and unlikely people came together to produce this exceptional aircraft.

There was a direct connection between the development of the F-15 and the F-16. The reformers were unhappy with the way the F-15 had turned out, believing it had been compromised beyond help. They were correct that the USAF would attempt to enhance aircraft performance, and in so doing add complexity, weight, and expense to the fighter as it matured. All would agree that these changes would detract from *flying* performance, but the reformers claimed that *fighting* performance also declined, which was disputed by the es-tablishment. Therefore, once the ultimate path of the F-15 was clear, the re-formers worked to develop an aircraft closer to their ideals. An admiring bi-ographer has written that they were involved in "late night meetings, assumed

The USAF sought to supplement its F-15s with a smaller, cheaper, and more maneuverable stable mate. The General Dynamic F-16 Falcon's exceptional performance, especially its maneuverability (made possible by new "fly-by-wire" electronic control system) emerged through a successful flyoff competition. This F-16C is carrying an ECM pod on its left outboard pylon and a LANTIRN navigation pod on the side of its engine intake. Photo courtesy of Defense Visual Information Center.

names, all night work sessions in local motels, and the sort of collusion and intrigue that is now certainly illegal and was questionable then. But without it, the F-16 would never have been developed. For the F-16 was developed in spite of the system, outside the system, and in competition with the system as it then existed."[1] The reformers' goal was to produce a small, simple, reliable, and inexpensive lightweight fighter with the best performance for visual, close-in, maneuvering, air-to-air combat.

Curiously, the reformers and the establishment essentially wanted the same thing. Air Force leaders realized they could not afford to equip all their fighter units with the F-15, and therefore pushed for what was deemed a "high-low" mix, a fighter force consisting of F-15s and lower cost, but still high-performing, fighters. One problem with this approach was that the low-cost fighter could

not be too good or else it would threaten the F-15.[2] As seen by the reformers: "Within the Air Force, loyalty to the F-15 became what profession of faith in the Blessed Virgin is within the Church; a prerequisite act of belief for all who seek membership."[3] In addition to the reformers and the establishment, three other groups played a significant role in the F-16's development.

The sea service was a third party to the F-16's story. The Air Force was fearful during the late 1960s and 1970s that it would again be forced to employ Navy designed and developed equipment as it had with both the F-4 and A-7. One of the uniformed reformers concluded his briefings to his Air Force audiences in 1970 with the assertion that there were two threats menacing the USAF, one external and one internal. His final slide read: "Unless the U.S. Air Force thoroughly studies high performance austere fighters and is prepared to consider them as a necessary complement to other air superiority aircraft, the U.S. Air Force may be either outgamed by the Navy (again), and/or outfought by the Russians."[4] The rank order of the threats may be instructive.

A fourth player in this unusual saga was the Office of the Secretary of Defense (OSD). A change from Democratic to Republican control of the administration in 1968 led to a turnover in personnel at the top of the Department of Defense (DoD). This, along with torrid criticisms of the performance difficulties and cost overruns of the F-111 and C-5A aircraft, generated an increased interest in a different process for selecting aircraft for development.

Finally, the F-16 received a big boost from overseas. The North Atlantic Treaty Organization's desire to modernize its fighter arm led four European countries to propose a joint manufacturing venture with the United States. The lure of standardizing NATO aircraft, as well as earning profits overseas propelled the F-16 above the normal Air Force and defense politics. That it was to survive and flourish is yet another testament to its inherent worth, and most of all to its good fortune. What should be stressed is that the timing just happened; it probably could not have been better planned to permit this unusual fighter to make its way to success through so hostile an environment.

Developing a Concept: The Lightweight Fighter and Prototyping

Fighters have grown larger and heavier throughout their history, which added to some of their performance elements but subtracted from others. Throughout, many fighter pilots expressed a marked preference for a small, light, high-performing aircraft, equating a better *flying* machine with a better *fighting* machine. One problem, made clear, for example, by a 1964 Tactical Air Force pilot conference, was that pilots could not agree on which performance elements to emphasize: speed and ceiling or maneuverability. The next year the Air Force conducted formulation studies that included the F-X (fighter experimental) aircraft, as well as another lighter machine called ADF (Advanced Day Fighter). The latter was designed to outperform the MiG-21 by 25 percent. As already noted, the ADF idea was swept aside in the quest for what became the F-15.[5]

This general concept received a boost in the 1960s, when the United States attempted to produce a simple, inexpensive, high-performing fighter for its allies. In 1962 the United States picked the Northrop N-156, which became known as the F-5 Freedom Fighter, for this role. The single-seat, twin-engine aircraft's low cost, ease of maintenance, and high reliability made it a very attractive aircraft, but not to the USAF. Although the USAF successfully tested one squadron in the Vietnam War in late 1965 and early 1966, the Air Force did not adopt the Northrop fighter. It wanted a more capable, more advanced, more sophisticated aircraft. Nevertheless, twenty-six countries have employed F-5s.[6]

The lightweight fighter concept received another boost in July 1969 when President Richard Nixon delivered a speech on Guam that put forth the policy of the United States backing up local forces in fights against aggression, the so-called Guam or Nixon Doctrine. The Department of Defense followed up by pushing for the development of new aircraft for foreign arms sales. The government wanted a fighter with a 100 nm radius in a counter-air role and the ability to provide close air support. Although the Air Force favored the Vought design, a revised F-8, Secretary of the Air Force Robert Seamans picked the F-5 in November 1970. Here was a fighter in the spirit of the reformers.[7]

At the same time, the reformers were pushing toward the same goal of a lightweight, high-performance fighter. Pierre Sprey and John Boyd were advocating Sprey's concept called the "F-XX," a small, single-engine, fixed-wing fighter weighing less than 25,000 pounds and propelled by an engine with 35,000 pounds of thrust. The idea was to cut weight ruthlessly in all areas, emphasize maneuverability over speed, and forego radar-guided air-to-air missiles. As a consequence of the last requirement, only 500 pounds would be allocated for avionics, including radar. Although such an aircraft would have a top speed no greater than Mach 1.6, it would have twice the acceleration, slightly more range, and better turn performance than the F-4. And costs would be significantly lower than the Navy's F-14 or the Air Force's F-15. Sprey formulated this concept as early as 1968 and had the audacity to tout such a machine in a keynote speech he delivered at the American Institute for Aeronautics and Astronautics conference held in March 1970 in St. Louis, home of McDonnell-Douglas and the F-15. Instead of being the good guest and praising the triumphant F-15 team, Sprey encouraged greater efforts on the part of the design establishment to produce a fighter better than the F-15. Further, he called for a nose-to-nose flyoff competition to select the best aircraft for the air superiority role.[8]

Others had similar ideas. In 1968 Assistant Secretary of Defense Alain Enthoven authorized General Dynamics (GD) and Northrop to study the design of such an aircraft. Another contributor was Colonel Everest Riccioni, an Air Force fighter pilot, aeronautical engineer, and a thinker. Riccioni was allied in spirit and mind with the reformers and had written an Air War College thesis in 1968 that endorsed their ideas and explicitly acknowledged Boyd.[9] However, it was not until he was posted to the Pentagon in January 1970 that he joined them directly in their fight for what would become the F-16. As one scholar has put it: "Boyd ultimately sold Congress on the F-16, Sprey sold OSD and the Secretary of Defense and Riccioni fought the fight within the Air Staff. They made quite a formidable team."[10]

Riccioni was able to keep the ball rolling in February 1971 by making a small amount of money (certainly by Washington standards) available to General Dynamics ($150,000) and Northrop ($100,000) to study the concept.[11] The Air Force considered three different lightweight fighter designs: a single-engine fighter built around the F-15's Pratt and Whitney F100 engine, and a single-engine and twin-engine aircraft designed around a General Electric engine. These machines would carry limited avionics and armament for visual conditions in order to keep the weight below 20,000 pounds, and preferably as low as 17,000 pounds. Speed over Mach 1.6 was not specified. When Riccioni learned that the Navy was also studying a lightweight fighter, he skillfully used this information to prod the Air Force establishment into action.

Although he was able to move the Air Force, he did so at some personal sacrifice. The reformers believe the Air Force sent him to an assignment in South Korea as an exile because of his support for the lightweight fighter. The Air Force establishment saw it somewhat differently: Riccioni disobeyed a direct order to not raise the lightweight fighter issue.[12]

At this point the lightweight fighter was gaining support within the DoD, albeit not at the highest levels. As early as mid-1969 a draft Presidential Memo on Tactical Air emerged from DoD suggesting that both the USAF and Navy adopt such an aircraft as a substitute for their expensive F-14s and F-15s. Both services objected. The lines were drawn between the establishment that wanted as many F-14s and F-15s as possible, and the reformers who presented an alternative.[13]

Support for the lightweight fighter then emerged from the top echelons of the DoD. The Air Force was under pressure to change its procurement process because of both cost overruns and performance shortfalls demonstrated embarrassingly in two of its high profile programs, the F-111 and C-5A. Senior decision makers believed that the existing system of buying aircraft by means of paper competition and then locking in the price by contract (Total Package Procurement) was producing scandals and headaches, instead of first-rate, reasonably priced equipment. In addition to criticisms of the cost and performance problems, there were allegations of companies buying in at unrealistically low prices and then jacking up the costs by "gold-plating" (adding very costly extras), not to mention taking unnecessary risks by using unproven technologies. The new deputy secretary of defense, David Packard, favored selection on the basis of actual hardware in realistic tests, a "fly-before-you-buy" concept. (Not mentioned in most accounts is that this was a return to previous practices.) More important, both Secretary of Defense Melvin Laird and Secretary of the Air Force Robert Seamans supported this view. Therefore, when a Blue Ribbon Presidential Commission in July 1970 strongly recommended that prototyping be used, the stage was set for a change in procedure.[14]

This turn of events caught the services by surprise. The USAF may not have liked this change but used prototyping to its advantage. It was able to employ the new method in the A-X program approved by DoD in March 1970 that evolved into the A-10 (see chapter 5), but it had to scramble to come up with other suitable programs. Secretary Packard had $200 million and the USAF meant to obtain as much of it as possible, certainly its "fair" share. Air Force Systems Command sifted through 220 proposals before selecting six nominees. One was clandestinely funded as the Have Blue program (see chapter 6), and two others were made a part of the prototyping experiment. In August 1971, DoD released a Program Decision Memorandum that approved Air Force plans and funds for the lightweight fighter and advanced transport. (One source claims that they were the only ones that could be ready on such short notice.)[15] Packard made clear the intention of the program in testimony to Congress in the fall of 1971. He stated that DoD was "interested in pursuing a lightweight fighter, principally to demonstrate technology, high maneuverability, and good control ability throughout the performance range of the aircraft."[16]

In January 1972 the Air Force released the lightweight fighter request for proposal (RFP) to industry. The request met the spirit of the new procedure in a number of ways. First, at twenty-one pages it was physically much shorter than previous instructions and limited contractor's responses to sixty pages. These documents were simple and clear, in contrast to previous RFPs that ran to hundreds, if not thousands, of pages and contractor's responses measured in feet! Second, it gave the contractors much more latitude than in the past, establishing goals to achieve, rather than mandating rigid specifications. Earlier the Air Force Prototype Study Group had suggested goals that were generally followed. These included a maximum weight of 20,000 pounds, exceptional performance and maneuvering in the transonic region (Mach .8 to 1.6), operations in high "g" environment, and a top speed of Mach 1.0 to 1.2 at sea level and Mach 2.0 at altitude. The group expected both excellent pilot visibility and handling in an aircraft armed with a high-velocity cannon and low-cost air-to-air missiles. It was to have wing hardpoints for munitions, electronic countermeasures (ECM), and systems to provide a credible air-to-ground capability. As the aircraft was a demonstration vehicle, not a fully combat-ready weapons system, its avionics were to be held to a mission-essential minimum. The government expected the fighter to cost about $3 million each (flyaway cost) on a run of three hundred aircraft over three years. (At the bidder's briefing, General James Stewart emphasized that the contractors had great freedom in everything but the price.) The Air Force issued a program memorandum in

December 1971 that laid out the requirements, about the same as those noted above with two exceptions: the top speed was reduced to Mach 1.6, and unrefueled radius extended to 500 nm. The Air Force also expected the companies to experiment and demonstrate various advanced technologies suitable for the next generation of fighters, not high-risk technologies.[17]

Five of the nine companies contacted responded with their proposals in February 1972. Each company included not only the sixty pages of paper but wind tunnel data and wind tunnel models as well. (USAF testing of the models failed to confirm two contractors' submissions.) The secondary sources are unclear about the rank order for the top three but indicate that Boeing and General Dynamics (GD) were either first or second, and Northrop was ranked third. One source writes that Northrop was included in the final cut rather than Boeing because of the similarities between the Boeing and GD designs, whereas the Northrop design was somewhat different. The pairing of GD and Northrop would compete designs of single-engine against twin-engine, one vertical tail versus two, and fly-by-wire as opposed to conventional controls. It may have been that the GD design was picked over the Boeing design because it offered more advanced technology.

As in most competitions, there were other elements involved aside from technical merit. Some of these were undoubtedly factors, but others were the cynical comments of critics and the sour grapes of losers. These include that GD needed the work, GD had the most supersonic experience, GE needed work (its engines would power the Northrop aircraft), and that Boeing had no experience with high performance fighter aircraft.[18] In April 1972 the Air Force awarded contracts of just under $40 million to General Dynamics and Northrop. Each company would build two aircraft, respectively designated the YF-16 and YF-17, that would be flight tested for about three hundred hours. The Air Force stressed that though there was a hope for production, there was no government promise or commitment.[19]

YF-16

General Dynamics had begun work on the lightweight fighter design about 1964. It responded to the F-X project with two concepts, one aimed at the specific requirement and the other a simpler "gunfighter" aircraft. The ideas of the reformers prospered under the hand of Harry Hillaker, top GD man on the project, who had been close to John Boyd for a number of years. The two men not only kept in contact, they collaborated on what became the F-16. Hillaker today concedes that what he and Boyd did could well be considered suspect by the current tightened standards. As a result, GD had done considerable work on a low-cost complement to the F-X well before major contracts became a possibility.[20]

At first glance the General Dynamics YF-16 appeared to be a small, conventional aircraft. Perhaps its only distinguishing characteristics were its large, seemingly oversize, clear, bulbous canopy, extending far in front of the wing, and its large underslung intake. In fact, the Fighting Falcon combined a number of new technologies that made it the hottest fighter in the skies. Its wing featured leading and trailing edge flaps that automatically adjusted for optimum performance at varying flying conditions. This variable camber yielded the maximum lift-to-drag ratio, improved directional stability, and minimized buffet.[21] GD made a number of innovations in the aircraft's fuselage configuration. One new technology was the blended body that smoothly flared the wing into the fuselage, avoiding the typically abrupt, 90-degree junction. This innovation increased lift at high angles of attack, reduced drag at transonic speeds, and enlarged internal fuel capacity. The construction also saved about 570 pounds of weight.[22] GD used a third device that GD had been testing since 1966: sharp-edged forebody strakes, a highly swept extension of the wing's leading edge close to the fuselage, extending toward the nose. The strakes increased lift, improved directional stability, reduced trim drag, and delayed wing stall, especially at high angles of attack. The strakes also allowed a reduction in the wing size and saved, according to one account, 500 pounds.[23] GD investigated various tail arrangements but concluded that a twin tail configuration would have greater risk than a single one. Thus, the company used a conventional single vertical-tail unit but added two small, fixed, ventral fins beneath the conventional horizontal-tail unit.[24]

Another distinguishing characteristic of the design was the underbody engine air intake. This fixed geometry inlet reduced complexity, cost, and weight relative to a variable inlet. It was optimized for the middle of the flight envelope where most aerial combat was expected to occur, whereas the more efficient, complex, expensive, and heavier, variable inlets are most effective at the high-speed portion of that envelope. The fixed inlet achieved better air flow and was pushed by Pierre Sprey to further enhance air flow at high angles of attack.[25] Although vulnerable to foreign object damage because of its underslung position, the inlet's location forward of the nose wheel did lessen the ingestion problem.

The GD fighter was powered by the Pratt and Whitney F100 engine that had been developed for the F-15. Hillaker summed up the F-16 design philosophy by quoting famed German fighter designer, Willy Messerschmitt, "Wrap the smallest aircraft possible around the largest engine you can find."[26] The F-16 would have some difficulties with the engine, but these problems were not as critical as those encountered by the F-15. There was more concern with the single-engine GD fighter, however, as the F-15 had twin engines. As a result, the designers added a back-up fuel control system and modified cooling system, which added 54 pounds to the F-16 engine. GD picked the Pratt engine instead of twin GE engines, since it was more advanced and engine development costs could be spread between the two fighter programs. The single-engine configuration also weighed less and promised less drag. This choice would also make the Air Force more dependent on P&W, as its two top fighters employed the same power plant.[27]

GD introduced a number of innovations into the F-16's cockpit. Its frameless canopy gave the pilot fantastic visibility in all directions, albeit at the cost of increased drag. The YF-16 and YF-17 were the first aircraft to have Head-Up Display (HUD) designed into the initial versions.[28] The GD fighter featured a high acceleration cockpit. The pilot's seat was inclined rearward 30 degrees (the normal angle was 13 degrees) and the pilot's heels elevated six inches, allowing him to withstand as many as 1.5 to 2.0 more "g"s than in a normal seat. The drawback was that the elevated heel position also reduced the area available for panels and displays. More radical was the replacement of the control stick with a sidestick controller on the right-hand console.[29] This substitution uncluttered the cockpit forward of the pilot, and enhanced the pilot's resistance to blackout during high-acceleration maneuvering by permitting a more reclined body position while supporting the pilot's arms.[30]

GD designed the aircraft to be more maintainable than previous fighters. Compared to the F-4, which had 510 separate lubrication points, 281 fuel connections, and 294 avionics units, the GD fighter had respectively 84, 90, and 52. The aircraft was easier to service because about 60 percent of the YF-16's surface area could be removed, and its 228 access doors could be operated with only four different tools. Mechanics could reach about 80 percent of the systems without using stands.[31]

Undoubtedly the most important new technology introduced by the F-16 was its fly-by-wire control system. Standard controls transmit the pilot's physical commands from the stick-and-rudder pedals through cables or rods to the aircraft's control surfaces. As speed and size of aircraft increased, boosted controls appeared, whereby the pilot's commands were amplified by hydraulic systems. The difficulties with these systems included possible damage to the system, the fire hazard of flammable hydraulic fluid, the weight and volume of the system, and the time delays and inertia in the response of the controls.

An alternative was to send electrical signals directly to the control surfaces where motors would move them.[32] The next step was to use a computer to integrate the pilot's commands. Direct Air Force involvement in this idea can be traced back to 1956, when the Air Force Flight Dynamics Laboratory began systematic studies of the concept. The system was used aboard all of America's manned spacecraft and the Air Force tested parts of the system in a number of experimental aircraft. The Air Force flew the first full system test (pitch only) in a B-47 in December 1967. Later, testers added controls for the roll axis, along with a sidestick. The project gained momentum when analysis indicated that failures in the flight control system caused 30 percent of aircraft losses in the Vietnam War.[33]

In July 1969 the Flight Dynamics Laboratory began a project known as the Survivable Flight Control System Program. Although its primary purpose was to increase aircraft survivability, the developers also thought in terms of improved handling, stability, and performance. The USAF took this approach for funding purposes, although it was understandably more interested in direct and quick practical applications than in long-term theoretical work because it was fighting a war. The Air Force had McDonnell-Douglas reconfigure an F-4 with both the fly-by-wire system and a sidestick for these tests, and then, in 1970, the lab demonstrated a backup system for pitch control, a system retrofitted into Air Force F-4Es. The experiment then progressed to full fly-by-wire controls.

The new control system first flew in April 1972 and demonstrated it could control and automatically trim the aircraft. The test pilot who flew the F-4 noted that the aircraft's control "noticeably improved."[34] This system first took to the air in January 1973 on the first of 72 highly successful flights.[35]

An additional effort was required to take full advantage of this new technology. Conventional aircraft are designed to be stable; that is, when trimmed up and when the pilot takes his hands and feet off the controls, the controls attempt to maintain their flight path and during a turn the aircraft moves in the direction in which the nose is pointed. (More technically, this requires the center of gravity to be forward of the center of lift.) To capitalize on the fly-by-wire technology, the aircraft can be made unstable (shifting the center of gravity aft of the center of lift) and yet maintain control. Such an arrangement, called "relaxed static stability," offers a number of benefits: the aircraft can perform tighter turns and maneuvers, is more responsive, and can be designed with less drag and greater lift.[36]

The Air Force and industry demonstrated outstanding cooperation on this program. In December 1968, Wright-Patterson's Flight Dynamics Laboratory sponsored a two-day conference on the subject, which attracted sixty-six government and seventy-four industrial attendees, indicating that the concept had moved to a point from which practical applications could be expected shortly.[37] The question was, what operational aircraft would be the first to employ fly-by-wire control systems? As already noted (in chapter 3), McDonnell-Douglas, one of the pioneers in the fly-by-wire control experiments, had looked at and then chosen not to use the system in the F-15.

Convair had studied such flight control systems as early as 1957 and had made some use of them in both their B-58 and F-111 bombers. However, most of the work had been done by the military, particularly at Wright-Patterson. Jim Dabold of Aeronautical Systems Division made this information available to both competitors in the lightweight fighter competition, but only GD took advantage of it.[38] In 1969 GEC Astronics began work on an analog fully fly-by-wire system for the F-16. GD designed the F-16 with its center of gravity aft of its center of lift in subsonic flight, although as speed increases, the center of lift moves rearward, restoring stability in supersonic flight. One source claims the F-16's fly-by-wire flight control system and blended body and wing saved approximately 1,300 pounds of weight. It cost the Air Force less than $20 million to support this project.[39]

The fly-by-wire system was the most risky technology aboard the F-16. In 1991 GD's Harry Hillaker noted, "If the fly-by-wire didn't work, our relaxed static stability wasn't going to work. And then the airplane would have had higher drag and would have been less responsive, [and] less maneuverable."[40] So GD took the risk and thus would be the first to employ it.

GD rolled out the YF-16 in December 1973, three and a half months before the YF-17 emerged. The new aircraft first flew in January 1974, although not as envisioned. During a high-speed taxi test, the GD test pilot encountered pilot-induced roll oscillations caused by flight control settings that were too sensitive. These went out of control and the left wing and tail hit the ground. The pilot elected to fly rather than try to stop under such conditions and in this way made a six-minute flight. The first official flight took place two weeks later.[41]

YF-17

Northrop's YF-17 was similar in some respects to its rival, but was a more conservative design, although Northrop made greater use of composite materials than did GD. The YF-17 was larger and about a ton (9 percent) heavier than the YF-16. Physically, the YF-17 was distinguished by its twin vertical "V" tail mounted to the rear of the wing and forward of the standard horizontal tail. This arrangement gave the YF-17 control at very high angles of attack; wind-tunnel tests indicated it was controllable up to 45 degrees. More significant, it was powered by two engines, giving it about one-quarter more power than the YF–16.[42] Both aircraft used forebody strakes, automatic variable wing, fixed geometry inlets, and a HUD cockpit. Northrop reclined the pilot's seat 18 degrees and elevated his feet 5 inches, more than the typical fighter of the day, but less than that of the YF-16. Northrop went with conventional flight controls.[43]

Northrop's fighter had evolved from a successful line of aircraft, beginning with the company's low-cost, lightweight fighter, N-156, the superb T-38 trainer, and the impressive F-5 fighter.[44] Northrop responded to the lightweight fighter RFP with both a single-engine and twin-engine version. The Air Force picked the latter to compete with the GD entry. Despite its early start, Northrop did not move as quickly as GD, and therefore its new aircraft did not make its initial flight until June 1974, six months after its rival.[45]

Under the original plan, GD would complete its competition course by

January 1975 and Northrop by April 1975. Then the Air Force would pick a winner.[46] But unexpected events not only shortened the schedule, they dramatically increased the importance of the competition.

One factor was the Air Force decision to buy the lightweight fighter. The 1973 Arab-Israeli War indicated that high attrition rates could be expected in a future high-intensity conflict (as in case of a Soviet attack in central Europe) and reinforced the need for numbers of aircraft. It was clear by this time that the high costs of both the Air Force's F-15 and Navy's F-14 were working toward fewer numbers of U.S. fighter aircraft. In March 1974 the chief of staff of the Air Force, General George Brown, formed a study group (Air Force Tactical Fighter Modernization Group) to look for a replacement for the F-4. It concluded that a fighter replacement had to be very sensitive to cost. It foresaw that the future Tactical Air Command (TAC) would be equipped with F-15s, A-10s, and lightweight fighters, the last of which would perform both air-to-air and air-to-ground roles. At the same time (April 1974), Secretary of Defense James Schlesinger decided the winner of the lightweight fighter competition should be bought by the Air Force.

A second factor emerged in May 1974, when representatives of four NATO countries met and formed a group to look for a replacement for their aging F-104 fighters. This contract was attractive to the United States for a number of reasons. Money was certainly a driving force, not only profits for the winner but also the fact that if the American entry was picked, the government could recover some of its research and development costs. A larger production run would also drive down the fighter's unit price. In addition, adoption of one aircraft by both the United States and the four NATO countries would be a giant step toward standardizing the Alliance's fighter equipment.

In addition to procuring 384 aircraft, the Europeans wanted a coproduction agreement that would give them a piece of the economic pie and enhance their technology. The complication was that the Europeans wanted a decision as early as September 1974.[47] These considerations eventually led to a DoD decision to select a winner of the lightweight fighter competition by 1 January 1975.[48]

This decision did not come without a fight. There were those within the Air Force who opposed acquiring the lightweight fighter, as they thought primarily in terms of higher and faster. However, the reformers were able to get their views to Secretary of Defense Schlesinger. Apparently the secretary was already convinced by the economic arguments that both the Air Force and Navy should add lightweight fighters to their inventories. After taking over the post in July 1973, he unsuccessfully tried to get the chief of staff of the Air Force to agree to USAF acquisition of the lightweight fighter. General Brown refused even though he knew as early as fiscal year 1973 that his service would not get funding to reequip all of its authorized tactical fighter wings with F-15s. Schlesinger did better with Brown's successor, General David Jones. In brief, in late 1974 Schlesinger made a deal with Jones for the Air Force to buy both the F-15s and lightweight fighters, and to add four tactical fighter wings to the Air Force's existing authorized level of twenty-two. Ten of these wings would be equipped with lightweight fighters. Jones obtained permission for the USAF to "redesign" the aircraft to meet Air Force requirements and agreed that the Air Force would not seek additional funding or people regarding these fighters.[49] The USAF also agreed to the DoD decision to advance the decision date for the lightweight fighter competition. The shift to January 1975 was inconvenient for GD, as more time is always useful, but it was even more difficult for Northrop, whose test flight program was behind GD's.[50]

The two aircraft were wrung out in the flyoff competition. As was expected, both aircraft showed some deficiencies. GD's problems centered on the aircraft engine; nevertheless, it achieved the Air Force's goals, in many cases exceeded projections, and exhibited excellent handling. One unanticipated problem uncovered was stalls at high angles of attack. Initially the aircraft's controls were too sensitive, but this was easily adjusted. Throughout flight testing the fly-by-wire system demonstrated high reliability. Part of the success of the GD testing program was the high reliability and low maintenance of the aircraft.

Like the YF-16, the Northrop machine also performed better than any existing fighter other than the F-15. Most impressive was its ability to fly at high angles of attack. It is asserted that the YF-17 was the first U.S. aircraft to break the sound barrier in level flight without an afterburner. But it too had its lapses. It did not meet Air Force goals in supersonic acceleration and range. It also had engine problems, as might be expected with an engine under development.[51]

The issue, however, was how the two aircraft compared. The F-16 showed superior turning, acceleration, deceleration, and range, as well as better visibility and resistance to "g" forces, and it could transition more quickly from maneuver to maneuver. Thus, it was superior in the air-to-air role. Its engine was further developed, offered fewer risks, and as it also powered the F-15, offered advantages of lower initial and support costs. The evaluators believed the F-16 would be easier and quicker to bring into production. And it was cheaper both to purchase and operate. According to most accounts, the test pilots preferred the YF-16.[52]

On the other hand, the larger YF-17 could carry about 25 percent more payload and boasted a greater growth potential. In contrast, the YF-16 was a densely packed aircraft in the tradition of its Fort Worth predecessors, with little room for future growth. The Northrop entry was also better than the GD fighter at takeoff, climbing, low speeds, high angles of attack, subsonic acceleration, and some turning maneuvers.[53]

The competition was complicated by the Navy, which also was expected to purchase the winner of the lightweight fighter competition. Packard had made such a suggestion in the summer of 1971. In August 1974, Congress mandated that the Navy "make maximum use of the Air Force lightweight fighter . . . technology and hardware."[54] But most informed observers thought that, at best, the Navy would only go with the Northrop entry, as it favored twin-engine aircraft and saw the Northrop aircraft better suited to carry the larger radar and missiles it desired. In view of the sea service's track record with the F-111 and F-X, cynics doubted that the Navy would ever buy an Air Force designed and developed aircraft. Northrop, of course, used this argument as a powerful club as it applied intense lobbying pressure on behalf of its product.[55]

The test team unanimously concluded that the YF-16 was the better aircraft. In January 1975 Secretary of the Air Force John McLucas announced that GD had won the competition because of its superior performance. Cost was also a factor, perhaps the deciding one.[56] Northrop believed that the shortened test schedule hurt them. In addition, they claimed they were hampered by the prototype engines that produced 5 percent less thrust than they anticipated. Some believe that if this had been a paper competition, Northrop would have won because its design was less risky. Some also maintain that GD needed the work.[57]

In June 1975 the NATO Four announced that they, too, had selected the GD fighter. The initial plan called for the USAF to buy 650 fighters and the Europeans another 348.[58] The program would go well beyond this; approximately 4,000 F-16s have been produced.[59]

This was not the end of the YF-17, however. The Navy was able to evade both the congressional and DoD pressure to buy the F-16, and in May 1975 they picked the losing Northrop design. Northrop teamed up with McDonnell-Douglas to "navalize" the YF-17, added almost 5,000 pounds (28 percent), and redesignated it F/A-18. After some problems and many criticisms, it turned out to be a successful aircraft in two roles: air superiority and attack. Almost 1,300 have been built and are serving in eight foreign countries, as well as in the Navy and Marine Corps. It has become the Navy's major fighter and attack aircraft supplementing the larger, older, more expensive F-14.[60]

F-16

GD's task now was to modify the competition, test, and demonstration YF-16 into a warplane. A number of changes ensued. The USAF increased the size of the nose cone to accommodate a more sophisticated radar, which could pick low-flying aircraft out of the ground clutter. Although extending the fighter's electronic capability, it was still considerably simpler than the F-15's radar, with only 30 percent the number of parts and twice the reliability. As the only new avionics designed for the F-16, it was considered the most risky component of the Fighting Falcon program.[61] It proved to be a problem.

After flight tests, Westinghouse bested Hughes for the radar contract that was awarded in 1975. Although Westinghouse proved superior on financial and technical grounds, it had difficulties. Flight tests of the first radar-equipped F-16, delivered in June 1977, revealed detection ranges half that of the requirement, unrecognizable ground maps, and an inability to track targets during maneuvers. Additionally, not all of the radar sets that Westinghouse delivered were operable. However, an Air Force review team concluded in July 1977 that the problems could be surmounted, and flight tests the next month demonstrated improvement. Progress was slow. At the conclusion of 364 flights in October 1979, the USAF conceded that not all objectives were accomplished but nevertheless upgraded its assessment of the radar from unsatisfactory to marginally satisfactory.[62] The Air Force brought some of these problems on itself by pushing too hard for the state-of-the-art and overspecifying requirements.

Other problems proved less difficult. The USAF made a number of changes to the F-16's structure. It beefed up the airframe by about 25 percent so that the fighter could perform 9.0 "g" maneuvers throughout its flight envelope, and strengthened the landing gear. The manufacturer lengthened the fuselage by almost a foot to allow both the single-seat and twin-seat versions to use the same basic airframe. At the same time, GD added 400 more pounds of fuel, additional stores stations to give the F-16 nine hardpoints, and a tail hook. To satisfy the pilots, some motion was put into the nonmoving sidestick.[63] The canopy presented problems. To obtain undistorted vision, the canopy required special materials and highly involved processing, but it proved inadequate against bird strikes. The solution was to replace the half-inch thick material with a three-quarter-inch canopy coated with a new material. GD also increased the wing area from 280 to 300 square feet (Boyd wanted 320 to 325 square feet), and the vertical tail area from 42 to 49 square feet.[64]

These changes added almost a ton of weight. There are those who maintain that the Air Force deliberately loaded up the fighter, using NATO requirements as an excuse, to reduce its performance so it would not be seen as a competitor to the F-15. As a result the fighter evolved from a pure air-superiority aircraft, as the reformers desired, toward a multirole one as traditionally desired by the USAF. The NATO Four pushed toward broader capabilities, as did the Air Force Tactical Fighter Modernization Group.[65]

GD had to work through a number of problems. The General Accounting Office (GAO) described some of these in a 1977 report. The engine continued to be dogged by stall stagnation, mostly in the F-15, as well as by difficulties with air restarts. There also were problems with turbine blade containment and engine control reliability. To give the single-engine pilots depending on the F100 engine a greater safety margin, the Air Force added a backup fuel control and a different intake. This modification rendered the F100 less common, and thus, though the F-15 engine retained the designation F100-PW-100, in August 1978 the F-16 engine was redesignated the F100-PW-200.

Another problem was excessive taxi speeds caused by the engine's great power and the aircraft's light weight that wore out brakes. Reducing the idle solved this one. Norway's concern about landing on icy runways proved slightly more difficult. McDonnell considered thrust reversers but discarded the concept because of complexity, weight, and cost. Therefore the Norwegians equipped their F-16s with drag chutes. The F-16's other problems included its small size that limited space for additional equipment and concerns about its vulnerability, especially in the air-to-ground role. The manufacturer considered a number of potential solutions; however, the Air Force did not judge the vulnerability issue as significant. The GAO also mentioned the rising costs as well as the delays caused by the European participation.[66]

The single-seat production model became the F-16A and weighed one more ton than the YF-16. The two-seat, trainer version was designated F-16B. An upgrade program was planned for the Falcon called Multinational Staged Improvement Program (MSIP). Upgrades included rewiring and changing the structure of the "A" and "B" models to accommodate future Air Force equipment and improving the radar's air-to-ground capability. The most visible change increased the size of the horizontal stabilizer by 30 percent to improve control, especially at high angles of attack.[67]

The first USAF F-16 unit achieved initial operating capability (IOC) in the fall of 1980. GD delivered the first MSIP modified aircraft to TAC in November 1981. The first Air National Guard Unit began to reequip with F-16s in 1983, followed the next year by Air Reserve units. The USAF's demonstration and publicity aerobatic team, the Thunderbirds, acquired F-16s in 1982 and began flying shows with their new mount the next year.[68]

The next versions were the "C" (single-seat) and "D" (dual seat) models. In 1984 the USAF began deliveries of aircraft with MSIP II changes, among them improved cockpit displays and an inertial navigation system (INS). New avionics equipment included identification friend or foe (IFF) and radar altimeter, as well as radar-warning receiver, chaff, and flares, along with external ECM. These aircraft could carry the AGM-65D Maverick, the AMRAAM (Advanced Medium-Range Air-to-Air Missile) that was under development, and the AGM-45 Shrike and AGM-88 HARM (high-speed antiradiation missiles). The Air Force applied the system of "blocks" to distinguish the various versions of the aircraft, applying "Block 25" to these first F-16Cs and Ds.

The next major improvement (Block 30) increased the width of the engine inlet by a foot and modified the engine bay in order to accommodate either the Pratt and Whitney F100-PW-220 or the more powerful (5,000 pounds of thrust) and heavier (800 pounds) General Electric F110-GE-100.

The two engines are not interchangeable, and therefore a fighter wing employed only one engine type.[69] Thus, weight and range increased, while maneuverability decreased. As a pilot who flew both the "A" and "C" models noted with some disgust, "Compared to the 'A,' the 'C' was flat champagne."[70]

At this point two serious problems appeared. In October 1987 a wing on a Block 30 aircraft failed during a routine static test. This failure led GD to beef up the wing and retrofit the F-16 fleet beginning in mid-1988.[71] The Block 30 aircraft were also more likely to become uncontrollable ("depart") and more difficult to recover from a stall. Tests indicated that this tendency resulted from the larger engine inlet. The manufacturer developed an angle-of-attack limiter that restricted angle-of-attack, roll rate, and rudder movement for air-to-ground operations that was successfully tested in the first half of 1980.[72]

On the other hand, the "C" and "D" were proving to be more reliable than the earlier models. At the end of fiscal year 1986, for example, they were posting fully mission capable rates of greater than 93 percent compared with the "A" and "B" rates of more than 87 percent.[73]

The USAF got its first MSIP III (Block 40) F-16s in December 1988, which included further upgrades of the radar, expansion of the computers, advanced IFF, Global Positioning System (GPS), and structural improvements (notably stronger landing gear) that permitted heavier gross weights. Low Altitude Navigation and Targeting Infrared System for Night (LANTIRN) navigation and targeting pods were part of this modification. The USAF also added improved performance engines and automatic terrain-following radar.[74]

Variants

The F-16 was to appear and was considered in a number of variants, more than a hundred distinct versions according to one source. In October 1983 the Air Force decided to replace its F-4 and F-106 interceptors with new aircraft. The competition narrowed between the two F-16 versions ("A" and "B") and the Northrop F-20 (a derivative of the F-5). On the last day of October 1986 the secretary of the Air Force announced that the F-16A had won the contract for 270 aircraft.[75] The USAF would arm the fighter with the AMRAAM, AIM-9 Sidewinder, and AIM-7 Sparrow missile along with an internal 20 mm gun. Advanced IFF, GPS, and APG-66 radar would highlight its avionics. These aircraft were modifications of the standard F-16s and were built on the same production line. GD began conversions of the standard aircraft to the air defense versions in December 1988. The company delivered the first to the Air Force in March 1989, which achieved IOC when the twelfth fighter was delivered in November of that year.[76]

In 1988 the USAF proposed a close air support, interdiction version and suggested it be designated A-16. At the same time the Air Staff was pushing the A-16, OSD looked to a variant of the block 50 bird for this mission.[77] After some effort, in November 1990 the Air Force was ordered to retain two A-10 wings, thus eliminating the A-16 proposal.[78]

Meanwhile the Air Force studied ways to enhance the night capability of both the A-10 and F-16. The Night Attack Program investigated and developed head-steered, forward-looking infrared (FLIR), helmet mounted display (HMD), and night vision goggles. Its primary solution to the problem was FLIR. In 1989 the Flight Dynamics Laboratory completed five flights of a specially configured F-16 called Advanced Fighter Technology Integration testing new equipment. In December 1990 TAC chose a head-steered FLIR with a binocular HMD for the night close air support (CAS) mission.[79]

In 1989 the Air Force fitted 30 mm Gatling guns (GAU-5A) onto F-16As of the 138th Fighter Squadron (174TFW, New York Air National Guard) to test the four-barrel, 2,400-shots-per-minute gun in the ground attack role. The Pave Claw gun was mounted in a centerline pod and fitted to two dozen aircraft. The unit's pilots, who had transitioned from A-10s, were positive about the aircraft's performance, specifically citing its speed, maneuverability, small size, and capable fire control computer. The 174th's Pave Claw was tested against moving targets, whereas other F-16s were tested in the air-to-ground role against fixed ones. During 1990 the USAF begin to modify twenty of the unit's F-16s with the automatic target hands-off system avionics, and by the end of the year the unit had eight of the modified aircraft as it prepared to deploy in support of Desert Shield.[80]

As with the F-15, American pilots would not be the first to fly the F-16 in combat. That distinction again fell to the Israelis, who employed the Falcon to bomb an Iraqi nuclear reactor at Osirak in June 1981. In June 1982 the Israelis successfully employed the F-16s in a pure air-superiority role in the large, intense, but brief air battles over the Bekaa Valley in Lebanon. Here Israeli aircraft destroyed 85 to 92 Soviet-built fighters piloted by Syrians in air-to-air combat with one or no Israeli losses. The F-16s are credited with 42 to 44 of these victories and F-15s with another 40, most downed by AIM-9L Sidewinder missiles.[81] Israeli F-16s have downed 52 Arab aircraft. In action near the Afghan-Pakistan border, Pakistani F-16s claimed a minimum of eight Soviet and Afghan aircraft destroyed, a figure that may be as high as thirteen.[82]

The USAF has been quite happy with the F-16, which has been relatively trouble free when compared to other Air Force and Navy aircraft. The Falcon has established an outstanding safety record, especially in view of the aggressive way the pilots fly the bird, and considering that it is a single-engine machine. One Air Force report in 1990 dubbed the F-16 the safest single-engine fighter in Air Force history.[83] The GD fighter has also satisfied the Air Force in the fighter-bomber role. For example, compared with the F-4's bombing accuracy of 150 feet circular error probable (CEP),[84] F-16 crews achieved averages of 30 to 35 feet, with some crews scoring as close as nine feet.[85]

It is difficult to account easily for the F-16's success, as there were so many obstacles and so many disparate factors that came together in an unpredictable way. Unconnected events such as the rising costs of the F-15, the great momentum to change the prototyping procurement system, the 1973 Arab-Israeli War, and the European interest in a replacement fighter were the most important. A number of people were pivotal in the story as well. Members of the reformers stayed true to their ideals and fought not only the good fight, but a skillful and successful one. Top civilians in the DoD were also important, from Packard who pushed prototyping to Schlesinger who wanted a cheap, common fighter. And the achievement of the GD team should not be understated. They took a variety of existing and new technologies and molded them into a very successful flying and fighting machine. GD won the Air Force contract in a contest against a good design. The success of both competitors since that flyoff is a testament to GD's achievement. As one writer has so well put it: "Fortune had not merely smiled; she had taken General Dynamics [and I would add, the USAF] into her embrace like a loving and long-absent aunt."[86] But to quote a well-worn cliché, battle is the payoff. It would not come for American forces until 1991.

5

The A-10

Supporting the Troops

The A-10 is an aircraft in sharp contrast to the high performance F-15 and F-16. These two fighters with their cutting-edge technologies symbolize what the Air Force has emphasized throughout its history: better and better flying performance and multipurpose aircraft. The A-10, on the other hand, has a rather pedestrian flying performance, incorporating simple technologies for one very specific task: close air support (CAS). Thus, the A-10 is a counterpoint to the high technology, expensive fighters that pilots, the public, and the Air Force admire and favor. Nevertheless, it is an excellent example of the designer meeting the needs of the warfighter.

Throughout its history the Air Force has been dominated by a few basic principles. First and foremost, air superiority is given pride of place. In the words of Field Marshal Bernard Montgomery (words quoted as freshman knowledge at the Air Force Academy since its inception): "First of all you must win the battle of the air. That must come before you start a single land or sea engagement."[1]

As a second principle the Air Force believes that air power is most effective when directed against targets deep behind the battlefront; the deeper the