AIR COMMAND AND STAFF COLLEGE

STUDENT REPORT

THE SEARCH FOR AN ADVANCED FIGHTER: A HISTORY FROM THE XF-108 TO THE ADVANCED TACTICAL FIGHTER

MAJOR ROBERT P. LYONS, JR. 86-1575

"insights into tomorrow"

DISCLAIMER

REPORT NUMBER 86-1575

TITLE THE SEARCH FOR AN ADVANCED FIGHTER: A HISTORY FROM THE XF-108 TO THE ADVANCED TACTICAL FIGHTER

AUTHOR(S) MAJOR ROBERT P. LYONS, JR., USAF

FACULTY ADVISOR R. CARGILL HALL, GM-14, USAF HRC/RI

SPONSOR R. CARGILL HALL, GM-14, USAF HRC/RI

Submitted to the faculty in partial fulfillment of requirements for graduation.

AIR COMMAND AND STAFF COLLEGE
AIR UNIVERSITY
MAXWELL AFB, AL 36112

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT STATEMENT "A" Approved for public release Distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) 86-1575	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION ACSC/EDCC 6b. OFFICE SYMBOL *(If applicable)*	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS *(City, State and ZIP Code)* Maxwell AFB AL 36112-5542	7b. ADDRESS *(City, State and ZIP Code)*
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL *(If applicable)*	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS *(City, State and ZIP Code)*	10. SOURCE OF FUNDING NOS. PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT NO.
11. TITLE *(Include Security Classification)* THE SEARCH FOR AN ADVANCED FIGHTER:	

12. PERSONAL AUTHOR(S)
Lyons, Robert P., Jr., Major, USAF

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT *(Yr., Mo., Day)*	15. PAGE COUNT
	FROM ______ TO ______	1986 April	98

16. SUPPLEMENTARY NOTATION
ITEM 11: A HISTORY FROM THE XF-108 TO THE ADVANCED TACTICAL FIGHTER

17. COSATI CODES			18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
FIELD	GROUP	SUB. GR.	

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

This report traces the Air Force's progress in developing advanced fighters from the XF-108 and the YF-12A for long-range supersonic interception; through the F-111 with its goal of multi-mission commonality; through the F-15 air superiority fighter; then to the Lightweight Fighter Prototypes (YF-16 and YF-17) and the Air Combat Fighter competition won by the F-16. The report also covers the technology and fighter enhancement programs (such as AFTI, HiMAT, X-29A, and MSIP) which build the base for the Advanced Tactical Fighter now in Concept Development.

Keywords AFTI (Advanced Fighter Technology Integration), MSIP (Multi-Staged Improvement Program), Mission profiles, Air Force procurement, Interceptors, Tradeoff analysis.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☒ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL ACSC/EDCC Maxwell AFB AL 36112-5542	22b. TELEPHONE NUMBER *(Include Area Code)* (205) 293-2483 22c. OFFICE SYMBOL

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE. UNCLASSIFIED

PREFACE

I wrote this paper to put the Air Force's current search for the Advanced Tactical Fighter of the 1990s into an historical perspective. Mr. R. Cargill Hall of the USAF Historical Research Center advised me the Air Force Systems Command is writing detailed histories of many of its major weapons systems so those of us in the research, development, and acquisition fields can avoid mistakes of the past. We believed it would be useful to compile a general USAF advanced fighter development history as a backdrop to the more detailed histories of individual fighters. This history was drawn primarily from open sources to ease further research for others, who, like myself, are bound for assignments in system program offices where the next advanced fighters will evolve.

I want to acknowledge the unstinting assisstance of the staff of the USAF Historical Research Center, who were always helpful regardless of the hour. Dr. Jim Kitchens was particularly gracious with his time and advice. Dr. Richard Hallion at Edwards AFB, California sent me some seminal documents and infected me with his enthusiasm for the subject. Lieutenant Jerry Estepp and Colonel Zeke Barnett of the Advanced Tactical Fighter System Program Office at Wright-Patterson AFB, Ohio also sent me useful documents, and shared their views with me. My good friends in the advanced technology industry encouraged me and supplied me with useful documents. Mr. R. Cargill Hall inspired me with his knowledge and insights into the history of USAF fighters, and was my mentor through this effort.

I must also thank my wife, Judy, for her help in locating myriads of documents in the stacks at the Air University Library, and for her untiring support during this project. (She did get just a little bit tired during the "Great Bibliography Debacle of 1986".) My sons, Bob and Bill, also helped me with this effort by letting me on the computer whenever I wanted it, and by "being there" even when I wasn't.

ABOUT THE AUTHOR

Major Robert P. Lyons, Jr. enlisted in June 1968 and was a nuclear instrumentation technician until attending New Mexico State University under the Airmen's Education and Commissioning Program. He graduated with a Bachelor of Science in Electrical Engineering degree with honors, and was a distinguished graduate of Officers' Training School. He earned his Master of Science in Electrical Engineering degree at the Air Force Institute of Technology, where he won the Commandant's Award for his thesis titled, "Ion Implantation of Diatomic Sulfur into GaAs (Gallium Arsenide)". Major Lyons also attended the Program Managers' course at the Defense Systems Management College. He has served in Air Force Systems Command (AFSC) laboratories, product divisions, and headquarters, working in electron device and avionics research and development, technology planning, and command and control systems acquisition management.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TABLES

EXECUTIVE SUMMARY

REPORT NUMBER 86-1575

AUTHOR(S) MAJOR ROBERT P. LYONS, JR., USAF

TITLE THE SEARCH FOR AN ADVANCED FIGHTER: A HISTORY FROM THE XF-108 TO THE ADVANCED TACTICAL FIGHTER

The USAF Historical Research Center needed a history of the Air Force's fighter development trends as a backdrop for detailed histories of individual Air Force fighters. This report is a history of the Air Force's search for an advanced fighter starting with the XF-108 and the YF-12A and progressing up to the Advanced Tactical Fighter now in Concept Exploration.

Chapter One: The XF-108, the companion supersonic interceptor to the XB-70 bomber, was designed to intercept bombers at very long range using semi-autonomous weapons guidance and missiles. The XF-108 was progressing well when its development was abruptly canceled in the face of unconfirmed Soviet bomber threats and the overwhelming trend toward offensive and defensive nuclear missiles in the late 1950s and early 1960s. The YF-12A grew out of the mysterious A-11, developed in great secrecy for either U-2 follow-on, or for interceptor missions like those envisioned for the canceled XF-108. Both the XF-108 and the YF-12A were designed for supersonic cruise and missile carriage, and although they both used advanced technology, neither was very flexible in mission application. The F-111, which came out of the TFX (Tactical Fighter Experimental) program, was to be the most flexible aircraft yet developed. The DoD hoped this airplane could serve

CONTINUED

the needs of all three Services, but the F-111 was eventually so compromised it could only do well Air Force interdiction missions; the Navy dropped out of the program when it was evident the F-111 could not meet the needs of fleet defense. The F-111 did, however, advance the state of development of variable-geometry swept wings. The Air Force started the FX (Fighter Experimental) program to build a single-mission air superiority aircraft as a response to the failed attempt to make the F-111 perform several missions.

Chapter Two: The Air Force developed and produced the F-15 from the original FX designs. The F-15 was designed specifically to exploit the advantages of high maneuverability in air combat, something earlier advanced fighters had given up for speed. The new Energy Maneuverability Theory predicted high maneuverability for aircraft with high thrust-to-weight ratio and low wing loading, so the F-15 was designed accordingly. It was the first aircraft to exceed a 1.0 to 1.0 thrust-to-weight ratio. With its low wing loading it could turn inside any fighter in the world, and could maneuver so wildly as to cause initial concern about pilots' abilities to control the aircraft. But because the Soviet fighter threat was looming large, and the DoD had not completely given up on the idea of commonality and inexpensive fighters, the Air Force started a Lightweight Fighter Prototype program to investigate the possibilities of high technology day fighters. When the Europeans needed to replace their aging F-104 fleets and the number of new Soviet fighters became disconcerting, the prototype demonstration was turned into a competition for a low cost Air Combat Fighter to augment the F-15 force structure, and to be sold overseas. The F-16 won the competition and became an advanced fighter with excellent air superiority and good air-to-ground capabilities.

Chapter Three: Throughout the 1970s both the F-15 and the F-16 were the Air Force's advanced fighters. These fighters joined the force structure along with F-4s, F-111s, and A-10s, and gradually displaced some of them in a move toward force modernization that still continues. Both fighters underwent significant enhancements to make them more formidable weapons systems since their earliest introductions into the inventory. Even the "not a pound for air-to-ground" F-15 has evolved into models with powerful interdiction capabilities through planned enhancements known as the Multi-Staged Improvement Program. Similarly, the F-16 has

CONTINUED

increased its adverse weather capabilities through staged improvements. Even before the Air Force was willing to admit the F-15 (or F-16) would need to do a larger share of the air-to-ground missions formerly performed by F-4s and F-111s, the defense industry produced an F-15 Strike Eagle to demonstrate its bombing and strafing capacity. The Air Force helped fund an F-16 SCAMP which ultimately competed with the Strike Eagle for dedicated air-to-ground modifications. The F-15E won the competition to modify some of the enhanced F-15C/Ds for strike missions.

Chapter Four: The Air Force recognized it would need to begin work on a replacement for the F-15 as soon as the F-15 began development if another twenty years between air superiority fighters was not to elapse. The Air Force's development and laboratory planners put together concepts and technologies which began to emerge in the late 1970s and early 1980s as the foundations of the next Advanced Tactical Fighter (ATF). Among the technology programs applicable to the ATF are the Advanced Fighter Technology Integrator (AFTI) programs, which develop unconventional flight and fire control systems and mission adaptive wings; the Air Force/NASA Highly Maneuverable Aircraft Technology demonstrator; and the Air Force/DARPA X-29A forward-swept wing experimental aircraft. All of these programs integrate various aspects of airframe, avionics, propulsion, flight control, fire control, and weapons technologies to help reduce the risk in the ATF, the most tightly integrated aircraft ever envisioned. The ATF will be the product of all that preceded it, and will possess all the attributes found singly in earlier advanced fighters.

INTRODUCTION

The search for an advanced fighter for the United States Air Force began with the XF-108 of the "Century Series" in the 1950s and the YF-12A supersonic interceptor of the early 1960s, and has continued ever since, most recently in efforts to develop the Advanced Tactical Fighter. This paper considers the evolution of fighter missions and procurement philosophies, and how they affected airframe, propulsion, armament, and avionics technologies. Some of the "advanced fighters" never flew at all; others never lived up to their initial promise. A few of them experienced radical shifts in requirements. But all of these fighters and their related technology programs made indelible marks on Air Force fighter procurement, aerodynamics, and on the doctrine of air warfare. It was fully twenty years between the F-86, the last true air superiority fighter (26:66; 82:28), and the F-15; another twenty years will likely elapse between the deployment of the the F-15 and the Advanced Tactical Fighter. It is important to understand how the Advanced Tactical Fighter benefited from the technology and procurement efforts that went before it.

Chapter One

FIRST EFFORTS TO SECURE AN ADVANCED FIGHTER

After the Korean War, the Tactical Air Command and the Air Defense Command seemed to get lost in a Defense Department "nuclear shuffle" that favored the Strategic Air Command. In the days of American nuclear superiority, the strategic bombing doctrine of Giulio Douhet could be vindicated by intercontinental bombers and eventually missiles carrying nuclear weapons. In the 1950s and 1960s, the Air Force was led by men still flushed with the success of World War II strategic bombing and the potential of nuclear bombs and missiles. In this doctrinal environment, the tactical air forces sought to "go nuclear" to survive. The F-102 and F-106 interceptors were equipped with nuclear missiles; they also became the first fighters procured without the usual dogfighter's tool, the gun. And the F-100 and F-105 fighters became fighter-bombers capable of dropping nuclear bombs. The dilemma that faced leaders of the tactical air forces was one that claimed penury in classic fighter missions, and another that demanded a niche in the nuclear world. The dilemma prompted a search first for an advanced tactical fighter that could fly at high supersonic speeds and shoot nuclear missiles; then to a search for one that could do all of the classic tactical fighter missions. The failure of these fighters to live up to expectations, an increasing threat from Soviet fighters, and the high costs of new air superiority fighters next drove the search for an advanced fighter to one that could do both air superiority and air-to-ground missions at low cost. The search continued and eventually came full circle, back to pure air superiority fighters.

XF-108

The MX1554 "Ultimate Interceptor, 1954" produced the Convair F-102 that fell far short of the planned speed, altitude, and range performance (95:159-165). It could only fly at 677 knots at 35,000 feet, with a maximum ceiling of 51,800 feet and a 566 nautical mile combat radius (95:173). While the F-102 and its follow-on F-106 served as "interim interceptors," the Air Force developed requirements for a long range interceptor. These long range interceptor requirements, first developed in April 1953, were rewritten in July 1955 and November 1956, after several attempts failed to get an acceptable proposal from competing airframe contractors (114:Ch 2). The Air Force sought an interceptor to counter the perceived 1960 bomber threats of Mach 2.0 speed at 61,000 feet, and the revised 1963 bomber threats of Mach 2.2 to 2.7 speed at 65,000 feet (118:7,32; 114:Ch 2). Design studies to satisfy these requirements began in 1953 at Air Research and Development Command and in industry with the MX1554 designed to achieve a Mach 4.5, 150,000 pound gross takeoff weight aircraft, but the aircraft appeared to be beyond the state of the art (118:7,Fig 24). So another round of design studies attempted to meet the 1955 LRI (long range interceptor) requirements. These studies called for an aircraft with a cruise speed of Mach 1.7 at 60,000 feet and combat speed of Mach 2.5 at 63,000 feet, with a gross takeoff weight of 98,500 pounds. But this aircraft would have had only marginal capability against the postulated 1963 bomber threat (118:7,Fig 24).

A subsequent design competition in 1955 between Lockheed, Northrop, and North American was little better than previous ones, but North American came closest to meeting the goals (114:23). North American Aviation's letter contract of 6 June 1956 called for a long range interceptor that could operate at 70,000 feet with a combat speed of at least Mach 3. The all-weather interceptor aircraft was to have two engines, two crewmen, and at least two internally carried nuclear or conventional air-to-air missiles (95:330-331). Their Weapon System 202 configuration sported a single vertical tail and large delta wing, and was adopted in 1958 after considering iterations with as many as three vertical tails and a large canard (118:7,Fig 24; 95:331).

In 1960, toward the end of the heyday of the "Century Series" fighter aircraft, Weapon System 202, renamed the XF-108 Rapier interceptor, promised to serve the Air Force with a Mach 3 cruise speed and 1,000 nautical mile range as a companion to the proposed B-70 supersonic bomber (106:44). The XF-108 design evolved to meet all of the expected Soviet bomber threats of the early 1960s.

It was to have been fabricated from stainless steel sheet, a welded sandwich and honeycomb, rather than aluminum to withstand the high temperatures and stresses of sustained supersonic flight. Its two General Electric J93-5 turbojet engines were to have used a special high energy synthetic fuel (ethyl borane) (7:14). It would also use the ASG-18 fire control system, and the GAR-9 missile. All these were under development simultaneously with the basic airframe. This combination of features allowed a totally new concept of long range interception of the supersonic bombers believed to be under development by the Soviet Union. The F-108, with its superior radar and high speed missile, was to patrol the DEW (Distant Early Warning) Line and make SAGE (Strategic Air Ground Environment) directed, semi-autonomous interceptions well before incoming bombers could launch their weapons against the major cities of Canada or the United States (118:7-8,Fig 25-26,Fig 28-30).

But intelligence sources eventually proved a serious Soviet bomber threat did not exist. That news reinforced growing concerns in the Department of Defense (DoD) over the cost and viability of manned aircraft. Offensive and defensive missiles now seemed to be the logical technological choice for the 1960s (7:14; 8:7). In August 1959 the Air Force canceled the chemical fuel development program (7:14), and on 23 September canceled F-108 development (94:402; 8:7). The Air Force announced that the program had no technical difficulties and had met all goals at the time of cancellation, but that there was a shortage of funds and programming priorities had changed (57:63). Both the fire control system and the missile developments continued at a lower level of funding. The cost estimate of five to eight billion dollars for a few squadrons of F-108s was more than could be accepted to replace the F-106, given the doubtful nature of the threat (7:14) and the unresolved fate of future manned aircraft.

With the cancellation of the F-108, there appeared temporarily to be a hiatus in supersonic interceptor work in the United States. Indeed, although the Air Force continued trying to gain support for new interceptors in general and the F-108 in particular, the DoD continued to oppose the requirement pending verification of a threat (9:3). On the West Coast, however, significant work was underway on a new supersonic aircraft at Lockheed's famous "Skunkworks".

A-11/YF-12A

On 29 February 1964 President Lyndon Johnson announced the existence of an aircraft capable of operating above 70,000 feet at a speed of 2,000 miles per hour (9:3). This aircraft, the A-11, had been under development since 1959, and the tail number (06934) in two sideview photographs indicated it had been built in fiscal year 1960 (100:98). The aircraft, powered by two Pratt & Whitney JT11D-20B turbojets with afterburners, provided 34,000 pounds of thrust each (100:98). The A-11 was made largely of titanium (157:344) to lighten the weight (the aircraft gross weight was estimated to be between 120,000 and 150,000 pounds (1:7; 37:36)), while maintaining structural stability under the extremely high temperatures (as high as 1050 degrees F) caused by aerodynamic heating at Mach 3+ speeds (82:377).

The President said the A-11 was being tested to find the plane's capabilities as a long-range interceptor, but that it would also prove invaluable in the development of supersonic transports (82:377). It is truly amazing the plane's existence could have remained secret for five years, and the tantalizingly small amount of information sparked a collection of very well done "scientific intelligence" articles by several trade and technical journals here and abroad (see, for example 82:377-379; 101:421-422; 37:33-37,50A-50B; 1:6-7,65) on the possible planform of the aircraft, its ultimate capabilities, and its mission. None of these articles put much stock in the notion of interception as the primary mission for the A-11 because of its lack of maneuverability at very high speed; most believed i' was a spy plane to replace the U-2. Not until the President later announced on 24 July 1964 the SR-71's existence (123:2), and the Air Force publicly demonstrated for the news media the YF-12A (the upgraded A-11) on 1 October 1964 at Edwards AFB (52:667), did the actual picture become any clearer.

Much heavier than the A-11, the approximately 170,000 pound (113:175) SR-71 reconnaissance aircraft (123:2) and the YF-12A fighter-interceptor were outgrowths of the experimental A-11 originally started in 1959. All three aircraft used the same engines, were made of 96% to 98% titanium (105:789), and featured essentially the same planform. The YF-12A used the same fire control system, the ASG-18, developed under the XF-108 program, and carried from two to six AIM-47A missiles derived from the GAR-9, also from the XF-108 (117:28; 39:36).

The YF-12A represented a complete break with earlier concepts for interceptors (107:13-17). No longer was maneuverability the important issue; speed and tremendous range were now key to the concept of intercepting supersonic or even subsonic bombers. With its long range, supersonic speed, and sophisticated avionics, the F-12A could streak out to the threat using either its own targeting information or that supplied by any other source, and knock it out with its high-speed, high-maneuverability missiles (20:10-12). The F-12A's 3,500 to 4,000 mile range, fire control and armament allowed it to cover the same territory as an estimated nine F-106s (178:46-47).

This 100 foot long "fighter" with a 50 foot wingspan weighed between 150,000 and 200,000 pounds (about the gross weight of a B-47!) and clearly differed from earlier machines (178:47). The sixty degree delta wing planform had trailing edge cutouts near the engine exhausts (93:16,21). The wing blended to the fuselage with fairings running up to the radome. The twin vertical tails canted inward and were mounted atop the wing-mounted engines, and both six foot diameter engine intakes had a moveable cone inside them. Outboard of the engine nacelles, there was also a distinctive downward camber and twist of the wingtips (93:21).

Development and test of the three YF-12s produced by Lockheed continued through the late 1960s amid continuing debate over the need for manned interceptors. The Air Force nevertheless put money in the Fiscal Year 1968 budget, and wrote a new Required Operational Capability for an F-12B that would cruise and fight at 70,000 feet, have an unrefueled combat radius of 1,350 nautical miles, a new fire control system capable of detecting small targets at 125 miles, and carry six missiles (90:236-242). The F-12B would also possess more maneuverability than the YF-12. But DoD remained unconvinced about the need for a new five billion dollar interceptor program, especially when a new multi-mission aircraft had become available to handle a potential supersonic bomber threat.

TACTICAL FIGHTER EXPERIMENTAL (TFX) AND F-111

This aircraft was the F-111, developed in the early 1960s. President Kennedy first announced a new tri-service fighter in his Military Budget Message to Congress for the 1962 Defense Budget (75:15). Defense Secretary Robert S. McNamara and Air Force Chief of Staff General Thomas D. White explained to Congress that the plane would have low speed maneuverability for close air support of ground and naval forces, operate from unimproved runways and aircraft carriers, and be able to fly supersonically from low levels up to more than 60,000 feet for penetrating heavy enemy defenses (75:15). Almost immediately service disagreement with Secretary McNamara's position erupted (116:15,36). In 1961 the Secretary directed a DoD Tactical Air Committee to resolve the differences between the services over the kind of common aircraft to be developed. This committee found a need for a close air support aircraft for the Army and Marines, and a different aircraft to meet the needs of the Navy for fleet defense and the Air Force for tactical interdiction (151:1694-1695).

Both the Navy and Air Force Secretaries appealed to the Secretary of Defense to put their requirements foremost. In a 7 June 1961 directive, Secretary McNamara put the Air Force in charge--with strong Navy participation--of developing the new aircraft, now called the Tactical Fighter Experimental or TFX (151:1694-1695). On 7 October 1961 requests for proposals with specifications for an Air Force version with a slightly smaller, but mostly common, Navy design were sent to six airframe manufacturers or teams (151:1695). The new aircraft would weigh between 50,000 and 70,000 pounds, reach 60,000 feet in altitude, fly at greater than Mach 2 over a radius of 500 nautical miles, and have a subsonic, unrefueled ferry range of 3,000 nautical miles. The Navy version had to fit on aircraft carrier elevators, and the Air Force version had to operate off 3,000 foot unimproved runways. Only Boeing and General Dynamics/Grumman had designs worth pursuing, and after intense competition and several reversals of the Air Force's preferred position, Secretary McNamara selected the General Dynamics/Grumman team to produce nearly 1,700 F-111s (151:1695-1697). Senator John L. McClellan investigated this decision for more than seven years, and was never satisfied with the probity of Secretary McNamara in either the original selection decision nor his subsequent management of the TFX/F-111 program (152:22; 110:565-566; 47:22-23; 58:9; 88:17-18; 174:39-44; 173:25-29).

Secretary McNamara's goal was to have 85% commonality of components between the Air Force and Navy versions, believing this would save more than one billion dollars (174:40). The basic structure, propulsion system, refrigeration package, secondary power system, crew escape module, and penetration aids were all common in the final F-111 design (45:534). Only the Navy's F-111B radome was shorter, the vertical tail somewhat lower, the nose wheel smaller, and the wingtips slightly longer than on the Air Force's F-111A to accommodate the special flight conditions on aircraft carriers (45:534).

The most distinctive feature of either version of the General Dynamics/Grumman F-111 fighter-bomber design was their use of variable geometry sweep wings, the first ever in a production aircraft to be reconfigurable in flight. This met the requirements for efficient slow and supersonic speeds in the same aircraft so it could maintain the required operational and ferry ranges. Until the F-111, aircraft were designed for single flight regimes and had wings optimized for that regime. If the plane flew outside its flight regime, the wing performance declined, usually with increased drag, but sometimes with complete loss of aerodynamic lift. The concept of variable sweep wings on high speed aircraft had been demonstrated in 1951 by the X-5 (10:80; 34:70) and the XF10F-1 in 1952 (34:70), but never in a production aircraft. After continual problems with the airplane's growing weight (from a proposed value of about 50,000 pounds to over 70,000 pounds (59:234)), the production F-111s were fitted with full-span wing slats having variable camber and full-span, double-slotted flaps to increase lift by 9% (45:535). These complex wings had a continuously variable sweep range from 16 degrees to 72.5 degrees (45:534), and were proven in the F-111's first variable-sweep flight on 6 January 1965, 24 days ahead of schedule (45:533-534).

The F-111's engines were as advanced as its wings. Its two Pratt & Whitney TF30 afterburning turbofan engines each produced 20,000 pounds of thrust. The afterburners were continuously variable between 20% and 100% of thrust, unlike the usual "on or off" afterburner of other jets (171:10; 52:167-168). There was a moveable spike in each air intake to automatically change inlet geometry and adjust the inlet shock wave pattern (171:10). This was the world's first afterburning turbofan engine, the first jet engine with an integral, aerodynamically adjusting nozzle, and it had the first gas turbine qualified for sea level supersonic operations (52:168). The engine was actually a single-point design optimized for supersonic operation at Mach 1.2 at sea level, and it caused problems matching the intake to the inlets over the flight envelope (170:48).

Although the F-111 suffered technical problems, cost growth, political battles, several fleet groundings, and production quantity decreases over its life, it was well-liked by the pilots who flew it, the maintenance men who kept it flying, and its planners, who had, after all, no other all-weather fighter-bomber to employ. From its first flight on December 1964, two years after contract award, it did prove itself as a potent weapon system that might be modified as an intermediate range strategic bomber, and also as a potential supersonic interceptor to compete with the F-12A (although its range would need great improvements to overcome its weight increases during production). This aircraft nevertheless departed from the established practice of designing the best aircraft for a specific mission, and it was arguably a failure at fulfilling its multi-mission promise. Designed by committee, it tried to be "Everyman's" fighter, and it was not up to the task.

The F-111 was to be produced in quantity for both the Navy and the Air Force straight from paper designs (in an effort to save money and acquire the aircraft as soon as possible), without going through prototyping. The F-111 was the first aircraft program managed on a daily basis by the civilian leadership in the Pentagon, rather than by the military organizations normally charged with developing and procuring aircraft. Given the personality of Defense Secretary McNamara and his strongly-held belief in the possibility of a common aircraft for the Navy and the Air Force, and their equally strongly-held belief it couldn't be done, perhaps the program could have proceeded no other way. Even so, the Navy dropped out of the program in 1968 when Congress canceled F-111B funds, even after their aircraft was flying in development tests (43:29; 46:28). Furthermore, the Air Force version that should have been able to perform several missions, became too expensive to buy in sufficient quantity for meaningful interdiction, too costly to risk in close air support, and never possessed enough cockpit visibility (42:11) and maneuverability for air-to-air combat.

Something had to change. For more than ten years the search for the elusive "advanced fighter" had proceeded without success. The F-111 fighter-bomber proved its earliest critics correct. So the Air Force stretched the service life of the F-106s to meet the suspected bomber threat. It used aging F-100s and F-105s for air and ground combat. And much to the chagrine of almost everyone in the Air Force, the Navy's F-4 was adopted and procured as the first line air superiority and ground attack fighter-bomber! Secretary of the Air Force Harold Brown declared in March 1966:

> ...we must build for the future a balanced fighter force. This should include a family of aircraft, each designed to do one mission extremely well--counter air, close support, interdiction, or reconnaissance--and one or more others creditably well. A most important member of this family should be a fighter which will defeat the best enemy aircraft in air-to-air combat (35:46).

He expressed the concern of many other senior service leaders in the 1960s about the inability of the U.S. to field advanced fighters capable of defeating the Soviet Union's Foxbat (22:4). His was the first major statement by the Air Force's leadership contrary to the DoD position on "commonality" since the earliest days of the TFX. But by 1965 it was obvious the Air Force needed a fighter to secure air superiority over the battlefield, and the

Air Force requested funds for an FX (Fighter Experimental) or the ZF-15A as it was eventually called (85:17; 63:21). The notion of multi-mission fighter aircraft was still alive and well in the DoD at that time, even considering the problems of reduced F-111 capability over expected results. For three more years the Air Force groped to find exactly what it wanted in a fighter (85:17) while the DoD environment softened toward single mission aircraft.

FIGHTER EXPERIMENTAL (FX): PRECURSOR TO THE F-15

Dr. Alain C. Enthoven, Assistant Secretary of Defense for Systems Analysis, still argued in 1968 that the F-111 would cost less than the FX, though its unit cost at that time was $12.9 million (85:16). He contended, moreover, that aircraft were needed only as missile launching platforms, and could therefore be low cost standoff machines (85:16-17). By now, however, the Air Force leadership sought to avoid at all costs the earlier mistakes of the F-111. The new family of fighters introduced by the Soviets at the 1967 Moscow Air Show reinforced the Air Force's decision to modernize its air combat fighter force (172:16) regardless of any residual pressure for multi-service or multi-mission commonality. Air Force Chief of Staff, General J. P. McConnell, testified at a Senate hearing that the sole purpose of the FX was to secure air superiority, and any attempts to expand that mission to include close ground support capability would occur "over my dead body" (85:17-18). During the three years of Concept Formulation from 1965 to 1968 all the disparate issues were debated and the background analyses performed; the consensus was the aircraft would be a single-point-designed air-superiority fighter (120:38).

The government and industry also investigated over 500 conceptual variations (26:66; 161:30-31; 54:30) to determine the qualities needed by the new advanced fighter. This new Air Force fighter would have a single seat, two engines (120:40; 84:590), radar and infrared missiles (108:10), and would reintroduce a gun for dogfighting (83:5; 54:30). (The F-111 also had a gun, but to this day it is rarely employed.) This information was issued on 30 September 1968 requesting proposals for Contract Definition from eight airframe manufacturers (120:38-39). Fairchild Hiller, McDonnell Douglas, and North American survived the first competition and produced outstanding proposals (119:43). McDonnell Douglas won the FX, now called F-15, development and production contract competition on 23 December 1969 (108:10; 172:16) after months of technical evaluation.

Although the F-15 was another "paper airplane" like the F-111, and drew the wrath of many who wanted to return to the days of purchasing only airplanes that had proved themselves as prototypes (47:22-23), it did feature concurrent, separate prototyping of key elements of the weapon system. Westinghouse Electric Corp. and Hughes Aircraft Co. won contracts on 5 November 1968 for competitive attack radar development programs, with a fly-off for production twenty months later (161:32). General Electric and Pratt & Whitney won competitive engine development contracts in

August 1968 awarded jointly by the Navy and Air Force for F-14B/F-15 fighters. At the end of the eighteen month contracts, one engine would be selected for production (161:30-31). Hughes and Pratt & Whitney were the respective winners. And, finally, Philco Ford won a contract to develop the GAU-7A 25 mm caseless ammunition gun (54:30; 83:5).

Reversion to an aircraft designed for a specific mission and the increased use of prototyping were only two of the significant changes in the F-15 program over the F-111 program. Total package procurement was now replaced (161:31-32) by an incremental contracting strategy with incentives (172:16) and milestones to be passed before the next increment took effect (11:21; 137:7-8). No one above the Air Force program manager overturned the source selection decisions, and most importantly, the Air Force program director became responsible for the daily program decisions with no interference from the DoD (172:16; 11:21). He reported directly to the Commander of Air Force Systems Command, the Chief of Staff, and the Secretary of the Air Force (119:41-43; 11:21; 137:8).

The F-15 program marked a reversal of Defense Secretary McNamara's policies and practices (172:16), and in large measure was a response to the F-111's shortcomings. The program to produce the first true air-superiority fighter since the F-86 (26:66; 161:28) more than twenty years before was in good shape and took the search for an advanced fighter into the 1970s.

Chapter Two

EFFORTS TO SECURE AN ADVANCED FIGHTER IN THE 1970s

For the Air Force, the 1960s passed with the introduction and production of only the F-111 as an advanced fighter. The F-4 and A-7 were also produced for Air Force use, but were not what could be truly called the "advanced" fighter that the service wanted. None of these fighters were true air superiority machines, but were used in several roles, or primarily in air-to-ground service. Neither the F-108 nor the F-12 were produced for interceptor or air superiority missions, and, indeed, neither was designed expressly for that role. With the FX studies and the F-15 development program the Air Force returned to a single-mission fighter designed specifically for air superiority, repudiated the multi-service, multi-mission "commonality" approach to aircraft design, and settled firmly on the mission requirements nobody could agree to in the early 1960s. In 1968 General William W. Momyer, the Commander of Tactical Air Command, declared the need of a new air superiority fighter to be obvious and urgent (175:31).

F-15

After analyzing air combat from the earliest days through the Vietnam war, and considering the Soviet stable of new fighters, the F-15 was designed for high maneuverability at supersonic speeds up to about Mach 2. Dogfight tactics dictated supersonic speed to arrive at the air battle. But once engaged, fighters almost invariably slowed to around Mach 1 in the midst of the "fur ball," where high maneuverability became the key to a kill. Thus the primary requirement for the F-15 was high maneuverability (26:66) with high, but not blinding, supersonic speed (38:39; 23:20). The new Energy Maneuverability theory of Colonel John Boyd and Thomas Christie (115:vii; 29:44-45) showed that to change a fighter's direction without losing speed required low wing loading (aircraft weight divided by wing area, in units of pounds per square foot or kilograms per square meter) and high thrust-to-weight ratio (22:4).

This new advanced fighter would not feature variable sweep wings (38:37) like the F-111, nor would it use the new supercritical wing technology (161:30). It used instead a fixed wing (161:30) with no extraneous high lift devices (such as leading edge slats) (60:814), but only electrically controlled plus or minus 30 degree trailing edge flaps (126:149; 68:365). Aeronautical Systems Division selected a simple, clean wing for the aircraft after analyzing 800 variations of over 100 wings (79:27; 68:365). (One of these wing variations was retrofitted to the F-4E to give it high maneuverability with leading edge slats (68:365).) The F-15's wing design was optimized for the highest efficiency low drag at high lift near Mach 1. It used conventional and conical camber to meet the requirement for efficient transonic flight (68:365).

With an aircraft operating weight of about 40,000 pounds (21:290), the F-15's 608 square foot wing (68:365) provided a low wing loading (called for by the Energy Maneuverability theory) of 54 to 56 pounds per square foot (133:38; 68:365). To keep weight down, the aircraft was designed with 26.7% titanium in the bottom surface of the wing (79:27) and in the aft fuselage skin, stringer, and firewall bulkhead; 35.5% aluminum in the top wing surface and the forward fuselage; and 37.8% composites (in the horizontal stabilators and vertical tails) and other materials (for example, boron skinned honeycomb) (68:365; 21:292). The airframe was of semimonocoque, skin stringer construction and was a multi-stiffened design with redundant load paths for survivability (68:365). This arrangement of materials assured high G tolerance and low weight (68:365; 21:292).

To ensure high maneuverability and high thrust-to-weight ratio, the F-15 used two fuselage-mounted 25,000 pound thrust Pratt & Whitney F100 engines, a smokeless engine specially developed for the F-15. It was an advanced turbofan afterburning engine with a variable geometry nozzle, a 13-stage compressor, and a 4-stage turbine using lightweight materials (103:22; 21:291). Each engine inlet had an automatic 3-stage variable ramp to optimize airflow to the engine at all angles of attack (126:148). Even at takeoff weight, the F-15 had a thrust-to-weight ratio greater than one to one, and at combat weight its thrust-to-weight ratio approached 1.4 to 1.0 (133:38). Never before had a U.S. fighter achieved this performance (12:54; 158:14). (See Appendix Table 1.)

This unique combination of airframe and engines made the F-15 accelerate and maneuver better than any fighter in history; as an index of maneuverability, it could sustain 5 G loads indefinitely (103:23)! At a gross weight of 37,400 pounds the airframe G limit was 7.33 Gs (86:7). These high G levels allowed exceptionally steep banks and tight turns, so that the F-15 could perform radical maneuvers without damage.

But could a pilot handle the Gs? Could a pilot perform aerial combat in such an environment? Instead of dealing with an occasional high G maneuver, F-15 pilots would work in an aircraft that produced a sustained high G environment (79:29). General Momyer noted the F-15 had more G potential than a pilot can physically take (54:30), and Major General Benjamin N. Bellis, the F-15 Program Director, was concerned that we may be reaching the physical limits for fighter pilots (103:23). The test program begun in 1972 proved, however, that the F-15's pressure regulated anti-G suit (86:5), augmented flight controls, and fully integrated avionics suite, allowed its pilots to outperform pilots of any other contemporary fighter aircraft.

The F-15 was indeed a fighter pilot's airplane. Its flight control system used hydraulic actuators with a new two-channel Control Augmentation System (CAS) to distribute pilot commands. The CAS sensed control surface responses and added or subtracted deflection to them to achieve the desired handling properties (126:148-149). The aircraft's fire control system was based on the Hughes AN/APG-63 pulse Doppler radar. This radar had a clean screen display in its look-down-shoot-down mode (69:192), and could detect and track multiple targets at long or short range. These unprecedented capabilities were the result of digital signal processing (69:192). Even though the F-108 and F-12A would have used the GAR-9 target search radar, the F-15 was the first fighter to emphasize both long range target acquisition/tracking radar and IFF (Identification Friend or Foe) (23:15). The weapon delivery system also used an inertial navigation system to keep track of target and airframe positions, and an IBM digital computer to control overall avionics integration and performance (69:192). All targeting and flight information was displayed on a Head-Up and Head-Down display (69:192). And with the automatic Armament Control System and a full suite of electronic countermeasures equipment, the F-15 was a potent one-man weapon system.

Compared with the F-111, the F-15 had surprisingly few problems and changes during its development phase. It eventually used an M61 20 mm gun because of problems developing the 25 mm caseless ammunition for the Philco gun (68:362). And the Pratt & Whitney F100 engine qualification test slipped eight months until October 1973 (61:6) when an engine exploded at 132 hours of a congressionally mandated 150 hour operational test (13:9). (The engine problem was traced to faulty turbine blades (14:20).) The engine also experienced difficulties with slow acceleration and afterburner relight at altitude (21:291). But all other F-15 problems were fairly minor.

After the Air Force approved the airframe in late 1970, a major design review showed a need to redesign the engine inlets and radome, move the horizontal surfaces and wing slightly aft of their original positions, and increase the fin area and height (21:291). During development test and evaluation 4.5 square feet of the trailing edge of the wingtips was shaved off, giving the wing a raked appearance (68:362; 69:194). The leading edge of the stabilator was also changed to a sawtooth configuration (69:194). These changes improved flutter performance and interference of airflow among the aircraft's surfaces, as did changing the shape and the area of the speed brake from 20 to 31.5 square feet (69:194; 68:365; 86:7). The speed brake change and a beefed up undercarriage and CAS also improved the aircraft's crosswind landing performance (69:194). The FX's exhaustive investigation of requirements and concepts, and the F-15's easily reprogrammed all-digital avionics and tough ground tests payed off in a relatively trouble free development and flight test program (51:1178).

The F-15 rolled out on 26 June 1972 (103:22), made its first flight 27 July 1972 (79:25; 21:289), and was flown supersonically for the first time on 3 August 1972 (79:26). In 1974 the F-15's avionics was demonstrated in a successful intercept of a high altitude Mach 3 SR-71 reconnaissance aircraft (69:190; 68:362). The plane also demonstrated Mach 2.55 flight, 103,000 feet altitude, 9.0 positive Gs and 3.0 negative Gs, 110 degrees angle of attack (more than vertical), 6.0 Gs at 50,000 feet and Mach 2.3 (68:362; 133:38), and slow speed performance of 15 knots at a 67 degree angle of attack (133:38). And, in Project Streak Eagle in the last two weeks of January 1975, the F-15 broke all eight time-to-climb records for altitudes from 3,000 to 30,000 meters formerly held by a Navy F-4 since 1962 and a MiG-25 Foxbat since 1973 (133:39; 24:1; 68:367). The F-15 also demonstrated outstanding performance against seven U.S. fighters and attack aircraft in Air Combat Maneuvering tests in 1975.

LIGHTWEIGHT FIGHTER PROTOTYPES (LWF)

Even before the F-15 rolled out, it was clear to senior DoD and Air Force officials in 1971 that work must begin on the next generation of advanced fighters (99:19) to avoid another 15 to 20 year hiatus in production. The F-15 also used relatively low risk state-of-the-art technologies, and had not opted for such high performance technologies as fly-by-wire and supercritical wings. With the alarming increase in the quantity and quality of Soviet prototype and production fighters, the next generation of advanced Air Force fighters would likely need a higher level of sophistication than the F-15 had. In this environment there were renewed calls to use industry's innovative talents and prototyping skills as in the days of the "Century Series", rather than the detailed government specifications for paper designs and production aircraft that characterized the F-15 procurement. Thus the stage was set in 1972 for a new DoD Advanced Prototype Development Program with streamlined procurement (99:19). Under this DoD program, the Lightweight Fighter (LWF) prototype project (there was also a project for an airlift prototype) planned to use advanced technology, high thrust-to-weight ratio engines like the one under development for the F-15/F-14 (99:19). Advanced aerodynamic concepts and designs were to be combined and optimized for extremely high maneuverability and controllability in the prototypes (99:19).

Thus, in early January 1972 the Air Force issued a 21 page request for proposal to nine companies, requesting a maximum 60 page proposal to be submitted in February 1972 for two prototype advanced fighters (99:19). Aeronautical Systems Division's Prototype Program Office awarded Lightweight Fighter prototype contracts to Northrop and General Dynamics in the spring of 1972 (163:62; 73:693). In contrast, the F-111 and the F-15 had had about 250 page requests for proposal and over 2000 page proposals (99:19), and they took the better part of a year for evaluation and contract award.

These companies were to produce two complete prototype aircraft each (73:693), a definite reverse in the paper studies solicited in the 1950s and 1960s (83:2; 121:37). The prototypes would be designed expressly for clear-weather, daytime, air-to-air fighting (83:5), they would use advanced technology to decrease procurement and operations costs, and would, like the F-15, be optimized for transonic acceleration and maneuverability (163:65; 166:52). The Air Force planned no production--only tests, and there was to be no competition between the Northrop YF-17 and the General Dynamics YF-16 during their independently scheduled 300 hour, 12 month flight tests (70:1315; 156:57).

YF-17

The Air Force YF-17 was Northrop's proposed Model P-600, based on upgrades to their Model P-530 originally designed in 1966 for export (73:693; 163:65). The YF-17 had a single seat and two General Electric YJ101 15,000 pound thrust afterburning twin-spool turbojets (71:538; 132:34) derived from the B-1 engine (70:1312; 163:65). This was the first self-cooled turbojet engine, and it had higher pressure levels than other turbojets for higher altitude operation (163:66). The aircraft's structure was largely conventional (70:1317), using 73% aluminum, 8% graphite advanced composites (180:31), 10% steel, 7% titanium (significantly less than the F-15), and 2% other materials (163:66).

The YF-17 had twin, outwardly canted vertical tails set well forward of its large horizontal tail (156:58). During development the hybrid wing planform set in the middle of the fuselage was modified from one with leading edge flaps to one with automatically controlled, double droop or variable camber twin trailing edge flaps (156:58; 70:1316) for high maneuverability.

The YF-17 also had long leading edge strakes extending far forward and covering the nostril engine inlets (156:58). This arrangement gave the aircraft inherent stability without using fly-by-wire or control configured vehicle technology (163:65). The aircraft used conventional controls (163:65) with a single-channel augmentation system to optimize air combat handling (156:59). The YF-17 carried a single 20 mm cannon and two wingtip-mounted AIM-9L missiles solely to demonstrate its stability as a weapons launching platform (156:58). Besides the minimal avionics required in a prototype, Northrop added (as did General Dynamics in their YF-16) a range only radar to aid gun aiming (121:40).

Just as the F-15 had a thrust-to-weight ratio greater than one, so did the YF-17 as fuel was burned off from the plane's 23,000 pound takeoff weight (more than 10,000 pounds less than the F-15) to its combat weight at its 500 nautical mile combat radius (180:30). Its 350 square foot wing surface gave it about 64 pounds per square foot wing loading (156:59), low enough to combine with its high thrust-to-weight ratio (about 1.3 to 1.0 at combat weight (132:35)) to get the significant combat maneuverability predicted by the Energy Maneuverability theory. At 55.5 feet long, 35 feet in span (180:30), and 14.5 feet high (17:21) the YF-17 was a small, hard to catch target. But just in case, it had an ejection seat capable of safe ejections inverted at only 200 feet of altitude (180:31). This seat was reclined at 18 degrees, rather than the normal 13 degrees in most fighters, to help the pilot cope with the high G environment of the YF-17 (180:31).

YF-16

The other participant in the Lightweight Fighter prototype program, the Air Force YF-16, was General Dynamics's proposed Model 401 (73:693). The YF-16 had a single seat and, unlike the twin-engine YF-17, one Pratt & Whitney F100 engine, the same 25,000 pound thrust turbofan used by the F-15 (70:1317). The YF-16's structure was conventional, with 80.6% aluminum alloy, 7.6% steel, 2.8% advanced composites, 1.5% titanium, and 7.5% other materials (153:300).

The aircraft used an aerodynamically blended wing-body (somewhat like the YF-12A) and a single tail (83:5; 166:51; 156:58). This configuration was chosen after parametric studies of both a simple, conventional wing-body shape and a blended wing-body shape, both analyzed with one and two vertical tails (74:39). The resultant design integrated the best features of both configurations (74:39-41). This blended wing-body gave the YF-16 a large internal fuel and equipment space (65:8) and body lift at high angles of attack (156:58; 6:1241). The wing was a clipped delta with both leading and trailing edge flaps, giving the wing variable camber (156:58). These flaps were automatically programmed for Mach number and angle of attack (65:8) for high manoeuverability.

The YF-16 also used highly-swept forebody strakes extending along the fuselage to get vortex lift and reduce the wing aspect ratio, while increasing stability at high angles of attack (179:156; 156:58; 144:6). To meet high maneuverability requirements, the large ventral engine inlet was designed for best operation at a single Mach number in the transonic region where most dogfights take place (74:40; 179:156). A variable-geometry inlet was ruled out as too heavy and expensive for the YF-16 (74:40; 65:8; 144:6). The YF-16 also employed fly-by-wire (65:8; 121:40) (the first U.S. fighter to be so designed without mechanical backup (144:6)) with four redundant channels, a side stick controller (121:40: 166:53), and control configured vehicle technologies (166:52; 156:58; 179:156). These technologies allowed the YF-16 to have a 10% negative static margin or instability at subsonic speeds (166:52). That instability made the aircraft exceptionally maneuverable in aerial combat (166:52-53), but also meant the pilot could not safely fly the aircraft without the fly-by-wire system. These technologies also allowed the flight controls to be optimized electronically (166:53), and they could be designed to override pilot inputs that might overstress the airframe (or himself) (6:1241-1242). The YF-16 carried the same armament as the YF-17, two AIM-9L missiles and an M61 gun (179:156), and had the same small amount of avionics.

At takeoff weight of 27,000 pounds, the YF-16 had a thrust-to-weight ratio of nearly one to one, and at combat radius of 500 nautical miles (156:57) its thrust-to-weight ratio was about 1.3 to 1.0, or about the same as the YF-17 (166:52). Its

280 square feet of wing surface gave the YF-16 about 64 pounds per square foot of wing loading at combat configuration, again comparable with the YF-17. The aircraft was 47 feet long, 30 feet in wingspan, and 16 feet high (179:156; 156:57), a bit smaller than the YF-17. Besides the side stick controller and arm rest, the 30 degree reclined ejection seat contributed to the pilot's comfort and ability to handle the 7 to 9 Gs for which the airframe was stressed (156:58).

AIR COMBAT FIGHTER (ACF) AND F-16

At its outset, there was to be no competition between the YF-16 and the YF-17 in the Lightweight Fighter program (156:57); there was also to be no production, only independent flight evaluations of promising prototype fighter technologies. But the F-15's F100 engine experienced significant "growing pains," and caused the overall F-15 program costs to soar by 1974. At the same time the Soviets began to upgrade their fighter forces with large numbers of high performance Foxbats. There was also concern in Congress and the DoD that the F-15 was too heavy and complex, and, hence, expensive, for the air superiority mission. Many believed the Air Force (and Navy) needed a so-called "high-low" mix of small and cheap fighters to augment the F-15 (and F-14) high cost, high performance fighter force structure.

Of course, there was strong opposition to the cheap fighter concept in some parts of Congress, and the Air Force did not want anything to interfere with the F-15 program. To complicate matters, the Europeans were looking for a replacement for their F-104 fleets (6:1240; 17:21; 109:18; 55:33), and the F-15 appeared to be "too [illegible] fighter" for their needs. No one doubted the F-15 could handle the all-weather air superiority mission, but at more than $20 million a copy there were insufficient funds available among European countries to procure them. Something like the Lightweight Fighter prototypes could accomplish the day, clear weather fighter missions at a price more people could afford. And since these would be complementary to, rather than competitive with the F-15, the Air Force finally endorsed the idea of the "high-low" fighter mix to get the large number of fighters they would need in the decade ahead. So, during the YF-16 and YF-17 flight tests the rules were changed, pitting the two prototype aircraft against each other for full scale development and production of the "Air Combat Fighter" (ACF) (144:5), the advanced fighter that would become the "low end" of the "high-low" fighter mix, and also a competitor in the European market.

The YF-16 rolled out on 13 December 1973 (65:8), experienced an unscheduled first flight during high speed taxi tests on 20 January 1974 (15:26; 121:40), and went supersonic on its third test flight on 5 February 1974 (121:40). The YF-17 rolled out on 4 April 1974 (71:538), and made its maiden flight on 9 June 1974 (132:34). When Defense Secretary James R. Schlesinger announced on 29 April 1974 that the Pentagon was seriously considering moving one of the Lightweight Fighter prototypes into full scale development and subsequent production of a low cost Air Combat Fighter (67:34: 55:33), the test schedule was accelerated and made competitive between the YF-16 that was already flying and the YF-17 that had only jus rolled out. To help with the competitive evaluation, Air Force test pilots flew both aircraft in the last months of the test program (67:35).

The Air Combat Fighter was to be a full-fledged member of the fighter force structure. It could not get by with the minimal radar and fire control system of the Lightweight Fighter prototype designed to demonstrate a collection of advanced airframe and flight performance technologies. So the Aeronautical Systems Division awarded contracts in November 1974 to Westinghouse and Hughes Aircraft Company for a competitive development and flyoff of radars that would rival the performance of the AN/APG-63 in the F-15 (164:58-59). Westinghouse won the final competition with a modern digital radar (168:44).

Even though the Air Combat Fighter was to be the "low end" of the "high-low" fighter force spectrum (98:1249), it was to have an explicit air-to-ground combat capability along with its air-to-air capability. (The F-15 had some air-to-ground potential by default, but not at the expense of any air-to-air capability.) The Air Combat Fighter also had the same requirement for high energy maneuverability of the Lightweight Fighter and the F-15, and fly-by-wire control was mandated for the Air Combat Fighter's flight controls (164:61).

The Air Force was well pleased with both Lightweight Fighter contractors and their aircraft (55:33), but the YF-16 had a slight edge in the flight competition (17:21) and in cost considerations. In the Lightweight Fighter program cost was, for the first time, made coequal with schedule and performance. The Air Combat Fighter program went a step further in controlling cost; now cost was the first among equals and the aircraft had a strict design-to-cost goal. With a planned buy of 650 aircraft for the Air Force (55:33; 18:5) and another 350 planned for coproduction with four NATO countries (104:47), any cost savings added up rapidly. Since the YF-16's F100 engine was common with the F-15 (176:1192; 74:39), and the development costs and risks were largely behind it, the new buy would spread costs over a much larger quantity of F100s and reduce costs for both the F-15 and the F-16. The common engine also had far reaching implications for reducing training, maintenance manpower, and spares costs over the life cycle of the F-16 (55:34). The efficacy of one versus two engines in a fighter was debated, but there appeared to be no overwhelming advantage for one configuration over the other. (In fact, a detailed study of the problem by Lieutenant Colonel Robert G. Dilger published in Spring 1975 said, "...if a literal interpretation is valid, combat data suggests the single engine aircraft has the advantage." (53:13-22).)

Secretary of the Air Force John L. McLucas announced in January 1975 that the F-16 had been selected as the new Air Combat Fighter (144:4-5; 104:44). The combination of high performance and low cost was exactly what the Air Force needed; it's exactly what the F-16 provided. To make the YF-16 into a first line fighter, it required additional combat avionics. It needed to have its wing area increased by 20 square feet to 300 square feet (144:8) to maintain low wing loading for high maneuverability. The YF-16 also needed its length increased by one foot to 48 feet to accommodate the added avionics and 400 gallons of additional fuel (for a total of 6,900 gallons) for improved combat radius (144:8). And its maximum gross weight needed to be increased by 5,000 pounds to 33,000 pounds MTOW to handle all the modifications (144:8).

The first developmental F-16 flew in December 1976, right on schedule (62:18; 127:16). Westinghouse's first radar was integrated into the third developmental F-16 in March 1977 (167:54; 64:164). The F-16 also had a full suite of electronic countermeasures and communications integrated into its well laid out cockpit (167:55). There were seven digital computers, all connected by a multiplex bus, to keep the F-16's Stores Management System, Head-Up display, radar control and display, fire control and navigation systems functioning together (130:4,6-7; 31:39). After completing operational test and evaluation successfully, the F-16 went into operational service with Tactical Air Command on 6 January 1979 (50:35).

Thus concluded one of the most productive decades in fighter aircraft history. The return to prototyping and single mission aircraft, a renewed emphasis on advanced technology to increase performance and reliability, and an increased emphasis on cost control and innovative contractual arrangements presaged great things for a successor to an advanced tactical fighter in the 1980s.

Chapter Three

EVOLUTION OF THE F-15 AND THE F-16

The decade of the 1970s saw the introduction in quantity of the F-15 designed especially for the air superiority role. Lower cost alternatives to the F-15 were vigorously investigated, too, because of growing needs in the United States and in Europe for more advanced fighters to counter increasing numbers of Warsaw Pact fighters and to modernize aging force structure. The 1970s also saw a return to the practice of prototyping fighter aircraft before committing to production. This environment drove the development of the F-16 as an advanced day fighter with powerful air-to-air combat capabilities, but also with acceptable air-to-ground weapon delivery modes. Fighter technology base development also proceeded at a rapid pace, and by 1980 there was a large amount of advanced technology available to upgrade existing F-15s and F-16s and to set the foundation for the search for the Advanced Tactical Fighter of the late 1980s and 1990s.

With so many parallel efforts underway, the story of the Air Force's search for an advanced fighter must temporarily depart from the simple chronological approach of single sequential events. The story will now cover the evolution of the F-15 and F-16 separately through 1982 when they competed for continued development. Then the story goes back to the mid-1970s to trace the important technology programs that ran in parallel with the evolving F-15 and F-16 fighters. The story continues then with the Advanced Tactical Fighter currently under development.

F-15 STRIKE EAGLE

At the end of the 1970s McDonnell Douglas, Hughes Aircraft, Sperry, Litton, and IBM put $50 million of their own funds into refurbishing an early two-seat F-15 to produce what they called the "Strike Eagle" (77:1188; 27:49; 162:57; 145:1068). This aircraft was built specifically because they felt the Air Force would need to augment the F-111 force structure for all-weather air-to-ground missions in Europe (77:1188; 27:48; 145:1068). The aircraft kept all of its old air-to-air armament and fire controls (145:1068; 131:34; 77:1189), but carried advanced avionics and a tremendous load of bombs. Although the Air Force had no written requirements for this kind of capability, there was "strong interest" in the Strike Eagle (145:1068; 77:1189). There were also some officers in Europe who were not at all happy about replacing their all-weather F-4 fighter-bombers with clear-weather F-16s (77:1189). This new aircraft certainly represented a radical departure from the "not a pound for air-to-ground" mentality that surrounded the development of the F-15.

The Strike Eagle flew for the first time on 8 July 1980, and was introduced to the public at the 1980 Farnborough International air show (145:1068; 77:1188). It used McDonnell's FAST (fuel and sensor, tactical) packs, large conformal tanks that fit the fuselage of the F-15 and carried their bomb loads snugly against the airframe to reduce drag (145:1068; 77:1188). The Strike Eagle could carry 22 MK 82 500 pound bombs on its MER (multiple ejection racks) which were rated for Mach 1.4 carriage (77:1189). It could carry a total of 24,000 pounds of combined air-to-air and air-to-ground weapons (145:1066) along with its 20 mm gun. Even with all of this ordnance, the Strike Eagle had a low wing loading of about 70 pounds per square foot (145:1068). This allowed the aircraft to retain much of its old manueverability, but made for a very rough ride at low altitude during air-to-ground operations (145:1068). (The F-111 and the Tornado both had wing loadings of about 120 pounds per square foot, which made them handle well at low altitude (145:1068).)

McDonnell Douglas believed that air-to-ground operations would require a two-man aircraft, so they put advanced controls and displays in the Strike Eagle's rear cockpit (77:1189). These controls and displays were linked to the upgraded AN/APG-63 radar which used a new programmable digital signal processor to provide high resolution synthetic aperture radar (SAR) modes for ground mapping, targeting, and navigation (145:1068; 77:1189). This signal processor had been added to all F-15s produced since May 1980 (145:1068), and it was the key to many enhancements like terrain-following/terrain-avoidance radar to be added later (145:1068; 77:1198). To prove the Strike Eagle could fill the as yet unstated need of the Air Force for all-weather air-to-ground missions in the F-15, McDonnell Douglas set up a two phase flight test of these new technologies and capabilities. The first phase was designed to demonstrate the weapons delivery potential of SAR techniques in the rough ride at low altitudes and high speeds, and the second phase, which began in the Spring of 1981, tested the integration of the SAR with other sensors and guided weapons (145:1068; 77:1189).

The Strike Eagle developers in industry lobbied heavily for Air Force funding to complete the flight tests of their all-weather fighter-bomber, but in June 1981, Lieutenant General Kelly Burke, the Air Force Deputy Chief of Staff for Research, Development, and Acquisition, stated, "We're not looking at the F-15 Strike Eagle, but we are looking with great interest at some air-to-ground enhancements to the F-15, less grand, less sophisticated, than the Strike Eagle" (36:61).

What the Air Force was looking at was the F-15E. The budgeted funds were to pay for research and development of the enhanced air-to-air and air-to-ground F-15 capabilities provided by a larger HUD (head-up display), a more powerful computer, more cooling for this computer, and better air-to-ground avionics and rewiring to support Maverick and AMRAAM (Advanced Medium Range Air-to-Air Missile) (160:118).

F-16XL SCAMP (SUPERSONIC CRUISE AND MANEUVERING PROTOTYPE)

Since 1976 General Dynamics had been working with NASA on a new highly swept "cranked arrow" wing for the F-16 (76:167; 160:118; 30:120-121). This advanced graphite composite wing (72:102; 76:168; 49:24; 28:53), with 70 and 50 degree leading edge sweeps (76:167), had more than twice the area (633 square feet) (72:102; 49:24; 28:53) of and 60% more overall lift than the original F-16 wing (76:167). Although the wing was originally considered for demonstrating supercruiser sustained supersonic speed performance for interception, by 1981 the wing was designed for conformal stowage of external stores for penetration missions (98:1248-1249). The final low drag wing, selected from more than 150 wing designs (150:74; 28:53), doubled the F-16's bomb load and gave the aircraft a 15,000 pound combined bomb and fuel load capability (160:118; 72:102). The new wing also made the F-16 more manueverable, and gave it a shorter takeoff and landing distance (160:118).

In early 1981 the Air Force gave two F-16 airframes to General Dynamics (28:53; 72:102) for modification with the cranked arrow wing and a fuselage stretched by 56 inches. The added length increased internal fuel load by 80%, and added 40 cubic feet for new avionics and sensors (33:102; 76:168; 49:24-25). The first airframe, a single-seat F-16A, was scheduled to fly in mid 1982, and the second, a two-seat F-16B, was scheduled to fly by the end of 1982 (72:102; 76:167; 33:102; 98:1248-1249). These aircraft were known as the F-16XL or "SCAMP", for Supersonic Cruise and Maneuvering Prototype, and eventually as the F-16E. According to Neil Anderson, General Dynamics's Director of International Flight Evaluation and Engineering, the purpose of the F-16XL program was to "blend the cranked arrow wing with the existing flight controls and avionics" and find what increased range and reduced drag benifits could be extracted from the new wing design (49:24).

In June 1981 the Air Force put $700 million in the Fiscal Year 1983-1987 POM (Program Objective Memorandum) for research and development of the F-16XL with the new General Electric F-101 (sic) Derivative Fighter Engine (160:118). (By the end of the summer, in August 1981, the latest version of the POM also carried $341 million for research and development of the F-15E (160:118), the "less grand, less sophisticated" single seat version of the F-15 Strike Eagle mentioned by General Burke.) At the roll out of the first F-16XL on 2 July 1982, Lieutenant General Lawrence Skantze, Commander of Aeronautical Systems Division, stated that until an Advanced Tactical Fighter is defined (to replace F-15s and F-16s), the Air Force would have to evolve its fighters into "high performers" (28:50).

The F-16XL flew for the first time on 3 July 1982 (28:53; 72:102), and, like the Strike Eagle F-15 before it, was clearly a step on the road to evolving the F-16 into a higher performing air-to-ground and air-to-air fighter. Although it had a lower thrust-to-weight ratio than the F-16, the F-16XL had much lower drag, so its excess thrust was higher (28:53; 76:168). The cranked arrow wing showed that vortex lift and extra span eliminated the high drag other delta wings experienced in maneuvering flight (150:748). And semi-conformal external stores carriage yielded up to 60% reduction in drag over conventional techniques (28:54-55; 49:25). This combination of excess thrust from the General Electric F-110 engine's 27,500 pounds of thrust (33:102) and the low aircraft drag gave the F-16XL a 9 G maneuvering envelope, more than twice as large as that of the original F-16 (76:168; 150:747). It could also pitch and roll faster than the F-16 (150:747). With a full load of ordnance the F-16XL could sustain 7.33 Gs, while the F-16A could only handle 5.5 Gs (150:747; 76:168). And the F-16XL could carry twice the payload 44% farther than the F-16 (28:52; 150:747).

The F-16XL's maximum takeoff weight was 48,000 pounds, compared with the F-16's 43,700 (72:102). At 34 feet 2 inches in span, it was slightly more than three feet wider than the F-16 (72:102). It was also 54 feet long, compared to the 48 foot long F-16 (72:102). And the F-16XL was 17 feet 7 inches high, while the F-16 was only 16 feet high (72:102). The F-16XL's thrust-to-weight ratio never exceeded 1.0 to 1.0 even at its combat weight of 43,000 pounds and using the higher thrust F-110 engine. This situation had been considered by the F-16XL's designer, Harry Hillaker of General Dynamics (150:748). He stated that high instantaneous airframe maneuverability in the early 1980s was not as important as it was in the late 1960s when it was sought in the F-16 (150:748). Improved gunsights and new missiles (150:748) now reduced the need for radical airframe maneuvering. So his design gave up some sustained maneuverability to gain the greatly expanded 9 G envelope and higher instantaneous maneuverability (150:748).

F15C/D AND F-16C/D MULTI-STAGED IMPROVEMENT PROGRAMS (MSIP)

The F-15 Strike Eagle and the F-16 SCAMP represented significant improvements over their progenitor F-15A/B and F-16A/B single- and two-seat models in the areas of weapons load and performance envelope. But these two new demonstrator aircraft depended upon planned Air Force upgrades of the F-15 and F-16 to become C (single-seat) and D (two-seat) models to achieve their full potential. Since their earliest introductions into the Air Force inventory, both the F-15 and the F-16 had had to leave out systems that would eventually be needed to counter future threats. But when funding and technology became available, it was the Air Force's plan to implement phased insertion through the late 1980s of the new systems, and to call these upgraded fighters C and D models. This was much like the programmed upgrades to the F-111 using the so-called Mark II Avionics Suite (98:1249). The programs of upgrades to the F-15 and F-16 production lines were called Multi-Staged Improvement Programs (MSIP) (76:166-167; 141:11), but the literature often calls the F-16 MSIP, "Mutli-National Staged Improvement Program" (97:258; 169:50; 49:22), because many of its changes affected the F-16s being supplied to NATO.

ıe F-15 MSIP was fairly modest when compared with that for the F-16. The F-15 MSIP included programmable armament control, improved memory for its central computer, improved radar hardware, and an expanded electronic warfare system (169:49; 48:49). It included increasing the F-15's internal fuel load by 2,000 pounds (76:166-167); the gross weight was also increased by 12,026 pounds to 68,144 pounds (76:166-167). The new Hughes developed programmable digital signal processor for the AN/APG-63 radar was added to increase the F-15's air-to-air combat capabilities (76:166-167) and provide growth for air-to-ground modes. Provisions were made for the conformal fuel tanks developed by McDonnell Douglas, but they were not initially procured under the program (76:166-167). The F-15 MSIP also included provisions for BRU-26A/A multi-station bomb racks certified for Mach 1.4 operation, and AMRAAM (AIM-120), AIM-7M monopulse radar Sparrow, and AIM-9M Sidewinder missiles (76:166-167). There were also provisions for communications improvements (possibly to include SEEK TALK and new High Frequency (HF) radios, and JTIDS (Joint Tactical Information Distribution System)), and electronic warfare improvements (possibly to include chaff and flare dispensers, internal countermeasures sets, and enhanced radar warning receivers) (76:166-167). The F-15 MSIP prepared the aircraft to accept the new systems in development, but not ready for immediate installation in the production F-15C/Ds.

Because the F-16 was designed to be the "low end" of the "high-low" mix of Air Force fighters with the F-15, it had very limited capabilities for beyond visual range attack, or for night and all-weather combat (98:1249). The F-16 MSIP would overcome these shortcomings and make the F-16 viable against emerging Soviet fighter threats, like the MiG-29 and Su-27. The F-16 MSIP embraced three phases in which the aircraft were first prepared for later incorporation of new systems (MSIP I); new systems were then added to improve air-to-air capabilities (MSIP II); and, finally, other new systems could be added to improve air-to-ground mission accomplishment (141:10-17).

The F-16 MSIP I started at the end of 1981 with the wiring of all F-16s after the 330th U.S. fighter (49:23-24) for later plug-in of an improved AN/APG-63 radar, beyond visual range missile systems, LANTIRN (Low-Altitude Navigation and Targeting Infrared for Night System) and HUD (Head-Up Display), radar altimeter, increased air conditioning, and an enlarged tailplane (98:1249; 76:166-167; 97:258). The F-16 MSIP II started in mid-1984 with the expanded "core avionics", including a new AN/APG-66 radar and radar altimeter (98:1249; 97:258). As of January 1986, F-16 MSIP III included a new inertial navigation system, AMRAAM, Infrared Maverick, a new HUD, a new gear box, the ALR-69 radar threat warning receiver, a new Identification, Friend or Foe (IFF) system, the Precision Location Strike System (PLSS), the Advanced Self-Protection Jammer (ASPJ), terminals and displays for the Global Positioning System (GPS), and the new General Electric F110 engine (48:43). The first F-16C/Ds came off the line in July 1984 (98:1249).

F-15E SELECTION OVER F-16E

With the F-15 Strike Eagle and the F-16XL SCAMP demonstrators available and the two Multi-Staged Improvement Programs starting to provide enhanced capability in the F-15C/D and the F-16C/D production runs, the Air Force undertook to develop Derivative Fighters of both fighter families, designated E models. The Air Force planned to put about 400 of these aircraft in the inventory starting in 1987 or 1988 (76:165; 136:90). The E models would be dual purpose air-to-air and air-to-ground (with the emphasis on air-to-ground) fighters taken from planned F-15C/D and/or F-16C/D production quantities. These new fighters would be the first step on the path to a totally new advanced tactical fighter for the 1990s (76:165).

In 1981 the Air Force decided to compare the F-15E and F-16E to learn which could best serve its needs (159:80) for the dual role mission. To upgrade the F-15 to an E model would require adding sensors, avionics, and stores management (76:166; 136:92), but the airframe would require little change (76:166). The F-16, on the other hand, would need the new cranked arrow wing demonstrated in the F-16XL, and, possibly, a new engine (76:166,168). Both would need provisions for carrying nuclear weapons (76:166; 136:91). For the evaluation, the two F-16XLs were redesignated F-16Es. Three F-15s were evaluated: an F-15C with conformal fuel tanks and weapon adapters; an F-15D with a

Ford Aerospace/Texas Instruments FLIR and laser tracker/marker; and the F-15B that had been modified as the Strike Eagle, now known as the F-15 AFCD (Advanced Fighter Capabilities Demonstrator), with synthetic aperture radar and a PAVE TACK FLIR/laser pod (76:166).

The F-15E was selected over the F-16E in February 1984, with full scale development starting in May 1984 (136:90; 30:120). McDonnell Douglas was to deliver in 1988 the first of 392 F-15Es (136:90; 48:45), which were included as modifications of some of the overall 1472 F-15C/D force structure (136:90). General Charles A. Gabriel, Chief of Staff of the Air Force, said when announcing the winner of the F-15E/F-16E competition, that the F-15E would augment the F-111 in the ground attack role (136:90). The F-15E was now known as the Dual Role Fighter, and had significant improvements for both air-to-ground and air-to-air combat. Its airframe was strengthened to handle 9 G maneuvers (48:49). It started using air superiority avionics from the F-15 MSIP beginning in 1985 (169:49; 136:92-93), and it will incorporate the AN/APG-63 radar, which will be upgraded to the Doppler beam sharpened/synthetic aperture AN/APG-70 radar (136:92-93; 169:49). It was also picked to use LANTIRN (136:96; 169:49) and AMRAAM before the F-16C (48:45), because of its more demanding dual role.

The F-15E's combat radius is planned to be about 700 nautical miles, fully loaded for both air-to-air and air-to-ground missions (136:91), with its gross weight increased from the F-15C's 68,000 pounds to 81,000 pounds (48:45). The aircraft's rear section will have to be redesigned to accommodate either the Pratt & Whitney F100-PW-220 or the one inch larger diameter General Electric F110 engine (48:45), which will maintain the high thrust-to-weight ratio required for both air-to-air and air-to-ground missions.

Once the F-15E was selected, the two F-16Es were put in "flyable storage" (48:40). The designation "F-16E" was also retired, and the F-16XL was picked to be the F-16F development and production model of the F-16 swing role interdiction fighter with air superiority backup capability (48:40). Lack of funds caused the Air Force to concentrate on the F-15E dual role, deep interdiction fighter, and the F-16F was set aside indefinitely (48:40).

Both the F-15 and the F-16 served admirably as advanced fighters from their first introduction into the fighter inventories of the U.S. and other nations (e.g., Japan, Isreal, and several NATO countries.) They continue to be improved by the addition of new systems. But even with a continuous stream of improvements, neither fighter will indefinitely be able to counter the ever-increasing capabilities of their opposite numbers in enemy inventories.

The Air Force undertook a number of technology base development programs concurrently with the production, deployment, and enhancement of the F-15 and F-16, so there would be adequate technology available to produce the advanced fighter of the 1990s. These technology programs are the next step in the search for the Advanced Tactical Fighter of the 1990s.

Chapter Four

MOST RECENT EFFORTS TO SECURE AN ADVANCED FIGHTER

The F-15 and F-16 advanced fighters provided the Air Force with potent aerial weapon systems to carry on into the 1990s. But even as those fighters were being introduced and modified, it was clear there would need to be technology development programs to lay the groundwork for the advanced fighters to follow them. The story of the search for the Advanced Tactical Fighter of the 1990s, the successor of the earlier advanced fighters, began with important technology programs that will eventually determine the newest fighter's characteristics.

ADVANCED FIGHTER TECHNOLOGY INTEGRATION (AFTI) AND RELATED PROGRAMS

The Air Force, Navy, and the National Aeronautics and Space Administration (NASA) started a long-term technology program in March 1974 (98:1249; 96:24; 122:4; 112:107) aimed at putting into one aircraft as many advanced aerospace technologies dealing with fighter performance as possible (16:32; 162:58). This Advanced Fighter Technology Integration (AFTI) program encouraged prototype development (16:32; 164:61; 176:1194) to demonstrate such technologies as direct side force and direct lift (165:54), air-slewing (fuselage aiming) (164:61), fore and aft canards, jet flaps, computer controlled fly-by-wire flight controls (16:32; 165:54), high thrust-to-weight ratio engines, high energy fuels, and advanced composites construction (164:61). Three contractors were selected to perform configuration studies (165:54; 16:32) for an aircraft incorporating some of these technologies. Rockwell's design focused on canards and composite material construction (165:55). McDonnell Douglas designed an aircraft with vectored thrust, a variable incidence wing, a movable chin canard, two moveable vertical stabilizers, and a two-dimensional nozzle (165:55). And Fairchild Republic's design featured a two-dimensional nozzle for vectored thrust (165:55). In support of the overall AFTI program (176:1194), NASA also initiated a remotely piloted vehicle program called "HiMAT", for Highly Maneuverable Aircraft Technology (165:58; 159:85).

The radio-controlled HiMAT vehicle was to pioneer highly unconventional flight controls and aerodynamics configurations (159:85), and demonstrate technologies integrated especially for a new generation of fighters (32:23; 96:23). In 1975 Rockwell won a design competition with Grumman (96:25), to build two 44% scale models of a 17,000 pound fighter (96:25). The HiMAT vehicle weighed 4,300 pounds, had a span of 15.2 feet, and a length of 21.1 feet (32:26). It was powered by a 5,000 pound thrust General Electric J85-21 engine (96:25), so its thrust-to-weight ratio exceeded 1.0 to 1.0 at takeoff. It was constructed of strong, lightweight composite materials to withstand 8 G maneuvers at subsonic speeds (96:25). Although the aircraft was point-designed for Mach 0.9 at 30,000 feet, it demonstrated (by 1980) Mach 1.2 speed and 6 Gs at 30,000 feet, and a top speed greater than Mach 1.5 (96:25). Its first flyable configuration had a forward canard, a single tail, and swept wings with upturned wingtips (159:85), but the modular HiMAT design allowed almost any advanced fighter technology to be accommodated (96:25).

While the HiMAT was under development, the first YF-16 prototype aircraft was modified under the Control Configured Vehicle (CCV) program of the Air Force Flight Dynamics Laboratory to explore fully the potential of CCV technology for direct lift and side force flight control (165:55; 32:23; 153:302). The main change to the airframe was the addition of two independently movable, inlet-mounted, eight square foot canards (153:302). Until the YF-16, with its quadruple-redundant fly-by-wire flight control system, aerodynamicists were constrained to use theory and wind tunnel simulations to test the possibilities of CCV technology (153:302). With CCV technology the center of gravity of the airframe could be varied in flight to cause the nose to pitch up or down without changing flight path (153:302). The addition of direct side force and direct lift, all under control of the fly-by-wire computers, allowed the fighter to make unbanked turns, move straight up, down, or sideways, or slew through the air with its nose pointing in any direction without changing flight path (153:302). All of these nonclassical flying modes made possible more lethal attacks (by keeping the gunsight on the target longer) and more survivable, unpredictable flight in combat

(153:302). From its first flight on 24 March 1976 through the next year, the CCV/YF-16 successfully demonstrated the new technology of "decoupled" (the flight controls do not act in a classical, coordinated fashion), or six-degrees of freedom, flight modes (153:302).

Based on the studies of 1974 and 1975, and the Control Configured Vehicle YF-16 flight tests at Edwards AFB, California, the AFTI program was divided into three "Technology Sets". The first Tech Set, AFTI-I, concentrated on fire and flight control technologies leading to improved air-to-air and air-to-ground combat capabilities (164:62). The second, AFTI-II, dealt with wing technology for multiple flight regimes, and, possibly, two-dimensional nozzles (165:58), rough field landing gear, STOL (short takeoff or landing) concepts, and low speed, high angle of attack controlled lift (162:59). And AFTI-III was planned to integrate the results of the first two Tech Sets into a potential new manned or remotely piloted experimental aircraft, or as modifications to existing fighters (165:54-58).

Under AFTI-I, the Flight Dynamics Laboratory contracted in December 1978 with McDonnell Douglas to modify an F-15 and General Dynamics to modify an F-16 for integrated fire and flight control technology test beds (165:54; 162:58; 96:26). The AFTI/F-15 used only existing control surfaces and a conservative approach to decoupling them to achieve airframe pointing (96:26). But the AFTI/F-16 used a higher risk approach to exploring full six-degrees of freedom flight and fire control, based on the technology demonstrated by the CCV/F-16 project (96:26).

Even with its limited application of control configured vehicle technology, the AFTI/F-15 was highly successful in adding to the advanced fighter technology base. By changing the control laws in its control augmentation system, adding an ATLIS-II electro-optical target tracker pod (78:169), and adding a special interface unit to tie the flight and fire control systems together, the AFTI/F-15 achieved a slight control surface decoupling (96:26; 78:169). The AFTI/F-15 automatically fine-tuned the fire control cues and decoupled flight control surfaces (i.e., made them work independently), then limited maneuvers to plus or minus 1 G during the final seconds of weapons delivery or gun firing (96:26). This arrangement allowed air-to-air gunnery, strafing, and bombing from unusual flight profiles (78:170). In August 1982 the AFTI/F-15 completely destroyed with a two second burst a maneuvering PQM-102 drone in a most difficult gun firing condition (78:169-170; 96:26). (The PQM-102 was flying at 420 knots, in a 4 G right turn into its attacker, while the AFTI/F-15 was in a 3.3 G right turn at 400 knots, for a 130 degree aspect attack at 1.7 kilometers (78:169).) The new integrated fire and flight control system also allowed a spiral strafing run, rather than the usual straight pass at the target. This promised to give greater survivability against linear-predictor anti-aircraft artillery (78:170). And in late 1982 the AFTI/F-15 accurately dropped bombs while performing 3.5 G maneuvers from ranges of 1200 to 5200 meters; it had the same accuracy as a normal F-15 in wings-level approaches (78:170).

The other major contractor for the AFTI-I Tech Set, General Dynamics, began in December 1978 (162:58) a much riskier integration of advanced fighter technologies in their AFTI/F-16 (96:26). This aircraft explored the full range of six-degree-of freedom nonclassical flying with tightly integrated fire control and weapons delivery (162:58; 96:26). The AFTI/F-16 used the same dual chin-canards as the CCV/F-16 (162:58; 78:171) to achieve direct side force and direct lift. It also had a long dorsal fairing to house additional avionics and test equipment (122:4). Since the radars in the AFTI/F-15 and AFTI/F-16 were not accurate target trackers, both aircraft augmented their fire control systems with high precision trackers (96:26). But the AFTI/F-16 used a FLIR (forward looking infrared) system, rather than an ATLIS-II tracker pod (96:26; 147:1198). The AFTI/F-16 also used a "two-failure-safe" triple-redundant digital flight control system instead of the quadruplex analog fly-by-wire system on standard F-16s (96:24; 2:91; 25:22). Now, for the first time, both fire and flight controls were put under the same digital computer control (96:26). This allowed rapid control law changes and integrated fire and flight control optimization through software modifications. Even the AFTI/F-15 could not boast this kind of capability, because it still used an analog Control Augmentation System.

The AFTI/F-16 also employed a number of innovative man-machine interface technologies to ease pilot workload in its wildly maneuverable weapons delivery and gun firing environment. It first used two (25:22) and later, three, multipurpose cockpit displays (149:688) for finger-tip selection and display of flight and weapon information of the pilot's own choosing. The AFTI/F-16 had voice controlled weapons designation, arming, and firing (2:88; 122:4; 25:23; 3:107; 41:40; 135:99-100; 149:688; 91:22-23). This feature significantly reduced the pilot's difficulty in putting ordnance on target while operating in a high G, high threat environment. And with its helmet mounted sight (149:689; 122:4; 2:88; 41:40) integrated into the fire and flight control system, the AFTI/F-16 gave its pilot an "evil eye" as lethal as his voice.

In AFTI-II, Boeing, General Dynamics, and Grumman studied mission adaptive wing (MAW) technology for a testbed F-111 (165:57). Aerodynamic theory showed that a symmetrical airfoil wing is best in supersonic flight, while a supercritical airfoil wing has the best performance transonically (about Mach 0.8 to Mach 1.2), and the ideal wing for low to medium-subsonic speeds has high camber (165:57; 162:59). The so-called AFTI/F-111 MAW changed its wing camber to suit its flight speed regime--takeoff, landing, supersonic cruise, or transonic maneuvering--by varying the shape of its smooth, flexible wing skin without using a large number of the usual high lift devices (165:57; 162:59). In other aircraft, for example the F-111 and the F-14, variable camber is provided by high lift devices such as leading edge slats and trailing edge maneuvering flaps. (Note that variable wing sweep is not at issue here, only the shape of the airfoil. In the AFTI/F-111 MAW the variable sweep wings did add another dimension to the wing optimization tests across a wide range of speeds.) The goal of the AFTI/F-111 MAW was to test the feasibility of smooth variable camber wings that could automatically optimize their camber for flight conditions (162:59; 78:170). The AFTI/F-111 MAW also sought to test active flight control, including relaxed static margin (the negative margin or instability that gave the F-16 its superior maneuverability), maneuver and load control, gust alleviation, and direct lift (96:25).

Boeing built the mission adaptive wing (147:1198; 96:25) for the AFTI/F-111. The wing had a single-segment leading-edge flap, a 3-segment trailing-edge flap, and a flexible composite material skin (147:1199). But it did not have conventional slats, flaps, spoilers, or ailerons (41:38-39). The standard F-111 has 32 movable trailing edge surfaces, but the AFTI/F-111 wing has only 12, with a similar ratio for the leading edge (96:25). That simplicity was not easy to achieve. The AFTI/F-111 MAW development program was hampered by technical difficulties and schedule slips, but the test program finally got underway in August 1983 (78:170; 96:25; 41:38). In AFTI/F-111 MAW's two-phased test program, the aircraft is scheduled to test manual control of variable wing camber (96:25) through May 1986, and automatic control through May 1987 (48:28).

At this writing there are no AFTI-III technology programs in existence; the earlier AFTI programs are still in full swing. But there is a new experimental aircraft, the first since the X-15 was retired in the 1960s, that embodies much of the newest AFTI technology, as well as the latest advances in aerodynamics and materials. This aircraft is the X-29A, and it promises to have an impact on the Advanced Tactical Fighter.

X-29A ADVANCED TECHNOLOGY DEMONSTRATOR

Although Rockwell won the HiMAT competition, Grumman's unsuccessful HiMAT studies sparked the genesis of the X-29A (129:52), the first manned experimental aircraft since the X-15 was retired in the 1960s (56:28-29). The objective of this DARPA (Defense Advanced Research Projects Agency) funded, Air Force Flight Dynamics Laboratory administered (19:23) technology program was to "develop, integrate, and flight-validate advanced aerodynamic technologies of a forward-swept wing aircraft for new design options for future military and commercial aircraft" (169:54; 48:55). Among the many technologies included in the X-29A were aero-elastically tailored forward-swept composite material covered wings (112:76,78; 147:1197; 138:34), discrete variable camber trailing edges (112:78; 147:1197; 129:56) (in contrast to the continuously variable camber of the AFTI/F-111 MAW), relaxed static stability (128:49; 129:52; 40:61), and digitally controlled 3-surface pitch control using close-coupled, full-authority forward canards (169:54; 48:55).

The forward-swept wing concept was not new. Its theory had been advanced in 1935 (129:52; 56:33). Sweeping a wing either forward or aft reduces shock as the aircraft approaches the speed of sound, but forward sweep produces less shock (56:28-29; 129:52). Forward-swept wings resist low speed stalling, whereas aft-swept wings tend to stall at the wingtips, causing loss of control (56:29; 128:48). Because low-speed stalling begins at the wing roots, forward sweep gives better slow speed control and resists spin (56:28-29; 128:48), since air flow over the wing and wing tips stays attached to the wing longer. But forward-swept wings are also subjected to massive distortions at high speed, called "structural divergence", that can tear the wing apart, unless it is very strong (128:48; 129:54). Until the X-29A all attempts at forward-swept wing aircraft were for slow speed applications, because stiff, high-strength wings could not be built.

The Germans successfully flew in 1944 a four-engine jet medium bomber, the Ju-287, which had 23 degrees of forward sweep (128:48; 56:30 (claims only 15 degrees of sweep); 112:76,78). The aircraft was designed for subsonic flight only, so it had no problem with wing twist leading to stalling or destruction (112:76,78; 128:48; 56:30). The Ju-287 and its partially completed companion were, incidentally, captured by the Russians (129:52). In the late 1940s the Swiss performed wind tunnel tests of 25- and, later, 13-degree forward-swept wing aircraft under their P-25 project (112:76,78). The West German HFB-320 Hansa corporate jet was built by the same team that developed the Ju-287, and it flew for the first time in March 1964 (56:30; 128:48; 112:76,78). Forty

HFB-320s were produced, but this forward-swept wing aircraft was not a commercial success (112:76,78). All of these historic forward-swept wing aircraft were subsonic, and did not experience the destructive forces of transonic and supersonic flight; these flight regimes had to wait until advances in aerodynamics, materials, structural design, and computer-based flight control systems came together in the 1970s (129:52).

In 1973, United States Air Force Colonel Norris Krone performed computer studies of forward-swept wings as part of his doctoral research (56:33). His studies showed the feasibility of building high-strength forward-swept wings using aero-elastic tailoring with carefully layed out composite material fabrics (56:33). These wings would be up to 30% lighter than metal wings, yielding a 20% lighter fighter (56:31). By 1976 Grumman started the X-29A as a design concept using these new composite wings (129:52). The X-29A flight demonstration program started in January 1981 (19:23; 28:32), and DARPA funding for two aircraft began in December 1981 (19:23). The X-29A would be the first manned forward-swept wing aircraft to explore supersonic flight (112:76).

Grumman kept the X-29A's cost down by using the forward fuselage and cockpit from an F-5 (147:1198), the landing gear of an F-16 (147:1198), and the 16,000 pound thrust General Electric 404 augmented turbofan engine from an F-18 (56:31; 129:54; 12:76,78; 128:47). The dual inlets were in the wing roots of its forward canard (112:76). This large, stubby canard contained 20%

of the wing area (19:23; 129:57; 128:49). The X-29A used the first thin supercritical forward-swept wing, made possible by the new technology of aero-elastic tailoring with composite materials (112:76,78; 138:34; 128:49; 129:56). Aero-elastic tailoring meant that sheets of graphite composite material were layed out in stacks in various computer-determined directions, then bonded with epoxy to minimize twisting and bending moments which destroyed older wings at the onset of structural divergence (147:1197; 112:76,78). Its large-area strakes ran from aft of the wing roots to the rear of the fuselage (112:76), terminating in independently controlled 30-inch maneuvering flaps alongside the nozzle (129:57).

The single-seat (19:23), single-engine (112:76,78) X-29A had a gross weight of 16,200 pounds (129:55), giving it a thrust-to-weight ratio of about 1.0 to 1.0 at takeoff. Although the X-29A's slow speed stall and drag characteristics were superior, its forward-swept wing made the airplane highly unstable in almost all flight regimes. With 35% subsonic instability, the X-29A was absolutely the most unstable aircraft ever built (128:49; 129:52-53; 56:31; 40:61). Notwithstanding the high degree of instability, the low-drag forward-swept wings and high thrust-to-weight ratio promised unprecedented maneuverability from subsonic through supersonic speeds, but only if it could be controlled through novel three-surface flight controls with digital fly-by-wire computers (66:39; 129:57; 147:1198). The aircraft used a triply redundant (two digital and one backup analog) fly-by-wire system (129:57; 40:61) that updated the control surfaces 40 times a second (40:61). No human could fly the X-29A without help from this flight control system (56:31). The canards were the primary control surfaces, providing direct lift and trim (40:61), but they worked in tight conjunction with the automatic aluminum trailing-edge flaps of the forward-swept wing and the strake flaps for maneuver under computer control (129:57; 128:50; 138:34; 66:39; 40:61).

The X-29A rolled out in August 1984 and flew for the first time in December 1984 (56:32; 44:32,41). The aircraft was small at 27 feet in span, 48 feet in length, and 14 feet in height (112:76,78; 128:50; 129:55), making it an ideal fighter technology testbed aircraft. The combination of selected technologies promised a smaller, lighter, more fuel efficient, and highly maneuverable fighter (129:52), but it is an experimental aircraft with no plans for production (56:30-31). As it continues flight testing at Edwards AFB California (5:18), the X-29A is amassing data that, combined with those from the AFTI and HiMAT programs, could obviate the need for a prototype of the Advanced Tactical Fighter (147:1197).

ATF (ADVANCED TACTICAL FIGHTER)

It is to the Air Force's credit that its organizations continue to investigate the requirements, concepts, technologies, and possibilities for the future, even as certain development and production programs start or stop in concert with the prevailing political environment. Had the Air Force succumbed to the belief that the F-15 would satisfy its needs for the foreseeable future, the Advanced Tactical Fighter (ATF) might be farther behind in development than it already is. Lieutenant General Thomas H. McMullen, Commander of Aeronautical Systems Division, said in 1985 that the F-15 appeared 14 years after the F-4, but the ATF was only a concept and already more than 18 years behind the F-15 (92:19). Furthermore, he contended, the leap from the P-51 to the F-86 was smaller than that from the F-4 to the F-15, and the leap from the F-15 to the ATF would be greater still (41:36). He also observed that the Soviets had added three new fighter types since the introduction of the F-16 in 1979 (92:19). The Air Force had to plan for the ATF to replace the F-15.

Efforts had been underway to define the ATF since the very earliest days of the F-15 and F-16 development and production programs. While the F-15 program was in full swing, the Tactical Air Command conducted the "TAC-85" study in 1969 and 1970 (89:3-5) to learn what the Air Force would need in advanced air-to-air and air-to-ground fighters for 1985 and beyond. The first ATF concept of operations also was developed by Tactical Air Command in 1971, and subsequently revised in 1972, after Aeronautical Systems Division produced preliminary and point design studies for an advanced fighter (89:4). The Tactical Air Command then produced an ATF Required Operational Capability in 1973-1974, and another in 1975-1976 (89:4).

The Flight Dynamics Laboratory started a series of future fighter technology studies and plans in 1975 while the F-16 program was underway; these studies finished in 1981 with the "1995 Fighter Study" (89:4). Aeronautical Systems Division subsequently conducted the "Offensive Air Support Mission Analysis" in 1976 and 1977. And in 1980-1981, the division conducted three mission area analyses which had significant impact on the ATF program (89:4). These three analyses were the "Advanced Tactical Attack System Mission Analysis" (ATASMA), the "Advanced Counterair Engagement Mission Analysis" (ACEMA), and the "Advanced Tactical Fighter Mission Analysis" (ATFMA) (89:5). The first of these mission analyses, ATASMA, studied manned fighter air-to-ground problems of the 1990s (89:5). The second, ACEMA, examined eight aircraft concepts to meet air-to-air needs in North America, Europe, and Southeast Asia in the 1990s (89:5). As these two analyses neared completion in 1981, the third analysis, ATFMA, was initiated to integrate them and examine multirole considerations for advanced fighters (89:5).

This third conceptual study suffered from lack of funding, but industry was very interested in helping--at no cost to the government--to further define the ATF's requirements (89:5-6). So the Air Force issued a Request For Information (RFI) to seven major airframe manufacturers in May 1981 asking for their insights into the requirements of an advanced air superiority fighter for the 1990s (87:53; 148:174; 89:6). At a kickoff meeting in June 1981, the Air Force supplied these airframe contractors and five propulsion contractors with technical briefings and an extensive technical data base outlining the Air Force's studies to date (89:6). The contractors responded in August 1982 with their system performance descriptions, effectiveness data, technology availability assessments, basing options, and cost data (89:8; 148:174) for air-to-air, air-to-ground, and multirole configurations (89:6). The government used its original studies as modified by the contractors' inputs during the Request For Information phase to focus its requirements for the ATF's continued evolution in the Concept Exploration phase (89:6).

When the ATF Mission Element Need Statement (MENS) was approved by the Defense Resources Board in November 1981 (125:2), the program passed its first hurdle on its way to becoming a major system program. Following MENS approval, the ATF program entered formal Concept Exploration. In this phase of the ATF program, the Air Force sought an aircraft that combined supersonic cruise with high-speed, high-altitude maneuvering, short takeoff and landing (STOL) from 600 meter runways, 1000-1500 kilometer combat radius and 5,500-6,500 kilometer unrefueled ferry range, and all-weather attack and armament systems with low observability (stealth) (148:172). All of these features had been demonstrated (except for low observability) individually in earlier advanced fighters, but never had they been combined in one aircraft. The F-15C/D/Es and F-16C/Ds equipped with AMRAAMs were expected to handle the Soviet fighter threat through the early 1990s, but the ATF was supposed to match the sophisticated Soviet fighter capabilities anticipated in the middle 1990s (125:2; 148:172). Only the combination of features described above was believed to meet the requirements for an advanced fighter that would be operational into the next century.

Aeronautical Systems Division awarded seven Concept Exploration contracts on 2 September 1983 (87:53) to the airframe contractors--Boeing, General Dynamics, Grumman, Lockheed, McDonnell Douglas, Rockwell International, and Northrop--which had taken part in the RFI exercise (111:48; 41:35; 135:100; 125:3; 134:63; 48:38; 89:6). The Air Force also awarded developmental engine contracts in October 1983 to General Electric and Pratt & Whitney for the so-called Joint Advanced Fighter Engine (the Navy never funded their share of the program) to power the ATF (155:895-896). Finally, the Air Force initiated a number of avionics and armament technology and risk reduction programs to complement those described earlier.

As the next air superiority fighter to replace the F-15 (135:97; 92:16), the (most likely) single-seat, two-engine (41:41; 33:102) ATF would also have inherent air-to-ground capability (92:16), a trait by now understood as essential. (By 1986 even F-15Cs were destined to carry bombs as part of the F-15 MSIP, and the F-15E was designed specifically for air-to-ground missions; so much for single mission F-15 air superiority fighters!) It appeared the new aircraft would also have to have its avionics, airframe, and engines integrated to achieve low radar cross section (RCS) and low observables emissions and supersonic cruise capability (135:97,100). The ATF would probably also need new lifting-body superconformal, guided-submunitions (148:173) with lower drag than standard weapons mounted on the low drag racks designed for the F-16XL, F-15 Strike Eagle, and the F-15E. Colonel Albert C. Piccirillo, Advanced Tactical Fighter Program Director, described the task of the Concept Exploration contractors:

> What we're aiming for in the Advanced Tactical Fighter is to integrate the man and machine to an unprecedented extent, to where everything--pilot, airframe, engines, weapons, fire controls, flight controls, sensors--is interfaced and working as a total system (41:35).

Among the most important aspects of the ATF development program was the engine development program that ran in parallel with the Concept Exploration contracts. The Air Force instituted an Advanced Technology Engine Study to look at the requirements of durable supercruiser engines. The target was a gain of 25% to 40% in supersonic specific fuel consumption (fuel efficiency), adequate thrust-to-weight ratio engines for transonic maneuvering, and three to four times improvement in durability, with 25% to 60% reduction in parts count (148:174). The Air Force also wanted to avoid using fuel-guzzling, infrared-targetable afterburners in the ATF (except, perhaps, on takeoff) (41:36). This study led to the Joint Advanced Fighter Engine program.

In this engine program General Electric and Pratt & Whitney received identical fixed price contracts (in October 1983) lasting 50 months (155:895; 134:63; 4:6). In 1988 one of the engines is to be selected for full scale development, and neither engine would actually fly until integrated into the ATF airframe (155:895). General Electric's engine was advanced in its aerodynamic design, using variable cycle technology (155:895-896). It acts as a high bypass turbofan in subsonic flight, and passes more air through the turbine for sustained efficient supersonic flight (155:895-896). It uses composite materials in the non-rotating structures, and powder metallurgy turbine blades (155:896). Pratt & Whitney's PW5000 engine is more aerodynamically conventional than General Electric's engine (155:895-896). The PW5000 is a low bypass ratio augmented turbofan with advanceo materials for higher temperature operation (155:895-896). It employs single crystal turbine blades for high durability (155:896). Both engines could have 50% fewer parts than conventional engines, and both use full-authority digital controls (155:896). The Air Force plans to test both in realistic flight environments rather than using the arbitrary test cycles that got the service in so much trouble with the Congress in the F100 engine program (155:896).

The ATF Program Office also sponsored two risk reduction programs starting in 1984 to investigate a STOL Demonstrator and a survivable supersonic fighter that incorporate many of the ATF's needed capabilities (148:173). The first of these, the STOL

Demonstrator, will use an F-15 to examine some of the following technologies: advanced high-lift systems; integrated flight and propulsion controls; auto-landing guidance systems; 2-dimensional, afterburning, thrust vectored/reversing nozzles; and rough field landing gears (148:173). The survivable supersonic fighter, planned to start later, will explore reduced radar cross section techniques compatible with the STOL Demonstrator; aerodynamics/flight control for supersonic, high-altitude maneuvering; closed-loop environmental controls; and airframe/weapons integration (148:173).

An aircraft as highly integrated as the ATF will need not only the technology being demonstrated in the AFTI, X-29A, and the two planned ATF risk reduction programs, it will also require a specially integrated avionics architecture to tie everything together. This avionics architecture is to be provided by the Pave Pillar program. Pave Pillar integrates target acquisition and tracking, navigation and guidance, terrain-following and terrain-avoidance radar, weapons management and delivery, and electronic countermeasures using high-speed digital multiplex buses (41:39; 80:105), and perhaps fiber optics buses (80:104). The ATF will also use INEWS (Integrated Electronic Warfare System) and ICNIA (Integrated Communications, Navigation, and Identification Avionics), programs already underway at the Avionics Laboratory (80:104; 135:97-98).

Even before Concept Exploration identified the possible options to meet the broadly stated goals of the ATF program, it became clear that the aircraft would need to use digital fly-by-wire to handle thrust-induced trim changes and control configured vehicle technology (148:172; 80:104). The ATF will also require both internal (perhaps synthetic aperture radar and/or FLIR) and external sensors (for example, Precision Location Strike System and Joint STARS) for air-to-ground targets (148:173-174). It will use conventional air-to-air armament like the AMRAAM, AIM-9L, and a 30 mm gun (148:174; 135:99; 4:9; 134:63); there was nothing else in the Air Force budget available in time for the ATF's expected initial operational capability in 1995. And there could be no doubt the ATF will use the new VHSIC (Very High Speed Integrated Circuits) data and signal processors to perform the huge number of computations to keep such a sophisticated weapon system as the ATF flying and fighting through the turn of the century (41:36; 80:104).

The Air Force issued a Draft Request For Proposal for Demonstration and Validation on 16 October 1984, with a cutoff date for comments from the seven Concept Exploration contractors of 13 November 1984 (125:4-5). By that date the government had received 1,450 comments (125:4-5)! The Air Force's plan to select only two to four contractors for the three-year (80:103) second stage of ATF development (48:45; 135:101; 125:3; 134:63) was taken very seriously by the competitors. The Air Force planned to issue the final Request For Proposal in September 1985 (134:63), but it was modified to increase attention to low-observable characteristics, and the response date was extended past March

1986 (80:103). Full Scale Development using the design of only one contractor will probably slip past 1989 (80:103), jeopardizing the scheduled first flight in 1990 or 1991 (135:100-101; 125:3; 134:65).

It is too soon to tell what the contractors are considering for their ATF designs--the designs are proprietary and not available. What is available concerning the ATF Demonstration and Validation phase is contained in the latest version of the Request For Proposal. Colonel Piccirillo (134:63) defines the principal requirements as supersonic cruise at high altitude; high maneuverability at supersonic speeds; low-observable or stealth technology for increased survivability; advanced avionics for long-range detection and intercept; and STOL capability (2,000 foot runway operation). The ATF is expected to weigh about 50,000 pounds in its air-to-air configuration (the F-15C weighs 68,000 pounds in that configuration) (48:38; 134:63), and have two 30,000 pound thrust class engines (134:63).

CONCLUSION

The Air Force's search for an advanced fighter from the XF-108, which was never even produced in prototype form, to the ongoing development of the Advanced Tactical Fighter, currently in Concept Exploration, has proceeded in fits and starts. Tactical Air Command's early schizophrenia over nuclear-armed fighter-bombers vice gun-equipped air superiority fighters claimed 15 years from the search for advanced fighters. It was not until after the Vietnam era that the Air Force again pursued in earnest truly advanced air superiority aircraft. Since that time economics and the realities of modern high technology warfare--not a drive to find a home in the "nuclear world"--forced the search for advanced fighters in different directions.

In the early 1950s the advanced fighter was supposed to have supersonic dash speed to high altitude, where it would intercept penetrating bombers far away from the vulnerable cities of the United States. This class of advanced fighter would have used only missiles rather than guns to destroy the threat; the missiles maneuvered, but the aircraft did not.

By the early 1960s the advanced fighter search branched into two paths: one employing advanced material and aerodynamic styling to achieve extremely high speed and altitude performance; the other, developing proven variable-geometry swept wing technology to achieve multi-service, multi-mission fighter and bomber performance. The former approach is best exemplified by the A-11 and the YF-12A, the latter by the F-111. Although the

A-11 and the YF-12A demonstrated superior high speed and high altitude performance, they did not have the flexibility to do more than intercept bombers--at a time when the bomber threat was virtually non-existent. These two aircraft did give rise to the SR-71 reconnaissance plane, but otherwise they left the promise of supersonic cruise for fighters unfulfilled. The F-111, on the other hand, was driven by the very real threat emerging from other fighters during the Vietnam era. In this aircraft, cost and commonality between services' missions seemed to dominate the search for an advanced fighter that could fly low and slow for close air support, fly high and fast for fighter interception, and perform long-range interdiction of enemy ground targets from unprepared runways. Unfortunately, the F-111's performance was compromised so badly, and its cost rose so steeply, it never achieved its potential; it set back the search for an advanced fighter more than it helped. The "commonality" sought in the F-111 still dogs the search for an advanced fighter. (For an excellent discussion of commonality in fighters see "The Historical Evolution of Commonality in Fighter and Attack Airframe Development and Usage" by Dr. Richard Hallion, published by the Air Force Flight Test Center History Office in September 1985.)

After hitting these two dead ends in the 1960s, the search for an advanced fighter for the Air Force returned to the air superiority mission with the F-15. This fighter retreated from the high supersonic speeds thought so necessary in the 1950s and 1960s, and concentrated on the transonic region, where it excelled in maneuverability for the single mission of dogfighting with the newest Soviet fighters. The F-15 could fly supersonically, accelerate to combat altitude, and maneuver at rates never before achieved. It used low risk technologies, and is rated among the best fighters ever produced.

Cost, as always, drove the search to find a fighter that could complement the expensive F-15 in air superiority roles, while also delivering a modicum of air-to-ground capability. In the early 1970s, the Lightweight Fighter Prototypes, the YF-16 and the YF-17, combined the latest technologies to demonstrate their applicability to fighter missions. These two prototypes used advanced technologies which were either not available or too risky for the F-15, with the goal of keeping cost as low as possible for as much performance as possible. The F-16 evolved from the YF-16 and was the Air Force's next advanced fighter. It concentrated on a high maneuverability air superiority role in the same speed range as the F-15, but for a lower cost.

From the mid-1970s to today the search for an advanced fighter has concentrated on combining advanced technologies in new ways to achieve the next breakthrough in performance. Flight and fire controls have been integrated to allow unconventional, and survivable, flight profiles. New wing structures and planforms have been combined with advanced propulsion systems. Aircraft weights and wing loadings have gone through a remarkable evolution as airframe materials and propulsion systems have improved (see Appendix Tables 1 and 2). Cockpit environments have been enhanced to allow man to operate safely and comfortably in aircraft stressed for 5 to 12 Gs of continuous maneuvers. Digital electronics and integration of some avionics, fire control, sensors, weapons, flight controls, and propulsion controls have further increased capabilities of advanced fighters.

The Advanced Tactical Fighter of the 1990s will explore new aerodynamics regimes with the X-29A and the AFTI/F-111 MAW, the advanced fire, flight, and propulsion control technologies in the other AFTI programs, the avionics integration technologies of the PAVE PILLAR program, and the newest weapons and propulsion systems. This fighter will be the product of all that went before it, offering the supersonic cruise speed and high altitude performance of the earliest advanced fighters, but it will have endurance they could never achieve. It will feature greater maneuverability than the current F-15s and F-16s, and fly in unconventional ways demonstrated by the AFTI and X-29A demonstrators. Furthermore, it will take off and land in shorter distances than the best expected from the F-111. And its propulsion system will perform over a broader range of flight regimes, with higher efficiency and availability than any other fighter. Its weapons will be integrated with every other system, rather than added as an afterthought. The only Advanced Tactical Fighter capability not already demonstrated will be its low observability. This aircraft is clearly the next step in the Air Force's search for an advanced fighter.

REFERENCES

1. "A-11 Enigma." Flying Review (May 1964), pp. 6-7+.

2. "AFTI/F-16: Flying Testbed for Future Avionics." Defense Electronics (August 1982), pp. 88-91.

3. "Advanced Fighter Technology Integration." Signal (November 1983), p. 107.

4. "Advanced Tactical Fighter." Defence Update (1985), pp. 2-12.

5. "Advanced Tactical Fighter." Defence Science and Electronics (May 1985), pp. 14-16+.

6. "Air Combat Fighter Flight Evaluation Completed." Interavia (December 1974), pp. 1240-1242.

7. Air Force Times. 15 August 1959, p. 14.

8. Air Force Times. 3 October 1959, p. 7.

9. Air Force Times. 11 March 1964, p. 3.

10. Air Force Times. 24 June 1964, p. 30.

11. Air Force Times. 4 March 1970, p. 21.

12. Air Force Times. 19 July 1972, p. 54.

13. Air Force Times. 5 September 1973, p. 9.

14. Air Force Times. 10 October 1973, p. 20.

15. Air Force Times. 27 February 1974, p. 26.

16. Air Force Times. 17 April 1974, p. 32.

17. Air Force Times. 15 January 1975, p. 21.

18. Air Force Times. 29 January 1975, p. 5.

19. Air Force Times. 18 January 1982, p. 23.

20. "Air Force's Swift New Interceptor." United Aircraft Quarter Bee-Hive (Fall 1964), pp. 10-12.

21. Allward, Maurice. "F-15, America's Superior Eagle." Air Pictorial (August 1974), pp. 289-293.

22. Andrews, Walter. "Decision Imminent On FX Program." Armed Forces Journal (31 August 1967), pp. 4+.

23. -----. "F-15: Problems and Prospects." Armed Forces Journal (31 May 1969), pp. 15+.

24. "At Home and Away. (Records broken by the F-15)." Airman (April 1975), p. inside front cover.

25. "Automation of the Airplane? AFTI/F-16 Flights Showing the Way." Flying Safety (October 1983), pp. 22-23.

26. Bellis, Benjamin N., Brig Gen, USAF. "For Air Superiority The F-15." Ordnance (July-August 1970), pp. 64-67.

27. Berry, Clifton F., Jr. "Flying In the Enhanced Eagle." Air Force Magazine (May 1981), pp. 44-49.

28. -----. "Revolutionary Evolution of the F-16XL." Air Force Magazine (November 1983), pp. 50-55.

29. Blair, Ed. "The Fighter's Fighter." Airman (June 1969), pp. 42-45.

30. Boutacoff, David A. "Will This Be the Next F-16?" Defense Electronics (September 1984), pp. 120-121+.

31. Boyle, Dan. "F-16 The Multi-National, Multi-Role Aircraft." Interavia (January 1979) pp. 39-43.

32. Braybrook, Roy. "Fighters for the 1990s: Building on Today's Technology." Interavia (January 1978) pp. 23-27.

33. -----. "Tactical Combat Aircraft for the 1990s." Armada International (January-February 1984), pp. 92+.

34. -----. "Variable Sweep." Flying Review (September 1968), pp. 68-73.

35. Brown, Harold. "USAF's Foreseeable Future." Air Force/Space Digest (May 1966), pp. 43-46.

36. Burke, Kelly H., Lt Gen. "It's the Great Air Show of the World." Armed Forces Journal International (June 1981), pp. 57-62.

37. Butz, J. S., Jr. "A-11 Born in the Skonk Works (sic), Reared in Secret It Blazes New Heights in Aircraft Performance." Air Force Magazine (April 1964), pp. 33-37+.

38. -----. "There's No Substitute for Flight-Testing." Air Force Magazine (February 1969), pp. 36-43.

39. -----. "Aerospace Technology." Air Force/Space Digest International (January 1965), pp. 36-38.

40. Canan, James W. "Forward Sweep." Air Force Magazine (January 1985), pp. 60-61.

41. -----. "Toward the Totally Integrated Airplane." Air Force Magazine (January 1984), pp. 34-41.

42. Cannon, Howard. "The F-111- A Pilot's Report." Data (September 1968), pp. 10-12.

43. "Committee Scraps F-111B; Funds Substitute." Journal of the Armed Forces (6 April 1968), p. 29.

44. Cooper, Robert S. "X-Aircraft for World Leadership in Aeronautics." Aerospace America (February 1986), pp. 26-59.

45. Cosby, J. T. "New Aerial Fighter." Ordinance (March-April 1965), pp. 533-535.

46. Cossaboom, Bruce. "Committee Prods DoD On AMSA, F-12, Nuclear Submarines; Urges Speed-Up In Bomber Defense, Eliminates FDL Program." Armed Forces Journal (13 July 1968), pp. 28-29.

47. ----- and James D. Hessman. "McClellan On F-15, Congress, DoD Procurement." Armed Forces Journal (20 December 1969), pp. 22-23.

48. Coyne, James P. "Aerospace World News, Views and Comments." Air Force Magazine (January 1986), pp. 28-55.

49. Culkin, Dennis. "New Fight For The Fighting Falcon." Defense & Foreign Affairs (May 1983), pp. 20-21+.

50. Day, Bonner. "The F-16 Goes Operational." Air Force Magazine (January 1979), pp. 34-37.

51. Dennison, John M. "Making the McDonnell Douglas F-15 even better." Interavia (December 1978), pp. 1178-1180.

52. "Developing a Multi-mission Aircraft." Interavia (February 1966), pp. 166-169.

53. Dilger, Robert G., Lt Col. "One Hole or Two?" USAF Fighter Weapons Review (Spring 1975), pp. 13-22.

54. "Eagle." TAC Attack (September 1972), pp. 29-30.

55. "Everything Works: LWF (Light Weight Fighter) to ACF (Air Combat Fighter) to F-16." Government Executive (March 1975), pp. 33+.

56. "Experimental: As in X-29A." Airman (April 1985), pp. 28-33.

57. "F-108 Cancelled." Canadian Avionics (November 1959), p. 63.

58. "F-111 Hearings To Reopen." Armed Forces Journal (17 January 1970), p. 9.

59. "F-111A, YF-12A." Air Force/Space Digest (September 1967), p. 234.

60. "F-15 Eagle Starts Flight Trials." Interavia (August 1972), pp. 813-814.

61. "F-15 Scores 87% Kills in 202 Air Combat Maneuvering Engagements." Armed Forces Journal International (July 1975), p. 6.

62. "F-16 Development Aircraft First Flight." Armed Forces Journal International (January 1977), pp. 18-19.

63. "FX Named ZF-15A." Armed Forces Management (December 1968), p. 21.

64. "First Full-Scale Radar for F-16." Signal (May-June 1977), p. 164.

65. "First of a New Breed." Armed Forces Journal International (January 1974), pp. 8-10.

66. Friedman, Norman. "X-29A The First Of A New Breed?" Defense Science 2002 + (October 1984), pp. 36-40+.

67. Frisbee, John L. "YF-16 vs. YF-17 The Lightweight Fighter: Headed for Production?" Air Force Magazine (June 1974), pp. 34-35.

68. Furlong, R.D.M. "Operational Aspects of the F-15 Eagle." International Defense Review (March 1975), pp. 361-371.

69. Geddes, J. Philip. "High Performance and the F-15." Interavia (February 1975), pp. 190-195.

70. -----. "The Light-Weight High-Performance YF-17." Interavia (December 1973), pp. 1315-1318.

71. -----. "Northrop's YF-17 Makes Its Bow." Interavia (June 1974), pp. 538-539.

72. "General Dynamics F-16XL." Asian Defence Journal (October 1982), pp. 102-103.

73. "General Dynamics and Northrop To Build Lightweight Fighter Prototypes." Interavia (July 1972), p. 693.

74. "General Dynamics' YF-16: Design Considerations and Evolution." Interavia (January 1975), pp. 39-41.

75. "General White Reports Details On Proposed Tri-Service Fighter, Secretary Zuckert Reasserts Air Force Requirement For B-70." Army Navy Air Force Journal, Vol 98 (15 April 1961), p. 15.

76. Gilson, Charles. "Future Fighters for the US AirForce, Part I: Enhancing the Present Fleet." International Defense Review (February 1983), pp. 165-168.

77. -----. "Strike Eagle Proposed For Air-to-Ground Missions." International Defense Review (August 1980), pp. 1188-1189.

78. -----. "Part 2: Technology for the Next Generation." International Defense Review (February 1983), pp. 169-171.

79. Gulick, John F., Capt, USAF. "The Eagle Makes the Scene." Airman (October 1972), pp. 24-30.

80. Gumble, Bruce. "ATF Facing Cost/Capability Trade-offs." Defense Electronics (March 1986), pp. 102-109.

81. Gunston, Bill. An Illustrated Guide to Modern Fighters and Attack Aircraft. New York: Arco Publishing Company, 1980.

82. Gunston, W. T. "A-11 Some Thoughts On A 2,000 m.p.h. Aircraft." Flight (12 March 1964), pp. 377-379.

83. Hansen, Grant L. "Fly-Before-Buy Explained." AF Policy Letter for Commanders, Supplement No. 3 (March 1973), pp. 2-7.

84. Haugland, Vern. "New Fighter Aircraft." Ordnance (May-June 1969), pp. 590-593.

85. Hausch, John. "Our Tactical Air Forces Are In Trouble." Data (January 1969), pp. 16-19.

86. Hawks, George W., Jr. "Flying the F-15 Eagle." Aerospace Historian (March 1980), pp. 2-8.

87. Haystead, John. "Sleek, Swift, Superior A Look At Tomorrow's Advanced Tactical Fighter For the USAF." Journal of Electronic Defense (November 1983), pp. 53-54.

88. "Hill Continues F-111 Debate." Armed Forces Journal (25 April 1970), pp. 17-18.

89. "History of the ATF: Semiannual Report Jan-Jun 1982" (U). Fragmentary document provided by Advanced Tactical Fighter Program Office, ASD/TA Wright-Patterson AFB, Ohio. SECRET. Classified by ATF Security Classification Guide, June 1981. Declassify on OADR. "Unclassified information only used from this source."

90. History of the Air Defense Command. (U) January-June 1967. Colorado Springs, CO: HQ ADC/HO, 1967. SECRET-SECTIONS DECLASSIFIED. "Unclassified information only used from this source."

91. Hoey, Brian, Capt. "Flying Into the Future." Airman (July 1985), pp. 21-27.

92. -----. "Fighter of Tomorrow." Airman (August 1985), pp. 16-21.

93. "Johnson's Masterpiece the YF-12A." Flying Review International (January 1965). pp. 16+.

94. Kennedy, William V. "Future of the Fighter." Ordnance (January-February 1970), pp. 402-406.

95. Knaack, Marcelle Size. Encyclopedia of US Air Force Aircraft and Missile Systems, Volume 1. Washington, D.C.: Office of Air Force History, 1978.

96. Lambert, Mark. "Fighters for the 1990s." Interavia (January 1981), pp. 19-26.

97. -----. "F-16 Improvement Program Making the Digits Count." Interavia (March 1981), pp. 258-259.

98. -----. "F-16 Passing the 2,000 Mark." Interavia (December 1981), pp. 1248-1249.

99. "Lightweight Fighter Prototype RFPs Out." Armed Forces Journal (February 1972), p. 19.

100. "Lockhead A-11." Air Pictorial (April 1964), p. 98.

101. "Lockheed's A-11: a Mach 3.5 Surprise." Interavia (April 1964), pp. 421-422.

102. Loftin, Laurence K., Jr. Quest for Performance: The Evolution of Modern Aircraft. Washington, D.C.: National Aeronautics and Space Administration, 1985.

103. Loosbrock, John F. "F-15 Eagle--USAF's Top Priority Fighter." Air Force Magazine (August 1972), pp. 22-23.

104. Manning, Steve, Capt. "The Lightweight Classic." Airman (September 1975), pp. 43-47.

105. May, Daryl. "Five Hours At Edwards." Flight International (23 May 1968), pp. 788-790.

106. McCormack, James, Jr., Maj Gen, USAF (Ret). "How the Air Force Is Buying Its Newest Manned Weapons." Skyline (Fall 1958), pp. 44-47.

107. McDonald, Allen K., Col. "The YF-12A Interceptor Weapon System." Air University Review, Vol 16 (March-April 1965), pp. 13-17.

108. "McDonnell Douglas Takes F-15 Contract." Armed Forces Journal (3 January 1970), p. 10.

109. "McLucas: YF-16 Better & Cheaper." Armed Forces Journal International (February 1975), p. 18.

110. "McNamara on TFX." Flight International (18 April 1963), pp. 565-566.

111. Meyer, Deborah G. "Futuristic Multirole Aircraft Could Guard High Frontier." Armed Forces Journal International (September 1983), p. 48.

112. Muller, Felix. "X-29A- The Grumman Approach to Advanced Fighter Technology." Armada International (July-August 1983), pp. 76+.

113. Munson, Kenneth. US War Birds From World War I to Vietnam. Poole, Dorset: New Orchard Editions, 1985.

114. "NORAD's Quest for NIKE Zeus and a Long-Range Interceptor." (U). Ent AFB, CO: HQ NORAD/HO, 1962. SECRET-Declassified 31 December 1982. "Unclassified information only used from this source."

115. Neufeld, Jacob. "The F-15 Eagle: Origins and Development

1964-1972." (U). Pentagon, Washington, D.C.: HQ USAF/HO November 1974. SECRET "Unclassified information only used from this source."

116. "No Unanimity On Tri-Service Plane; Secretary of Defense says "Yes"; Others Have Their Doubts." Army Navy Air Force Journal, Vol 98 (3 June 1961), p. 1+.

117. "Official Fact Sheet On YF-12A." Journal of the Armed Forces (10 October 1964), p. 28.

118. Parsons, T. R. "B-70 and F-108 Perspectives on Supersonic Cruise." Proceedings of the Conference On the Operational Utility of Supersonic Cruise (U). Vol I Historical Review (U). Wright-Patterson AFB, OH: ASD/XR, May 1977. SECRET-Declassified "Unclassified information only used from this source."

119. Powell, Craig. "F-15: Can This Management Prototype Pass the "Real World" Test?" Armed Forces Management (November 1969), pp. 41-43.

120. -----. "The FX: Designed To Control the Skies." Armed Forces Management (November 1968), pp. 38-40.

121. -----. "Competitors or Companions?" Government Executive (April 1974), pp. 37-41.

122. Preble, Cecilia. "The AFTI/F-16: Not A Flight Of Fantasy." Flying Safety (March 1983), p. 4.

123. "President's Announcement On the SR-71." Air Force Policy Letters For Commanders, Vol 9 (August 1964), p. 2.

124. "Project Streak Eagle. (F-15 Eagle Has Shattered Eight World Class Time-to-Climb Records)." Electronic Warfare (March/April 1975), p. 39.

125. Rait, Steve. "Streamlining the Advanced Tactical Fighter." Program Manager (March-April 1985), pp. 2-5.

126. "Report On the F-15 Programme." Interavia (February 1973), pp. 148-149.

127. Rider, James G., Lt Col, USAF. "F-16 Pilot Report." Aerospace International (January-February 1977), pp. 12-24.

128. Rifkin, Lawrence D. "Sweeping Changes: The X-29 Advanced Technology Demonstrator." Defence Update, Vol 50 (1984), pp. 47-50.

129. Roemer, Robert L. "Report On the X-29." Defense Science 2002+ (June 1984), pp. 50-52+.

130. Rosserri, Paul, Capt. "F-16...., Just Fact." USAF Fighter Weapons Review (Fall 1978), pp. 3-8.

131. Russ, Robert D., Maj Gen, USAF. "Tactical Fighter Development We Have Debated Long Enough." Air Force Magazine (April 1981) pp. 31-35.

132. Schemmer, Benjamin F. "The Airplane Nobody Wanted." Armed Forces Journal International (October 1974), pp. 34-42.

133. -----. "The Eagle Is Not A Turkey or A Dove." Armed Forces Journal International (March 1975), pp. 38-40+.

134. Schultz, James B. "Advanced Technology to Blossom In Next-Generation Fighter." Defense Electronics (August 1985), pp. 62-69.

135. -----. "New Air Force Fighter to Employ Stealth Design and Advanced Electronics." Defense Electronics (April 1984), pp. 97-102.

136. -----. "Production Nears for F-15E Dual-Role Fighter." Defense Electronics (September 1984), pp. 90-96.

137. Seamans, Robert C., Jr. "Air Force Authorization Request, FY71. (Statement to Senate Armed Services Committee, March 10, 1970)." Air Force Policy Letter for Commanders (10 May 1970) pp. 4-8.

138. Seidenman, Paul, and David J. Spanovich. "The X-29A Experimental Aircraft." National Defense (July-August 1984), pp. 32-34.

139. Smith, Richard K. "The Intercontinental Airliner and the Essence of Airplane Performance, 1929-1939." Technology and Culture, Vol 24, Number 3 (July 1983), pp. 428-449.

140. -----. "The Weight Envelope: An Airplane's Fourth Dimension---Aviation's "Bottom Line"." Unpublished Manuscript.

141. Sromek, Mike, Maj. "The F-16 Evolution." USAF Fighter Weapons Review (Winter 1984), pp. 10-17.

142. "Standard Aircraft Characteristics, Fighter 1949-1956." (U). ARDC Chart Book, Vol 1. SECRET-Declassified. "Unclassified Information only used from this source."

143. "Standard Aircraft Characteristics, Fighter 1949-1956." (U).

ARDC Chart Book, Vol 2. SECRET-Declassified. "Unclassified Information only used from this source."

144. Stickell, Dean, Maj. "Twenty Thousand Pounds Of Fighter Performance." TAC Attack (August 1975), pp. 4-8.

145. "Strike Eagle The All-Weather Strike Version of the F-16.." Interavia (November 1980), pp. 1068-1069.

146. Swanborough, Frederick Gordon and Peter M. Bowers. United States Military Aircraft Since 1908. London: Putnam and Company Limited, 1971.

147. Sweetman, Bill. "Advanced Fighter Technology New Experimental Aircraft Starting To Fly." Interavia (November 1983), pp. 1197-1199.

148. -----. "Part 3: Advanced Tactical Fighter The Sape Of Things To Come." International Defence Review (February 1983), pp. 172-174.

149. -----. "Challenges For the One-Man Cockpit In the ATF." International Defense Review (May 1985), pp. 687-689.

150. -----. "F-16XL GD Hatches a New Falcon." Interavia (July 1983), pp. 747-748.

151. "TFX-The Story Behind America's Largest Aircraft Programme." Interavia (November 1963), pp. 1694-1697.

152. "TFX/F-111: The Continuing Probe." Armed Forces Journal (20 December 1969), p. 22.

153. Taylor, John W. (ed). Jane's All the World's Aircraft 1977-1978. New York: Franklin Watts Inc., 1978.

154. ----- and Frederick Swanborough. Military Aircraft of the World. New York: Scribner, 1979.

155. Turk, Paul. "Power for the ATF GE and P&W Prepare for Battle." Interavia (September 1984), pp. 895-896.

156. "US Lightweight Fighter Program." International Defense Review (January 1974), pp. 57-60.

157. "Us Military Aircraft." Flight International (5 March 1964), pp.344-345.

158. "USAF Gets Its First F-15." Armed Forces Journal International (December 1974), p. 14.

159. "USAF R&D: Meeting the Challenge." Military Technology

(July 1982), pp. 78-85.

160. "USAF to Fund F-16XL Development, Plus F-15E." Armed Forces Journal International (August 1981), p. 118.

161. Ulsamer, Edgar E. "The F-15: Tomorrow's Champion of the Dogfight Arena." Air Force/Space Digest (July 1969), pp. 28-34.

162. -----. "In Aeronautics Affordability Is King." Air Force Magazine (December 1980), pp. 55-61.

163. -----. "The Lightweight Fighter Halts the Cost Spiral." Air Force Magazine (October 1973), pp. 64-67.

164. -----. "New Ways To Fly and Fight." Air Force Magazine (September 1974), pp. 56-66.

165. -----. "On the Threshold of "Nonclassical" Combat Flying." Air Force Magazine (June 1977), pp. 54-58.

166. -----. "YF-16 On Time, On Track, On Budget." Air Force Magazine (January 1974), pp. 51-54.

167. Walsh, Bill. "Countdown On A New International Deterrent." Countermeasures (January 1977), pp. 28+.

168. "Westinghouse Starts Full-Scale Development of the F-16 Radar." NATO's Fifteen Nations (August-September 1976), pp. 43-48.

169. "What's Happining In Aeronautics At ASD." AirForce Magazine (January 1985) pp. 46-58.

170. "Will the F-11 Fighter-Bomber TFX Be Able To Live Down Its Trouble-Filled Past?" Armed Forces Management (September 1965), pp. 47-50.

171. "Wings That Sweep." Interceptor (April 1967), pp. 8-12.

172. Witze, Claude. "Airpower In the News Back on the Track." Air Force/Space Digest (February 1970), pp. 16-18.

173. -----. "Is the Stage Being Set For A Political Power Grab In the Petagon?" Air Force Magazine (May 1963), pp. 25-29.

174. -----. "Project Icarus and the F-111." Air Force Magazine (9 July 1970), pp. 39-44.

175. -----. "TAC: Facing a New Moment of Truth." Air Force Magazine (January 1969), pp. 27-31.

176. Wootton, Eric J. "Facets of the Future Fighter Spectrum - Part I." Interavia (December 1974), pp. 1192-1194.

177. "YF-12A Public Debut of a 2,000 m.p.h. Interceptor." Flight International (15 October 1964), pp. 667-669.

178. "YF-12A Nine Times Better." Air Force Magazine (November 1964), pp. 46-47.

179. "YF-16: General Dynamics' Lightweight Challenger Enters the Ring." Interavia (February 1974), p. 156.

180. "YF-17 Joins Lightweight Fighter Arena." Armed Forces Journal International (April 1974), pp. 30-31.

APPENDIX

FIGHTER	MAX THRUST (LBS)	MTOW (LBS)	COMBAT WT (LBS)	T/W RANGE AT MTOW & CMBT
P-38F *	2,650	18,000	--	0.15- --
P-40N-20 *	1,360	8,850	--	0.15- --
P-51D/K *	1,490	11,600	--	0.13- --
F-80C	5,400	16,856	12,330	0.32-0.44
F-84F	7,220	27,099	18,325	0.27-0.39
F-84G	5,600	23,042	15,288	0.24-0.37
F-86F	5,910	20,174	15,079	0.29-0.39
F-86H	8,920	23,842	19,185	0.37-0.46
F-89C	6,800	42,026	31,680	0.16-0.21
F-89D	7,200	46,610	36,179	0.15-0.20
F-94B	6,000	16,844	13,474	0.36-0.45
F-94C	8,750	22,643	15,946	0.39-0.55
F-100C	16,000	34,864	27,196	0.46-0.59
F-100D	16,000	35,792	28,040	0.45-0.57
F-101A	15,000	49,998	38,995	0.30-0.38
F-102A	14,800	28,583	23,989	0.52-0.62
F-104A	14,350	23,526	17,538	0.61-0.82
F-104G	15,600	29,083	--	-- --
F-105A	15,500	41,248	28,530	0.38-0.54
F-105B	26,000	40,000	--	0.65- --
F-105D	24,500	52,838	--	0.46- --
F-106A	24,000	34,510	--	0.70- --
F-4E	35,800	61,651	--	0.58- --
F-5E	10,000	20,486	--	0.49- --
F-111A	37,000	91,500	--	0.40- --
F-111D	41,780	98,850	--	-- --
F-14A	40,000	74,348	--	0.54- --
F-15A	47,808	40,000	37,400	1.20-1.28
F-15C	47,808	68,000	--	0.70- --
F-16A	23,830	34,500	--	0.69- --

* These propeller aircraft use brake horsepower rather than thrust, and power loading rather than thrust-to-weight ratio. The terms are anologous to those for jet aircraft.
"--" indicates data are not available.
MTOW is the maximum takeoff weight of the aircraft.
Combat Weight (COMBAT WT) is the weight of the aircraft at its combat radius, after burning fuel and/or dropping excess tanks.
T/W is the thrust-to-weight ratio, given here for the range of aircraft weights from MTOW to Combat Weight (CMBT).

Table 1. Aircraft Thrust-To-Weight Ratios (139:--; 140:--; 102:--; 142:--; 143:--; 146:--; 154:--; 81:--)

FIGHTER	MTOW (LBS)	EMPTY WT (LBS)	LOAD/ TARE	WG AREA (SQ FT)	WING LD AT MTOW
P-38F *	18,000	12,264	32:68	327.5	54.96
P-40N-20 *	8,850	6,000	32:68	236.0	37.50
P-51D/K *	11,600	7,125	39:61	133.0	87.22
F-80C	16,856	8,240	51:49	237.6	70.94
F-84F	27,099	13,420	50:50	324.7	83.46
F-84G	23,042	11,095	52:48	260.0	88.62
F-86F	20,174	11,064	45:55	287.9	70.07
F-86H	23,842	14,346	40:60	287.9	82.81
F-89C	42,026	23,645	44:56	606.0	69.35
F-89D	46,610	24,911	47:53	606.0	76.91
F-94B	16,844	10,064	40:60	234.8	71.74
F-94C	22,643	12,453	45:55	232.8	97.26
F-100C	34,864	19,146	45:55	385.2	90.51
F-100D	35,792	20,004	44:56	400.0	89.48
F-101A	49,998	24,970	50:50	368.0	135.86
F-102A	28,583	17,945	37:63	661.5	43.21
F-104A	23,526	11,269	52:48	191.0	123.17
F-104G	29,083	13,996	52:48	196.1	148.31
F-105A	41,248	18,501	55:45	385.0	107.14
F-105B	40,000	--	--	385.0	103.90
F-105D	52,838	26,855	49:51	385.0	137.24
F-106A	34,510	24,038	30:70	697.8	49.46
F-4E	61,651	29,535	52:48	530.0	116.32
F-5E	20,486	9,588	53:47	186.0	110.14
F-111A	91,500	--	--	525.0	174.29
F-111D	98,850	46,172	53:47	525.0	188.29
F-14A	74,348	39,930	46:54	565.0	131.59
F-15A	40,000	28,700	28:32	608.0	65.79
F-15C	68,000	28,000	59:41	608.0	111.84
F-16A	34,500	14,567	58:42	300.0	115.00

*These are propeller aircraft; the rest are jet aircraft.
"--" indicates data are not available.
MTOW is the maximum takeoff weight of the aircraft.
Empty Weight (EMPTY WT) for a fighter is the same as its Tare Weight, the weight of the fighter fully equipped for flight, but without the crew, fuel, and consumable munitions.
Disposable Load (LOAD) is the difference between the MTOW and the Tare weight of the fighter.
Wing Loading (WING LD) is the amount of the aircraft's weight carried by each square foot of wing area (WG AREA).

Table 2. Aircraft Load-To-Tare Ratios and Wing Loading (139:--; 140:--; 102:--; 142:--; 143:--; 146:--; 154:--; 81:--).