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This study determines the essential characteristics of an air superiority fighter. Its importance stems from the assumption that air superiority is paramount in any military operation and that fighter aircraft play a major role. Air superiority as well as roles, functions, and missions are defined in chapter one to develop an understanding of the operative terms and definitions used throughout the thesis. This thesis is an in-depth study of the historical characteristics of the air superiority fighter. A complete review of air superiority fighter evolution is divided into four distinct generations. The review includes example aircraft that highlight the consistent characteristics found in each generation. The thesis research and analysis chapters focus on three key areas of interest. They are: (1) aircraft design, (2) avionics and weapons, and (3) training. The key areas of interest are coupled with a discussion of cost considerations during analysis. Fiscal constraints are a major factor in design and employment limitations. The thesis concludes that there are three essential characteristics of an air superiority fighter: (1) the aircraft is designed for the air-to-air role, (2) the aircraft has the first launch opportunity, and (3) the aircraft is flown by singularly trained air-to-air pilots.

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AIR SUPERIORITY FIGHTER CHARACTERISTICS

A thesis presented to the Faculty of the U.S. Army Command and General Staff College in partial fulfillment of the requirements for the degree

MASTER OF MILITARY ART AND SCIENCE

by

JAMES S. BROWNE, Major, USAF
B.S., USAF Academy, Colorado Springs, Colorado, 1986
M.S., Columbia University, New York, New York, 1987

Fort Leavenworth, KS
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The opinions and conclusions expressed herein are those of the student author and do not necessarily represent the views of the U.S. Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

ABSTRACT

AIR SUPERIORITY FIGHTER CHARACTERISTICS by Major James S. Browne, USAF, 97 pages.

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Thanks to my wife, Alison. This may be the only paper I publish with an acknowledgments section and I've always wanted to write that.

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CHAPTER ONE

INTRODUCTION

Aircraft are perhaps the most technically sophisticated of all machines man has devised, and U.S. military fighters are the most complex of aircraft systems.[1] Combining this technical sophistication with a military objective of airspace dominance further compounds the complexity required in a modern day fighter.

Today, the United States Air Force is spending billions of dollars developing the Advanced Tactical Fighter (ATF). It has taken shape as the F-22 Raptor, an air superiority fighter and successor to the aging F-15C Eagle. The F-22 ushers in new technological advances. Dr. Paul G. Kaminski, Under Secretary of Defense for Acquisition and Technology states; "The F-22 is the first weapons system designed from the outset with its principal focus on exploiting the ongoing information revolution while simultaneously denying the enemy the ability to do the same. The F-22's low-observable characteristics, supersonic cruise speed, maneuverability and advanced avionics will guarantee its effectiveness in the air superiority role."[2] However, much controversy has risen over the cost of this new technologically advanced fighter. A dwindling defense budget is forcing huge spending cutbacks and each military service is likewise constrained by these reductions. Therefore, military developmental programs, like the F-22, are being scrutinized and greatly curtailed or cancelled. New designs, faced with an austere budget, must be effective and efficient. In other words, the military can only afford the essentials. This quandary formulates the basis for this thesis' research question.

Research Question

What are the essential characteristics of an air superiority fighter?

Secondary Questions

What are the consistent historical characteristics of air superiority fighters? What constitutes a successful air superiority fighter; the aircraft design, the avionics and weapons, or the pilot? How do cost considerations impact air superiority fighter characteristics?

Importance

The F-22 is a reality; however, shaping its niche in the U.S. Air Force inventory is not. Debates continue over the number of F-22s to produce, what capabilities it should have, and how it should be employed. The conclusions drawn from this thesis may help provide some insight for making the correct decision regarding the F-22 Raptor.

Background

At the opening of the Twentieth century, the roles and missions of military airpower were undefined. Lethargic balloons and dirigibles had limited capabilities and therefore, airpower had minimal tactical value to ground warfare. However, the advent of fixed wing aircraft in the early 1900s forced military thinkers to recognize that aviation provided the means to exploit a new dimension in warfare. In 1921, Giulio Douhet, an

Italian airpower advocate, published his book The Command of the Air. In it he stated; "Aeronautics opened up to men a new field of action, the field of the air. In doing so it created a new battlefield."[3]

This new battlefield has rapidly evolved throughout the century. Like a chess game, strategies developed into tactics and counter-tactics. Aircraft initially served as reconnaissance platforms, but were soon used to attack the enemy on and behind his own lines. To counter enemy air operations, friendly force protection was developed, such as, surface-to-air defenses and air-to-air fighter aircraft. Thus, the new battlefield not only supported ground warfare, but a battle was fought over who controls the air. This control of the air is called air superiority.

Fighter aircraft were called upon to secure the sky for aerial operations. The evolution of fighters suited to gaining and maintaining air superiority began as early as World War I. *Pursuit* aircraft debuted as the early *air superiority* fighters. They were small fabric covered airframes with piston engine-driven propellers and a machine gun. These pioneering designs were the predecessors of today's high tech, jet fighters.

U.S. air superiority fighter evolution fell behind other nations prior to World War II. Since then; however, the U.S. has developed a formidable line of air superiority fighters. Today, the underpinning demand for airspace dominance is embodied in the F-15C Eagle, the world's premier air superiority fighter. This ground-based, day/night all-weather single-role fighter replaced the multi-role F-4 Phantom II in the mid-70s. Since then, the Eagle has amassed an impressive combat record, credited with a 26:0 kill ratio during Operation DESERT STORM, amounting to over half of the air-to-air kills scored during the conflict.[4]

However, the Eagle is approaching twenty-five years of operational duty in the Air Force inventory. The 1997 United States Air Force Issues Book highlights that the F-15 fleet is experiencing several problems, two of which are avionics parts obsolescence and high average airframe age fleet wide.[5] According to Dr. Kaminski; "The air superiority fleet will reach an average age of twenty years around 2003."[6] Therefore, a replacement aircraft must be developed and fielded prior to the F-15's demise.

Fielding the next generation air superiority fighter will not be easy. Technology is a high price item, but inherent to aviation. Budget constraints and political pressures will tailor the next aircraft's design and capabilities. Therefore, choices must be made that balance performance, capabilities, and training with economics. Questions to be reconciled include:

1. What aircraft and avionics performance capabilities are required?

2. Is the organizing, training, and equipping of a single-role aircraft flying units necessary?

Operative Terms and Definitions

> How many a dispute could have been deflated into a single paragraph if the disputants had just dared to define their terms.[7]
>
> Aristotle

> The beginning of wisdom is calling things by their right names.[8]
>
> Confucius

In order to effectively answer the research question, it is important to establish an understanding of the key terminology and concepts. A common viewpoint will make reading the contents of this thesis more clear and meaningful. This section will expand on some key ideology concepts.

The phrase "air superiority fighter" may bring to mind visions of fighter aircraft intertwined in a towering dogfight high above the battlefield. That vision is accurate in some cases; however, the phrase "air superiority fighter" can be confusing when used in a doctrinal discussion. Often times the description fits but does not match the doctrinal definition or vice versa. Thus, there are two key concepts and definitions that must be understood; they are air superiority and defining an aircraft's role.

The concepts of air superiority and air supremacy are crucial to this thesis. According to Joint Publication 1-02; "Air superiority is that degree of dominance that permits friendly land, sea, and air forces to operate at a given time and place without prohibitive interference by the opposing force. Air supremacy is that degree of air superiority wherein opposing air and space forces are incapable of effective interference anywhere in a given theater of operations."[9] Simply stated, air superiority is a level of control, an end state for a given objective. The key difference between air superiority and supremacy is the capacity of the enemy forces to interfere with friendly operations. Air supremacy infers complete air superiority with an enemy incapable of conducting effective aerial operations, either airborne or with surface-to-air assets.

Air superiority is one of six U.S. Air Force *core competencies.* Core competencies are at the heart of the Air Force's strategic perspective and thereby at the heart of the Service's contribution to our nation's total military capabilities.[10] Therefore, the phrase "air superiority fighter" is a misnomer. Air superiority is a condition not an aircraft function. How an aircraft contributes in achieving air superiority is best described by its role, function or mission

It is worthwhile to discuss the interrelationship between role, function, and mission and how they impact air superiority or air supremacy. The terms have simple definitions. However, they are a hierarchy of terms; each lower echelon nests within the auspices of the higher echelon's guidance.

AFDD-1, the U.S. Air Force's Basic Doctrine Manual, describes sixteen "functions" encompassed by the Air Force's core competencies. The Air Force's basic functions are the broad, fundamental, and continuing activities of air and space power.[11] The function pertaining directly to air superiority is counterair. AFDD-1 states; "Counterair consists of operations to attain and maintain a desired degree of air superiority by the destruction or neutralization of enemy forces. Counterair's two elements—offensive counterair and defensive counterair—enable friendly use of otherwise contested airspace and disable the enemy's offensive air and missile capabilities to reduce the threat posed against friendly forces."[12] Offensive counterair (OCA) is often the most effective and efficient method for achieving the appropriate degree of air superiority. This function consists of operations to destroy, neutralize, disrupt, or limit enemy air and surface-to-air missile power as close to its source as possible and at a time and place of the friendly force's choosing.[13] Defensive counterair (DCA) is synonymous with air defense and consists of active and passive operations to defend friendly airspace and protect friendly forces, materiel, and infrastructure from enemy air and missile attack. It entails detection, identification, interception, and destruction of attacking enemy aircraft and armaments, and normally takes place over or close to friendly territory.[14] It is noteworthy to point out that, the counterair function encompasses attacks on airborne enemy assets as well as assets on the ground. Many different forms of friendly assets can carry out the counterair function via various mission types.

Missions are tasks. They are directive and have quantifiable objectives. According to Joint Publication 1-02:

> Mission: (DOD) 1. The task, together with the purpose, that clearly indicates the action to be taken and the reason therefore. 2. In common usage, especially when applied to lower military units, a duty assigned to an individual or unit; a task. 3. The dispatching of one or more aircraft to accomplish one particular task.[15]

On top of functions and missions lies an aircraft's role. Roles are broad and general while missions are more specific. Technically, AFDD-1 replaced the term *role* with *function*. However, for purposes of this thesis, *role* will still be used for two reasons. First, historically aircraft functions have been described as roles. Second, the term role will be used as a discriminator to describe an aircraft's medium of engagement. These will be defined as either air-to-air or air-to-ground operations. Air-to-air operations focus on the destruction of enemy airborne aircraft, while air-to-ground operations concentrate on enemy assets on the ground. Therefore, an aircraft's role is defined as either air-to-air or air-to-ground.

How functions, missions and roles tie together is best described with an example. Given a notional air tasking order to, *gain air superiority over a specified area prior to a strategic attack,* the following assets may be utilized accordingly. Table 1, on the following page, depicts each asset's function, role, and mission.

Table 1. Notional Air Superiority Tasking

ASSET	FUNCTION	ROLE	MISSION
F-15C	Counterair	Air-to-Air	Airborne Force Protection - Neutralize enemy airborne assets
F-16CJ	Counterair	Air-to-Ground	Suppression of Enemy Air Defenses (SEAD) - Neutralize enemy airborne assets
B-1B	Counterair	Air-to-Ground	Air Interdiction (AI) - Destroy enemy airfield

Note the commonality in function, the difference in roles, and the varied missions all aimed toward achieving air superiority. Clearly, each of the above aircraft could be called an air superiority aircraft to some extent in this illustration. Many aircraft are capable of achieving air superiority for a specific scenario. However, this thesis will focus on fighter aircraft only and an "air superiority fighter" must be able to achieve aerial dominance. In other words, an "air superiority fighter" is capable of conducting the air-to-air *role*. In order to conduct air-to-air operations, an aircraft must meet certain design, armament, avionics, and pilot training criteria.

Assumptions

The primary assumption for this thesis is the undeniable need for air superiority. Douhet wrote that; "Command of the air is a necessary and sufficient condition of victory."[16] Doctrinally, each service recognizes the value of air superiority. For example, according to the Army's Operations Manual FM 100-5; "Control of the air enables land forces to execute operations without interference from the enemy's air forces. Without this control, tactical flexibility is lessened."[17] The United States National Military Strategy emphasizes; "Air superiority is essential so we can move forces into theater and attack the enemy at will. Air control provides the joint force numerous operational and tactical advantages while facilitating land and naval maneuver."[18]

Historically, air superiority is paramount. In his book The Air Campaign, Colonel John A. Warden III, USAF, recounts; "Air superiority is a necessity. Since the German attack on Poland in 1939, no country has won a war in the face of an enemy air superiority, no major offensive has succeed against an opponent who controlled the air, and no defense as sustained itself against an enemy who had air superiority. Conversely, no state has lost a war while it maintained air superiority, and attainment of air superiority consistently has been the prelude to military victory."[19] This clearly illustrates the value of air superiority. During Operation DESERT STORM, such a high emphasis was placed on achieving air superiority, that coalition forces achieved total "air dominance." Former Secretary of Defense William J. Perry stated; "Desert Storm taught us something about air dominance. We had it, we liked it, and we're going to keep it."[20] Secretary of Defense, William S. Cohen iterates; "...we want to be able to continue to dominate the airspace wherever we are."[21] General Merrill McPeak, Chief of Staff of the U.S. Air Force during Desert Storm, reflects:

> The first doctrinal lesson of Desert Storm is well known to us all. At the high end of modern conventional conflict, no form of military power—land, sea or air—has been employed effectively without first controlling the skies. Because the coalition established air supremacy early, we were able to roam at will over Iraq, while at the same time our own ground forces operated underneath an air sanctuary. Obviously, this was a priceless advantage.[22]

It is safe to say that air superiority will be a priority during any U.S. combat operation. This thesis will assume, given current technology that fighter aircraft will conduct counterair missions to achieve air superiority. This helps to further focus the primary research question. There will be an air superiority fighter; however, should it be single-role or multi-role? Additionally, is it the aircraft, the avionics or the pilot that makes an effective air-to-air fighter capable of achieving air superiority?

Limitations

This thesis will answer the research question by focussing primarily on U.S. fighter aviation. However, other nations as well as non-fighter aircraft innovations have played a part in sculpting U.S. fighter development. Therefore, these contributions will be incorporated into the thesis.

One other major limitation to the research question is the lack of indisputable evidence justifying what the next generation air superiority fighter should or should not be. Nothing is black or white; therefore, the research material is subject to interpretation. Every service, every commander, and servicemen has their own opinion regarding this subject.

Additionally, discerning the tactical attributes of a dedicated air superiority fighter is subjective as well. Important considerations vary depending on a point of view. Political pressures, technical misunderstanding, or parochial alliances may skew opinions.

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[1] William D. White, U.S. Tactical Airpower: Missions, Forces and Costs (Washington, D.C.: The Brookings Institution, 1974), 2.

[2] Ibid., 3.

[3] Giulio Douhet, The Command of the Air (New York.: Arno Press, 1972), 3.

[4] "Fact Sheet: F-15 Eagle," [on-line]; available at http://www.af.mil/news/factsheets/F_15_Eagle.html, October 1992, 2.

[5] "F-22 Key Messages: 1997 United States Air Force Issues Book," [on-line]; available at http://www.afa.org/iib7.html 1997, 1.

[6] Paul G. Kaminski, "The DoD Tactical Aviation Modernization Program" [on-line]; available at http://www.acq.osd.mil/ousda/testimonies/aviation_modernization.html, March 5 1997, 3.

[7] Charles M. Westenhoff, Military Airpower: The Cadre Digest of Airpower Opinions and Thoughts (Maxwell Air Force Base: Air University Press, October 1990), 174.

[8] Ibid., 174.

[9] U.S. Department of Defense. JP 1-02: DoD Dictionary Approved Terminology Vol. I: Basic Aerospace Doctrine [CD ROM JEL] Washington, D.C.: U.S. Government Publishing Office, April 1997, 30.

[10] U.S. Department of the Air Force. AFDD 1 Basic Aerospace Doctrine [on-line] Available at http://hqafdc.maxwell.af.mil, October, 1997, 27.

[11] Ibid., 45.

[12] Ibid., 46.

[13] Ibid., 46.

[14] AFDD-1, 47.

[15] Ibid., 349.

[16] Douhet, 142.

[17] U.S. Department of the Army. FM 100-5, Operation (Washington, D.C.: U.S. Government Printing Office, June 1993), 2-18.

[18] The White House. National Military Strategy of the United States of America (Washington, D.C.: U.S. Government Publishing Office, 1995), 14.

[19] John A. Warden III, The Air Campaign: Planning for Combat (Washington, D.C.: Brassey's, 1989), 10.

[20] "F-22 Key Messages: 1997 United States Air Force Issues Book" [on-line]; available at http://www.af.mil/lib/afissues/1997/app_b_2.html, 1997, 1.

[21] Ibid., 1.

[22] Merrill A. McPeak, Selected Works 1990 - 1994 (Maxwell Air Force Base, AL.: Air University Press, August 1995), 224-225.

CHAPTER TWO

RESEARCH METHODOLGY AND LITERATURE REVIEW

Research Methodology

To answer the research question, this thesis focuses on a chronological review of four key facets that impact the success of air superiority fighters. These facets are: (1) aircraft, (2) avionics and weapons, (3) pilot training, and (4) cost considerations. The following paragraphs highlight the theme as well as the significance of each of the thesis' chapters.

Chapter Three: Historical Review

This chapter is an anthology of four distinct fighter generations spanning from World War I to present day. A chronological review of each of the key facets is presented, focusing on the important successful attributes. However, it is not a detailed review of each individual air superiority fighter fielded to date. Rather, the chapter presents exemplary aircraft that embody significant or consistent characteristics within a generation.

Chapter Four: Analysis

This chapter examines the critical aspects required to effectively execute air-to-air operations and achieve air superiority. It delineates the key historical characteristics, past and present, which make a successful air superiority fighter. In addition, a chronological analysis of fighter cost over the past century is examined.

Chapter Five: Conclusions and Recommendations

This chapter provides a summary of the essential characteristics of an air superiority fighter. These subjective answers are derived as objectively as possible using the historical data and analysis from the preceding chapters. In addition, this chapter highlights possible further research areas for the next generation fighters.

Literature Review

Reference literature on airpower topics is plentiful. The excitement and mystique of aerial combat has generated numerous historical dissertations. However, the question of the relative importance of different facets of aircraft performance, armament, and aircrew proficiency in aerial combat is a matter of continuing discussion.[1] There are four literary focal areas for the thesis research; they are published books, government publications, periodicals, and unpublished material. The following paragraphs highlight the applicability of each of the thesis' literary focal areas.

Historical documentation, such as, nonfiction books and biographies are useful in garnering airpower advocate theories as well as identifying key characteristics. Air campaign results, starting with World War I to the present, provide historic evidence of the air superiority fighter's impact. Additionally, documented accounts from combat experienced fighter pilots are also an excellent source for credible opinions.

Military publications include doctrinal, political, tactical, and technical information. Obviously, the value of doctrinal information is illustrated in terms the overall use of airpower and the role of air superiority. Political publications, such as congressional speaker memos, are a good source of current and past political debates as well as their solutions. Tactical and technical publications provide the empirical background for the aircraft and weapon systems as well as pilot training considerations. This thesis is unclassified; therefore, technical data, potential enemy threat statistics, and tactics will be taken from open source literature and are discussed in broad, unclassified terms.

Current events media is a vast wealth of information. It provides the most up-to-date and controversial data. Magazines like Air Force, Jane's Defence Weekly, Jane's Intelligence Review, and Aviation Week & Space Technology as well as newspapers, such as the Air Force Times, contain information pertinent to technology versus cost and historic reviews. Several previous research thesis topics from the Command and General Staff College at Fort Leavenworth and the Air Command and Staff College at Maxwell Air Force Base contain some parallel information as well as some direct support for this thesis. Additionally, their bibliographies have numerous potential sources of relevant research data.

Personal accounts and interviews with combat commanders, airmen (pilots, navigators, etc.), and other military members provide two key elements. Interviews and accounts are opinions based on (1) perception or (2) fact. Facts are based on empirical data or experiences, such the number of kills achieved during combat. Perceptions or points of view are more cognitive and variable; however, valid if the source is credible. For example, a combat commander's or a fighter ace's opinion regarding the value of the air superiority fighter is believable where an inexperienced fighter pilot's may not be. Therefore, caution must be exercised when drawing conclusions from opinions.

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[1] William D. White, U.S. Tactical Airpower: Missions, Forces and Costs (Washington, D.C.: The Brookings Institution, 1974), 45.

CHAPTER THREE

HISTORICAL REVIEW

> The job of the fighter pilot is to roam his allotted area in any way he likes, when he spots an enemy, he shoots him down. Anything else is rubbish.[1]
>
> Baron Manfred von Richthofen

The Red Baron summarized the air-to-air fighter's job with a simple explanation for a difficult task. This chapter will present a chronology of air superiority fighter characteristics commencing with World War I. This thesis breaks down the evolution of air-to-air fighters into four distinct generations. Table 2 depicts each generation and its corresponding title.

Table 2. Fighter Generations

First Generation:	The Biplanes
Second Generation:	The Monoplanes
Third Generation:	The Early Jets
Fourth Generation:	The Hybrid Jets

First generation aircraft were the pioneers, like those seen in World War I. The advent of the stressed skin monoplane along with increased aerodynamic performance distinguished the second generation. The arrival of the jet engine spawned the third generation. Today's fourth generation jets are a combination of the best characteristics from previous generations coupled with solid state technology and most significantly, beyond-visual-range avionics and weapons. This chapter is broken down by each generation. Within each generation, the significant characteristics pertinent to the research question are the focal areas; they include the aircraft design, the weapons and avionics, as well as the training.

Important aircraft design features include size, speed, operating altitude, maneuverability, and range as well as human factors engineering. Human factors include cockpit design and visibility. A superb performing aircraft with restrictive visibility can seriously hinder its air-to-air effectiveness. Weapons and avionics enhance an aircraft's design. Avionics capabilities are a measure of the fighter's ability to detect, identify and target the enemy, while weapons are the ability to shoot. Targeting an enemy is the ability to effectively monitor his actions and, if needed, support weapons employment. Important weapons considerations are payload, range, guidance and accuracy. Included in avionics and weapons considerations are countermeasures. Countermeasures are intended to limit the enemy's ability to use his avionics. Countermeasures come in many forms, they may be highly sophisticated electronic jamming suites or as basic as a camouflage paint scheme. Pilot training and experience is the last area to be touched upon in each of the four generations. Key issues concerning pilot training include number of hours flying fighter aircraft, number of hours in a specific aircraft, type and number of training missions flown prior to combat and combat experience. All these considerations will be highlighted during the course of the chronology of the air superiority fighter.

The First Generation: The Biplanes

Aircraft Design

On 5 October 1914, a German aircrew took off in an Aviatik B-Type aircraft on a standard reconnaissance mission behind enemy lines. French pilot Sergeant Joseph Franz and his observer were flying air patrol that day when they spotted the German Aviatik. The Frenchmen were flying a rear-engined Voisin, commonly called the "chicken coop" due to its unique design. The observer sat in the front of the aircraft and manned the Hotchkiss machine gun. Franz brought his aircraft alongside the German aircraft, his observer opened fire and shot down the plane and her unsuspecting crew. The poor Germans may have been "unsuspecting" indeed as stories from those early days tell of cheery waves exchanged by reconnaissance pilots whose paths crossed as they went about their business, regardless of whose side they were on. That camaraderie was rudely shattered that day.[2]

The above paragraph is an account of the first aircraft shot down in combat. Its not the typical glamorous tale of two airplanes engaged in an "aerial dogfight" high over the battlefield. It illustrates that the early aircraft to enter combat at the front in World War I were "flying machines" rather than combat aircraft. For their accepted role of reconnaissance there was no reason for them to be much else. It was only after the requirement to engage and destroy other aircraft in combat that the inadequacies of the designs became apparent.[3] Both offensive and defensive measures had to be taken.

Two-seat reconnaissance aircraft, like the Aviatik and the Voisin, were large and lumbering. They needed large lightweight wings to carry the two-man crew and their equipment and compensate for the lack of power. Thus, the limiting factors to performance in most early aircraft designs were the engine and the aircraft's structural integrity. Engines simply did not generate enough thrust and aircraft materials were fairly fragile. These factors lead to specialized aircraft designs that complemented each other in the air. In other words, this laid the foundation for three basic types of early combat aircraft: the bomber, the observation aircraft and the pursuit aircraft. Each type of aircraft had special design characteristics that enabled it to conduct its mission successfully. As technology rapidly advanced so did the number of variations to the three basic types over the course of World War I. Prior to the United States involvement in the war, one British official remarked that the types of aircraft required at the front lines "changed more rapidly than women's millenary."[4] The following table illustrates the number of different types of aircraft developed by four major powers during World War I to fulfill three basic airpower functions. It clearly reveals the high rate of flux in aircraft design.[5]

Table 3. Number of Aircraft Designs by Category

Country	Observation	Pursuit	Day Bombers	Night Bombers
Britain	20	27	10	10
France	22	31	7	4
Italy	11	13	4	7
Germany	10	12	none	6

Source: I. B. Holley Jr., Ideas and Weapons. (Hamden, CT.: Archon Books, 1975), 124.

The pursuit aircraft was the first air-to-air fighter aircraft. When the larger and less maneuverable two-seat observer or reconnaissance aircraft did their missions, they were escorted and protected from enemy airborne attack by the more nimble single-seat pursuit or scout aircraft. This led to pursuit aircraft conducting offensive patrols in search of enemy reconnaissance and scout aircraft.[6] Early pursuit aircraft design characteristics laid the foundation for modern day fighters.

Early pursuit aircraft were lightweight and highly maneuverable. Making the aircraft smaller as well as single seat reduced weight. This compensated for the relatively low horsepower generated by early engine designs.

The first true fighter was the German Eindecker, which entered service in 1915. Ironically, this aircraft was a monoplane in the biplane generation. It was light, maneuverable, and climbed well with its small 80 horsepower engine. Its top speed was 83 miles per hour and had an operating ceiling of 15,000 feet above sea level. A successful aircraft in combat, the Eindecker's mono-wing design was an anomaly and was soon replaced as engine capabilities increased. By the close of World War I, first generation fighters were capable of 140 miles per hour top speed and operated at altitudes above 22,000 feet. These two statistics, speed and altitude, became the most important features required of an early pursuit aircraft. The ability to out climb and out run the enemy was key.

Size and weight also contributed to maneuverability; however, lack of structural integrity plagued early designs. Weak airframes would come apart when maneuvered aggressively or at excessive speeds. Initially, built of wood and fabric, the first generation fighters were incapable of enduring aggressive maneuvers or extremely high speeds. This problem was evident in the first aircraft flown by U.S. pilots in World War I, the Nieuport N28C-I.

The Nieuport N28 suffered two dramatic structural flaws. The first was the fuel lines cracked due to excessive engine vibration. This would cause the aircraft to burst into flames in mid-flight. Secondly, during high speed dives, the wing fabric would rip away, which immediately caused a loss of lift and structural damage.[7] Therefore, innovations in structural designs were developed. Reinforced plywood and steel-frame tubing replaced the weak wooden frames.[8]

Early fighter design sported many wing shapes to increase performance. Most notable was the tri-plane such as the Sopwith Triplane and the infamous Fokker DR-1 or Red Baron. These aircraft were highly maneuverable, requiring a light touch to fly and could turn very quickly in a dogfight. However, they were slower than other fighters, but preferred by experienced pilots due to the maneuverability.[9] In order to generate such high turn rates, stability was compromised, therefore, only experienced pilots could manage these tricky fighters.

Pilot visibility was affected by wing design as well. To detect enemy aircraft, a pilot had to maintain a vigilant lookout. Therefore, smaller lower wings were incorporated in aircraft design to help the pilot see below him. Additionally, pilots would mount small rearview mirrors in the cockpit to assist them in their visual scan pattern.

Avionics and Weapons

Avionics and instrumentation were virtually non-existent in early fighter aviation. Pilots relied on maps, timing and visual lookout for navigation and spotting the enemy. Advances in weaponry rather than avionics were more significant in the first generation fighters. Efforts focussed around the weaponry aspect, since it was offensive by nature and aimed at the destruction of the enemy. Several ingenious methods were attempted. Experiments included, dropping rocks onto the opponent's aircraft from above and more advanced proposals incorporated steel darts or flechettes used in the same manner.[10] Another method was to tow an anchor on a long rope and try to snare the opponent's aircraft, pulling the canvas from the machine and shattering the wooden propeller.[11] A variation of this method included a small bomb affixed to a grapnel trailed behind the aircraft and the bomb was detonated electronically from the cockpit when in position.[12] Although these alternate methods were novel, the advantages of the more conventional hand-held pistol, and later the rifle and machine gun, would prove be the most effective weapons due to their simplicity and lethality.

However, there was a problem of aiming and firing any sort of gun since in many aircraft the crew was surrounded by wires and obstructions. There were wooden struts, large bi-plane wings and wooden propellers in the way; thus, any mis-shooting by the crew could seriously damage their own aircraft.[13] In addition, aiming a gun of any type at a moving target was challenging and required a two-man crew. A pilot alone could not effectively attack or defend himself. But, an inline forward firing weapon aligned along the fuselage axis would improve aiming accuracy and decrease workload. But, the propeller was an obstacle that had to be overcome. Designers mounted guns above and to the side of the propeller, but this proved difficult to aim. "Pusher" aircraft were developed, placing the propeller behind the pilot giving him a clear avenue of fire.[14] This was a viable option; however, aircraft performance was unacceptable. Thus, innovations in synchronizing the forward-firing machine gun's rate of fire with the aircraft's propeller became the best option.

Crude attempts at synchronization included fitting steel wedge-shaped deflectors to the propeller in order to deflect misfires. This technique proved hazardous to the pilot as well as the aircraft due to the high potential of ricochets.[15] It was Dutch designer Anthony Fokker, while making aircraft for the Germans during World War I, who developed an adequate synchronization system. A simple engine-driven system of cams and pushrods connecting the engine and the machine gun changed the face of aerial combat.

Training

Tactics, training and pilot skills evolved as rapidly as innovations in design and weapons. First generation pursuit pilots received formal basic flight school training and rudimentary instruction in combat tactics. Perhaps the Germans were the one's that conducted the most intense training. Under the leadership of Manfred von Richthofen, young pilots had to demonstrate practiced marksmanship skills and navigational competency prior to entering combat. Additionally, Richthofen required the pilots to fly in a chase position, fifty meters behind and to one side of their leader, in order to learn from the flight leader.[16] Another German fighter pilot was Oswald Boelcke, known as the "father of the fighting pilots" of World War I and Richthofen's mentor.[17] He established rules, later called the *Dicta Boelcke,* that set general principles for air fighting.

However, the most critical training was experience in World War I. The longer a pilot survived the more skilled he became. His ingenuity and killer instinct supplemented his extensive training. One key to survival was visual lookout.

A sharp lookout was vital to a pilot's survival and the paramount rule was never let an enemy "get on your tail."[18] Understandably, surprise was the preferred method of attack. Height above the enemy was an advantage and a diving high speed attack, opening fire at close range on an unsuspecting adversary would lead to a quick kill. This type of attack exposed the attacker to minimum risk.

First Generation Summary

First generation air-to-air fighters were pursuit aircraft: lightweight, small, and maneuverable. They were simple aircraft armed with various forms of machine guns. The pilots who flew them polished their basic flying skills and developed new tactics through experience in combat.

The Second Generation: The Monoplanes

Aircraft Design

Considerable technological advances were made in aviation by the early 1930s. Thus, the second generation air-to-air fighters were technological improvements on basically sound designs aimed at increasing performance. Designs focussed on improving maneuverability, speed, and range and operating altitudes.

Engine power increased dramatically and the introduction of the supercharger boosted speed at high altitude. The increased power overstressed wood and canvas airframes; therefore, metal airframes utilizing aluminum were designed.[19] Stressed skin began to appear on new types, making for easier repair of battle damage and greater simplicity.[20] Fabric covering was more difficult to repair than thin sheet metal. Additionally, the metal skin could bear some of the structural stress, which meant that lighter weight internal frames could be used. The monoplane layout began to come onto its own due to the new structural material. It had two major advantages over multiple-wing designs. First, it decreased drag, and second, it improved visual lookout. Other improvements included retractable landing gear and enclosed cockpits.

The British Hawker Hurricane was the first operational fighter in this class, capable of achieving 300 miles per hour and had an operational ceiling of 33,000 feet. Successful World War II fighter aircraft varied only slightly in design. The German ME-109, the mainstay of the Luftwaffe fighter arm, sported a fuel injection system. This ensured the engine would operate under aggressive maneuvers and negative "gravity forces," commonly referred to as negative "Gs." The British Spitfire had an elliptical wing design to enhance its maneuverability. There were several types of American air-to-air fighters employed during World War II.

The Curtiss P-36 was the mainstay of the small U.S. Army Air Corp prior to World War II. By the end of 1939, only 243 P-36s constituted the fighter arm of the Air Corp's 800 airplane strength.[21] As World War II approached a rapid buildup of forces commenced. The outdated P-36 soon gave way to more advanced Curtiss P-40.

The Curtiss P-40, nicknamed the "Warhawk," was the foremost fighter of the newly organized United States Army Air Force (USAAF) at the onset of World War II. Eventually, over fourteen thousand were produced and used by twenty-eight nations.[22] A workhorse capable of conducting a multitude of missions, it served in the European and the Pacific theaters. However, the Warhawk was never equal in speed, climb, maneuverability, and firepower to that of the Allied or German fighters. Thus, with few exceptions, the P-40 was primarily used as a ground-attack aircraft.[23]

The P-51 Mustang was the United States' premier second generation pursuit aircraft. Originally called the NA-73, it was built to British specifications. It was adopted by the United States Army Air Force (USAAF) in 1941 as a photo reconnaissance and ground-attack aircraft due to its limited high altitude performance. An adaptation to British Roll-Royce "Merlin" engine improved performance and in 1943 the Mustang entered service in Europe.[24] No other fighter had its combination of speed, range, and maneuverability.[25] The Mustang's simple design incorporated a laminar flow wing to reduce drag. It also, had excellent cockpit visibility from its bubble canopy. Additionally, the P-51 was capable of flying long-range missions due to a large internal fuel capacity and external fuel tank hardpoints.

Another standout U.S. fighter was the Lockheed P-38 Lightning. It was designed in 1937 as a high-altitude interceptor. Late in 1942, it debuted during the North African campaign where the German Luftwaffe named it *Der Gabelschwanz Teufel*--"The Forked-Tail Devil."[26] The P-38 was an advanced design for its time, with its twin tail booms, a bubble canopy, tricycle landing gear, and turbo-supercharged engines.[27] Equipped with droppable fuel tanks under its wings, the P-38 was a successful long-range escort fighter and saw action in practically every major combat area of the world. Built as an interceptor, the Lightning was also used for dive-bombing, level bombing, ground strafing, and photo reconnaissance missions.[28]

Second generation fighter designs were somewhat specialized. However, it is evident that most fighter aircraft assumed multiple roles. They were able to carryout air-to-air or air-to-ground missions. The overlying requirement for maneuverability, speed, and altitude determined how successful an aircraft would be in air-to-air combat. An example of an aircraft originally designed as an interceptor but used for air-to-ground due to its faults was the P-47 Thunderbolt.[29] Designed to counter the top line European fighters like the ME-109, the Thunderbolt was the largest and heaviest single seat aircraft ever built in the 1940s.[30]

It could be heavily armed but lacked the maneuverability that lighter aircraft enjoyed. Thus, it was primarily used in a ground-attack role.

Avionics and Weapons

The machine gun carried on as the mainstay of the fighter arsenal. Variations in mounting, number of barrels, and caliber were the extent of weapons development in air-to-air munitions. However, accuracy improved through better gunsight technology. Gyroscopic gunsights were developed in the latter stages of World War II. A pilot could adjust his gunsight to the wingspan of an adversary and the computing sight automatically displayed the correct gun tracking solution. The fighter pilot needed only to put the enemy aircraft under the pipper and then open fire.[31]

Avionics developments, significantly improved in second generation fighters. They had better navigation equipment and were capable of flying in all weather conditions. Additionally, reliable radio communication was available. A pilot could talk with flight members or ground-based units.

Technological advances had increased fighter aircraft performance and correspondingly, the pilot's workload. Due to faster speeds and higher altitude capability, the pilot had more airspace to scan in less time. Radar, or radio detection and ranging, was developed in the late 1930s. [32] It allowed forces to see beyond the range of the unaided human eye. That meant detection at a greater distance as well as in differing sky conditions, for example clouds, fog, or darkness. Radar would assist the fighter pilot in detecting the enemy.[33]

Early radars were ground based due to their size. Ground operators would vector fighter pilots towards the enemy until they made visual contact. By 1940, radar technology had advanced in terms of size and power requirements making it possible to mount a radar in an aircraft.[34] Initially, this technology was useful only for larger fighter aircraft. This necessitated their use at night to avoid the more agile day fighters. The first American aircraft specifically designed as a night fighter and equipped with an airborne radar was the Northrop P-61A Black Widow.[35] Resembling a bomber more than a fighter, the Black Widow was relatively maneuverable for its design. But, its greatest attribute was its airborne radar. It was the predecessor of modern day air-to-air fighter avionics.

For every technological breakthrough there was a countermeasure. Physical and electronics means were used to counter radar technology. Physical means included "chaff," which were thin strips of foil or metalized fiber, scattered in the air by aircraft or artillery in order to hide from or confuse an enemy's radar scope. Electronic means included jamming systems that distorted or masked radar signals. These countermeasures were the foundation of modern electronic warfare (EW).[36]

Training

In 1939, the USAAF established an aircrew training program. A pilot earned his "wings" after completing three flight schools: Primary, Basic and Advanced. The Primary Flight School was a screening course run by civilians. The cadets flew Stearman, Ryan, and Fairchild trainers owned by the AAF with civilian instructors. Each cadet was given sixty hours of flight training in nine weeks before moving on to the basic flight school.[37] During Basic School, a cadet received approximately seventy hours in the air during a nine-week period and transitioned from civilian-trained Primary School graduates into military pilots. In addition to operating an airplane of greater weight, horsepower, and speed, the cadet was taught how to fly at night, via instruments, in formation, and cross-country. The planes were also equipped with two-way radios and a two-pitch propeller. Basic Flight School was another screening process for pilot aptitude and it was the point where it was decided whether he would go to single-engine or twin-engine advanced flying school.[38] Single-engine Advanced Flight School consisted of an additional seventy flight hours during another nine-week period. Pilots learned aerial gunnery and combat maneuvers and increased their skills in navigation, formation, and instrument flying.[39]

Once a pilot earned his wings, he went on to Transition training. Here the young pilot learned to fly in the combat aircraft he was selected to fly. The course was roughly two months long, depending on the type of fighter.[40] This concept of pilot training is still utilized today.

However, once a young pilot arrived in his combat unit, additional training was required prior to him being declared "combat ready." An example of this form of training is the American Volunteer Group (AVG), led by General Claire Chennault during World War II. General Chennault developed an extensive training curriculum for new pilots in the organization. They received ground instruction plus specialized flying training and only when Chennault was personally satisfied with their performance would he allow them into combat. As a result, the AVG *Flying Tigers* were one of the most successful units in Pacific.[41]

Second Generation Summary

The evolution of second generation fighters took the propeller-driven aircraft higher, farther, and faster. It was made possible through more powerful engines, better aerodynamic designs, and stronger structural integrity. Avionics improved, which gave the fighter all-weather and night capabilities as well as in-flight communication via radio. Air-to-air weapons advances were simple improvements to existing technology, mainly the machine gun. Finally, more formal training with increased specialization evolved during the second generation.

The Third Generation: Jet Fighters

Aircraft Design

Over Europe during the last few months of World War II, the Luftwaffe flew the first combat jet aircraft, the ME-262.[42] It was faster than anything else in the air with a top speed over 540 miles per hour and it could climb to 30,000 feet in seven minutes. Fortunately for the Allies, Adolf Hitler decided to use the ME-262 primarily as a bomber rather than an air-to-air fighter.[43] Because of his decision, the 262 saw limited action, but the race was on to perfect the best jet air-to-air fighter.

While World War II jets were too few and arrived too late to affect the outcome of the war, the jet fighter would have a lasting impact on air-to-air combat.[44] Early operation jet fighters included the United States' Lockheed F-80 Shooting Star. It was operational in 1946 and capable of 580 miles per hour and maximum altitude of 42,000 feet MSL. The F-80 was only slightly faster than the ME-262 due to its straight thick wings. Designed as a fighter-bomber, this jet found its place as an air-to-air fighter at the onset of the Korean conflict. The Shooting Star was the victor in the first jet versus jet aerial combat in 1950.[45] However, it was soon relegated to ground attack as follow-on jet design improved.

The next significant leap in technology was in wing design. A swept back wing gave the jet improved speed performance and maneuverability. The North American F-86 Sabre was the first U.S. jet to incorporate this sleek aerodynamic design. The F-86 was specifically designed for air-to-air operations and was fully fielded by 1950.[46] It arrived in Korea to face off with the Russian made MIG-15, another swept-wing fighter flown by the Chinese. Remarkably similar in appearance, each jet had slightly different strengths and weaknesses. The MIG could climb faster and turn better at higher altitudes while the Sabre was larger, had a better gun system, and was more stable at high speeds.[47] The F-86 emerged as the undisputed champion with a 14-to-1 kill ratio.[48]

Advances in technology would further change the design of third generation air-to-air fighters. Additionally, the Cold War mentality influenced aircraft designs. The "Century Series" fighters, appropriately named after their numerical designations all beginning with one hundred, were the product.

The first of the series was the F-100 Super Sabre. Its significant contribution to the evolution of the air-to-air fighter was as the world's first fighter capable of sustained supersonic speed and originated as a follow-on air superiority fighter for the F-86.[49]

The F-102 Delta Dagger, was the first design that reflected the Cold War mentality of air superiority. The F-102 was a radical design with delta shaped wings and no horizontal tail empennage. It was built for speed not maneuverability and called an "interceptor" rather than a fighter. Its mission was to down potential Russian jet bombers, not other fighters. An interim aircraft, the F-102 was operational in April 1956 and soon replaced by the similarly designed F-106 in 1959.

The USAF issued operational requirements in December 1952 for a lightweight day superiority fighter to replace the F-100 in 1956, the F-104 Starfighter was the result.[50] The F-104 was also a dramatic design change. Its sharp stubby wings and pointed fuselage earned it the nickname, "rocket with a man inside." Needless to say its performance in a turning fight was less than optimum, but it was extremely fast (capable of twice the speed of sound). The Starfighter never succeeded as a combat air superiority fighter due to its poor maneuverability and endurance, but became a largely exported fighter.[51]

The last of the third generation fighters to serve in the air-to-air arena was the F-4 Phantom II. Intended for the Navy, the Phantom was initially designed as a carrier based, high altitude, high speed fleet defense interceptor.[52] It was larger than the "Century Series" aircraft in order to carry more sophisticated armament. However, the Phantom had a high wing-loading like its predecessors, which meant that it did not turn well in a dogfight. Thus, the F-4 received several design modifications to enhance its air-to-air combat capabilities after a demonstrated lack of success at the onset of the Vietnam conflict. A slotted stabilator and leading edge slats were the primary airframe modifications aimed at increasing the F-4's maneuverability.[53] With these improvements, the Phantom became a viable air-to-air fighter in the dogfight arena.

Another air combat fighter intended to conduct fleet defense for the U.S. Navy was the General Dynamics F-111. It was the first operational U.S. fighter with variable-geometry wings. The major advantages of this design feature are: (1) high supersonic performance with the wings swept back, (2) economical subsonic cruising speed with them fully spread, (3) a long operational ferry range, and (4) relatively short takeoff and landing capabilities at very high weights.[54] The F-111 was unique in its inception. The USAF was looking for a strike fighter to replace the F-105 and the USN was looking for a fleet defender to replace the aging F-4 Phantom. Thus, in the early 1960s, the Department of Defense decreed that the two requirements would be combined in a single program known as the TFX, Tactical Fighter Experimental.[55] This joint venture proved to be a disaster and a set back to future joint endeavors. Each service unrelentingly stressed different performance criteria for the aircraft. As a result the F-111's design suffered, it was unable to meet performance criteria and the Navy eventually cancelled their involvement in the project. The Air Force went on to employ the F-111 as a bomber with little-to-no air-to-air capability. Because of the fiasco in its development and disappointing performance, the F-111 was informally nicknamed the "Aardvark."[56] More importantly, it forced apart the sister service procurement and development process that would effect the creation of the fourth generation fighters.

Avionics and Weapons

Prior to the "Century Series," the aircraft arming process was largely an adaptation of ground weapons to aerial combat. Early jets, like the F-80 and F-86, were armed only with gun systems. The developmental curve for air-to-air armament remained rather flat for the first forty years of military aviation. The curve made a sharp turn upwards entering the Korean conflict and the new technology would be operational in Vietnam.[57]

As the Cold War began, missiles replaced guns. Lessons learned from World War I and World War II illustrated that long protracted aerial engagements were undesirable. Short or unnoticed attacks lead to the greatest success rates.[58] Therefore, as missile technology evolved, it was embraced because missiles had three advantages over a gun system. First, missiles afforded a greater standoff capability through longer range shots, reducing a pilot's vulnerability. Second, missiles had large warheads for attacking large targets such as bombers. Lastly, missiles capitalized on speed and altitude, the key ingredients of aerial combat up to that point in time.

Air-to-air missiles developed in two basic variants, heat seeking and radar guided. Heat seeking missiles track the infrared (IR) spectrum of light generated by an aircraft's heat source, like the engine exhaust.

Radar guided missiles use the radar signal from the launching aircraft to home in on the target. This means that the launching aircraft must have a radar and must maintain radar track on the target throughout the missile's time of flight. On the other hand, the IR missile is a true "fire and forget" weapon; once the missile is fired, it no longer requires any guidance from the launching aircraft.

In 1956, the U.S. fielded its first operational guided missile, the AIM-4 Falcon. The Falcon was fielded in heat seeking and radar guided variants along with a variety of warheads.[59] In the late 1950s, the U.S. Navy unveiled the AIM-9 Sidewinder and AIM-7 Sparrow guided missiles. Thousands have been produced since and both remain in service to this day in the USAF, USN and USMC.[60] The Sidewinder is a heat seeker. Early versions, were limited to stern only employment envelopes and they had limited range capability. The Sparrow is a radar guided missile. It is larger and has longer range capabilities than the AIM-9. However, like the AIM-9, early versions of the AIM-7 had limited all-aspect employment envelopes and low success rates. These missiles complemented the Cold War interceptors when aimed at relatively large and poor maneuvering targets, such as bombers.

However, an over-reliance on missiles alone was a bad idea. The flaw in this concept was evidenced in the Vietnam conflict with the F-4. Early missiles had a low probability of kill (Pk). It was not unusual for a USAF fighter to expend 4 to 8 missiles to destroy one MIG.[61] This could occur while a pilot was actively engaged with one or more adversaries, essentially leaving the pilot unarmed in the fight. General Robin Olds, a veteran Vietnam F-4 pilot, recalls,

> Air-to-air missiles gave our fighter a tremendous capability relative to the MIG-17, which carried only cannon and rockets. But fighting a MIG with gunless F-4 is like fighting a guy with a dragger when he's got a sword or maybe vice versa. A fighter without a gun, which is the most versatile air-to-air weapon, is like an airplane without a wing. Five or six times, when I had fired all my missiles, I might have been able to hot a MIG if I'd had a cannon, because I was so close his motion was stopped in my gunsight.[62]

This sentiment lead to reinstating gun systems in air-to-air fighters for use in conjunction with air-to-air missiles.

Missile technology brought with it the need for other tactically valuable and sophisticated equipment. A radar missile required continual guidance via an airborne intercept (AI) radar. Thus, the F-102, F-106 and F-4 all had AI radars for target detection and missile guidance. The radar increased the pilot's situational awareness and decreased his reliance on ground based radar controllers. However, early AI radars were primitive, difficult to operate and unreliable.

Countermeasures to defeat enemy radars and missiles, both air-to-air and ground-to-air, were also incorporated into third generation fighters. Chaff and IR flare dispensers were mounted to the fighters and dispensed to deny a radar lock-on or disrupt/decoy a missile in-flight.[63] Additionally, electronic jamming equipment as well as radar warning receivers were developed. The radar warning receiver gave a pilot notice that an enemy's radar had acquired him while his jamming equipment attempted to deny or decoy the radar lock-on.

Training

With the jet came a new bred of fighter pilot. Gone to some extent were the "seat-of-the-pants" flyers of World War I and World War II. Faster speeds and more sophisticated instrumentation required increased skill, accuracy and precision.[64] The fighter pilot had to cope with a dynamic environment with little room for error. This meant increased and specialized training was required.

In 1946, the fledgling United States Air Force gave Air Defense Command (ADC) responsibility for North American air defense. ADC fighters were only concerned with air-to-air combat; therefore, the command's training plan reflected a large amount of air-to-air combat training. By July 1954, the USAF Interceptor Weapons School was created. It was an advanced flying school to train intercept controllers and fighter crews as an interceptor weapons instructor team. This concept originated with the British in World War II, when they realized the importance of a dedicated and skilled team was a requirement to accomplish the most difficult aerial intercept problems.[65]

Air Defense Command initiated the first dissimilar air combat training (DACT) program. Realizing that the F-106 would not face another F-106 in combat, ADC extended its air combat raining to include dogfighting between dissimilar airplanes. In 1968, COLLEGE DART, the only formalized USAF Air Superiority Tactics Training (ASTT) course, was created for all F-106 pilots. It was two to three weeks of concentrated air defense and air superiority training against dissimilar aircraft.[66]

The other fledgling fighter command was Tactical Air Command (TAC). It was tasked with managing the multi-role fighter force training programs. The primary mission of TAC was air-to ground; therefore, minimum emphasis was placed on air-to-air training. Air-to-air training requirements were several times less than units with specialized air-to-air missions. Advanced air-to-air training practically ceased and suffered realism. As a result, TAC-trained F-4 crews were unprepared for air-to-air operations in Vietnam. This lesson would spawn increased air-to-air training tempo and realism as well as the development of the fourth generation fighters.

Third Generation Summary

The third generation jets achieved supersonic speeds, taking faster and farther to new heights. These attributes overshadowed maneuverability during the Cold War nuclear threat era. However, maneuverability was reinstated following the Korean and Vietnam conflicts. The third generation fighters saw the beginnings of the air-to-air missile as well as the persistent value of a gun system. Training became more demanding and specialized during the third generation.

The Fourth Generation: Today's Fighters

Aircraft Design

Coupling technological advances with lessons learned created the fourth generation air combat fighter. Modern fourth generation U.S. fighters are hybrids. Their heritage stems from the early "pursuit" fighters of World War I and World War II.[67] Their designs incorporate the successful characteristics of the past and combine them with current technology. The demarcation between third and fourth generation fighters stems from the type of threat that these aircraft were designed to counter. The third generation "Century Series" were designed to face second generation Soviet fighters and their heavy bombers as the Cold War broke out. The development of the F-4 occurred in the early 1950s, hence its initial design was built to face the same threat. However, the F-4 Phantom II would undergo many modifications throughout its long career. The Phantom literally spanned the gap between third and fourth generation fighter.

The real scramble to generate all new fourth generation fighters began when the Soviet Union unveiled a new fleet of military aircraft at the Domodedovo Airshow in 1967. The MIG-23 Flogger and the MIG-25 Foxbat posed substantial threats. Both the USAF and the United States Navy were looking for air superiority fighters to challenge the Soviet threat and a common design was considered.[68] However, the F-111 disaster was still fresh in minds of service leaders and separate procurement paths were eventually taken.

The first air superiority fighters to emerge were the USAF's F-15 Eagle and the USN's F-14 Tomcat. Both were fielded in the early 1970s, optimized for air-to-air combat and similar in many aspects.[69] These fighters were designed to fly higher, fly faster and to out maneuver any other fighter airborne as well as carry a lethal air-to-air weapons payload. This created several design considerations. Both aircraft sported twin tails and two engines; however, the F-14 utilized variable-geometry wings while the Eagle used a fixed wing design. These design features were optimized for high altitude operations as well as maneuverability. High speeds and intense "G" forces required that the aircraft have strong structural integrity. This led to an increase in aircraft weight. Additionally, the aircraft were larger than any other previous fighters due to the avionics and weapons requirements, this also added to the weight problem. However, jet engine design improvements as well as the installation of two engines made it possible to generate acceptable thrust-to-weight ratios to ensure high speeds and sufficient power to sustain high "G" maneuvers. While the F-15 and F14 were undergoing development, an additional agenda was underway, the LightWeight Fighter (LWF) program.

Jet fighters were getting bigger, heavier, more complex and costly. As a result, in the early 1970s, the USAF's LWF program was initiated to investigate the possibility of developing a lightweight, low-cost, high performance air superiority fighter.[70] The result was the F-16 Fighting Falcon and later the U.S. Navy's F-18 Hornet. These fourth generation fighters were approximately 25 percent smaller than the Eagle or the Tomcat and they incorporated even more advanced technology. Computer technology was incorporated into the aircraft design and flight control systems. To reduce size, their wings had to be smaller and they needed a high degree of maneuverability. This was possible through the use of "live wing" designs. Both the F-16 and F-18 incorporate maneuverable computer-controlled wing slats or strakes that react to given flight conditions and maintain optimum performance. The F-16 has the first "fly-by-wire" flight control system.[71] Previous designs used hydraulics and a series of cables and pulleys to activate the flight controls. The Falcon's computer electronically activates the flight control system. In addition, the computer will prevent the pilot from entering any adverse flight control inputs in order to maintain optimum performance and not over stress the aircraft under high "G" forces. Furthermore, the LWFs included the use of composite materials. High-strength composites replaced many of the heavier metal components of previous fighter designs.

Improved human factors design features arrived in fourth generation fighters. One improvement was cockpit visibility. Previous designs, like the F-4 and F-100 series, had streamline cockpits with large bulkheads at the rear of the cockpit. Advances in windscreen materials made it possible to create a "bubble" canopy, most prominent on the F-16. This gives the pilot a 360-degree view around his aircraft and improves his ability to visually acquire an adversary. Other improvements included ejection seat designs that allowed the pilot to more easily withstand the high "G" forces generated and an expanded safe ejection envelopes to increase pilot survivability.

Avionics and Weapons

Vast improvements in avionics and weapons typify fourth generation fighters. Avionics advances improved with the advent of lightweight, high-speed computers. In the following section, the most significant improvements are highlighted.

AI radar enhancements included improved detection ranges outside 100 nautical miles. Additionally, AI radars had true "look-down" capability, the ability to detect targets at lower altitudes. Previous radar technology could not decipher targets from ground clutter in look-down situations. Moreover, AI radars could track multiple targets simultaneously. This form of radar processing, known as track-while-scan or TWS, provided accurate radar information on several targets suitable for monitoring threats or launching multiple radar-guided missiles. Coupled with the AI radar were air-to-air interrogators or AAI. Found only on the F-15 and F-14 as well as the late model F-4s, the AAI gave the aircrew an ability to identify friend or foe electronically.

Previously, ground controlled radar sites were the pilot's BVR eyes and identification means. AI radars and electronic identification (EID) capabilities afforded more autonomy.

Due to the increase in information available there was a distinct possibility of information overload, therefore the new systems had to be user friendly. The F-14 designers elected to utilize a two-man crew to distribute the workload, the others were single seat. Three key improvements reduced the pilot's workload: (1) synthetic radar displays, (2) Hands-On-Throttle-And-Stick (HOTAS) switchology, and (3) the Head-Up Display (HUD). Each of these made the fighter pilots job simpler. Synthetic radar displays presented the pilot with enhanced raw radar information making the information easier to decipher.[72] Inside the cockpit, operating the various radar, navigation and fire control systems required many switch actuations. HOTAS engineering put the vital switches on the aircraft flight control stick and throttles. This allowed the pilot to make necessary switch movements without having to remove his hands from the aircraft flight controls. For example, in the F-15, there are fourteen HOTAS switches designed to reduce the pilot's workload. The HUD, a combining glass with projected navigation, radar and weapons system information, sat at eye-level on the dash in front of the pilot. This allowed the pilot to focus his eyes outside the cockpit and still have visual cues as to what was going inside the cockpit. This also afforded the pilot a greater visual lookout capability, to maintain position in formation as well as search for enemy aircraft.

Improved detection and targeting potential gave the air superiority fighter greater beyond-visual-range capabilities. Radar-guided missiles were improved. The AIM-9 Sidewinder achieved an all-aspect weapons employment envelope, allowing the pilot to shoot anywhere from stern to head-on shots. An increase in maximum range and better counter-countermeasures logic also enhanced the missile's lethality. The AIM-7 Sparrow, first flown on the F-4 Phantom was improved as well over time. However, one drawback was that the Sparrow was only a "semi-active" radar missile; this meant that the missile required guidance cues from the launching aircraft throughout its flight to the target. This tied the shooting aircraft's radar to a single target for an extended period of time. This problem was solved with the advent of the "active" radar missile appearing in the mid-1970s.

Essentially, an active missile contains a small AI radar in its guidance system. This miniature radar acquires the target designated by the launching aircraft. Once the missile is tracking the target, it no longer needs the signal from the launching aircraft and it "actively" guides itself to the target. The first generation active missile was the AIM-54 Phoenix, built specifically for carriage on the F-14. The Phoenix is a large missile with a large warhead and was designed the shoot at long range versus large non-maneuverable targets. The more modern active missile is the AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM). It is smaller and more maneuverable than the Phoenix and widely carried by all U.S. radar equipped fighters. Active missiles allow the shooter to "launch-and-leave" or "launch-and-forget" the missile once it has gone into its active mode. This gives the shooter greater engagement options. He may react to defeat enemy weapons or defend himself from surface threats while the active missile continues to track its target.

Training

At the dawn of the fourth generation fighter, aerial combat training was invigorated. Basic aerial combat tactics had given way to an over reliance on standoff missiles and the emphasis on air-to-ground attack in the third generation fighter era. The U.S. Navy and the USAF's Tactical Air Command air-to-air combat training programs had atrophied. This was evidenced by a dismal kill ratio at the onset of the Vietnam conflict.[73] Investigations, studies and reports were conducted. The results found that air combat training was inadequate to the combat task.[74] From this reason, several training improvements came to fruition.

Both the Navy and the Air Force adopted similar training methods within each service. For the USAF, Air Defense Command's DACT program was expanded. Air combat training was increased as well as extended to include dogfighting between dissimilar airplanes. In the late 1970s, the USAF formed the "Aggressors," squadrons of Northrop F-5Es painted to resemble enemy paint schemes. The Aggressor pilots were USAF pilots trained in enemy tactics to best simulate real aerial combat.[75]

A study of aerial combat in southeast Asia, code named RED BARON, coupled with other informal studies revealed one common factor: If a pilot survived his first ten combat encounters, his chances of continued survival went up from 50 percent to approximately 90 percent.[76] This evidence spawned one of the most significant training exercises ever developed, RED FLAG.[77]

RED FLAG is a full-scale aerial combat simulation that includes all forms of airpower assets. It provides realistic large-scale training, exposing aircrews to the fog of war. Nellis AFB, located in Las Vegas, is RED FLAG's home and the simulated air wars are conducted over the high desert training ranges in southern Nevada. The range complex is the size of the country of Switzerland and contains a myriad of realistic threat simulators. From ground targets to "Aggressors", simulated full-scale air battles are fought and recorded on the RED FLAG Measuring and Debriefing System or RFMDS. Via RFMDS, each aircraft can be tracked and recorded in three dimensions throughout the battle. Versatile computers recreate the entire battle for the exercise debriefing. Tactics of the opposing sides are analyzed and critiqued. The replay has the broad capability to depict the God's eye view of the entire battle and the minute detail of an individual cockpit view to assess who killed who.[78] This form of debriefing reinforces the value of properly executed tactics and individual performance.

The flying in RED FLAG is very close to actual combat, the only thing lacking is real bullets and missiles being fired.[79] To provide that training, the Weapons System Evaluation Program or WSEP was developed. WSEP's goal is two-fold. First, it enables a fighter pilot to experience the real thing, firing an AIM-7 or AIM-9 at a moving target. Second, it gives the Air Force a statistical check of weapons system reliability, both of the missiles as well as aircraft fire control systems.[80]

An additional training advance in fourth generation fighters was better cockpit-recording devices. Aerial gun camera film was used to validate aerial victories as early as World War I. However, fourth generation fighters have high technology video equipment that records the action for an entire mission. A color video replay of the pilot's actions and reactions as well as audio information provides an excellent tool to critique the pilot's performance. Better critique leads to better understanding of mistakes and improved performance on the next mission.[81]

Fourth Generation Summary

The hybrid fighters that make up the fourth generation are technological marvels. They are capable of high speeds, high altitudes, and they are highly maneuverable. Their avionics and weapons give them a true BVR "look-down, shoot-down" lethality. All fourth generation fighter pilots receive air-to-air training emphasis. However, dedicated air-to-air units exist, similar to the third generation air defenders.

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CHAPTER FOUR

ANALYSIS

Military aviation has undergone eighty years of technological change. Many characteristics carry on from generation to generation, being improved upon as technology advances. However, some characteristics become obsolete. Thus, to answer the research question, this chapter will analyze the historical commonalties of each generation to find the consistent characteristics of air superiority fighters. The analysis will focus on the three key areas addressed in chapter three: aircraft design, avionics and weapons as well as training. A fourth area for analysis is cost, which stems from the inherently high price of technology. Therefore, fiscal restrictions influence the characteristics of an air superiority fighter. This chapter will analyze these four key areas of interest.

Aircraft Design

There are three important characteristics of aircraft design. They include aerodynamic performance, size, and visibility. The following section will address each of these characteristics.

Aerodynamic performance is measured in terms of aircraft speed, altitude, range, and maneuverability. The importance placed on each particular aspect has differed throughout the evolution of the air-to-air fighter. However, "high" ratings in each area are desired. This is illustrated plainly in a U.S. Army Air Corps study board report. The board was convened in 1935 to establish performance standards and specifications for pursuit aircraft. The board prescribed the following specifications:

- Construction safety factors at least as high as those required for interceptors
- Range at least as great as that of a bomber
- Service ceiling as high preferably higher than, those of a bomber
- Top speed at least 25% greater than that of a bomber
- High rate of climb.[1]

Simply stated, the air-to-air fighter had to outperform all other airplanes. This can be seen throughout the air-to-air fighter's evolution. Each generation has shown incremental advances in maximum speed, altitude, and range. This is illustrated in Table 4 on the following page. It shows several aircraft characteristics from each generation. The following section will highlight the significance of each of these aerodynamic performance characteristics.

Range

Fighters must have adequate range or loiter time to accomplish their mission. Since an air-to-air fighter may be tasked to conduct various missions, such as air defense or escort, its combat radius and endurance requirements vary. An example of a shortfall in this area was the second generation escort fighters used during the World War II.

Table 4. Aircraft Aerodynamic Characteristics

Aircraft Type	Maximum Speed	Service Ceiling	Cruise Range	Maximum Weight
First Generation				
Fokker Dr1	103 MPH	19,685 ft MSL	185 miles	1,291 lbs
Sopwith F1 Camel	112 MPH	19,000 ft MSL	300 miles	1,482 lbs
Nieuport 17	122 MPH	17,000 ft MSL	180 miles	1,625 lbs
Second Generation				
Curtiss P-40 Warhawk	362 MPH	30,000 ft MSL	850 miles	9,100 lbs
Messerschmidt Me109 Gustav	387 MPH	38,500 ft MSL	615 miles	6,980 lbs
North American P-51 Mustang	437 MPH	41,900 ft MSL	1000 miles	12,100 lbs
Third Generation				
North American F-86 Sabre	685 MPH	49,000 ft MSL	1200 miles (with tanks)	13,791 lbs
Lockheed F-104 Starfighter	1,320 MPH	58,000 ft MSL	1820 miles (with tanks)	25.300 lbs
McDonnell DouglasF-4C Phantom II	1,400 MPH	59,600 ft MSL	1750 miles (with tanks)	58,000 lbs
Fourth Generation				
McDonnell Douglas F-15C Eagle	1,600 MPH	65,000 ft MSL	2500 miles (with tanks)	68,000 lbs
Grumman F-14 Tomcat[2]	1,564 MPH	56,000 ft MSL	2000 miles (with tanks)	74,348 lbs
Gen Dynamics F-16 Fighting Falcon	1,500 MPH	50,000 ft MSL	2415 miles (with tanks)	42,500 lbs

Source: U.S. Department of the Air Force. U.S. Air Force Museum. [on-line]; available at http://www.wpafb.af.mil/museum/research, February, 1998.

The fighters lacked the long-range capability required to protect the Allied bombers on missions into the German heartland. This sent hundreds of bombers into deep into enemy territory totally unescorted and, consequently, they suffered heavy losses at hands of the Luftwaffe.[3] Obviously, the largest contributors to extending range are fuel capacity and fuel efficiency. Therefore, second generation fighters, like the P-47 and P-51, were adapted to carry more internal fuel as well as external drop tanks.[4] Additionally, fuel efficiency was increased with improved engine performance and higher cruising altitude capability.

Altitude

High operating altitudes give the air-to-air fighter numerous advantages. This was realized early in military aviation. Oswald Boelcke, Germany's "father of the fighting pilots" of World War I, wrote the *Dicta Boelcke*. It was a rulebook for all air combat tactics. The top two rules were:

> 1. Always try to secure an advantageous position before attacking. Climb before and during the approach in order to surprise the enemy from above and dive on him swiftly from the rear when the moment to attack is at hand.
>
> 2. Try to place yourself between the sun and the enemy. This puts the glare of the sun in the enemy's eyes and makes it difficult to see you and impossible for him to shoot you with any accuracy.[5]

In addition to surprise and the potential energy advantage, higher altitude operations have several other advantages. As previously mentioned, fuel efficiency increases with altitude as the atmosphere becomes thinner. As a result of thinner air, there is less drag on the aircraft and its weapons. This improves the aircraft's maximum speed capability. Improved cockpit designs also allow higher altitude flight. From the early open cockpit designs, today's fighters have fully pressured cockpits and are capable of operating at altitudes over 60,000 feet and twice the speed of sound.[6]

Speed

Early air-to-air combat aircraft were called "pursuit" fighters. That name alludes to the importance of speed in an air superiority fighter. Early aviation pioneers recognized the value of the high-speed dash to safety or the ability to run down a fleeing enemy. Additionally, speed at a given altitude can be transferred into more altitude; in other words, kinetic energy can be exchanged for potential energy. Speed's kinetic energy also assists the aerodynamics of air-to-air weaponry. Missiles launched at high speed have greater energy at impact.

An aircraft's speed capabilities are a function of its thrust, weight, and drag. Thrust has to overcome the aircraft's weight as well as drag. Powerful engines create high thrust. However, more powerful engines are heavier and require more fuel as well as greater aircraft structural strength to house the engine forces. This is illustrated in Table 4. Note that aircraft weights have continued to increase from generation to generation. Since these factors create more weight and potentially more drag, aircraft engines must be highly efficient. They must complement the aerodynamic design by contributing more thrust while minimizing weight and drag.

Maneuverability

An air-to-air fighter's maneuverability is measured in terms of turn rate and turn radius as well as its handling characteristics. Quick tight turn circles are an advantage. However, a more maneuverable aircraft is generally less stable; therefore, more difficult to control. This fact was learned early in military aviation. For example, the World War I Sopwith Camel design. Its rotary engine torque gave the fighter turning capabilities previously unseen. The highly sensitive controls responded instantly to the pilot's inputs. For the experienced pilot this was a welcomed response.[7] Another example, the German Fokker Dr1, outclassed the Camel design. The Dr1 was nimble, very maneuverable, light on the controls and, although it was slower than either the Camel or SE5, only a brave RFC pilot took on a Triplane. It could turn very quickly, so in a dogfight it would gain the advantage.[8] These comparisons illustrate the quandary between the accolades of maneuverability versus speed and which is more important.

The advent of faster second generation fighters shunned aircraft maneuverability. In an RAF training manual dated 1938, the chapter on *Air Fighting Tactics* quoted; "Single-seater fighter attacks at high speed must be confined to a variety attacks from the general direction of astern. Maneuver at high speeds in air fighting is not now practicable, because the effect of gravity on the human body during the rapid changes of direction at high speed caused temporary loss of consciousness.[9] Aerodynamically, that statement is true. Figure 1 depicts the mathematical equations that determine turn rate and turn radius.

$$TurnRadius = \frac{V^2}{gGr}$$

$$TurnRate = \frac{KGr}{V}$$

Where:
V = Velocity
G_r = Radial G
K = Constant
$g = 32.2$ ft/sec^2

Figure 1. Turn Rate and Turn Radius Equations

Both are dependent on velocity and radial "G." Radial "G" is the force of gravity mentioned in the Royal Air Force manual. It is best described as the centrifugal force experienced while in a turn. In order to have a high turn rate and small turn radius, the aircraft must increase "G" or slow down. The number of "G" forces that a pilot can endure is finite (today's aircraft are 9 "G" aircraft). Therefore, the other variable, velocity, must be decreased. Slower speeds yield higher turn rates and smaller turn radii. However, it is obvious that an aircraft must maintain some minimum velocity to remain airborne and velocity is a function of thrust. Therefore, a compromise between maneuverability and speed is inevitable. This fact fuels the philosophic controversy of whether maneuverability or speed more important.

The best answer is both are important. This lesson was learned during Vietnam. In the 1950s and 60s, U.S. air superiority fighters, like the F-102, F-106, and the F-4, relied on speed and standoff air-to-air missiles.[10] They were not designed for the aerial dogfight. Over-reliance on speed and unrefined technology lead to dismal combat kill ratios in aerial combat, as mentioned in chapter three. In his 1990 thesis, Gerald Pelletier, a USAF fighter pilot, proved the inevitability of close in aerial fighting. He noted that; "Even though speed appears to be the most desired trait in a fighter by many fighter pilots, the importance of maneuverability is undeniable. In World War I, 95 percent of the kills made were in maneuvering dogfights, while the other 5 percent were made in hit-and-run combat. In World War II, the percentage dropped to the low sixties. But, in both Korea and Vietnam, the percentage of aircraft killed in maneuvering dogfights was above 80 percent."[11]

Today, fourth generation fighters, like the F-15 Eagle, incorporate the lessons learned from Vietnam. The F-15 was designed as an air superiority fighter that could out-turn and out-speed enemy fighters at all altitudes. Unlike the F-4, the Eagle's great maneuverability is derived from its large wing area and high twin-engine thrust-to-weight ratio.[12] Each engine is capable of producing over 20,000 pounds of thrust propelling the 30,000 pound Eagle with a greater than 1-to-1 thrust-to-weight ratio.[13] This gives the Eagle high speed, high altitude capability as well as excellent sustained velocity during turns.

Aerodynamically, the characteristics of range, altitude, speed, and maneuverability have consistently improved throughout fighter evolution. Speed and maneuverability are equally important to the air superiority fighter and require complicated design features to maximize these characteristics. The value of sustained turn performance is dominant.

Size

Fighters have gotten bigger throughout their evolution. As previously noted, larger engines and larger payloads yielded larger airframe requirements. Size is also expressed in terms of weight as well as physical dimensions (reference Table 4). Obviously, a small lightweight aircraft requires less thrust than a larger aircraft. This is important to fighter maneuverability, recall that velocity and "G" determine an aircraft's turn performance. Additionally, larger aircraft are more sluggish due to greater inertia. Once again making them less maneuverable. Thus, a reduction in size to reduce weight is desirable. Another more important facet of size is detection.

Early combat aviators relied on their visual lookout and keen eyesight to acquire the enemy.[14] A small aircraft was more difficult to spot. With advent of radar, aircraft could be detected beyond-visual-range (BVR). This aided the pilot in focussing his visual scan pattern to acquire the enemy. Once BVR missiles were developed, the fighter pilot could shoot without ever visually seeing the enemy. This led to attempts in reducing the fighter's radar-cross-section (RCS). The RCS is the geometric cross-sectional reflectivity and directivity of a target.[15] As early as the 1950s, RCS reduction techniques were under development in military aviation. The advantage of a reduced RCS is the ability to go undetected until at close range. Therefore, the "stealth" fighter could engage and destroy his enemy before the enemy is able to detect him. Today, "stealth" technology can not be overlooked. According to General Merrill McPeak, former Chief of Staff of the U.S. Air Force, "The number one hardware lesson of the Gulf War is the revolutionary impact of stealth. Stealth restores surprise to the tactical engagement. And surprise, if you can achieve it, conveys almost overwhelming operational advantage. We all know this. The ambush is nearly always effective, even on TV. Stealth means that, once again, aircraft can ambush targets."[16] Like the World War I fighter pilots that held high above their enemy and then sweeping down out of the sun, stealth gives the air-to-air fighter the advantage.

Visibility

Visibility outside the cockpit is another important air-to-air fighter characteristic. As mentioned in chapter three, early innovations to improve visibility were high priorities. Visual lookout was the only means to acquire the enemy from frontal attack or from being attacked from behind. Even after the advent of radar, the primary means of detecting the enemy from behind is via visual lookout. Air Force Colonel John Boyd, creator of the "OODA" logic loop, also stressed the importance of cockpit visibility. He analyzed the success of the F-86 in the Korean conflict to find why the F-86 faired so well versus the MIG-15. He concluded that the F-86 pilot could see out much better than the MIG-15. The F-86's bubble canopy gave its pilot very good outward vision, while the MIG's canopy gave the pilot a more restrictive view. Boyd felt this gave the Saber pilots an advantage to rapidly acquire and react to enemy.[17] Realizing the importance of visibility, fourth generation cockpit designs, like the F-15 and F-16, have 360 degree unimpeded views.

Avionics and Weapons

For purposes of this thesis, avionics and weapons impact a fighter's ability to detect, target, identify, and shoot the enemy. Key characteristics derived from these areas are first-launch-opportunity (FLO), autonomy, pilot work load, and dogfight weapons. The following section will highlight each of these characteristics.

First-Launch-Opportunity

FLO is a term used to describe the capability to shoot the enemy prior to him achieving a shot. In order to enjoy this advantage, an air-to-air fighter must be able to detect, target, and identify the enemy as well as have a weapon in an employment envelope prior to the enemy. Early fighter pilots visually detected and identified their prey. They attempted to attack unnoticed from astern and waited until close range to open fire.[18] The advent of radar and BVR missiles expanded the weapons envelopes available to the fighter pilot. Hence, fourth generation fighters have sophisticated systems to detect, target, and shoot at long-range. However, identification is less tangible and can be lumped into two distinct categories, visual or electronic. Visual identification (VID) is the oldest form of ID used when a pilot is within-visual-range. Some early aviators had flamboyant paint schemes to broadcast their presence as a form of distinction or intimidation. Modern fighters have subdued paint schemes to minimize visual detection. Electronic identification (EID) has many variations and sources. These sophisticated means allow the fighter to ID an enemy BVR; however, not all fighters are equipped the same. Some forms of EID may have to come from off-board sources. Rules of engagement ultimately determine the level of identification necessary prior to shooting at a target. Generally, several means of ID are required prior to taking the first shot. Restrictive ID criteria or delayed off-board ID sources can decrease the fighter's first-launch-opportunity.

Autonomy

The first-launch advantage is heavily dependent on identification. Therefore, an air superiority fighter needs the capability to ID autonomously and not be forced to rely on off-board sources. This statement is supported indirectly by a basic tenet of air and space power found in Air Force Doctrine Document 1 (AFDD-1). Centralized-control and decentralized-execution is the "delegation of execution authority to responsible and capable lower-level commanders is essential to achieve effective span of control and to foster initiative, situational responsiveness and tactical flexibility."[19] An example of a fourth generation shortfall in this area is the F-16 and F-18 ID systems. Each relies heavily on off-board "declarations" of friend-or-foe in most air-to-air scenarios. AWACS, the Air Force command and control aircraft, the F-15, and F-14 are able to interrogate the friend-or-foe codes. Thus, while the Eagle and the Tomcat can make autonomous ID decisions, the F-16 and F-18 may have to rely on others for part of the ID equation.

This hinders the Fighting Falcon and Hornet pilot's ability to operate autonomously and may impact their FLO. Additionally, as the "fog of war" escalates in any conflict, waiting for an off board ID is impractical and once again may force a friendly fighter inside an enemy's FLO without a shot.

Pilot work load

Pursuit fighters were lightweight and agile. Out of necessity, a single pilot manned them. Engines were unable to produce enough thrust to carry more than one flyer and his weapons. While power is no longer the limitation, fighters remain relatively small and nimble. Thus, a fighter is typically, manned by one or two crew members, yet weapons and avionics systems grow increasingly more complex. At an airpower symposium in 1977, Air Chief Marshal Sir Frederick Rosier, Director of the British Aircraft Corporation, pointed out that future aircraft designs must; "Lower the work load for the pilot to make his job easier, requiring better cockpit visibility so that he can have more time "head out" and less time "computing."[20] Combining multiple sources of information into one succinct location or display is commonly referred to as *sensor fusion.* This form of information can be digested quickly by the pilot. Simple examples are the synthetic radar display and the HUD found in fourth generation fighters like the F-15. (discussed in chapter three).

Dogfight Weapons

The "fog of war" is a factor is all combat situations. Pelletier determined that the "fog of war" is a cause for the inevitability of the close in dogfight. Even in the air battles of the future it is foreseeable that air superiority fighters will be engaged in close combat.[21] If this is true, then Napoleon's quote; "One can never have too many guns, one never has enough" is still viable.[22] An important lesson learned in Vietnam was the value of the gun system. As General Robin Olds emphatically pointed out in chapter three, the gun is "the most versatile weapon."[23] In actuality, gun systems are simple, reliable and inexpensive. Therefore, a reliable close-range weapon is desirable in the most sophisticated air-to-air fighter.

Pilot Training

Much has been written about training considerations. Air-to-air fighter training has been constantly improved and refined throughout the evolution of military aviation. The importance of training has never been underestimated. As early as World War I, Baron Manfred von Richthofen's Air Combat Operations Manual outlined a disciplined training regiment for young fighter pilots.[24] Two key training characteristics that apply to the air-to-air fighter are experience and specialized training.

Experience

Aerial combat veterans realize the value of combat experience. World War I theorists contested that the longer a pilot survived, the more skilled he became.[25] General Charles Yeager, the first pilot to fly faster than the speed of sound and a World War II combat veteran with 13 kills, expressed; "I have flown in just about everything, with all kinds of pilots in all parts of the world--British, French, Pakistani, Iranian, Japanese, Chinese--and there wasn't a dime's worth of difference between any of them except for one unchanging, certain fact: the best, most skillful pilot had the most experience."[26] This became blazingly evident during Vietnam. The RED BARON studies, discussed in chapter three, indicated the need for realistic combat simulation. RED FLAG exercises and others, like Cope Thunder and Tandem Thrust, are as close as possible to the real thing. After returning from a combat mission during Desert Storm, one aircrew remarked, "RED FLAG was harder."[27]

Specialized Training

The paramount training characteristic for an air superiority fighter is a cadre of pilots trained solely to conduct air-to-air missions. U.S. Air Force Captain Steve Richie, America's first ace in Vietnam, commented on the value of training; "The pilot most likely to succeed is the one most highly trained. Stated another way, a superior pilot in an inferior aircraft will defeat an inferior pilot in a superior aircraft."[28] Specialized training and specialized aircraft came about as a result of Vietnam.

Thus, the F-15 Eagle was built and is flown in the air-to-air role exclusively, and correspondingly, the pilots that fly the Eagle are akin to air-to-air operations only. This shift in philosophy has its roots in Air Defense Command. As discussed in chapter three, ADC conducted air-to-air missions only. Air Force Lt Colonel Allan Kelly was an Air Defense Command instructor pilot and the Supervisor of Tactics Research and Development at USAF Interceptor Weapons School. He wrote a research report for the Air War College in 1976, sighting in his recommendations that; "Air-to-air responsibilities should be assigned to a dedicated force and not be fragmented by assignment to units having alternate missions and roles."[29] His assessment was made based on his study of the combat records of flying units tasked solely with the air-to-air mission. A more in-depth study of combat results was conducted in 1994. In his thesis, Major Michael Ford, conducted research regarding the effectiveness of single-role versus multi-role fighter forces. He analyzed objective and subjective data from combat units spanning World War II to the Falkland Islands. He concluded that; "Single-role air-to-air fighter forces are more effective than multi-role fighter forces in the conduct of air-to-air combat operations."[30] To illustrate the difference in training requirements for an air-to-air unit versus a multi-role fighter unit, Table 5 compares the F-15C to the F-16C Weapons School Syllabus.

Table 5. Weapons School Syllabus Comparison

Role	F-15C[31]	F-15E[32]	F-16C[33]
Air-to-Air	34 Sorties 38 Hours	15 Sorties 19.8 Hours	22 Sorties 22.9 Hours
Air-to-Ground	Not Applicable	22 Sorties 28.2 Hours	18 Sorties 22.5 Hours
Total	34 Sorties 38 Hours	37 Sorties 48 Hours	40 Sorties 45.4 Hours

Source: U.S. Department of the Air Force. U.S. Air Force Museum. [on-line]; available at http://www.wpafb.af.mil/museum/research, February, 1998.

Note that the air-to-air training is nearly double for the air-to-air F-15 syllabus. This increase illustrates how training for multi-mission aircrews lacks air-to-air emphasis.

Specialized air-to-air flying units are not specific to the United States. The F-15 Eagle is flown as an air-to-air fighter in Saudi Arabia, Israel, and Japan. The British fly the Panavia Tornado F-3 a multi-role aircraft modified to perform air superiority duties exclusively.[34] This shows the importance that other nations, as well as the U.S., place on the air-to-air trained pilot.

Cost Considerations

Aviation is inherently tied to technology and technology is expensive. One World War II author expressed; "The reason that the jet era did not arrive sooner was not due to lack of technology."[35] Cost is most certainly a consideration in determining the essential characteristics of an air superiority fighter. It impacts aircraft design, avionics and weapons as well as training.

Historically, the problem facing airpower was simply to design and build better weapons than the enemy. Comparatively simple design changes often led to worthwhile performance improvements and as a result new aircraft appeared at frequent intervals. This was true throughout fighter evolution up to today's fourth generation fighters. In general, the approach to designs were broad and costs were not a major problem. However, over the past fifty years, developments in technology have led to increasingly impressive performance capabilities accompanied by an enormous rise in costs. A high performance fighter today costs nearly a thousand times more than its World War II counterpart.[36] Table 6 illustrates a comparison of production cost per aircraft and numbers produced.

Table 6. Fiscal Evolution of U.S. Fighter Aircraft.[37]

Aircraft	Year	Cost per Aircraft	Number Produced
P-40	1940	$200,000	13,738
P-51	1942	$190,000	14,686
P-47	1943	$310,000	15,682
F-86	1950	$760,000	6,227
F-100	1955	$1,600,000	2,294
F-105	1958	$4,600,000	833
F-4	1961	$3,800,000	4,600
F-111	1967	$15,000,000	449
F-14	1973	$17,000,000	322
F-15	1975	$9,200,000	729

Source: William D. White, U.S. Tactical Airpower: Missions, Forces and Costs (Washington, D.C.: The Brookings Institution, 1974.), 47.

The figures are taken from William White's book, U.S. Tactical Airpower: Missions, Forces and Costs, written in 1975. Thus, the dollar values are in terms of 1975 dollars, this accounts for the relatively low cost (9.2 million for an F-15).[38] This data clearly brings to light that production numbers have decreased commensurate with cost. However, the total production costs for a single type of aircraft are within 15 to 25 percent of each other. An example is the P-47 compared to the F-14, depicted in Table 7.

Table 7. Cost Comparison of P-47 to F-14

P-47		F-14
15,682	**Number Produced**	322
310,000	**Cost per Aircraft**	17 Million
4.8 Billion	**Total Cost**	5.4 Billion

Source: William D. White, U.S. Tactical Airpower: Missions, Forces and Costs (Washington, D.C.: The Brookings Institution, 1974.), 47.

The table shows that individual aircraft prices are understandably higher, but fewer are required to get the job done. Air Chief Marshal Rosier, stated that improving aircraft features would make fewer aircraft more efficient and cost effective. He pointed out three examples where technological improvements would decrease the number of aircraft required. They were: (1) increased radar detection capabilities, (2) greater endurance via enhanced engine and airframe designs, and (3) decreased maintenance turnaround time due to better systems reliability.[39]

Rosier also, stressed that; "Improved survivability can come about through the development of an air vehicle which, by virtue of its size, its design and its performance, will minimized the chances of being detected and being destroyed."[40]

Perhaps the greatest debate relative to cost and effectiveness is whether or not to design and operate single-role or multi-role aircraft. This debate has plagued fighter aviation throughout its evolution. However, U.S. fighter development has almost exclusively centered around multipupose airframes. In his thesis, Ford points out:

> Throughout most of the USAF's history, multi-role fighter forces have been the norm and have tended to resemble the swing role air-to-air and air-to-ground fighter units of those employed during World War II, In fact, with the exception of the F-15C and the dedicated continental air defense interceptors, every fighter flown by the USAF has been used to operationally to drop bombs and attack ground targets.[41]

Even the F-15C carried and dropped practice bombs during its operational debut and still contains the air-to-ground computer software providing a surface attack capability. The Navy's Tomcat also has the structural provisions to deliver large payloads against ground targets. In terms of versatility, these "air superiority" fighters conform to the tradition for U.S. fighter designs.[42] This bolsters Ford conclusion that fighter units, composed of multi-role aircraft, tasked with a single-role of air-to-air were more effective at air-to-air missions than units tasked to conduct multi-role operations. Therefore, an air superiority fighter's design must be suitable for performing the air-to-air role. Adding multi-role capabilities is a question of design cost.

Advocates for multipupose designs argue that it is more economical with fewer aircraft varieties in the inventory. They reason that designing one aircraft and making minor modifications so that its capable of carrying out several different missions can lead to developmental savings and in operating and maintenance through standardization. The most prolific example of this is the F-4 Phantom II, that spanned the gap between the third and fourth generation fighters due to its versatility. The disadvantage of building a highly versatile aircraft is the "jack of all trades, master of none" catchall. In other words, it will be less proficient at doing any single task. Additionally, an aircraft intended to perform several operations must be designed to fulfill the most difficult. Thus, the aircraft is inherently over-designed to perform the simpler or less demanding tasks.[43]

Advocates of single purpose aircraft embrace specialization and mastery of a single niche. The pros and cons are opposite to those of the multi purpose fighter. In addition, a large disadvantage posed by specialization is the lack of flexibility. A multipurpose fighter can be adapted to perform other missions, a highly specialized fighter may not be able to perform some missions without undergoing major modifications.[44]

[1] William R. Emerson, "Operation POINTBLANK: A Tale of Bombers and Fighters" Reprinted in U.S. Army Command and General Staff College, C610 The Evolution of Modern Warfare, 238-263. (Ft Leavenworth, KS.: USACGSC, December 1997), 247.

[2] Bill Gunston, The Encyclopedia of World Airpower (New York: Crescent Books, 1981), 194.

[3] Norman Franks, Aircraft versus Aircraft: The Illustrated Story of Fighter Pilot Combat Since 1914 (New York: Macmillian Publishing Company, 1986), 131.

[4] David A. Anderton, The History of the U.S. Air Force (New York: Crescent Books, 1981), 104.

[5] Franks, 26.

[6] Gunston, 253.

[7] Franks, 38.

[8] Ibid., 42.

[9] Ibid., 77.

[10] Gerard A. Pelletier, "The Aerial Dogfight: A Valid Part of Today's and Tomorrow's Air War" Master of Military Arts and Science Thesis (U.S. Army Command and Staff College, Ft. Leavenworth, KS, 1990), 18.

[11] Ibid., 28.

12 [12] Walter J. Boyne, Silver Wings: A History of the United States Air Force (New York: Simon & Schuster, 1993), 281.

[13] Gunston, _253.

[14] Franks, 18.

[15] George W.Stimson, Introduction to Airborne Radar (El Segundo, CA.: Hughes Aircraft Company, 1983), 171.

[16] Merrill A. McPeak, Selected Works 1990 - 1994 (Maxwell Air Force Base, AL.: Air University Press, August 1995), 223.

[17] William S. Lind, Maneuver Warfare Handbook. (Boulder, CO.: Westview Press Inc., 1972), 5.

[18] Franks, p. 44.

[19] U.S., Department of the Air Force. AFDD 1 Basic Aerospace Doctrine [on-line]; available at http://hqafdc.maxwell.af.mil, October, 1997, 23.

[20] E.J. Feuchtwanger and R. A. Mason, Airpower in the Next Generation (London, England: The Macmillan Press, 1979), 104.

[21] Pelletier, 106.

[22] Charles M. Westenhoff, Military Airpower: The Cadre Digest of Airpower Opinions and Thoughts (Maxwell Air Force Base, AL.: Air University Press, October 1990), 93.

[23] Franks, 178.

[24] Peter Kilduff, Richthofen: Beyond the Legend of the Red Baron (New York: John Wiley & Sons, Inc., 1993), 236-237.

[25] Franks, 45.

[26] Westenhoff, 23.

[27] McPeak, 178.

[28] Michael W. Ford, "Air-to-Air Combat Effectiveness of Single-Role and Multi-Role Fighter Forces" Master of Military Arts and Science Thesis, U.S. Army Command and Staff College, (Ft. Leavenworth, KS, 1994), 8.

[29] Allan J. Kelly, "A Study of Air-to-Air and Air Defense Training Philosophies and Requirements?" (Research Report, Air War College, Maxwell Air Force Base, AL, 1976), 73.

[30] Ford, 113.

[31] U.S., Department of the Air Force. ACC Syllabus: USAF Weapons Instructor Course F-15 (Langley AFB, VA.: Headquarters Air Combat Command, July 1997), 12-13.

[32] U.S., Department of the Air Force. ACC Syllabus: USAF Weapons Instructor Course F-15E (Langley AFB, VA.: Headquarters Air Combat Command, July 1997), 15.

[33] U.S., Department of the Air Force. ACC Syllabus: USAF Weapons Instructor Course F-16 (Langley AFB, VA.: Headquarters Air Combat Command, July 1997), 13-14.

[34] Gunston, 292.

[35] Bruce D. Callander, "The Fielding of the F-86" Air Force Magazine (December 1997), 52.

[36] Feuchtwanger, 105-106.

[37] Ibid., 47.

[38] William D. White, U.S. Tactical Airpower: Missions, Forces and Costs (Washington D.C.: The Brookings Institution, 1974.), 47.

[39] Feuchtwanger, 104-105.

[40] Ibid., 95.

[41] Ford, 5.

[42] White, 53.

[43] Ibid., 56.

[44] Ibid., 58.

CHAPTER FIVE

CONCLUSION AND RECCOMMENDATIONS

Conclusion

The data presented in the preceding chapters provides the information necessary to answer the research question. A complete review of air superiority fighter evolution was divided into four distinct generations. Within each generation, the research and analysis focused on three key areas of interest in order to determine the consistent characteristics. The key areas of interest: (1) aircraft design, (2) avionics and weapons, as well as (3) training were coupled with a discussion of cost considerations in chapter four.

Table 8. Characteristics of Air Superiority Fighters

Aircraft Design	Avionics and Weapons	Training
-Highly Maneuverable	-First-Launch-Opportunity	-Experienced Aircrews
-High Speed and Altitude	-Autonomy	-Specialized Training
-Long Range	-Low Cockpit Work Load	
-Small Size	-Dogfight Weapons	
-Good Visibility		

The results yielded an in-depth database for determining the essential characteristics of an air superiority fighter. The following section will draw conclusions from the results found in chapter four.

Aircraft Design

The air superiority fighter must outperform all other aircraft. In terms of aircraft design, this means that the most successful air-to-air fighters were the ones designed for the air-to-air role. Obvious examples include the F-15, the F-86, and the P-51. These designs were tailored to meet the key performance characteristics required for air-to-air success. The dominant performance characteristics are maneuverability and speed. High altitude capabilities are essential to enhance these performance qualities as well as increase weapons engagement envelopes and fuel efficiency. Additionally, long-range capabilities are imperative. The air-to-air fighter must have the endurance to perform escort duties as well as have adequate on-station time for various counterair missions. An air superiority fighter's size is another important characteristic. Smaller is better; however, by necessity aircraft have gotten larger with technological advances. Therefore, design methods that reduce visual silhouette as well as radar signature are paramount. Finally, the pilot must have superior visibility outside the cockpit to increase his visual lookout capabilities.

Avionics and Weapons

The successful air superiority fighter has the first shot in air-to-air combat. Superior avionics and weapons gives the pilot the ability to achieve the first launch opportunity. That opportunity is also a product of the fighter's autonomy and pilot workload. As mentioned at the beginning of chapter three, Baron Manfred von Richthofen once said; "The job of the fighter pilot is to roam his allotted area in any way he likes, when he spots an enemy, he shoots him down. Anything else is rubbish."[1] That may sound arrogant, but his quote stressed the importance of autonomy to the air superiority fighter. In the dynamic air-to-air combat environment, it is critical for the pilot to have the ability to make quick and accurate engagement decisions. Autonomy coupled with streamlined cockpit information reduces the pilot workload. Labor intensive equipment and displays hinder the pilot's ability to achieve the first shot. Easy-to-use equipment with clear, concise and uncluttered information gives the fighter the advantage. A final characteristic is the dogfight weapon. Close-in combat remains a viable threat in any air-to-air combat arena; therefore, the air superiority fighter must be equipped with a relatively simple and reliable dogfight weapons system.

Training

Fighter aviation is an extremely dynamic environment and air-to-air is the most demanding role. The most imperative characteristic of the air superiority fighter is a singularly trained cadre of pilots to fulfill the air-to-air role. History shows that there is a combat advantage gained from experience and dedicated air-to-air training. They are paramount to an air superiority fighter's success. The book titled Introduction to Advanced Fighter Tactics, written around the time of the Korean conflict, stressed this philosophy. "When two aircraft of relatively similar performance meet, pilot ability will probably be the deciding factor."[2] Thus, in absence of actual combat, realistic air-to-air training is imperative.

Cost Considerations

Aviation is inherently expensive. Cost considerations fit into the analysis as a leveler for desired characteristics and the reality of what is affordable. From aircraft design to the flying hours allocated for pilot training, fiscal restrictions effect all three of the key areas of interest. The prevailing U.S. philosophy of producing multi-role fighters is an aircraft design feature that is directly related to cost considerations. This remains a constant; however, there are two key considerations that hold true. First, the air superiority fighter aircraft must be built to conduct the air-to-air role. This is based on the overlying characteristic of "outperformance," as mentioned in the aircraft design conclusions. Modifications to multi-role capability may stem from the initial design once the air-to-air performance characteristics are satisfied. Second, there must be a dedicated cadre of pilots that train exclusively for the air-to-air role. An example of this is the F-15 Eagle. Today, the F-15 C-model serves as a dedicated air superiority fighter. Pilots that fly the C-model are trained and tasked to conduct air-to-air missions only. Conversely, the F-15E is a variant of the Eagle modified to effectively carry out the air-to-ground role. F-15E aircrews train for both the air-to-air and air-to-ground roles; however, their primary mission is air-to-ground.

Summary

To answer the thesis research question, the preceding conclusions boil down to the following statement. There are three essential characteristics of an air superiority fighter:

1. The aircraft is designed for the air-to-air role
2. The aircraft has the first launch opportunity
3. The aircraft is flown by singularly trained air-to-air pilots.

Importance

This thesis focused primarily on the past. It drew out the historical essential characteristics of the air superiority fighter. These findings are a foundation to build upon and they are important to the development of the next generation fighter.

The F-22 Raptor is a fifth generation fighter. Conceived in the 1980s, the F-22 was specifically designed for the air superiority mission and it embodies the "outperformance" qualities essential for success. However, apart from aircraft design, its future is still malleable. Thus, the essential characteristics found in this thesis may still be applied in defining its endgame production and use.

The National Defense Panel (NDP), invoked by Congress in 1996, was created to give a second opinion to the Pentagon's Quadrennial Review. In its report, *Transforming Defense; National Security in the 21st*

Century, the panel asserted that the U.S. must begin now to create a force for the future so that we are proactive not reactive to the next threat.[3] Several force characteristics included in the report marry directly to the findings in this thesis. Table 9 illustrates the force characteristics highlighted in the NDP report.

Table 9. NDP Proposed Force Characteristics

Systems Architectures. Information technologies could dramatically enhance the ability to integrate the actions of widely dispersed and dissimilar units. Such systems architectures would enable highly distributed, network-based operations.
Information System Protection. The defense of our commercial and military information architecture will be critical and will allow us to protect our forces and our platforms from the enemy's reconnaissance efforts. New means to protect information systems and identify the origin of cyber attacks must be the highest priority, Today. we are vulnerable.
Information Operations. Significant improvements in the application of military force will be achieved by electronic strike capability. We need to develop the ability to insert viruses, implant 'logic bombs,' conduct electromagnetic pulse and directed energy strikes and conduct other offensive electronic operations.
Automation. (to include the migration into space and unmanned platforms). The major advantage automation gives us is speed. Given that time will be an increasingly scarce resource in future warfare, automation-aided operations can temporarily compress operations.
Small Logistics Footprint. Not only do we require lighter, more mobile forces, but we also require lean logistics. There may be no secure rear areas. A smaller logistics footprint will represent less of a target and at the same time, less of a strain on indigenous infrastructures and our own strategic air and sealift.
Mobility. The ability to move our forces rapidly and in the right configuration is key to their effectiveness. Most importantly, the greater their mobility, the greater their protection.
Stealth. Increasingly, any force that can be seen is-likely to be hit. The best protection, therefore, is not to be seen. At the same time, the ability to avoid detection affords the opportunity for tactical surprise–which in turn can allow for strategic and operational surprise The stealth embodied in our planes and submarines today will be increasingly important to our air, sea, and ground forces tomorrow.
Speed. Given advances in the speed of information flow and communications, the unfolding and duration of critical engagements–indeed the tempo of war itself–has shrunk dramatically. The rate at which we can mobilize, deploy, set, act, and reset for any action–preemptive or reactive–will likely be fundamental to success.
Increased Operational and Strike Range. We will need increased ranges to ensure the safety of our forces and their ability to achieve desired effects from disparate locations. Greater ranges will also offset the growing vulnerability of forward forces.
Precision Strike. Precision weapons will enable the use of far fewer platforms, with no loss in force capabilities. Precision and the ability to discriminate among targets near each other will limit collateral damage.

Source: John A. Tirpak, "The NDP and the Transformation Strategy," Air Force Magazine (March 1998), 23.

Highlighted in the report were automation, mobility, stealth, speed, precision strike and increased range. Although not expressed in the exact same terms, those same characteristics are part of this thesis' conclusions.

Recommendations

This topic has innumerable avenues for exploration. Since military aviation is a relatively new tool of modern warfare—seventy-five years versus over two thousand years of ground battle—there are many issues to address and debate. This section will pose some additional areas for further research that were beyond the scope of this thesis.

Is there a justifiable need for the Joint Strike Fighter (JSF)? Modifying the F-22 to multi-role may be more cost effective. This thesis points out that a multi-role fighter is acceptable as an air superiority fighter. The F-22 could be altered, like the F-15E. However, there must be units designated solely for air-to-air and have pilots trained specifically for that role. Thus, one possibility is the production of a larger number of F-22 aircraft and diversify their roles and functions. For example, there could be air-to-air units, air-to-ground units and SEAD units all composed of F-22 variants flown by specifically trained pilots. Further research may also focus on the feasibility or compatibility of the F-22 in these functions.

The F-22 versus the F-18E/F, which is a better choice? The F-18E/F is touted as the USN and USMC multi-role fighter of the future. A study could focus of the feasibility of modifying the F-22 to suit both the services' needs. Like the previously mentioned research topic, this study could measure the benefits of reconfiguring the F-22 versus acquiring more types of aircraft.

What are the essential hardware items needed in the F-22 to face the threat now and in the future? This topic is an application of the essential characteristics found in this thesis to the F-22 specifically. Given the current threat and a projected threat model, the study could focus on determining what the F-22 must have in terms of avionics and weapons. This research should be classified; however, its near- and long-term findings may be influential in fifth generation fighter development.

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[1] Ronald L. Hanson, "Evolution of the Modern Dogfight," (Student Report, Air Command and Staff College, Maxwell Air Force Base, AL, April 1987), 1.

[2] Norman Franks, Aircraft versus Aircraft: The Illustrated Story of Fighter Pilot Combat Since 1914 (New York: Macmillian Publishing Company, 1986), 173.

[3] John A. Tirpak, "The NDP and the Transformation Strategy," Air Force Magazine (March 1998), 22.

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