# LONELY SKIES:
# AIR-TO-AIR TRAINING FOR A 5TH GENERATION FIGHTER FORCE

BY

MAJOR JASON C. ZUMWALT

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## ABOUT THE AUTHOR

Major Jason C. Zumwalt was commissioned in 2001 following graduation from the United States Air Force Academy. He is a senior pilot with more than 1200 hours in the F-15C Eagle. His flying assignments include Eglin AFB, Elmendorf AFB, Great Falls, MT, and Nellis AFB. While at Nellis AFB, Major Zumwalt served as a United States Air Force Weapons School Instructor and Chief of Adversary Integration where he was responsible for providing realistic airborne training aids for USAF Weapons School flying programs. He holds a Bachelor of Science degree in Political Science from the United States Air Force Academy, a Master of Business Administration from Oklahoma State University, and a Master of Military Operational Art and Science from the US Air Force Air Command and Staff College. Following Major Zumwalt's studies, he will report to RAF Lakenheath as a member of the 48th Fighter Wing.

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## ABSTRACT

This study analyzes how the US Air Force can use training to prepare its F-22 and F-35 pilots to meet future operational requirements. The author begins by reviewing six historic examples of the Air Force's use of combined flight and simulator training to provide a representative environment for pilot training. The author then shows how the lessons learned from these examples have led to the development of an air-to-air training approach that requires representative flight and simulator training at the squadron level. Next, this approach is analyzed as it has been applied to F-22 and F-35 air-to-air training to meet the combatant commanders' requirement for the pilots to be proficient at air combat against enemy 4th generation fighter threats. This analysis reveals several shortfalls in the current training approach for the F-22 and F-35 fighter aircraft pilots. Contemporary F-22 and F-35 pilots do not train against sufficient quantities of representative threats in flight or adequately dynamic threats in simulators. The author concludes that these deficiencies could lead to pilots applying the wrong lessons learned in training, which could reduce their effectiveness in combat. The author then analyses three potential changes the Air Force could make to fill the training gaps in the current approach. These gaps and proposed solutions provide insight into the requirement for the Air Force to invest not only in new technologies, but also in the means to train pilots of advanced aircraft.

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## INTRODUCTION

*What is chiefly needed is skill rather than machinery.*

Wilbur Wright in letter to Octave Chanute,
13 May 1900

In October 1967, the Department of Defense published a report titled "Air-to-Air Encounters in Southeast Asia." This report was the first of many Red Baron Reports to analyze fighter performance in Vietnam. Based upon their research, the Project Red Baron team concluded that insufficient and unrealistic training was a primary reason for the poor performance of fighter pilots in Vietnam.[1] After conducting over 400 interviews and reconstructing 78 engagements, the Red Baron team found that US aircrew believed their peacetime training lacked practice against adversaries that looked or acted like enemy aircraft.[2] The aircrew also noted that their training did not prepare them for maneuvers at low altitude, where most of the air-to-air engagements in Vietnam took place.[3] Because of these factors, pilots often reacted incorrectly and either lost the advantage or failed to take it away from the enemy during combat. Based on the reports and Tactical Air Command's (TAC) initiative to provide "Readiness through Realism," US Air Force Col. Lloyd "Boots" Boothby helped establish the Dissimilar Air Combat Tactics (DACT) and aggressor programs.[4] These programs were the command's

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[1] DOD Weapons Systems Evaluation Group, "Air-to-Air Encounters in Southeast Asia, Volume 1: Account of F-4 and F-8 Events prior to 1 March 1967" (Washington D.C.: Department of Defense, October 1, 1967), 256, Document is now declassified.
[2] DOD Weapons Systems Evaluation Group, "Air-to-Air Encounters in Southeast Asia," 256.
[3] DOD Weapons Systems Evaluation Group, "Air-to-Air Encounters in Southeast Asia," 111.
[4] Ellery Wallwork, "Fighter Pilot Balanced Tactics, Safety, Effectiveness," *US Air Force History Office*, December 5, 2006, 1, http://www.af.mil/News/ArticleDisplay/tabid/223/Article/128840/fighter-pilot-balanced-tactics-safety-effectiveness.aspx.

attempt to provide realistic training for US Air Force fighter pilots and to improve their performance in air combat.

Colonel Boothby recognized the operational requirement for better tactical performance in Vietnam and instituted training programs to prepare fighter pilots to meet that need. In the past, the US Air Force has used new technologies and methods to address training deficiencies. From basic instrument flying to complex combat tasks, the Air Force has used realistic training to prepare its aircrew. One of the cornerstones of Air Force air-to-air training has been the ability of its pilots to train against threat-representative adversaries both in the air and in the simulator. The newest fighters in the Air Force inventory, the F-22 and F-35, however, face challenges in replicating enemy aircraft for training. To obtain this training, these 5th generation fighters rely on dissimilar training support from older aircraft, such as the F-15, F-16, or 1950's-era T-38. As the Air Force prepares to purchase 1,763 F-35 fighters and retire its older 4th generation fighters, it must plan for how to train its fighter pilots properly against an enemy that it may no longer be able to replicate in peacetime.

The cost of failing to provide a representative adversary in training is that pilots may take the wrong lessons into combat. F-22 and F-35 pilots may not codify faulty tactics in doctrine; but daily training affects how pilots react in combat, just as in the Vietnam War. As the Air Force outpaces the technology of its potential enemies, it also loses the ability to provide itself with accurate training. This trend requires careful consideration of how to maintain air-to-air readiness against likely adversaries.

In 1973, renowned British historian Michael Howard commented on the difficulty of determining operational requirements in peacetime and then preparing the military to meet those requirements in war. He stated, "In discerning operational requirements the real conceptual difficulties of military science occur. If there is not rigorous thinking at

this level, neither technology nor money can help. With inadequate thinking about operational requirements, the best technology and the biggest budget in the world will only produce vast quantities of obsolete equipment; bigger and better resources for the wrong war."[5] Howard asserts that it may be impossible to predict what the operational requirements of the next war may be and that it is especially difficult in peacetime. He further concludes that the winner in conflict is often the one that can most rapidly adapt their doctrine to meet new challenges in war. While this seems to imply the Air Force does not need to worry about how it prepares, so long as it can rapidly adapt when a war does break out; Howard cautions that, "It is the task of military science in an age of peace to prevent doctrines from being too badly wrong."[6] Based on Howard's wisdom, the military scientist must aim at the imperfectly determined target of a future operational requirement and prepare the military forces to meet that requirement. Thus, this paper seeks to determine what the Air Force's future air-to-air operational requirement will likely be based on unclassified training directives, analyze current training preparation to meet that requirement, and suggest future means to better prepare US Air Force pilots and avoid, as Michael Howard said, being too badly wrong.

### ***Methodology***

This paper employs a historical, qualitative, and conceptual analysis of technical means and training methods used to meet the operational requirements of the US Air Force. This analysis is designed to answer the question, how can the Air Force prepare its newest fighters' pilots for air-to-air combat?

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[5] Michael Howard and A.J. Wilson, "Military Science in an Age of Peace," *The RUSI Journal* 119, no. 1 (March 1, 1974): 5.
[6] Howard and Wilson, "Military Science in an Age of Peace," 7.

To answer this question, Chapter 1 examines how the Air Force has adapted past training to prepare its aircrew to meet operational requirements. From flying in the weather to massive and complex air battles, this chapter analyzes how the Air Force adopted a combination of methods to reinforce and enhance training rather than relying on a single method. In order to teach the pilots difficult flying skills and prepare them for combat, the combination of flight and simulator training focused on providing a representative environment. The current air-to-air training approach evolved from the lessons learned during these historic cases.

Based upon unclassified direction from combatant commanders, Chapter 2 defines what the air-to-air operational requirement is for F-22 and F-35 fighter squadrons. This operational requirement then drives the type of training that is required to achieve pilot proficiency in the required tasks. Given these pre-requisites for air-to-air proficiency, Chapter 2 analyzes how the Air Force applied training approaches to train F-22 and F-35 pilots for air-to-air tasks and how the approach has left gaps in the reinforced desired skills for F-22 and F-35 fighter pilots. Chapter 2 identifies the reasons for the shortfalls in flight and simulator training for both F-22 and F-35 pilots and discusses the costs of failing to change the current training approach.

In an effort to provide a solution to training shortfalls, Chapter 3 suggests three programs the Air Force could implement to ensure that its pilots are prepared commensurate with their expected capabilities. This chapter analyzes these solutions based upon their intended impact on air-to-air training and their costs. This analysis reinforces the historic examples explored in Chapter 1, which reveals there is often no single answer to effective training. Instead, each of the three programs provides a portion of the solution.

### *Scope*

In order to provide a detailed analysis, this paper has a narrow focus on only the air-to-air aspect of F-22 and F-35 pilot training. While both aircraft have other missions, the analysis will center on air-to-air operational requirements and the necessary training to prepare pilots to meet them. Further research is required to determine the requirements and training effectiveness for air-to-surface, counter surface-to-air, and other missions for these aircraft. Additionally, because the Air Force has just begun investigating the proposed solutions, this analysis could not accurately estimate their future financial costs. Further research is required to determine the costs as the technology matures and then apply the benefits and costs to individual units to achieve a tailored solution at the wing and squadron levels.

In keeping with this narrow scope, the focus is on the training approach at the squadron level with broader implications for the Air Force as a whole. The timeframe included in this analysis ranges from the 1934 introduction of the Link Trainer to the present day training of fighter pilots.

The intended audience for this analysis is any party interested in maintaining the combat readiness of the US Air Force's fighter pilots. As such, the language and explanation may seem rudimentary to the initiated but provides the necessary background to understand a complex problem for a large portion of interested readers. The analysis aims for a balance between military pilot jargon for those familiar with training and combat and accessibility for those who are not.

Based on this desire for accessibility, it is necessary to define some commonly referred to terms. The term *operational requirement* means a capability or characteristic of a system, including people and processes, to achieve a desired result in a given time span. For example, an operational requirement could be the need to resupply an airbase with weapons during a conflict. While this requirement has many essential

tasks included in meeting it, in this example it requires a transport aircraft with a trained aircrew that can safely accomplish the re-supply mission on time. A key aspect of the solution to this hypothetical operational requirement is the integration of technology, the transport aircraft, and people - the trained aircrew. This thesis is based on the premise that any solution to an operational requirement must include preparing the people part of the system.

The study will refer to *4th generation fighters* as the previous technological generation of fighter aircraft which include the F-15C Eagle, F-15E Strike Eagle, and F-16 Fighting Falcon in the US Air Force. Enemy 4th generation fighters include the Russian MiG-29 Fulcrum and SU-27 Flanker variants. 4th generation fighters represent one generation removed from state-of-the-art technologies and capabilities. *5th generation fighters* refer to the newest generation of fighter aircraft. This generation of aircraft includes the F-22 Raptor and the F-35 Lighting II, which represent significant technological advances in sensors and stealth over 4th generation fighters. While other nations are working on future 5th generation aircraft, such as Russia's Sukhoi T-50 and China's Chengdu J-20, the 5th generation fighters referred to in this paper will be the F-22 and F-35.

When discussing training, the paper will use the terms defined in the Department of Defense and Air Force's guidance on modeling and simulation. The Department of Defense defines these terms as follows:

- *Model* – "A physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process."[7]
- *Simulation* – "A method for implementing a model over time."[8]

[7] United States Air Force, "Air Force Modeling and Simulation Vision for the 21st Century" (Washington D.C.: United States Air Force, July 6, 2010), 23.
[8] United States Air Force, "Air Force Modeling and Simulation Vision for the 21st Century," 24.

- *Virtual Simulation* – "A simulation involving real people operating simulated systems. Virtual simulations inject human-in-the-loop in a central role by exercising motor control skills, decision skills, or communication skills."[9]
- *Simulator* – "For training, a device [that] duplicates the essential features of a task situation and provides for direct human operation."[10]
- *Live Simulation* – "A simulation involving real people operating real systems."[11]
- *Flight Training* – A type of live simulation involving real people flying real aircraft.
- *Live* – "Real people operating real systems."[12]
- *Virtual* – "Real people operating simulated systems."[13]
- *Constructive* – "Simulated people operating simulated systems."[14]
- *Live, Virtual, Constructive (LVC)* – Training approach that integrates live, virtual, and constructive elements into a single simulation.

These terms describe aspects of training used by the Air Force to prepare its pilots. At times, the paper will use a shortened form for ease of reference. For instance, *flight* or *flight training* refers to live simulation

[9] United States Air Force, "Air Force Modeling and Simulation Vision for the 21st Century," 25.
[10] United States Air Force, "Air Force Modeling and Simulation Vision for the 21st Century," 24.
[11] United States Air Force, "Air Force Modeling and Simulation Vision for the 21st Century," 23.
[12] U.S. Department of Defense (DoD), "DoD Modeling and Simulation Master Plan, DoD 5000.59-P" (Washington D.C.: Under Secretary of Defense for Acquisition and Technology, October 1995), A–6.
[13] U.S. Department of Defense (DoD), "DoD Modeling and Simulation Master Plan, DoD 5000.59-P," A–6.
[14] U.S. Department of Defense (DoD), "DoD Modeling and Simulation Master Plan, DoD 5000.59-P," A–6.

using real flying aircraft. Likewise, *simulation* refers to a virtual simulation using a simulator.

### *Theoretical Application*

In 2011, US Air Force Chief of Staff, General Norman Schwartz, unveiled his vision for preparing the Air Force for future conflicts and avoiding a "hollow force" by focusing on readiness.[15] General Schwartz said, "My pledge for the coming year is to strengthen unit readiness and avoid a creeping hollow force that provides only the illusion of Global Vigilance, Reach, and Power."[16] This vision raises the question, how does the US Air Force train its pilots to meet future operational requirements? The following study shows that it takes multiple training approaches, and each must reinforce the lessons of the other. Future technical progress will demand constant review of training methods to ensure that the Air Force is still preparing its pilots for what it is asking them to do in war. Solving one aspect of the training shortfall is unlikely to solve all of the readiness problems. Preparing a fighter pilot requires proper flight training and simulation to reduce the costs of flying and exploit the simulator's ability to provide timesaving repetition.

Since 1934, the Air Force has used this combined method of training its pilots. While the tasks performed in simulators have expanded to include complex tactical employments, proper preparation requires both accurate flight training and simulation with expert feedback to achieve proficiency. The pilot's readiness will suffer if the precision of training available in flight or in the simulator falls short. If both flight training and simulator training fail to meet the mark, the US Air Force cannot reasonably expect its pilots to be prepared for the tasks it will give them.

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[15] J. Paul Croxon, "CSAF Announces 2011 'Vector,'" *Defense Media Activity - Air Force,* July 7, 2011, 1, http://www.kunsan.af.mil/news/story.asp?id=123263425.
[16] Croxon, "CSAF Announces 2011 'Vector,'" 1.

Determining future operational requirements during peacetime is an imperfect science, but the attempt brings the military's forces closer to where they will likely need to be at the start of the next conflict.[17] The Air Force has determined that F-22 and F-35 pilots have an operational requirement to engage in air-to-air combat against a 4th generation fighter threat.[18] Based upon this requirement, it is the responsibility of the Air Force to provide adequate training to its pilots to dominate the skies in the future.



[17] Howard and Wilson, "Military Science in an Age of Peace," 7.
[18] HQ ACC/A3T et al., "F-22A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015" (US Air Force, October 1, 2014), 15–17; HQ ACC/A3T, ACC/A3G, and AFRC/A3T, "F-35A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015" (US Air Force, October 1, 2014), 17–21.

## Chapter 1

## Meeting Operational Requirements

*The air battle is not necessarily won at the time of the battle. The winner may have been determined by the amount of time, energy, thought and training an individual has previously accomplished in an effort to increase his ability as a fighter pilot.*

Colonel Gregory "Pappy" Boyington, USMC

The US Air Force, and the Army Air Corps before it, has used training to prepare its aircrew for missions it anticipated needing in the future. These expectations drove the training methods used by the Air Force and resulted in a mix of live, virtual, and constructive training means. While each means had limitations and benefits, each was required for adequate aircrew training. In the past, the Air Force has used combinations of training methods to address training shortfalls that did not adequately prepare aircrew to meet operational requirements. This chapter will present six such historic cases of how the US Air Force has provided training solutions to address training needs and will evaluate how those solutions have evolved into its current approach to air-to-air training. These examples provide a glimpse of how the US Air Force has dealt with training shortcomings in the past and suggest a framework for developing training programs for 5th generation fighter aircrew.

### *Blind Flying - 1934*

On February 9, 1934, President Franklin D. Roosevelt signed Executive Order 6591 ordering the US Army Air Corps to provide the Postmaster General with aircraft, airfields, pilots, personnel, and

equipment to move all of the country's airmail.[1] The executive order gave the Air Corps only ten days to prepare to assume this new mission and came as a surprise to the Air Corps leadership. When the Air Corps took over the airmail mission, it was unprepared due to inadequate training of its pilots and inadequate navigation equipment in its aircraft.[2] These inadequacies resulted in sixty-six crashes and the death of 12 pilots in the 78 days of flying. All of the deaths occurred while flying in adverse weather conditions or at night.[3] These deaths highlighted the importance of investment in both navigation equipment and pilot training.

The US Army Air Corps failed to prepare its pilots adequately for "blind flying," or what pilots today call "instrument flying." To deliver mail, Air Corps pilots had to control their aircraft through takeoff, cruise, and landing at night or in clouds. Control in conditions of restricted visibility outside the aircraft required the pilots to transition back and forth from outside visual references to instrument indications inside the cockpit. This operational requirement drove the development of a new means to train pilots, the Link Trainer.

The blind flying environment was very different from a visual flight environment. When flying in reference to outside visual cues, such as the horizon, pilots could employ a "seat-of-the-pants" method of control. When flying by the seat of their pants, pilots use quick visual scans of the horizon and feelings of acceleration on their body to monitor aircraft performance. Pilots could then continuously monitor the desired performance of the aircraft with a cross-check of visual and kinesthetic cues without generally having to refer to flight instruments.

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[1] Norman E. Borden Jr., *Air Mail Emergency 1934* (Freeport, ME: The Bond Wheelwright Company, 1968), 8.
[2] Borden Jr., *Air Mail Emergency 1934*, 37.
[3] Neil Sheehan, *A Fiery Peace in a Cold War: Bernard Schriever and the Ultimate Weapon*, 1st Vintage Books ed (New York, NY: Vintage Books, 2010), 21.

Flying without access to accurate visual cues was a significant challenge to safely operate aircraft. First, pilots had to reference displays of flight instruments and interpret information that visual scans outside the cockpit could no longer provide. Pilots had to translate information from the instruments in the cockpit to determine aircraft performance, attitude, and location.

Second, pilots in blind flight could not trust the kinesthetic feedback they used during visual flight because it deceived pilots about the actual aircraft attitude and acceleration. 1st Lt James Doolittle used Doctor David Meyers' research to prove that seat-of-the-pants flying did not work for blind flight. Dr. Meyer's found that rotations and accelerations fooled the pilots' vestibular systems into believing that the aircraft attitude was different than it actually was, which resulted in vertigo.[4] As an early blind flying pioneer and leader, Doolittle believed that pilots should learn to ignore their physical sense of motion while flying blind and to trust their instruments.[5] Only experience taught General Doolittle this lesson. Less then four years earlier he had told students not to rely on their instruments while instructing at Rockwell.[6]

Finally, the instruments available to the Army Air Corps in 1934 were often inadequate to practice or operate in non-visual flight conditions. The aircraft the US Army Air Corps used to deliver mail often lacked critical instruments, such as an attitude indicator, to display the pitch and bank of the aircraft.[7] Figures 1, 2, and 3 demonstrate airmail aircraft that had instruments such as a compass, altimeter, airspeed indicator, vertical velocity indicator, engine performance instruments, and a turn–and-slip indicator for determining coordinated flight. Two of

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[4] James Harold Doolittle, *I Could Never Be so Lucky Again: An Autobiography* (New York, N.Y: Bantam Books, 1991), 129.
[5] Doolittle, *I Could Never Be so Lucky Again*, 130.
[6] Doolittle, *I Could Never Be so Lucky Again*, 129.
[7] Borden Jr., *Air Mail Emergency 1934*, 26; Sheehan, *A Fiery Peace in a Cold War*, 21.

these three aircraft, however, were missing the critical attitude indicator. In 1934, most US Army Air Corps aircraft were not properly equipped with an attitude indicator because pilots trained during the day in clear skies.

Figure 1. Keystone B-6A Cockpit without Attitude Indicator
*Source: The National Museum of the Air Force*

Most of the aircraft used had no attitude indicator, but the BT-2B (Figure 2) enjoyed a full suite of instruments. While others like the A-12 (Figure 3) had instrument shortages. Without the attitude indicator, pilots relied on the turn-and-slip indicator for indications of aircraft attitude. But, the turn-and-slip indicator only represented trends in aircraft turns and yaw, not aircraft pitch or bank.

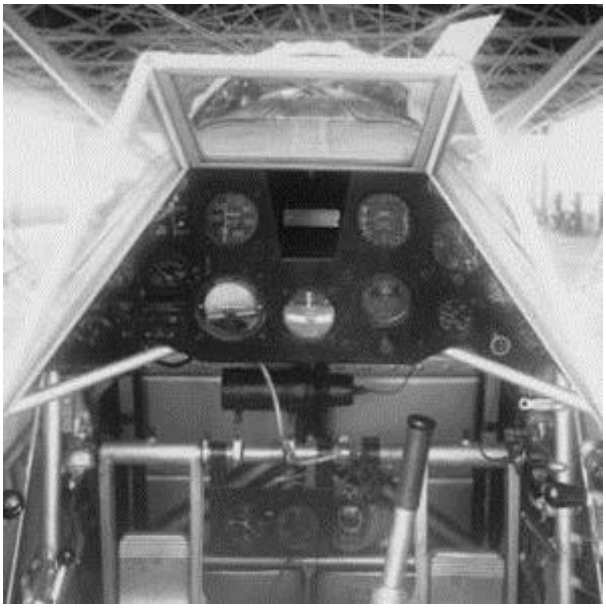

Figure 2. Douglas BT-2B Cockpit with Full Instrument Suite
*Source: The National Museum of the Air Force*

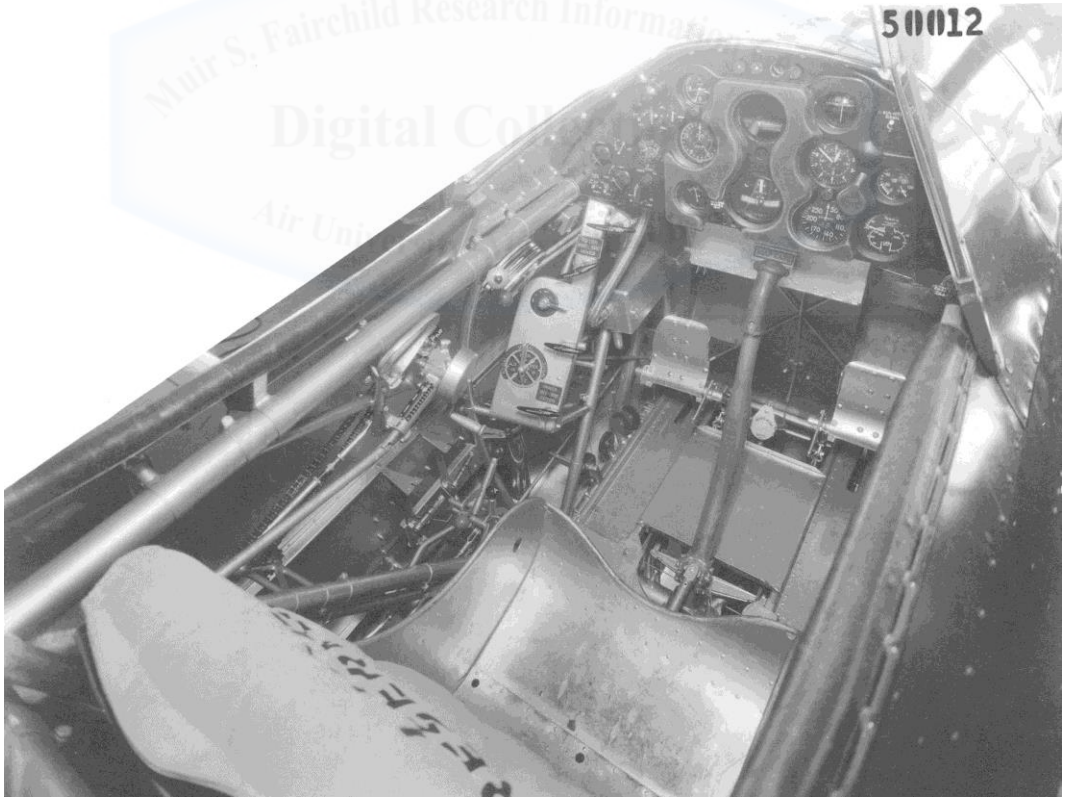


Figure 3. Curtiss A-12 Cockpit Missing Attitude Indicator
*Source: The National Museum of the Air Force*

Despite efforts of the US Army Air Corps to fly aircraft equipped with proper instruments, the service had become complacent in its training regimen due to a lack of sufficient funding for flight training. In response to the budgetary restrictions, the Air Corps cut individual flight training to the absolute minimum to maintain basic pilot proficiency, usually only four hours per month.[8] A lack of foresight also caused the Air Corps to prioritize daytime training in fair weather. At the time there was no impetus to push for all-weather training.[9] When the Air Corps began flying the mail, the average pilot had only five hours of instrument training. Pilots trained for blind flight using a visual restricting hood in an aircraft with a safety pilot.[10] Figure 4 shows Doolittle prepared for a flight with the visual restricting hood stowed on the side railings of his cockpit.

Figure 4. 1st Lt James Doolittle during Blind Flight Test
*Source: The National Air and Space Museum, Smithsonian Institution*

[8] Borden Jr., *Air Mail Emergency 1934*, 39; Sheehan, *A Fiery Peace in a Cold War*, 20.
[9] Borden Jr., *Air Mail Emergency 1934*, 39.
[10] Borden Jr., *Air Mail Emergency 1934*, 41.

The Army Air Corps Mail Operation (AAMCO) revealed that there was a significant lack of training in blind flight; but AAMCO leadership did not have sufficient funds, aircraft available for dedicated instrument flight training, or qualified and experienced instructors to train pilots for the regime.[11] As a result, blind-flight training in aircraft alone did not provide pilots with the experience necessary to fly safely without visual reference to the world outside the aircraft.

Blind flying proved impractical for training due to the lack of sufficient funding and the inherent risk of flying aircraft in hazardous conditions. AAMCO sought another solution to address the training problem and found one in Edwin Link's blind-flight simulator, known as the Link Trainer.[12]

The Link Trainer replicated a flying aircraft by producing appropriate indications on the instruments in the cockpit and responding to commands from the pilot. It had a generic aircraft cockpit, instructor workstation, and tracking table where the machine recorded the simulated flight path. Pilots could conduct an entire simulated blind flight in the Link Trainer without ever leaving the ground. Pilots could also repeatedly practice specific blind flight-tasks, such as level turns, to practice the instrument cross-checks and interpretations required for blind flight.

In 1934, Lieutenant Orvil Anderson, the chief AAMCO instructor, conducted a test of the trainer by giving twenty hours of blind flight instruction to six pilots.[13] Lt Anderson found that the Link Trainer was an extremely useful device to prepare pilots for blind flying in real aircraft.[14] The Air Corps immediately ordered ten Link Trainers and distributed them to the AAMCO bases of operation. Subsequently, the

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[11] Borden Jr., *Air Mail Emergency 1934,* 42.
[12] Borden Jr., *Air Mail Emergency 1934,* 99.
[13] Borden Jr., *Air Mail Emergency 1934,* 101.
[14] Borden Jr., *Air Mail Emergency 1934,* 101.

Air Corps ordered future-generation Link Trainers to train and maintain pilot proficiency in blind flying.[15] For some pilots the Link Trainer prepared them for blind flying before ever setting foot into the cockpit. For others it honed their skills and increased their proficiency.

While the Link Trainer provided the repetition needed to train pilots, it lacked the ability to replicate the kinesthetic feedback that the pilots experienced in the air. Pilots could not trust their seat-of-the-pants physical feedback instincts while blind flying. The Link Trainer could not teach the pilot to ignore the kinesthetic feedback experienced in flight because it could not replicate the acceleration of flight. Additionally, the Link Trainer had a generic cockpit layout that was unlike any aircraft in the Army Air Corps' inventory. Therefore, pilots could learn blind-flight fundamentals in the Link Trainer but had to practice specific instrument cross-check procedures and techniques in the aircraft itself. Despite these shortcomings, the Link Trainer provided a cost effective means for training that was otherwise impossible due to budget and risk constraints.

Figure 5. An Early Link Trainer Cockpit
*Source: National Museum of the Air Force*

[15] Lloyd L. Kelly, *The Pilot Maker* (New York, N.Y.: Grosset and Dunlap, 1970), 59.

Prior to 1934, the US Army Air Corps insufficiently funded and prioritized the training necessary to fly safely in the weather. To fill this training gap the Air Corps adopted a training approach that used both live flight and simulation. While the combined training method was only one of many changes that the US Army Air Corps implemented in the aftermath of the Air Mail Scandal of 1934, it played a critical role in establishing a new means of training that helped prepare the Air Corps pilots for World War II. In 1966 Lt Gen Ira Eaker wrote, "The deficiencies in organization, training and equipment glaringly revealed by the Army air mail experience were undoubtedly significant, perhaps decisive, in preparing for the world war which was but seven years away."[16] The Air Corps used flight training and simulation to prepare its pilots to fly in adverse weather conditions and at night. The combination of flight training and simulated flight with restricted visibility outside the aircraft not only helped prepare pilots for airmail operations, but it also prepared them for the challenging weather conditions they faced in combat during World War II.

### *Precision Bombing – 1944*

In the aftermath of World War I (WWI), the US Army Air Corps developed a strategy that required its bombers to bypass the front lines and drop bombs deep in the heart of the enemy nation, breaking its ability and will to fight. To achieve this feat, the Air Corps developed bombers to carry weapons over long distances and through the weather, if required. It also developed bombsights to deliver bombs on their intended targets.[17] This led to the Air Corps' strategy of high-altitude-daylight-precision bombing used in Europe during World War II (WWII).

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[16] Borden Jr., *Air Mail Emergency 1934*, 7.
[17] Stephen Lee McFarland, *America's Pursuit of Precision Bombing, 1910-1945*, Smithsonian History of Aviation Series (Washington: Smithsonian Institution Press, 1995), 4.

The Air Corps' precision doctrine led to the need for pilots and bombardiers to control the aircraft and release the bombs with sufficient accuracy to destroy static ground targets. The Air Corps used both flight training and simulation to train its pilots and bombardiers because neither option was alone sufficient to gain proficiency.

In the 1930's and 1940's, the Air Corps worked to develop its doctrine of precision bombing. While the Norden bombsight increased success rates, it did not provide sufficient accuracy to execute the Air Corps' planned strategy.[18] This deficiency in precision resulted from both an overstatement of the sight's capabilities to account for high winds at high altitude and inadequate proficiency by bombardiers.[19] As a result, the Air Corps began employing bombers in large formations to drop large amounts of ordnance on single targets in the hopes of increasing the probability of achieving a hit.[20] Despite changing formation tactics and the increased capabilities of the Norden M-1 bombsight over the D-4 variant, Stephen McFarland notes that, "the greatest single cause for error continued to be bombardier error."[21] Precision bombing required bombardiers to have precise timing and skill gained from experience. In order to address this human error, the Air Corps conducted flight and simulated training to prepare bombardiers for WWII.

Live-flight training was effective because it exposed bombardiers to stresses experienced in flight, such as noise and vibration and required them to coordinate with pilots for control of the aircraft. Coordination was necessary because the Norden bombsight system employed an autopilot that gave aircraft control to the bombardier in the final

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[18] McFarland, *America's Pursuit of Precision Bombing, 1910-1945*, 96.
[19] McFarland, *America's Pursuit of Precision Bombing, 1910-1945*, 97.
[20] McFarland, *America's Pursuit of Precision Bombing, 1910-1945*, 96.
[21] McFarland, *America's Pursuit of Precision Bombing, 1910-1945*, 98.

moments of a bombing run.[22] Flight training was not the most efficient means of training bombardiers in bombing procedures, however, because each flight was also spent training pilots on takeoff, landing, and navigation skills. During flight training, crews divided practice time between repeating the bombing process and satisfying other training requirements.

Flight training at the time was also not representative of the wartime high-altitude operations. From 1930-1938, the Air Corps dropped less than three percent of practice bombs from above 16,000 feet due to fuel shortages.[23] Of the 678,190 practice bombs dropped in the first half of 1944, bombers dropped more than half below 10,000 feet and only 12,000 bombs from above 20,000 feet, again due to shortages in aviation fuel.[24] Flight training failed to provide bombardiers with adequate repetition or a representative bombing environment because precision bombing was supposed to take place from above 20,000 feet.[25]

Bombardiers had to practice from higher altitudes because the effects of aircraft speed and wind over a long duration bomb fall reduced accuracy. But bombardiers could not practice high-altitude bombing in flight because of the constraints imposed by fuel shortages. Instead, bombardiers in the Air Corps used bombing trainers on the ground to simulate high-altitude bombing operations. These simulators gave bombardiers the ability to practice bombing procedures safely and cost-effectively while also simulating bomb drops from higher altitudes. These training devices complemented the training received in flight and helped fill the gap between available flight training and the need for proficient bombardiers.

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[22] McFarland, *America's Pursuit of Precision Bombing, 1910-1945*, 98, 159.
[23] McFarland, *America's Pursuit of Precision Bombing, 1910-1945*, 95.
[24] McFarland, *America's Pursuit of Precision Bombing, 1910-1945*, 159.
[25] McFarland, *America's Pursuit of Precision Bombing, 1910-1945*, 159.

From 1934-1936, Henry H. Arnold's crews tested and proved the idea that practice could improve bombing accuracy while using Norden bombsights on Keystone B-9 and B-10 bombers.[26] Through repetition and "considerable practice Arnold's crews achieved improved accuracy."[27] The A-2 and later A-6 ground trainers gave bombardiers practice in bombing procedures and techniques that was representative of higher employment altitudes.

Until 1944, The A-2 ground trainer (Figure 6) provided bombardiers with the ability to practice bombing procedures in a representative virtual environment. The trainer consisted of a ten-foot high platform, which a pilot drove in response to direction from the trainee bombardier.[28] The A-2 trainer allowed bombardiers to practice bombing while simulating the effects of drift and airspeed on bomb trajectory. The A-2, however, lacked the ability to replicate high-altitude operations accurately.

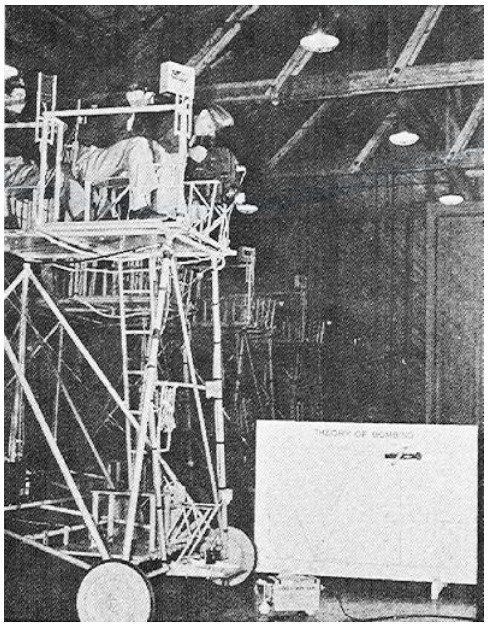

**Figure 6. A-2 Bombardier Trainer**
*Source: The National Museum of the Air Force*

[26] McFarland, *America's Pursuit of Precision Bombing, 1910-1945*, 96.
[27] McFarland, *America's Pursuit of Precision Bombing, 1910-1945*, 96.
[28] McFarland, *America's Pursuit of Precision Bombing, 1910-1945*, 159.

In 1944, the Link A-6 Bombing Trainer (Figure 7) became the solution to the shortcomings of the A-2 trainer. The A-6 could replicate altitudes up to 18,000 feet, much closer to anticipated employment altitude of 20,000 feet. The A-6 also replaced the platform and driver system with an autopilot interface so bombardiers could practice Norden-bombsight operations. The A-6 trainer also saved the Army Air Forces $150 per hour of bombardier training when compared to an hour of flight training. This was equivalent to $2,017 in 2014 dollars.[29] The A-6 provided a cost-effective training method that was better able to replicate bombing conditions and the autopilot interface than the A-2 trainer.

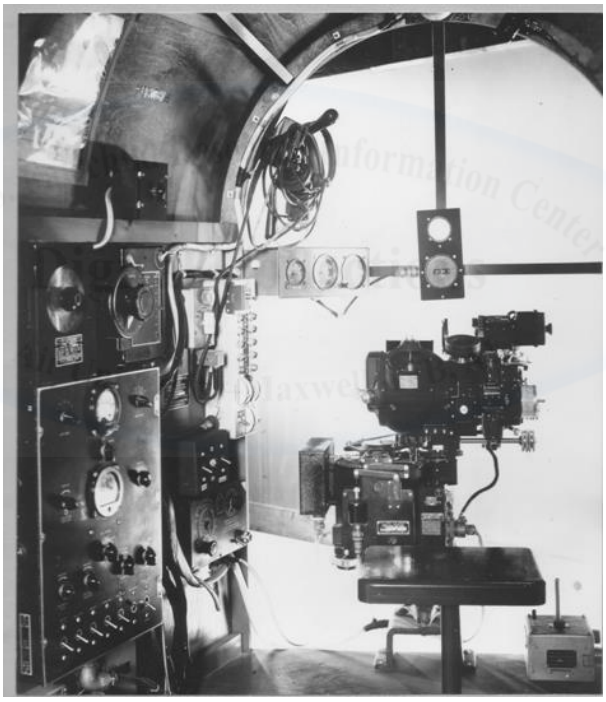

Figure 7. Link A-6 Bombing Trainer
*Source: The National Museum of the Air Force*

The US Army Air Corps' doctrine of precision bombing created a need to control an aircraft and release weapons accurately against static ground targets. The Army Air Corps used both flight training and

[29] McFarland, *America's Pursuit of Precision Bombing, 1910-1945*, 159; Bureau of Labor Statistics, *Consumer Price Index Inflation Calculator*, 2015, http://www.bls.gov/data/inflation_calculator.htm.

ground-based simulator training to provide the necessary practice for its aircrew. Flight training provided effective training for aircrew coordination and acclimated the crew the stresses of flight such as noise, vibration, and weather impacts on bombing runs. Flight training, however, was costly and suffered from limitations on flight altitude and quantity of sorties that led to inadequacies in bombardier training. Simulated bombardier training with the A-2 and A-6 ground trainers provided additional repetition for the bombardier in the procedural aspects of bombing, while the A-6 also provided training representative of high-altitude operations. In sum, to achieve the desired level of bombing proficiency the US Army Air Corps used complementary flight and simulation training.

### *Emergency Procedures – 1949*

With the advent of jet fighters and trainers such as the Lockheed P/F-80 and T-33 (a trainer version of the P-80), pilots faced growing complexity in their aircraft systems. The introduction of more advanced engine and hydraulic systems increased the requirement for pilots to be familiar with a wide range of time-critical emergency procedures. Pilots had to control these complex jet aircraft safely with malfunctioning equipment. In order to handle emergencies in a jet aircraft, the pilot was required to maintain basic aircraft control while interpreting the emergency indications presented by the cockpit instruments. Many emergencies required time-sensitive reactions from the pilot to recover the aircraft and avoid disaster. Examples of some emergencies that pilots practiced included: "engine fire, fuel pump failure, hot tailpipe, pitot and wing icing, [and] hydraulic system failure."[30] In order to train pilots to handle these emergencies, the Air Force trained using both live

[30] Kelly, *The Pilot Maker,* 80.

and simulated flight. This practice capitalized on the benefits of each, while minimizing each method's limitations.

The first method for training pilots to handle complex emergencies was to simulate the emergencies during flight. This involved taking actions to induce emergency-like scenarios in the cockpit. One such example was reducing the F-80 throttle to idle while airborne to simulate a jet engine flameout. This type of training was beneficial because it forced the pilot to think through emergency procedures while under the stresses of actual flight. The pilots also had to coordinate simultaneously with ground agencies to handle the simulated emergency. Additionally, in-flight simulations allowed pilots to visualize the sight pictures and visual references used to recover an emergency aircraft, such as the steeper approach needed to recover from an engine failure. This type of training carried some risk, however, because pilots could either react incorrectly or improperly prioritize the handling of the simulated emergency higher than flying the aircraft safely. Another disadvantage of airborne emergency training was the cost. Flying the T-33 cost about $500 per hour, and any time spent performing emergency training was time taken away from other training priorities.[31] Simulating emergencies during flight also failed to represent actual emergencies acurately. For instance, pilots simulating an engine failure retarded the throttle to idle power. In idle power, pilots had indications on the instruments that did not accurately represent an engine failure. The jet engine still produced thrust, which increased aircraft performance during the simulated emergency. Despite these inaccurate aspects of in-flight training, it did provide pilots the required experience of handling emergencies with the stresses of actual flight.

Another option for training pilots for emergency procedures was using simulators. In 1949, the Air Force ordered the Link C-11 Trainer

[31] Kelly, *The Pilot Maker,* 84.

(Figure 8) to train its jet pilots in emergency procedures.[32] The Link C-11 trainer provided both blind flying and emergency procedure training for the new F-80 and T-33 jet aircraft.[33] Unlike its predecessor, the Link Trainer, the C-11 accurately represented the F-80 and T-33 cockpit to allow pilots to practice both instrument flight and emergency procedures with the same layout and equipment as the actual aircraft. The C-11 trainer also allowed an instructor to monitor the trainee's performance; provide feedback; and introduce system failures, which the simulator's instruments accurately represented.[34]

The C-11 system allowed pilots to repeat the diagnosis of system failures and execution of emergency procedures before flying the aircraft itself. The C-11 also allowed experienced pilots to maintain proficiency in procedural tasks throughout their flying careers. The instructor was able to provide external feedback concerning the trainee's performance and to teach emergency procedures and techniques in simulated flight. This type of feedback was not, however, available in a single-seat jet fighter such as the F-80.

The C-11 trainer was also economical. It was about one-fourth the cost of an aircraft, roughly $40,000-$50,000 per trainer, with operating costs of the unit only about $15 per hour, compared to nearly $500 per hour for the F-80 aircraft.[35] Thus, training in the Link C-11 simulator was less expensive, safer, and more accurate than flight training in the F-80 and T-33.

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[32] Kelly, *The Pilot Maker,* 79.
[33] Kelly, *The Pilot Maker,* 79.
[34] Kelly, *The Pilot Maker,* 80.
[35] Kelly, *The Pilot Maker,* 84.

Figure 8. Link C-11B Trainer Cockpit
*Source: The National Air and Space Museum, Smithsonian Institution*

The dawn of the jet age involved new complex systems with time-critical emergencies that required extensive pilot training. The Air Force addressed this needed training by using both in-flight training of simulated emergencies and ground-based simulation in trainers such as the C-11. These complementary training methods provided pilots with the opportunity to practice emergencies in the stressful flight environment and gain exposure to non-standard flight profiles associated with emergencies. This approach also gave pilots experience through repetition and instructor feedback in ground-based simulators.

### *Air-to-Air Missile Employment – 1970's*

In the 1960s, the US Air Force and US Navy introduced the F-4 Phantom II fighter into their inventories.[36] It was designed as supersonic interceptor based on the belief that air combat would be fought exclusively with missiles at high altitude. The aircraft and its air-to-air missiles were optimized for combat against bombers flying at high altitude. The F-4 relied on these air-to-air missiles to shoot down enemy

[36] 31st Fighter Wing Public Affairs Office, "USAF Factsheets: 555th Fighter Squadron 'Triple Nickel,'" April 15, 2009, http://www.aviano.af.mil/library/factsheets/factsheet.asp?id=4353; Anthony M. Thornborough, *The Phantom Story* (London ; New York: Arms and Armour : Distributed in the USA by Sterling Pub. Co, 1994), 260.

bombers. The aircraft's software provided the pilot with missile employment information based on the assumptions that the target was a slowly maneuvering bomber flying at high altitude. Because of these assumptions, the F-4 also lacked an internal gun until the late 1960s. When the F-4 gained a gun, it lacked an accurate gun sight. Experience during the Vietnam War challenged the assumptions used in the F-4's development because pilots were required to engage at low altitude against highly maneuverable fighter adversaries. As a result, both the Navy and the Air Force had to train their pilots to employ air-to-air missiles against reactive adversaries.

Air-to-air missile employment in Vietnam did not meet the pre-war expectations of either the Navy or Air Force.[37] Only 10% of all missiles fired resulted in a kill.[38] US fighters were only destroying enemy fighters at a rate between 1-2 enemy aircraft destroyed per friendly aircraft lost. In response, the US Navy commissioned a study called the "Air-to-Air Missile System Capability Review" in 1968. The purpose of the study was to determine the reason for the lower-than-expected success rate of missile engagements in Vietnam.[39] This study reviewed all available engagement data from the war and found that the major cause of failed air-to-air missile engagements was poor "missile envelope recognition [and] identification at low altitude."[40] Pilots were firing their missiles out of range, which meant that the missiles did not have enough energy to

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[37] Naval Air Systems Command, "Report of the Air-to-Air Missile System Capability Review," January 1969, 1, http://www.history.navy.mil/research/histories/naval-aviation-history/naval-aviation-records-research-and-collections/ault-report/sesctions-1-4.html.

[38] Naval Air Systems Command, "Report of the Air-to-Air Missile System Capability Review," 1.

[39] Naval Air Systems Command, "Report of the Air-to-Air Missile System Capability Review," 1; Robert K. Wilcox, *Wings of Fury: From Vietnam to the Gulf War: The Astonishing True Stories of America's Elite Fighter Pilots* (New York: Pocket Books, 1996), 179.

[40] Naval Air Systems Command, "Report of the Air-to-Air Missile System Capability Review," 35.

reach their targets. The report cited two reasons for this poor recognition of the missile envelope: poor design of the aircraft weapons display and inadequate training.[41]

Air-to-air combat is an intensely stressful and dynamic environment where each pilot makes rapid assessments, decisions, and actions to survive and kill the enemy. To employ a missile beyond visual range (BVR), nominally outside 5 nautical miles, pilots of the 1970's were required to achieve a radar lock, verify in the cockpit displays that they were inside a radar missile (AIM-7) engagement envelope, fire a radar-guided missile, and support the missile by keeping the aircraft's radar locked on the target until impact. Pilots took these actions by referring to their cockpit instruments because the enemy was beyond visual range. Because the F-4 was a high-altitude interceptor, its weapons software did not compensate for low-altitude employment or maneuverable targets.[42] The Navy's study concluded that the "missile control system computer [was] mechanized for a high altitude, non-maneuvering bomber."[43] Because of this design assumption, the F-4 display indicated that the selected missile could reach a target further away than it actually could. In combat, pilots had to make split-second decisions to shoot. The compressed time to make these decisions and the inaccurate weapons displays led pilots to fire missiles that could not reach their intended targets.

The study recommended two solutions: fix the weapons display in the cockpit and provide better training for the pilots by using an

[41] Naval Air Systems Command, "Report of the Air-to-Air Missile System Capability Review," 35.
[42] Naval Air Systems Command, "Report of the Air-to-Air Missile System Capability Review," 21.
[43] Naval Air Systems Command, "Report of the Air-to-Air Missile System Capability Review," 21.

instrumented training range.[44] The first recommendation of fixing the weapons display was expensive and time consuming because it required an extensive change to the aircraft software's logic. While industry worked to fix the software shortcomings, the Navy and the Air Force sought to train their pilots to recognize the real capabilities of the missiles despite the inaccurate cockpit displays.

As a result of the Air-to-Air Missile Capability Review's findings, the US Navy established the Fighter Weapons School (TOPGUN) in 1969 to train instructor pilots in advanced fighter tactics.[45] TOPGUN instructors developed rules-of-thumb for air-to-air missile employment to help pilots recognize missile envelopes based on a dynamic air-to-air fight. To train pilots to use and recognize these techniques, however, the Navy turned to another of the report's suggestions, the expansion of instrumented air combat maneuvering (ACM) ranges available to fighter units.[46] These range complexes had the capability to track and record the position and movements of aircraft engaged in training exercises. Upon completion of training missions, pilots could watch virtual reconstructions of their flight and engagements against simulated adversaries.

With this instrumented system in place, instructors could provide feedback about pilot performance and weapons employment. The debrief delivering this feedback, facilitated by the information recorded on the instrumented range, gave the participants accurate information about their performance and weapons employment and allowed them to focus their training on perceiving the missile engagement envelope more precisely in the future. The enhanced training provided by these

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[44] Naval Air Systems Command, "Report of the Air-to-Air Missile System Capability Review," 36.
[45] Naval Air Systems Command, "Report of the Air-to-Air Missile System Capability Review," 37.
[46] Naval Air Systems Command, "Report of the Air-to-Air Missile System Capability Review," 35.

instrumented ranges allowed pilots to develop better tactics to fly to an advantageous position and employ their missiles within range of their targets. The subsequent turn-around in kill ratio for the Navy fighters in Vietnam validated these training improvements.

Before TOPGUN and the ACM range training programs, Navy fighters held an average 3.7:1 kill ratio.[47] Afterward the ratio increased to 13:1.[48] While the Air Force was slower to implement the Navy's solutions, it did purchase and deploy air-combat-maneuvering instrumentation (ACMI) on the ranges north of Nellis Air Force Base in 1977. The Air Force used its new range to train USAF Fighter Weapons School students and Red Flag participants, much as the Navy used its range for TOPGUN students in 1969.[49] Instrumented ranges provided instructors the ability to augment and reinforce flight training. This resource reduced the gap in training that caused fighter employment in Vietnam to fall short of the operational requirement to kill at low altitude with a weapon system designed for high altitude engagements.

While the Link Trainer, A-6 bombing trainer, and Link C-11 trainers provided supplemental means to train pilots, the instrumented training range, when combined with expert instruction, facilitated accurate and constructive feedback to enhance pilot learning. The services' emphasis on enhancing flight training increased the capabilities of aircrew to employ air-to-air missiles effectively.

### *Tactical Fighter Employment*

After poor fighter performance in Vietnam, the Air Force sought new methods to ensure that its fighter pilots were ready for the next air-to-air conflict. After years of conflict in the midst of the Cold War, the

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[47] Benjamin S. Lambeth, *The Transformation of American Air Power*, Cornell Studies in Security Affairs (Ithaca, N.Y: Cornell University Press, 2000), 47.
[48] Lambeth, *The Transformation of American Air Power*, 48.
[49] Lambeth, *The Transformation of American Air Power*, 66.

specter of another war was evident. This environment created a need to ensure that the Air Force's fighter pilots could effectively employ their weapons systems and tactics in the presence of counter-air threats. To address this need, the Air Force developed the Aggressor and Red Eagle programs, created a cadre of tactical experts at the US Air Force Fighter Weapons School, and improved its tactical simulation capabilities.

In order to train pilots effectively for their tactical missions and meet the operational need of doing so in a threat environment, the Air Force had to create a realistic training environment. This meant creating training against airborne adversaries and surface-to-air threats, while ensuring that the threats provided representative indications to the pilot both in the visual and virtual worlds. In the visual world, this meant making the training aid look and perform like the anticipated threat. In the virtual world, this involved making the aircraft systems respond and display symbols that were representative of the enemy. This included the simulated adversary's providing appropriate input into the aircraft's Radar Warning Receiver (RWR), RADAR, and infrared (IR) sensors, such as the sensor in the trainee's AIM-9 missile. The first step the Air Force took to address the need for representative training was to establish aggressors.

In response to the unsatisfactory air-to-air kill ratio in Vietnam, the Air Force created a dedicated dissimilar adversary squadron to provide air-to-air training against Soviet tactics and fighter capabilities.[50] In the years leading up to the conflict in Vietnam, the US Air Force had largely neglected air-to-air training for its fighter forces and instead focused on the delivery of tactical nuclear weapons.[51]

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[50] Matthew P. Donovan, "Full Circle? The Transformation of Dedicated Adversary Air Training in the USAF" (School of Advanced Aipower Studies, Air University, 1998), 1.
[51] Donovan, "Full Circle? The Transformation of Dedicated Adversary Air Training in the USAF," 8.

In 1972, the Air Force established the 64th Fighter Weapons Squadron (64th FWS) to provide air-to-air training for its fighter pilots. This squadron was equipped with T-38 aircraft and directed to replicate the Soviet Mig-21.[52] It traveled to Tactical Air Command (TAC) bases to train fighter pilots in Soviet tactics and threat aircraft capabilities through both flight training against dissimilar aircraft and academic instruction.[53] The 64th FWS became a repository of threat experts who could proliferate their knowledge throughout the USAF fighter community. This innovative training technique allowed pilots to recognize the differences between their own aircraft and tactics and those of their adversaries. This led to both the development of new tactics and a deeper understanding of enemy capabilities and actions in a combat environment.[54]

The aggressor program grew, stabilizing at four squadrons of about 90 aircraft in the 1980s. The type of aircraft flown by the aggressors also progressed to keep pace with the changing Soviet threats. In 1976 the aggressors transitioned to the F-5, which was better able to replicate the Soviet fire control systems than its predecessor the T-38. They later transitioned to the F-16 in 1988 and F-15C aircraft in 2005 as the Soviet Union fielded advanced fighters such as the MiG-25, MiG-29, MiG-31, and SU-27.[55]

The aggressors strived to recreate the threat in both the visual and virtual training worlds. In the visual world, the aggressors painted their aircraft in distinct patterns to provide a distinguishing feature compared

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[52] Donovan, "Full Circle? The Transformation of Dedicated Adversary Air Training in the USAF," 14.
[53] Donovan, "Full Circle? The Transformation of Dedicated Adversary Air Training in the USAF," 14.
[54] Donald L. Gish, "F-4 Air-to-Air Training," *USAF Fighter Weapons Review*, Fall 1975, 2.
[55] Donovan, "Full Circle? The Transformation of Dedicated Adversary Air Training in the USAF," 16.

to similar friendly systems. Aggressors flew their formations and maneuvers in accordance with Soviet rather than US doctrine and tactics, making an engagement distinct from fighting other US fighters. The aggressors were, however, flying US fighter aircraft and could not completely replicate the characteristics of enemy fighters, such as visual signature and maneuverability. The aggressors also used their own offensive and defensive systems in a manner consistent with Soviet tactics to create realistic threat signatures in the electromagnetic spectrum and accurate indications in trainees' cockpits. Despite these efforts, the aggressors could not completely replicate the characteristics of an enemy fighter, such as radar capabilities and radar cross-section, because they were flying US fighters. This meant that for trainees in F-15Cs, threat indications in the RWR looked the same from adversary F-16s as they did from friendly F-16s. While the aggressors approximated threat capabilities such as detection ranges and their employment of offensive capabilities by restricting the use of their US systems, they could not completely replicate the threat in either the visual or the electromagnetic spectrum.

In addition to air-to-air training, the aggressors also established a surface-to-air squadron that operated surface-to-air missile simulators on a few ranges throughout the United States. These systems and trained professionals could represent threat systems by emulating their electromagnetic emissions and tactics to provide appropriate indications in the fighter pilots' cockpits. The simulated SAMs provided excellent training, but the system could not visually replicate an actual SAM missile launch. The aggressors did have systems called "Smoky SAMSs" that launched a small rocket during a simulated launch, but these systems did not accurately represent the size or duration of a SAM launch's visual signature. Despite limitations in the inability to simulate missile systems visually, the aggressor SAMs provided pilots effective

flight training and prepared them to execute their tactical mission in a threat environment.

While the aggressors provided excellent dissimilar training to Air Force fighter pilots, their biggest limitation was their scarcity. With only a few aggressor squadrons, their impact was limited to the squadrons that they visited and those pilots who were able to fly against them as a student or instructor at the Weapons School or a Red Flag exercise. Due to budget constraints, the Air Force closed the aggressor squadrons in 1990 only to re-activate them in 2003 and to close one of the three remaining aggressor squadrons in 2014.[56] Most of the aggressor aircraft provide support to Red Flag exercises, Weapons School training, and the testing of new equipment and tactics. The availability of aggressors to provide support and training for fighter pilots has varied over the last 40 years due to Air Force budget priorities. Despite these budget limitations, the aggressor-training methods provided a roughly representative enemy force against which USAF fighter pilots could practice their tactics.

In addition to aggressor squadrons of US fighter aircraft, a parallel flight-training operation exposed USAF aircrew to actual enemy aircraft. In 1977, the USAF started a secret program called CONSTANT PEG that used experienced USAF and USN fighter pilots to fly Soviet MiGs against USAF fighters in training scenarios.[57] The Red Eagles of the 4477th Test and Evaluation Squadron operated Soviet MiGs until 1988. Operations shut down due to declining budgets and the inability of the Red Eagles to replicate Soviet 4th generation fighters such as the MiG-29 and SU-27 because they were equipped with the older MiG-17, MiG-21, and MiG-23 aircraft.[58]

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[56] Donovan, "Full Circle? The Transformation of Dedicated Adversary Air Training in the USAF," 25.
[57] Steve Davies, *Red Eagles: America's Secret MiGs* (Oxford ; New York: Osprey Pub, 2008), 64.
[58] Davies, *Red Eagles*, 328.

The secret Red Eagles attempted to fill the training gap left by the aggressors. Because the Red Eagles were flying Soviet aircraft, they were able to provide pilots with accurate visual and electromagnetic threat information on their aircraft displays. The Red Eagle pilots attempted to give Air Force fighter pilots the ability to use their tactics against a threat aircraft employing Soviet doctrine and tactics.[59] While the Red Eagles solved many of the shortcomings of the aggressors, they had a significant limitation as well. The Red Eagles were a scarce commodity, and their existence was secret. Their impact was limited to those pilots who traveled to Nevada to fight them on the Nellis ranges where they operated from the Tonopah Test airfield.[60] While Red Flag integrated the Red Eagles into some exercises, perhaps their most persistent and enduring influence was flying against the Fighter Weapons School students and instructors.[61]

Tracing its roots back to 1949 as the Aircraft Gunnery School, the USAF Fighter Weapons School's role was to create tactical experts to instruct and educate the fighter pilots of the Air Force. The school and curriculum have changed over the years; but the course itself was a combined academic, flight-training, and simulator-based course designed to create weapons officers who were tactical experts in both their weapon system and their assigned missions. The Weapons School benefited from programs such as CONSTANT PEG and the aggressors, both of which shared the skies north of Nellis AFB in Las Vegas. As a result, the students and instructors at Weapons School on a regular basis received some of the most realistic threat training in the entire Air Force. Because of the scarcity of the Red Eagle and aggressor resources, the Air Force used the Weapons School to reduce the risk of not exposing all of

[59] Gail Peck, Former 4477 TES Comander, Personal, June 3, 2014.
[60] Peck, Former 4477 TES Comander.
[61] Peck, Former 4477 TES Comander.

its pilots to this training.[62] Wing commanders selected promising instructors to become weapons officers and then sent them to operational squadrons because not all fighter pilots had the training opportunities available at Nellis. After graduation, they passed on expert knowledge and instructed on both enemy and US tactics based on first hand experience of training against the Red Eagles and the aggressors. Weapons officers developed new tactics and applied the valuable training from the course to inform their decisions. By creating a cadre of expert instructors, the Air Force used its scarce representative training aids to create a larger circle of influence than simply providing flight training.

In addition to augmenting flight training with the aggressors and Red Eagles and creating a cadre of tactical experts at the Weapons School, the Air Force used simulation to fill a gap in representative pilot training. The rise of aircraft representative trainers capable of reinforcing multiple skills began with the awarding of the F-80 trainer contract in 1949 to the Link Company and has continued through today.[63] After Vietnam, simulators such as the F-4 weapons system trainer (Figure 9) provided a representative cockpit that allowed pilots to practice not only instrument and emergency procedures, but also tactics and weapons employment in a virtual threat environment.

[62] Peck, Former 4477 TES Comander.
[63] Kelly, *The Pilot Maker*, 79.

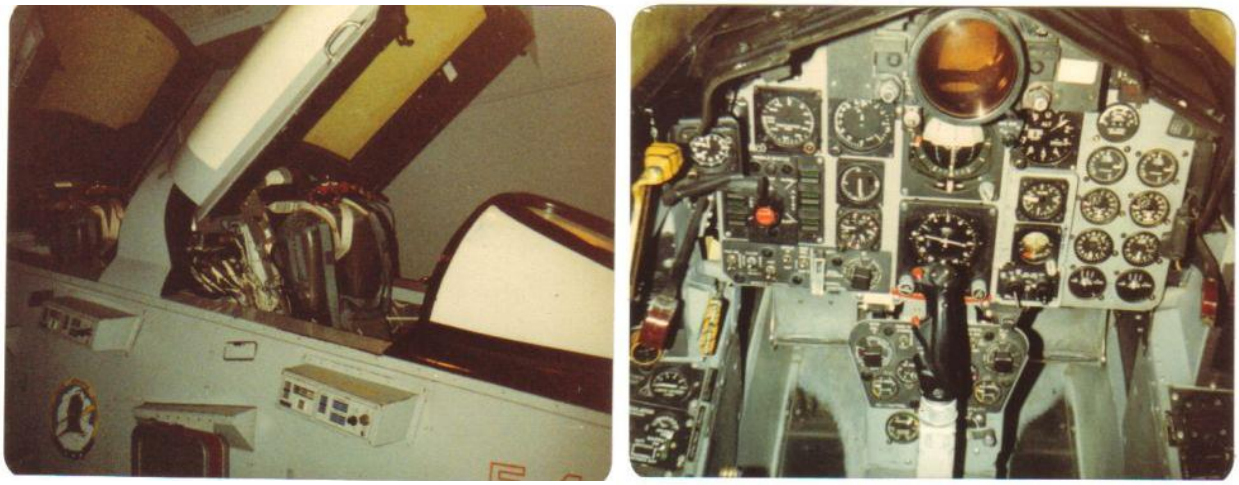

Figure 9. F-4C Weapons System Trainer
*Source: The National Museum of the Air Force*

Scientific research validated the important role that these simulators played in training pilots. The Naval Training Systems Center Human Factors Division conducted a meta-analysis of flight simulator training research and determined that, "over 90 percent of experimental comparisons favored [a] simulator and aircraft trained group over [a] aircraft-only trained group."[64] Simulation provided the Air Force with a cost-effective means of generating a representative training environment. In the case of tactical training, the virtual environment could be made to present the pilot with displays that replicated what appeared against an actual adversary. The RWR and Radar indications in the simulator matched those seen in combat and allowed the pilot to make tactical decisions based on an accurate representation of threat symbology and capabilities. While simulators provided practice in an accurate virtual environment, AFRL research determined that simulation alone could not completely replace live flight training due to the limitations of replicating the physical environment of flying in a virtual simulation.[65] Later tactical simulators added visual and auditory feedback to represent the flight

[64] John W. Jacobs et al., "A Meta-Analysis of the Flight Simulator Training Research" (Orlando, FL: Naval Training Systems Ceneter HUman Factors Division, August 1990), 55.
[65] Robert T. Nullmeyer and V. Alan Spiker, "Simulation-Based Misison Rehearsal and Human Performance," in *Aircrew Training and Assessment*, ed. Harold F. O'Neil, Jr. and Andrews, Dee H. (Mahwah, NJ: Lawrence Erlbaum Associates, 2000), 135.

environment.[66] These tactical trainers continued to progress and later included dynamic, nearly 360°, visual fields of the virtual environment (Figure 10).

Figure 10. F-15C Full Mission Trainer
*Source: Maxwell AFB Media Library*

The benefits of using simulation included increasing a pilot's proficiency in procedural tasks, decision-making skills, and mission employment. Mission employment involved operating with other aircraft as a team to accomplish an objective. The mission training center (MTC) simulators introduced in the late 1980s allowed pilots to practice simulated missions as a tactical team, which is referred to as mission rehearsal in the AFRL studies. As pilots became more proficient in each skill area, they became more tactically proficient in a contested environment. Simulation provided a cost-effective complement to flight training and provided training that was not practical to conduct in flight due to either cost or risk constraints.

[66] Kelly, *The Pilot Maker,* 112.

AFRL studies have also shown that simulation provided repetitive rehearsal and promoted stimulus encoding, which enabled the pilot to recall and reuse a skill learned in the simulator later in flight.[67] O'Neil and Andrews argue that through encoding, "cognitive or mental rehearsal has also been found to facilitate performance."[68] The Air Force used its mission trainers to facilitate this encoding process and provided an environment that was sufficiently similar to real aircraft. This meant that when similar situations arose in flight, the procedures, decisions, and mission employment skills the pilot learned in the simulator would be useful in flight. The key to effective encoding mechanisms was to "ensure that the behaviors and cognitions acquired during rehearsal [could] be executed during the mission."[69] Following the principle of encoding, the Air Force invested in realistic mission trainers that mimicked the aircraft and operating environment as closely as practical.[70] Realistic simulation increased the tactical performance of the pilots by encoding complex tasks and creating the ability for cognitive recall before they performed the same tasks in the live-flight environment.

Simulation also provided a cost-effective environment for repeated practice. Nullmeyer and Spiker's 2000 study of simulation-based rehearsal concluded that, "Through repetition of a behavioral or cognitive response over time, [mission rehearsal] affords participants an opportunity to hone or tune the skills and behaviors needed in the

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[67] Harold F. O'Neil and Dee H. Andrews, eds., *Aircrew Training and Assessment*, Human Factors in Transportation (Mahwah, N.J: Lawrence Erlbaum Associates, 2000), 14.
[68] Nullmeyer and Spiker, "Simulation-Based Misison Rehearsal and Human Performance," 135.
[69] Nullmeyer and Spiker, "Simulation-Based Misison Rehearsal and Human Performance," 136.
[70] Col (Ret) Thomas Schiess, Lockheed Martin F-15C Simulator Instructor and Site Manager, Telephone, January 29, 2015.

criterion environment."[71] Practice in a simulated environment significantly enhanced both procedural skills and decision-making skills.[72]

The simulated environment allowed for what Nullmeyer and Spiker called "deliberate practice."[73] Deliberate practice focuses on a specific desired learning outcome, and the two researchers argued that it is the best method for reinforcing and encoding complex tasks.[74] For instance, MTC instructors could introduce situations addressing fuel consumption, weather, airspace constraints, or systems anomalies, or they could remove those factors completely to focus on the pilot's tactical decision-making process. Simulation allowed for focused training on specific tactical tasks much in the same way that the A-6 bombsight trainer provided repetitive training without having to share time with non-related training events. It was impossible to achieve this level of singular training focus in the flight environment because competing interests such as cost intervened.

The Air Force also used simulation to provide tactical-mission rehearsal. In this case, a combat representative environment replaced the deliberate practice model to allow pilots to practice tactical tasks in a realistic, contested environment. According to Nullmeyer and Spiker, the repetitive aspect of both deliberate and mission rehearsal practice has provided positive performance results.[75] In many ways, operating in a

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[71] Nullmeyer and Spiker, "Simulation-Based Misison Rehearsal and Human Performance," 136.
[72] Gary Klein, "How Can We Train Pilots to Make Better Decisions?," in *Aircrew Training and Assessment*, ed. Harold F. O'Neil, Jr. and Andrews, Dee H. (Mahwah, NJ: Lawrence Erlbaum Associates, 2000), 186–187.
[73] Nullmeyer and Spiker, "Simulation-Based Misison Rehearsal and Human Performance," 137.
[74] Nullmeyer and Spiker, "Simulation-Based Misison Rehearsal and Human Performance," 137.
[75] Nullmeyer and Spiker, "Simulation-Based Misison Rehearsal and Human Performance," 137.

virtual, constructive environment also provided more combat realism than flight training. For instance, flight training usually included restrictions on the available number and type of adversaries, available airspace altitudes for employment, defensive countermeasure restrictions, and electronic attack restrictions.[76] In these respects, simulation gave participants more flexibility in defining the desired operating environment in which to practice.

Simulation was effective for stimulus encoding and practice, but it also provided a cost-effective means to provide critical feedback. As the Air Force increased its use of simulators, it also increased its investment in the ability to derive accurate and timely feedback from simulation training.[77] While the early Link Trainers had the ability to show students their flight paths using a rudimentary table-top presentation of the line they flew across the virtual sky, mission trainers provided the ability to re-play entire training sessions. This capability allowed instructors to observe each pilot's actions. It recorded the cockpit displays, the audio communications, and the spatial relationships among all of the players during the engagement.[78] Nullmeyer and Spiker concluded that the face-to-face debrief was one of the most effective methods for improving performance.[79] They also concluded that, "to be effective, feedback must be accurate, timely, credible, and constructive."[80] The debrief systems allowed instructors to provide constructive feedback, which reinforced the individual feedback each pilot experienced while training in the simulator.

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[76] O'Neil and Andrews, *Aircrew Training and Assessment*, 14.
[77] Kelly, *The Pilot Maker*, 11; Schiess, Lockheed Martin F-15C Simulator Instructor and Site Manager.
[78] Kelly, *The Pilot Maker*, 11; Schiess, Lockheed Martin F-15C Simulator Instructor and Site Manager.
[79] Nullmeyer and Spiker, "Simulation-Based Misison Rehearsal and Human Performance," 138.
[80] Nullmeyer and Spiker, "Simulation-Based Misison Rehearsal and Human Performance," 139.

While simulation filled a gap in representative training, it did not provide all of the necessary tactical training for pilot proficiency. The virtual and constructive environment of the simulator lacked the ability to replicate the operating environment of live flight and therefore could not replace the requirement for flight training.

As previously noted, simulation offers a realistic training environment in some respects, but it diverges from reality in other critical aspects. Simulation lacked realistic fidelity in the visual arena.[81] Air Force simulation development focused only on producing sufficient visual fidelity for the trainee to accomplish the desired training tasks.[82] Typical pilot evaluations of simulation visual fidelity indicated a lack of realistic depth perception and perceived visual acuity that either far exceeded or underwhelmed pilots compared to what they experienced during flight training.[83] This was an important detail, especially in a visual fight in which small, detailed cues of range, angle, and closure rate meant the difference between life and death. While in a visual fight, pilots rely on accurate perceptions of performance and trend details to make both offensive and defensive decisions. Information about range, angle, and closure rates tell the pilot about when to employ ordnance and take defensive actions. The simulator did not replicate the required level of detail to train these skills effectively.

Another aspect of training in which simulation failed to replicate flight training is kinesthetic feedback and stress. In flight pilots contend with a "seat of the pants" sensation imposed by the force of gravity on their bodies. These forces have a negative influence on the pilot's performance by restricting the ability to communicate or in extreme

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[81] Keith K. Niall and Byron Pierce, "Assessment of Visual Requirements for Flight Simulation," in *Aircrew Training and Assessment*, ed. Harold F. O'Neil and Andrews, Dee H. (Mahwah, NJ: Lawrence Erlbaum Associates, 2000), 278.
[82] Niall and Pierce, "Assessment of Visual Requirements for Flight Simulation," 278.
[83] Schiess, Lockheed Martin F-15C Simulator Instructor and Site Manager.

cases loss of consciousness during high-g maneuvers. Kinesthetic feedback also provides positive feedback to pilots such as feelings of acceleration and deceleration without having to cross-check their instruments while in a visual engagement. In a simulator, even a motion simulator, these kinesthetic forces are not present, which forces the trainee to change his habit patterns. For example, pilots modify their instrument scan inside the cockpit to check their speed more often in a simulator than they do in flight because they did not have the sound of wind rush over the canopy or feelings of acceleration. Pilots also have to check their altitude more often in a simulator because the lack of depth perception prevents an accurate assessment of height above the ground. These changed habit patterns during simulation do not replicate combat behaviors because they allow pilots to focus more on their instruments in the cockpit. In combat or flight training the consequences of inattentiveness to the outside world are much greater than in the simulator. If pilots fail to prioritize their attention outside the cockpit during a live flight, the risks of a midair collision or hitting the ground increase dramatically.

One limitation of simulation was that the performance of constructive adversaries was dependent on the accuracy of the computer modeling used to determine their capabilities and reactions. Unrealistic constructive elements included adversaries that acted and reacted with "perfect situational awareness" or others that would not engage in combat and drove straight to their death without interacting in the simulated fight.[84] Neither situation represented flight training or combat in which adversaries were likely to act in the middle of this situational-awareness continuum. To be effective, the constructive entities required complex algorithms and flexibility to interact with student pilots in a dynamic environment. While constructive adversaries became

[84] Schiess, Lockheed Martin F-15C Simulator Instructor and Site Manager.

increasingly intelligent in their programing, simulator instructors often had to override their programing to make the constructive entities do something different in order to present student pilots with a range of tactical problems to solve.

Another aspect of simulation that pilots often reported as being different from flight training was their concern with survival.[85] Pilots were less concerned with maintaining accurate formation position relative to other aircraft. The result was that pilots were able to devote more of their time to tactical tasks within the cockpit, while neglecting visual attentiveness to avoid a midair collision with their wingman. An informal survey by instructors revealed that most pilots admit they maneuver their aircraft more aggressively and focus on "eyes inside" tasks such as monitoring their radar display more in the simulator than they did in flight.[86] While this aggressiveness in combat tasks was a desired outcome of simulation, it had to blend with caution in live flight. This tendency revealed that while simulation was effective at providing realistic practice, the limits of its realism created what the pilot community referred to as "simisms."[87]

The existence of these "simisms," such as lack of depth perception and visual cues, lack of kinesthetic feedback, and reduced concern for survival revealed that simulation is not a one-for-one replacement for flight training. Simulation, however, did provide targeted training, practice, and feedback of tactical skills in a high threat environment. Despite the limitations of simulation, pilots were able to practice instrument flying, emergency procedures, and tactical employment and learned lessons they could apply in the air.

The US Air Force implemented programs such as the aggressors and Red Eagles, created tactical experts at the USAF Weapons School,

[85] Schiess, Lockheed Martin F-15C Simulator Instructor and Site Manager.
[86] Schiess, Lockheed Martin F-15C Simulator Instructor and Site Manager.
[87] Schiess, Lockheed Martin F-15C Simulator Instructor and Site Manager.

and developed and invested in simulators where pilots could practice in a representative environment to address training shortfalls. Each approach had benefits for pilot training. They also had limitations such as the availability of the aggressors and Red Eagles; the small number of weapons officers; and the inability of simulation to recreate the visual, auditory, and kinesthetic flight regimes. Due to these limitations, no single approach provided the training needed for pilot proficiency. Therefore, a balanced approach to tactical training that took advantage of each of these programs provided pilots with the necessary skills, repetition, and practice to meet the operational needs of the Air Force.

### *Operational Package Employment*

Another requirement that became clear during Vietnam and continued in the post-Vietnam Air Force was the need for fighter pilots to be able to execute their tactics as part of a larger package with other complementary weapons systems. A package is a grouping of different types of aircraft that worked together on a single mission. Driven by heavy losses in Vietnam, the Air Force sought to address this issue by training fighter pilots in integrated tactics with other weapons systems before actual combat. Integrated tactics were different from the tactical employment previously discussed. During integrated employment, pilots would modify their tactics to take advantage of the strengths of the other aircraft in their packages. This integration also allowed the package to help cover some of the individual aircraft weaknesses and vulnerabilities through teamwork. To train for this need, the Air Force used networked simulation and large force exercises (LFE). These methods provided fighter pilots with training to employ their tactics as part of a large and complex mission package.[88]

[88] A large force exercise (LFE) is flight training that simulates mission package operations.

In 1975, only three years after the aggressors began to provide threat training, Major Richard "Moody" Suter suggested a new training method to provide pilots with a combat-like experience before actual combat. He proposed this new training exercise to reduce the high mortality rate for fighter pilots during their first ten missions in Vietnam.[89] Statistics showed that if a pilot could survive past his tenth combat mission, his overall chances of survival increased dramatically.[90] Major Suter's idea was to create a training exercise that provided young pilots with the same level of experience through the planning and participation in complex combat scenarios. Major Suter found a sympathetic leader in the TAC Commander, General Robert Dixon, who ordered the establishment of Red Flag at Nellis AFB to prepare pilots for the rigors of combat.[91] To make a realistic exercise, Major Suter incorporated surface-to-air missile threats and aggressor aircraft.[92] Red Flag was expensive because it required large numbers of aircraft and ground support, but it provided excellent training designed to reduce pilot attrition in combat.

Major Suter's intent was to give every inexperienced fighter pilot a chance to fly ten missions integrated into a package of other weapons systems, but the scope of Red Flag has evolved since its inception. Red Flag's early years were focused on the tactical execution of fighter, bomber, and support aircraft; but Red Flag later evolved to reflect the changes in the way the US Air Force waged war.[93]

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[89] Davies, *Red Eagles*, 35.
[90] Davies, *Red Eagles*, 35.
[91] Alexander Berger, "Beyond Blue 4: The Past and Future Transformation of Red Flag" (Air Command and Staff College, Air University, 2004), 1.
[92] Davies, *Red Eagles*, 36.
[93] While assigned as a USAF Weapons School instructor at Nellis AFB, the author, Maj Jason Zumwalt, served as an adviser to the Red Flag staff and helped develop the Red Flag training missions from 2011-2013. He also acted as the "tactical mentor" for the planning, execution, and debrief of eight Red Flag missions from 2011 through 2013. Those experiences inform these views.

While Red Flag provided the most intense training that USAF pilots were able to experience, it also provided training in an expanded set of mission areas. Rather than merely integrating the tactical fighters, bombers, and support aircraft, Red Flag included training that focused on a wider range of combat missions. This shift provided excellent integrated tactical training for pilots. It also exposed and trained participants to understand the broader context of the conflict they were fighting and how their tactical mission fit into the larger effort. This training proved invaluable to pilots who have participated in Red Flag and then participated in combat. Many pilots have attributed their successes in combat to Red Flag, and some have even commented that when compared to Red Flag combat was easier.[94]

Despite the excellent threat-representative training that Red Flag has provided, fiscal constraints reduced the ability of units to participate. In the 1980s, a fighter unit was able to attend a Red Flag Exercise about once every twenty months. During these early years, pilots received an average of ten training sorties per exercise, which met Suter's original goal.[95] In the 1990s and 2000s, however, the effects of Combat Air Force (CAF) reduction and fiscal constraints have reduced opportunities for Red Flag training. Since 2010, fighter squadrons average forty months or longer between Red Flags, and each pilot averaged only five sorties per exercise.[96] A consequence of this reduction in both quantity and frequency of participation in Red Flag exercises is that pilots are less likely to receive package training. For example, the average operational assignment for an F-15C Eagle fighter pilot lasts about 36 months. As a

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[94] Wilcox, *Wings of Fury*, 274.
[95] Taylor T. Ferrell, "Air Superiority by the Numbers: Cutting Combat Air Forces in a Time of Uncertainty" (School of Advanced Aipower Studies, Air University, 2014), 29.
[96] Ferrell, "Air Superiority by the Numbers: Cutting Combat Air Forces in a Time of Uncertainty," 29.

result, pilots may never experience the benefits of Red Flag if their unit only attends a Red Flag every 40 months.

Red Flags increased aircrew performance through exposure to integrated package training on a large scale. The reduced opportunities to participate in a Red Flag exercise have shifted some of the responsibility for this training to the units themselves. Fighter squadrons, however, did not have the aircraft, aggressor air support, aggressor SAM support, or joint, coalition, and interagency partners to support the complex exercises available at Red Flag. To help squadrons provide this training most fighter wings procured linked mission simulators in the early 2000s.

In order to provide LFE and smaller integrated training opportunities on a more regular basis, the Air Force invested in and expanded its use of distributed mission operations (DMO). According to John Fawcett, "DMO is an Air Force readiness initiative to allow warfighters to train as they would expect to fight; maintain primary combat readiness at home or deployed; and conduct mission rehearsal in an operational environment as realistic as necessary."[97] DMO provided a network of interconnected simulators for Red-Flag-like training. While not a replacement for flight training at Red Flag, DMO gave pilots additional opportunities for mission package practice. US Air Force DMO linked, "current and future weapons systems and high fidelity simulators and simulations with other command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) systems to create an interactive operational environment to provide distributed training, rehearsal, or operations support for warfighting in

[97] John M. Fawcett Jr., "Distributed Mission Operations and Distributed Mission Training: A USAF Construct for the LIve, Virtual, and Constructive Environment" (Command and Control Research Program, 2004), 2.

the global battlespace."[98] The size of these training events varied daily, but ranged from two different types of units operating together to semi-annual DMO exercises, which included hundreds of participants in a virtual LFE.[99] The DMO events provided a forum to practice the critical skills of large force coordination, communication prioritization, information sharing and filtering, and modified tactics to take advantage of another platform's strengths while minimizing weaknesses. DMO provided a cost-effective means for the US Air Force to train its pilots in decision-making skills and mission rehearsal in package operations.[100]

Just as tactical-level simulation had benefits and limitations, so too did package-level simulation. Pilots participating in Red Flag exercises gained important perspective through interpersonal interactions with experts from other weapons systems. In addition to the already discussed limitations of simulation, this personal interaction and education did not take place during DMO training.

The Air Force used live-flight exercises and distributed-mission operations to provide package-sized training in a robust threat environment. While neither was sufficient on its own, due to Red Flag's infrequency and the non-representative aspects of simulation, together they provide pilots the opportunity to employ in large and complex operations that represented the anticipated threat environment.

### *An Air-to-Air Training Approach*

In the early 2000s, the US Air Force developed an approach to air-to-air training that emphasized the use of both simulation and flight training. For this section, analysis focuses on the F-15C aircrew-training

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[98] Fawcett Jr., "Distributed Mission Operations and Distributed Mission Training: A USAF Construct for the LIve, Virtual, and Constructive Environment," 4.
[99] Walter Johnson, ACC/A3TO DMO/DTC, Telephone, February 25, 2015.
[100] Nullmeyer and Spiker, "Simulation-Based Misison Rehearsal and Human Performance," 148; Johnson, ACC/A3TO DMO/DTC.

program since it best relates to air-to-air training. The October 2014 F-15C Ready Aircrew Program (RAP) Tasking memorandum (RTM) outlined the requirements for the training of combat ready F-15C pilots.[101] This document provided guidance for squadron commanders to develop a realistic training program to meet any future tasking and directs that combat-ready F-15C squadrons be prepared to fight against enemy 4th generation air-to-air threats.[102] The result of this training guidance and the lack of aggressor support was a squadron-based approach that incorporated simulator training and periodic large force exercises.

The aggressors were a traveling band of adversaries that went to geographically separated units to provide adversaries for flight training and expert academic instruction about threats. In 2014, the two remaining fighter aggressor squadrons (the 64th AGRS at Nellis AFB, NV and 18th AGRS at Eielson AFB, AK) usually stayed at their home stations in support of Red Flag exercises, Weapons School syllabus training, and operational test and evaluation support. As a result, fighter units provided their own adversaries. This approach has been successful for three reasons: a 4th generation fighter squadron could provide itself with realistic adversaries to train against, it could generate sufficient sorties to accomplish effective training, and the squadron could augment its flight training with simulators.

While opportunities for fighter squadrons to train against dissimilar aircraft provide exceptional training, primary flight training used similar aircraft. This training was effective because a fighter such as the F-15C Eagle adequately replicated an adversary 4th generation fighter. The F-15C and adversary 4th generation fighters are not

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[101] USAF HQ ACC/A3T, "F-15C Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," n.d., 1.
[102] USAF HQ ACC/A3T, "F-15C Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 1.

precisely the same; but general aircraft characteristics, such as speed, maneuverability, radar cross section, and electromagnetic emissions, were similar. Additionally, the pilot flying the F-15C would use its systems to replicate enemy capabilities and tactics. This practice provided representative employment considerations and opportunities to practice and learn air-to-air tactics. The visual and virtual representations, however, were not as good as when fighting against aggressors. The simulated enemy aircraft looked and performed just like another F-15C in the visual arena and registered as an F-15C on the radar and RWR displays.

Another aspect that this training lacked compared to the aggressor approach was expertise on threat tactics and capabilities. F-15C pilots that were simulating enemy aircraft referred to a manual to learn how to fly like an enemy, whereas the aggressors trained extensively to become expert replicators. The lack of formal training reduced the fidelity of replication that in-house adversaries could produce in flight training. When weighed against the cost of maintaining sufficient adversaries for all USAF fighter squadrons, however, this approach provided a cost-effective means for fighter squadrons to train against representative threats.[103]

This training approach also worked because 4th generation squadrons generated enough sorties to provide its own adversaries. Two key assumptions are embedded in this principle. The first was that air-to-air training took place in scenarios in which there are more enemy than friendly aircraft. The second was that a single squadron could generate sufficient sorties to allow for scenarios where adversaries outnumbered friendly aircraft.[104] For example, a typical F-15C mission

[103] Donovan, "Full Circle? The Transformation of Dedicated Adversary Air Training in the USAF," 68.
[104] USAF HQ ACC/A3T, "F-15C Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 1.

consisted of four aircraft that used US Air Force tactics as F-15C Eagles and six aircraft that replicated adversary aircraft. As long as the squadron generated at least ten aircraft with sufficient spare aircraft for attrition, it could self-support this training mission. Squadrons with 24 assigned primary aircraft, such as the 67th Fighter Squadron at Kadena AB, Okinawa, typically generated sufficient aircraft to meet this demand. Squadrons with only 18 primary assigned aircraft, such as the 493 FS at RAF Lakenheath, England, generated a maximum of ten primary aircraft for training, leaving little room for error or attrition.[105] Another disadvantage of this approach is that only 40% of the pilots taking part in this mission received instruction. The rest employed enemy tactics and habit patterns. Despite this shortcoming, if squadrons generated enough aircraft to self-support training missions then they could conduct representative flight training.

When developing training plans, squadrons used the RAP Tasking memorandum as the baseline since it established the operational requirements and the minimum number and type of sorties that each pilot had to accomplish for proficiency. Based on those calculations, the Air Force gave squadrons flying hours to complete the required training. Flying hours were analogous to a budget that squadrons used to complete the required annual training. Instead of dollars, the Air Force gave squadrons hours of flight time to manage as their resource. USAF fighter squadrons, therefore, relied on sufficient flying hour resources to complete the minimum required training. Since 2005, the Presidential Budget Request Action has requested less than the required flying hours to meet the minimum level of proficiency for fighter pilots, and the

[105] Ferrell, "Air Superiority by the Numbers: Cutting Combat Air Forces in a Time of Uncertainty," 25.

deficiency has grown wider.[106] The 2013 budget funded the flying-hour program at less than 75% of the minimum requirements to maintain proficiency.[107] Sequestration further reduced the budget to less then 65% of the RAP minimum.[108] Self-sufficient training had been effective in the past, but it required sufficient resources to maintain proficient aircrews. In the absence of the required resources, pilot proficiency suffered. As pilots became less proficient, the risk of losing pilots in combat and mission failure increased.

The final assumption of this training approach is the availability of simulators. Pilots have used simulation to augment and enhance flight training and improve performance. This training approach required simulators with which to practice instrument flying, emergency procedures, tactical employment, and linked package employment. The 2015 F-15C Ready Aircrew Program Tasking memorandum directed that all active duty pilots complete three simulator events each month to maintain proficiency.[109] Simulation filled the gaps in flight training and was required to maintain the readiness of pilots that were ready for combat.

The current training approach evolved from the Air Force's desire for representative flight training and simulation to prepare its pilots for combat. This self-sufficient approach was based on three assumptions: a 4th generation fighter squadron could provide itself with a realistic adversary to train against, the squadron was resourced for and generated enough sorties to accomplish effective training, and the squadron could

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[106] Scott M. Di Gioia, "Dying on the Vine: Air Combat Command's Struggle to Provide Combat-Ready Aircrews with Limited Resources" (School of Advanced Airpower Studies, Air University, 2014), 6.
[107] Di Gioia, "Dying on the Vine: Air Combat Command's Struggle to Provide Combat-Ready Aircrews with Limited Resources," 6.
[108] Di Gioia, "Dying on the Vine: Air Combat Command's Struggle to Provide Combat-Ready Aircrews with Limited Resources," 6.
[109] USAF HQ ACC/A3T, "F-15C Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 3.

augment its flight training with simulators. These conditions provided Air Force fighter pilots with the minimum required training to be proficient in the combatant commanders' desired skills.[110]

### *Conclusion*

To prepare pilots for combat, the Air Force has turned to developing methods of training that provide complementary learning. From the Link Trainer to the modern training approach the Air Force has used representative flight training, simulation, a cadre of experts, and systems to make the debrief of live-flight training more effective. These solutions have created an air-to-air force that proved superior to its adversaries with a 31-0 kill ratio in Operation Desert Storm.[111] These solutions were critically dependent on the adequate resourcing of fighter squadrons to maintain high levels of proficiency. When the required resources or representative training was not available, pilot proficiency suffered. Airmail pilots died in 1934 because they were not proficient at flying at night or in the weather. Later, US fighter pilots in Vietnam died because they were not proficient at employing their weapons at low altitude or integrating into mission packages. It is important to remember that the combatant commanders consider the required training to be the minimum to maintain pilot proficiency. Failing to meet the minimum requirement for proficiency can have lethal consequences. In combat the impact of those failures can affect the outcome of the war itself.

These historic lessons are important because they show how the Air Force has historically responded to shortfalls in training. These examples, and the training principles that drove them, can serve as

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[110] USAF HQ ACC/A3T, "F-15C Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 1.
[111] Wilcox, *Wings of Fury*, 300.

models for developing future training programs to address shortfalls in 5th generation air-to-air training.

## Chapter 2

## Current Air-to-Air Training

*I'd hate to see an epitaph on a fighter pilot's tombstone that says, 'I told you I needed training.'*

Lt Col Lloyd "Boots" Boothby
"Father of the Aggressors"

In December 2005 Air Combat Command (ACC) declared that the F-22 Raptor had reached its initial operational capability. The US Air Force's first fifth-generation fighter and its pilots were prepared to execute Operation Noble Eagle (ONE) in defense of the homeland.[1] Two years later, ACC declared that the F-22s at Langley Air Force Base's 1st Fighter Wing had, after extensive training, reached full operational capability (FOC).[2] At the time, Langley AFB was home to both the new F-22 and the F-15C fighter aircraft. Many pilots at Langley recognized that the F-15C provided adversary support for the F-22 because the F-22 could not realistically support itself. The fledgling F-22 squadron could not provide enough aircraft to fly as adversaries, and it could not provide representative adversaries for air-to-air training. Today there are no 4th generation fighter squadrons based with 5th generation fighter squadrons. The method for training these pilots has changed. Today, F-22 pilots rely on three adversary sources for air-to-air training: 4th generation fighters, T-38s, or other F-22s.[3] The goal of this air-to-air training is to meet the combatant commander's requirements as defined

[1] David Hopper, "F-22 Receives FOC Status at Langley" (US Air Force Air Combat Command, December 12, 2007), http://www.acc.af.mil/news/story.asp?id=123079128.
[2] Hopper, "F-22 Receives FOC Status at Langley."
[3] Unattributed Interview, F-22 Pilot, interview by the author, February 28, 2015.

in the RAP tasking memorandum.[4] These requirements demand pilots who are proficient at air-to-air combat against a 4th generation fighter threat.[5] The resources currently available to 5th generation fighter squadrons make training challenging because neither F-22s nor T-38s provide representative flight training as adversaries.[6] This chapter will define the air-to-air requirements for each fifth-generation fighter, present the training methods used to prepare pilots, and identify shortfalls.

## Defining the Requirements

Air Combat Command (ACC) provides a source of requirements for fighter squadrons by publishing a Ready Aircrew Program (RAP) Tasking Memorandum each year. This memorandum includes an attachment that identifies the latest combatant commander expectations and priorities.[7] Common expectations for both the F-22 and F-35 include conducting both offensive and defensive air-to-air operations during combat. Offensive operations entail flying into enemy territory and securing freedom of maneuver in the air by destroying or denying the enemy's SAMs, fighters, or a combination of both. Offensive operations provide air superiority to enable other operations such as strikes against ground targets or reconnaissance. Defensive operations provide air superiority over and around friendly operating areas. These areas can

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[4] HQ ACC/A3T et al., "F-22A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 1; HQ ACC/A3T, ACC/A3G, and AFRC/A3T, "F-35A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 1.
[5] USAF HQ ACC/A3T, "F-15C Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 16–17; HQ ACC/A3T, ACC/A3G, and AFRC/A3T, "F-35A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 18–20.
[6] Unattributed Interview, F-22 Pilot, Email, February 24, 2015.
[7] HQ ACC/A3T et al., "F-22A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 1; HQ ACC/A3T, ACC/A3G, and AFRC/A3T, "F-35A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 1.

include forward bases or important command-and-control aircraft such as the E-3 AWACS. Both the F-22 and F-35 are directed to conduct both offensive and defensive air-to-air missions against enemies that employ 4th generation fighters.[8]

Based upon the combatant commander's priority missions for each fighter, squadrons develop training programs to prepare pilots for the projected threats. The plans for squadron training are the syllabi that provide guidance within the squadrons. In accordance with the current RAP tasking memoranda, F-22 and F-35 syllabi guide training to make pilots proficient in executing both offensive and defensive air-to-air operations against 4th generation threats.[9]

The 2015 F-22 RAP Tasking Memorandum (RTM) defines three primary mission priorities: Offensive Counterair (OCA), Defensive Counterair (DCA), and Offensive Counterair – Attack Operations (OCA-AO).[10] The memorandum also provides the expectation that the F-22 will be the primary air-to-air platform in all theaters of operation.[11] The RTM also defines the critical skills that F-22 pilots must be proficient in meeting the combatant commander's expectations. The RTM defines proficient as, "[having] a thorough knowledge of mission area but occasionally make an error [of] omission or commission. Aircrew are able to operate in a complex, fluid environment and are able to handle most

[8] HQ ACC/A3T et al., "F-22A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 15; HQ ACC/A3T, ACC/A3G, and AFRC/A3T, "F-35A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 18.
[9] HQ ACC/A3T et al., "F-22A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 15–17; HQ ACC/A3T, ACC/A3G, and AFRC/A3T, "F-35A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 17–21.
[10] HQ ACC/A3T et al., "F-22A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 15.
[11] HQ ACC/A3T et al., "F-22A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 15.

contingencies and unusual circumstances. Proficient aircrew are prepared for mission accomplishment on the first sortie in theater."[12]

The RTM further divides the required air-to-air skills by priority mission type. The first requirement is for F-22 pilots to be proficient in tactics, techniques, and procedures against enemy 4th generation fighters.[13] This skill requires pilots that can effectively defeat 4th generation fighters in either offensive or defensive operations. In order to defeat enemy fighters, pilots must be able to find the enemy using on-board systems such as radar, identify the targets they have found as enemy aircraft, and employ their weapons. While engaging enemy aircraft pilots must also be proficient in defending themselves from enemy attacks. For pilots to become proficient in these skills, practice is required against 4th generation-like adversaries to ensure the tactics and techniques that the pilots are applying are appropriate for the threat they may face in combat. Training must be able to reproduce enemy tactics in addition to enemy aircraft characteristics that validate tactics to find, identify, and engage enemy aircraft. If the practice the pilots receive does not match the expected threat, the lessons they apply in combat may be inappropriate for the enemy they are fighting. This mis-match could increase the risk of losing aircraft and pilots, especially against a well-equipped and proficient enemy.

The 2015 F-35 RTM defines four primary mission priorities and one secondary mission: Offensive Counterair – Suppression of Enemy Air Defenses (OCA-SEAD), Air Interdiction (AI), Offensive Counterair – Attack Operations (OCA-AO), Defensive Counterair/Aerospace Control Alert

[12] HQ ACC/A3T et al., "F-22A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 16.
[13] HQ ACC/A3T et al., "F-22A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 61.

(DCA/ACA), and Offensive Counterair (OCA).[14] The RTM also emphasizes the expectation that F-35 squadrons be proficient in self-escort against 4th generation fighter threats.[15] The expectation described is that F-35 pilots will focus on offensive operations while still being proficient at defensive operations.

Combatant commanders expect F-35 pilots to be proficient in tactics, techniques, and procedures against enemy 4th generation fighters. The skill set required for the F-35 pilots are the same as those required for F-22 pilots, though their platform's tactics and systems may be different. Expectations for F-35 air-to-air capability, however, are lower in the air-to-air regime because the F-22 will be the primary air-to-air platform in combat. Due to this lower expectation and because the F-35 does not carry as many air-to-air weapons as the F-22, training scenarios for F-35 pilots will require less adversaries than similar training for an equal number of F-22 pilots.

Combatant commanders expect that both F-22 and F-35 pilots be proficient in conducting offensive and defensive missions against 4th generation fighters. To accomplish these missions, pilots must be able to operate their on-board systems to find, identify, and engage the enemy aircraft.[16] They must also be proficient in self-defense tactics against the same threats.[17] Finally, pilots must be able to operate as a team to accomplish the bigger offensive or defensive mission. To ensure that pilots are proficient in these critical skills, each squadron develops a

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[14] HQ ACC/A3T, ACC/A3G, and AFRC/A3T, "F-35A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 17.
[15] HQ ACC/A3T, ACC/A3G, and AFRC/A3T, "F-35A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 17.
[16] HQ ACC/A3T et al., "F-22A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 16; HQ ACC/A3T, ACC/A3G, and AFRC/A3T, "F-35A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 18.
[17] HQ ACC/A3T et al., "F-22A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 16; USAF HQ ACC/A3T, "F-15C Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 18.

training program in accordance with the guidance provided in the Ready Aircrew Program Tasking Memorandum.

## The Current Training Approach

The requirement for the F-22 and F-35 to employ both offensive and defensive air-to-air tactics against a 4th generation threat drives the Air Force's development of training programs for both fleets of aircraft. Both aircrafts' syllabi for initial qualification and pilot upgrade training reflect this approach to training. These syllabi represent the Air Force's translation of the combatant commanders' needs into training events that prepare pilots for combat. Pilots must be able to maneuver and employ their aircraft as a team to find, identify, and engage the enemy while defending themselves from attack. Pilots must therefore be proficient in cognitively translating both the visual and virtual data presented by their eyes and the aircraft systems. They then must make appropriate decisions based upon that data and then communicate and carry out those decisions. This process requires practice and feedback of each pilot's performance. The Air Force has again chosen to use flight training and simulation to prepare pilots for these tasks.

The RTM directs that fighter squadrons focus home-station training on the primary missions outlined in the RTM.[18] F-22 training uses a building-block approach to incrementally develop air-to-air skill sets. This approach progresses from within visual range (WVR) to beyond visual range (BVR). In general, WVR is an engagement that takes place with less than 5 nautical miles between the friendly fighter and the enemy aircraft. The following sections will look at how F-22 pilots currently train in each of the air-to-air training blocks and highlight the strengths and weaknesses of the training within each block.

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[18] HQ ACC/A3T et al., "F-22A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 1; HQ ACC/A3T, ACC/A3G, and AFRC/A3T, "F-35A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 1.

### *F-22 WVR Training*

The training program begins with visual-fighting skills in short range WVR engagements. F-22 training syllabi call this phase of training Basic Fighter Maneuvers (BFM). During this phase trainee F-22 pilots fight against another F-22 that restricts its allowable angle-of-attack (AOA), the angle between the aircraft wing's chord line and the air it is moving through, to match the performance of an adversary 4th generation fighter. Even an AOA-limited F-22 does not perfectly replicate a 4th generation fighter in terms of performance; for example, the F-22 can still turn and accelerate faster. Despite these shortcomings, this approach does provide pilots the ability to learn the skills of visual maneuvering by discerning trends over time, making decisions, and executing complex maneuvers.[19]

Another limitation of using the F-22 for High Aspect BFM training is the inability for the adversary F-22 to simulate employing a high-off-bore-sight, heat-seeking missile in flight. The expected 4th generation adversary will likely be equipped with the Russian AA-11 Archer missile or a similar variant that can be cued and employed far off the bore-sight of the aircraft during a engagement. The F-22 cannot realistically replicate this capability in the air because it does not have a helmet-mounted sight or carry the AIM-9X heat-seeking missile. Because the F-22 lacks this capability, pilots must estimate when they are near an employment zone for the simulated enemy missile and pretend to fire the missile without having to gain a missile lock on the target. This practice does not take into account the difficulty of gaining a missile lock during a dynamic fight at high-off-bore sight angles or the techniques that pilots may use to deny missile lock. Therefore, pilots must rely on de-brief information to try to determine when the simulated adversary was in a

[19] Unattributed Interview, F-22 Pilot, February 28, 2015.

missile employment envelope.[20] The limitation of this training is that pilots cannot get visual feedback for when the adversary reached a missile engagement envelope. Pilots are forced to try to recall the sight picture gained in the air during de-brief on the ground. In F-15C squadrons, adversaries communicate on the radio when they fire a simulated missile because the pilot can replicate the high-off-bore sight capability of a threat aircraft. In this case, the trainee hears the call and sees the visual cue at nearly the same time, reinforcing the learning objective.

The simulator provides good practice for the procedural setup of the fight including formation position, airspeed control, pacing, and timing. The limitations of the visual presentation in the simulator, however, prevent accurate assessments of important visual maneuvering cues, such as range and closure rate.[21] In the simulator it is difficult for pilots to judge virtual distance from an aircraft using only visual cues. These cues are critical for training pilots in BFM concepts because the pilot's perception of these cues drives follow-on offensive and defensive decisions and maneuvering.

Achieving proficiency in BFM requires pilots to understand the effects of their control inputs based upon kinesthetic feedback. For instance, pilots will be able to determine if their aircraft is decelerating based upon the Gs felt and the feel of the aircraft over time without having to look at their airspeed indicators. In the simulator, these cues are absent, which forces pilots to rely on instruments more often than in flight. This reduces their ability to watch the adversary closely for critical visual cues that drive decisions. As a result, the simulator is a poor venue for effective BFM training.

[20] US Air Force, "CAF Raptor F-22A Training Syllabus," January 1, 2015, 26.
[21] Unattributed Interview, F-22 Pilot, February 28, 2015.

The next block of air-to-air training begins from a beyond visual range and transitions to within-visual-range engagements. The air combat maneuvering (ACM) training mission is a BVR setup with two F-22s against four adversaries.[22] ACM engagements begin BVR but also train pilots to transition from BVR to WVR maneuvering. According to the F-22 syllabus, the adversaries should be 4th generation fighters equipped with advanced electronic attack.[23]

Becuase 4th generation adversary support is scarce, F-22 pilots often fly this block of training against other F-22s or against a mix of F-22 and T-38 adversaries. Both Tyndall AFB and Langley AFB have dedicated T-38 adversaries to support F-22 training. Each base can launch eight T-38s twice a day to provide adversaries in support of two F-22 squadrons.[24] The two F-22 squadrons at Elmendorf AFB do not have dedicated adversaries, but the units are able to train against the F-16s of the 18th Aggressor Squadron (AGRS) about 250 miles north of Elmendorf AFB.[25] The 18th AGRS typically provides six F-16 adversaries twice a day for use by both squadrons at Elmendorf. The single F-22 squadron at Hickam AFB in Hawaii has no dedicated adversaries and must train against F-22s as adversaries.[26]

There are limitations to each type of support in ACM training. When flying against F-22s, the simulated adversaries cannot sufficiently "dumb down" their systems to provide threat replication for the training fighters. Additionally, the F-22 cannot carry training electronic attack pods such as the AN/ALQ-188. Therefore, F-22 adversaries cannot provide the desired radar jamming. If they prove to be consistently unsuccessful in training, this leads F-22 pilots mistakenly to reconsider

[22] US Air Force, "CAF Raptor F-22A Training Syllabus," 94.
[23] US Air Force, "USAF Weapons School F-22A WIC Syllabus," August 2012, 70.
[24] Unattributed Interview, F-22 Pilot, February 28, 2015.
[25] Unattributed Interview, F-22 Pilot, Email, February 24, 2015.
[26] Unattributed Interview, F-22 Pilot, Email, February 24, 2015.

their tactics. Weapons officers in each squadron address this problem by providing academic instruction on proper tactics and reassure pilots of the validity of sound tactics.

Two other aspects of using F-22s as adversaries limit the efficiency of the training approach. First, the pilots flying as adversaries are not receiving tactical training during the sortie. In the case of an ACM sortie, 66% of the participating pilots are not training to meet the C-NAF requirements. While they are arguably gaining experience in their aircraft, they are not employing their systems or tactics as they do in combat. Second, the F-22 aircraft themselves are being used, thereby incrementally reducing their total lifespan. Using F-22s as adversaries means that squadrons must fly three aircraft hours for every single hour of ACM training.

Other approaches to ACM adversary support are to fly one or two F-22s as adversaries and add T-38s as the remainder of adversaries or to use just T-38s in support. This approach alleviates some of the inefficiencies of using four F-22s as adversaries but introduces new limitations to the effectiveness of the training. The T-38 is a training jet originally introduced into the Air Force in 1961. The aggressors used the T-38 as an adversary aircraft in 1972 until 1975 when the F-5 replaced it. Later the F-16 and F-15 replaced the F-5 because it could no longer replicate advanced Soviet aircraft. The T-38 does not have any sensors to search or track other aircraft, cannot employ simulated weapons, and cannot punish trainee tactical errors by defeating them in the air.

In the visual engagement, the performance of the T-38 does not accurately represent any 4th generation adversary.[27] The T-38 cannot replicate weapons employment, except notionally if it points itself at the F-22 and subsequently evaluates potential weapons envelopes in debrief.

[27] Unattributed Interview, F-22 Pilot, February 28, 2015.

The primary value of the T-38 as an adversary is to provide additional targets for the F-22 pilots to prioritize and engage.[28]

Because the T-38 does not have radar, it also fails to provide threat-representative emissions to force a defensive response from the F-22 pilot. The RTM requires pilots to be proficient in defensive tactics against airborne threats. If F-22s are training against T-38s, pilots will not receive warning via the aircraft systems of enemy attack and will not have to exercise defensive tactics. While there are clear drawbacks to using T-38s, the T-38 is less expensive to operate per flying hour than the F-22 and allows more pilots to train in counter-air tactics.

The final approach for adversary support in ACM training is to use operational 4th generation fighters as adversaries. The benefits of using F-16 and F-15 fighters are that the F-22 pilots receive the most representative training available and it maximizes the number of F-22 pilots that receive training given the limited number of available sorties. Since the desired threat aircraft is a 4th generation fighter, a US 4th generation fighter provides a close approximation for training. This approach solves many of the limitations of using either F-22s or the T-38s as adversaries. The primary limitations of using 4th generation fighters for adversary support are the high flying hour costs, negative training for the adversary pilots, and wear and tear on the 4th generation aircraft.

In addition to flight training, F-22 pilots practice ACM in the simulator. Simulation can accurately re-create the virtual world inside the cockpit and is especially effective for BVR training. By executing the BVR portion of ACM in the simulator, pilots are able to practice different scenarios in less time and at reduced cost when compared to flying. This repetition allows the pilot to make quicker decisions while airborne. Since the ACM mission requires a transition into a visual fight, the

[28] Unattributed Interview, F-22 Pilot, February 24, 2015.

simulator loses effectiveness when visual maneuvering begins. Another of the desired learning objectives of the ACM mission is mature-fight-entry execution.[29] The simulator allows pilots to practice procedural aspects of such engagements, such as radio calls and establishing fight-entry geometry, while supporting and joining a mature visual engagement between an F-22 pilot's wingman and an adversary. The simulator's visual limitations and lack of kinesthetic feedback, however, reduce the quality of training in the visual engagement. Nevertheless, pilots can practice the procedural aspects of tactics effectively in simulators.[30]

F-22 flight training is less effective when using F-22s or T-38s as adversaries because they cannot replicate the threat enough to validate the tactics of the F-22. BFM training suffers because F-22 pilots cannot gain an accurate visual sight picture for a HOBS threat while fighting a non-HOBS capable platform. Additionally, the flight characteristics of either an AOA limited F-22 or a T-38 do not match current threat aircraft performance. Flight training against 4th generation fighters provides the most threat-representative performance and weapons employment capabilities to train F-22 pilots, but the approach is expensive and opportunities are scarce. While the F-22 simulators have proven useful in providing training for the administrative aspects of visual range training, the simulator does not provide effective WVR training because it lacks sufficient visual fidelity and kinesthetic feedback.

To meet the requirements established in the RTM, F-22 pilots must be proficient in both BVR and WVR offensive and defensive skills. F-22 and T-38 adversaries reduce the effectiveness of WVR training because they cannot replicate threat capabilities or performance. The consequence of continuing to train against these platforms is that F-22

[29] US Air Force, "CAF Raptor F-22A Training Syllabus," 73.
[30] Unattributed Interview, F-22 Pilot, February 28, 2015.

pilots may adopt tactics and habit patterns developed in training that are disastrous in combat against actual enemy aircraft. Because the Air Force bases its air superiority paradigm on the idea that a small number of technologically superior aircraft can defeat larger numbers of less capable adversaries, a failure in combat could have grave repercussions to an operation. It would only take a few F-22 losses in combat to significantly affect the ability to conduct air-superiority operations.

### *F-22 BVR Training*

When the visual blocks of training are complete, F-22 pilots focus on scenarios that begin with over 60 nautical miles of separation between blue and red forces. Despite the longer ranges of these scenarios, each engagement has the potential to end in visual maneuvering. These missions require between four and fourteen adversaries. Both flight training and simulation fulfill these BVR training requirements.[31]

Just as with WVR training, F-22 pilots train against other F-22s, T-38s, or 4th generation adversaries. According to a current F-22 squadron commander, the biggest limitation of using the F-22 as an adversary is that the adversary is too capable and not representative of a threat aircraft.[32] This means that properly executed tactics may not defeat the simulated enemy even though the tactics would be successful against a real enemy. While F-22 adversaries do provide the ability to practice defensive reactions because they can engage the trainees, pilots tend to become averse to offensive tactics because they tend to die when facing other F-22s.[33] This trains F-22 pilots to be conservative in their tactical selections when faced with a 4th generation adversary. Due to this unrealistic training, pilots develop a false understanding of their

[31] US Air Force, "CAF Raptor F-22A Training Syllabus," 7.
[32] Unattributed Interview, F-22 Pilot, February 28, 2015.
[33] Unattributed Interview, F-22 Pilot, February 28, 2015.

offensive and defensive potential. This tendency negates some of the superior capabilities and tactics that a 5th generation fighter such as the F-22 can bring to an air-to-air fight. The impact of this negative lesson is that F-22 pilots may not fully use their advantages in combat, which may allow an adversary to survive or even kill a friendly aircraft. The weapons officer instructs F-22 pilots on the true capabilities of their systems and tactics. Experience has shown, however, that repeated airborne feedback can be difficult to overcome with academic instruction.[34]

In addition to the quality of training problem, using F-22s as adversaries creates a quantity problem. Without additional support from either T-38s or 4th generation fighters, the 43 FS could only produce eight new F-22 pilots per year. With T-38 and 4th generation fighter support, however, that number now stands at 31 new F-22 pilots per year.[35] It is not efficient to train F-22 pilots using only other F-22s due to the large number of adversaries that are required.

Like the F-22, using the T-38 as the primary adversaries also has drawbacks in the BVR arena. Because the T-38 lacks any sensors, it cannot force the F-22 to react defensively in the BVR arena, which is one of the C-NAF required critical skills. This tends to train F-22 pilots to become too offensively minded.[36] Because the T-38 has no way of detecting or targeting F-22s, pilots can execute tactics poorly without suffering the consequences. Decisions and actions that would likely lead to death against a 4th generation threat are rewarded with success when fighting against T-38s.[37] Both T-38 and F-22 adversaries train F-22 pilots to make poor assumptions about both the enemy's and their own

[34] Unattributed Interview, F-22 Pilot, February 28, 2015.
[35] Unattributed Interview, F-22 Pilot, February 28, 2015.
[36] Unattributed Interview, F-22 Pilot, February 28, 2015.
[37] Unattributed Interview, F-22 Pilot, February 28, 2015; Unattributed Interview, F-22 Pilot, February 24, 2015.

capabilities. The former chief F-22 instructor pilot at Weapons School noted that new students, who were already experienced F-22 instructor pilots, did not understand why tactics were developed the way they were or how to apply them appropriately in dynamic air-to-air engagements. These students tended to apply the negative lessons they learned while training against T-38 or F-22 adversaries. One example was an F-22 student who had never been defeated in flight training before Weapons School. When that student executed the same tactics he had used to fight T-38s against F-16 and F-15 adversaries he was "killed" in multiple training missions.[38] The F-22 syllabus specifies that 4th generation fighters are always the desired adversary for most training missions because they can best replicate threat capabilities.[39] More accurate replication reinforces the codified F-22 tactics for the pilots and leads to better understanding of their capabilities and limitations in an air-to-air engagement.[40] While T-38 support provides the required number of adversaries and is far better than nothing, it does not accurately represent a 4th generation threat aircraft and can lead to negative training outcomes if used by itself.

Just as in WVR training, using a 4th generation fighter to replicate the threat provides the best available BVR training.[41] 4th generation fighters provide platforms that most closely represent threat aircraft performance and capabilities in speed, turn performance, altitude, sensors, and detection range. These training aids also provide the most representative indications to the F-22 pilots via their cockpit displays. For instance, F-22 pilots will detect an F-15C acting as an adversary at a similar range to a SU-27 Flanker. The F-15C also provides the F-22 pilot

[38] F-22 Pilot, Personal Interview, November 15, 2014.
[39] US Air Force, "CAF Raptor F-22A Training Syllabus," 50; Unattributed Interview, F-22 Pilot, February 28, 2015.
[40] Unattributed Interview, F-22 Pilot, February 28, 2015.
[41] Unattributed Interview, F-22 Pilot, February 28, 2015.

with defensive indications if it is able to lock on to the Raptor with its radar, just as a SU-27 does. This type of virtual feedback to the F-22 pilot is not available when fighting T-38s. F-22 training syllabi currently list 4th generation adversaries as "highly desired" because of these characteristics.[42]

The 43 FS at Tyndall AFB has funds available to invite adversaries to support air-to-air training, but it is becoming more difficult to recruit outside squadrons to help.[43] Many fighter squadrons are busy fulfilling training requirements to meet their own taskings. As a result, the 43 FS often has to make do without outside adversaries. The impression of the 43 FS instructor pilots is that student pilots who do not train against F-16s and F-15s are less prepared to employ successful tactics in combat.[44] This problem will grow larger as the F-35 replaces current F-16 squadrons. The 4th generation fighters provide the best adversaries for F-22 flight training but they cannot be the single solution to F-22 pilot training needs.

In addition to flight training, F-22 pilots train for BVR missions in simulators. Simulation provides repetition and high-fidelity threats, which are particularly important because pilots cannot practice some tactics and procedures in flight due to security concerns. There are three types of simulators used by F-22 pilots. The first is the WTT. The WTT is a small trainer with only a forward-view screen for a visual depiction of the virtual environment. The WTTs are located in the fighter squadrons and provide practice in aircraft systems, emergency procedures, and basic tactical tasks. The fidelity of these simulators is low, and constructive threat aircraft are not adaptive to the scenario. F-22 pilots primarily use WTTs for practicing procedural tasks and verifying aircraft systems questions.

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[42] Unattributed Interview, F-22 Pilot, February 28, 2015.
[43] Unattributed Interview, F-22 Pilot, February 28, 2015.
[44] Unattributed Interview, F-22 Pilot, February 28, 2015.

The second type of simulator used is the Full Mission Trainer (FMT). FMTs are located with the active-duty fighter units and generally consist of four cockpits equipped with full 360° visual presentations. The grouping of these four or more simulators is a Mission Training Center (MTC). The F-22 FMTs also link to other platform simulators through the DMO system.[45] This networking allows pilots to train in integrated tactics with other aircraft and systems.

While the FMT provides pilots with practice and repetition, it does not accurately replicate threat aircraft or their tactics. As previously noted, constructive adversaries do not accurately replicate threat capabilities or tactics.[46] While the pilots receive indications on their instruments in the cockpit that are more representative than they receive in flight training, the actions of the constructive entities are not realistic.[47] One example is that once the F-22 reaches a certain range from a simulated enemy in the FMT, that enemy always gains awareness of the F-22 and begins employing ordnance.[48] The situational awareness granted to the constructive enemies does not match the awareness observed in flight training or testing. The problem with constructive entities is that their ability to adapt and react to stimuli in the virtual world is limited to the complexity of the algorithms governing their behavior. In the above example, the threat aircraft was unable to detect the F-22 outside a certain range, but once inside that range the threat has perfect awareness. Constructive adversaries that are more capable than reality can lead to negative learning for the pilots, much like flight training against other F-22s does. Pilots may decide that they should never cross inside the artificial range that often results in death during simulator training. If applied in combat, this has the potential to limit

[45] Johnson, ACC/A3TO DMO/DTC.
[46] Unattributed Interview, F-22 Pilot, February 28, 2015.
[47] Unattributed Interview, F-22 Pilot, February 28, 2015.
[48] Unattributed Interview, F-22 Pilot, February 28, 2015.

the tactics that the pilot may chose based upon improper training replication. This example shows the importance of having accurate threat modeling and algorithms for constructive adversaries.

An answer to the problem of FMT adversaries is available at the Air Combat Simulator (ACS) located in Marietta, GA. The ACS facility has four F-22 cockpits with 360-degree visual displays. The main differences between the ACS and FMT simulators are the logic of the software and the ability to train against human-controlled adversaries.[49] The F-22 pilot community widely regards the ACS as the best virtual training available.[50] The ACS software's logic uses intricate models of actual systems and provides a very high-fidelity simulation. As an example of the difference in complexity between the ACS and the FMT, consider the ability of an adversary to lock its virtual radar on to a virtual F-22 during the simulation. In the FMT, when the range between the adversary and the F-22 is sufficiently close, the adversary has the ability to lock on to the F-22. At the ACS, the algorithm takes into consideration operator inputs, mode of the enemy radar, electromagnetic spectrum noise, range, closure rate, angle, angle rate, environmental clutter, and many more factors.[51] The ACS's accurate threat modeling and complex algorithms provide a realistic virtual environment for air-to-air training.

In addition to its accurate modeling and complexity, the ACS provides virtual adversary cockpits that allow F-22 pilots to train against human controlled adversaries. Having an operator in the loop gives the ACS the unique feature of having 12 adaptive and thinking enemies to fight against, something that the FMT currently lacks. The ACS has 12 adversary flight stations where a pilot or contractor can control an

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[49] Unattributed Interview, F-22 Pilot, February 28, 2015.
[50] Unattributed Interview, F-22 Pilot, February 28, 2015; Unattributed Interview, F-22 Pilot, Telephone Interview, February 21, 2015; Unattributed Interview, F-22 Pilot, February 24, 2015.
[51] Unattributed Interview, F-22 Pilot, February 21, 2015.

adversary aircraft against the F-22 flight of fighters within the virtual training world. While these systems provide representative training, the ACS still suffers from visual fidelity limitations and lack of kinesthetic feedback.

The biggest limitation of the ACS is its availability. It is far away from the F-22 units in Virginia, Florida, Alaska, Nevada, California, and Hawaii. Pilots must travel on TDY status to train there. While travel costs are expensive, squadron leaders consider ACS training to be money well spent.[52] Despite the willingness for squadrons to pay for the training, many interests compete for time at the ACS. For instance, the Weapons School, operational test and evaluation units, F-22 B-course, six operational squadrons, and now F-35 units all have to share time at the ACS. The F-35 and F-22 have to split ACS time since the system will only support one or the other platform at a time with only four pilots per simulated event. The 2014 ACS schedule demonstrates this limited availability. During 2014, the 3rd Fighter Wing in Anchorage, AK, had 9 days of ACS training available for its two F-22 squadrons. The 1st Fighter Wing had 14 total days to share between its two operational squadrons. Despite the outstanding training that the ACS can provide, it is a scarce resource and is most effective in combination with other training.

Beyond visual range training for F-22 pilots suffers from many of the same issues as within visual range training. The current approach of using T-38s and F-22s as adversaries fails to provide representative training because pilots adopt habit patterns that are based on a threat that is either too capable or insufficiently capable when compared to potential enemies. F-22 pilots require adversaries that replicate the capabilities and tactics of enemy fighters, but the current approach cannot provide that training in sufficient quantity to make the pilots

[52] Unattributed Interview, F-22 Pilot, February 28, 2015.

proficient. While the ACS and flight training against 4th generation fighters provide appropriate replication, their limited availability reduces their positive impact on pilot proficiency.

**F-35 Air-to-Air Training**

The F-35 pilot training program is still developing and has not yet met the expected requirements as outlined in the RAP tasking memorandum. Due to current aircraft development limitations and availability, the F-35 transition and instructor upgrade training at Eglin AFB has only one air-to-air flight requirement. It is a single tactical intercept mission that relies on training against similar F-35s or, if available, 4th generation fighters from other units.[53] The 58th Fighter Squadron Director of Operations anticipates that future requirements will be similar to the F-22 training program. Because the F-35 carries less ordnance and is not the primary air-to-air platform, its pilots will require fewer adversaries per training mission when compared to the F-22. The 58th FS Director of Operations anticipates that achieving representative training in both flight and simulation will mirror the current challenges of the F-22.[54]

Simulator training for F-35 pilots will be similar to the current F-22 training. Each F-35 unit will have mission training centers with similar capabilities and limitations as the F-22 full mission trainers.[55] The F-35 simulators, however, will not be to connect to the DMO network until 2018. When connected, the F-35 will also be able to connect to US Navy and coalition simulation networks.[56]

F-35 pilots also have access to Lockheed Martin's Air Combat Simulator (ACS) but must share time with F-22 pilots. F-35 pilots,

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[53] Unattributed Interview, F-35 Pilot, March 2, 2015.
[54] Unattributed Interview, F-35 Pilot.
[55] Arden Dahl, ACC/A5FI, F-35 Air Systems Requirements Analyst, March 10, 2015.
[56] Dahl, ACC/A5FI, F-35 Air Systems Requirements Analyst.

however, will not use the ACS for training. Instead, the ACS will only support operational test and evaluation activities for the F-35. The F-35 has another simulation site in Fort Worth, TX called the validation simulator (V-Sim).[57] The V-Sim uses a similar complex model and algorithm as the ACS and provides highly accurate systems representation, but it will only be used as a developmental test site with no pilot training available.[58]

While the F-35 community is still developing its training programs, it is evident that it cannot provide its own representative adversaries.[59] Despite this shortcoming, there is currently no existing plan to provide F-35 squadrons with T-38s or any other adversaries to augment their flight training.[60] Additionally, F-35 training will lack a high-fidelity and man-in-the-loop simulator system such as the ACS for the F-22. This means that the constructive models of the simulators will limit the air-to-air threat replication. The RAP tasking memorandum requires that inexperienced F-35 pilots fly at least nine times per month and execute at least four Full Mission Simulator activities per month.[61] The memorandum also requires F-35 pilots to complete at least one DMO simulator mission per month, despite the fact that the F-35 Full Mission Simulator (FMS) is not currently capable of participating in distributed mission operations until 2018.[62] It is clear that current and future F-35 training plans will utilize a combination of flight training and simulator training to prepare F-35 pilots, but non-effective adversary replication will reduce their proficiency against 4th generation fighter threats.

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[57] Dahl, ACC/A5FI, F-35 Air Systems Requirements Analyst.
[58] Dahl, ACC/A5FI, F-35 Air Systems Requirements Analyst.
[59] Unattributed Interview, F-35 Pilot.
[60] Unattributed Interview, F-35 Pilot.
[61] HQ ACC/A3T, ACC/A3G, and AFRC/A3T, "F-35A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 4.
[62] HQ ACC/A3T, ACC/A3G, and AFRC/A3T, "F-35A Ready Aircrew Program (RAP) Tasking Memorandum, Aviation Schedule 2015," 4; Dahl, ACC/A5FI, F-35 Air Systems Requirements Analyst.

## Conclusion

Both the F-22 and F-35 have adopted similar training approaches to make pilots proficient at offensive and defensive air-to-air operations against 4th generation fighter threats. Each platform uses a combination of flight training and simulation. The F-15C relied upon three assumptions to make its training approach effective: a fighter squadron can provide itself with a realistic adversary to train against, the squadron must be resourced for and generate enough sorties to accomplish effective training, and the squadron can augment its flight training with high-fidelity simulators. Applying these assumptions to the current training approach for F-22s and F-35s reveals some shortfalls. The use of F-22s and F-35s as adversaries is inefficient for training pilots, and does not provide a representative adversary against which to train. Furthermore, the simulator does not adequately provide the missing training.

Using F-22 and F-35 aircraft as adversaries fails to replicate the expected threat adequately, and it is not an efficient use of valuable resources. Aircraft have a finite lifespan, and the F-22 and F-35 are no exceptions. Each hour flown as an adversary is an hour not used to train a pilot and is one less hour in the lifespan of the aircraft. In 2013, it cost about $62,000 per hour to operate an F-22 and $47,000 for the F-35.[63] Other training adversaries are far less expensive to operate; the F-15C costs about $39,000 per hour, the F-16C $23,000, and the T-38C only $9,000 per hour.[64] Using F-22s and F-35s as adversaries is also inefficient in terms of training volume. According to a current F-22 squadron commander, if his unit was forced to train against only their own F-22s they would lose 75% of their training capacity.[65] Training

[63] Lt Col David McClanahan, "Breaking Paradigms to Modernize USAF Fighter Pilot Training," July 21, 2014, 17.
[64] McClanahan, "Breaking Paradigms to Modernize USAF Fighter Pilot Training," 17.
[65] Unattributed Interview, F-22 Pilot, February 28, 2015.

capacity will become even more important for the F-35, which does not have plans to augment training with T-38 support. Additionally, the near term rise in F-35 procurement will see a corresponding drop in available 4th generation adversaries as the Air Force retires the older platforms to make room for the newer aircraft. In order to maintain proficient fighter pilots, F-22 and F-35 squadrons will require adversaries other than themselves. If the Air Force does not find a solution to this problem, pilots will likely be unable to maintain the minimum required levels of proficiency in air-to-air tasks. The cost of supporting training operations with only F-22 or F-35 adversaries is too high to sustain. Additionally, the Air Force must expect a lower level of proficiency against 4th generation threats with a corresponding increase in the risk of loss or mission failure while conducting any air-to-air combat operations.

The current approach limits pilot proficiency to conduct operations against the combatant commanders' priority air-to-air threat, the 4th generation fighter. In Nullmeyer and Spiker's study of mission rehearsal and human performance, they concluded that realistic practice and repetition increased pilot performance.[66] They also determined that to be effective, practice must be representative of the situation in which it was to be used.[67] If pilots cannot train against a representative adversary, their proficiency in air-to-air tasks will suffer.

The consequences of that loss in proficiency will vary depending on the threat and the type of mission. Conducting offensive operations against a well-trained and equipped adversary with superior numbers poses the highest risk of loss to the 5th generation force if its pilots are not proficient. On the opposite side, defensive operations against an

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[66] Nullmeyer and Spiker, "Simulation-Based Misison Rehearsal and Human Performance," 136.
[67] Nullmeyer and Spiker, "Simulation-Based Misison Rehearsal and Human Performance," 137.

inferior adversary with few aircraft carries less risk of failure due to lower pilot proficiency. In either extreme case, any reduction in pilot proficiency will increase both the risk of loss and mission failure. This potential for mission failure would threaten the ability of the United States to project power into enemy territory by threatening air, land, and sea operations. The joint force relies on air superiority to conduct operations. Therefore, any threat to air superiority threatens the ability of the United States to use military force to achieve its political objectives.

# Chapter 3

## The Future of Air-to-Air Training

*We may have concentrated too extensively on improving the machine and have not spent enough on the man who must fly it or on the training, which he must have to make the machine an exploitable advantage.*

Official Tactical Air Command Journal during the Vietnam War

In order to create pilots that can take advantage of the air-to-air capabilities of their weapons systems, the US Air Force must provide its pilots sufficient training against adversaries that accurately represent the expected threats they may face in the future. The current requirements demand that USAF F-22 an F-35 pilots be proficient in conducting offensive and defensive air-to-air operations against 4th generation threats such as the MiG-29 Fulcrum and SU-27 Flanker. The current training approach used for both the F-22 and F-35 fails to provide adequately representative training against a 4th generation threat. The problem will only grow as the Air Force continues to replace its 4th generation fighter fleet with F-35 fighters. This training shortfall can lead to pilots learning inappropriate tactical lessons that could reduce combat effectiveness in the future. Historical examples from the Link Trainer to the Red Flag exercises and Distributed Mission Operations (DMO) have shown that a combination of flight and simulator training provides the most efficient and cost-effective means of training combat pilots. Therefore, the US Air Force must invest in future programs to address the shortfalls in current flight and simulator training.

This chapter will present possible solutions to the training shortfalls in both flight and simulator training. It will examine flight training that incorporates a new adversary aircraft, the T-X and a flight training concept that incorporates live, virtual, and constructive (LVC) elements into a single training environment. It will also examine ways to improve simulator training through the incorporation of the key elements that make the Air Combat Simulator (ACS) a successful training system. Each of these programs has the potential to help alleviate the current training shortfalls, but no single program is sufficient. Future training solutions must address the shortfalls in both flight and simulator training to provide effective air-to-air training for F-22 and F-35 pilots.

## An Adversary Version of the T-X

On 20 March 2015, the US Air Force released requirements for a T-38 replacement aircraft. The Air Force intends to purchase 350 T-X advanced trainers to replace its 431 T-38 aircraft.[1] While the Air Force has not included a requirement that the T-X be designed to perform as an adversary, it has included questions for industries to address when preparing their proposals. These questions include: "To what degree is your current design open/flexible to accommodation of future capability modifications?" and are there "limiting factors in your current design that would preclude future system modification of wing pylons, radar systems, datalinks, and defensive systems?" [2] One of the main requirements for the T-X is improved sustained G performance over the T-38; this may give a T-X aircraft handling performance similar to a 4th

[1] Jason Smith, "TX, Future T-38 Jet Replacement, Requirements Released," *Air Education and Training Command Public Affairs*, March 20, 2015, 1, http://www.af.mil/News/ArticleDisplay/tabid/223/Article/581073/t-x-future-t-38-jet-replacement-requirements-released.aspx.
[2] Aaron Mehta, "USAF Issues T-X Requirements," *Defense News*, March 20, 2015, 1, http://www.defensenews.com/story/defense/air-space/support/2015/03/20/usaf-issues-tx-requirements/25080555/.

generation threat aircraft.[3] Additionally, the Air Education and Training Commander, General Robin Rand, said, "A T-X variant is just one option for red air if we decide there is a requirement for it."[4] Air Combat Command also sent out a request recently to weapons officers for ideas about what is required to make a T-X variant an effective adversary. These questions and General Rand's sentiment indicate that the US Air Force is considering a variant of the T-X aircraft. This variant could provide a cost-effective means to replace the T-38 with a more effective adversary platform.

An adversary version of the T-X might be a cost-effective means of training F-22 and F-35 fighter pilots. While the Air Force has not selected the platform that will become the T-X, trainers and 4th generation fighters are less expensive than 5th generation fighters to operate per hour of flight time. For example, in 2013 the T-38 was almost seven times less expensive per hour of operation compared to the F-22, and the F-16 was almost three times less expensive then the F-22.[5] As a conservative estimate, the T-X will cost as much as an F-16 to operate. If the Air Force provides each fighter base with T-X aircraft, each fighter wing could provide more cost-effective flight training for its fighter pilots compared to only F-22s or F-35s as adversaries. For example, if an F-22 squadron were going to fly a one-hour training mission with four F-22s against six other F-22s replicating enemy aircraft, it would take ten flying hours in F-22s to get four hours of training. In 2013 operating costs, this training mission for four pilots costs $620,000.[6] However, if the F-22 squadron had an adversary squadron to rely on that provided 12 adversary aircraft, it could greatly

[3] Smith, "TX, Future T-38 Jet Replacement, Requirements Released," 1.
[4] Smith, "TX, Future T-38 Jet Replacement, Requirements Released," 1.
[5] McClanahan, "Breaking Paradigms to Modernize USAF Fighter Pilot Training," 17.
[6] This analysis only considers operating costs. System development and procurement costs are not included.

increase the training capacity each mission. Table 1 shows the costs of executing a flying event using ten F-22 fighters using three training approaches.

Table 1: Cost of Adversary Support for F-22 Training

| Mission Type | Blue Air Training | F-22 Red Air | Dedicated Adversaries | Cost of F-22 sorties | Cost of Adversary sorties | Total cost of training mission |
|---|---|---|---|---|---|---|
| **Only F-22s** | | | | | | |
| Dynamic Targeting | 4 | 6 | | $620,000.00 | | $620,000.00 |
| ***# of F-22 pilots trained*** | ***4*** | | | | ***Total Cost*** | ***$620,000.00*** |
| **F-22s with Support (F-16 operating cost)** | | | | | | |
| Dynamic Targeting | 4 | | 6 | $248,000.00 | $138,000.00 | $386,000.00 |
| Dynamic Targeting | 4 | | 6 | $248,000.00 | $138,000.00 | $386,000.00 |
| Basic Fighter Maneuvers | 2 | | | $124,000.00 | $0.00 | $124,000.00 |
| ***# of F-22 pilots trained*** | ***10*** | | | | ***Total Cost*** | ***$896,000.00*** |
| **F-22s with Support (T-38 operating cost)** | | | | | | |
| Dynamic Targeting | 4 | | 6 | $248,000.00 | $55,800.00 | $303,800.00 |
| Dynamic Targeting | 4 | | 6 | $248,000.00 | $55,800.00 | $303,800.00 |
| Basic Fighter Maneuvers | 2 | | | $124,000.00 | $0.00 | $124,000.00 |
| ***# of F-22 pilots trained*** | ***10*** | | | | ***Total Cost*** | ***$731,600.00*** |
| ***Assumptions per flying event: F-22 squadron will generate 10 aircraft, and dedicated adversary squadron will generate 12 aircraft*** | | | | | | |

*Source: Author's work based on "Breaking Paradigms to Modernize USAF Fighter Pilot Training"*

The first approach uses only F-22s, trains four pilots, and costs $620,000. The same mission conducted with dedicated adversaries costs between $303,800 (T-38) and $386,000 (F-16). This example assumes operating costs similar to the F-16 or T-38 aircraft for the T-X. While the cost to develop and procure the T-X is not included, the operating cost savings are significant.

Another advantage of using dedicated adversaries is the ability to perform more training on each mission. If the fighter wing can generate twelve T-X aircraft and ten F-22s for each mission, ten F-22 pilots could receive training at a cost of $896,000 (F-16 operating costs assumed). This approach would yield a 150% increase in pilot training at a 45% increase in cost. If the T-X operating cost were similar to the T-38's cost, there would still be a 150% increase in F-22 pilot training, but at only an 18% increase in cost compared to using only F-22 adversaries.

The T-X provides a disproportionately high training return compared to operating cost. This return would increase F-22 pilot proficiency through greater repetition and increased threat numbers. This approach also has the potential to reduce the total number of F-22

sorties required to keep pilots proficient. Because F-22s would no longer be required to fly as adversaries, the squadron could fly only the number of aircraft required to train its pilots against dedicated adversaries. Reducing total F-22 sorties also extends the lifespan of the aircraft and reduces wear incurred as adversaries. The lower operating costs of flying the T-X as an adversary platform provides a high training return, but the cost of procuring the aircraft requires a significant investment from the Air Force. The procurement of additional T-X aircraft over the 350 planned purchase will likely drive the overall cost per aircraft lower, gaining benefits for the entire purchase through a larger economy of scale. The training benefits of operating the T-X as an adversary are significant and could help the long-term sustainment of the F-22 and F-35 fleets.[7]

In addition to providing a cost-effective solution to training, an adversary version of the T-X could provide a more representative adversary for F-22 and F-35 training. The T-X program could address many of the flight training shortfalls that plague the current approach. It would provide an adversary with better turn and acceleration performance, the ability to integrate sensors, jammers, weapons, datalinks, and onboard radar.[8]

One of the disadvantages of using the T-38 for flight training against the F-22 is the aircraft's non-representative performance in a visual engagement. The T-38 cannot replicate the sustained or instantaneous Gs of a 4th generation fighter. The T-38 cannot rapidly and aggressively turn to employ weapons like many 4th generation threats can.[9] The T-38 also cannot accelerate or decelerate as quickly as

[7] Unattributed Interview, F-22 Pilot, February 28, 2015.
[8] Mehta, "USAF Issues T-X Requirements," 1; Unattributed Interview, F-22 Pilot, February 28, 2015.
[9] Unattributed Interview, F-22 Pilot, February 24, 2015.

a 4th generation threat.[10] The Air Force, however, has made increased aircraft performance an important requirement in the T-X program.[11] One likely competitor for the T-X contract is the Lockheed T-50 Golden Eagle.[12] The T-50 performs similar to the F-16 Fighting Falcon and could provide representative maneuverability in a visual engagement.[13]

In addition to aircraft performance, the T-X could provide representative training in both WVR and BVR training in the electromagnetic spectrum. The T-38, F-22, and F-35 fall short of being able to replicate a 4th generation fighter threat in the electromagnetic spectrum. Based on the questions posed in the Air Force T-X requirements about possible modifications, an aggressor variant of the T-X could be equipped with an on board radar. It would also be capable of carrying training missiles, such as the AIM-9X heat-seeking missile, podded sensors such as an Infrared Search and Track system (IRSTs), and radar jammers.[14] With these enhancements, the T-X could provide a more representative threat for the sensors of the F-22 and F-35. This addresses the training shortfalls caused by the T-38 lacking any sensors and the F-22 and F-35 being too capable to replicate a threat aircraft.

The modified T-X could provide pilots with representative indications in the cockpits of both the F-22 and F-35. These indications are from sensors detecting and processing the electromagnetic signals from the T-X. This not only provides the pilots with the ability to react and use their offensive and defensive tactics as required by the C-NAF,

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[10] Unattributed Interview, F-22 Pilot, February 24, 2015.
[11] Smith, "TX, Future T-38 Jet Replacement, Requirements Released," 1.
[12] Stephen Trimble, "US Air Force, Industry Prepare for T-38 Replacement," *Flight International*, June 22, 2010, 1, http://www.flightglobal.com/news/articles/us-air-force-industry-prepare-for-t-38-replacement-343393/.
[13] Lockheed Martin, "T-50 Trainer" (Lockheed Martin, April 1, 2015), 1, http://www.lockheedmartin.com/us/products/t50/t-50-performance.html.
[14] Unattributed Interview, F-22 Pilot, Telephone, February 21, 2015; Mehta, "USAF Issues T-X Requirements."

but also tests the aircraft itself on a regular basis in training.[15] Because the T-38 cannot provide a hostile radar signal, pilots that fly against T-38s may not know if all of their sensors and systems are operating correctly. The T-X allows F-22 and F-35 pilots to react against an adaptive adversary that has similar capabilities to an enemy 4th generation fighter. This reinforces appropriate tactical decisions while punishing improper tactical actions and reverses the trend of negative learning that dominates when fighting against T-38, F-22, or F-35 adversaries.

While the T-X could address the performance and electromagnetic representation shortfalls of the current approach to flight training, it is not a panacea. If the Air Force equips all of its fighter wings with T-X adversaries that could generate enough sorties on its own to support the training requirements of every F-22 and F-35 pilot, the program might be a stand-alone solution. But the number of aircraft and pilots required are prohibitive. The creation of an air arm to train combat fighter pilots could require a large share of the Air Force's budget. This would be especially difficult with today's shortage of pilots in the Air Force. Therefore, it is more realistic for the Air Force to invest in enough T-X aircraft to augment the existing training approach and apply it to both the F-22 and the F-35 communities. Further research is required in the context of each fighter wing's training requirements and unique circumstances to determine the required number of T-X support at a given base. While this solution does not answer all of the problems of the current approach, it does provide the opportunity for a representative adversary for flight training. Based on budget and work force realities, the remaining shortfall in flight training is generating sufficient adversary numbers per mission to make the training effective.

[15] Unattributed Interview, F-22 Pilot, February 28, 2015.

## Live, Virtual, and Constructive

Another answer that could help the problems of both threat representative and sufficient numbers of adversaries is to use a blended live, virtual, and constructive (LVC) approach to training. LVC is an approach to training that integrates live, virtual, and constructive elements into a single training event. For clarity, the Department of Defense defines live, virtual, and constructive as follows. "*Live* training involves real people operating real systems (e.g. people flying aircraft). *Virtual* training involves real people operating simulated systems (e.g., a person operating an aircraft simulator. *Constructive* training involves simulated people operating simulated systems (e.g., a computer program generating and controlling missile threats against a real person in an aircraft simulator)."[16] An LVC training approach blends elements from each medium into a single training exercise. LVC enhances flight training through large quantities of adaptable and representative adversaries. While LVC seems to be an inexpensive solution to fill pilot training shortfalls, it is not a stand-alone solution. LVC has shortfalls in its ability to provide training for the transition from BVR to WVR. It also fails to test aircraft systems because it bypasses sensors to display information in the cockpit. Finally, the training it provides is only as good as the threat models used to develop the simulation software.[17]

## How Does LVC Work?

An integrated live, virtual, and constructive approach uses networked systems to provide interactive training. The technique integrates networked simulators, constructive elements, and live players to create a single interactive environment. To create this integrated

[16] John A. Ausink et al., "Investment Strategies for Improving Fifth-Generation Fighter Training" (Santa Monica, CA: RAND Project Air Force, 2011), 2.
[17] Johnson, ACC/A3TO DMO/DTC.

environment, each element communicates via fiber optic cables or radio waves with a central computer system.

Figure 12 shows a simplified example of using an LVC approach to provide both virtual and constructive adversaries for a flight training exercise. In this scenario, F-22 pilots fly four real aircraft, four adversary pilots operate ground-based simulators, and four constructive adversaries participate in the training scenario. The virtual adversaries and constructive adversaries integrate in the simulation center, just like a normal DMO simulation. In LVC training, a radio then transmits that virtual world into the cockpits of the flying aircraft.[18] The aircraft in turn share their current parameters, from position and speed to sensors and weapons status, back to the ground based simulation center. To the pilot, the virtual and constructive entities appear on his offensive and defensive sensors as if they are flying in the airspace with the live participants.[19] To the simulator operators, the live and constructive entities appear on the cockpit and visual displays as if the live players are operating in linked simulators.

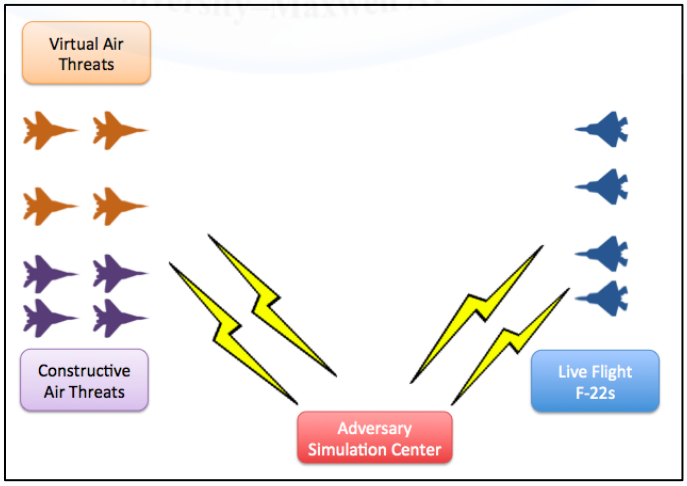


Figure 11. Virtual and Constructive Adversaries for Flight Training
*Source: Author's Original Work*

[18] Johnson, ACC/A3TO DMO/DTC.
[19] Johnson, ACC/A3TO DMO/DTC.

Current development of the LVC systems is at an "advanced technology demonstration phase," meaning that further research and development are needed to field an operational system.[20] ACC estimates that an LVC system might see operation within the next five years.[21] The LVC approach links each system through securely wired communications between the ground-based elements and encrypted radio signals to and from live aircraft.[22] This connection may require the modification of existing aircraft software to process and display LVC inputs on the cockpit displays.[23] The system also requires the installation of an antenna or an external pod to each aircraft.[24] For this system to work, bases with fighters will need computers linked into an LVC system and ground-based radios to provide the link to the airborne participants. Additionally, if units want to incorporate their own pilots flying virtual aircraft, they need a simulator facility linked into the LVC system.[25] An integrated LVC approach requires a large Air Force investment to procure the required communications and simulation systems and integrate them with existing and future aircraft. Such an investment would provide enhanced flight training for pilots and help address the current shortfalls in flight training.

[20] Johnson, ACC/A3TO DMO/DTC.
[21] Johnson, ACC/A3TO DMO/DTC.
[22] Johnson, ACC/A3TO DMO/DTC.
[23] Johnson, ACC/A3TO DMO/DTC.
[24] Lockheed Martin, "Lockheed Martin Advances Live, Virtual, Constructive Training in Flight Test" (Lockheed Martin, September 15, 2014), 1, http://www.lockheedmartin.com/us/news/press-releases/2014/september/140915-mst-lvc-lockheed-martin-advances-live-virtual-constructive-training-in-flight-test.html.
[25] United States Air Force, "Air Force Modeling and Simulation Vision for the 21st Century," 6.

**Enhanced Flight Training**

The LVC training approach addresses two of the current flight training shortfalls: adequate numbers of adversaries and threat representative adversaries. LVC augments existing airborne adversaries with virtual or constructive ones. These additional adversaries look like real world threats on the fighter cockpit displays because the virtual and constructive adversaries integrate directly onto the displays. Another benefit of the virtual and constructive adversaries is that they can accurately represent the capabilities of any known threat. Fighter pilots could train against one type of threat one day and a different the next, or then train against a wide variety of threats in a single mission. For instance, the virtual adversaries could replicate SU-27 Flanker fighters as the primary air-to-air threat and the pilots could add a constructive cruise missile threat to practice against at the same time. The LVC system could allow pilots to train against more dynamic threats with accurate representation of enemy systems on their cockpit displays.

The LVC training approach also provides greater threat numbers to enhance flight training. The desired force ratio for a F-22 Defensive Counter Air (DCA) mission, where the fighters defend a friendly area on the ground or a lane of airspace, is two F-22s against eight adversaries.[26] Due to a lack of adversaries, however, pilots often must fly it against only four T-38 or F-22 adversaries.[27] This shortfall in adversary capacity degrades daily pilot training and reduces their ability to practice difficult offensive and defensive tactics against 4th generation threats. Air-to-air experts developed the F-22 syllabus to meet the demands of training F-22 pilots. This failure to meet that requirement indicates that USAF fighter pilots are not receiving the training they need. This failure could lead to losses in combat that would jeopardize the Air Force's ability to

[26] US Air Force, "CAF Raptor F-22A Training Syllabus," 55.
[27] Unattributed Interview, F-22 Pilot, February 28, 2015.

secure air superiority in future conflicts. LVC provides a partial solution to this problem and augments the required number of adversaries available without adding more aircraft. For instance, four virtual adversaries could augment the same DCA mission previously mentioned and provide the eight desired adversaries when combined with the live ones. LVC allows pilots to practice BVR engagements more effectively, which increases their proficiency in long-range offensive and defensive tactics. This air-to-air proficiency is vital if the Air Force expects F-22 pilots to provide air superiority during both offensive and defensive missions.

There are several options for providing virtual adversaries for live-training missions. One option includes building simulator stations at each base and allowing fighter pilots to operate them against their fellow pilots within the LVC construct. This option provides the most flexibility at the local level and allows units to operate their own virtual aggressor force. Another option is to build a regional hub that supports multiple squadrons across multiple regional bases.[28] This option allows a small number of operators to provide training to multiple units from one facility but it lacks the flexibility of the local option since it is a shared resource. A third option is the combination of the two previous, i.e., each base has four simulators in addition to the regional hub that provides additional support. This option provides the most flexibility and allows individual bases to be self-supporting if there were a scheduling conflict with another base for the valuable regional adversaries. The third option also allows for greater numbers of adversaries in a given scenario because each base could contribute their own four simulators in addition to the regional ones.[29] Regardless of option, LVC provides enhanced live training at a significantly reduced cost in terms of flying hours. Table 2

[28] Johnson, ACC/A3TO DMO/DTC.
[29] Johnson, ACC/A3TO DMO/DTC.

shows how the previous cost assumptions change when adding virtual and constructive adversaries to the training equation. The cost of operating LVC is unknown right now, but it should share many of the cost-saving characteristics of simulators when compared to flight expenses.[30]

Table 2. Flying Hour Costs Using LVC

| Mission Type | Blue Air Training | F-22 Red Air | Dedicated Adversaries | Virtual Adversaries | Cost of F-22 sorties | Cost of Adversary sorties | Total cost of training mission |
|---|---|---|---|---|---|---|---|
| **Only F-22s** | | | | | | | |
| Dynamic Targeting | 4 | 6 | | | $620,000.00 | | $620,000.00 |
| ***# of F-22 pilots trained*** | ***4*** | | | | | ***Total Cost*** | ***$620,000.00*** |
| **F-22s with Support (F-16 operating cost) and Virtual Adversaries** | | | | | | | |
| Dynamic Targeting | 4 | | 3 | 3 | $248,000.00 | $69,000.00 | $317,000.00 |
| Dynamic Targeting | 4 | | 3 | 3 | $248,000.00 | $69,000.00 | $317,000.00 |
| Basic Fighter Maneuvers | 2 | | | | $124,000.00 | $0.00 | $124,000.00 |
| ***# of F-22 pilots trained*** | ***10*** | | | | | ***Total Cost*** | ***$758,000.00*** |
| **F-22s with Support (T-38 operating cost) and Virtual Adversaries** | | | | | | | |
| Dynamic Targeting | 4 | | 3 | 3 | $248,000.00 | $27,900.00 | $275,900.00 |
| Dynamic Targeting | 4 | | 3 | 3 | $248,000.00 | $27,900.00 | $275,900.00 |
| Basic Fighter Maneuvers | 2 | | | | $124,000.00 | $0.00 | $124,000.00 |
| ***# of F-22 pilots trained*** | ***10*** | | | | | ***Total Cost*** | ***$675,800.00*** |
| ***Assumptions per flying event: F-22 squadron will generate 10 aircraft, dedicated adversary squadron will generate 6 aircraft, and Virtual will provide remaining required threats*** | | | | | | | |

*Source: Author's work based on "Breaking Paradigms to Modernize USAF Fighter Pilot Training"*

If LVC provides half of the required adversaries, the cost of supporting this mission with T-38s is only 9% higher than flying only F-22s, but it trains 150% more pilots. If the cost of live adversaries is equivalent to F-16 operating costs then a 22% increase in flying-hour costs can train 150% more pilots. Compared to the T-X only model presented earlier in this chapter, LVC saves between 10-16% of flying hour costs while maintaining the 150% gain in capacity to train F-22 and F-35 pilots. Using virtual and constructive adversaries to enhance flight training helps address the shortfall in the quantity of threats, but it also contributes to the quality of live training.

As noted in Chapter 2, one of the major limitations of current training is the ability to accurately represent a threat system's capabilities on the cockpit displays of F-22 or F-35 pilots. Neither the T-38 nor F-22 can provide an adversary platform that gives accurate

[30] Johnson, ACC/A3TO DMO/DTC.

offensive or defensive feedback to the pilots.[31] This deficiency results in pilots that either over or under-estimate the capabilities of a 4th generation adversary. LVC injects accurate representations of threat systems, including their capabilities to detect, target, and engage the F-22 and F-35. Virtual and constructive threats also provide pilots indications on their cockpit displays that accurately replicate what they see against an actual enemy system.[32] Additionally, virtual and constructive threats require only a software update to keep pace with changing worldwide threats.[33] For instance, if an enemy developed a stealth fighter, the threat software can change to include the new fighter. Additionally, LVC could introduce surface-to-air missile threats into the training scenarios in locations that do not have access to real world ground emitters for training. The ability to update and change the threat models used by virtual and constructive threats in an LVC environment gives the system a lot of flexibility to provide accurate training for pilots.

Another aspect of LVC that provides superior training is the option to have a manned virtual adversary. Just as the ACS system provides better training for F-22 pilots with manned adversaries, virtual adversaries can do the same for flight training. As noted earlier, constructive adversaries can be useful but the complexity of their algorithms defines their capabilities. A virtual adversary, however, can adapt to complex situations by placing a pilot in the operating seat of the aircraft. This virtual approach allows live adversaries flying T-X or other types of aircraft to directly communicate with the virtual adversaries that are augmenting their mission through a UHF radio.[34] This link allows for a coordinated adversary force that can adapt in real time during a dynamic air battle. The ability to react using the information that is

[31] Unattributed Interview, F-22 Pilot, February 28, 2015.
[32] Johnson, ACC/A3TO DMO/DTC.
[33] Johnson, ACC/A3TO DMO/DTC.
[34] Johnson, ACC/A3TO DMO/DTC.

available to a live enemy pilot could provide F-22 and F-35 pilots with dynamic adversaries compared to the predictable behavior of constructive aircraft.[35]

Despite the potential benefits of an LVC approach to training, it is not the sole solution to all the training shortfalls identified in Chapter 2. While virtual and constructive adversaries can provide increased threat numbers and provide accurate indications on the cockpit displays, they cannot train the pilot to transition from beyond visual range to within visual range.[36] Pilots will have every indication that there is a threat in front of them, but they will not be able to see and react to it with their eyes. Effective WVR training will still require live adversaries, and since air-to-air engagements are likely to transition into a visual environment, live adversaries are still required.[37]

Mixing live, virtual, and constructive adversaries in the same mission could ameliorate this limitation. While the engagement is still beyond visual range, the range training officer (RTO) manages and simulated kills against the adversaries and removes the virtual or constructive participants first to leave the live T-X or equivalent alive. The RTO is a pilot who monitors training missions from the ground with a radio link to the participants as well as a real time view of all the participants' positions. To determine a simulated kill, the RTO uses published criteria to determine the success of air-to-air weapons employment during the training mission and chooses which participant to remove. When using virtual and constructive adversaries, the RTO could kill out those members of a formation first while leaving the T-X alive to continue to a visual engagement. This is not a perfect system,

[35] Unattributed Interview, F-22 Pilot, February 28, 2015.
[36] Johnson, ACC/A3TO DMO/DTC.
[37] Unattributed Interview, F-22 Pilot, February 21, 2015; Unattributed Interview, F-22 Pilot, February 21, 2015.

but the approach could account for some of the limitations virtual or constructive adversaries in live training.

Another limitation is that LVC does not use aircraft sensors to find threats.[38] This means that the training mission does not test the various sensors or the computers the aircraft processes to collect data and present it to pilots. One way pilots determine if their systems are not working properly is by noting sub-standard performance during training missions. Because LVC bypasses the aircraft sensors, the pilots may not know the condition of critical systems.[39] The solution to this problem is the same as that noted above. A live adversary that can simulate enemy characteristics, such as radar emissions and jamming, must fly with the LVC adversaries so the F-22 and F-35 pilots can check aircraft sensor performance.

The final limitation of using virtual and constructive adversaries for flight training is that the training will only be as good as the sophistication of the models used to generate those threats.[40] This problem is similar to the difference in the quality of training between the ACS and MTC simulators used to train F-22 pilots. If the simulator uses an overly simplistic threat model as the virtual or constructive threat, flight training will suffer from the same negative effects currently experienced in F-22 MTC training. If the adversary model is overly capable, pilots will learn to be more conservative than required in their tactics, which negates the asymmetric advantages that stealth provides them. If, instead, the adversary models are less capable than real enemy threats, pilots may become too aggressive since they are not punished for mistakes made in training.[41] Therefore, the development of virtual and

[38] Johnson, ACC/A3TO DMO/DTC.
[39] Johnson, ACC/A3TO DMO/DTC.
[40] Unattributed Interview, F-22 Pilot, February 28, 2015.
[41] Unattributed Interview, F-22 Pilot, February 28, 2015.

constructive adversary capabilities must focus on including sufficient complexity in their modeling, such as the ACS systems.

A live, virtual, and constructive training approach could address some of the training shortfalls identified in Chapter 2, but the approach is not adequate on its own. While LVC can provide larger numbers of adversaries for live training, it cannot train pilots on the requirement of within visual range engagement. LVC can provide greater replication of the threat capabilities and reproduce accurate indications in the cockpit displays of the F-22 and F-35, but it is limited by the sophistication of the constructed threats. LVC provides critical capabilities for flight training and facilitates an increase in training capacity with reduced flying costs. The Air Force should use LVC in combination with other training solutions, such as the T-X, to address each of the shortfalls in the current flight training programs. While the Air Force can use LVC and the T-X to address the shortcomings in flight training, addressing the shortcomings in 5th generation simulator training requires additional measures.

### Simulator Fidelity

Increasing simulator threat fidelity and providing a manned adversary option, such as the ACS, could provide a more representative training environment and help eliminate negative tactical lessons from MTC training. One of the shortfalls identified in Chapter 2 was the unrealistic performance of constructive adversaries used in MTC simulator training. There are two solutions that could help alleviate this problem: provide manned adversary stations to provide virtual threats during simulation and increase the complexity of the threat models in the MTC.

The first option of providing manned virtual adversaries during simulation has proven successful during ACS training.[42] The human-controlled adversary is better able to adapt and punish mistakes made by the training pilots and provides better tactical lessons. In this approach, the F-22 or F-35 pilots operate simulators for their own training and other pilots operate simulators that replicate enemy aircraft in the simulation. F-22 pilots that have used the ACS for training indicate that this method of air-to-air training is more representative of fighting a real 4th generation threat than actual flight training against T-38 or F-22 aircraft.[43] One option for providing this capability is to use adversary simulators that support LVC flight training. This approach uses the same threat simulators to provide virtual adversaries for either flight training or simulated training.

The second option of increasing the complexity of the threat models in the MTC improves training against constructive and virtual adversaries. If the MTC modeled the simulated adversary, F-22, and F-35 systems on a more complex algorithm, it could provide training that better reflects expected tactical outcomes against enemy aircraft. One of the biggest complaints of current F-22 pilots is that after they fly within a certain range of a constructive enemy, that enemy gains perfect situational awareness of the F-22 and is nearly always able to begin employing weapons immediately.[44] When compared to actual flight training against 4th generation fighters, this is not the case. This lack of complexity in the MTC constructive modeling may lead pilots to conclude that they should avoid flying inside that magic range, counter to established tactics and procedures. This lack of complex modeling is not

[42] Unattributed Interview, F-22 Pilot, February 28, 2015.
[43] Unattributed Interview, F-22 Pilot, February 28, 2015; Unattributed Interview, F-22 Pilot, February 21, 2015; Unattributed Interview, F-22 Pilot, February 21, 2015.
[44] Unattributed Interview, F-22 Pilot, February 24, 2015; Unattributed Interview, F-22 Pilot, February 28, 2015.

only an F-22 problem. The Air Force is currently building the F-35 MTC simulators using similar types of threat models.[45] Changing this problem will not be easy or inexpensive, because one of the primary determinants is computing power available at the MTCs compared to the ACS or V-Sim.[46] The Air Force should upgrade the simulators because they are one of the primary means of training according to the RAP tasking memorandums for both the F-22 and F-35. The Air Force can close a critical gap in its training approach and reinforce proper tactics through cost-effective simulator training if it invests in more complex modeling.

The training that F-22 and F-35 pilots receive in the MTC would be more representative of actual threats if the threat modeling and interaction became more complex and provided manned virtual adversaries.[47] This increased fidelity would reinforce established tactics and procedures while providing a cost-effective means of gaining the learning benefit of repetition in the simulator. Accurate virtual and constructive adversaries are more important to F-22 and F-35 training compared to past fighters since the 5th generation fighters cannot produce representative adversaries for air-to-air training in flight.[48] Because of the expectation that simulation can make up for realism shortfalls during flight training, it is important that the USAF invest in improving MTC simulation to provide the needed training. The ability of pilots to train to meet the C-NAF operational requirement of executing offensive and defensive tactics against a 4th generation threat requires updating the MTC threat modeling to accurately reflect adversary, F-22, and F-35 capabilities.

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[45] Dahl, ACC/A5FI, F-35 Air Systems Requirements Analyst.
[46] Dahl, ACC/A5FI, F-35 Air Systems Requirements Analyst.
[47] Unattributed Interview, F-22 Pilot, February 28, 2015.
[48] Unattributed Interview, F-22 Pilot, February 28, 2015.

## Conclusion

An adversary version of the T-X, LVC, and increased simulator complexity each address a shortfall in current air-to-air training but none solve the problem alone. If the Air Fore invests in these programs, it can provide representative training that can adapt as the threat changes to prepare pilots for expected future conflicts. An adversary version of the T-X is an effective way to address the poor performance of T-38s, F-22s, and F-35s as adversaries. The T-X, however, could probably not provide the quantity of adversaries required to complete the required training. Using virtual and constructive adversaries in the LVC approach addresses the quantity problem but does not provide adequate within-visual-range training or exercise the aircraft sensors and systems. Both solutions taken together provide an effective means to train, but do not provide the practice needed to gain and maintain proficiency. Upgrading the MTC simulators with more accurate threat modeling and an option for manned virtual adversaries provides a means to conduct representative training in the simulators that positively reinforces both flight training and established tactics and procedures. Taken together these three programs could address the major shortfalls in current F-22 and F-35 training, but each one alone is insufficient to fill the current gap between the desired level of pilot proficiency and the current state of pilot readiness.

## Conclusions

*My pledge for the coming year is to strengthen unit readiness and avoid a creeping hollow force that proves only the illusion of global vigilance, reach, and power.*

Air Force Chief of Staff General Norman Schwartz in 2011

Experience has demonstrated that the most effective means of training pilots is with a combination of flight training and simulation. Resource constraints often mean that flight training alone cannot provide the repetition or focus necessary to reach the desired proficiency levels. Simulation, however, cannot replace all flight training since it cannot replicate the conditions of actual flight. The Link Trainer demonstrated that ground-based simulation can have a positive impact on blind flying proficiency because it could virtually replicate the instrument conditions. In 1944 the A-6 Bombing Trainer provided a training environment that better represented the altitudes bombardiers were expected to employ from and provided additional practice that was impractical to get in flight due to high costs. In 1949, the Link C-11 simulator provided a safe environment to practice emergency procedures and was effective because the simulator accurately represented the performance and characteristics of the F-80. In the 1970's, the US Air Force and US Navy invested in instrumented ranges to enhance flight training and provide accurate feedback to pilots. In the aftermath of the Vietnam War, the US Air Force created the aggressors to provide threat representative flight training and introduced mission simulators to practice tactical fighter employment. The US Air Force also established the Red Flag training exercise and created linked simulators to address shortfalls in integrated mission performance. In each of these examples, the US Air Force has sought a balance between cost, time, and training effectiveness. To

address the cost and time aspects of the equation, the Air Force has developed simulators that can provide training that augments or enhances flight training, thereby saving flying hour costs and wear on their aircraft. To address the training effectiveness side of the equation, the US Air Force has invested in making training as representative of potential combat scenarios as possible. This investment includes creating virtual models that accurately represent threat systems and employing threat representative air-to-air adversaries for flight training. Each example showed that no single approach to training worked by itself. Both flight and simulator training have benefits and drawbacks, but used together they yielded a training approach that adequately prepared pilots.

The US Air Force has determined that F-22 and F-35 pilots must be proficient at air-to-air combat against a 4th generation threat, but F-22 and F-35 squadrons cannot provide themselves with a representative threat to train against. Both flight training and the simulator models fail to accurately replicate the capabilities of the enemy. These shortfalls in training accuracy can lead pilots to apply the wrong lessons to future training scenarios and employ improper tactics in combat.

Flying against T-38s fails to provide appropriate feedback to pilots about their performance and masks their airborne mistakes because the T-38 has no sensors or weapons. Flying against other F-22s or F-35s punishes their appropriate decisions since the F-22 and F-35 are too capable to replicate enemy threats. Using only F-22s or F-35s as adversaries also means that each squadron is unlikely to be able to provide enough adversaries for effective training. It is also inefficient to use scarce F-22s and F-35s to fly as adversaries since the pilots do not receive relevant tactical training. F-22 and F-35 flying hours are expensive compared to other platforms and training pilots for actual expected missions should be the priority for those scarce flying hours.

Inaccurate threat modeling in the simulator likewise can teach pilots the wrong lessons since the constructive adversaries have too much capability. This drives pilots toward overly conservative tactics, negating the offensive potential that a 5th generation fighter provides.

Any solution to these problems should address all of them because no single method of training will provide the desired proficiency at a reasonable cost. Purchasing an aggressor version of the T-X that has RADAR and can carry external pods and weapons could better replicate a 4th generation threat than either the F-22 or the T-38. This solution provides better flight training in both visual and beyond visual ranges (BVR). It is impractical, however, to purchase enough T-X aircraft to supply all 5th generation flight training needs. Therefore, a live, virtual, and constructive (LVC) approach to BVR flight training could provide sufficient numbers of representative adversaries to make larger missions effective. While each flight training solution contributes to solving the current problems, neither can solve them on their own. If the Air Force only purchases the T-X, there will not be enough adversary capacity. If the Air Force only uses LVC's virtual and constructive adversaries, transitioning from beyond visual range to within visual range and subsequent maneuvering is difficult.

The Air Force must address both issues to provide critical air-to-air training for F-22 and F-35 pilots. If the flight training issues are resolved but the simulator still fails to replicate enemy capabilities accurately, pilots will not be able to practice the precise skills they must employ in the air while in the simulator. Therefore, the training simulators for both the F-22 and F-35 should include sufficient threat modeling and complexity to reinforce the proper tactics required in flight. Virtual and constructive adversaries should provide pilots with the opportunity to train against threats that may not be practical to reproduce in flight such as enemy radar and jammer capabilities. If the virtual threat models are unrealistic, the benefits of tactical training against them are lost.

While the combination of all three recommendations provides comprehensive training for F-22 and F-35 pilots, the resources required to make them operational may not be immediately available to the Air Force. Of the three recommendations, LVC provides the most return on investment. The LVC approach is adaptable and can be applied to older aircraft like the F-15 and F-16, current fighters like the F-22 and F-35, and future platforms. Of all of the solutions, it has the potential to provide the most threat representative training for live flight. To ameliorate the limitations of LVC, F-22 and F-35 pilots should continue to train against T-38s, 4th generation fighters, and other F-22s and F-35s to provide within visual range training. The LVC approach's ability to provide sufficient numbers of adversaries at reduced flying costs makes it an attractive solution in a fiscally constrained environment. The Air Force, however, must also prioritize flight training against live adversaries on a regular basis to verify F-22 and F-35 sensor and systems operations. Failing to invest in LVC means that the Air Force will have to chose between buying large numbers of adversary aircraft, flying its expensive fighters as adversaries, or accepting a lower standard of proficiency in its air superiority pilots.

The consequence of failing to provide representative training for fighter pilots is an increased risk of loss in combat, which would threaten the Air Force's ability to establish and maintain air superiority. As a force that values quality over quantity, combat losses have a significant impact on the ability to conduct sustained operations. A loss of air superiority also jeopardizes the Air Force's ability to project power or protect US and coalition forces, especially against a well-trained and equipped adversary.

As the Air Force continues to make recapitalization of its fighter fleet a top priority, it should also invest in the future of training for its pilots. The examples examined in Chapter 1 revealed that failing to prepare aircrew to meet expected requirements could have lethal

consequences. Failing to practice against a representative threat can lead to both over-confident and under-confident pilots, but more importantly will influence combatant commanders' expectations of performance. Michael Howard suggested that predicting the future of war is like navigating in a fog, but preparing to be as close as possible to reality will yield the best results.[1] After thinking critically about future operational requirements, the US Air Force must invest in representative training to prepare its pilots to meet them.



[1] Howard and Wilson, "Military Science in an Age of Peace," 7.

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