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Investment Strategies for Improving Fifth-Generation Fighter Training

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Preface

The U.S. Air Force is finding it increasingly difficult to safely and affordably train combat air force (CAF) aircrews so that they will be prepared for combat conditions. Increased combatant commander (CCDR) requirements coupled with reduced force structure are stretching the ability of units to support sufficient training. Reduced flying hours are insufficient to meet Ready Aircrew Program (RAP) training requirements, and training ranges are insufficient to properly train and support new combat capabilities. In addition, safety considerations, mission complexity, airspace and range restrictions, and real-world commitments and costs limit the amount of training that can be accomplished in live aircraft. Air Force training experts believe that the increased use of simulators; distributed mission operations (DMO); and new applications of live, virtual, and constructive (LVC) training[1]—in particular, the ability to "inject" battlefield effects and simulated or constructed threats into live aircraft systems—are required to mitigate training risks.

The Office of the Deputy Chief of Staff for Operations, Plans and Requirements (AF/A3/5) asked RAND Project AIR FORCE to explore investment strategies that allow fifth-generation fighter aircraft to take advantage of the potential training benefits of LVC media. This technical report documents the results of RAND's research on this topic. The report examines the nature of any training gaps that might exist for fifth-generation aircraft and then uses rough cost comparisons to show that continued investments in simulators and DMO capabilities must continue before large investments are made in more exotic LVC technology.

Readers may also be interested in the following related RAND documents:

- *Fighter Drawdown Dynamics: Effects on Aircrew Inventories*, William W. Taylor, James H. Bigelow, and John A. Ausink (MG-855-AF).
- *Absorbing and Developing Qualified Fighter Pilots: The Role of the Advanced Simulator*, Richard Marken, William W. Taylor, John A. Ausink, Lawrence M. Hanser, C. R. Anderegg, and Leslie Wickman (MG-597-AF).
- *Absorbing Air Force Fighter Pilots: Parameters, Problems, and Policy Options*, William W. Taylor, James H. Bigelow, S. Craig Moore, Leslie Wickman, Brent Thomas, and Richard Marken (MR-1550-AF).
- *The Air Force Pilot Shortage: A Crisis for Operational Units?* William W. Taylor, S. Craig Moore, and C. Robert Roll, Jr. (MR-1204-AF).

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[1]   Existing Department of Defense definitions include the following: *Live* training involves real people operating real systems; *virtual* training involves real people operating simulated systems (e.g., a person operating an aircraft simulator); and *constructive* training involves simulated people operating simulated systems (e.g., a computer program generating and controlling missile threats against a person in an aircraft simulator).

The research described in this report was conducted within the Manpower, Personnel, and Training Program of RAND Project AIR FORCE as part of a fiscal year 2009 study "Business and Operational Case for Distributed Mission Operations Versus Live Flying in Fifth-Generation Fighter Continuation Training." This report should interest military leadership and policymakers involved in decisions related to investments in LVC training approaches for fifth-generation aircraft.

RAND Project AIR FORCE

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Summary

Since 1997, the Air Force has argued that it is increasingly difficult to safely and affordably train CAF aircrews the way they will be required to fight. CCDR requirements are increasing, but reduced force structure stretches the ability of units to support sufficient training. Budget constraints have led to reduced funding for flying hours to the point that they are insufficient to meet RAP training requirements. Safety considerations, increased mission complexity for fifth-generation aircraft, airspace and range restrictions, and real-world commitments limit the amount of training that can be accomplished in live aircraft.[1]

Air Force training experts believe that the increased use of simulators, more widespread and effective use of DMO (the ability to connect simulators and/or aircraft at widely dispersed locations worldwide), and new applications of LVC media are required so that fifth-generation pilots are able to acquire the skills they need and so that training risks can be mitigated. Regarding LVC media, these training experts are particularly interested in increasing the ability to "inject" battlefield effects and simulated or constructive threats into live aircraft systems. Developing a *persistent* (always available) environment in which training participants cannot distinguish among live, simulated, and constructive entities might not only lower costs (by decreasing the amount of training that must be accomplished in live aircraft) but also simplify the coordination and accomplishment of exercises that involve large numbers of participants. Full-mission "rehearsal" will become easier.

The potential benefits of LVC training are accompanied by technological uncertainties in the development of some capabilities, so the Air Force needs to take a careful approach to investing in LVC. It is particularly important for the Air Force to understand what its training needs really are in order to determine whether investments in LVC are necessary (or worthwhile) to fill potential training gaps.

This study uses a variety of data sources to determine whether there are training gaps for fifth-generation fighter aircraft. These sources include a 2008 survey jointly conducted by the U.S. Air Force, Air Combat Command (ACC), and the Warfighter Readiness Research Division of the Air Force Research Laboratory (AFRL); interviews with F-22 pilots and other personnel involved in fighter pilot training; mission essential competencies (MECs) developed for the F-22; and flying hour data for current fighter training. For the following three reasons, we conclude that the evidence for a training gap is strong:

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[1]   These limits to training in live aircraft were described in Clark, 2009.

1. Inexperienced F-22 pilots are currently accomplishing only six or seven live sorties per month. They are unable to achieve RAP training minimums and are flying excessive "red air" missions.[2]
2. F-22 respondents to the ACC survey (AFRL, 2008) indicate the need for an increase in both live and simulator training, as well as a change in the distribution of mission categories flown.
3. Preliminary MEC analyses show that there are existing and potential gaps between experiences that F-22 pilots need to have and what they are able to receive.

With this evidence for a training gap, we use a linear programming model to examine the potential to redistribute training in order to increase training effectiveness. We start with the assumption that F-22 flying is funded so that RAP minimums (ten aircraft sorties per month, three simulator missions per month[3]) can be accomplished. We then use the model to determine the optimal training distribution between live and simulator sorties if pilots fly at least eight live blue sorties per month (RAP establishes a maximum of two red-air sorties per month). This information is used to establish a framework to compare the costs of ensuring that the minimum of eight blue sorties can be flown. Our conclusion is that, in the long run, development of the LVC ability to inject simulated and constructive threats into live aircraft may be the only fiscally responsible approach to improving training. However, the technological uncertainty that remains in developing this capability requires a careful investment approach.

Conclusions

One of our major findings is that fully documented training requirements for realistic training scenarios are extremely scarce in RAP and other training documentation. The Realistic Training Review Boards that are conducted regularly to address these issues are reluctant to document specific training requirements that cannot be accomplished in the normal course of events because this could ensure that large numbers of aircrew members would have to be decertified from combat mission status when the difficult-to-complete training events were not accomplished. However, if the Air Force does not articulate its training needs more effectively, resources that are essential for effective operational training could be lost.

Our determination of the existence of a training gap for fifth-generation fighters and our analysis of costs associated with the development of improved LVC training capabilities leads us to the following conclusions:

1. The Air Force needs to ensure that funding for the F-35 mission training center (MTC) is sufficient to make it DMO capable. Unless the F-35 MTC can connect to the Dis-

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[2] These are missions in which the pilots play the role of an adversary. "Red air" adversaries are an important component for almost all air-to-air (as well as some tactical surface attack) training missions, but flying as an adversary provides less training than flying a "blue" (U.S. and allied forces) training sortie.

[3] At the time the model was developed, 60 simulator missions were required over a 20-month period for the F-22 (see HQ ACC, 2008). In October 2009, this requirement was changed to 26 simulator sorties over a 12-month period for slightly more than two simulator sorties per month.

tributed Mission Operations Network (DMON), there is little chance that the benefits of virtual and constructive training can be fully realized.

2. The Air Force needs to maintain investments in threat-generation capabilities to make sure that they remain concurrent with existing aircraft and integrated air defense system threats. Expansion of the Distributed Training Operations Center (DTOC) or the development of a DTOC-like facility elsewhere will be crucial for the maintenance of an Air Combat Simulator–like capability for the F-22 and F-35.

3. Funding for the DMON must be maintained. The network is already used successfully for training—most notably by the DTOC, but also for Virtual Flag exercises—and a networking capability is an important component of any persistent virtual training capability.

4. Continued investments in developing solutions to various multilevel security and cross-domain solution problems must be made in order to enable the MTCs at different locations to participate in training and to allow connections with other organizations for joint and combined virtual exercises.

5. The F-35 has the capability to accept an embedded-threat module, and it can also accommodate a "P5 pod," which allows some types of simulated training in the aircraft.[4] Both of these capabilities are first steps in the ability to inject virtual and constructive threats into aircraft systems, so they should be funded if possible.

Investments in these areas alone will improve fifth-generation fighter training. The potential is high that injecting battlefield effects and virtual and constructive threats into live aircraft will yield even greater improvements. However, because of the technological uncertainties related to this capability, the best way to proceed is to maintain targeted, relatively small investments in injection development. Only when technological uncertainties are resolved should larger investments be made.

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[4] The pod is part of the fifth-generation P5 Combat Training System/Tactical Combat Training System designed by Cubic Corporation. (See Shamim, 2007.)

Acknowledgments

Abbreviations

711 HPW/RHAS	Warfighter Readiness Research Division in the Human Effectiveness Directorate of the 711th Human Performance Wing
ACC	Air Combat Command
ACC/A3TO	Air Combat Command, Operational Training Branch
ACM	air combat maneuvering
ACS	Air Combat Simulator
Aegis	Advanced Electronic Guidance and Instrumentation System
AF/A3/5	Office of the Air Force Deputy Chief of Staff, Director of Operations, Plans and Requirements
AF/A3O-AT	Office of the Air Force Deputy Chief of Staff, Director of Operations, Operational Training Division
AFAMS	Air Force Agency for Modeling and Simulation
AFB	Air Force base
AFI	Air Force instruction
AFRL	Air Force Research Laboratory
AF/XO	U.S. Air Force Office of the Deputy Chief of Staff for Air and Space Operations
AHC	aircraft handling characteristics
ANG	Air National Guard
ARCNet	Air Reserve Component Network
AWACS	Airborne Warning and Control System
BFM	basic fighter maneuvers
CAF	combat air force
CCDR	combatant commander
CFTR	composite force training

CPFH	cost per flying hour
DCA	defensive counterair
DMO	distributed mission operations
DMOC	Distributed Mission Operations Center
DMON	Distributed Mission Operations Network
DMT	distributed mission training
DoD	Department of Defense
DTOC	Distributed Training Operations Center
FY	fiscal year
GAMS	General Algebraic Modeling System
GS	Global Strike
HQ	headquarters
IADS	integrated air defense system
IAW	in accordance with
IPT	Integrated Process Team
JSTARS	Joint Surveillance Target Attack Radar System
LFE	large-force employment
LVC	live, virtual, and constructive
MAJCOM	major command
MEC	mission essential competency
MLS/CDS	multilevel security and cross-domain solution
MTC	mission training center
N/A	not applicable
NOC	network operations center
O&M	operations and maintenance
OCA	offensive counterair
PAF	RAND Project AIR FORCE
PMAI	primary mission aircraft inventory
Q	quarter
RA	red air

RAP	Ready Aircrew Program
SAM	surface-to-air missile
SCM	sorties per crew per month
SRR	short-range response
TDY	temporary duty
TI	tactical intercepts
v.	versus
WPC	Warrior Preparation Center
WRAP MTS	Warfighter Readiness Assessment and Performance Measurement Tracking System
XCITE	Expert Common Immersive Theater Environment

Introduction

Background

In November 1997, the Vice Chief of Staff of the Air Force, Lt Gen Ralph E. Eberhart, signed an operational requirements document for distributed mission training (DMT) systems. The deficiency this document was meant to address was described as follows:

> CAF [combat air force] aircrews do not have the capability to safely and affordably train the way they will be required to fight. Safety considerations, mission complexity, airspace and range restrictions, real-world commitments and costs limit the ability of CAF aircrews to effectively train across the spectrum of Air Force core competencies using aircraft sorties. Existing simulation . . . [limited primarily to individual/crew trainers] . . . do[es] not always reflect latest aircraft configuration and . . . [is] not designed for interoperable combined exercises. Only basic, single-ship, aircraft training (instruments, emergency procedures, and intercepts) can be accomplished. There is no capability to conduct basic engaged maneuvering and no linkage to allow multiple aircraft to train together to develop complex fighting concepts (large and/or composite force employment) or conduct full mission training in a simulated combat environment at the basic employment formation level. (U.S. Air Force, 1997, para. 3.1.) [1]

DMT was described as a "revolutionary" approach to warfighting readiness that would "provide a distributed simulation mission space that allows exercise participants to receive, process, and transmit commands and information across geographically dispersed locations" (U.S. Air Force, 1997, para. 3.1), and would consist of

- a hardware and software environment to host simulations
- simulated mission space that represents the real-world environment in which air operations occur
- model representations of physical entities (bases, aircraft, weapons, sensors, and targets)
- behavioral models that govern the interaction between the entities
- links to "real-world" command, control, and intelligence sources
- technical support operations and modules (e.g., scenario and database preparation; translators for interfacing with real-world command, control, communications, computers, and intelligence systems; and familiarization training).

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[1]   In our report, a *sortie* means an aircraft mission from takeoff to landing or a simulator mission from beginning to end. An *event* is a specific training element, function, or task, for example, delivering a certain type of weapon during a training sortie. We use *activity* to refer to a training event or sortie.

The DMT operational requirements document used existing Department of Defense (DoD) definitions for live, virtual, and constructive (LVC) training. *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).[2] Although generally accepted, this taxonomy has long been recognized as being problematic because "there is no clear division between these categories. The degree of human participation in the simulation is infinitely variable, as is the degree of equipment realism. This categorization of simulations also suffers by excluding a category for simulated people working real equipment" (DoD, 1998, p. 132).

Various Air Force organizations have been working for years with DMT-related issues, though *DMO* (distributed mission operations) has replaced DMT as the term for the concept of linking personnel at different locations in simulated operations. Indeed, complex organizational arrangements and processes have made management of DMO and LVC issues a challenge. The Office of the Air Force Deputy Chief of Staff, Director of Operations, Operational Training Division (AF/A3O-AT) is responsible for DMO policy, resource advocacy, and oversight to each major command (MAJCOM). The Air Force Materiel Command executes and oversees DMO acquisition, sustainment, and support. But the U.S. Air Force Warfare Center under the Air Combat Command (ACC) has been designated the lead organization for DMO/LVC integration,[3] while the U.S. Air Force Agency for Modeling and Simulation (AFAMS), which reports to the Office of the Secretary of the Air Force's Chief of Warfighting Integration and Chief Information Officer, is the lead organization for integrating LVC capabilities in "full-spectrum operations" (see AFAMS, undated).[4]

Attempts to improve coordination and to develop a more strategic approach to DMO and LVC have been made. In June 2004, the Air Force's Office of the Deputy Chief of Staff for Air and Space Operations (having at the time the office symbol AF/XO) established a DMO Integrated Process Team (IPT) (U.S. Air Force, 2004). The IPT

> includes representatives from all MAJCOMs and oversees the planning, programming, and execution of the AF DMO Program. The DMO IPT ensures DMO-related operational capabilities, requirements, security issues, architectures, and technologies are defined and prioritized. In addition, the IPT ensures joint interoperability across the Air Force and eliminates redundant capabilities. (U.S. Air Force, 2004, p. 3.)

The same office[5] is currently developing at least three documents related to LVC and DMO training: a DMO concept of operations, a DMO implementation plan, and an LVC

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[2]   The definitions are from DoD, 1995, p. A-6.

[3]   In December 2007, it was agreed that the U.S. Air Force Warfare Center would become the Air Force lead integrator for LVC training. See McKinney, 2007.

[4]   According to a personal communication from AF/A3O-AT, AFAMS was reorganized and placed under the Office of the Air Force Deputy Chief of Staff, Director of Operations, Plans and Requirements (AF/A3/5) in March 2010.

[5]   The Air Force changed to an "A-staff" structure in 2006. AF/XO was changed to the Office of the Deputy Chief of Staff for Operations, Plans and Requirements with office symbol AF/A3/5.

concept of operations white paper.[6] AFAMS has recently produced *USAF Live, Virtual, and Constructive (LVC) Integrating Architecture (LVC-IA) Plan* (Shelton, 2009), the goal of which is to ensure that the Air Force has a chartered LVC–integrating architecture program to efficiently and effectively address current shortfalls, establish common standards, and reduce duplication and redundancy (Shelton, 2009). All of these documents assume the existence of a training problem and the efficacy of LVC in solving it.

The Problems According to ACC[7]

In the view of ACC, the current shortfalls of LVC include the training problems raised in the DMT operational requirements document (U.S. Air Force, 1997), which will be exacerbated for fifth-generation fighters, as well as other problems. The other problems include reduced flying hours, because of budget restrictions. Flying hours are insufficient for pilots to fly the minimum number of missions prescribed by the Ready Aircrew Program (RAP). Also, training ranges are insufficient to support new combat capabilities because of the difficulty in providing representative advanced threats, expanded information-warfare training-range requirements, and larger "footprints" for modern weapons. In addition, reduced force structure and expanding combatant commander (CCDR) requirements are stretching the Air Force's ability to support training requirements. Combined, these shrinking training resources and expanding mission requirements are jeopardizing the ability to meet CCDR proficiency standards to accomplish wartime missions.

For ACC, the term DMO refers only to the concept of linking simulators around the world. ACC uses *integrated LVC* to describe the ability to connect live systems to virtual or constructive systems, and it views the increased use of DMO and integrated LVC as necessary to mitigate training risks in the future.

A popular slide in ACC briefings is entitled "LVC Nirvana" and is reproduced in Figure 1.1. The vision is that all LVC training media could be connected to provide realistic, *persistent* (always available) training to personnel worldwide. Live F-22 aircraft in Guam could "fly" with F-15C and F-16 pilots who are operating simulators in Osan Air Base and Kadena Air Base. Computer-generated air and ground threats would be seen by pilots in simulators and pilots in live aircraft. A live Airborne Warning and Control System (AWACS) from Kadena would be able to observe the entire battlespace and direct live F-22 aircraft against constructive air threats or virtual F-16 aircraft against constructive ground threats. The live AWACS could also help a virtual F-15C "join up" with a live F-22 to assist against a threat. The exercise could be made joint with the participation of a live or virtual Aegis (Advanced Electronic Guidance and Instrumentation System) cruiser.

Such an arrangement would obviously make full mission rehearsal cheaper, by not requiring as many live aircraft, and more realistic, by using simulation to make it seem that the

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[6]   All documents were in draft form as of the writing of this technical report in October 2009. In an effort to improve DMO/LVC management, AF/A3/5 also established the LVC-DMO General Officer Steering Group, consisting of the directors of operations (A3s) from the Air Force's MAJCOMs and led by the Deputy Chief of Staff for Air and Space Operations.

[7]   The problems described in this section are based on Clark, 2009.

Figure 1.1
LVC Nirvana
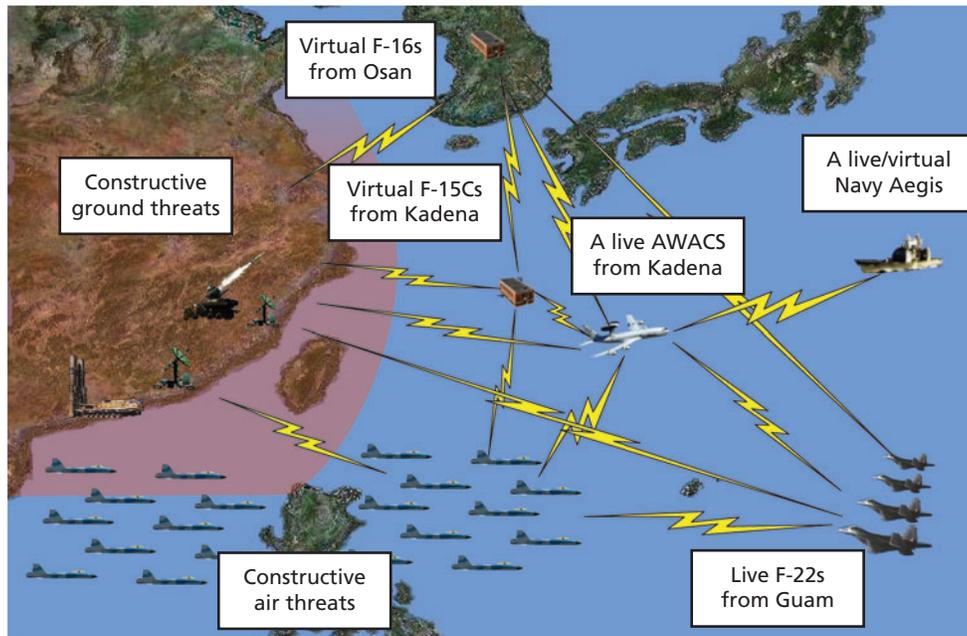
SOURCE: Similar figures appear in multiple ACC briefings. For example, see Clark, 2009.
RAND *TR871-1.1*

exercise is being conducted in the expected threat environment instead of requiring pilots at a range in Nevada to imagine that they are instead flying over the ocean.

Fifth-Generation LVC Reality

The Air Force has significant simulator, network, and training center capabilities, but the currently funded LVC environment for fifth-generation fighters falls short of LVC nirvana.

Simulators and Mission Training Centers

The Air Combat Simulator (ACS), which is operated by Lockheed in Marietta, Georgia, has four "blue" cockpits for F-22 pilots to fly at one time. The simulator also has eight manned "domes" (simulator cockpits with 360-degree visual displays) that are operated by pilots who serve as "red air" opponents for the F-22s (which are "blue air"). The system includes man-in-the-loop surface-to-air missile (SAM) threats and a ground-control-intercept station that allows a controller to guide enemy aircraft against the F-22 pilots in the simulator. Training in the ACS is universally praised by F-22 pilots who have experienced it—one pilot we interviewed said, "After two days at the ACS you feel like you've been at Red Flag for two or three weeks!" However, the ACS is not owned by the Air Force, and as F-22 simulators come online,

F-22 pilots, who currently go to the ACS approximately twice a year, will no longer be trained in it.[8]

The F-22 mission training center (MTC) (consisting of four connected simulators) is up and running only at Langley Air Force Base (AFB); Holloman and Elmendorf AFBs plan to have an F-22 simulator capability by fiscal year (FY) 2012. There is some concern among F-22 pilots that the F-22 MTCs will not replicate the effectiveness of the ACS—in part because the visual system is not as good, in part because the threat capabilities (red air, SAMs) are not yet in place. However, ACC feels that the F-22 MTCs will provide excellent training.

The F-35 MTC—which has not yet been built—is planned to be in place at Eglin, Hill, and Nellis AFBs in FY 2013 but will need additional Air Force investments to be DMO capable. One challenge that the Air Force faces is that the F-35, or Joint Strike Fighter, is a joint venture, yet the other services are not as interested in DMO capability for this MTC as the Air Force is. Despite that limitation, the F-35 MTC will still provide high-fidelity simulators with excellent capability at the unit level.

Networks

The Air Force has access to two persistent simulator training networks. One is the Distributed Mission Operations Network (DMON), which allows connection of simulators at different locations and would be an important element of LVC nirvana. The DMON is capable of functioning at various security levels; locations that desire to be connected to the DMON must purchase a DMON "portal." The DMON is leased by the Air Force from Northrop-Grumman Mission Systems, which manages connections through commercial transmission lines from the network operations center (NOC) in Orlando, Florida, and in 2008 had about 40 sites that were functioning or were being tested (Clark, 2008). CAF DMO program element funds that are managed by ACC are used to pay for the DMON (677 Aeronautical Systems Group, 2008).

The Air Reserve Component Network (ARCNet), which is operated by the Air National Guard, has different networks that operate at different security levels. Organizations that desire to join ARCNet must purchase ARCNet portals. ARCNet has a DMON portal, so units that can connect to ARCNet can also be connected to the DMON (assuming appropriate security provisions have been made). In 2008, ARCNet connected about 53 sites (Martin, 2008). Several other DoD networks exist, but not all of them are persistent, nor are they capable of connecting fifth-generation simulators.[9]

Centers

The Distributed Mission Operations Center (DMOC), which is funded by ACC, is located at Kirtland AFB and employs about 200 personnel. The DMOC conducts four Virtual Flag events per year, during which 350 to 600 personnel in simulator environments around the world can participate in exercises based on real-world operational plans. The DMOC integrates networks for the exercises and monitors them for security and operational functionality. The

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[8] The ACS was not, in fact, meant to provide regular training for F-22 pilots. It was developed by Lockheed to be a testbed for operational flight programs. However, it has been incorporated into formal F-22 training (author communication with an F-22 pilot on May 13, 2009).

[9] Among them are the Missile Defense Agency Network, the Joint Distributed Engineering Plant, the Defense Research and Engineering Network, and the Joint Training and Experimentation Network.

DMOC is not a persistent environment; the Virtual Flag exercises are unique, with systems and connections designed specifically for one event then torn down after the event is completed. The DMOC also conducts "warfighter focus events," which are scripted exercises for 15–20 participants. The DMOC ensures cross-domain integration (that is, safe connections among systems that might be operating at different security levels) and *works the seams* in joint warfare (facilitates communication and cooperation among participants).

The Distributed Training Operations Center (DTOC) in Des Moines, Iowa, which is funded by the Air National Guard, has about 50 personnel and focuses on frequent, small-scale, team-level tactical training for units that connect to the DTOC through ARCNet. Training through the DTOC is user driven: Users tell the DTOC exactly what they hope to accomplish in a mission, and DTOC personnel design an exercise and provide the trainers (which may include computer-generated threat resources and a manned *white force* that plays certain roles required for the mission). In FY 2008, the DTOC schedule averaged more than 80 training events per month, and the number has been growing. The DTOC is connected to the DMON, and many ACC units (including those flying AWACS, Joint Surveillance Target Attack Radar System [JSTARS], and B-1s) use the DTOC as a training aid.[10]

Thus we see that the Air Force has some of the capabilities needed for LVC nirvana—the primary two being the ability to connect different locations through the DMON or ARCNet and the ability to conduct simulated training exercises at various levels, from those involving only small units to those requiring the employment of large forces. F-22 simulators are expected to have excellent capabilities, but it must be noted that multilevel security issues remain, that is, the F-22 MTC at Langley AFB can connect through the DMON only to the F-15C simulators that are also at Langley. Security solutions do not yet exist to allow connections through the DMON to other locations. The ability to generate constructive and virtual threats has been demonstrated in large-force Virtual Flag exercises conducted by the DMOC, as well as in smaller day-to-day training exercises conducted by the DTOC.[11] One missing piece in the nirvana puzzle is the ability to inject constructive and virtual threats into a live aircraft's systems—a key capability in the Guam scenario illustrated in Figure 1.1. A key research question for us was: What investment approach could be used to obtain that capability?

Research Approach and Organization of This Technical Report

We began our research by examining the evidence to see whether training gaps exist that can be closed with DMO and LVC capabilities. The next chapter uses interviews with subject-

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[10] Additionally, the U.S. Air Forces in Europe Warrior Preparation Center executes "theater exercises to support realistic warfighter training by employing full-spectrum LVC capability" (from the Warrior Preparation Center [WPC] mission statement, *WPC Tribune*, 2009). The WPC is not as sophisticated as the DMOC or the DTOC, but it is connected to the DMON. Also, the Distributed Training Center, which is funded by Air Mobility Command, is under development at Scott AFB and will become operational in FY 2011. The Distributed Training Center will connect with the DMOC, the DTOC, the DMON, and the Joint Training and Experimentation Network. It will be used primarily for daily, persistent training for mobility aircraft.

[11] BigTac is a constructive threat generator used by the DMOC in Virtual Flag exercises. It was developed by Boeing and is an old system, but it has been proven in some areas. Expert Common Immersive Theater Environment (XCITE) is used by the DTOC. In the past, AFRL managed XCITE, but the DTOC is now responsible for the system's development. XCITE apparently has higher fidelity than BigTac but a lower number of threats.

matter experts and an analysis of data from a comprehensive 2008 training survey of operational units in the combat air forces to argue that there is a training gap for pilots of fifth-generation fighter aircraft. Chapter Three expands the analysis of the survey data and uses a mathematical model to examine the effects of redistributing certain types of training sorties among live aircraft and simulators. It then develops a framework for comparing the costs of using different approaches to providing the red-air (adversary) threats that are so important for realistic training in fifth-generation aircraft. Chapter Four uses this analysis to suggest an investment strategy for components of LVC training. Appendix A provides the General Algebraic Modeling System (GAMS) code for the linear programming model used in the analysis. Appendix B is a copy of the survey instrument used by ACC and the Air Force Research Laboratory (AFRL). Appendix C shows how costs for various training options were estimated. Appendix D discusses potential consequences of reducing funding for live sorties.

Training Gap for Fifth-Generation Fighter Units

To make intelligent investment decisions regarding LVC capabilities, the Air Force must address a critical question: Is there a training gap in fifth-generation fighter operational units? If there is no gap, there can be little justification for the expenditures needed to meet the technological challenges that must be overcome to achieve a functional LVC capability. An answer affirming training shortfalls in these units, on the other hand, generates additional issues that require resolution before an effective cost-benefit analysis can occur. These include the following: (1) What is the specific nature of the training gap? (2) What resources can be used to fill it, and what are their associated costs? (3) What information do F-22 training shortfalls provide regarding the potential for training problems in F-35s as they enter the operational Air Force inventory?

To address whether there is a training gap for fifth-generation fighters, we examine the evidence that is currently available regarding training issues.

Fifth-Generation Training Requirements

Training requirements documentation for fifth-generation systems is still under development. Basic syllabus and RAP requirements are available for the F-22, but not for the F-35.[1] An analysis of F-22 mission essential competencies (MECs) has been conducted, which identified the set of skills required for that aircraft and also highlighted confirmed or potential training gaps related to those skills.[2]

Our own analysis of the F-22–identified MEC gaps indicates that as many as 19 of the 27 confirmed training gaps and three of the six potential gaps may be addressable using simulators, including full-mission trainers and the ACS facility at Marietta, Georgia, or the embedded-threat capability and the DMO networking systems that are currently (or soon will be) associated with F-22 units. Many of the gaps identified conditions that are difficult to replicate in live training situations, such as operating in adverse weather or threat-restrained conditions, countering realistic enemy integrated air defense systems, coordinating composite

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[1] RAP, which is managed jointly by ACC and the Warfighter Readiness Research Division of AFRL, is designed precisely to determine the skills that combat aircrews must develop, identify any confirmed and potential training shortfalls that limit mission accomplishment, develop methods that the operational units can use to service these skills, and document the corresponding training in the RAP training requirements documentation. See Colegrove and Bennett, 2006.

[2] The F-22 MECs are described in APTIMA, 2008. Table 2 of that document lists experiences for the F-22A Raptor. ACC provided us with an official list of these experiences and those for which there were training gaps.

force integration issues, and actual experience employing live missiles. While the formal MEC analysis for the F-22 is complete, the F-35 MEC development has not yet begun.

AFRL is also working with ACC to develop a Warfighter Readiness Assessment and Performance Measurement Tracking System (WRAP MTS), which is designed to track aircrew performance on critical knowledge and skill as part of

> a cohesive and comprehensive training environment involving simulation (high-fidelity and deployable), a competency-based training program, subjective/objective measurement tools, and brief/debrief capabilities. (Portrey, 2007)[3]

As these systems mature, they may provide more definitive measurement tools to exhibit training shortfalls. Meanwhile, we examined the empirical evidence that is already available for F-22 units.

Examples That Argue for the Existence of a Fifth-Generation Training Gap

An Insatiable Demand for Red Air

Virtually every F-22 pilot who discussed training with us raised the issue of the F-22's insatiable appetite for red air. The ability to operate against realistic air-to-air threats is also identified in the MEC analysis as one of the existing training gaps. The limited numbers of F-22s virtually ensure that its employment in an air supremacy mode against a near-peer adversary will require it to fight in an outnumbered environment. F-22 units, therefore, want to train in a few v. many mode,[4] in which they can use their advanced technology—such as low observable characteristics, long-range radar capabilities, advanced systems, and supersonic cruise—to engage and defeat a numerically superior force. Most units, however, are required to provide their own red-air component, flying similar F-22 aircraft because there are only limited numbers of dissimilar adversary aircraft available for normal day-to-day training. A single 4 v. 8 training mission would normally exhaust all of the aircraft that a typical 18–primary mission aircraft inventory (PMAI) squadron could generate to fly on any given day.[5] A steady diet of such missions means that most of that unit's flying would have to be red air, which limits tactics and aircraft capabilities used and represents degraded training for the pilots, who should be training primarily in the blue-air mode.

A final problem for fifth-generation units using similar aircraft as red-air adversaries is that the low radar cross sections, coupled with vectored thrust and other advanced capabilities, also degrade the training of those pilots flying as blue air. In this situation, blue-air pilots do not get radar contacts as early as they would against actual near-peer adversaries, limiting their ability to train effectively in a few v. many mode by restricting the opportunity to plan and execute their attacks effectively in order to accomplish all of the steps required to engage and

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[3]   The Performance Evaluation and Tracking System is a component of this system.

[4]   Air superiority pilots often refer to training engagements in terms of blue versus red numbers. This is often abbreviated as "b v. r," in which b is for blue and r is for red. Thus, "few v. many" engagements would include such missions as "4 v. 8" or "4 v. 12," (we will use this type of abbreviation) in which a four-ship of F-22s expects to engage and defeat eight or 12 adversaries in a single training mission (such missions are often identified as "4 v. X" missions in training document discussions).

[5]   PMAI is used to specify aircraft authorizations for operational flying units.

achieve simulated kills against their adversaries. Thus, when similar adversaries are used, the blue-air training available is degraded in addition to the training that must be lost by generating large quantities of similar red air.[6]

Range and Airspace Limitations

The mission profiles described above also demand long-range setups that require large volumes of restricted airspace where supersonic flight is authorized. Such airspace restrictions for military use are becoming difficult to establish and maintain because of increasing airspace requirements for the Federal Aviation Administration to manage commercial and general air traffic.[7]

Also, a primary purpose of fifth-generation fighters is to enable successful operations in an antiaccess environment featuring an integrated air defense system (IADS) that includes advanced SAM systems, jamming, and other electronic attack modes networked into a cooperative arrangement designed to deny key communication, navigation, and precision attack capabilities to the blue forces. Units need to be able to train in a realistic threat environment that accurately replicates these IADS components. Existing threat simulation systems that were developed during the Cold War and are currently available on the Nellis ranges (and other select training locations) do not include the fidelity required to trigger the advanced warning systems that have been developed expressly to enable successful IADS penetration and antiaccess operations for fifth-generation systems. Indeed, many knowledgeable officers whom we interviewed indicated that, while this training limitation is already apparent for F-22 units, it may be an even greater problem for F-35 training as these aircraft strive for a FY 2013 initial operational capability in their multimission role.[8]

Lack of Documentation for Training Requirements

While these examples may seem compelling, we must emphasize that these training needs, which are not being met in F-22 units, also are not currently documented in unit RAP training requirements and that the training shortfall seems to have little effect on pilot combat-mission-ready status or unit combat readiness ratings. As an example, one squadron, in which a 4 v. X evaluation sortie was required in the operations group upgrade syllabus for four-ship flight-lead qualification, indicated that its preference was to conduct this training in the ACS facility at Marietta, Georgia, rather than to fly the profile as a live training sortie. However, neither ACS training nor 4 v. X sorties were included as official RAP requirements when our analysis was completed.[9] Unit supervisors felt that the ACS provided better training for 4 v. X profiles than committing significant squadron resources in an effort to generate the similar red-air sorties required for the mission.

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[6] Decreasing the time available to attack an adversary makes the problem more difficult. While it might seem that a more difficult problem would enhance training, in this case the opposite is true. The targeting and sorting problems, coupled with axis-of-attack decisions, become very complex in a few v. many environment and require extensive real-time training to master.

[7] See Williams et al., forthcoming, and Robbert et al., 2001, for more information on range and airspace issues.

[8] According to these officers, F-35 systems are more difficult to fool with existing threat simulators than are F-22 systems.

[9] The rules do allow ACS training to receive RAP credit if approved by the squadron commander (see Air Force Instruction [AFI] 11-2F-22A, para. 4.2.1.4), and ACC is currently considering increasing simulator requirements in RAP.

Indeed, one of our major findings is that fully documented training requirements for realistic training scenarios are extremely scarce in RAP and other training documentation. Our contacts at ACC indicated that the Realistic Training Review Boards that are conducted regularly to address these issues are reluctant to document specific training requirements that cannot be accomplished in the normal course of events because such documentation could ensure that large numbers of aircrew members would have to be decertified from combat mission status when the difficult-to-complete training events were not accomplished. While this perspective is understandable, training resources that require monetary investments need to have conclusive justification in order to compete successfully with other budget demands in the current fiscal environment. If the Air Force does not articulate its training needs more effectively, resources that are essential for effective operational training (such as flying hours, range and airspace operations, and threat system replications) could be lost. While there are reasons for maintaining only resource-constrained training requirements, there are also reasons for maintaining clearly articulated training requirements that are unmet at current and projected funding levels.

Combat Air Forces' Training Survey Information

In late 2008, ACC and the Warfighter Readiness Research Division of AFRL jointly conducted a comprehensive training survey of operational units in the combat air forces. They traveled worldwide to every fighter; bomber; and command, control, intelligence, surveillance, and reconnaissance unit and asked instructors and supervisors a set of detailed questions regarding the quantity and quality of live and simulator training required for experienced and inexperienced aircrews to maintain standards at two proficiency levels: proficient and highly proficient.[10] The questions addressed every potential training profile required to achieve designed operational capability–specified[11] unit taskings in a variety of different training environments that included DMO-linked and unlinked simulators, local live sorties, and live sorties flown as part of live composite force training (CFTR) or large force employment (LFE) exercises.[12] The surveys also included questions such as, "What training can only be achieved during live flight?" and "What training can only be achieved in the simulator?"[13]

ACC and AFRL representatives shared their data with us and authorized us to conduct independent analyses of fifth-generation training needs in support of our study. Using these data and other training data from ACC, we developed the chart in Figure 2.1, which displays a

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[10] AFRL, 2008, uses combatant commanders' definitions for proficient and highly proficient pilots. AFRL, 2008, pp. 1 and 4, defines *proficient* as follows: "Proficient: Squadron members have a thorough knowledge of mission area and occasionally may make an error of omission or commission. Aircrew are able to operate in a complex, fluid environment and are able to handle most contingencies and unusual circumstances. Proficient aircrew are prepared for mission taskings on the first sortie in theater."

[11] A unit's "designed operational capability" is the mission for which a unit has been designed, equipped, and organized.

[12] See Appendix B for a copy of one version of the survey. CFTR and LFE exercises were described in the survey as scenarios employing multiple flights of aircraft, each under the direction of its own flight leader acting in an LFE scenario to achieve a common tactical objective. Scenarios should be opposed by air and surface threats and should include at least eight blue aircraft.

[13] These questions are direct quotes from the survey used in F-22 units.

Figure 2.1
Recent Monthly Averages and RAP Requirements Fall Short of Survey Response Requirements for Inexperienced F-22 Pilots
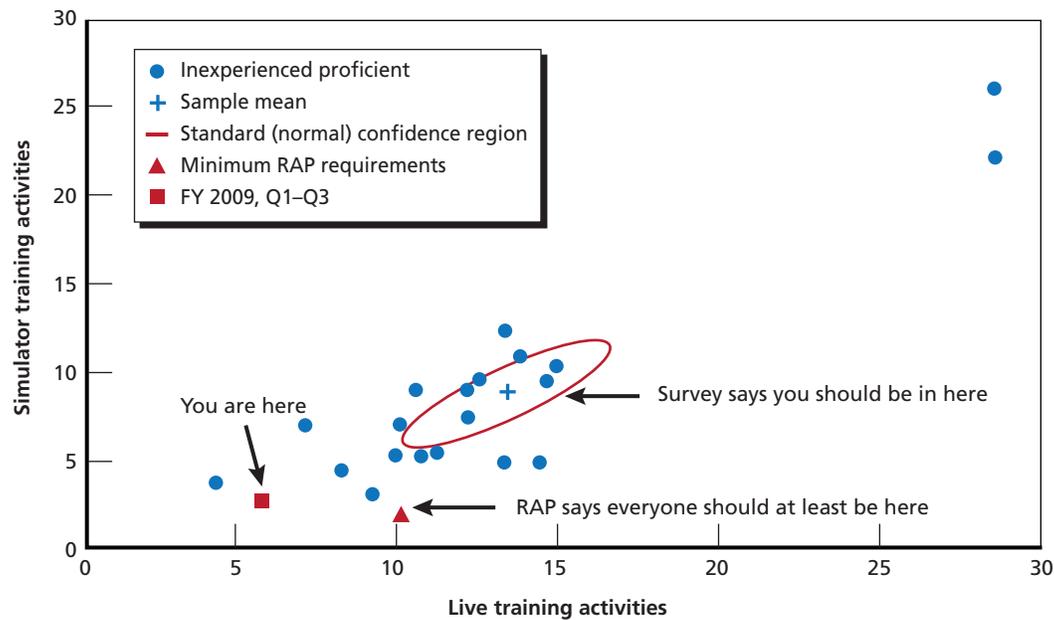
SOURCES: Survey response data from AFRL, 2008; FY 2009 flying-hour data from HQ ACC/A3, 2009; F-22 RAP requirements from HQ ACC, 2009.
RAND *TR871-2.1*

variety of information related to the training needed by inexperienced F-22 pilots[14] to become proficient.

Each blue dot in Figure 2.1 represents an instructor's (or supervisor's) aggregated response for the monthly training required for an inexperienced F-22 pilot to maintain a proficient competency level. The information is based on data from every respondent who completed the appropriate sections of the survey questionnaire.[15] The plus symbol (+) denotes the sample mean of about 13 live sorties and nearly nine simulator sessions required per month to ensure that inexperienced pilots remain proficient. The red ellipse represents the 95-percent confi-

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[14] Over the four quarters of FY 2009, the average number of inexperienced F-22 pilots in the one operational flying wing at Langley AFB was 19, and the average number of experienced pilots was 40, for an experience ratio of 68 percent, which exceeds the Air Force goal that 55 percent of the pilots in a unit be experienced. The F-22 is not currently an "absorbable system," in which formal training units and operational units can accept a fair share of newly trained pilots. As a result, the vast majority of current F-22 pilots were previously experienced in another fighter. We focused on inexperienced pilots because our previous research on operational training and fighter pilot absorption indicates that this category has the most perishable skills and is the most difficult to train. Based on our prior research on aircrew inventory and experience issues, the Air Force should strive to turn both the F-22 and F-35 into absorbable systems as rapidly as possible. See Taylor et al., 2000; Taylor et al., 2002; Marken et al., 2007; and Taylor et al., 2009, for more information on the earlier research. We believe that inexperienced pilots represent the group whose training should be most carefully monitored, and we feel confident that the survey responses provide the best information available regarding their training needs.

[15] We elected to use data from every respondent because there were so few respondents (22, with one providing only partial responses) to begin with. In their presentations, AFRL analysts used conservative statistical methods to eliminate outlying data points, and we fully understand their motivation for doing so. In the final analysis, however, this decision had little effect on our interpretation of the data. We should also acknowledge that the elliptical confidence region in the figure is based on the assumption that the data points are drawn from a bivariate normal distribution. Our statistical tests confirmed that this assumption seems valid. Finally, we have actual simulator data available for only the third quarter of FY 2009.

dence region that contains the actual distribution mean. The periodic RAP tasking messages that MAJCOMs send to F-22 units establish the minimum training required for pilots by experience level and combat mission status. The red triangle denotes ACC's minimum F-22 requirements (for inexperienced pilots in combat-mission-ready status) of ten live sorties and about two simulator sessions per month. One would suppose that, in order to meet these minimum requirements, every pilot's monthly training accomplished would have to plot at a point that is above and to the right of the red triangle. While data are not available at the individual level of resolution, the red square (at approximately six live sorties and slightly less than three simulator activities) denotes the average monthly training for FY 2009 that was actually achieved by inexperienced combat-mission-ready pilots in ACC F-22 units. We should note that this average includes every sortie flown by unit pilots, including those that could not be counted toward RAP minimums in accordance with the governing directives. Since this average is well below the specified RAP-credited live minimums, we can suppose that a sizable number of inexperienced pilots regularly fail to meet RAP minimum requirements.

Interpreting the Data

If we regard the survey responses as accurately depicting training requirements, our initial conclusion would be that the actual average training accomplished by inexperienced pilots in the squadrons should be reasonably close to the sample mean derived from the surveys. The 95-percent confidence region is a generally accepted statistical method for measuring closeness in this context.[16] If the actual F-22 training averages were within the ellipse shown in the figure, then a sizable majority of inexperienced pilots would actually achieve their minimum RAP training requirements each month. As it is, however, the average training that is actually accomplished in the units is well below and to the left of the ellipse, and the live training accomplished is well below RAP minimum requirements. A larger ellipse would result from a higher confidence level, but the 95-percent value seems reasonably consistent with the minimum RAP requirements because the lower-left edge of the ellipse is fairly close to a vertical line projected upward from the red triangle. The minimum monthly simulator requirement, however, seems much smaller than the ellipse would suggest because a horizontal line through the triangle is well below the ellipse.[17]

More Simulator Training Should Be Required

The first conclusion we draw from the data[18] is that, while the survey results seem to confirm the minimum RAP requirements for the live training needed by the pilots in question, the

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[16] We surmise that the true training requirements distribution mean has a 95-percent probability of falling within the elliptical region in the figure, assuming that the distribution is bivariate normal and the survey responses are sufficiently accurate.

[17] Statistical analyses commonly use significance levels corresponding to confidence regions of either 95 percent or 99 percent, depending on the nature of the research involved, with smaller regions (corresponding to higher error probabilities and lower confidence values) normally used for investigations in which there are "many possible sources of error because of uncertain theoretical hypotheses and simplifying assumptions" (van der Waerden, 1972, p. 32).

[18] As we briefed initial results of this research, we encountered some skepticism regarding the objectivity of determining training requirements by surveying fighter pilots. However, the survey results were consistent with our earlier analyses of training needs and likely represent a reasonably accurate assessment of training needs in the aggregate. We expect that

minimum RAP requirements for simulator training seem to be much lower than they should be. We feel that these simulator requirements should be raised (and met) as soon as the F-22 simulator upgrades become available to the units. Our own interviews with F-22 supervisors and instructors affirmed a universal belief that the training provided by the ACS facility was especially beneficial, and, in subsequent discussions, we will return to the implications for developing ACS-like training capabilities.

Live Training RAP Minimums Need to Be Achieved

The second conclusion we draw from the data is that a minimum amount of RAP live training needs to be accomplished. We found remarkable agreement that the 6.1 sorties per month that were flown, on average, by inexperienced F-22 pilots were inadequate to maintain pilot proficiency at required levels. We also discovered that two factors made fundamental contributions to this shortfall:

1. The F-22's need for low-observable characteristics caused maintenance issues that in turn caused a low aircraft utilization rate. These issues have driven the maintenance man-hour per flying-hour figures to extremely high levels.[19]

2. There is an excessive number of pilots at Langley AFB, the only operational F-22 unit in ACC during FY 2009. This problem resulted from an earlier decision to create an F-22 "total force classic associate unit"[20] with the Virginia Air National Guard (ANG). When that decision was made, Langley was programmed to possess three 24-PMAI F-22 squadrons, each of which would support approximately one-third of the nearly 40 pilots authorized in the Virginia ANG. Subsequent decisions to reduce the total number of F-22s purchased by the Air Force, however, caused Langley to be reprogrammed with only two 18-PMAI F-22 squadrons supporting the same number of ANG pilots. This change meant that the units would have to support more pilots per airframe, which has, in turn, resulted in fewer possible live sorties per pilot per month.[21]

The Air Force is well aware of both of these factors and has been working diligently to correct them. Indeed the F-22 sortie trends during FY 2009 have reflected a great deal of improvement. A first quarter average of only 4.46 sorties per crew per month (SCM) for inexperienced pilots has increased to 7.71 SCM for the fourth quarter, yielding an overall inexperienced-pilot

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AFRL's WRAP MTS effort will shed more light on specific pilot requirements. This is an important area that requires more analysis because of budget pressures to reduce flying hours.

[19] We have been asked whether degraded low-observable characteristics in a training environment might be acceptable if they allow higher utilization rates. This is not feasible, however, for operational units that are tasked to maintain specified mission-capable rates, because too many aircraft require full employment capability.

[20] Classic total force associations typically include Guard or Reserve aircrews flying regular Air Force airframes alongside the expected regular Air Force crew complement. The total force is also examining "active associations," in which regular Air Force aircrews fly airframes assigned to the Guard or Reserve.

[21] This decision cut the F-22 airframe authorizations at Langley in half (from 72 to 36), and the ANG unit was authorized about 38 total pilots (including line, supervisory, and staff authorizations). Therefore, the number of ANG pilots that the wing had to support with each airframe was doubled (from about 0.528 to about 1.056 ANG pilots per authorized airframe). These pilots are in addition to the regular Air Force authorizations of 23 API-1 (line) and two API-6 (supervisory) pilots per 18-PMAI squadron, plus the need to provide training support to a pro rata share of the wing's remaining 25 API-6 (staff) authorizations outside of the operational squadrons.

SCM average for the entire fiscal year of 6.11 sorties. Both of these problems may be corrected with improved maintenance methods and a gradual redistribution of pilot authorizations in due time, but these changes may not end the training gap issues.[22]

There is little question regarding the existence of an F-22 training gap as long as inexperienced pilots are averaging fewer sorties per month than the monthly RAP minimums, but a training gap may still exist in terms of the quality of training available even if the aircraft utilization and overmanning issues can be resolved. Training issues may still arise from the distribution of sorties available as well as from range or airspace limitations and/or fidelity issues for the threat environment available in which to conduct the training.

An F-15C Illustrative Example on Training Distribution

We examine the sortie distribution issue further by analyzing results from the F-15C, which is a more mature system with similar designed operational capability requirements, an effective simulator MTC, and quite similar mission profiles for both live and simulated training activities. Moreover, the F-15C can currently approach its aircraft utilization objectives and does not share the overmanning problems caused by reduced aircraft buys, so it should provide insight into the potential F-22 training environment if current utilization and manning problems were corrected.

Figure 2.2 contains, for the F-15C, the same data that Figure 2.1 depicted for the F-22. It includes all of the F-15C instructor and supervisor responses to the comprehensive survey accomplished by ACC and the Warfighter Readiness Research Division of AFRL.

Note that the F-15C sample data have less dispersion than the F-22 data, resulting in a smaller 95-percent confidence region. We also see that the sample mean for the F-15C pilots is about 12 live sorties and five simulator sessions per month for inexperienced pilots, who, unlike the F-22 pilots, probably meet the true definition of *inexperienced*, with a sizable majority starting their flying careers in F-15Cs.[23] Observe that, for live training, actual sortie averages exceed the RAP minimums, with the points denoting actual training averages and minimum RAP requirements almost superimposed. The actual amount of simulator training, however, is still well below levels recommended by the survey respondents. If we project vertically upward, however, we can see that the actual training averages could be quite close to the ellipse if simulator training requirements were increased and accomplished.

As the F-22 program matures, we expect that the live sorties achieved will approach the RAP minimums as they have for the F-15C. However, merely achieving the total RAP minimums, on average, may not ensure that pilots are adequately trained because many individual pilots could still be well below the aggregated RAP minimum requirements. Additionally, there are other RAP requirements on the distribution and quality of training profiles that are more difficult to track and evaluate. This motivates us to compare the F-15C mission profiles that are actually accomplished with more-effective training profiles, such as those recommended by the survey respondents.

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[22] Further research is needed to examine means of redistributing pilots into more workable ratios using both active and classic associations over all of the fifth-generation fighter units.

[23] The Air Force definition of experienced fighter pilots requires them to have 500 hours in their primary aircraft unless they have had previous Air Force flying experience (see AFI 11-412, para. 3.4.6). Note that the primary aircraft experience requirement drops to 100 hours for pilots who have previously become experienced in another fighter.

Figure 2.2
Although 2009 Monthly Averages Meet RAP Minimums for F-15C Pilots, Survey Respondents Felt That More Training Is Necessary
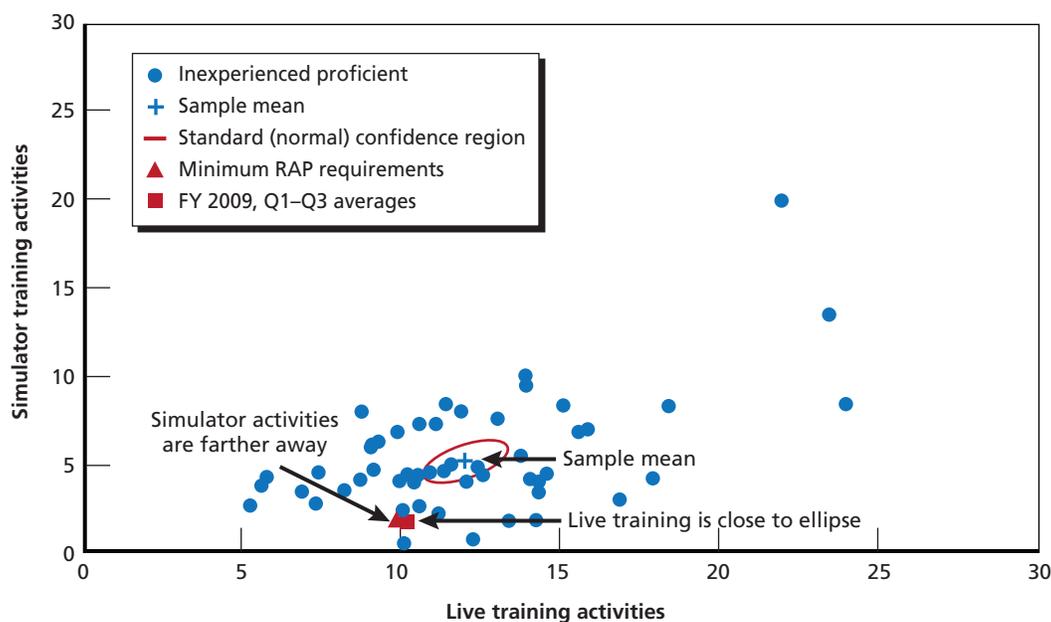
SOURCES: Survey response data from AFRL, 2008; FY 2009 flying-hour data from HQ ACC/A3, 2009; F-15C RAP requirements from HQ ACC, 2007.
RAND TR871-2.2

Figure 2.3 addresses the distribution of live and simulator training for F-15C units among the various mission training profiles that are available to pilots in these units.[24] The two bars that include "(survey)" in their labels depict the survey respondents' collective view of the appropriate monthly mix of live and simulated training profiles required to ensure that inexperienced pilots maintain a proficient status in every mission element for which their units are responsible. We aggregated this information from the survey responses themselves. Actual training distributions are normally not reported outside of the squadrons, so we took the actual live and simulator training totals and, based on interviews with knowledgeable F-15C squadron supervisors and training functional area managers within ACC headquarters, constructed an estimated distribution among the available training profiles. This information is depicted in the two columns labeled "(actual total, with distribution estimated)."

Note that nearly half of the monthly live training attributed to inexperienced pilots is flown as red air, whereas the survey respondents indicated that only a small portion of their total live training should be flown in that mode. Therefore, the combat-related profiles, such

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[24] These profiles include red air (to provide the adversaries that are essential in an air-to-air training environment), instrument training (to ensure units' all-weather mission capability), and the following combat training profile abbreviations: TI = tactical intercepts, OCA = offensive counterair, DCA = defensive counterair, ACM/SRR = air combat maneuvering/short-range response, BFM = basic fighter maneuvers, and AHC = aircraft handling characteristics. While the distributions of training profiles recommended by the survey respondents appear to correlate highly with the mix of training profiles incorporated into the RAP documents, they probably yield a better representation of a desired training mix because they do not include the flexibility afforded by the "commander's option" provision in RAP, which could result in less-desirable training profile distributions under certain circumstances. We will make use of this observation in our cost analyses in the next chapter.

Figure 2.3
Current F-15C Pilot Training Distribution Includes Sorties That Provide Less-Effective Training
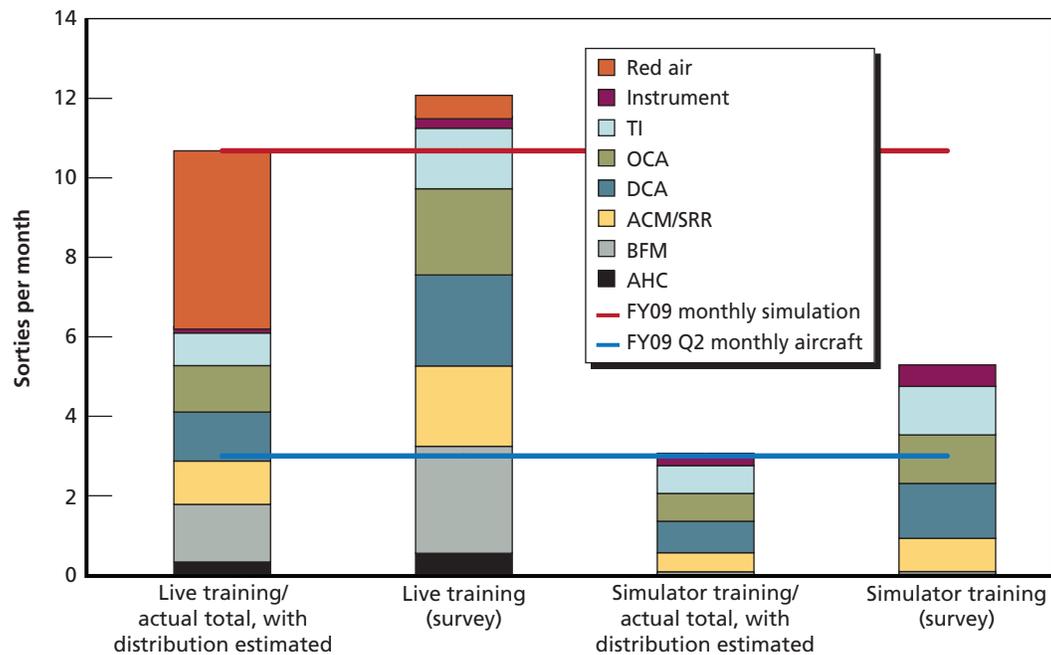
SOURCES: Survey response data from AFRL, 2008; FY 2009 flying-hour data from HQ ACC/A3, 2009.
RAND *TR871-2.3*

as OCA and DCA, are flown much less than the subject-matter experts' recommendations. These profiles, however, are precisely the ones that demand the highest red-air ratios for training effectiveness, so any effort by the squadrons to conduct more combat-related training will also mean they need to fly more red air. Red-air sorties are universally recognized as providing less-effective training than the other training profiles, which are designed to provide a building-block approach to service the skills required for the more advanced combat-related training profiles.[25]

The excessive requirement for red-air sorties for the F-15C, as well as other "cost-of-business" sorties that limit training effectiveness, was a principal motivation for the combat air forces to develop RAP training requirements in the 1990s to replace the graduated combat capability that had previously governed aircrew combat mission status. The RAP tasking messages specify minimum quantities of various training profiles and a maximum number of allowable red-air sorties that can receive RAP credit (the latter are often called "RAP counters"). The actual sortie reports, however, include all sorties flown, and no record of the actual numbers of RAP counters flown is available outside the units. A certain number of sorties allowable as RAP counters are also designated as *commander's option* sorties, which give squadron commanders a certain amount of flexibility in determining whether pilots need to be decertified and lose their combat status as the result of not meeting minimum RAP standards. The original purpose and

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[25] See Chapter Two of Marken et al., 2007, for more details on the building-block approach to training and a more thorough discussion of the training issues associated with red-air sorties.

current intent of RAP is to ensure that pilots fly adequate mixes of training profiles and do not receive credit for excessive red-air and other cost-of-business sorties.[26]

An adversary air capability is built into the more advanced simulator systems, in which red-air entities can be computer generated and, in some instances, can even be virtually controlled by the simulator instructors. This led us to examine the potential effectiveness of requiring that more of the most red-air-intensive training profiles, such as OCA and DCA, be accomplished in the simulator, as more advanced high-fidelity simulators become available. Our findings are presented in the F-22 cost comparison calculations in the following chapter.

Chapter Summary

There is little question that a serious F-22 training gap exists as long as inexperienced pilots are accomplishing only six or seven live sorties per month, which will remain the case at least until units are able to achieve RAP minimums. The problem will be exacerbated as the number of truly inexperienced F-22 pilots continues to grow. Correcting this problem is not just an LVC investment issue, and the Air Force, appropriately, is striving to correct it with improved manning and additional maintenance efficiencies. The larger question, however, is: Will there still be a training gap for fifth-generation units once the sortie issue is resolved? The examples that we examined clearly suggest that a training gap will remain for F-22 units after inexperienced pilots are meeting their minimum RAP requirements because they will remain unable to meet both the spirit and intent of the existing limits on red-air sorties and other training profile requirements. Our subsequent cost analyses will be predicated on the need for units to meet RAP sortie minimums, at least on average, using RAP counters that meet the recommended training profile distributions, without including sorties that exceed existing RAP-specified red-air sortie maximums. We feel that this defines a lower bound on the extent of the existing fifth-generation training gap.

If the F-22 training gap is not addressed, training problems could increase as the F-35 is brought into the operational inventory with its own specialized training requirements derived from its mission to penetrate and operate effectively in an antiaccess environment—an environment that includes advanced IADS capabilities; multiple advanced threats, including double-digit SAMs; electronic attack and other jamming capabilities; and significant enemy numerical advantages in terms of combat aircraft available. Therefore, a future fifth-generation training gap could well be larger than the lower bound that we defined above.

A training gap could require significant fiscal and other resources to correct, which could lead to very difficult decisions for the Air Force leadership, because significant expenditures in the projected fiscal environment will likely have to be offset by corresponding spending cuts in other programs. Therefore, training resources may compete directly with combat capability in terms of aircraft numbers, weapon system modernization, and other factors in the budgetary process. Our principal concern here is that training requirements for fifth-generation systems should be deliberately determined by operational readiness issues and not be forced by fiscal issues (although fiscal constraints will certainly apply).

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[26] Other examples of cost-of-business sorties include sorties required for deployments or evacuations, maintenance test sorties, and certain contingency operations, such as airborne alert sorties supporting Operation Noble Eagle homeland defense tasking. These are also addressed more thoroughly in Marken et al., 2007, Chapter Two.

Closing the Fifth-Generation Fighter Unit Training Gap

We saw in the last chapter that there is compelling evidence that a gap in fifth-generation fighter training exists. What options are there to fill it? This chapter presents some options to fill the gap, uses a mathematical model to describe how using different options might affect the distribution of training, and then develops a framework to compare the costs of these options.

Approaches to Filling a Training Gap

The last chapter showed that a training gap exists not only because the total number of training events accomplished per month in the F-22 and the F-15C is lower than recommended by the survey (and, for the F-22, is lower than the RAP minimums), but also because the recommended mission distribution differs from the existing one. This gap exists primarily because of the need for units to provide their own red-air adversaries on missions that require training against a threat.

There are several ways the Air Force could reduce this gap:

- Increase both live and simulator training activities. This option would bring both live and simulator training sorties closer to the numbers recommended by participants in the survey. It would also allow an increase in the number of blue-air sorties flown, but, of course, this increase would be accompanied by an increase in the number of red-air sorties flown to provide red-air threats.

- Increase dissimilar red-air availability from resources that are not from the unit. For example, the F-22 unit at Holloman AFB has T-38 aircraft available to fly as red air (the missions are flown by supervisors who are dual-qualified in the F-22 and the T-38). Another option would be to use fourth-generation aircraft from other operational units to provide red air. This option is currently used by the F-22 training squadron at Tyndall AFB—other units are willing to spend some time in Florida flying as red air even if their own training may be degraded as a result (and, according to one pilot we interviewed, Tyndall has a large budget to pay for them). Alternatively, existing Air Force aggressor[1] forces could be boosted or contract adversaries could be used.

- Provide expanded ACS-like capabilities (with realistic virtual threats) at each unit. This does not mean an actual ACS facility like the one currently operated by Lockheed, but

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[1] *Aggressor pilots* are Air Force pilots who are specifically trained in enemy tactics and weapon employment. There are currently aggressor units located at Nellis and Elmendorf AFBs. They principally support Red Flag and advanced training operations.

instead the capability that the ACS has—perhaps achieved through expanded use of a DTOC-like facility to provide threats. This choice would allow the accomplishment of more red-air-threat-intensive sorties in the simulator so that live sorties currently flown as red air could be converted to blue air.

- Develop the capability to inject ACS-like virtual and constructive threats accurately into live cockpits (achieving ACC's LVC nirvana).
- Build adequate range and airspace resources with realistic virtual (or actual) threats that most pilots would encounter during Red Flag–type exercises.

There are at least two important constraints to any of these approaches. First, while they are being developed, the Air Force needs to ensure that existing training resources remain current and sustainable. High-fidelity simulators are perishable resources, requiring continued funding to ensure their supportability and to maintain concurrency with aircraft software and threat suites. Second, the Air Force must determine whether any F-22 training shortfalls extend to the F-35 and whether there exist shortfalls unique to the F-35. Differences between training gaps for the two aircraft could influence which training approach is best.

Different Approaches Require Different Investments

The different approaches to closing the training gap that results from the demand for red air require different investments.

Increasing live and simulator hours to accommodate more red-air sorties requires an increased investment in available flying hours. Using resources outside the flying unit to provide red air requires an increased investment in flying hours for the other aircraft and, potentially, the purchase or lease of new aircraft.

The Air Force currently has the capability to inject live and virtual threats into the simulator and/or MTC environment—the DTOC does this on a daily basis, and the DMOC does it at least quarterly in its Virtual Flag exercises. Further investments would be necessary to achieve capabilities similar to those at the ACS facility. For example, currently the F-22 simulators at Langley AFB can connect through the DMON to F-15C simulators—but only F-15C simulators at Langley AFB.[2] More work needs to be done to resolve multilevel security and cross-domain solution (MLS/CDS) problems so that fifth-generation connections are allowed outside the base. Connecting more simulators through the DMON for ACS-like capability may also require the expansion of simulator capacity—either with more simulators or more available simulator hours. It may also require an expansion of a manned white force capability such as the one at the DTOC or the development of a new, active-duty DTOC-like facility. Recall that the ACS has four blue cockpits and eight manned domes for red-air threats. It also has a ground-control intercept controller for the red-air threats and man-in-the-loop SAM threats.[3] This level of training capability is what the Air Force will want to reproduce through the MTCs, the DMO, and expanded threat generation.

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[2]   There is a plan to expand DMO usage, and when the facilities have the right security accreditations, the F-22 simulators will be able to connect to F-15C simulators at other locations.

[3]   Based on an author communication with an F-22 pilot on May 5, 2009.

Reducing the need for live red air by developing the ability to inject virtual and constructive threats into a live aircraft's systems requires an investment in injection technology—hardware and software that enables the capability in the aircraft and on the range.

To estimate costs for these investment approaches, we first return to survey results for the F-22.

Expectation of Increased Use of Simulators for the F-22

Figure 3.1 shows survey results of F-22 pilot opinions about the relative importance of different mission types and the proportion of each type that can be satisfied in a simulator. For example, according to the survey, about 46 percent of the total monthly training (live and simulated) for the F-22 should be devoted to OCA (as shown in Figure 3.1).[4] The small black box inside the OCA bar shows that of these OCA missions, about one-third should be accomplished in the simulator. (Forty-six percent of F-22 training should be devoted to OCA; 39 percent of OCA training can be done in the simulator; 0.39×0.46 gives the value 0.18, where the small black box is plotted.)

As the figure shows, the only mission categories for which simulator training is not appropriate are AHC and BFM. With this acknowledgment of the value for a fifth-generation air-

Figure 3.1
Survey Estimates of Training That Can Be Accomplished in a Simulator Environment
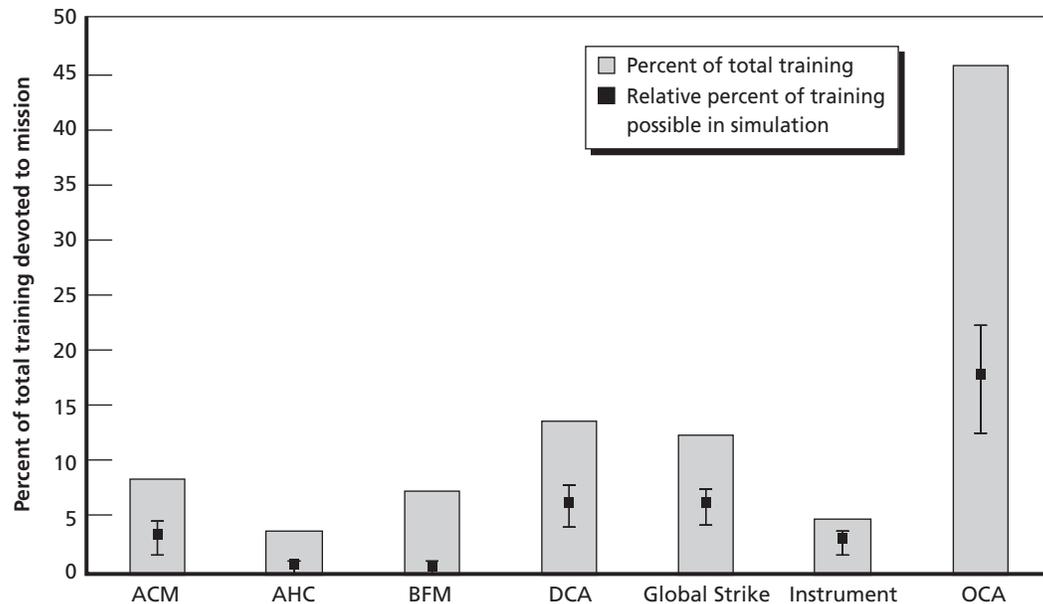
NOTE: The "whiskers" coming from the small black boxes show the range of responses for what can be accomplished in the simulator (plus and minus one standard deviation).
RAND TR871-3.1

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[4] The survey asked about five categories of OCA: OCA-DEAD, OCA-Escort, OCA-SAT, and OCA-Sweep. We have combined these into a single OCA category.

craft of training that is not live, we can model the possibility of improving live training by moving unproductive red-air sorties into a different training environment.

Modeling the Use of Mission Training Centers to Make Live Training More Effective

Figure 3.2 displays the F-22 survey results for the sorties needed by an inexperienced pilot to maintain proficiency and our modeling of alternative sortie distributions.

In the figure, the survey bars show the total training activities recommended per month in each environment (13.5 for live activities and 9 for simulator activities) and the distribution of those activities among different mission types. Note, in particular, that the recommended number of red-air sorties is less than one.

Suppose that the Air Force fully funds ten live sorties for the F-22 per month, as recommended in the current RAP memorandum (HQ ACC, 2009).[5] We assume that three simulator missions are accomplished per month as well (as are currently accomplished). We also prioritize the sortie mission profiles using a building-block approach to pilot mission qualification based on expert opinion and previous research.[6] Finally, we assume that there is no limit to

Figure 3.2
F-22 Survey Responses and Alternative Distributions for Live and Simulator Activities
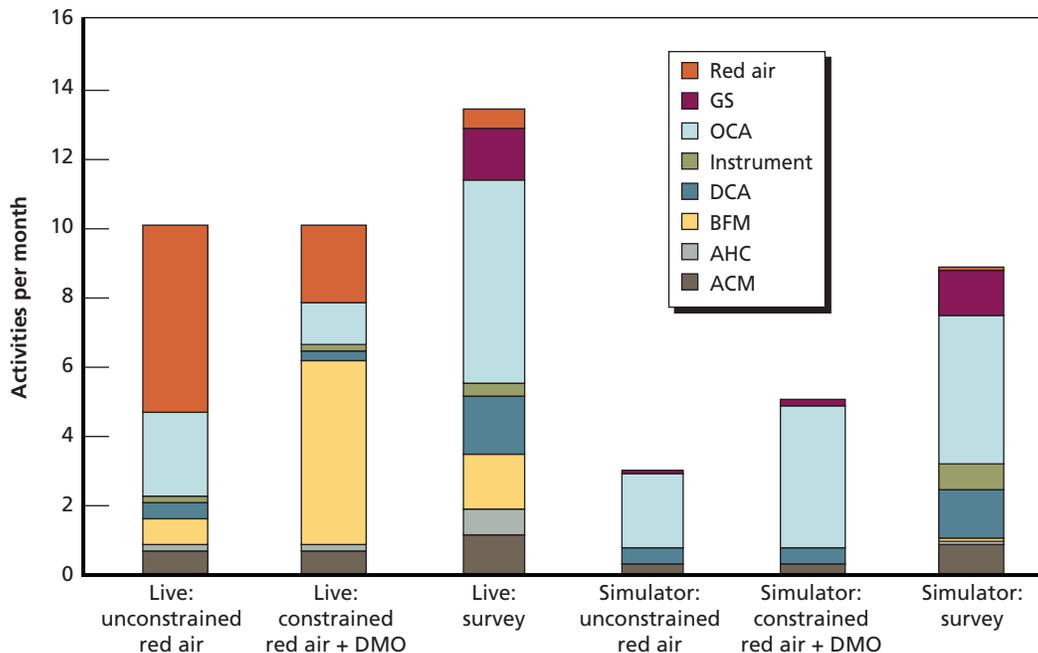
RAND TR871-3.2

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[5] Appendix D performs the same analysis described below under the assumption that only eight live sorties are funded.

[6] Mission sortie types are described in AFI 11-2F-22A, para. 3.4.5. We assumed that the priority (from lowest to highest) is instrument, AHC, BFM/ACM, OCA, DCA, and Global Strike (GS). See Chapter Two of Marken et al., 2007, for a discussion of the building-block approach.

the number of red-air sorties an individual can fly for credit per month. A linear program to maximize the value of monthly training based on these assumptions leads to the result in the unconstrained red-air bars in the figure.[7]

As seen in the figure, the optimized training distribution represented by the "Live: unconstrained red air" bar leads to flying slightly more than five red-air sorties per month in order to provide the threats needed in blue air—only half of the sorties flown by an individual in a month are effective blue-air sorties (which, as we saw in Figure 2.3, is about what happened in F-15C units in FY 2009). Comparing the "Live: unconstrained red air" bar with the "Live: survey" bar, we also see that the OCA and DCA sorties flown amount to fewer than desired and that GS sorties are not flown at all.

We now use the model to take into account the survey results that more training can be done in the simulator and to take into account the RAP restriction that only 2.25 red-air sorties be flown per month.[8] The resulting distributions are shown in the constrained red air plus DMO bars.

The first thing to notice in these bars is that the number of simulator missions accomplished (the "Simulator: constrained red air + DMO" bar) has increased from three to five and the increase has been in red-air-intensive OCA missions.[9] The "Live: constrained red air + DMO" bar shows that the number of live red-air sorties has been limited to two, the number of OCA sorties has declined, and the number of BFM sorties flown has increased—beyond what is recommended in the survey.[10] The good news is that some missions have been moved to the simulator environment and that the number of red-air sorties flown has been reduced. The bad news is that, since there is less live red-air capability, fewer live blue-air sorties that require red air can be flown.

Nonetheless, the model results show that it is possible to shift red-air-intensive sorties to the simulator in order to make more live blue-air sorties available. We will use this concept to develop a framework to compare the costs of different investment approaches to reducing the training gap driven by the requirement for red air.

Estimating the Costs of Different Options

Our goal is to increase the number of effective live blue-air sorties—to at least the eight sorties per month shown to be possible by the model. There are at least three ways to do this:

1. Make no investment in red-air alternatives, but instead fly more F-22 sorties at the current high proportion of red air.
2. Shift red-air-intensive missions to the simulator and increase simulator activities in the MTC or the ACS (which was done with the model example above).

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[7] The GAMS code for the linear program is in Appendix A.

[8] When the model was developed, the red-air limit was 45 sorties in a 20-month period, or 2.25 per month.

[9] F-22 simulator data on the number of funded simulator hours make it appear that an increase of two simulator missions per month per pilot is possible.

[10] Note that while the number of live red-air sorties flown has decreased by three (from five to two), the number of simulator sorties required has increased by only two. This is because some of the red-air-intensive sorties moved to the simulator eliminate the need for more than one red-air threat.

3. Provide red air to live aircraft by using an adversary (or aggressor) squadron or LVC capability.

These are in keeping with the investment options mentioned above when we discussed closing the training gap in general.

Flying the F-22 is very expensive: $48,000 per flying hour, so a 1.5 hour sortie costs $72,000.[11] If a local unit wanted to provide its own live red air and still fly eight effective live blue-air sorties, and we assume the same ratio of red to blue sorties as determined by our model (1:1), each pilot would have to fly 16 sorties per month to fly eight blue ones. This increase by six total sorties results in an increase of only three blue sorties for each pilot. Six sorties cost $432,000, but because only three of them are blue, the cost per blue sortie is effectively $432,000 ÷ 3 = $144,000. Note that this is a conservative cost estimate because many blue sorties require more than one red opponent. This information is summarized in the first row of Table 3.1.

A second option is to use the simulator environment to provide the red-air threat, and as we saw in Figure 3.2, this means increasing the number of simulator missions by two. Assuming that sufficient simulator hours are funded to accommodate this increase, we need to estimate the cost of providing the threat. In FY 2008, the DTOC had a budget of about $4.5 million, and the organization managed 960 training "events" that year for a cost of $4,680 per event. If the two additional simulator training sorties count as two training events, the cost of providing the threat through the DTOC is $9,360. This investment allows three live red-air sorties to be flown as blue air instead, for a cost of about $3,100 per blue sortie.

If we assume that the DTOC is open 40 hours a week (2,080 hours per year) and is at full capacity, the operating cost per hour is about $2,100. Using the DTOC to provide the threat for two new 1.5-hour simulator events would cost $6,300, and, again, since this investment allows three live red-air sorties to be flown as blue air, the cost is $2,100 per blue sortie.

Table 3.1
Costs of Using Different Resources for Red Air in Order to Accomplish Eight Blue Sorties per Month

Option	Additional Activities per Month	Additional Cost (000s)	Additional Cost per Blue-Air Sortie (000s)
Use F-22 assets to provide red-air threat	6 live F-22 sorties (3 blue, 3 red)	$432	$144
Move some red-air-intensive sorties to the simulator/ DMO environment	2 simulator activities	$6.5 to $9.4	$2.1 to $3.1
Move some red-air-intensive sorties to the ACS	2 ACS activities	$3.6 to $5.3	$1.2 to $1.8
Use adversary aircraft to provide red-air threat	3 adversary sorties	$23 to $48	$7.6 to $16
Use LVC to inject red-air threats into live aircraft	unknown	unknown	unknown

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[11] According to the Air Force Total Cost of Ownership database, in FY 2008, only a small portion—$7,300—of the $48,000 was spent on unit-level consumption (including fuel and depot-level repairs). The rest of the cost is related to the contractor logistics-support contract and the cost of mission personnel.

The range of costs for moving some red-air intensive sorties to the simulator/DMO environment and using the DTOC is in the second row of Table 3.1.

The two additional simulator missions could also be accomplished in the ACS, which is already enthusiastically supported by F-22 pilots. RAND estimates of the cost of using the ACS for these two sorties are from $3,600 to $5,300, for an investment of $1,200 to $1,800 per new blue-air sortie. This information is in row three of Table 3.1.

Finally, we consider the possibility of using resources that are not part of the unit to provide live red air. For a T-38–like aircraft as the adversary, flying-hour costs, operations and maintenance (O&M) costs, depreciation, and the assumption that red-air pilots make $150,000 per year flying 15 sorties per month (each sortie 1.3 hours long) lead to a total cost of $22,780 for an adversary flying three sorties per month (see Appendix C for more-detailed cost calculations).[12] If an F-16–like aircraft is used instead, the same assumptions (because of higher flying-hour and O&M costs) lead to a cost of $48,325 per month for three red-air sorties. This range of adversary aircraft costs is summarized in row four of Table 3.1. Row five of Table 3.1 reminds us that the costs of LVC options are unknown.

Note that the costs in the third column of Table 3.1 are *in addition* to the baseline costs of flying F-22 RAP minimums (ten live sorties and three simulator sorties): Using other assets to allow the conversion of three red-air sorties to blue-air sorties is not free. Note also that the second and third rows in Table 3.1 (which move red-air-intensive sorties into the simulator/DMO or ACS environments) result in suboptimal live training in the sense that, because a live red-air option is not available, the new blue sorties need to be BFM (or other sorties that do not require red air), and more of these are flown than are needed.

How Much Should the Air Force Be Willing to Invest in LVC?

Determining the return on investment for LVC—specifically, the ability to inject simulated or constructive threats into a live aircraft—is not a trivial problem, since few of the costs and none of the benefits are known quantitatively. The ability to link LVC training entities will clearly leverage existing live, simulator, DMO, constructive, and network infrastructure, but basic technologies to accomplish this are not yet solidified, let alone priced. Uncertainty remains, for example, about the costs of integrating across different aircraft mission design series.[13] One thing is clear: To be a good investment, injection capability must cost less overall than existing alternatives for providing the threat capability to live aircraft.[14]

From the values in Table 3.1, using F-22s for three red-air sorties per pilot per month for a fleet of 183 F-22 aircraft costs roughly $592 million a year above current flying-hour costs;

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[12] We use the T-38 as an example because one unit is currently using this aircraft as an adversary, and the cost can be considered a lower bound for adversary alternatives.

[13] Other technological problems are the integration of fifth-generation aircraft, whose time-space-position information must be encrypted, and developing a range-instrumentation-waveform that allows transmission of information within bandwidth limitations (Glover, undated). As one of our reviewers pointed out, injection also raises safety of flight issues (it would be unsafe for a pilot to make a dangerous maneuver to avoid a conflict with a simulated threat) and the security issue of injection being potentially exploited by an adversary.

[14] As one of our reviewers pointed out, the benefits of the ability to inject threats into a live aircraft must also be studied further: There needs to be clear evidence that an injection capability adds value beyond that provided by well-designed training in the simulator.

fourth-generation adversaries would cost $132 million a year, and using a training aircraft (e.g., the T-38) would cost $63 million a year.[15]

To put these costs in perspective with respect to LVC, we will use some preliminary data provided by the Boeing Company. Boeing has been using its own development funds for a research project called Project Alpine, which allows a live F-15E to "fly" with an F-15E simulator on the ground and to encounter simulated and constructive threats. Boeing and the Air Force plan to cooperate in further development of this technology in a pilot project that may start as early as 2010.[16] The cost of providing a system with the capability of Project Alpine to five F-15E squadrons would be about $200 million (Lechner, 2009). Assume this cost holds for a similar system for the F-22 and assume that it is available for five squadrons, each with 18 aircraft and a crew ratio of 1.25. This means that training will be provided for 113 pilots (this is a low estimate since the crew ratio does not take into account all of the pilots in the squadron). Let us also assume that the $200 million pays for a system that has a ten-year life-cycle and that there is also a $10-million annual cost for maintenance and upgrade. This would make the annual cost of the system $30 million. Since the numbers are notional, we do not take into account the present value of future costs. Thus, if Boeing's numbers can be applied to an F-22 LVC system, a $30-million per-year investment would provide red-air training for 113 pilots per year.[17]

From Table 3.1 we know that it costs $23,000 per pilot per month to provide three red-air sorties using a trainer-type aircraft, or $276,000 per year. Thus, a $30 million investment in trainer-type adversaries would buy training for $30 million ÷ $276,000 = 109 pilots. Similarly, the $30 million would buy training for 52 pilots if F-16–like aircraft are used as adversaries, but for only six pilots if actual F-22 aircraft are used! This information is summarized in Table 3.2, the other rows of which compare the number of pilots who can be provided training with different levels of spending.[18]

Table 3.2 provides a strong case that, if there is a training gap that can be addressed by making investments in alternative approaches to providing red-air threats, investment in LVC may be the only fiscally feasible approach. We stress, though, that the $200-million figure is a guess for an LVC system that is not fully developed, has not been tested on fifth-generation aircraft, and has not addressed issues related to connecting to the DMON or other networks—all issues that must be resolved in order to achieve LVC nirvana. Nonetheless, the argument of the previous pages and the display of the costs of providing red air through different means help

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[15] This assumes a 1.25 crew ratio for the F-22, so the calculations are as follows:

F-22 aggressors: 183 × 1.25 × 72,000 × 3 × 12 = $592.92 million

T-38 aggressors: 183 × 1.25 × 23,000 × 12 = $63.135 million

F-16 aggressors: 183 × 1.25 × 48,000 × 12 = $131.76 million.

[16] This is according to "LVC Pilot Demo(s)" slides (Clark, 2009).

[17] We are tacitly assuming for comparison that this investment provides the three red-air sorties that have been used so far in the analysis. It could provide more, but we are taking into account only the cost of buying and maintaining the system, not the cost per sortie.

[18] Boeing estimates that the cost per flying hour using its system is approximately $2,500 (or $3,750 for a 1.5 hour sortie)—the same order of magnitude as the simulator/DMO and ACS costs—but this does not take into account the initial cost of the system. By showing in Table 3.2 how many pilots could be provided additional adversary sorties at different costs, we ignore the cost of an LVC sortie and instead annualize the cost of buying the system.

Table 3.2
Number of F-22 Pilots for Whom Three Additional Red-Air Adversary Sorties Can Be Bought with Various Levels of Spending

Annual Cost (millions of dollars)	LVC Injection	Trainer Aircraft, Red Air	Fourth-Generation Red Air	Fifth-Generation Red Air
10	N/A	36	17	2
30	113	109	52	6
50	N/A	181	87	10
100	N/A	362	174	20

NOTE: N/A = "not applicable."

us develop a reasonable investment strategy for the improvement of fifth-generation fighter training.

An LVC Investment Strategy

We have presented three pieces of evidence that a fifth-generation fighter training gap exists: the inability of the F-22 to achieve its RAP minimums, the poor distribution of mission types in the sorties flown (too much red air), and survey evidence from supervisors that more live training and simulator training are needed. Since this gap manifests itself most plainly in the requirement of individual units to provide red-air resources that, in effect, decrease the amount of blue-air training that can be accomplished, we have focused on some very basic ways to compare costs of various approaches to providing red air. We have noted that based on costs (under the very tenuous assumption that estimates for the F-15E LVC system might apply to the F-22), it seems clear that an investment in LVC should be made. Let us look more closely at the investment options as displayed in Table 4.1.

Table 4.1 is a reminder that investments in the ACS, the MTC, and the DMO only indirectly improve live training by enabling an increase in the quality of simulator missions and shifting red-air-intensive missions to the simulator environment. The result is a better mix of training because fewer red-air sorties are needed in the aircraft, but the training mix is still suboptimal in the sense that there is still no way to fly live blue-air sorties that require a red-air

Table 4.1
Investments and Outcomes

Investment Area	Capabilities Purchased	Opportunities	Outcomes	
ACS	Simulated training with excellent threat and visual environment	Increased number and quality of simulated sorties	An increased number of live blue-air sorties with red-air-intensive blue sorties shifted to a simulator . . . yields a better, but suboptimal, mix	Simulated training is directly improved Live training is indirectly improved
MTC	Improved organic simulated threat and visual environment			
DMO	Training capabilities connected among units, other players, and ranges	Increased MTC mission complexity	The quality of simulated missions is increased	
LVC	Range-level connection between live and simulated assets	Increased number of threats to live aircraft	The number of live blue-air sorties is increased by substituting other threats for live red-air sorties	Live training is directly improved
Aggressor squadrons	Live blue-air allies or live red-air threats			

threat without providing a live red-air threat. Only by using adversary squadrons or developing LVC capability can live training be directly improved by allowing units to replace red-air sorties with blue ones that can fly against a threat. Nonetheless, Table 4.1 implies an approach to investments that has the potential to lead to LVC nirvana.

An LVC environment requires simulators that are concurrent with the aircraft—otherwise pilots will not be training the way they will fight, so the first part of an investment strategy is to ensure that the MTCs are funded to ensure this is the case. Substituting simulator sorties for live sorties that require red air will not be possible unless convincing constructive and/or manned simulated threats are available, so the development of these threats must next be funded. The ability to provide persistent training to pilots at widely separated locations is one of the ultimate goals of LVC training, so the DMO network (and other networks) must be funded. These three components of a system directly improve simulated training and indirectly improve live training, but *even if an injection capability proves too difficult*, they will still be necessary for training that is of the quality achieved in the ACS.

A final investment can be made in injection capability to directly improve live training. If injection capability is achieved, the high-quality MTCs, constructive threats, and DMO network already developed will enable the injection capability to be a true training force multiplier. Multilevel security issues must be resolved for both DMO and injection connections to ensure LVC capability for large-scale exercises.

Significant Factors That Affect Investment Decisions

One of the difficulties of this research was determining the quantitative nature of any training gap that might exist. Ideally, operational readiness considerations should be used to determine adequate funding levels for training-related program elements, and so the Air Force needs to devote resources to such programs as MECs and WRAP-MTS research that will help quantify readiness considerations. If a live training gap exists, injection may be the only fiscally feasible way to satisfy fifth-generation red-air and other threat requirements.

The fiscal environment is always constrained, but it is clear that, in order to fund any major technological investments related to LVC, offsets will be required. Cutting flying hours (or other training program elements) in the short run to make large investments in injection to achieve LVC nirvana does not seem wise, as the uncertainties involved in the technology are too great. Additionally, in an environment in which F-22 pilots are flying fewer than half the hours they are supposed to fly according to RAP minimums, cutting flying hours would be a mistake.

As mentioned above, MLS/CDS issues must be addressed in order to develop and exploit DMO links both in the simulator environment and, potentially, to the aircraft.

As operational training requirements are developed, the relative importance of day-to-day training and large-force training needs to be better understood. One of the strengths of the DTOC is its ability to provide—cheaply—training that aircrew members need on a small scale, e.g., helping a JSTARS crewmember learn how to better monitor aircraft in a fighter formation. Large-scale exercises such as Virtual Flag and Northern Edge have value, but participating in them does not necessarily allow pilots to check off any RAP requirements.

Recommendations

The Air Force should make several relatively low-risk, high-payoff investments:

1. Ensure that funding for the F-35 MTC is sufficient to make it DMO capable. Unless the F-35 MTC can connect to the DMON, there is little chance that the benefits of virtual and constructive training can be fully realized.[1]
2. Maintain investments in threat-generation capabilities. Boeing's BigTac threat-generating system is used in Virtual Flag exercises; the DTOC uses XCITE software ("Alion-Operated Modeling," 2009). The Air Force needs to ensure that these and follow-on threat-generation systems remain concurrent with existing aircraft and IADS threats. A strength of the DTOC is its manned white-force capability, which allows not only human intervention with constructive threats but also role-playing by professional trainers during DTOC exercises, e.g., experienced personnel can play the role of an air traffic controller or an Army enlisted person who is calling in an air strike. Expansion of this capability will be necessary if the demand envisioned for LVC nirvana materializes, and either the DTOC will need to be expanded or the Air Force will need to develop a DTOC-like facility elsewhere. This is crucial for the maintenance of an ACS-like capability for the F-22 and the F-35, but it will not be fully effective until RAP minimums for simulator training are increased and the minimums are accomplished.
3. Ensure continued funding of the DMON. The network is already used successfully for training—most notably by the DTOC, but also for Virtual Flag exercises—and a networking capability is an important component of LVC nirvana.
4. Continue investments in developing solutions to various MLS/CDS problems. These investments must be made in order to enable the MTCs at different locations to participate in training and to allow connections with other organizations for joint and combined virtual exercises.
5. Fund two capabilities for the F-35. The aircraft can accept an embedded-threat module, and it can also accommodate a P5 pod that allows some types of simulated training in the aircraft. Both of these capabilities are first steps in injecting virtual and constructive threats into aircraft systems.

If investments are made in the above areas alone, fifth-generation fighter training capabilities will improve. The evidence for this is in the enthusiasm that F-22 pilots have for the training value of the ACS and in the fact that the ACC utilization rate of the DTOC more than doubled when ACC connected to the DTOC through a new DMON portal (Martin, 2008).

The potential is high for even greater improvement by making injection of virtual and constructive threats into live aircraft possible—as we have seen, this is the only way to *directly* improve live training in a fiscally responsible way. Because of the technological uncertainties related to this capability, however, the best way to proceed is to maintain targeted, relatively

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[1] This was a problem for the F-22: The original MTCs were incapable of connecting to the DMON and suffered from other deficiencies. This mistake must not be repeated with the F-35.

small investments in injection capabilities (such as the CORONA-directed pilot project).[2] Only when technological uncertainties are resolved should larger investments be made.

_____

[2] Investing in solutions to MLS problems is consistent with the third recommendation of the Air Force Scientific Advisory Board's 2009 study on virtual training technologies described in Van Wie, 2009. Investing in an LVC pilot project is consistent with the fourth recommendation of the Scientific Advisory Board study.

Linear Program for Distributing Live and Simulator Mission Sorties

The linear programming model used to redistribute F-22 sorties among live and simulator training environments is written in the GAMS language (detailed information can be found on the GAMS website). GAMS was designed and is generally used to generate the large data structures used in mathematical programming (i.e., optimization) models, and the GAMS application is distributed with a number of powerful solvers for such problems. For this research, the model works to optimize totval, which is essentially the sum of mission priorities—that is, the model tries to distribute sorties so that the maximum number of high-priority sorties is accomplished. Below is a copy of the program.

```
$offlisting
$TITLE Allocate training IAW the F-22 RAP message, AEF Cycle 7

**************************
* *
* Global Options Section *
* *
**************************

Options
 lp = cplex
 limrow = 0
 limcol = 0
 solprint = on
 iterlim = 1000000
 reslim = 10000
 profile = 1
 profiletol = 1
 ;

$offupper offsymxref offsymlist onmixed onmulti inlinecom { }

sets

mission Mission types
/
```

mACM
mAHC
mBFM
mDCA
mINS
mOCA-DEAD
mOCA-Escort
mOCA-SAT
mOCA-Sweep
mGS
/

sortie Sortie types
/
rACM
rAHC
rBFM
rDCA
rINS
rOCA-DEAD
rOCA-Escort
rOCA-SAT
rOCA-Sweep
rGS
rRA
/

ratio Mission to red air ratio
/
1v0
2v1
1v1
1v2
1v3
1v4
/

envir Environments
/
SAsim
DMO
local
LFE
/

live(envir) Live fly environments

```
/
local
LFE
/

sim(envir) Simulator environments
/
SAsim
DMO
/

rapay(envir) Environments where unit pilots must fly own Red Air
/
SAsim
local
/

cases cases to loop over
/ case1*case10 /
;

alias (envir, env2);
```

+
* Indicators of which missions can be performed

```
TABLE RAPtot(mission,ratio) Total RAP requirements over all environments
 1v0 2v1  1v1  1v2  1v3  1v4
mACM 18
mAHC 4
mBFM 14
mDCA 6 6 5 3
mINS 3
mOCA-DEAD 4 4 3 3
mOCA-Escort 6 6 6 5
mOCA-SAT 3 3 2 1
mOCA-Sweep 3 3 3 3
mGS 1 1 1
;

Parameter RAPsim(mission) Total RAP simulator requirements
/
mACM = 5
mAHC = 0
mBFM = 0
mDCA = 10
mINS = 0
```

```
mOCA-DEAD = 5
mOCA-Escort = 5
mOCA-SAT = 5
mOCA-Sweep = 5
mGS = 5
/
;

TABLE RAPpri(mission,ratio) Priority ranking for RAP sorties
 1v0 2v1  1v1  1v2  1v3  1v4
mACM 5
mAHC 6
mBFM 5
mDCA 4 3 2 1
mINS 6
mOCA-DEAD 4 3 2 1
mOCA-Escort 4 3 2 1
mOCA-SAT 4 3 2 1
mOCA-Sweep 4 3 2 1
mGS 4 3 2 1
;

TABLE CCpri(mission,ratio) Priority ranking for CC sorties
 1v0 2v1  1v1  1v2  1v3  1v4
mACM 0.03
mAHC 0.01
mBFM 0.02
mDCA 0.08 0.18 0.32 0.5
mINS 0.01
mOCA-DEAD 0.08 0.18 0.32 0.5
mOCA-Escort 0.08 0.18 0.32 0.5
mOCA-SAT 0.08 0.18 0.32 0.5
mOCA-Sweep 0.08 0.18 0.32 0.5
mGS 0.08 0.18 0.32 0.5
;

TABLE possmsn(mission,ratio,envir) Possible missions
 1v0.SAsim 2v1.SAsim 1v1.SAsim 1v2.SAsim 1v3.SAsim 1v4.SAsim
mACM 1
mAHC
mBFM
mDCA 1 1 1
mINS 1
mOCA-DEAD 1 1 1
mOCA-Escort 1 1 1
mOCA-SAT 1 1 1
```

```
mOCA-Sweep 1 1 1
mGS 1 1 1

 + 1v0.DMO 2v1.DMO 1v1.DMO 1v2.DMO 1v3.DMO 1v4.DMO
mACM 1
mAHC
mBFM
mDCA 1 1 1 1
mINS
mOCA-DEAD 1 1 1 1
mOCA-Escort 1 1 1 1
mOCA-SAT 1 1 1 1
mOCA-Sweep 1 1 1 1
mGS 1 1 1 1

 + 1v0.local 2v1.local 1v1.local 1v2.local 1v3.local 1v4.local
mACM 1
mAHC 1
mBFM 1
mDCA 1 1
mINS 1
mOCA-DEAD 1 1
mOCA-Escort 1 1
mOCA-SAT 1 1
mOCA-Sweep 1 1
mGS 1 1

 + 1v0.LFE 2v1.LFE 1v1.LFE 1v2.LFE 1v3.LFE 1v4.LFE
mACM 1
mAHC
mBFM
mDCA 1 1 1 1
mINS
mOCA-DEAD 1 1 1 1
mOCA-Escort 1 1 1 1
mOCA-SAT 1 1 1 1
mOCA-Sweep 1 1 1 1
mGS 1 1 1 1
;

Parameter sortXmisn(sortie,mission,ratio,envir) Sorties per mission;
 sortXmisn(sortie,mission,ratio,envir) = 0;
 sortXmisn("rACM","mACM",ratio,envir) = 1;
 sortXmisn("rAHC","mAHC",ratio,envir) = 1;
 sortXmisn("rBFM","mBFM",ratio,envir) = 1;
 sortXmisn("rDCA","mDCA",ratio,envir) = 1;
```

```
sortXmisn("rINS","mINS",ratio,envir) = 1;
sortXmisn("rOCA-DEAD","mOCA-DEAD",ratio,envir) = 1;
sortXmisn("rOCA-Escort","mOCA-Escort",ratio,envir) = 1;
sortXmisn("rOCA-SAT","mOCA-SAT",ratio,envir) = 1;
sortXmisn("rOCA-Sweep","mOCA-Sweep",ratio,envir) = 1;
sortXmisn("rGS","mGS",ratio,envir) = 1;
sortXmisn("rRA",mission,"2v1",rapay) = 0.5;
sortXmisn("rRA",mission,"1v1",rapay) = 1;
sortXmisn("rRA",mission,"1v2",rapay) = 2;
sortXmisn("rRA",mission,"1v3",rapay) = 3;
sortXmisn("rRA",mission,"1v4",rapay) = 4;


Table cap(envir,cases) maximum missions per time period by environment
 case1 case2 case3 case4 case5 case6 case7 case8 case9 case10
SAsim 0 0 0 0 0 0 0 0 0 0
DMO 0 20 40 60 80 100 120 140 160 180
local 200 200 200 200 200 200 200 200 200 200
LFE 0 0 0 0 0 0 0 0 0 0
;

Parameters
 maxevents Maximum events per time period
 ralim(envir) Max Red Air sorties
 capcas(envir) Capacities by environment for one case
;
 maxevents = 300;
 ralim(envir) = 9999;
 ralim("local") = 45;
 capcas(envir) = cap(envir,"case1");
*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*
* Variable declarations

Positive Variables

 RAPmisn(mission,ratio,envir) Number of RAP missions performed
 CCmisn(mission,ratio,envir) Number of CC missions performed
 TOTmisn(mission,ratio,envir) Total missions performed
 events(sortie,envir) Number of events per time period
;

Free Variables

 totval Total value of missions and packets
;
```

```
*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*
* Equation declarations

Equations

 bndRAPtot(mission,ratio) Constrain total RAP missions
 bndRAPsim(mission) Constrain RAP simulator missions
 calcALL(mission,ratio,envir) Calculate total missions
 eventnum(sortie,envir) Count events by type and environment
 sortlim(envir) Sorties by environment
 eventlim Limit on total events
 boundra(envir) Max Red Air sorties
 maxval Objective function
;


*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*
* Equation definitions
bndRAPtot(mission,ratio)..

 sum(envir$(possmsn(mission,ratio,envir) gt 0), RAPmisn(mission,ratio,envir))

 =L=

 RAPtot(mission,ratio)
;
*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*
bndRAPsim(mission)..

 sum((ratio,sim)$(possmsn(mission,ratio,sim) gt 0),
 RAPmisn(mission,ratio,sim))

 =L=

 RAPsim(mission)
;
*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*
calcALL(mission,ratio,envir)$(possmsn(mission,ratio,envir) gt 0)..

 RAPmisn(mission,ratio,envir) + CCmisn(mission,ratio,envir)

 =E=

 TOTmisn(mission,ratio,envir)
;
*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*
eventnum(sortie,envir)..
```

sum((mission,ratio)$(possmsn(mission,ratio,envir) gt 0),
sortXmisn(sortie,mission,ratio,envir)*TOTmisn(mission,ratio,envir))

=E=

events(sortie,envir)

;
+
sortlim(envir)..

sum(sortie, events(sortie,envir))

=L=

capcas(envir)
;
+
eventlim..

sum((sortie,envir), events(sortie,envir))

=L=

maxevents
;
+
boundra(envir)..

events("rRA",envir)

=L=

ralim(envir)
;
+
maxval..

totval

=E=

sum((mission,ratio,envir)$(possmsn(mission,ratio,envir) gt 0),
10*RAPpri(mission,ratio)*RAPmisn(mission,ratio,envir)
+ CCpri(mission,ratio) *CCmisn(mission,ratio,envir))

```
+ sum((mission,ratio,sim)$(possmsn(mission,ratio,sim) gt 0),
 RAPpri(mission,ratio)*RAPmisn(mission,ratio,sim))
;
*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*
* Declare model

Model rap7
/
 bndRAPtot
 bndRAPsim
 calcALL
 eventnum
 sortlim
 eventlim
 boundra
 maxval
/;


*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*
* Solve all cases, save outputs

Parameters
 savstat(cases)
 savRAP(mission,ratio,envir,cases)
 savCC(mission,ratio,envir,cases)
 savTOT(mission,ratio,envir,cases)
 savevents(sortie,envir,cases)
;

LOOP (cases,
 capcas(envir) = cap(envir,cases);
 Solve rap7 using lp maximizing totval;
 savstat(cases) = rap7.modelstat;
 savRAP(mission,ratio,envir,cases) = RAPmisn.l(mission,ratio,envir);
 savCC(mission,ratio,envir,cases) = CCmisn.l(mission,ratio,envir);
 savTOT(mission,ratio,envir,cases) = TOTmisn.l(mission,ratio,envir);
 savevents(sortie,envir,cases) = events.l(sortie,envir);
);


*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*
```

ACC/AFRL Survey Questionnaire[1]

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[1] This appendix is one version of the questionnaire from AFRL, 2008.

Total F-22 Flight Hours‗‗‗‗‗‗‗‗‗‗‗‗‗‗‗   **Rank**‗‗‗‗‗‗‗‗‗‗‗‗‗‗‗

Section 1

What is the maximum number of training events that you can realistically accomplish in one month (22 work days)? *Training Event:* Live or simulator events where you brief, fly, and debrief ‗‗‗‗‗‗‗‗‗‗‗‗‗‗‗.

Section 2

INSTRUCTIONS:
Enter the number of training events that YOU FEEL are required to be **PROFICIENT** across a 6-month period of time in the following four environments for an inexperienced and experienced pilot.

Environments:
1. *Stand-alone simulator:* Simulators not connected to another unit's sim (e.g., UTD). If available can be connected to form a flight (e.g., F-15 or B-1 MTC).
2. *DMO:* Simulation with the capability to link to another unit's sim.
3. *Local Live Fly Training:* Local training at your home unit.
4. *Live Composite Force Training (CFTR) /Large Force Employment (LFE):* Scenarios employing multiple flights of aircraft, each under the direction of its own flight leader acting in a LFE scenario to achieve a common tactical objective. Scenarios should be opposed by air and surface threats and should include at least 8 blue aircraft.

Definitions:
Proficient: Squadron members have a thorough knowledge of mission area and **_occasionally may make an error of omission or commission_**. Aircrew are able to operate in a complex, fluid environment and are able to handle most contingencies and unusual circumstances. Proficient aircrew are prepared for mission taskings on the first sortie in theater.

Training Event: Live or simulator events where you brief, fly, and debrief.

Example:
You may feel that an inexperienced pilot needs 50 DCA training events across a 6-month training period and an experienced pilot needs 44 DCA training events across a 6-month training period. See the table below to see how you might distribute your ratings.

			Inexperienced <500 Flight Hours						Experienced ≥500 Flight Hours					
		Month →	1	2	3	4	5	6	1	2	3	4	5	6
DCA	SIM	Stand-alone simulator	2	2	2	2	2	2	1	1	1	1	1	1
		DMO	2	2	2	4	2	2	2	2	2	4	2	2
	Live Fly	Local live fly training	4	4	4	4	4	4	4	4	4	4	4	4
		Live CFTR/LFE												
		Total per month	8	8	8	10	8	8	7	7	7	9	7	7

PROFICIENT RATINGS

			Inexperienced <500 Flight Hours						Experienced ≥500 Flight Hours					
		Month →	1	2	3	4	5	6	1	2	3	4	5	6
AHC	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												
DCA	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												
OCA-Escort	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												
OCA-Sweep	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												
OCA-DEAD	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												

			Inexperienced <500 Flight Hours						Experienced ≥500 Flight Hours					
		Month →	1	2	3	4	5	6	1	2	3	4	5	6
OCA-SAT	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												
Global Strike	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												
ACM	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												
BFM	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												
Red Air	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												
Instrument	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												

Section 3

INSTRUCTIONS:
Enter the number of training events that <u>YOU FEEL</u> are required to be **HIGHLY PROFICIENT** across a 6-month period of time in the following four environments for an inexperienced and experienced pilot.

Environments:
1. *Stand-alone simulator:* Simulators not connected to another unit's sim (e.g., UTD). If available can be connected to form a flight (e.g., F-15 or B-1 MTC).
2. *DMO:* Simulation with the capability to link to another unit's sim.
3. *Local Live Fly Training:* Local training at your home unit.
4. *Live Composite Force Training (CFTR)/Large Force Employment (LFE):* Scenarios employing multiple flights of aircraft, each under the direction of its own flight leader acting in a LFE scenario to achieve a common tactical objective. Scenarios should be opposed by air and surface threats and should include at least 8 blue aircraft.

Definitions:
Highly Proficient: Squadron members have a thorough knowledge of mission area and ***rarely make an error of omission or commission***. Aircrew are able to operate in a complex, fluid environment and are able to handle most contingencies and unusual circumstances. Highly proficient aircrew are prepared for the mission taskings on the first sortie in theater.

Training Event: Live or simulator events where you brief, fly, and debrief.

Example:
You may feel that an inexperienced pilot needs 68 DCA training events across a 6-month training period and an experienced pilot needs 62 DCA training events across a 6-month training period. See the table below to see how you might distribute your ratings.

			Inexperienced <500 Flight Hours						Experienced ≥500 Flight Hours					
		Month →	1	2	3	4	5	6	1	2	3	4	5	6
DCA	SIM	Stand-alone simulator	3	3	3	3	3	3	2	2	2	2	2	2
		DMO	3	3	3	5	3	3	3	3	3	5	3	3
	Live Fly	Local live fly training	5	5	5	5	5	5	5	5	5	5	5	5
		Live CFTR/LFE												
		Total per month	**11**	**11**	**11**	**13**	**11**	**11**	**10**	**10**	**10**	**12**	**10**	**10**

HIGHLY PROFICIENT RATINGS

			Inexperienced <500 Flight Hours						Experienced ≥500 Flight Hours					
		Month →	1	2	3	4	5	6	1	2	3	4	5	6
AHC	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												
DCA	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												
OCA-Escort	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												
OCA-Sweep	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												
OCA-DEAD	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												

			Inexperienced <500 Flight Hours						Experienced ≥500 Flight Hours					
		Month →	1	2	3	4	5	6	1	2	3	4	5	6
OCA-SAT	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												
Global Strike	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												
ACM	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												
BFM	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												
Red Air	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												
Instrument	SIM	Stand-alone simulator												
		DMO												
	Live Fly	Local live fly training												
		Live CFTR/LFE												
		Total per month												

Section 4

If you were part of a team completely redesigning your training program that included live fly and high-fidelity simulation, what decision would you make with regard to the ratio of simulator training to live fly training? Please select the mix that would be optimal.

	Live:	More	_____	Sim:	More	_____
		Same	_____		Same	_____
		Less	_____		Less	_____

Please provide rationale for this decision.

What type of simulator does your unit have access to?

What shortfalls and training gaps do you see in your unit's simulator?

Fiscal realities will dictate that some training be migrated to a high-fidelity simulator. If you had unlimited access to a high-fidelity simulator training environment what training can only be achieved during live flight?

What training can only be achieved in the simulator?

Please prioritize the order of importance for having live flight training in each of the following missions (1=most important and 11=least important).

_____ AHC
_____ DCA
_____ OCA-Escort
_____ OCA-Sweep
_____ OCA-DEAD
_____ OCA-SAT
_____ Global Strike
_____ ACM
_____ BFM
_____ Red Air
_____ Instrument

What are the benefits and/or disadvantages of relying on a regional sim training center (TDY required) vs. an MTC at home station?

Cost Calculations

This appendix contains the detailed sources and methods we used to estimate the cost of different resources required for red air to accomplish eight blue-air sorties per month, as summarized in Table 3.1.

The following three ways were identified:

1. Fly more F-22 sorties at the current proportion of red air.
2. Shift red-air intensive missions to the simulator and increase simulator activities in the MTC or the ACS.
3. Provide red air to live aircraft by using an adversary (or aggressor) squadron.

Flying the F-22

For the first option, flying the F-22 is very expensive: according to the Air Force Total Cost of Ownership database, $48,082 per flying hour. This implies a 1.5-hour sortie cost of roughly $72,000. We assume that each pilot must fly 16 sorties per month in order to fly eight blue-air ones, for an increase of only three blue-air sorties for each pilot. Six sorties cost 6 × $72,000 = $432,000, but because only three of them are blue, the cost per blue sortie is $432,000 ÷ 3 = $144,000.[1]

In the MTC or the ACS

The second option is to use the simulator environment to provide the red-air threat, which requires increasing the number of simulator missions by two. In FY 2008, the DTOC had a budget of about $4.5 million. There are two ways of looking at the cost of running the DTOC: time and events. The time view looks at what costs would be if DTOC capacity were completely filled, using current manpower levels; the event view uses sortie levels' current capacity and ignores fixed cost. The time view underestimates the average cost; the event view overestimates average cost.

---

[1] It could be argued that this overestimates the cost of doubling the number of F-22 sorties per pilot, as the fixed cost for depot repair would be spread over more sorties, leaving a lower average cost per flying hour. However, many flying-hour costs for the F-22 are variable costs that rise in proportion to sortie count: The $11,000 for Mission Personnel and $6,300 for Fuel are entirely marginal, while the $27,000 for Contractor Logistics Support and $2,300 for Indirect Support contain some fixed costs along with substantial variable costs; however, we have no visibility into the mix of variable and fixed costs.

First we will show the time view of DTOC cost. If we assume the DTOC is open and available 24 hours a day, 7 days a week, or 24 × 365 = 8,760 hours per year, then the cost per hour is $4.5 million ÷ 8,760 = $513.[2] Then the cost of two additional 1.5-hour simulator sorties is $513 × 1.5 × 2 = $1,541. Using these two simulator sorties for red-air-intensive missions means that three live red-air sorties can now be flown as blue air instead, so the cost per blue-air sortie is also about $513 ($1,541 ÷ 3).

Looking at DTOC costs in terms of events yields a very different answer. Again, the DTOC budget in FY 2008 was $4.5 million; the organization managed 960 training "events" that year for a cost of $4.5 million ÷ 960 = $4,687 per event. Two additional simulator training sorties cost $4,687 × 2 = $9374, roughly $10,000. This investment again allows three live red-air sorties to be flown as blue air instead, for a cost of $3,300 per blue-air sortie.

Alternatively, the two additional simulator missions could be accomplished in the ACS, which is already enthusiastically supported by F-22 pilots. RAND estimates of the cost of doing this are from $3,600 to $5,300, for an investment of $1,200 to $1,800 per new blue-air sortie.

F-22 Systems Program Office personnel estimate the cost of the ACS to be roughly $15,000 per day.[3] But it is how the ACS is used that determines its cost per sortie. The Air Force sends a group of pilots to the ACS, which is dedicated to training over a several-day period. To calculate sortie cost, we made a number of assumptions about the number of personnel and how long they stay, the number of missions conducted, and the cost of providing support personnel. The assumptions and calculations are laid out in Table C.1.

There are three main costs of sending pilots to the ACS: the facility, the instructors, TDY (temporary duty), and airfare. We assume that pilots are sent to train for two days, at a facility cost of $15,000 per day × 2 days = $30,000 per visit. Instructors cost roughly $19,200 per visit: $150 per hour × 8 hours × 8 instructors × 2 days. TDY and airfare cost $22,500 per visit:[4] $2,500 per pilot × 5 pilots + $400 per day per pilot × 5 pilots × (2 days on site + 3 days travel). Summed, this yields a total cost of $71,700 for five pilots per visit. Assuming pilots require 24 ACS sorties each year (two per month), and eight sorties are performed per visit, three visits to the ACS are required each year. Hence, the visit cost per month per pilot is $3,585: $71,700 × 3 visits ÷ 5 pilots ÷ 12 months. We round up to $3,600 per month.

However, this cost ignores some of the funds that the Air Force has been spending on upgrading and maintaining the testing facility to meet training needs. This cost has been highly variable, but it will roughly be $2,000,000 per year. Right now, there are roughly 100 F-22 pilots: This yields an average investment cost of $1,667 per pilot per month: $2,000,000 ÷ 100 ÷ 12.

Adding the visit cost per pilot ($3,585) and the investment cost per pilot ($1,667), we have a total cost of $5,252, which we round up to $5,300. As above, two new simulator sorties free up three red-air sorties to be converted to blue air, leaving a cost for new blue-air sorties of between $1,200 ($3,600 ÷ 3) and roughly $1,800 ($5,300 ÷ 3).

---

[2]   In the main text, we assumed the DTOC operated for only 40 hours a week, or 2,080 hours per year, which gave a cost per hour of $2,100.

[3]   The ACS is a software testing facility and is not designed for training. The indefinite-delivery, indefinite-quantity contract under which it operates does not specify costs in terms useful for this report.

[4]   TDY, airfare, and instructor support costs are rough estimates for the purpose of discussion.

Table C.1
ACS Cost Calculations

Variable	Estimate	Explanation
Activity assumption		
Site days	2	
Travel days	3	
Number of pilots	5	
Number of instructors	8	
Hours per sortie	1.6	The facility can provide 5 sorties per day (5 × 1.6 = 8 hours/day)
Sorties per day	4	Each pilot flies 4 sorties per day; 8 during the TDY
Hours per day	8	
Per visit calculation		
Facility cost per visit	$30,000	2 days × $15,000
Instructor cost per visit	$19,200	2 days × 8 hours per day × 8 instructors × $150/day
TDY and airfare	$22,500	5 pilots × $2,500 airfare + $400 × 5 pilots × (2 days + 3 travel days)
Total cost per visit for 5 pilots	$71,700	
Cost per month calculations		Explanation
Annual sorties	24	
Annual visits	3	
Visit cost per pilot per month	$3,585	$71,700 × 3 visits ÷ 5 pilots ÷ 12 months
Annual ACS investment	$2,000,000	
Investment per pilot per month	$1,667	$2,000,000 ÷ 100 pilots ÷ 12 months
Total cost per pilot per month	$5,252	$3,585 + $1,667

NOTES: Cost assumptions are as follows: Facility cost = $15,000 per day; TDY cost = $400 per day per pilot; airfare for travel to the ACS facility = $2,500 per pilot per visit; instructor support = $150 per instructor per hour.

Aggressors

For the third option, we consider the possibility of using resources that are not part of the unit to provide live red air. In Table C.2, we examine the cost for a dedicated aggressor trainer aircraft (a mix of T-38 and T-45), or an F-16, to replace three red-air sorties flown by an F-22.

There are three costs we are trying to calculate: O&M, aggressor pilots, and depreciation. For O&M, we multiply an average of 1.3 flying hours per sortie times the number of sorties times the cost per flying hour. A T-38 has a $3,200 cost per flying hour, while an F-16 has an $8,000 cost per flying hour (from AFI 65-503). Three sorties per month times 1.3 flying hours

Table C.2
Aggressor Squadron Cost Estimates

	3 Red Sorties in Trainer	3 Red Sorties in F-16
Red-air sorties/month/fighter pilot replaced	3	3
Average red-air sorties/month/aggressor pilot	15	15
Aggressor pilots required	0.2	0.2
Red-air pilot sorties/month	3	3
Flying hours/sortie	1.3	1.3
Flying hours/month	3.9	3.9
Cost per flying hour (CPFH)	$3,200	$8,000
O&M cost/month (CPFH × hours/month)	$12,480	$31,200
O&M cost/year	$149,760	$374,400
Aggressor pilot salary/year	$150,000	$150,000
Cost of pilot/year	$30,000	$30,000
Trainer flying hours required/year	46.8	46.8
Procurement cost	$30,000,000	$30,000,000
Average end life in flying hours	15,000	8,000
Number of aircraft "used up" per year (flying hours per year ÷ flying hours for the life of the aircraft)	0.00312	0.00585
Annual depreciation cost (aircraft used up × procurement cost)	$93,600	$175,500
Total annual red-air cost (O&M + aggressor pilot + annual depreciation)	$273,360	$579,900
Total monthly red-air cost	$22,780.00	$48,325.00
Monthly cost per blue-air sortie	$7,593.33	$16,108.33
Average flying hours/year/aircraft	400	400
Aircraft required (46.8 ÷ 400)	0.117	0.117
Up front procurement cost (0.117 × procurement cost)	$3,510,000	$3,510,000

times the cost per flying hour yields $12,480 and $31,200, respectively, per month in O&M for the trainer aircraft and F-16.

The cost of aggressor pilots depends on the number of pilots and their salaries. We assume that an aggressor pilot can fly 15 sorties per month either in a trainer aircraft or an F-16; hence it takes 0.2 of an aggressor pilot to replace three red-air sorties of an F-22 pilot. The cost of an aggressor pilot, at a fifth of the $150,000 assumed annual salary, comes to $30,000 per year.

The cost of depreciation is calculated as the number of flying hours used in the aggressor role divided by life expectancy times the cost of procurement. The procurement cost of a T-38 aircraft was not available, so the cost of the more advanced T-45 was substituted; it is assumed that a basic version of either the T-45 or F-16, appropriate for the aggressor role, can be procured for no more than $30 million each. The number of flying hours in three red-air sorties

per month is 1.3 × 3 × 12 = 46.8. The end life in flying hours is roughly 15,000 for the T-45 and 8,000 for the F-16, yielding an annual depreciation cost of $30 million × 46.8 ÷ 15,000 = $93,600 for the trainer aircraft, and $30 million × 46.8 ÷ 8,000 = $175,000 for the F-16.

In sum, for a trainer aircraft flying three sorties per month as an adversary, flying-hour costs, O&M costs, and depreciation lead to a total cost of $22,780 per month for an adversary aircraft. If an F-16–like aircraft is used instead, the same assumptions lead to a cost of $48,325 per month for three red-air sorties.

Potential Consequences of Reducing Funding for Live Sorties

One of the assumptions made in the modeling done in the main body of this report was that the Air Force would fund flying hours to maintain ten live sorties per month for the F-22. With that assumption, we showed different approaches to abiding by the RAP limit of flying two red-air sorties a month and making the other eight sorties more effective blue-air sorties. The model showed that if some red-air-intensive sorties were flown in the simulator and/or MTC instead of the aircraft, pilots could fly more effective blue-air live sorties. However, the *distribution* of those sorties would still be less than optimal: Since fewer red-air sorties were available, fewer live blue-air sorties could be flown against red-air opponents and more of the live blue-air sorties would have to be BFM sorties that do not require an opponent. In addition, this redistribution of training resulted in an overall increase in the number of activities a pilot has to accomplish per month: He or she would still fly ten live sorties, but the number of simulator activities would increase by two; total activities per month would thus increase from 13 to 15.

Since this result means that a pilot ends up flying more of a certain sortie type (BFM) than is needed, it is not unreasonable to ask what would happen if fewer live sorties per month were funded in the first place. From a budgetary point of view, we see that this change would save money by decreasing spending on expensive flying hours; from a training point of view, it might be efficient in the sense of moving sorties that do not have to be accomplished in the aircraft to the simulator environment. We note that this argument is one that can strike fear into the heart of the training community: In the past, the Air Force has cut flying hours to save money under the assumption that the affected live-flying training could be accomplished in the less expensive simulator environment instead, only to fail to provide the necessary funding to ensure that the simulator training is an adequate replacement. Once cut, the flying hours are difficult or impossible to recover. Nonetheless, given existing fiscal pressures, the potential consequences of a decrease in flying hours need to be addressed.

Figure D.1 shows results from the linear program. The figure begins with the examples from the main text and adds a case in which monthly flying hours are reduced.

The two survey bars in the figure serve as references for the distributions of sortie types in the different training environments according to respondents. Recall that this distribution would require almost 14 live sorties per month and nine simulator and/or MTC sorties per month for a total of 23 activities per month.

As in the main body of this document, we start with the assumption that ten live sorties per month and three simulator sorties per month are funded with no restrictions on red air. The distributions of sorties determined by the linear program are shown by the "Live: unconstrained red air (10)" bar at the far left of the figure and the "Simulated: unconstrained red air

Figure D.1
Sortie Distribution If the Number of Live Sorties Is Decreased
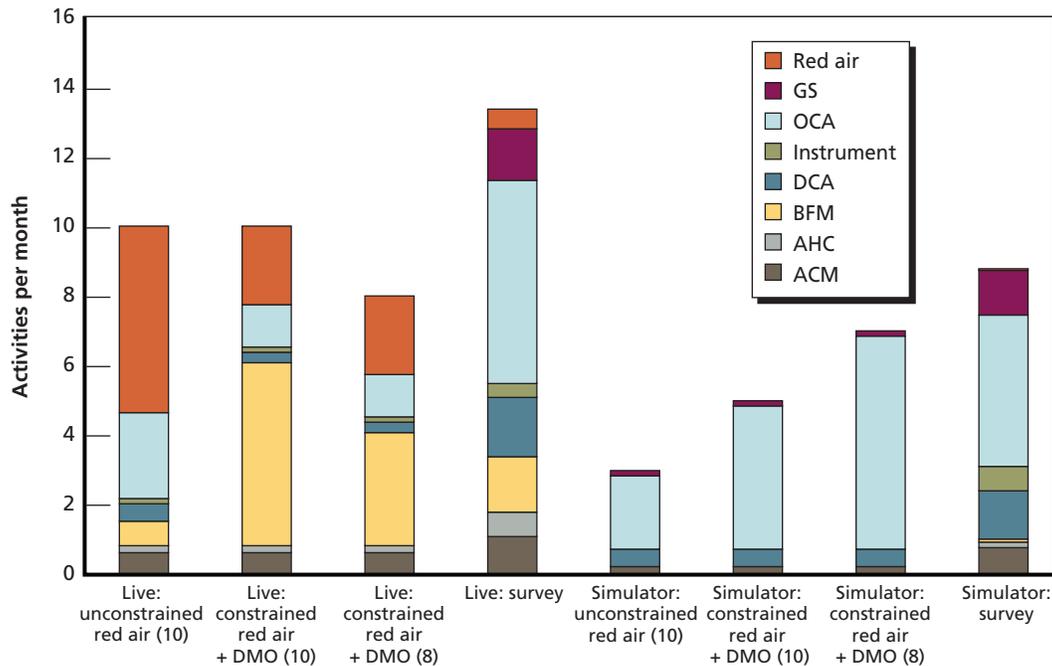
(10)" bar. We again note that five sorties per month need to be flown as red air as we saw in the main text—more than desired, according to the survey.

Next, we limit red-air sorties to the RAP maximum of two. This gives the "Live: constrained red air + DMO (10)" and the "Simulated: constrained red air + DMO (10)" bars in the figure. As in the figures in the main text, these show that with sufficient capacity (and threat capability), live training can be improved (in the sense of flying more blue-air sorties) by moving some red-air-intensive sorties into the simulator environment. The downside is that, without some sort of live red-air capability, the best distribution might mean that pilots fly more live BFM sorties than supervisors think is necessary.

Finally, we assume that flying hours have been cut to eight live RAP sorties per month and that simulators are able to take up some of the slack—that is, the total number of activities is still 15, as it was when ten live sorties were flown per month. This gives the "Live: constrained red air + DMO (8)" bar and the "Simulated: constrained red air + DMO (8)" bar. Live red air is still limited to two sorties, and in one sense training has improved because two fewer unnecessary BFM sorties are flown live. The number of ACM, AHC, DCA, instrument, and OCA sorties remains unchanged. On the simulator side, the number of ACM, DCA, and GS activities has not changed, but the number of OCA missions has increased by two so that the total number of OCA missions is more than that recommended by the survey respondents. In other words, to maximize the value of training after the reduction in monthly live flying hours, the model essentially converted two live BFM sorties into two simulator OCA sorties.

These results depend, of course, on the underlying assumptions of the linear programming model. Changing the value of mission types (that is, the level of importance a commander or the RAP tasking memorandum attaches to each mission type) and modifying assumptions about simulator and/or MTC capabilities would lead to different mission distributions.

Nonetheless, this exercise highlights the fact that reducing monthly flying hours may save money in flying-hour costs, but maintaining the value of training introduces costs in the simulator environment. The most obvious cost, of course, is that for more simulator time for new sorties, which, as we have seen, is relatively low compared to live flying time. If an increase in simulator requirements fleet-wide exceeds the capacity of currently funded MTCs, however; costs would increase significantly because of the need to increase the number of simulator cockpits. In addition, the movement of threat-intensive missions to the simulator environment assumes that the threats can be generated there. As discussed in the body of this report, appropriate investments need to be made in constructive threats or in DTOC-like infrastructure (including human trainers) in order to ensure that this is the case.

One reason the Air Force needs to do a better job of establishing and validating training requirements is that some justification needs to be developed for the number of live sorties that a pilot needs even when the simulated environment has become more realistic. Otherwise it is difficult to respond to budgeting determinations that the savings from cutting flying hours are worth the risk in training effectiveness, because, without validated training requirements, that risk cannot be quantified.

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