LIGHTNING IN A MODEL: EVOLVING THE TRAINING MIX FOR THE F-35

BY

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APPROVAL

The undersigned certify that this thesis meets masters-level standard of research, argumentation, and expression.

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DISCLAIMER

ABOUT THE AUTHOR

LtCol Heijs was a 2000 graduate of the Royal Netherlands Military Academy where he majored in military operations. His 18-year career on active duty starting as an F-16 pilot has taken him to a variety of assignments and places. LtCol Heijs performed several squadron duties at Volkel Airbase, to include squadron weapons officer and flight commander, and instructor at the European F-16 weapons school. After several deployments in Afghanistan and Libya, LtCol Heijs started in 2013 as a policy advisor at the air operations division of the Directorate of Plans and concerned himself with requirements for Dutch fighter aircraft. He holds a Master of Military Operational Art and Science from the U.S. Air Force Air Command and Staff College. Following LtCol Heijs' study at the School for Advanced Air and Space Studies, he will report back to the Netherlands to command the 322 Squadron at Leeuwarden Airbase.

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ABSTRACT

This study explores the limits of the shift from training in real aircraft towards training in simulators. This study analyzes the considerations to determine the proper balance and identifies strategic consequences of overreliance on simulation. The author begins by reviewing historical examples of simulator development and analyzes how simulation can be beneficial to pilot training. The author then describes the drawbacks of simulation and highlights which factors are important in determining the live-simulator mix. After the author reviews how the USAF currently determines the training mix, he analyses both qualitative and quantitative research relevant to the subject. The author then uses the results to develop a model applicable to current F-35 training. The proposed model suggests which missions, and in what quantity, can be transferred to the simulator. Although this study identifies several limitations of the model, it concludes decisionmakers should use a prudent approach to training transfer as current understanding of the psychophysiological and hormonal responses of actual flight conditions as well as retention of complex skills are still limited. Of a number of options assessed, the author concludes the best solution is to take a gradual approach to transfer of training that allows for a more responsible assessment and management of the process.

CONTENTS

LIST OF TABLES AND FIGURES

TABLES

FIGURES

Introduction

The United States Air Force (USAF) suggests the future operating environment will be characterized by "increasing speed and proliferation of technological change, geopolitical instability, increasing scarcity of natural resources, and an increasingly important and vulnerable global commons."[1] To adapt swiftly to continuously changing future environments, the U.S. Air Force will leverage operational agility, which is "the ability to rapidly generate and shift among multiple solutions for a given challenge."[2] One of the inherently agile tools is the F-35 Joint Strike Fighter. The F-35 replaces the current fleet of A-10s, F-15s, F-16s, and other legacy aircraft in the United States (U.S.) and in allied nations. To be ready for a future fight, air forces around the world have adopted similar training programs for their pilots that include greater use of flight simulators.

Flight simulation is an essential element of pilot training. Decades ago, systems like the Unit Lever Trainer (ULT) were meant to train pilots in emergency procedures. As aircraft have become more advanced in generational capabilities, to today's fifth-generation, so too have simulators. Today's advanced simulators allow pilots to train in scenarios that they cannot practice in the real aircraft for a variety of reasons. As simulators have become more sophisticated, the divide between real flying and training in the simulator continues to shift the advantage towards the latter.

If it is possible pilots can fly more hours in simulators without loss, or perhaps even with an increase of proficiency, air forces can train more pilots with the same number of aircraft and the available flying

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[1] Air Force Future Operating Concept, A View of the Air Force in 2035, September 2015.
[2] Ibid.

hours that can be applied to an actual combat increase. As such, simulators can significantly enhance a nation's combat capability. As simulators are significantly cheaper to operate than real aircraft, more use of simulation seems to be an attractive choice. There is little scholarly consideration, however, of the downsides of such a heavy reliance on simulators. More specific, there is little scholarly inquiry on the force-employment implications this training mix might have. For small states, operating with limited resources and means, over-reliance on simulation to create combat-ready pilots at lower financial costs may have strategic impacts.

This thesis explores the limits of this shift by answering the following research questions: what considerations determine the training balance between flying actual aircraft or spending time in simulators when preparing pilots for combat? What are the strategic consequences of an over-reliance on simulator training for the combat capabilities for air forces of small states?

To answer these questions, this thesis explores the tension between what simulators can provide for the warfighter and what they cannot. The limits of simulation, in turn, determine the amount of training that must be done in the real aircraft. This thesis first identifies the consequences of the hypothetical case in which all training is conducted in the simulator to create a better understanding of why simulation has limitations and what additional factors are of influence. This thesis then examines the factors that determine what missions must be trained in real flight. To do so, this thesis analyzes existing qualitative scientific research on aircrew training and quantitative research such as surveys, interviews, and current aircrew training instructions. To develop a case for the F-35, for which there is yet little practical experience, parallels will be drawn to F-15 and F-22 training concepts. A comparison with the F-15 highlights the differences in simulation needs between fourth and fifth-generation aircraft while the F-22 training requirements are comparable to the F-35. The results are used to develop a model to determine an appropriate live-simulator mix. To avoid confusion about the meaning of “simulated” throughout this thesis, “live” refers to training in the actual aircraft and “simulated” refers to training in the simulator.

Part I: Simulation

Chapter 1

Why Simulators?

There is little doubt that simulators are useful. In 2011, the Government Business Council conducted a meta-analysis of 26 studies on simulator effectiveness. In over 80 percent of the studies, "the use of simulators resulted in knowledge transfer to trainees equal to or greater than live training."[3] This chapter provides a historical overview of simulator development and explains the benefits and limits of simulator use in a training environment.

Historical Overview

Flight simulation has followed the technological evolution of airplanes. Historically, the two key elements in simulation have been realism and training effectiveness. Realism, at first, meant that simulators literally were scaled down replicas of real aircraft. The earliest simulators were not designed to train pilots. Before the Second World War, bombardiers needed to practice high-altitude bombing, as it was difficult to aim with a long bomb time-of-fall. Bombing training was expensive because it required considerable fuel to get to the desired altitude. Due to budget constraints, bombardiers had to find alternative ways to train on the ground which led to the development of the A-2 ground trainer.[4] After the Second World War, jet fighters with advanced engines and hydraulic systems led to the development of the Link C-11

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[3] Jean Archer et al., "Determining the Appropriate Live-Fly and Virtual Training Mix for Flight Training" (Maxwell AFB, AL: Air Command and Staff College, 2017), 3

[4] Jason C. Zumwalt, "Lonely Skies: Air-to-Air Training for a 5th Generation Fighter Force" (Maxwell AFB, AL: School for Advanced Air and Space Studies, June 2015), 21

Trainer in 1949. The C-11 allowed pilots to practice both instrument flight and emergency procedures.[5]

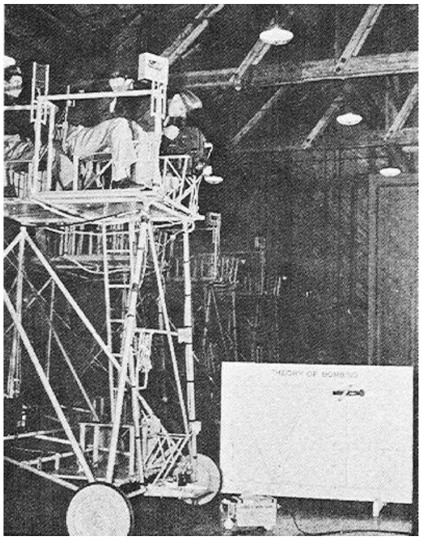

FIGURE 1: Early Bombardier Training SOURCE: National Museum of the US Air Force

FIGURE 2: Link Trainer SOURCE: National Museum of the US Air Force

The new trainers changed from a miniature version of the actual airplane to designs that more resemble simulators used today.[6] In 1965, the USAF introduced the first system to train air tactics: the Simulator for Air-to-Air Combat (SAAC).[7] After an evaluation of SAAC in 1976, researchers recognized how important visual cues are to pilots' performance.[8] The new focus led to the development of the 360-degree wrap-around field of view and the Weapon System Trainer (WST).[9] In the

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[5] Jason C. Zumwalt, "Lonely Skies: Air-to-Air Training for a 5th Generation Fighter Force" (Maxwell AFB, AL: School for Advanced Air and Space Studies, June 2015), 26

[6] Shaun R. McGrath, "Leveraging DMO's Hi-Tech Simulation Against the F-16 Flying Training Gap" (Maxwell AFB, AL: Air Command and Staff College, April 2005), 14

[7] Ibid., 15

[8] Visual cues are discussed on page 19-20.

[9] Shaun R. McGrath, "Leveraging DMO's Hi-Tech Simulation Against the F-16 Flying Training Gap" (Maxwell AFB, AL: Air Command and Staff College, April 2005), 19.

late 80s, the USAF replaced the WST with the Multi-Task Trainer (MTT), designed to provide training in emergency procedures, instrument flight, and weapon delivery. In the F-16 community, the MTT evolved to the Unit Training Device (UTD) and the Weapons Task Trainer (WTT).[10] Both systems filled the need for basic training but not for complex missions. Pilots frequently complained about the lack of accurate visual cues and that the simulators were not up to date with the latest software in the actual aircraft.[11] A large difference between the aircraft and simulator has a negative impact on how skills learned in a simulator transfer to the actual aircraft.[12] The pilots' desires for improved visual capabilities led to the development of high-tech simulators called Distributed Mission Trainers (DMTs), to mission training centers (MTCs), and finally, to Distributed Mission Operations (DMO).[13]

The first MTC became operational in 2000 for the F-15C, the USAF's single-seat, all-weather air-superiority fighter.[14] MTCs are essentially locally interconnected or networked simulators that incorporate high-resolution visual graphics and realistic cockpit components. Some MTCs even make use of actual cockpits. Most MTC facilities have briefing and debriefing rooms available to increase the training value.[15] MTCs can be regarded as training resources that can provide a nearly unlimited supply of red-air support.[16] Red-air forces are

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[10] Shaun R. McGrath, "Leveraging DMO's Hi-Tech Simulation Against the F-16 Flying Training Gap" (Maxwell AFB, AL: Air Command and Staff College, April 2005), 19
[11] Ibid., 20
[12] Ibid., 20
[13] Ibid., 12
[14] George Alliger et al., "Defining the Training Mix – Sorties, Sims, and Distributed Mission Operations" *Interservice/Industry Training, Simulation, and Education Conference*, no. 9166 (2009), 3
[15] Richard S. Marken et al., *Absorbing and Developing Qualified Fighter Pilots,* 2007034639 (Santa Monica, CA: RAND, 2007), 21
[16] Ibid., 25

opposing forces against which blue, or friendly forces, train.[17] Networking MTC's among different bases creates DMO capabilities.

DMO is the ability to: "network disparate, geographically separated simulators over a worldwide dedicated network designed for persistent, daily use."[18] DMO, as such, is not a simulator type but a capability.[19] Shaw Air Force Base, South Carolina, was one of the first F-16 bases to receive an MTC with DMO functionality.[20] A networked environment enables the pilot to train higher-order skills.[21] Such skills include surface-to-air missile reactions, air-combat tactics, and use of electronic countermeasures.[22] DMO also creates the opportunity to rehearse missions in specific theaters to prepare for actual combat operations.[23] In 2005, the then Air Force Chief of Staff, General John Jumper, recognized DMO's potential when he described it as, "the cornerstone of Air Force training transformation….providing mission rehearsal in an operationally realistic environment to maintain combat readiness and provide support to operations."[24] MTCs and DMO provide the best means for training, "enabling the virtual simulation world to train inexperienced pilots into combat-ready fighter pilots with superior operational

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[17] Blue air are friendly forces

[18] George Alliger et al., "Defining the Training Mix – Sorties, Sims, and Distributed Mission Operations" *Interservice/Industry Training, Simulation, and Education Conference*, no. 9166 (2009), 3

[19] Richard S. Marken et al., *Absorbing and Developing Qualified Fighter Pilots,* 2007034639 (Santa Monica, CA: RAND, 2007), 22

[20] Shaun R. McGrath, "Leveraging DMO's Hi-Tech Simulation Against the F-16 Flying Training Gap" (Maxwell AFB, AL: Air Command and Staff College, April 2005), 25

[21] Winston Bennett and Brian T. Schreiber, *Distributed Mission Operations Within-Simulator Training Effectiveness Baseline Study: Summary Report,* AFRL-HE-AZ-TR-2006-0015-Vol I (Mesa, AZ, Air Force Research Laboratory, 31 March 2006), iv

[22] Ibid., 1

[23] Richard S. Marken et al., *Absorbing and Developing Qualified Fighter Pilots,* 2007034639 (Santa Monica, CA: RAND, 2007), 27

[24] Ibid., 23

awareness."[25] In an Air Force Research Laboratory (AFRL) study in 2006 on the effectiveness of DMO, Brian Schreiber and Winston Bennett found significant competency improvements from distributed simulator training.[26] DMO combines virtual elements (V), a person in a simulator, as well as computer-generated constructed elements (C). Future plans envision that live sorties (L) connect to V and C elements into an LVC environment.[27]

According to one Air Force official, LVC is the "Holy Grail" of simulator training with "blue forces going against aggressors at every level for full-spectrum combat training."[28] In the *Concept for Future Air Force Operations Concept 2035,* the USAF states LVC will "improve the realism of training for combat and multi-domain challenges."[29] Currently, however, LVC technology is still in its infancy.[30] Additional research and development are needed to deliver an operational system to the Air Force, and that requires significant investments. Given LVC is regarded as a future development for the F-35, it is not included in the following section that describes the benefits of simulation for fifth-generation aircraft.

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[25] Shaun R. McGrath, "Leveraging DMO's Hi-Tech Simulation Against the F-16 Flying Training Gap" (Maxwell AFB, AL: Air Command and Staff College, April 2005), 2

[26] Winston Bennett and Brian T. Schreiber, *Distributed Mission Operations Within-Simulator Training Effectiveness Baseline Study: Summary Report,* AFRL-HE-AZ-TR-2006-0015-Vol I (Mesa, AZ, Air Force Research Laboratory, 31 March 2006), v

[27] Office of the Under Secretary of Defense, *Readiness and Training Policy and Programs* (Washington, DC: Office of the Under Secretary of Defense, 23 September 2010), 10

[28] James Drew, "Analysis: Next-gen Simulation Preps F-35 Units for Battle," *Flightglobal* (15 February 2016): 1, https://flightglobal.com

[29] Air Force Future Operating Concept, A View of the Air Force in 2035, September 2015, 43

[30] Jacob Hammons, "Advanced Readiness 2025: Balanced Investments Across Live, Virtual, and Constructive," *Interservice/Industry Training, Simulation, and Education Conference*, no. 17241 (2017), 10

Benefits of Simulators

Cost of Operation

Decision makers increasingly view simulation as a cost-effective alternative to conducting training in actual airplanes, especially in a budget-constrained environment.[31] The cost savings that result from the transfer of training to a simulator are significant. In general, high-technology simulators in MTCs are roughly ten times cheaper to operate than live flights.[32] That factor seems to be relatively constant throughout history. In a report to Congress in 1973, the Comptroller General of the United States reported the average cost for the F-4 and the A-7 was about USD 843 per hour compared to USD 80 for the simulator.[33] For the F-35 specifically, a RAND study in 2013 estimated the cost of acquisition, maintenance, and operation of the F-35 Full Mission Simulator (FMS) was USD 5,000 per hour compared to USD 32,500 for live flight.[34] Besides being much cheaper, training in simulators is also much safer.

Safety

Simulators after the Second World War were primarily used to train emergency procedures.[35] Many safety experts agreed that

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[31] Samuel Powell et al., "Flying Hours versus Simulator Hours: A Cost Comparison and Methodology Standard," *Interservice/Industry Training, Simulation, and Education Conference*, no. 16257 (2016), 1

[32] Shaun R. McGrath, "Leveraging DMO's Hi-Tech Simulation Against the F-16 Flying Training Gap" (Maxwell AFB, AL: Air Command and Staff College, April 2005), 29

[33] Comptroller of the United States, *Report to the Congress: Greater Use of Flight Simulators in Military Pilot Training Can Lower Cost and Increase Pilot Proficiency* (Washington, DC: General Accounting Office, 9 August 1973), 2

[34] Tommy C. E. Thomas et al., "Full 3D Visuals for Advanced Training in Single Seat Fighters," *Interservice/Industry Training, Simulation, and Education Conference*, no. 17050 (2017), 4

[35] Jason C. Zumwalt, "Lonely Skies: Air-to-Air Training for a 5th Generation Fighter Force" (Maxwell AFB, AL: School for Advanced Air and Space Studies, June 2015), 25

"simulators are actually more valuable than an airplane" for emergency training.[36] Older simulators allowed pilots only to investigate the cause of a system failure and execute the required emergency procedures. Modern systems also provide training in handling emergencies under combat conditions, such as battle damage, fuel problems, and critical system failures, which cannot be practiced as efficiently during live training.[37] Other limitations have to do with the training environment.

No Airspace and Range Restrictions

In real flight, pilots must adhere to airspace and range restrictions. Live training for fifth-generation aircraft with advanced sensors and weapons demands long-range setups against red air opponents, which requires large volumes of restricted airspace.[38] Current airspace structures may not be large enough, and not every training airspace allows supersonic flight or unlimited use of electronic warfare. Live training can also be hampered by restrictions put on the expenditure of ordnance such as live or practice bombs, or chaff and flares. In a virtual environment, these restrictions do not exist. In a paper that focuses on performance measurements in LVC environments, Jaclyn Hoke et al. asserted that the "range spaces have become too constrained to support the advanced capabilities of our forces and advanced threats of our adversaries."[39] Hoke et al. also point out another benefit of simulation: availability of advanced threats.

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[36] Shaun R. McGrath, "Leveraging DMO's Hi-Tech Simulation Against the F-16 Flying Training Gap" (Maxwell AFB, AL: Air Command and Staff College, April 2005), 16

[37] Richard S. Marken et al., *High-Fidelity Simulators with Mission Training Centers* (Santa Monica, CA: RAND, 2007), 25

[38] John Ausink et al., *Investment Strategies for Improving Fifth-Generation Fighter Training Modeling Framework for Optimizing F-35A Strategic Basing Decisions to Meet Training Requirements* (Santa Monica, CA: RAND, 2011), 11

[39] Jaclyn Hoke et al., "Performance Measurement in LVC Distributed Simulations: Lessons from OBW," *Interservice/Industry Training, Simulation, and Education Conference*, no. 17207 (2017), 3

Advanced Threats

Fifth-generation aircraft are specifically designed to fight advanced threats. The current live surface-to-air threat systems and red-air opponents cannot meet the demand for blue-air training, both in quality and in quantity. Offensive-counter-air (OCA) and defensive-counter-air (DCA) training demand high red-air ratios to be effective. In these two missions, pilots practice using their fifth-generation advanced sensors and stealth characteristics in air-to-air fights against aircraft that are superior in numbers. To supplement the limited number of dissimilar opponents, F-22 pilots often fly red-air missions.[40] As a result, pilots train for fewer offensive- and defensive-counter-air sorties than subject-matter experts recommend.[41] Additionally, as the capabilities of adversaries grow, it is difficult, if not impossible, to replicate this in a purely live training environment.[42] In a virtual environment, fifth-generation simulators can easily replicate advanced-adversary threats.[43] Red-air opponents in the simulator can also quickly reset to their starting positions, which can take considerable time, given the ranges and distances of engagements.

Time Efficiency

MTC training missions do not involve ground operations, departure procedures, and transition time to and from the airspace. In a simulator, a mission can be quickly reset to initiate a new setup or, in case of an

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[40] John Ausink et al., *A Modeling Framework for Optimizing F-35A Strategic Basing Decisions to Meet Training Requirements,* RR1546 (Santa Monica, CA: RAND, 2016), 3
[41] Ibid., 18
[42] Jaclyn Hoke et al., “Performance Measurement in LVC Distributed Simulations: Lessons from OBW,” *Interservice/Industry Training, Simulation, and Education Conference*, no. 17207 (2017), 3
[43] John Ausink et al., *A Modeling Framework for Optimizing F-35A Strategic Basing Decisions to Meet Training Requirements,* RR1546 (Santa Monica, CA: RAND, 2016), 19

instructional sortie, suspended to explain certain tactical considerations.[44] Without transit time and long resets in between setups, the same amount of training can be accomplished in a simulator in much less time.

Virtual Flags

MTCs with DMO capability further provide opportunities to train Large Force Employment (LFE) missions or the Flag series of exercises. Exercises such as Red Flag at Nellis Air Force Base, Nevada, take tremendous effort to organize and are very costly, given the large numbers of attendees and weapon systems required for support.[45] Instead, DMO provides pilots with the opportunity to fly virtual Flags in preparation for actual combat from their home base. Although many improvements have been made in flight simulation, simulation and live flight have not become identical.

Drawbacks of Simulation

Some elements inherent in live flight cannot be replicated in a synthetic environment, even in the most advanced simulators. This section examines these limitations and concludes there needs to be a balance between the two.

Lack of Fidelity

The first challenge with simulators is they have an inherent lack of fidelity. There are the three different aspects to this: psychological, physical, and visual. Psychological stress, caused by anticipation of

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[44] Richard S. Marken et al., *High-Fidelity Simulators with Mission Training Centers* (Santa Monica, CA: RAND, 2007), 24

[45] Richard S. Marken et al., *High-Fidelity Simulators with Mission Training Centers* (Santa Monica, CA: RAND, 2007), 26

catastrophic or even fatal consequences of mistakes cannot be simulated.[46] Regardless of the errors made, one can always "walk away from a simulator." Said in a slightly different way, no one ever died from making errors in a simulator. Pilots easily fly at a lower altitude in the simulator than they would in real flight. Second, a simulator cannot replicate the G-forces pilots have to deal with during live training. Continuous high-G maneuvers can easily be done in a simulator but lead to fatigue in actual flight. The last limitation in simulator fidelity is a lack of depth perception and visual cues. When pilots fly close enough to the ground or other aircraft to perceive depth, for example in air-to-air refueling, formation flying, or in low-level flight missions, they require three-dimensional visualization to assess range. Although computer graphics and visual display systems continue to improve, "they still lack lifelike resolution."[47] Simulators can display only a two-dimensional visual environment.[48] Additionally, it is difficult to visually identify airborne objects and ground references in a simulator, especially during high-speed operations.[49] Many respondents of a survey for a study to develop a strategy for investment in LVC mentioned a desire for increased visual acuity.[50]

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[46] Richard S. Marken et al., *High-Fidelity Simulators with Mission Training Centers* (Santa Monica, CA: RAND, 2007), 28

[47] Tommy C. E. Thomas et al., "Full 3D Visuals for Advanced Training in Single Seat Fighters," *Interservice/Industry Training, Simulation, and Education Conference*, no. 17050 (2017), 6

[48] Full 3D Visuals is currently being studied for part task trainers. See Thomas, Kelley Kearl, Orsua, and Sidor, "Full 3D Visuals for Advanced Training in Single Seat Fighters."

[49] Richard S. Marken et al., *Absorbing and Developing Qualified Fighter Pilots,* 2007034639 (Santa Monica, CA: RAND, 2007), 29

[50] Jacob Hammons, "Advanced Readiness 2025: Balanced Investments Across Live, Virtual, and Constructive," *Interservice/Industry Training, Simulation, and Education Conference*, no. 17241 (2017), 8

It is important, however, to compare simulator training to live *training* which is different than *real life.* Market et al. assert in a RAND study to develop qualified fighter pilots, for example, that "certain issues, such as the stark realities of the catastrophic loss of a flight member in an explosion or crash, cannot be simulated very effectively."[51] Although the authors are correct in regard that a catastrophic event cannot be simulated, it also cannot be trained for live flight either. If a pilot flies only in a simulated environment, he or she will never experience *unplanned* events. Unplanned events and the ability and experience to handle the situation is important to developing airmanship.

Airmanship

A simulator training mission usually starts at the "fights-on" moment at a preset distance between blue and red air. Pilots do not fly towards the training area in a simulator as they do in real flight. Not having to go to and from the area saves time but also has its disadvantage. Pilots gain airmanship from encounters with unexpected airborne traffic, unanticipated weather conditions, and from handling emergencies that happen in an actual flight. To lead a formation of airplanes to and from the training area in bad-weather conditions is more stressful than to start a simulator training at the beginning of a "setup." In live situations, flight leads must also monitor the fuel states of their flight members, where in a simulator there is always a "fuel freeze" option.[52] John Ausink et al. concluded in 2016 that "airmanship issues were precisely the reason the Air Education and Training

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[51] Richard S. Marken et al., *Absorbing and Developing Qualified Fighter Pilots,* 2007034639 (Santa Monica, CA: RAND, 2007), 38

[52] Winston Bennett and Brian T. Schreiber, *Distributed Mission Operations Within-Simulator Training Effectiveness Baseline Study: Summary Report,* AFRL-HE-AZ-TR-2006-0015-Vol I (Mesa, AZ, Air Force Research Laboratory, 31 March 2006), 21

Command (AETC) has resisted replacing live sorties with simulator training in the formal training unit programs that initially qualify new fighter pilots."[53] Simulation takes away certain aspects of live flight that make a pilot become an experienced flight lead.

Conclusion

In sum, fifth-generation aircraft are designed to execute successful operations in an anti-access environment featuring an integrated air defense system (IADS) that includes advanced surface-to-air missile systems (SAMs) and advanced air threats with jammers and other electronic attack modes designed to prevent blue forces from attacking.[54] To train live missions in such a hostile environment is almost impossible as the threat systems and airspace required to support them are not readily available. Furthermore, given the airspace restrictions and limitations imposed on blue forces for security reasons, training would be suboptimal even if advanced-threat systems were available. Samuel Powell et al. concluded in their research to determine the cost per simulator hour that "deteriorating ranges, ballooning weapon system sustainment costs, evolving training requirements and the decrease of our military's flying hours all strengthen the argument for investment in higher fidelity training systems as a supplemental tool for live training methods."[55] As such, to execute high-end training, in an unrestricted,

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[53] John Ausink et al., *A Modeling Framework for Optimizing F-35A Strategic Basing Decisions to Meet Training Requirements,* RR1546 (Santa Monica, CA: RAND, 2016), 64

[54] John Ausink et al., *Investment Strategies for Improving Fifth-Generation Fighter Training Modeling Framework for Optimizing F-35A Strategic Basing Decisions to Meet Training Requirements* (Santa Monica, CA: RAND, 2011), 11

[55] Samuel Powell et al., "Flying Hours versus Simulator Hours: A Cost Comparison and Methodology Standard," *Interservice/Industry Training, Simulation, and Education Conference*, no. 16257 (2016), 11

yet safe, environment and at an affordable cost, a simulation provides a good alternative to live flights.

Simulators, however, even the most modern ones, are noticeably different than actual flight. There is no substitute for live missions from the viewpoint of building airmanship. Simulation is meant to be an alternative solution to practical training issues as "it was never intended to replace all live training."[56] Simulators have many benefits, as described in this Chapter, but there are some inherent limitations to training in a virtual environment. It is therefore important to determine the right balance between live flight and simulation. To illustrate the importance of this balance, the next chapter describes the consequences if the use of simulation is taken to hypothetical limits: to train pilots exclusively in a virtual environment.

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[56] Samuel Powell et al., "Flying Hours versus Simulator Hours: A Cost Comparison and Methodology Standard," *Interservice/Industry Training, Simulation, and Education Conference*, no. 16257 (2016), 11

Chapter 2

An Extreme Example

This Chapter explains the consequences of the extreme case in which all flight training is done in a simulator. It is not meant to be a repetition of the previous Chapter, yet some arguments inevitably will be the same. To stop training in real aircraft is not a realistic option, but analyzing the consequences of doing so deepens the understanding of the tension between live and simulator training and highlights additional factors that play a role in defining the training mix that otherwise may go unnoticed.

All Training in a Simulator

Positive Consequences

In the hypothetical case that no training at all will be conducted in the actual aircraft, the most obvious benefit is significant cost savings. The F-35 operating and maintenance costs would be kept to a minimum. Aside from some mandatory inspections, the aircraft could remain in the shelters untouched until needed for combat operations. Additionally, peacetime losses would be eliminated, which prevents additional procurement to maintain the same number of aircraft. Also, not flying means that current training infrastructures do not require additional investments. For example, one of the primary missions of the F-35 is Suppression of Enemy Air Defense (SEAD). To train this mission in live flight against advanced opponents, additional purchases must be made in emitters, targets, opponent aircraft, and range support. Such purchases can "easily be an order of magnitude higher than the cost to operate simulators."[1]

Besides financial benefits, there are some tactical advantages of not flying real aircraft. In live flight, the use of jamming is often restricted because it is necessity to keep certain techniques classified. Not training high-end missions in real airplanes keeps the F-35 tactics sensitive and classified. Furthermore, if adversaries can observe the ranges at which blue air executes particular tactics, they can estimate the capability of certain weapons. As such, if an adversary does not have an opportunity to assess the strength and weaknesses of the F-35, it will be advantageous for the U.S. and its allies. Although the aforementioned financial and tactical benefits seem very attractive, decision makers must also give consideration to the downsides of not training with the real aircraft.

Negative Consequences

Simulators can replicate almost anything the aircraft can do in the air, save an important one: the feeling of motion and the G-forces that act on the pilot's body during maneuvers.[2] Marken et al. asserted, in a RAND report on the role of advanced simulators in pilot training, that less-experienced pilots might not be able to maintain their skills in partial simulator training.[3] If all training were to be done in simulation, skill decay most certainly is the case. Some researchers, therefore, caution for a proficiency that is primarily based on the fidelity of a

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[1] George Alliger et al., "Defining the Training Mix – Sorties, Sims, and Distributed Mission Operations" *Interservice/Industry Training, Simulation, and Education Conference*, no. 9166 (2009), 11

[2] Ibid.

[3] Richard S. Marken et al., *Absorbing and Developing Qualified Fighter Pilots,* 2007034639 (Santa Monica, CA: RAND, 2007), 29

simulator because of the limited ability to replicate the actual dynamic flight environment in live fighter operations.[4]

Besides skill decay, pilots cannot build confidence in the actual system or gain self-confidence in their ability to execute combat missions needed if they train only in simulators. Confidence in the system and one's own abilities does not only apply to pilots, but also to the maintainers of the aircraft. If pilots train only in a virtual environment, maintainers must practice in simulators as well. Researchers already look into the possibilities of using virtual reality (VR) tools for maintenance training.[5] Virtual training, however, prevents maintainers from getting a "feel" for the aircraft. Every type of airplane has its specifics. Some parts could break more regularly than others, for example. With experience, maintainers develop an understanding of the parts or sections that need more frequent inspections. The specific "behavior" of an airplane should be learned in peacetime instead of during combat. Live flight in peacetime is not only beneficial to train maintainers, but it is also important for the whole aircraft industry in sustaining the F-35.

Sustainment for the F-35 aircraft is a large and complex undertaking. All F-35 customers, including the international partners, share a global pool of spare parts that is unique to the F-35 system.[6] Almost one-fifth of F-35 parts have a lead time of more than two years.[7]

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[4] George Alliger et al., "Defining the Training Mix – Sorties, Sims, and Distributed Mission Operations" *Interservice/Industry Training, Simulation, and Education Conference*, no. 9166 (2009), 4

[5] Shannon K. T. Bailey et al., "Using Virtual Reality for Training Maintenance Procedures," *Interservice/Industry Training, Simulation, and Education Conference*, no. 17108 (2017), 1

[6] Government Accountability Office, *Report to Congressional Committees: F-35 Sustainment Cost,* GAO-22-234 (Washington, DC: Government Accountability Office, October 2017), 15

[7] Ibid., 15

A sophisticated system called the Autonomic Logistics Information System (ALIS) is designed to support the global F-35 sustainment.[8] ALIS, however, cannot meet the many complex supply-chain challenges yet. In 2017, approximately 22 percent of F-35 aircraft were unable to fly because they were awaiting spare parts.[9] Assuming that the United States and its partner nations are not continually at war, not flying during peacetime removes the opportunity for the F-35 supply-and-sustainment chain to mature. Additionally, the demand in spare parts would significantly decrease since there is no need for them. Low demands may even cause subcontractors to stop producing spare parts if it is not profitable anymore. Also, both the supply chain and the global pool of spare parts may not be able to support a sudden surge in demand after a conflict starts. In turn, not having sufficient forces available when needed, especially in an unexpected crisis, may have strategic consequences. Although the mentioned consequences of simulation on the logistic and supply chain are outside the scope of this thesis, it is a subject worth of further research.

Finally, to reduce all live-training hours to practically zero also introduces additional costs. If all training is done in simulators, the resulting increase in simulator training demand may exceed the capacity of the current MTCs, which would require additional investments in new simulators.[10] Costs increase even more if additional contractor personnel to operate and maintain additional simulators must be hired.[11]

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[8] Ibid., 23

[9] Ibid., 14

[10] John Ausink et al., *A Modeling Framework for Optimizing F-35A Strategic Basing Decisions to Meet Training Requirements,* RR1546 (Santa Monica, CA: RAND, 2016), 61

[11] Government Accountability Office, *Report to Congressional Committees: Air Force Training, Actions Needed to Better Manage and Determine Costs of Virtual Training Efforts,* GAO-12-727 (Washington, DC: Government Accountability Office, July 2012), 16

Ultimately, the savings from not flying far outweigh the additional costs for extra simulator capacity. Yet, real flying has manifold corollary benefits.

Conclusion

The hypothetical scenario of doing all F-35 training missions in a simulator highlights that the balance of a mix is essentially a tradeoff between financial cost and risk. Besides the few tactical benefits of training everything in a virtual environment, the biggest advantage is financial. Not flying, although financially attractive, comes at a cost. A simulated environment is not the same as real flight. Pilots who train only in simulators are not familiar with high G-forces and stresses that exist in real flight. Nor can they build confidence in their system. Furthermore, the F-35 maintenance and support systems, as well as its supply chain, will suffer from doing so to the point where they may not be able to sustain operations in wartime. The negative consequences mentioned pose a significant strategic risk. Peacetime financial benefits should not outweigh high risk in war. Said differently, it is impossible to train fighter pilots for combat operations exclusively in simulators if the F-35 weapon system as a whole is required to be well prepared for the task. It is therefore important to define the right balance.

Part II: Existing Research

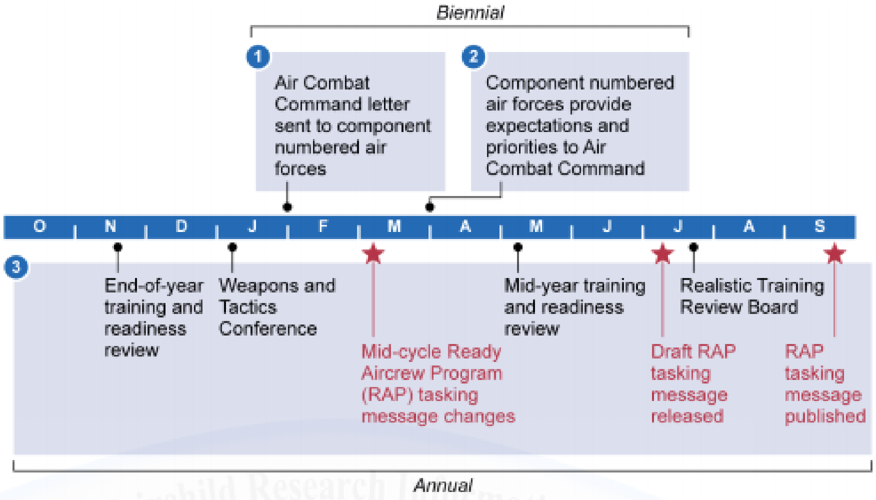
Chapter 3

Qualitative Analyses

Previous studies to determine the optimal ratio between live flight and simulation took two different approaches. The first is a scientific approach which uses objective, measurable data. Scientific research should, in theory, provide more accurate answers. Most of the research in aviation takes place in the civilian world, however, and the results do not always easily apply to fast military jets. The second method involves analysis of subjective data, mostly from surveys provided by subject matter experts. Surveys are more readily available and easily tailored toward specific topics, but the results are less accurate because survey respondents typically are biased. This chapter examines previous scientific research into the factors that play a role in determining a training mix. Before doing so, this Chapter first lays out how training is currently documented within the USAF.

Defining the Training Mix

In the USAF, the training requirements are documented in the Air Force Instruction (AFI) 11-2X-XX series. AFI 11-2F-35A Volume 1, for example, describes the training needs for F-35 pilots. The AFIs represent the standards for training and qualifying personnel performing duties in the form of a Ready Aircrew Program (RAP). To maintain their combat-ready status, pilots follow a Continuation Training (CT) program. For the F-35, here are two aspects of CT. First, the RAP requirements in AFI 11-2F-35 consists of training in basic flying skills. Second, specific mission-related training requirements are documented in the RAP tasking memos (RTMs). As such, AFI 11-2F-35 is supplemented with the F-35-specific RTM to establish the total training requirements. Combined, these documents give guidance to "develop combat skills or practical tactical employment relevant to the unit's tasking."[1] Figure 1 below graphically depicts the process of how total training requirements are determined:



Source: Air Force. | GAO-16-864

Figure 3: Ready Aircrew Program Process
SOURCE: GAO REPORT 2016, 11

The training requirements are continuously updated by the Realistic Training Review Boards (RTRBs). The RTRBs semiannually discuss for each weapon system if the requirements are still up to date. Headquarters Air Combat Command (HQ ACC) chairs the RTRBs in which the SMEs for each applicable active and reserve component are represented. Any requests for changes to the AFI-11-2F-35 must be submitted to the RTRBs.[2] The RTRBs ultimately determine the ratio between live flight and simulation. To determine the ratio, the SMEs collect user inputs, as well as qualitative and quantitative research on the subject. The relevant studies are described in the next sections.

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[1] Air Force Instruction (AFI) 11-2F-35A, Volume 1, *F-35 Aircrew Training,* 13 September 2010, 6
[2] Ibid., 5

Psychophysics and Cortisol

The combined results of two studies between 2002 and 2004 indicate some factors that have a negative impact on pilots' performance exist only in the real aircraft. A simulator cannot replace live flight to train pilots to cope with these stresses. Research to explore the utility of using psychophysical responses to measure performance under stress revealed that increased workload affected these responses, and measuring them could predict performance.[3] Psychophysics is "a branch of psychology concerned with the effect of physical processes on the mental processes of an organism."[4] The researchers found that a higher workload, indicated by heavy breathing and an increase in heart rate and body movements, directly correlates to a decrease in performance. A high-G environment also increases a pilot's workload, and fighter pilots have similar physical responses when exposed to G-forces. It follows, therefore, that performance under such circumstances also degrades. In this regard, military fighter pilots operate under unique circumstances compared to their civilian counterparts.

Additionally, J.A. Veltman found in his study that the levels of cortisol, better known as the stress hormone, increased when pilots experience G-forces. An increase in cortisol was absent when the pilots flew the same mission in a simulator.[5] Not only G-forces stimulate the body to release cortisol. To experience fear has the same effect. Anxiety, caused by flying close to another airplane or close to the ground on low-level missions, or by dropping live ordnance from an aircraft, can also stimulate cortisol release. These stresses are absent in a synthetic

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[3] Jean Archer et al., "Determining the Appropriate Live-Fly and Virtual Training Mix for Flight Training" (Maxwell AFB, AL: Air Command and Staff College, 2017), 6

[4] Merriam-Webster, 1004

[5] Jean Archer et al., "Determining the Appropriate Live-Fly and Virtual Training Mix for Flight Training" (Maxwell AFB, AL: Air Command and Staff College, 2017), 9

world. A pilot can experience certain stressful situations and develop mechanisms and behavior to cope with the negative consequences of stress only in the actual aircraft and not in the simulator.

Transfer

Differences between a simulator and live flight also influence the extent to which simulator training can transfer to the real aircraft. A high transfer of training means that skills learned in simulation can be used in the actual aircraft without any additional effort. According to Paul Hoffman and Robert Feltovich, the similarity of the conditions between synthetic training and live flight has the largest impact on performance.[6] Said differently, a pilot’s performance in the real aircraft after a simulated flight depends on how well the simulator resembles the live conditions. Simulation and reality are not the same in high-dynamic environments or in other stressful situations specific to live flight. It follows, therefore, that certain skills can be learned and maintained only in the real aircraft and not in the simulator.

Christopher McClernon came to a similar conclusion in 2007. He asserted that if “a motion simulator for flight training gives a very real, yet slightly inaccurate representation of motion” it may increase simulator performance but when the pilot transitions to a real aircraft “the stimuli and responses differ resulting in negative transfer.”[7] McClernon concluded that many researchers found that transfer of training is very task dependent and may be more crucial for highly

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[6] Paul Feltovich and Robert Hoffman, *Accelerated Proficiency and Facilitated Retention: Recommendations Based on an Integration of Research and Findings from a Working Meeting,* AFRL-RH-AZ-2011-0001 (Mesa, AZ, Air Force Research Laboratory, December 2010), 10

[7] Christopher K. McClernon, *Stress Effects on Transfer from Virtual Environment Flight Training to Stressful Flight Environments* (Montery, CA: Naval Post Graduate School, 2009), 21

dynamic, visual-spatial tasks than for more mundane cognitive tasks.[8] These scenarios include basic fighter maneuvers (BFM), air combat maneuvers (ACM), and low-level flights. How often that specific training in a live environment needs to be repeated depends on how long pilots can retain their skills. As such, research of what analysts label "facilitated retention" is relevant for the live-simulation question.[9]

Retention

The 2010 report *Retention of Piloting Skills* published the results from a workshop on accelerated learning. The workshop, hosted by the Florida Institute for Human and Machine Cognition, brought together leading academic, private sector, and Department of Defense (DoD) specialists to discuss the subject of accelerated learning.[10] The workshop's participants concluded that significant skill decay could occur within relatively short timeframes, even days, regardless the complexity of the task. One of the issues the report's authors attempted to resolve is how to ensure that training has a stable and lasting effect. As already mentioned, high G-forces or the stress of actual danger have a negative effect on performance, and skills to cope with these stresses must be learned in the real aircraft. The retention time of such skills, therefore, can be indicative of the maximum allowable time between two live sorties. Said differently, skill retention determines the minimum amount of live training because rapid skill decay necessitates frequent re-training.[11]

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[8] Ibid., 41

[9] Defined as how to ensure that training has a stable and lasting effect (Hoffman and Feltovich, 8).

[10] A primary goal of the DoD Accelerated Learning Technology Focus Team was to identify critical research challenges that were underfunded or not funded.

[11] Paul Feltovich and Robert Hoffman, *Accelerated Proficiency and Facilitated Retention: Recommendations Based on an Integration of Research and Findings from a Working*

Other researchers found that more complicated skills decay faster than basic flying ones.[12] Healy (2008), for example, determined from F-16 refresher trainer that "no one comes back after a hiatus of more than a few months at greater than 80 percent proficiency. After a long hiatus, proficiency upon return is estimated at 40-30 percent."[13] An example of a performance-decay curve after intensive bombing training on a different platform, the F/A-18, is depicted in Figure 2 below.[14] As with any skill, coping with stress decay follows a similar curve.

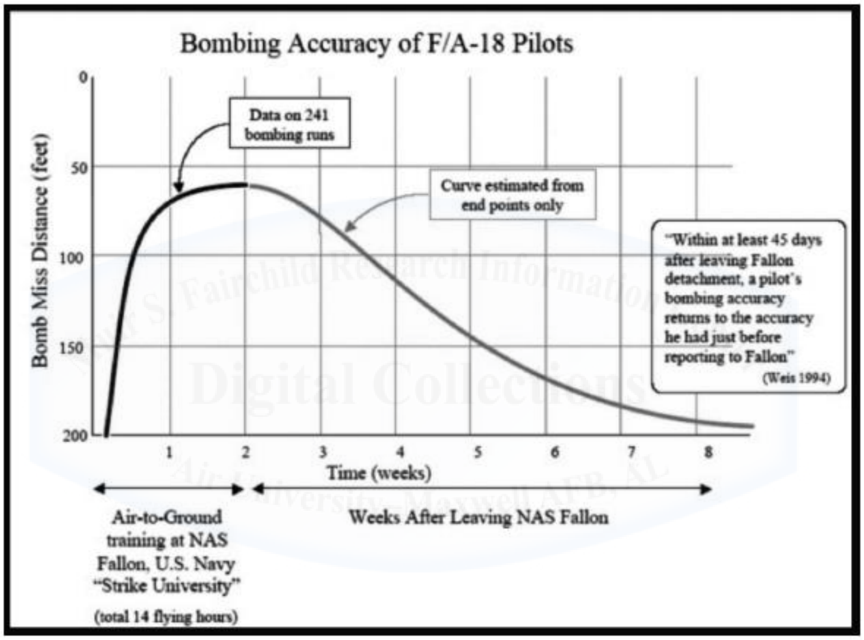

Figure 4: Skill Decay Example
SOURCE: Hoffman and Feltovich, 75.

Meeting, AFRL-RH-AZ-2011-0001 (Mesa, AZ, Air Force Research Laboratory, December 2010), 9

[12] Ibid., 79

[13] Ibid., 80

[14] Used in the Air Forces of the US, Canada, and Australia.

Several researchers have found that retention improves in a randomized training schedule.[15] In randomized training, the same task is never practiced on successive trials. If repeated on multiple occasions, randomized training results in “superficial massive rehearsal” which allows for greater long-term retention.[16] To stimulate long-term retention, therefore, this research suggests that similar events, whether of live or simulated, should be spread throughout the year. To date, however, insufficient research has been done both in civilian and in military aviation to determine the skill decay of coping with physical or emotional stress specific to real flight. The minimum performance level to be maintained is also unclear.

Subjective Measures

The importance of scientific research into psychophysics, stress, G-forces, and skill retention is highlighted in another study by Rowe, Prost, Schreiber, and Bennett (2008). The research performed by AFRL focussed on a method of combining objective and subjective data to assess DMO training. They concluded, “subjective measures of training performance are best used when coupled with additional, objective measures” because both measurements did somewhat correlate but not in a manner that was statistically significant.[17] This is not to say that subject matter experts are always wrong; quite the contrary. Some authors even assert that aircrew and operators should have decisive input in future discussions to determine the right balance of live versus

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[15] Paul Feltovich and Robert Hoffman, *Accelerated Proficiency and Facilitated Retention: Recommendations Based on an Integration of Research and Findings from a Working Meeting,* AFRL-RH-AZ-2011-0001 (Mesa, AZ, Air Force Research Laboratory, December 2010), 43

[16] Ibid., 43

[17] Leah J. Rowe et al., “Assessing High-Fidelity Training Capabilities Using Subjective and Objective Tools,” *Interservice/Industry Training, Simulation, and Education Conference*, no. 8206 (2008), 6

simulation because they are the "informed customer."[18] The point Rowe, Prost, Schreiber, and Bennett make is that subjective measures and assessments are simply more accurate when backed up with additional quantitative and qualitative objective data. This conclusion holds true to determine the live-simulator mix.

Conclusion

Simulator technology progressively closed the gap between live flight and a synthetic environment, yet the two are not the same. For both, increased workloads introduce psychophysiological responses that impact performance. Compared to a simulator, however, more of these responses can be expected in live flight. Busy airspace, unexpected traffic, turbulence, and most importantly, high G-forces and chances of physical harm introduce more stress. The last two release cortisol as well, which further degrades performance. To experience psychophysiological and hormonal responses specific to live flight and to develop skills to cope with it, pilots must train in the real aircraft. Furthermore, such developed skills decay. There is no data available, however, to predict at what speed. A randomized training schedule can somewhat improve retention, but there is no scientific research done to determine what should be the minimum live-flight interval. To transfer training to the simulator without a full understanding of the psychophysiological and hormonal responses for the different circumstances of live flight can lead to situations where pilots are incapable of coping with stress when needed in wartime. In the process of determining the proper mix between live and simulation, the psychophysiological and hormonal responses during fighter training

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[18] Jacob Hammons, "Advanced Readiness 2025: Balanced Investments Across Live, Virtual, and Constructive," *Interservice/Industry Training, Simulation, and Education Conference*, no. 17241 (2017), 3

must be understood. In the absence of objective data, military leaders have no other choice but to make their decisions on reports based on subjective data gathered from surveys that may be biased.

Chapter 4

Quantitative Analysis

In the last two decades, much research on the utility of flight simulators in pilot training has been conducted based on surveys. The earliest survey included in this chapter was taken in 2000 and gives a good indication of pilot-training requirements before training was even considered to be transferred to the simulator. Later studies were specifically done to determine an optimum training mix, and the data shows that pilots preferred to train more in the simulator than was required. This chapter includes three significant research projects and an audit by the Government Accountability Office (GAO).

2003 RAND Report

The first quantitative report explored here was published by RAND in 2003. The report is significant because it provides a baseline of total training required before training transfer was even possible. In the report, Bigelow, Taylor, Moore, and Thomas introduced two similar models to calculate how to optimize pilot training. The models serve three purposes. First, they attempt to justify the number of flying hours needed to train pilots. This is necessary, according to the authors, because flying hours are often targeted during budget cuts.[1] Second, the models attempt to estimate sortie requirements. Previous were based on a simple spreadsheet and did not accurately account for the supervision requirements for inexperienced pilots. Third, the authors suggest that by using their more accurate models, no more spin-up sorties to prepare for deployment are required. A need for spin-up sorties indicates a shortfall

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[1] James Bigelow et al., *Models of Operational Training in Fighter Squadrons,* MR-1701 (Santa Monica, CA: RAND, 2003), iii

in training, according to the authors.[2] To determine how much training is required to become proficient, the authors used data from surveys taken in 2000 and conducted interviews. The consensus among instructor pilots and flight leads was that 12 sorties per month (three per week) would provide adequate training.[3] The proposed models for the A-10, F-15, and F-16 also included one simulator per month for inexperienced pilots. Since the model did not specify the type, the simulator is assumed to be emergency-procedures training and did not provide a transfer of tactical training.[4] Since the survey in 2000, simulators continued to improve to the point that transfer has become a consideration. Since then, how to define the optimum training mix has been the central question in many studies, one of which was published in 2011.

2011 RAND Report

The 2011 RAND report was published as part of RAND Project Air Force (PAF). The study, *Investment Strategies for Improving Fifth-Generation Fighter Training,* was part of a 2009 research project into distributed mission operations versus live flying in fifth-generation fighter continuation training.[5] The study included, among others, a 2008 jointly conducted survey by Air Combat Command (ACC) and AFRL on how to define the optimum training mix along with interviews with F-22 subject matter experts. The authors concluded that in 2008 a gap existed between the stated Ready Action Pilot training requirements and what was actually achieved. With this evidence, RAND developed a

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[2] Ibid., xi

[3] Ibid., x

[4] James Bigelow et al., *Models of Operational Training in Fighter Squadrons,* MR-1701 (Santa Monica, CA: RAND, 2003), 33

[5] John Ausink et al., *A Modeling Framework for Optimizing F-35A Strategic Basing Decisions to Meet Training Requirements,* RR1546 (Santa Monica, CA: RAND, 2016), iv

model to examine the potential to redistribute training between live and simulation to increase efficiency and determine the cost of doing so. RAND concluded that the development of a LVC capability might be the only feasible means to improve training, given budgetary constraints.[6] The data used for this RAND report, as well as its graphs, provide useful considerations on the subject of transferring live training sorties to the simulator. The RAP requirements in 2009 for inexperienced pilots were ten live sorties and two simulator missions per month, a total of twelve events.[7] The reason RAND focused on inexperienced pilots is that this category is the most difficult to train.[8] The 2008 survey results and the 2009 RAP requirements are combined in the chart below.

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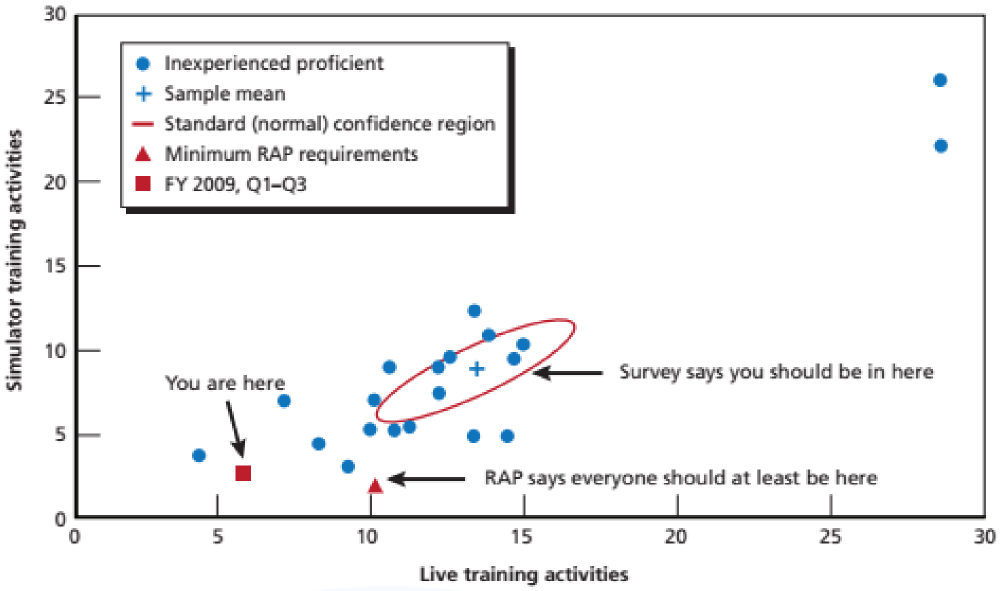
[6] Ibid., xii

[7] According to the USAF instruction, a pilot is considered experienced if he or she has flown at least 500 hours in their primary aircraft unless previously experienced (AFI 11-2F-22AV1, 69).

[8] John Ausink et al., *A Modeling Framework for Optimizing F-35A Strategic Basing Decisions to Meet Training Requirements,* RR1546 (Santa Monica, CA: RAND, 2016), 13

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.

Figure 5: F-22 Survey 2008
SOURCE: 2011 RAND Report: Investment Strategies for Improving Fifth-Generation Fighter Training, 13

The magenta square in Figure 3 above indicates that the actual accomplishment is far below what is minimally required (the magenta triangle). In other words, the pilots were only able to fly six of the ten sorties they were supposed to fly. This represents the aforementioned training gap. The blue dots represent the individual SME responses for what they considered the optimum training mix, and the blue plus symbol (+) denotes the mean. The magenta ellipse displays the 95-percent confidence region. If the actual flying average (magenta square) would fall within this region, the majority of the pilots should have received enough training. The left-lower corner of the ellipse represents the minimum requirement suggested by the SME's, or put differently, the minimum RAP according to the SMEs. In Figure 3, that point indicates that the suggested live training activities match what current RAP prescribes (points line up vertically). The number of simulator activities, however, is currently half of what is suggested. Table 1 shows the values of each point and the percentage of simulator training relative to the total number of events per year.

Table 1: F-22 Simulator Percentages

Data Point	Live Activity	Simulator Activity	Total Events	Percentage Simulator
RAP Current	120	26	146	18
SMEs Minimum	120	72	192	38
SMEs Optimum	156	108	264	41

SOURCE: 2011 RAND Report: Investment Strategies for Improving Fifth-Generation Fighter Training, 13

At the time Ausink et al. did their research, the F-35 RAP prescribed three simulator activities per month. In 2009, however, the F-22 RTRB changed this requirement to 26 simulator sorties per 12 months, slightly more than two per month.[9] The reason for this change is unknown, yet the downward trend ran counter to what the interviewed pilots proposed. Figure 4 plots the data form the 2008 survey for the F-15C.

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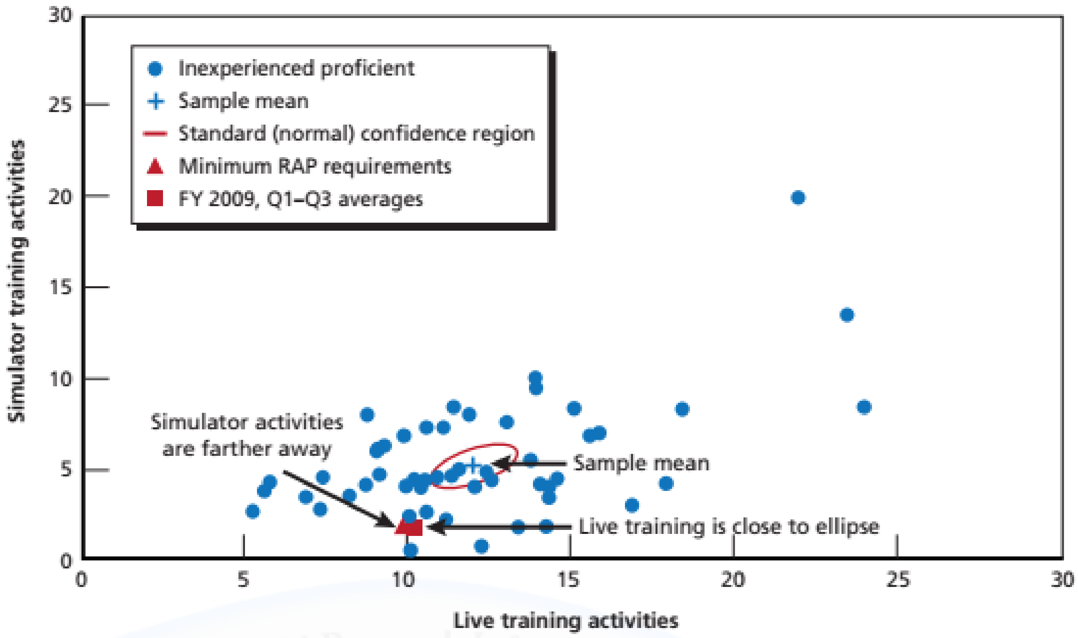
[9] John Ausink et al., *A Modeling Framework for Optimizing F-35A Strategic Basing Decisions to Meet Training Requirements,* RR1546 (Santa Monica, CA: RAND, 2016), xii

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.

Figure 6: F-15 Survey 2008
SOURCE: 2011 RAND Report: Investment Strategies for Improving Fifth-Generation Fighter Training, 17

The F-15C data show somewhat similar results when comparing the current RAP with the survey’s 95-percent ellipse: live-training RAP is close to what is suggested in the survey. The RAP minimum simulator activities for the F-15 were actually accomplished in 2009. As with the F-22, the F-15 SMEs suggested that the minimum simulator activities needed to more than double. The data are presented in Table 2.

Table 2: F-15C Simulator Percentages 2008

Data Point	Live Activity	Simulator Activity	Total Events	Percentage Simulator
RAP Current	120	26	146	18
SMEs Minimum	132	48	180	27
SMEs Optimum	144	60	204	29

SOURCE: 2011 RAND Report: Investment Strategies for Improving Fifth-Generation Fighter Training, 17

Comparing Table 1 and Table 2 reveals that the current RAP requirements to train in the simulator, determined by each aircraft type's RTRB, is the same for both airframes: 18 percent. The advised minimum and the optimum simulator training by the surveys, however, are about 40-percent higher for the F-22 compared to the F-15C. The significantly higher percentages highlights the different training needs between fourth- and fifth-generation fighters.

In the interviews for the 2008 study, the F-22 pilots virtually all raised the issue of not having enough red air. The limited numbers of F-22s necessitate fighting the air superiority battle in an outnumbered environment. The pilots, therefore, prefer to train few-versus-many scenarios to take advantage of their superior fifth-generation capabilities such as low observability and advanced radar techniques.[10] As there are only limited dissimilar assets to train against, F-22s must often provide red air themselves. To fly support missions with F-22s does not only reduce the overall opportunities to fly blue-air missions but also makes the training less effective. The F-22's low radar cross section (RCS)

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[10] John Ausink et al., *A Modeling Framework for Optimizing F-35A Strategic Basing Decisions to Meet Training Requirements,* RR1546 (Santa Monica, CA: RAND, 2016), 10

causes very late radar pick-ups, which makes the standard tactics much harder to execute. As a result, F-22 supervisors felt that the ACS facility in Marietta, Georgia, was more suitable for large air-to-air training missions than using their own airplanes for red air.[11]

In addition to having too few air opponents, fifth-generation fighters are designed to operate in hostile environments with complex integrated-air-defense systems (IADS) and advanced surface-to-air missile systems (SAMs). These systems are mostly unavailable to train against because they are very difficult to acquire, if at all. The absence of actual modern threat systems may become even more problematic for the F-35, as the airplane is specifically designed for Suppression of Enemy Air Defense (SEAD) missions.[12] Modern simulators, capable of distributed mission operations against programmable air and surface threats, that also operate on the actual aircraft's Operational Flight Program (OFP), can provide unrestricted high-end training, which is becoming increasingly harder to accomplish in the actual aircraft, and at a significantly lower cost compared to the alternatives.[13] Ausink et al. determined that to move some of the red-air intensive sorties to the simulated environment is five to ten times cheaper than to have dissimilar aircraft fly support missions.[14]

The 2008 survey also explored how F-22 pilots valued simulator training for each of the different mission types they are expected to execute. The data provides further insight into the mission

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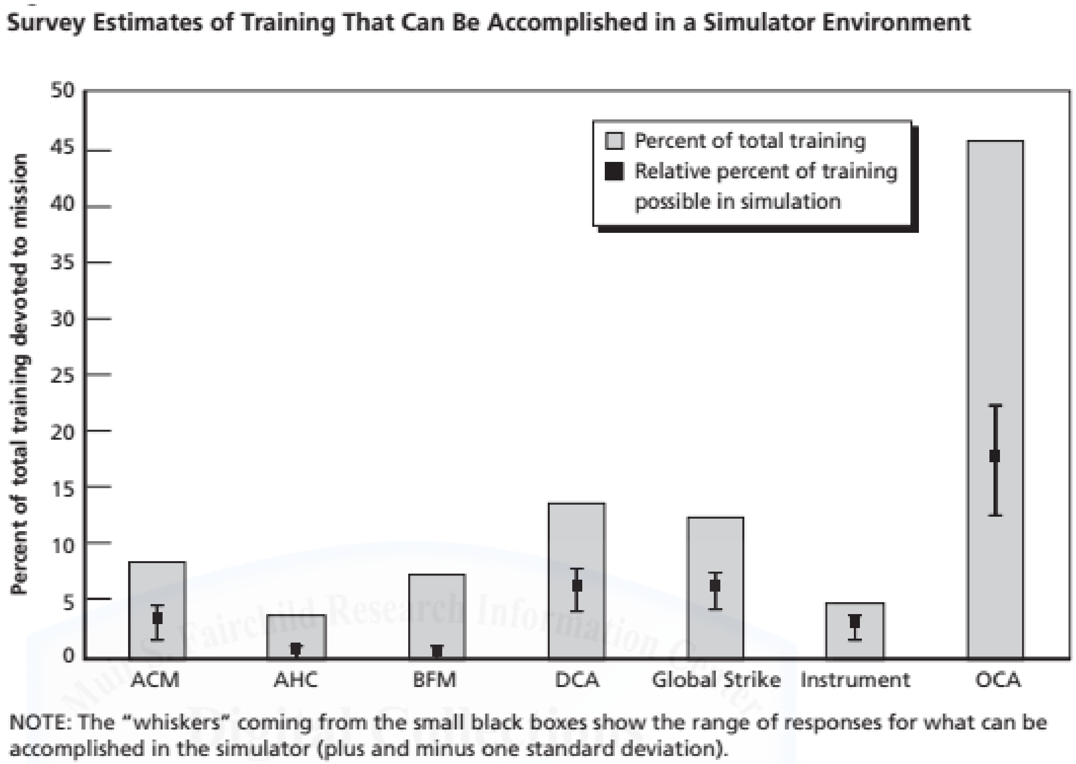
[11] Ibid., 11

[12] John Ausink et al., *A Modeling Framework for Optimizing F-35A Strategic Basing Decisions to Meet Training Requirements,* RR1546 (Santa Monica, CA: RAND, 2016), 11

[13] The simulator and the actual aircraft operate on the same software.

[14] John Ausink et al., *A Modeling Framework for Optimizing F-35A Strategic Basing Decisions to Meet Training Requirements,* RR1546 (Santa Monica, CA: RAND, 2016), 27

characteristics that make a sortie more suitable to transfer to the simulator. The results of this survey are presented in Figure 5.



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).

Figure 7: Simulator Suitability
SOURCE: 2011 RAND Report: Investment Strategies for Improving Fifth-Generation Fighter Training, 23

The vertical bars depict the relative importance of each mission. The DCA bar, for example, indicates that, according to the survey, about 14 percent of all F-22 training should be devoted to this mission set. About 50 percent of this training could be accomplished in the simulator as indicated by the position of the black box inside the bar. The relevance of this graph is that it indicates to what extent, according to the F-22 SMEs, the simulator is suitable to train certain mission types. Table 3 below shows both the percentage of total training as well as the percentage of training that is relatively suitable for simulation per mission type.

Table 3: F-22 Breakdown Per Sortie

Mission[15]	ACM	AHC	BFM	DCA	GS	INS	OCA[16]
Total Percentage of Simulation	9	4	8	14	13	5	47
Absolute Percentage[17]	3	1	0	7	7	3	19
Suitability Percentage	33	25	0	50	54	60	40
Suitability Ranking	5	6	7	3	2	1	4

SOURCE: 2011 RAND Report: Investment Strategies for Improving Fifth-Generation Fighter Training, 23.

Table 3 is significant as it indicates the missions that require more precise aircraft handling should not be trained in the simulator and must be practiced in the aircraft instead. Examples of such maneuvers are: low-speed, high-angle-of-attack (AOA) flight; high-G repositions during basic fighter maneuvers; and the dynamic portions of air-combat training. The table further shows that training missions that require optimizing aircraft sensors against advanced threats can be transferred to the simulator about half of the time. These missions combined, OCA, DCA, and Global Strike, cover about 70 percent of the total training. As such, the survey highlights that simulators have significant value in fifth-generation training.

Three conclusions can be drawn from the second RAND study. First, both F-15C and F-22 SMEs proposed to increase the use of simulators by 60 and 120 percent respectively than was required for

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[15] ACM: Air Combat Maneuvers; AHC: Advanced Handling Characteristics; BFM: Basic Fighter Maneuvers; DCA: Defensive Counter Air; GS: Global Strike; INS: Instrument Flying; OCA: Offensive Counter Air.

[16] OCA is the combined number of OCA Escort, Sweep, Destruction of Enemy Air Defense (DEAD), and Surface Attach Tactics (SAT).

[17] The absolute percentages of simulator training add up to 40 percent which represents the Optimum RAP percentage from figure X.

RAP. Second, simulator training is more suitable for fifth-generation aircraft compared to legacy fighters because they have a higher demand for more advanced threats, both air-to-air as well as surface-to-air. This conclusion is supported by the interviews of three squadron commanders of fifth-generation aircraft mentioned in a 2016 Government Accountability Office (GAO) audit report. All three commanders cited training limitations, such as airspace size, lack of advanced surface threat, and the unavailability of air threat. All affected training.[18] Third, the character of the mission determines if it is suitable to transfer to simulators. A simulator is not wellsuited to train dynamic missions in high-G environments and missions in which a "feel" for the aircraft is required. Training missions against advanced threats, both in numbers and in capabilities, are more suitable for transfer.

The third conclusion of the RAND study is not unique. In 2009, Alliger et al. came to a similar conclusion in their study *Defining the Training Mix: Sorties, Sims, and Distributed Mission Operations.* The authors analyzed data from 317 fighter and bomber responders and attempted to identify a range of practical, realistic options for live training and simulation.[19] In the surveys, the SMEs pointed out that "dynamic flight (decision making under 'G') and mission elements that require accurate visual representations of the real world" were reasons to identify missions that could be trained only in the aircraft.[20]

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[18] Government Accountability Office, *Report to Congressional Committees: Air Force Training, Further Analysis and Planning Needed to Improve Effectiveness,* GAO-16-864 (Washington, DC: Government Accountability Office, September 2016), 20

[19] George Alliger et al., "Defining the Training Mix – Sorties, Sims, and Distributed Mission Operations" *Interservice/Industry Training, Simulation, and Education Conference*, no. 9166 (2009), 3

[20] Ibid., 11

Besides training optimization, Alliger et al. stated there is another reason to document the amount and the type of training that cannot be transferred to the simulator. The authors cautioned that overly optimistic reports of simulator capabilities raise expectations of those outside the flying communities and perhaps create a false idea that there is a direct "one-for-one trade" between live and simulation.[21]

Ausink, Taylor, Bigelow, and Brancato reached the same conclusion in 2011. According to them, the Air Force needs to do a better job of validating training requirements in terms of live sorties in case it needs to respond to budgeting determinations that require training transfer. The authors argue that, without validated requirements, the risk associated with such decision cannot be quantified.[22] Interestingly, the need to quantify the training because of the threat of budget cuts was already brought up six years earlier by Bigelow et al. in 2003.[23]

2017 Report

A third study on simulator training was published in 2017 by Jacob Hammons. Hammons' research includes surveys conducted across Air Force Warfare Center SMEs, and he proposes a strategy to determine which training is best done or done only in live flight and which in simulators. Hammons argues in *Advanced Readiness 2025: Balance Investment Across Live, Virtual, and Constructive* that the Air Force needs to re-balance its LVC efforts. Pilots need more training in

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[21] George Alliger et al., "Defining the Training Mix – Sorties, Sims, and Distributed Mission Operations" *Interservice/Industry Training, Simulation, and Education Conference*, no. 9166 (2009), 12

[22] John Ausink et al., *A Modeling Framework for Optimizing F-35A Strategic Basing Decisions to Meet Training Requirements,* RR1546 (Santa Monica, CA: RAND, 2016), 61.

[23] James Bigelow et al., *Models of Operational Training in Fighter Squadrons,* MR-1701 (Santa Monica, CA: RAND, 2003), iii

the simulator to be ready for an Anti-Access/Area Denial scenario (A2/AD).[24] Hammons further asserts that the current USAF training infrastructure is not optimized to train for adversaries with advanced technology.[25] He suggests there is little quantitative data available to determine the right balance of L, V, and C, and, as a result, aircrew and operators who develop and support such training should have a crucial input. The surveys indeed reveal that current RAP training is regarded as inadequate for fighting in future A2/AD environments. The data is presented in table 4 below.

Table 4: AWC SME Survey 2017 A2/AD Scenario Per Year (LFE)

Data Point	Live Activity	Simulator Activity	Total Events	Percentage Simulator
A2/AD Current[26]	N/A	2.0	N/A	N/A
Experienced	7.4	4.6	12.0	38.3
Inexperienced	8.0	6.4	14.4	44.4

SOURCE: Hammons, 2008, 6

The SMEs polled by Hammons suggest the use of simulators for A2/AD training should more than triple for inexperienced pilots. This suggestion is remarkable because most of the SMEs rated current DMO capabilities marginally effective.[27] Many respondents would like to see even further increased realism in the simulator to include “the ability to

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[24] Jacob Hammons, “Advanced Readiness 2025: Balanced Investments Across Live, Virtual, and Constructive,” *Interservice/Industry Training, Simulation, and Education Conference*, no. 17241 (2017), 1
[25] Ibid., 2
[26] Live sorties were not stated
[27] Jacob Hammons, “Advanced Readiness 2025: Balanced Investments Across Live, Virtual, and Constructive,” *Interservice/Industry Training, Simulation, and Education Conference*, no. 17241 (2017), 8

degrade systems, better threat integration and threat models, and increased visual acuity."[28]

The percentages of simulator training for A2/AD missions suggested by the SMEs are similar to the 2008 survey which showed that between 40 and 50 percent of training that requires optimizing aircraft sensors against advanced threats could be trained in the simulator. More simulator training does not mean that live flight will become obsolete. Eighty-two percent of the respondents strongly agreed it is important to train in the actual system against live threats. The study consensus was that live training "in all cases be greater than 50 percent of training for every mission area surveyed."[29] Hammons included the following missions in the survey: basic fighter maneuvers, advanced combat maneuvers, close air support, basic surface attack, offensive counter air, and defensive counter air. Although fifth-generation desire advanced live training against the most modern air and surface threats, it will be hard to achieve in reality and is certainly more expensive than alternatives in a synthetic environment. The need to fight against advanced threats further validates the necessity for continuous investments in DMO.[30] Hammons' findings also confirm the 2008 RAND report conclusions to transfer missions to the simulator if the real environment is too restrictive, and not to do so for missions in high-G, dynamic environments.[31] Despite the apparent need for more simulation training, however, actual RAP requirements have stayed the same.

Audit

Based on an audit conducted from June 2015 to September 2016, the Government Accountability Office (GAO) concluded that the

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[28] Ibid., 8
[29] Ibid., 7
[30] Ibid., 11
[31] Ibid., 7

assumptions about the total annual live-fly sortie requirements and the mix between live and simulation did not change from 2012 to 2016 for the F-15, F-16, F-22, and the F-35. The 2016 GAO study reviewed the Air Force's training plans and requirements. The GAO study differs from the previous reports because the GAO is not tasked by the Air Force. The GAO reports to Congress to provide objective oversight regarding the spending of public funds, including those on the U.S. Air Force. The authors assert that the simulator requirement for each platform should be based on an extensive analysis of the platforms' different needs. Instead, the Air Force set the requirement for all aircraft at 36 based on the simulator capacity at Shaw Air Force Base, South Carolina, which could not support more simulator missions due to the high demand.[32] *The only exception is the F-35, for which the requirement is 48 simulator events per year. ACC officials could not explain, as mentioned in the report, why the F-22 did not also require an additional simulator event each month. The GAO concluded, therefore, that ACC had not "comprehensively assessed the assumptions underlying its annual training requirements" including the total requirements and the mix between live and simulator training.*[33] *Table 5 below shows the RTMs between 2012 and 2018 for the various aircraft.*

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[32] Government Accountability Office, *Report to Congressional Committees: Air Force Training, Further Analysis and Planning Needed to Improve Effectiveness,* GAO-16-864 (Washington, DC: Government Accountability Office, September 2016), 14

[33] Ibid., 21

Table 5: RTMs 2012-2018

Type	Year	Live	Sim	Total	% Sim
F-15C	2012-2018	108	36	144	25
F-15E	2012-2018	108	36	144	25
F-16 (1)	2012-2018	108	36	144	25
F-22	2012-2018	108	36	144	25
F-35	2013-2018	108	48	156	31

SOURCE: Various RTMs

Although the Air Force's procedure to establish RAP is a biannual event in which the Realistic Training Review Boards evaluate each platform's training requirements, Table 5 seems to confirm the GAO's notion that the underlying assumptions have not been reassessed. As such, the RTMs most likely are not aircraft-specific regarding simulator training.

Conclusion

The three studies and the GAO audit paint the following picture: First, simulation can train pilots in environments that are hard to create in real flight, especially for fifth-generation aircraft, which increases the need for training transfer. In the 2000 survey, the need for tactical training was not yet acknowledged. That conclusion should not be a surprise because the first MTCs were delivered in that year. Simulator technology has significantly improved since then to include DMO functionalities, which made possible a transfer of training from the aircraft to simulation. The second survey in 2008 first reflected these new simulator capabilities. The F-15 SMEs recommended a 60 percent increase in synthetic training, and the F-22 SMEs advocated more than double (120 percent) simulator use. Noticeably, of the total training, the fifth-generation aircraft subject matter experts suggested more simulator training than the for F-15C (27 percent vs 38 percent of total training).

Second, despite the need to determine the mix between live and simulation based on platform-specific needs, the current mix is set the same for the F-15, F-16, F-22, and the F-35 and did not change since 2012.[34] Twenty-five percent of total training is currently done in a simulator (31 percent for the F-35) which is significantly less than the surveys suggest it should be. Why the actual requirements do not differentiate between each platform and their missions is unknown.

Third, the character of the mission determines its suitability for transfer to simulators. The more dynamic missions that require a feel for the aircraft cannot be trained in the simulator, whereas training against advanced threats is more suitable for transfer. Half of the latter training can be transferred to the simulator, especially when the mission requires optimum sensor usage against advanced threats that are not available on the training ranges or in the air. This finding is confirmed in the 2016 GAO report. This report also emphasized that the use of advanced simulators in fifth-generation training was particularly important because of the limitations the live environment imposed on the use of advanced capabilities.[35]

The conclusion that dynamic missions are less suitable for transfer to simulation is reinforced by the scientific research described in Chapter 4. Both the surveys and scientific research point out that training for missions that involve within-visual-range maneuvering, high G-forces, or other forms of stress that are absent in simulators, substitution is not desired. Additionally, for other facets of training where substitution may be possible based on the flight characteristics, changes must be made

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[34] Except for one extra simulator per month for the F-35. Perhaps the numbers were similar in earlier years, but this study does not include RTM's from before 2012.

[35] Government Accountability Office, *Report to Congressional Committees: Air Force Training, Further Analysis and Planning Needed to Improve Effectiveness,* GAO-16-864 (Washington, DC: Government Accountability Office, September 2016), 6

with caution. Given the limited current understanding of the psychophysiological and hormonal responses for all the different phases of flight, radical changes should be avoided. Without such knowledge, abrupt changes may prevent pilots from learning critical skills needed for the actual fight. Any change, therefore, should be done incrementally to make a continuous assessment of pilot skills possible to keep their training up to standards. The next part develops a model that addresses which sorties are suitable for transfer.

Part III: Building a Model

Chapter 5

F-35 Training

This Chapter focuses on how both qualitative and quantitative research for F-22 pilot training can help define parameters for a transfer model that can apply to the F-35. First, the current training program will be discussed in more detail, as well as the status of the F-35 Full Mission Simulator (FMS). The Chapter examines the options and limitations to transfer training from live flight to the simulator. In addition, it incorporates recommendations and conclusions from the previous chapters.

Training Program

The latest F-35 RAP Tasking Memorandum for the fiscal year 2018 prioritizes training requirements based on current aircraft capabilities and divides training into primary and secondary categories based on the JSF Operational Requirements Document (ORD) and projected Component-Numbered Air Force (C-NAF) expectations.[1] The ORD specifies what the aircraft *can* do, and the C-NAF expectations dicatate what it *must* do. Additionally, the F-35 RTM contains basic requirements and what is defined here as extra sorties.[2] RAP defines the "*minimum* required mix of annual sorties, simulator missions, and training events pilots must accomplish to sustain combat mission readiness."[3] As

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[1] F-35A Ready Pilots Program (RAP) Tasking Memorandum, Aviation Schedule 2018, (AS-18), (Effective 01 Oct 17), 1; the numbers indicated are for inexperienced pilots.

[2] These are Red Air sorties, CC options, and Emergency Procedure sorties (simulated). CC Options are sorties assigned by the Squadron Commander to Primary/Secondary/Basic Skills missions to tailor training as they see fit.

[3] F-35A Ready Pilots Program (RAP) Tasking Memorandum, Aviation Schedule 2018, (AS-18), (Effective 01 Oct 17), 1.

indicated by the emphasis added in the F-35 RTM, the minimum requirements in Table 6 below represent the number of sorties by mission type needed to sustain combat readiness.

Table 6: F-35 RAP Tasking Memorandum

Mission[4]	Live	Sim	Total	% Sim
OCA-SEAD	20	12	32	38
AI/OCA-AO	14	9	23	39
CAS	12	7	19	37
Primary	46	28	74	38
OCA-ESCORT	6	2	8	25
DCA	7	4	11	36
SCAR	6	2	8	25
Secondary	19	8	27	30
TI	6	4	10	40
AHC	2		2	0
BSA	3		3	0
BFM	6		6	0
ACM	6		6	0
INS	4	2	6	33
Basic	16	2	18	11
CC OPTION	6		6	0
RED AIR	10		10	0
EP		6	6	100
Extra	16	6	22	100
TOTAL	108	48	156	31

SOURCE: F-35 RTM 2018

The F-35's main missions are more air-to-surface orientated compared to those of the F-22s, which focus almost exclusively on air-to-air combat. The F-35 and the F-22 are air platforms designed to complement each other. Currently, the secondary missions of the F-22, air interdiction and offensive counter air, are the primary missions of the F-35. The primary missions of the F-22, escort and defensive counter

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[4] SEAD: Suppression of Enemy Air Defense; AI: Air Interdiction; OCA-AO: Offensive Counterair-Attack Operations; CAS: Close Air Support; SCAR: Strike Coordination and Reconnaissance; TI: Tactical Intercept; BSA: Basic Surface Attack.

air, in contrast, are the secondary missions of the F-35.[5] For both aircraft, the more difficult scenarios either involve multiple advanced air opponents or advanced surface threats, such as offensive counter air and defensive counter air, currently take up between 35 and 40 percent of the total training. The quantitative research in Chapter 4 suggests up to 50 percent of these sorties can be trained in the simulator. Tactical intercepts (TI) are also very suitable to train in the simulator. These are training missions to practice basic air-to-air fundamentals: to maneuver an aircraft to intercept an opponent, for example, or to execute beyond visual range (BVR) tactics. Tactical intercepts are part of the basic missions described in Table 6. The rest of the basic missions, except instrument flight training, are not suitable to transfer to the simulator because they involve within-visual-range maneuvering, generate high-G forces, or require a "feel for the aircraft."[6]

The addition of close air support (CAS) and strike coordination and reconnaissance (SCAR) in the F-35 training program is a significant departure from F-22 training. CAS and SCAR encompass about 17 percent of the total training, one-third of which currently takes place in the simulator. CAS and SCAR missions are less suitable to train in the simulator because both require high levels of air-to-ground coordination and "looking out the window." Due to highly dynamic interaction with ground forces, pilots must spend much time to build situational awareness based on outside factors. To determine any suitability for substituting live flight for simulators, however, one must first closer examine the quality and capabilities of the F-35 FMS.

F-35 Simulator

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[5] Current F-22 RTM primary mission is OCA-Escort/Sweep and DCA, secondary is AI/OCA-AO

[6] See conclusion Chapter 5.

The Lockheed Martin F-35 Lightning II FMS provides a very realistic training environment according to a defense analyst for the website Flight Global. Currently, more than 50 percent of the *initial qualification* flights take place in the simulator since the F-35 does not have a dual-cockpit variant. New F-35 pilots require additional simulator training before they can make their first flight with an instructor who monitors their performance from a chase aircraft.[7] To provide realistic continuation training, the FMS is designed to provide a similar operating environment as do fully equipped training ranges.[8] Each simulator carries the most recent or operational flight program which gives the FMS characteristics similar to the capabilities and handling qualities of the aircraft. A 360° visual display incorporates the helmet-mounted display and the distributed aperture system (DAS) that contributes to the F-35 pilot's situational awareness.[9] Since the F-35 simulator, unlike older simulators, runs off the same Operational Flight Program as the actual aircraft, pilots can make unrestricted use of otherwise sensitive capabilities such as electronic warfare.

Future Concepts

Future training concepts with the FMS include building an international network of American and Allied simulators to participate in joint, combined distributed-training events from around the globe.[10] Currently, however, DMO connectivity does not exist for the F-35 FMS. The F-35 squadrons at Nellis Air Force Base, Nevada, will first have DMO capabilities in early 2020. Other bases are expected to follow suit. From

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[7] James Drew, "Analysis: Next-gen Simulation Preps F-35 Units for Battle," *Flightglobal* (15 February 2016): 1, https://flightglobal.com

[8] Ibid., 1

[9] Ibid., 1

[10] Ibid., 1

2020 onward, American F-35 pilots can expect to train their missions in a distributed environment.

It remains to be seen, however, if training in a virtual environment will also be possible with the F-35 partner nations in NATO. The European NATO nations face similar challenges regarding live training and exercises, and NATO acknowledges that distributed simulation presents a solution to them. Unfortunately, NATO does not have what is called MTDS (Mission Training through Distributed Simulation) capability.[11] NATO has mandated the use of High-Level Architecture (HLA) as the preferred one to make possible a multi-national network for broader distributed training. Currently, however, gateways and bridges are still required to support all the different simulation standards and versions. As such, a virtual, coalition, Flag-style exercise in a mature MTDS environment will occur only after a lengthy development process.[12] The US and most NATO members consider a fully functional LVC environment, the next step beyond DMO capabilities, to be an area for future growth. Because the analyses in Part II used surveys that included a functioning DMO capability, and the USAF is expecting F-35 DMO capability from 2020 onward, the next chapter analyzes the transfering training from the aircraft to the F-35 FMS *with DMO functionality.*[13]

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[11] Arjan Lemmers et al., “NATO Initiatives in Multi-National Mission Training through Distributed Simulation” *Interservice/Industry Training, Simulation, and Education Conference*, no. 17200 (2017), 1

[12] Ibid., 12

[13] Which is expected from 2020 and onward.

Chapter 6

A Transfer Model

This chapter builds on the previous sections and lays out a model that can be used to determine the live-simulation mix specifically for the F-35. After the model is applied to the current F-35 training program, Chapter 6 explains why the model should be used with caution.

Assumptions

The F-35 community worldwide is growing, but the airframe's manufacturer, Lockheed Martin, has not reached full-rate production yet. The F-35 training program was established only a few years ago and will most likely change over time as more and more pilots become experienced with the airplane and can better specify the training needs. Given that the training program is not mature yet, and the F-35 community is still comparatively small, it is no surprise that there are no specific F-35s surveys available that have addressed the effectiveness of simulator training. Given the absence of F-35 surveys, and some similarity between the F-35 and the F-22 described below, the F-22 surveys can be used instead to help define the training mix.

The F-22 and the F-35 are quite similar for several reasons. Both aircraft are fifth-generation airplanes, and their training requirements are similar. Pilots for both types of aircraft must fly primary, secondary, and basic missions to be mission qualified. The basic missions are identical for both. In the primary and secondary role, each type is required to fly offensive counter air and defensive counter air. The only difference is that the F-22 is more air-to-air orientated and the F-35 more air-to-ground. What the two further have in common is that the primary and secondary missions are high-end ones that require large amounts and advanced red support, both air-to-air and air-to-surface, and are therefore comparable regarding the suitability to train in simulators. The biggest difference between the two training programs, as already mentioned, is that the F-35 in its air-to-surface role has two specific missions the F-22 does not execute: close air support and strike coordination and reconnaissance. The model developed in this Chapter accounts for this difference. Given the many general similarities between the two airframes and the missions they must to execute, the transfer model assumes that the F-22 surveys are representative for the F-35 community as well.

The transfer model is built on a few other assumptions. First, the model assumes that a DMO capability exists in the F-35 FMS, although the simulator does not have it yet. All the quantitative data used to develop the model is based on having DMO capability, which is to be expected in the U.S. from 2020 onward when most other nations will not yet have declared an Initial Operational Capability (IOC). By the time the U.S. and the F-35 allied nations have fully matured F-35 programs, DMO should be an option around the globe. Second, the model is based on the training requirements of an inexperienced pilot with less than 500 hours because they need more training sorties than experienced pilots. Third, the model assumes that the total amount of training required in the current RTM is correct.[14] In other words, no additional sorties are added and no sorties are deleted. All that takes place is transfer from live flight to simulation.

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[14] Transfer of live flight to simulation decreases the necessity for red air. Any reduction in red air is added to CC option because a red sortie, although limited, does have some training value, for example airmanship.

Model

Based on the qualitative and quantitative analyses in part II and the assumptions mentioned above, the model developed here divides the F-35 missions in thee categories. The reason for limiting the categories is to prevent the model from becoming too complicated. Category 1 missions are those whose transfer is not advised but possible. This category contains most of the basic missions. Category 2 missions are those for which limited transfer is possible and can be beneficial under certain circumstances. This category specifically addresses the close-air support and strike-coordination-and-reconnaissance missions. In Category 3 missions, transfer is highly possible and advised to certain limits such as for the high-end, most-demanding missions. The three categories applied to the F-35 missions results are outlined in Table 7 below:

Table 7: Mission Categories

TYPE	PRIMARY			SECONDARY			BASIC					
MISSION	OCA SEAD	AI/ AO	CAS	OCA ESC	DCA	SCAR	TI	AHC	BSA	BFM	ACM	INS
CATEGORY	3	3	2	3	3	2	3	1	1	1	1	3

Next, to make the amount of transfer quantifiable, each category is given a percentage range for transfer. These percentages are based on a combination of both the qualitative and quantitative analyses in Part II. For the first category, between zero and 20 percent of the missions are transferable, a maximum of one-fifth of the training. This range corresponds with both the scientific research that suggests limiting transfer from dynamic training environments and the F-22 surveys displayed in Figure 5. In the second category between 20 and 35 percent can be transferred, a maximum of one-third. Given the F-22 does not train close air support and strike coordination and reconnaissance, the percentage of this category represents what is currently required in the F-35 RTM. In Category 3, between 35 and 50 percent can be transferred. Since many respondents agreed that no more than half of any training should be transferred, the model is limited to 50 percent.

Categories Applied

The mission categories in Table 7 can be combined with the F-35 assigned missions in the previous chapter. When the mission categories are overlaid on the F-35 minimum training requirements and adjusted for the maximum allowable percentages, the combined result indicates the transfer possible from live flight to the simulator as shown in Table 8 below:

Table 8: Maximum Transfer

	Current			
Mission[15]	Live	Sim	Category	Max
OCA-SEAD	20	12	3	4
AI/OCA-AO	14	9	3	2
CAS	12	7	2	0
OCA-ESCORT	6	2	3	2
DCA	7	4	3	1
SCAR	6	2	2	0
TI	6	4	3	1
AHC	2		1	0
BSA	3		1	0
BFM	6		1	0
ACM	6		1	0
INS	4	2	3	1
TOTAL				11

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[15] SEAD: Suppression of Enemy Air Defense; AI: Air Interdiction; OCA-AO: Offensive Counterair-Attack Operations; CAS: Close Air Support; SCAR: Strike Coordination and Reconnaissance; TI: Tactical Intercept; BSA: Basic Surface Attack.

The Maximum Transfer column in Table 8 indicates how many transfers are possible if maximum transfer is applied for each mission. For example, to change the live-simulation relation to fifty-fifty (Category 3 assumption) in the OCA-SEAD mission, a total of four sorties can transfer: from 20 live sorties versus 12 simulator missions to 16:16. Combined, Table 8 indicates 11 training events can be transferred to the simulator. The F-35 training program, in that case, could be modified as follows:

Table 9: F-35 Training with Maximum Transfer

	Maximum Transfer*			
Mission	Live	Sim	Total	Percentage
OCA-SEAD	16 (20)	16 (12)	32	50 (38)
AI/OCA-AO	12 (14)	11 (9)	23	48 (39)
CAS	12	7	19	37
Primary	40 (46)	34 (28)	74	46 (38)
OCA-ESCORT	4 (6)	4 (2)	8	50 (25)
DCA	6 (7)	5 (4)	11	45 (36)
SCAR	6	2	8	25
Secondary	16 (19)	11 (8)	27	41 (30)
TI	5 (6)	5 (4)	10	50 (40)
AHC	2		2	0
BSA	3		3	0
BFM	6		6	0
ACM	6		6	0
INS	3 (4)	3 (2)	6	50 (33)
Basic	25 (27)	8 (6)	33	24 (18)
CC OPTION**	8 (6)		8	0
RED AIR	8		8	0
EP		6	6	100
Extra	16	6	22	100
TOTAL	97 (108)	59 (48)	156	38 (31)

* The number in brackets represents the current RTM numbers
** The model assumes that per six sorties, one less Red Air is required

Table 9 indicates that if transfer is maximized according the different categories, both the primary and the secondary missions increase the total percentage of simulator training by about 10 percent. For the more demanding sorties in the higher end of the spectrum, transfer is indeed possible and is advised, based on the feedback from surveys in Chapter 4. In the second category, close-air support and strike coordination and reconnaissance, there are no changes to the live-simulator mix. Combined, the two already train one out of three missions in a virtual environment. In basic training, only tactical intercepts and instrument training are maximized. The other basic sorties are not transferable, based on their highly dynamic characteristics. The model assumes that the total training required is set correctly and does not change.[16] The only change is a shift from live to flight simulation.

For the F-35 training program in total, the simulator usage increases from around 30 percent to almost 40 percent. With the assumption that a pilot typically only can do one event per day, either in the simulator or an actual flight, it follows that transfer does not necessarily lead to a faster training cycle. What changes is that maximum transfer significantly decreases the required numbers of actual flight hours. Second, and more important, the transfer from live to simulation *should* be beneficial for overall training given the research results in Chapter 4. With the maximum transfer, there is also less live red-air support required. Less actual blue-air training logically lowers the requirements for red air. The model assumes a 1:6 ratio: one less support sortie per six transfers.[17] The two sorties that are "saved" with the maximum transfer are given back to the commanders to provide

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[16] If needed, one sortie could actually transfer from simulation to live to go from 37 to 31 percent in accordance with the proposed percentages per category.

[17] The same ratio is used in the current RTM.

additional training where they see fit. One important notion needs to be discussed in this regard.

Red-air *simulator support* is not included in the current F-35 RTM. When transfer increases, especially for the more demanding sorties, so does the demand for virtual red-air support. Perhaps these forces can all be constructed elements, but it is too soon to conclude, since the F-35 FMS is not DMO capable yet. It could very well be that, in case of maximum transfer, pilots also need to man red-air simulators. If pilots need to fly red air simulators, they may not have enough time available to fly the extra blue-air training sorties.

Benefits

The model suggests that the demand for actual flight hours decreases by 10 percent while simulator usage increases by almost 23 percent. A decrease in flight-hour demand can be beneficial in three different ways, all of which can have a strategic impact. First, if the total available F-35 flight hours annually produced remain the same, a decrease in required training hours means more hours are available to sustain combat operations. As training demand for flight hours decreases by 10 percent, available combat hours increase by 10 percent. An increase in combat hours means more aircraft can support current operations or aircraft can fly longer or more combat missions. Both options significantly increase a nation’s combat power without sacrificing pilot readiness back home.

Second, commanders can allocate unused F-35 training hours to train more pilots if these hours are not needed or used for combat operations. All things being equal, a 10-percent decrease in required live training means that for every ten pilots, a squadron can train one additional pilot. In other words, transferring training to simulators can, if fully implemented, lead to a 10-percent increase in the overall numbers of F-35 pilots. A ten percent increase in combat pilots is significant. For the USAF, this approach may not help solve the current pilot shortage, but for other F-35 nations that do not have a shortage, training transfer can increase those nation's combat potential.

What both options, increasing combat hours or training more pilots, have in common is that the savings resulting from transfer are reinvested in the F-35 program. Decisionmakers must reinvest financial benefits to create strategic benefits for the F-35.

Lastly, it is also an option *not* to produce more F-35 combat hours or to produce extra pilots. In that approach, training transfer can generate significant financial savings. Given the cost of actual flight hours are roughly ten times the cost of simulation, a transfer of 11 sorties to the simulator roughly equates to saving the cost of one flight hour. It is an understatement to say that fifth-generation aircraft are expensive to operate. One can assume the cost per flight hour is somewhere between USD 40,000 and USD 50,000 which results in a net savings of between five and seven hundred thousand dollars *per F-35 pilot per year* for an average sortie length of 1.3 hours.[18] Decisionmakers can choose to reallocate financial benefits from F-35 transfer in various manners. Whether strategic benefits can be gained from this approach depends on where decisionmakers decide to reinvest. Decisionmakers must realize that to create strategic advantages for the F-35, they must reinvest savings from transfer in the same program. Given the benefits discussed above, maximum transfer seems an easy choice to make. There are, however, some cautions that must be considered.

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[18] John Ausink et al., *A Modeling Framework for Optimizing F-35A Strategic Basing Decisions to Meet Training Requirements,* RR1546 (Santa Monica, CA: RAND, 2016), 25

Caution

Although the benefits of transfer seem significant enough to justify maximum transfer at the first possible opportunity, a few issues discussed in this thesis need further consideration. The first set of cautions has to do with limitations to the model. Although the model assumes that the F-35 simulators, like the ones for the F-22 and F-15 are DMO capable, the FMS is not - at least not yet. From 2020 and on, the FMS at different locations in the U.S. should begin to introduce distributed operation. Without DMO, the model cannot be applied to F-35 training requirements as it is based on having distributed operation capabilities. Additionally, the F-35 training requirements have not changed over the last few years. The requirements most likely did not change because the training program is not yet fully developed as the USAF F-35 is not IOC yet. Transfer of F-35 missions before the FMS has DMO capability and without a mature F-35 training program is not justified based on this model's assumptions. Once these two requirements are in place, training transfer could start.

A second limitation of the model is that it is partly built on subjective data. The qualitative studies in Chapter 4 concluded that subjective data is best used when supported by objective measures, as subjective reports are prone to biases and memory lapses. In the absence of objective data, military leaders have no other choice but to make their decisions on reports based on subjective data gathered from surveys, which may be unintentionally biased. Particularly, researchers found that some pilots in surveys tended to underestimate the actual level of mental workload and its impact on their performance. Scientists caution against models based on objective measurements alone. It is important to realize that part of this model is based on subjective inputs too. For Category 1 missions, both qualitative analysis and quantitative analysis in Chapters 3 and 4 support the argument that dynamic, high-G sorties, or other mission that require a feel for the aircraft should not be transferred or very limited. For Category 3 missions, however, the model is based only on surveys. As such, the model does not account for the consequences of psychophysiological or hormonal responses, or the effects of skill decay in training complex tasks. Given the limited scientific understanding in these areas, the model suggests transfer is possible based only on what SMEs *believe* to be the optimal use of simulators. As concluded in Chapter 4, without such knowledge, transfer from live flight to simulators may prevent pilots from learning critical skills. Category 3 missions are relatively more complex ones, so any transfer of skill in this category without verification and assessment might leave pilots ill prepared to execute difficult tasks when needed.

A third limitation of the model relates to supervision. The surveys used to develop the model did not originate from the F-35 community. Even though the F-22 is also a fifth-generation aircraft and its mission sets are somewhat similar, it is not the same airplane. Every aircraft has its unique mission, and each C-NAF's expectations are different. Therefore, each airplane should have a training program tailored to its mission. The F-35 pilot community is growing but it is still relatively small. As the number of F-35 pilots in the U.S. and partner nations increase, specific F-35 surveys will most likely become available. When they do, it is possible to develop a more accurate model based on F-35-specific needs. Most likely, there will be more scientific research done as well to support such a model. A combined approach, similar to the one suggested in this study, will provide the best data for the experts to ultimately decide on the proper mix.

The second caution concerns implementation of the model. The model suggests that maximum transfer has tactical and operational benefits (optimized training depending on the training needs) and strategic implications (more pilots, more combat hours, monetary savings, or a combination of the three). Maximum transfer to the simulator, however, may not be possible if the increased demand exceeds simulator capacity. Simulator demand is already higher for fifth-generation airplanes compared to legacy platforms. Currently, the F-35 minimum simulator training required without DMO is already higher than respondents suggested in the F-15 survey with DMO.[19] An increase in simulator usage of almost twenty-five percent as a result of maximum training transfer is quite significant. If the number of FMS cannot accommodate increased demand, more simulators must be acquired. Assuming FMS cannot be procured commercially or military off the shelf (COTS/MOTS), new simulators not only require additional investments but also take time to produce and build. As such, current simulator capacity might restrict the options for transfer of training until new simulators are delivered.

The last caution concerns the tempo at which transfer takes place. First, a fast transfer may not turn out to be as beneficial as decisionmakers may envision. The research on which the model is based suggests it is more prudent to take a slow approach. The qualitative research in Chapter 3 explains that although the gap between live flight and simulation closes, the two are not the same. Live flight is expected to trigger more psychophysiological responses than simulation. The effect of stress on the transfer of training skills from the simulator to the aircraft and the retention of these skills in a different environment are still largely unknown. To maximize simulator training in a short period, without a full understanding of all the relevant psychophysiological and hormonal responses to live flight, can lead to situations where pilots are ill-prepared to cope with real stress.

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[19] 31 versus 29 percent.

Second, once a training program gets shortened, for budgetary or other reasons, it may never return to its former size if the savings are reinvested elsewhere. In other words, once decision-makers choose for fast and maximum transfer, there is no guarantee that the training program can be restored if unforeseen negative consequences of transfer become apparent. Fear of irreversible decisions could explain why the RAP requirements over the years have been more conservative than the surveys. The key to aligning Air Force training lines of effort, therefore, "must come from an informed customer input; in this case, the aircrew and operators."[20] Informed inputs can be made only when the effects of a transfer on live performance are properly assessed. To be able to assess these effects properly, a more gradual approach is needed. A questionable approach would be a fast and maximum transfer of training to the simulator without taking the time to assess the consequences.

Risk Full Approach

The previous section describes limitations of the transfer model based on the qualitative and quantitative analyses in Chapters 3 and 4. Air forces should be very reluctant to start transfer without having DMO capabilities in place or without verifying that the existing infrastructure can sufficiently support an increased demand. Without DMO, the model is invalid, and, without enough capacity, transfer is impossible. Decisionmakers should be hesitant to transfer all applicable training missions simultaneously to the limits of the model without having an assessment procedure in place to monitor the consequences. The missions that are most suitable for transfer are the high-end missions which are inherently more difficult. The suitability of transfer for these

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[20] Jacob Hammons, "Advanced Readiness 2025: Balanced Investments Across Live, Virtual, and Constructive," *Interservice/Industry Training, Simulation, and Education Conference*, no. 17241 (2017), 3.

missions is based on subjective measurements only. Simulator training for challenging missions may not be as effective as SMEs suggested. Transferring these missions too fast may make assessment of the consequences difficult as well as making for a less controllable transition. If the savings generated by transfer are not reinvested in the F-35 enterprise, and instead locked in different programs, or worse, part of a desired budget cut, a subsequent correction to any overreliance on simulation may be impossible. Overrelying on simulators, without a solid procedure in place for checks and balances, may lead to a situation in which pilots are unable to execute the missions their respective nations need. An incremental approach to training transfer is more controllable and managable.

Incremental Approach

Transfer must be a deliberate process. Given the limited understanding of the psychophysiological and hormonal responses for all the different phases of flight, it is advised to learn through experience as suggested in Chapter 4. The effect of transfer on actual flight performance must take a central position in the discussion. A thorough and manageable transfer process takes time. The model developed in this thesis suggests that once the F-35 FMS is DMO-capable, a total of eleven training missions can be transferred. Transfer of these sorties results in a situation that F-35 pilots train almost forty percent of their total training requirements in a virtual environment. To transfer eleven missions responsibly, for example two per year, makes it possible to adequately assess the effects of transfer on live flight while retaining the option to correct when necessary. In general, making assessments may be easier after nations declare IOC because the F-35s community is then moving towards a full operational capability (FOC). The F-35 training program will be more mature then and more supervisors and other SMEs can voice their expert opinion.

Part IV: Conclusion

Chapter 7

A Gradual Approach

Today's advanced simulators allow pilots to train in scenarios they cannot practice in the actual aircraft. Simulators are also much cheaper to operate than real airplanes. As simulators have become more sophisticated, the gap between actual flying and training in the simulator is closing. This thesis explored the limits of the transfer from live flight to the use of simulators. To determine the training balance between flying the actual aircraft or spending time in the simulator this thesis finds that several factors need to be considered.

Currently, the training requirements, and with that, the current live-simulation mix, are determined by SMEs. Unfortunately, SME inputs are subjective. Research has shown that SMEs may unintentionally be biased and may not always provide an objective opinion. Experts prefer that subjective judgment is backed up by objective, measurable data. Not all the mental and physical stresses professional combat pilots must deal with every mission, however, can be objectively measured. Nor can they be replicated in simulators. G-forces, for example, introduce considerable stress on the body that cannot be reproduced in a virtual environment. Real fear of physical damage or loss of life, and the stresses it introduces, can also not be simulated. Differences between a simulator and live flight also influence the extent to which skills learned in simulator training can transfer to the real aircraft. In situations where the actual environment is very different from the synthetic world, training transfer could be negative. A pilot can experience certain stressful situations and develop skills to cope with the negative consequences of stress only in the actual aircraft.

To transfer too much training to the simulator without a full understanding of the psychophysiological and hormonal responses for all the different circumstances of live flight is unwise. An overreliance on simulator training for combat capability can lead to situations where a pilot is proficient enough in the simulator yet inept to perform the same task in real flight under stress. That is not to say, however, that transfer is not possible. It certainly is. The question becomes how much and how fast?

Simulator technology progressively closes the gap between live flight and a synthetic environment, yet the two will never be the same. If a training environment is substantially different in live flight than in a simulated environment, that mission must be trained in the real aircraft. Most of the basic flying skills, except for instrument flying, are dynamic and require a feel for the aircraft. BFM and ACM training, for example, should be exclusively trained in the real aircraft. Other missions, however, are quite suitable to transfer to simulation. Several restrictions put on live training, such as airspace restrictions and limited availability of advanced opposing forces, make high-end training very attractive to transfer to the simulator. F-15 and F-22 surveys in which SMEs responded to questions about the use of simulation concluded that they preferred more simulator training in certain areas compared to what was required for RAP training.

In this thesis, the author developed a model based on both scientific research as well as the SME surveys. Applied to the current F-35 training program, the model suggests further training transfer seems possible. A prerequisite for transfer, however, is that F-35 simulators obtain DMO capability. After that, if decisionmakers determine to do so, training transfer must be done gradually. A sudden maximum transfer may turn out not to be a quick win, even if an overcapacity of simulators exists. It may look financially attractive to transfer as much and fast as possible, but experts still do not fully understand how all the mental and psychophysiological factors play a role in the transfer of training. Transferring missions too fast may make assessment of the consequences difficult and contribute to a less-controllable transition. If the savings generated by transfer are not reinvested in the F-35 enterprise, a subsequent correction to the training requirements may be impossible. Overreliance on simulators without a solid procedure in place for checks and balances may lead to a situation in which pilots are unable to execute the missions their respective nations need. A more prudent approach is to gradually transfer training and then to reassess. By the time the FMS has DMO capabilities, the F-35 community should be large enough globally to make such assessment possible. A gradual approach would require two things. First, the SMEs involved would have to be aware of their inherent biases and judge as objectively as possible, and second, policymakers should set financial determinism aside and trust these SMEs to act in the best interest of their nation. A gradual approach to transfer has the benefit of providing motivated and trained airmen for the Air Force without running the risk of being incapable to execute the real fight from over-reliance on simulators that are fundamentally different than airplanes. A gradual approach also keeps the ultimate decision and transfer management regarding live-simulator mix with those in charge of the daily execution of the F-35 training program.

Recommendations

The United States Air Force and its allied partners should continue to invest in the following six areas:

1. Ensure continued funding for DMO capabilities. DMO makes virtual scenarios possible in a joint, combined environment against highly capable threat systems which may not be possible in live exercises;

2. Promote continued research into psychophysiological factors, tress, and skill retention that play a role in pilot training in live and virtual environments;
3. Continue investments in Live, Virtual, and Constructive technology to expand future training possibilities;
4. As the F-35 community grows, continue to conduct surveys that specifically address the subject of simulated training and continue to use this data, complemented by scientific research, to be best informed on the optimum mix;
5. Promote research into the consequences of transferring training on the F-35 supply chain and logistics support; and
6. Promote research into the capacity of the current simulator infrastructure.

Today's advanced simulators can create realistic training environments that allow pilots to train missions that are difficult, if not impossible, to practice in live flight. Transferring to simulators is not only possible but can even improve overall training efficiency. Doing so, however, needs to be done with caution. If done in a slow and responsible manner, with generated savings reinvested in the F-35 program, strategic advantages can be gained. Transferring missions quickly with only an eye on the financial benefits, may achieve the opposite effect where pilots, although well-trained in simulation, are unable to execute live missions when called upon, leading to losses and potential strategic failure.

LIST OF ABBREVIATIONS

ACC	Air Combat Command
ACM	Air Combat Maneuvers
AETC	Air Education and Training Command
AFI	Air Force Instruction
AFRL	Air Force Research Laboratory
ALIS	Autonomic Logistics Information System
BFM	Basic Fighter Maneuvers
CAS	Close Air Support
CT	Continuation Training
CAS	Close Air Support
COTS	Commercial Off the Shelf
DAS	Distributed Aperture System
DCA	Defensive Counter Air
DMO	Distributed Mission Operations
DMT	Distributed Mission Trainer
FMS	Full Mission Simulator
FOC	Full Operational Capability
GAO	Government Accountability Office
HLA	High-Level Architecture
IADS	Integrated Air Defense System
IOC	Initial Operational Capability
LFE	Large Force Employment
LVC	Live, Virtual, and Constructive
MOTS	Military Off the Shelf
MTDS	Mission Training through Distributed Simulation
MTT	Multi-Task Trainer
NAF	Numbered Air Force
OCA	Offensive Counter Air
OFP	Operational Flight Program
ORD	Operational Requirements Document
RAP	Ready Aircrew Planning
RCS	Radar Cross Section
RTM	RAP Tasking Memorandum
RTRB	Realistic Training Review Board
SAAC	Simulator for Air-to-Air Combat
SAM	Surface-to-Air Missile
SCAR	Strike Coordination and Reconnaissance
SEAD	Suppression of Enemy Air Defense
UTD	Unit Training Device
VR	Virtual Reality
WST	Weapon System Trainer
WTT	Weapon Task Trainer

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