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Optimizing adversary training and the structure of the Navy adversary fleet

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THESIS

OPTIMIZING ADVERSARY TRAINING AND THE STRUCTURE OF THE NAVY ADVERSARY FLEET

by

J. Ryan McLaughlin

September 2013

Thesis Co-Advisors: Robert F. Dell
W. Matthew Carlyle

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Simulation of threat aircraft tactics and capabilities during training is an integral component of maintaining the combat readiness of the United States Navy. A dedicated adversary air force supports the majority of adversary training missions, but these airframes are aging and lack the sortie generation capacity and the performance capabilities to completely satisfy the training requirements. The Navy currently uses other opposition forces to fill the gap between the adversary air force capacity and the demand for training. This training *gap* will grow over the next decade as current airframes reach their flight hour limits, and as resources become scarcer, the task of determining efficient assignment of these resources becomes more difficult for planners and the resulting solutions are more expensive than necessary. This thesis presents the Adversary Sortie Optimization Tool, which uses an integer-linear program to optimize the assignment of adversary air sorties to meet the annual fleet training demands over a 20-year planning horizon, and prescribes yearly upgrades to the adversary air force, including procurement of performance enhancing aircraft pods, improved radar, new aircraft, and system upgrades. Solutions provide a reduction in operating costs of hundreds of millions of dollars using efficient sortie assignment, aircraft and system upgrades, and managing the home base location of aircraft. These savings are achieved while also improving the quality of training and saving valuable hours on fleet aircraft.

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OPTIMIZING ADVERSARY TRAINING AND THE STRUCTURE OF THE NAVY ADVERSARY FLEET

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ABSTRACT

Simulation of threat aircraft tactics and capabilities during training is an integral component of maintaining the combat readiness of the United States Navy. A dedicated adversary air force supports the majority of adversary training missions, but these airframes are aging and lack the sortie generation capacity and the performance capabilities to completely satisfy the training requirements. The Navy currently uses other opposition forces to fill the gap between the adversary air force capacity and the demand for training. This training *gap* will grow over the next decade as current airframes reach their flight hour limits, and as resources become scarcer, the task of determining efficient assignment of these resources becomes more difficult for planners and the resulting solutions are more expensive than necessary. This thesis presents the Adversary Sortie Optimization Tool, which uses an integer-linear program to optimize the assignment of adversary air sorties to meet the annual fleet training demands over a 20-year planning horizon, and prescribes yearly upgrades to the adversary air force, including procurement of performance enhancing aircraft pods, improved radar, new aircraft, and system upgrades. Solutions provide a reduction in operating costs of hundreds of millions of dollars using efficient sortie assignment, aircraft and system upgrades, and managing the home base location of aircraft. These savings are achieved while also improving the quality of training and saving valuable hours on fleet aircraft.

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LIST OF ACRONYMS AND ABBREVIATIONS

ADSOT	Adversary Sortie Optimization Tool
ADFOR	Adversary Forces
AESA	Actively Electronically Scanned Array
ATAC	Airborne Tactical Advantage Company
BFM	Basic Fighter Maneuvering
CAS	Contracted Air Services
CAPT	Captain
CBA	Capabilities Based Assessment
CNA	Center for Naval Analysis
CNAF	Commander of Naval Air Forces
COMPTUEX	Composite Training Unit Exercise
CTX	Composite Training Unit Exercise
CPH	Cost Per Flight Hour
CVW Fallon	Air Wing Fallon
DRFM	Digital Radio Frequency Memory
DRRS-N	Department of Defense Readiness Reporting System - Navy
EA	Electronic Attack
FRS	Fleet Replacement Squadron
FRTP	Fleet Response Training Plan
FWT	Fighter Weapons and Tactics
GAMS	Generalized Algebraic Modeling System
HOBS	High Off Boresight
IRST	Infrared Search and Track
JHMCS	Joint Helmet Mounted Cueing System
JSF	Joint Strike Fighter
JTFEX	Joint Task Force Exercise
LVC	Live, Virtual, Constructive
MiG	Mikoyan
NSAWC	Naval Strike and Air Warfare Center
OPFOR	Opposition Forces

POR	Program of Record
RC	Reserve Component
SFARP	Strike Fighter Advanced Readiness Program
SFTI	Strike Fighter Tactics Instructor
SFWT	Strike Fighter Weapons and Tactics
SLEP	Service Life Extension Program
SME	Subject Matter Expert
T&R	Training and Readiness
TSW	Tactical Support Wing
UAV	Unmanned Air Vehicle
ULT	Unit Level Training
WVR	Within Visual Range

EXECUTIVE SUMMARY

Simulation of threat aircraft tactics and capabilities during training is an integral component of maintaining the combat readiness of the United States (U.S.) Navy. *Red air* is the generic term for any aircraft and aircrew combination performing this mission. A dedicated adversary air force (ADFOR), consisting of the F-5 Tiger II, the F/A-18 Hornet, and the F-16 Falcon, supports the majority of *red air* missions. These airframes are aging and lack the sortie generation capacity and the performance capabilities to completely satisfy training requirements. The U.S. Navy currently uses other opposition forces (OPFOR), such as contracted air services (CAS), or fleet aircraft flying in the adversary role, to fill the gap between the ADFOR capacity and the demand for training. This training *gap* will grow over the next decade as current airframes reach their flight hour limits.

The biggest demand for adversary training events comes from the requirement to generate and maintain the readiness of fleet strike-fighter squadrons. The Fleet Response Training Plan (FRTP) provides the overarching guidance regarding the training and readiness for naval forces. Different training phases, as delineated in the FRTP, have corresponding training requirements that may call for the use of adversary aircraft. The total adversary training requirement is a combination of required training events from different training phases, where a training *event* consists of a single adversary aircraft performing the *red air* mission. Each training event demands different *red air* presentations that stress various training objectives. Often, training requires the combination of multiple adversary aircraft with different capabilities (multiple adversary events).

This thesis presents the Adversary Sortie Optimization Tool (ADSOT), which uses an integer-linear program to optimize the assignment of *red air* sorties, for various opposition force platforms, to meet the annual fleet training demands over a 20-year planning horizon. OPFOR platform options include ADFOR aircraft, CAS aircraft, or fleet aircraft flying the adversary role (commonly referred to as *organic red air*). For a given procurement budget, ADSOT prescribes yearly upgrades specific to the ADFOR,

including procurement of performance enhancing aircraft pods, improved radar, new aircraft and system upgrades. ADSOT minimizes the operating cost and capability shortfall to provide an optimal yearly training plan over a 20-year planning horizon. We use a training utility value to capture the quality of a particular solution as the percentage of the training objective met by prescribed OPFOR aircraft. ADSOT imposes constraints that annually constrain and/or manage budgets, flight hours, aircraft inventory, CAS contract limits, and aircraft home base locations. Output includes OPFOR yearly aircraft sortie assignment, projected yearly costs, projected yearly flight hour expenditure, and aggregated yearly training utility delivered.

All ADSOT analysis uses input gathered from multiple fleet sources and is the result of extensive coordination with several subject matter experts. Analysis of a base case derived from current resources and requirement verifies that the model effectively approximates the current use of OPFOR sorties to meet training requirements. ADSOT excursions allow for various increases in procurement funding (*injects*). These show that procurement in the near term will result in improved training utility values, while lowering both operating costs and the number of *red air* sorties flown by fleet aircraft. For a $300 million procurement inject, ADSOT sortie prescription increases overall training utility by as much as seven percent, decreased operating costs by $490 million over 20 years, and predicted a savings of over 250,000 flight hours on fleet aircraft.

One ADSOT excursion considered the relaxation of ADFOR flight hour restrictions, aircraft base location, and planned procurement. ADSOT achieved significant savings in both total flight hours and operating cost. Over the 20-year planning horizon the fleet flight hour savings is over 100,000 hours and the operating cost savings is $720 million. This was achieved while improving in training utility by up to six percent during some early years, and only minimally degrading training utility over some later years.

Additional ADSOT excursions consider more advanced training requirements and investments into live, virtual, constructive (LVC) training ranges. LVC ranges incorporate simulation technologies and computer generated adversaries into training to decrease the actual live adversary aircraft requirement. In the case of more advanced training requirements, the current OPFOR platforms have difficulty achieving an overall training utility value greater than 70 percent. Even with an investment of $300 million the highest training utility achieved over any given year throughout the 20-year planning horizon is 79 percent. A hypothetical LVC range is modeled with limited fidelity to improve performance of ADFOR aircraft when using the range. Results indicated that improvements in training utility by over 10 percent annually over the base case are possible. This improvement in training is also marked by a concurrent decrease in total operating cost by $1.7 billion dollars, and decrease in total fleet flight hour expenditure by 194,000 hours over the 20-year planning horizon.

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I. INTRODUCTION

Simulation of threat aircraft tactics and capabilities during training is an integral component of maintaining the combat readiness of the United States (U.S.) Navy. *Red air* is the generic term for any aircraft and aircrew combination performing this mission. The U.S. Navy uses a dedicated adversary air force (ADFOR), consisting predominately of the F-5 Tiger II, to support the majority of *red air* missions. The F-5 is an aging platform that lacks capability when compared with the fleet's modern, more technologically advanced aircraft. The ADFOR also operates some newer aircraft in limited numbers, including the F/A-18 Hornet and F-16 Falcon, but still cannot meet the training demands of the fleet. The forecast is for this training *gap* to grow over the next decade as current airframes reach their flight hour limits. The U.S. Navy currently uses other opposition forces (OPFOR), such as contracted air services (CAS), or fleet aircraft flying in the adversary role (commonly referred to as *organic red air*), to fill the gap.

This thesis presents the Adversary Sortie Optimization Tool (ADSOT), which uses an integer-linear program to optimize the assignment of *red air* sorties, for various OPFOR platforms, to meet the fleet training demands over a 20-year planning horizon. OPFOR platform options include ADFOR aircraft, CAS aircraft, or *organic red air*. ADSOT allows for upgrades specific to the ADFOR, including procurement of performance enhancing aircraft pods, improved radar, new aircraft and system upgrades. As an analytical tool ADSOT provides the ability to conduct analysis of multiple aspects regarding how the Navy conducts adversary training. This thesis focuses on the effects of different procurement dollar increases, or *injects*, into the system. Additional excursions consider the effects of changing the requirements and the potential impact of upgrading training ranges to incorporate the live, virtual, constructive (LVC) concept. LVC ranges incorporate simulation technologies and computer generated adversaries into training to decrease the actual live adversary aircraft requirement (CDR R. Van Diepen, OPNAV Simulator Requirements Officer, personal communication, June, 2013).

A. TRAINING REQUIREMENT

Requirements for *red air* missions span many different platforms in the naval service and require adversaries with different capabilities. Front line, fleet fighter pilots engage in basic fighter maneuvering (BFM) training in preparation for actual air-to-air combat. Other aviation platforms, such as the EA-6B “Prowler” and the H-60 “Seahawk” perform defensive maneuver training against adversary aircraft. Surface combatants, such as destroyers and cruisers, require training against adversary aircraft in order to hone their anti-air capabilities. Adversaries can also be used to simulate incoming missiles to test fleet defensive capabilities. In the future, new platforms, such as the F-35 Joint Strike Fighter (JSF) (see Figure 1) will also require adversary support.

The total adversary training requirement is a combination of required training events from different training phases, where a training *event* consists of a single adversary aircraft performing the *red air* mission. Each training event demands different *red air* presentations that stress various training objectives. Often, training requires the combination of multiple adversary aircraft with different capabilities (multiple adversary events).

Figure 1. JSF F-35C in flight over the Atlantic Test Ranges. Future platforms such as the F-35C will require adversary training into the latter half of the twenty-first century (From Naval Air Systems Command, 2011a).

The biggest demand for adversary training events (and the focus of this thesis) comes from the requirement to generate and maintain the readiness of fleet strike-fighter squadrons. The Fleet Response Training Plan (FRTP) provides the overarching guidance regarding the training and readiness (T&R) for naval forces. Different training phases, as delineated in the FRTP, have corresponding training requirements that may call for adversary aircraft. Different training requirements for each phase can be further broken down into core and non-core events. Core events require standardized, professional adversary support, from appropriately qualified OPFOR, and include training in conjunction with the following (Naval Strike and Air Warfare Center, 2012):

- Strike-fighter advanced readiness program (SFARP);
- Carrier air wing training (CVW Fallon);
- Strike-fighter tactics instructor (SFTI) course (TOPGUN); and
- Fleet replacement squadron (FRS) fighter weapons and tactics (FWT) phase.

Both SFARP and CVW Fallon are training phases, approximately a month long, that an entire squadron or airwing, respectively, completes as a unit. SFTI and FRS are both individual orientated training. Each aircrew must complete the FRS before joining an operational squadron; it is the basic level of strike-fighter training. SFTI is the most advanced level of strike fighter training. Otherwise known as TOPGUN, SFTI is a school where a select few, seasoned naval aviators attend to become subject matter experts (SMEs) in the art of strike-fighter tactics and execution.

Non-core events are other training events that do not require professional adversary support. Examples of non-core events include, but are not limited to:

- Strike-fighter weapons and tactics (SFWT) sorties;
- Joint task force exercise (JTFEX);
- Composite training unit exercise (COMPTUEX); and
- Unit level training (ULT) sorties.

JTFEX and COMPTUEX are training phases similar to SFARP and CVW Fallon, however the syllabi are not as stringently defined as that of the core events. SFWT events consist of an individual aircrew executing a structured syllabus to progress through different qualifications. SFWT events can be completed in conjunction with other training events. For example, during an SFARP syllabus flight a pilot can also get credit for an SFWT event.

ULT events are unique in that they are often not delineated as a set syllabus with well-structured events. ULT events are flights flown in addition to all the other training in order to maintain specified T&R readiness levels. T&R credit is the common term for the amount of readiness credit an aircrew receives for performing a specific sortie. This depends on multiple factors, such as sortie type, whether or not the flight occurred at night, or if the flight was against professional adversaries or not. An aircrew accrues some T&R credit for every flight regardless of what training phase they are participating in at the time. Most T&R readiness requirements are satisfied while conducting other core and non-core training events. ULT events are additional flights required to satisfy any T&R readiness requirements that were not satisfied.

Commander of Naval Air Forces (CNAF) maintains the capabilities-based T&R matrix, which provides specific details regarding the strike-fighter aircrew training requirement. The T&R matrix is a tool developed to support the Department of Defense Readiness Reporting System—Navy (DRRS-N) by providing information regarding how many, and how often, each type of training event is required (Commander Naval Air Forces, 2012). Figure 2 shows an excerpt of the current T&R matrix for the F/A-18-18C.

The T&R matrix is unique for each aircraft type. It prescribes tasks and skills, which must be completed within a given periodicity to support different T&R levels. The "O" and "R" corresponds to whether or not a skill is "optional" or "required" for each task. For example, for a pilot to be considered "ready" in the skill of "Counter EA" (next to last column), they must perform the skill a minimum of four times every 365 days. The have the option of performing the skill during either a AAW 110, "Counter EA (Electronic Attack)" task and or the AAW 210 "Counter Advanced EA" task (Note that this example only addresses fields shown in this excerpt from Figure 2.) The T&R matrix also details different qualifications and events that a minimum number of aircrew of each squadron must complete, as shown in the additional excerpt of the T&R matrix (see Figure 3). The column designations correspond to different qualifications that either individuals or the squadron must complete. For example, in the case of the "L3 pilots," the squadron must have a minimum of seven to be considered "ready." In the case of the squadron assessments (last two columns), the squadron, as a whole, must complete (denoted as "SAT").

VFA F/A-18C 21 JAN 2011		Defensive Considerations (A/A)	Section A/A Employment	Division A/A Employment	Defensive Counter Air (DCA)	Offensive Counter Air (OCA)	Perch BFM	High Aspect BFM	Counter EA	CSAR / RESCORT / RESCAP
	Flight Periodicity	60	270	270	270	270	360	270	365	540
	# Required for Pilot	2	6	6	6	6	4	1	4	1
STW 112	**SELF-ESCORT STRIKE**	O								
AAW 105	**BFM-DISSIMILAR**									
AAW 106	**BFM-2vX**									
AAW 107	**TACINT**	O								
AAW 309	**INTERCEPT AND ESCORT**				O					
AAW 110	**COUNTER EA**	O							R	
AAW 210	**COUNTER ADVANCED EA**								O	
AAW 111	**HIGH / VERY HIGH FAST FLIER**									
AAW 112	**MSI**									
AAW 113	**RED AIR**	O								

Figure 2. Excerpt of the F/A-18C T&R matrix promulgated by CNAF. Columns include different aircrew skills. Rows correspond to different T&R tasks, generally speaking, aircrew log one task per sortie. Not all tasks and skills are shown (After Commander of Naval Air Forces, 2011)

The Marine Corps also requires adversary support that they provide primarily by their own dedicated ADFOR, a single squadron of F-5s that operate out of Yuma, Arizona. For the Marine Corps units that are integrated into Navy air wings, they progress through the FRTP as a Navy squadron, subject to the same Navy requirements. For this thesis, the specific Marine Corps adversary requirements, and ADFOR capabilities, are not addressed directly. The requirements for Marine Corps units that are integrated into Navy air wings are included.

≥ L4 Pilots	≥ L3 Pilots	≥ L2 Pilots	≥ L1 Pilots	NVG Qual	JMPS SME	CVW STK LEAD	CVW FALLON (NMETL-BASED ASSESSMENT) (Note 6)	COMPTUEX (NMETL-BASED ASSESSMENT) (Note 7)
ACTC Quals								
5	7	12	15	12		3	SAT	SAT

Figure 3. Excerpt of the F/A-18C T&R matrix promulgated by CNAF (2011). Columns include different individual and squadron qualifications required. The row indicates either the minimum number of squadron aircrew required to complete or a "SAT" indicating the squadron must complete as a whole.

B. ADVERSARY GAP

The requirement for adversary training is difficult to quantify because of the diversity of demands requiring different training, however, it is abundantly clear that the fleet demand for adversary training exceeds the sortie capacity of the ADFOR. The Center for Naval Analysis (CNA) estimates the total number of annual adversary training events at 38,000 (Huntzinger, Grund, & Luen, 2011). With the addition of the JSF, and an increasing inventory of EA-18 Growlers to the U.S. Navy inventory, the requirements are expected to increase.

In a more recent study, the commander for the Tactical Support Wing (TSW) responsible for the airframes and aircrew that make up the ADFOR, Captain (CAPT) Nichols (2012), estimates the demand for adversary training events at 33,933 events annually (see Table 1). By all estimates, the requirement for adversary training is significantly higher than the computed ADFOR annual capacity of 16,093 sorties (including CAS aircraft). The capacity assumes that each adversary aircraft flies an average of 327.6 hours per year and the average length of each sortie is 1.18 hours (Nichols, 2012).

Training Demand		ADFOR Capacity	
Source	Events Required	ADFOR aircraft	Maximum Sorties
FRS	7,409	F-5 Tiger II	7,793
SFARP	5,080	F/A-18 A-D Hornet	4,900
CVW NFL	1,576	F/A-18 E/F Super Hornet	850
SFTI	2,864	F-16 Viper	1,850
SFWT	9,406	CAS type IV	700
OVHD	6,500		
CSG	1,098		
Total	33,933	Total	16,093

Table 1. Demand for annual training compared to ADFOR sortie capacity by aircraft type as estimated by the TSW. Both core and non-core events are included. This assumes no double cycle capability from the ADFOR for capacity calculations. Also, note that CAS type IV support is included in capacity calculations (After Nichols, 2012).

In some cases, adversary aircraft can satisfy the requirement for multiple events through a practice commonly referred to as *double cycling*. Double cycling is the practice of an adversary aircraft remaining airborne long enough to provide training for two separate blue force waves. The result is longer sortie lengths but the ability to meet the demand for multiple training events. Even considering an optimistic double cycle capability of 33 percent of the total events, the capacity gap between the demand for training and the number of sorties that the ADFOR can provide is still significant at $33{,}933-(1.33*16093)\approx 12{,}500$ sorties.

ADFOR sortie capacity depends on an aging inventory of ADFOR aircraft. Figure 4 depicts the past and projected inventory of ADFOR from 2008 through 2029, including aircraft operated by the Naval Strike and Air Warfare Center (NSAWC), and the reserve component (RC). The current inventory of F-16 A/B and F-5 N/F will decrease starting in the end of 2013, increasing the ADFOR capacity (Nichols, 2012).

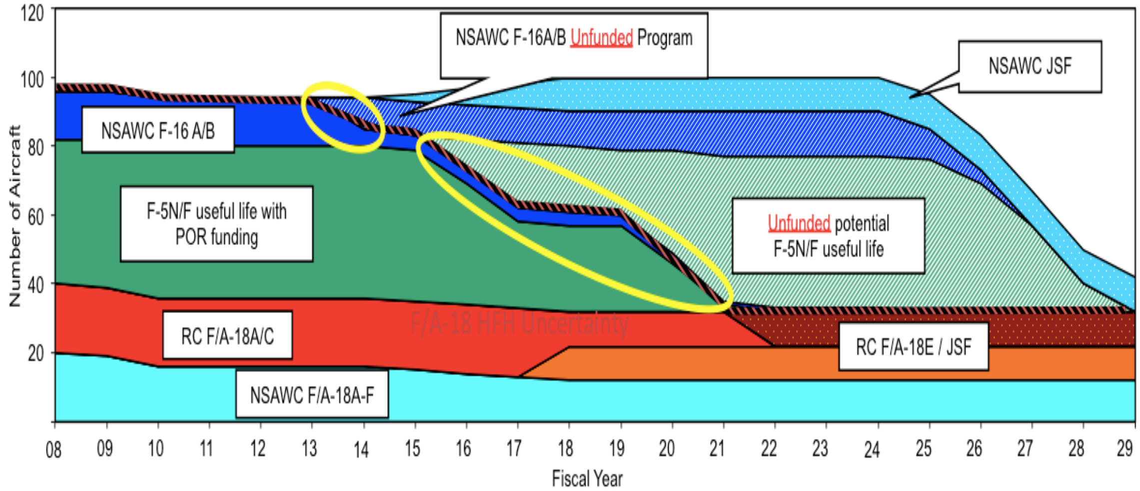

Figure 4. ADFOR projected aircraft inventory levels from 2008 through 2029. With no replacement funded for F-5 and F-16 aircraft the ADFOR inventory is expected to drop. NSAWC and RC aircraft are both considered part of the ADFOR (After Nichols, 2012)

In addition to an inadequate sortie capacity, current adversary platforms are also challenged to properly represent advanced threat aircraft. The U.S. Navy originally designed the F-5 (see Figure 5) in the 1950s to fulfill a requirement to operate a small, lightweight fighter, flying off of smaller escort carriers. Despite being updated numerous

Figure 5. Navy F-5 from VFC-111 in Key West, FL. F-5 aircraft make up the majority of the ADFOR despite being more than a generation removed from the modern fleet fighters they train against (From NAVAIR, n.d.)

times since inception, the F-5 lacks many of the capabilities desired for present day adversary training. The F-5 is not nearly as maneuverable, and lacks the technologically advanced weapons systems of more modern threat aircraft. Figure 6 shows a depiction of the F-5 capabilities when compared to possible threat aircraft currently operated abroad. The color-coding of “green”, “yellow”, and “red” corresponds to the ability of the F-5 to simulate the different aircraft as “good”, “marginal”, and “none” respectively. In general, the F-5 does not provide the desired threat representation capability.

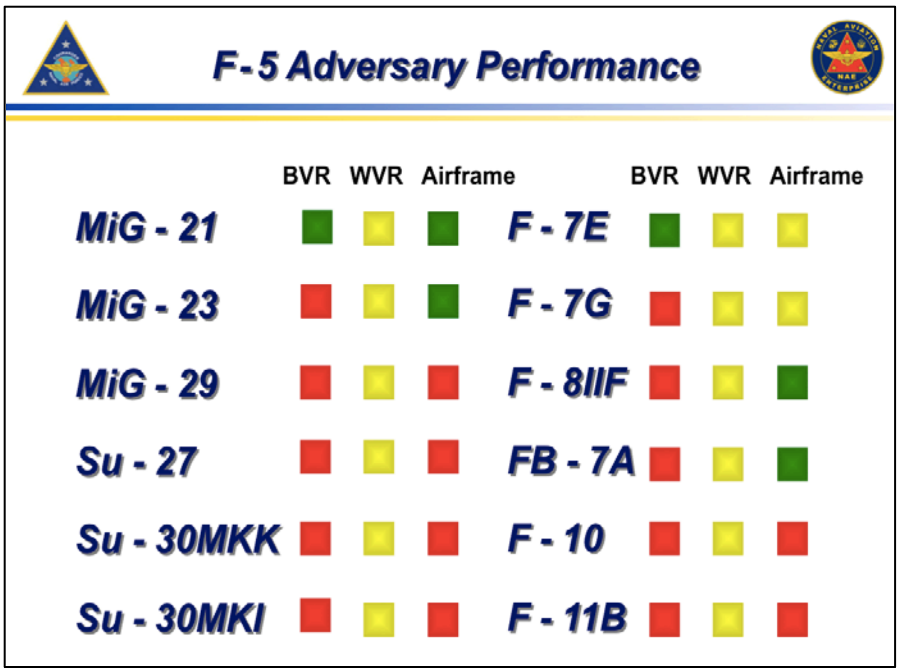

Figure 6. Excerpt from brief on F-5 Avionics systems. Depicted is the capability shortfall of the F-5 to be able to simulate different threat aircraft. Beyond visual range (BVR) and within visual range (WVR) correspond to specific air combat regimes. Colors “Green”, “Yellow”, and “Red” correspond respectively to “good”, “marginal”, and “none” capability simulation (From Taylor, 2012).

The discussion focus has been on the F-5 because it contributes 67 percent of all ADFOR sorties (Roy, 2013). However, there are also capability shortfalls present with the other ADFOR platforms. The F-16s do not have powerful enough radar systems to adequately simulate the threat aircraft for many of the *red air* missions. They also lack technologically advanced systems such as high off-boresight (HOBS) weapons systems. The ADFOR F/A-18s are older model Hornets that also do not have many of the upgraded weapons systems of the newer fleet aircraft. In addition, the F/A-18 is considered to be similar to other aircraft in the fleet, and dissimilarity is a highly desired characteristic for adversary training.

The sortie capacity shortfall and the ADFOR aircraft capability shortfall together make up a significant adversary gap. The U.S. Navy faces this growing gap with no clear solution in place for the future.

C. THESIS SCOPE

This thesis analyzes the current and future U.S. Navy fleet of adversary support aircraft. Currently the Navy primarily relies on three different aircraft to provide adversary support, the F-5 Tiger II, the F-16 Falcon and the F/A-18 Hornet. CAS aircraft, operated by civilian companies such as Airborne Tactical Advantage Company (ATAC), supplement the ADFOR. The annual cost to provide this adversary support is in the billions of dollars. In light of the proliferation of advanced threat aircraft worldwide, which are one to two generations ahead of our capability to represent in training, and forced retirement of older adversary aircraft, an optimized future adversary aircraft structure is paramount. This thesis provides a mathematical model to optimize the Navy's future fleet of adversary support aircraft.

The scope of this thesis includes aspects of the Navy adversary training requirements and the platforms to provide adversary training support. The specific naval inventory considered for the ADFOR includes the following squadrons (location); VFC-13 (Fallon, NV), NSAWC (Fallon, NV), VFC-111 (Key West, FL), VFC-12 (Oceana, VA), and VFA-204 (New Orleans, LA). CAS, and *organic* adversary support is also included. All budgetary figures are in terms of constant FY13$.

In chapter II we discuss the relevant background, in chapter III we present ADSOT, in chapter IV we present the results of analyzing four scenarios, and we conclude in chapter V with insights we have gained and suggestions for further study.

II. BACKGROUND

Air superiority is integral to success in modern armed conflict. This axiom was foundational to combat success in battles such as the invasion of Normandy, during World War II, and to the more recent conflicts in Iraq and Afghanistan. Precedence has been given to establishing air superiority before other tasks, even in smaller, limited operations such as Operation Odyssey Dawn, in Libya. As a result, no U.S. service members have been killed by an enemy air attack since three were killed during the Korean War (Roughton, 2013). Enemy aircraft employing air-to-air missiles, air-to-surface missiles, and bombs can jeopardize air superiority and endanger friendly forces. A standing air force of appreciable size with an appropriate level of proficiency is required to ensure air superiority. This requires the execution of a robust training syllabus, including air combat training against a capable adversary.

Adequate training ensures that our forces are ready when called upon. It is dangerous, dynamic training, demanding the highest level of aircrew skill and competency. The combat capability of naval forces depends not only on the technology of the systems employed, but also the degree to which a well-trained operator can employ the weapons systems. For the training to be effective, the aircrew and aircraft simulating the enemy have to be representative of current and future threats. As recently as the 1980’s actual foreign military aircraft were used in the adversary role. The U.S. Air Force had multiple classified programs, which acquired Soviet made Mikoyan (MiG) fighters from countries with crumbling economies. Both Navy and Air Force fighter pilots trained against MiG-17s, MiG-21s and MiG-23s at remote training ranges in Nevada (Davies, 2008).

A. THE *RED AIR* MISSION

Performing the *red air* mission involves an in-depth knowledge of threat tactics and the ability to execute those tactics effectively while airborne. This requires a skilled aircrew that can make real time assessments regarding blue force performance, and an appropriate aircraft that effectively simulates threat aircraft performance. NSAWC is the

Navy Command responsible for standardization of adversary training, and promulgation of the specific adversary requirements. NSAWC defines a professional adversary aircrew as one that has completed the appropriate level of the approved adversary syllabus (NSAWC, 2012). The intensive syllabus focuses on aircraft handling, threat aircraft performance and tactics, and the ability to recall all aspects of the flight in order to discuss training lessons learned with blue forces.

B. ADVERSARY TRAINING PLATFORMS AND CAPABILITIES

The primary method that the Navy uses to meet the demand for adversary training is professional adversary pilots flying ADFOR aircraft. If the ADFOR isn't available, then *organic red air*, and CAS can be used. Flight simulators can also be used for some very specific training, although they are limited by their lack of realism in many aspects of flight. Combinations of flight simulators and real aircraft are currently being explored in a concept known as LVC (CDR R. Van Diepen, OPNAV Simulator Requirements Officer, personal communication, June, 2013). Understanding the capabilities and limitations of each different platform is essential to providing adequate training.

Aircraft capabilities such as speed, maneuverability, and weapon systems define an aircraft's "generation." Of course, these very broad categories are open to interpretation. Figure 7 shows a generally accepted breakdown of fighter aircraft generations. The R3 descriptor is another accepted way to describe aircraft. An R3 aircraft is one that: uses a radar to track air targets; employs a radar warning receiver to determine if itself is being targeting; and is able to react tactically in an attempt to defeat enemy radar lock or subsequent air-to-air missiles. A Non-R3 aircraft is simply one that lacks this capability combination.

Generation	Qualities
Generation 1:	Jet Propulsion (F-80, German Me 262)
Generation 2:	Swept wings; range-only radar; infrared missiles (F-86, MiG-15)
Generation 3:	Supersonic speed; pulse radar; able to shoot at targets beyond visual range (F-105, F-4, **F-5,** MiG-17, MiG-21)
Generation 4:	Pulse-doppler radar; high maneuverability; look-down, shoot-down missiles (F-15, **F-16**, **F-18** Mirage 2000, MiG-29)
Generation 4+:	High agility; sensor fusion; reduced signatures (Eurofighter, Su-30, **advanced versions of F-16 and F/A-18**, Rafale)
Generation 4++:	Active electronically scanned arrays (AESA); continued reduced signatures or some "active" (waveform canceling) stealth; (F-15SE, Su-35)
Generation 5:	All-aspect stealth with internal weapons, extreme agility, full-sensor fusion, integrated avionics, some or full supercruise (F-22, **F-35**)
Potential Generation 6:	Extreme stealth; highly networked; extremely sensitive sensors; directed energy weapons (Future aircraft)

Figure 7. Category description for different generations of modern fighter aircraft. U.S. Navy ADFOR aircraft are in bold. The F-5 makes up the majority of the ADFOR although only considered a third generation fighter (After Tirpak, 2009).

1. Adversary Air Force (ADFOR)

The ADFOR primarily consists of naval reserve squadrons operating the F-5 Tiger and the F/A-18A/C Hornet, supplemented by F-16 Falcon and F/A-18E/F Super Hornet aircraft operated and maintained by NSAWC. At publication, this amounted to 97 total ADFOR aircraft with an aggregate sortie capacity of approximately 15,000 sorties annually. Table 2 is the current inventory of ADFOR aircraft, sorted by squadron and location.

Squadron	Location	Aircraft Type	Inventory
VFC-12	NAS Oceana, Virgina	F/A-18C	10
VFC-13	NAS Fallon, Nevada	F-5F/N	14
VFC-111	NAS Key West, Florida	F-5F/N	18
VFA-204	NAS New Orleans, Lousiana	F/A-18A+	12
NSAWC	NAS Fallon, Nevada	F/A-18C	21
NSAWC	NAS Fallon, Nevada	F/A-18E/F	8
NSAWC	NAS Fallon, Nevada	F-16A/B	14
		Total	97

Table 2. Inventory of the number of aircraft assigned to each squadron. This does not necessarily reflect the number of aircraft available for training. Maintenance demands often cause sustained periods of aircraft unavailability (LCDR G. Hughes, CNAFR TACAIR Program Manager, personal communication, December, 2012).

The F-5 Tiger II makes up the majority of the ADFOR with a total of 32 aircraft. Two variants of the Tiger II are currently in use by the Navy: the F-5N and a two-seat variant, the F-5F. NSAWC considers the F-5 a third generation aircraft. It is supersonic, and comes equipped with the AN/APQ-159 pulse radar, which provides air-to-air search for target detections with range and azimuth at a range up to 20 nm.

Compared to the Navy’s more modern air force, the F-5 is over matched. It is only moderately maneuverable, not considered R3 due to a weak radar with no radar warning receiver, and does not completely fulfill the requirements for many of the adversary-required events. The radar is not representative of the threat aircraft and only useful at relatively short ranges. This restricts the F-5’s usefulness on some of the more advanced training events. The F-5 is extremely cost effective, and operated abroad by many nations, including the U.S. recognized threat nation of Iran.

The F-16 Falcon is perhaps the most formidable ADFOR aircraft when it comes to BFM training events. This is the typical dogfight type of air combat, where both aircraft maintain sight of each other, and are trying to maneuver in able to shoot the other at relatively short range. NSAWC operates 14 of these fourth generation aircraft, of both

A and B variants. They are equipped with the AN/APG-66/68 radar warning system, which provides a decent R3 capability and a short to medium range radar.

Versions of both the F/A-18A-D Hornet and the F/A-18E/F Super Hornet are also flown by the ADFOR. These fourth generation aircraft are on par in many regards with the fleet F/A-18s. They are highly maneuverable with an advanced R3 suite, providing medium range radar resolution with the APG-65 and APG-73 radar. However, they lack many of the upgraded weapon systems that the fleet carries such as the active electronically scanned array (AESA) long range radar and HOBS systems. They also do not satisfy the requirement to perform adversary training against dissimilar aircraft.

Both the current F-16s and a large portion of the F/A-18s used by the ADFOR are severely restricted in the number of remaining flight hours they can fly before reaching the airframe limit. Effectively, by the year 2020 the ADFOR stands to lose 42 aircraft, or 47 percent of its sortie capacity (Roy, 2013). Although there are multiple programs to increase the flight hour availability for both aircraft, there is limited funding. Initially the F-16 aircraft were limited to 3,000 hours. FALCON UP, funded at $8M in 2013, increases the hour limit of the F-16 to 4,250 hours (Blair, 2013). Another program, FALCON STAR, would increase the limit further to 8,000, however, it has little promise of receiving funding (LCDR G. Hughes, CNAFR TACAIR Program Manager, personal communication, August, 2013). The service life extension program (SLEP) for the F/A-18 has been effective in increasing flight hour limit to 8,600 for most aircraft.

a. ADFOR Procurement and Upgrades

Multiple options for procurement and upgrades to the ADFOR exist. One of the most significant recent upgrades was the procurement of electronic attack (EA) digital radio frequency memory (DRFM) pods. Electronic attack is an action to impede the enemy’s use of some aspect of the electromagnetic spectrum. Aircraft carrying the DRFM pods can jam enemy radar, making it difficult for them to be targeted. Acquisition of these pods significantly enhances the capability of the ADFOR and enables advanced training, which was previously unavailable. Pods are typically externally mounted on the aircraft, as is the case for the F-16 and F/A-18, however for the

F-5 it is carried internally. This is an important difference, as the externally mounted pods are much easier to rotate between aircraft; therefore, more use can be obtained from each individual pod.

Other pods are being considered but have not been procured yet. The SLEEPER pod is an emulator that can be used to mimic different threat aircraft systems and increase the radar range indications of the operating aircraft. An infrared search and track (IRST) pod is available that will provide a method for tracking objects that give off infrared radiation, heat.

Some more permanent upgrades to the airframes are also available. Upgrades to the radar system of both the F-5 and the F-16 could drastically improve their R3 capability. Improvements would include increased search and track capabilities, and in the case of the F-5, data recording and a radar warning receiver. A HOBS, which increases the BFM capability of aircraft is readily available and can be installed in the F-5 and F-16. A joint helmet mounting cueing system (JHMCS), in conjunction with the AIM-9X, is already used by fleet forces and can be added to the ADFOR F/A-18s to provide a similar capability.

b. Event Multiplier and Double Cycle Events

It is often the case that a single *red air* sortie can meet multiple event requirements. This can occur when multiple aircrew that require training are in the same flight. This is common in the FRS phase, where a flight of four aircraft typically contains two or three aircrew that are satisfying multiple syllabus requirements simultaneously.

Double cycling adversaries can also enable single *red air* sorties to meet multiple event requirements. Double cycling is the practice of adversary aircraft launching on a single sortie, providing *red air* presentations for multiple successive blue force events. For example, an event multiplier of 1.86 (Price & Doll, 2012) was computed for VFC-12. Assuming this was accomplished solely by double cycling, that equates to approximately 13 blue events supported for every seven *red air* missions. More explicitly, out of seven aircraft, six engaged double cycle events.

A consequence of using double cycle adversary aircraft is that each aircraft has less fuel for each event, and therefore less time to dedicate to the blue force training. In order to be able to double cycle these types of events, the adversaries often fly at slower, more fuel conserving air speeds in order to be able to remain airborne long enough to support multiple events. This results in a "watered down" training which may be adequate for the FRS event but not for other levels of training. If the requirement calls for multiple presentations at tactical airspeeds, double cycling the *red air* may be infeasible.

2. Contracted Air Service (CAS)

The use of CAS to provide adversary support has grown in popularity and utility. CAS provides a diversified range of aircraft, with a sortie "on demand" capability. In May, 2013, ATAC announced that it had flown over 30,000 (Bannon, 2013) hours in support of the Navy and Air Force. This type of support has proven integral in supplementing the limited sortie capacity of the ADFOR.

ATAC and L-3 Communications Flight International Aviation LLC are two CAS providers currently under contract by the DoD. ATAC maintains a fleet of 23 aircraft, which includes five F-21 Kfir (see Figure 8), four L-39 Albatross, and 14 MK-58 Hawker Hunters. This gives ATAC the capability to provide both a third and fourth generation threat simulation. L-3 operates a fleet of Learjets, which can be configured with pods to conduct electronic attack (EA) *red air* missions. Draken International, a prospective CAS provider, announced in July that it had entered into a contract with a Polish company to acquire 25 Russian made Mig-21 front line fighter aircraft (Draken International, 2012), and will be competing for work from the DoD. The Mig-21 is one of the most proliferated fighters in the world and provides an exceptional training capability against a real world third generation threat. The range of aircraft and capabilities available through CAS continues to improve.

Figure 8. The Israeli produced F-21 Kfir fighter is operated by ATAC and is one of many aircraft available for contract service from private industry. (From ATAC, n.d.)

3. *Organic* Adversaries

A common practice in the fleet is to use other fleet assets to perform adversary training. For example, four aircraft from the same squadron alternate training in a two-versus-two scenario, in which they alternate flying in the adversary role. This is commonly referred to as *organic* adversary support, as generally the aircraft come from the same squadron or same air-wing. This type of training requires little coordination and can be effective for certain training objectives. However, there are some concerns regarding the use of *organic* adversaries. Very few fleet aircrew are professional adversary pilots, therefore there are some limitations on which training events can be performed with *organic* adversaries.

The cost of supplying *organic* adversaries can be high. Between 2006 and 2010 the cost of operating an F-5 was as much as 31 percent lower than that of an F/A-18. Table 3 shows the cost comparison between the two aircraft.

Year	F-5 Tiger II	F/A-18 Hornet	Percentage Savings of F-5
2006	$ 5,570	$ 7,749	28%
2007	$ 6,507	$ 7,496	13%
2008	$ 5,870	$ 8,523	31%
2009	$ 7,177	$ 8,012	10%
2010	$ 6,513	$ 8,375	22%

Table 3. Flight hour cost comparison between F-5 and a fleet F/A-18 (After Huntzinger et al., 2011). All dollars are $FY11.

There is also an opportunity cost of flying valuable flight hours on a fleet F/A-18. These aircraft must be removed from service after reaching 8,600 hours. In 2010 it was estimated that there would be a shortfall of approximately 100 Navy F/A-18s approaching the year 2020. In a statement to the House Armed Service Committee in March of 2012, the strike-fighter shortfall was projected to be less than previously thought, but still roughly 65 aircraft (Department of the Navy's Aviation, 2012). The real cost of flying *red air* sorties with fleet aircraft goes beyond the higher operating cost, it also accelerates the attrition of assets that have finite flight hour restrictions in the face of a predicted shortfall within a decade.

4. Simulators

Technology developments over the past two decades have dramatically increased the fidelity of flight simulators and training via simulation. The ability to accurately depict real combat scenarios continues to improve. Almost all levels of aircrew training in the U.S. Navy involve some amount of simulator use. A limitation of simulation is that it does not provide "end-to-end" training. "End-to-end" training occurs when the entire system of getting an airplane and aircrew combination ready for combat occurs; loaded with the appropriate ordnance, aircraft maintained properly and ready to fly, and a sufficiently trained and capable aircrew. Current simulators leave much to be desired in the simulation of air-to-air combat. They do not provide for many of the sensory inputs that come from increased G-forces, and spatial disorientation that are often encountered during a real flight. They also are lacking in the high fidelity visual cueing required for practicing close in BFM training.

5. Live, Virtual, Constructive (LVC)

The LVC concept is loosely defined as any training in which these three elements are involved.

- Live—real people operating real equipment;
- Virtual—real people operating simulators; and
- Constructive—computer generated entities.

Currently, there is on-going development in the Navy to incorporate the LVC concept into training. LVC ranges would be able to supplement the current capabilities of ADFOR aircraft in order to make them more representative of threat aircraft. They also would be able to provide virtual and constructive targets, which would serve as a force multiplier for adversary training presentations. As an example, a training event requiring six adversary aircraft simulating fourth generation aircraft could be accomplished with just two F-5s. LVC ranges come at a high cost and at a minimum, would consist of updating range antennas, updating pods for the aircraft, and an overhaul of existing computers and encryption in the range operations centers (CDR R. Van Diepen, OPNAV Simulator Requirements Officer, personal communication, June, 2013).

C. PAST STUDIES

Previous attempts have been made to address *red air* shortfalls and potential changes to ADFOR. CNA completed two studies, one as recent as 2012, addressing these issues. Both studies proposed solutions to meet the future demand for *red air* involving various upgrades to the force and changes to the utilization of CAS. Multiple Master's degree theses have been completed using simple calculus, and statistics approaches, to address the adversary gap. Finally, optimization has demonstrated effectiveness for similar DoD applications.

CNA (Huntzinger et al., 2011) at the request of OPNAV N88 (now N98), used a capabilities based assessment (CBA) to conduct a study of adversary requirements through 2025. Assuming about 25 percent of adversary cost goes into overhead, they estimated that the annual cost of an ADFOR of sufficient size to meet the training requirements was about $530 million. This was $48 million less than what was currently estimated as being spent on the ADFOR, and suggested that there was room for some cost savings by not flying fleet aircraft in the adversary role, and using the money saved to buy better adversary support. This option also included using more CAS to supplement the existing ADFOR. In order to facilitate the study, CNA (Huntzinger et al., 2011) developed an alternative method for classification of the adversary requirements. Their method uses five general levels of capability that provide more fidelity than the generation categories or the "R3 and non-R3" grouping currently used and focuses on the capability required for training rather than the aircraft. This enabled aggregation of the training requirements throughout the different training cycles of the FRTP. Table 4 shows the study's recommended force structure and the number of sorties required.

Adversary type	FY2011 Sorties Required	FY2018 Sorties Required	FY2025 Sorties Required
CAS	2,535	2,484	2,408
Current configured F-5	4,965	4,866	4,717
F-16 with HOBS upgrades	3,725	3,651	3,539
F-5 with radar and HOBS upgrades	28,106	27,543	26,700
Current configured F-16	9,338	9,151	8,871
F-16 with EA upgrades	1,020	1,000	969
Totals	**49,689**	**48,695**	**47,204**

Table 4. CNA study results of proposed adversary platform upgrades and the number of sorties required to meet the training demand. (After Huntzinger et al., 2011)

A second study, at the request of CNAF, to analyze where improvements to ADFOR could be made, and what possible secondary benefits active duty component units achieved flying *red air* sorties, followed the initial CNA work. In order to accomplish this, Price and Doll (2012) developed multiple models and analyzed data from 31 pilots attached to CVW-1 during their training in preparation for deployment. Focus was on the sustainment level training for the core events only. They leveraged the requirement categorization system used in the previous CNA adversary study (Huntzinger et al., 2011). Price and Doll (2012) found that fleet pilots flying the adversary role accrued as much T&R credit as 57 percent of a flight flown as blue air. This is a significant observation, noting that when squadrons use *organic red air* they do accrue T&R credit. This would mean that if exclusively ADFOR or CAS aircraft flew *red air* sorties, readiness of the fleet would be negatively impacted, as there would be a loss of those training flight hours. However, if those hours were re-capitalized for more fleet training, this would not be the case and a higher level of proficiency could be attained. Also significant in the study was their preliminary work regarding the relative cost-benefit from different upgrades of the ADFOR. Price and Doll used an optimization approach using simulated annealing to seek optimized upgrades for the ADFOR. They found that there was a clear dominance of the radar system improvements, including R3 enhancements, over any other upgrades, but they provide no measure of the optimality of their solution.

Integral to the model developed by CNA were the utility assignments for each airframe and upgrade combination (see Figure 9). The utility value of 1.0 equates to a platform configuration that completely meets the requirement. A value of 0.0 equates a platform configuration that does not meet the requirement at all. Other values between 0.0 and 1.0 indicate varying degrees of utility and are color-coded. A short explanation is provided if the utility value is not 1.0. Using a simulated annealing heuristic algorithm in conjunction with the utility assignments, CNA found, in order of priority, that the following upgrades returned the greatest targeted capability improvements, when mapped to the requirements, on investments up to $250–300 million:

- R3 upgrades to F-16s and F-5s;
- DRFM EA upgrades; and
- HMS/HOBS upgrades.

Subjective utility assignments

		Non-R3			R3								
		< 180	> 180 degrees of turn										
Aircraft	UPGRADE	A2	B1	B2	C1	C2	C3	D1	D2	D3	E1	E2	E3
F-5	B/L -- No UPGR	Imrop. Cue	Aero Perf	Imrop. Cue	No HOBS	Imrop. Cue	No EA	A/C Range	A/C Range	A/C Range	A/C Range	A/C Range	A/C Range
F-5	DRFM EA	Imrop. Cue	Aero Perf	Imrop. Cue	No HOBS	Imrop. Cue	Imrop. Cue	A/C Range	A/C Range	A/C Range	A/C Range	A/C Range	A/C Range
F-5	Sleeper Pod	GCI	Aero Perf	GCI	No HOBS	GCI	No EA	A/C Range	A/C Range	A/C Range	A/C Range	A/C Range	A/C Range
F-5	DRFM EA + Sleeper Pod	GCI	Aero Perf	GCI	No HOBS	GCI	GCI	A/C Range	A/C Range	A/C Range	A/C Range	A/C Range	A/C Range
F-5	R3		Aero Perf		No HOBS		No EA	A/C Range	A/C Range	A/C Range	A/C Range	A/C Range	A/C Range
F-5	R3 + DRFM EA (R3D)		Aero Perf		No HOBS			A/C Range	A/C Range	A/C Range	A/C Range	A/C Range	A/C Range
F-5	HMS/HOBS	Imrop. Cue	Aero Perf	Imrop. Cue	Aero Perf	GCI	No EA	A/C Range	A/C Range	A/C Range	A/C Range	A/C Range	A/C Range
F-5	DRFM EA + HMS/HOBS	Imrop. Cue	Aero Perf	Imrop. Cue	Aero Perf	GCI		A/C Range	A/C Range	A/C Range	A/C Range	A/C Range	A/C Range
F-5	R3 + HMS/HOBS		Aero Perf		Aero Perf		No EA	A/C Range	A/C Range	A/C Range	A/C Range	A/C Range	A/C Range
F-5	R3D + HMS/HOBS		Aero Perf		Aero Perf			A/C Range	A/C Range	A/C Range	A/C Range	A/C Range	A/C Range
F-5	R3D + IRST		Aero Perf		No HOBS			A/C Range	A/C Range	A/C Range	A/C Range	A/C Range	A/C Range
F-5	R3D + HMS/HOBS + IRST		Aero Perf		Aero Perf			A/C Range	A/C Range	A/C Range	A/C Range	A/C Range	A/C Range
F-16	B/L -- No UPGR				No HOBS	No HOBS	No EA	No HOBS	No EA	No EA/PT	Radar Rng	Radar Rng	Radar Rng
F-16	DRFM EA				No HOBS	No HOBS	No HOBS	No HOBS	No HOBS	No PT	Radar Rng	Radar Rng	Radar Rng
F-16	R3				No HOBS	No HOBS	No EA	No HOBS	No EA	No EA/PT	No HOBS	No EA	No EA/PT
F-16	R3 + DRFM EA (R3D)				No HOBS	No HOBS	No HOBS	No HOBS	No HOBS	No PT	No HOBS	No HOBS	No PT
F-16	HMS/HOBS						No EA		No EA	No EA/PT	Radar Rng	Radar Rng	Radar Rng
F-16	DRFM EA + HMS/HOBS									No PT	Radar Rng	Radar Rng	Radar Rng
F-16	R3 + HMS/HOBS						No EA		No EA	No EA/PT		No EA	No EA/PT
F-16	R3D + HMS/HOBS									No PT			No PT
F-16	R3D + IRST				No HOBS	No HOBS	No HOBS	No HOBS	No HOBS	No HOBS	No HOBS	No HOBS	No HOBS
F-16	R3D + HMS/HOBS + IRST												
F-18 APG-65/73	B/L -- No UPGR		Not Diss		Multiple	No HOBS	No EA	No HOBS	No EA	No EA/PT	Radar Rng	Radar Rng	Radar Rng
F-18 APG-65/73	DRFM EA		Not Diss		Multiple	No HOBS	No HOBS	No HOBS	No HOBS	No PT	Radar Rng	Radar Rng	Radar Rng
F-18 APG-65/73	JHMCS + AIM 9X		Not Diss		Multiple	No HOBS	No EA	No HOBS	No HOBS	No EA/PT	Radar Rng	Radar Rng	Radar Rng
F-18 APG-65/73	DRFM EA + JHMCS + AIM 9X		Not Diss		Multiple	No HOBS	No HOBS	No HOBS	No HOBS	No PT	Radar Rng	Radar Rng	Radar Rng
F-18 APG-79 JHMCS + AIM-9X	B/L -- No UPGR		Not Diss		Multiple		No EA	Imrop. Cue	Imrop. Cue	Imrop. Cue	Imrop. Cue	Imrop. Cue	Imrop. Cue
F-18 APG-79 JHMCS + AIM-9X	DRFM EA		Not Diss		Multiple			Imrop. Cue	Imrop. Cue	Imrop. Cue	Imrop. Cue	Imrop. Cue	Imrop. Cue
F-18 APG-79 JHMCS + AIM-9X	Sleeper Pod		Not Diss		Multiple		No EA	UNK Cap	No EA	No EA/PT	UNK Cap	No EA	No EA/PT
F-18 APG-79 JHMCS + AIM-9X	DRFM EA + Sleeper Pod		Not Diss		Multiple			UNK Cap	UNK Cap	No PT	UNK Cap	UNK Cap	No PT
F-18 APG-79 JHMCS + AIM-9X	DRFM EA + Sleeper Pod + IRST		Not Diss		Multiple			UNK Cap	UNK Cap	UNK Cap	UNK Cap	UNK Cap	UNK Cap

0.00	0.25	0.50	0.75	1.00

CNA

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Figure 9. Excerpt of table depicting utility assignments from CNA 2012 study. The columns represent the capability binning of the requirements used from the CNA 2011 study. The rows each correspond to an aircraft and upgrade combination. The colors correspond to the amount of utility for each requirement and aircraft configuration combination. (From Price & Doll, 2012)

After $300 million, CNA found that procurement of additional F-16s was required to make further significant improvements to the adversary fleet. It is important to note that the above results were not completely modeled in the CNA study, and they acknowledge that much more work by their SMEs needs to be conducted.

Roy (2013) attempted the task of quantifying the actual adversary capability shortfall through the use of survey analysis. Roy conducted surveys of two separate air-wings after completing the SFARP and CVW Fallon training phases. He asked a series of questions related to the quality of training and the quality of the adversary representation given. He showed that there is agreement amongst fleet pilots that the existing ADFOR is not capable of meeting the training objectives in the future.

Brazelton, Hughes and Pearce (2010) took a more mathematical approach in their capstone project, focusing on a single squadron located in Key West, to compare capabilities and limitations with requirements during the FRS training phase. VFC-111 in Key West is the primary provider for FRS adversary training support. According to Brazelton et al., VFC-111 had a support capacity of 3,273 sorties in FY2011. This is based on an annual flight hour budget of 4,800 hours, an overhead requirement of 25 percent, and an average of 1.1 flight hours per sortie. They compute this at 321 sorties below the requirement of 3,594. These sorties do not correspond directly to the number of events required. The FRS uses a high rate of double cycle *red air* and only meets the minimum required adversary aircraft for each syllabus hop. Brazelton et al., found the FRS demand peaked in 2011 and will remain high through at least 2015 when the Joint Strike Fighter FRS begins conducting training. They found that the lack of adversary support was the single largest limiting factor in completing the FRS air-to-air training requirements and concluded that in order to meet the demand, VFC-111 would need two additional aircraft, at least two additional aircrew, and to increase funding to support 5,600 flight hours per year.

There is precedence using optimization models to address similar scheduling problems in the Navy. Madson (2010) developed an integer linear program for the scheduling squadrons to match air-wing assignments. Her model showed the number of squadron moves could be decreased from eleven to five in the first year through more efficient planning. Garcia (2001) built on a integer linear program by both Baran (2000) and Field (1999), for planning the procurement and retirement of both ships and aircraft. Garcia effectively modeled specifics of aircraft planning including factors such as: increasing operations and maintenance costs as aircraft age increases; varying mission effectiveness based on aircraft age; and the use of unmanned air vehicles (UAV). The study showed that increasing aircraft ages have direct impact on the optimal procurement and retirement planning.

Brown (1995) developed a bicriteria mixed integer program to address scheduling of Marine Corps aviation units in order to maintain readiness in accordance with the T&R program. The model maximized readiness over a 90-day schedule while enforcing T&R requirements and squadron manning constraints. His model solved in as little as 10 minutes on a personal computer. Brown also incorporated a notion he referred to as "equity" which attempted to capture the practice of units to "pursue equity of opportunity and workload among individuals to preserve morale" (Brown, 1995). He found that a schedule could be developed that approached optimal readiness levels while reducing "inequities" by 79.9 percent.

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III. MODEL DEVELOPMENT

A. ADVERSARY SORTIE OPTIMIZATION TOOL (ADSOT)

ADSOT is an integer linear program that prescribes the annual assignment and procurement of specifically configured adversary training platform to meet *red air* mission requirements. ADSOT accomplishes this while minimizing cumulative operating costs and penalties associated with platform capability and training requirement mismatches. Budget parameters, contracting limits, procurement schedules, annual flight hour usage, and aircraft flight hour limits all constrain the results. ADSOT prescribes annual operating cost, procurement cost, training utility, aircraft retirement schedules, and procurement schedules over a 20-year planning horizon with annual fidelity.

B. MAJOR PLANNING ASSUMPTIONS

1. Training Platforms

Three categories of training platform considered for the *red air* mission are: dedicated ADFOR, CAS, and fleet aircraft (*organic red air*). LVC model excursions integrate into ADFOR as a force multiplier when enabled. ADSOT can prescribe aircraft upgrades and pod configurations in order to improve performance for the ADFOR only. The number of events each ADFOR can satisfy is specifically constrained by aircraft inventory, annual flight hour limits, and aircraft home base location. ADSOT constrains multiple CAS aircraft configurations by the service contract, aircraft home base location, and capability limitations. ADSOT allows the use of fleet aircraft subject to capability limitations. ADSOT does not model any procurement or flight hour parameters for fleet aircraft.

2. Sorties and Events

ADSOT prescribes sorties from the eligibly configured training platforms to meet required training events. Each sortie has the ability to satisfy multiple events based on an event multiplier (in some cases the event multiplier is one). Each specific requirement location and the home base location of the servicing training platform are used to determine both the event multiplier the average sortie duration.

3. Requirements

The requirements include both core and non-core events including: FRS, SFARP, CVW Fallon, SFTI, COMPTUEX, JTFEX, STWT and ULT (T&R required) training phases. Each adversary required equates to an event requirement. For example, if a FRS syllabus flight requires four adversaries, then that equates to four required events.

ADSOT uses requirement bins as developed by CNA (Huntzinger et al., 2011). These bins enable the aggregation of requirements into 13 different categories allowing for efficient computation of the data, and for ease in presentation of information. Note that although ADSOT uses requirement bins, the specific training phase and location for each requirement is still preserved. This enables differentiation of the ability to meet requirements for different training phases, allowing ADSOT increased fidelity to identify specific shortages. Table 5 depicts the different requirement bins used for ADSOT, with a detailed description of each.

ADSOT defines different training platform capabilities to be mapped both to the requirement bins and the different training platform configurations. Table 6 shows the different capability categories. ADSOT uses the capabilities to develop training utility values. These values correspond to the ability of each platform to meet the requirements. Training utilities range between zero and one, with one representing a training platform configuration, which meets the training requirement at 100 percent.

Requirement	Description	Example Event
A2	Beyond visual range (BVR) intercept against a non-R3 adversary with no within visual range (WVR) training (e.g. FRS FAWI, CTX ADEX Events)	FRS FAWI, CTX ADEX
A3	A2 + Electronic Attack (EA) (e.g. CTX Advanced ADEX Events)	CTX Advanced ADEX
B1	WVR against a fourth generation type adversary (e.g. FRS BFM flights)	FRS BFM Solo
B2	B1 + BVR intercept against a non-R3 adversary (e.g. FRS early stage FWT flights)	FRS early stage FWT
C1	WVR against a fourth generation type adversary equipped with High Off Boresite (HOBS) weapons systems (e.g. SFWT BFM Hop)	SFWT BFM
C2	C1 + BVR intercept (e.g. FRS late stage FFWT Hop, Early SFWT and SFARP BVR Hops)	FRS FWT, Early SFWT
C3	C2 + EA (e.g. advanced training events)	SFARP events
D1	BVR intercept with longer range R3 cueing and transition to WVR against a fourth generation type adversary equipped with HOBS	SFARP events
D2	D1 + EA	Future Requirement
D3	D1 + D2 + Infrared Search and Targeting (IRST) capability	CVW Fallon event
E1	BVR intercept with longest range R3 cueing and transition to WVR against a fourth generation type adversary equipped with HOBS	Advanced SFARP event
E2	E1 + EA + transition to WVR against a fourth generation type adversary equipped with HOBS	CVW Fallon event
E3	E1 + E2 + IRST	Advanced SFTI event

Table 5. Requirement bins used in ADSOT. Binning enables similar requirements from all training phases to be aggregated together for ease of model computation. Example events requiring the associated training with each bin is provided. (After Huntzinger et al., 2011).

4. Costs

ADSOT minimizes operational and maintenance cost based on cost per flight hour (CPH) for each training platform. Location of the training demand, location of OPFOR provider, and duration of training event influence the number of flight hours executed. Procurement costs are modeled as one-time procurement injects and annual allowances. Options for use of procurement dollars are limited to new ADFOR aircraft, ADFOR upgrades, and performance enhancing pods for ADFOR aircraft.

5. Training Platform Capabilities

Capability	Description	Capable Aircraft
WVR(III)	WVR training to include BVR comparable to a third generation threat aircraft	F-5
WVR(IV)	WVR training to include BVR comparable to a fourth generation threat aircraft	F-16
BVR	Enough fuel to perform BVR training for appropriate number of presentations	F-5
BVR(HP)	Enough fuel for high performance (HP) BVR training for appropriate number of presentations	F-16
RAD(SR)	R3 capable at short ranges	F-5
RAD(MR)	R3 capable at medium ranges	F-18
RAD(LR)	R3 capable at long ranges	F-18E
RWR Ind	Provide accurate RWR indications to other aircraft	F-16 w/ radar upgrade
RWR	RWR equipped	F-5 w/ R3 upgrade
DIS	Dissimilar (DIS) aircraft (When compared to fleet)	F-5
ITEMS	Able to deploy expendibles to defeat targeting and tracking solutions	F-18
EA	Electronic attack capable	F-16 with DRFM EA Pod
IR	Infa-red targeting capable	F-16 with IRST Pod
HOBS	High off boresight systems equipped	F-18E

Table 6. Training platform capabilities, descriptions and sample capable aircraft. These capabilities are used to formulate training utility values.

6. Penalties

ADSOT objective function coefficients are equal to the CPH for each training platform. The objective function also uses a penalty to account for any capability deficit. This capability penalty guides ADSOT to always assign the most capable available training platform to meet the requirement.

C. FORMULATION

SETS AND INDICES

$a \in A$	ADFOR aircraft: $(a' \in A)$
$g \in AG$	ADFOR aircraft type groups
AGM_g	ADFOR aircraft groups $\left(a \in AGM_g \subseteq A\right)$
$c \in C$	CAS types
$f \in F$	fleet aircraft
$l \in L$	locations: $(l' \in L)$
$p \in P$	aircraft performance enhancing pod configurations: $(p' \in P)$
PD_p	aircraft pods p' that are part of configuration p: $p' \in PD_p$
Pac_p	aircraft a that can carry configuration $p\left(a \in Pac_p \subseteq A\right)$
$r \in R$	requirements
$t \in T$	training ranges
$a' \in U_a \subseteq A$	upgrades available for aircraft a: $a' \in U_a$
$y \in Y$	years of the planning horizon: $y = \{1,2,3...,\|Y\|\}(y', y'' \in Y)$
$(y,y') \in ProA_a$	available procurement intervals (between years y and year y', inclusive) for aircraft a
$(y,y') \in ProP_p$	available procurement intervals (between years y and year y', inclusive) for pod p
$(y,y') \in ProPU_{aa'}$	available procurement intervals (between years y and year y', inclusive) for aircraft a upgrades to a'

PARAMETERS

- Objective-terms: Penalties

$rpen_{ry}$	penalty for shortage in capability for requirement r in year y (\$/sortie)
$bpen^{+}_{y}$	penalty for expenditure excess of total budget in y (\$/\$)

$bpen_y^-$ penalty for expenditure shortage of total budget in y (\$/\$)

$tompen_y^+$ penalty for expenditure excess of total operations budget in y (\$/\$)

$tompen_y^-$ penalty for expenditure shortage of total operations budget in y (\$/\$)

$ompen_y^+$ penalty for expenditure excess of ADFOR operations budget in y (\$/\$)

$ompen_y^-$ penalty for expenditure shortage of ADFOR operations budget in y (\$/\$)

$ppen_y^+$ penalty for expenditure excess of procurement budget in y (\$/\$)

$ppen_y^-$ penalty for expenditure shortage of procurement budget in y (\$/\$)

$conpen_y^+$ penalty for expenditure excess of CAS budget in y (\$/\$)

$conpen_y^-$ penalty for expenditure shortage of CAS budget in y (\$/\$)

- Airframe Data

inv_{al}^0 initial inventory of aircraft a at location l (# aircraft)

$\overline{inv}_{gl}$ maximum inventory of aircraft in group g at location l (# aircraft)

$\underline{inv}_{gl}$ minimum inventory of aircraft in group g at location l (# aircraft)

$\overline{hrs}_{ay}$ maximum flight hours for aircraft a in year y (# hour)

$\underline{hrs}_{ay}$ minimum flight hours for aircraft a in year y (# hour)

$hrsreq_{lr}$ hours required for training platform from location l to meet requirement r (# hour)

$hrssor_r$ hours required for single sortie to meet requirement r (# hour)

$hrsbase_{ay}$ base flight hours already flown for aircraft a procured in year y (# hour)

$hrsfln_{ayy'}$ flight hours flown for aircraft a in year y procured in y' (# hour)

$hrslife_a$ maximum flight hour life for aircraft a (# hour)

$hrsovrhd_a$ percentage of flight hours flown as overhead for aircraft a (hour/hour)

- Other Platforms Data

$invpd_{lp}^0$ initial inventory of pods p at location l (# pod)

$pnum_{p'p}$ one if pod p' is used in pod configuration p

$podmult_{ap}$	multiplier for the frequency to use pod p for aircraft a (sortie/sortie)
$invtrn_t^0$	initial inventory of training ranges t (# range)
$trngcap_t$	maximum capacity of training ranges t (# sortie)
$trngmult_{art}$	multiplier of additional sorties capability when using aircraft a to meet requirement r on training range t (# sortie)
$\overline{hrscon_{cy}}$	maximum hours to fly with CAS c in year y (# sortie)
$\underline{hrscon_{cy}}$	minimum hours to fly with CAS c in year y (# sortie)
$\overline{sorfleet_{fy}}$	maximum sorties to fly with fleet aircraft f in year y (# sortie)
$maxfltsor$	maximum sorties to fly with fleet aircraft (# sortie)

- Requirement Data

$sortreq_{ry}$	number of events needed to meet requirement r in year y (# event)
$evtfac_{l,r}$	number of requirements r met with each sortie from location l (# event)
$evtfacflt_r$	number of requirements r met with each sortie (sortie/event)
$effect_{apr}$	effectiveness of airframe a with pod p to meet requirement r (sortie/event)
$coneff_{cr}$	effectiveness of CAS aircraft c to meet requirement r (sortie/sortie)
$flteff_{fr}$	effectiveness of fleet aircraft f to meet requirement r (sortie/sortie)
$trngeff_{art}$	effectiveness of aircraft a to meet requirement r on training range t (# sortie)

- Procurement Parameters

epy	final year for procurement (year)
$\overline{tproclim_a}$	maximum total number of aircraft a to procure (# aircraft)
$\underline{tproclim_a}$	minimum total number of aircraft a to procure (# aircraft)
$\overline{proclim_{ay}}$	maximum number of aircraft a to procure in year y (# aircraft)
$\underline{proclim_{ay}}$	minimum number of aircraft a to procure in year y (# aircraft)
$\overline{tpdproc_p}$	maximum total number of pod p to procure (# pod)

$\underline{tpdproc}_{p}$ minimum total number of pod p to procure (# pod)

$\overline{pdproc}_{py}$ maximum number of pod p to procure in year y (# pod)

$\underline{pdproc}_{py}$ minimum number of pod p to procure in year y (# pod)

$\overline{tupproc}_{aa'}$ maximum total number of upgrade u to procure (# upgrade)

$\underline{tupproc}_{aa'}$ minimum total number of upgrade u to procure (# upgrade)

$\overline{upproc}_{aa'}$ maximum number of upgrade u to procure in year y (# upgrade)

$\underline{upproc}_{aa'}$ minimum number of upgrade u to procure in year y (# upgrade)

- Budget Parameters

$omcost_{ay}$ operating CPH cost of aircraft a in year y($/sortie)

$concost_{cy}$ contracting CPH cost of CAS c in year y($/sortie)

$fltcost_{fy}$ fleet cost of CPH fleet f in year y($/sortie)

$pcost_{ay}$ procurement cost of aircraft a in year y($/aircraft)

$podcost_{p}$ procurement cost of pod p for aircraft a ($/pod)

$ucost_{aa'y}$ upgrade cost of aircraft a upgraded to aircraft a' in year y ($/upgrade)

$trngcost_{ty}$ cost of training range t in year y($/training range)

$tnxrcst_{a}$ cost of to transfer aircraft a to a new location ($/transfer aircraft)

$\overline{ombud}_{y}$ maximum ADFOR operating cost budget in year y($)

$\underline{ombud}_{y}$ minimum ADFOR operating cost budget in year y($)

$\overline{pbud}_{y}$ maximum procurement budget in year y($)

$\underline{pbud}_{y}$ minimum procurement budget in year y($)

$\overline{tombud}_{y}$ maximum total *red air* operating cost budget in year y($)

$\underline{tombud}_{y}$ minimum total *red air* operating cost budget in year y($)

$\overline{conbud}_{y}$ maximum CAS cost budget in year y($)

$\underline{conbud}_{y}$ minimum CAS cost budget in year y($)

$pinjbud$ maximum procurement ($)

DECISION VARIABLES

- Elastic Variables

Z objective function value

α_{ry}^{R} requirement r capability shortage in year y (# sortie)

α_{ry}^{Cap} requirement r capacity shortage in year y (# sortie)

α_{y}^{OMB+} amount over allowed ADFOR operations budget year y ($)

α_{y}^{OMB-} amount below allowed ADFOR operations budget in year y ($)

α_{y}^{PB+} amount over allowed procurement budget in year y ($)

α_{y}^{PB-} amount below allowed procurement budget in year y ($)

α_{y}^{TOB+} amount over allowed total operations budget in year y ($)

α_{y}^{TOB-} amount below allowed total operations budget in year y ($)

α_{y}^{TB+} amount over allowed total budget in year y ($)

α_{y}^{TB-} amount below allowed total budget in year y ($)

α_{y}^{CB+} amount over allowed CAS budget in year y ($)

α_{y}^{CB-} amount below allowed CAS budget in year y ($)

- Training Platform Prescription Variables

$ASSGN_{alpry}$ number of sorties of aircraft a at location l configured with pod p that satisfies requirement r in year y (# sorties)

$CONT_{clry}$ number of sorties of CAS types aircraft c from location l to fly for requirement r in year y (# sorties)

$FLEET_{fry}$ number of sorties of fleet aircraft type f to fly for requirement r in year y (# sorties)

$TRNRG_{alrty}$ number of sorties of aircraft a at location l to fly on training range t that satisfies requirement r in year y (# sorties)

$UPGR_{aa'lyy'}$ number of aircraft a at location l to upgrade to a' in year y that were procured in year y' (# upgrade)

$TNXR_{all'yy'}$ number of aircraft a at location l to transfer to location l' in year y that were procured in year y' (# transfers)

$PROC_{aly}$ number of aircraft a at location l to procure in year y (# aircraft)

$PROCPD_{lpy}$ number of pod p to procure in year y at location l (# pod)

$PROCTR_{ty}$ number of training range t to procure in year y (# training range)

$RET_{alyy'}$ number of aircraft a at location l to retire in year y that were procured in year y' (# aircraft)

- Control Decision Variables

$INV_{alyy'}$ inventory of available aircraft a at location l in year y procured in year y' (# aircraft)

$FLTHRS_{ay}$ total pool of flight hours expended on aircraft of type a, year y (# hour)

POD_{lpy} number of pods p available at location l, year y (# pod)

$TRINV_{ty}$ inventory of training range t, year y (# training range)

$ISINV_{agly}$ binary variable with value one if maintaining aircraft group g at location l in year y

$PROA_{ayy'}$ binary variable with value one if procure aircraft a from year y to year y'

$PROPD_{pyy'}$ binary variable with value one if procure pod p from year y to year y'

$PROU_{aa'yy'}$ binary variable with value one if upgrade aircraft a to a' from year y to year y'

Objective function (Minimize penalty for not meeting capability requirements and total adversary operations and maintenance costs)

$$\min Z = \sum_{r,y} rpen_{ry}\alpha_{ry}^{R} + \sum_{a,l,p,r,y} \frac{hrsreq_{alr}omcost_{ay}}{hrsovrhd_{a}} ASSGN_{alpry} + \sum_{a,l,r,t,y} \frac{hrsreq_{alr}omcost_{ay}}{hrsovrhd_{a}} TRNRG_{alrty}$$
$$+ \sum_{c,l,r,y} hrsreq_{lr}concost_{cy}CONT_{clry} + \sum_{f,r,y} hrssor_{r}fltcost_{fy}FLEET_{fry} + \sum_{y} bpen_{y}^{+}\alpha_{y}^{TB+} + \sum_{y} bpen_{y}^{-}\alpha_{y}^{TB-}$$
$$+ \sum_{y} ompen_{y}^{+}\alpha_{y}^{OMB+} + \sum_{y} ompen_{y}^{-}\alpha_{y}^{OMB-} + \sum_{y} ppen_{y}^{+}\alpha_{y}^{PB+} + \sum_{y} ppen_{y}^{-}\alpha_{y}^{PB-} + \sum_{y} conpen_{y}^{+}\alpha_{y}^{CB+}$$
$$+ \sum_{y} conpen_{y}^{-}\alpha_{y}^{CB-} + \sum_{y} tompen_{y}^{+}\alpha_{y}^{TOB+} + \sum_{y} tompen_{y}^{-}\alpha_{y}^{TOB-}$$

subject to:

- Airframe Inventory

$$INV_{alyy'} = inv_{al}^{0}, \qquad \forall a,l,y=1,y'=1 \qquad (1)$$

$$INV_{alyy'} = PROC_{alyy'} \qquad \forall a,l,y>1,y'=y \qquad (2)$$

$$INV_{alyy'} = INV_{aly-1y'} - RET_{alyy'}$$
$$+ \sum_{a' \mid a \in U_{a'}} UPGR_{a'alyy'} - \sum_{a' \in U_{a}} UPGR_{aa'lyy'} \qquad \forall a,l,y>1,y'<y \qquad (2)$$
$$+ \sum_{l'} TNXR_{al'lyy'} - \sum_{l'} TNXR_{all'yy'}$$

$$\sum_{a \in AG_{g}, y' \le y} INV_{alyy'} \le \overline{inv}_{gl} ISINV_{gly} \qquad \forall g,l,y \qquad (3)$$

$$\sum_{a \in AG_{g}, y' \le y} INV_{alyy'} \ge \underline{inv}_{gl} ISINV_{gly} \qquad \forall g,l,y \qquad (4)$$

- Airframe Flight Hours

$$FLTHRS_{ay} = \sum_{l,y' \le y} hrsbase_{ay} INV_{alyy'} \qquad \forall a,y=1 \qquad (5)$$

$$FLTHRS_{ay} \geq FLTHRS_{ay-1} + (1/hrsovrhd_a)(\sum_{l,p,r} hrsreq_{lr} ASSGN_{alpry-1}$$
$$+\sum_{l,r,t} hrsreq_{lr} TRNRG_{alrty-1}) + \sum_{l} hrsbase_{ay} PROC_{aly}$$
$$+ \sum_{a'|a \in U_{a'},l,y'<y} hrsfln_{ayy'} UPGR_{a'alyy'} - \sum_{a' \in U_a,l,y'<y} hrsfln_{ayy'} UPGR_{aa'lyy'}$$
$$-\sum_{l,y'<y} hrsfln_{ayy'} RET_{alyy'} \qquad \forall a, y > 1 \qquad (6)$$

$$FLTHRS_{ay} \leq \sum_{l,y' \leq y} hrslife_a INV_{alyy'} \qquad \forall a, y \qquad (7)$$

- Airframe Pods, Upgrades and Transfers

$$POD_{lpy} = invpd^0_{lp} \qquad \forall l, p, y = 1 \qquad (8)$$

$$POD_{lpy} = POD_{lpy-1} + PROCPD_{lpy} \qquad \forall l, p, y > 1 \qquad (9)$$

$$\sum_{l'} TNXR_{all'yy'} \leq INV_{aly-1y'} \qquad \forall a, l, y > 1, y' < y \qquad (10)$$

$$\sum_{a' \in U_a} UPGR_{aa'lyy'} \leq INV_{aly-1y'} \qquad \forall a, l, y > 1, y' < y \qquad (11)$$

$$PROC_{aly} = inv^0_{al} \qquad \forall a, l, y = 1 \qquad (12)$$

$$\sum_{l',y'>y} TNXR_{all'y'y} \leq PROC_{aly} \qquad \forall a, l, y > 1 \qquad (13)$$

- Airframe Sortie

$$\sum_{p,r} hrsreq_{lr} ASSGN_{alpry} + \sum_{r,t} hrsreq_{lr} TRNRG_{alrty}$$
$$\leq \sum_{y' \leq y} \overline{hrs}_{ay} hrsovrhd_a INV_{alyy'} \qquad \forall a, l, y \qquad (14)$$

$$\sum_{p,r} hrsreq_{lr} ASSGN_{alpry} + \sum_{r,t} hrsreq_{lr} TRNRG_{alrty}$$
$$\geq \sum_{y' \leq y} \underline{hrs}_{ay} hrsovrhd_a INV_{alyy'} \qquad \forall a, l, y \qquad (15)$$

$$\sum_{p',a \in Pac_{p'},r} \frac{pnum_{pp'} hrsreq_{lr} ASSGN_{alrp'y}}{podmult_{ap} \overline{hrs}_{ay}} \leq POD_{lpy} \qquad \forall l, p, y \qquad (16)$$

- Other Platforms

$$TRINV_{ty} = invtrn^0_t \qquad \forall t, y = 1 \qquad (17)$$

$$TRINV_{ty} = TRINV_{ty-1} + PROCTR_{ty} \qquad \forall t, y > 1 \qquad (18)$$

$$\sum_{alr} TRNRG_{alrty} \le trngcap_t TRINV_{ty} \qquad \forall t, y \qquad (19)$$

$$\sum_{l,r} hrsreq_{lr} CONT_{clry} \le \overline{hrscon_{cy}} \qquad \forall c, y \qquad (20)$$

$$\sum_{l,r} hrsreq_{lr} CONT_{clry} \ge \underline{hrscon_{cy}} \qquad \forall c, y \qquad (21)$$

$$FLEET_{fry} \le \overline{sorfleet_{fr}} \qquad \forall f, r, y \qquad (22)$$

$$\sum_{f,r} FLEET_{fry} \le maxfltsor \qquad \forall y \qquad (23)$$

- Requirements

$$\begin{aligned}&\sum_{a,l,p} evtfac_{l,r} ASSGN_{alpry} + \sum_{c,l} evtfac_{l,r} CONT_{cry} + \sum_{f} evtfacflt_{fr} FLEET_{fry} \\ &+ \sum_{a,l,t} rngmult_{art} evtfac_{l,r} TRNRG_{alrty} \le sortreq_{ry}\end{aligned} \qquad \forall r, y \quad (24)$$

$$\begin{aligned}&\sum_{a,l,p} evtfac_{l,r} effect_{apr} ASSGN_{alpry} + \sum_{c} evtfac_{l,r} coneff_{cr} CONT_{cry} \\ &+ \sum_{f} evtfacflt_{fr} flteff_{fr} FLEET_{fry} \\ &+ \sum_{a,l,t} rngmult_{art} trngeff_{art} evtfac_{l,r} TRNRG_{alrty} + \alpha^{R}_{ry} \ge sortreq_{ry}\end{aligned} \qquad \forall r, y \quad (25)$$

- Procurement and Retirement

$$RET_{aly'y} \le INV_{aly-1y'} \qquad \forall a, l, y > 1, y' < y \qquad (26)$$

$$\sum_{l,y>1} PROC_{aly} \le \sum_{(y,y')\in ProPA_a} \overline{tproclim_a} PROA_{ayy'} \qquad \forall a \qquad (27)$$

$$\sum_{l,y>1} PROC_{aly} \ge \sum_{(y,y')\in ProPA_a} \underline{tproclim_a} PROA_{ayy'} \qquad \forall a \qquad (28)$$

$$\sum_{l} PROC_{aly} \le \sum_{(y',y'')\in ProPA_a | y' \le y \le y''} \overline{proclim_{ay}} PROA_{ay'y''} \qquad \forall a, y > 1 \qquad (29)$$

$$\sum_{l} PROC_{aly} \ge \sum_{(y',y'')\in ProPA_a | y' \le y \le y''} \underline{proclim_{ay}} PROA_{ay'y''} \qquad \forall a, y > 1 \qquad (30)$$

$$\sum_{(y,y')\in ProPA_a | y' \le y} PROA_{ayy'} \le 1 \qquad \forall a \qquad (31)$$

$$\sum_{a,l,y} PROCPD_{alpy} \le \sum_{(y,y')\in ProPP_p | y' \le y} \overline{tpdproc_p} PROPD_{pyy'} \qquad \forall p \in PD \qquad (32)$$

$$\sum_{a,l,y} PROCPD_{alpy} \ge \sum_{(y,y')\in ProPP_p | y' \le y} \underline{tpdproc_p} PROPD_{pyy'} \qquad \forall p \in PD \qquad (33)$$

$$\sum_{a,l} PROCPD_{alpy} \le \sum_{(y',y'')\in ProPP_p | y' \le y \le y''} \overline{pdproc_{py}} PROPD_{py'y''} \qquad \forall y, p \in PD \qquad (34)$$

$$\sum_{a,l} PROCPD_{alpy} \ge \sum_{(y',y'')\in ProPP_p | y' \le y \le y''} \underline{pdproc_{py}} PROPD_{py'y''} \qquad \forall y, p \in PD \qquad (35)$$

$$\sum_{(y,y')\in ProPP_p | y' \le y} PROPD_{pyy'} \le 1 \qquad \forall p \in PD \qquad (36)$$

$$\sum_{l,y,y'} UPGR_{aa'lyy'} \le \sum_{(y,y')\in ProPU_{aa'}} \overline{tupproc_{aa'}} PROU_{aa'yy'} \qquad \forall a,a' \in U_a \qquad (37)$$

$$\sum_{l,y,y'} UPGR_{aa'lyy'} \ge \sum_{(y,y')\in ProPU_{aa'}} \underline{tupproc_{aa'}} PROU_{aa'yy'} \qquad \forall a,a' \in U_a \qquad (38)$$

$$\sum_{l,y'} UPGR_{aa'lyy'} \le \sum_{(y',y'')\in ProPU_{aa'} | y' \le y \le y''} \overline{upproc_{aa'y}} PROU_{aa'y'y''} \qquad \forall y,a,a' \in U_a \qquad (39)$$

$$\sum_{l,y'} UPGR_{aa'lyy'} \ge \sum_{(y',y'')\in ProPU_{aa'} | y' \le y \le y''} \underline{upproc_{aa'y}} PROU_{aa'y'y''} \qquad \forall y,a,a' \in U_a \qquad (40)$$

$$\sum_{(y,y')\in ProPU_{aa'} | y' \le y} PROU_{aa'yy'} \le 1 \qquad \forall a,a' \in U_a \qquad (41)$$

- Budget

$$\sum_{a,l,p,r} \frac{hrsreq_{lr} omcost_{ay}}{hrsovrhd_a} ASSGN_{alpry} + \sum_{a,l,r,t} \frac{hrsreq_{lr} omcost_{ay}}{hrsovrhd_a} TRNRG_{alrty} + \alpha_y^{OMB-} \ge \underline{ombud_y} \qquad \forall y \qquad (42)$$

$$\sum_{a,l,p,r} \frac{hrsreq_{lr} omcost_{ay}}{hrsovrhd_a} ASSGN_{alpry} + \sum_{a,l,r,t} \frac{hrsreq_{lr} omcost_{ay}}{hrsovrhd_a} TRNRG_{alrty} - \alpha_y^{OMB+} \le \overline{ombud_y} \qquad \forall y \qquad (43)$$

$$\begin{aligned} &\sum_{a,l,y'} pcost_{ay} PROC_{alyy'} + \sum_{a,l,p} podcost_{ap} PROCPD_{alpy} \\ &+ \sum_{a,a'\in U_a,l} ucost_{aa'y} UPGR_{aa'lyy'} + \sum_{t} trngcost_{ty} PROCTR_{ty} \\ &+ \sum_{l',y'<y} tnxrcst_a TNXR_{all'yy'} + \alpha_y^{PB-} \ge \underline{pbud_y} \end{aligned} \qquad \forall y \qquad (44)$$

$$
\begin{aligned}
&\sum_{a,l,y'} pcost_{ay} PROC_{alyy'} + \sum_{a,l,p} podcost_{ap} PROCPD_{alpy} \\
&+ \sum_{a,a' \in U_a,l} ucost_{aa'y} UPGR_{aa'lyy'} \sum_{t} trngcost_{ty} PROCTR_{ty} \\
&+ \sum_{l',y'<y} tnxrcst_{a} TNXR_{all'yy'} - \alpha_{y}^{PB+} \leq \overline{pbud_{y}}
\end{aligned}
\qquad \forall y \qquad (45)
$$

$$
\begin{aligned}
&\sum_{a,l,l<y<epy,y'} pcost_{ay} PROC_{alyy'} + \sum_{a,l,p,y<epy} podcost_{ap} PROCPD_{alpy} \\
&+ \sum_{a,a' \in U_a,l,y<epy} ucost_{aa'y} UPGR_{aa'lyy'} \sum_{t,y<epy} trngcost_{ty} PROCTR_{ty} \\
&+ \sum_{l',y<epy,y'<y} tnxrcst_{a} TNXR_{all'yy'} \leq pinjbud
\end{aligned}
\qquad (46)
$$

$$
\sum_{c,l,r} concost_{cy} hrsreq_{lr} CONT_{clry} + \alpha_{y}^{CB-} \geq \underline{conbud_{y}} \qquad \forall y \qquad (47)
$$

$$
\sum_{c,l,r} concost_{cy} hrsreq_{lr} CONT_{clry} - \alpha_{y}^{CB+} \leq \overline{conbud_{y}} \qquad \forall y \qquad (48)
$$

$$
\begin{aligned}
&\sum_{a,l,p,r} \frac{hrsreq_{lr} omcost_{ay}}{hrsovrhd_{a}} ASSGN_{alpry} + \sum_{a,l,r,t} \frac{hrsreq_{lr} omcost_{ay}}{hrsovrhd_{a}} TRNRG_{alrty} \\
&\sum_{c,l,r} concost_{cy} hrsreq_{lr} CONT_{clry} + \alpha_{y}^{TOB-} \geq \underline{tombud_{y}}
\end{aligned}
\qquad \forall y \qquad (49)
$$

$$
\begin{aligned}
&\sum_{a,l,p,r} \frac{hrsreq_{lr} omcost_{ay}}{hrsovrhd_{a}} ASSGN_{alpry} + \sum_{a,l,r,t} \frac{hrsreq_{lr} omcost_{ay}}{hrsovrhd_{a}} TRNRG_{alrty} \\
&\sum_{c,l,r} concost_{cy} hrsreq_{lr} CONT_{clry} - \alpha_{y}^{TOB+} \leq \overline{tombud_{y}}
\end{aligned}
\qquad \forall y \qquad (50)
$$

$$
\begin{aligned}
&\sum_{a,l,p,r} \frac{hrsreq_{lr} omcost_{ay}}{hrsovrhd_{a}} ASSGN_{alpry} + \sum_{a,l,r,t} \frac{hrsreq_{lr} omcost_{ay}}{hrsovrhd_{a}} TRNRG_{alrty} \\
&+ \sum_{c,l,r} concost_{cy} hrsreq_{lr} CONT_{clry} + \sum_{a,l,y'} pcost_{ay} PROC_{alyy'} \\
&+ \sum_{a,l,p} podcost_{ap} PROCPD_{alpy} + \sum_{a,a' \in U_a,l} ucost_{aa'y} UPGR_{aa'lyy'} \\
&+ \sum_{t} trngcost_{ty} TRNGPC_{ty} + \sum_{l',y'<y} tnxrcst_{a} TNXR_{all'yy'} + \alpha_{y}^{TB-} \geq \underline{bud_{y}}
\end{aligned}
\qquad \forall y \qquad (51)
$$

$$\sum_{a,l,p,r} \frac{hrsreq_{alr} omcost_{ay}}{hrsovrhd_a} ASSGN_{alpry} + \sum_{a,l,r,t} \frac{hrsreq_{alr} omcost_{ay}}{hrsovrhd_a} TRNRG_{alrty}$$
$$+\sum_{c,l,r} concost_{cy} hrsreq_{lr} CONT_{clry} + \sum_{a,l,y'} pcost_{ay} PROC_{alyy'}$$
$$+\sum_{a,l,p} podcost_{ap} PROCPD_{alpy} + \sum_{a,a' \in U_a, l} ucost_{aa'y} UPGR_{aa'lyy'}$$
$$+\sum_{t} trngcost_{ty} TRNGPC_{ty} + \sum_{l',y'<y} tnxrcst_a TNXR_{all'yy'} - \alpha_y^{TB-} \leq \overline{bud_y} \qquad \forall y \qquad (52)$$

- Non-negativity Bounds

$$\alpha_{ry}^{R} \geq 0, \ \ \alpha_{ry}^{R} \geq 0 \ \ , \alpha_{ry}^{Cap} \geq 0 \qquad \forall r, y \qquad (53)$$

$$\alpha_y^{OMB-} \geq 0, \ \alpha_y^{OMB+} \geq 0, \ \alpha_y^{TOB-} \geq 0, \ \alpha_y^{TOB+} \geq 0, \ \alpha_y^{PB-} \geq 0$$
$$\alpha_y^{PB+} \geq 0, \ \alpha_y^{UB-} \geq 0, \ \alpha_y^{UB+} \geq 0, \ \alpha_y^{TB-} \geq 0, \ \alpha_y^{TB+} \geq 0 \qquad \forall y \qquad (54)$$

- Integer Variables

$$PROC_{aly} \in Z^+ \qquad \forall a, l, y \qquad (55)$$

$$PROCPD_{alpy} \in Z^+ \qquad \forall a, l, p, y \qquad (56)$$

$$PROCTR_{ty} \in Z^+ \qquad \forall t, y \qquad (57)$$

$$UPGR_{aa'ly} \in Z^+ \qquad \forall a, a', l, y \qquad (58)$$

$$RET_{alyy'} \in Z^+ \qquad \forall a, l, y, y' \qquad (59)$$

$$TNXR_{all'y} \in Z^+ \qquad \forall a, l, l', y \qquad (60)$$

- Binary Variables

$$PROA_{ayy'} \in (0,1) \qquad \forall a, y, y' \qquad (61)$$

$$PROPD_{pyy'} \in (0,1) \qquad \forall p, y, y' \qquad (62)$$

$$PROU_{aa'yy'} \in (0,1) \qquad \forall a, a', y, y' \qquad (63)$$

$$ISINV_{aly} \in (0,1) \qquad \forall a, l, y \qquad (64)$$

D. EQUATION EXPLANATION

Constraints (1) set the initial aircraft inventory; (2) track aircraft inventory yearly; (3) track aircraft inventory yearly; (4) constrain the aircraft inventory to a maximum; (5)

constrain the aircraft inventory to a minimum; (6) set the initial flight hours; (7) track flight hours yearly; (8) constrain the flight hours by the aircraft life; (9) set the initial aircraft pod inventory; (10) track aircraft pod inventory yearly; (11) constrain the number of transfers by the available inventory; (12) constrain aircraft upgrades by the current inventory; (13) set the initial procurement amount; (14) constrain the number of aircraft transfers by the number procured; (15) constrain the maximum number of flight hours flown on each aircraft; (16) constrain the minimum number of flight hours flown on each aircraft; (17) constrain the number of sorties flown with pods by the available pods; (18) set the initial advanced training range inventory; (19) track advanced training range inventory yearly; (20) constrain the number of sorties flown on the advanced training ranges; (21) constrain the maximum flight hours flown by CAS; (22) constrain the minimum flight hours flown by CAS; (23) constrain the maximum number of sorties flown by fleet aircraft for each requirement yearly; (24) constrain the maximum total number of sorties flown by fleet aircraft yearly; (25) constrain the maximum total number of sorties from all platforms by each requirement; (26) measures any capability shortfall; (27) constrain aircraft retirement; (28) through (42) constrain the procurement of aircraft, aircraft pods and aircraft upgrades; (43) through (53) apply budget constraints; (54) and (55) define positive variables; (56) through (61) define integer variables; (62) through (65) define binary variables.

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IV. IMPLEMENTATION AND ANALYSIS

A. IMPLEMENTATION

ADSOT uses the Generalized Algebraic Modeling System (GAMS) to generate its integer linear program and CPLEX to solve it (GAMS, 2013). GAMS is a commercial modeling system specifically designed for modeling linear, nonlinear and integer linear optimization problems. ADSOT uses the CPLEX solver version 12.4.0.0 within GAMS. The model solves in less than one hour for most excursions when run on a PC (personal computer) with dual Intel(K) Xeon(R) 2.13Ghz CPU (central processing unit) and 48 GB of RAM when accepting the first solution guaranteed to be within one percent of optimal.

B. BASE CASE

All ADSOT analysis uses input gathered from multiple fleet sources and is the result of extensive coordination with several subject matter experts. Analysis of the ADSOT base case verifies that the model effectively approximates the current use of OPFOR sorties to meet training requirements. This includes assumptions regarding available ADFOR platforms and parameters such as the planned flight hour execution each year and expected overhead percentages. ADFOR airframes are also restricted to their current home base locations; therefore they cannot permanently relocate in order to realize any efficiency due to co-location of training aircraft with requirements. Procurement is limited to replacement of existing ADFOR F/A-18 aircraft with recapitalized F/A-18 aircraft on a one-for-one basis. Analysis of the base case provides an opportunity for rudimentary verification of the model. It also provides a comparison point for other excursions that allow performance improving courses of action, such as procuring new aircraft, changing the home port location of aircraft, or upgrading aircraft.

1. Base Case Assumptions

a. Training Platforms

Table 7 provides the initial aircraft and pods available for ADFOR. Note that we aggregate different variants of the F-5, F-16 and F/A-18 A-D together as a single aircraft type. The total number of aircraft available, 83, is significantly less than the value of 97 provided by TSW (see Table 1). This is due to the current decreased availability of many of the NSAWC aircraft (LCDR B. Blair, NSAWC F-16 Program Manager, personal communication, June–August, 2013).

Aircraft	Inventory by Location [a]	Pods Available [c]
F-5F/N	14 Fallon 18 Key West	12 DRFM EA Pod
F-16A/B	14 Fallon [b]	21 DRFM EA Pod [d]
F/A-18A/B	1 Fallon [b] 12 New Orleans	
F/A-18A/C	10 Oceana 6 Fallon [b]	
F/A-18E/F	8 Fallon	

[a] CNA (Price & Doll, 2012) with exception of F16

[b] NSAWC (LCDR B. Blair, NSAWC F-16 Program Manager, personal communication, June-August, 2013)

[c] TSW (Nichols, 2012)

[d] DRFM EA for F-16 and F-18 is interchangeable

Table 7. ADFOR aircraft and pods available for the base case. No upgrades or additional pods are considered.

Table 8 provides the initial parameters for the ADFOR aircraft. The "minimum hours to fly per year" is 10 percent less than the maximum hours in order to provide ADSOT some limited flexibility for scheduling while adhering to the forecast flight hour usage over the next 20-years. This constraint prevents ADSOT from grounding more expensive training platforms until they reach their flight hour limit. The "overhead hours" refers to the percentage of flight hours required for each aircraft that aren't directly related to performing a *red air* mission. These hours are typically required for training of adversary pilots, maintenance check flights on the aircraft, and transit flights where no training is accomplished. All costs are in terms of FY13 (Table 8).

Table 9 presents a sample of the capability and platform configuration matchups for the current available OPFOR. A complete list is offered in Appendix A.

Airframe Types Available	Minimum Hours to Fly per Year	Maximum Hours to Fly per Year [a]	Airframe Maximum Flight Hour Life [b]	Average Flight Hour Life Expended [c]	Overhead Hours [d]	Operations Cost per Flight Hour [e]
F-5F/N	255	284	8000	4500	40%	$6,554.00
F-16A/B	165	183	4250	2000	48%	$8,902.00
F/A-18A/B	201	224	8600	7800	36%	$10,713.00
F/A-18C/D	214	238	8600	7000	36%	$10,200.00
F/A-18E/F	242	269	6000	5000	28%	$12,723.00

[a] OPNAV 4.2 (D. Harris, OPNAV TOC Lead , personal communication, December 2012)

[b] 2013 Adversary Update Brief (Blair, 2013)

[c] TSW (Nichols, 2012) and 2013 Adversary Update Brief (Blair, 2013)

[d] CNAFR (LCDR G. Hughes, CNAFR TACAIR Program Manager, personal communication, August, 2013)

[e] CNAL/P N813/N816 (CDR R. Turner, CNAFR N8 -Requirements, personal communication, August, 2013)

Table 8. Key parameters for ADFOR aircraft. Note the high average flight hours already expended on the aircraft.

ADFOR Platform	Pod	WVR(III)	WVR(IV)	BVR	BVR(HP)	RAD(SR)	RAD(MR)	RAD(LR)	RWR-Ind	RWR	DIS	ITEMS	EA	IR	HOBS
F-5	None	1	0	1	0	1	0	0	0	0	1	0	0	0	0
F-5	**EA**	**1**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**0**
F-16	None	1	1	1	1	1	1	0	0	1	1	1	0	0	0
F-16	**EA**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**0**	**0**
F/A-18A/B	None	1	1	1	1	1	1	0	0	1	0	1	0	0	0
F/A-18A/B	**EA**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**1**	**0**	**1**	**1**	**0**	**0**
F/A-18C/D	None	1	1	1	1	1	1	0	0	1	0	1	0	0	0
F/A-18C/D	**EA**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**1**	**0**	**1**	**1**	**0**	**0**
F/A-18E/F	None	1	1	1	1	1	1	0	0	1	0	1	0	0	1
F/A-18E/F	**EA**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**1**	**0**	**1**	**1**	**0**	**1**
F/A-18E/F+AESA	None	1	1	1	1	1	1	1	0	1	0	1	0	0	1
F/A-18E/F+AESA	**EA**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0**	**1**	**0**	**1**	**1**	**0**	**1**
CAS Platforms															
CASII		**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**
CASII+EW		0	0	1	0	1	0	0	0	0	1	0	1	0	0
CASIII		**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**
CASIV		0	0	1	1	1	0	0	1	0	1	0	0	0	0
Fleet Platforms															
FLT_18C		**1**	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**1**
FLT_18E		1	1	1	1	1	1	0	0	1	0	1	0	0	1

Table 9. Matrix of training platform configuration (row) and capability (column) matchups (a value of one denotes that the platform configuration is capable of performing the requirement capability).

Figure 10 depicts the matrix of training utilities for each requirement bin. These values are weighted to reflect the author's judgment regarding the relative importance of each capability and requirement pairing. As an example, reference Table 9 to see that a base F-5 (F-5 none) is capable of the following capabilities; WVR(III), BVR, RAD(SR) and DIS. When performing a B2 training requirement, an F-5 achieves a training utility of 85 percent (25%+35%+20%+5%). The same aircraft only achieves a training utility of 70 percent (25%+25%+15%+5%) for executing a C2 training requirement.

	WVR(III)	WVR(IV)	BVR	BVR(HP)	RAD(SR)	RAD(MR)	RAD(LR)	RWR Ind	RWR	DIS	ITEMS	EA	IR	HOBS
A2	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
A3	0%	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	50%	0%	0%
B1	55%	30%	0%	0%	5%	0%	0%	0%	0%	5%	5%	0%	0%	0%
B2	25%	10%	35%	0%	20%	0%	0%	0%	0%	5%	5%	0%	0%	0%
C1	40%	25%	0%	0%	5%	0%	0%	5%	5%	5%	5%	0%	0%	10%
C2	25%	5%	25%	5%	15%	0%	0%	5%	5%	5%	5%	0%	0%	5%
C3	5%	10%	10%	10%	10%	0%	0%	5%	5%	5%	5%	25%	0%	10%
D1	15%	15%	15%	15%	5%	10%	0%	5%	5%	5%	5%	0%	0%	5%
D2	5%	5%	10%	10%	5%	5%	0%	5%	5%	5%	5%	35%	0%	5%
D3	5%	5%	10%	5%	5%	5%	0%	5%	5%	5%	5%	20%	20%	5%
E1	10%	5%	15%	15%	5%	10%	15%	5%	5%	5%	5%	0%	0%	5%
E2	5%	5%	10%	10%	5%	5%	10%	5%	5%	5%	5%	25%	0%	5%
E3	0%	0%	10%	10%	5%	5%	5%	5%	5%	5%	5%	20%	20%	5%

Figure 10. Matrix of percentage of training accomplished for each Requirement Bin (row) compared to each training platform capability (column).

ADSOT implements parameters for CAS flight hour costs and contracted flight hour usage. Actual values are not published in this thesis, as the specific details regarding CAS contracts are proprietary. Estimates for the values are provided by CNA (Huntzinger et al., 2011) as follows:

- CAS type 2 approximately $5,000 CPH;
- CAS type 3 approximately $9,000 CPH; and
- CAS type 4 approximately $11,500 CPH.

For the base case, ADSOT uses the limits from Naval Air Systems Command (NAVAIR) request for proposal (NAVAIR, 2011b). Specifically, up to 4,000 hours annually for high subsonic aircraft (third generation) and 1,400 hours annually for supersonic aircraft (fourth generation), including provisions for EA.

ADSOT assumes two types of fleet aircraft capable of meeting the demand for *red air* training: F/A-18A/C and F/A-18E/F. ADSOT penalizes fleet aircraft in order to incentivize the use of ADFOR and CAS before fleet aircraft. Table 10 provides CPH data for fleet aircraft.

Fleet Aircraft CPH		
F/A-18 A-D Hornet	$	10,937
F/A-18 E/F Super Hornet	$	9,388

Table 10. CPH for fleet aircraft flying in the *red air* roll for the base case ADSOT runs. (CDR R. Turner, CNAFR N8 – Requirements, personal communication, August 2013)

b. Sorties and Events

Table 11 depicts the event factors and the average sortie length by training location. These values are aggregated from two CNA studies (Huntzinger et al., 2011; Price & Doll, 2012) and inputs from SMEs.

Training Location	Multiple Event Factor (Events/Sortie)	Average Sortie Length (Hours)
Fallon	1.3	1.25
Key West	1.5	1.19
Lemoore	1.1	1.26
Oceana	1.6	1.26
San Diego	1	1.5

Table 11. Event factor and average sortie length based on the location where the training is being conducted.

c. Requirements

Table 12 provides the number of adversary events required for each training phase and location pair. For the base case ADSOT uses adversary event requirement data as compiled by CNA (Huntzinger et al., 2011), including counts of total number of events. for each training phase and requirement bin.

	A2	A3	B1	B2	C1	C2	C3	D1	D2	D3	E1	E2	E3
SFARP-Fallon	-	-	-	746	-	523	150	224	-	-	149	-	-
CVW-Fallon	80	-	36	324	-	324	68	-	-	80	-	64	-
SFTI-Fallon	-	-	144	-	452	1,478	-	-	-	1,536	-	-	936
SFARP-Key West	-	-	-	746	-	523	150	224	-	-	149	-	-
FRS-Oceana	1,096	-	1,115	236	-	-	-	-	-	-	-	-	-
FRS-Lemoore	1,096	-	1,115	236	-	-	-	-	-	-	-	-	-
FRS-Key West	-	-	-	-	-	5,392	-	-	-	-	-	-	-
SFWT-Oceana	**192**	**74**	-	**1,238**	-	**1,324**	-	**1,178**	**319**	**160**	**178**	**30**	**29**
SFWT-Lemoore	**192**	**74**	-	**1,238**	-	**1,324**	-	**1,178**	**319**	**160**	**178**	**30**	**29**
ULT-Oceana	-	-	-	-	-	**210**	**1,950**	-	**1,050**	-	-	-	-
ULT-Lemoore	-	-	-	-	-	**210**	**1,950**	-	**1,050**	-	-	-	-
LFE-Oceana	**131**	-	-	-	-	**65**	-	-	-	-	-	-	-
LFE-San Diego	**131**	-	-	-	-	**65**	-	-	-	-	-	-	-
Total	**2,918**	**148**	**2,410**	**4,764**	**452**	**11,438**	**4,268**	**2,804**	**2,738**	**1,936**	**654**	**124**	**994**
	Total Core Event				**19392**		**Total Non-Core Event**					**16256**	

Table 12. Number of annual adversary events required for each training phase and location, sorted into different requirement bins. Shaded rows denote the core training phase events (After Huntzinger et al., 2011)

d. Training Platform Capabilities

Table 13 provides the aggregated training utility provided by each adversary training platform configuration used in the base case.

e. Procurement, Upgrades and Transfers

The ADSOT base case model limits ADFOR procurement options to the replacement of aging NSAWC and RC F/A-18s with newer, recapitalized F/A-18E and F/A-18C aircraft previously used by the fleet. The procurement of these assets is strictly regulated to mirror their expected procurement based on the timeline provided in Figure 4. Specifically, this planned procurement amounts to $360M for recapitalization of 36 F/A-18 aircraft in ADSOT. For clarity purposes, this amount is referred to as "planned procurement." Aircraft upgrades and the procurement of new pods are not allowed in the base case model. Aircraft transfers are also not allowed in the base case model.

f. Penalties

For the base case penalties are adjusted so that the completion of core phase training events are at a higher priority than non-core phase training events. A penalty is also added for using fleet aircraft prior to exhausting sortie capacity of ADFOR and CAS. All penalties are discounted for years later in the planning horizon.

ADFOR	A2	A3	B1	B2	C1	C2	C3	D1	D2	D3	E1	E2	E3
F-5F/N	1.00	0.50	0.65	0.85	0.50	0.70	0.30	0.40	0.25	0.25	0.35	0.25	0.20
F-5F/N+EA	1.00	1.00	0.65	0.85	0.50	0.70	0.55	0.40	0.60	0.45	0.35	0.50	0.40
F-16A/B	1.00	0.50	1.00	1.00	0.85	0.90	0.60	0.90	0.55	0.50	0.75	0.55	0.45
F-16A/B+EA	1.00	1.00	1.00	1.00	0.85	0.90	0.85	0.90	0.90	0.70	0.75	0.80	0.65
F/A-18A/B	1.00	0.50	0.95	0.95	0.80	0.85	0.55	0.85	0.50	0.45	0.70	0.50	0.40
F/A-18A/B+EA	1.00	1.00	0.95	0.95	0.80	0.85	0.80	0.85	0.85	0.65	0.70	0.75	0.60
F/A-18C/D	1.00	0.50	0.95	0.95	0.80	0.85	0.55	0.85	0.50	0.45	0.70	0.50	0.40
F/A-18C/D+EA	1.00	1.00	0.95	0.95	0.80	0.85	0.80	0.85	0.85	0.65	0.70	0.75	0.60
F/A-18E/F	1.00	0.50	0.95	0.95	0.90	0.90	0.65	0.90	0.55	0.50	0.75	0.55	0.45
F/A-18E/F+EA	1.00	1.00	0.95	0.95	0.90	0.90	0.90	0.90	0.90	0.70	0.75	0.80	0.65
F/A-18E/F+AESA	1.00	0.50	0.95	0.95	0.90	0.90	0.65	0.90	0.55	0.50	0.90	0.65	0.50
F/A-18E/F+AESA+EA	1.00	1.00	0.95	0.95	0.90	0.90	0.90	0.90	0.90	0.70	0.90	0.90	0.70
CAS													
CAS II	1.00	0.50	0.10	0.60	0.10	0.45	0.25	0.25	0.20	0.20	0.25	0.20	0.20
CAS II +EA	1.00	1.00	0.10	0.60	0.10	0.45	0.50	0.25	0.55	0.40	0.25	0.45	0.40
CAS III	1.00	0.50	0.05	0.40	0.05	0.30	0.15	0.20	0.15	0.15	0.20	0.15	0.15
CAS IV	1.00	0.50	0.10	0.60	0.15	0.55	0.40	0.45	0.35	0.30	0.45	0.35	0.35
FLEET													
F/A-18C	1.00	0.50	0.95	0.95	0.90	0.90	0.65	0.90	0.55	0.50	0.75	0.55	0.45
F/A-18E/F	1.00	0.50	0.95	0.95	0.90	0.90	0.65	0.90	0.55	0.50	0.75	0.55	0.45

Table 13. OPFOR training utilities for the training platforms available in the base case. A complete list is available in Appendix A.

2. Base Case Results

As prescribed by ADSOT, Figures 11 and 12 show the percentage of training met by each OPFOR platform in the base case for FY15 and FY33 (two of the 20 years available).

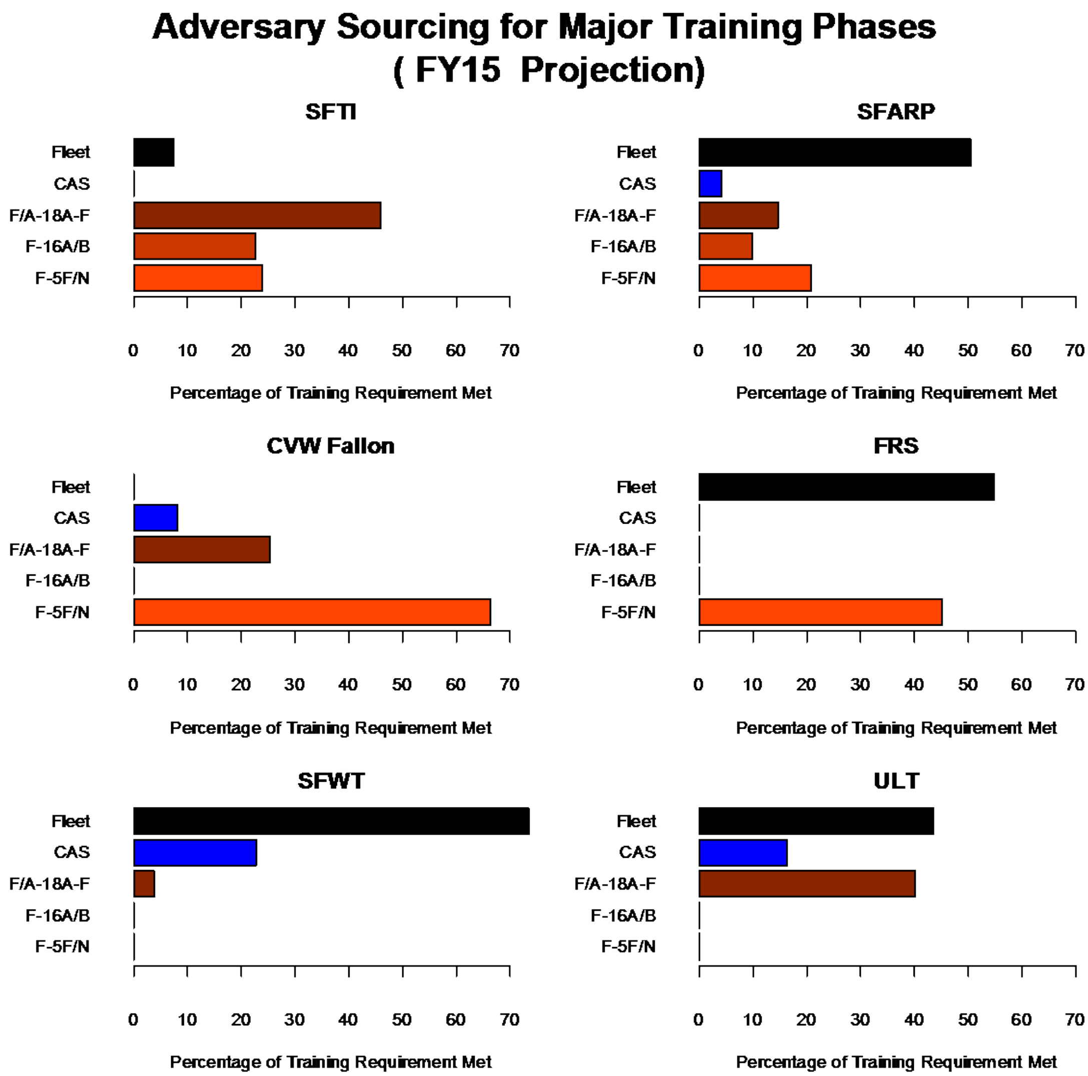


Figure 11. Depiction of predicted sources of adversary support ADSOT prescribes for the base case in FY15. The percentage of training met by each different OPFOR is shown. Note that the ADFOR aircraft are broken down into three separate categories, F-5F/N, F-16A/B and F/A-18A-F.

In FY15, ADSOT prescribes ADFOR F-5s and fleet aircraft with the vast majority of the training as they have the greatest number of sorties to allocate. We also see a concentration of F/A-18 and F-16 aircraft in the training phases that typically have the greatest number of more advanced training requirements (those denoted as D1 or above), such as SFTI and CVW Fallon.

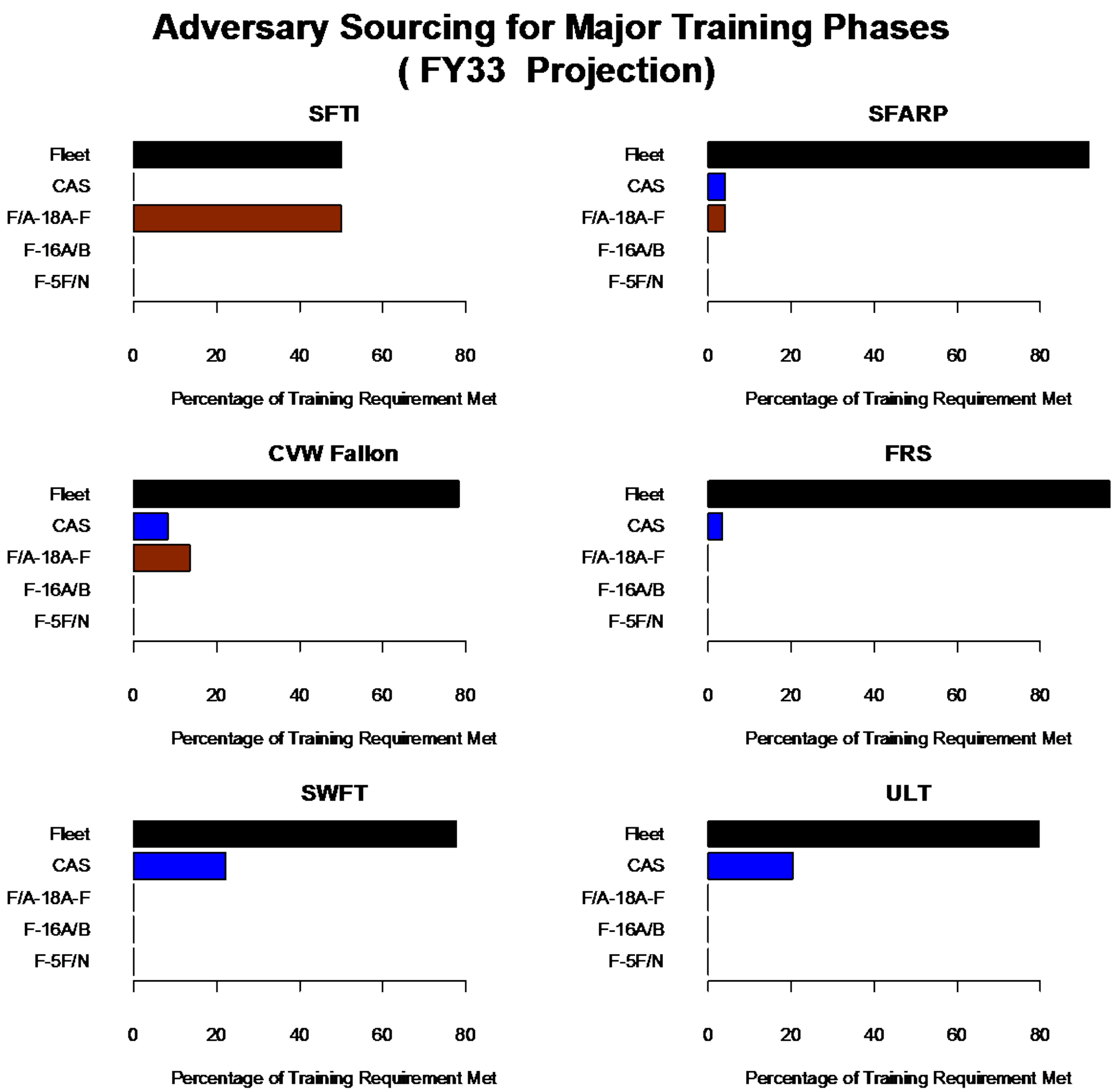


Figure 12. Depiction of sources of adversary support ADSOT prescribes for the base case in FY33. The percentage of training met by each different OPFOR is shown.

In FY33 (Figure 12) no training is completed by F-5s or F-16s. This is because we have reached the flight hour limits for both these aircraft and no longer have any in the inventory. This is a likely consequence of a lack of ADFOR procurement.

Figure 13 depicts the ADFOR aircraft inventory over the 20-year planning horizon. For the base case ADSOT prescribes the retiring of NSAWC and RC F/A-18A/B and F/A-18A/C aircraft beginning in FY17. ADSOT replaces these aircraft by recapitalizing fleet F/A-18E/F Super Hornets, including some equipped with the AESA radar system. The schedule of retiring and procuring aircraft is slightly optimistic when compared to Figure 4 (Nichols, 2012), however, ADSOT determines this is possible under current business practices and proposed future flight hour usage.

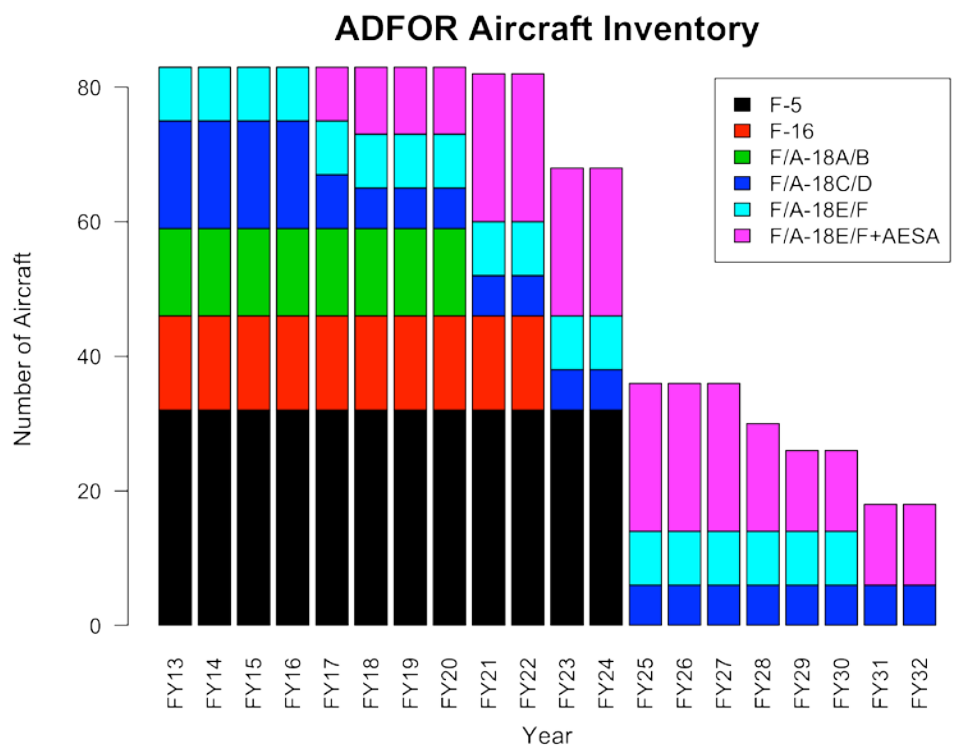


Figure 13. Depiction of ADFOR aircraft inventory ADSOT prescribes by type for the base case over the 20-year planning horizon. There exists no plan to replace aging F-5 and F-16 aircraft. F/A-18 aircraft are replaced eventually with AESA equipped F/A-18E/F.

As prescribed by ADSOT in the base case, Figure 14 shows the training utility by requirement bins for three different glimpses into the planning horizon, FY15, FY20, and FY25 (three of the 20 years available). The less rigorous training requirements (towards left) are met at 100 percent training utility or close to it. The more advanced training requirements (towards right) are met at significantly less training utility, sometimes close to 60 percent. Figure 14 also shows that in many cases the training utility is actually going up over time. This is a result of the fact that as aging aircraft, such as the F-5, are retiring, more technologically advanced fleet assets are performing a greater share of the training.

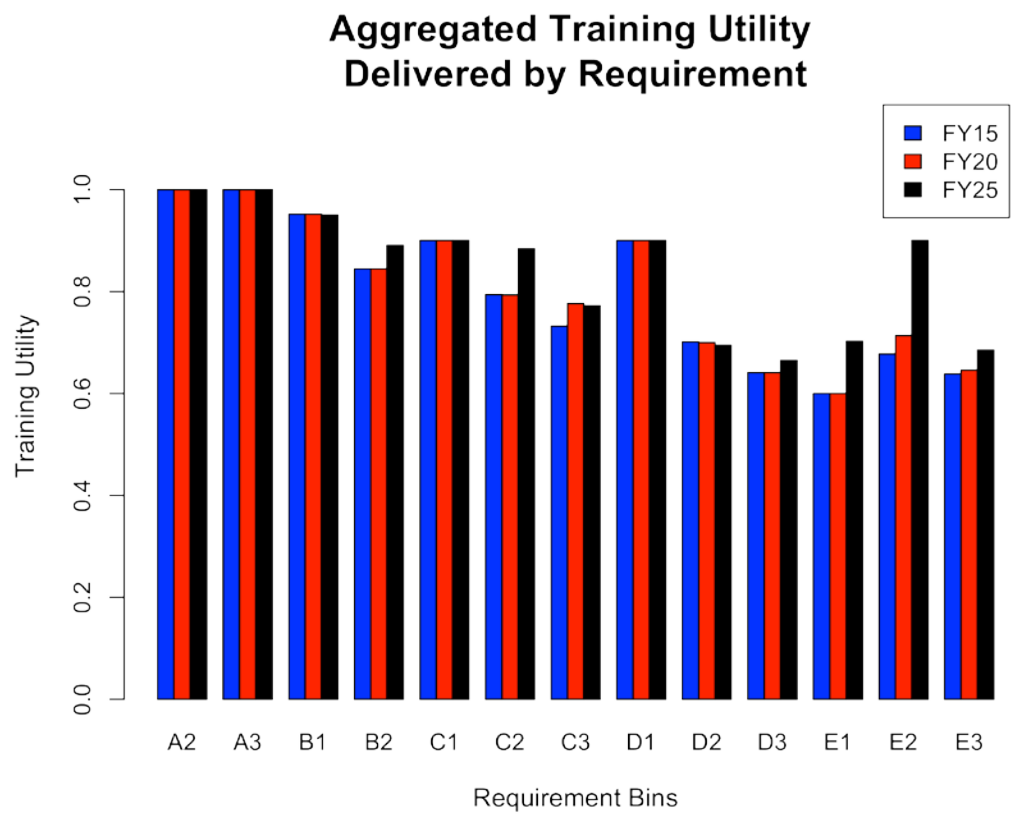


Figure 14. Graph of training utility across the different requirement bins for FY15, FY20 and FY25 as prescribed by ADSOT in the base case. As older (less capable) aircraft are retired the training utility actually goes up over time as more advanced fleet aircraft and new ADFOR F/A-18E/F fill the gap.

Figure 15 depicts the annual flight hour usage of the ADFOR aircraft as compared to the fleet as prescribed by ADSOT in the base case. The fleet flight hour usage climbs as the size of the ADFOR shrinks and more adversary training is accomplished using *organic red air*.

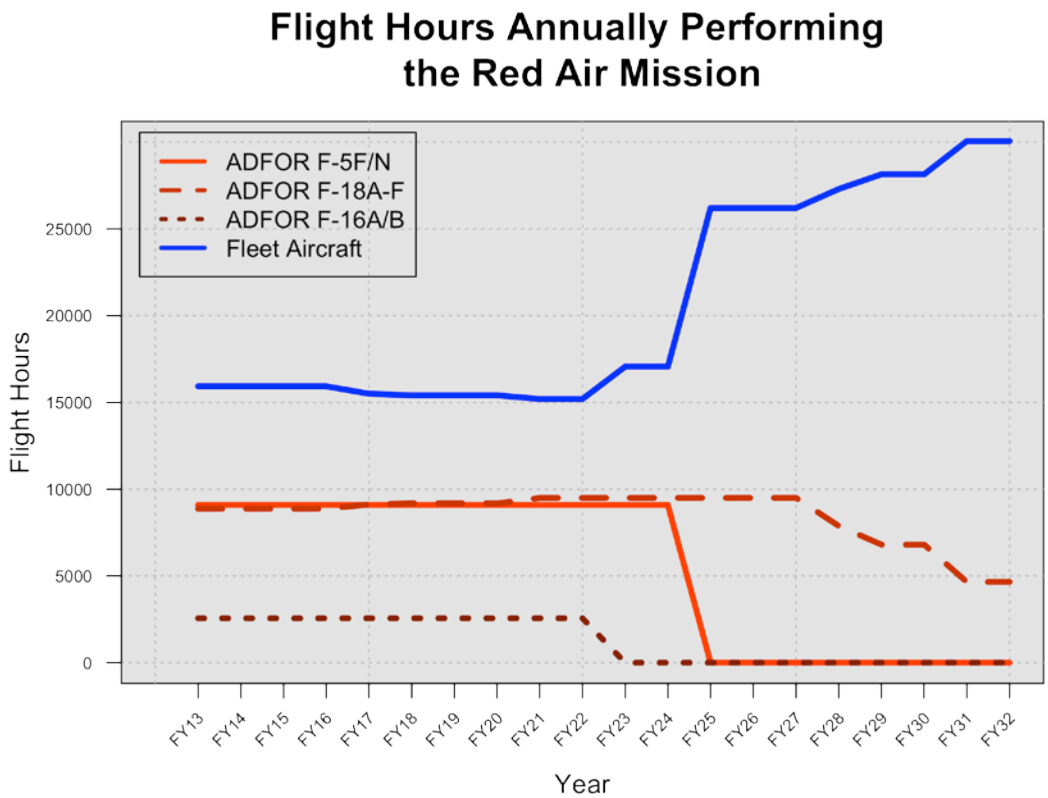


Figure 15. Projected hours flown by fleet and ADFOR assets performing the *red air* mission as prescribed by ADSOT for the base case.

Figure 16 shows the total operating cost for the ADSOT prescriptions over the 20-year planning horizon. Initially the cost is fairly level at $380M and begins a shallow decrease until FY24 as aging, more expensive, F/A-18 aircraft are retired. When the F-5 aircraft retire in FY24 the cost increases to just short of $400M as more expensive fleet aircraft are forced to cover the gap in training.

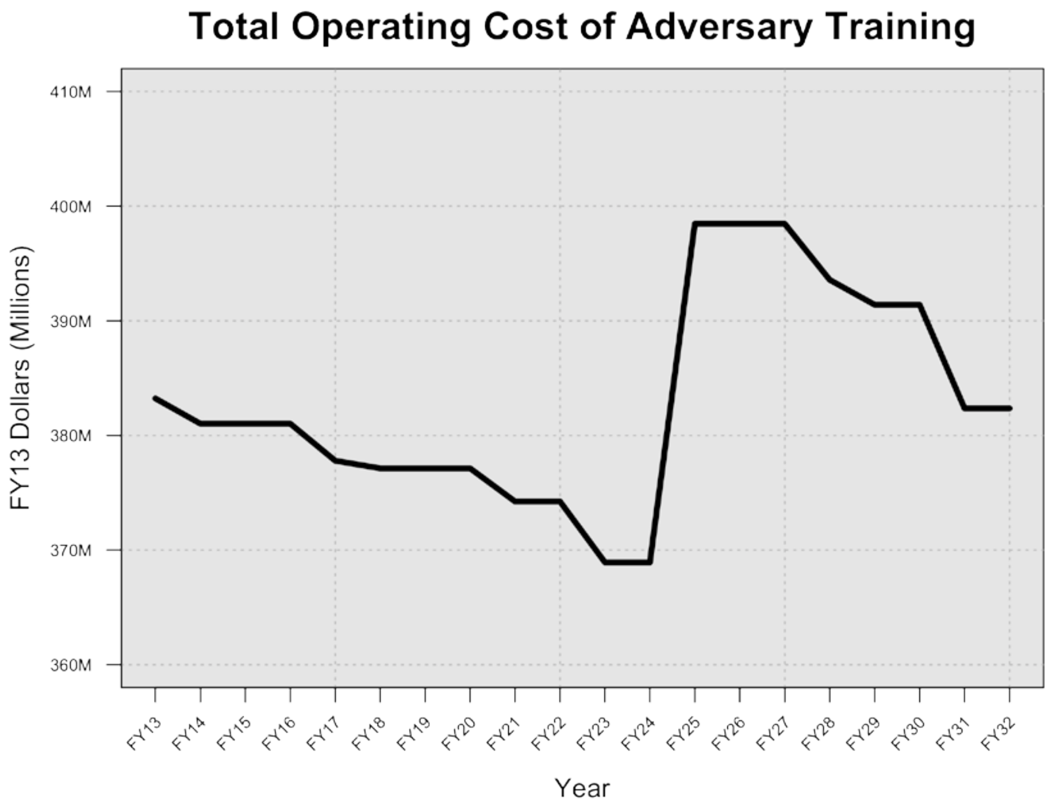


Figure 16. Total operating cost for ADSOT prescriptions over the 20-year planning horizon.

C. PROCUREMENT INJECT EXCURSIONS

For the procurement inject excursions we expand on the base case by adding the possibility of three different procurement inject amounts; $100M, $200M and $300M. These amounts are in addition to the base case planned procurement dollars of $360M for recapitalization of fleet assets. We limit procurement options to new ADFOR aircraft, ADFOR upgrades and ADFOR pods. The planned procurement of re-capitalized F/A-18 aircraft to replace aging aircraft on a one-for-one basis is relaxed so those monies can be applied to other airframes, pods or upgrades. These planned procurement amounts are not reflected as part of the additional procurement inject, therefore, the $100M inject excursion has $100M+$360M=$460M available for procurement. Constraints regarding the fixed home base locations of ADFOR aircraft are also relaxed. Most of the parameters used in the base case remain the same, however, in specific instances detailed below, we change the parameters to account for the procurement inject. The apportionment of the procurement inject is an ADSOT optimization result.

1. Procurement Inject Excursion Assumptions

a. Procurement, Upgrades and Transfers

Table 14 provides the list of aircraft procurement options and applicable data. Costs for the F-16 is for a brand new aircraft, while both F-5 and F/A-18 aircraft are based on the ability to recapitalize "used" aircraft. In the case of the F-5s, these could possibly be acquired from the Swiss as was the previous batch (NAVAIR, 2009). It is assumed that the F/A-18s are prior fleet assets that can be transferred to the ADFOR. There is currently a plan in place to do this beginning in year FY17 (Nichols, 2012). This explains the "average hours expended" in Table 14. These are the hours on the aircraft already flown when received by the ADFOR.

ADSOT replicates standard multi-year procurement contracts, including maximum and minimum procurement limits, in terms of number of aircraft, on both an annual basis and throughout the total life of the contract. For all excursions in this thesis, if a procurement contract is executed, the minimum procurement is set at one and the maximum at 50 for both the annual and total limits.

In this implementation ADSOT allows transfer of ADFOR aircraft to new or alternate locations in order to realize efficiencies of locating the ADFOR closer to the training location.

Aircraft Procurement Options	Average Hours Expended	Overhead Hours	Operations Cost per Flight Hour	Procurement Costs
F-5F/N	3000	40%	$6,554.00	$ 4,000,000
Block 50 F-16	0	48%	$10,302.00	$ 50,000,000
F-18E/F AESA	3000	38%	$3,000.00	$ 10,000,000

Table 14. Aircraft procurement options available for the procurement inject excursion and appropriate parameters. Limited and conflicting data is available regarding procurement costs. These values are estimates (After SMEs).

Table 15 shows the different Pod and aircraft upgrade procurement options with appropriate costs. The procurement cost data is adapted from the CNA study in 2012 (Price & Doll, 2012). Note that the "# of pod required per aircraft" refers the ability to move pods from one aircraft to another in order to improve effectiveness. A lower number indicates a pod that can be moved.

Pod and Upgrade Procurement Options (Compatible Aircraft)	# Required per Aircraft	Procurement Costs
EA (F-5)	1	$ 640,000
EA (F-16 & F/A-18)	0.5	$ 645,000
Sleeper (F-5)	0.5	$ 500,000
Sleeper (F-16 & F/A-18)	0.5	$ 500,000
IR (F-16 & F/A-18)	0.5	$ 2,000,000
HMS (F-5)	1	$ 550,000
HMS (F-16)	1	$ 1,000,000
R3 (F-5)	1	$ 7,000,000
R3 (F-16)	1	$ 10,000,000

Table 15. Pod and aircraft upgrade procurement options available and appropriate parameters. (After Price & Doll, 2012)

2. Procurement Inject Excursion Results

Figure 17 shows the total procurement prescribed by ADSOT over the planning horizon for the three different inject amounts in the procurement inject excursion. With the base case procurement constraints relaxed regarding the recapitalized F/A-18 aircraft, ADSOT prescribes less procurement of those aircraft in favor of the less expensive F-5 Tiger II until reaching the $300 million mark. This is because of the relative low CPH of the F-5. At all three procurement levels, pod prescriptions are the same. The only prescribed upgrades are for the HMS systems, which occur at the $300 million level. With the exception of the base case, the ADSOT prescribed procurements are nested in that each prescribed procurement is a subset of procurements prescribed for greater inject amounts. Each procurement inject also shares the fact ADSOT elects to transfer F/A-18 aircraft from New Orleans LA, to Lemoore CA, Oceana VA and Key West FL. This is in addition to adding F-5 aircraft at both locations and moving some F-16 aircraft to Key West from Fallon.

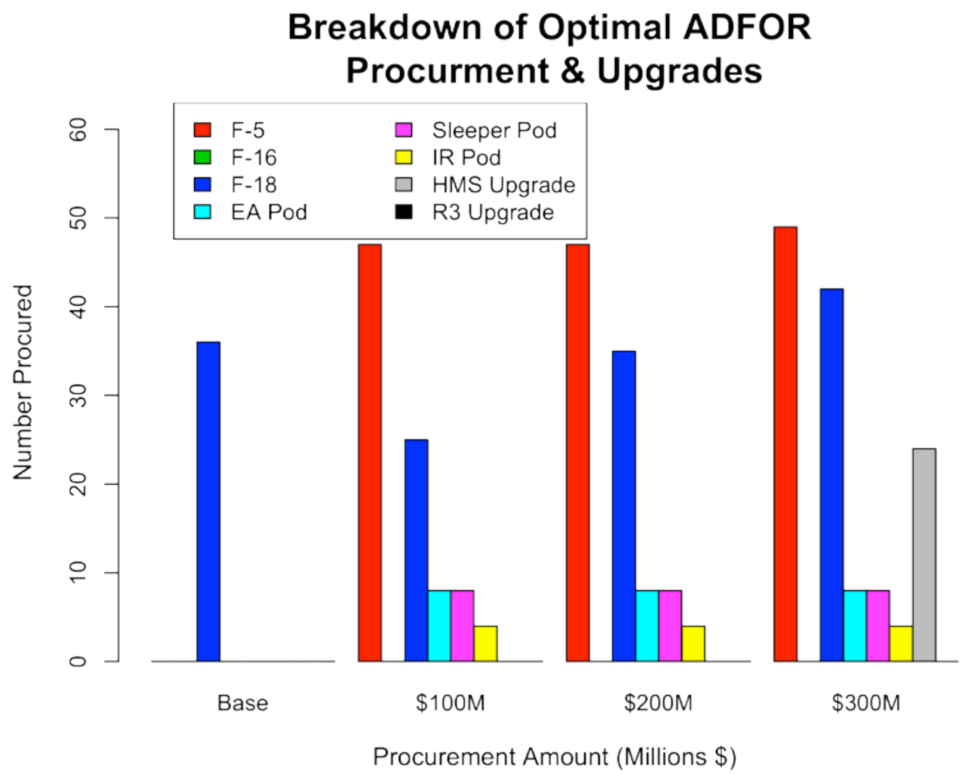


Figure 17. Procurement and upgrades prescribed by ADSOT for four different procurement inject amounts in the procurement inject excursion.

These ADSOT procurements prescribed vary significantly from those found by CNA in their study (Price & Doll, 2012). CNA found that R3 (radar systems) upgrades on the aircraft make the biggest impact on improving performance of the ADFOR fleet, followed by HMS and EA upgrades. These differences are due primarily to the fact that CNA didn't consider procurement of new or recapitalized aircraft in their study. CNA also quantified the training utility differently than ADSOT. More weight is given in the CNA study to R3 capability as a single factor. ADSOT is more granular and uses five capabilities that together equate to R3, which gives more "partial" credit to some airframes.

Figure 18 is the resulting training utility values by requirement bin for the $300M procurement level prescribed by ADSOT. As expected, by procuring additional aircraft, pods and upgrades, the training utility goes up. In the case of the E3 bin, we have risen from a value of approximately 65 percent in the base case (see Figure 14) to a value approaching 90 percent. That is close to a 40 percent increase in the training utility for that requirement bin. We see similar increases in most other bins with the exception of D2, which has dropped slightly. This is because the D2 requirements occur during SFWT and ULT training which are a slightly lower priority than the core events.

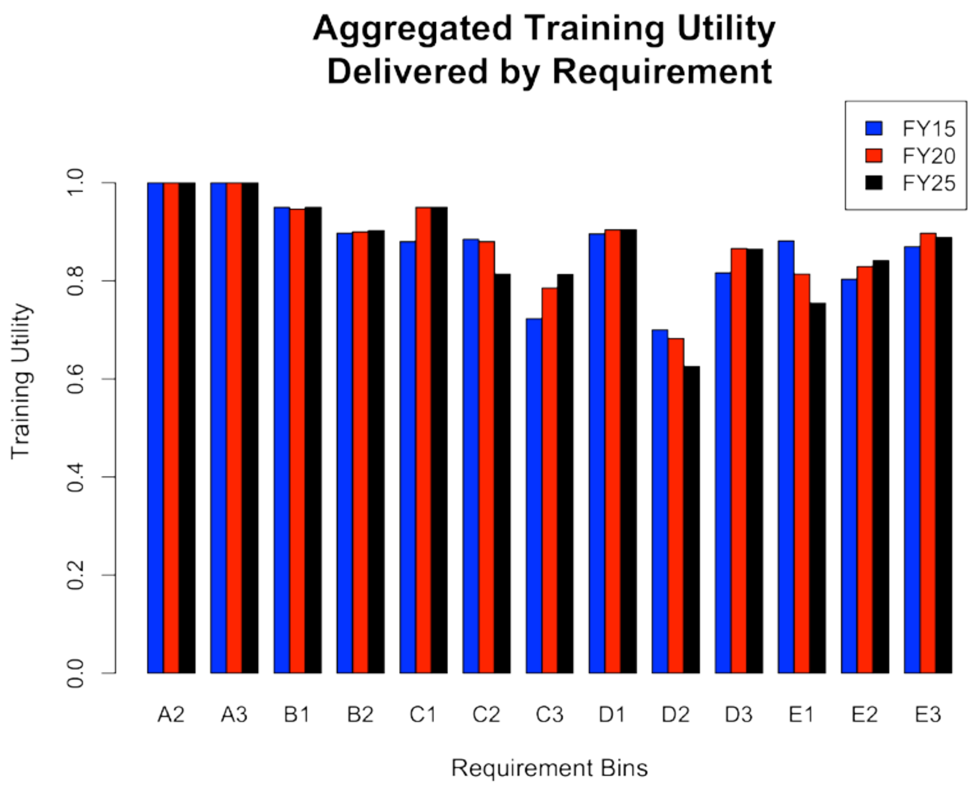


Figure 18. Aggregated training utility by requirement bin as prescribed by ADSOT with a $300 million procurement inject allowed.

Figure 19 is the annual projected aggregated training utility by year as prescribed by ADSOT in the procurement inject excursion. In the case of all procurement injects we see a rise in the projected training utility.

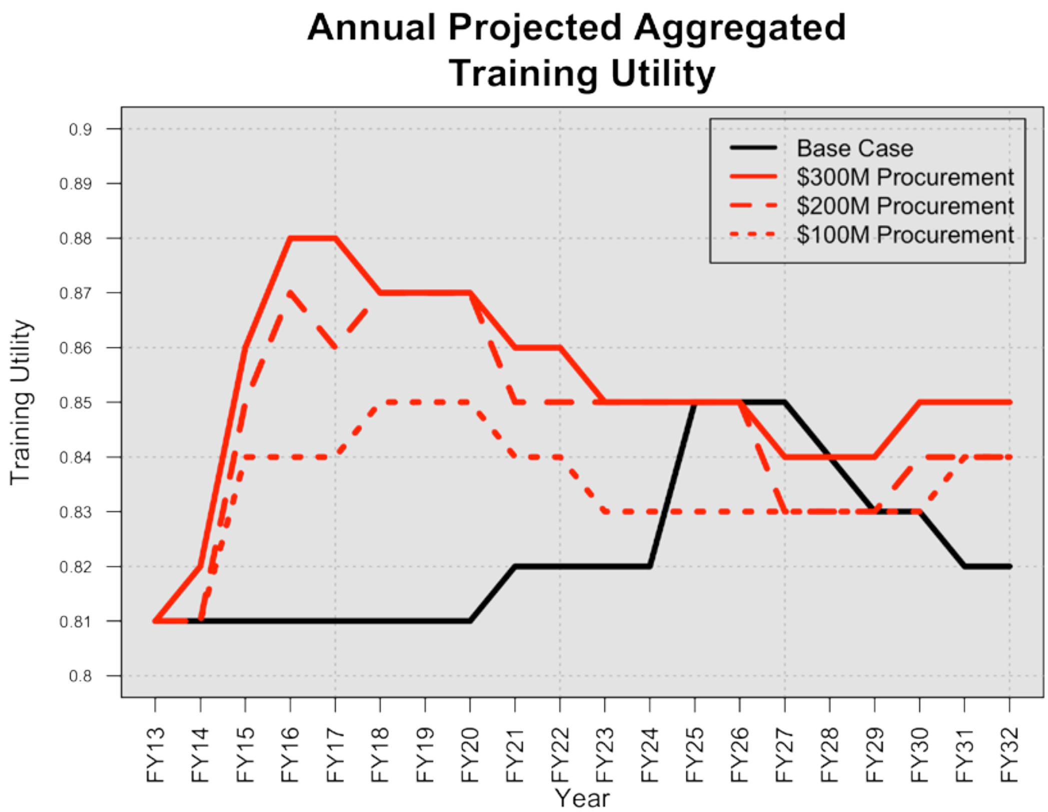


Figure 19. Annual aggregated training utility prescribed by ADSOT in the procurement inject excursion. All procurement injects raise the training utility significantly over the first 11 years of the planning horizon.

Figure 20 shows the fleet flight hours flown as *red air* over the 20-year planning horizon for the base case and each inject amount. With the ability to procure more ADFOR aircraft there is a substantial reduction in fleet hours. Consider the $100 million inject level. ADSOT prescribes the procurement of 47 F-5 aircraft, 25 F/A-18 aircraft (recapitalized from the fleet) and 20 performance enhancing pods. Compared to the base case, which only allows for the recapitalization of 36 F/A-18 aircraft, the $100M inject excursion prescribes an additional 36 ADFOR aircraft. The higher sortie capacity of the ADFOR, coupled with better F-5 performance using pods, results in fewer hours flown on fleet aircraft (Figure 20), and higher training utility achieved (Figure 19).

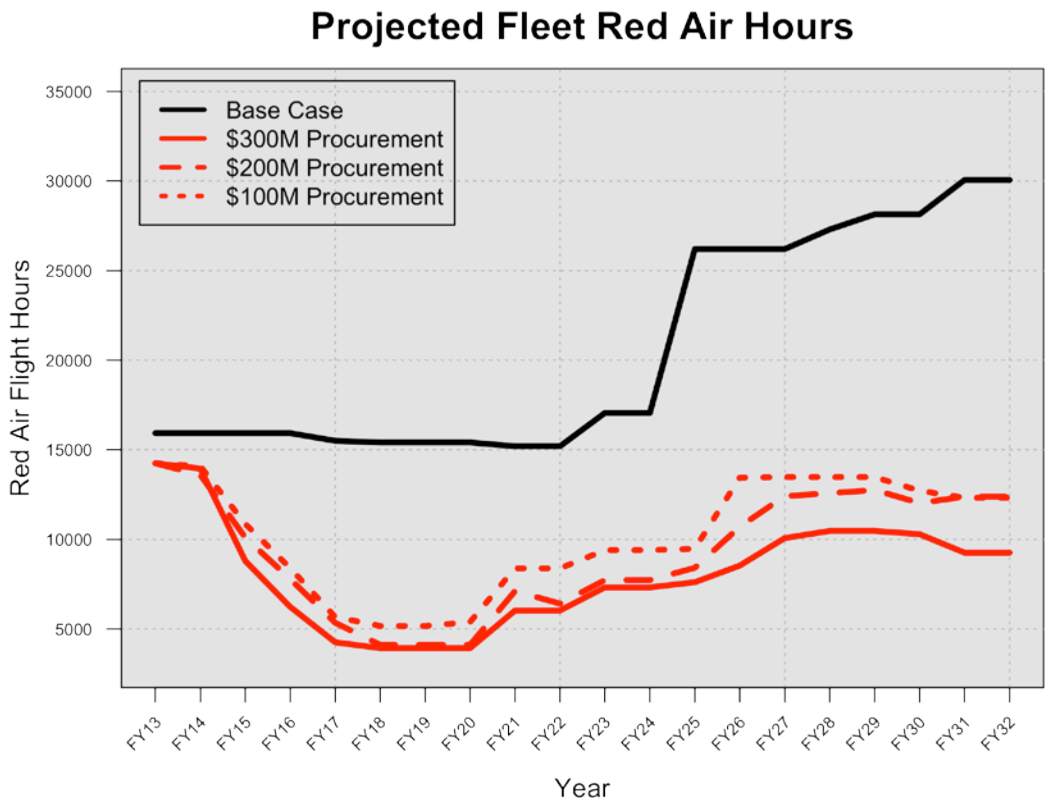


Figure 20. Fleet hours expended performing the *red air* mission as prescribed by ADSOT in the procurement inject excursions. Even at the procurement level of $100 million there is substantial flight hour savings.

Figure 21 shows the total operating cost for all adversary training. This is the sum of the operating cost of the ADFOR, CAS and fleet aircraft flying in the adversary role. In the first few yeas the cost is lower than the base case, even before the procurement. This is because ADSOT optimizes over the entire planning period, placing a premium on training utility when compared to operating cost. With more ADFOR assets available in the future it can be more efficient with the sortie assignments in the early years while maximizing the training utility values. Specifically, F-5 hours can be applied more liberally and operated at a lower cost. Eventually, the cost rises to above that of the base case in all procurement scenarios because of the increased flying of the expensive high flight time aircraft in an effort to maximize the training utility. As with the base case, when the more expensive, aging F/A-18 aircraft reach their flight hour limit and are retired we see the operating cost drop.

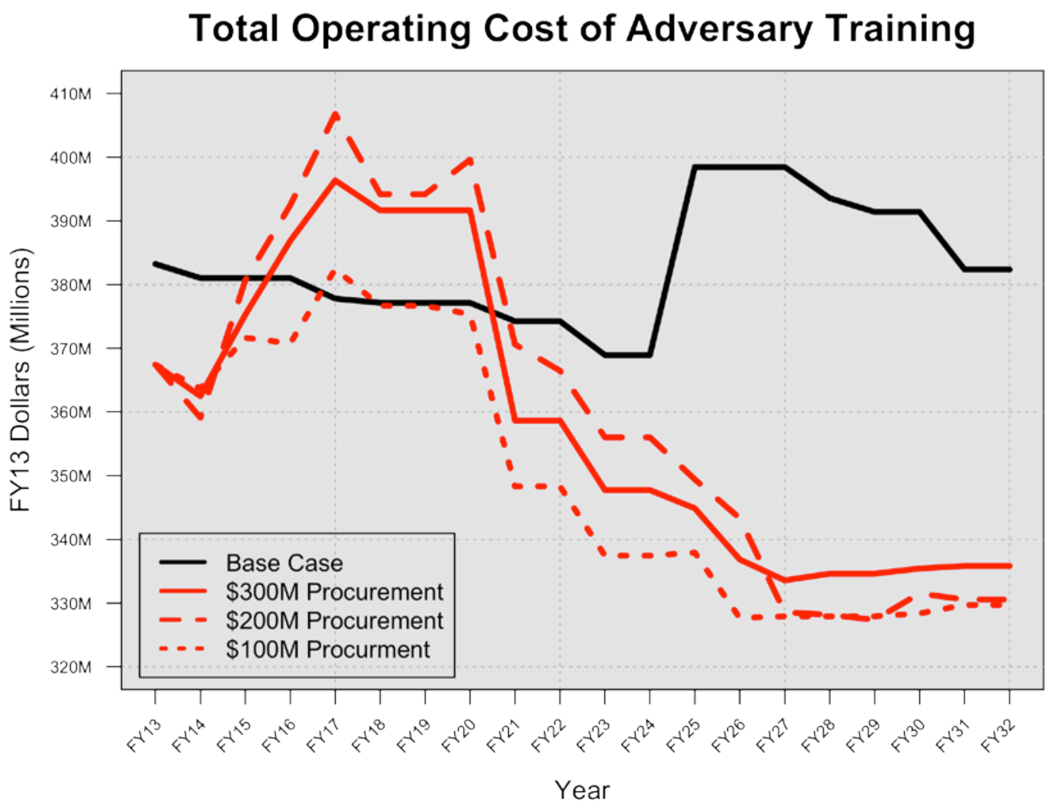


Figure 21. Total operating cost for adversary training. Includes the cost of ADFOR, CAS and fleet aircraft flying in the adversary role.

ADSOT shows that procurement injects and transfers of ADFOR aircraft to different locations improve training utility values, while lowering operating costs and the flight hour usage of the fleet. For the $300M procurement inject, the training utility value rose by as much as seven percent for some years. The total cost to provide training over the entire planning horizon dropped by $490M, resulting in a net savings of $490M-$300M=$190M. Finally, over 250,000 flight hours are saved on fleet aircraft.

D. RELAXED CONSTRAINT EXCURSION

The ADSOT base case constrains ADFOR annual minimum flight hour usage to 10 percent below the budgeted usage by OPNAV. As a result, we see in Figure 21 that the operating cost of the ADFOR initially increases when procurement options are pursued as older, more expensive aircraft are utilized. This is despite the fact that those aircraft may not be the most efficient or cost effective training platform to meet the training requirement. The base case also constrains the location of ADFOR aircraft to their current bases. In the relaxed constraint excursion, these flight hour usage and aircraft location constraints are relaxed along with conditions regarding the planned procurement.

1. Relaxed Constraint Excursion Assumptions

a. Training Platforms

Table 16 provides the updated ADFOR parameters to use in this excursion. The "minimum hours to fly per year" and "maximum hours to fly per year" data has been altered from the base case to reflect a hypothetical lower and upper bound of 20 percent and 120 percent of the budgeted flight hour amounts used in the base case.

Airframe Types Available	Minimum Hours to Fly per Year	Maximum Hours to Fly per Year [a]	Airframe Maximum Flight Hour Life [b]	Average Flight Hour Life Expended [c]	Overhead Hours [d]	Operations Cost per Flight Hour [e]
F-5F/N	56	340	8000	4500	40%	$6,554.00
F-16A/B	36	220	4250	2000	48%	$8,902.00
F/A-18A/B	44	268	8600	7800	36%	$10,713.00
F/A-18C/D	47	286	8600	7000	36%	$10,200.00
F/A-18E/F	53	322	6000	5000	28%	$12,723.00

OPNAV 4.2 (D. Harris, OPNAV TOC Lead , personal communication, December 2012)

[b] 2013 Adversary Update Brief (Blair, 2013)

[c] TSW (Nichols, 2012) and 2013 Adversary Update Brief (Blair, 2013)

[d] CNAFR (LCDR G. Hughes, CNAFR TACAIR Program Manager, personal communication, August, 2013)

[e] CNAL/P N813/N816 (CDR R. Turner, CNAFR N8 -Requirements, personal communication, August, 2013)

Table 16. Key parameters for ADFOR aircraft. Red shading reflects changed parameters for the ADSOT relaxed constraint excursion.

b. Procurement, Upgrades and Transfers

The ADSOT relaxed constraint excursion allows no additional procurement inject but does allow for relaxed allocation of the planned procurement monies ($360 million). Constraints regarding airframe transfers between available home base locations have also been lifted.

2. Relaxed Constraint Excursion Results

Figure 22 shows the location of the three types of ADFOR aircraft prescribed over the planning horizon.

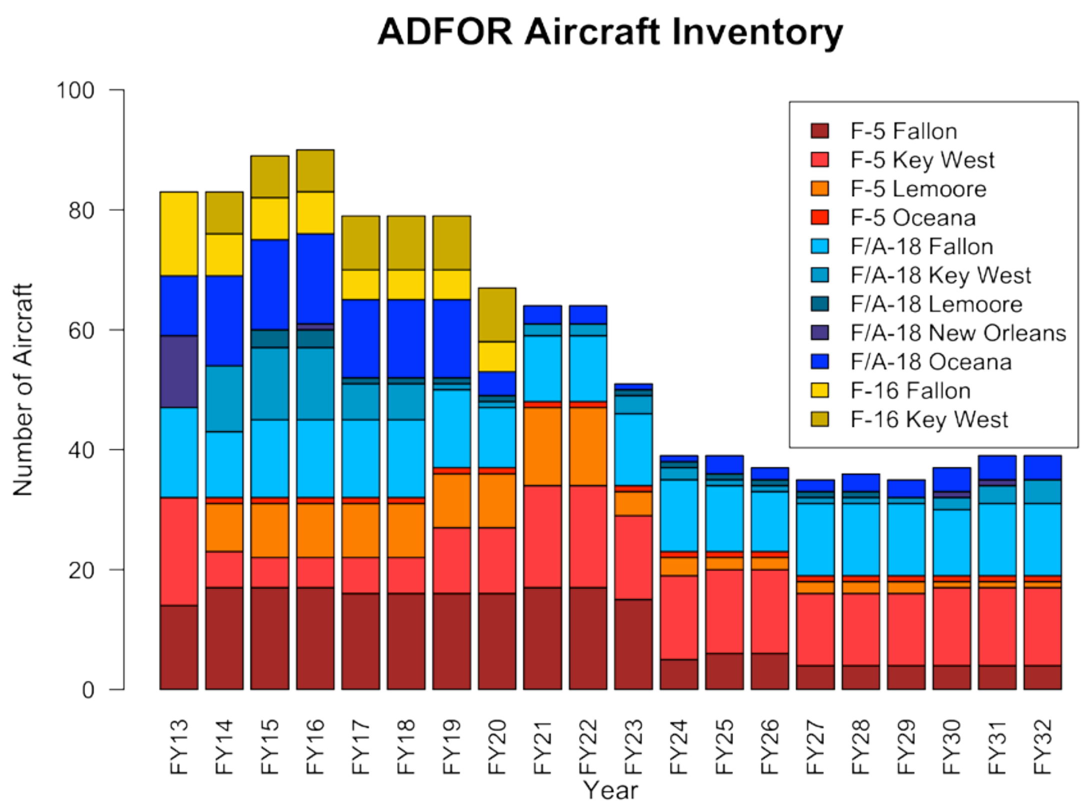


Figure 22. ADFOR Inventory by location over the 20-year planning horizon for the relaxed constraint excursion as prescribed by ADSOT.

ADSOT elects to move the location of ADFOR aircraft closer to the demand locations. Aircraft move out of New Orleans, as there are no demand sources at that location. F-5s shift to Lemoore and some F-16 aircraft to Key West to reflect a better matching of ADFOR capabilities with location driven requirements.

Figure 23 shows the allocation of the planned procurement dollars as prescribed by ADSOT for the relaxed constraint excursion. Recall that in the base case the planned procurement is fixed at $360 million to procure 36 F/A-18 aircraft to replace aging aircraft on a one-for-one basis. In the relaxed constraint excursion those monies are applied to seek more efficiencies in adversary training.

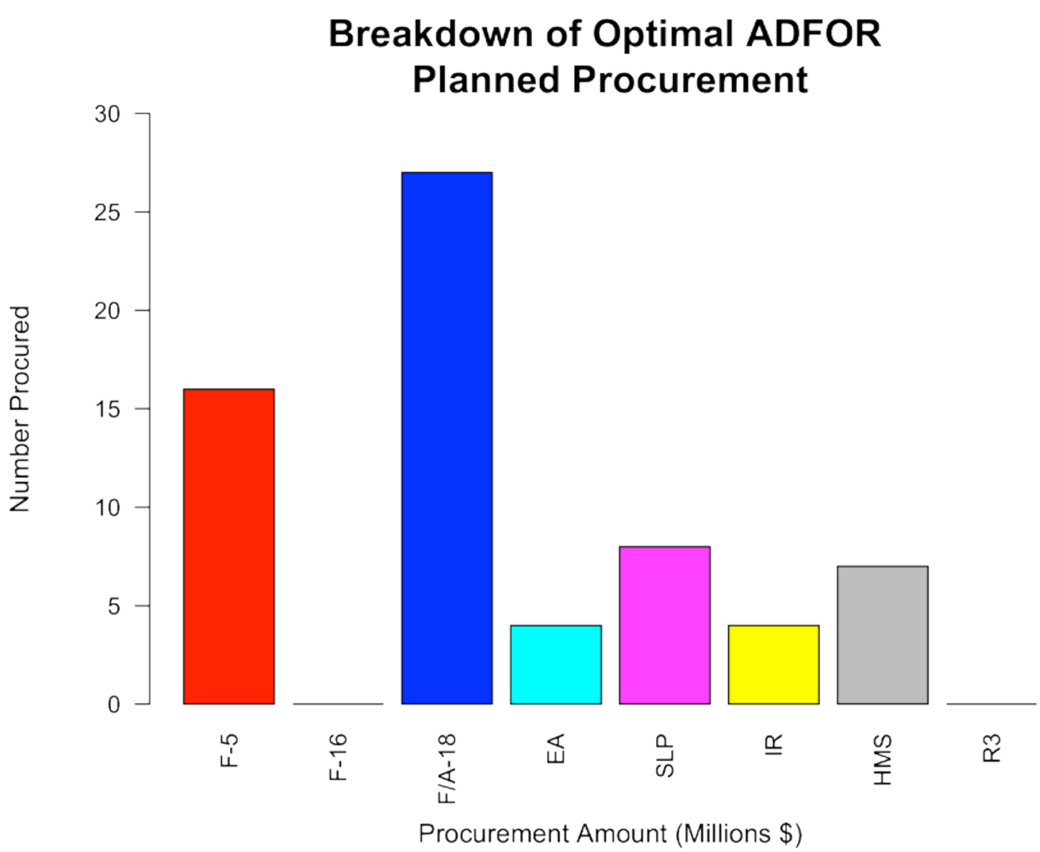


Figure 23. Procurement and upgrades prescribed by ADSOT for the relaxed case excursion using planned procurement dollars of $360M.

Figure 24 shows the aggregated training utility achieved as prescribed by ADSOT in the relaxed constraint excursion compared to the base case.

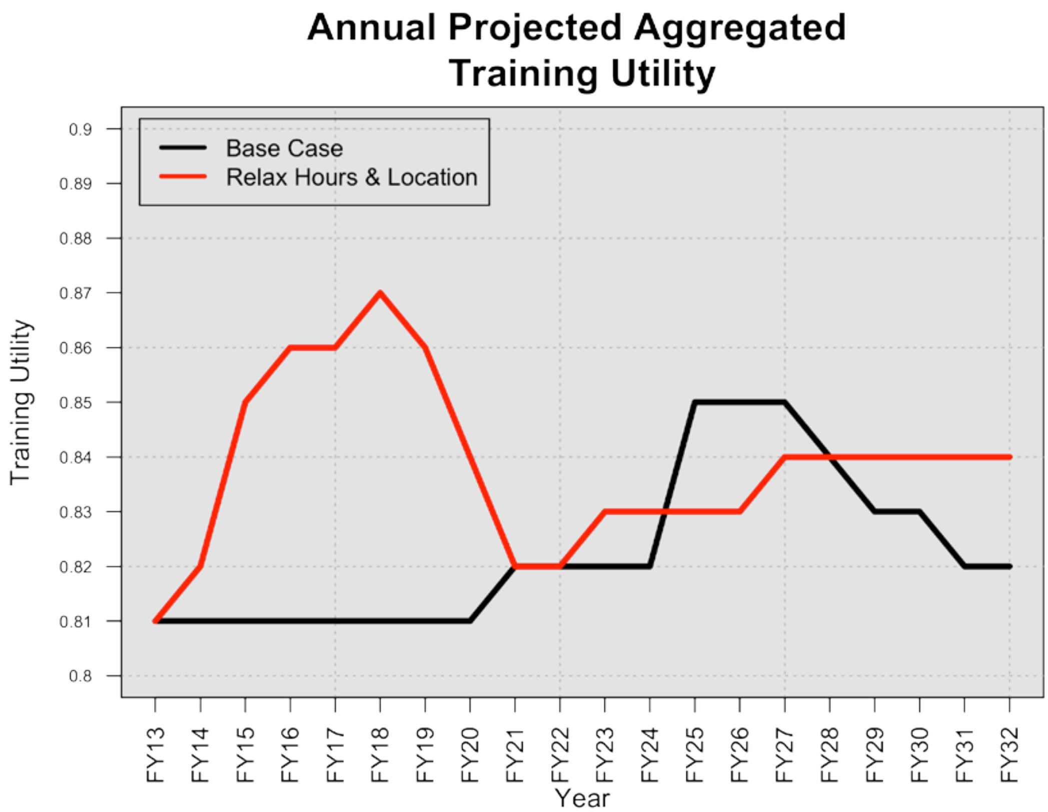


Figure 24. Annual aggregated training utility prescribed by ADSOT for the relaxed constraint excursion compared to the base case.

More efficient use of the ADFOR results in generally higher training utilities over the planning horizon with some exceptions during FY24 through FY27. In some cases the improvement is as high as six percent.

Figure 25 shows the prescribed fleet flight hour usage of the relaxed constraint excursion compared to the base case.

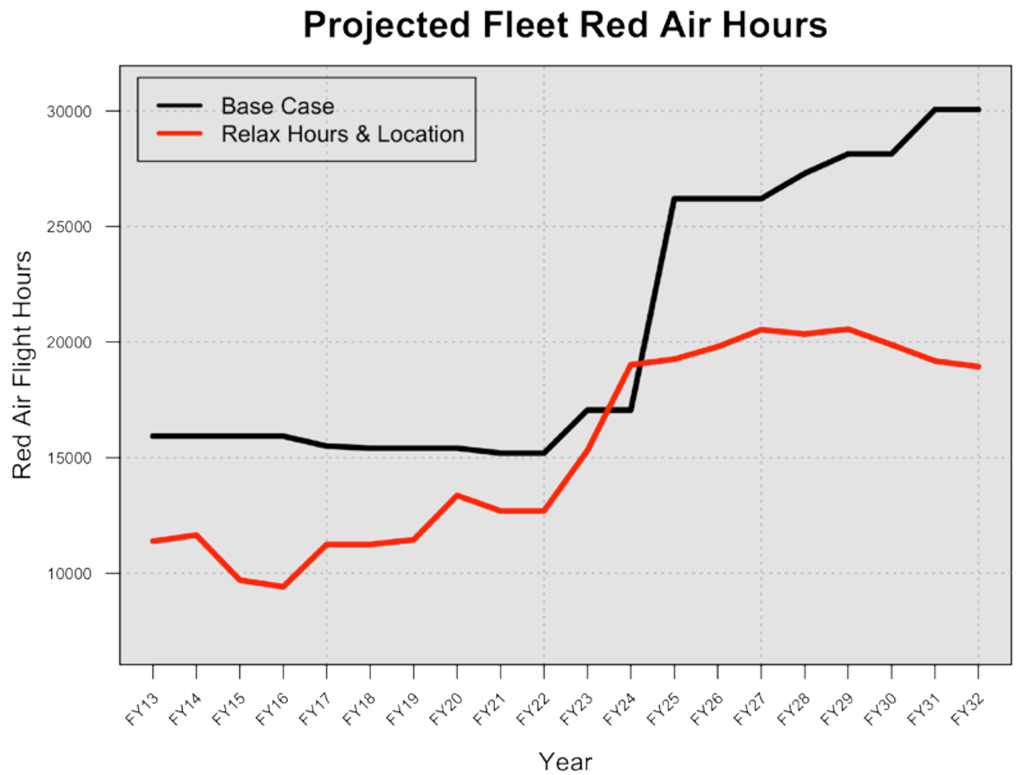


Figure 25. Fleet hours expended performing the *red air* mission as prescribed by ADSOT in the relaxed constraint excursion. Total savings of 105,000 hours are realized over the entire planning horizon.

In the relaxed constraint excursion ADSOT can co-locate aircraft with requirements and more efficiently meet the demand. Also, with the minimum flight hours relaxed, F-5 aircraft can be used more efficiently throughout the planning horizon. The result is a savings of 105,000 hours on fleet airframes over the planning horizon.

Figure 26 shows the annual total operating cost of the relaxed constraint case compared to the base case. In the relaxed constraint excursion ADSOT is able to manage the flight hours more efficiently throughout the planning horizon. This coupled with the acquisition of additional F-5 aircraft lead to lower operating costs throughout the planning horizon. Relaxing the constraints allows for a total savings of $720 million.

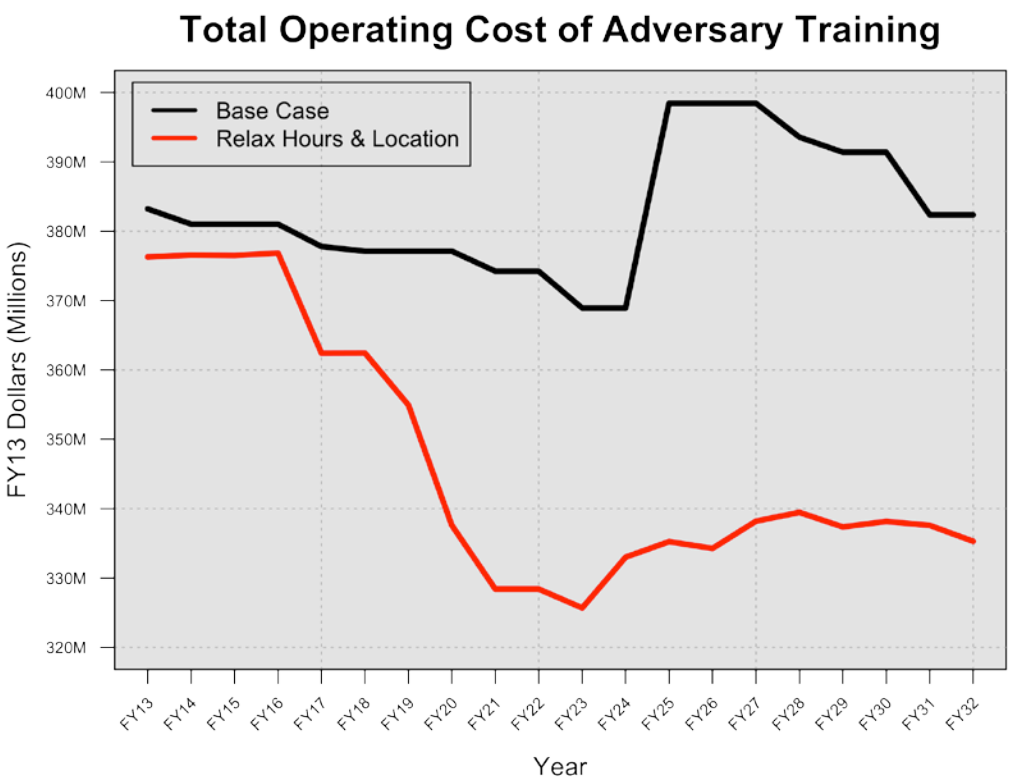


Figure 26. Total operating cost of adversary training for the relaxed constraint excursion compared to the base case.

E. ADVANCED REQUIREMENT EXCURSION

Currently there is much debate amongst the stakeholders as to what is the actual requirement for adversary training (LCDR B. Harjer, OPNAV Adversary Requirements Officer, personal communication, March, 2013). Training requirements are based, at least in part, on the capability of OPFOR to meet them. Multiple training demand sources further complicate the issue. In the advanced requirement excursion the total number of required events remains the same, however, events are shifted from less complex requirement bins to more complex bins. This reflects a hypothetical shift to training with increased capability requirements of the adversary aircraft. All other parameters remain the same as in base case and when appropriate, the procurement injects excursion.

1. Advanced Requirement Excursion Assumptions

a. Requirements

Table 17 provides the updated requirement counts. The total core and non-core events have not changed. The basic requirement bins have been removed and their values have been added to the more complicated requirement bins.

	C1	C2	C3	D1	D2	D3	E1	E2	E3
SFARP-Fallon	-	746	-	-	523	150	373	-	-
CVW-Fallon	36	404	-	-	324	68	-	64	80
SFTI-Fallon	144	-	-	452	1,478	-	-	-	2,472
SFARP-Key West	-	746	-	-	523	150	373	-	-
FRS-Oceana	1,115	1,332	-	-	-	-	-	-	-
FRS-Lemoore	1,115	1,332	-	-	-	-	-	-	-
FRS-Key West	-	-	-	-	5,392	-	-	-	-
SFWT-Oceana	-	**1,430**	**74**	-	**1,324**	-	**1,356**	**349**	**189**
SFWT-Lemoore	-	**1,430**	**74**	-	**1,324**	-	**1,356**	**349**	**189**
ULT-Oceana	-	-	-	-	**210**	**1,950**	-	**1,050**	-
ULT-Lemoore	-	-	-	-	**210**	**1,950**	-	**1,050**	-
LFE-Oceana	-	**131**	-	-	**65**	-	-	-	-
LFE-San Diego	-	**131**	-	-	**65**	-	-	-	-
Total	**2,410**	**7,682**	**148**	**452**	**11,438**	**4,268**	**3,458**	**2,862**	**2,930**
	Total Core Event		**19392**		**Total Non-Core Event**			**16256**	

Table 17. Updated requirements to reflect a shift to more advanced training requirements.

2. Advanced Requirement Excursion Results

Figure 27 shows annual aggregated training utility values achieved by ADSOT prescriptions for the advanced requirement excursion. With the increased complexity of the requirement we see that training utility generated in the base case is much lower. The "limited procurement" mirrors the base case in terms of constraining procurement only to the planned replacement of aging F/A-18s. For the base case, we see that training utility values range between 65 and 71 percent. Even with procurement up to $300 million the highest training utility we can attain is only 79 percent. ADSOT provides an analytical tool to help better define these relationships.

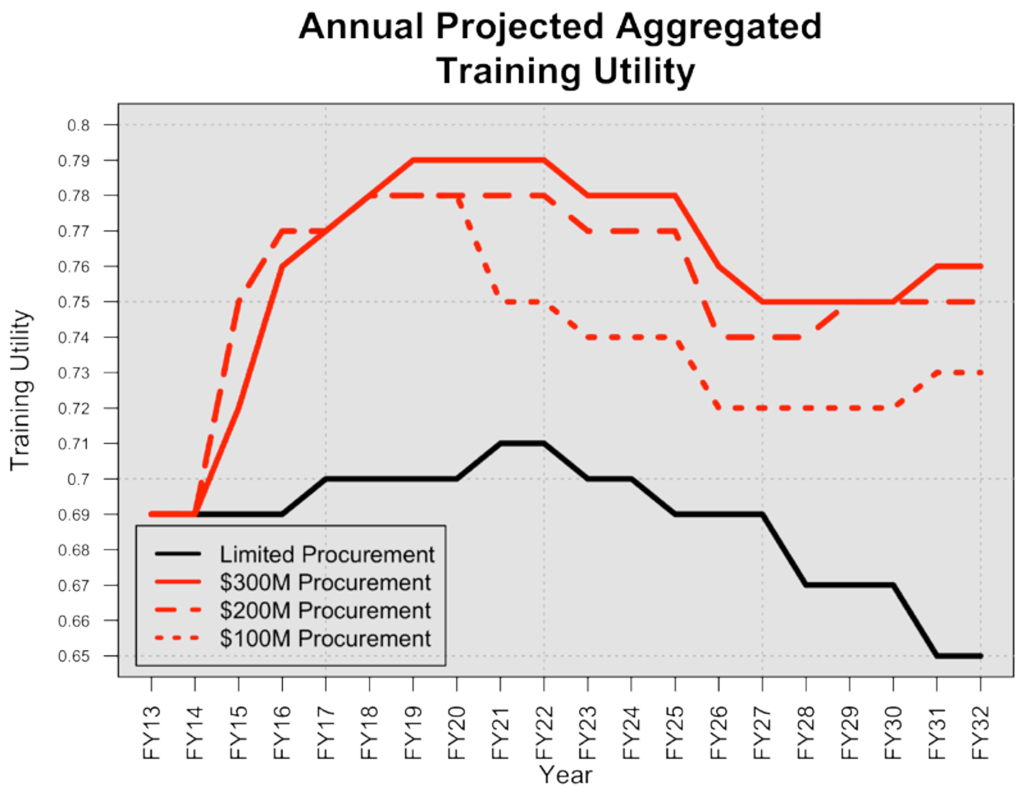


Figure 27. Annual aggregated training utility prescribed by ADSOT for the advanced requirements excursion procurement injects compared to the base case.

F. LVC TRAINING RANGE EXCURSION

ADSOT models the LVC concept as a hypothetical range, which improves the capabilities of ADFOR aircraft by augmenting aspects of their performance through constructive and simulated inputs to the Blue force aircraft weapons systems. For example, an F-5 can look like a SU-30 on the radar on the proposed LVC range. LVC ranges can also increase the sortie capacity of ADFOR by requiring less aircraft to meet requirements. For example, a training event that requires four adversary aircraft may only require two aircraft if flown on an LVC range.

In the LVC excursion, ADSOT allows the procurement of an LVC range at a procurement cost of $180 million dollars. Planned procurement of re-capitalized F/A-18 aircraft to replace aging aircraft on a one-for-one basis is relaxed so those monies can be applied to other airframes, pods or upgrades. Only ADFOR aircraft can take advantage of the LVC range's enhancement of capabilities.

1. LVC Training Range Excursion Assumptions

a. Sorties and Events

Table 18 provides the event multiplier for performing training on an LVC range. The multiplier only applies for events that require multiple *red air*, therefore it is only a factor for requirements in bins C2 and up. For example, for a C2 binned event, the ADSOT LVC excursion only prescribes two adversary aircraft to meet a four event requirement.

Requirement Bin	A2	A3	B1	B2	C1	C2	C3	D1	D2	D3	E1	E2	E3
Multiple	1	1	1	1	1	2	2	1	2	2	1	2	3

Table 18. Multiplier for performing training on an LVC range.

b. Training Platform Capabilities

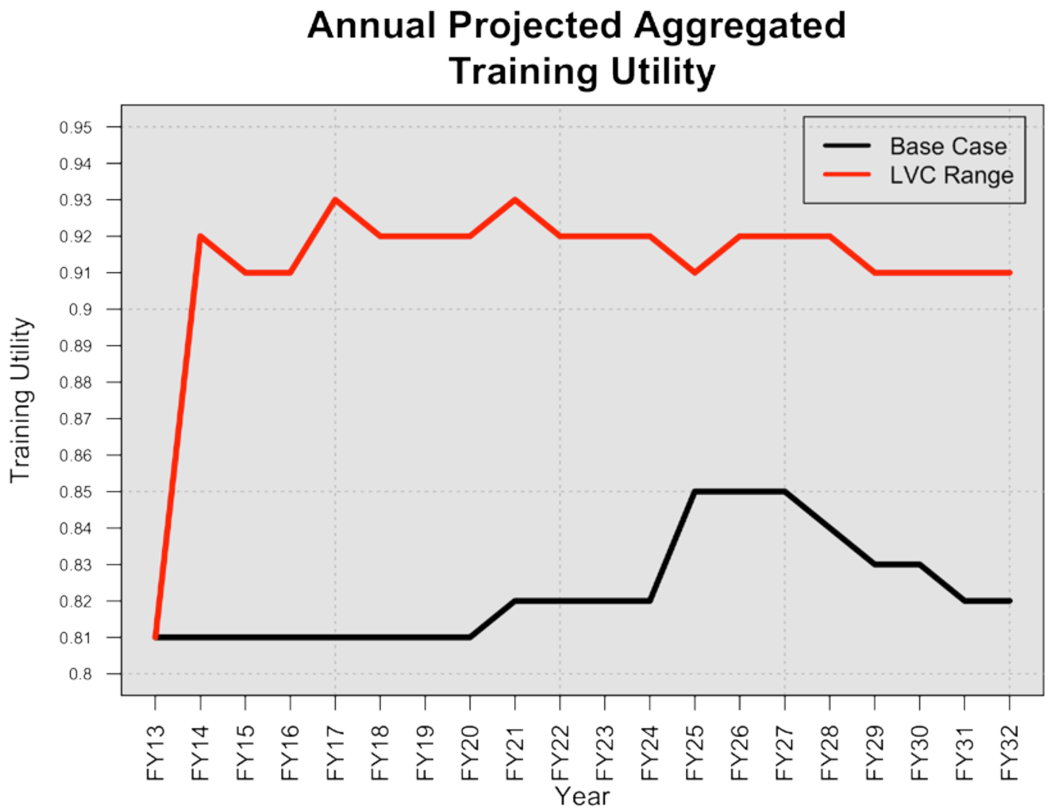
Table 19 provides training utility for each ADFOR aircraft when flown on the LVC range. Note that the range improves the performance of all aircraft and in most cases it maximizes its value at one. In the case of the F-5, performance is still degraded because of the failure of the F-5 to provide a "WVR IV" training capability.

ADFOR	A2	A3	B1	B2	C1	C2	C3	D1	D2	D3	E1	E2	E3
F-5F/N	1.00	1.00	0.50	0.75	0.55	0.75	0.90	0.85	0.95	0.95	0.95	0.95	1.00
F-16A/B	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
F-18A/B	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
F-18C/D	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
F-18E/F	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
F-18E/F+AESA	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 19. Updated training utility values reflecting the ability of an LVC range to augment the performance capability of aircraft.

2. LVC Training Range Excursion Results

Figure 28 shows annual aggregated training utility values for an LVC range when compared to the base case. We see that once the LVC range is procured by the second year the training utility immediately increases to above 90 percent for the remainder of the planning horizon.



Annual aggregated training utility values achieved by ADSOT prescription for an LVC range when compared to the base case.

Figure 29 shows the annual fleet flight hour expenditure performing the *red air* mission as prescribed by ADSOT for the LVC excursion. Over the 20-year planning horizon total fleet flight hour expenditure is reduced by 194,000 hours.

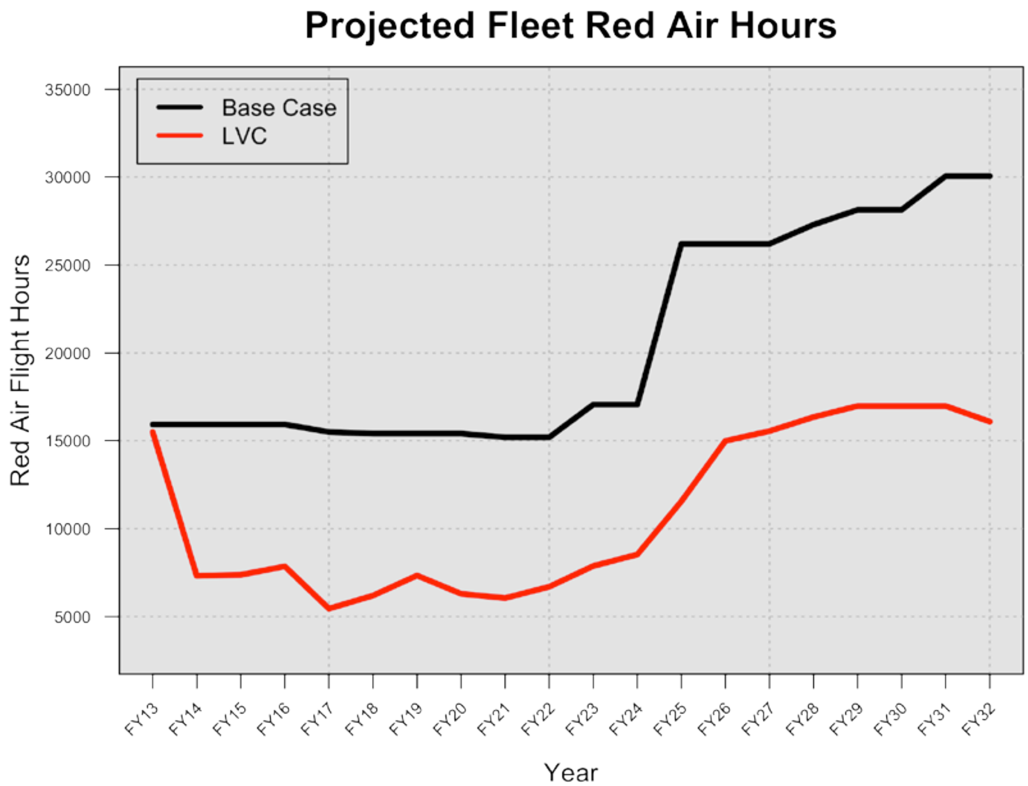


Figure 28. Fleet hours expended performing the *red air* mission as prescribed by ADSOT for LVC range excursion compared to base case.

Figure 30 shows the total operating cost to provide adversary training for the LVC range and the base case for comparison purposes. Over the 20-year planning horizon total operating cost declines by over $1.5 billion dollars.

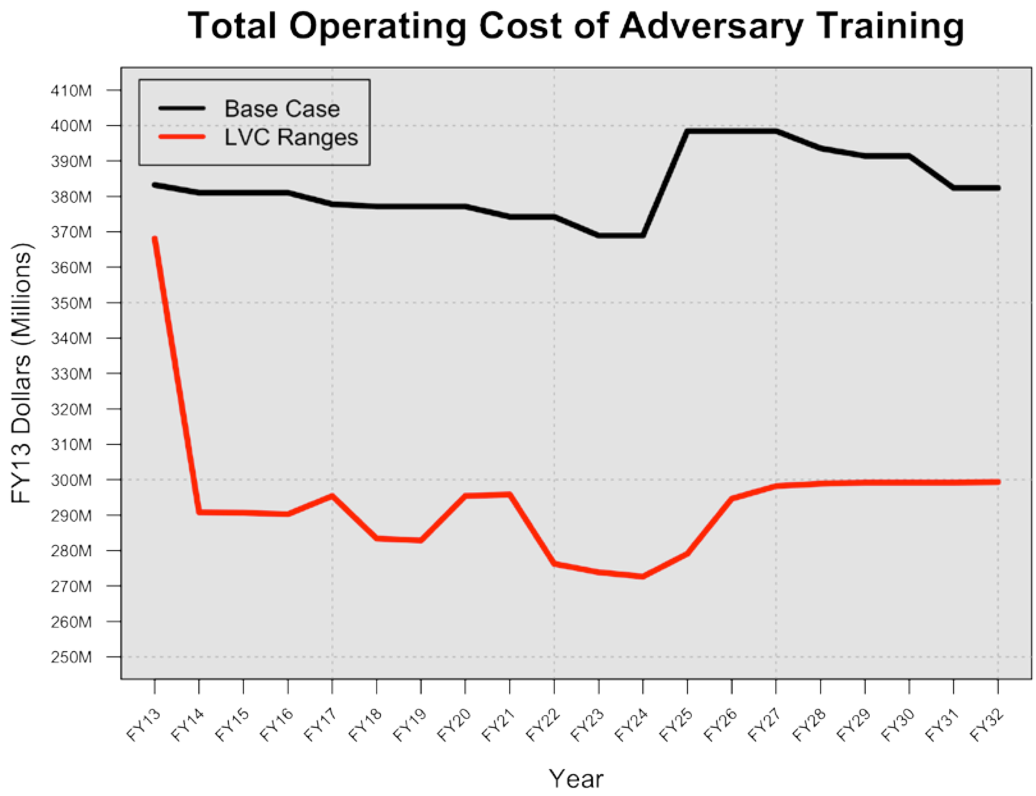


Figure 29. Total operating cost for adversary training using a LVC range compared to the base case. Includes the cost of ADFOR, CAS and fleet aircraft flying in the adversary role.

V. CONCLUSION

A. CONCLUSION

Adversary training is a critical requirement for the Navy's fleet of strike-fighter aircraft and aircrew. Currently, a significant gap exists between the ADFOR and the demand for training in terms of both sortie capacity, and aircraft capability. Simply put, there aren't enough aircraft and the existing ones are technologically lagging compared to the threat aircraft that they are simulating in training. CAS and fleet aircraft are flown to supplement adversary training and help to fill the gap. The gap is forecast to grow as early as 2013 when aging ADFOR aircraft begin to reach their flight hour limits. The Navy has no plan in place for replacing or updating its fleet of ADFOR aircraft.

ADSOT uses an integer-linear program to optimize the assignment of *red air* sorties, for various OPFOR platforms, to meet the annual fleet training demands over a 20-year planning horizon. ADSOT minimizes the operating cost and capability shortfall to provide an optimal yearly training plan over a 20-year planning horizon. A training utility value captures the capability shortfall for a requirement as the percentage of the training objective met by prescribed OPFOR aircraft. ADSOT imposes constraints that annually constrain and/or manage budgets, flight hours, aircraft inventory, CAS contract limits, and aircraft home base locations. Output includes OPFOR yearly aircraft sortie assignment, projected yearly costs, projected yearly flight hour expenditure, and aggregated yearly training utility delivered.

All ADSOT analysis uses input gathered from multiple fleet sources and is the result of extensive coordination with several subject matter experts. Analysis of the ADSOT base case verifies that the model effectively approximates the current use of OPFOR sorties to meet training requirements. ADSOT excursions allow for various levels of procurement dollar injects. These show that procurement in the near term will result in improved training utility values, while lowering both operating costs and the number of *red air* sorties flown by fleet aircraft. For a $300 million procurement inject, ADSOT sortie prescription increases overall training utility by as much as seven percent, decreased operating costs by $490 million over 20 years, and predicted a savings of over 250,000 flight hours on fleet aircraft.

One ADSOT excursion considered the relaxation of ADFOR flight hour, location, and planned procurement. ADSOT found that significant savings in both flight hours and operating cost are achieved. Over the 20-year planning horizon the fleet flight hour savings is over 100,000 hours and the operating cost savings is $720 million. This was achieved while improving training utility by up to six percent during some early years, and only minimally degrading training utility over some later years.

Additional ADSOT excursions consider more advanced training requirements and investments into LVC training ranges. In the case of more advanced training requirements, the current OPFOR platforms have difficulty achieving an overall training utility value greater than 70 percent. Even with an investment of $300 million the highest training utility achieved over any given year throughout the 20-year planning horizon is 79 percent. A hypothetical LVC range is modeled with limited fidelity to improve performance of ADFOR aircraft when using the range. Results indicated that improvements in training utility by over 10 percent annually over the base case are possible. This is accomplished by decreasing the total operating cost by $1.7 billion dollars, and total fleet flight hour expenditure by 194,000 hours over the 20-year planning horizon.

B. FUTURE RESEARCH

ADSOT provides a methodology that can easily be manipulated to allow for many other considerations for optimization of performing the *red air* mission.

1. Add Stochastic Requirements

This thesis performs one requirement excursion. Much more work in this area is necessary. The task of quantifying the requirement is difficult as it depends on many competing factors such as the training phase, training type and the training customer. This is complicated by the fact that many of the requirements are overlapping and dependent on randomness inherent in the system. Deployment schedules, aircrew manning, efficiency in scheduling and future platform capabilities are just a few examples of this. ADSOT can be altered to provide more flexibility and perhaps some stochastic properties in terms of the requirements. The model could then be incorporated into a design of experiments to determine which factors most significantly affect the results.

2. Consider Revisions to Capabilities

The capabilities used to match the training platforms to requirements are a key component to ADSOT. These capabilities are the result of extensive research by the author and input from multiple fleet SMEs. More work can be done to refine these capabilities and determine the impact of subtle changes to the results. There is another opportunity here for a design of experiments to determine what levels of training utility value represent significant differences in ADSOT results.

3. Adjust Costs to Account for Lost Opportunity Cost

As touched upon in this thesis, the use of fleet aircraft to fly in the adversary role uses up flight hours on aircraft that could be used for other purposes, such as blue force training, or more importantly, executing real world missions. This lost opportunity cost of the aircraft needs to be analyzed. The actual cost savings of expanding the ADFOR might be significantly greater than indicated when this is taken into account.

4. Incorporate Other Benefits of the ADFOR

The operating and maintaining of a dedicated adversary force has other benefits that aren't incorporated into this study. For one, having an ADFOR ensures a cadre of experienced military aircrew who are at the ready in the event of a national emergency. It is hard to quantify this benefit, but as with the National Guard and the Air Force, there is certainly some utility to having a fleet of reserve fighters and aircrew standing at the ready.

There are also other opportunities for using very cost effective third generation aircraft such as the F-5. They could be used as a lead or wingman for multi-ship formations in training where the instructor doesn't need to fly the more expensive fleet aircraft. This savings could be significant when considering aircraft such as the JSF which is projected to cost close to $30 thousand (Butler, 2013) per flight hour.

5. Incorporate More Simulator Training

The fidelity of simulators continues to increase as they become more and more able to approximate actual flight. The potential value of these training simulators can be easily tested by ADSOT.

APPENDIX. PLATFORM CONFIGURATIONS

Table 20 provides a matrix of ADFOR platform configuration (rows) and capability (columns) matchups. A value of one denotes that the platform configuration is capable of performing the column's capability.

ADFOR Platform	Pod	WVR(III)	WVR(IV)	BVR	BVR(HP)	RAD(SR)	RAD(MR)	RAD(LR)	RWR-Ind	RWR	DIS	ITEMS	EA	IR	HOBS
F-5	None	1	0	1	0	1	0	0	0	0	1	0	0	0	0
F-5	EA5	1	0	1	0	1	0	0	0	0	1	0	1	0	0
F-5	SLP5	1	0	1	0	1	0	0	1	0	1	0	0	0	0
F-5	EA5+SLP5	1	0	1	0	1	0	0	1	0	1	1	1	0	0
F-16	None	1	1	1	1	1	1	0	0	1	1	1	0	0	0
F-16	EA18	1	1	1	1	1	1	0	0	1	1	1	1	0	0
F-16	SLP18	1	1	1	1	1	1	0	1	1	1	1	0	0	0
F-16	IR18	1	1	1	1	1	1	0	0	1	1	1	0	1	0
F-16	EA18+SLP18	1	1	1	1	1	1	0	1	1	1	1	1	0	0
F-16	EA18+IR18	1	1	1	1	1	1	0	0	1	1	1	1	1	0
F-16	IR18+SLP18	1	1	1	1	1	1	0	1	1	1	1	0	1	0
F-18AB	None	1	1	1	1	1	1	0	0	1	0	1	0	0	0
F-18AB	EA18	1	1	1	1	1	1	0	0	1	0	1	1	0	0
F-18AB	SLP18	1	1	1	1	1	1	0	1	1	0	1	0	0	0
F-18AB	IR18	1	1	1	1	1	1	0	0	1	0	1	0	1	0
F-18AB	EA18+SLP18	1	1	1	1	1	1	0	1	1	0	1	1	0	0
F-18AB	EA18+IR18	1	1	1	1	1	1	0	0	1	0	1	1	1	0
F-18AB	IR18+SLP18	1	1	1	1	1	1	0	1	1	0	1	0	1	0
F-18CD	None	1	1	1	1	1	1	0	0	1	0	1	0	0	0
F-18CD	EA18	1	1	1	1	1	1	0	0	1	0	1	1	0	0
F-18CD	SLP18	1	1	1	1	1	1	0	1	1	0	1	0	0	0
F-18CD	IR18	1	1	1	1	1	1	0	0	1	0	1	0	1	0
F-18CD	EA18+SLP18	1	1	1	1	1	1	0	1	1	0	1	1	0	0
F-18CD	EA18+IR18	1	1	1	1	1	1	0	0	1	0	1	1	1	0
F-18CD	IR18+SLP18	1	1	1	1	1	1	0	1	1	0	1	0	1	0
F-18EF	None	1	1	1	1	1	1	0	0	1	0	1	0	0	1
F-18EF	EA18	1	1	1	1	1	1	0	0	1	0	1	1	0	1
F-18EF	SLP18	1	1	1	1	1	1	0	1	1	0	1	0	0	1
F-18EF	IR18	1	1	1	1	1	1	0	0	1	0	1	0	1	1
F-18EF	EA18+SLP18	1	1	1	1	1	1	0	1	1	0	1	1	0	1
F-18EF	EA18+IR18	1	1	1	1	1	1	0	0	1	0	1	1	1	1
F-18EF	IR18+SLP18	1	1	1	1	1	1	0	1	1	0	1	0	1	1
F-18EF+AESA	None	1	1	1	1	1	1	1	0	1	0	1	0	0	1
F-18EF+AESA	EA18	1	1	1	1	1	1	1	0	1	0	1	1	0	1
F-18EF+AESA	SLP18	1	1	1	1	1	1	1	1	1	0	1	0	0	1
F-18EF+AESA	IR18	1	1	1	1	1	1	1	0	1	0	1	0	1	1
F-18EF+AESA	EA18+SLP18	1	1	1	1	1	1	1	1	1	0	1	1	0	1
F-18EF+AESA	EA18+IR18	1	1	1	1	1	1	1	0	1	0	1	1	1	1
F-18EF+AESA	IR18+SLP18	1	1	1	1	1	1	1	1	1	0	1	0	1	1

Table 20. Matrix of ADFOR platform configuration (row) and capability (column) matchups. Note that the pods EA5 and SLP5 denote the EA pod and Sleeper pod for the F-5. The pods EA18, SLP18 and IR18 denote the EA, Sleeper and IR pod for the F-16/F/A-18.

ADFOR Platform	Pod	WVR(III)	WVR(IV)	BVR	BVR(HP)	RAD(SR)	RAD(MR)	RAD(LR)	RWR-Ind	RWR	DIS	ITEMS	EA	IR	HOBS
F-5+HMS	None	1	0	1	0	1	0	0	0	0	1	0	0	0	1
F-5+HMS	EA5	1	0	1	0	1	0	0	0	0	1	0	1	0	1
F-5+HMS	SLP5	1	0	1	0	1	0	0	1	0	1	0	0	0	1
F-5+HMS	EA5+SLP5	1	0	1	0	1	0	0	0	0	1	0	1	0	1
F-5+R3	None	1	0	1	0	1	1	1	0	1	1	0	0	0	0
F-5+R3	EA5	1	0	1	0	1	1	1	0	1	1	0	1	0	0
F-5+R3	SLP5	1	0	1	0	1	1	1	1	1	1	0	0	0	0
F-5+R3	EA5+SLP5	1	0	1	0	1	1	1	1	1	1	0	1	0	0
F-5+HMS+R3	None	1	0	1	0	1	1	1	0	1	1	0	0	0	1
F-5+HMS+R3	EA5	1	0	1	0	1	1	1	0	1	1	0	1	0	1
F-5+HMS+R3	SLP5	1	0	1	0	1	1	1	1	1	1	0	0	0	1
F-5+HMS+R3	EA5+SLP5	1	0	1	0	1	1	1	1	1	1	0	1	0	1
F-16+HMS	None	1	1	1	1	1	1	0	0	1	1	1	0	0	1
F-16+HMS	EA18	1	1	1	1	1	1	0	0	1	1	1	1	0	1
F-16+HMS	SLP18	1	1	1	1	1	1	0	1	1	1	1	0	0	1
F-16+HMS	IR18	1	1	1	1	1	1	0	0	1	1	1	0	1	1
F-16+HMS	EA18+SLP18	1	1	1	1	1	1	0	1	1	1	1	1	0	1
F-16+HMS	EA18+IR18	1	1	1	1	1	1	0	0	1	1	1	1	1	1
F-16+HMS	IR18+SLP18	1	1	1	1	1	1	0	1	1	1	1	0	1	1
F-16+R3	None	1	1	1	1	1	1	1	0	1	1	1	0	0	0
F-16+R3	EA18	1	1	1	1	1	1	1	0	1	1	1	1	0	0
F-16+R3	SLP18	1	1	1	1	1	1	1	1	1	1	1	0	0	0
F-16+R3	IR18	1	1	1	1	1	1	1	0	1	1	1	0	1	0
F-16+R3	EA18+SLP18	1	1	1	1	1	1	1	1	1	1	1	1	0	0
F-16+R3	EA18+IR18	1	1	1	1	1	1	1	0	1	1	1	1	1	0
F-16+R3	IR18+SLP18	1	1	1	1	1	1	1	1	1	1	1	0	1	0
F-16+HMS+R3	None	1	1	1	1	1	1	1	0	1	1	1	0	0	1
F-16+HMS+R3	EA18	1	1	1	1	1	1	1	0	1	1	1	1	0	1
F-16+HMS+R3	SLP18	1	1	1	1	1	1	1	1	1	1	1	0	0	1
F-16+HMS+R3	IR18	1	1	1	1	1	1	1	0	1	1	1	0	1	1
F-16+HMS+R3	EA18+SLP18	1	1	1	1	1	1	1	1	1	1	1	1	0	1
F-16+HMS+R3	EA18+IR18	1	1	1	1	1	1	1	0	1	1	1	1	1	1
F-16+HMS+R3	IR18+SLP18	1	1	1	1	1	1	1	1	1	1	1	0	1	1
F-18CD+HMS	None	1	1	1	1	1	1	0	0	1	0	1	0	0	1
F-18CD+HMS	EA18	1	1	1	1	1	1	0	0	1	0	1	1	0	1
F-18CD+HMS	SLP18	1	1	1	1	1	1	0	1	1	0	1	0	0	1
F-18CD+HMS	IR18	1	1	1	1	1	1	0	0	1	0	1	0	1	1
F-18CD+HMS	EA18+SLP18	1	1	1	1	1	1	0	1	1	0	1	1	0	1
F-18CD+HMS	EA18+IR18	1	1	1	1	1	1	0	0	1	0	1	1	1	1
F-18CD+HMS	IR18+SLP18	1	1	1	1	1	1	0	1	1	0	1	0	1	1
F-16BLK50	None	1	1	1	1	1	1	1	0	1	1	1	1	1	1
F-16BLK50	SLP18	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 20 (continued).

Table 21 provides the matrix of training utility values for each training platform configuration and requirement pairing.

ADFOR Platform	Pod	A2	A3	B1	B2	C1	C2	C3	D1	D2	D3	E1	E2	E3
F-5	None	1	0.5	0.65	0.85	0.5	0.7	0.3	0.4	0.25	0.25	0.35	0.25	0.2
F-5	EA5	1	1	0.65	0.85	0.5	0.7	0.55	0.4	0.6	0.45	0.35	0.5	0.4
F-5	SLP5	1	0.5	0.65	0.85	0.55	0.75	0.35	0.45	0.3	0.3	0.4	0.3	0.25
F-5	EA5+SLP5	1	1	0.7	0.9	0.6	0.8	0.65	0.5	0.7	0.55	0.45	0.6	0.5
F-16	None	1	0.5	1	1	0.85	0.9	0.6	0.9	0.55	0.5	0.75	0.55	0.45
F-16	EA18	1	1	1	1	0.85	0.9	0.85	0.9	0.9	0.7	0.75	0.8	0.65
F-16	SLP18	1	0.5	1	1	0.9	0.95	0.65	0.95	0.6	0.55	0.8	0.6	0.5
F-16	IR18	1	0.5	1	1	0.85	0.9	0.6	0.9	0.55	0.7	0.75	0.55	0.65
F-16	EA18+SLP18	1	1	1	1	0.9	0.95	0.9	0.95	0.95	0.75	0.8	0.85	0.7
F-16	EA18+IR18	1	1	1	1	0.85	0.9	0.85	0.9	0.9	0.9	0.75	0.8	0.85
F-16	IR18+SLP18	1	0.5	1	1	0.9	0.95	0.65	0.95	0.6	0.75	0.8	0.6	0.7
F-18AB	None	1	0.5	0.95	0.95	0.8	0.85	0.55	0.85	0.5	0.45	0.7	0.5	0.4
F-18AB	EA18	1	1	0.95	0.95	0.8	0.85	0.8	0.85	0.85	0.65	0.7	0.75	0.6
F-18AB	SLP18	1	0.5	0.95	0.95	0.85	0.9	0.6	0.9	0.55	0.5	0.75	0.55	0.45
F-18AB	IR18	1	0.5	0.95	0.95	0.8	0.85	0.55	0.85	0.5	0.65	0.7	0.5	0.6
F-18AB	EA18+SLP18	1	1	0.95	0.95	0.85	0.9	0.85	0.9	0.9	0.7	0.75	0.8	0.65
F-18AB	EA18+IR18	1	1	0.95	0.95	0.8	0.85	0.8	0.85	0.85	0.85	0.7	0.75	0.8
F-18AB	IR18+SLP18	1	0.5	0.95	0.95	0.85	0.9	0.6	0.9	0.55	0.7	0.75	0.55	0.65
F-18CD	None	1	0.5	0.95	0.95	0.8	0.85	0.55	0.85	0.5	0.45	0.7	0.5	0.4
F-18CD	EA18	1	1	0.95	0.95	0.8	0.85	0.8	0.85	0.85	0.65	0.7	0.75	0.6
F-18CD	SLP18	1	0.5	0.95	0.95	0.85	0.9	0.6	0.9	0.55	0.5	0.75	0.55	0.45
F-18CD	IR18	1	0.5	0.95	0.95	0.8	0.85	0.55	0.85	0.5	0.65	0.7	0.5	0.6
F-18CD	EA18+SLP18	1	1	0.95	0.95	0.85	0.9	0.85	0.9	0.9	0.7	0.75	0.8	0.65
F-18CD	EA18+IR18	1	1	0.95	0.95	0.8	0.85	0.8	0.85	0.85	0.85	0.7	0.75	0.8
F-18CD	IR18+SLP18	1	0.5	0.95	0.95	0.85	0.9	0.6	0.9	0.55	0.7	0.75	0.55	0.65
F-18EF	None	1	0.5	0.95	0.95	0.9	0.9	0.65	0.9	0.55	0.5	0.75	0.55	0.45
F-18EF	EA18	1	1	0.95	0.95	0.9	0.9	0.9	0.9	0.9	0.7	0.75	0.8	0.65
F-18EF	SLP18	1	0.5	0.95	0.95	0.95	0.95	0.7	0.95	0.6	0.55	0.8	0.6	0.5
F-18EF	IR18	1	0.5	0.95	0.95	0.9	0.9	0.65	0.9	0.55	0.7	0.75	0.55	0.65
F-18EF	EA18+SLP18	1	1	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.75	0.8	0.85	0.7
F-18EF	EA18+IR18	1	1	0.95	0.95	0.9	0.9	0.9	0.9	0.9	0.9	0.75	0.8	0.85
F-18EF	IR18+SLP18	1	0.5	0.95	0.95	0.95	0.95	0.7	0.95	0.6	0.75	0.8	0.6	0.7
F-18EF+AESA	None	1	0.5	0.95	0.95	0.9	0.9	0.65	0.9	0.55	0.5	0.9	0.65	0.5
F-18EF+AESA	EA18	1	1	0.95	0.95	0.9	0.9	0.9	0.9	0.9	0.7	0.9	0.9	0.7
F-18EF+AESA	SLP18	1	0.5	0.95	0.95	0.95	0.95	0.7	0.95	0.6	0.55	0.95	0.7	0.55
F-18EF+AESA	IR18	1	0.5	0.95	0.95	0.9	0.9	0.65	0.9	0.55	0.7	0.9	0.65	0.7
F-18EF+AESA	EA18+SLP18	1	1	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.75	0.95	0.95	0.75
F-18EF+AESA	EA18+IR18	1	1	0.95	0.95	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
F-18EF+AESA	IR18+SLP18	1	0.5	0.95	0.95	0.95	0.95	0.7	0.95	0.6	0.75	0.95	0.7	0.75

Table 21. Adversary training platform training utilities for each platform configuration (row) and requirement bin (column) matchings.

ADFOR Platform	Pod	A2	A3	B1	B2	C1	C2	C3	D1	D2	D3	E1	E2	E3
F-5+HMS	None	1	0.5	0.65	0.85	0.6	0.75	0.4	0.45	0.3	0.3	0.4	0.3	0.25
F-5+HMS	EA5	1	1	0.65	0.85	0.6	0.75	0.65	0.45	0.65	0.5	0.4	0.55	0.45
F-5+HMS	SLP5	1	0.5	0.65	0.85	0.65	0.8	0.45	0.5	0.35	0.35	0.45	0.35	0.3
F-5+HMS	EA5+SLP5	1	1	0.65	0.85	0.6	0.75	0.65	0.45	0.65	0.5	0.4	0.55	0.45
F-5+R3	None	1	0.5	0.65	0.85	0.55	0.75	0.35	0.55	0.35	0.35	0.65	0.45	0.35
F-5+R3	EA5	1	1	0.65	0.85	0.55	0.75	0.6	0.55	0.7	0.55	0.65	0.7	0.55
F-5+R3	SLP5	1	0.5	0.65	0.85	0.6	0.8	0.4	0.6	0.4	0.4	0.7	0.5	0.4
F-5+R3	EA5+SLP5	1	1	0.65	0.85	0.6	0.8	0.65	0.6	0.75	0.6	0.7	0.75	0.6
F-5+HMS+R3	None	1	0.5	0.65	0.85	0.65	0.8	0.45	0.6	0.4	0.4	0.7	0.5	0.4
F-5+HMS+R3	EA5	1	1	0.65	0.85	0.65	0.8	0.7	0.6	0.75	0.6	0.7	0.75	0.6
F-5+HMS+R3	SLP5	1	0.5	0.65	0.85	0.7	0.85	0.5	0.65	0.45	0.45	0.75	0.55	0.45
F-5+HMS+R3	EA5+SLP5	1	1	0.65	0.85	0.7	0.85	0.75	0.65	0.8	0.65	0.75	0.8	0.65
F-16+HMS	None	1	0.5	1	1	0.95	0.95	0.7	0.95	0.6	0.55	0.8	0.6	0.5
F-16+HMS	EA18	1	1	1	1	0.95	0.95	0.95	0.95	0.95	0.75	0.8	0.85	0.7
F-16+HMS	SLP18	1	0.5	1	1	1	1	0.75	1	0.65	0.6	0.85	0.65	0.55
F-16+HMS	IR18	1	0.5	1	1	0.95	0.95	0.7	0.95	0.6	0.75	0.8	0.6	0.7
F-16+HMS	EA18+SLP18	1	1	1	1	1	1	1	1	1	0.8	0.85	0.9	0.75
F-16+HMS	EA18+IR18	1	1	1	1	0.95	0.95	0.95	0.95	0.95	0.95	0.8	0.85	0.9
F-16+HMS	IR18+SLP18	1	0.5	1	1	1	1	0.75	1	0.65	0.8	0.85	0.65	0.75
F-16+R3	None	1	0.5	1	1	0.85	0.9	0.6	0.9	0.55	0.5	0.9	0.65	0.5
F-16+R3	EA18	1	1	1	1	0.85	0.9	0.85	0.9	0.9	0.7	0.9	0.9	0.7
F-16+R3	SLP18	1	0.5	1	1	0.9	0.95	0.65	0.95	0.6	0.55	0.95	0.7	0.55
F-16+R3	IR18	1	0.5	1	1	0.85	0.9	0.6	0.9	0.55	0.7	0.9	0.65	0.7
F-16+R3	EA18+SLP18	1	1	1	1	0.9	0.95	0.9	0.95	0.95	0.75	0.95	0.95	0.75
F-16+R3	EA18+IR18	1	1	1	1	0.85	0.9	0.85	0.9	0.9	0.9	0.9	0.9	0.9
F-16+R3	IR18+SLP18	1	0.5	1	1	0.9	0.95	0.65	0.95	0.6	0.75	0.95	0.7	0.75
F-16+HMS+R	None	1	0.5	1	1	0.95	0.95	0.7	0.95	0.6	0.55	0.95	0.7	0.55
F-16+HMS+R	EA18	1	1	1	1	0.95	0.95	0.95	0.95	0.95	0.75	0.95	0.95	0.75
F-16+HMS+R	SLP18	1	0.5	1	1	1	1	0.75	1	0.65	0.6	1	0.75	0.6
F-16+HMS+R	IR18	1	0.5	1	1	0.95	0.95	0.7	0.95	0.6	0.75	0.95	0.7	0.75
F-16+HMS+R	EA18+SLP18	1	1	1	1	1	1	1	1	1	0.8	1	1	0.8
F-16+HMS+R	EA18+IR18	1	1	1	1	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
F-16+HMS+R	IR18+SLP18	1	0.5	1	1	1	1	0.75	1	0.65	0.8	1	0.75	0.8
F-18CD+HMS	None	1	0.5	0.95	0.95	0.9	0.9	0.65	0.9	0.55	0.5	0.75	0.55	0.45
F-18CD+HMS	EA18	1	1	0.95	0.95	0.9	0.9	0.9	0.9	0.9	0.7	0.75	0.8	0.65
F-18CD+HMS	SLP18	1	0.5	0.95	0.95	0.95	0.95	0.7	0.95	0.6	0.55	0.8	0.6	0.5
F-18CD+HMS	IR18	1	0.5	0.95	0.95	0.9	0.9	0.65	0.9	0.55	0.7	0.75	0.55	0.65
F-18CD+HMS	EA18+SLP18	1	1	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.75	0.8	0.85	0.7
F-18CD+HMS	EA18+IR18	1	1	0.95	0.95	0.9	0.9	0.9	0.9	0.9	0.9	0.75	0.8	0.85
F-18CD+HMS	IR18+SLP18	1	0.5	0.95	0.95	0.95	0.95	0.7	0.95	0.6	0.75	0.8	0.6	0.7
F-16BLK50	None	1	1	1	1	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
F-16BLK50	SLP18	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 21 (continued).

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