RAND

Models of Operational Training in Fighter Squadrons

James H. Bigelow, William W. Taylor,
S. Craig Moore, Brent Thomas

Prepared for the
United States Air Force

Project AIR FORCE

1. REPORT DATE **2003**	2. REPORT TYPE	3. DATES COVERED -
4. TITLE AND SUBTITLE **Models of Operational Training in Fighter Squadrons**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of the Air Force,Strategic Planning Division,Directorate of Plans,Washington,DC,20330**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**131**	

The research reported here was sponsored by the United States Air Force under Contract F49642-01-C-0003. Further information may be obtained from the Strategic Planning Division, Directorate of Plans, Hq USAF.

Library of Congress Cataloging-in-Publication Data

Models of operational training in fighter squadrons / James H. Bigelow ... [et al.].
p. cm.
"MR-1701."
Includes bibliographical references.
ISBN 0-8330-3465-0 (pbk. : alk. paper)
1. Fighter pilots—Training of—United States. 2. United States. Air Force.
I. Bigelow, J. H.

UG638.M64 2003
358.4'35'0973—dc22

2003018861

Published 2003 by RAND
1700 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138
1200 South Hayes Street, Arlington, VA 22202-5050
201 North Craig Street, Suite 202, Pittsburgh, PA 15213-1516
RAND URL: http://www.rand.org/
To order RAND documents or to obtain additional information, contact Distribution Services: Telephone: (310) 451-7002; Fax: (310) 451-6915; Email: order@rand.org

Preface

Operational squadrons in the U.S. Air Force spend most of their time training to accomplish two objectives: to maintain readiness to deploy and operate in wartime, contingencies, and other engagements, and to prepare aircrew members for subsequent assignments at wings, major air commands, and the Air Staff. Although some operational training is needed to achieve these objectives, it has been difficult historically to justify any specific amount of flying. In addition, operational training is expensive and is often targeted when budget cuts must be made.

This report describes two models of aircrew training in operational fighter squadrons. The first is an optimization model (a so-called linear program), and the second is a much smaller, simpler "repro" model, so called because it reproduces selected results from the linear program. The repro model can be used as a subprocedure in a spreadsheet or simulation model. Earlier versions of both models underlie the research reported in Taylor, Moore, and Roll, *The Air Force Pilot Shortage: A Crisis for Operational Units?* RAND MR-1204-AF, 2000, and in Taylor et al., *Absorbing Air Force Fighter Pilots: Parameters, Problems, and Policy Options*, RAND MR-1550-AF, 2002. Variants of both models exist for A/OA-10, F-15C, F-15E, F-16 HTS, and F-16 LANTIRN squadrons.

The report should be of interest to analysts. Through the report's written descriptions and the data files on the accompanying CD, this report makes all variants of the models available for their analyses. For example, we have used the optimization model largely to explore the effects of changes in unit manning on sortie requirements, and we offer an example of using that model to examine the effect of deployments. As a test, we configured a version of it to represent a reserve component unit, but we have yet to study active/reserve differences. Other possible uses for the model could be for investigating the effect of changing the mission tasking of a unit, substituting simulator training for some flying, and changing the sorties flown at composite force or Red Flag exercises.

This work was sponsored by AF/XO, AF/DP, and ACC/DO and was conducted in the Manpower, Personnel, and Training Program of RAND's Project AIR FORCE.

Project AIR FORCE

Project AIR FORCE (PAF), a division of RAND, is the U.S. Air Force's federally funded research and development center for studies and analyses. PAF provides the Air Force with independent analyses of policy alternatives affecting the development, employment, combat readiness, and support of current and future aerospace forces. Research is performed in four programs: Aerospace Force Development; Manpower, Personnel, and Training; Resource Management; and Strategy and Doctrine.

Additional information about PAF is available on our web site at http://www.rand.org/paf.

Contents

Tables

Summary

Operational squadrons in the U.S. Air Force spend most of their time training to accomplish two objectives. The primary objective is to maintain readiness to deploy and operate in wartime, contingencies, and other engagements. The second objective is to prepare aircrew members for subsequent assignments at wings, major air commands, and the Air Staff. While it is generally agreed that some operational training is needed to achieve these objectives, historically it has been difficult to justify any specific amount of flying for this purpose. Moreover, operational training is expensive, and it is often targeted when there is pressure to cut the Air Force budget.

In response to these issues, this report describes a model of aircrew training in an operational fighter squadron.[1] Originally, we built the model to estimate how much operational training is needed. The Air Force was simultaneously developing the Ready Aircrew Program (RAP) for estimating operational training requirements for individual pilots. Our method goes beyond RAP in three respects: (1) It takes into account the need for flight leads or instructor pilots (IPs) to provide in-flight supervision of wingmen; (2) it reflects skills that underlie mission capabilities, and (3) it allows the user of the model to impose requirements on a squadron other than those for operational training (e.g., sorties for deployments).

The fundamental model is formulated as a linear program. The user specifies the number of pilots (or for the F-15E, pilots and weapon system officers [WSOs])[2] by qualification, and the model calculates the minimum number of sorties that must be flown in each half-year to provide all assigned crew members with the operational training they need.

Numerous skills underlie the ability of crew members to perform each type of mission. Crew members with different qualifications need different combinations of skills and different amounts of practice to maintain them. Different types of

[1]Operational fighter squadrons deploy and conduct combat missions during wartime, contingencies, and other engagements. They exclude squadrons dedicated to formal training or test-and-evaluation missions.

[2]The A/OA-10, F-15C, and F-16 fly combat missions as single-seat fighters, so the pilot is the whole aircrew. The F-15E flies combat missions with two aircrew members, a pilot and a WSO. Each operational F-15C and F-16 squadron has a few two-seat versions that are used for training. There is no two-seat version of the A/OA-10.

training sorties enable crew members to practice different skills at different levels of difficulty and realism.

With considerable input from experts in operational units and at the Air Combat Command (ACC), we have developed data and versions of the model to reflect these relationships for A/OA-10, F-15C, F-15E, F-16 HTS,[3] and F-16 LANTIRN[4] squadrons. We calibrate our models to a level of flying that experienced pilots say will provide "adequate training" for a highly experienced squadron. "Adequate training" means training that is good enough that the squadron will need no spin-up sorties before performing any of its assigned missions in combat.

Through interviews and surveys, we found a rough consensus among IPs and flight leads that 13 sorties per month provide adequate training for an inexperienced pilot, and about a sortie less than that was adequate for an experienced pilot (see pages 33–34). But this view was by no means unanimous. Moreover, we do not know why some IPs and flight leads thought 13 sorties per month was more than enough, or why others thought it was too little. We don't know what IPs and flight leads think pilots might gain if they flew more, or lose if they flew less.[5] Finally, we spent most of our effort calibrating the F-16 LANTIRN version of the model, less effort on A/OA-10 model calibration, and very little effort on F-16 HTS, F-15C, and F-15E model calibration. We think the models as they stand are suitable for analysis, but they should be more carefully calibrated before they are used for management purposes (e.g., to calculate formal Air Force requirements for flying hours).

Because optimization models tend to be somewhat cumbersome, we also developed so-called "repro" models, which are greatly simplified and more concise models whose fewer inputs and outputs nevertheless closely mirror selected inputs and outputs of the more detailed models (see Chapter 4). They can be implemented in straightforward spreadsheets (e.g., spreadsheets created in Microsoft Excel). In this form, they could supplement the Air Force RAP models for calculating squadron sortie requirements.

The RAP model is distributed in the form of a spreadsheet, with squadron manning as the basic input. It estimates squadron sortie requirements as the sum of the training requirements of individual crew members, plus a small allowance

---

[3]HTS stands for HARM Targeting System, and HARM stands for high-speed anti-radiation missile.

[4]LANTIRN stands for Low Altitude Navigation and Targeting, Infrared for Night.

[5]Our current work may shed some light on this question.

for collateral sorties, attrition sorties, and "scheduling efficiency" sorties.[6] Supplementing this model with our repro model, possibly with adjusted coefficients, would improve estimated squadron sortie requirements by including the in-flight supervision requirement (see pages 36–39). To illustrate the importance of the supervision requirement, we compare the sortie requirement for a squadron with a 65-percent experience level to the requirement for a squadron with a 35-percent experience level.[7] While the RAP model estimates that the two squadrons need essentially the same number of sorties per month, our model estimates that the 35-percent-experience-level squadron needs about 20 percent more sorties than the 65-percent-experience-level squadron (see Table 3.4).

We have extended the repro models by constraining the number of sorties per month that can be flown by a fighter squadron (see Chapter 4 and Appendixes A through D). (The optimization models estimate only required sorties; they have not been configured to allocate a fixed number of sorties among categories of pilots.) In this form, the repro models enable one to examine how limitations in sortie availability, overmanning or undermanning, deployments, and production of new pilots from undergraduate flying training (UFT) and formal training units (FTUs) would affect newcomers' accumulation of experience and qualifications.

It would be useful to incorporate in the optimization models an ability to constrain sorties. We would need to develop good measures of the consequences of flying fewer sorties than are required. One measure (used in Taylor, Moore, and Roll, 2000, and in Taylor et al., 2002) is the rate at which inexperienced pilots accumulate flying hours—the so-called aging rate. This measure speaks to one of the objectives of operational squadrons: to provide pilots with the experience they need for subsequent assignments at wings, major air commands, and the Air Staff.

But we have no measure for the effect of a sortie constraint on the other, primary objective of an operational squadron: to maintain readiness to deploy and conduct combat missions during wartime, contingencies, and other engagements. We supposed that if a squadron flies the required number of

---

[6]These are all sorties that must be flown as part of the price of operating a squadron, but which provide no training benefit. *Collateral sorties* include, e.g., ferry flights, deployments, orientation flights, and air shows. *Attrition sorties* are training sorties that are launched but are then aborted (e.g., due to weather or malfunction of the aircraft). *Scheduling efficiency sorties* are sorties flown in excess of an individual's training requirements (e.g., to fill a position in a four-ship flight).

[7]The Air Force uses a rather esoteric definition of experience level, but the squadrons in question are manned as follows: The squadron with a 65-percent experience level has 12 pilots out of 29 who need supervision, and the 35-percent-experience-level squadron has 17 of 29 pilots who need supervision. See Chapter 3 for more information.

sorties—i.e., the number estimated by our methodology—it will need no spin-up sorties to prepare for a deployment. So, it seems reasonable to measure a shortfall in training sorties in terms of the spin-up sorties that would be needed to counter it. At the time of this writing, we are engaged in research that may enable us to develop such a relationship.

Acknowledgments

The models documented in this report could never have been developed without the participation of knowledgeable active Air Force, Air Force Reserve, and Air National Guard experts over an extended period of time. Functional area managers for every fighter mission design series from the Current Operations Branch in Air Combat Command provided guidance and assistance as we developed and refined lists of essential skills and the training activities available to develop those skills. We discussed preliminary model components and results with a later generation of Branch members, additional experts in the Weapons and Tactics Branch at ACC headquarters, and representatives from units in the field. We visited operational units at Shaw AFB, South Carolina; Hill AFB, Utah; Pope AFB, North Carolina; Davis-Monthan AFB, Arizona; Langley AFB, Virginia; McEntire ANGB, South Carolina; and the Air Force Reserve unit at Carswell Naval Joint Reserve Base, Texas. We received instructional syllabi and specific grading criteria from formal training units at Davis-Monthan and the Arizona ANG unit at Tucson International Airport, Arizona. We also conducted very useful telephone conversations with subject-matter experts at Seymour Johnson AFB, South Carolina, and in the New Mexico ANG at Kirtland AFB, New Mexico.

We would also like to thank our project points of contact in both the Operational Training Division and the Rated Force Policy Branch of the Air Staff and in the Aircrew Management Branch at ACC. As the original version of the model approached its final form, they provided a great deal of support, encouragement, and constructive criticism. Their involvement helped to guide the models that are discussed here and pushed us to take a much wider view of the factors and issues that affect the quality of training in operational units. We also value the original readiness issues posed by the Operational Readiness Division of the Air Staff that originally motivated us to undertake constructing an operational training model. Finally, we appreciate the careful and thoughtful reviews from our RAND colleague, Bart Bennett, and RAND Fellow, Lieutenant Colonel Pete Hirneise. Their efforts definitely improved the presentation and organization of this report.

Acronyms

1v1	One versus one
AAGS	Army Air-to-Ground System
AAR	Air-to-air refueling
ACC	Air Combat Command
ACM	Air combat maneuvers
ACMI	Air combat maneuvering instrumentation
ACT	Air combat tactics
AFB	Air Force Base
AFI	Air Force Instruction
AFORMS	Air Force Operations Resource Management System
AFSC	Air Force Specialty Code
AGM	Air-to-ground missile
AHC	Aircraft handling characteristics
AI	Air intercept
ANG	Air National Guard
ANGB	Air National Guard Base
AOR	Area of responsibility
API	Aircrew position indicator (formerly RPI)
ARMS	Aviation Resource Management System (formerly AFORMS)
ASC	Air Strike Control
ATO	Air tasking order
AWACS	Airborne warning and control system
BDA	Bomb damage assessment
BFM	Basic fighter maneuvers
BMC	Basic mission capable
BSA	Basic surface attack
BVR	Beyond visual range
C2	Command and control
C3	Command, control, and communications
CAP	Combat air patrol
CAS	Close air support

CFX	Composite force exercise
CINC	Commander in chief
CMR	Combat mission ready
CSAR	Combat search and rescue
CWT	Chemical warfare training
DART	Deployable aerial reflective target
DCA	Defensive counter-air
DIS	Sortie flown against dissimilar aircraft
DOC	Designated operational capability
DOTB	Flight Management Branch (Flight Operations Division, Directorate of Aerospace Operations, ACC)
EC	Electronic Combat
ECM	Electronic countermeasures
FAC	Forward air control/controller
FAIP	First Assignment Instructor Pilot
FL	Flight lead
FLG	Flag exercise
FLIR	Forward looking infrared
FLUG	Upgrade to flight lead
FTU	Formal training unit
FY	Fiscal year
GAMS	General Algebraic Modeling System
GBU	Guided bomb unit
GCI	Ground-controlled intercept
HARM	High-speed anti-radiation missile
HTS	HARM Targeting System
INS	Instruments
IP	Instructor pilot
IPC	IP Chase
IPR	Rear Cockpit IP
IPUG	Upgrade to instructor pilot
IW	Instructor WSO
JAAT	Joint air attack team
JSTARS	Joint surveillance target attack radar system
KS	Killer scout
KST	Killer scout training

LANTIRN	Low Altitude Navigation and Targeting, Infrared for Night
LASTD	Low-Altitude Step-Down Training
LNTL	Low-altitude LANTIRN
LNTLO	Low-altitude LANTIRN upgrade
LNTM	Medium-altitude LANTIRN
LNTMD	Medium-altitude LANTIRN upgrade
LP	Linear program
MAV	Maverick
MCC	Mission commander
MDS	Mission design series
MQT	Mission qualification training
N/A	Not applicable
NAIR	Night Air-to-Air Training
NAOR	Night Area of Responsibility
NASC	Night Air Strike Control
NBSA	Night Basic Surface Attack
NCA	National Command Authority
NCAS	Night Close Air Support
NGBU	Night Guided Bomb Unit
NINS	Night Instruments
NIPC	Night IP Chase
NIPR	Night Rear Cockpit IP
NROT	Night rotating aircraft
NSAR	Night Combat Search and Rescue
NSAT	Night Surface Attack Tactics
NSEAD	Night SEAD
NVG	Night Vision Goggles
OCA	Offensive counter-air
OCA–S	Offensive counter-air, air-to-surface
O&M	Operations and maintenance
PAA	Primary aircraft authorization
PDM	Programmed depot maintenance
RA	Red air
RAP	Ready aircrew program
ROT	Rotating aircraft

RPI	Rated position indicator (has been replaced by API)
SA	Strategic attack
SAM	Surface-to-air missile
SAT	Surface attack tactics
SATQ	Surface Attack Tactics, Nuclear
SEAD	Suppression of Enemy Air Defenses
SEAD–A	Suppression of Enemy Air Defenses–Antiradiation
SEAD–C	Suppression of Enemy Air Defenses–Conventional
SIM	Simulator
SIMIN	Simulator instructor
TACS	Theater Air Control System
TF	Terrain following
TGP	Targeting pod
TINT	Tactical Intercept
UFT	Undergraduate flying training
UTE	Aircraft utilization rate
WSO	Weapon system officer

1. Introduction

This report describes an aircrew training model for operational fighter squadrons.[1] Variants of that model exist for A/OA-10, F-15C, F-15E, F-16 HTS,[2] and F-16 LANTIRN[3] squadrons. The user of the model specifies the number of pilots (or for the F-15E, pilots and weapon system officers [WSOs])[4] by qualification, and the model calculates the minimum number of sorties that must be flown in each half-year to provide all assigned crew members with the operational training they need.

Operational fighter squadrons have two missions. The primary mission is to deploy and conduct combat missions during wartime, contingencies, and other engagements. They must be ready to conduct missions ranging from patrolling air space to intercepting and destroying enemy aircraft to spotting, assessing, targeting, and destroying stationary and mobile targets on the ground, all while coping with enemy deception, camouflage, electronic interference, ground fire, surface-to-air missiles (SAMs), and combat aircraft. To conduct such missions, they use sophisticated technologies and tactics, operate in close coordination with combat aircraft of various types, and depend on a complex support system for intelligence information, command and control, and logistics support. The ability to perform this very difficult work successfully is crucial to deterring threats to U.S. interests, to prevailing in combat when deterrence fails, and to limiting casualties and other losses on both sides of a conflict. The difference between good and poor pilot performance can mean the difference between life and death.

The fighter squadrons' second mission is to provide operational knowledge and mission experience to aircrew members. This knowledge and experience will qualify the aircrew to subsequently fill assignments at wings, major air commands, and at the Air Staff. Many of those aircrew members must become

---

[1]Operational fighter squadrons deploy and conduct combat missions during wartime, contingencies, and other engagements. They exclude squadrons dedicated to formal training or test-and-evaluation missions.

[2]HTS stands for HARM Targeting System, and HARM stands for high-speed anti-radiation missile.

[3]LANTIRN stands for Low Altitude Navigation and Targeting, Infrared for Night.

[4]The A/OA-10, F-15C, and F-16 fly combat missions as single-seat fighters; therefore, the pilot is the whole aircrew. The F-15E flies combat missions with two aircrew members, a pilot and a WSO. Each operational F-15C and F-16 squadron has a few two-seat versions that the squadron uses for training. There is no two-seat version of the A/OA-10.

instructor pilots to train the next cohorts of fighter pilots. Some will eventually command operational fighter squadrons.

Upon graduation from the formal training unit (FTU) basic course, every pilot must be assigned to an operational unit. In no other assignment can he or she acquire the operational knowledge and experience needed for later assignments. Therefore, operational units are burdened with all the inexperienced pilots, and if (as at the present time) the Air Force is trying to increase its inventory of fighter pilots, this burden can compromise the ability of the operational units to perform their primary mission. Moreover, operational units have limited capacity to provide inexperienced pilots with knowledge and experience, and hence those units form a bottleneck in the development of fighter pilots.

Operational fighter squadrons spend most of their time training. In a qualitative sense, it is easy to justify training as the means for achieving both of the squadrons' missions. But quantifying the minimum amount of training required to ensure that aircrews build and maintain specific capabilities and skills has proven to be difficult. Nevertheless, determining the appropriate amount of required training is important because operational training is expensive and might be targeted when other priorities are inadequately funded in the budgetary process.[5] As shown in Table 1.1, the cost of operating the aircraft in operational fighter squadrons is $3 billion per year for fuel, spare parts, depot maintenance, and munitions, not counting labor at the squadron or wing level.

Squadrons categorize most of their training in one of two ways, as either upgrade training or continuation training:

- *Upgrade training* develops specific skills to advance to the next higher level—e.g., newcomers upgrade to become combat-mission-ready (CMR) wingmen, wingmen advance to become flight leads, flight leads advance to become instructor pilots, and instructor pilots become mission commanders.
- *Continuation training* maintains and refines the skills needed to perform the squadron's assigned missions and prepare for the next upgrade.

Although each category involves training both in the air and on the ground, this report concentrates on the flying portion. Flight simulators are also included in this analysis because they require expensive resources and are the principal mechanism for developing and demonstrating the capabilities needed in combat.

---

[5]As documented in Larson, Orletsky, and Leuschner (2001), defense spending was inadequate throughout most of the 1990s to support U.S. strategy. As a result, both readiness and modernization were underfunded.

Table 1.1

Squadrons, Aircraft Inventories, and Annual Operating Costs

Aircraft	Number of Operational Squadrons[a]	Number of Authorized Aircraft[a]	Annual Flying Hours/ Aircraft[b]	Cost/Flying Hour[c]	Annual Cost ($M)
			Active		
A/OA-10	6	126	458	$3,512	202.7
F-15C	11	246	291	$10,191	729.5
F-15E	6	132	330	$11,687	509.1
F-16C	21	420	313	$5,119	672.9
			Air National Guard		
A/OA-10	6	90	266	$3,512	84.1
F-15A	6	90	245	$8,004	176.5
F-16C	25	375	268	$5,119	514.5
			Air Force Reserve		
A/OA-10	2	30	258	$3,512	27.2
F-16C	4	60	271	$5,119	83.2
Total	87	1,569	—	—	2,999.7

[a]From the Air Force Program Data System as of January/February 2001. Maintained by AFXPPE (the Office of Program Integration within the Directorate of Plans and Programs).

[b]Derived from the Air Force Program Data System. Programmed flying hours differ by major command. We have used averages.

[c]From Air Force Instruction AFI 65-503 (2001). Fuel, parts, and depot maintenance costs per flying hour are shown in Table 2 of the AFI; munitions cost per flying hour are shown in Table 12.

Widely regarded as the best in the world, operational fighter training in the U.S. Air Force is governed by the Ready Aircrew Program (RAP). RAP prescribes minimum numbers and types of sorties that pilots should fly to maintain their proficiency and upgrade to higher levels. For example, in the Active component's operational squadrons that fly the F-16CG, inexperienced[6] "line pilots"[7] should fly at least 116 sorties per year, and experienced pilots should fly at least 96 sorties per year. In addition, specific collections of 12 and 11 sorties are needed to upgrade from wingman to four-ship flight lead and from flight lead to instructor pilot, respectively.[8]

In recent years, somewhat fewer flying hours have been funded,[9] the fighter force has spent more time engaged in peacekeeping and peacemaking operations

---

[6]Although other criteria may also distinguish inexperienced pilots from experienced ones, the most commonly used criterion is that experienced pilots must have accumulated at least 500 flying hours in their primary mission aircraft.

[7]"Line pilots" fill so-called API-1 positions (API stands for aircrew position identifier; API was formerly RPI [rated position indicator]). API-6 designates flying positions within wings that contain squadrons and API-8 designates flying positions in organizations above the wing level.

[8]See Air Force Instruction AFI 11-2F-16, 1998.

[9]In fiscal year (FY) 2001, the Air Force leadership reversed this trend by giving greater priority to funding flying hours. This ended the previous practice of using some operations and maintenance (O&M) funds for other priorities.

(activities with less training value than flights intended solely for training), and many experienced pilots have left the Air Force. As stated at the start of this chapter, this report describes a set of models developed to estimate the number of sorties that operational squadrons need to fly in order to maintain their pilots' proficiencies and mission capabilities and do so under these altered circumstances.

We developed our models in parallel with the Air Force's development of RAP. Our models enable analysis that goes deeper than RAP's, allowing us to examine the effects of changes in missions or squadron manning, for instance. As an illustration, RAP's guidelines would give an operational squadron (for example, 18 authorized F-16CG aircraft and 23 line pilots) 3,761 sorties per year for 15 experienced and 8 inexperienced line pilots, compared with 3,903 sorties per year (4 percent more) for 8 experienced and 15 inexperienced line pilots.[10] In contrast, our framework shows that 20 percent more sorties would be needed in the latter case. The difference between RAP's guidelines and our estimate arises because our framework makes explicit that (1) the squadron's inexperienced wingmen never fly without flight leaders or instructor pilots, most of whom are experienced, and (2) when a high proportion of a squadron's pilots are inexperienced, most of the experienced pilots must fly many more sorties beyond the number needed to maintain their own proficiencies simply to supervise and train the squadron's inexperienced wingmen.

In the broadest overview, our models specifically reflect the following:

- Numerous skills underlie the ability to perform each type of mission.
- Different categories of pilots need different combinations of skills and different amounts of practice to maintain those skills.
- Different types of training sorties allow pilots to practice various skills and at various levels of quality.

With considerable input from experts in operational units and on the Air Combat Command (ACC) staff, we developed data and models to reflect these relationships for different types of fighter squadrons. We calibrated our models to reflect a level of flying that experienced pilots have told us will provide "adequate training" for individual pilots. "Adequate training" means training that is good enough that no aircrews in the squadron will need spin-up sorties before performing the assigned missions for which they are specifically qualified.

---

[10]RAP allocates sorties for non-training purposes and additional training sorties for API-6 and API-8 "overhead" pilots, many of whom maintain only basic-mission-capable (BMC) status, plus training sorties for pilots who maintain special capabilities—e.g., combat search and rescue (CSAR).

We found a rough consensus among instructor pilots (IPs) and flight leads concerning how much training is adequate, but there was also substantial variation of opinion. We think the models as they stand are suitable for analysis, but they should be more carefully calibrated before they are used for management purposes (e.g., to calculate formal Air Force requirements for flying hours).

After the models have been calibrated, we can then vary the manning to see how the required flying must change in order for a squadron to continue to provide "adequate training" for all of its pilots. As a result, we can find the minimum number of training sorties a squadron with given characteristics should fly per month.[11] We emphasize that these models are designed to help determine and justify resource requirements, not to allocate or schedule available sorties. We believe allocation and scheduling are best left in the hands of individual squadrons.[12]

Because these optimization models tend to be somewhat cumbersome, we have also developed so-called "repro" models. They are much simpler than the optimization models, with many fewer inputs and outputs. Nevertheless, their outputs closely mirror selected outputs from the more detailed models. Implemented in straightforward spreadsheets (using Microsoft Excel), the repro models enable one to examine how various policies and practices affect operational training—e.g., how limitations in sortie availability, overmanning or undermanning, deployments, and production of new pilots from undergraduate flying training (UFT) and FTUs would affect newcomers' accumulation of experience and qualifications.

Chapter 2 describes the structure of our optimization models, using the F-16 LANTIRN version of the model as an example. Chapter 3 compares the F-16 LANTIRN model with RAP. It also illustrates the model's use to examine some important, real-world questions: What if squadrons' experience levels decline? What if peacetime engagements required extensive flying with little training value? Chapter 4 describes the development of the repro models and shows how

---

[11]To calculate this number, we use the General Algebraic Modeling System (GAMS for short, a commercially available product). For more information, see Brooke, Kendrick, and Meeraus (1991). Also visit the GAMS Web site at www.gams.com.

[12]We assume that no sorties are wasted or used suboptimally, but day-to-day circumstances will ensure that an actual unit will get less than the theoretical maximum training value from some sorties. The RAP allocates 2 percent more sorties than the base requirement for *attrition* and *scheduling inefficiency*. Attrition sorties compensate for training sorties for which a major portion of valid training is not accomplished due to poor weather, air aborts, and other factors. As an explanation of scheduling inefficiencies, suppose Pilot Smith needs to fly one or more elementary sorties before he is ready to fly a more advanced sortie. It may be necessary for Pilot Jones, who is ready to fly more advanced sorties, to fill out a four-ship flight so that Pilot Smith can get the elementary sorties under his belt.

they can help analyze the Air Force's absorption of new pilots and examine the long-term effects of policies on the inventory of pilots. Chapter 5 summarizes our observations and outlines developments that would further enhance and employ the utility of this research.

Appendixes A through D present details of the versions of both the optimization and repro models for the F-16 HTS, the A/OA-10, the F-15C, and the F-15E, respectively. These versions have many features in common with the F-16 LANTIRN version, and so we have presented only the differences between the F-16 LANTIRN version and others in the appendixes. Even so, the appendixes are repetitive. We could have condensed the appendix material into a single appendix, but we felt that a single appendix would have been confusing for the greater part of our audience, who we believe are more concerned with the version for a particular mission design series (MDS) than with comparisons across versions.

The inputs to the optimization models include arrays that are so large that printed versions of them would not be practical. We, therefore, include a CD with this report that contains the data for each version of our linear program (LP) model (described in Chapter 2) in the form of an Excel spreadsheet. The accompanying CD also contains all the GAMS files (see Footnote 11) implementing the models.

2. Formulation of the Linear Program

In this chapter, we describe the formulation of our aircrew training model for operational fighter squadrons as a linear program,[1] using an F-16 LANTIRN squadron version of the model as an example. The objective of the LP is to minimize the number of sorties a squadron flies over a fixed training period.[2] The variables are the numbers of sorties of various types flown by crew members in various jobs. The constraints of the LP ensure that all assigned crew members receive the operational training they require.

However, the LP cannot estimate the absolute requirement for training sorties. Rather, as discussed in Chapter 1, we calibrate the model to reflect a level of flying that experienced pilots have told us will provide "adequate training" for a highly experienced squadron. "Adequate training" equates to training that is good enough that a squadron will need no spin-up sorties before performing any of its assigned missions in combat. We then vary the manning or other parameters to determine how the required sorties must change for the squadron to continue to provide "adequate training." In the calibration step, the required sorties are *inputs* of the model. When we vary the manning or other parameters, the required sorties are *outputs* of the model.

To express the model in mathematical notation, we let

j = Job. Each crew member has a job, such as "inexperienced wingman" or "instructor pilot." (See Table 2.1 for a complete list of F-16 LANTIRN pilot jobs.) These descriptions also include specific missions that the squadron is tasked to perform.

p = Profile. Each training sortie has a profile that determines aircraft configurations and range/airspace requirements to conduct training. Example profiles are "aircraft handling characteristics" (AHC) and "surface attack tactics" (SAT). (See Table 2.2 for a complete list of sortie profiles in the F-16 LANTIRN model.)

---

[1] Linear programming is a standard operations research methodology. According to Hillier and Lieberman (1998), p. 29, "The most common type of application [of linear programming] involves the general problem of allocating limited resources among competing activities in the best possible (i.e., optimal) way."

[2] For historical reasons, our model is based on a training period of six months.

v = Version. Some profiles are further partitioned into versions. Most sorties are flown in the basic version, meaning at the home station with no dissimilar aircraft. Other versions are FLG (a flag exercise, flown away from home) and DIS (a sortie flown against dissimilar aircraft); these versions provide training opportunities that differ from the training opportunities with the basic version. (See Table 2.3 for a complete list of sortie versions in the F-16 LANTIRN model.)

Y_{jpv} = Number of sorties of profile p and version v flown by crew members in job j.

c_{jpv} = Whether or not a crew member in job j flying a sortie of profile p and version v requires a sortie by an aircraft (0 if no; 1 if yes). No aircraft is required for a simulator sortie. If an IP rides in the rear cockpit for an upgrade sortie (in those aircraft that have a rear cockpit), the IP will not require a separate aircraft. The WSO in an F-15E does not require a separate aircraft. In all other cases, a sortie by a crew member requires a sortie by an aircraft.

The objective of the LP is to minimize the number of sorties needed to provide the pilots assigned to a squadron with the training they need. The objective can be written as follows:

$$Min\ z = \sum_{j,p,v} c_{jpv} \cdot Y_{jpv} \tag{2.1}$$

Table 2.1

Jobs for F-16 LANTIRN Pilots, by Pilot Category and Capability

Pilot Category	Specific Capability			Job
Pilots in mission qualification training		None		NMQ
Inexperienced wingmen		None		NWG
	Killer Scout			NWK
Experienced wingmen		None		XWG
			LANTIRN	XWL
Inexperienced flight leads		None		NFL
Experienced flight leads		None		XFL
	Killer Scout			XFMK
			LANTIRN	XFML
	Killer Scout		LANTIRN	XFKL
Instructor pilots		None		XIP
	Killer Scout			XIMK
			LANTIRN	XIML
	Killer Scout		LANTIRN	XIKL
Basic mission capable		None		BMC

N/A = Not applicable.

Pilots' Jobs

For each run of the F-16 LANTIRN model, the user must specify the number of pilots in each of the 15 jobs shown in Table 2.1. (For this particular aircraft, the pilot is the sole crew member.) We denote:

N_j = Number of pilots in job *j*.

Mission qualification training (MQT) consists of a specified sequence of sorties, which must be completed by each pilot within 90 days of joining the squadron. In our model, we specify the total number of MQT sorties of each profile that must be flown during each training period and the number N_{NMQ} of pilots in MQT. The model then determines the sorties per pilot. For technical reasons, the solution to the LP will be the same regardless of the number of MQT pilots specified; therefore, we always set the number to be equal to 1.[3]

The major distinctions among the remaining jobs are (1) whether the pilot is inexperienced or experienced; (2) whether the pilot is CMR or BMC; (3) in the case of CMR pilots, whether the pilot is qualified as a wingman, a flight lead, or an instructor pilot; and (4) the specific mission capabilities for which a pilot has qualified.

Inexperienced Versus Experienced Pilots

There are many subjective descriptions of what constitutes an "experienced" pilot—e.g., a pilot who has a "fundamental understanding of the operational mission," or who has "operational knowledge and mission experience." But, for management purposes, the U.S. Air Force has implemented objective criteria based on accumulated flying hours. For example, a fighter pilot who proceeds directly to fighters from UFT is considered experienced after he or she accumulates 500 flying hours in the primary mission aircraft. A pilot with an intervening flying assignment (such as a First Assignment Instructor Pilot [FAIP]) becomes experienced after 1,000 hours of total flying time and 300 hours in the primary mission aircraft.[4] Historically, meeting the objective criterion has

---

[3]We could have instead chosen to specify MQT sorties per pilot and calculated total MQT sorties as a product of the number of pilots and sorties per pilot. Had we done so, the number of pilots in MQT would affect the solution.

[4]The total hours must be logged as *first pilot* or *instructor pilot* time; *copilot* time is not allowed (e.g., if the crew member's earlier experience was in transports or bombers). To allow for changes from one aircraft to another, the provision is 100 hours in the primary mission aircraft for pilots who were previously experienced in another fighter.

ensured that the subjective description is also fulfilled, though there have been questions recently about whether this remains true in today's environment.[5]

Pilots graduate from the FTU basic course with about 80 flying hours in the primary mission aircraft. Their first assignment following graduation must be to an operational squadron because they are inexperienced and therefore not qualified to fill any other kind of billet.[6] Each operational squadron will, therefore, be assigned a share of the inexperienced pilots.[7]

CMR Versus BMC Pilots

A pilot is considered combat mission ready if he is "qualified and proficient in all of the primary missions tasked to his assigned unit and weapon system." A pilot is basic mission capable if he is "familiarized in all, and may be qualified and proficient in some, of the primary missions tasked to his assigned unit and weapon system."[8] Both CMR and BMC pilots can deploy, but BMC pilots are expected to need some spin-up sorties to prepare them for combat. CMR pilots are supposed to be prepared to perform the missions of the squadron with no spin-up requirement. CMR pilots should occupy all primary mission billets (i.e., API-1) in the squadron. BMC pilots may occupy API-6 flying billets with staff responsibilities that directly support flying operations. The squadron commander and the operations officer should be CMR even though they fill API-6 billets.

Wingmen Versus Flight Leads Versus Instructor Pilots

Fighter aircraft usually fly in formations of two or (more typically) four aircraft. The aircraft in positions 1 and 3 must be flown by pilots qualified as flight leads. These pilots have responsibility for "planning and organizing the mission, leading the flight, delegating tasks within the flight, and ensuring mission accomplishment."[9] Wingmen can pilot an aircraft only in positions 2 and 4. They "help the leader plan and organize the mission. They have visual lookout and radar responsibilities, perform back-up navigation tasks, and are essential to

[5]See Taylor et al. (2002).

[6]This issue is discussed in Taylor et al. (2002).

[7]F-117 squadrons are an exception among fighter squadrons. Only pilots who are experienced in some other fighter are permitted to fly an F-117.

[8]Air Force Instruction AFI 11-2F-16 (1998), paragraph 1.4.4.1 for CMR pilots, paragraph 1.4.4.3 for BMC pilots.

[9]Air Force Instruction AFI 11-2F-16 (1998), paragraph 2.9.

target destruction objectives. Wingmen engage as briefed or when directed by the leader and support when the leader engages."[10]

Therefore, flight leads provide in-flight supervision for wingmen. Sometimes, however, more expert supervision is needed than a minimally qualified flight lead can provide. When that happens, an IP will occupy the 1 and/or 3 position. This may be the case if the mission involves introducing a wingman or flight lead to new tasks or correcting previous deficiencies. An IP is also required to supervise a pilot (wingman or not) who is upgrading to a new job.

Specific Mission Capabilities

A squadron's mission statement will specify the core missions and any special missions it is assigned. All CMR pilots must be qualified to perform the core missions, but only some pilots must be qualified for the special missions. In the F-16 LANTIRN model, the special missions are Killer Scout and LANTIRN. The Killer Scout mission identifies, validates, and marks targets, coordinates attack aircraft, and assesses battle damage. LANTIRN is a laser-based precision-guidance system for navigation and air-to-ground missiles.[11]

Sortie Profiles and Versions

Sorties come in several profiles and versions. Profiles (see Table 2.2) typically determine the aircraft configuration, weapons load, range/airspace requirements, and other resources needed to exercise certain kinds of skills. Different versions (see Table 2.3) of the same profile exercise much the same skills, but in different venues, under different conditions, or with a somewhat different emphasis. Thus, the versions account for training differences. Not every sortie profile comes in all versions.[12]

---

[10] Air Force Instruction AFI 11-2F-16 (1998), paragraph 2.10.

[11] Specific missions in F-16CG units have evolved since the original model was built. For example, the Killer Scout and low-level LANTIRN taskings have been replaced in many units by CSAR and Night Vision Goggles (NVG) taskings. The model can readily accommodate such changes.

[12] It is simple to incorporate additional versions of sorties, such as Red Air, Surge, or flights of less than four aircraft, in the linear program. We found additional versions to be unnecessary in the F-16 LANTIRN model, but we have used some additional versions in models for other aircraft (e.g., Red Air sorties in the F-15C model).

Table 2.2

Sortie Profiles in the F-16 LANTIRN Model

Profile	Description	Permitted Version[a]					
BSA	Basic surface attack, day	B				IP	
NBSA	Basic surface attack, night	B				IP	
SAT	Surface attack tactics, day	B	FLG	CFX		IP	
NSAT	Surface attack tactics, night	B				IP	
LNTM	Medium-altitude LANTIRN	B				IP	
LNTL	Low-altitude LANTIRN	B				IP	
CAS	Close air support, day	B		CFX		IP	KST
NCAS	Close air support, night	B				IP	
BFM	Basic fighter maneuvers	B			DIS	IP	
ACM	Air combat maneuvers	B			DIS	IP	
ACT	Air combat tactics	B	FLC	CFX	DIS	IP	
NAIR	Air-to-air, night	B				IP	
AHC	Aircraft handling characteristics	B				IP	
INS	Instruments, day	B				IP	
NINS	Instruments, night	B				IP	
ROT	Rotating aircraft, day	B					
NROT	Rotating aircraft, night	B					
IPR	Rear cockpit IP sortie, day	B					
NIPR	Rear cockpit IP sortie, night	B					
AOR	Familiarization w/ area of responsibility (AOR), day	B					
NAOR	Familiarization w/ AOR, night	B					
SIM	Simulator	B					

[a]See Table 2.3 for definitions of the versions.

Table 2.3

Sortie Versions in the F-16 LANTIRN Model

Version	Description
B	Basic, flown at home station
FLG	Flag exercise, an exercise away from home station
CFX	Composite force exercise
DIS	Sortie flown against dissimilar aircraft
IP	Sortie flown by an instructor pilot grading an upgrade sortie
KST	Killer Scout training

Three of the sortie versions (FLG, CFX, and DIS) are considered *enhanced* versions. An enhanced version of a sortie is more realistic than the basic version of the same profile. Accordingly, the enhanced version provides somewhat more skill units.[13]

Not every pilot is permitted to fly sorties of every profile and version. The legal combinations of job, profile, and version are shown in Table 2.4. The sums in Constraint (2.1) shown earlier are taken over the legal combinations of job, profile, and version, as determined by combining Tables 2.2 and 2.4.

The following paragraphs describe the sortie profiles:

BSA (Basic Surface Attack) sorties are flown locally on a controlled conventional range as a two-, three-, or four-ship flight (a single ship can be authorized in unusual circumstances). BSA sorties are essential for maintaining air-to-surface proficiency and qualification and are required in all fundamental upgrade programs (e.g., MQT, upgrade to flight lead [FLUG], upgrade to instructor pilot [IPUG]). BSA sorties stress conventional munitions delivery procedures and accuracy rather than combat realism.

NBSA (Night Basic Surface Attack) sorties are BSA sorties flown at night.

Table 2.4

Legal Profile-Version-Job Combinations in the F-16 LANTIRN Model

Profile	Version	Permitted Job
All *except* LNTL, IPR, NIPR	B	All
LNTL	B	XWL, XFML, XFKL, XIML, XIKL
IPR, NIPR	B	XIP, XIMK, XIML, XIKL
All	FLG, CFX, DIS	All *except* NMQ
All *except* LNTL, CAS, NCAS	IP	XIP, XIMK, XIML, XIKL
LNTL	IP	XIML, XIKL
CAS, NCAS	IP	XIMK, XIKL
CAS	KST	NWK, XFMK, XFKL, XIMK, XIML

[13]Some readers may note that a Red Air sortie version is conspicuously absent from the F-16 LANTIRN version of the model. Red Air sorties are flown to provide a mock adversary during sorties with air-to-air profiles (i.e., BFM, ACM, ACT, and NAIR). They have less training value than the basic version of the same profile. If a squadron has primarily an air-to-air mission, it is important to include a Red Air version and constrain the pilots to fly appropriate numbers of them, which we did in the F-15C version of the LP (see Appendix C). But the F-16 LANTIRN model described here is configured to represent a squadron with primarily an air-to-ground mission; therefore, we omitted Red Air.

Since the attacks of September 11, 2001, many F-16 units have been given more air-to-air responsibilities. To represent squadrons with the new mix of missions, the model would need adjustment, including the addition of Red Air versions of air-to-air sortie profiles. The F-15C model can serve as a guide for how to add a Red Air sortie version to the model.

SAT (Surface Attack Tactics) sorties are flown locally or deployed on a tactics range as a two- or four-ship flight. Tactical scenarios should strive for combat realism consistent with Designated Operational Capability (DOC) tasking in a strategic attack (SA), air intercept (AI), conventional suppression of enemy air defenses (SEAD–C), or offensive counter-air, air-to-surface (OCA-S) role. Enhanced training versions (FLG, CFX, and DIS) incorporate actual Red assets (e.g., adversary air and threat emitters) and actual Blue assets (e.g., counter-air and defense suppression support aircraft); when the latter is the result of a composite force or FLG exercise scenario, additional Blue resources (e.g., other attack flights, jammers, airborne warning and control systems [AWACS], RIVET JOINT, and such) may also become available.

NSAT (Night Surface Attack Tactics) sorties are SAT sorties flown at night.

LNTM (Medium-Altitude LANTIRN) sorties are a demanding type of SAT sortie, stressing the employment of precision-guided munitions.

LNTL (Low-Altitude LANTIRN) sorties are another demanding type of SAT sortie, stressing the full capability of the LANTIRN system. These sorties are flown only at night.

CAS (Close Air Support) sorties are flown locally or deployed on a tactics range as a two-, three-, or four-ship flight. The tactical scenario should include realistic ground combat circumstances to support DOC tasking. Enhanced training versions (e.g., flown during AIR WARRIOR exercises) involve external forward air controller (FAC) support and U.S. Army participation with actual Theater Air Control System (TACS) and/or real (or realistically simulated) ground forces.

NCAS (Night Close Air Support) sorties are CAS sorties flown at night.

BFM (Basic Fighter Maneuvers) sorties are flown locally in an air-to-air area or an air combat maneuvering instrumentation (ACMI) range as a two-ship flight (1v1 [one versus one] against a similar or dissimilar adversary).[14] BFM sorties are essential for maintaining air-to-air proficiency and are a required element in all fundamental upgrade programs (e.g., MQT, FLUG, IPUG). There is no night version of BFM.

ACM (Air Combat Maneuvers) sorties are flown locally in an air-to-air area or ACMI range as a three-ship flight (2v1 against a similar or dissimilar adversary).

[14]In general, in standard Air Force usage, XvY denotes X aircraft flying against Y aircraft in a mock engagement. Along the same lines, 1v1 denotes one aircraft versus a single adversary, 4v2 denotes a four-ship flight engaging a two-ship flight, and so forth.

ACM are essential for maintaining air-to-air proficiency and are a required element for MQT and IP upgrade training. There is no night version of ACM.

ACT (Air Combat Tactics) sorties are flown locally or are deployed in an air-to-air area or an ACMI range as a two- or four-ship flight (2v2 against similar adversaries or 2vX or 4vX against dissimilar adversaries). Tactical scenarios should strive for combat realism consistent with defensive counter-air (DCA) and offensive counter-air (OCA) DOC tasking and also be adequate to ensure self-protection and survival if the flight is engaged air-to-air while conducting operations in SA, AI, SEAD-C, OCA-S, or CAS roles.

NAIR (Night Air-to-Air Training) sorties are the nighttime counterpart to ACT sorties, although they do not provide true air combat *tactics* training because actual engagements cannot be conducted. NAIR sorties stress tactical intercepts plus the sorting and targeting phases that occur prior to engagement. They can be flown locally or deployed in a designated air-intercept area or other appropriate airspace with ground-controlled intercept (GCI) support as a two-, three-, or four-ship flight (2v1 or 2v2 with no engagements). Scenarios should stress training in night intercept, beyond visual range (BVR) employment, initial response, and commitment (from a combat air patrol [CAP]) criteria that are essential for the DCA DOC tasking as well as self-protection operations required for other DOC tasking. Enhanced training versions could include multiple-bogey decision processes or baron[15] intercepts during night SAT or CAS training profiles.

AHC (Aircraft Handling Characteristics) sorties can be flown locally in appropriate airspace as a single-ship flight (although portions of the profile can be flown as a two-ship flight to practice formation departures or recoveries or to practice basic formation procedures). They are essential for maintaining progress of the air-to-ground, air-to-air, and low-altitude training and are required for MQT and IPUG upgrade programs. This profile can be combined with the INS profile detailed next to improve overall training opportunities. There is no night version of AHC.

INS (Instruments) sorties can be flown locally or at alternative airfields as a single-ship flight (although portions of the profile can be flown as a two-ship flight to practice formation departures or recoveries or to practice basic formation

---

[15]A "baron intercept" is a mock attack conducted by one aircraft against another aircraft when both are in transit to or from the training area. It is named after the Red Baron of Germany (Baron Manfred von Richthofen of World War I fame, also famous as Snoopy's adversary in the Peanuts comic strip). Although baron intercepts are not the primary purpose of any sortie, they increase its training value.

procedures). A second aircraft may chase other portions of the instrument-training profile. INS sorties are essential for all flying and are required for MQT and IPUG upgrade programs. Each pilot's instrument proficiency is measured annually using a formal "check ride" (which typically also includes emergency landing procedures and a representative sampling of aircraft handling maneuvers). This profile can be combined with the AHC profile detailed earlier to improve overall training opportunities.

NINS (Night Instruments) sorties are the same as INS sorties except that they are flown at night.

ROT (Deploying or Rotating Aircraft) sorties are flown to move aircraft between locations in required quantities (ranging from one to every aircraft possessed by a unit). It is not a true *training* profile but rather is a necessary responsibility for unit mission tasking and training. Aircraft deployments can be generated for diverse needs including RED FLAG (or other exercise) participation, aircraft transfers between units, programmed depot maintenance (PDM) input or return, plus essential aircraft rotation to a long-term deployment area of responsibility (AOR).

NROT (Night Deploying or Rotating Aircraft) sorties are the night version of ROT sorties. For the most part, units deploy or rotate aircraft during the day, although combat or other emergency circumstances can generate night requirements.

IPR (Rear Cockpit IP) sorties are flown to provide supervision and (possibly) instruction for upgrades, recurrencies, and requalifications. They require an F-16D. Their purpose is to provide training for the supervised pilot, not for the IP. They can be flown in many of the daytime profiles shown in Table 2.3, but the actual training afforded the IP is extremely limited.

NIPR (Night Rear Cockpit IP) sorties are IPR sorties flown at night. They can be flown in many of the nighttime profiles shown in Table 2.3.

AOR (Area of Responsibility) sorties are flown in support of actual national command authority (NCA) and commander in chief (CINC) requirements in a designated area of responsibility or as part of a deployed air expeditionary force.

NAOR (Night Area of Responsibility) sorties are the nighttime equivalent of AOR sorties.

SIM (Simulator) sorties provide an essential training opportunity for emergency and combat-related procedures and tasks. Enhancements and degradations of training value relative to actual flying may be related to differences in the types of training devices available at various locations, plus the ability of those devices to be linked in more realistic scenarios.

Skill Acquisition and Practice

The aircrew training model's most important constraints relate to the skills that pilots learn and practice when they fly the various profiles and versions of sorties. We identified 154 individual skills that contribute to mission capabilities of F-16 LANTIRN pilots, which we grouped into nine categories (see Table 2.5).

The model ensures that pilots receive adequate amounts of skills practice. We measure skills in terms of "units." We define the following:

s = Skill

$Sprac_{spv}$ = Number of units of skill s provided by a sortie of profile p and version v (i.e., the *supply* of skill units per sortie)

$Dprac_{sj}$ = Number of units of skill s that a crew member in job j must accumulate during each training period (i.e., the *demand* for skill units per pilot per period)

The $Sprac_{spv}$ and $Dprac_{sj}$ arrays can be found on the CD that accompanies this report.

The skill acquisition constraints are as follows:

$$\sum_{p,v} Sprac_{spv} \cdot Y_{jpv} \geq Dprac_{sj} \cdot N_j \quad \forall s, j \neq NMQ \qquad (2.2)$$[16]

Note that there are no skill acquisition constraints for pilots yet to complete MQT.

Note also that multiplying all the *Sprac* and *Dprac* entries for skill s by the same positive factor will have no effect on the solutions to Constraints (2.2).[17] The absolute number of units of a given skill provided by a particular sortie is arbitrary. What matters is the ratio of units required by a pilot to units provided by a sortie.

[16] The symbol $\forall$ is standard mathematical notation meaning "for all" or "for every." Thus in Constraints (2.2), $\forall s, j \neq NMQ$ indicates that there is a separate constraint for every combination of a skill s and a job j, excluding $j = NMQ$.

[17] Although it is standard practice in a report such as this to label numbered formulas as "equations," our constraints may be either equations or inequalities. Therefore, we refer to the numbered equations and inequalities alike in this report as "constraints."

Table 2.5

F-16 LANTIRN Skill Categories, with Examples

SUPPORTING SKILLS
Basic airmanship; instruments; aircraft handling; navigation; formation; air-to-air refueling (AAR)
GENERAL SKILLS FOR ALL COMBAT TASKING
Communications procedures; combat mission planning; switchology; large force employment integration; target deconfliction; hung ordnance/aircraft damage procedures
GENERAL SKILLS FOR AIR-TO-GROUND MISSIONS
Air-to-surface delivery systems; surface-to-air threats; attack options; delivery methods; impact accuracy; fuel management; egress options; battle damage response/wounded bird procedures
GENERAL SKILLS FOR AIR-TO-AIR MISSIONS
Air-to-air systems; weapon selection options; attack options (day, night); commit criteria
SKILLS SPECIFIC FOR CLOSE AIR SUPPORT
Tactical air control system; command, control, and communications (C3); joint air attack team (JAAT) procedures; FAC control/holding point; target identification and attack restrictions
SKILLS SPECIFIC TO AI, SEAD-C, AND OCA-S MISSIONS
Route and formation selection; threat interpretation and response; AWACS, Rivet Joint, joint surveillance target attack radar system (JSTARS), and other systems issues; target area contingencies; updates/execution/verification
SKILLS SPECIFIC TO MAVERICK MISSIONS
Air-to-ground missile (AGM) 65 B/D/G differences; targeting pod (TGP) targeting options; alternative targeting and missile handoff options
SKILLS SPECIFIC TO LANTIRN MISSIONS
Integrated steerpoint selection and target acquisition; forward looking infrared (FLIR) tuning and boresight; terrain following (TF) operations and limits
SKILLS SPECIFIC TO KILLER SCOUT MISSIONS
Kill boxes/kill zones; air tasking order (ATO) target validation; weather issues; target area flow and mission coordination; target marking and identification; bomb damage assessment (BDA)

We can interpret the ratio $Dprac_{sj} / Sprac_{spv}$ as the minimum number of sorties of profile p and version v that a pilot in job j must fly to acquire the minimum required amount of skill s during a training period, assuming that all of the pilot's practice of skill s occurs during this one kind of sortie. In general, of course, this assumption will not hold; a pilot can practice each skill during several different kinds of sorties. Constraints (2.2) ensure that the practice a pilot gets, summed over all the sorties he flies, at least equals the practice he needs.

The skill categories and relative weights used for both the supply (*Sprac*) and demand (*Dprac*) arrays were developed interactively with Air Force experts. We initially worked with existing Air Force training directives to create lists of proposed skill categories. These lists were then discussed in detail with appropriate staff agencies, generating substantial additions and modifications to the initial list. Once we had general agreement among staff agencies on the skill categories and their relative weights, we visited operational units to ensure that their concerns were also addressed and incorporated. The relative weights used in the F-16 LANTIRN model were used as prototypes to develop *Sprac* and *Dprac* values for the other MDSs. We had to recalibrate the *Dprac* values in some of the other models to resolve redundancies that were created when new lists of mission-specific skills were introduced.[18]

Air Force Mandates for Particular Sorties

The Air Force requires each pilot who has completed MQT to fly particular numbers of some sorties.[19] Each pilot must fly at least one AHC sortie, two instrument sorties, and two night sorties per six month training period. That is,

$$Y_{j,'AHC','B'} \geq N_j \quad \forall j \neq NMQ \tag{2.3}$$

$$Y_{j,'INS','B'} \geq 2N_j \quad \forall j \neq NMQ \tag{2.4}$$

$$\sum_{p,v \in Night} Y_{jpv} \geq 2N_j \quad \forall j \neq NMQ \tag{2.5}$$

Experienced pilots must log at least four simulator turns, and inexperienced pilots must log at least six turns, per training period. We also impose upper limits of five and seven simulator turns per training period on experienced and inexperienced pilots, respectively. From Table 2.1, we define the sets of inexperienced and experienced jobs as follows:

$$\mathcal{INEXP} = \{NWG, NWK, NFL, BMC\}$$

$$\mathcal{EXP} = \begin{Bmatrix} XWG, XWL \\ XFL, XFMK, XFML, XFKL \\ XIP, XIMK, XIML, XIKL \end{Bmatrix}$$

---

[18]The training documents reviewed for this study include all three volumes of the AFI 11-2X-XX training directives for fighter MDSs, instructional syllabi for applicable formal training courses, Air Force Operations Resource Management System (AFORMS, now Aviation Resource Management System [ARMS]) training accomplishment records, and RAP implementation instructions. Additional inputs were obtained through discussions and interviews. We received primary staff support from members of the Operational Training and Weapons and Tactics branches of ACC's Division of Training (ACC/DOT). The Air Staff Operational Training Division (AF/XOOT) reviewed and approved the results. Both of these divisions were primary project points of contact throughout our study. We made initial site visits to operational wings at Hill Air Force Base (AFB), Langley AFB, Shaw AFB, Davis-Monthan AFB, and McEntire Air National Guard Base (ANGB). We subsequently visited Pope AFB and returned to Hill, Langley, and Davis-Monthan. The primary *Dprac* re-calibration occurred in the F-15C model to resolve redundant requirements in the specific and general air-to-air skill demands.

[19]Air Force Instruction AFI 11-2F-16 (1998), paragraph 4.2.

$$6 \cdot N_j \le Y_{j,'SIM','B'} \le 7 \cdot N_j \quad \forall j \in \mathcal{INEXP} \tag{2.6}$$

$$4 \cdot N_j \le Y_{j,'SIM','B'} \le 5 \cdot N_j \quad \forall j \in \mathcal{EXP} \tag{2.7}$$

Preparation for Demanding Sorties

The Air Force identifies *demanding* sorties as “[s]orties that task the aircrew to the extent that flying frequency and continuity are most critical.”[20] Specific sortie profiles, including BFM, ACM, ACT, CAS, and SAT, are considered to be demanding, and night sorties are more demanding than day sorties.

A pilot must have “demanding mission currency” in order to fly demanding sorties. In our model, we represent the requirement for maintaining demanding mission currency as a requirement for pilots to fly less-demanding sorties in preparation for more-demanding ones. Thus, each category of pilot must fly at least as many BSA sorties in daylight as at night:

$$\sum_v Y_{j,'BSA',v} \ge \sum_v Y_{j,'NBSA',v} \quad \forall j \ne NMQ \tag{2.8}$$

Each category of pilot must fly at least as many SAT and CAS sorties (in total) in daylight as at night:

$$\sum_v \left(Y_{j,'SAT',v} + Y_{j,'CAS',v}\right) \ge \sum_v \left(Y_{j,'NSAT',v} + Y_{j,'NCAS',v}\right) \quad \forall j \ne NMQ \tag{2.9}$$

We also impose an overall constraint that at most three-fourths of all sorties can be flown at night. We previously defined z as the total sorties (see Constraint 2.1). The constraint is

$$\sum_{j,p \in \mathcal{NIGHT},v} Y_{jpv} \le 0.75 \cdot z \tag{2.10}$$

where we define the set of sortie profiles p flown at night to be

$$\mathcal{NIGHT} = \begin{Bmatrix} NBSA, NSAT, LNTM, LNTL, NCAS, \\ NAIR, NINS, NROT, NIPR, NAOR \end{Bmatrix}$$

At least 25 percent of each pilot category’s total air-to-ground sorties must be BSA sorties:

$$\sum_v Y_{j,'BSA',v} \ge 0.25 \cdot \sum_v \left(Y_{j,'BSA',v} + Y_{j,'SAT',v} + Y_{j,'CAS',v}\right) \quad \forall j \ne NMQ \tag{2.11}$$

[20] Air Force Instruction AFI 11-2F-16 (1998), p. 89.

Of each pilot category's total BFM and ACM sorties, at least 25 percent must be BFM sorties:

$$\sum_{v} Y_{j,'BFM',v} \geq 0.25 \cdot \sum_{v} \left(Y_{j,'BFM',v} + Y_{j,'ACM',v} \right) \quad \forall j \neq NMQ \tag{2.12}$$

Of each pilot category's total ACM and ACT sorties, at least 25 percent must be ACM sorties:

$$\sum_{v} Y_{j,'ACM',v} \geq 0.25 \cdot \sum_{v} \left(Y_{j,'ACM',v} + Y_{j,'ACT',v} \right) \quad \forall j \neq NMQ \tag{2.13}$$

Availability and Distribution of Enhanced Sorties

Certain sortie versions are considered *enhanced* because they provide more skill units than the basic version. Sorties flown at exercises (the FLG and CFX versions) are enhanced, as are sorties flown against dissimilar aircraft (the DIS version).

Typically, a unit has limited opportunities to fly enhanced sorties. Therefore, we place an upper bound on total sorties of each enhanced version. During a training period, a squadron can fly no more than 90 sorties at flag exercises, 180 sorties at composite force exercises, and 180 sorties against dissimilar aircraft:

$$\sum_{j,p} Y_{jpv} \leq XColLim_v \quad \forall v \tag{2.14}$$

To avoid constraining non-enhanced versions, we set $XColLim_v$ for these versions to a very large number.

Wingmen are prohibited from flying more than their "fair share" of enhanced sorties. The constraints are

$$\sum_{p} Y_{jpv} \leq \left(\frac{N_j}{\sum_{jj \in \mathcal{CMR}} N_{jj}} \right) \cdot XColLim_v \quad \forall j \in \mathcal{WG}, v \tag{2.15}$$

where the sets of CMR pilots and wingmen are

$$\mathcal{CMR} = \begin{Bmatrix} NWG, NWK, XWG, XWL, \\ NFL, XFL, XFMK, XFML, XFKL, \\ XIP, XIMK, XIML, XIKL \end{Bmatrix}$$

$$\mathcal{WG} = \{NWG, NWK, XWG, XWL\}$$

Upgrade Requirements

An *upgrade* is the process by which a pilot becomes qualified for a job or mission. Table 2.6 lists the 15 upgrades that were included in the F-16 LANTIRN model. Each upgrade consists of a specified sequence of sorties (a syllabus) flown by the upgradee under the supervision of an IP. The final sortie in the syllabus is a check ride, a kind of final examination. If the upgradee does not perform satisfactorily on a particular sortie, he or she will repeat it, although we ignore this possibility in our model.

Upgrade Descriptions

When a pilot first joins an operational squadron, he or she must complete mission qualification training. This is just as true for a flight lead or IP joining the squadron as it is for a new inexperienced pilot just graduated from an FTU, although a flight lead or IP will often be allowed to complete an abbreviated syllabus. Some of the other upgrades are completed simultaneously with MQT. Those upgrades are Maverick qualification (MAV), medium-altitude LANTIRN (LNTMD), and Chemical Warfare Training (CWT).

Table 2.6

Upgrades in the F-16 LANTIRN Model

Upgrade	Description
MQT	Mission Qualification Training
MAV	Maverick Qualification
LNTMD	Medium-altitude LANTIRN
LNTLO	Low-altitude LANTIRN
KS	Killer Scout
FLUG2	Two-Ship Flight Lead
FLUG4	Four-Ship Flight Lead
FL24	Two- to Four-Ship Flight Lead
IPUG	IP Upgrade
MCC	Mission Commander
LOW3	Low-Altitude Step-Down Training (LASDT) 300 feet
LOW1	LASDT 100 feet
TOW	Deployable Aerial Reflective Target (DART) Tow
CWT	Chemical Warfare Training
SIMIN	Simulator Instructor

Sorties flown by the upgradee during MQT (and the upgrades completed at the same time) do not count toward skill acquisition, although the supervising IP will get some credit toward skill acquisition.[21] Pilots must complete MQT to become CMR or BMC, and only sorties flown by CMR and BMC pilots count toward skill acquisition and toward satisfying RAP requirements. Because only CMR pilots are eligible for the other upgrade types (in our model, we assume BMC pilots never upgrade further), all of their upgrade sorties do count.

After a wingman gains sufficient skill and judgment (typically after 2–2.5 years with the squadron), the squadron commander may recommend the wingman for upgrade to flight lead. The pilot can upgrade from wingman to two-ship flight lead (FLUG2), which qualifies him to lead a two-ship element or to pilot the third aircraft in a four-ship flight. Or the pilot can upgrade directly to four-ship flight lead (FLUG4), which qualifies him to lead a four-ship flight. The two- to four-ship flight lead (FL24) upgrade advances a two-ship flight lead to a four-ship flight lead. The squadron commander has the discretion to determine whether pilots upgrade to four-ship flight lead in one step or two. Almost all pilots eventually upgrade to flight lead. It is usual for a pilot to be upgraded directly from wingman to four-ship flight lead, and the upgrade to four-ship flight lead occurs at approximately the same time a pilot becomes experienced. Thus, there tends to be very few inexperienced flight leads or experienced wingmen.

After a flight lead gains sufficient additional skill and judgment, the squadron commander may recommend the flight lead for upgrade to IPUG. This sometimes happens at the end of a pilot's first operational tour, but more typically occurs early in his second tour. Pilots are upgraded to IP on the basis of a squadron's need, so not all pilots will have the opportunity to become IPs.

Two upgrades qualify pilots for the special mission capabilities mentioned previously. A pilot becomes Killer Scout qualified through the KS upgrade and LANTIRN qualified through the LNTLO upgrade.

The remaining upgrades correspond to acquiring qualifications that are not explicitly acknowledged in our list of 14 jobs. A flight lead can upgrade to simulator instructor (SIMIN). This upgrade requires one turn in the simulator supervised by an IP already qualified as a simulator instructor but includes no actual sorties.

Upon recommendation by the squadron commander, an IP (or occasionally a flight lead) will upgrade to mission commander (MCC). Other qualifications an

---

[21] A small fraction of MQT upgrade sorties can be supervised by a four-ship flight lead. We ignore this possibility.

IP can acquire are low-level flight qualifications (LOW3 to 300 feet above ground level, LOW1 to 100 feet above ground level) and deployable area reflective target (DART)/Aerial gunnery target system tow qualification (TOW).

Modeling Upgrades

The user of the model must specify the number of upgrades of each type that must be flown during a training period. The model then requires each pilot type to fly a number of sorties of each profile that corresponds to those upgrade counts. We define the following::

u = Upgrade index. It ranges over the upgrade types listed in Table 2.6.

$Upgd_u$ = Number of upgrades of type u. Specified by the user.

$UGAlloc_{ju}$ = Indicator of which pilots are eligible for upgrades. 1 if pilot type j can fly upgrade type u, 0 if not.

$IPSort_{pu}$ = Number of profile p sorties in the syllabus for upgrade type u.

$FCIPSort_{pu}$ = Number of profile p sorties in the syllabus for upgrade type u for which the supervising IP flies in the front cockpit.

The four data arrays above can be found on the CD that accompanies this report.

Because only one pilot can fit in the front cockpit, the sorties in *FCIPSort* are those for which the upgradee and supervising IP fly in different aircraft. The difference between *IPSort* and *FCIPSort* is the set of sorties for which the upgradee flies in the front cockpit and the IP in the rear cockpit of the same aircraft.[22]

We assume that all upgrade sorties are flown in the basic version. In practice, this is largely, although not entirely, true.

We calculate the number of upgrade sorties of profile p flown by upgrading pilots in class j as follows (we deal with the supervising IP sorties later):

[22] In our model, all rear cockpit sorties occur during upgrade sorties. In a real squadron, an IP may fly continuation training sorties in the rear cockpit with a pilot who is lagging in some skill or skills simply to help that pilot catch up.

$$UGSort_{jp} = \sum_u \left(IPSort_{pu} \cdot Upgd_u \cdot \frac{UGAlloc_{ju} \cdot N_j}{\sum_{jj} UGAlloc_{jj,u} \cdot N_{jj}} \right) \quad \forall j, p \tag{2.16}$$

This formula allocates sorties in each upgrade type proportionately to all pilots eligible for that upgrade. For example, all types of wingmen are eligible for the FLUG4 upgrade. Suppose there are six pilots of type NWG, one each of types NWK and XWG, and none of type XWL, for a total of eight wingmen in all. Then, six-eighths of all FLUG4 sorties will be allocated to NWG pilots, and one-eighth each to NWK and XWG pilots. Because we assume that all upgrade sorties are flown as the basic version, we impose Constraints (2.17) to ensure that all upgradee sorties will be flown, including requirements for pilots undergoing MQT (j = '*NMQ*'):

$$Y_{jp,'B'} \geq UGSort_{jp} \quad \forall j, p \tag{2.17}$$

We now turn to the upgrade sorties flown by supervising IPs. The supervising IP flies most upgrade sorties in the front (i.e., the only) cockpit of one aircraft, while the upgradee flies in the front (i.e., the only) cockpit of a second aircraft. We have defined a special version of each sortie, the IP version, for these sorties. Therefore, we use

$$\sum_{j \in \mathcal{IP}} Y_{jp,'IP'} \geq \sum_u FCIPSort_{pu} \cdot Upgd_u \quad \forall p \tag{2.18}$$

where we define the set of instructor pilots to be

$$\mathcal{IP} = \{XIP, XIMK, XIML, XIKL\}$$

It would be equally correct to express Constraints (2.18) as equations instead of inequalities, but the value in skill units of a basic sortie is always at least as high as the value of an IP sortie of the same profile. So, there is always a solution to the LP for which Constraints (2.18) are satisfied as equalities.

There are two constraints, similar to (2.18), that ensure that only IPs with a LANTIRN qualification supervise LANTIRN upgrades, and only IPs with a Killer Scout qualification supervise Killer Scout upgrades. Those constraints are:

$$\sum_{j \in \{XIML, XIKL\}} Y_{jp,'IP'} \geq FCIPSort_{p,'LNTLO'} \cdot Upgd_{'LNTLO'} \quad \forall p \tag{2.19}$$

$$\sum_{j \in \{XIMK, XIKL\}} Y_{jp,'IP'} \geq FCIPSort_{p,'KS'} \cdot Upgd_{'KS'} \quad \forall p \tag{2.20}$$

We also force each group of IPs to fly approximately its share of front cockpit upgrade sorties. We write these constraints as:[23]

$$\sum_{p} Y_{jp,'IP'} \geq \left(\frac{N_j}{\sum_{jj \in \mathcal{IP}} N_{jj}} \right) \cdot \sum_{jj \in \mathcal{IP}, p} Y_{jj,p,'IP'} - 0.1 \cdot N_j \quad \forall j \in \mathcal{IP} \tag{2.21}$$

There are analogous constraints for upgrade sorties in which the supervising IP flies in the rear cockpit while the upgradee flies in the front cockpit. (During the IPUG upgrade, there is a sortie in which the supervising IP rides in the front while the upgradee rides in the rear, but it still contributes only one aircraft sortie.) We calculate the number of rear cockpit sorties as follows:

$$RCIPSort_{pu} = IPSort_{pu} - FCIPSort_{pu} \quad \forall p, u \tag{2.22}$$

We have defined two types of rear cockpit sorties, IPR sorties for day and NIPR sorties for night (see Table 2.3). Both are basic version sorties, and can be flown only by IPs. Total daytime and nighttime rear cockpit sorties will be

$$\sum_{j \in \mathcal{IP}} Y_{j,'IPR','B'} \geq \sum_{u, p \notin \mathcal{NIGHT}} RCIPSort_{pu} \cdot Upgd_u \tag{2.23}$$

$$\sum_{j \in \mathcal{IP}} Y_{j,'NIPR','B'} \geq \sum_{u, p \in \mathcal{NIGHT}} RCIPSort_{pu} \cdot Upgd_u \tag{2.24}$$

One nighttime sortie is flown during the LNTLO upgrade for which the IP rides in the rear cockpit. The IP for this sortie needs to be LANTIRN qualified, hence the following constraint is used:

$$\sum_{j \in \{XIML, XIKL\}} Y_{j,'NIPR','B'} \geq \sum_{p \in \mathcal{NIGHT}} RCIPSort_{p,'LNTLO'} \cdot Upgd_{'LNTLO'} \tag{2.25}$$

No rear cockpit sorties are required for the Killer Scout upgrade, so there is no counterpart to Constraints (2.20).

Finally, we force each type of IP to fly its share of rear cockpit sorties.[24] Constraints (2.26) implement this requirement for day sorties, while Constraints (2.27) implement this requirement for night sorties:

---

[23]The quantity $0.1 \times N_j$ allows some flexibility in the allocation of sorties. The factor 0.1 was chosen to enforce an approximately proportionate sharing of sorties without increasing total required sorties by much.

[24]The quantity $0.25 \times N_j$ allows some flexibility in the allocation of sorties. We chose the factor 0.25 because it enforces an approximately proportionate sharing of sorties without increasing the total required sorties by much.

$$Y_{j,'IPR','B'} \geq \left(\frac{N_j}{\sum_{jj \in \mathcal{IP}} N_{jj}} \right) \cdot \sum_{jj \in \mathcal{IP}} Y_{jj,'IPR','B'} - 0.25 \cdot N_j \quad \forall j \in \mathcal{IP} \tag{2.26}$$

$$Y_{j,'NIPR','B'} \geq \left(\frac{N_j}{\sum_{jj \in \mathcal{IP}} N_{jj}} \right) \cdot \sum_{jj \in \mathcal{IP}} Y_{jj,'NIPR','B'} - 0.25 \cdot N_j \quad \forall j \in \mathcal{IP} \tag{2.27}$$

Requirement for In-Flight Supervision

As described earlier, fighter aircraft typically fly in formations of two or four aircraft, half of which must have pilots qualified to be flight leads or IPs. A few sortie profiles are exceptions to this rule. A wingman can fly AHC, INS, NINS, ROT, and NROT sorties without supervision.[25] The set of sortie profiles requiring in-flight supervision is

$$\mathcal{SUP} = \left\{ \begin{matrix} BSA, NBSA, SAT, NSAT, LNTM, LNTL, CAS, \\ NCAS, BFM, ACM, ACT, NAIR, AOR, NAOR \end{matrix} \right\}$$

We need two blocks of constraints to represent the requirement for in-flight supervision, one for basic sorties and one for all other versions. The constraints for basic sorties must include upgrade sorties, which are supervised by IPs. The constraints for the other sortie versions cover only continuation training.

The simpler constraints, for nonbasic versions of sorties, are written as

$$\sum_{j \in \mathcal{FL} \cup \mathcal{IP}} Y_{jpv} \geq \sum_{j \notin (\mathcal{FL} \cup \mathcal{IP})} Y_{jpv} \quad \forall p \in \mathcal{SUP}, v \neq 'B' \tag{2.28}$$

where the set of flight leads is

$$\mathcal{FL} = \{NFL, XFL, XFMK, XFML, XFKL\}$$

The constraints for basic sorties are written as follows:

$$\sum_{j \in \mathcal{FL} \cup \mathcal{IP}} \left(Y_{jp,'B'} + Y_{jp,'IP'} \right) \geq \left(\begin{matrix} \sum_{j \notin (\mathcal{FL} \cup \mathcal{IP})} Y_{jp,'B'} - \\ \sum_{u} RCIPSort_{pu} \cdot Upgd_u \end{matrix} \right) \quad \forall p \in \mathcal{SUP} \tag{2.29}$$

---

[25] A 2v1 ACM flight includes one supervisor (flight lead or IP) and two wingmen (one as the bandit). ACM can also be flown with an extra supervisor for the bandit (i.e., as 2v1 + 1). We have made no provision in our model for the lower supervisor-to-supervisee ratio in ACM sorties.

Constraints (2.29) look rather complicated. On the left-hand side of the inequality sign is the sum of basic and IP versions of all sorties flown by flight leads or IPs. These are the sorties available to supervise wingmen. On the right-hand side of the inequality sign we find two terms. The first term calculates all sorties flown by pilots other than flight leads and IPs (i.e., pilots in MQT, wingmen, and BMC pilots). The second term subtracts the sorties that are supervised from the rear cockpit.

The term on the left-hand side of the inequality sign counts sorties by upgrading flight leads and IPs. But can a flight lead or IP *who is undergoing an upgrade* (e.g., a flight lead upgrading to an IP) simultaneously supervise wingmen? We say yes. The upgradee is already qualified to lead flights and is adding a qualification to do something else simultaneously. So, we presume the upgrade syllabus will require the upgradee to do both—upgrade and supervise—at once.

Selecting a Solution

As described in this chapter, the LP has many solutions. Considering each pilot type separately, there is some flexibility in the mix of sortie profiles and versions that are used to provide the necessary skill units (Constraints [2.2]) in a minimum number of sorties. This flexibility exists because different sortie profiles and versions can offer similar mixes of skills. Even if one sortie doesn't offer as many units of a particular skill as does another sortie, perhaps the corresponding skill acquisition constraint is not binding—i.e., perhaps the pilot is acquiring more than enough of that skill from other sorties. Then, in a practical sense, the second sortie can substitute for the first.

Opportunities also exist for sorties by one type of pilot to substitute for sorties by another type. If a squadron is manned with a high ratio of wingmen and BMC pilots to flight leads and IPs, the in-flight supervision Constraints (2.29) and (2.30) will force flight leads and IPs to fly more than necessary to acquire and practice skills. There will be a great deal of flexibility in how the extra sorties are distributed among the different types of flight leads and IPs.

We have devised an ad hoc method for selecting one of the many optimal solutions to the LP. First, we define some new variables that measure deviations in the sortie mix flown by individual pilot types from the average mix over all pilots:

$$PosDev_{jpv} \geq \left(\frac{\sum_{jj} Y_{jj,p,v}}{\sum_{jj} N_{jj}} \right) - \left(\frac{Y_{j,p,v}}{N_j} \right) \quad \forall j,p,v \tag{2.30}$$

$$NegDev_{jpv} \geq \left(\frac{Y_{j,p,v}}{N_j} \right) - \left(\frac{\sum_{jj} Y_{jj,p,v}}{\sum_{jj} N_{jj}} \right) \quad \forall j,p,v \tag{2.31}$$

Next, we solve the LP, with Constraint (2.1) as the objective function and Constraints (2.2) through (2.29) as the constraints, plus the requirement that all the Y_{jpv} be greater than or equal to zero. We let *zmin* be the minimum total number of sorties required, as determined by that solution. Then, we define a new LP with all the old constraints (2.2) through (2.29), plus Constraints (2.30) and (2.31), plus the requirement that the total number of sorties is no larger than an optimal solution to the old LP:

$$\sum_{j,p,v} c_{jpv} \cdot Y_{jpv} \leq zmin \tag{2.32}$$

The objective function of this new LP is:

$$Min \quad TotDev = \sum_{j,p,v} \left(PosDev_{jpv} + NegDev_{jpv} \right) \tag{2.33}$$

The sums in Constraints (2.32) and (2.33) are understood to be taken over only those triples (j,p,v) for which pilots of job type j are allowed to fly sorties of profile p and version v (see Tables 2.3 and 2.4).

The value of *TotDev* can never be negative because both $PosDev_{jpv}$ and $NegDev_{jpv}$ are non-negative. (For $PosDev_{jpv}$ [or $NegDev_{jpv}$] to be negative, each pilot type would have to fly more [or fewer] sorties per pilot of profile p and version v than the average over all pilot types—an obvious impossibility.) To make *TotDev* equal to zero, its theoretically minimum possible value, every pilot must fly the same number of sorties of each profile and version. Therefore, minimizing *TotDev* will tend to make pilots of each type fly much the same number and mix of sorties.

3. Example Results from the F-16 LANTIRN Version of the Model

To illustrate the sort of results the aircrew training model might produce, in this chapter we present sample results from the F-16 LANTIRN version of the model. We first calibrate the model to an 18-PAA (primary aircraft authorization) squadron manned at 100 percent of authorizations and with a high (65-percent) experience level. We then vary the model's manning to reflect an 18-PAA squadron manned at 100 percent of authorizations and with a very low (35-percent) experience level and re-estimate the required sorties. We then discuss the differences between the official Air Force Ready Aircrew Program requirements and the sortie requirement estimates from our model.

Finally, we explore the effect of contingencies on sortie requirements. Sorties flown during contingency operations, such as Northern Watch, have limited training value. In terms of our model, they do not offer a mix of profiles that will provide practice on all the various kinds of skills a pilot must acquire. Therefore, in this case, the total number of required sorties must increase.

Calibrating the Model to a Base Case

Like all models, ours must be calibrated. *Calibration* is the process of adjusting the various model parameters, in this case $Sprac_{spv}$ and $Dprac_{sj}$, so that the model agrees with a known base case. After the model is calibrated, it can be used to estimate required sorties in other cases by adjusting its inputs. Two questions arise regarding calibrations: First, how completely and exactly is the base case known? That is, by how much could one change the total number of sorties or their distribution over profiles and versions before one would have to say that the base case is no longer valid? Second, what is the model's range of validity? That is, after the model is calibrated, by how much can one vary its inputs and still obtain valid estimates of required sorties? In the following discussion, we touch on both issues.

As stated above, our base case is an F-16 LANTIRN squadron with 18 PAA. The specified crew ratio for the F-16 is 1.25; therefore, this squadron is authorized $1.25 \times 18 = 22.5$ API-1 pilots, which the Air Force rounds up to 23. All the API-1 pilots will be CMR. The squadron will have two additional CMR pilots, the squadron commander and the operations officer, who occupy API-6 billets. They will be experienced pilots, probably IP-qualified. An additional four pilots from wing or other staff functions will be assigned to this squadron. They will be BMC pilots occupying API-6 billets.[1]

These 29 pilots will be assigned to jobs as shown in Table 3.1. Eight of the CMR pilots (seven wingmen and one flight lead) are inexperienced, while 17 CMR pilots are experienced. The Air Force calculates the experience level as the ratio of experienced API-1 pilots to authorized API-1 billets. As already mentioned, two of the experienced CMR pilots occupy API-6 billets, so the experience level is (17 – 2)/23 = 65.2 percent.

We developed the $Sprac_{spv}$ and $Dprac_{sj}$ arrays in consultation with experienced F-16 pilots at Hill AFB, Utah; Shaw AFB, South Carolina; Carswell Naval Joint

Table 3.1

Required Monthly Sorties for the F-16 LANTIRN Base Case, by Pilot Type

Pilot Type	Number of Pilots	Sorties per Pilot per Month	Total Sorties per Month
NMQ[a]	N/A	N/A	18.75
NWG	6	13.18	79.08
NWK	1	13.33	13.33
XWG	1	12.06	12.06
XWL	0	N/A	0.00
NFL	1	13.52	13.52
XFL	3	12.04	36.13
XFMK	1	12.19	12.19
XFML	2	12.71	25.42
XFKL	1	12.90	12.90
XIP	2	13.68	27.35
XIMK	2	13.40	26.80
XIML	2	14.75	29.49
XIKL	3	13.31	39.94
BMC	4	10.29	41.16
Total Sorties per Month			388.12

[a]As explained earlier, we formulated the model in such a way that the user specifies the total number of upgrade sorties by type of upgrade, and the model allocates the sorties to pilot types. MQT upgrade sorties are all allocated to NMQ pilots, and these pilots fly no other sorties. Therefore, the model's results do not depend on the number of pilots of this type.

[1]An actual squadron will often have additional attached pilots. It would be a simple matter to add such pilots to our model. In the meantime, the base case results we report do not include attached pilots, and should be adjusted appropriately before being compared with actual sorties flown by squadrons that do have attached pilots.

Reserve Base, Texas; McEntire ANGB; and functional area managers from the Current Operations Branch in ACC. When we ran the F-16 LANTIRN linear program for the base case, it produced the requirements shown in Table 3.1—a little more than 13 sorties per month for inexperienced pilots and a little less than that number for experienced pilots.[2] Upon seeing these results, the subject matter experts we consulted for this study agreed in both face-to-face interviews and survey responses that pilots should fly close to these numbers of sorties to maintain proficiency and to progress to higher positions (e.g., wingman to flight lead, flight lead to IP).[3, 4]

In one survey conducted for this study,[5] about half (9 of 17) of the respondents gave an estimate of 13 sorties per month for inexperienced pilots, but the remaining respondents chose a different number, from as few as 8 to as many as 15 sorties per month. The popularity of the number 13 suggests that it is the best number to use. However, it would be worthwhile to probe deeper into the reasoning behind the different choices. Perhaps respondents who chose numbers lower than 13 thought that 8 or 10 sorties per month would be adequate *for a limited period of time* (e.g., a few months), provided the number was subsequently increased. (That is not what we intended to ask, but our questions may not have been specific enough.) Perhaps lower numbers reflected respondents' thoughts that pilots probably did not need to train for combat environments as stressful as those once anticipated for a conflict with the Warsaw Pact states during the Cold War. Perhaps lower numbers were deemed adequate only because respondents expected that pilots would have an opportunity to fly spin-up sorties before deploying to remedy training shortfalls.

Only a few respondents chose a number greater than 13 sorties per month. The ones who did may have had more exacting standards than their fellows. Or

---

[2]We calibrated the other versions of the LP differently. We took 13 sorties per month for an inexperienced pilot (and a little fewer than that for an experienced pilot) as the inputs and adjusted the $Sprac_{spv}$ and $Dprac_{sj}$ arrays to achieve those results. See Appendixes A through D for more information.

[3]Twelve sorties per month for an inexperienced pilot was the modal response, but the survey respondents and interviewees usually arrived at 12 sorties per month by multiplying three sorties per week by four weeks per month. Actually, a month is somewhat longer than four weeks, so three sorties per week scales up to just over 13 sorties per month.

[4]According to the experts we consulted, highly experienced pilots require even fewer sorties, perhaps as few as 10 or 10.5 sorties per month. A highly experienced pilot is one who has been a flight lead or IP long enough that he has learned all the techniques there are to learn and needs to fly only to maintain his skills. For the F-16, this experience level is achieved after 1,000 to 1,500 flying hours in the MDS. This information is not currently relevant for an active squadron because active squadrons have no highly experienced pilots. Many National Guard pilots are highly experienced, however, so this information could be useful if the model were revised to represent integrated or associated Active/Guard units.

[5]It was a survey of 17 IPs and flight leads in the 388th Fighter Wing at Hill AFB, Utah. The survey was conducted during a site visit in August 2000.

perhaps each respondent, in his or her heart of hearts, would have chosen a higher number if he or she thought there was a realistic chance of providing pilots with that many sorties. Respondents could have been reluctant to specify too many sorties because they would seem to be saying that the Air Force was incapable of providing its fighter pilots with adequate training.

All this is speculation, however. As we interpret the respondents' judgments, 13 sorties per month for inexperienced pilots (and a sortie less for experienced pilots) should be adequate for a unit to maintain readiness in all of its assigned missions so that it can deploy with few or no preparatory spin-up sorties. A squadron might get by with flying fewer sorties, but its pilots would progress more slowly than desired, and the squadron would require spin-up sorties prior to deploying. (As mentioned in Chapter 2, any BMC pilots deploying with the squadron would be expected to need some spin-up sorties to prepare for combat.)

One other quantity worth examining is the aircraft utilization rate (UTE). In the process of developing its budget, the Air Force selects a programmed UTE. In FY 2000, the Air Force selected 20.1 sorties per F-16 aircraft per month. For an 18-PAA squadron, this UTE would make 361.8 sorties available per month, which is 26.32 sorties short of the requirement calculated by our LP for the base case. Equivalently, it would take a UTE of almost 20.6 sorties per F-16 aircraft per month to provide the number of sorties that our model estimates require.

The LP selects the sortie profiles and versions shown in Table 3.2. The Total row includes all the rows in the body of the table and equals the number of sorties by pilots. The Front Cockpit row excludes turns in the simulator (the SIM row) and sorties flown by instructor pilots in the rear seat of the aircraft. Thus the Front Cockpit row equals the number of aircraft sorties.

For several reasons, we do not present a comparison between the detailed results from Table 3.2 and data from actual squadrons. First, our model calculates *required* sorties. By contrast, units report *actual* sorties in the ARMS.[6] Second, our model represents a nominal squadron, whereas each actual squadron faces its own unique circumstances, and thus flies its own unique schedule. For example, a squadron may be tasked to fly sorties for operational rather than training reasons (e.g., on a deployment).

Moreover, the F-16 has both air-to-air and air-to-ground capabilities, and each unit must adjust its mix of training sorties to reflect the roles specified in its DOC

[6]As noted in Chapter 2, ARMS replaced AFORMS.

Table 3.2

Required Monthly Sorties for the F-16 LANTIRN Base Case, by Sortie Profile and Version

	Version						
Profile	B	FLG	CFX	DIS	IP	KST	Total
BSA	37.18				3.19		40.37
SAT	23.85	15.00	23.20		8.02		70.07
CAS	40.03		0.00		1.13	8.00	49.15
BFM	7.05			0.00	3.19		10.24
ACM	18.51			0.00	2.44		20.95
ACT	15.49	0.00	6.80	30.00	2.81		55.10
AHC	9.83				1.29		11.12
INS	10.60				0.00		10.60
ROT	0.40						0.40
IPR	5.02						5.02
AOR	0.00						
SIM	32.85						32.85
NBSA	17.01				0.94		17.95
NSAT	49.78				1.88		51.66
LNTM	0.94				0.94		1.88
LNTL	12.58				0.75		13.33
NCAS	20.51				0.00		20.51
NAIR	11.86				0.47		12.33
NINS	0.56				0.00		0.56
NROT	1.91						1.91
NIPR	1.88						1.88
NAOR	0.00						
Total	317.84	15.00	30.00	30.00	27.03	8.00	427.87
Front Cockpit	278.09	15.00	30.00	30.00	27.03	8.00	388.12

NOTE: Blank cells in this table correspond to profile-version combinations that are not allowed; see Table 2.2.

tasking. The mix of sortie profiles in Table 3.2 reflects a heavy emphasis on air-to-ground missions (68 percent of sorties have profiles BSA, SAT, CAS, NBSA, NSAT, LNTM, LNTL, or NCAS) and little emphasis on air-to-air missions (only 25 percent of sorties have profiles BFM, ACM, ACT, and NAIR, and there are no Red Air sorties). An actual unit might have a more balanced emphasis. For example, ARMS data from October 2001 through May 2002 indicate that the 388th Fighter Wing at Hill AFB flew about equal numbers of air-to-air and air-to-ground sorties (leaving aside sorties labeled "Contingency Operations"). This period, of course, followed immediately upon September 11, 2001, when it was entirely reasonable that air-to-air missions would receive greater emphasis.

Thus, it would be necessary to recalibrate the LP to reflect a heavier emphasis on air-to-air missions. To do so, one would change the *Dprac* array to reflect increases in demands for air-to-air skills and decreases in demands for air-to-ground skills (see Table 2.5). One would also introduce Red Air sorties, which would be versions of BFM, ACM, and ACT sorties with degraded training value. Indeed, any significant change in a unit's DOC statement would require that the model be recalibrated.

Example Squadron with a Low Experience Level

Next, we examine an 18-PAA squadron with a 35-percent experience level. The example squadron has 25 CMR pilots, as does the base case, but 15 are inexperienced and only ten are experienced. Table 3.3 shows how we have assigned those pilots to jobs and how many sorties the LP estimates they must fly to have adequate training.

Comparison of the Linear Program with the RAP Model

The Air Force was developing the Ready Aircrew Program model at the same time we were developing our linear program, but for a somewhat different purpose. The RAP model was intended to establish the minimum sorties required for training aircrews in operational squadrons and to justify that minimum in the budget process. It was developed, however, at a time when operational units had a preponderance of experienced pilots, and therefore the RAP model did not take into account the extra demands for sorties that the need for flight leads and IPs to supervise wingmen would generate.

The RAP model[7] starts with an absolute minimum number of sorties that a pilot must fly to remain BMC or CMR. For the F-16, these "RAP counters" amount to

- 116 sorties per year for an inexperienced pilot to remain CMR
- 96 sorties per year for an experienced pilot to remain CMR
- 72 sorties per year for an inexperienced pilot to remain BMC
- 60 sorties per year for an experienced pilot to remain BMC.

---

[7] The RAP model is incompletely described in the Air Force Instruction AFI 11-2, Vol. 1, for each aircraft. The model is implemented in a spreadsheet that is updated annually by the Directorate of Aerospace Operations at ACC, Flight Management Branch (ACC/DOTB). See the Air Force Instruction (AFI) documents listed in the Bibliography.

Table 3.3

Required Monthly Sorties for the F-16 LANTIRN 35-Percent Experience Level Case, by Pilot Type

Pilot Type	Number of Pilots	Sorties per Pilot per Month	Total Sorties per Month
NMQ[a]	N/A	N/A	18.75
NWG	11	13.25	145.72
NWK	1	14.02	14.02
XWG	1	12.07	12.07
XWL	0	N/A	0.00
NFL	3	17.87	53.61
XFL	1	15.33	15.33
XFMK	0	N/A	0.00
XFML	1	17.00	17.00
XFKL	1	18.27	18.27
XIP	1	20.06	20.06
XIMK	1	21.00	21.00
XIML	1	21.71	21.71
XIKL	3	22.97	68.92
BMC	4	10.29	41.16
Total Sorties per Month			467.61

[a]See note in Table 3.1.

In addition, each BMC and CMR pilot must fly two AHC and four INS sorties, and CMR pilots must fly another six sorties referred to as "navigation training." There are still more sorties allocated to inexperienced and experienced CMR pilots for MQT and special capabilities (e.g., CSAR). The RAP model also makes allowance for collateral sorties, attrition sorties, and scheduling efficiency, for which this squadron adds an "overhead" of about 8 percent.[8]

Table 3.4 compares the monthly sorties per pilot calculated from the RAP model with the monthly sorties per pilot from the LP. The numbers in the two columns from the RAP model differ only slightly. The differences occur because constant numbers of sorties are allocated to inexperienced and experienced CMR pilots for special capabilities, and the number of these sorties per pilot must therefore change when the squadron experience level changes. For the 65-percent and 35-percent experience cases from the LP, monthly sorties per pilot can be calculated from the data in Tables 3.1 and 3.3.

---

[8]We have not allowed for "overhead" sorties in the LP.

Table 3.4

Monthly F-16 LANTIRN Sorties per Pilot: The RAP Model Versus the Linear Programming Model

	RAP Model		LP Model		
	65-Percent Experience	35-Percent Experience	Individual	65-Percent Experience	35-Percent Experience
Inexperienced CMR	12.32	12.05	13.21	13.24	14.22
Experienced CMR	10.76	11.27	12.46	13.08	19.44
BMC	5.94	5.92	10.29	10.29	10.29

We calculate individual requirements from the LP model by turning off the supervision constraints—Constraints (2.28) and (2.29) in Chapter 2. This makes the LP model individual requirements directly comparable to the RAP model results, which impose no requirement that flight leads and IPs supervise wingmen. But the individual requirements hardly differ from the results for a squadron with a 65-percent experience level (the base case).

The sets of inexperienced and experienced CMR pilot types are as follows:

$$NCMR = \{NWG, NWK, NFL\}$$

$$XCMR = \begin{Bmatrix} XWG, XWL, XFL, XFMK, XFML, XFKL, \\ XIP, XIMK, XIML, XIKL \end{Bmatrix}$$

The individual requirements that the LP calculates for CMR pilots are somewhat higher than those from the RAP model. We attribute this difference to the fact that the RAP model sought to specify a minimum requirement, whereas the LP reflects the judgments of experienced pilots as to the amount pilots must fly to be ready to deploy with no spin-up sorties. The difference between the two models is much greater for BMC pilots. Experienced pilots will surely insist that they spin up before deploying if they fly no more than the RAP model specifies.

When comparing the far-right column of Table 3.4 with any of the other columns in the table, one can see that experienced CMR pilots have a much higher requirement for sorties in a squadron with a 35-percent experience level than in a squadron with a 65-percent experience level. This illustrates the primary difference between the RAP model and our LP. The RAP model includes sorties for IPs to supervise upgrades, but does not require that flight leads or IPs supervise non-upgrade (i.e., continuation training) sorties by wingmen. When enough of a squadron's pilots are flight leads and IPs (as in the base case), the sorties they fly to accumulate their own required skill units will provide all the supervision needed for wingmen and BMC pilots.[9] But when too few of a squadron's pilots are flight leads and IPs (as in the 35-percent experience case), they must fly extra sorties.

Exactly this situation has arisen in recent years. The Air Force has a shortage of fighter pilots, so the Air Force has sought to increase the production of new pilots. More new pilots are assigned to operational squadrons, lowering the ratio of flight leads and IPs to wingmen. The greater number of new pilots assigned to operational squadrons has increased the amount that flight leads and IPs must fly.

But there is another important consequence of the increased production of new pilots that the LP does not address. As suggested in the earlier discussion of the UTE, there is a limit to the number of sorties a squadron can generate. The flood of new pilots into operational units increases the required sorties far beyond that limit. So all pilots, including wingmen, may fly fewer sorties than are required by the LP, or even by the RAP model. In Chapter 4, we describe a crude way we have devised to deal with a constraint on the number of sorties.

The Effect of Deployments on Required Sorties

To represent a deployment, we add two constraints to the LP. Those constraints require the squadron to fly at least a specified number of AOR and NAOR sorties, and they prohibit BMC pilots from flying any of them. The constraints are as follows:

$$\sum_{j \in \mathcal{CMR},v} Y_{j,'AOR',v} \geq RqdAOR \tag{3.1}$$

$$\sum_{j \in \mathcal{CMR},v} Y_{j,'NAOR',v} \geq RqdNAOR \tag{3.2}$$

Note from Table 3.2 that no AOR or NAOR sorties are flown in the base case. They are not very attractive profiles for training purposes.

---

[9]We have assumed that BMC pilots fly all their sorties as wingmen, thus requiring supervision by a flight lead or IP. Many, perhaps most, BMC pilots actually have qualified as flight leads or IPs. But their primary duties are non-flying ones, so it is important to limit the time they devote to flying.

Flying as a wingman requires less time per sortie than flying as a flight lead or IP. The flight lead or IP must plan the mission, brief it, fly it, debrief it, and document it. The wingman avoids planning and documenting the sortie.

In a pinch, however, BMC pilots can (and sometimes do) fly as flight leads or IPs. If we were to allow for this, the LP would estimate less flying by experienced CMR pilots in units with low experience levels (e.g., the far-right column of Table 3.4).

We selected AOR and NAOR sorties to represent deployed sorties on the basis of the earlier descriptions of the various sortie profiles. AOR sorties, and their nighttime counterparts the NAOR sorties, are flown in support of actual NCA and CINC requirements in a designated area of responsibility or as part of a deployed air expeditionary force. However, when we chose the skill units for these profiles, we had in mind sorties of normal duration (about 80 minutes long). Sorties flown during actual deployments (e.g., Northern Watch or Southern Watch) may be much longer, and may involve multiple aerial refuelings. Per flying hour, therefore, actual sorties on a deployment may offer less practice of combat skills (although more aerial refueling practice) than the AOR and NAOR sorties provide.[10]

Table 3.5 shows the results of a series of cases in which we varied both parameters *RqdAOR* and *RqdNAOR* (the right-hand sides of constraints 3.1 and 3.2) from zero to 720 sorties per half-year. For an 18-PAA squadron, the high end mounts to 40 AOR sorties and 40 NAOR sorties per aircraft per half-year. Given a UTE of approximately 20 sorties per airframe per month, this case amounts to a deployment lasting four out of six months. As we have done for all previous examples, in Table 3.5 we converted these figures to a monthly basis.

Each row of Table 3.5 shows results for one case. The first row corresponds to the base case (see Tables 3.1 and 3.2), in which no AOR or NAOR sorties are required. Subsequent rows correspond to cases requiring the number of (N)AOR sorties per month shown in the far-left column. For this illustration, half of these sorties are required to be AOR sorties, the other half NAOR sorties. The second column contains the LP's estimate of the total monthly sorties required to provide all the squadron's pilots with adequate training.

The third column is calculated from the second column and shows the difference between the total monthly sorties for each case compared with the case above it. That difference is the extra sorties the squadron must fly as a result of being forced to fly 30 more AOR-plus-NAOR sorties.

Each entry in the fourth column equals the corresponding entry from the third column divided by 30, which is the incremental number of AOR-plus-NAOR sorties from one case to the next. So, the fourth column measures the degree to which (N)AOR sorties can substitute for other kinds of sorties in operational training. The first few (N)AOR sorties can each substitute for about 0.42 sorties of some other profile or mix of profiles, leaving an increase of 0.58 total sorties per

---

[10]Sorties flown in some deployments may have very good training value. We could represent this case by selecting a different sortie profile than the AOR/NAOR profile for the deployed sorties. We could even define a new sortie profile for this purpose.

(N)AOR sortie required. But as the (N)AOR sortie requirement rises, the model quickly runs out of sorties for which (N)AOR sorties can profitably substitute.

Table 3.5

Effect of Deployment on F-16 LANTIRN Total Required Sorties

(N)AOR Monthly Sorties	Total Monthly Sorties	Incremental Monthly Sorties	Slope
0 (Base Case)	388.12	—	—
30	405.50	17.38	0.58
60	430.31	24.81	0.83
90	457.04	26.73	0.89
120	484.60	27.56	0.92
150	514.42	29.82	0.99
180	544.27	29.85	0.99
210	574.23	29.96	1.00
240	604.23	30.00	1.00

At a (N)AOR sortie requirement of about 150 per month, each new (N)AOR sortie results in essentially a one-for-one increase in total sorties required.

Limitations of the Linear Program

The LP model, as described in Chapter 2 and exercised here in this chapter, is extremely flexible. It has inputs that can be varied to represent a wide range of circumstances that an actual operational squadron might face. For example, the user can change the detailed manning or DOC tasking and use the model to estimate the effect on the squadron's sortie requirements. However, the model's size and the amount of input data it needs make the model somewhat cumbersome.

Moreover, the LP estimates the required sorties. Currently, the Air Force faces a shortage of fighter pilots, and thus needs to train large numbers of them (Taylor, Moore, and Roll, 2000). But there are limits on the number of sorties that can be flown, due to (among other things) shortages of maintenance personnel and spare parts. So we needed a model that, instead of estimating required sorties, would let us impose a constraint on the available sorties and tell us how those sorties would be distributed among various types of pilots. The next chapter describes how we have addressed both of these limitations.

4. A "Repro" Model of the Linear Program

The "repro" model of the linear program developed for this study is so called because it reproduces (approximately) selected results from the LP. The repro model is greatly simplified in comparison with the LP, with many fewer inputs and outputs. In fact, it is sufficiently small and simple to be used as part of a spreadsheet or a simulation model. Although the repro model cannot represent as wide a variety of circumstances as the LP can, it does allow one to examine how policies and practices regarding unit manning and experience levels affect required sorties. Moreover, we have crudely modified the repro model to estimate how limitations in sortie availability would affect newcomers' accumulation of experience and qualifications.

Formulation and Testing

We designed the repro model to estimate sorties as a function of the inventories of pilots. For use in this model, we aggregate the 14 categories of pilot inventories (excluding pilots in MQT) from the LP (see Table 2.1) into only four categories:

$N(InexpWing)$ = Number of inexperienced wingmen ($N_{'NWG'} + N_{'NWK'}$)

$N(ExpWing)$ = Number of experienced wingmen ($N_{'XWG'} + N_{'XWL'}$)

$N(FL\_IP)$ = Number of flight leads and IPs ($N_{'NFL'} + N_{'XFL'} + N_{'XFMK'} + N_{'XFML'} + N_{'XFKL'} + N_{'XIP'} + N_{'XIMK'} + N_{'XIML'} + N_{'XIKL'}$)

$N(BMC)$ = Number of BMC pilots ($N_{'BMC'}$)

Similarly, we denote the sorties flown by pilots in each category as follows:

$S(InexpWing)$ = Total sorties by inexperienced wingmen

$S(ExpWing)$ = Total sorties by experienced wingmen

$S(FL\_IP)$ = Total sorties by flight leads and IPs

$S(BMC)$ = Total sorties by BMC pilots

$S(MQT)$ = Total sorties by pilots in MQT

$S(RC)$ = Rear cockpit IP sorties

For the repro model, we assume that $S(InexpWing)$, $S(ExpWing)$, and $S(BMC)$ are proportional to $N(InexpWing)$, $N(ExpWing)$, and $N(BMC)$, respectively. Sorties flown by pilots in MQT and sorties flown by IPs in the rear cockpit, which we denote as $S(MQT)$ and $S(RC)$, respectively, are specified by the user of the model as part of the description of upgrade requirements. If the number of flight leads and IPs, $N(FL\_IP)$, is large enough (as determined by calibrating to results from the LP), then $S(FL\_IP)$ will be proportional to $N(FL\_IP)$. But if $N(FL\_IP)$ is too small, then $S(FL\_IP)$ will equal the sum of $S(InexpWing)$, $S(ExpWing)$, $S(BMC)$, and $S(MQT)$, less the rear cockpit sorties $S(RC)$, plus a few extra sorties, mostly to account for the single-ship AHC and instrument sorties that flight leads and IPs must fly.

We calibrated the repro model to 11 cases, which differed only in the numbers of pilots in the different classes, which are shown in Table 4.1. Each case has 25 non-BMC pilots. In the first case, which is the base case we introduced in Chapter 3, 17 of those pilots are experienced. To compute the experience level, we omit two experienced pilots (the squadron commander and the operations officer) and form the ratio of the remaining experienced CMR pilots to the total remaining CMR pilots. So, the experience level in Case 1 (see Table 4.1) is 65.2 percent ([17 – 2]/[25 – 2]). In subsequent cases, the number of experienced pilots drops, and the number of inexperienced pilots increases. By the time we reach Cases 10 and 11, the experience level is only 34.8 percent ([10 – 2]/[25 – 2]). (Case 10 is the low-experience case we used as an example in Chapter 3.)

When we calibrated the "repro" model to these cases, we obtained the following equations:[1]

$$S(InexpWing) = 13.26626 \times N(InexpWing) \quad (4.1)$$

$$S(ExpWing) = 12.05152 \times N(ExpWing) \quad (4.2)$$

$$S(BMC) = 10.2889 \times N(BMC) \quad (4.3)$$

$$S(MQT) = 18.75 \quad (4.4)$$

$$S(RC) = 6.89583 \quad (4.5)$$

$$S(FL\_IP) = Max\left\{\begin{array}{l}[13.24621 \times N(FL\_IP)],\\ \left[\begin{array}{l}1.09385 \times N(FL\_IP) + S(InexpWing)\\ +S(ExpWing) + S(BMC) + S(MQT) - S(RC)\end{array}\right]\end{array}\right\} \quad (4.6)$$

[1]We keep five decimal places in the coefficients simply to maintain an audit trail. The accuracy of the model does not justify it.

Table 4.1

Pilot Inventories for 18-PAA F-16 LANTIRN Cases

Pilot Type	Case Number 1	2	3	4	5	6	7	8	9	10	11
NMQ[a]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NWG	6	7	8	9	9	10	10	10	10	11	11
NWK	1	1	1	1	1	1	1	1	1	1	1
XWG	1	1	1	1	1	1	1	1	1	1	1
XWL	0	0	0	0	0	0	0	0	0	0	0
NFL	1	1	1	1	2	2	2	3	3	3	3
XFL	3	3	3	3	2	1	1	1	1	1	1
XFMK	1	1	0	0	0	0	0	0	0	0	0
XFML	2	2	2	2	2	2	2	2	2	1	1
XFKL	1	1	1	1	1	1	1	1	1	1	1
XIP	2	1	1	1	1	1	1	1	1	1	1
XIMK	2	2	2	2	2	2	2	1	1	1	1
XIML	2	2	2	1	1	1	1	1	1	1	1
XIKL	3	3	3	3	3	3	3	3	3	3	3
BMC	4	4	4	4	4	4	3	4	3	4	2
InexpWing	7	8	9	10	10	11	11	11	11	12	12
ExpWing	1	1	1	1	1	1	1	1	1	1	1
FL_IP	17	16	15	14	14	13	13	13	13	12	12
BMC	4	4	4	4	4	4	3	4	3	4	2

[a]See Table 3.1 note.

When these equations are applied to the pilot inventories from Table 4.1, and aggregated as shown, the repro model calculates the numbers of sorties by pilot category, as shown in Table 4.2.

The results shown in Table 4.2 approximate the LP results very closely. Table 4.3 displays the differences between sorties calculated by the repro model and sorties calculated by the LP. The largest error in total sorties occurs in Case 3; it amounts to about 1.6 percent of the LP's results.

The largest error (which is nonetheless quite small) occurs in Case 3 for the following reason: Between the 60-percent and 50-percent experience levels, in this series of cases, the number of flight leads and IPs, *N(FL_IP)*, ranges from being large enough that *S(FL_IP)* is proportional to *N(FL_IP)*, to being small enough that *S(FL_IP)* is largely determined by wingman sorties. In the LP, there is a smooth transition between these two regimes. In the repro model, on the

Table 4.2

Sortie Distribution as Calculated by the Repro Model for the Cases Shown in Table 4.1

Case Number	Experience Level	Inexperienced Wing Sorties	Experienced Wing Sorties	BMC Sorties	MQT Sorties	FL_IP Sorties	Total Sorties
1	65.2%	92.86	12.05	41.16	18.75	225.19	390.01
2	60.9%	106.13	12.05	41.16	18.75	211.94	390.03
3	56.5%	119.40	12.05	41.16	18.75	200.87	392.22
4	52.2%	132.66	12.05	41.16	18.75	213.04	417.66
5	47.8%	132.66	12.05	41.16	18.75	213.04	417.66
6	43.5%	145.93	12.05	41.16	18.75	225.21	443.10
7	43.5%	145.93	12.05	30.87	18.75	214.92	422.52
8	39.1%	145.93	12.05	41.16	18.75	225.21	443.10
9	39.1%	145.93	12.05	30.87	18.75	214.92	422.52
10	34.8%	159.20	12.05	41.16	18.75	237.38	468.53
11	34.8%	159.20	12.05	20.58	18.75	216.80	427.38

Table 4.3

Repro Model Results Minus the LP Results for the Cases Shown in Table 4.1

Case Number	Experience Level	Inexperienced Wing Sorties	Experienced Wing Sorties	BMC Sorties	FL_IP Sorties	MQT Sorties	Total Sorties
1	65.2%	0.46	–0.01	0.00	0.00	1.44	1.88
2	60.9%	0.45	–0.01	0.00	0.00	–1.44	–1.00
3	56.5%	–0.82	–0.01	0.00	0.00	–5.46	–6.29
4	52.2%	0.06	0.01	0.00	0.00	0.20	0.27
5	47.8%	0.00	0.01	0.00	0.00	0.00	0.02
6	43.5%	0.01	0.01	0.00	0.00	–0.02	–0.01
7	43.5%	0.16	0.01	0.00	0.00	–0.37	–0.20
8	39.1%	0.01	0.01	0.00	0.00	0.73	0.75
9	39.1%	0.13	0.01	0.00	0.00	0.35	0.48
10	34.8%	–0.55	–0.01	0.00	0.00	1.49	0.93
11	34.8%	0.08	0.01	0.00	0.00	1.33	1.42

other hand, the transition is abrupt. Case 3 is centered between the two regimes. Every other case is clearly in one regime or the other.

Applying the Repro Model to 24-PAA Squadrons

The cases shown in Table 4.3 correspond to an 18-PAA squadron, but the Air Force is planning to consolidate their F-16s into 24-PAA squadrons. Therefore,

Table 4.4

Pilot Inventories for 24-PAA F-16 LANTIRN Cases

	Case Number												
Class	1	2	3	4	5	6	7	8	9	10	11	12	13
NMQ[a]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NWG	8	9	10	11	11	12	13	13	13	14	14	14	14
NWK	1	1	1	1	1	1	1	1	1	1	1	1	1
XWG	1	1	1	1	1	1	1	1	1	1	1	1	1
XWL	0	0	0	0	0	0	0	0	0	0	0	0	0
NFL	1	1	1	1	2	2	2	3	3	3	3	4	4
XFL	4	4	4	4	3	3	2	2	2	2	2	1	1
XFMK	1	1	0	0	0	0	0	0	0	0	0	0	0
XFML	2	2	2	2	2	2	2	2	2	1	1	1	1
XFKL	1	1	1	1	1	1	1	1	1	1	1	1	1
XIP	3	2	2	2	2	1	1	1	1	1	1	1	1
XIMK	3	3	3	3	3	3	3	2	2	2	2	2	2
XIML	3	3	3	2	2	2	2	2	2	2	2	2	2
XIKL	4	4	4	4	4	4	4	4	4	4	4	4	4
BMC	6	6	6	6	6	6	6	6	5	6	5	6	4
InexpWing	9	10	11	12	12	13	14	14	14	15	15	15	15
ExpWing	1	1	1	1	1	1	1	1	1	1	1	1	1
FL_IP	22	21	20	19	19	18	17	17	17	16	16	16	16
BMC	6	6	6	6	6	6	6	6	5	6	5	6	4

[a]See Table 3.1 note.

we need to test how well the repro model will reproduce the LP's results for the 24-PAA squadrons. We used the 13 cases shown in Table 4.4. The experience levels range from a high of 66.7 percent (Case 1) to a low of 36.7 percent (Cases 12 and 13).

Several blocks of constraints in the LP are not homogeneous in the pilot inventories. Constraints (2.14) limit the numbers of sorties of enhanced versions (FLG, CFX, and DIS) that a squadron is allowed to fly. A sortie flown in one of these versions provides more skill units than a basic sortie of the same profile. If we do not increase the numbers of these sorties when we increase the manning to equal that of a 24-PAA squadron, there will be fewer enhanced sorties per pilot; hence, the total sorties per pilot will have to increase.

Blocks of constraints that involve upgrades are also not homogeneous in the pilot inventories. Upgrades cause only a slight increase in the number of sorties an upgradee must fly, but they place a large burden on the IPs who must supervise those upgradees. Thus, for each of the 13 cases listed in Table 4.4, we run four variants:

- Nominal constraints on enhanced sortie versions and nominal numbers of upgrades (where “nominal” means “same as in the 18-PAA cases”)
- Numbers of enhanced sortie versions scaled up in proportion to PAA, but nominal numbers of upgrades
- Nominal constraints on enhanced sortie versions, but numbers of upgrades scaled up in proportion to PAA
- Numbers of enhanced sortie versions and numbers of upgrades both scaled up in proportion to PAA.

Table 4.5 compares the repro model results for each case listed in Table 4.4 with the LP’s results for the first two variants listed above, both of which have nominal upgrades. The two variants differ in whether enhanced sorties have been scaled in proportion to PAA (i.e., if $XColLim_{FLG}$, $XColLim_{CFX}$, and $XColLim_{DIS}$ are increased from 90, 180, and 180 to 120, 240, and 240, respectively, in Constraints (2.14). As one can readily see from Constraints (4.1) through (4.6) presented earlier, the numbers of enhanced sorties do not influence the repro model results.

Table 4.6 compares the repro model results for each case with the LP’s results for the third and fourth variants listed earlier. These are the two variants in which required upgrade sorties are scaled in proportion to PAA. This scaling affects the numbers of MQT sorties and rear cockpit IP sorties, so that $S(MQT) = 25$ and $S(RC) = 8.52778$.

With nominal values for enhanced versions, the repro model underestimates the required sorties. The underestimate is not very large, however, amounting at worst to 3 to 4 percent of the requirement estimated by the LP (Case 3 in Table 4.6). If we scale the number of enhanced versions, the repro model agrees more closely with the LP’s estimates. The error is 1.7 percent in the worst case (Case 1 in Table 4.5), and less than 1 percent for most cases. Scaling upgrades has a smaller effect than scaling the number of sorties of enhanced versions.

Whether or not enhanced sortie versions or upgrades are scaled, however, the repro model as calibrated for an 18-PAA squadron provides a very good estimate of the LP’s estimates for a 24-PAA squadron. The largest errors occur when enhanced sorties are not scaled and upgrades are scaled (see the Nominal Enhanced columns in Table 4.6). In these cases, the repro model underestimates the LP results, but never by more than about 3.8 percent.

Table 4.5

Comparison of Repro Model and LP Results for the Cases Shown in Table 4.4, for Nominal Upgrades

			Nominal Enhanced		Scale Enhanced	
Case Number	Experience Level	Repro Model	Total Sorties	Delta Sorties	Total Sorties	Delta Sorties
1	66.7%	503.35	513.78	–10.43	494.00	9.35
2	63.3%	503.37	515.74	–12.37	496.87	6.50
3	60.0%	503.39	518.19	–14.81	501.55	1.84
4	56.7%	517.35	528.49	–11.15	516.63	0.71
5	53.3%	517.35	529.38	–12.04	516.92	0.42
6	50.0%	542.79	550.54	–7.75	540.55	2.23
7	46.7%	568.22	580.28	–12.06	566.38	1.84
8	43.3%	568.22	579.40	–11.17	565.58	2.64
9	43.3%	547.65	556.15	–8.50	545.27	2.38
10	40.0%	593.66	610.02	–16.35	590.01	3.65
11	40.0%	573.09	585.88	–12.80	569.55	3.53
12	36.7%	593.66	610.10	–16.44	590.10	3.57
13	36.7%	552.51	562.31	–9.80	549.29	3.22

Table 4.6

Comparison of Repro Model and LP Results for the Cases Shown in Table 4.4, for Scaled Upgrades

			Nominal Enhanced		Scale Enhanced	
Case Number	Experience Level	Repro Model	Total Sorties	Delta Sorties	Total Sorties	Delta Sorties
1	66.7%	509.60	525.06	–15.46	505.74	3.86
2	63.3%	509.62	527.34	–17.72	508.51	1.11
3	60.0%	509.64	529.89	–20.25	513.10	–3.46
4	56.7%	528.22	541.11	–12.89	528.66	–0.45
5	53.3%	528.22	542.02	–13.80	528.99	–0.77
6	50.0%	553.65	562.05	–8.40	552.38	1.28
7	46.7%	579.09	592.00	–12.91	578.15	0.94
8	43.3%	579.09	591.13	–12.03	577.36	1.73
9	43.3%	558.52	567.92	–9.41	557.07	1.45
10	40.0%	604.53	621.74	–17.20	601.81	2.72
11	40.0%	583.95	597.60	–13.65	581.33	2.62
12	36.7%	604.53	621.82	–17.29	601.89	2.64
13	36.7%	563.38	574.03	–10.66	561.07	2.31

Imposing a Constraint on the Number of Sorties

We typically want to use the repro model to distribute sorties to the various pilot classes in a sortie-constrained environment, something the LP is not designed to do.[2] The UTE rate is strictly limited (e.g., by maintenance capacity and spare parts availability). So, if a squadron is manned in excess of 100 percent of its authorization or is manned with an excess of inexperienced pilots, the squadron will be unable to fly as many sorties as the LP says are required. As reported in Taylor et al. (2002), squadrons in just this condition were examined, and the consequences for the ability of operational squadrons to absorb new pilots being graduated from FTUs were explored. The constrained "repro" model used in that work is slightly different from, but quite consistent with, the one described in this report.

We chose the following formulation for solving this problem. We take as given the numbers of pilots in three categories—*N(InexpWing)*, *N(ExpWing)*, and *N(FL_IP)*. We also take as given the numbers of sorties in three categories—*S*(*BMC*), *S*(*MQT*), and *S*(*RC*). Finally, we are given *Stot*, the total number of sorties available to the squadron. Our task is to modify Constraints (4.1), (4.2), and (4.6) in some sensible way so that they scale the sorties flown by inexperienced wingmen, experienced wingmen, and flight leads/IPs until they fit within the constraint on total sorties.[3] Thus, the quantities to be calculated by the constrained version of the repro model are as follows:

SC(*InexpWing*)	=	Constrained sorties by inexperienced wingmen
SC(*ExpWing*)	=	Constrained sorties by experienced wingmen
SC(*FL_IP*)	=	Constrained sorties by flight leads and IPs

We introduce a scale factor, *Sfac*, and rewrite Constraints (4.1), (4.2), and (4.6) as follows:

$$SC(InexpWing) = Sfac \times 13.26626 \times N(InexpWing) \quad (4.7)$$

[2]Extending the LP to deal with a constraint on the number of sorties would be a major task. The LP minimizes the number of sorties flown, subject to constraints that ensure that the training they provide is "adequate." Simply imposing a constraint on sorties flown would either not change the answer at all (if the constraint allowed enough sorties to provide adequate training) or would prevent the LP from finding any solution (if the constraint allowed too few sorties). Instead, one would have to develop a function that estimated the "adequacy" of training. Then the LP could maximize training adequacy subject to the constraint on sorties flown. In Chapter 5, we briefly discuss current work that bears on this issue.

[3]Other formulations are possible. Instead of setting aside fixed numbers of sorties *S*(*BMC*), *S*(*MQT*), and *S*(*RC*), we could introduce equations for calculating them. For example, we could treat *S*(*BMC*) in the same fashion as *S*(*InexpWing*), *S*(*ExpWing*), or *S*(*FL_IP*). Or we could estimate *S*(*MQT*) from the numbers of pilots. We leave use of these variants up to the reader as he or she finds necessary.

$$SC(ExpWing) = Sfac \times 12.05152 \times N(ExpWing) \quad (4.8)$$

$$SC(FL\_IP) = Max\left\{\begin{bmatrix}[Sfac \times 13.24621 \times N(FL\_IP)], \\ \begin{bmatrix} Sfac \times 1.09385 \times N(FL\_IP) + SC(InexpWing) \\ +SC(ExpWing) + S(BMC) + S(MQT) - S(RC) \end{bmatrix}\end{bmatrix}\right\} \quad (4.9)$$

These adjustments penalize—i.e., slow the development of—all three categories of pilots on a pro-rata basis.

We choose *Sfac* to be as large as possible, up to a limit of 1.0, while still satisfying Constraint (4.10) on the total number of sorties. We limit *Sfac* at 1.0 because at this point the constrained repro model becomes identical to the unconstrained model.

$$\begin{bmatrix} SC(InexpWing) \\ +SC(ExpWing) \\ +SC(FL\_IP) \end{bmatrix} + S(BMC) + S(MQT) \le Stot \quad (4.10)$$

Calculating the value of *Sfac* is straightforward. First, we define the coefficients K1, S1, K2, and S2 in Constraints (4.11) through (4.14):

$$K1 = \begin{bmatrix} 13.26626 \times N(InexpWing) \\ +12.05152 \times N(ExpWing) \\ +13.25621 \times N(FL\_IP) \end{bmatrix} \quad (4.11)$$

$$S1 = Stot - S(BMC) - S(MQT) \quad (4.12)$$

$$K2 = \begin{bmatrix} 2 \times 13.26626 \times N(InexpWing) \\ +2 \times 12.05152 \times N(ExpWing) \\ +1.09385 \times N(FL\_IP) \end{bmatrix} \quad (4.13)$$

$$S2 = S1 - S(BMC) - S(MQT) + S(RC) \quad (4.14)$$

If *N(FL_IP)* is large enough that *S(FL_IP)* is proportional to *N(FL_IP)*, we will be using the first of the two maximands in Equation (4.9). In this case, *Sfac* will be the solution to the equation *K1* x *Sfac* = *S1*. It is easy to see why this is so by simply substituting (4.7), (4.8), and the first maximand of (4.9) into (4.10) and collecting the terms.

If *N(FL_IP)* is so small that we must use the second of the two maximands in Equation (4.9), *Sfac* will be the solution to the equation *K2* x *Sfac* = *S2*. Again, it is easy to see why this is so by simply substituting (4.7), (4.8), and the second maximand of (4.9) into (4.10) and collecting the terms.

Overall, then, we calculate *Sfac* as follows:

$$Sfac = Min\left\{\frac{S1}{K1}, \frac{S2}{K2}, 1\right\} \quad (4.15)$$

Substituting this value for *Sfac* into Constraints (4.7), (4.8), and (4.9) yields the desired numbers of sorties.

To illustrate this process, we will constrain a squadron manned at the 35-percent experience level (shown in Table 3.3 in Chapter 3) to the sortie total from the base case (see Table 3.1). We quickly find that flight leads and IPs fly in excess of their individual requirements, so when we apply Constraints (4.11) through (4.15), we find that $Sfac = S2/K2 = 0.77387$. Accordingly, the various types of pilots fly the numbers of sorties shown in Table 4.7.

When Experience but Not Qualifications Is Known

To apply the constrained repro model just described, we must know the inventories *N*(*InexpWing*), *N*(*ExpWing*), and *N*(*FL_IP*). But, in our LP and repro models, as in the RAP model, we often know only the numbers of inexperienced and experienced CMR pilots assigned to a unit, which we can denote by *N*(*InexpCMR*) and *N*(*ExpCMR*), respectively.[4] Therefore, we need a way to estimate the former (*N*(*InexpWing*), *N*(*ExpWing*), and *N*(*FL_IP*)) from the latter (*N*(*InexpCMR*) and *N*(*ExpCMR*)).

The following assumptions work well for the cases defined in Tables 4.1 and 4.4, which represent both 18-PAA and 24-PAA squadrons. We define:

$$N(TotCMR) = N(InexpCMR) + N(ExpCMR) \quad (4.16)$$

$$N(NFL) = Max\{1, 0.33 \times N(TotCMR) - 0.5 \times N(ExpCMR)\} \quad (4.17)$$

Then, we calculate the inventories for the constrained repro model's three pilot categories as follows:

$$N(InexpWing) = N(InexpCMR) - N(NFL) \quad (4.18)$$

[4]Pilots' qualifications (e.g., wingman, flight lead, or IP) are known at the squadron level, but they are not reported to higher levels. If one relies on Air Force–wide data systems, one must describe squadron manning in terms of experience levels rather than qualifications.

Table 4.7

**Unconstrained Versus Constrained Sorties, F-16 LANTIRN
35-Percent Experience Level Case**

		Unconstrained Sorties		Constrained Sorties	
	Number of Pilots	Sorties per Pilot per Month	Total Sorties per Month	Sorties per Pilot per Month	Total Sorties per Month
Inexperienced Wing	12	13.27	159.20	10.27	123.20
Experienced Wing	1	12.05	12.05	9.33	9.33
FL/IPs	12	19.78	237.38	16.31	195.69
BMC	4	10.29	41.16	10.29	41.16
MQT	N/A	N/A	18.75	N/A	18.75
Rear Cockpit IP	N/A	N/A	6.90	N/A	6.90
Total Front Cockpit			468.54		388.13

$$N(ExpWing) = 1 \tag{4.19}$$

$$N(FL\_IP) = N(ExpCMR) - N(ExpWing) + N(NFL) \tag{4.20}$$

We can now apply Constraints (4.7) through (4.15) to these inventories to calculate *SC*(*InexpWing*), *SC*(*ExpWing*), and *SC*(*FL_IP*). To convert these figures into sorties flown by inexperienced and experienced CMR pilots, we compute:

$$SC(NFL) = \frac{N(NFL)}{N(FL\_IP)} \times SC(FL\_IP) \tag{4.21}$$

$$SC(InexpCMR) = SC(InexpWing) + SC(NFL) \tag{4.22}$$

$$SC(ExpCMR) = SC(ExpWing) + SC(FL\_IP) - SC(NFL) \tag{4.23}$$

Constraint (4.21) assumes that inexperienced flight leads fly as much as experienced flight leads or IPs. If the user of the model believes that inexperienced flight leads fly less than experienced flight leads or IPs, the user can modify this expression accordingly.

General Comments on Repro Modeling

It is fairly common to build a repro model (sometimes called a "metamodel") of a larger, more complex model (sometimes called the "target model"). Often, the repro model is obtained by fitting a regression equation to results from the target model. The regression equation need not have a phenomenological relation to the modeled system; it may only have a statistical relation. In this case, however, we specified a structure of our repro model that mirrors the structure of our target model (the LP) very closely. Pilots who fly as wingmen (inexperienced and experienced wingmen and BMC pilots) must fly specified numbers of sorties per month. Pilots who fly as flight leads and IPs must likewise fly a minimum specified number of sorties per pilot per month. But they may need to fly more sorties to provide supervision for pilots who fly as wingmen.

There is reason to believe (see Davis and Bigelow, 2003) that basing the structure on phenomenological considerations results in closer agreement between the repro model and the target model. As we have shown in this chapter, the repro model described by Constraints (4.1) through (4.6) reproduces results from the LP very closely. Moreover, a phenomenological basis for the repro model should make one more confident in using the repro model to extrapolate beyond the LP cases to which it was calibrated.

It makes no sense to speculate on whether the repro model with a constraint on available sorties agrees with the LP because we have not devised a way to constrain sorties in the LP model. But neither do we know whether the constrained repro model agrees with what happens in the field. We assumed that wingman, flight lead, and IP sorties would be scaled back if sorties were constrained, and that BMC and MQT sorties would remain the same. However, we could have made other assumptions and thereby obtained other results. Further study is needed to explore which assumptions are most reasonable. We comment on this issue, among others, in the next chapter.

5. Final Thoughts

We have described in this report a methodology, implemented in the form of a linear program, that estimates sortie requirements of fighter squadrons. We developed different versions of the methodology for A/OA-10, F-15C, F-15E, F-16 HTS, and F-16 LANTIRN squadrons. The Air Force has an official procedure for estimating these requirements (the RAP model) that differs from our methodology. But our method goes beyond RAP in three respects: (1) It takes into account the need for flight leads or IPs to provide in-flight supervision of wingmen; (2) it reflects skills that underlie mission capabilities, and (3) it allows the user to impose sortie requirements other than those for operational training on a squadron (for example, sorties for deployments).

Calibration is a weak point of the LP models. Through interviews and surveys, we found a rough consensus among F-16 and A/OA-10 IPs and flight leads that 13 sorties per month provided adequate training for an inexperienced pilot, and about one sortie less was adequate for an experienced pilot. But this view was by no means unanimous. Moreover, we don't know why some IPs and flight leads thought 13 sorties per month was more than enough, or why others thought it was too few. Further, we do not know what IPs and flight leads think pilots might gain if they flew more sorties, or what they might lose if they flew fewer sorties. Finally, we spent most of our efforts in this study calibrating the F-16 LANTIRN version of the model, spent less effort on A/OA-10 model calibration, and very little effort on F-16 HTS, F-15C, and F-15E model calibration. We think the models as they stand are suitable for analysis, but they should be more carefully calibrated before they are used for management purposes (e.g., to calculate formal Air Force requirements for flying hours).

The linear programs are more complicated and larger than what are needed for many purposes. Therefore, we developed smaller and simpler "repro" models that reproduce selected results from the LPs. We have used an earlier version of these repro models to estimate the capacity of the operational fighter force to absorb new pilots (see Taylor, Moore, and Roll, 2000; Taylor et al., 2002).

Our repro models could also be used in place of the Air Force RAP models for the various squadrons. The RAP model is distributed in the form of a spreadsheet, with squadron manning as the basic input. Replacing this model with our repro model, possibly with adjusted coefficients, would improve the

RAP model by including the in-flight supervision requirement. To illustrate the importance of the supervision requirement, we compared the sortie requirement for a squadron with a 65-percent experience level to the sortie requirement for a 35-percent experience squadron (see Chapter 3). The RAP model estimates that the two squadrons need essentially the same number of sorties per month. Our model estimates that the 35-percent experience-level squadron needs about 20 percent more sorties than the 65-percent experience-level squadron.

Perhaps the most useful extension to our methodology would be the ability to constrain sorties. As presently formulated, the LP estimates the number of sorties a squadron needs in order to provide "adequate" training to all of its aircrews. We have developed an ad hoc method to constrain sorties in the repro models, but that method is based on the untested assumption that the best response to a sortie constraint is to proportionately reduce sorties for all CMR pilots.

Moreover, we don't have good measures of the consequences of flying fewer sorties than are required. The measure we used in our studies of pilot absorption is the rate at which inexperienced pilots accumulate flying hours—the so-called aging rate. Given that the Air Force determines when a crew member becomes experienced solely on the basis of accumulated flying hours, the aging rate translates directly into the number of crew members per year who become experienced. This measure speaks to one of the objectives of operational squadrons: to prepare pilots for subsequent assignments at wings, major air commands, and the Air Staff. Ideally, only experienced crew members would fill these assignments.

But we have no measure for the effect of a sortie constraint on the other, primary objective of an operational squadron: to maintain readiness to deploy and conduct combat missions during wartime, contingencies, and other engagements. We have supposed that if a squadron flies the required number of sorties—i.e., the number estimated by our methodology—it will need no spin-up sorties to prepare for a deployment. So, it seems reasonable to measure a shortfall in training sorties in terms of the spin-up sorties that would be needed to counter that shortfall. At the time of this writing, we are engaged in research that may enable us to develop such a relationship.

A. The F-16 HTS Model

Formulation of the Linear Program

In this appendix, we describe the formulation of the F-16 HTS version of the linear program model. All the versions of the model (the A/OA-10, F-15C, F-15E, and F-16 LANTIRN as well as the F-16 HTS) are similar. We briefly mention the points of similarity and describe in detail the points of difference.

In all versions of our model, the objective is to minimize the number of sorties a squadron flies over a training period. The variables are numbers of sorties of different types flown by crew members in different jobs. The constraints ensure that all assigned crew members receive the operational training they require. Using the notation from Constraint (2.1) in Chapter 2, the objective function can be written as:

$$Min \quad z = \sum_{j,p,v} c_{jpv} \cdot Y_{jpv} \tag{A2.1}$$

As in the F-16 LANTIRN model, the coefficients c_{jpv} indicate which pilot sorties require sorties by aircraft. We count an aircraft sortie for each pilot sortie flown in the front cockpit. A simulator turn requires no aircraft sortie, and neither does a rear cockpit IP sortie. Thus, the coefficients c_{jpv} for all front cockpit sorties are equal to one, while the coefficients for simulator turns and rear cockpit IP sorties are zero.

Pilots' Jobs

The F-16 HTS model has only seven jobs (shown in Table A.1), instead of the 15 for the F-16 LANTIRN.

As before, we specify the total number of MQT sorties of each profile that must be flown during each training period, and the number N_{NMQ} of pilots in MQT. The model then determines the sorties per pilot. For technical reasons, the solution to the LP will be the same regardless of the number of MQT pilots we specify, so we always set it to be equal to 1.

Table A.1

Jobs for F-16 HTS Pilots

Pilot Category	Job
Pilots in MQT	NMQ
Inexperienced wingmen	NWG
Experienced wingmen	XWG
Inexperienced flight leads	NFL
Experienced flight leads	XFL
Instructor pilots	XIP
Basic Mission Capable	BMC

The major distinctions among the remaining jobs are (1) whether the pilot is inexperienced or experienced; (2) whether the pilot is CMR or BMC; and (3) for CMR pilots, whether the pilot is qualified as a wingman, a flight lead, or an instructor pilot. All pilots in the F-16 HTS model fly all the assigned missions of the squadron, so there are no specific mission capabilities for which only some pilots have qualified.

The model makes use of various subsets of jobs. Those subsets are wingmen, flight leads, and IPs, and for the F-16 HTS model they are defined as follows:

$$\mathcal{WG} = \{NWG, XWG\}$$

$$\mathcal{FL} = \{NFL, XFL\}$$

$$\mathcal{IP} = \{XIP\}$$

Sortie Profiles and Versions

Sorties come in several profiles and versions. Each profile (see Table A.2) is designed to exercise certain kinds of skills. Different versions (see Table A.3) of the same profile exercise much the same skills, but in different venues or under different conditions or with a somewhat different emphasis. Not every sortie profile comes in all versions.[1]

[1] We have not included a Red Air sortie version in the F-16 HTS model. Red Air sorties are flown to provide a mock adversary during sorties with air-to-air (i.e., BFM, ACM, ACT, and NAIR) profiles. They have less training value than the basic version of the same profile. If a squadron has primarily an air-to-air mission, it is important to include a Red Air version and constrain the pilots to fly appropriate numbers of them. We have done so in the F-15C version of the LP (described in Appendix C). But the F-16 HTS model described here is configured to represent a squadron with primarily an air-to-ground mission, so we have omitted Red Air.

Table A.2

Sortie Profiles in the F-16 HTS Model

Profile	Description	Permitted Version (see Table A.3)				
BSA	Basic surface attack, day	B				IP
NBSA	Basic surface attack, night	B				IP
SAT	Surface attack tactics, day	B	FLG	CFX		IP
NSAT	Surface attack tactics, night	B				IP
SEAD	Suppression of enemy air defenses, day	B	FLG	CFX		IP
NSEA	Suppression of enemy air defenses, night	B				IP
BFM	Basic fighter maneuvers	B			DIS	IP
ACM	Air combat maneuvers	B			DIS	IP
ACT	Air combat tactics	B	FLG	CFX	DIS	IP
NAIR	Air-to-air training, night	B				IP
AHC	Aircraft handling characteristics	B				IP
INS	Instruments, day	B				IP
NINS	Instruments, night	B				IP
ROT	Rotating aircraft, day	B				
NROT	Rotating aircraft, night	B				
IPR	Rear cockpit IP sortie, day	B				
NIPR	Rear cockpit IP sortie, night	B				
AOR	Familiarization w/ AOR, day	B				
NAOR	Familiarization w/ AOR, night	B				
SIM	Simulator	B				

Table A.3

Sortie Versions in the F-16 HTS Model

Version	Description
B	Basic, flown at home station
FLG	Flag, an exercise away from home station
CFX	Composite force exercise
DIS	Flown against dissimilar aircraft
IP	Flown by an IP grading an upgrade sortie

The model makes use of various subsets of profiles, namely profiles flown at night and profiles that require in-flight supervision. For the F-16 HTS model, they are defined as follows:

$$\mathcal{NIGHT} = \begin{Bmatrix} NBSA, NSAT, NSEA, NAIR, \\ NINS, NROT, NIPR, NAOR \end{Bmatrix}$$

$$\mathcal{SUP} = \begin{Bmatrix} BSA, NBSA, SAT, NSAT, SEAD, NSEA, \\ BFM, ACM, ACT, NAIR, AOR, NAOR \end{Bmatrix}$$

Not every pilot is permitted to fly sorties of every profile and version. The rules are shown in Table A.4. The sums in Constraint (A2.1) are taken over the legitimate combinations of job, profile, and version, as determined by combining Tables A.2 and A.4.

The F-16 HTS model shares most of its sortie profiles with the F-16 LANTIRN model, and their descriptions can be found in Chapter 2. The only new profiles are as follows:

SEAD (Suppression of Enemy Air Defenses) sorties are designed to develop proficiency in day SEAD-Antiradiation (SEAD-A) and SEAD-Conventional (SEAD-C) employment. A four-ship SEAD-A mission requires a minimum of two operating HTS pods employing on an electronic combat (EC) range against multiple, non-collocated operating threat emitters.

NSEA sorties are SEAD sorties flown at night.

Skill Acquisition and Practice

The model's most important constraints deal with the skills that pilots practice when they fly the various profiles and versions of sorties. We have identified 154 individual skills that contribute to mission capabilities of F-16 HTS pilots, which we group into eight categories (see Table A.5). The first seven categories are identical to the F-16 LANTIRN skill categories found in Table 2.5 in Chapter 2. But where the F-16 LANTIRN model has skills related to the LANTIRN and Killer Scout missions, the F-16 HTS model has skills related to the SEAD-A

Table A.4

Legitimate Profile-Version-Job Combinations in the F-16 HTS Model

Profile	Version	Permitted Job
All *except* IPR, NIPR	B	All
IPR, NIPR	B	XIP
All	FLG, CFX, DIS	All *except* NMQ
All	IP	XIP

Table A.5

F-16 HTS Skill Categories, with Examples

SUPPORTING SKILLS
Basic airmanship; instruments; aircraft handling; navigation; formation; air-to-air refueling
GENERAL SKILLS FOR ALL COMBAT TASKING
Communications procedures; combat mission planning; switchology; large force employment integration; target deconfliction; hung ordnance/aircraft damage procedures
GENERAL SKILLS FOR AIR-TO-GROUND MISSIONS
Air-to-surface delivery systems; surface-to-air threats; attack options; delivery methods; impact accuracy; fuel management; egress options; battle damage response/wounded bird procedures
GENERAL SKILLS FOR AIR-TO-AIR MISSIONS
Air-to-air systems; weapon selection options; attack options (day, night); commit criteria
SKILLS SPECIFIC FOR CLOSE AIR SUPPORT (CAS)
Tactical air control system; command, control, and communications; joint air attack team procedures; forward air control control/holding point; target ID and attack restrictions
SKILLS SPECIFIC TO AI, SEAD-C, AND OCA-S MISSIONS
Route and formation selection; threat interpretation and response; AWACS, Rivet Joint, JSTARS, and other such issues; target area contingencies; updates/execution/verification
SKILLS SPECIFIC TO MAVERICK MISSIONS
AGM 65 B/D/G differences; TGP targeting options; alternative targeting and missile handoff options
SKILLS SPECIFIC TO SEAD-A MISSIONS
Threat identification, assessment, and analysis; SEAD tactics; HTS search responsibilities; HTS/HARM employment; SEAD targeting; EC principles

mission. While the F-16 HTS model has a different list of skills than the F-16 LANTIRN model, and different skill unit demand ($Dprac_{sj}$) and supply ($Sprac_{spv}$) arrays, its skill acquisition constraints look exactly the same as those in Constraints (2.2) in Chapter 2.

Air Force Mandates for Particular Sorties

The Air Force requires each pilot who has completed MQT to fly particular numbers of some sorties. Each pilot must fly at least one AHC sortie, two instrument sorties, and two night sorties per six-month training period. Experienced pilots must log at least four simulator turns, and inexperienced pilots must log at least six turns, per training period. We also impose upper limits of five and seven simulator turns per training period on experienced and inexperienced pilots, respectively. The constraints for the F-16 HTS model are the same as for the F-16 LANTIRN model, namely Constraints (2.3) through (2.7) in Chapter 2.

Preparation for Demanding Sorties

The Air Force identifies certain sorties as *demanding*, and a pilot must have "demanding mission currency" in order to fly them. Some of the constraints that represent the requirement for maintaining demanding mission currency in the F-16 HTS model are somewhat different from the constraints in the F-16 LANTIRN model because the list of sortie profiles is different. We have the same requirement that each category of pilots must fly at least as many BSA (basic surface attack) sorties in daylight as at night (see Constraints [2.8]). But F-16 HTS pilots fly SEAD and NSEA sorties in place of CAS and NCAS sorties. So we replace Constraints (2.9) with the constraint that each category of pilots must fly at least as many SAT (surface attack tactics) and SEAD sorties (in total) in daylight as at night:

$$\sum_{v}\left(Y_{j,'SAT',v} + Y_{j,'SEAD',v}\right) \geq \sum_{v}\left(Y_{j,'NSAT',v} + Y_{j,'NSEA',v}\right) \quad \forall j \neq NMQ \qquad \text{(A2.9)}$$

We again impose the overall constraint that at most three-fourths of all sorties can be flown at night (Constraint [2.10]).

At least 25 percent of each pilot category's total air-to-ground sorties must be BSA sorties. This requirement is similar to Constraints (2.11), but with the CAS profile replaced by SEAD:

$$\sum_{v} Y_{j,'BSA',v} \geq 0.25 \cdot \sum_{v}\left(Y_{j,'BSA',v} + Y_{j,'SAT',v} + Y_{j,'SEAD',v}\right) \quad \forall j \neq NMQ \qquad \text{(A2.11)}$$

Of each pilot category's total BFM and ACM sorties, at least 25 percent must be BFM (Constraints [2.12]). Of each pilot category's total ACM and ACT sorties, at least 25 percent must be ACM (Constraints [2.13]).

Availability and Distribution of Enhanced Sorties

The F-16 HTS model has the same constraints on the number and distribution of enhanced sorties as does the F-16 LANTIRN model. As discussed in Chapter 2, sorties flown at exercises (versions FLG and CFX) and against dissimilar aircraft (version DIS) are enhanced. The applicable constraints are (2.14) and (2.15).

Upgrade Requirements

Table A.6 lists the 13 upgrades considered in the F-16 HTS model. They differ from the F-16 LANTIRN upgrades in that the upgrades related to the LANTIRN and Killer Scout missions have been dropped, and an upgrade for the HARM Targeting System has been added.

The user must specify the number of upgrades of each type that must be flown during a training period. The model then requires each pilot type to fly a number of sorties of each profile that corresponds to those upgrade counts. The constraints relating to upgrades are simpler in the F-16 HTS model than in the F-16 LANTIRN model because of the lack of special mission upgrades that specially qualified IPs were required to supervise. Thus, the F-16 HTS model includes Constraints (2.16) through (2.18), (2.21) through (2.24), (2.26), and (2.27). Constraints (2.19), (2.20), and (2.25) are not needed.

Requirement for In-Flight Supervision

As described earlier, flight leads or IPs must supervise pilots in MQT, wingmen, and BMC pilots. To represent the requirement for in-flight supervision, the F-16 HTS model includes the same constraints as the F-16 LANTIRN model, namely Constraints (2.28) and (2.29).

Table A.6

Upgrades Considered in the F-16 HTS Model

Type	Description
MQT	Mission Qualification Training
MAV	Maverick Qualification
HTS	HARM Targeting System
FLUG2	Two-Ship Flight Lead
FLUG4	Four-Ship Flight Lead
FL24	Two- to Four-Ship Flight Lead
IPUG	IP Upgrade
MCC	Mission Commander
LOW3	Low Altitude Step-Down Training (LASDT) 300 feet
LOW1	LASDT 100 feet
TOW	DART Tow
CWT	Chemical Warfare Training
SIMIN	Simulator Instructor

Selecting a Solution

Like the F-16 LANTIRN version, the F-16 HTS version of the model has many solutions. We use the same method here for selecting one of them. (See Constraints [2.30] through [2.33] in Chapter 2.)

The Base Case for the F-16 HTS Model

Our base case is an F-16 HTS squadron with 18 PAA. This squadron is authorized 23 API-1 pilots, all of whom will be CMR. It will have two additional CMR pilots, the squadron commander and the operations officer, who occupy API-6 billets. An additional four BMC pilots will occupy API-6 billets and perform staff functions.

These 29 pilots will be assigned to jobs as shown in Table A.7. Eight of the CMR pilots are inexperienced (seven wingmen and one flight lead), while 17 CMR pilots are experienced. The Air Force calculates the experience level as the ratio of experienced API-1 pilots to authorized API-1 billets. As explained above, two of the experienced CMR pilots occupy API-6 billets, so the experience level is (17– 2)/23 = 65.2 percent.

We calibrated the F-16 HTS model by adjusting the $Sprac_{spv}$ and $Dprac_{sj}$ arrays so that the model would produce a requirement of a little more than 13 sorties per month for inexperienced pilots, and a little fewer than that for experienced pilots. In other words, our model does not justify this level of flying; it was adjusted to agree with it. We assumed that the survey and interview data we used to calibrate the F-16 LANTIRN model applied equally to the F-16 HTS model. We had no independent source of data specific to the F-16 HTS.

Table A.7

Required Monthly Sorties for the F-16 HTS Base Case, by Pilot Type

Pilot Type	Number of Pilots	Sorties per Pilot per Month	Total Sorties per Month
NMQ	N/A	N/A	22.50
NWG	7	13.33	93.33
XWG	1	12.37	12.37
NFL	1	13.52	13.52
XFL	7	12.42	86.96
XIP	9	13.03	117.24
BMC	4	10.33	41.33
Total Sorties per Month			387.26

A "Repro" Model of the F-16 HTS Linear Program

Formulation and Testing

We next describe a "repro" model of the F-16 HTS LP (see Chapter 4 for a discussion of this model). The repro model estimates sorties as a function of the inventories of pilots. We aggregate flight leads and IPs into a single combined category. So the repro model for the F-16 HTS linear program includes the same four categories of pilots as the repro model for the F-16 LANTIRN linear program:

N(*InexpWing*) = Number of inexperienced wingmen ($N_{'NWG'}$)

N(*ExpWing*) = Number of experienced wingmen ($N_{'XWG'}$)

N(*FL_IP*) = Number of flight leads and IPs ($N_{'NFL'} + N_{'XFL'} + N_{'XIP'}$)

N(*BMC*) = Number of BMC pilots ($N_{'BMC'}$)

Similarly, we denote the sorties flown by pilots in each category as:

S(*InexpWing*) = Total sorties by inexperienced wingmen

S(*ExpWing*) = Total sorties by experienced wingmen

S(*FL_IP*) = Total sorties by flight leads and IPs

S(*BMC*) = Total sorties by BMC pilots

S(*MQT*) = Total sorties by pilots in MQT

S(*RC*) = Rear cockpit IP sorties

The equations for the F-16 HTS repro model have the same form as the F-16 LANTIRN repro model constraints shown in Chapter 4, but with slightly different coefficients:

$$S(InexpWing) = 13.36417 \times N(InexpWing) \quad \text{(A4.1)}$$

$$S(ExpWing) = 12.39187 \times N(ExpWing) \quad \text{(A4.2)}$$

$$S(BMC) = 10.3333 \times N(BMC) \quad \text{(A4.3)}$$

$$S(MQT) = 22.5 \quad \text{(A4.4)}$$

$$S(RC) = 7.125 \quad \text{(A4.5)}$$

$$S(FL\_IP) = Max\left\{\begin{bmatrix}[12.91998 \times N(FL\_IP)], \\ \begin{bmatrix} 0.0 \times N(FL\_IP) + S(InexpWing) \\ +S(ExpWing) + S(BMC) + S(MQT) - S(RC) \end{bmatrix}\end{bmatrix}\right\} \quad (A4.6)$$

When these equations are applied to the pilot inventories from calibration cases for both 18-PAA and 24-PAA squadrons, the results match the LP estimates very closely. The largest errors are only a few percent of the LP's results.

Imposing a Constraint on the Number of Sorties

To use the repro model in a sortie-constrained environment, we follow the recipe shown in Chapter 4, Constraints (4.7) through (4.15). These equations provide a way to scale the sorties flown by inexperienced wingmen, experienced wingmen, and flight leads/IPs until they fit within a constraint on total sorties. Only the coefficients in Constraints (4.7) through (4.9) must be changed to agree with those in Constraints (A4.1), (A4.2), and (A4.6).

When We Know the Experience but Not the Qualifications

To apply the constrained repro model just described, we must know the inventories *N*(*InexpWing*), *N*(*ExpWing*), and *N*(*FL_IP*). But, in our models, we often know only the numbers of inexperienced and experienced CMR pilots who are assigned to a unit, which we may denote by *N*(*InexpCMR*) and *N*(*ExpCMR*), respectively. Constraints (4.16) through (4.23) in Chapter 4 provide a way to estimate the former versus the latter. They can be applied without making changes to the F-16 HTS repro model.

B. The A/OA-10 Model

Formulation of the Linear Program

In this appendix, we describe the formulation of the A/OA-10 version of the linear program. An A/OA-10 squadron is quite different from an F-16 LANTIRN or HTS squadron. It has two different missions, close air support and forward air control, which are referred to as A-10 missions and OA-10 missions, respectively (despite the fact that the A-10 and the OA-10 are the same aircraft). No version of the A-10 has a rear cockpit, so an IP must supervise all upgrade sorties from a second aircraft. And there is no A-10 simulator.

Nonetheless, the A/OA-10 version of our model is surprisingly similar to the F-16 versions. As in all versions, the objective is to minimize the number of sorties a squadron flies over a training period. The variables are the numbers of sorties of different types flown by pilots in different jobs. The constraints ensure that all assigned pilots receive the operational training they require.

Using the notation from Chapter 2, the objective function for this version is written as

$$Min \quad z = \sum_{j,p,v} Y_{jpv} \tag{B2.1}$$

Note that, unlike the F-16 LANTIRN model, the objective function has no coefficients c_{jpv}. In the F-16 versions, these coefficients indicated whether a pilot in job j flying a sortie of profile p and version v required a sortie by an aircraft. Neither simulator turns nor rear cockpit IP sorties required an aircraft to be flown by the pilot performing the sortie. Because the A/OA-10 has no simulator, and no version of the aircraft has a rear cockpit, every pilot sortie requires an aircraft sortie.

Pilots' Jobs

The A/OA-10 model includes the 15 jobs shown in Table B.1. As before, we specify the total number of MQT sorties of each profile that must be flown during each training period, and the number N_{NMQ} of pilots in MQT. The model then determines the sorties per pilot. For technical reasons, the solution to the LP will

Table B.1

Jobs for A/OA-10 Pilots

Aircraft	Pilot Category	CSAR Status	Job
	Pilots in MQT		NMQ
A-10 only	Inexperienced wingmen		NWA
	Experienced wingmen		XWA
	Inexperienced flight leads		NFA
	Experienced flight leads		XFA
	Instructor pilots		XIA
A/OA-10	Inexperienced wingmen		NWO
	Experienced wingmen		XWO
	Experienced flight leads		XFO
		Sandy 1	XFS1
		Sandy 2	XFS2
	Instructor pilots		XIO
		Sandy 1	XIS1
		Sandy 2	XIS2
	Basic Mission Capable		BMC

NOTE: A blank cell in the CSAR Status column indicates that pilots in that job are not CSAR qualified.

be the same regardless of the number of MQT pilots we specify, so we always set that number to be equal to 1.

The major distinctions among the remaining jobs are (1) whether the pilot is inexperienced or experienced; (2) whether the pilot is CMR or BMC; (3) for CMR pilots, whether the pilot is qualified as a wingman, a flight lead, or an instructor pilot; (4) also for CMR pilots, whether the pilot can fly only the A-10 or both the A-10 and the OA-10; and (5) for OA-10 qualified flight leads and IPs, what level of CSAR qualification the pilot possesses. Distinctions (1) through (3) are discussed in Chapter 2. Here, we discuss only distinctions (4) and (5).

A-10 Versus OA-10 Pilots. The primary mission of an A/OA-10 squadron is to provide day and night close air support for friendly ground forces and to act as forward air controller to coordinate and direct friendly air forces in support of ground forces. The primary function of the A-10 is close air support, while that of the OA-10 is airborne FAC.

CSAR Qualification. CSAR is a secondary mission of an A/OA-10 squadron. A formation of two aircraft will fly to the area where a pilot has gone down, search for him, and coordinate his rescue. The leader of the flight is called a “Sandy 1.” He or she becomes the on-scene commander of the CSAR mission. The wingman is the “Sandy 2,” with the responsibility to control strike assets for suppressing enemy attempts to overrun the downed pilot's position. In our model, we show all CSAR-qualified pilots to be OA-10-capable as well because "FAC experience is highly desirable" for the CSAR mission.[1]

The model makes use of various subsets of these jobs, namely wingmen, flight leads, and IPs. For the A/OA-10 model, these subsets are defined as follows:

$$\mathcal{WG} = \{NWA, XWA, NWO, XWO\}$$

$$\mathcal{FL} = \{NFA, XFA, XFO, XFS1, XFS2\}$$

$$\mathcal{IP} = \{XIA, XIO, XIS1, XIS2\}$$

Sortie Profiles and Versions

Sorties come in several profiles and versions. Each profile (see Table B.2) is designed to exercise certain kinds of skills. Different versions (see Table B.3) of the same profile exercise much the same skills, but in different venues or under different conditions or with a somewhat different emphasis. Not every sortie profile comes in all versions.

The model uses various subsets of profiles, namely those flown at night and those that require in-flight supervision. For the A/OA-10 model these subsets are:

$$\mathcal{NIGHT} = \begin{Bmatrix} NBSA, NSAT, NCAS, NASC, NSAR, \\ NAIR, NINS, NROT, NIPC, NAOR \end{Bmatrix}$$

$$\mathcal{SUP} = \begin{Bmatrix} BSA, NBSA, SAT, NSAT, CAS, NCAS, \\ ASC, NASC, CSAR, NSAR, BFM, \\ ACM, ACT, NAIR, AOR, NAOR \end{Bmatrix}$$

Not every pilot is permitted to fly sorties of every profile and version. The rules are shown in Table B.4. The sums in Constraint (B2.1) are taken over the legitimate combinations of job, profile, and version, as determined by combining Tables B.3 and B.4.

---

[1]See Air Force Instruction AFI 11-2A/OA-10 (2000), paragraph 6.6, Combat Search and Rescue (CSAR).

Table B.2

Sortie Profiles in the A/OA-10 Model

Profile	Description	Permitted Version (See Table B.3)				
BSA	Basic surface attack, day	B				IP
NBSA	Basic surface attack, night	B				IP
SAT	Surface attack tactics, day	B	FLG	CFX		IP
NSAT	Surface attack tactics, night	B	FLG	CFX		IP
CAS	Close air support, day	B	FLG	CFX		IP
NCAS	Close air support, night	B	FLG	CFX		IP
ASC	Air strike control, day	B	FLG	CFX		IP
NASC	Air strike control, night	B	FLG	CFX		IP
CSAR	Combat search and rescue, day	B	FLG	CFX		IP
NSAR	Combat search and rescue, night	B	FLG	CFX		IP
BFM	Basic fighter maneuvers	B			DIS	IP
ACM	Air combat maneuvers	B			DIS	IP
ACT	Air combat tactics	B			DIS	IP
NAIR	Air-to-air training, night	B				IP
AHC	Aircraft handling characteristics	B				IP
INS	Instruments, day	B				IP
NINS	Instruments, night	B				IP
ROT	Rotating aircraft, day	B				
NROT	Rotating aircraft, night	B				
IPC	IP chase sortie, day	B				
NIPC	IP chase sortie, night	B				
AOR	Familiarization w/ AOR, day	B				
NAOR	Familiarization w/ AOR, night	B				

Table B.3

Sortie Versions in the A/OA-10 Model

Version	Description
B	Basic, flown at home station
FLG	Flag, an exercise away from home station
CFX	Composite force exercise
DIS	Flown against dissimilar aircraft
IP	Flown by an IP grading an upgrade sortie

Table B.4

Legitimate Profile-Version-Job Combinations in the A/OA-10 Model

Profile	Version	Permitted Job
All *except* ASC, NASC, CSAR, NSAR, IPC, NIPC	B	All
ASC, NASC	B	NMQ, NWO, XWO, XFO, XIO, XFS1, XFS2, XIS1, XIS2
CSAR, NSAR	B	NMQ, XFS1, XFS2, XIS1, XIS2
IPC, NIPC	B	XIA, XIO, XIS1, XIS2
All *except* ASC, NASC, CSAR, NSAR	FLG, CFX, DIS	All *except* NMQ
ASC, NASC	FLG, CFX, DIS	NWO, XWO, XFO, XIO, XFS1, XFS2, XIS1, XIS2
CSAR, NSAR	FLG, CFX, DIS	XFS1, XFS2, XIS1, XIS2
All *except* ASC, NASC, CSAR, NSAR	IP	XIA, XIO, XIS1, XIS2
ASC, NASC	IP	XIO, XIS1, XIS2
CSAR, NSAR	IP	XIS1, XIS2

The A/OA-10 model shares many sortie profiles with the F-16 LANTIRN model, and their descriptions are given in Chapter 2. The new profiles are:

ASC (Air Strike Control) sorties are designed to develop proficiency in airborne forward air control of armed attack fighters in support of ground forces. Mission elements include interfacing with the Theater Air Control System/Army Air-to-Ground System (TACS/AAGS) command and control (C2) network, target acquisition and identification, target marking, positive control of fighters attacking those targets, integration of ground and heliborne fire support elements, and identification and neutralization of enemy air defenses.

NASC (Night Air Strike Control) sorties are ASC sorties flown at night.

CSAR (Combat Search and Rescue) sorties develop proficiency in the recovery of distressed personnel during war or military operations other than war. Mission elements include interfacing with the TACS C2 network, electronic and visual search patterns and procedures, identification and authentication of the survivor(s), positive control of fighters attacking threats to the survivor(s), identification and neutralization of enemy air defenses along ingress and egress routes, and rescue force protection.

NSAR (Night Combat Search and Rescue) sorties are CSAR sorties flown at night.

IPC (IP Chase) sorties are flown to provide supervision and (possibly) instruction for upgrades, recurrencies, and requalifications. They are the counterpart of rear cockpit IP sorties in the F-16 LANTIRN or HTS models, except that because there is no version of the A-10 aircraft with a rear seat, the IP must fly in a separate aircraft. The purpose of IPC sorties is to provide training for the supervised pilot, not for the IP. They can be flown in many of the daytime profiles shown in Table 2.3 in Chapter 2, but the actual training afforded the IP is extremely limited.

NIPC (Night IP Chase) sorties are IPC sorties flown at night. They can be flown in many of the nighttime profiles shown in Table 2.3.

Skill Acquisition and Practice

The model's most important constraints deal with the skills that pilots practice when they fly the various profiles and versions of sorties. We have identified 166 individual skills that contribute to mission capabilities of A/OA-10 pilots, which we group into nine categories (see Table B.5). The first seven categories are identical to the F-16 LANTIRN skill categories found in Table 2.5 in Chapter 2. However, the A/OA-10 has Air Strike Control and CSAR mission skills, rather than the F-16's LANTIRN and Killer Scout skills. Even for skills that the two aircraft have in common, the skill unit arrays $Dprac_{sj}$ and $Sprac_{spv}$ will generally have different entries. Despite this, the skill acquisition constraints for the A/OA-10 model look exactly like Constraint (2.2) in Chapter 2.

Air Force Mandates for Particular Sorties

The Air Force requires each pilot who has completed MQT to fly particular numbers of some sorties. Each pilot must fly at least one AHC sortie, two instrument sorties, and two night sorties per six-month training period. However, there is no simulator for the A/OA-10, so there can be no requirement for simulator turns. Accordingly, the A/OA-10 model has Constraints (2.3) through (2.5), but *not* Constraint (2.6) or (2.7).

Preparation for Demanding Sorties

The Air Force identifies certain sorties as *demanding*, and a pilot must have "demanding mission currency" in order to fly them. The constraints that represent this requirement in the A/OA-10 model are identical to Constraints (2.8) through (2.13) in the F-16 LANTIRN model.

Table B.5

A/OA-10 Skill Categories, with Examples

SUPPORTING SKILLS	Basic airmanship; instruments; aircraft handling; navigation; formation; air-to-air refueling
GENERAL SKILLS FOR ALL COMBAT TASKING	Communications procedures; combat mission planning; switchology; large force employment integration; target deconfliction; hung ordnance/aircraft damage procedures
GENERAL SKILLS FOR AIR-TO-GROUND MISSIONS	Air-to-surface delivery systems; surface-to-air threats; attack options; delivery methods; impact accuracy; fuel management; egress options; battle damage response/wounded bird procedures
GENERAL SKILLS FOR AIR-TO-AIR MISSIONS	Air-to-air systems; weapon selection options; attack options (day, night); commit criteria
SKILLS SPECIFIC FOR CLOSE AIR SUPPORT (CAS)	Tactical air control system; command, control, and communications; joint air attack team procedures; forward air control control/holding point; target ID and attack restrictions
SKILLS SPECIFIC TO AI, SEAD-C, AND OCA-S MISSIONS	Route and formation selection; threat interpretation and response; AWACS, Rivet Joint, JSTARS, and other such issues; target area contingencies; updates/execution/ verification
SKILLS SPECIFIC TO MAVERICK MISSIONS	AGM 65 B/D/G differences; TGP targeting options; alternative targeting and missile handoff options
SKILLS SPECIFIC TO AIR STRIKE CONTROL MISSIONS	TACS coordination; target ID, plotting, and marking; fighter rendezvous and control
SKILLS SPECIFIC TO CSAR MISSIONS	Search procedures; survivor location and contact; suppression of threats to survivor; route reconnaissance; survivor pickup

Availability and Distribution of Enhanced Sorties

The A/OA-10 model has the same constraints on the number and distribution of enhanced sorties (i.e., sorties of versions FLG, CFX, and DIS) as does the F-16 LANTIRN model. Those constraints are (2.14) and (2.15).

Upgrade Requirements

Table B.6 lists the ten upgrades considered in the A/OA-10 model.

The user of the model must specify the number of upgrades of each type that must be flown during a training period. The model then requires each pilot type to fly a number of sorties of each profile that corresponds to those upgrade

Table B.6

Upgrades Considered in the A/OA-10 Model

Type	Description
MQA	Mission Qualification Training, A-10 Pilots
MQO	Mission Qualification Training, OA-10 Pilots
NVG	Night Vision Goggles
FLUGA	Flight Lead for A-10 missions
FLUGO	Flight Lead for OA-10 missions
IPUG	Instructor Pilot for A-10 missions
IPFAC	Instructor Pilot for OA-10 missions
S2	Sandy 2 (wingman for CSAR mission)
S1	Sandy 1 (flight lead for CSAR mission)
MCC	Mission Commander

counts. The A/OA-10 model requires most of the same upgrade constraints as the F-16 LANTIRN model. It requires Constraints (2.16) through (2.18), (2.21), (2.22), and (2.26) without change. Constraints (2.23) and (2.24) must be modified to replace rear cockpit IP sorties with IP chase sorties:

$$\sum_{j \in \mathcal{IP}} Y_{j,'IPC','B'} \geq \sum_{u,p \notin \mathcal{NIGHT}} RCIPSort_{pu} \cdot Upgd_u \qquad \text{(B2.23)}$$

$$\sum_{j \in \mathcal{IP}} Y_{j,'NIPC','B'} \geq \sum_{u,p \in \mathcal{NIGHT}} RCIPSort_{pu} \cdot Upgd_u \qquad \text{(B2.24)}$$

Constraints (2.19), (2.20), and (2.25) can be dropped. They relate to requirements for specially qualified IPs to supervise LANTIRN and Killer Scout upgrades. It would be reasonable to include analogous requirements for FAC and CSAR-related upgrades in the A/OA-10 model but we have not done so.[2]

Requirement for In-Flight Supervision

As described earlier, flight leads and IPs must supervise pilots in MQT, wingmen, and BMC pilots. The A/OA-10 model represents this requirement with the same constraints as the F-16 LANTIRN model, namely Constraints (2.28) and (2.29).

[2]These possible constraints would require that only XIO, XIS1, or XIS2 pilots supervise FAC-related upgrades (MQO, FLUGO, and IPFAC); that only XIS1 or XIS2 pilots supervise the S2 upgrade; and that only XIS1 pilots supervise the S1 upgrade. These constraints would affect the distribution of sorties among pilot types, but they should not affect the total sorties flown by the squadron as a whole.

Selecting a Solution

Like the F-16 LANTIRN model, the A/OA-10 model has multiple solutions. We use the same method used with the F-16 LANTIRN model for selecting one of them. See Constraints (2.30) through (2.33) in Chapter 2.

The Base Case for the A/OA-10 Model

Our base case is an A/OA-10 squadron with 12 A-10 and six OA-10 aircraft, for a total of 18 PAA. The specified crew ratios are 1.5 for the A-10 and 2.0 for the OA-10, so C is authorized $1.5 \times 12 + 2.0 \times 6 = 30$ API-1 pilots, all of whom will be CMR. The squadron will have two additional CMR pilots, the squadron commander and the operations officer, who occupy API-6 billets. They will be experienced pilots, usually IP-qualified. An additional six pilots will be assigned to this squadron to perform staff functions. They will be BMC and will occupy API-6 billets.

These 38 pilots will be assigned to jobs as shown in Table B.7. Ten of the CMR pilots (nine wingmen and one flight lead) are inexperienced, while 22 CMR pilots are experienced. The Air Force calculates the experience level as the ratio of experienced API-1 pilots to authorized API-1 billets. As explained above, two of the experienced CMR pilots occupy API-6 billets, so the experience level is $(22 - 2)/30 = 66.7$ percent.

Note that there are 14 CMR pilots who can fly only A-10 missions (i.e., close air support), and 18 pilots who can fly either the A-10 or the OA-10 missions (i.e., forward air control). At the specified crew ratios, this squadron needs 18 pilots for A-10 missions. Thus, pilots who are also qualified to fly OA-10 missions must fly some A-10 missions.

We calibrated the A/OA-10 model by adjusting the $Sprac_{spv}$ and $Dprac_{sj}$ arrays so that the model would produce a requirement of a little more than 13 sorties per month for inexperienced pilots, and a little less than that for experienced pilots. In other words, our model does not justify this level of flying; it was adjusted to agree with it. These figures reflect the expert judgment of flight leads and IPs[3] about the amount pilots must fly to maintain proficiency and progress to higher positions (e.g., wingman to flight lead, or flight lead to IP). As we interpret their judgment, these flying rates should be adequate for the unit to maintain

[3]We collected survey and interview data for the A/OA-10 model from the 23rd Fighter Group at Pope AFB, North Carolina (August 2000), and the 355th Fighter Wing at Davis-Monthan AFB, Arizona (October 2000). All the caveats mentioned in Chapter 3 about the uncertainties and limitations of our calibration of the F-16 LANTIRN model apply equally to the A/OA-10 model.

Table B.7

Required Monthly Sorties for the A/OA-10 Base Case, by Pilot Type

Pilot Type	Number of Pilots	Sorties per Pilot per Month	Total Sorties per Month
NMQ	N/A	N/A	31.00
NWA	7	13.16	92.10
NFA	1	13.16	13.16
XWA	0	N/A	0.00
XFA	3	11.99	35.96
XIA	3	12.45	37.36
NOW	2	14.70	29.39
XWO	1	12.72	12.72
XFO	3	12.53	37.60
XIO	3	13.47	40.41
XFS1	1	13.28	13.28
XFS2	2	13.28	26.56
XIS1	3	14.12	42.36
XIS2	3	14.12	42.36
BMC	6	10.44	62.67
Total Sorties per Month			516.91

readiness in all of its assigned missions, so that it could deploy with few or no preparatory spin-up sorties. A squadron might get by with flying fewer sorties, but its pilots would progress more slowly than desired, and it would require spin-up sorties prior to deploying.

A Repro Model of the A/OA-10 Linear Program

We next describe a "repro" model of the A/OA-10 LP. As explained in Chapter 4, the repro model reproduces (approximately) selected results from the LP, and we have extended it to extrapolate the LP's results for cases in which total available sorties are constrained. Much simpler than the LP, it can be used as part of a spreadsheet or a simulation model.

Formulation and Testing

We designed the repro model to estimate sorties as a function of the inventories of pilots. For use in the repro model, however, we aggregate the jobs in Table B.1 (excluding pilots in MQT) into only four categories:

$N(InexpWing)$ = Number of inexperienced wingmen ($N_{'NWA'} + N_{'NWO'}$)

$N(ExpWing)$ = Number of experienced wingmen ($N_{'XWA'} + N_{'XWO'}$)

$N(FL\_IP)$ = Number of flight leads and IPs ($N_{'NFA'} + N_{'XFA'} + N_{'XIA'} + N_{'XFO'} + N_{'XIO'} + N_{'XFS1'} + N_{'XFS2'} + N_{'XIS1'} + N_{'XIS2'}$)

$N(BMC)$ = Number of BMC pilots ($N_{'BMC'}$)

Similarly, we denote the sorties flown by pilots in each category as:

$S(InexpWing)$ = Total sorties by inexperienced wingmen

$S(ExpWing)$ = Total sorties by experienced wingmen

$S(FL\_IP)$ = Total sorties by flight leads and IPs

$S(BMC)$ = Total sorties by BMC pilots

$S(MQT)$ = Total sorties by pilots in MQT

The constraints for the A/OA-10 repro model have the same form as those for the F-16 LANTIRN repro model in Chapter 4, but with slightly different coefficients. Also, the constraint for rear cockpit IP sorties is missing because the A/OA-10 has no rear cockpit:

$$S(InexpWing) = 13.62006 \times N(InexpWing) \qquad \text{(B4.1)}$$

$$S(ExpWing) = 12.73231 \times N(ExpWing) \qquad \text{(B4.2)}$$

$$S(BMC) = 10.49162 \times N(BMC) \qquad \text{(B4.3)}$$

$$S(MQT) = 31.0 \qquad \text{(B4.4)}$$

$$S(FL\_IP) = Max\left\{\begin{matrix}[13.18407 \times N(FL\_IP)], \\ \begin{bmatrix}0.25796 \times N(FL\_IP) + S(InexpWing) \\ +S(ExpWing) + S(BMC) + S(MQT)\end{bmatrix}\end{matrix}\right\} \qquad \text{(B4.6)}$$

When these constraints are applied to the pilot inventories from our calibration cases, the results match the LP estimates very closely. The largest errors are only a percent or so of the LP's results.

Imposing a Constraint on the Number of Sorties

To use the repro model in a sortie-constrained environment, we follow the recipe from Chapter 4—Constraints (4.7) through (4.15)—which scales the sorties flown by inexperienced wingmen, experienced wingmen, and flight leads/IPs until they fit within a constraint on total sorties. The coefficients in Constraints (4.7) through (4.9) must be changed to agree with those in Constraints (B4.1), (B4.2), and (B4.6).

When We Know the Experience but Not the Qualifications

To apply the constrained repro model just described, we must know the inventories *N*(*InexpWing*), *N*(*ExpWing*), and *N*(*FL_IP*). But, in our models, we often know only the numbers of inexperienced and experienced CMR pilots that are assigned to a unit, which we may denote by *N*(*InexpCMR*) and *N*(*ExpCMR*), respectively. Constraints (4.16) through (4.23) in Chapter 4 provide a way to estimate the former versus the latter. They can be applied without change to the A/OA-10 repro model.

C. The F-15C Model

Formulation of the Linear Program

In this appendix, we describe the formulation of the F-15C version of the linear program. The mission of the F-15C is air superiority. Unlike the F-16 and the A/OA-10, it has no air-to-ground mission. Nonetheless, the F-15C version of the model is very similar to the F-16 LANTIRN model discussed in Chapters 2 through 4. Here, we briefly mention the points of similarity and describe in detail the points of difference.

As explained earlier, in all versions of our model, the objective is to minimize the number of sorties a squadron flies over a training period. The variables are numbers of sorties of different types flown by pilots in different jobs. The constraints ensure that all assigned pilots receive the operational training they require.

Using the notation from Chapter 2, we write the objective function as:

$$Min \quad z = \sum_{j,p,v} c_{jpv} \cdot Y_{jpv} \qquad \text{(C2.1)}$$

As in the F-16 LANTIRN model, the coefficients c_{jpv} indicate which pilot sorties require sorties by aircraft. A simulator turn requires no aircraft sortie, and neither does a rear cockpit IP sortie. Thus, the coefficients c_{jpv} for all front cockpit sorties are equal to one, whereas the coefficients for simulator turns and rear cockpit IP sorties are zero.

Pilots' Jobs

The F-15C model includes the nine jobs shown in Table C.1. As was done with other versions of the model, we specify the total number of MQT sorties of each profile that must be flown during each training period and the number N_{NMQ} of pilots in MQT. The model then determines the sorties per pilot. For technical reasons, the solution to the LP will be the same regardless of the number of MQT pilots we specify, so we always set that number to be equal to 1.

Table C.1

Jobs for F-15C Pilots

Pilot Category	Job
Pilots in MQT	NMQ
Inexperienced wingmen	NWG
Experienced wingmen	XWG
Inexperienced two-ship flight leads	NF2
Inexperienced four-ship flight leads	NF4
Experienced two-ship flight leads	XF2
Experienced four-ship flight leads	XF4
Instructor pilots	XIP
Basic Mission Capable	BMC

The major distinctions among the remaining jobs are (1) whether the pilot is inexperienced or experienced; (2) whether the pilot is CMR or BMC; and (3) for CMR pilots, whether the pilot is qualified as a wingman, a two-ship flight lead, a four-ship flight lead, or an instructor pilot. All pilots fly all missions, so there are no specific mission capabilities for which only some pilots are qualified.

The model makes use of subsets of jobs, namely wingmen, flight leads, and IPs. For the F-15C model, these subsets are:

$\mathcal{WG} = \{NWG, XWG\}$

$\mathcal{FL} = \{NF2, NF4, XF2, XF4\}$

$\mathcal{IP} = \{XIP\}$

Sortie Profiles and Versions

Sorties come in several profiles and versions. Each profile (see Table C.2) is designed to exercise certain kinds of skills. Different versions (see Table C.3) of the same profile exercise much the same skills, but in different venues or under different conditions or with a somewhat different emphasis. Not every sortie profile comes in all versions.

The model makes use of various subsets of profiles, namely profiles flown at night and profiles that require in-flight supervision. For the F-16 HTS model, these subsets are defined as:

$\mathcal{NIGHT} = \{NAIR, NINS, NROT, NIPR, NAOR\}$

$\mathcal{SUP} = \{TINT, OCA, DCA, BFM, ACM, NAIR, AOR, NAOR\}$

Table C.2

Sortie Profiles in the F-15C Model

Profile	Description	Permitted Version (see Table C.3)					
TINT	Tactical intercept	B				IP	
BFM	Basic fighter maneuvers	B			DIS	IP	
ACM	Air combat maneuvers	B			DIS	IP	RA
OCA	Offensive counter-air	B	FLG	CFX	DIS	IP	RA
DCA	Defensive counter-air	B	FLG	CFX	DIS	IP	RA
NAIR	Air-to-air training, night	B				IP	RA
AHC	Aircraft handling characteristics	B				IP	
INS	Instruments, day	B				IP	
NINS	Instruments, night	B				IP	
ROT	Rotating aircraft, day	B					
NROT	Rotating aircraft, night	B					
PR	Rear cockpit IP sortie, day	B					
NIPR	Rear cockpit IP sortie, night	B					
AOR	Familiarization w/ AOR, day	B					
NAOR	Familiarization w/ AOR, night	B					
SIM	Simulator	B					

Table C.3

Sortie Versions in the F-15C Model

Version	Description
B	Basic, flown at home station
FLG	Flag, an exercise away from home station
CFX	Composite force exercise
DIS	Flown against dissimilar aircraft
IP	Flown by an IP grading an upgrade sortie
RA	Red Air

Not every pilot is permitted to fly sorties of every profile and version. The rules are shown in Table C.4. The sums in Constraint (2.1) in Chapter 2 are taken over the legitimate combinations of job, profile, and version, as determined by combining Tables C.2 and C.4.

Table C.4

Legitimate Profile-Version-Job Combinations in the F-15C Model

Profiles	Version	Permitted Job
All *except* PR, NIPR	B	All
PR, NIPR	B	XIP
All	FLG, CFX, DIS, RA	All *except* NMQ
All *except* PR, NIPR	IP	XIP

The F-15C shares many sortie profiles with the F-16 LANTIRN model, and their descriptions can be found in Chapter 2. The following are new profiles for the F-15C:

TINT (Tactical Intercept) sorties are single- or multi-ship intercepts. The fighter should counter threat maneuvers and weapons engagement zones, consider environmental factors, attain turning room and energy at end game, and take valid shots if warranted.

OCA (Offensive Counter-Air) sorties develop proficiency at using sweep/roving CAP tactics to sterilize a predetermined area of enemy aircraft. The Red Air version provides a simulated enemy aircraft to practice against.

DCA (Defensive Counter-Air) sorties develop proficiency in tactics to detect, engage, and negate aircraft employing adversary tactics and weapons capabilities for the purpose of penetrating protected airspace or attacking a specific target area. The Red Air version provides a simulated enemy aircraft to practice against.

Skill Acquisition and Practice

The model's most important constraints deal with the skills that pilots practice when they fly the various profiles and versions of sorties. We have identified 92 individual skills that contribute to mission capabilities of F-15C pilots, which we group into five categories (see Table C.5). The first three categories are identical to the F-16 LANTIRN skill categories found in Table 2.5 in Chapter 2. But where the F-16 LANTIRN model has skills related to the LANTIRN and Killer Scout missions, the F-15C model has skills related to offensive and defensive counter-air missions. In addition, F-15C pilots have no need of air-to-ground skills. While the F-15C model has a different list of skills than the F-16 LANTIRN model, and different skill unit demand ($Dprac_{sj}$) and supply ($Sprac_{spv}$) arrays, its skill acquisition constraints look exactly the same as Constraints (2.2).

Table C.5

F-15C Skill Categories, with Examples

SUPPORTING SKILLS
Basic airmanship; instruments; aircraft handling; navigation; formation; air-to-air refueling
GENERAL SKILLS FOR ALL COMBAT TASKING
Communications procedures; combat mission planning; switchology; large force employment integration; target deconfliction; hung ordnance/aircraft damage procedures
GENERAL SKILLS FOR AIR-TO-AIR MISSIONS
Air-to-air systems; weapon selection options; attack options (day, night); commit criteria
SKILLS SPECIFIC TO THE OFFENSIVE COUNTER-AIR MISSION
Route and formation selection; sweep/roving CAP alternatives; SEAD support issues; electronic countermeasures (ECM) intercepts; tactical maneuvering and weapons employment
SKILLS SPECIFIC TO THE DEFENSIVE COUNTER-AIR MISSION
CAP/lane/point defense options; specific radar/visual responsibilities; shot options; ECM intercepts; tactical maneuvering and weapons employment

Air Force Mandates for Particular Sorties

The Air Force requires each pilot who has completed MQT to fly particular numbers of some sorties. Each pilot must fly at least one AHC sortie, two instrument sorties, and two night sorties per six-month training period. Experienced pilots must log at least four simulator turns, and inexperienced pilots must log at least six turns, per training period. We also impose upper limits of five and seven simulator turns per training period on experienced and inexperienced pilots, respectively. The constraints for the F-15C model are the same as those for the F-16 LANTIRN model, namely Constraints (2.3) through (2.7).

Preparation for Demanding Sorties

The Air Force identifies certain sorties as *demanding*, and a pilot must have "demanding mission currency" in order to fly them. Some of the constraints that represent the requirement for maintaining demanding mission currency in the F-15C model are somewhat different from the constraints in the F-16 LANTIRN model because the list of sortie profiles is different. We have the same requirement that each category of pilots must fly at least as many sorties in daylight as they do corresponding sorties at night. In the F-16 LANTIRN model, we defined separate blocks of constraints for each sortie profile with this requirement. Thus Constraints (2.8) required that as many BSA sorties be flown as NBSA sorties, and Constraints (2.9) required that at many SAT + CAS sorties be flown as NSAT + NCAS sorties. For the F-15C model we have written all the "night requires day" constraints as a single block. We first specify the set of correspondences between nighttime and daylight profiles:

$$\mathcal{NIGHT2DAY} = \left\{ \begin{matrix} (NAIR, OCA), (NAIR, DCA), (NAIR, TINT), \\ (NINS, INS), (NROT, ROT), (NIPR, IPR), (NAOR, AOR) \end{matrix} \right\}$$

Each element in this set is a pair of profiles. The first of each pair is a nighttime profile, and the second is a corresponding daylight profile, one of the profiles that can be flown to prepare for the nighttime profile. For any nighttime profile, we can determine the set of corresponding daylight sorties by examining the set *NIGHT2DAY*. GAMS, the software we are using to implement these models (see Footnote 11 in Chapter 1) does this automatically. In effect, it constructs the sets as follows:

$$\mathcal{DAY}(p) = \left\{ pp \mid (p, pp) \in \mathcal{NIGHT2DAY} \right\}$$

The "night requires day" constraints for the F15C model are then:

$$\sum_{v} Y_{jpv} \geq \sum_{pp \in \mathcal{DAY}(p), v} Y_{j,pp,v} \quad \forall j \neq NMQ, p \in \mathcal{NIGHT} \qquad \text{(C2.8)}$$

We again impose an overall constraint that at most three-fourths of all sorties can be flown at night (Constraint [2.10]). Because the F-15C flies no BSA sorties, the F-15C version of our model does not include Constraints (2.11).

Of each pilot category's total BFM and ACM sorties, at least 25 percent must be BFM (Constraints [2.12]). Of each pilot category's total ACM, OCA, and DCA sorties, at least 25 percent must be ACM. This requirement is similar to Constraints (2.13), but modified for the difference in profiles flown by the F-15C as compared with the F-16 LANTIRN:

$$\sum_{v} Y_{j,'ACM',v} \geq 0.25 \cdot \sum_{v} \left(Y_{j,'ACM',v} + Y_{j,'OCA',v} + Y_{j,'DCA',v} \right) \quad \forall j \neq NMQ \qquad \text{(C2.13)}$$

Availability and Distribution of Enhanced Sorties

The F-15C model constrains the numbers of enhanced sorties (versions FLG, CFX, and DIS) in the same way as the F-16 LANTIRN model. The constraints in this case are (2.14) and (2.15).

Upgrade Requirements

Table C.6 lists the ten upgrades considered in the F-15C model.

The user of the model must specify the number of upgrades of each type that must be flown during a training period. The model then requires each pilot type to fly a number of sorties of each profile that corresponds to those upgrade counts. The constraints relating to upgrades are simpler in the F-15C model than are those in the F-16 LANTIRN model because there are no special mission capabilities that require supervision by specially qualified IPs. Thus, the F-15C model includes Constraints (2.16) through (2.18), (2.21) through (2.24), (2.26), and (2.27). Constraints (2.19), (2.20), and (2.25) are not needed.

Red Air Sorties

Because the mission of the F-15C is air superiority, its pilots must demonstrate their skills against other aircraft. In the F-15C model, we require that for every OCA, DCA, or ACM sortie by an upgradee, there be two Red Air sorties of the same profile. Our rationale is that the upgradee will be in a flight of two or four aircraft, which will be opposed by two aircraft playing the role of Red Air. Thus, we define:

$$YRA_p = \sum_u Upgd_u \cdot \left(IPSort_{pu} + FCIPSort_{pu}\right) \quad p \in \{OCA, DCA, ACM\}$$

Table C.6

Upgrades Considered in the F-15C Model

Type	Description
MQT	Mission Qualification Training
FLUG2	Two-Ship Flight Lead
FLUG4	Four-Ship Flight Lead
FL24	Two- to Four-Ship Flight Lead
IPUG	IP Upgrade
MCC	Mission Commander
LOW1	Low Altitude Step-Down Training (LASDT) 100 feet
TOW	DART Tow
CWT	Chemical Warfare Training
SIMIN	Simulator Instructor

Then, the new constraint is:[1]

$$\sum_{j \neq 'NMQ'} Y_{j,p,'RA'} = YRA_p \quad p \in \{OCA, DCA, ACM\} \qquad \text{(C.N1)}$$

Requirement for In-Flight Supervision

As described earlier, flight leads or IPs must supervise wingmen and BMC pilots during most sortie profiles. To represent the requirement for in-flight supervision, the F-15C model includes the same constraints as the F-16 LANTIRN model, namely Constraints (2.28) and (2.29).

Selecting a Solution

Like the other versions, the F-15C model has many solutions. We use our standard method for selecting one of them (see Constraints [2.30] through [2.33] in Chapter 2).

The Base Case for the F-15C Model

Our base case is an F-15C squadron with 18 PAA. The specified crew ratio for the F-15C is 1.25, so this squadron is authorized 1.25 × 18 = 22.5 API-1 pilots, which is rounded up to 23. All the API-1 pilots will be CMR. The squadron will have two additional CMR pilots, the squadron commander and the operations officer, who occupy API-6 billets. An additional four BMC pilots will occupy API-6 billets and perform staff functions.

These 29 pilots will be assigned to jobs as shown in Table C.7. Eight of the CMR pilots (seven wingmen and one flight lead) are inexperienced, while 17 CMR pilots are experienced. The Air Force calculates the experience level as the ratio of experienced API-1 pilots to authorized API-1 billets. As explained above, two of the experienced CMR pilots occupy API-6 billets, so the experience level is (17 – 2)/23 = 65.2 percent.

We calibrated the F-15C model by adjusting the $Sprac_{spv}$ and $Dprac_{sj}$ arrays so the model would produce a requirement of about 13 sorties per month for inexperienced wingmen, and a little fewer than that for experienced pilots. In other words, our model does not justify this level of flying; it was adjusted to

[1]We number this constraint N1 because it is new. It has no counterpart in Chapter 2.

Table C.7

Required Monthly Sorties for the F-15C Base Case, by Pilot Type

Pilot Type	Number of Pilots	Sorties per Pilot per Month	Total Sorties per Month
NMQ	N/A	N/A	10.83
NWG	7	12.94	90.60
XWG	1	11.81	11.81
NF2	1	13.03	13.03
NF4	0	N/A	0.00
XF2	3	11.89	35.68
XF4	4	11.89	47.58
XIP	9	12.76	114.86
BMC	4	10.37	41.47
Total Sorties per Month			365.86

agree with it. We assumed that the survey and interview data we used to calibrate the F-16 LANTIRN model applied equally to the F-15C model. We had no independent source of data specific to the F-15C. Thus, not only do the caveats we noted in Chapter 3 about calibration apply here, one must also ask whether F-15C IPs and flight leads would agree with F-16 IPs and flight leads.

A Repro Model of the F-15C Linear Program

Formulation and Testing

We next describe a "repro" model of the F-15C LP. It includes the same four pilot categories as the F-16 LANTIRN repro model discussed in Chapter 4:

$N(InexpWing)$ = Number of inexperienced wingmen ($N_{'NWG'}$)

$N(ExpWing)$ = Number of experienced wingmen ($N_{'XWG'}$)

$N(FL\_IP)$ = Number of flight leads and IPs ($N_{'NF2'} + N_{'NF4'} + N_{'XF2'} + N_{'XF4'} + N_{'XIP'}$)

$N(BMC)$ = Number of BMC pilots ($N_{'BMC'}$)

Similarly, we denote the sorties flown by pilots in each category as follows:

$S(InexpWing)$ = Total sorties by inexperienced wingmen

$S(ExpWing)$ = Total sorties by experienced wingmen

$S(FL\_IP)$ = Total sorties by flight leads and IPs

$S(BMC)$ = Total sorties by BMC pilots

$S(MQT)$ = Total sorties by pilots in MQT

$S(RC)$ = Rear cockpit IP sorties

The constraints for the F-15C repro model have the same form as the F-16 LANTIRN repro model, but with slightly different coefficients:

$$S(InexpWing) = 12.94275 \times N(InexpWing) \quad \text{(C4.1)}$$

$$S(ExpWing) = 11.81205 \times N(InexpWing) \quad \text{(C4.2)}$$

$$S(BMC) = 10.41564 \times N(BMC) \quad \text{(C4.3)}$$

$$S(MQT) = 10.83333 \quad \text{(C4.4)}$$

$$S(RC) = 4.16667 \quad \text{(C4.5)}$$

$$S(FL\_IP) = Max\left\{ \begin{array}{l} [12.43971 \times N(FL\_IP)], \\ \left[\begin{array}{l} 0.11004 \times N(FL\_IP) + S(InexpWing) \\ +S(ExpWing) + S(BMC) + S(MQT) - S(RC) \end{array} \right] \end{array} \right\} \quad \text{(C4.6)}$$

When these equations are applied to the pilot inventories from calibration cases for both 18-PAA and 24-PAA squadrons, the results match the LP estimates closely. The largest errors are just over 1 percent.

Imposing a Constraint on the Number of Sorties

To use the repro model in a sortie-constrained environment, we follow the recipe described in Constraints (4.7) through (4.15) of Chapter 4. Only the coefficients in Constraints (4.7) through (4.9) must be changed to agree with those in Constraints (C4.1) through (C4.6).

When We Know the Experience but Not the Qualifications

To apply the constrained repro model just described, we must know the inventories $N(InexpWing)$, $N(ExpWing)$, and $N(FL\_IP)$. But, in our models, we often know only the numbers of inexperienced and experienced CMR pilots who are assigned to a unit, which we may denote by $N(InexpCMR)$ and $N(ExpCMR)$, respectively. Constraints (4.16) through (4.23) in Chapter 4 can be applied without change to the F-15C repro model.

D. The F-15E Model

Formulation of the Linear Program

In this appendix, we describe the formulation of the F-15E version of the linear program. The F-15E differs from all other aircraft we have considered in that it has a crew of two—a pilot and a weapon system officer. As always, the objective is to minimize the number of sorties a squadron flies over a training period, and the variables are numbers of sorties of different types flown by crew members in different jobs. But this version of the model must have not only constraints that ensure that all assigned crew members receive the operational training they require, the constraints must also coordinate pilot and WSO training. Thus, for every sortie by a pilot, there must be a corresponding sortie by either a WSO or an IP occupying the rear seat.

Using the notation from Constraint (2.1) in Chapter 2, we write the objective function as:

$$Min \quad z = \sum_{j,p,v} c_{jpv} \cdot Y_{jpv} \qquad \text{(D2.1)}$$

As in other versions of the model, the coefficients c_{jpv} in the objective function indicate whether a crew member in job j flying a sortie of profile p and version v requires a sortie by an aircraft. WSO sorties, rear seat IP sorties, and simulator turns do not need an aircraft, and hence their coefficients c_{jpv} are zero. Sorties flown by pilots in the front seat of the aircraft have coefficients of one.

In this appendix, we have written out all the constraints, rather than referring readers to Chapter 2 as we did in Appendixes A through C. The notation for the F-15E model must be expanded to include WSOs as well as pilots; thus, it differs enough from the F-16 LANTIRN notation that it would be confusing not to write the constraints out completely. As will be shown, however, the F-15E version of the model is structurally very similar to the other versions we have described.

Pilots' Jobs

The F-15E model includes the 24 jobs shown in Table D.1. As before, we specify the total number of MQT sorties of each profile that must be flown during each

Table D.1

Jobs for F-15E Crew Members

Position	Main Qualification	Special Qualifications		Job
Pilot	In MQT			PMQ
	Inexperienced wingmen			NP
	Experienced wingmen			XP
	Inexperienced flight leads			NF
		GBU-15		NFG
	Experienced flight leads			XF
		GBU-15		XFG
		GBU-15	AGM-130	XFA
	Instructor pilots			IP
		GBU-15		IPG
		GBU-15	AGM-130	IPA
	Basic Mission Capable			BMP
WSO	In MQT			WMQ
	Inexperienced wingmen			NW
		GBU-15		NWG
	Experienced wingmen			XW
		GBU-15		XWG
		GBU-15	AGM-130	XWA
	Instructor WSO			IW
		GBU-15		IWG
		GBU-15	AGM-130	IWA
	Basic Mission Capable			BMW
		GBU-15		BMG
		GBU-15	AGM-130	BMA

training period and the number N_{NMQ} of pilots in MQT. For the F-15E model, however, we must also specify MQT sorties for WSOs and the number N_{WMQ} of WSOs in MQT. The model then determines the sorties per pilot and per WSO. For technical reasons, the solution to the LP will be the same regardless of the number of MQT pilots and WSOs we specify, so we always set that number to be equal to 1.

The major distinctions among the remaining jobs are (1) whether a crew member is a pilot or a WSO; (2) whether he or she is inexperienced or experienced; (3) whether he or she is CMR or BMC; (4) for CMR crew members, whether he or she is qualified as a wingman, a flight lead (pilots only), or an instructor pilot or WSO; and (5) the specific mission capabilities for which a pilot or WSO has qualified. In Chapter 2, we discussed distinctions (2) through (4) for pilots. Here, we discuss distinctions (1) and (5) for pilots and distinctions (2) through (4) for WSOs.

Pilot Versus Weapon System Officer. The pilot sits in the front seat and flies the airplane. The WSO sits in the back seat. The WSO is responsible for navigation, target acquisition and identification, and weapons employment.

Inexperienced Versus Experienced WSO. In Chapter 2, we discussed what it means to be an experienced pilot. For WSOs, the definition of "experienced" is very similar. Subjectively, experienced WSOs must have a "fundamental understanding of the operational mission" or "operational knowledge and mission experience." For management purposes, the Air Force has implemented objective criteria based on flying hours logged in aircraft assigned an Air Force Specialty Code (AFSC) of 12F3X or 12F4X (i.e., time spent in the navigator position of a fighter aircraft). To become experienced, a WSO requires 500 hours in the F-15E, or 1,000 total fighter hours, of which 300 are in the F-15E.

CMR Versus BMC WSOs. For CMR versus BMC, the same criteria apply to WSOs and to pilots. A WSO is considered CMR if he or she is "qualified and proficient in all of the primary missions tasked to his assigned unit and weapon system."[1] A WSO is BMC if he or she is "familiarized in all, and may be qualified and proficient in some, of the primary missions tasked to his assigned unit and weapon system."[2]

Wingman WSO Versus Instructor WSO. In Chapter 2, we discussed what it means for a pilot to be a wingman, flight lead, or instructor pilot. There is no counterpart of a flight lead for a WSO, only wingmen and instructors. A wingman WSO can occupy the rear seat of any of the aircraft in a flight, regardless of whether a flight lead is required in the pilot (front) seat. However, if the mission involves introducing a WSO to new tasks or correcting previous discrepancies, an instructor WSO (IW) must supervise from another aircraft. An IW is also required to supervise a WSO who is upgrading to a new job.

Specific Mission Capabilities. In the F-15E model, the special missions are the employment of the precision weapons guided bomb unit (GBU)-15 and air-to-ground missile (AGM)-130. Both pilots and WSOs must qualify to use these weapons. Qualification for the GBU-15 is a prerequisite for the AGM-130.

The model makes use of various subsets of these jobs. We define the subsets of pilots and WSOs as:

$$\mathcal{PLT} = \{NP, XP, NF, NFG, XF, XFG, XFA, IP, IPG, IPA, BMP\}$$

[1] Air Force Instruction AFI 11-2F-15E (1998), paragraph 1.4.4.1.

[2] Air Force Instruction AFI 11-2F-15E (1998), paragraph 1.4.4.2.

$$\mathcal{WSO} = \{NW, NWG, XW, XWG, XWA, IW, IWG, IWA, BMW, BMG, BMA\}$$

We also define the subsets of wingmen, flight leads, instructors, and BMC crew members. These subsets include both pilots and WSOs. Subsets that contain only pilots or only WSOs can be obtained by forming the intersection of the PLT or WSO subset with one of the following:

$$\text{WG} = \{NP, XP, NW, NWG, XW, XWG, XWA\}$$

$$\mathcal{FL} = \{NF, NFG, XF, XFG, XFA\}$$

$$\mathcal{INST} = \{IP, IPG, IPA, IW, IWG, IWA\}$$

$$\mathcal{BMC} = \{BMP, BMW, BMG, BMA\}$$

Sortie Profiles and Versions

Sorties come in several profiles and versions. Each profile (see Table D.2) is designed to exercise certain kinds of skills. Different versions (see Table D.3) of the same profile exercise much the same skills, but in different venues or under different conditions or with a somewhat different emphasis. Not every sortie profile comes in all versions.[3]

The model uses subsets of profiles for sorties flown at night and sorties that require in-flight supervision. For the F-15E model, these subsets are:

$$\mathcal{NIGHT} = \{NBSA, NSAT, NGBU, NAIR, NINS, NROT, NIPR, NAOR\}$$

$$\mathcal{SUP} = \begin{Bmatrix} BSA, NBSA, SAT, SATQ, NSAT, GBU, NGBU, \\ BFM, ACM, ACT, NAIR, AOR, NAOR \end{Bmatrix}$$

Not every pilot is permitted to fly sorties of every profile and version. The rules are shown in Table D.4. The sums in Constraint (D2.1) are taken over the legitimate combinations of job, profile, and version, as determined by combining Tables D.2 and D.4.

[3]We have not included a Red Air sortie version in the F-15E model. Red Air sorties are flown to provide a mock adversary during sorties with air-to-air (i.e., BFM, ACM, ACT, and NAIR) profiles. They have less training value than the basic version of the same profile. If a squadron has primarily an air-to-air mission, it is important to include a Red Air version and constrain the pilots to fly appropriate numbers of sorties. We did just that in the F-15C version of the LP (see Appendix C). But the F-15E model described here is configured to represent a squadron with primarily an air-to-ground mission, so we have omitted Red Air.

Table D.2

Sortie Profiles in the F-15E Model

Profile	Description	Permitted Version (see Table D.3)				
BSA	Basic surface attack, day	B				IP
NBSA	Basic surface attack, night	B				IP
SAT	Surface attack tactics, day	B	FLG	CFX		IP
SATQ	Surface attack tactics, nuclear	B				IP
NSAT	Surface attack tactics, night	B				IP
GBU	Guided bomb unit drills, day	B				IP
NGBU	Guided bomb unit drills, night	B				IP
BFM	Basic fighter maneuvers	B			DIS	IP
ACM	Air combat maneuvers	B			DIS	IP
ACT	Air combat tactics	B	FLG	CFX	DIS	IP
NAIR	Air-to-air training, night	B				IP
AHC	Aircraft handling characteristics	B				IP
INS	Instruments, day	B				IP
NINS	Instruments, night	B				IP
ROT	Rotation of aircraft, day	B				
NROT	Rotation of aircraft, night	B				
IPR	Rear cockpit IP sortie, day	B				
NIPR	Rear cockpit IP sortie, night	B				
AOR	Familiarization w/ AOR, day	B				
NAOR	Familiarization w/ AOR, night	B				
SIM	Simulator	B				

Table D.3

Sortie Versions in the F-15E Model

Version	Description
B	Basic, flown at home station
FLG	Flag, an exercise away from home station
CFX	Composite force exercise
DIS	Flown against dissimilar aircraft
IP	Flown by an IP or IW grading an upgrade sortie

Table D.4

Legitimate Profile-Version-Job Combinations in the F-15E Model

Profiles	Version	Permitted Job
All *except* GBU, NGBU, IPR, NIPR	B	All
GBU, NGBU	B	PMQ, NFG, XFG, XFA, IPG, IPA, WMQ, NWG, XWG, XWA, IWG, IWA, BMG, BMA
IPR, NIPR	B	IP, IPG, IPA, IW, IWG, IWA
All	FLG, CFX, DIS	All *except* PMQ and WMQ
All *except* GBU, NGBU	IP	IP, IPG, IPA, IW, IWG, IWA
GBU, NGBU	IP	IPG, IPA, IWG, IWA

The F-15E model shares most of its sortie profiles with the F-16 LANTIRN model, and their descriptions can be found in Chapter 2. The new profiles are:

SATQ (Surface Attack Tactics, Nuclear) sorties are surface attack sorties tailored for nuclear weapons delivery.

GBU (Guided Bomb Unit) drill sorties are designed to achieve proficiency in the employment of the GBU-15 or AGM-130. In reality, there are separate sortie types for the two weapons, but we represent them in the F-15E model with a single profile. The sortie includes tactical mission planning, execution, and simulated or actual weapons delivery.

NGBU sorties are GBU sorties flown at night.

Skill Acquisition and Practice

The model's most important constraints deal with the skills that pilots practice when they fly the various profiles and versions of sorties. We have identified 133 individual skills that contribute to mission capabilities of F-15E crew members, which we group into seven categories (see Table D.5). The first six categories are identical to the F-16 LANTIRN categories found in Table 2.5. The F-15E model has skills associated with using the GBU-15 and AGM-130 precision weapons that the F-16 LANTIRN model does not have.

The skill acquisition constraints for the F-15E model are:

$$\sum_{p,v} Sprac_{spv} Y_{jpv} \geq Dprac_{sj} \cdot N_j \quad \forall s, j \notin \{PMQ, WMQ\} \qquad \text{(D2.2)}$$

Table D.5

F-15E Skill Categories, with Examples

SUPPORTING SKILLS
Basic airmanship; instruments; aircraft handling; navigation; formation; air-to-air refueling
GENERAL SKILLS FOR ALL COMBAT TASKING
Communications procedures; combat mission planning; switchology; large force employment integration; target deconfliction; hung ordnance/aircraft damage procedures
GENERAL SKILLS FOR AIR-TO-GROUND MISSIONS
Air-to-surface delivery systems; surface-to-air threats; attack options; delivery methods; impact accuracy; fuel management; egress options; battle damage response/wounded bird procedures
GENERAL SKILLS FOR AIR-TO-AIR MISSIONS
Air-to-air systems; weapon selection options; attack options (day, night); commit criteria
SKILLS SPECIFIC TO AI, SEAD-C, AND OCA-S MISSIONS
Route and formation selection; threat interpretation and response; AWACS, Rivet Joint, JSTARS, and other such issues; target area contingencies; updates/execution/verification
SKILLS SPECIFIC TO LANTIRN MISSIONS
Integrated steerpoint selection and target acquisition; forward looking infrared tuning and boresight; terrain following operations and limits
SKILLS SPECIFIC TO GBU-15 AND/OR AGM-130
Attack options, data link evaluation, line-of-sight/masking, bomb guidance, target identification

Of course, the F-15E model has its own unique $Sprac_{spv}$ and $Dprac_{sj}$ arrays. There are skill acquisition constraints for both pilots and WSOs, but there are no skill acquisition constraints for pilots or WSOs yet to complete MQT.

Air Force Mandates for Particular Sorties

The Air Force requires each pilot who has completed MQT to fly particular numbers of some sorties. Each pilot and WSO must fly at least one AHC sortie, two instrument sorties, and two night sorties per six-month training period. Experienced pilots and WSOs must log at least four simulator turns, and inexperienced pilots and WSOs must log at least six simulator turns, per training period. We also impose upper limits of five and seven simulator turns per training period on experienced and inexperienced pilots, respectively. The constraints are:

$$Y_{j,'AHC','B'} \geq N_j \quad \forall j \notin \{PMQ,WMQ\} \qquad \text{(D2.3)}$$

$$Y_{j,'INS','B'} \geq 2N_j \quad \forall j \notin \{PMQ,WMQ\} \qquad \text{(D2.4)}$$

$$\sum_{p \in \mathcal{NIGHT}, v} Y_{jpv} \geq 2N_j \quad \forall j \notin \{PMQ, WMQ\} \tag{D2.5}$$

$$6 \cdot N_j \leq Y_{j,'SIM','B'} \geq 7 \cdot N_j \quad \forall j \in \mathcal{INEXP} \tag{D2.6}$$

$$4 \cdot N_j \leq Y_{j,'SIM','B'} \leq 5 \cdot N_j \quad \forall j \in \mathcal{EXP} \tag{D2.7}$$

where the sets of inexperienced and experienced crew members are:

$$\mathcal{INEXP} = \begin{Bmatrix} NP, NF, NFG, BMP \\ NW, NWG, BMW, BMG, BMA \end{Bmatrix}$$

$$\mathcal{EXP} = \begin{Bmatrix} XP, XF, XFG, XFA, IP, IPG, IPA \\ XW, XWG, XWA, IW, IWG, IWA \end{Bmatrix}$$

Preparation for Demanding Sorties

The Air Force identifies certain sorties as demanding, and an aircrew must have "demanding mission currency" in order to fly them. The constraints that represent this requirement in the F-15E model are similar to Constraints (2.8) through (2.13) in the F-16 LANTIRN model. Thus, pilots and WSOs must fly at least as many BSA sorties in daylight as at night:

$$\sum_v Y_{j,'BSA',v} \geq \sum_v Y_{j,'NBSA',v} \quad \forall j \notin \{PMQ, WMQ\} \tag{D2.8}$$

Each category of pilot must fly at least as many SAT and GBU sorties (in total) in daylight as at night:

$$\sum_v \begin{pmatrix} Y_{j,'SAT',v} + Y_{j,'SATQ',v} \\ +Y_{j,'GBU',v} \end{pmatrix} \geq \sum_v \left(Y_{j,'NSAT',v} + Y_{j,'NGBU',v} \right) \quad \forall j \notin \{PMQ, WMQ\} \tag{D2.9}$$

We also impose an overall constraint that at most three-fourths of all sorties can be flown at night. We previously defined z as the total sorties (see Constraint [D2.1]). This constraint is:

$$\sum_{j \in \mathcal{PLT}, p \in \mathcal{NIGHT}, v} Y_{jpv} \leq 0.75 \cdot z \tag{D2.10}$$

At least 25 percent of each pilot category's total air-to-ground sorties must be BSA sorties:

$$\sum_v Y_{j,'BSA',v} \geq 0.25 \cdot \sum_v \begin{pmatrix} Y_{j,'BSA',v} + Y_{j,'SAT',v} \\ +Y_{j,'SATQ',v} + Y_{j,'GBU',v} \end{pmatrix} \quad \forall j \notin \{PMQ, WMQ\} \tag{D2.11}$$

Of each pilot category's total BFM and ACM sorties, at least 25 percent must be BFM:

$$\sum_{v} Y_{j,'BFM',v} \geq 0.25 \cdot \sum_{v} \left(Y_{j,'BFM',v} + Y_{j,'ACM',v} \right) \quad \forall j \notin \{PMQ, WMQ\} \qquad \text{(D2.12)}$$

Of each pilot category's total ACM and ACT sorties, at least 25 percent must be ACM:

$$\sum_{v} Y_{j,'ACM',v} \geq 0.25 \cdot \sum_{v} \left(Y_{j,'ACM',v} + Y_{j,'ACT',v} \right) \quad \forall j \notin \{PMQ, WMQ\} \qquad \text{(D2.13)}$$

Availability and Distribution of Enhanced Sorties

The F-15E model constrains the number and distribution of enhanced versions of sorties (versions FLG, CFX, and DIS). The constraints are very similar to the enhanced sortie constraints in the F-16 LANTIRN model (Constraints [2.14] and [2.15]):

$$\sum_{j \in \mathcal{PLT}, p} Y_{jpv} \leq XColLim_v \quad \forall v \qquad \text{(D2.14)}$$

Note that the sum is taken over pilots only. Sorties by WSOs are not counted. This is because we wish to constrain aircraft sorties, and the number of aircraft sorties is necessarily equal to the number of pilot sorties (barring sorties by pilots in the rear seat, which never happen in the model for enhanced versions).

Wingmen are prohibited from flying more than their "fair share" of enhanced sorties. The constraints are:

$$\sum_{p} Y_{jpv} \leq \left(\frac{N_j}{\sum_{jj \in \mathcal{WG} \cup \mathcal{FL} \cup \mathcal{INST}} N_{jj}} \right) \cdot XColLim_v \quad \forall j \in \mathcal{WG}, v \qquad \text{(D2.15)}$$

Note that both pilots and WSOs who are wingmen are prevented from flying more than their fair share of these sorties.

Upgrade Requirements

Table D.6 lists the 22 pilot and WSO upgrades considered in the F-15E model. Some upgrades have both pilot and WSO counterparts, while others are for pilots only.

Table D.6

Upgrades Considered in the F-15E Model

Pilot Upgrade	WSO Upgrade	Description
MQTP	MQTW	Mission Qualification Training
MAVP	MAVW	Maverick Qualification
GBU15P	GBU15W	Qualification for GBU-15
AGM130P	AGM130W	Qualification for AGM-130
FLUG2	N/A	2-Ship Flight Lead
FLUG4	N/A	4-Ship Flight Lead
FL24	N/A	2-to-4-Ship Flight Lead
IPUG	IWUG	Upgrade to Instructor
MCC	N/A	Mission Commander
LOW3P	LOW3W	Low-Altitude Step-Down Training (LASDT) 300 feet
LOW1P	LOW1W	LASDT 100 feet
TOW	N/A	DART Tow
CWT	N/A	Chemical Warfare Training
SIMINP	SIMINW	Simulator Instructor

The user of the model must specify the number of upgrades of each type that must be flown during a training period. The model then requires pilots and WSOs to fly a number of sorties of each profile that corresponds to those upgrade counts.

We calculate the number of upgrade sorties of profile *p* flown by upgrading crew members in job *j* as follows (we deal with the supervising IP and IW sorties later):

$$UGSort_{jp} = \sum_{u} \left(IPSort_{pu} \cdot Upgd_u \cdot \frac{UGAlloc_{ju} \cdot N_j}{\sum_{jj} UGAlloc_{jj,u} \cdot N_{jj}} \right) \quad \forall j, p \qquad \text{(D2.16)}$$

This formula is identical to Constraints (2.16) in the main text. It allocates sorties in each upgrade type proportionately to all pilots eligible for that upgrade. We assume that all upgrade sorties are flown as the basic version, so we impose Constraints (D2.17) to ensure that all upgradee sorties will be flown, including requirements for pilots and WSOs undergoing MQT (*j* = *PMQ*, *WMQ*):

$$Y_{jp,'B'} \geq UGSort_{jp} \quad \forall j, p \qquad \text{(D2.17)}$$

Now, we turn to the upgrade sorties flown by supervising IPs and IWs. When a pilot upgrades, the supervising IP flies most upgrade sorties in the front cockpit of one aircraft, while the upgradee flies in the front cockpit of a second aircraft. When a WSO upgrades, the supervising IW flies all upgrade sorties in the rear cockpit of one aircraft, while the upgradee flies in the rear cockpit of a second aircraft. We have defined a special version of each sortie, the "IP" version, for these sorties. Thus:

$$\sum_{j \in \mathcal{INST}} Y_{jp,'IP'} \geq \sum_{u} FCIPSort_{pu} \cdot Upgd_{u} \quad \forall p \tag{D2.18}$$

There are four blocks of constraints, which are similar to Constraints (D2.18), for special missions.[4] They ensure that only IPs and IWs with a GBU-15 qualification supervise GBU-15 upgrades, and only IPs and IWs with an AGM-130 qualification supervise AGM-130 upgrades. Those constraints are:

$$\begin{pmatrix} Y_{'IPG',p,'IP'} \\ +Y_{'IPA',p,'IP'} \end{pmatrix} \geq \begin{pmatrix} FCIPSort_{p,'GBU15P'} \cdot Upgd_{'GBU15P'} \\ +FCIPSort_{p,'AGM130P'} \cdot Upgd_{'AGM130P'} \end{pmatrix} \quad \forall p \tag{D.N1}$$

$$\left(Y_{'IPA',p,'IP'}\right) \geq \left(FCIPSort_{p,'AGM130P'} \cdot Upgd_{'AGM130P'}\right) \quad \forall p \tag{D.N2}$$

$$\begin{pmatrix} Y_{'IWG',p,'IP'} \\ +Y_{'IWA',p,'IP'} \end{pmatrix} \geq \begin{pmatrix} FCIPSort_{p,'GBU15W'} \cdot Upgd_{'GBU15W'} \\ +FCIPSort_{p,'AGM130W'} \cdot Upgd_{'AGM130W'} \end{pmatrix} \quad \forall p \tag{D.N3}$$

$$\left(Y_{'IWA',p,'IP'}\right) \geq \left(FCIPSort_{p,'AGM130W'} \cdot Upgd_{'AGM130W'}\right) \quad \forall p \tag{D.N4}$$

We also force each IP to fly his or her share of front cockpit upgrade sorties. We write the constraints as:

$$\sum_{p} Y_{jp,'IP'} \geq \left(\frac{N_j}{\sum_{jj \in (\mathcal{PLT} \cap \mathcal{INST})} N_{jj}} \right) \cdot \sum_{jj \in (\mathcal{PLT} \cap \mathcal{INST}),p} Y_{jj,p,'IP'} + 0.1 \cdot N_j \quad \forall j \in (\mathcal{PLT} \cap \mathcal{INST}) \tag{D2.21}$$

Note that we identify IPs as pilots who are also instructors, i.e., jobs $j \in (\text{PLT} \cap \text{INST})$.

There are constraints for pilot upgrade sorties that require the supervising IP to fly in the rear cockpit while the upgrading pilot flies in the front cockpit. (During the IPUG upgrade, there is a sortie in which the supervising IP rides in the front while the upgradee rides in the rear, but it still contributes only one aircraft sortie.) We calculate the number of rear cockpit sorties as follows:

---

[4]We number these constraints D.N1, D.N2, D.N3, and D.N4 because they are new to the F-15E model, although the F-16 LANTIRN model does have the analogous Constraints (2.19) and (2.20) for its special mission upgrades.

$$RCIPSort_{pu} = IPSort_{pu} - FCIPSort_{pu} \quad \forall p,u \tag{D2.22}$$

We have defined two sorts of rear cockpit sorties, IPR sorties for day and NIPR sorties for night (see Table D.3). Both are basic version sorties and can be flown only by IPs. Total daytime and nighttime rear cockpit sorties will be:

$$\sum_{j \in \mathcal{IP}} Y_{j,'IPR','B'} \geq \sum_{u,p \notin \mathcal{NIGHT}} RCIPSort_{pu} \cdot Upgd_u \tag{D2.23}$$

$$\sum_{j \in \mathcal{IP}} Y_{j,'NIPR','B'} \geq \sum_{u,p \in \mathcal{NIGHT}} RCIPSort_{pu} \cdot Upgd_u \tag{D2.24}$$

Finally, we force each IP to fly his or her share of rear cockpit sorties. The constraints are:

$$Y_{j,'IPR','B'} \geq \left(\frac{N_j}{\sum_{jj \in (\mathcal{PLT} \cap \mathcal{INST})} N_{jj}} \right) \cdot \sum_{jj \in (\mathcal{PLT} \cap \mathcal{INST})} Y_{jj,'IPR','B'} - 0.25 \cdot N_j \quad \forall j \in (\mathcal{PLT} \cap \mathcal{INST}) \tag{D2.26}$$

$$Y_{j,'NIPR','B'} \geq \left(\frac{N_j}{\sum_{jj \in (\mathcal{PLT} \cap \mathcal{INST})} N_{jj}} \right) \cdot \sum_{jj \in (\mathcal{PLT} \cap \mathcal{INST})} Y_{jj,'NIPR','B'} - 0.25 \cdot N_j \quad \forall j \in (\mathcal{PLT} \cap \mathcal{INST}) \tag{D2.27}$$

Requirement for In-Flight Supervision

As described earlier, pilots who are flight leads or instructors must supervise pilots who are wingmen or BMC. There are no requirements that IWs must supervise wingmen WSOs during continuation (i.e., non-upgrade) training.

We need two blocks of constraints to represent the requirement for in-flight supervision, one for basic sorties and one for all other versions. The constraints for basic sorties must include upgrade sorties, which are supervised by IPs. The constraints for other versions cover only continuation training.

The simpler constraints, for non-basic versions of sorties, are written as:

$$\sum_{j \in (\mathcal{PLT} \cap (\mathcal{FL} \cup \mathcal{INST}))} Y_{jpv} \geq \sum_{j \notin (\mathcal{PLT} \cap (\mathcal{FL} \cup \mathcal{INST}))} Y_{jpv} \quad \forall p \in \mathcal{SUP}, v \neq 'B' \tag{D2.28}$$

The constraints for basic sorties are written as follows:

$$\sum_{j \in (\mathcal{PLT} \cap (\mathcal{FL} \cup \mathcal{INST}))} \left(Y_{jp,'B'} + Y_{jp,'IP'} \right) \geq \left(\begin{array}{l} \displaystyle\sum_{j \notin (\mathcal{PLT} \cap (\mathcal{FL} \cup \mathcal{INST}))} Y_{jp,'B'} - \\ \displaystyle\sum_{u} RCIPSort_{pu} \cdot Upgd_{u} \end{array} \right) \quad \forall p \in \mathcal{SUP}$$

(D2.29)

Requirement to Fill Both Front and Rear Seats in Every Sortie

For every sortie, there must be a pilot in the front seat and either a WSO or (for a few upgrade sorties) an IP in the rear seat. We represent this requirement by two blocks of constraints, one for basic sorties and one for all other versions. The constraints for basic sorties include the rear seat IP sorties. There are no such sorties included in other versions. The new constraints are:

$$\sum_{j \in \mathcal{PLT}} Y_{jpv} = \sum_{j \in \mathcal{WSO}} Y_{jpv} \quad \forall p \notin \{IPR, NIPR\}, v \neq 'B' \qquad \text{(D.N5)}$$

$$\left(\begin{array}{l} Y_{'PMQ',p,'B'} + \\ \displaystyle\sum_{j \in \mathcal{PLT}} \left(Y_{j,p,'B'} + Y_{j,p,'IP'} \right) \end{array} \right) = \left(\begin{array}{l} Y_{'WMQ',p,'B'} + \\ \displaystyle\sum_{j \in \mathcal{WSO}} \left(Y_{j,p,'B'} + Y_{j,p,'IP'} \right) + \\ \displaystyle\sum_{u} RCIPSort_{pu} \cdot Upgd_{u} \end{array} \right) \quad \forall p \notin \{IPR, NIPR\}$$

(D.N6)

Selecting a Solution

Like the F-16 LANTIRN model, the F-15E model has multiple solutions. We use the same method with both models for selecting one of those solutions. We define variables that measure deviations in the sortie mix flown by individual types of crew members from the average mix over all crew members. They are defined by the following constraints:

$$PosDev_{jpv} \geq \left(\frac{\sum_{jj} Y_{jj,p,v}}{\sum_{jj} N_{jj}} \right) - \left(\frac{Y_{j,p,v}}{N_j} \right) \quad \forall j, p, v \qquad \text{(D2.30)}$$

$$NegDev_{jpv} \geq \left(\frac{Y_{j,p,v}}{N_j} \right) - \left(\frac{\sum_{jj} Y_{jj,p,v}}{\sum_{jj} N_{jj}} \right) \quad \forall j, p, v \qquad \text{(D2.31)}$$

Next, we solve the LP described in this appendix, with the objective function (D2.1) and all the constraints defined above. From the solution, we let *zmin* be the minimum total number of sorties required. We then define a new LP with all the old constraints, plus Constraints (D2.30) and (D2.31), plus the requirement that the total number of sorties is no larger than an optimal solution to the old LP:

$$\sum_{j,p,v} c_{jpv} \cdot Y_{jpv} \le zmin \tag{D2.32}$$

The objective function of this new LP is:

$$Min \quad TotDev = \sum_{j,p,v} \left(PosDev_{jpv} + NegDev_{jpv} \right) \tag{D2.33}$$

The sums in Constraints (D2.32) and (D2.33) are understood to be taken over only those triples (*j*,*p*,*v*) for which pilots of type *j* are allowed to fly sorties of profile *p* and version *v* (see Tables D.3 and D.4).

The Base Case for the F-15E Model

Our base case is an F-15E squadron with 24 PAA. The specified crew ratio for the F-15E is 1.25, so this squadron is authorized 1.25 × 24 = 30 API-1 pilots. All the API-1 pilots will be CMR. The squadron will have two additional CMR pilots, the squadron commander and the operations officer, who occupy API-6 billets. They will be experienced pilots, usually IP-qualified. An additional six pilots will be assigned to this squadron to perform staff functions. They will be BMC and will occupy API-6 billets. For every pilot there is a WSO. Thirty-two WSOs are CMR, while another six are BMC.

Table D.7 shows how the 38 pilots in the F-15E base case are assigned to jobs, and how much pilots in each job must fly. Ten of the CMR pilots are inexperienced (nine wingmen and one flight lead), while 22 CMR pilots are experienced. The Air Force calculates the experience level as the ratio of experienced API-1 pilots to authorized API-1 billets. As explained above, two of the experienced CMR pilots occupy API-6 billets, so the experience level is (22 – 2)/30 = 66.7 percent.

We calibrated the F-15E model by adjusting the $Sprac_{spv}$ and $Dprac_{sj}$ arrays so the model would produce a requirement of a little more than 13 sorties per month for inexperienced pilots and a little fewer than that for experienced pilots. In other words, our model does not justify this level of flying; it was adjusted to agree with it. We assumed that the survey and interview data we used to calibrate the F-16 LANTIRN model applied equally to the F-15E model. We had

Table D.7

Required Monthly Front Seat Sorties by Pilot Type in the F-15E Base Case

Job	Number of Pilots	Front Seat Sorties per Pilot per Month	Total Sorties per Month
PMQ	N/A	N/A	26.50
NP	9	13.21	118.93
XP	1	12.33	12.33
NF	1	13.15	13.15
XF	2	11.88	23.76
NFG	0	N/A	0.00
XFG	1	12.41	12.41
XFA	5	12.52	62.59
IP	7	12.65	88.53
IPG	1	14.38	14.38
IPA	5	13.50	67.50
BMP	6	10.40	62.38
Total Front Seat Sorties per Month			502.46

no independent source of data specific to the F-15E. Thus, not only do the caveats about calibration in Chapter 3 apply here, one must also ask whether F-15E IPs and flight leads would agree with F-16 IPs and flight leads.

Table D.8 shows how the 38 WSOs are assigned to jobs, and how much WSOs in each job fly in the base case. In the base case, Constraints (D.N5) and (D.N6) force WSOs to fly more than their own individual training needs require. These are the constraints that require that there be the same number of rear seat and front seat sorties. For this reason, it was unnecessary to consider how to calibrate the model to properly estimate WSO sortie requirements. Before this model can be used in a situation in which the total sorties required to train WSOs exceed the requirements for pilots, its WSO-related $Sprac_{spv}$ and $Dprac_{sj}$ parameters must be calibrated.

A Squadron with Only a Few Pilots

To determine the required WSO sorties, we constructed a squadron with only a few pilots. Table D.9 shows the numbers of pilots by job for this squadron, as well as the amount of (front seat) flying those pilots must do. Clearly, the model demands an unrealistic amount of flying from these pilots, but in this case, we are interested in WSO sorties, not pilot sorties.

Table D.8

Required Monthly Rear Seat Sorties by WSO Type in the F-15E Base Case

Job	Number of WSOs	Rear Seat Sorties per WSO per Month	Total Sorties per Month
WMQ	N/A	N/A	19.88
NW	9	13.10	117.91
XW	5	11.81	59.05
NWG	1	13.48	13.48
XWG	1	12.29	12.29
XWA	4	14.08	56.33
IW	5	11.90	59.52
IWG	1	13.01	13.01
IWA	6	13.26	79.54
BMW	3	10.32	30.97
BMG	2	10.31	20.62
BMA	1	11.08	11.08
Rear Seat IP Sorties per Month			8.79
Total Rear Seat Sorties per Month			502.46

Table D.9

Required Monthly Front Seat Sorties by Pilot Type in the F-15E "Few Pilots" Case

Job	Number of Pilots	Front Seat Sorties per Pilot per Month	Total Sorties per Month
PMQ	N/A	N/A	26.50
NP	1	17.05	17.05
XP	1	16.59	16.59
NF	1	15.94	15.94
XF	1	15.92	15.92
NFG	1	17.36	17.36
XFG	1	56.58	56.58
XFA	1	69.28	69.28
IP	1	89.78	89.78
IPG	1	84.30	84.30
IPA	1	59.01	59.01
BMP	1	23.24	23.24
Total Front Seat Sorties per Month			491.54

Table D.10 shows how the 38 WSOs are assigned to jobs, and how much the WSOs in each job must fly (rear seat) in the squadron with few pilots. In this case, Constraints (D.N5) and (D.N6) force pilots to fly more than their own training needs require, so it is the WSO sorties that reflect the individual training requirements.

A Repro Model of the F-15E Linear Program

We next describe a "repro" model of the F-15E LP. As discussed in Chapter 4, this model reproduces (approximately) selected results from the LP, and we have extended it to extrapolate the LP's results for cases in which total available sorties are constrained. Much simpler than the LP, it can be used as part of a spreadsheet or a simulation model.

Formulation and Testing

We have designed the repro model to estimate sorties as a function of the inventories of pilots and WSOs. First, we calculate the sorties that pilots are required to fly, the equations for which are essentially identical to the repro

Table D.10

Required Monthly Rear Seat Sorties by WSO Type in the F-15E "Few Pilots" Case

Job	Number of WSOs	Rear Seat Sorties per WSO per Month	Total Sorties per Month
WMQ	N/A	N/A	19.88
NW	9	13.03	117.24
XW	5	11.76	58.81
NWG	1	13.44	13.44
XWG	1	12.12	12.12
XWA	4	13.04	52.17
IW	5	12.26	61.31
IWG	1	12.78	12.78
IWA	6	13.19	79.15
BMW	3	9.17	27.50
BMG	2	9.32	18.64
BMA	1	9.69	9.69
Rear Seat IP Sorties per Month			8.79
Total Rear Seat Sorties per Month			491.54

models of the previous versions of the model. Next, we calculate the sorties that WSOs are required to fly, a step that is needed only in the F-15E model. Third, we determine the required front seat and rear seat sorties, and, finally, we take the total required sorties to be the larger of the front seat and rear seat requirements.

Pilot Sorties. We aggregate the 11 pilot jobs (excluding pilots in MQT) from Table D.1 into four categories:

$P(InexpWing)$	=	Number of inexperienced wingmen pilots ($N_{'NP'}$)
$P(ExpWing)$	=	Number of experienced wingmen pilots ($N_{'XP'}$)
$P(FL\_IP)$	=	Number of flight leads and IPs ($N_{'NF'} + N_{'NFG'} + N_{'XF'} + N_{'XFG'} + N_{'XFA'} + N_{'IP'} + N_{'IPG'} + N_{'IPA'}$)
$P(BMC)$	=	Number of BMC pilots ($N_{'BMP'}$)

Similarly, we denote the sorties flown by pilots in each category as:

$SF(InexpWing)$	=	Front seat sorties by inexperienced wingmen pilots
$SF(ExpWing)$	=	Front seat sorties by experienced wingmen pilots
$SF(FL\_IP)$	=	Front seat sorties by flight leads and IPs
$SF(BMC)$	=	Front seat sorties by BMC pilots
$SF(MQT)$	=	Front seat sorties by pilots in MQT
$SR(IP)$	=	Rear seat IP sorties

The constraints for pilot sorties have the same form as those for the F-16 LANTIRN repro model, but with different coefficients:

$$SF(InexpWing) = 13.21432 \times P(InexpWing) \quad \text{(D4.1)}$$

$$SF(ExpWing) = 12.32148 \times P(ExpWing) \quad \text{(D4.2)}$$

$$SF(BMC) = 10.34211 \times P(BMC) \quad \text{(D4.3)}$$

$$SF(MQT) = 26.5 \quad \text{(D4.4)}$$

$$SR(IP) = 8.79167 \quad \text{(D4.5)}$$

$$SF(FL\_IP) = Max\left\{\begin{bmatrix}[12.92169 \times P(FL\_IP)], \\ \begin{bmatrix}1.04415 \times P(FL\_IP) + SF(InexpWing) \\ +SF(ExpWing) + SF(BMC) \\ +SF(MQT) - SR(IP)\end{bmatrix}\end{bmatrix}\right\} \quad \text{(D4.6)}$$

When these constraints are applied to the pilot inventories from calibration cases in which pilot sortie requirements exceed WSO sortie requirements, the results match the LP estimates very closely. The largest errors are under 1 percent.

WSO Sorties. We aggregate the 11 WSO jobs (excluding WSOs in MQT) from Table D.1 into four categories:

$W(InexpWing)$ = Number of inexperienced wingmen WSOs ($N_{'NW'} + N_{'NWG'}$)

$W(ExpWing)$ = Number of experienced wingmen WSOs ($N_{'XW'} + N_{'XWG'} + N_{'XWA'}$)

$W(IW)$ = Number of IWs ($N_{'IW'} + N_{'IWG'} + N_{'IWA'}$)

$W(BMC)$ = Number of BMC WSOs ($N_{'BMW'} + N_{'BMG'} + N_{'BMA'}$)

Similarly, we denote the sorties flown by WSOs in each category as:

$SR(InexpWing)$ = Rear seat sorties by inexperienced wingmen WSOs

$SR(ExpWing)$ = Rear seat sorties by experienced wingmen WSOs

$SR(IW)$ = Rear seat sorties by IWs

$SR(BMC)$ = Rear seat sorties by BMC WSOs

$SR(MQT)$ = Rear seat sorties by WSOs in MQT

We assume that $SR(InexpWing)$, $SR(ExpWing)$, $SR(IW)$, and $SR(BMC)$ are proportional to $W(InexpWing)$, $W(ExpWing)$, $W(IW)$, and $W(BMC)$, respectively. The new constraints for WSO sorties are:

$$SR(InexpWing) = 13.0924 \times W(InexpWing) \quad \text{(D.N7)}$$

$$SR(ExpWing) = 12.40391 \times W(ExpWing) \quad \text{(D.N8)}$$

$$SR(IW) = 12.74198 \times W(IW) \quad \text{(D.N9)}$$

$$SR(BMC) = 9.30884 \times W(BMC) \quad \text{(D.N10)}$$

$$SR(MQT) = 19.875 \quad \text{(D.N11)}$$

When these constraints are applied to the pilot inventories from calibration cases in which WSO sortie requirements exceed pilot sortie requirements, the results again match the LP estimates very closely. The largest errors are under 1 percent.

Total Sortie Requirement. To calculate the total requirement for sorties, we calculate front seat sortie requirements and rear seat sortie requirements, and take the larger of the two. The front and rear seat requirements are:

$$SF(Tot) = \begin{pmatrix} SF(InexpWing) + SF(ExpWing) \\ +SF(FL\_IP) + SF(BMC) + SF(MQT) \end{pmatrix} \quad \text{(D.N12)}$$

$$SR(Tot) = \begin{pmatrix} SR(InexpWing) + SR(ExpWing) \\ +SR(IW) + SR(IP) + SR(BMC) + SR(MQT) \end{pmatrix} \quad \text{(D.N13)}$$

And the total sortie requirement is:

$$S(Tot) = Max\{SF(Tot), SR(Tot)\} \quad \text{(D.N14)}$$

Imposing a Constraint on the Number of Sorties

To constrain sorties in the F-15E repro model, we introduce two scale factors. One (*Splt*) will scale back pilot sorties, while the other (*Swso*) will scale back WSO sorties. But we will not scale back MQT sorties, sorties by BMC pilots or WSOs, or rear seat IP sorties. Thus, the quantities to be calculated by the constrained version of the repro model are:

SFC(*InexpWing*) = Constrained front seat sorties by inexperienced wingmen pilots

SFC(*ExpWing*) = Constrained front seat sorties by experienced wingmen pilots

SFC(*FL_IP*) = Constrained front seat sorties by flight leads and IPs

SRC(*InexpWing*) = Constrained rear seat sorties by inexperienced wingmen WSOs

SRC(*ExpWing*) = Constrained rear seat sorties by experienced wingmen WSOs

SRC(*IW*) = Constrained rear seat sorties by IWs

Constraining pilot sorties. We write the constraints for the front seat sorties to be scaled back as follows:

$$SFC(InexpWing) = Splt \times 13.21432 \times P(InexpWing) \quad \text{(D4.7)}$$

$$SFC(ExpWing) = Splt \times 12.32148 \times P(ExpWing) \tag{D4.8}$$

$$SFC(FL\_IP) = Max\left\{\begin{bmatrix} Splt \times [12.92169 \times P(FL\_IP)], \\ \begin{bmatrix} Splt \times 1.04415 \times P(FL\_IP) + SFC(InexpWing) \\ +SFC(ExpWing) + SF(BMC) \\ +SF(MQT) - SR(IP) \end{bmatrix} \end{bmatrix}\right\} \tag{D4.9}$$

These adjustments penalize—i.e., slow the development of—all three categories of pilots on a pro-rata basis. We choose *Splt* to be as large as possible, up to a limit of 1.0, while still satisfying Constraint (D4.10) on the total number of sorties:

$$\begin{bmatrix} SFC(InexpWing) \\ +SFC(ExpWing) \\ +SFC(FL\_IP) \end{bmatrix} + SF(BMC) + SF(MQT) \le SF(Tot) \tag{D4.10}$$

Calculating the value of *Splt* is straightforward. First, we define the coefficients KF1, SF1, KF2, and SF2 in Constraints (D4.11) through (D4.14):

$$KF1 = \begin{bmatrix} 13.21432 \times P(InexpWing) \\ +12.32148 \times P(ExpWing) \\ +12.92169 \times P(FL\_IP) \end{bmatrix} \tag{D4.11}$$

$$SF1 = SF(Tot) - S(BMC) - S(MQT) \tag{D4.12}$$

$$KF2 = \begin{bmatrix} 2 \times 13.21432 \times P(InexpWing) \\ +2 \times 12.32148 \times P(ExpWing) \\ +1.04415 \times P(FL\_IP) \end{bmatrix} \tag{D4.13}$$

$$SF2 = SF1 - SF(BMC) - SF(MQT) + SR(IP) \tag{D4.14}$$

If it turns out to be appropriate to use the first maximand in Constraint (D4.9), we will determine *Splt* by solving $KF1 \times Splt = SF1$.

If it turns out to be appropriate to use the second maximand in Constraint (D4.9), we will determine *Splt* by solving $KF2 \times Splt = SF2$.

Overall, then, we calculate *Splt* as follows:

$$Splt = Min\left\{\frac{SF1}{KF1}, \frac{SF2}{KF2}, 1\right\} \tag{4.15}$$

Substituting this value for *Splt* into Constraints (D4.7), (D4.8), and (D4.9) yields the desired numbers of pilot sorties.

Constraining WSO Sorties. We write the constraints for scaling back the rear seat sorties as:

$$SRC(InexpWing) = Swso \times 13.0924 \times W(InexpWing) \quad \text{(D.N12)}$$

$$SRC(ExpWing) = Swso \times 12.40391 \times W(ExpWing) \quad \text{(D.N13)}$$

$$SRC(IW) = Swso \times 12.74108 \times W(IW) \quad \text{(D.N14)}$$

We will choose *Swso* to be as large as possible, up to a limit of 1.0, while still satisfying the following constraint on the total number of sorties:

$$\begin{bmatrix} SRC(InexpWing) \\ + SRC(ExpWing) \\ + SRC(IW) \end{bmatrix} + SR(BMC) + SR(MQT) + SR(IP) \quad SR(Tot) \quad \text{(D.N15)}$$

It is straightforward to calculate the value of *Swso*. First, we define the following coefficients:

$$KR1 = \begin{bmatrix} 13.0924 \times W(InexpWing) \\ +12.40391 \times W(ExpWing) \\ +12.74108 \times W(IW) \end{bmatrix} \quad \text{(D.N16)}$$

$$SR1 = SR(Tot) - SR(BMC) - SR(MQT) - SR(IP) \quad \text{(D.N17)}$$

Then, we calculate *Swso* as:

$$Swso = Min\left\{\frac{SR1}{KR1}, 1\right\} \quad \text{(D.N18)}$$

Substituting this value for *Swso* in Constraints (D.N12), (D.N13), and (D.N14) yields the desired numbers of WSO sorties.

Overall Sortie Constraint. After the two scale factors are applied to the sorties that we have scaled (*Splt* to the front seat sorties, *Swso* to the rear seat sorties), the total sorties will meet the sortie constraint. It is possible for both scale factors to be equal to 1, in which case the unconstrained model meets the sortie constraint. Or both scale factors may be smaller than 1, in which case both pilots and WSOs will fly less than the LP estimates they require to be ready to deploy with no spin-up sorties. It is also possible that $Splt<1$ and $Swso = 1$, or $Splt = 1$ and $Swso < 1$. In these instances, one group will fly fewer sorties than the LP estimates they require, and the other group will fly their full requirement.

When We Know the Experience but Not the Qualifications

To apply the constrained repro model just described, we must know the inventories *P*(*InexpWing*), *P*(*ExpWing*), *P*(*FL_IP*), *W*(*InexpWing*), *W*(*ExpWing*), and

W(*IW*). But, in our models, we often know only the numbers of inexperienced and experienced CMR pilots and WSOs who are assigned to a unit, which we may denote by *P*(*InexpCMR*), *P*(*ExpCMR*), *W*(*InexpCMR*), and *W*(*ExpCMR*). So, we need a way to estimate the former (inexperienced wings, experienced wings, and flight leads/IPs, both pilots and WSOs) from the latter (inexperienced and experienced CMR, both pilots and WSOs). We propose using the same methodology as we used for the F-16 LANTIRN model and applying it to both pilots and WSOs.

Pilots. First, we define:

$$P(TotCMR) = P(InexpCMR) + P(ExpCMR) \qquad \text{(D4.16)}$$

$$(N_{'NF'} + N_{'NFG'}) = Max\{1, 0.33 \times P(TotCMR) - 0.5 \times P(ExpCMR)\} \qquad \text{(D4.17)}$$

Then, we calculate the inventories for the constrained repro model's three pilot categories:

$$P(InexpWing) = P(InexpCMR) - (N_{'NF'} + N_{'NFG'}) \qquad \text{(D4.18)}$$

$$P(ExpWing) = 1 \qquad \text{(D4.19)}$$

$$P(FL\_IP) = P(ExpCMR) - P(ExpWing) + (N_{'NF'} + N_{'NFG'}) \qquad \text{(D4.20)}$$

Now we can apply the repro model constraints to these inventories to calculate *SFC*(*InexpWing*), *SFC*(*ExpWing*), and *SFC*(*FL_IP*). To convert these figures into sorties flown by inexperienced and experienced CMR pilots, we compute:

$$SFC(InexpFL) = \frac{(N_{'NF'} + N_{'NFG'})}{P(FL\_IP)} \times SFC(FL\_IP) \qquad \text{(D4.21)}$$

$$SFC(InexpCMR) = SFC(InexpWing) + SFC(InexpFL) \qquad \text{(D4.22)}$$

$$SFC(ExpCMR) = SFC(ExpWing) + SFC(FL\_IP) - SFC(InexpFL) \qquad \text{(D4.23)}$$

Constraint (D4.21) assumes that inexperienced flight leads fly as much as experienced flight leads or IPs. If the user of the model believes that inexperienced flight leads fly less than experienced flight leads or IPs, the user can modify this expression accordingly.

WSOs. We are given *W*(*InexpCMR*) and *W*(*ExpCMR*). All inexperienced WSOs are wingmen because there are no WSO flight leads. So, the problem is partitioning *W*(*ExpCMR*) into *W*(*ExpWing*) and *W*(*IW*). We propose to divide *W*(*ExpCMR*) in half, as such:

$$W(InexpWing) = W(InexpCMR) \qquad \text{(D.N19)}$$

$$W(ExpWing) = 0.5 \times W(ExpCMR) \quad \text{(D.N20)}$$

$$W(IW) = 0.5 \times W(ExpCMR) \quad \text{(D.N21)}$$

We can now apply the repro model constraints to these inventories to calculate *SFC*(*InexpWing*), *SFC*(*ExpWing*), and *SFC*(*FL_IP*). To convert these figures into sorties flown by inexperienced and experienced CMR pilots, we compute:

$$SRC(InexpCMR) = SRC(InexpWing) \quad \text{(D.N22)}$$

$$SRC(ExpCMR) = SRC(ExpWing) + SRC(IW) \quad \text{(D.N23)}$$

Bibliography

Air Force Instruction AFI 11-2F-16, *Flying Operations, Vol. 1: Aircrew Training*, May 1, 1998.

Air Force Instruction AFI 11-2F-15E, *Flying Operations, Vol. 1: Aircrew Training*, October 1, 1998.

Air Force Instruction AFI 11-2A/OA-10, *Flying Operations, Vol. 1: Aircrew Training*, February 11, 2000.

Air Force Instruction AFI 11-2F-15, *Flying Operations, Vol. 1: Aircrew Training*, February 11, 2000.

Air Force Instruction AFI 65-503, *Air Force Cost and Planning Factors,* September 2001.

Brooke, A., D. Kendrick, and A. Meeraus, *GAMS: A User's Guide*, San Francisco: The Scientific Press, 1991 (see also the GAMS Web site at http://www.gams.com).

Davis, P. K., and J. H. Bigelow, *Motivated Metamodels: Synthesis of Cause-Effect Reasoning and Statistical Metamodeling*, Santa Monica, Calif.: RAND, MR-1570-AF, 2003.

Hillier, F. S., and G. J. Lieberman, *Introduction to Operations Research*, 7th ed., New York: McGraw-Hill, 1988.

Larson, E. V., D. T. Orletsky, and K. Leuschner, *Defense Planning in a Decade of Change*, Santa Monica, Calif.: RAND, MR-1387-AF, 2001.

Taylor, W. W., J. H. Bigelow, S. C. Moore, L. Wickman, B. Thomas, and R. Marken, *Absorbing Air Force Fighter Pilots: Parameters, Problems, and Policy Options*, Santa Monica, Calif.: RAND, MR-1550-AF, 2002.

Taylor, W. W., S. C. Moore, and C. R. Roll, *The Air Force Pilot Shortage: A Crisis for Operational Units?* Santa Monica, Calif.: RAND, MR-1204-AF, 2000.

U.S. Air Force, Headquarters Air Combat Command (ACC), *RAP Flying Hour Program Model*, updated annually (model is controlled by ACC/DOTB).