



ANNA JEAN WIRTH, THOMAS LIGHT, DANIEL M. ROMANO, SHANE TIERNEY, RONALD G. MCGARVEY, MOON KIM, MICHAEL J. LOSTUMBO, AMANDA NGUYEN, PAUL EMSLIE, JOHN G. DREW

Evaluating Alternative Maintenance Manpower Force Structure Concepts for the F-35A



For more information on this publication, visit www.rand.org/t/RR4433

Library of Congress Cataloging-in-Publication Data is available for this publication.

ISBN: 978-1-9774-0534-0

Published by the RAND Corporation, Santa Monica, Calif.

© Copyright 2020 RAND Corporation

RAND® is a registered trademark.

Cover: U.S. Air Force photo/Naoto Anazawa

Limited Print and Electronic Distribution Rights

This document and trademark(s) contained herein are protected by law. This representation of RAND intellectual property is provided for noncommercial use only. Unauthorized posting of this publication online is prohibited. Permission is given to duplicate this document for personal use only, as long as it is unaltered and complete. Permission is required from RAND to reproduce, or reuse in another form, any of its research documents for commercial use. For information on reprint and linking permissions, please visit www.rand.org/pubs/permissions.

The RAND Corporation is a research organization that develops solutions to public policy challenges to help make communities throughout the world safer and more secure, healthier and more prosperous. RAND is nonprofit, nonpartisan, and committed to the public interest.

RAND's publications do not necessarily reflect the opinions of its research clients and sponsors.

Support RAND

Make a tax-deductible charitable contribution at
www.rand.org/giving/contribute

www.rand.org

Preface

This report provides a summary of the research and findings from a RAND Corporation Project AIR FORCE project “Evaluating Alternative Maintenance Force Structure Concepts for the F-35A,” which was sponsored by Headquarters, United States Air Force, A4L. The objective of this project was to evaluate the costs and benefits of merging F-35A maintainer Air Forces. The methodology of this work generally followed the framework of the following project, which considered the costs and benefits of merging maintenance Air Force specialties for the KC-135:

- Light, Thomas, Daniel M. Romano, Michael Kennedy, Caolionn O’Connell, and Sean Bednarz, *Consolidating Air Force Maintenance Occupational Specialties*, Santa Monica, Calif.: RAND Corporation, RR-1307-AF, 2016. As of August 15, 2019:

https://www.rand.org/pubs/research_reports/RR1307.html

The research was conducted within the Resource Management Program of RAND Project AIR FORCE and should be of interest to the Air Force maintenance community and Air Force personnel concerned with F-35A operating and support costs and maintenance manpower issues.

RAND Project AIR FORCE

RAND Project AIR FORCE (PAF), a division of the RAND Corporation, 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 air, space, and cyber forces. Research is conducted in four programs: Force Modernization and Employment; Manpower, Personnel, and Training; Resource Management; and Strategy and Doctrine. The research reported here was prepared under contract FA7014-16-D-1000.

Additional information about PAF is available on our website: www.rand.org/paf

This report documents work originally shared with the U.S. Air Force on September 23, 2019. The draft report, issued on September 26, 2019, was reviewed by formal peer reviewers and U.S. Air Force subject-matter experts.

Contents

| | |
|---|------|
| Preface | iii |
| Figures | vi |
| Tables | vii |
| Summary..... | viii |
| Acknowledgments | xi |
| Abbreviations | xii |
| 1. Introduction | 1 |
| Objective | 2 |
| Approach | 2 |
| Outline of This Report..... | 4 |
| 2. Approaches for Organizing and Training F-35A Maintainers | 6 |
| Baseline F-35A Maintenance AFS Concept | 7 |
| F-35A Experimental AFS Concepts Being Tested by USAF | 9 |
| PAF-Developed AFS Concepts..... | 13 |
| Summary of AFS Concepts..... | 15 |
| 3. Technical School Times and Costs Under Alternative Air Force Specialty Concepts | 17 |
| Technical School Times Under the Current F-35A Training Concept | 17 |
| Technical School Times for Merged AFS Concepts..... | 18 |
| Technical School Costs | 21 |
| Assumptions and Caveats of This Analysis | 23 |
| 4. Maintainer Availability Under Alternative Maintenance Manpower Force | |
| Structure Concepts..... | 24 |
| Estimating Maintainer Availability Under the Baseline F-35A AFS Concept | 24 |
| Maintainer Availability Under AFS Consolidation Concepts..... | 28 |
| Adjusting for Retention Rates | 32 |
| Caveats of This Analysis..... | 33 |
| 5. Sortie-Generation Capability and Costs of Alternative AFS Concepts..... | 34 |
| How LCOM Is Used in This Analysis | 34 |
| Findings from the LCOM Manpower Analysis | 41 |
| Some Merged AFS Concepts Offer the Opportunity for Manpower Savings, Even When Availability Reductions Due to Training Are Considered..... | 45 |
| If Some Merged AFS Concepts Are Adopted, O&S Costs Can Decrease | 46 |
| 6. Performance of Merged AFS Concepts Under Alternative Combat Operational Concepts | 47 |
| The Threat to Air Bases | 47 |
| USAF Adaptation to the Threat | 48 |
| 7. Implementation Challenges of Merged AFS Concepts | 56 |
| Methodology | 56 |

| | |
|--|----|
| Implementation Challenges | 57 |
| 8. Summary of Conclusions and Recommendations | 71 |
| Conclusions | 71 |
| Recommendations | 72 |
| Appendix A. Lessons Learned from Rivet Workforce | 74 |
| Appendix B. Impacts of Merged AFS Consolidation on Maintainer Proficiency | 77 |
| Appendix C. Sensitivity of Availability Analysis Results to Uncertainty in Assumptions | 86 |
| Appendix D. Using LCOM to Find Efficient Combinations of AFSs | 89 |
| Appendix E. Other Ways to Organize the Maintenance Force | 92 |
| References | 94 |

Figures

| | |
|---|----|
| Figure 1.1. Methodological Approach..... | 3 |
| Figure 2.1. Share of F-35A Maintainers at Hill AFB in Nine AFSs Shown in Table 2.1, FY 2018 | 9 |
| Figure 2.2. Baseline F-35A, BOLT, and LIT Concepts | 10 |
| Figure 2.3. PAF-Developed Concepts..... | 13 |
| Figure 3.1. Example of Calculation of Technical School and FTU/FTD Times for a LIT Maintainer..... | 19 |
| Figure 3.2. Relationship Between Up-Front Training Length and Cost per Trainee for Select 2A and 2W AFSs | 22 |
| Figure 4.1. Share of Time Spent on Different Activities for a TAMS AFS Under Current System | 25 |
| Figure 4.2. Comparison of Time Allocation for a TAMS and a LIT Maintainer..... | 31 |
| Figure 4.3. Retention Rate from Active-Duty Maintainers (FYs 2015–2018)..... | 32 |
| Figure 5.1. Sortie Generation at Varying Manpower Levels for the First Seven Days of the Campaign..... | 39 |
| Figure 5.2. Performance of Merged AFS Concepts in Very High Sortie Rate Scenarios..... | 44 |
| Figure B.1. Model for How Merging AFSs Affects Maintainer Proficiency..... | 78 |
| Figure B.2. Skill Retention in Procedural Tasks | 81 |
| Figure C.1. Relative Sensitivity of Availability Analysis Results to Underlying Assumptions ... | 87 |
| Figure D.1. Average Utilization by AFS, from LCOM Run with Notional Flying Schedule..... | 90 |
| Figure D.2. Evaluating AFS Pairs, Using MMH/Day and Correlation of Utilization | 91 |

Tables

| | |
|--|----|
| Table S.1. Percentage Change in Unit-Level Maintenance Manpower Costs Under Merged AFS Concepts Relative to Baseline Concept..... | ix |
| Table 2.1. Current F-35A Maintenance Career Fields | 8 |
| Table 2.2. Summary of AFS Concepts..... | 16 |
| Table 3.1. Current F-35A Training Course Locations and Lengths..... | 18 |
| Table 3.2. Estimates of Time Spent at Technical Schools and FTD/FTU by Career Field | 20 |
| Table 3.3. Estimates of Weighted Average Time Spent at Technical Schools and FTD/FTU by AFS Concepts..... | 21 |
| Table 3.4. Estimates of the Weighted Average Cost of Up-Front Training (BMT, Technical School, and FTD/FTU) for Each AFS Concept | 23 |
| Table 4.1. Estimate of Maintainer Availability for Current F-35A AFSs over a 15-Year Career | 28 |
| Table 4.2. Training Assumptions for Baseline and Consolidated AFS Concepts..... | 29 |
| Table 4.3. Average Maintainer Availability Under Baseline and Consolidated AFS Concepts over the Course of a 15-Year Career | 31 |
| Table 4.4. Maintainer Availability Under Baseline and Consolidated AFS Concepts After Accounting for Retention | 33 |
| Table 5.1. Sortie Schedule Used in LCOM Simulations (24 Aircraft) | 36 |
| Table 5.2. Sortie-Completion Rates for the First Seven Days at Varying Manning Levels | 42 |
| Table 5.3. Estimated Direct Manpower Requirement for Alternatives as a Percentage of Baseline Manpower Requirement With and Without Consideration of Up-Front Training Burden..... | 45 |
| Table 5.4. Percentage Change in Unit-Level Maintenance Manpower and Training Costs Under Merged AFS Concepts Relative to Baseline Concept..... | 46 |
| Table 6.1. Links Between Combat Strategies and Maintenance AFS Concepts..... | 49 |
| Table 7.1. Implementation Challenges of Merged AFS Concepts..... | 57 |
| Table 7.2. AFS Consolidation Concepts | 59 |
| Table 7.3. Percentage of Maintenance Workforce (on Average) Encountering Tasks at Proficiency-Retaining Frequencies | 65 |
| Table B.1. Mathematical Formulation of Outcome Measures | 83 |
| Table B.2. Percentage of Maintenance Workforce (on Average) Encountering Tasks at Proficiency-Retaining Frequencies | 84 |

Summary

What are the costs and benefits of consolidating maintenance career fields in terms of managing the force and meeting emerging operational requirements?

The U.S. Air Force (USAF) has a goal of reducing the life cycle operating and support (O&S) costs of the F-35A (“Lightning”) by 43 percent (U.S. Government Accountability Office, 2019b). Aircraft maintenance is one of the largest functions of aircraft O&S and is often a consideration when determining options to reduce overall O&S costs.

Consolidation and reorganization of maintenance career fields are often motivated by a desire to reduce unit-level maintenance manpower cost. But USAF leaders additionally are interested in exploring how consolidation and reorganization apply to other objectives, including reducing aircraft downtime that arises because of maintenance;¹ improving combat resiliency; and developing a maintenance workforce that can be employed in leaner, more-mobile adaptive basing concepts.

This analysis considers the following three framing questions to inform USAF leadership on the costs and benefits of merged maintenance career fields for the F-35A:

- How do merged maintenance specialty concepts change F-35A O&S costs?
- Can merged maintenance specialty concepts improve wartime performance (e.g., sortie generation)?
- Are there significant potential implementation barriers for merged maintenance specialty concepts?

Approach

RAND Project AIR FORCE (PAF) conducted a cost and benefit analysis of five merged maintenance career fields. Maintainers are grouped into career fields called *Air Force specialties* (AFSs). Two of the merged AFS concepts were developed and are currently being tested by the USAF: the Blended Operational Lightning Technician (BOLT) and the Lightning Integrated Technician (LIT), and three concepts were developed by PAF as part of this effort. Of the PAF concepts, two (PAF 1 and PAF 3) offer less-aggressive AFS consolidations than either BOLT or LIT, and PAF 2 applies LIT to only a portion of the maintenance workforce.

The analysis considers the penalties of increased training time for maintainers in merged AFS concepts and the greater sortie-generation efficiency potential of merged AFS concepts. The evaluation additionally uses a qualitative framework to identify potential barriers and challenges to implementation of merged AFS concepts that warrant further consideration and

¹ This analysis does not consider the availability of spares, which is a strong driver of aircraft downtime.

study (e.g., cultural resistance, unique challenges facing the Air Reserve Component, recruiting and retention issues).

Conclusions

In our analysis, we reached the following conclusions:

- For some merged AFS concepts, the cost-savings potential in terms of fewer maintenance personnel needed is greater than the increase in training costs.² If manpower is not reduced, merged AFS concepts increase the sortie-generation potential with a small O&S cost increase. These costs are summarized in Table S.1.
- Concepts that aggressively consolidate AFSs (BOLT and LIT) have cost and readiness benefits even when applied to only part of the force (PAF 2). Smaller consolidations do not offer enough benefit to justify the challenges of implementation.
- Merged AFS concepts contribute to readiness for integrated basing concepts and agile operations by better enabling operations from smaller footprints and resisting performance degradation in high casualty environments.
- There are implementation concerns for merged AFS concepts that must be addressed, particularly personnel-retention issues, cultural resistance to implementation, and training.

Table S.1. Percentage Change in Unit-Level Maintenance Manpower Costs Under Merged AFS Concepts Relative to Baseline Concept

| | At Baseline Manning Levels (Percent) | Adjusted Manning Levels (Percent) |
|-------|--------------------------------------|-----------------------------------|
| BOLT | +2 to +3 | -11 to -15 |
| LIT | +3 to +5 | -8 to -13 |
| PAF 1 | +1 to +2 | +0 to +1 |
| PAF 2 | <+1 to +1 | -11 to -12 |
| PAF 3 | <+1 to +1 | +5 |

NOTES: Unit-level maintenance manpower cost differences are percentages relative to the baseline concept calculated as (concept cost – baseline cost) / (baseline cost). Costs include training costs, as described in Chapter 3 and Table 3.4, and direct maintenance manpower costs. The “at baseline manning levels” column includes only training costs because manpower levels are being held constant. The “adjusted manning levels” column reduces manpower levels under each concept such that sortie-generation rates equal those under the baseline AFS concept, as summarized in Table 5.2. The annual cost per maintainer is estimated using the annualized enlisted pay in fiscal year 2019 as estimated in Air Force Instruction 65-503, 2018, Table A.19-2.

² Costs associated with unit-level maintenance manpower comprise approximately 23 percent (\$277 million) of the \$1.197 billion in spending on F-35A O&S costs during fiscal year 2018. The AFS concepts considered here have the potential to affect future spending on unit-level maintenance manpower.

Recommendations

This analysis shows that greater net benefits can potentially be achieved by adopting more-aggressive AFS consolidation concepts. However, the following are key elements of implementation that will be critical for the realization of the benefits of merged AFS concepts:

- Ensure adequacy of training to provide the required knowledge, proficiency, and experience necessary to conduct the broader set of tasks required of maintainers.
- Invest in change management to facilitate smoother transition to new AFS concepts.³
- Invest in strategies to retain maintainers, particularly at the senior level, who are trained into merged AFS concepts.

³ *Change management* refers to approaches to prepare, support, and help individuals, teams, and organizations in making organizational change.

Acknowledgments

The team is grateful for the sponsorship of this project by Maj Gen. Cedric George (HAF/A4L, retired) and Brig Gen. Linda Hurry (HAF/A4L).⁴ We are also grateful for the support provided by the study points of contact: Maj Summer Kolcun (HAF/A4LM), Chief Master Sergeant Brock Mayfield (HAF/A4LM), and Lieutenant Colonel Tyler Schroeder (HAF/A4LM). Several other staff in HAF/A4LM provided valuable guidance and input to the study, including Chief Master Sergeant Dong Kim, Mr. Roger Harms, and Chief Master Sergeant Robert Rafferty.

We received helpful feedback and insight on the Blended Operational Lightning Technician experiment from Col. Michael Miles (Air Combat Command [ACC] 388 Maintenance Group [MXG]/CC) and the Lightning Integrated Technician experiment from Col. Michael Allison (Air Education and Training Command [AETC] 56 MXG/CC) and their staff. We are also grateful for discussions about the implementation concerns of merged Air Force specialty concepts with stakeholder communities, including Maj Adam Nichols (ANG 158th MXG), Maj Wesley Wade (AETC 359 TRS/TT), Sabrina Booker (AETC 359 TRS/TRR), CMSgt Benjamin Carpenter (ACC/A4F35), and Brian Bastow (AETC 19th AF/LGP). We also received outstanding and valuable support from subject-matter experts within the Logistics Composite Model (LCOM) community, including Sam Beasley, Phil Torres (AFMAA 2 Manpower Requirement Squadron/MRL), and Greg Boughton (AFMC AFLCMC/EZJS).

Several colleagues at the RAND Corporation provided support to this project. We particularly appreciate input provided to us during this project by Obaid Younossi, Pat Mills, Anu Narayanan, Natalie Crawford, Michael Boito, and Michael Kennedy, and the formal reviews provided by Mel Eisman, James Hosek, and Carra Sims. Brent Thomas provided very helpful support to the LCOM modeling efforts. Maria Falvo provided administrative support for this project. Gordon Lee provided editorial assistance.

Acknowledgement of these individuals does not imply their endorsement of the views expressed in this report.

⁴ All offices and ranks are current as of the time of the research.

Abbreviations

| | |
|----------|--|
| 2A3X5B | Avionics |
| 2A3X7B | Tactical Aircraft Maintenance specialist |
| 2A6X2 | Aerospace Ground Equipment |
| 2A6X3 | Egress |
| 2A6X4 | Fuels |
| 2A7X1 | Metals Tech |
| 2A7X2 | nondestructive inspection |
| 2A7X5 | low observable aircraft structural maintenance |
| 2W1X1 | Weapons |
| A&E | avionics and electrical and environmental |
| ACC | Air Combat Command |
| AETC | Air Education and Training Command |
| AFB | Air Force base |
| AFSC | Air Force Specialty Code |
| AFS | Air Force specialty |
| AGE | Aerospace Ground Equipment |
| ALIS | Autonomic Logistics Information System |
| ALS | Airman Leadership School |
| AMXS | Aircraft Maintenance Squadron |
| ARC | Air Reserve Component |
| ATC | Academic Training Center |
| Avionics | Advance Fighter Aircraft Integrated Avionics |
| BMT | basic military training |
| BOLT | Blended Operational Lightning Technician |
| CAF | Combat Air Force |
| CFETP | Career Field Education and Training Plan |

| | |
|-------------|--|
| CUT | cross-utilization training |
| DoD | U.S. Department of Defense |
| Egress | aircraft egress systems |
| EOD | explosive ordnance disposal |
| FTD | field training detachment |
| FTU | field training unit |
| Fuels | aircraft fuel systems |
| FY | fiscal year |
| ICT | Integrated Combat Turn |
| JPO | Joint Program Office |
| LCOM | Logistics Composite Model |
| LIT | Lightning Integrated Technician |
| LO | low observable |
| LOASM | low observable aircraft structural maintenance |
| MAF | Mobility Air Force |
| MAJCOM | Major Command |
| MDS | mission design series |
| Metals Tech | Aircraft Metals Technology |
| MMH | maintenance man-hours |
| MOS | Military Occupational Specialty |
| MRBM | medium-range ballistic missile |
| MSgt | Master Sergeant |
| MXG | Maintenance Group |
| MXS | Maintenance Squadron |
| NATO | North Atlantic Treaty Organization |
| NCOA | Noncommissioned Officer Academy |
| NCO | noncommissioned officer |
| NDI | nondestructive inspection |

| | |
|---------|--|
| NTT | nose-to-tail |
| O&S | operating and support |
| OJT | on-the-job training |
| PAA | Programmed Aircraft Authorization |
| PACAF | Pacific Air Force |
| PAF | Project AIR FORCE |
| PME | Professional Military Education |
| QDR | Quadrennial Defense Review |
| SE | support equipment |
| SrA | Senior Airman |
| SSgt | Staff Sergeant |
| TAMS | Tactical Aircraft Maintenance specialist |
| TR | Traditional National Guardsman and Reservist |
| USAF | U.S. Air Force |
| UTC | Unit Type Code |
| UTE | utilization rate |
| Weapons | aircraft armament systems |

1. Introduction

The F-35 Lightning II is the largest acquisition program in U.S. Department of Defense (DoD) history. Over its life cycle, the cost to DoD of operating and supporting the planned 2,443 fielded F-35s across three services is expected to exceed \$1 trillion. The U.S. Air Force (USAF) has a goal of reducing the life cycle operating and support (O&S) costs of its fleet of conventional takeoff and landing F-35s—the F-35A variant—by 43 percent, while maintaining the fleet’s effectiveness (U.S. Government Accountability Office, 2019b).⁵

Aircraft maintenance is one of the largest O&S functions and is often a consideration when determining options for reducing overall sustainment costs. Maintainers are grouped into career fields, called AFSs, with different subsets of AFSs maintaining different mission design series (MDS) aircraft across USAF fleets.

To manage manpower requirements, costs, and readiness, the USAF has adopted new maintenance AFS concepts over time. In some cases, multiple AFSs have been combined, and in other cases, the Air Force has opted to split a single AFS into two or more. The trend has been toward consolidation of AFSs, with the number of maintenance AFSs declining from 43 in the late 1980s to 27 today. Some of this consolidation is associated with the Rivet Workforce initiative, which was phased in with a general drawdown in force structure (both aircraft and people) following the end of the Cold War.⁶

Although consideration of new, consolidated AFS concepts often is motivated by a desire to reduce unit-level maintenance manpower cost, USAF leadership is interested in exploring their applicability to other objectives, including reducing aircraft downtime because of maintenance and improving combat resiliency.⁷ There are also efforts underway to develop new deployed basing postures that incorporate more-dispersed operations than have been considered in the past. Dispersed operations are intended to be lean, mobile, and relatively autonomous, and would likely benefit from a more-broadly trained maintenance workforce.

⁵ Costs associated with unit-level maintenance manpower comprise approximately 23 percent (\$277 million) of the \$1.197 billion in spending on F-35A O&S costs during fiscal year (FY) 2018. The Air Force specialty (AFS) concepts considered in this report have the potential to affect future spending on unit-level maintenance manpower.

⁶ In 1987, the Air Force was at a high point in terms of the number of maintainers and aircraft, and both saw a steady decline after the end of the Cold War. For example, in 1987 during the time of Rivet Workforce, manpower was at about 172,000 total force maintainers; today, there are about 84,000 total force maintainers, a 51 percent decline. Similarly, the number of aircraft in the fleet was about 9,450 total force aircraft in 1987; today, that number is around 5,350 aircraft, a 56 percent decline. Much of the decline in both personnel and aircraft occurred during the 1990s.

⁷ As an example, former Secretary of Defense Jim Mattis established an 80 percent mission-capable rate requirement for the F-35 in 2018, which is not being achieved as of the end of FY 2019.

Objective

To assist the USAF in its evaluation of different maintenance career field concepts, the RAND Corporation's Project AIR FORCE (PAF) analyzed the likely training, manpower, and readiness implications of combining different maintenance AFSs. This report provides an analysis of alternative maintenance AFS concepts for the F-35A. We draw on concepts explored by the Air Force, including the Blended Operational Lightning Technician (BOLT) and Lightning Integrated Technician (LIT),⁸ and three other concepts that we developed from discussions with stakeholders and subject-matter experts.⁹

This report seeks to address the following questions:

- How are F-35A maintainers currently organized and trained, and how might that change under alternative AFS concepts?
- How will an increase in training requirements from AFS consolidation affect training costs and the availability of maintainers to perform maintenance?
- How might maintenance effectiveness be influenced by training maintainers on a broader range of tasks under AFS consolidation?
- What are the potential impacts of AFS consolidation on maintenance manpower requirements, costs, and readiness?
- Are consolidated AFS concepts able to support new and evolving combat strategies designed to better address emerging threats?
- If the Air Force pursues new AFS concepts, what obstacles is it likely to face and what steps might it take to improve outcomes?

Approach

As noted by Light et al. (2016), reducing the number of maintenance AFSs has the potential to both positively and negatively affect the maintenance mission. It will require maintainers to spend more time being trained (in technical school and on base performing upgrade and qualification training) and training others, which will reduce a maintainer's *availability* to contribute to the maintenance mission. There is also the potential for increased training costs, particularly by Air Education and Training Command (AETC), because maintainers must spend more time at technical school learning a broader range of skills. There might also be significant implementation challenges that must be overcome. There are, however, potential benefits of

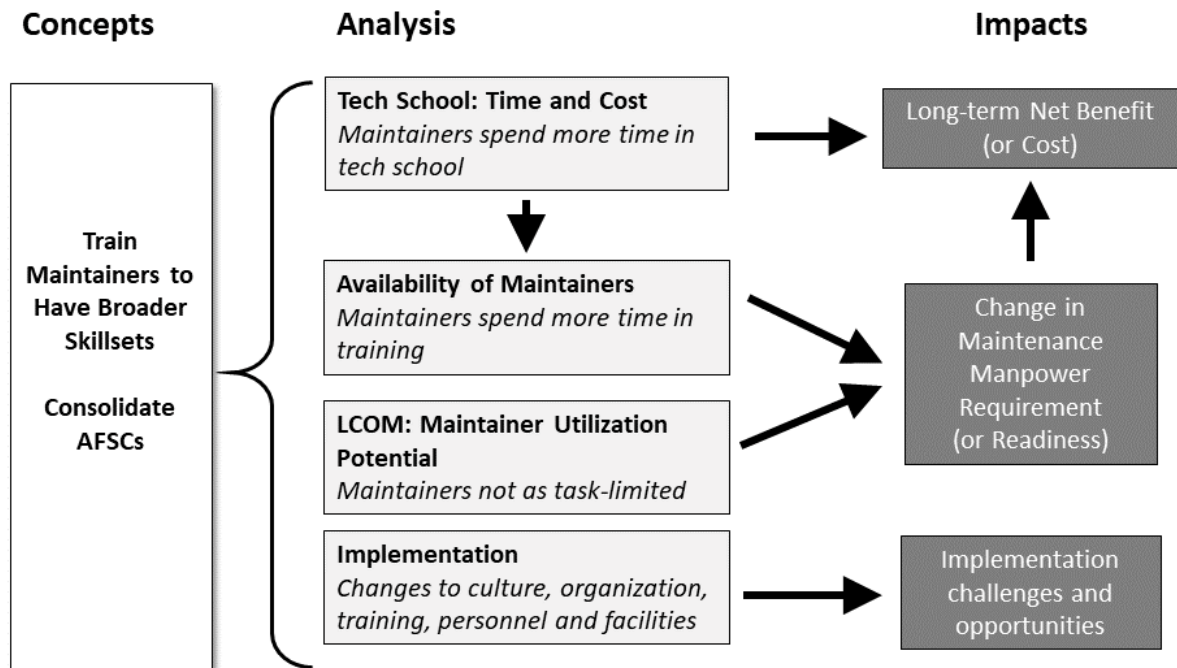
⁸ On January 1, 2020, a new initiative called the Lightning Technician Program (LTP) was formulated. The LTP initiative combines elements of BOLT and LIT.

⁹ Input for this study was provided by senior maintainers and staff from several organizations, including Headquarters, USAF, Logistics, Engineering and Force Protection (AF/A4); Air Combat Command, Directorate of Logistics, Engineering and Force Protection (Air Combat Command [ACC]/A4); Air Education and Training Command, Logistics, Engineering and Force Protection (Air Education and Training Command [AETC]/A4); 388 Maintenance Group (MXG) at Hill Air Force Base (AFB); 56 MXG at Luke AFB; 158 MXG at the Vermont National Guard; F-35 Academic Training Center (ATC) at Eglin AFB; 2nd Manpower Requirements Squadron at Langley AFB; and the F-35 Joint Program Office (JPO).

consolidating AFSs. In particular, there is the potential for greater utilization of maintainers who are less task-limited once they receive training on a broader set of tasks. These impacts and their integration into our analytical approach are depicted in Figure 1.1.

The potential costs associated with the consolidation include the increased amount of time spent in technical school and the reduced availability of maintainers because of increased training burden over their careers (e.g., increased time spent in technical school, additional upgrade requirements), while the potential benefits reflect the increased utilization of maintainers associated with being less task-limited. The implementation issues are not easily quantified but are critical to consider when deciding whether to move to a new AFS concept. We considered these issues as part of our analysis. The “Impacts” identified in Figure 1.1 represent the combinations of costs, benefits, and risks that we sought to identify through our analysis.

Figure 1.1. Methodological Approach



NOTE: LCOM = Logistics Composite Model; AFSC = Air Force Specialty Code.

To understand the impacts of AFS consolidation on technical school time and costs, we collected information on current technical school course lengths, locations, and costs. We then spoke with subject-matter experts to understand how course lengths might change if new technical school training curricula were established to support new AFSs. We extrapolated the additional technical school costs that AETC will incur using the increased time each pupil is likely to spend in technical school under each concept.

To understand how the increased training requirements associated with AFS consolidation are likely to affect the availability of maintainers to perform maintenance over their career,

current training requirements for maintainers were reviewed, with a focus on those assigned to support F-35A maintenance operations. The research team reviewed literature and spoke with subject-matter experts to understand how F-35A maintainers currently spend their time.¹⁰ Input from subject-matter experts was used to develop two scenarios that describe how maintainer training requirements will change following AFS consolidation. Information on retention rates for active-duty maintainers was integrated into this analysis to account for the effect of separations.

To analyze the implications of AFS consolidation on maintainer *utilization*, we used the LCOM and the F-35 Joint Program Office (JPO)'s LCOM input database. This database reflects current expectations of maintenance and other requirements for the F-35A at its maturity. The Air Force uses LCOM to derive wing and squadron maintenance manpower requirements. LCOM also can be adapted to look at how policy changes, such as AFS consolidation, affect measures of readiness, such as sortie-generation rates under high sortie demand schedules. Within the F-35A LCOM, the manpower levels are varied under both the existing AFS concept and the consolidated concept to observe how sortie-generation rates vary over the course of a hypothetical 180-day combat operation. This information was combined with estimates of the reduced availability of maintainers to arrive at overall findings on manpower requirement and readiness implications of AFS consolidation.

To supplement the LCOM analysis of wartime sortie-generation potential of merged AFS concepts, we included an assessment of how new combat concepts might be enhanced by a more-consolidated AFS structure. As a final step, we documented implementation challenges and opportunities using a review of literature on previous AFS consolidation efforts and discussions with subject-matter experts.

Most of the analysis presented in this report considers the impact of AFS consolidation on active-duty F-35A maintenance personnel. A quantitative assessment of the impact of AFS consolidation on National Guard and Reserve personnel was beyond the scope of this study, although we did identify some specific implementation challenges and opportunities for the Air National Guard and Air Force Reserve Command, which we discuss as part of our implementation analysis.

Outline of This Report

This report proceeds as follows:

- Chapter 2 discusses the baseline F-35A maintenance AFS concept and other concepts evaluated in this report.
- Chapter 3 summarizes our findings on how technical school time and costs are likely to change under each AFS concept.

¹⁰ The subject-matter experts we consulted for this research included senior maintainers and managers.

- Chapter 4 evaluates the effect of AFS consolidation on maintainer availability to perform maintenance.
- Chapter 5 presents the LCOM analysis and our extrapolation of the overall effects on manpower requirements, costs, and readiness.
- Chapter 6 considers how more-consolidated AFS concepts might support new and evolving combat strategies designed to better address emerging threats.
- Chapter 7 discusses implementation challenges.
- Chapter 8 concludes with a summary of our findings and recommendations.

Various technical analyses are presented in appendixes that appear at the end of the report, including a review of lessons learned from the Rivet Workforce initiative (Appendix A), an assessment of proficiency concerns stemming from AFS consolidation (Appendix B), a sensitivity analysis of the maintainer-availability analysis presented in Chapter 4 (Appendix C), an analysis of the efficiencies of combining different AFSs (Appendix D), and a discussion of other ways to organize the maintenance force (Appendix E).

2. Approaches for Organizing and Training F-35A Maintainers

This chapter describes the six maintenance force structure concepts that are examined in this analysis. Although there are many ways that the maintenance workforce can be organized—Appendix E, for example, discusses cross-MDS training and cross-functional training, and Rivet Workforce is discussed in Appendix A—this analysis focuses on concepts that merge maintenance career fields. The first concept is the baseline concept, which is how the F-35A maintenance specialties are organized today. The next two concepts are the BOLT and LIT concepts that are currently being demonstrated at Hill Air Force Base (AFB) and Luke AFB, respectively. The final three concepts are the following, which PAF developed:

- ***PAF Concept 1*** is similar to the baseline concept but applies crew chief tasks from the Tactical Aircraft Maintenance specialist (TAMS) to all other specialties.
- ***PAF Concept 2*** is similar to the LIT concept but only trains 30 percent of personnel in the four specialties that make up the LIT merged AFS into a merged specialty, while the remaining 70 percent of Advance Fighter Aircraft Integrated Avionics (Avionics), TAMS, Weapons, and low observable aircraft structural maintenance (LOASM) personnel remain in those specialties.
- ***PAF Concept 3*** combines some specialties using the similarities of the tasks they perform.

Although there are many more potential AFS consolidations that could be examined, these six provide a reasonable range of options in terms of the number of specialties assigned to an Aircraft Maintenance Squadron (AMXS) and Maintenance Squadron (MXS).¹¹ These six concepts also provide a reasonable range of the amount of consolidation each concept results in as indicated by the overall total number of specialties. This analysis examines a range of consolidation concepts to help USAF decisionmakers understand the trade-offs of alternative AFS concepts for the F-35A. We discuss each AFS concept in the following sections.

¹¹ The AMXS maintainers perform on-equipment activities necessary to support operations with properly configured, mission-ready aircraft to meet contingency or training sortie requirements. Personnel in the AMXS are responsible for most on-equipment and direct sortie-generation maintenance activities. The MXS supports operations by providing centralized back-shop support to perform on and off equipment maintenance tasks (see Air Force Instruction 21-101, 2020).

Baseline F-35A Maintenance AFS Concept

The USAF trains and organizes aircraft maintainers into a variety of AFSs. Each AFS is associated with a five-digit AFSC.¹² In some cases, an additional suffix is added to the end of the five-digit AFSC (a “shred”) denoting positions associated with a particular weapon system or set of weapon systems within a single specialty. For the F-35A, there are nine primary AFSs that perform flight-line and back-shop maintenance.¹³ Table 2.1 provides a description of each AFS.

The first two digits of the AFSC designation denote the career field. AFSCs that begin with “2A” indicate the aerospace maintenance career field, and “2W” indicates the weapons career field. The third and fifth digits represent a further career field division. The fourth digit of the AFSC indicates skill level. A maintainer’s skill level, denoted with an “X” in the AFSCs shown in Table 2.1, can vary as follows:

- *Helper (1-level)*: An enlisted maintainer receives this designation once they enter technical school.
- *Apprentice (3-level)*: On graduation from technical school, an enlisted maintainer is designated as this skill level.
- *Journeyman (5-level)*: After a period of on-the-job training and correspondence courses (usually 12 to 18 months as a 3-level), a maintainer is awarded this skill level.
- *Craftsman (7-level)*: Once promoted to Staff Sergeant (SSgt), a maintainer enters training for the 7-level skill level, which includes correspondence coursework, on-the-job training, and, in some instances, additional 7-level technical school course time.
- *Superintendent (9-level)*: Once an enlisted maintainer is promoted to senior master sergeant (E-8), the individual is designated a 9-level maintainer.

Maintainers at the 3-, 5-, and 7-levels are engaged in physical maintenance activities (e.g., “wrench turning”), while 9-level maintainers perform management functions.

For the baseline F-35A concept, there are nine primary AFSs that perform flight line and back-shop maintenance as described in Table 2.1. Three of the nine AFSs—TAMS, Avionics, and aircraft armament systems (Weapons)—are in the AMXS, and the other six AFSs—Aerospace Ground Equipment (AGE), aircraft egress systems (Egress), aircraft fuel systems (Fuels), Aircraft Metals Technology (Metals Tech), nondestructive inspection (NDI), and LOASM—are in the MXS.

¹² In practice, AFS and AFSC often are used interchangeably. The other services use somewhat different terminology. For example, the Army and Marines use the term *military occupational specialty* (MOS) and the Navy and Coast Guard use the term *rating* to indicate enlisted career fields.

¹³ Although civilians and officers also can maintain the F-35A airframe in various contexts, this report will use the terms *F-35A maintainers* or simply *maintainers* to refer to just these nine enlisted AFSs.

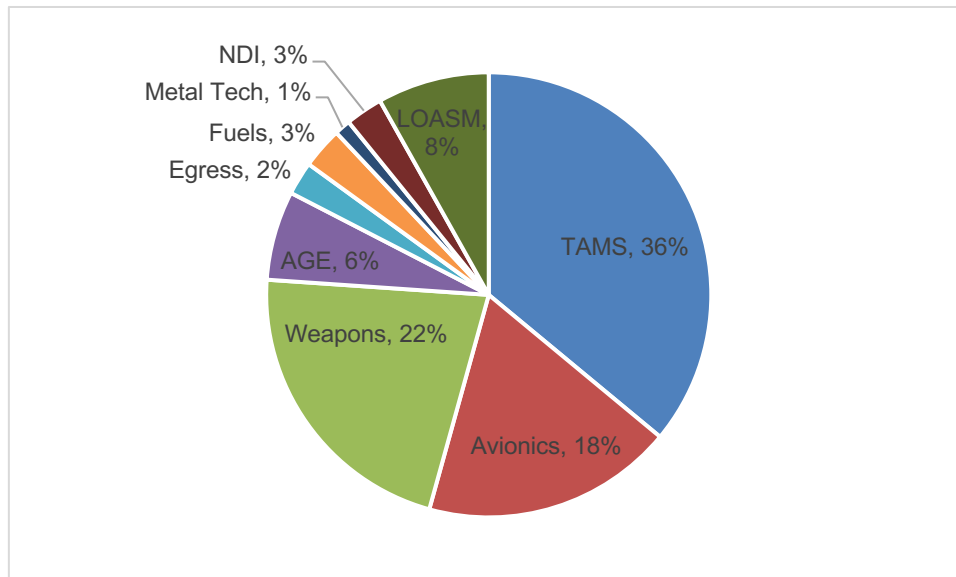
Table 2.1. Current F-35A Maintenance Career Fields

| AFSC | Name | Description |
|-------------|--|---|
| 2A3X7B | TAMS (fifth generation) | Maintains aircraft, support equipment (SE), forms, and records. Performs and supervises flight chief, expeditor, crew chief, repair and reclamation, quality assurance, and maintenance support functions. Shred: A = F-22; B = F-35A. |
| 2A3X5B | Advanced Fighter Aircraft Integrated Avionics (Avionics) | Maintains avionics and electrical and environmental (A&E) systems at the organizational level. Troubleshoots, inspects, removes, installs, repairs, modifies, and operates aircraft A&E systems, components, and associated SE. Performs and supervises general aircraft servicing and handling procedures. Shred: A = F-22; B = F-35A; C = MQ-1, MQ-9, RQ-4. |
| 2W1X1 | Aircraft Armament Systems (Weapons) | Loads and unloads nuclear and nonnuclear munitions, explosives, and propellant devices on aircraft. Manages, controls, maintains, and installs aircraft bomb, rocket, and missile release, launch, suspension, and monitor systems; guns and gun mounts; and related munitions handling, loading, and test equipment. |
| 2A6X2 | AGE | Maintains AGE to support aircraft systems or subsystems. Manages AGE functions and activities. |
| 2A6X3 | Aircrew Egress Systems (Egress) | Maintains aircraft egress systems with ejection seats, canopies, and hatches; explosive components; electro-explosive devices; subsystems; and related SE. |
| 2A6X4 | Aircraft Fuel Systems (Fuels) | Removes, repairs, inspects, installs, and modifies aircraft fuel systems including integral fuel tanks, bladder cells, and external tanks. Maintains associated hardware and equipment. |
| 2A7X1 | Aircraft Metals Technology (Metals Tech) | Designs, welds, heat-treats, fabricates, and machines precision tools, components, and assemblies for aerospace weapon systems and related SE. |
| 2A7X2 | NDI | Inspects aerospace weapon systems components and SE for structural integrity using NDI methods and performs fluid analysis. |
| 2A7X5 | LOASM | Evaluates, installs, removes and repairs low observable (LO) coatings. Designs, repairs, modifies, and fabricates aircraft, metal, plastic, composite, advanced composite, LO, and bonded structural parts and components. Applies preservative treatments to aircraft, AGE, and SE. |

SOURCE: Air Force Personnel Center, 2019.

Figure 2.1 provides a summary of the share of active-duty F-35A maintainers stationed at Hill AFB at the end of FY 2018 in the nine AFSs shown in Table 2.1. In later chapters, we use the shares shown in Figure 2.1 to calculate the weighted average impacts of each AFS concept on the population of F-35A maintainers. Airmen in the TAMS, Avionics, and Weapons AFSs (which largely reside in the AMXS) together make up over three-fourths of the F-35A maintainers in the nine AFSs considered in this analysis.

Figure 2.1. Share of F-35A Maintainers at Hill AFB in Nine AFSs Shown in Table 2.1, FY 2018



SOURCE: Air Force Personnel Center, Airman Extract Data Set, obtained on December 6, 2018.

The baseline F-35A concept offers some consolidation from AFS concepts used in the past by other fighter platforms. Specifically, TAMS combines the crew chief, engines, and hydraulic AFSs; Avionics consists of legacy avionics, electro-environmental, and communication and navigation AFSs; and LOASM combines the LO and sheet-metal AFSs. The other six AFSs are similar to AFSs currently assigned to any other fighter MDS.

The organizational structure is traditional, with typical AFSs assigned to the AMXS and MXSs that align with the mission of each squadron. In other, more-consolidated concepts, we will see some AFSs shift from the MXS to the AMXS.

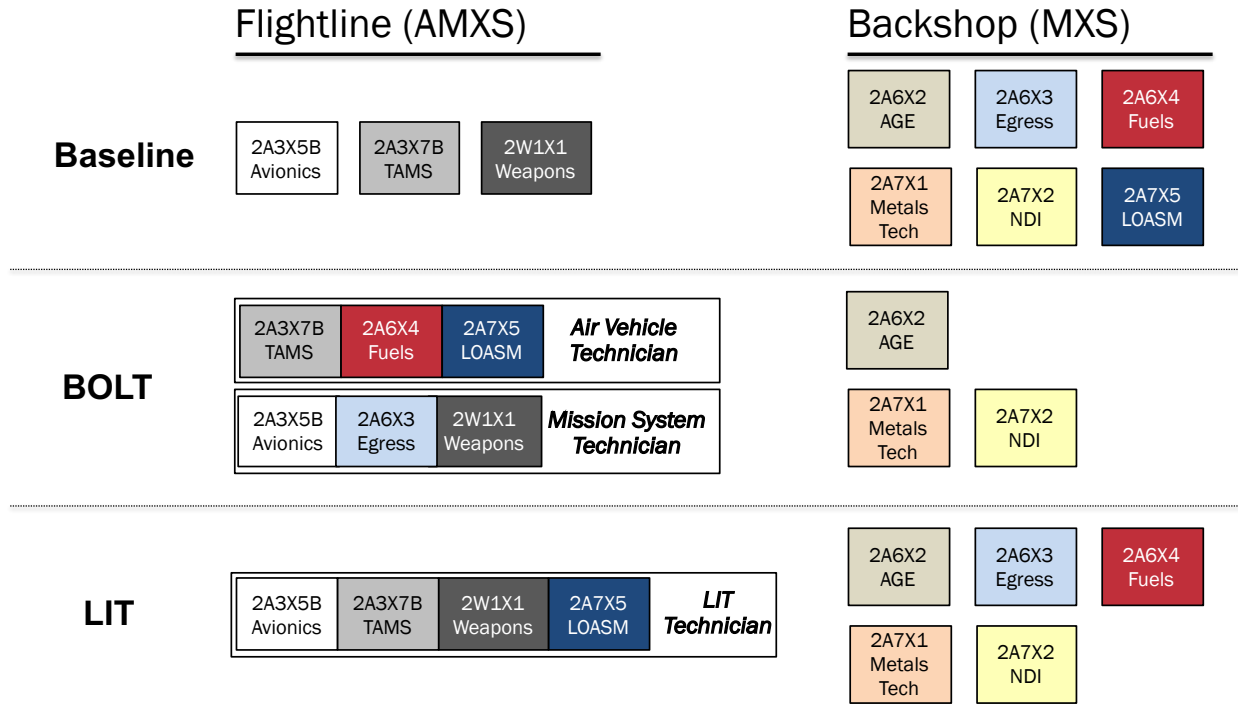
F-35A Experimental AFS Concepts Being Tested by USAF

Currently, two unit-level maintenance experiments are underway that are particularly relevant to the F-35A and our study: the BOLT program at Hill AFB and the LIT program at Luke AFB.

It is important to note that each of these experiments has been locally formulated and implemented. They both represent important efforts to learn about the potential impacts of reformulating the way maintainers are trained and organized. Both efforts were initiated recently and were scheduled to undergo a more-formal internal evaluation during calendar year 2019. They both were formulated as responses to a desire to increase maintenance effectiveness and improve combat sortie-generation capability.

Figure 2.2 depicts the BOLT and LIT concepts as conceived at the start of FY 2019 and the baseline F-35A AFS concept. We discuss BOLT and LIT in the next section.

Figure 2.2. Baseline F-35A, BOLT, and LIT Concepts



SOURCE: Data provided by BOLT and LIT experiment personnel.

Blended Operational Lightning Technician Experiment

In an effort to explore potential manpower savings that can be achieved through more-broadly training F-35A maintainers and accommodating new adaptive basing concepts,¹⁴ the 388th Aircraft Maintenance Squadron at Hill AFB has designated a group of maintainers to participate in the BOLT program.

Under the BOLT program, Fuels, LOASM, and Egress are brought from the MXS to the aircraft maintenance unit on the flight line. Each BOLT maintainer is assigned to one of the following two tracks:

- **Air Vehicle:** This track performs activities associated with the TAMS, LOASM, and Fuels AFSs.
- **Mission Systems:** This track performs activities associated with the Avionics, Egress, and Weapons AFSs.

¹⁴ In 2017, the ACC Commander tasked wing commanders with developing initiatives that provide a level of autonomy of small teams of airmen and aircraft for short durations to execute adaptive basing concepts. Adaptive basing is not yet Air Force policy. In this report, we use the term *adaptive basing* to encompass the range of operating and basing concepts that require adaptiveness, responsiveness, and agility to survive and operate in future, complex operating environments.

Maintainers retain their primary AFS (including all training and certification requirements) and are cross-trained to take on certain high-frequency tasks associated with other AFSs in their track.

An entire BOLT aircraft maintenance unit for 24 aircraft was anticipated to require about 198 total personnel, excluding Fuels, Egress, or LO back-shop AFSs.¹⁵ It uses a dedicated specialist per aircraft calculation, consisting of eight maintainers per aircraft made up of a number of Air Vehicle and Mission System maintainers (Munn, 2018). These merged AFSs would become F-35-specific AFSs and the AGE, Metals Tech, and NDI AFSs would remain as currently defined.

Lightning Integrated Technician Experiment

The LIT program at Luke AFB aims to combine four AFSs (TAMS, LOASM, Weapons,¹⁶ and Avionics). Each LIT maintainer is trained in their primary AFS and the three others to be able to perform all launch, recover, and servicing actions and perform at least 80 percent of commonly occurring repair actions (Lammers, 2018). The LIT program was initiated in January 2018.

The LIT program was motivated in part by Lockheed Martin's nose-to-tail (NTT) maintenance concept that it employs in the maintenance of foreign-owned F-35As flown out of Luke AFB.¹⁷ Under the NTT maintenance concept, Lockheed Martin maintainers are cross-trained to perform nearly all common flight-line maintenance activities.

To support the LIT concept, a LIT Career Field Education and Training Plan (CFETP) is being developed to eliminate redundancies in requirements across AFSs and focus on the 20 percent of tasks that make up the most common workload (the tasks that occupy approximately 80 percent of a maintainer's time). This amounted to about 250 core tasks in which a LIT maintainer is trained. Maintainers participating in the LIT program currently participate in a one-week intensive course taught by Lockheed Martin and two weeks of intensive on-the-job training in which skills in the areas of aircraft power, LO processes, launch and recovery, service, inspection, tow, operations checks, and fiber cleaning are emphasized (Lammers, 2018).

¹⁵ The BOLT concept has been gradually phased in over time with refinements made along the way. At the time of our initial visit to Hill AFB in November 2018, the concept had been extended to four aircraft and 32 maintainers, with four maintainers assigned to the air vehicle cell and four maintainers assigned to the mission systems track for each of the four aircraft. As of summer 2019, the demonstration consisted of 88 BOLT-trained maintainers assigned to nine aircraft and was projected to reach 96 maintainers assigned to 12 aircraft by November 2019.

¹⁶ At the time of this demonstration, policy dictated that 2W1X1s (Weapons) were the only maintainers authorized to perform weapons loading using their standard three-person team.

¹⁷ Lockheed Martin's NTT maintainers are trained in standard maintenance tasks across all of the AFSs in the current F-35 construct (except AGE); their training starts with a three-week advance systems theory technical training course followed by a one-week on-the-job training general-maintenance course. The intent is to first qualify maintainers in general maintenance practices and specialize them as needed. The expectation is for a maintainer to become fully qualified as a Nose-to-Tail Maintainer in less than 24 months.

Under the LIT program, a maintenance crew of six or seven maintainers is assigned to a tail on a permanent basis. As of our visit to Luke AFB on December 6, 2018, the LIT program included 14 tails and approximately 100 personnel.¹⁸ By summer 2019, the demonstration had grown to consist of about 120 LIT maintainers and 15 aircraft. Like the BOLT concept, the LIT concept also takes advantage of the F-35A design with prognostic health maintenance systems, reducing the need for deep expertise.

Assumptions About How BOLT and LIT Would Be Implemented if Fully Adopted for the F-35A

A key to properly assessing the impact of an AFS consolidation effort is to separate the issues experienced as part of an experimental/demonstration implementation from the impacts that would likely be experienced if AFS consolidation were adopted ubiquitously for the F-35A. Some of the issues that are likely to differentiate current and potential future performance for these concepts are as follows:

- Initially, BOLT and LIT maintainers were hand-selected and likely do not reflect the average F-35A maintainer in terms of knowledge, proficiency, and experience. Our assessment seeks to generalize findings from consolidating AFS to the broader F-35A maintenance community.
- BOLT and LIT relied on cross-utilization training (CUT)¹⁹ to broaden the maintainers outside their primary AFS. Our assessment assumes that AFSs would be restructured and training requirements (e.g., technical school, CFETPs) would be reformulated to cover all aspects of the new AFSs.
- AFI 21-101 (2020) establishes certain policies for most AFSs that have an impact on the effectiveness of the BOLT and LIT concepts. In some cases, waivers are required to allow maintainers to conduct activities outside their primary AFS. If AFSs are formally consolidated, we assume these requirements would be adjusted to support and facilitate maintainers to conduct tasks within their new AFSs.

Other issues that make the BOLT and LIT experiments difficult to assess relative to performance observed under the conventional F-35A concept include differences in the number of maintainers per tail, a lack of 24-hour coverage (i.e., limited midshift maintainers who are training in either of the demonstrations), the use of teams of flight-line maintainers assigned on a permanent basis to a specific tail, differences in the age or block design of aircraft being used, and limited formal integration of associate unit personnel. These factors require a close examination and could influence outcomes observed under the BOLT and LIT experiments.

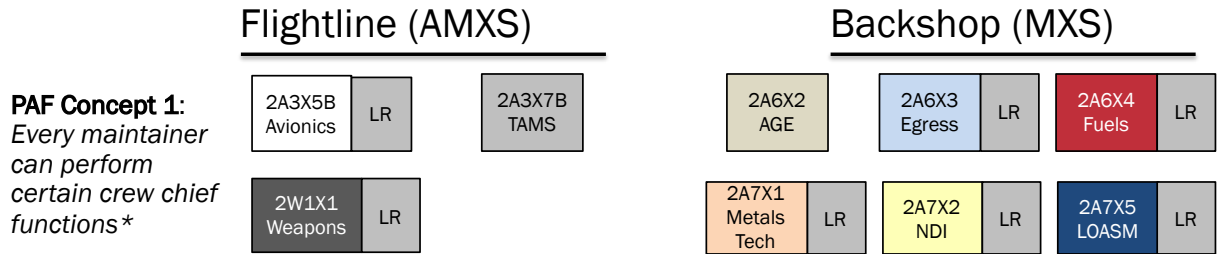
¹⁸ A fifteenth aircraft was added to the LIT program on December 26, 2018.

¹⁹ CUT is intended to provide units with internal flexibility by training individuals to perform tasks that are not in their primary AFS to offset periods of austere or low skill-level manning. CUT also enhances combat capability by developing a pool of qualified personnel to draw on during surges, but that pool is not created to train personnel for every task or be a long-term fix or management solution for an AFS shortfall (see AFI 36-2650, 2019, Chapter 1.13).

PAF-Developed AFS Concepts

In this section, we discuss three PAF-developed concepts that represent different degrees and forms of AFS consolidation relative to BOLT and LIT. The PAF AFS concepts are shown in Figure 2.3 and discussed below.

Figure 2.3. PAF-Developed Concepts

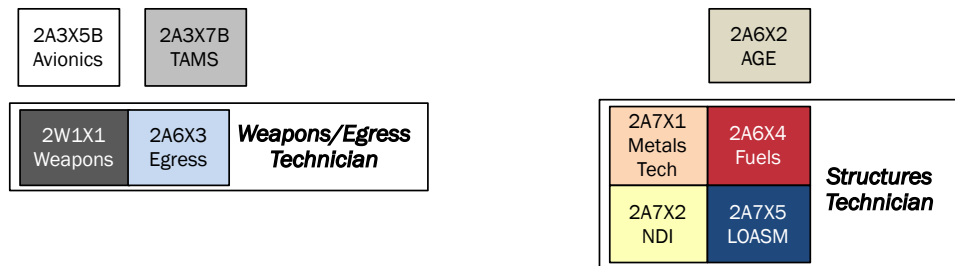


**In this concept, LR comprises certain launch and recovery, ground handling, and servicing TAMS tasks only*

PAF Concept 2:
LIT-like consolidation for only part of force

30 percent of Avionics, TAMS, Weapons, and LOASM personnel become LIT maintainers

PAF Concept 3:
Combines common skill-set AFSCs



NOTE: LR = Launch and Recover; it is composed of certain launch and recovery, ground handling, and servicing TAMS tasks only, reflecting the highest-frequency and shortest-duration TAMS tasks.

PAF Concept 1: Every Maintainer Can Perform Certain Crew Chief Functions

There are many maintenance actions that crew chiefs (i.e., TAMS) conduct daily to prepare aircraft and generate sorties, including launch and recovery sequences; ground handling operations such as aircraft inspections, towing, or wash; and operations such as refueling, engine oil servicing, or gaseous oxygen servicing. Such general maintenance actions are commonly process-driven and require limited specialty training. This concept adds many of the crew chief tasks from the TAMS AFS to all other specialties, including the typical back-shop AFSs except AGE, as shown in Figure 2.3. Under PAF Concept 1, when there are no maintenance actions required in a maintainer’s given specialty, the maintainer would be available to perform day-to-

day crew chief maintenance, creating additional capability.²⁰ This concept is broader in one respect than BOLT and LIT, because it expands the responsibilities required of eight of the nine maintenance AFSs. However, it might require less change and training and could be more easily applied to other MDSs because the degree of consolidation and the number of tasks required of any single AFS is less than in the BOLT and LIT concepts.

PAF Concept 2: A LIT Concept for Part of the Force

The PAF 2 concept trains 30 percent of the F-35A maintainers who would traditionally be in the TAMS, Avionics, Weapons, and LOASM AFSs as LIT maintainers. This is a variation on the LIT concept, which, we assume, would be a complete replacement for these four AFSs across the entire maintenance force. In practice, there might be a selection process to determine which maintainers are selected for the more-expansive LIT career fields; however, we do not formally consider this in this report.

PAF Concept 3: Combining AFSs with Common Skill Sets

The PAF 3 concept represents a different combination of AFSs than BOLT and LIT, a combination that is based on similarities in the type of knowledge and skills required, as shown in Figure 2.3. Consolidating AFSs in this manner might help reduce training times because of the similarities in the knowledge and skills required, potentially making it easier for trainees to grasp and understand the material. Further, a consolidation effort in this manner might be more likely to facilitate shred to other platforms, because it is based on aircraft subsystems. The primary skill areas combined are discussed below.

Structures Technician

The structural skill area generally considers AFSs that require knowledge and skills about the physical laws of airframe stresses, materials, and structural integrity. This new AFS would be a combination of LOASM and three legacy AFSs—Metals Tech, Fuels, and NDI—that are all generally structure-related:

- *LOASM*: Designs, repairs, modifies, and fabricates aircraft, metal, plastic, composite, advanced composite, LO, and bonded structural parts and components. Requires knowledge about painting, treating corrosion, and applying corrosion-protective and LO coatings. Also forms, cuts, bends, and fastens replacement or repair parts to damaged structures and components.
- *Metals Tech*: Designs, welds, heat treats, fabricates, and machines precision tools, components, and assemblies for aerospace weapon systems and related SE. Requires knowledge about metal repair and fabrication processes, composition of metals and

²⁰ One aspect of this concept that would need to be explored further is how the tasking of TAM tasks might be coordinated across maintainers assigned to the AMXS and MXS.

machinable materials, weld specifications, metal tempering, forging, and mechanical drawings.

- *Fuels*: Maintains the aircraft fuel systems and requires knowledge about fuel system parts (e.g., valves, lines, gauges, controls, pumps, and other attachments), sealing materials, sheet-metal parts, rubber properties, and organic sealing compound applications.
- *NDI*: Inspects the structural integrity of the airframe using nondestructive methods and requires knowledge of the characteristics of metals identification, metal discontinuity and flaw detection, and operation and maintenance of nondestructive test equipment.

Weapons Egress Technician

The explosives skill area generally considers AFSs that require knowledge and skills about the behavior and use of explosive materials and considers combining Weapons and Egress:

- *Weapons*: Load and unload explosives on aircraft (e.g., bombs, rockets, missiles, ammunition) and inspect and test suspension, launch, and release systems.
- *Egress*: Maintain aircraft egress systems including ejection seats, canopies, hatches, modules, and explosive components.

At the time of this analysis, the combination of weapons with any of the other maintenance AFSs considered in this analysis seemed to have the most issues because of safety, policy requirements, and the increased training schedule of Weapons compared with other AFSs. If the community intends on going forward with a consolidation option that includes weapons, combining Weapons with Egress has advantages because of the overlap in explosives knowledge required for both AFSs. Additionally, this consolidation is among the smallest in terms of the total number of tasks combined into a single AFS, which could ameliorate the demands on Weapons maintainers that arise because of their higher-frequency training requirements.

Summary of AFS Concepts

Each of the concepts described here, at face value, has merits. Taken together, they represent a spectrum of AFS consolidation approaches that vary significantly in their degree of consolidation (e.g., number of AFSs), combination of AFSs, and impact on workforce relative to the baseline AFS concept. Table 2.2 summarizes the various concepts in terms of some of these criteria. BOLT and PAF 3 consolidate to the fewest number of maintenance AFSs, while the PAF 2 concept would actually represent an expansion in the number of maintenance AFSs and include the nine current AFSs and the LIT career field. In terms of consolidation within the AMXS, LIT is the most consolidated, with a single AMXS career field. The PAF 3 concept and BOLT concepts represent the most significant consolidation within the MXS and would shift certain tasks to the AMXS (e.g., Egress).

Table 2.2. Summary of AFS Concepts

| AFS Concept | Total Number of AFSs | Number of AFSs in AMXS | Number of AFSs in MXS |
|--------------------|-----------------------------|-------------------------------|------------------------------|
| Baseline | 9 | 3 | 6 |
| BOLT | 5 | 2 | 3 |
| LIT | 6 | 1 | 5 |
| PAF 1 | 9 | 3 | 6 |
| PAF 2 | 10 | 4 | 6 |
| PAF 3 | 5 | 3 | 2 |

3. Technical School Times and Costs Under Alternative Air Force Specialty Concepts

In this chapter, we explore how the time and cost associated with technical school might change if each of the AFS concepts discussed in Chapter 2 is adopted. To conduct this analysis, we reviewed data and analysis on current training practices, times, and costs, and consulted subject-matter experts from AETC, Air Combat Command (ACC), and Headquarters, Air Force, and the results of the BOLT and LIT experiments. Using these inputs, we developed both a conservative and an aggressive set of technical school training assumptions, which are intended to reflect the inherent uncertainty of how technical school times might change if new AFS concepts are implemented.

Technical School Times Under the Current F-35A Training Concept

Currently, airmen start their Air Force careers with basic military training (BMT) at Lackland AFB. BMT takes approximately eight weeks to complete. During BMT, airmen learn basic warfighting skills, engage in physical fitness, perform drills and ceremonies, and become generally acquainted with Air Force life.

After BMT, airmen proceed to technical school for their AFS. At technical school, airmen can learn fundamentals in their AFS and receive MDS-specific training. Technical school course lengths can vary in location and duration depending on an airman's AFS.

After successfully completing technical school, airmen are awarded a 3-skill level. They might, however, be required to complete a field training unit (FTU) or field training detachment (FTD) course at their home station or another base location. Table 3.1 shows information collected in 2019 on BMT, technical school, and FTD/FTU courses, locations, and times.

Table 3.1. Current F-35A Training Course Locations and Lengths

| AFS | ASFC | Location | Training Title | Hours | Training Days | Calendar Days |
|------------|-------------|-----------------|--|--------------|----------------------|----------------------|
| All AFSs | All AFSs | Lackland | BMT | 320 | 40 | 56 |
| Avionics | 2A3X5B | Sheppard | Fundamentals | 312 | 39 | 54.6 |
| Avionics | 2A3X5B | Sheppard | Intermediate General Avionics Principles | 184 | 23 | 32.2 |
| Avionics | 2A3X5B | Eglin | F-35A | 352 | 44 | 61.6 |
| TAMS | 2A3X7B | Sheppard | Fundamentals | 184 | 23 | 32.2 |
| TAMS | 2A3X7B | Eglin | F-35A | 272 | 34 | 47.6 |
| TAMS | 2A3X7B | Luke | FTD w/ Engine | 368 | 46 | 64.4 |
| AGE | 2A6X2 | Sheppard | AGE course | 696 | 87 | 121.8 |
| Egress | 2A6X3 | Sheppard | Egress course | 248 | 31 | 43.4 |
| Egress | 2A6X3 | Eglin/Luke/Hill | F-35A FTD | 88 | 11 | 15.4 |
| Egress | 2A6X3 | Eglin/Luke/Hill | Flexible Linear Spaced Charges FTD | 80 | 10 | 14 |
| Fuels | 2A6X4 | Sheppard | Fuels course | 288 | 36 | 50.4 |
| Fuels | 2A6X4 | Luke/Hill | FTD | 48 | 6 | 8.4 |
| Metals | 2A7X1 | Pensacola | Metals Tech course | 544 | 68 | 95.2 |
| NDI | 2A7X2 | Pensacola | NDI course | 408 | 51 | 71.4 |
| LOASM | 2A7X5 | Pensacola | LOASM | 472 | 59 | 82.6 |
| Weapons | 2W1X1J | Sheppard | Fundamentals | 144 | 18 | 25.2 |
| Weapons | 2W1X1J | Eglin | F-35A | 216 | 27 | 37.8 |

SOURCE: Data provided by the F-35 Academic Training Center at Eglin AFB.

NOTES: Calendar days extrapolated by research team; totals do not include time for transit between locations. Transit time used in later calculations is assumed to be five days per move.

Technical School Times for Merged AFS Concepts

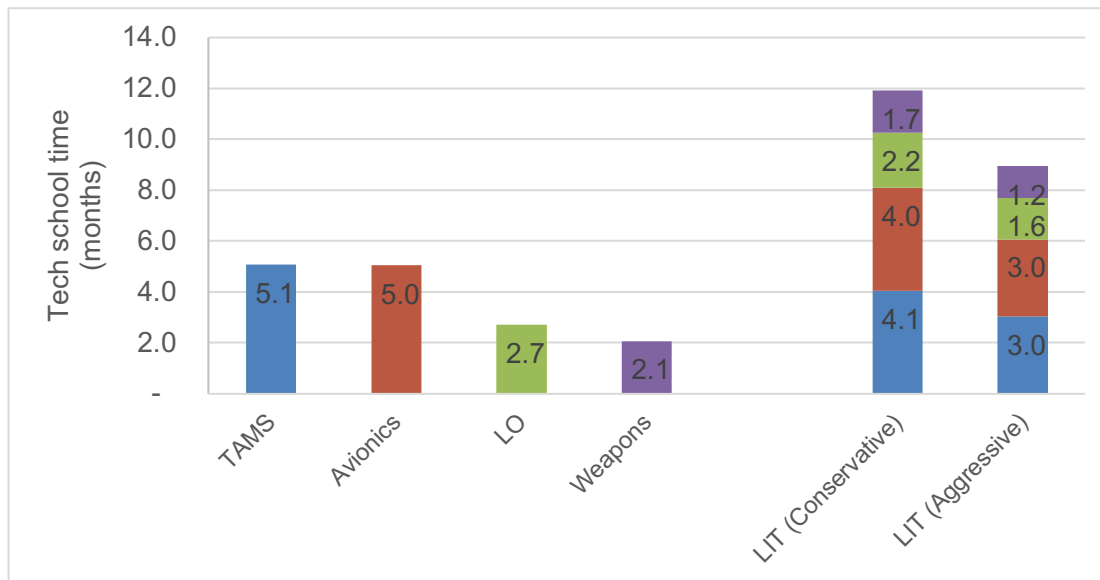
To estimate the amount of time airmen will spend in technical school and FTU/FTD for each new AFS concept described in Chapter 2 (i.e., the BOLT, the LIT, and the three PAF-developed concepts), we used the current technical school times and assumed varying amounts of overlap in the course curriculum that could be removed. As an example, “aircraft safe for maintenance” checks are a standard part of the curriculum for every maintenance AFS and will only need to be taught once if AFSs are combined. Under our conservative and aggressive assumptions, time spent on each subject can be reduced by 5 or 10 percent times the number of AFSs combined, respectively. For example, for the LIT AFS, which combines four AFSs (TAMS, Avionics, LOASM, and Weapons), we add up the current time spent in technical school for each of these AFSs and reduce that amount by 20 percent (5 percent times four AFSs combined) and 40

percent (10 percent times four AFSs combined) under our conservative and aggressive assumptions, respectively.²¹

Along with the training times spent in technical school for each course, the days spent on moving between bases for different trainings were calculated. The calculation for the number of moves required for an airman in training used the number of unique training locations required for each job grouping. One move was assumed to take five calendar days, with the assumption that trainings can be aligned so that an airman is not required to move back and forth from location A to location B.

Figure 3.1 shows an example of how our assumptions were applied to a LIT maintainer. We see that among the four AFSs that compose the LIT specialty field, technical school and FTU/FTD times range from approximately two months (for Weapons) to five months (for TAMS and Avionics). A LIT maintainer would spend nine to 12 months in technical school based on our aggressive and conservative assumptions, respectively. This does not include approximately two months spent at BMT.

Figure 3.1. Example of Calculation of Technical School and FTU/FTD Times for a LIT Maintainer



NOTES: The LIT conservative calculations reduce time training in each area by 20 percent (5 percent x four AFSs combined); LIT aggressive calculations reduce training in each area by 40 percent (10 percent x four AFSs combined). Times include five days for each move between training locations. Time spent at BMT not included.

²¹ Our conservative assumption on the amount of overlap is roughly in line with technical school course time estimates that were generated by the F-35 ATC at Eglin AFB for the BOLT concept. Subject-matter experts from the BOLT and LIT experiments suggested that additional redundancies could be eliminated from the technical school curriculum if BOLT- and LIT-specific courses were developed. We developed our more-aggressive technical school time assumptions to reflect this perspective. A detailed task analysis—i.e., an examination of all maintenance tasks falling under an AFS and the overlap of tasks between merged AFSs—was outside the scope of this study, but would increase precision in the technical school time estimates.

Using the calculation methodology explained above, the resulting estimates of technical school and FTD/FTU times for each AFS concepts are shown in Table 3.2.

Table 3.2. Estimates of Time Spent at Technical Schools and FTD/FTU by Career Field

| Concept | AFS or AFS Grouping | Conservative (months) | Aggressive (months) |
|-----------------|--------------------------|-----------------------|---------------------|
| Baseline | TAMS (includes engines) | 5.1 | |
| | Fuels | 2.1 | |
| | LO | 2.7 | |
| | Avionics | 5.0 | |
| | Weapons | 2.1 | |
| | Egress | 2.6 | |
| | NDI | 2.3 | |
| | Metals Tech | 3.1 | |
| | AGE | 4.0 | |
| BOLT | Avionics/Egress/Weapons | 8.3 | 6.9 |
| | TAMS/Fuels/LO | 8.6 | 7.2 |
| | NDI | 2.3 | |
| | Metals Tech | 3.1 | |
| | AGE | 4.0 | |
| LIT | Avionics/TAMS/Weapons/LO | 12.0 | 9.1 |
| | NDI | 2.3 | |
| | Metals Tech | 3.1 | |
| | AGE | 4.0 | |
| | Egress | 2.6 | |
| | Fuels | 2.1 | |
| PAF 1 | Avionics/TAMS | 8.4 | 7.5 |
| | Fuels/TAMS | 5.9 | 5.3 |
| | LO/TAMS | 6.6 | 5.9 |
| | Weapons/TAMS | 5.9 | 5.3 |
| | Egress/TAMS | 6.3 | 5.7 |
| | NDI/TAMS | 6.3 | 5.6 |
| | Metals Tech/TAMS | 7.0 | 6.3 |
| | AGE/TAMS | 7.6 | 6.8 |
| | TAMS | 5.1 | |
| PAF 2 | Avionics/TAMS/Weapons/LO | 12.0 | 9.1 |
| | TAMS (includes engines) | 5.1 | |
| | Fuels | 2.1 | |
| | LO | 2.7 | |
| | Avionics | 5.0 | |
| | Weapons | 2.1 | |
| | Egress | 2.6 | |
| | NDI | 2.3 | |
| | Metals Tech | 3.1 | |
| | AGE | 4.0 | |
| PAF 3 | Metals Tech/Fuels/NDI/LO | 8.4 | 6.4 |
| | Weapons/Egress | 4.3 | 3.9 |
| | Avionics | 5.0 | |
| | TAMS | 5.1 | |
| | AGE | 4.0 | |

NOTE: Does not include time spent at BMT. When training time is equal to existing AFSs' training time, a single value is shown indicating the conservative and aggressive times, which are assumed equal.

Table 3.3 provides a summary of the weighted average time an F-35A airman will spend in technical school and at FTD/FTU for each AFS concept.²² The LIT and BOLT concepts are associated with the greatest overall increase in additional technical school and FTD/FTU time. This stems from the fact that the consolidation of current AFSs affects a larger share of the airmen and requires broader training requirements.

Table 3.3. Estimates of Weighted Average Time Spent at Technical Schools and FTD/FTU by AFS Concepts

| AFS Concept | Weighted Avg. Technical School and FTD/FTU Time per Airman (months) | | Percentage Increase from Baseline | |
|-------------|---|------------|-----------------------------------|------------|
| | Conservative | Aggressive | Conservative | Aggressive |
| Baseline | 3.9 | | — | |
| BOLT | 7.9 | 6.7 | 103 | 71 |
| LIT | 10.6 | 8.2 | 172 | 109 |
| PAF 1 | 6.3 | 5.8 | 60 | 48 |
| PAF 2 | 5.9 | 5.2 | 51 | 33 |
| PAF 3 | 5.3 | 4.9 | 36 | 26 |

NOTES: Estimates based on weighted average for maintainers in nine current F-35A maintenance AFSs. In most concepts, some AFSs are not affected by consolidations.

Technical School Costs

To estimate the cost of initial airman training, we used data from Air Force Instruction 65-503 (2018), Table A18-1A, which provides information on the duration and variable cost of technical school and FTD/FTU training by AFS. These costs include

- recruiting and intake costs (e.g., cost of recruiting, initial travel, and clothing)
- cost per graduate for training courses required for specific AFS at basic skill level (including BMT)
- student pay and allowances
- travel costs
- time in transit and waiting for classes to begin.

The cost data contained in AFI 65-503 end in FY 2014 and have not been updated since then. Costs were inflated to FY 2019 dollars using the Gross Domestic Product Price Index of the Bureau of Economic Analysis (Bureau of Economic Analysis, 2020).

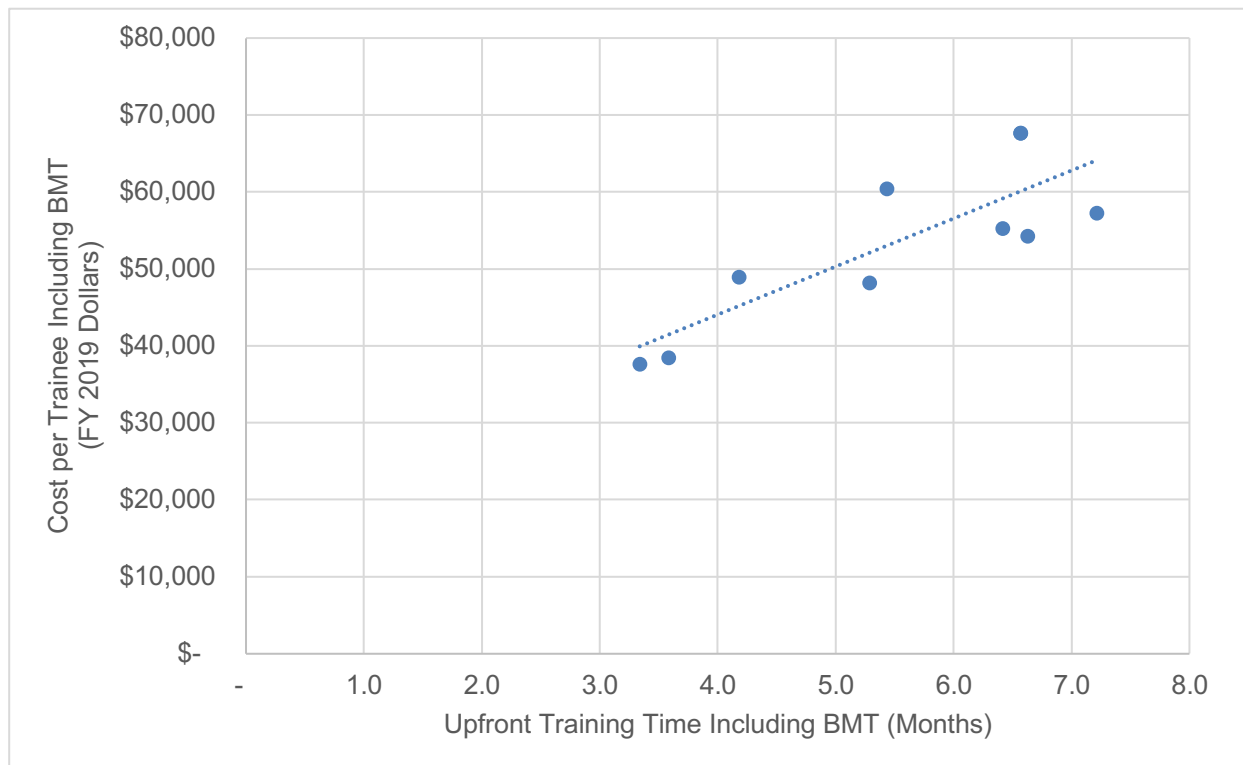
Figure 3.2 shows the general relationship between the amount of training days required for select fighter “2A” (aerospace) and “2W” (weapons) AFSs and the cost of training.²³ The time

²² The shares used in these calculations are shown Figure 2.1.

²³ The AFSs included in the analysis are 2A335B (Avionics, F-35); 2A337B (TAM specialty, F-35); 2A632 (AGE); 2A633 (Egress); 2A634 (Fuels); 2A731 (Metals Tech); 2A732 (NDI); 2A735 (LOASM); and 2W131J (Weapons, F-35).

and cost figures shown here include the BMT. We used regression analysis to estimate the relationship between the incremental cost of training a new airman and the duration of time they spend on up-front training (BMT, technical school, and FTU/FTD). Using a linear regression, with training cost as the outcome and the number of weeks as the covariate, the intercept of \$20,769 and a \$5,602 variable cost per month was calculated. We show the fitted regression line in Figure 3.2.

Figure 3.2. Relationship Between Up-Front Training Length and Cost per Trainee for Select 2A and 2W AFSs



SOURCE: AFI 65-503, 2018, Table A18-1A data.

NOTE: Costs inflated to FY 2019 using the Gross Domestic Product Price Index (Bureau of Economic Analysis, 2020).

We use the fitted relationship to estimate the cost of BMT, technical school, and FTD/FTU for each current and hypothetical AFS in FY 2019 dollars. A summary of the weighted average cost of up-front training under each concept is presented in Table 3.4.

Table 3.4. Estimates of the Weighted Average Cost of Up-Front Training (BMT, Technical School, and FTD/FTU) for Each AFS Concept

| AFS Concept | Weighted Avg. Up-Front Training Cost per Airman (FY 2019 Dollars) | | Percentage Increase From Baseline | |
|-------------|---|------------|-----------------------------------|------------|
| | Conservative | Aggressive | Conservative | Aggressive |
| Baseline | \$53,881 | | — | |
| BOLT | \$76,528 | \$69,472 | 42 | 29 |
| LIT | \$91,427 | \$77,832 | 70 | 44 |
| PAF 1 | \$67,076 | \$64,464 | 24 | 20 |
| PAF 2 | \$65,145 | \$61,067 | 21 | 13 |
| PAF 3 | \$61,837 | \$59,530 | 15 | 10 |

NOTE: Estimates use weighted average for maintainers in nine current F-35A maintenance AFSs. In most concepts, some AFSs are not affected by consolidations.

Assumptions and Caveats of This Analysis

The actual time and costs associated with the up-front training of airmen under new AFS concepts is uncertain. To address this uncertainty, we have developed estimates using both aggressive and conservative assumptions to highlight uncertainty in outcomes under each concept. Indeed, during our discussions with stakeholders and subject-matter experts, we encountered substantively different perspectives on how up-front training might change in the event that new AFS concepts, such as those considered here, are adopted.

In addition, other changes not discussed here could change the time and cost estimates presented in this chapter. For example, some stakeholders have suggested technical school times can be reduced dramatically by eliminating non-F-35A specific training, transitioning some training from technical school to on-the-job training at their home station, or both. Other changes, such as integrating new training approaches, could affect the way training is performed in the future (e.g., the integration of virtual reality training simulations) and affect actual outcomes relative to our estimates.

4. Maintainer Availability Under Alternative Maintenance Manpower Force Structure Concepts

If maintainers are required to take on additional tasks as part of new career field concepts, they will need to receive additional training beyond the up-front time spent in BMT and technical school and at an FTD/FTU, as discussed in the previous chapter.²⁴ The additional training burden has the potential to reduce the amount of time that maintainers are available to perform maintenance. A critical step in understanding the costs of AFS consolidation is to quantify the additional training burden that it will place on maintainers. This chapter presents analysis of the training burden of different career field concepts over the course of an entire Air Force career.

To accomplish this, we first characterized how time is spent on different activities over a 15-year career for each existing and consolidated AFS.²⁵ This provides a baseline from which to consider a maintainer's availability to perform maintenance activities. Then, current retention rates are applied to estimate the impact on active duty maintainer availability.

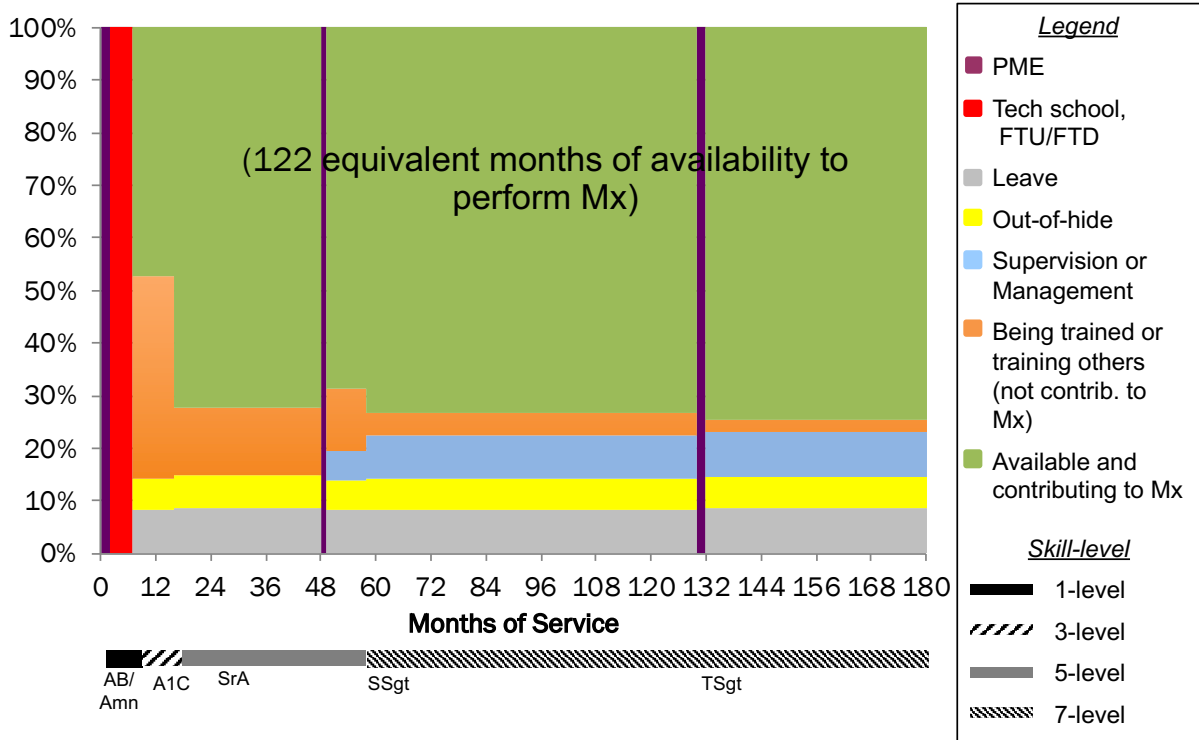
Estimating Maintainer Availability Under the Baseline F-35A AFS Concept

Aircraft-maintenance personnel spend a significant portion of time engaged in training and non-maintenance activities (Drew et al., 2008). In this section, we summarize assumptions derived from data, the literature, and input obtained from subject-matter experts, which support calculations of how maintainers spend their time over the course of their careers, under the current F-35A AFS structures. This includes assumptions about time spent on Professional Military Education (PME), technical school, leave, out-of-hide duties, supervision and management, and being trained and training others. We depict these factors and their relationships with maintainer availability for a TAMS maintainer in Figure 4.1. Although no maintainer's career will look exactly like what is depicted in Figure 4.1, the figure is intended to reflect a rough average of how a large population of TAMS maintainers might spend their time under current conditions. In the following subsections, we discuss the assumptions that we used in our analysis and that are portrayed in Figure 4.1.

²⁴ Throughout our analysis, we assume that training is expanded for each AFS consolidation concept to maintain maintainer competency in tasks that they can be assigned.

²⁵ After 15 years, Air Force maintainers are typically promoted to the rank of Master Sergeant (MSgt). Once attaining the rank of MSgt, the maintainer generally moves from being a first-line technical expert and supervisor to an operational leader and manager. At this point, the maintainer has moved away from hands-on aircraft maintenance (Light et al., 2016).

Figure 4.1. Share of Time Spent on Different Activities for a TAMS AFS Under Current System



NOTE: AB/Amn = Airman Basic/Airman; A1C = Airman First Class; Mx = Maintenance; SrA = Senior Airman; SSgt = Staff Sergeant; TSgt = Technical Sergeant.

Professional Military Education

As discussed in Chapter 3, every enlisted service member starts their military career with BMT, which lasts approximately eight weeks (excluding travel).²⁶ After about four years of service, maintainers will spend approximately 1.2 months (35 days) at Airman Leadership School (ALS). Following ALS, maintainers can take on supervisory and management roles. At 12 years of service, maintainers will typically spend 1.4 months (42 days) at Noncommissioned Officer Academy (NCOA).²⁷ The three PME events are depicted in purple in Figure 4.1. The timing and length of PME is assumed to be the same for existing AFSs and for consolidated AFS concepts.

²⁶ With travel included, time associated with BMT is slightly greater than eight weeks. We include travel time for various activities (e.g., BMT, technical school) in our calculations.

²⁷ In 2014, the NCOA course was changed to include a 12-month correspondence course designed to provide foundational concepts to noncommissioned officers (NCOs), prior to the four-week in-residence Intermediate Learning Experience. All Airmen with seven to 12 years in service (regardless of rank) are eligible to take the new NCOA course, and Airmen with more than 12 years in service are eligible to take the computer-based training portion only (Da Cunha, 2014). These changes make it possible for Airmen to attend NCOA earlier in their careers.

Technical School and FTU/FTD Training

After completing BMT, airmen attend technical school, where they learn basic maintenance skills and are introduced to Technical Orders and basic safety rules required to work in their assigned areas of specialization. The amount of time (and number of locations where training is performed) varies by AFS, as discussed in Chapter 3 and shown in Tables 3.1 and 3.2. Time spent in technical school and at FTD/FTU for TAMS maintainers is approximately five months and is depicted in red in Figure 4.1.

Leave

Currently, airmen receive one month of leave per year. Leave is represented in gray in the TAMS example shown in Figure 4.1.

Out-of-Hide Duties

Maintainers must perform out-of-hide tasks as part of their employment responsibilities. These include, for example, responsibilities associated with being the squadron resources manager, squadron small computer manager, dormitory manager, squadron safety NCO, Honor Guard, and other nonfunded positions.

Time spent on out-of-hide duties can vary significantly across individuals and over one's military career. Out-of-hide duties are assumed to reduce an active-duty maintainer's availability to perform maintenance by 0.7 months per year, on average.²⁸ Out-of-hide duties are shown in yellow in the TAMS example depicted in Figure 4.1.

Supervision or Management

SrAs and NCOs spend a portion of their time performing supervisory or management functions, such as mentoring, providing subordinate feedback, writing enlisted performance reports, and managing subordinate training and career development. Consistent with Light et al. (2016), for SrAs who have graduated from ALS, 0.5 months per year are allocated to supervision and management duties; for NCOs, one month per year is allocated for supervision and management activities. Supervisory or management roles are shown in blue in Figure 4.1.

Upgrade Times

Once arriving at their duty stations, maintainers will spend a significant portion of time on the Maintenance Qualification Training Program and on-the-job training. As part of this training, airmen spend some of their time working on an aircraft and learning or using new skills required

²⁸ This is in line with the share of authorized maintenance positions associated with out-of-hide positions reported in Drew et al. (2008) and assumed in similar analysis presented in Light et al. (2016).

by their specialty field. As maintainers advance in training, they move up in skill level, from 3- to 5- to 7-level.

In January 2019, the 12-month upgrade time in training required for the award of 5- and 7-skill level was eliminated, and it is now determined by the Career Field Manager (AFI 36-2651, 2019). Our understanding from staff at ACC/A4 and AF/A4L is that this change will likely reduce the average upgrade time from 3- to 5-level observed in FY 2018 from 13 months down to around nine months. For our assessment, we assume a nine-month average upgrade time from 3- to 5-level. We assume that at 58 months of service, maintainers are promoted to SSgt and transition to 7-level status.²⁹

Being Trained and Training Others

Consistent with Drew et al. (2008) and Light et al. (2016), it is assumed that 75 percent of a maintainer's time performing maintenance as a 3-level is in a training capacity (being trained), and this falls to 25 percent as a 5-level maintainer and 5 percent once a maintainer reaches 7-level status. Furthermore, it is assumed that 40 percent of the time that a maintainer spends being trained contributes to the maintenance mission.

Once maintainers become a 5-level, they start to train other maintainers. Under the current system, it is assumed that maintainers at the 5- and 7-level spend, on average, 1.8 months per year training others. It is assumed that maintainers are 85 percent productive and contributing to the maintenance mission when they are training others.³⁰ Time that maintainers spend doing independent maintenance (not being trained or training others) is assumed to be 100 percent effective. The example shown in Figure 4.1 depicts in orange the amount of time that a TAMS maintainer is being trained or training others and not contributing to the maintenance mission under the current system.

Available and Contributing to Maintenance

Using the assumptions outlined in the previous section, the amount of time that maintainers are available and potentially contributing to the maintenance mission for each of the existing F-35A maintenance AFSs is calculated.³¹ In Figure 4.1, this area is depicted in green. For the TAMS example shown in Figure 4.1, we calculate they are available and potentially contributing to the maintenance missions for 122 months (the area shown in green) over a 180-month (15-

²⁹ This is consistent with 7-level upgrade times observed in FY 2018.

³⁰ The assumptions on training and trainer productivity levels were derived by Drew et al. (2008) from Oliver (2001), Albrecht (1979), and Dahlman, Kerchner, and Thaler (2002).

³¹ The calculation of time "available and contributing to maintenance" incorporates the assumptions on effectiveness outlined in the previous section. For example, if a maintainer spends one hour being trained, they contribute 24 minutes (60 minutes x 40 percent effective) of equivalent time to the maintenance mission.

year) career. Table 4.1 reports our estimate of maintainer availability for other F-35A AFSs currently.

Table 4.1. Estimate of Maintainer Availability for Current F-35A AFSs over a 15-Year Career

| AFSC | AFS | Maintainer Availability to Perform Maintenance over 15-Year Career (equivalent months) |
|-------------|-------------------|---|
| 2A3X7B | Crew Chief (TAMS) | 122.3 |
| 2A3X5B | Avionics | 122.3 |
| 2W1X1 | Weapons | 124.5 |
| 2A6X2 | AGE | 123.0 |
| 2A6X3 | Egress | 124.1 |
| 2A6X4 | Fuels | 124.4 |
| 2A7X1 | Metals Tech | 123.7 |
| 2A7X2 | NDI | 124.3 |
| 2A7X5 | LOASM | 124.0 |

Maintainer Availability Under AFS Consolidation Concepts

To understand the potential increase in training burden associated with combining AFSs, we adjust the training assumptions discussed above and recalculate maintainer availability for each consolidated AFS concept. When making these calculations, we assume that (1) time spent on PME, leave, out-of-hide, and supervision and management activities will remain the same for each consolidated AFS concept and (2) training (e.g., technical school and FTD/FTU, time spent training while upgrading from 3- to 5- to 7-level) will potentially need to expand to accommodate the broader set of tasks that maintainers are expected to perform.

We summarize our key training assumptions for the current F-35A AFSs and the consolidated concepts we analyze in Table 4.2 and discuss each assumption in the following section. For technical school times and time spent as a 3-level, we assume a range to reflect uncertainty in the training requirements for consolidated AFS concepts.³²

³² The sensitivity of the overall availability results to uncertainty in the assumptions outlined in Table 4.2 was explored in a sensitivity analysis, which can be found in Appendix C.

Table 4.2. Training Assumptions for Baseline and Consolidated AFS Concepts

| | Consolidated AFS Concepts | | |
|---|---|--|---|
| | Baseline | Aggressive | Conservative |
| Technical school times | Based on AETC data | 10% overlap in course content for each combined AFS eliminated (see Chapter 3) | 5% overlap in course content for each combined AFS eliminated (see Chapter 3) |
| Time as a 3-level | 9 months | 9 months | 15 months |
| Time as a 5-level | Varies to Reach SSgt at 58.6 Months of Service | | |
| Percent of time being trained doing maintenance | <ul style="list-style-type: none"> 75 percent for 3-level 25 percent for 5-level 5 percent for new 7-level | <ul style="list-style-type: none"> 75 percent for 3-level 37.5 to 50 percent for 5-level depending on AFS concept 7.5 to 10 percent for new 7-level depending on AFS concept* | |
| Effectiveness while being trained | 40% | | |
| Time spent training others | 1.8 months/year for 5- and 7-levels | 2.7 to 3.6 months per year for 5- and 7-levels, depending on AFS concept* | |
| Effectiveness while training others | 85 percent | | |

NOTES: * = the lower end of the range is assumed for PAF Concept 1, which entails all maintainers being able to launch and recover the aircraft and ground handling and servicing tasks. The high end of the range is applied to the other consolidated AFS concepts (e.g., BOLT, LIT, PAF 2, and PAF 3).

Technical School

When AFSs are combined or expanded, we assume that technical school training times will need to increase to maintain adequate depth of knowledge among maintainers, as discussed in Chapter 3. In addition to being provided current technical school course times, we received an estimate of the technical school training times required for the BOLT concept developed by the F-35 Academic Training Center (ATC) at Eglin AFB. Analysis of that example suggests that, when combined, there is approximately 5 percent overlap in each technical school course content across the AFSs combined in the BOLT concept that could be eliminated.³³ Using this assumption as our conservative estimate, we developed an estimate of technical school times for each consolidated concept. We also developed more-aggressive estimates using input from some subject-matter experts that assumed greater overlap (10 percent) in course time.³⁴ Estimates of

³³ The ATC at Eglin was tasked to examine redundancies in training and to estimate how much training times could be reduced if the BOLT program were formally implemented. They provided us with those estimates.

³⁴ The assumption that technical school training times will increase when AFSs are combined is consistent with Light et al. (2016) but runs counter to Layne et al. (2001, p. 6), who suggest that “[a]s occupational specialties are combined, schoolhouse training may become shorter and more general, while more-specific tasks are learned through on-the-job training.”

the technical school training times for each consolidated AFS concept are shown in Chapter 3 in Table 3.2.

Upgrade Times and On-the-Job Training

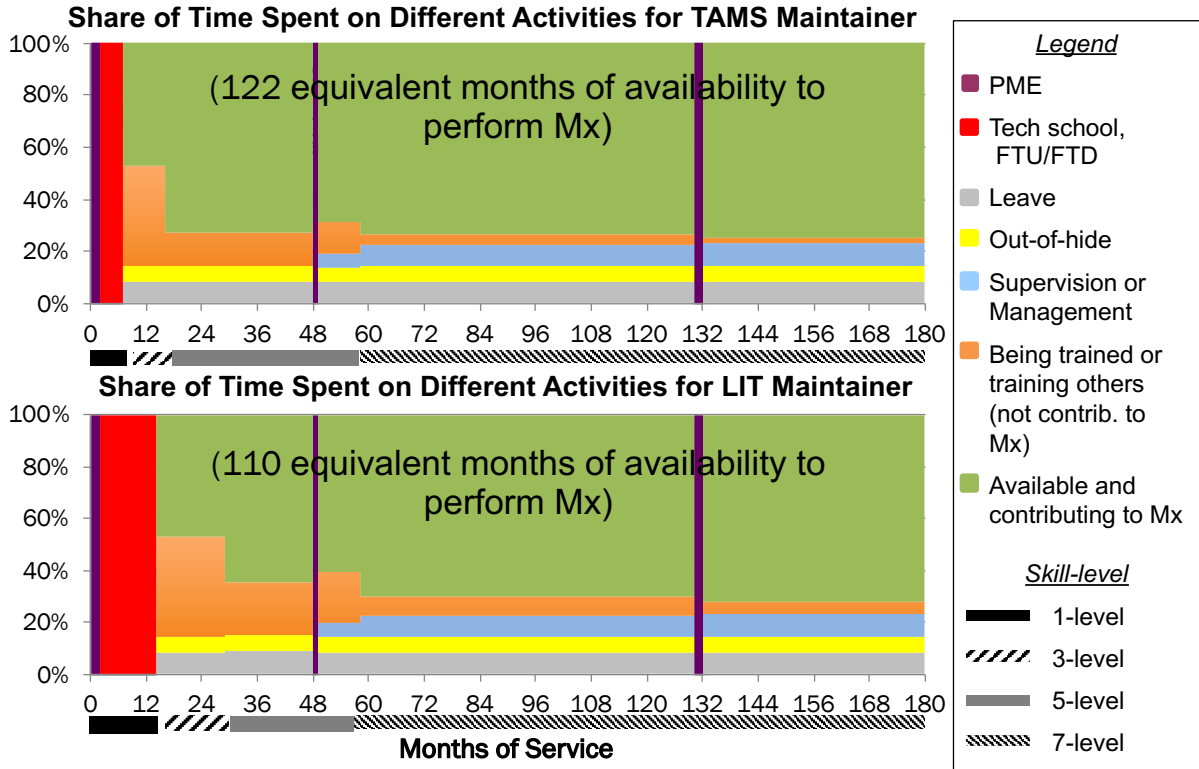
Under the aggressive and conservative consolidated AFS scenarios, the amount of time that maintainers spend, on average, as a 3-level maintainer varies between nine and 15 months. According to our discussions with subject-matter experts, this range reflects the varying perspectives we observed on the potential effects of AFS consolidation on 3-level upgrade times. Time being trained as a 3-level is assumed constant at 75 percent.

We assume that upgrade times from 5- to 7-level remain constant across scenarios at 58.6 months of service. This assumption will force time spent as a 5-level to be reduced when time spent in technical school and as a 3-level is assumed to increase. To account for the more compacted 5-level time, we assume 5-levels will see an increase in their time spent training from 25 percent to 37.5 percent for the PAF 1 concept and 50 percent for the BOLT, LIT, PAF 2 (LIT-trained maintainers), and PAF 3 concepts. Similarly, we assume 7-levels will see an increase in the time they spend being trained from 5 percent to either 7.5 percent (for the PAF 1 concept) or 10 percent for the other consolidated AFS concepts. To account for the increased training burden, we assume 5- and 7-levels see an increase in the amount of time they spend training others, as noted in Table 4.2. Consistent with Light et al. (2016), we hold the effectiveness while being trained and training others constant at 40 percent and 85 percent, respectively.

Maintainer Availability over 15-Year Career for Consolidated AFS Concepts

Figure 4.2 provides an example of how a TAMS and a LIT maintainer would spend their time over the course of a 15-year career. The LIT example assumes our conservative assumptions. In this example, the amount of time that the maintainer is projected to be available and potentially contributing to the aircraft maintenance mission changes from 122 equivalent months for a TAMS maintainer under the current system to 110 months for a LIT maintainer—a reduction in availability to perform maintenance activities of approximately 12 months or 10 percent.

Figure 4.2. Comparison of Time Allocation for a TAMS and a LIT Maintainer



NOTE: Conservative assumptions used for LIT maintainer calculations.

Table 4.3 summarizes the weighted average availability of maintainers in the nine current AFSs and the consolidated AFS concepts over the course of a 15-year (180-month) career.³⁵

Table 4.3. Average Maintainer Availability Under Baseline and Consolidated AFS Concepts over the Course of a 15-Year Career

| Concept | Equivalent Months of Availability | | Percentage Change from Baseline | |
|----------|-----------------------------------|------------|---------------------------------|------------|
| | Conservative | Aggressive | Conservative | Aggressive |
| Baseline | 123.1 | | — | |
| BOLT | 113.5 | 115.2 | -8 | -6 |
| LIT | 112.2 | 114.6 | -9 | -7 |
| PAF 1 | 118.8 | 119.8 | -4 | -3 |
| PAF 2 | 119.8 | 120.6 | -3 | -2 |
| PAF 3 | 119.1 | 119.7 | -3 | -3 |

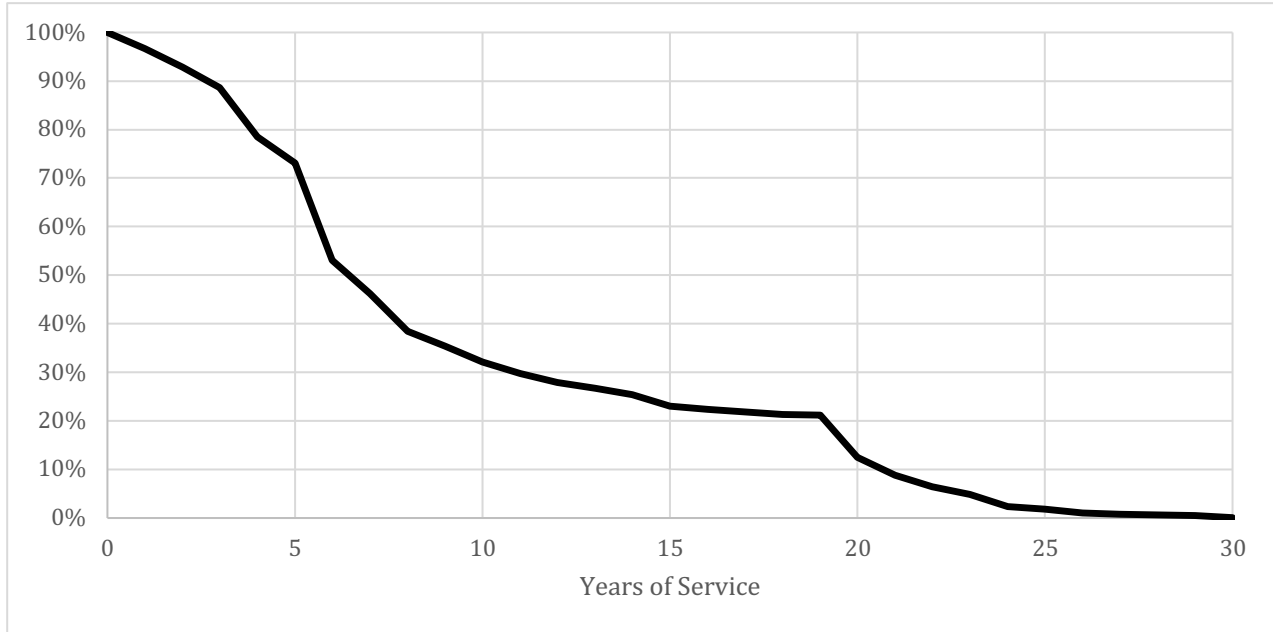
NOTES: Estimates use weighted average for maintainers in nine current F-35A maintenance AFSs. In most concepts, some AFSs are not affected by consolidations.

³⁵ The weighted average availability figures are based on the number of maintainers in each AFS under each concept.

Adjusting for Retention Rates

The maintainer availability estimates shown in Table 4.3 do not take into account maintainer retention. Figure 4.3 shows the retention curve for active-duty Air Force maintainers that was experienced between FY 2015 and FY 2018. Less than one-quarter of active-duty maintainers stay with the Air Force for 15 years; approximately half separate at six years of service.

Figure 4.3. Retention Rate from Active-Duty Maintainners (FYs 2015–2018)



SOURCE: Air Force Personnel Center, 2018.

Table 4.4 shows the research team’s calculations of maintainer availability for each AFS concept, which are adjusted using the retention curve in Figure 4.3.

Table 4.4. Maintainer Availability Under Baseline and Consolidated AFS Concepts After Accounting for Retention

| Concept | Equivalent Months of Availability | | Percentage Change from Baseline | |
|----------|-----------------------------------|------------|---------------------------------|------------|
| | Conservative | Aggressive | Conservative | Aggressive |
| Baseline | | 68.3 | | — |
| BOLT | 60.8 | 62.7 | -11 | -8 |
| LIT | 59.5 | 62.1 | -13 | -9 |
| PAF 1 | 64.9 | 65.8 | -5 | -4 |
| PAF 2 | 65.7 | 66.4 | -4 | -3 |
| PAF 3 | 65.3 | 65.9 | -4 | -4 |

NOTES: Estimates used weighted average for maintainers in nine current F-35A maintenance AFSs. In most concepts, some AFSs are not affected by consolidations.

When comparing the availability estimates that take into account retention before and after AFS consolidation, one sees larger percentage changes than when retention is not accounted for. For example, the LIT concept results in an availability drop of approximately 9 percent under our conservative assumptions before retention is taken into account. If the same comparison is performed after retention is taken into account for the same AFS consolidation example, the reduction in availability is approximately 13 percent. The percentage reduction in availability from AFS consolidation is worse when retention is accounted for because training is frontloaded.

Caveats of This Analysis

The prior analysis makes several assumptions. Both aggressive and conservative scenarios were developed to attempt to bookend the variety of outcomes that might be observed should AFS consolidation be pursued. Actual outcomes, however, could be different if the USAF shifts to new training approaches and concepts. For example, stakeholders noted that the following factors might influence our findings:

- changes to the intensity of fundamental training at technical school
- changes to the degree to which training at technical school focuses on maintenance specific to the F-35A versus other MDSs
- moving to staggered technical school training
- relying on CUT to train maintainers in new AFSs rather than establishing new, consolidated AFSs
- changes to retention rate
- changes to the rate at which F-35A maintainers are transitioned to other platforms
- unique training requirements experienced by the weapons career field that are difficult to quantify in this analysis.

5. Sortie-Generation Capability and Costs of Alternative AFS Concepts

In this chapter, we pulled together several analytic efforts to draw some of the primary conclusions of this report, which are that (1) BOLT, LIT, and PAF 2 offer the potential for O&S cost savings over the baseline, primarily through reduction in the manpower required to meet sortie demand; and (2) even if the opportunity for manpower savings is not exploited, these merged AFS concepts offer significant readiness benefits when implemented through greater sortie-generation capability and greater resistance to capability loss in high-casualty environments.

First, we used LCOM to evaluate how merging AFSs affects the efficiency of task allocation and, thus, the efficiency of sortie generation under a conventional warfighting scenario.³⁶ The task-allocation efficiencies gained by merging AFSs lower the numbers of maintainers needed to achieve a target sortie-generation rate, and LCOM enables quantitative determination of these efficiencies.

However, the LCOM analysis results do not include the penalties on manpower availability that arise for merged AFS concepts because of the increase in the up-front training burden. Thus, in this chapter's second analytic effort, we combined the results of the LCOM analysis with the availability analysis results presented in Chapter 4 to generate an estimate of the level of manpower required, relative to the baseline, to achieve a target sortie-generation rate for each concept that takes the up-front training burden into account.

Finally, we used these differences in relative manpower levels to estimate the differences in direct manpower costs between each concept. These are combined with the training costs described in Chapter 3 to ultimately provide a relative cost-benefit calculation for each merged AFS relative to the baseline concept.

How LCOM Is Used in This Analysis

LCOM is the tool used by the USAF to determine direct maintenance manpower requirements (AFI 38-101, 2019; Dahlman, Kerchner, and Thaler, 2002). Populated with information about aircraft break rates, repair time, and the manpower required for each type of break, LCOM models the maintenance activity at the wing level, which includes both scheduled and unscheduled maintenance. Although LCOM has capabilities to model the complexities of

³⁶ *Sortie-generation efficiency*, throughout this chapter, is generally defined as the rate of sortie production relative to maintenance manning levels, although more-precise measures such as *direct maintenance manpower requirement* will be defined and used. "Higher" sortie-generation efficiency corresponds to more sorties flown with lower levels of maintenance manning.

wing-level maintenance, such as supply-chains and facility capacity, in this report LCOM will be used only to understand the relationship between direct maintenance manpower levels and sortie generation potential. That is, we used LCOM to derive the direct maintenance manpower levels required for each AFS concept before the reduction in availability of maintainers resulting from increased training burden and retention effects (see Chapter 4) was considered.

The F-35 Joint Program Office F-35A LCOM Model

At the time of this report's publication, there was no USAF LCOM model of record for the F-35A because of the relative immaturity of the platform. The LCOM model used in this analysis is an F-35A model developed by the F-35 JPO.³⁷ This version of the F-35A LCOM is populated with engineering estimates of F-35A performance at maturity. Other F-35A LCOM models that were in development at the time of publication included a version populated with status quo break rates for the F-35A via historical F-35A maintenance data from the Failure Reporting, Analysis, and Corrective Action System and a modified version of the JPO model that incorporates some break rates and other data gathered from interviews with current F-35A maintainers.³⁸ Because the goal of this analysis was to look forward to how merged AFS concepts are likely to perform in the long term, the model used in this analysis that predicts performance at maturity is appropriate in the absence of a model populated with break rates and repair times for the mature platform.

The campaign we modeled involves a Programmed Aircraft Authorization (PAA) squadron of 24 aircraft flying a 180-day wartime scenario with three phases that vary in the rates of sorties scheduled, as shown in Table 5.1. Over the entire campaign, the average aircraft utilization rate (UTE) is approximately 1.4.³⁹ The first (seven-day) phase of the campaign is the most intense, with 40 to 80 sorties scheduled per day. The second (23-day) phase and third (150-day) phase involve less-intense flying.

³⁷ The F-35A model used is a JPO model current as of February 2019, which was provided to the research team by the Supportability Analysis Group (AFLCMC/EZIS) at Wright-Patterson Air Force Base.

³⁸ The modified version of the F-35 JPO model was built by 2nd Manpower Requirements Squadron personnel.

³⁹ UTE is defined as the number of sorties per aircraft per day.

Table 5.1. Sortie Schedule Used in LCOM Simulations (24 Aircraft)

| Days | Schedule | UTE (Sorties per Day per Aircraft) | Aircraft Hours per Day | Total Hours |
|--------|--|------------------------------------|------------------------|-------------|
| 1–7 | 40–80 sorties per day, launching ~ every 40 minutes | 1.7–3.3 | 150 | 1,050 |
| 8–30 | 28–56 sorties per day, launching ~ every 60 minutes | 1.2–2.3 | 105 | 2,415 |
| 31–180 | 14–28 sorties per day, launching ~ every 128 minutes | 0.6–1.2 | 52.5 | 7,875 |

NOTE: Average sortie duration was 2.5 hours for all phases of the campaign.

Implementing Merged AFS Concepts in LCOM

Most merged AFS concepts were modeled in LCOM as a complete merger of AFSs—that is, it was assumed that a new AFS created in a merged concept was the complete merger of all tasks associated with the parent AFSs.⁴⁰ The one exception is PAF 1, in which a small subset of TAMS tasks were added to most existing AFSs in the baseline concept. The TAMS tasks added were those that represented the highest-frequency, shortest-duration tasks that include, primarily, those associated with launch and recovery of the aircraft.⁴¹

For all concepts—except PAF 1 and PAF 2—each task in LCOM was broken down to the required manpower resources. Those resources were then mapped to their new AFSs in the concept at hand (e.g., Avionics, Egress, and Weapons technicians were mapped to the new Mission Systems Technician in the BOLT concept) and summed to determine the manpower requirement for the task with the new concept.⁴² PAF 1 and PAF 2 instead used substitution forms that followed this same method but were only activated in the event that traditional manpower resources were insufficient.

⁴⁰ LCOM defines a *task* as an activity that requires resources (e.g., spare parts, manpower) and has a duration (USAF, AFLCMC/EZJS, 2017, p. 70). Individual tasks are linked in task networks to describe the maintenance activity of a squadron. The tasks defined in LCOM and assigned to a particular career field in the LCOM model do not necessarily line up exactly with the way a career field’s tasks are defined in the CFETP, although validated LCOM models are expected to represent the activity of maintenance squadrons accurately.

⁴¹ To determine which tasks were associated with launch and recovery, we examined the frequency, duration, and number of TAM personnel required for each task in the LCOM model to determine the total maintenance man-hours (MMH) used for each task. We found that 73 tasks account for 80 percent of the total MMH for TAM personnel. Closer inspection of this reduced task list and the tasks’ relationships in the model’s tasking processes by analysts and subject-matter experts confirmed these to be launch and recovery tasks.

⁴² LCOM allows fractional manpower requirements, though tasks are only completed with whole numbers of maintainers. It achieves this by varying the demand each time the task is called to the whole numbers immediately above and below the fractional number with such frequency that the average use matches the fractional demand. When combining AFSs, this method results in the loss of the “tails” of these demand cases at the extreme high and low ends. For example, if a nominal AFS has a demand of 2.4 people on a task and another nominal AFS has a demand of 1.2 people on the same task, then that task will most commonly require three but sometimes four or five people to complete at any given instance. If those two AFSs are merged, then the new demand would be for 3.6 people for the merged AFS and will most commonly require four but sometimes three personnel. So, although the average manpower required remains unchanged, the specific manpower required for a given instantiation of the task is altered by the merging of AFSs.

Developing Manpower Requirements

Defining Manpower Requirements

Throughout this chapter, we refer to *direct manpower requirements*, which we define as the lowest number of maintenance personnel required to achieve a 90 percent sortie-generation rate in the first seven days of the simulated campaign.⁴³ Manpower requirements for the alternative concepts are expressed as a percentage of the direct maintenance manpower requirement for the baseline concept. Later, when the reduction in maintainer availability is considered in the calculation of the number of maintainers needed to produce a target sortie generation rate, we will use the term *direct manpower requirements, considering up-front training burden*.

This analysis does not attempt to derive a “true” maintenance manpower requirement—that is, one that could be used to set manning levels in future F-35A MXGs by the USAF. Indeed, no absolute manning levels are reported at all in this analysis; we simply reported the relative difference between the alternative concepts and the baseline concepts. There are several reasons for this. First, as is discussed in the next section, there is no USAF LCOM model of record for the F-35A. Given the immaturity of the F-35A program, it is premature to develop a maintenance manning plan while the mature maintainability and reliability of the aircraft are unknown.⁴⁴

Second, the focus of this analysis is on the relative efficiencies that can be gained by moving to alternative concepts. Although the changes in break rates or repair times of the F-35A that are inevitable as the aircraft matures will affect the direct manpower requirements modeled by LCOM, the *relative* differences in direct manpower requirements between the concepts should be less likely to change. These relative differences are going to be sensitive to changes in how tasks are allocated to career fields and the crew sizes required for tasks, which are elements of the LCOM model that are more stable over time. Thus, by focusing on relative direct manpower requirements rather than absolute numbers, the results of this analysis should be relatively stable across iterations of the F-35A LCOM model as it is continually improved with new data over time.

Using LCOM to Find Direct Maintenance Manpower Requirements

Generally speaking, the typical LCOM workflow has users input a set number of personnel and a sortie schedule, and LCOM runs a Monte Carlo simulation that attempts to fly those sorties. Breaks and schedule maintenance occur according to the reliability and maintainability of the aircraft, and the availability of manpower determines whether that maintenance is completed in time for sorties to depart on schedule. After many simulation runs, LCOM outputs

⁴³ The details of the campaign simulated in LCOM are discussed in the previous section and Table 5.1.

⁴⁴ As the aircraft matures and LCOM models are updated with mature reliability and maintainability estimates, the fidelity of the model will improve along with confidence in the results of the analysis.

a variety of statistics, including the percentage of scheduled sorties that can be flown with the specified number of personnel.

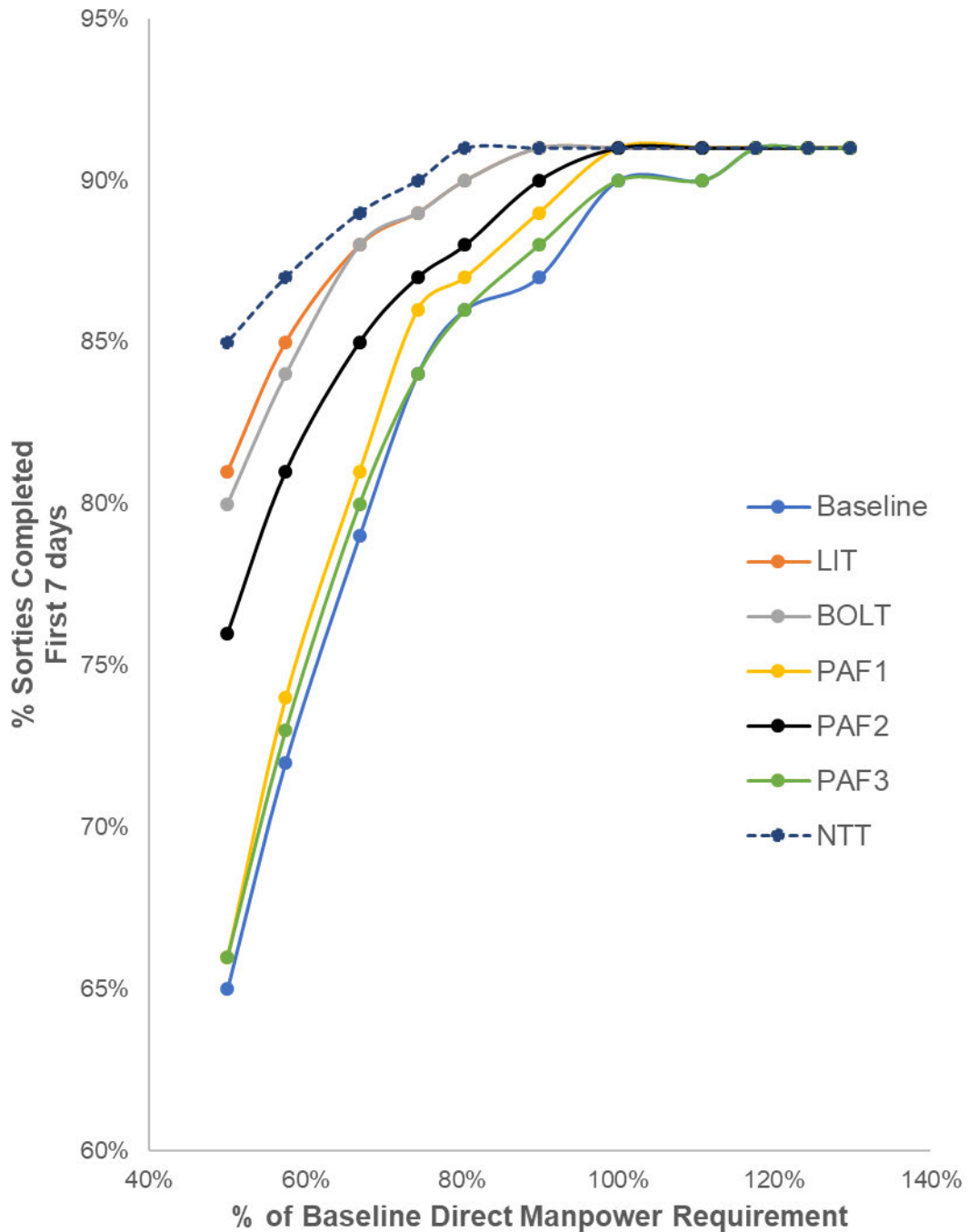
The LCOM optimizer function runs LCOM in reverse to determine the minimum number of personnel needed to meet a determined sortie schedule.⁴⁵ For each of the evaluated concepts, this starting manpower value was used to develop the initial manning level in each merged AFS and gradually decreased.⁴⁶ LCOM was run in its simulation mode to determine how much of the sortie schedule was flown for each manpower value. This yielded curves of maintenance manpower versus sortie completion percentage, as shown in Figure 5.1.⁴⁷

⁴⁵ In LCOM version 5.2, an optimizer determines the minimum manpower that can achieve 96 percent of a given sortie-generation schedule.

⁴⁶ Manpower was reduced proportionally to existing manpower, such that each shift for each AFS saw an approximately equal reduction in manpower percentage at each step. This reduction is approximate because we must have whole numbers of personnel, so some rounding was performed. In addition, no AFS was permitted to drop both of its shifts below the *minimum manpower threshold* for that AFS, defined as the minimum manpower required to complete all tasks to which that AFS is assigned.

⁴⁷ The maintenance manpower versus sortie completion percentage curves were used to estimate a direct manpower requirement for each concept. The manpower requirement was set as the lowest manpower level at which at least 90 percent of the sorties during the most demanding phase of the campaign—the first seven days—could be completed. Each alternative concept’s direct manpower requirement is expressed as a percentage of the baseline direct manpower requirement.

Figure 5.1. Sortie Generation at Varying Manpower Levels for the First Seven Days of the Campaign



NOTES: Percentage of baseline direct manpower requirement is calculated as the ratio of the total number of maintainers used in the simulation divided by the number of maintainers needed to obtain a 90 percent sortie-completion rate in the first seven days for the baseline maintenance concept. Results do not consider decrease in maintainer availability because of the up-front training burden of merged AFS concepts.

Adjusting Direct Maintenance Manpower Requirements to Account for Up-front Training Burden

The manpower requirement derived directly from LCOM, as described in the previous section, does not include the reduction in maintainer availability that occurs because of the increased up-front training burden of merged AFS concepts (see Chapter 4). To account for this, the direct maintenance manpower requirement from LCOM for each concept was modified by the availability reduction using the following equation (see Table 4.3):

$$\begin{aligned} & \textit{Direct manpower requirement, upfront training burden considered} \\ & = \textit{Direct manpower requirement} * (1 - \% \textit{ change in availability}) \end{aligned}$$

This modification increases the direct manpower requirement that is derived from LCOM by the percentage reduction in maintainer availability that occurs because of the up-front training burden. This “direct manpower requirement, up-front training burden considered” is the manpower requirement that carries through to the final O&S cost calculations.

Caveats of the LCOM Analysis

Several important caveats must be considered when interpreting these results:

- The LCOM model reflects estimated future performance of the F-35A and might not reflect actual future performance.⁴⁸
- The structure of the F-35A LCOM model merges the LOASM and Metals Tech AFSs.
- Merged AFS concepts are generally represented as complete unions of multiple AFSs when implemented in LCOM. This assumes that all maintainers in a merged AFS are equally as effective at all tasks as in unmerged AFSs. This could overestimate the effectiveness of merged AFS concepts, if maintainer performance on merged AFS concepts is reduced relative to the baseline.
- We assume that the way this LCOM model defines tasks and links those tasks to AFSs is consistent with how the AFSs will be structured in the future and, related to the previous assumption, how those AFSs would be structured if merged with other AFSs.
- The simulation is run assuming unlimited supply of parts, SE, and facilities—only manpower is constrained.
- This analysis calculates relative manpower requirements between the baseline concept and the merged AFS concepts and ultimately is used to understand the relative costs of merged AFS concepts to the baseline. Because there is no current F-35A LCOM model of record for the USAF, this analysis does not attempt to determine an absolute direct manpower requirement.
- There are many other caveats associated with LCOM analyses, in general, as is the case with all simulation models. A detailed discussion of LCOM, how it is used to generate manpower requirements, and the general caveats that should be considered can be found

⁴⁸ Conversations with LCOM subject-matter experts suggest, anecdotally, that this F-35A model shows generally higher reliability than legacy-fighter LCOM models.

in Dahlman, Kerchner, and Thaler (2002)'s analysis of the manpower requirements setting process in the USAF.

Findings from the LCOM Manpower Analysis

In our LCOM analysis, we sought to understand the relationship between maintenance manpower and sortie-generation potential for each concept. First, the sortie-generation rate was held constant and manpower was decreased to determine how merged AFS concepts are expected to perform with fewer personnel. Second, the sortie-generation rate was varied while manpower was held constant to determine the maximum sortie-generation potential of merged AFS concepts. Together, these two results help us understand how merged AFS concepts can contribute to O&S cost-reduction efforts or readiness enhancements.

Merged AFS Concepts Can Fly More Sorties with Less Manpower

Recall that Figure 5.1 plots the direct maintenance manpower level as a percentage of the baseline direct maintenance manpower requirement versus the sortie-completion rate for the first seven days of the campaign, when flying levels are most intense.⁴⁹ It shows the baseline maintenance concept and LIT, BOLT, and the three PAF-developed concepts. Additionally, it shows results under an NTT maintenance concept, which is based on the way Lockheed Martin currently provides contracted maintenance. Under the NTT concept, we assume there is no division of maintainers by AFS (e.g., all maintainers can do all maintenance tasks). Although the NTT concept is not being considered for adoption by the USAF and is not analyzed elsewhere in this report, it is shown here as an upper bound that represents the maximum efficiency that can be gained by merging AFSs.

As expected, the sortie-completion rate decreases as the number of personnel is decreased for all concepts. However, the merged AFS concepts show a less severe degradation of sortie generation rate than the baseline concept. Generally speaking, the more consolidated a concept, the higher sortie-generation rate that can be maintained as manpower is decreased; in other words, the more efficiently the maintenance workforce can generate sorties.⁵⁰ As can be seen in Table 5.2, the most-consolidated concepts—PAF 2, BOLT, and LIT—can maintain greater than 75 percent of the sortie schedule in the first seven days of the conflict with only half of the

⁴⁹ Note that this baseline manpower requirement is the number of maintenance personnel required for the baseline construct to achieve at least a 90-percent sortie-completion rate in the first seven days of the campaign.

⁵⁰ This increase in efficiency derives entirely from the reduction of maintainer downtime and the more-efficient allocation of tasks to maintenance personnel. When maintainers are more broadly trained, it is less likely that their time will be underused because they will spend less time waiting for tasks that they are qualified on to occur. Similarly, tasks are more likely to be completed without needing to wait for a maintainer, because there are more maintainers qualified on those tasks. This ultimately leads to a reduction in maintenance wait times. Other drivers of efficiency, such as changes in the time it takes a maintainer to complete a task once it is started (aircraft maintainability) or the frequency at which a task occurs (aircraft reliability), are not considered here. Similarly, this analysis does not consider the availability of spare parts, which can dramatically influence task completion time.

baseline manpower requirement, whereas the baseline concept at that manning level can complete only 65 percent of the sortie schedule.⁵¹

Table 5.2. Sortie-Completion Rates for the First Seven Days at Varying Manning Levels

| Percentage of Baseline Manpower Requirement | Percentage of Sorties Flown, Baseline | Percentage of Sorties Flown, BOLT | Percentage of Sorties Flown, LIT | Percentage of Sorties Flown, PAF 1 | Percentage of Sorties Flown, PAF 2 | Percentage of Sorties Flown, PAF 3 |
|---|---------------------------------------|-----------------------------------|----------------------------------|------------------------------------|------------------------------------|------------------------------------|
| 90 | 87 | 91 | 91 | 89 | 90 | 88 |
| 50 | 65 | 80 | 81 | 66 | 76 | 66 |

NOTES: Percentage of baseline direct manpower requirement is calculated as the ratio of the total number of maintainers used in the simulation divided by the number of maintainers needed to obtain 90 percent sortie-completion rate in the first seven days for the baseline maintenance concept. Results do not consider decrease in maintainer availability because of the up-front training burden of merged AFS concepts.

The high performance of merged AFS concepts at low maintenance manning levels—and, notably, the slower rate of degradation of sortie-generation capability as manpower is decreased—is helpful for understanding how merged AFS concepts might perform in environments with high casualty rates. Indeed, the merged AFS concepts improve resilience of sortie-generation capability to reductions in available personnel because there are more individuals who are qualified to do any single maintenance task, such that the loss of any individual is less likely to affect sortie-generation capabilities. This additional benefit of merged AFS concepts is discussed further in Chapter 6.

What underlies these observed advantages of merged AFS concepts with respect to sortie generation? First, merged AFS concepts generally outperform the baseline concept because of the greater efficiency of task allocation among personnel. That is, in the most general sense, the broader a career field, the less likely it is that personnel will experience downtime while they wait for the tasks that they have expertise in to come up. Second, the most efficient concepts—BOLT, LIT, and PAF 2—merge AFSs that are highly negatively correlated in the timing of their workload;⁵² specifically, Weapons and Avionics and Weapons and LOASM.⁵³ These AFS combinations have peaks in their typical demand occurring at different times, which enables the most-efficient allocations of tasks across available personnel.

⁵¹ These results do not include consideration of the loss of maintainer availability because of up-front training burdens.

⁵² When career fields have tasks that occur at different times from each other, their combination leads to a reduction in the downtime of a maintainer in the merged AFS.

⁵³ See Appendix D for a full discussion of this analysis.

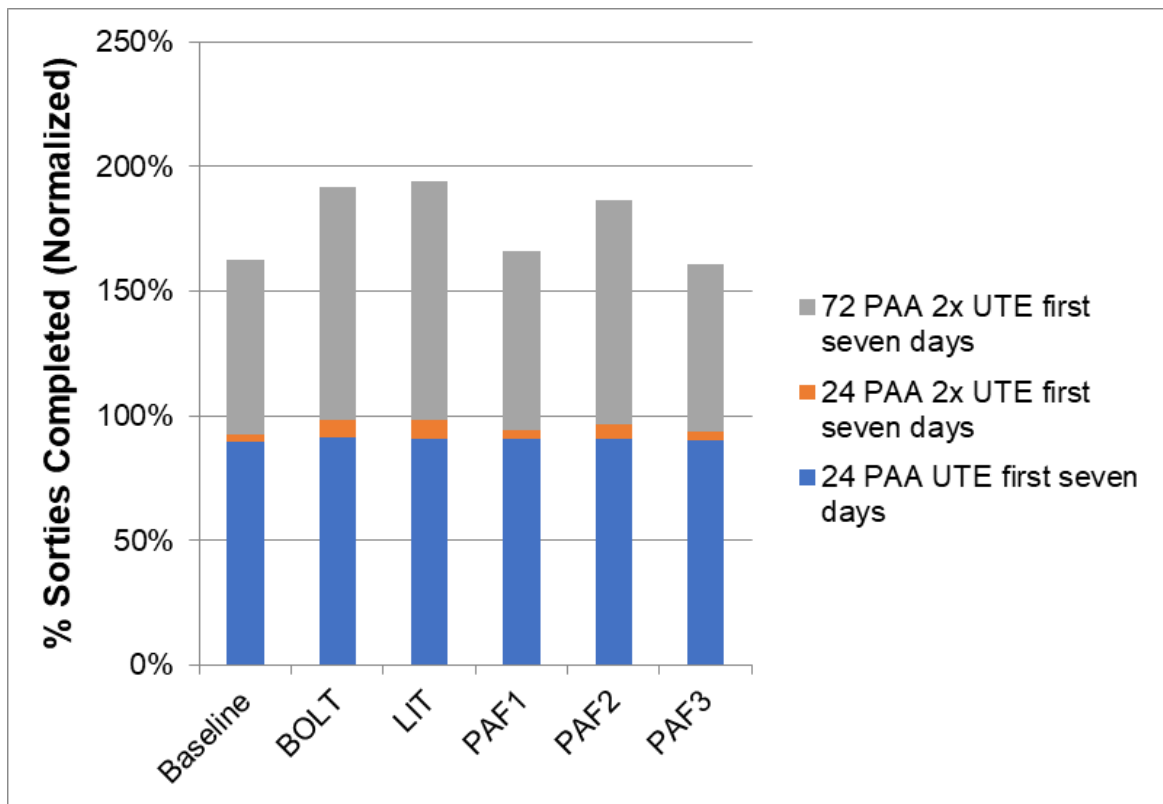
Merged AFS Concepts Have Greater Sortie Generation Potential in High-Demand Scenarios

One clear conclusion from Figure 5.1 is that some merged AFS concepts offer the opportunity for reductions in manpower because of their increased efficiency in sortie generation. We discuss this potential manpower reduction in more detail in the next section of this chapter. However, if the USAF does not reduce manpower—that is, if it retains the baseline manpower requirement—and adopts merged AFS concepts,⁵⁴ the greater efficiency of sortie generation it experiences can enable higher rates of sortie production beyond the programmed level. To explore this potential, the research team ran simulations in LCOM in which all concepts were manned at the baseline manpower requirement level and operated at a very high sortie rate over a seven-day campaign.

Figure 5.2 shows the results of these simulations. Three campaigns are simulated, varying in the squadron size and the UTE but with a constant manning level across all concepts. The 24 aircraft–lower demand case is equivalent to the first seven days of the campaign used to set manpower requirements and is shown in Figure 5.1. In Figure 5.2, the percentage of sorties completed for all three campaigns is normalized to this sortie generation rate. There are differences between the baseline concept and the merged AFS concepts, but these differences are relatively small. Similarly, when the requested sortie rate doubles but the squadron size is kept at 24 PAA, a similar effect is seen. This is because sortie generation is not constrained at this point by the manpower but rather by the maintainability and reliability of the aircraft and the size of the squadron. The model is in a regime where, no matter the efficiency of the manpower or the total amount of manpower provided, the sortie rate is not going to improve until additional aircraft are added to the squadron.

⁵⁴ The *baseline manpower requirement* is defined as the minimum manpower required under the baseline concept to meet 90 percent of the first seven days' sortie schedule.

Figure 5.2. Performance of Merged AFS Concepts in Very High Sortie Rate Scenarios



NOTE: The percentage of sorties completed for all UTE rates simulated is normalized to the “24 PAA UTE first seven days,” which is equivalent to the first seven days’ sortie rate used in the previous LCOM simulation seen in Table 5.1 and Figure 5.1.

However, when the number of aircraft is increased to 72 PAA, there is a significant difference between the concepts, comparable with the separation of performance observed in Figure 5.1 at lower manning levels. In this regime, in which manpower is the limiting factor on sortie generation, the greater efficiency of the merged AFS concepts has a significant impact on the maximum number of sorties that can be generated.

Summary of Insights from the LCOM Analysis

The results of this analysis show two potential benefits of the greater sortie generation efficiency of merged AFS concepts, depending on whether the USAF mans to the lower direct manpower requirements or to the baseline levels to increase readiness. The first benefit is *decreased cost*, in that programmed sortie generation rates can be achieved through lower manpower requirements with some merged AFS concepts; the potential manpower reductions are explored in detail in the next section, with adjustments for up-front training burden considered. The second is *increased readiness*: If manpower requirements are not lowered, greater sortie-generation potential beyond programmed rates can be attained with some merged AFS concepts.

Some Merged AFS Concepts Offer the Opportunity for Manpower Savings, Even When Availability Reductions Due to Training Are Considered

A direct manpower requirement as a percentage of the baseline requirement was determined for each concept by taking the minimum manpower that enables 90 percent of sorties to be flown in the first seven days of the conflict. Table 5.3 shows the direct manpower requirement of each concept, relative to the baseline concept. It also shows the availability-adjusted direct manpower requirement,⁵⁵ which accounts for the up-front training burden of merged AFS concepts. Numbers less than 100 percent indicate the potential for manpower savings compared with the baseline concept, whereas numbers greater than 100 percent indicate a greater manpower cost for a concept than the baseline.

Table 5.3. Estimated Direct Manpower Requirement for Alternatives as a Percentage of Baseline Manpower Requirement With and Without Consideration of Up-Front Training Burden

| Concept | Percentage of Baseline Manpower Requirement, Not Considering Up-Front Training Burden | Percentage of Availability Reduction Due to Up-Front Training Burden | Percentage of Baseline Manpower Requirement, Considering Up-Front Training Burden |
|----------------|--|---|--|
| BOLT | 78 | 8 to 11 | 84 to 86 |
| LIT | 78 | 9 to 13 | 85 to 88 |
| PAF 1 | 95 | 4 to 5 | 98 to 99 |
| PAF 2 | 84 | 3 to 4 | 87 to 88 |
| PAF 3 | 100 | 4 | 104 |

NOTE: Up-front training burden-adjusted manpower requirements were calculated as (percent baseline manpower requirement) * (1 + percent availability reduction).

The results shown in Table 5.3 echo the ordering of the curves seen in Figure 5.1. As expected, the greater task-allocation efficiency of some of the merged AFS concepts enable them to generate sorties with lower numbers of maintainers than the baseline concept, while others have about the same sortie-generation efficiency, before up-front training burden is considered. Because all merged concepts have a higher training burden than the baseline concept, availability is reduced and the manpower required increases when availability is considered. For some concepts, this increase leads to a nearly equal or higher manpower burden than the baseline concept; for others, required manpower remains lower than the baseline, representing the opportunity for manpower savings.

BOLT and LIT show an identical manpower requirement when up-front training burden is not considered. But when that up-front burden is taken into consideration, BOLT—because of its lesser training load—has a slightly lower direct manpower requirement than LIT when availability reductions are included. Both of these consolidated concepts, however, offer relatively high potential for manpower reduction. PAF 2 also has a lower manpower requirement

⁵⁵ See Chapter 4.

than the baseline even when availability is considered. These three concepts offer the greatest potential for manpower savings, even allowing for the increased training burdens of the merged AFS concepts, with a potential 12 to 16 percent reduction in manpower, depending on the concept and assumptions used.

If Some Merged AFS Concepts Are Adopted, O&S Costs Can Decrease

What does the direct manpower requirement look like when we bear in mind both the up-front training burden summarized in Table 5.3 and the training cost impacts shown in Table 3.4? The answer is shown in Table 5.4, which calculates the percentage change in unit-level maintenance manpower and training costs relative to the baseline for each merged AFS concept.⁵⁶ The cost differences are calculated under the following two assumptions:

1. Manpower levels are held constant at the baseline manpower requirement level (e.g., the USAF does not reduce manning).
2. Manpower is adjusted to the baseline manpower requirement considering up-front training burden (Table 5.2, last column) for each concept (e.g., the USAF takes advantage of the maximum manpower savings possible while keeping sortie-generation potential constant at 90 percent of sorties to be flown in the first seven days of the conflict).

As can be seen in Table 5.4, BOLT, LIT, and PAF 2 offer the greatest potential for unit-level maintenance manpower and training cost savings.

Table 5.4. Percentage Change in Unit-Level Maintenance Manpower and Training Costs Under Merged AFS Concepts Relative to Baseline Concept

| Concept | At Baseline Manning Levels (percentage) | Adjusting Manning Levels (percentage) |
|---------|---|---------------------------------------|
| BOLT | +2 to +3 | -11 to -15 |
| LIT | +3 to +5 | -8 to -13 |
| PAF 1 | +1 to +2 | +0 to +1 |
| PAF 2 | <+1 to +1 | -11 to -12 |
| PAF 3 | <+1 to +1 | +5 |

NOTES: Unit-level maintenance manpower cost differences are percentages relative to the baseline concept calculated as $(concept\ cost - baseline\ cost) / (baseline\ cost)$. Costs include training costs, as described in Chapter 3 and Table 3.4, and direct maintenance manpower costs. The “at baseline manning levels” column includes only training costs because manpower levels are being held constant. The “adjusted manning levels” column reduces manpower levels under each concept, such that sortie-generation rates equal those under the baseline AFS concept, as summarized in Table 5.2 (AFI 65-503, 2018, Table A19-2).

⁵⁶ In this analysis, O&S costs include direct maintenance manpower and some training costs, as defined in Chapter 3. There are, of course, many other drivers of F-35A O&S costs that are not considered in this analysis.

6. Performance of Merged AFS Concepts Under Alternative Combat Operational Concepts

The F-35A is important for the USAF, not only because it will be such a large fraction of the fleet, but also because fifth-generation aircraft are an extremely important component of U.S. air power. U.S. fifth-generation aircraft, such as the F-22 and F-35, are designed to be difficult for radars to detect. USAF fifth-generation aircraft need to have dominant lethality against both air-to-air and ground-to-air threats. In a future conflict, the USAF expects to initially face unfavorable force ratios and a complex battlespace featuring a mix of adversary fighter aircraft and ground-based surface-to-air missiles in integrated air defenses threatening aircraft in the air. Fighters could also be subject to attacks from long-range missiles while on the ground. At their air bases, these aircraft need to be able to withstand attacks and continue operating.

The ability of the F-35A to withstand airbase attacks and continue to generate enough combat power to meet the needs of the operation is closely linked to ground-support concepts and capabilities. Although the previous chapter considers how alternative AFS concepts compare in terms of their ability to support conventional warfighting operations, this chapter discusses the ability of more-consolidated AFS concepts to support new and evolving combat strategies designed to better address emerging threats.

The Threat to Air Bases

For over two decades, the USAF has been concerned about increasing adversary arsenals of long-range precision weapons that pose a threat to U.S. airbases.⁵⁷ The key modern feature of these long-range missile threats is their targeting precision, which is enabled by geolocation systems. Potentially, this allows adversaries to efficiently attack airfields from great distances and substantially disrupt U.S. airpower.

The 2001 Quadrennial Defense Review (QDR) identified anti-access threats as a key operational concern. It directed the Secretary of the Air Force to “develop plans to increase contingency basing in the Pacific and Indian Ocean, as well as in the Arabian Gulf” (U.S. Department of Defense, 2001, p. 27). More than a decade later, after Russia invaded Crimea and adopted a hostile posture toward the United States, this also became a concern in the European theater.

The 2018 National Defense Strategy continued these earlier policy statements. It emphasized the need for improved lethality of the force. It highlighted “forward force maneuver and posture

⁵⁷ The 1993 *Bottom-Up Review* identified protection from aircraft or cruise or ballistic missiles as a task to be accomplished in a major conflict (Aspin, 1993, p. 16).

resilience” as one of eight modernization capability priorities. Under this heading, it stated that “Investments will prioritize ground, air, sea, and space forces that can deploy, survive, operate, maneuver, and regenerate in all domains while under attack. Transitioning from large, centralized, unhardened infrastructure to smaller, dispersed, resilient, adaptive basing that include active and passive defenses will also be prioritized.”⁵⁸

There are a variety of ways that an adversary could use long-range precision missiles to disrupt airbase operations. Adversaries could target key sortie-generation infrastructure on an airfield. This would include targets such as runways, fuel storage, munitions storage, and parked aircraft. Similarly, they could target personnel, command and control networks, and power. Finally, they could target the logistics infrastructure needed to support operations. Commercial satellite imagery shows some evidence that China has practiced attacking these types of targets (Shugart, 2017).

A previous RAND analysis assessed the implications of precision airbase attacks. It calculated the number of medium-range ballistic missiles (MRBMs) needed to cut the runways of Kadena Air Base on Okinawa in Japan, and how long air operations could be disrupted with repeated attacks by a total of 36 missiles. This analysis suggested that fighter operations could be disrupted for four days and tanker operations for 11 days (because tankers require longer runways, fewer missiles are needed to prevent tanker operations). This is only one location but gives the disruptions created by possible attacks a sense of scale. To attack all the aircraft parking areas at Kadena with MRBMs with submunition warheads, it would take fewer missiles (27 MRBMs). The same analysis also calculated that 60 DH-10 cruise missiles could attack every fuel storage tank, hardened aircraft shelter, and hangar on Kadena (Heginbotham et al., 2015, pp. 60–65). Russia has a substantial number of accurate cruise missiles and, with the U.S. abrogation of the Intermediate-Range Nuclear Forces Treaty, could develop an arsenal of ground-based missiles to hold North Atlantic Treaty Organization (NATO) airbases and other key military assets at risk.

USAF Adaptation to the Threat

We do not know exactly how future commanders will want to employ the F-35A force. That will depend on many factors, including adversary capabilities, our objectives, and the level of risk we are willing to accept. Furthermore, the USAF has many programmatic decisions for consideration across many possible areas of improvement. To have options to base within the threat ring of adversary missiles, the USAF will need to consider a range of possible adaptations.

⁵⁸ See Mattis, 2018, p. 6. This builds off guidance from the 2014 QDR, which stated that “The Department will enhance capabilities to disperse land-based and naval expeditionary forces to other bases and operating sites, providing the ability to operate and maintain front-line combat aircraft from austere bases while using only a small complement of logistical and support personnel and equipment” (U.S. Department of Defense, 2014, p. 38). See also Weisgerber, 2014.

In peacetime, the USAF can make infrastructure enhancements to key airfields to make them harder to attack. In employing the force, the USAF could prepare for more dispersal (intrinsically lowering the density of aircraft per base), integrated basing (providing support from a network of locations, rather than support tied to one location), agile operations (the ability to complicate adversary targeting through movement and agility), and the expansion of base defenses and post-attack recovery capabilities.

Of these, merged AFS concepts are more-closely linked to the employment adaptations: dispersal, integrated basing, and agile operations. Without knowing exactly how the USAF might implement these decisions, we still sought to comment on how these maintenance concepts might improve USAF resilience by focusing on a few possible adaptations that are relevant to maintenance support. Table 6.1 lists possible resilience measures and identifies those that might influence or be influenced by the maintenance AFS concept adopted in the future for F-35As.

Table 6.1. Links Between Combat Strategies and Maintenance AFS Concepts

| Category | Strategy | Potential Link to Maintenance AFS Concept | Implications for Maintenance Force |
|-----------------|---|--|---|
| <i>Prepare</i> | Infrastructure hardening | No | Not applicable |
| <i>Employ</i> | Disperse | Yes | Smaller units of employment |
| | Integrated basing network | Yes | Flexible size detachments and level of support |
| | Agile operations | Yes | Maintenance might need to move, scale/up or down, or stay and fight |
| <i>Protect</i> | Active missile defense | No | Not applicable |
| | Defend location | No | Not applicable |
| <i>Recover</i> | Asset-specific recovery capability | No | Not applicable |
| | Degrade maintenance capability gracefully | Yes | Ability to endure attrition |

Table 6.1 seeks to link a wide variety of potential adaptations to adversary threats to the way in which the maintenance force is trained and organized. Ultimately, we sought to answer the question: Could training maintainers more-broadly contribute to future warfighting aims? The following sections address the areas where we see a link to the maintenance concept (indicated in the third column of Table 6.1). We explore whether more-consolidated maintenance AFS concepts can meet the evolving needs of the USAF and, when applicable, whether such concepts might contribute to or detract from greater resilience of the USAF in anti-access environments.

Dispersed Operations

Dispersal of aircraft to more bases is one way of coping with missile threats because it makes each airfield a less lucrative target. As aircraft are spread across more and more bases, the impact of shutting down operations at any one base is lower, and the number of weapons required to attack the force goes up.

Base density (that is, the number of aircraft per base) has gone down as the combat potential of aircraft has gone up. In the Vietnam War, the USAF used 19 main operating bases with an average base density of 44 combat and 40 support aircraft per base. In the first Gulf War, the USAF used 24 bases, averaging 34 combat aircraft and 20 support aircraft at each. In Operation Allied Force (NATO's 1999 bombing of Yugoslavia), the USAF used 23 bases and averaged ten combat aircraft per base and 13 support aircraft (Bowie, 2002, pp. 17–18). The lower density of the Allied Force experience notwithstanding, the USAF is structured to deploy and support squadrons, which is the USAF unit of action under a wing-command structure. Currently, most USAF fighter squadrons are composed of 24 aircraft, the exception being the F-22, which has squadrons of 21 or 18 aircraft. Smaller than squadron-size detachments can be deployed, but squadrons are not currently sized to create and support multiple detachments at different locations simultaneously.⁵⁹

We began with dispersal because it is one of the key capabilities called for in the National Defense Strategy and in analysis of the anti-access problem. We raise it more as context than as a discriminator, because the current force and all the maintenance AFS concepts are able to tailor detachments and thus contribute to dispersal (although with different footprint requirements).

The reduced manpower of more-consolidated AFS concepts, such as BOLT and LIT, improves the ability of the USAF to disperse. The results from Chapter 5 indicate that consolidated AFS concepts can either provide equal sortie-generation capacity with a smaller manpower footprint or provide greater sortie rates with an equal manpower footprint. We assume that these relationships hold as the detachment sizes get smaller. A reduced manpower footprint could have some tertiary benefits as well, such as a reduced USAF footprint at each dispersal location. That is because much of the combat service support at a location is tied to the population, so a smaller maintenance footprint could translate to a smaller combat service–support footprint, depending on how much the location requires housing, food, and other life-support and personnel-support functions.

Many factors other than maintenance could possibly constrain the ability of the USAF to disperse. Some are outside the control of the USAF, such as access to appropriate operating locations. Others represent more of a shared responsibility, such as logistics supportability (logistics infrastructure; access; and ability to procure, store, and move resources, including munitions). If the USAF has the needed access and feasible logistics supportability, constraints

⁵⁹ See McGarvey et al. (2013, p. 66), for a discussion of how equipment constraints limit multi-site operations and the costs involved to provide expanded capability for the F-35A squadrons.

on USAF dispersal could hinge on either maintenance support or other support to airbase operations.

USAF support to airfield operations is very flexible, with its maintenance unit type code (UTC) structure allowing the force to source needed support globally. Ultimately, there are limits. At some point, the level of dispersal will exceed the capacity of the USAF to provide desired capabilities. The timing of this will depend on the specific capabilities required across the theater and accounting for continuing requirements outside the theater. Previous RAND research created force demands and then assessed which capability fields constrained dispersal. Results indicated that factors such as security forces, explosive ordnance disposal (EOD), and emergency management were the first support capabilities to constrain greater dispersal. The USAF could elect to expand these capabilities to enhance its capacity to disperse, or it could explore how joint or coalition forces might fill or augment these roles. Tactical control is assigned through the USAF wings, and another limitation on dispersal could stem from span of control challenges (to include not just communications abilities, but the need for mission planning and possible challenges across multiple locations).⁶⁰

In an undegraded environment (i.e., without suffering attrition, which is considered in the “Degrade Gracefully” section later in this chapter), maintenance manpower will not constrain USAF dispersal when each squadron is called on to operate from one location (though not necessarily with the full squadron contingent for deploying forces). If there were a maintenance constraint, it would more likely come from equipment. The F-35A Autonomic Logistics Information System (ALIS) system is a data-intense, networked support system. A Director of Operational Test and Evaluation report in 2018 noted that “[t]he program has completed several deployments to established bases and to austere locations and ships. In each location, the complexities of ALIS have caused a variety of information technology problems that delay the unit’s ability to start generating sorties. Often, the timeframe to start flight operation is longer than that for legacy aircraft” (Director, Operational Test and Evaluation, 2018, p. 31). Similarly, the U.S. Government Accountability Office found in interviews with maintainers that “[u]sers are concerned about ALIS’s ability to deploy in operational environments because of the large . . . server size and connectivity requirements” (U.S. Government Accountability Office, 2016, p. 16). Although this raises concerns about the speed of employment, it does not say that ALIS would constrain dispersal. It does reinforce that, in F-35A dispersal decisions, the USAF needs to consider not just the availability of the equipment, but whether the connectivity needs of the equipment can be met. Other maintenance equipment is less likely than the factors considered above to be a binding constraint on the number of locations that the USAF can operate from in a theater. Furthermore, the maintenance squadrons are designed to support the flying units they are

⁶⁰ Chapter 3 of Mills et al. (2014) identifies support shortfalls in the ACS manpower force.

associated with and are tightly coupled with those units.⁶¹ Thus, maintenance manpower is a binding constraint on a USAF squadron wanting to operate in two locations simultaneously but would only be an issue if other binding constraints can be addressed.

Integrated Basing Network

Typically, we think of aircraft operating from a single location and getting full support at that location. But there are several situations in which it might be advantageous to integrate capabilities across two or more locations. Generally, the ideas for such integration involve a hub that provides full support and one or more other locations that provide more limited support. The motivation could be for survival or for increased operational potential. For instance, the USAF could group a large base with one or more modest locations, which would provide options to recover and turn aircraft, should their primary location come under attack, or simply to complicate adversary targeting to create uncertainties about operating locations and airfield dispositions. In April 2019, Pacific Air Force (PACAF) conducted the “Resilient Typhoon” exercise in support of this concept, in which aircraft dispersed from Andersen AFB in Guam to several operating locations in Guam, Tinian and Saipan in the Northern Mariana Islands, Micronesia, and Palau (Everstine, 2019).

Another type of base network might be designed to extend the combat potential of a distant airfield by linking operations with a forward location. This would allow aircraft at an airfield that is very far away from an operating area to extend their time in the combat area by recovering at a forward location, eventually returning to the original location to get more extensive support. The forward location could either be enduring or temporary. An example of the temporary version in the Pacific is Rapid Raptor, and another in Europe is Untethered Operations. These both involve deploying a small number of fighter aircraft to a location where they get support brought by dedicated transport aircraft loaded with maintainers, equipment, fuel, weapons, and replacement air crews (Brown, Spacy, and Glover, 2015; Harrington, 2014; and Schanz, 2013).

Such a network of operating locations might allow some of the force to base farther away to reduce the threat. This is an attractive option, but deserves some caution. First, the adversary can increase the range of its systems. For instance, China has already fielded a conventional intermediate-range ballistic missile (DF-26), with a range of over 3,000 km (Defense Intelligence Ballistic Missile Analysis Committee, 2017, p. 25). It also is not always possible to find appropriate standoff locations. Moving thousands of kilometers away from an adversary raises the cost for the United States because when basing from farther away, more aircraft are needed to keep the same level of battle presence that a closer force would provide. This is a problem for the USAF, which had built a force around fairly short-legged fighter aircraft with short-range

⁶¹ F-35 maintenance support is even more closely tied to the supported operating unit because the ALIS maintenance system is designed to support specific aircraft, not to interface with aircraft from other squadrons automatically. Support can be provided with advance planning but is not seamless.

precision-glide weapons.⁶² Despite these considerations, the USAF might still want to employ a network of operating locations, even when all or most of the locations are subject to attack.

A related but distinct networked operating concept provides different levels of support among two or more operating locations. Instead of moving the support, as is the case with untethered operations, the support remains in place, but the aircraft move through a network of locations. Not every location will necessarily provide full support to the aircraft. The USAF maintenance UTCs are generally structured to provide the ability to either turn aircraft or repair aircraft. Obviously, USAF aircraft cannot operate for long without repair capabilities, so locations that only turn aircraft are only valuable within a network of airfields. This network has some airfields that can repair aircraft and others that can just turn aircraft. One way this might be very useful is when there are gradations in threat depending on the distance from the operating location. In that case, a more distant airfield can provide turn and repair capabilities, while a more forward location, possibly under greater threat, can just turn aircraft. Aircraft can then cycle between those airfields. Such a system simultaneously seeks to (1) produce higher sortie rates overall by leveraging the closer base for some turns, and thus saving the long journey back to the rear base, and (2) provide needed repair capabilities and reduced overall exposure to attack compared with operating entirely from the forward position.⁶³

The merged-maintenance AFS concepts explored here are well-suited to generating smaller footprints to differently sized detachments. Employing integrated basing networks could require consideration of maintenance force structure depending on how many locations are envisioned. Unless the second location per squadron is small and fleeting, the baseline USAF maintenance structure would be forced to cannibalize maintainers and equipment from non-deploying units to alternate operating locations in an integrated network on a large scale.⁶⁴

Agile Operations

Movement and Scaling

Ideally, the USAF could avoid being subject to missile attacks by moving before the adversary can target a location. Aircraft do not need very long on the ground to rearm and refuel, so it is very enticing to want to have them move from location to location to avoid attack. Although aircraft are highly mobile, their maintenance support is not. Cross-training maintainers is one way to potentially reduce the footprint of the maintenance packages. Although these concepts reduce manpower modestly, they do not reduce the equipment demands. The practical

⁶² For a discussion of the differences between short-range precision weapons and long-range precision weapons and of the evolution of U.S. short-range precision-guided missile use since the Gulf War, see Watts, 2013.

⁶³ This section draws on unpublished RAND Corporation research undertaken in 2019 for the Air Force.

⁶⁴ Although the concepts studied here are likely to enable operation from smaller footprints, it is important to note that these alternative concepts were not formally analyzed. It is not clear whether the potential cost savings found in this analysis for conventional wartime operations would hold under alternative basing concepts.

implication is that these concepts will not improve the speed of movement and the lift required for the maintenance packages.

Agile operations could also be supported through the scaling of support at a location. This scaling could be in the type of support provided, in the number of aircraft that can be supported, or both. The maintenance concepts could offer modest benefits here if their footprints are much smaller than is currently the case. Could they provide rearming and refueling of aircraft support with a much smaller contingent? Or, as we considered earlier, could they support a small detachment of aircraft as an initial lead deployment, with the ability to scale up as follow-on detachments arrive? Although not formally analyzed here, we believe the AFS concepts explored will probably provide a modest advantage.

Reducing Ground Time

In a combat environment, the ability to turn aircraft quickly has obvious benefits. A quick turn allows greater utilization of aircraft and limits an aircraft's exposure to threats. In peacetime, the USAF approaches many ground functions in a way that maximizes safety and efficiently uses support, but in wartime, some of these calculations might be reconsidered. One possible change is to conduct refueling, repair, and rearming concurrently. This Integrated Combat Turn (ICT) concept was previously practiced by the USAF, but as of this writing, this is not the common approach (Moore, 2019). In a future conflict, if aircraft are heavily targeted (as opposed to airfield assets like runways), an ability to minimize time on the ground through concurrent servicing might be a key resilience capability. At a minimum, this would involve training to ensure safe practices and procedures.

The maintenance concepts were not designed to conduct ICTs per se; however, the analysis in Chapter 5 showed that the consolidated maintenance concepts are more efficient, meaning that the overall time on the ground is reduced. It is possible, with training and some modest modifications, that merged maintenance career field structures could be designed to conduct ICTs. If the USAF seeks to implement this on a wide scale, other constraints to consider would be the flight crew ratios that would need to be increased to match the increased aircraft availability and reduced ground time.

Defend and Recover

Degrade Gracefully

Ultimately, one key feature of a future conflict is the likelihood of airfields being subject to missile attack, so the ability of the maintenance concept to degrade gracefully under attack—that is, to retain sortie-production capability with fewer available personnel—is a key consideration. The idea of cross-training maintainers has appeal, in part for its potential ability to degrade more gracefully under attack. If some maintainers have broader experience across AFSs, they could possibly take up the duties of incapacitated comrades. However, a countervailing consideration is

that the size of the alternative maintenance concepts is smaller than the current baseline. The smaller size is a concern in that the loss of any individual represents a larger fraction of the whole.

As we showed in Chapter 5, all the alternative maintenance concepts analyzed in this report performed better under attack than the current practice. The BOLT and LIT concepts degraded most gracefully under attack, with greater than 75 percent of sortie production in the most demanding phase of conflict achieved even with a loss of 50 percent of the maintenance workforce.⁶⁵ Notably, all the concepts degrade well, with low to moderate losses. Policymakers can consider whether the loss of maintainers should be considered in isolation, which would assume they were the deliberate target of the adversary, or whether the risks of their losses should be seen as something that stems from a large attack on the entire base. The difference is that if the attack is on the maintenance personnel alone, the best recovery option might be to replace lost maintainers.⁶⁶ Alternatively, if substantial losses are sustained to the entire base, including the maintainers, then recovery becomes a major operation and shifting to another location might be the preferred response, which would require reserve forces.

Summary of Findings from This Chapter

As the USAF continues to adapt to challenges stemming from missile vulnerabilities, it is likely to implement a range of base improvements, employment changes, and several protection and recovery capabilities. For the most part, the merged-maintenance AFS concepts considered in this report either improve the resilience of the force or, at least, are able to support changes that can improve the resilience of the force.⁶⁷

The ability to disperse the force is well supported when considering some of the likely changes. In addition, it is desirable to be able to provide flexible, tailored forces with smaller footprints in support of integrated basing concepts and agile operations. However, the exact form of the changes remains in flux. The changes that might be orthogonal to the maintenance concepts considered in this report are those involving cross-training of maintainers to perform non-maintenance tasks.

Perhaps the greatest contribution from the new maintenance concepts is their ability to degrade more gracefully under attack. This case study supports the idea that cross-training of maintainers can allow more-graceful degradation, but the benefits mostly would come in cases with both fairly high sortie demands and fairly high attrition.

⁶⁵ See Figure 5.1 and Table 5.2. The 100-percent manpower level is the maintenance manpower requirement for the baseline manpower concept.

⁶⁶ Replacing lost maintainers could be easier under merged AFS concepts because of the ability to draw from a pool of more-broadly trained maintainers.

⁶⁷ It is important to note, however, that it is not clear whether the cost benefits of merged AFS concepts that are discussed in earlier chapters would hold true for these operating concepts.

7. Implementation Challenges of Merged AFS Concepts

In Chapters 5 and 6, the cost and readiness benefits of merged AFS concepts were evaluated. From that analysis we see that, for some merged AFS concepts, there are clear benefits of consolidation either in the form of increased readiness in wartime or reductions in unit-level manpower costs. However, merged AFS concepts raise many implementation concerns and complications that might be difficult to quantify from a cost or readiness standpoint but still require further consideration when facing the decision of whether to adopt a merged AFS concept.

A review of military and industry consolidation efforts found that consolidation initiatives in the logistics community—when not justified through large cost savings or capability enhancements—can lead to substantial capability loss because of the challenges of implementation (Brauner and Gebman, 1993). Lessons learned from Rivet Workforce also suggest that implementation failures contributed to the demise of that historical effort to merge AFSs in the maintenance community (see Appendix A). In this chapter, we use a qualitative analytic framework to comprehensively identify salient implementation concerns for merged AFS concepts and make recommendations of areas that the USAF should study further before it adopts any merged AFS concept.

Methodology

This analysis aims to identify for decisionmakers the full spectrum of implementation barriers that must be considered when weighing the decision of whether to adopt merged AFS concepts in the maintenance community. The goal of this qualitative analysis was to comprehensively identify USAF-wide implementation challenges that decisionmakers might encounter. To achieve this, an analytical approach loosely modeled on the Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities, and Policy framework was used to capture all dimensions of implementation (Joint Chiefs of Staff, 2018, p. B-G-F-1).

Using inputs from the literature, subject-matter experts, and discussions with stakeholders,⁶⁸ the analysis enumerates implementation concerns falling into five categories:

1. *Doctrine and culture*: How the USAF fights its conflicts.
2. *Organization*: How the USAF is organized to fight.

⁶⁸ The stakeholders and subject-matter experts who were included in discussions for this project were from 388 MXG (BOLT, Hill AFB), 56 MXG (LIT, Luke AFB), 158 MXG (Vermont National Guard), 309 AMXG (Ogden Air Logistics Complex), F-35 Academic Training Center (Eglin AFB), HAF/A4LM, ACC/A4, and Lockheed Martin.

3. *Training, leadership, and education*: How the USAF prepares its forces to fight and leaders to lead the fight.
4. *Personnel*: The availability of qualified personnel to support peacetime and wartime operations.
5. *Facilities and materiel*: The property, materiel, and installations that support the USAF.

For some implementation challenges, the analysis is purely qualitative; for others there are some supporting data and quantitative analysis that can inform understanding of that challenge. Challenges include barriers to implementation, additional implementation costs not included in the scope of the cost analyses in previous chapters, and areas that require further study before merged AFS concepts should be implemented.

Implementation Challenges

Table 7.1 summarizes the implementation challenges identified in this analysis, by category. Each of these implementation concerns is discussed in more detail in the following sections.

Table 7.1. Implementation Challenges of Merged AFS Concepts

| Category | Challenges |
|-------------------------------------|--|
| Doctrine and culture | <ul style="list-style-type: none"> • USAF leadership might need to overcome cultural resistance to merged AFS concepts |
| Organization | <ul style="list-style-type: none"> • Organizational structure of the maintenance group might require change |
| Training, leadership, and education | <ul style="list-style-type: none"> • USAF might need to develop new ways to measure maintainer proficiency that consider greater breadth of skills falling into one AFS • USAF might need to change how maintainers are trained • Maintainer proficiency might decrease under merged AFS concepts • The Air Reserve Component (ARC) could face challenges in meeting additional training requirements or proficiency standards • The ability to develop leaders might decrease if the number of command and supervisor positions is reduced as a result of organizational changes • Broader training could reduce deep technical expertise |
| Personnel | <ul style="list-style-type: none"> • Retention rates of maintainers could change, and recruiting qualified maintainers could become more difficult • Availability of maintainers for other platforms might be reduced |
| Facilities and materiel | <ul style="list-style-type: none"> • Additional training facilities including classroom space; training aids; dorm, sleep, and study space; and dining facilities might be required. |

Doctrine and Culture

USAF Leadership Might Need to Overcome Cultural Resistance to Merged AFS Concepts

The USAF has constantly adjusted its maintenance organizations and alignment of tasks and AFSs within those organizations since inception (Lynch et al., 2005, Appendix G). Every time a change is made, there is generally resistance to it. In particular, there was cultural resistance to merged AFS concepts among senior maintainers and leadership that arose during the Rivet

Workforce initiative (see Appendix A), which was a historical merger of AFSs within the USAF maintenance community. This resistance could arise again if new AFS concepts are adopted.

Additionally, some maintenance communities might be unwilling to explore the risks of merging AFSs or changing the way training and certifications are accomplished. For example, the Weapons AFS has proved challenging to merge with other AFSs in the BOLT and LIT experiments, because of the waivers that are required for nonprimary Weapons AFS personnel to complete Weapons loading tasks (Lammers, 2018; Munn, 2018). Although maintainers whose primary AFS is Weapons can take on additional tasks, cross-training other maintainers into Weapons loading has been difficult because the activities performed by the Weapons AFS are more regulated.

A strong change-management⁶⁹ approach coupled with senior leader buy-in could alleviate some of these concerns. A study of maintenance organizations, for example, found that top management commitment is the largest driver affecting the overall quality of maintenance because managers play a key role in establishing suitable infrastructure, manpower, and organization procedures (Shanmugam and Robert, 2015). Lessons learned from the Rivet Workforce initiative also suggest that senior leadership buy-in is critical for the success of structural changes to maintenance workforce organization (see Appendix A for more detail).

Other lessons learned from Rivet Workforce suggest that implementation of merged AFS concepts should not occur simultaneously with manpower cuts. Cuts to manpower that reportedly occurred simultaneously with the implementation of the Rivet Workforce initiative were viewed as creating unique readiness and maintenance challenges. Similar changes to the F-35A program—cutting manpower while making fundamental changes to how maintainers do maintenance—might lead to greater cultural resistance to merged AFS concepts.

Before implementing merged AFS concepts, the USAF should consider the following:

- further studying the cultural and institutional barriers of consolidating Weapons into a merged AFS
- making sure goals and objectives of AFS consolidation are known throughout affected communities
- delaying any cuts to manpower until after the impacts of AFS consolidation are validated
- developing a detailed change-management plan for merged AFS concepts.

Organization

The Organizational Structure of the Maintenance Group Might Require Change

Consolidation of AFSs could require a review of the overall organizational structure of an entire MXG. The AMXS(s) and MXS are the primary squadrons in an MXG that perform the maintenance on aircraft. In most of the consolidation concepts examined in this analysis, some

⁶⁹ *Change management* refers to approaches to prepare, support, and help individuals, teams, and organizations in making organizational change succeed.

AFSs are realigned under the AMXS, leaving the MXS with fewer maintainers than under the baseline concept.

Table 7.2 shows how the baseline nine AFSs are allocated between the AMXS and MXS in the baseline and alternative concepts. Notice, for example, that under the BOLT concept, only three AFSs remain in the MXS. A considerable portion of personnel and resources that support Fuels, LOASM, Egress, and Weapons all transition to the AMXS and form two consolidated AFSs with TAMS, Avionics, and Weapons, leaving only AGE, Metals Tech, and NDI in the MXS. As personnel and associated resources are moved from the MXS to the AMXS, the MXS might become too small, in terms of total personnel, to justify the need for an entire squadron.

Table 7.2. AFS Consolidation Concepts

| Concept | Number of AFSs in AMXS | Number of AFSs in MXS |
|----------|------------------------|-----------------------|
| BOLT | 6 | 3 |
| PAF 3 | 4 | 5 |
| LIT | 4 | 5 |
| PAF 2 | 4 | 5 |
| PAF 1 | 3 | 6 |
| Baseline | 3 | 6 |

NOTE: In this table, the original nine AFSs of the baseline concept are used to show the distribution of manpower between the AMXS and MXS, rather than the number of new merged AFSs.

A squadron is the basic building block of organizations in the USAF and has a substantive mission of its own that warrants organization as a separate unit, based on factors such as unity of command, functional grouping, and administrative control, all of which are balanced with efficient use of resources (AFI 38-101, 2019). If the functional grouping of AFSs is changed and traditional MXS AFSs shift to the AMXS, this could affect the unity of command and administrative control of maintainers and resources.

Further, USAF doctrine specifies that although squadrons might vary in size according to responsibility, they will have a minimum adjusted population of at least 35 and should not fragment a capability into multiple squadrons when a single squadron provides a parent wing or group commander the best approach in terms of a coordinated, focused capability under single direction (AFI 38-101, 2019). As a consolidated concept transfers AFSs from the MXS to the AMXS—particularly for those concepts that retain the fewest number of specialties in the MXS (specifically, BOLT, LIT, PAF 3, and PAF 2)—the structure of the MXS can come into question, raising the issue of whether the entire maintenance force is fragmented unnecessarily.

Before implementing merged AFS concepts, the USAF should consider

- evaluating whether the AMXS should control all maintenance personnel and resources and whether the MXS remains a large enough organization to remain a squadron

- evaluating the impact to bases that host more than one MDS if the MXS does not remain a squadron.

Training, Leadership, and Education

The USAF Might Need to Develop New Ways to Measure Maintainer Proficiency That Consider a Greater Breadth of Skills Falling into One AFS

Depending on how aggressively consolidated AFS concepts are put in place, they can vastly increase the number of tasks falling within a single AFS and the breadth of capability required of a single maintainer. Additionally, some expected outcomes of the merged AFS concepts being piloted in the USAF—BOLT and LIT—involve maintainers taking initiative for their own training, including: “Promote ‘the initiative of the subordinate’” and “habituate personnel to operate autonomously” (Lammers, 2018; Munn, 2018). These characteristics additionally require more skill from each maintainer. Such changes in what is expected of maintainers could require a change in how the USAF measures proficiency both at the time of upgrade and,⁷⁰ generally, over time to ensure that the different and potentially more-challenging expectations are being met and to avoid the loss of proficiency in the maintenance workforce over time.

A maintainer who has been upgraded to the 5- or 7-level has the required level of knowledge, proficiency, and experience commensurate to their skill level and is capable both of working independently and of training others. These characteristics are clearly difficult to measure under today’s maintenance concept. Any consolidated concept will add to this issue, inasmuch as each maintainer is required to do more and become more autonomous. Although it is difficult to prove or measure whether a maintainer is proficient enough to qualify for an upgrade, it should not be left as an unknown—which is what it is today. This becomes particularly salient under merged AFS concepts in which the challenge of determining the proficiency of maintainers in a broad set of tasks and skills could be significant.

Measuring proficiency is also important because of the recent changes to upgrade times that could affect merged AFS concepts. The mandatory minimum time in upgrade training, set by USAF policy, dropped from 18 months to 12 months (DeBlois et al., 2020), and in January 2019 it was eliminated.⁷¹ The average upgrade time to 5-level for active-duty maintainers on the KC-135 aircraft, for example, dropped from about 18 months in 2008 to about 13 months in 2018 (DeBlois et al., 2020). More recently, because the minimum upgrade time was eliminated, ACC/A4 indicated the average upgrade time to 5-level is about six to eight months as of this writing, and for specialties without career development course requirements, the upgrade from 3-

⁷⁰ Here, we consider a maintainer’s proficiency to conduct hands-on maintenance and progress from 3- to 5- to 7-level. We do not consider enlisted promotion criteria.

⁷¹ Minimums are now set at the discretion of the career field manager.

level to 5-level often happens after the completion of core tasks.⁷² At the time of this analysis, the BOLT and LIT experiments were training considerably more tasks than any legacy AFS in similar amounts of time (Lammers, 2018; Munn, 2018). Eliminating the minimum upgrade time is a fundamental shift in USAF policy, one that reduces opportunity for maintainers to gain proficiency and experience prior to upgrade. Such changes, particularly if paired with the adoption of merged AFS concepts that ask more of maintainers, suggest the need for better measurement of proficiency in the maintenance community.

The potential impacts of poor proficiency measurement could be severe. If maintainers continue to progress without assurance of their proficiency and experience, the maintenance force could begin to suffer by becoming less capable of performing independently or training others over time. As less-competent maintainers train other maintainers year after year, the competency of the maintenance force could precipitously decline over time, potentially with negative consequences on mission generation. These negative effects of maintainer competence might not be realized for some time because the F-35A is a relatively immature air frame and is not yet breaking in ways that might highlight a lack of competence. Although maintainability was emphasized in the design of the F-35A, maintenance challenges will increase in unexpected ways as the aircraft age, particularly during periods of high operational tempo when potential maintainer competency insufficiencies will become more evident. Further, at locations where there is an abundance of 3-levels and a relative shortage of 5- and 7-levels, the pressure to upgrade maintainers to meet the operational tempo could lead to even quicker upgrade times, further degrading maintainer competence.

As the USAF considers the adoption of merged AFS concepts, it will be important to evaluate whether current proficiency measurement standards are sufficient to ensure the successful implementation of the concepts.

Before implementing merged AFS concepts, the USAF should consider the following:

- developing proficiency measurement standards for merged AFSs that capture the broader skill set and autonomy required of them
- evaluating skills and competencies of maintainers more frequently to ensure that the broader skill set required of maintainers is not degrading competency
- reevaluating upgrade times and criteria that consider the broader skills of merged AFSs.

The USAF Might Need to Change How Maintainers Are Trained

Merged AFS concepts represent a much greater training burden than the status quo, as discussed in Chapter 3. However, this analysis assumes that the manner in which the USAF trains maintainers would be largely unchanged (i.e., the merged AFS training will be similar to the current pipeline for the individual AFSs that were merged). Several stakeholders raised the

⁷² In a conversation with individuals from ACC/A4 on March 26, 2019, they stated that the average upgrade time is about six to eight months.

question of whether current training practices are sufficient to effectively train maintainers in such a broad set of tasks.

Maintainers noted that the technical school training curriculum today relies more heavily on computer-based maintenance instruction (relative to hands-on touch time) than in the past. Although past studies of military training have found that technology-based classroom training can be quite effective (Winkler and Steinberg, 1997), a reevaluation of training practices might be warranted, given the dramatic increase in the amount of material maintainers trained into merged AFS concepts will be required to learn.

There also are questions about the balance between classroom training and the level of on-the-job training (OJT) that is ideal for merged AFS concepts. U.S. Army efforts to consolidate aviation MOSs shifted the burden of training from the classroom to OJT. A study of this effort found that this shift, although cost-effective, led to longer times before trainees showed basic proficiency and that breadth of training was prioritized at the expense of technical depth (Wild et al., 1993). Relatedly, efforts to reduce upgrade times from 3- to 5-level could be incompatible with the OJT demands of merged AFS concepts (as discussed in the previous section).

Finally, lessons learned from Rivet Workforce suggested that inadequate training was a fundamental factor underlying the challenges facing that initiative, with more-generalized training adopted to ease training burden (see Appendix A for a more-detailed discussion of this). A delay in the establishment of consolidated training programs and plans at AETC and at U.S. Major Command (MAJCOM) also contributed to training shortfalls.

Before implementing merged AFS concepts, the USAF should consider the following:

- determining the training requirements for merged AFS concepts
- evaluating whether existing training practices, courses, and pipelines are suited for merged AFS concepts
- establishing consolidated training programs prior to AFS consolidation.

Broader Training Could Reduce Deep Technical Expertise

Prior analysis has documented that consolidating career fields and asking maintainers to broaden their expertise can lead to a loss of deep technical expertise, particularly when training time is decreased (Wild et al., 1993). Whether this loss of deep technical expertise is problematic for the F-35A is a difficult question to answer. For example, the electronic technical orders and other decision support tools, such as the portable maintenance aids and the advanced test equipment, are eliminating some of the need for deep experience. Maintainers who are testing merged AFS concepts also find that the way the F-35A is designed improves its maintainability (Munn, 2018). However, as the percentage of F-35A maintainers in the maintenance force increases, the potential for a loss of deep technical expertise within the maintenance communities of legacy platforms is significant if merged AFS concepts are adopted for the F-35A.

Before implementing merged AFS concepts, the USAF should consider the following:

- studying how and in what fields broadening expertise might affect deep expertise, particularly in the back-shop specialties, if merged with flightline specialties
- determining the technical expertise that must be kept within the maintenance community, looking to the future of the USAF and future fifth-generation aircraft.

Maintainer Proficiency Might Decrease Under Merged AFS Concepts

The impact of merged AFS concepts on long-term proficiency of maintainers is unknown. There are a variety of potential drivers of proficiency, from downstream effects of ineffective training to the sacrifice of depth over breadth, to simply requiring more capability of maintainers than training can support. These drivers of proficiency are difficult to measure. However, one quantifiable, indirect measure of proficiency is how the encounter frequency of tasks changes under merged AFS concepts and how that change could affect proficiency.

We examined how merging AFSs changes the frequency at which maintainers have the opportunity to train on maintenance tasks in their new, merged career field, and whether this encounter frequency is enough to keep proficiency (for a more in-depth analysis, see Appendix B). In merged AFS concepts, the frequency at which a maintainer encounters a task increases (there is less downtime between tasks), but the frequency of tasks in a particular skill area (e.g., Avionics) decreases. For example, if the Avionics career field is merged with a second career field with comparable numbers of personnel, the total number of personnel who now must remain trained on Avionics tasks has doubled, but the number of times that those tasks occur has not changed (this also assumes that the reliability of the aircraft does not change). The result might be a decrease in the opportunity for individual airmen to perform these tasks. Less-frequent encounters of the same task result in nonuse of skills, and skill decay is a plausible consequence (Arthur et al., 1998).

Skill decay is a concern among active-duty personnel who only deploy periodically. However, it is especially a challenge for reservists, who compose close to 40 percent of total U.S. uniformed manpower (Office of the Assistant Secretary of Defense for Manpower and Reserve Affairs, 2017) but might receive training only once or twice per year. Military skill decay is acute and documented in various career fields such as sonar operators, gunners, bombers, air traffic controllers, radio operators, and mechanics (Hoffman et al., 2013). Different procedural tasks suffer skill decay at different rates over time without use or practice (Wisher, Sabol, and Ellis, 1999). Data suggest that for perceptual-motor performance (e.g., typing, aircraft flight control, target tracking, marksmanship, or riding a bike), skill degradation reached its peak at about four months; on the other hand, discrete procedural skills (e.g., performing cardiopulmonary resuscitation, administering first aid for shock, clearing an M-16 rifle, or basic combat skills) might be forgotten more rapidly, degrading after only one month without practice and with a sharp increase in degradation at four months (Sitterley and Berge, 1972). Informed by our review of the skill-retention literature and discussion with subject-matter experts, we considered encounter frequencies required to retain proficiency ranging from a lower bound of three times per year (or every four months) to an upper bound of 12 times per year (or every

month). The proficiency requirement represents the frequency at which maintainers need to encounter a task to keep proficiency.

We used LCOM (details in Chapter 5) to determine how frequently maintainers are likely to encounter tasks before and after consolidation during peacetime under the baseline F-35A AFS concept and under AFS consolidation consistent with the BOLT and LIT concepts.⁷³ Table 7.3 shows the percentage of maintainers encountering tasks at proficiency-retaining frequencies for tasks associated with four current AFSs, which are consolidated in one or both of the BOLT and LIT concepts.

Comparing the baseline values with those of the BOLT and LIT concepts suggests areas where proficiency concerns might be greatest and where targeted steps to maintain proficiency (e.g., use of maintenance drills and simulators) might be necessary. For example, this comparison suggests proficiency in Avionics tasks is likely to be negatively affected if the BOLT or LIT concept is pursued, although the concerns are likely to be larger under the LIT concept. Across all AFSs that are merged, the analysis shows that the encounter rates of tasks and, accordingly, proficiency are likely to be negatively affected by consolidation. Although only BOLT and LIT are studied here, the encounter rates of tasks within an AFS will decrease any time that AFS is consolidated, and proficiency is expected to decrease. Because PAF 1, PAF 2, and PAF 3 feature smaller degrees of consolidation than BOLT and LIT, the effect is expected to be smaller for those consolidations.

In general, as can be seen in Table 7.3, the greater the consolidation (i.e., the number of AFSs consolidated), the greater the expected impact to proficiency will be. For example, Avionics is consolidated in both the LIT and BOLT concepts, but in LIT it is merged with three other AFSs and in BOLT it is only merged in two. Accordingly, the percentage of maintainers who encounter Avionics tasks at proficiency-retaining rates is lower for LIT than it is for BOLT. On the other hand, when a career field is not consolidated—such as Egress for the BOLT concept—there are no changes to proficiency.

⁷³ BOLT merges TAMS, Fuels, and LOASM into the Air Vehicle AFS and Avionics, Egress, and Weapons into the Mission System Technician AFS. LIT merges Avionics, TAMS, Weapons, and LOASM into the LIT technician AFS.

Table 7.3. Percentage of Maintenance Workforce (on Average) Encountering Tasks at Proficiency-Retaining Frequencies

| | Avionics | | Egress | | Fuels | | LOASM | |
|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| | Lower (%) | Upper (%) | Lower (%) | Upper (%) | Lower (%) | Upper (%) | Lower (%) | Upper (%) |
| Baseline | 16 | 5 | 67 | 33 | 37 | 14 | 58 | 17 |
| LIT | 3 | 1 | 67 | 33 | 37 | 14 | 11 | 3 |
| BOLT | 8 | 3 | 4 | 2 | 3 | 1 | 16 | 5 |

NOTES: Maintainers are “proficient” in a task as defined in this analysis when encountering a task once a month (upper bound) or once every four months (lower bound). Average is calculated over all tasks in that AFS. The number of tasks in a parent AFS is assumed to not change when merged with another AFS in LIT or BOLT to generate new, merged AFSs.

It is important to caveat the results of this analysis by pointing out that this analysis uses an indirect measure of proficiency. This analysis can show that proficiency will decrease as AFSs are merged within the career fields that are affected by the merger using this indirect indicator of proficiency that takes into account only encounter frequency. It is notable that, by this measure of proficiency, the baseline concept does not provide frequent-enough encounters of tasks for maintainers to remain proficient in all of those tasks, particularly Avionics and Fuels. Because the USAF aircraft maintenance system does function at baseline, this encounter frequency metric alone clearly does not capture the full picture of proficiency. What this metric can help illuminate is a sense of the magnitude of proficiency changes that could occur once there is an AFS merger, but it cannot say very much about the true proficiency of the workforce. The direct measures of proficiency—specifically, the percentage of tasks completed successfully and the average time to complete a task in the merged versus the baseline concepts—would be a superior way to quantify the effect of an AFS merger on proficiency, although such measures are not currently available for analysis.

A few other caveats are important to consider: This analysis uses the F-35A LCOM model, which has all of the caveats discussed in Chapter 5. This analysis also assumes that a maintenance task must occur (i.e., that a particular break must happen) for a maintainer to encounter it and that only the number of maintainers required in the task crew size (as specified by LCOM) have the opportunity to train on that task. This does not consider other ways in which the maintenance force might increase maintainer exposure to rarer tasks, including additional training or training multiple maintainers on that task.

However, even with these caveats, the results of this analysis suggest that a focus on proficiency will be critical to the successful implementation of merged AFS concepts. Before implementing merged AFS concepts, the USAF should consider the following:

- developing a program to augment initial training, including potential refresher training in skills that occur less frequently
- exploring the impacts of consolidation on the reserve component, where operational tempo differences might lower the task encounter frequency even further

- using the results of the ongoing BOLT and LIT experiment to examine the impacts of merged AFSs on other drivers of maintainer proficiency beyond encounter frequency, including more direct measures of proficiency.⁷⁴

The Air Reserve Component Might Face Challenges in Meeting Additional Training Requirements or Proficiency Standards

The additional training burden of merged AFS concepts, particularly the aggressive consolidations that greatly increase the breadth of tasks falling under an AFS (e.g., BOLT, LIT), could pose challenges for the ARC with respect to increasing upgrade times. Although full-time ARC maintainers can generally be upgraded in a period like active duty, Traditional National Guardsman and Reservist (TR) upgrade times are extended because they have less opportunity to work on aircraft. During their two days a month and two weeks a year, they might not have aircraft touch time at all because of the press of many other requirements. These factors might considerably extend the time required to upgrade a TR and affect their proficiency in the consolidated AFS. Exploring the impacts of increased upgrade times for the ARC was outside the scope of this study, but it follows from the analysis in earlier chapters that delaying upgrade times could reduce the potential manpower savings or readiness enhancements observed for some merged AFS concepts.

However, the ARC has some traits not found in the active component that might counterbalance these potential training and proficiency challenges. ARC maintainers primarily remain at the same base on the same aircraft over their careers, which could be conducive to developing maintainers with broader expertise. Also, many senior NCO maintainers (e.g., Master Sergeant [MSgt], Senior Master Sergeant) still conduct aircraft maintenance: having such deep expertise on the flightline might help with the effective implementation of merged AFS concepts and the training of more-junior airmen.

Before implementing merged AFS concepts, the USAF should consider the following:

- studying how changing the F-35A maintenance force structure will affect the ARC
- staggering implementation of any type of consolidation effort in the ARC, which could help in upgrading TRs
- developing FTDs at ARC bases, even temporarily, to absorb the up-front training burden of a consolidated concept.

The Ability to Develop Leaders Could Decrease if the Number of Command and Supervisor Positions Are Reduced as a Result of Organizational Changes

Consolidation could change how maintenance is managed, which could affect the number of supervisor positions required. Similarly, a reorganization of the MXG—as discussed in the

⁷⁴ Accurate as of the time of publication. The BOLT and LIT experiments are expected to end at the close of calendar year 2019.

previous section—could change the number of command and supervising positions. Such changes could have a downstream impact on the ability of the USAF to train future leaders.

Merged AFS concepts could affect the number of supervising positions that are required in the MXG in several ways: through the coordination of work and the supervision of people. If the number of specialists decreases, the number of managers required will also decrease. Also, as the maintenance force becomes less subdivided or specialized, generally less-specialized managers and less coordination and supervision between specialties would be required.

For example, multiple production superintendents and multiple expeditors are often required to manage flightline operations.⁷⁵ As an AFS concept consolidates and more specialists shift to the AMXS, the need for production superintendents and expeditors generally decreases as the need for supervision of coordination between specialties and organizations decreases.

Similarly, the number of middle administrative managers could shrink as personnel become less specialized. Among their other duties, middle managers are required to oversee personnel, an assignment that requires close supervision and an understanding of personnel duties. Smaller or more-centralized organizations—such as a merged AFS concept—require fewer managers than larger, more decentralized organizations.

Before implementing merged AFS concepts, the USAF should consider the following:

- studying how organizational changes that might be required for implementation of merged AFS structures could affect the leadership training pipeline in the maintenance community.

Personnel

Retention Rates of Maintainers Could Change and Recruiting Qualified Maintainers Might Become More Difficult

An important consideration for the adoption of merged AFS concepts is effects on maintainer retention rates, which already are problematic in the USAF, particularly for senior maintainers (U.S. Government Accountability Office, 2019a). It is impossible to quantify, at this point, what the effect on retention rates from merged AFS concepts might be because there are potential drivers—both positive and negative—that could arise, depending on how the concept is implemented and received by the community.

However, several concerns raised by stakeholders could lead to reductions in maintainer retention or to increased costs needed to prevent retention rates from decreasing. First, merged AFS concepts generate more-broadly trained maintainers who might be attractive to industry and could be recruited out of the maintenance workforce, further compounding the problem of retaining experienced maintainers. This demand from Lockheed Martin, one current significant

⁷⁵ For example, often at least one production superintendent in the AMXS, depending on the number of aircraft, and one in the MXS.

industry draw for maintainers, could lessen over time, because its maintenance support of the F-35A will decrease as the platform matures.

Second, the reenlistment bonus structure might need to change to retain more-broadly trained maintainers. For example, in the current BOLT and LIT experiments, some maintainers are eligible for selective reenlistment bonuses based on their primary AFS, but colleagues who are trained into the same merged AFS but who are in a different primary AFS are not eligible for those bonuses.⁷⁶ Incentivizing maintainers to take on merged AFSs—which require more-significant training and will lead to, potentially, a more challenging work tempo—or incentivizing those maintainers to remain in the force might require selective reenlistment bonuses, which will come at an increased cost that was outside the scope of this analysis.

Third, some stakeholders expressed concerns that, if merged AFS concepts limit the ability of maintainers to shred to other platforms, this will negatively affect retention. For example, maintainers might be restricted to duty locations where the F-35A is based. Additionally, the ability of the USAF to fair-share overseas assignments could be reduced. These factors could affect workforce satisfaction and, thus, retention rates.

Recruiting qualified maintainers might also be challenging. For example, higher Armed Services Vocational Aptitude Battery scores might be required for merged AFSs. This could decrease the number of eligible enlistees for merged AFS concepts. Similarly, many stakeholders expressed that they did not believe that all of the maintenance workforce had the aptitude or interest to take on a merged AFS concept, which demands much more of a maintainer.

Considering potential retention concerns is of particular importance if merged AFS concepts are adopted. As discussed in detail in Chapter 4, the retention rate has profound impacts on the overall costs associated with merged AFS concepts because of the impact it has on the average availability of maintainers over their career. More-senior maintainers, generally speaking, are the most productive maintainers (because they no longer require supervision to do maintenance) and are also responsible for providing OJT for more-junior maintainers. If the percentage of the maintenance workforce skews more junior, the overall productivity of the maintenance workforce will decrease, the average availability of maintainers will decrease (see Figure 4.3, Table 4.3, and the related discussion), manpower requirements will increase, and the costs of merged AFS concepts will, accordingly, increase. Thus, if merged AFS concepts lead to retention issues—particularly of senior enlisted personnel—the potential cost benefits might decrease or could be completely eliminated.

Before implementing merged AFS concepts, the USAF should consider the following:

⁷⁶ For FY 2020, TAMS and LOASM were eligible for selective retention bonuses (USAF, 2019). BOLT maintainers in the Air Vehicle Track (merger of TAMS, Fuels, and LOASM) whose primary AFS is Fuels, for example, would not be eligible for selective retention bonuses for TAMS and LOASM, despite the fact that they are trained into those skill sets in the current implementation of the BOLT concept.

- evaluating recruiting standards for merged AFS concepts and the anticipated number of eligible recruits
- restructuring the reenlistment bonus program and other incentives for recruitment and retention for merged AFS concepts—particularly initiatives that incentivize midcareer retention and longer careers—to ensure that the USAF retains its investment in greater up-front training that is required for merged AFS concepts.

Availability of Maintainers for Other Platforms Could Be Reduced

Currently, some maintenance career fields are specialized to a particular aircraft only at certain levels (e.g., 3- and 5-level) or not at all (U.S. Government Accountability Office, 2019a, p. 17). Consequently, maintainers spend their careers across several aircraft. The USAF assignment system reassigns personnel using several criteria including, in the case of aircraft maintainers, being qualified to work on the aircraft at new locations to which they will be assigned. If the F-35A implements a consolidated concept that is specific to this aircraft only, how does this affect the overall USAF assignment system when it needs maintainers to change duty stations for USAF aircraft maintenance needs? Further, if other aircraft also develop different consolidated AFS concepts specific to one airframe, how does this further complicate the USAF assignment system when reassigning maintainers for USAF aircraft maintenance needs?

The primary factor in selection of an airman for permanent change of station is their qualifications to fill a valid manpower requirement and perform productively in the position under consideration. Permanent change of station eligibility factors, such as time-on-station—although important—are secondary. The primary criteria are based on qualifications, and if the aircraft maintenance community trains maintainers in specific concepts that only apply to one airframe, it will make it more difficult to reassign maintainers to other aircraft types without additional FTD and OJT. This potential additional training will decrease the amount of time that maintainers are available to do maintenance during their careers, which could increase O&S costs for legacy aircraft. Furthermore, if it was determined that F-35A maintainers were not qualified to shred to a new platform, this could have a significant impact on the availability of manpower for legacy fighter platforms.

Another potential concern is how merged AFS concepts will be implemented at locations that support multiple MDS and the impact that this will have on the maintenance personnel for the co-based aircraft. For example, the LIT concept at Luke AFB does not include Fuels and Egress in its LIT AFS because those maintainers also perform maintenance on F-16s located at the base. Other concepts—such as BOLT—that include these AFSs in the merged new AFSs might pose challenges with respect to personnel availability at locations that also host legacy fighters.

Before implementing merged AFS concepts, the USAF should consider the following:

- increasing FTD and OJT training as part of the assignment process to facilitate shred to other platforms

- evaluating the increase in O&S costs or decrease in personnel availability (or both) that could occur if merged AFS concepts are adopted for the F-35A
- choosing a merged AFS concept that can be applied across future fifth-generation platforms, so that as legacy platforms are retired, mismatch of career field structure is no longer a challenge.

Facilities and Materiel

Additional Training Facilities, Including Classroom Space; Training Aids; Dorm, Sleep, and Study Space; and Dining Facilities Might Be Required

This study did not examine one other category of implementation costs: changes to training facilities that might be required. For example, the F-35 ATC at Eglin AFB currently has a maximum number of students that can be trained that is limited by available instructors, classroom facilities, dormitory space, and dining facility space (359 Training Squadron and 372 Training Squadron Detachment 219, 2019). Expansions to this capacity are currently planned but have not yet been funded. If merged AFS concepts increase the amount of time that students spend at the ATC, either the throughput (e.g., number of maintainers that are trained per year) must decrease or the capacity of the facility must increase.⁷⁷ These potential cost increases are not unique to the ATC and could affect other maintenance courses and FTDs.

Before implementing merged AFS concepts, the USAF should consider the following:

- evaluating the increase in O&S costs or decrease in personnel availability (or both) for legacy platforms that could occur if merged AFS concepts are adopted for the F-35A.

⁷⁷ The capacity costs of education and training locations were not formally considered in the technical school analysis presented in Chapter 3.

8. Summary of Conclusions and Recommendations

In previous chapters, analyses considered the training burden of merged AFS concepts (Chapter 3), the availability of maintainers to do hands-on maintenance with variable up-front training burdens (Chapter 4), and the degree to which efficient task allocation among personnel decreases direct manpower requirements (Chapter 5). These results were integrated to yield the potential O&S cost impact of adopting merged AFS concepts (see Table 5.3). Additionally, the performance of merged AFS concepts in future combat concepts was discussed (Chapter 6), and the implementation challenges associated with these concepts enumerated (Chapter 7). This chapter summarizes the major findings of all of these analyses and offers recommendations for USAF leaders as they consider adopting merged AFS concepts for the F-35A.

Conclusions

Concepts that aggressively consolidate AFS (BOLT, LIT) have potential cost and readiness benefits, even when applied to only part of the force (PAF 2). Smaller consolidations offer limited or no benefit.

BOLT, LIT, and PAF 2—concepts that are aggressive consolidations that combine multiple, large AFSs—are the highest performers as gauged by their potential to reduce O&S costs and to improve sortie-generation efficiency. These significant potential benefits might justify the effort required to implement them and the major changes required of the F-35A maintainer community.

The concepts that have less-aggressive consolidation (PAF 1 and PAF 3), while potentially easier to put in place than the larger merged AFS concepts, provided limited or no additional benefit at the same or slightly greater cost. Their sortie-generation efficiency is also comparable with the baseline concept. Although these concepts might be easier to implement than the more-aggressive AFS mergers, their implementation still requires significant structural changes to the USAF maintenance workforce and produces only minimal benefits that are unlikely to justify the burden and expense.

If manpower is reduced, merged AFS concepts can offer O&S cost savings. If manpower is kept constant, merged AFS concepts increase the sortie-generation potential of the force with a small O&S cost increase.

The most-favorable merged AFS concepts—BOLT, LIT, and PAF 2—offer two different kinds of benefits, depending on how they are implemented by the USAF. If the USAF chooses to take advantage of potential direct manpower savings that merged AFS concepts offer from their greater sortie-generation efficiency, the potential O&S cost savings are significant.

If the USAF chooses to not seek to lower costs by lowering manpower levels, adoption of merged AFS concepts offers the opportunity to enhance the readiness of the force. The greater

efficiency of sortie generation that comes from merging career fields enables the force to surge to higher rates of sortie production under stressing scenarios.

Merged AFS concepts contribute to readiness for integrated basing concepts and agile operations.

Merged AFS concepts can contribute to emerging operational concepts in several ways. The option of maintaining current sortie-generation rates with fewer personnel supports the abilities to disperse the force and to provide flexible, tailored forces with smaller footprints. Another advantage comes from the merged AFS concepts' ability to degrade more gracefully under attack, which is well-suited to future conflicts in which attacks on airfields are a real concern.

To realize the potential benefits of merged AFS concepts, several implementation concerns must be addressed.

The most-salient implementation concerns for merged AFS concepts fall into the categories of doctrine and culture, training, and personnel. To successfully implement merged AFS concepts, changes might be required in training and in measuring proficiency to ensure that the greater demands of merged AFSs do not affect maintenance force effectiveness. Such training issues could be particularly acute for the ARC. Potential changes to the numbers of maintenance personnel across all platforms must also be considered. This includes looking at the impacts of retention changes and of the conflicting AFS structures required by F-35A and legacy aircraft. Finally, successfully implementing the cultural changes required to alter the AFS structure will necessitate significant investment from senior leadership in change management.

Recommendations

The findings of this analysis suggest that, *if the USAF chooses to implement merged AFS concepts, it should consider concepts that feature aggressive consolidation of career fields (i.e., BOLT-like or LIT-like) and that are applied to the entire force or a portion of the force (PAF 2).*

Additionally, the research presented here suggests the following key elements of implementation that will be critical for the successful realization of the benefits of merged AFS concepts:

- *Ensure adequacy of training:* If AFSs are consolidated, it is critical that training be expanded to provide the required knowledge, proficiency, and experience necessary to conduct the broader set of tasks required of maintainers. Developing ways to measure maintainer proficiency in merged AFS concepts will also be important to ensure that training is adequate. Particularly during initial implementation of new AFS concepts, increases in manpower could be necessary to compensate for new training issues, including the transition to a new learning curve, increased OJT burdens, and to fill in for those attending an FTD/FTU.⁷⁸

⁷⁸ As we discuss in Appendix A, Robinson (1989) makes this point in the context of the Rivet Workforce initiatives.

- *Invest in change management:* As we note in Chapter 7 and discuss in Appendix A in the context of the Rivet Workforce initiative, cultural and organizational issues could make the transition to new AFS concepts challenging. To help facilitate smoother transition to new AFS consolidation concepts, the USAF should invest in “change management” that involves
 - making sure goals and objectives of AFS consolidation are known throughout affected communities
 - time-phasing expectations of impacts to coincide with AFS consolidation implementation milestones
 - delaying any cuts to manpower until after the impacts of AFS consolidation are validated.
- *Invest in strategies to retain more-broadly trained maintainers:* For the benefits of merged AFS concepts to be realized, the investment that the USAF makes in the training of maintainers—particularly those who are trained more broadly—must be retained. If retention issues among senior maintainers continue, the benefits of merging AFSs will be significantly dampened. The USAF should pursue strategies to retain maintainers and incentivize recruitment into merged AFSs through such mechanisms as selective reenlistment bonuses.

Appendix A. Lessons Learned from Rivet Workforce

A prominent effort to combine AFSs to reduce O&S costs began in the late 1980s and is known as Rivet Workforce. USAF maintainers and leadership who are aware of the implementation of Rivet Workforce have indicated that it faced implementation obstacles. This appendix discusses the Rivet Workforce initiative and associated lessons learned.

Background on Rivet Workforce

Rivet Workforce restructured the job categories into which maintainers are grouped by combining jobs with similar underlying technologies, tailoring training policies for enlisted force development, and restructuring unit manning to allow reductions in total manpower levels. Robinson (1989, p. 16) stated that

the objectives of Rivet Workforce are to develop technical expertise on a particular weapon system, combine jobs with similar underlying technologies, tailor training policies for enlisted force development, and restructure unit manning to allow reductions in total manpower levels. Simply put, the concept of Rivet Workforce is aimed at doing more with less. As a result of combining AFSs, the Air Force seeks to increase productivity; improve combat capability; and, at the same time, reduce overall manpower requirements.

Boyle, Goralski, and Meyer (1985) discussed how Rivet Workforce would help support the development of a more-mobile, -flexible, and -autonomous maintenance workforce and could help address the diseconomies of scale experienced by smaller operational units. They noted that AFS consolidation would be supported by efforts to improve component reliability and maintainability and maximize “on-equipment” repair capabilities while reducing need for deployed SE and complex, colocated, “off-equipment” repair facilities. They described the principles underlying the Rivet Workforce initiative as follows:

1. Maintainers and maintenance tasks should be organized around “on-equipment” and “off-equipment” activities.
2. Consolidation of AFSs should occur within (but not between) on- and off-equipment maintenance specialties. On-equipment specialties should be weapon system-specific, and off-equipment career fields and training should not be tied to a specific weapon system.
3. Because “on-equipment” specialties represent the bulk of the deployed maintenance force, reducing specialization among on-equipment maintainers would have the largest benefits.
4. Consolidation of AFSs should be adjudicated to ensure task skill and learning breadth would be supportable by the USAF personnel management and training system. Additional training costs should be calculated and compared with other potential savings that could result from AFS consolidation.

5. Broad buy-in should be sought from the MAJCOMs, with recognition of the differences in missions, equipment, and maintenance requirements among them.

Boyle, Goralski, and Meyer (1985) recognized that changing the AFS structures would require changes to personnel and training management approaches. At the time Rivet Workforce was being implemented, greater reliance on computer-based instruction was also occurring (Correll, 1988).

Examples of the type of consolidation that occurred under Rivet Workforce include the establishment of the “Integrated Avionics” career field for flight-line repair of the F-16C/D Block 40 (AFS 452X2), which involved the combination of the following three previous AFSs (Robinson, 1989, p. 16):

- A Shop (AFS 326X6), which conducted repairs on attack control systems including radar and inertial navigation systems
- B Shop (AFS 326X7), which was responsible for avionics instruments and flight controls
- C Shop (AFS 326X8), which fixed communications, navigation, and penetration aids, including radios and electronic countermeasures.

Avionics technicians were specialized into A, B, and C Shop AFS shreds through 5-level. At 7-level, the shred was removed, and the Avionics Technician was qualified in all three areas. This transition was supported by crossover school held at a local FTD or the Lowry Technical Training Center in Colorado and by hands-on proficiency training. The conversion from the traditional A, B, and C Shop training to the Integrated Avionics Technician concept entailed a total of 17 weeks of absence from the flight line for cross-over training (Robinson, 1989).

Other areas of combination included combining environmental system specialists with electricians and crew chiefs with engine specialists. Robinson (1989) noted in the context of Rivet Workforce that it is difficult to cross-train crew chiefs on engine tasks, although the transition for engines specialists to crew chief tasks is more manageable.

Lessons Learned

Although there are few documented sources of lessons learned from Rivet Workforce, we spoke with numerous previous USAF leaders and staff familiar with the initiative and its implementation. Several themes arose during these discussions that are relevant should the USAF pursue a large AFS consolidation initiative in the future. We discuss these findings in the following sections.

Ensure Adequacy of Training

Several people we spoke with raised concerns with the adequacy of training when Rivet Workforce was first implemented.⁷⁹ We heard that technical school class curriculum and base-level training were “generalized” (e.g., more limited in depth) to ease the training burden and reduce time spent in technical school. We also heard that the transition to Rivet Workforce was challenged initially by a delay in the establishment of consolidated training programs and plans at AETC and at the MAJCOMs prior to beginning formal AFS consolidation.

In some cases, increases in manpower might be necessary to support the additional training burden. Robinson (1989, p. 18) notes that during the 388 Tactical Fighter Wing’s conversion to Rivet Workforce, “increased manning seems justified, not only to compensate for the learning curve and slower repair times on the new avionics systems, but also to provide on-equipment, on-the-job training to other technicians and to fill in the for those attending FTD or in-house maintenance training division classes.”

Invest in Change Management

Many individuals we spoke with noted the cultural challenges hampering the adoption of Rivet Workforce and other USAF maintenance initiatives. It was noted that, once individuals become part of an existing culture, they resist change. To help facilitate AFS consolidation initiatives, certain investments in change management should be pursued, including the following:

- Making sure the goals and objectives of AFS consolidation are known throughout affected communities.
- Time-phasing expectations of impacts to coincide with AFS consolidation implementation milestones.
- Delaying any cuts to manpower until after the impacts of AFS consolidation are completely understood and validated. Rivet Workforce was touted as a way of reducing maintenance manpower requirements by combining AFSs. Cuts to manpower that reportedly occurred simultaneous with the implementation of the Rivet Workforce initiative were viewed as creating unique readiness and maintenance challenges at the time. Individuals we spoke with commented that delays to personnel cuts should not have occurred until after the manpower impacts of AFS consolidation were validated.
- Documenting the impacts of AFS consolidation.

⁷⁹ As part of this and an earlier effort documented in Light et al. (2016), we spoke with individuals involved in USAF maintenance activities during the 1980s and 1990s, from retired enlisted maintainers to General Officers, to get their perspectives on Rivet Workforce.

Appendix B. Impacts of Merged AFS Consolidation on Maintainer Proficiency

As discussed in Chapter 6, one potential implementation challenge of merged AFS concepts is ensuring that the proficiency of maintainers does not decrease when they are asked to take on a much broader set of tasks. This appendix explores that implementation challenge in greater detail, with supporting analysis that uses a literature review and analysis of LCOM data to quantify how proficiency of maintainers could decrease after a merger of AFSs.

Overview

Proficiency in aircraft maintenance is a crucial component of mission readiness and, in the context of restructuring USAF career fields, becomes even more critical. Surprisingly, however, contributions to the literature examining knowledge retention and skill decay mention aircraft maintenance, if at all, only in passing. Nor is aircraft maintenance work studied in the more-critical academic literature on education, training, and human resource management. Although human factors literature extensively studies aircraft maintenance, this discipline mainly focuses on proficiency in relation to safety science.

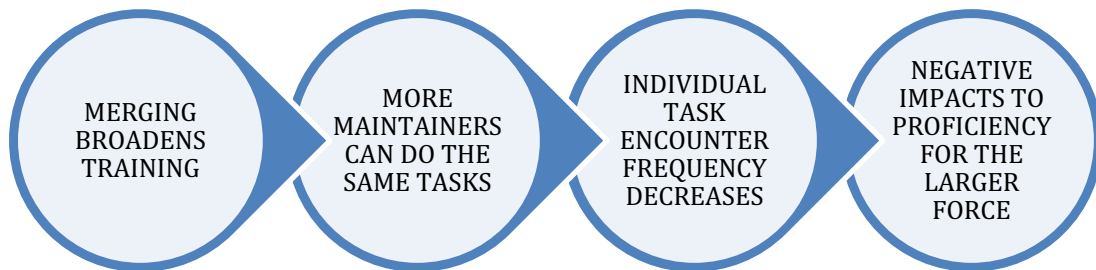
The fact that aircraft maintenance proficiency is absent from the literature highlights a risk that consolidation efforts for the maintenance force could proceed without a clear understanding of consequences to overall proficiency. Therefore, the goal of this appendix is to estimate the consequences of consolidating AFSs on maintainer proficiency.

The problem of how to maintain skills over time (i.e., to avoid skill decay) in the most cost-effective manner has been plaguing organizations since the advent of industrialization. This problem is especially prevalent in the military, where some tasks might be limited in terms of number of opportunities to perform. The issue becomes compounded by consolidation: Not only could maintainer proficiency be affected by the increased breadth of tasks falling into a single AFS, but also by changed frequencies at which maintainers encounter tasks.

This analysis focuses on this latter aspect of proficiency: how merging AFSs changes the frequency at which maintainers have the opportunity to train on maintenance tasks and whether this encounter frequency is enough to keep proficiency (see Figure B.1). To understand changes in task frequency, consider this example: If the Avionics AFS is merged with a second AFS with comparable numbers of personnel, the total number of personnel who now must remain trained on Avionics tasks has doubled, but the frequency at which those tasks occur is unchanged. The result is a decrease in the opportunity to perform these tasks. Fewer frequent encounters of the same task result in nonuse of skills and, inevitably, skill decay (Arthur et al., 1998; Wang et al., 2013). Thus, the primary questions guiding this work are: Does task encounter frequency

decrease as AFSs are merged, and would this change in task encounter frequency affect maintainer proficiency?

Figure B.1. Model for How Merging AFSs Affects Maintainer Proficiency



To explore these questions, this analysis uses a combined approach of (1) literature review to determine the encounter frequency necessary to maintain proficiency in maintenance tasks and (2) quantitative analysis of LCOM data to determine the frequency at which maintainers are expected to encounter tasks and how this might change as merged AFS concepts are adopted.

Review of Skill-Retention Literature

Literature Review Methodology

We sought to identify relevant published literature in educational psychology, memory and learning, human performance, human resource management, personnel psychology, and human factors to inform our understanding of proficiency from an individual to an organizational context. Published literature was identified using a combination of methods, including electronic database searching, cross-referencing, and discussions with subject-matter experts. The electronic search strategy involved searches of key words within key journals. “Skill retention,” “skill degradation,” “skill decay,” “skill acquisition,” “knowledge retention,” “knowledge transfer,” “task performance,” “task proficiency,” “proficiency retention,” “opportunity to perform,” and “frequency of encounters” were used as search terms. Key journals included *Human Factors*, *Human Performance*, *Personnel Psychology*, *Journal of Educational Psychology*, and *Journal of Experimental Psychology*. For military-specific studies, we used a similar electronic search strategy for searches of various technical reports published by DoD contractors, such as the Army Research Institute and Defense Manpower Data Center, accessed through the Defense Technical Information Center. The focus of the review was on the effects

that timely encounters with tasks had on proficiency of skills, and studies outside this scope—including those concerned with biology, cognitive ability, and aptitude—were excluded.

Skill Retention Over Time and Encounter Frequency

Retention of knowledge over time is a concern in several fields, especially with fewer frequent encounters of tasks. In the case of foreign language skills, Bahrlick (1979) found that much of the information acquired in the classroom is lost soon after final examinations were taken. Foreign language retention dropped by 20 percent after one year and 50 percent after three years. The same pattern of retention is found for maintenance of medical knowledge. In a meta-analysis of studies of basic medical science knowledge, Custers (2010) found that 70 percent of knowledge will be retained after one year, decreasing below 50 percent in the following year. Verbal recall is also not immune to skill decay. Even with distributed practice, of the 254 studies of spacing effect reviewed for verbal recall tasks, only 6 percent involved a retention interval of longer than one day (Cepeda et al., 2006).

In general, retention of skills declines over time. In a quantitative review and meta-analysis of 189 independent data points extracted from 53 articles on factors that influence skill decay and retention, Arthur et al. (1998) found an increase in the amount of skill decay as the length of the nonpractice or nonuse interval increased. After more than one year, the average participant was performing at less than 92 percent of their previous level. Arthur et al. (1998)'s review included such naturalistic skills as landings, instrument flying, a variety of military tasks, and computer-processing tasks.

Skill decay is a concern for the Total Force. Active-duty personnel only deploy periodically. Air Expeditionary Forces, for instance, have a 20-month cycle with four-month rotation. Skill decay is a particular challenge among reservists, who are close to 40 percent of total U.S. uniformed manpower but might receive training only once or twice per year (Office of the Assistant Secretary of Defense for Manpower and Reserve Affairs, 2017). In a measure of performance of 200 Army soldiers on the Comprehensive Performance Test immediately after basic training and six weeks after basic training, the reported average reduction in performance over time was 18 percent to 26 percent (Vineberg, 1975).

Leonard, Wheaton, and Cohen (1976) also studied skill retention of Army personnel, measuring performance immediately after training, six weeks after initial training, 17 weeks after initial training, six weeks after refresher training, and 17 weeks after refresher training. Their findings reported that longer retention intervals were associated with poorer performance and that refresher training improved performance on some but not all tasks compared with those who did not have the refresher training.

Wisher, Sabol, and Ellis (1999) investigated the decay of skills and knowledge with 20,000 reservists and found that gross motor skills decayed after approximately ten months, whereas cognitive skills, such as recall of procedures, decayed within approximately six months. Various

military career fields suffer skill decay, such as sonar operators, gunners, bombers, air traffic controllers, radio operators, and mechanics (Hoffman et al., 2013).

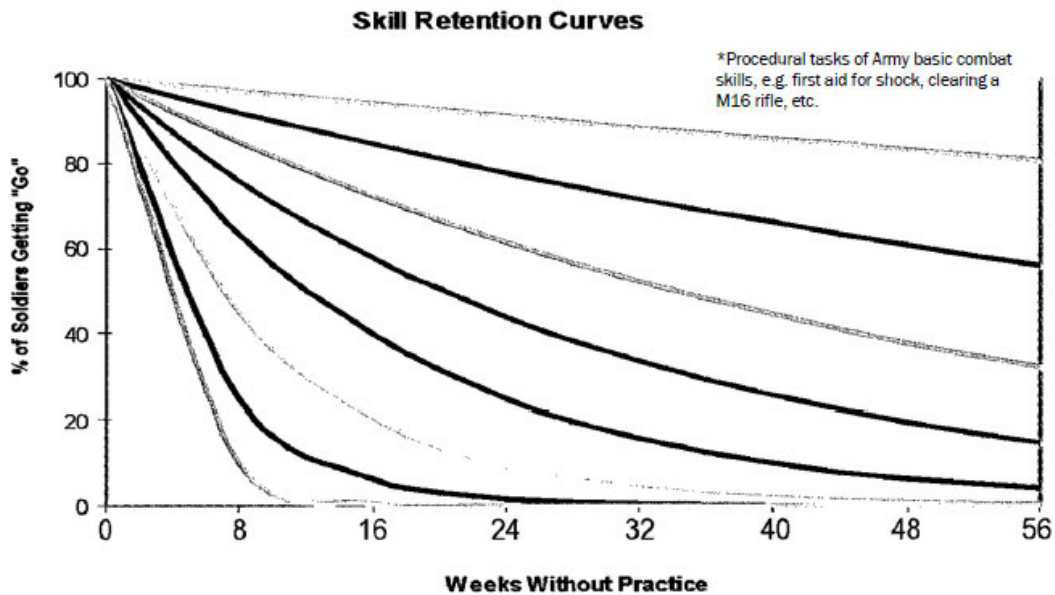
Quantifying Encounter Frequencies Required for Skill Retention in Maintainers

Skill decay, therefore, is a plausible consequence of nonuse of skills for the aircraft maintenance force, but what task or skill encounter frequency is sufficient to retain proficiency? Currently, there are limitations to the USAF's approaches of assessing maintainer proficiency after initial training. Additionally, the retention literature has limitations. Because retention of knowledge and skill decay are dynamic and multidimensional, it is difficult to precisely quantify how often tasks must be encountered within a given period to maintain proficiency. Therefore, for this analysis, we performed a semiquantitative analysis of the skill retention literature.

Different procedural tasks suffer skill decay at different rates over time without use or practice (Wisher, Sabol, and Ellis, 1999).⁸⁰ Wisher, Sabol, and Ellis (1999) find that, for the most extreme cases, some tasks show fairly constant performance month to month, while other tasks show a sharp decline in proficiency in almost the first eight weeks of nonuse of skill, as seen in Figure B.2. There are various tasks that lie between these extremes, which indicates that the frequency at which someone needs to encounter a task is not a single measure but rather a theoretical range.

⁸⁰ *Procedural tasks* involve performing a procedure or a sequence of actions.

Figure B.2. Skill Retention in Procedural Tasks



SOURCE: Wisher, Sabol, and Ellis, 1999, p. 9.

For instance, the cardiopulmonary resuscitation skill retention and decay literature provide evidence for skill decay over time with a substantial loss in skills occurring in the first year following training (McKenna and Glendon, 1985); in an occupational setting, only 12 percent were capable of performing effective cardiopulmonary resuscitation. McKenna and Glendon's 1985 study also found a linear decay in skills over time, with fewer than 20 percent of participants performing moderately after six months from original training. Similarly, Sitterley and Berge (1972) found that for perceptual-motor performance (e.g., typing, aircraft flight control, target tracking, marksmanship, or riding a bike), skill degradation reached its peak at about four months. On the other hand, discrete procedural skills (e.g., performing cardiopulmonary resuscitation, administering first aid for shock, clearing an M-16 rifle, or basic combat skills) might be forgotten more rapidly, degrading after only one month without practice and showing a sharp increase in degradation at four months.

After this semiquantitative analysis of the skill retention literature and discussion with subject matter experts, we selected an encounter frequency range to represent the proficiency standard going from an upper bound of 12 times per year (or every month) to a lower bound of three times per year (or every four months). In other words, our analysis estimates that maintainers should encounter tasks every one to three months to retain proficiency on those tasks.

Quantifying Task Encounter Frequency Before and After Consolidation

In the previous section, we used a literature review to estimate the frequency at which maintainers need to encounter tasks to retain proficiency on those tasks. In this section, we estimate how task-encounter frequencies change as AFSs are merged. The data used for the task frequency analysis are from LCOM.⁸¹ LCOM consists of large task networks assigned to different maintenance career fields, and these tasks are the full range of maintenance activities required for F-35A maintenance. This model was used to simulate a peacetime sortie schedule for a 24 PAA squadron (in other words, we simulated the tasks that would be required of the maintenance personnel in a 24 PAA F-35A squadron flying a relatively low-intensity sortie schedule), and the frequency that maintenance tasks occurred, the AFSs that could do those tasks, and the minimum crew size (i.e., number of maintainers) required for those tasks were extracted from the model and used as the underlying data for this analysis.

Using these data, we determined how frequently maintainers encountered tasks before and after consolidation under the baseline F-35A concept and whether AFSs were consolidated with the BOLT and LIT concepts. To do this, we first calculated for each task the number of maintainers who can maintain proficiency on that task based on the required encounter frequency (e.g., once per month to once every four months), the number of maintainers required to do that task (e.g., crew size), and the frequency with which the task occurred. Then, the percentage of maintainers who can maintain proficiency on a task was calculated using the previous measure and the total number of maintainers falling into the AFS that has responsibility for that task. The mathematical formulation for each of these measures is shown in Table B.1.

⁸¹ The LCOM model used was an F-35A model provided by the JPO that predicts performance at maturity via Lockheed Martin engineering estimates. This model is discussed in greater detail in Chapter 5.

Table B.1. Mathematical Formulation of Outcome Measures

| PRIMARY OUTCOME MEASURES | METHOD OF ANALYSIS |
|---|---|
| Number of maintainers that can maintain proficiency on a task, <i>i</i> , over one year* | <p><i>If $p > f_i$, then</i></p> $m_i = \frac{n_{i,A}f_i}{p}$ <p><i>$n_{i,A}$ = Number of maintainers of a particular career field, <i>A</i>, that are required to do task, <i>i</i></i> <i>f_i = Frequency that a task, <i>i</i>, occurs in a year*</i> <i>p = Proficiency standard (encounter frequency range)</i></p> |
| Percent of maintainers in a career field, <i>A</i> , that can maintain proficiency on a task, <i>i</i> , over one year* | <p><i>If task, <i>i</i>, requires career field, <i>A</i>, as a resource, then:</i></p> $Prof_{i,A} = \frac{m_i}{t_a}$ <p><i>m_i = Number of maintainers that can maintain proficiency on a task, <i>i</i></i> <i>t_a = Number of maintainers in each career field</i></p> |

*At peace-time demand

NOTE: The number of maintainers in each career field was adjusted to the baseline manpower requirement for the baseline, BOLT, and LIT concepts as described in Chapter 5 to reflect the potential manpower efficiencies gained through consolidation.

The resulting data set showed, for each task falling into each AFS or merged AFS, the percentage of maintainers who can maintain proficiency on that task. To report on the overall proficiency within a career field, this measure was averaged across all tasks falling into that AFS or merged AFS.

Consolidation Leads to Decreases in Maintainer Proficiency

From this analysis, we see that the percentage of maintainers in a career field who can maintain proficiency—as defined by task-encounter frequency—decreases with consolidation (Table B.2). This is true at both the upper and lower bounds of the proficiency standard. In other words, even if maintainers only need to encounter a task every four months to remain proficient, there is still a proficiency degradation following the merger of AFSs. As expected, when proficiency standards are higher (i.e., must encounter a task every month rather than every four months), proficiency is lower across the board for both the baseline and consolidated concepts.

Table B.2. Percentage of Maintenance Workforce (on Average) Encountering Tasks at Proficiency-Retaining Frequencies

| | Avionics | | Egress | | Fuels | | LOASM | |
|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| # of Tasks | 3,145 | | 49 | | 962 | | 1968 | |
| | Lower (%) | Upper (%) | Lower (%) | Upper (%) | Lower (%) | Upper (%) | Lower (%) | Upper (%) |
| Baseline | 16 | 5 | 67 | 33 | 37 | 14 | 58 | 17 |
| LIT | 3 | 1 | 67 | 33 | 37 | 14 | 11 | 3 |
| BOLT | 8 | 3 | 4 | 2 | 3 | 1 | 16 | 5 |

NOTES: Maintainers are “proficient” on a task as defined in this analysis when they are encountering a task once a month (upper bound) or once every four months (lower bound). Average is calculated over all tasks in that AFS. The number of tasks falling under each AFS (prior to any consolidation) is shown in the top row of the table. Tasks, in this case, are tasks as defined in the LCOM model, discussed in Chapter 5. The number of tasks in a parent AFS is assumed to not change when merged with another AFS in LIT or BOLT to generate new, merged AFSs.

Table B.2 shows the rates of proficiency under the lower and upper bound requirements for tasks associated with four current AFSs that are affected by at least one of the BOLT and LIT concepts. Comparing the baseline values with those of the BOLT and LIT concepts suggests areas where proficiency concerns might be greatest and where targeted steps to maintain proficiency (e.g., use of targeted maintenance drills and simulators) might be necessary. For example, it suggests proficiency in Avionics tasks is likely to be affected if either the BOLT or LIT concept is pursued, although the concerns are likely to be larger under the LIT concept. This overall trend is similar for the other career specialties, not surprisingly because the merged AFS concepts are requiring maintainers to complete a larger variety of tasks while the operational need to perform those tasks remains constant.

In general, as can be seen in Table B.2, the greater the consolidation (i.e., the number of AFSs consolidated), the greater the expected impact to proficiency will be. For example, Avionics is consolidated in both the LIT and BOLT concepts, but in LIT it is merged with three other AFSs and in BOLT it is only merged in two. Accordingly, the percentage of maintainers who encounter Avionics tasks at proficiency-retaining rates is lower for LIT than it is for BOLT. On the other hand, when a career field is not consolidated—such as Egress for the BOLT concept—there are no changes to proficiency.

It is important to caveat the results of this analysis by pointing out that this analysis uses an indirect measure of proficiency. This analysis can show that proficiency will decrease as AFSs are merged within the career fields that are affected by the merger using this indirect indicator of proficiency that takes into account encounter frequency *only*. It is notable that, by this measure of proficiency, the baseline concept does not provide enough frequent encounters of tasks for maintainers to remain proficient in all of those tasks, particularly Avionics and Fuels. Particularly in the case of Avionics, some of this lower proficiency—even in the baseline—might derive from the very high number of tasks the LCOM model assigns to that AFS. Because the USAF aircraft maintenance system does function at baseline, this encounter-frequency metric

alone clearly does not capture the full picture of proficiency. What this metric can help illuminate is a sense of the magnitude of proficiency changes that might occur once AFSs are merged, but it cannot say very much about the true proficiency of the workforce. The direct measures of proficiency—specifically, the percentage of tasks completed successfully and the average time to complete a task in the merged versus the baseline concepts—would be a superior way to quantify the impact of an AFS merger on proficiency, although such measures are not currently available for analysis.

A few other caveats are important to consider: This analysis is based on the F-35A LCOM model, which has all of the caveats discussed in Chapter Five. Notably, the number of tasks that are assigned to each AFS—which vary widely from AFS to AFS, as shown in Table B.2—is critically important in this analysis and is derived entirely from the LCOM model. This analysis also assumes that a maintenance task must occur (i.e., that a particular break must happen) for a maintainer to encounter it, and that only the number of maintainers required in the task crew size (as specified by LCOM) have the opportunity to train on that task. This does not consider other ways in which the maintenance force might increase maintainer exposure to rarer tasks, including additional training or training multiple maintainers on that task.

Conclusions and Recommendations

To summarize, as career specialties merge, maintainers encounter maintenance tasks less frequently, which could have the effect of decreasing the overall proficiency of the force. We caveat this conclusion by pointing out that proficiency standards for the maintenance community are not clear. This analysis can show that proficiency will decrease as AFSs are merged within the career fields that are affected by the merger. Whether the proficiency levels—as measured by this very specific metric that only takes into account encounter frequency—following the merger are acceptable to the USAF is outside the scope of the study.

However, the results of this study suggest that a focus on proficiency will be critical to the successful implementation of merged AFS concepts. In the event that more consolidated AFS concepts are pursued, we recommend the following:

- The USAF should consider whether a more-robust training program to augment proficiency might be warranted when AFSs are broadened, including potential refresher training in tasks that occur less frequently.
- The impacts of consolidation on the reserve component should be explored.
- New methods to measure maintainer proficiency to account for the breadth of training required for merging AFSs should be developed.

Appendix C. Sensitivity of Availability Analysis Results to Uncertainty in Assumptions

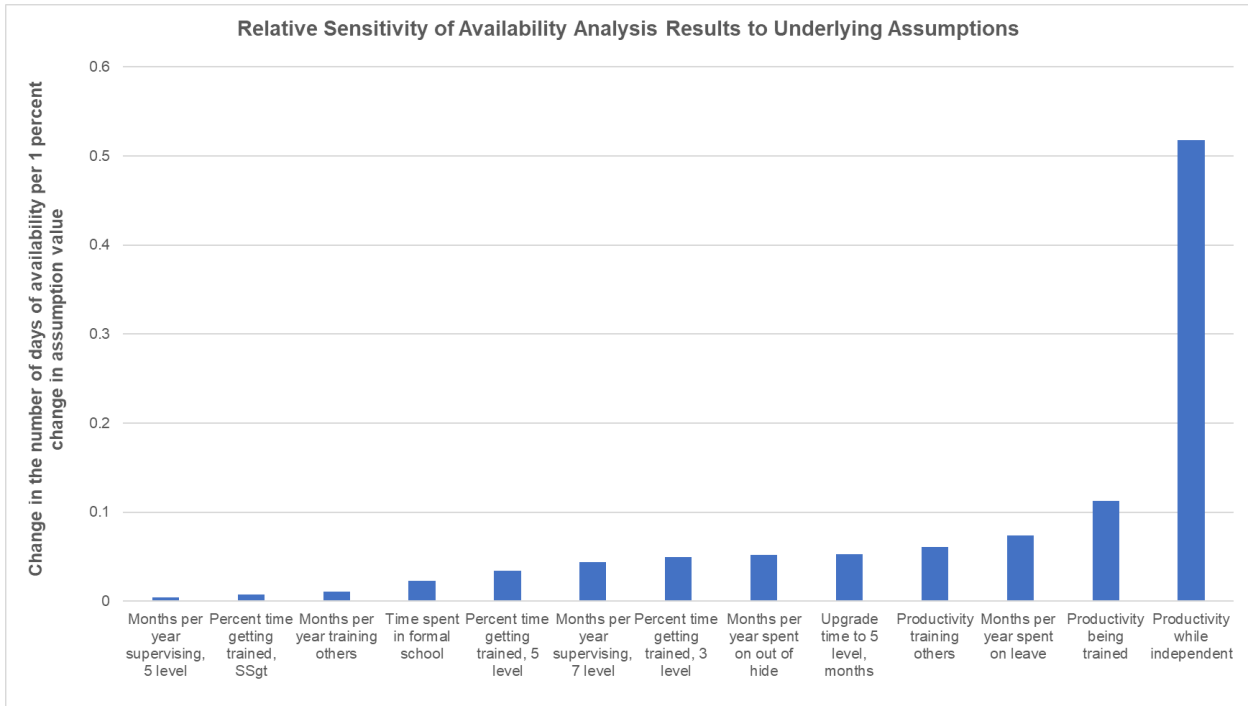
In Chapter 4, an availability analysis was used to evaluate how differences in training burdens across merged AFS concepts are expected to affect the total number of days in a maintainer's career that they can devote to hands-on maintenance. This analysis depended on several assumptions, which are documented in Chapter 4, Table 4.2. As discussed in Chapter 4, many of these assumptions are inherently qualitative, with uncertainty that is difficult to quantify.

Thus, a sensitivity analysis was used to evaluate the relative contribution of each of these assumptions to the result of the analysis: the total availability of maintainers. That is, the sensitivity analysis asked the question: Of the assumptions that were made, where is uncertainty going to have the greatest impact in the overall results of the analysis?

For the traditional maintenance concept, the assumptions listed along the x-axis in Figure C.1 were varied from -50 percent of the value used in the analysis to +50 percent of the value used in the analysis (values used in the analysis available in Table 4.2) and the total days available to do maintenance calculated by the methodology described in Chapter 4.⁸² For each assumption, the change in the number of days per 1 percent change in the assumption value was calculated. The larger this value, the greater the impact that error in that assumption will have on the overall results. Figure C.1 summarizes the results of the analysis.

⁸² The case studied in the sensitivity analysis was the baseline maintenance concept.

Figure C.1. Relative Sensitivity of Availability Analysis Results to Underlying Assumptions



We will use productivity while being trained as an illustrative example of how to interpret the results of the sensitivity analysis. Productivity while being trained is assumed to be 40 percent in the availability analysis. If that assumption was very wrong and productivity while being trained was actually 0 percent, this would decrease the total days available to do maintenance by 11. The equation for this is $(0.11 \text{ days per percent change in assumption} * 100 \text{ percent change in assumption value})$, representing a decrease of 16 percent in maintainer availability.

Productivity while independent, productivity while being trained, months per year spent on leave, and productivity while training others are the assumptions that have the most significant impact on the overall availability results. The uncertainty in these assumptions is variable. Months per year spent on leave is an assumption that is well defined because it is generally set by USAF policy. The productivity of maintainers while independent is not expected to vary from concept to concept, thus relative changes in this assumption are unlikely to affect the overall results of the analysis.

However, the productivity of maintainers while being trained or training others is very uncertain and might vary across different maintenance concepts depending on how they ultimately could be implemented. For example, under a merged AFS concept in which maintainers are expected to become proficient in many tasks, this productivity might go down, which would decrease the overall availability of maintenance personnel to do maintenance. If this were the case, the overall cost benefit of merged AFS concepts could decrease. Similar

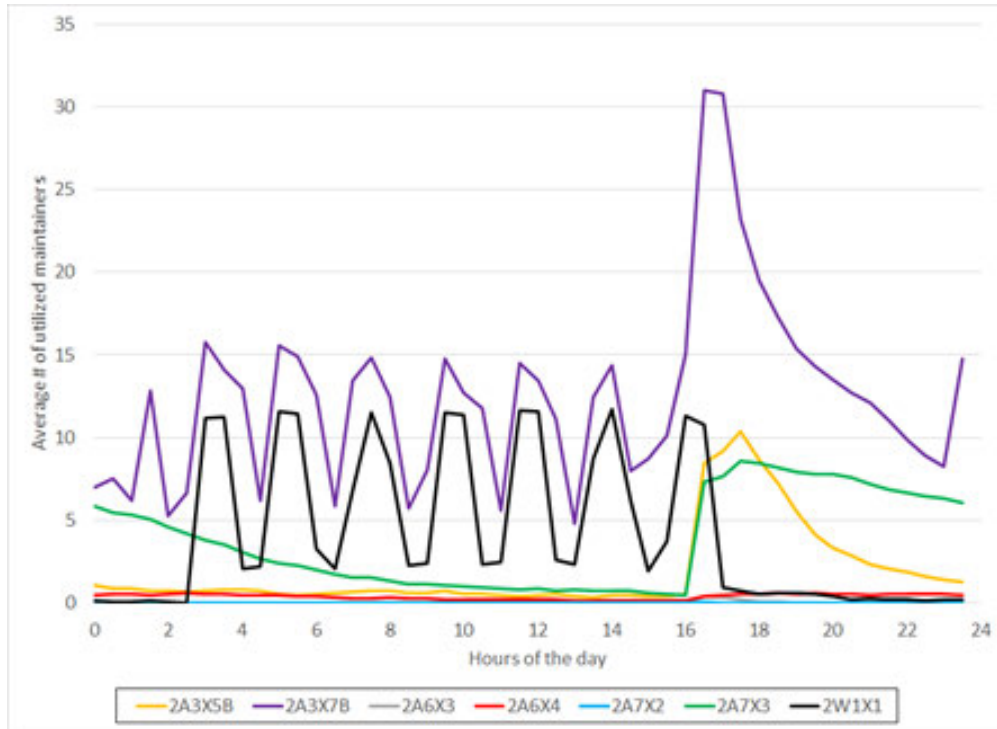
arguments can be made for all of the assumptions made in the availability analysis, although the results of the sensitivity analysis suggest that uncertainty in those assumptions will have a much less significant impact on the overall availability results.

Appendix D. Using LCOM to Find Efficient Combinations of AFSs

Before LCOM was used to determine manpower requirements, a task analysis was used to shed light on AFS combinations that are likely to lead to the most efficiencies. From a maintenance workload perspective, two AFSs would be good candidates for consolidation if there was a negative correlation between the times that they were working actively. For example, suppose that AFS i is only actively performing maintenance from 06:00–10:00, while AFS j is only busy from 10:00–14:00. In this case, a consolidated AFS could perform both workloads with significantly less manpower (at the extreme, eliminating a number of positions equal to the smaller of AFS i manpower and AFS j manpower). LCOM outputs present the number of maintainers actively used across the hours of the day. However, it is important to keep in mind that LCOM outputs are highly dependent on both the flying schedule that is being supported and the available pool of maintenance manpower.

Figure D.1 presents the average number of actively used maintainers, by AFS, tracked in 30-minute increments, for a representative LCOM simulation: Different AFSs have different patterns of workload throughout the day. TAMS has the largest average utilization at every time period, with two distinct workload shapes throughout the day. Between 02:00 and 14:00, the utilization has a periodic shape, cycling between a maximum and minimum of approximately 15 and seven used maintainers, on a two-hour cycle (corresponding to sortie launches and recoveries). Utilization surges at 16:00, then slowly decreases until 23:30, when demand surges again. Other AFSs have different patterns of utilization, e.g., 2A7X3 (LOASM and Metals Tech) and 2A3X5B (Avionics) have a surge in workload between 16:00 and 18:00 and a gently decreasing utilization for the rest of the day until 16:00.

Figure D.1. Average Utilization by AFS, from LCOM Run with Notional Flying Schedule

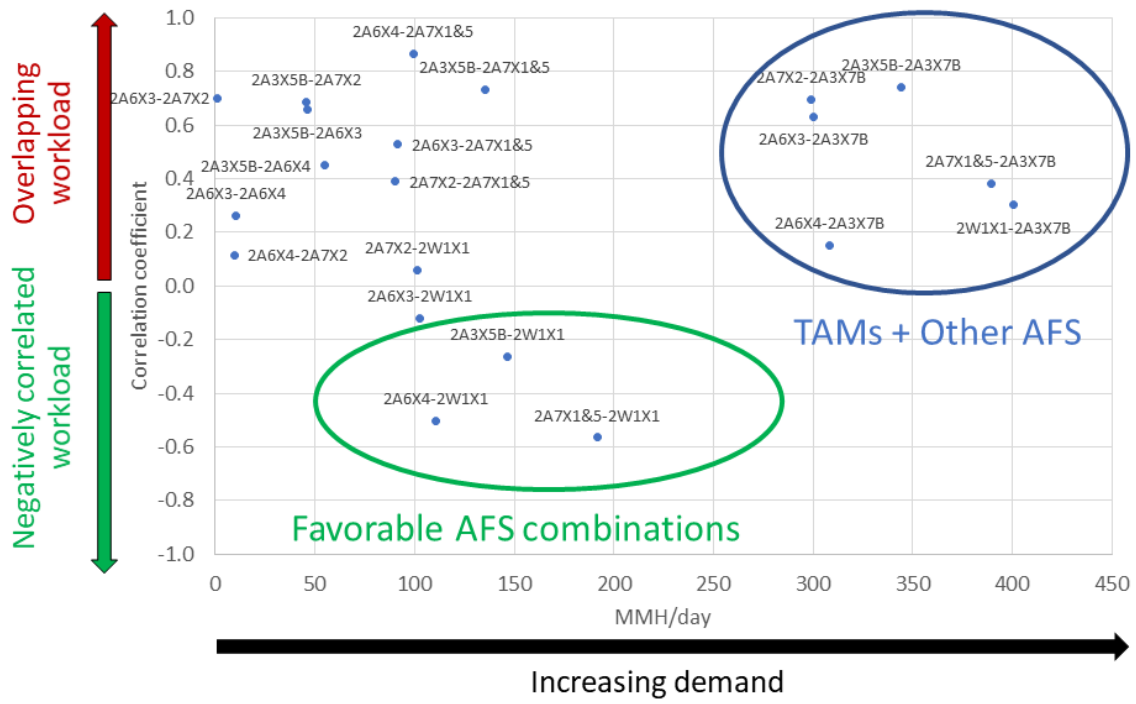


Correlation, which refers to the degree to which a pair of variables are linearly related, can be used to evaluate AFS combinations. AFS pairs with large manpower and negative correlation are attractive for consolidation, because they could potentially allow for large manpower reductions. Rather than evaluate a predetermined set of maintenance concepts, one could envision using this analytic approach to identify AFS pairs that are good candidates for consolidation. Figure D.2 presents such an analysis. There, the horizontal axis presents the sum total MMH/day across the pair of AFSs, a proxy for the size of manpower required under the AFS combination. The vertical axis presents the correlation coefficient between the pair's average utilization values. Because TAMS had an average MMH per day value much larger than any other AFS, the upper right quadrant is dominated by TAMS and other AFS pairs. Pairs appearing in the lower left quadrant of the graph are the candidates suggested by this analytic approach: 2W1X1 (Weapons) and 2A7X3 (LOASM and Metals Tech)⁸³ are the strongest candidate pair for merging; the next-best pairs are 2W1X1 (Weapons) with 2A6X4 (Fuels) and 2W1X1 (Weapons) with 2A3X5B (Avionics). 2A6X3 (Egress) and 2W1X1 (Weapons) also create a favorable combination.

Several of the most-promising combinations identified through this analysis are combined in either BOLT or LIT, which likely underlies some of the greater efficiencies observed for those concepts. Notably, weapons and avionics are combined in LIT, and Egress and Weapons are combined in BOLT.

⁸³ LOASM and Metals Tech are combined into a single AFS in the F-35A LCOM model used in this analysis.

Figure D.2. Evaluating AFS Pairs, Using MMH/Day and Correlation of Utilization



Appendix E. Other Ways to Organize the Maintenance Force

This report studies concepts for the organization of maintenance personnel that focus on merging career fields. This assumes that, generally speaking, maintainers focus on a single MDS at the start of their careers (they can spread to other platforms later in their careers) and are broadening their technical areas of expertise. There are, however, other strategies that either broaden across MDS or across function that can be considered. Although these were outside the scope of this study, we discuss them in this appendix within the context of their applicability to Agile Combat Support and other future concepts.

Cross-MDS Maintenance Support

Traditionally, the USAF tightly couples maintenance and fighter operating units. There are other possible support concepts the USAF could consider to get more flexibility and more resilience from the entire maintenance force. Instead of cross-training across different AFSs, such as Avionics and Egress, this concept would train Egress technicians to perform that function across all USAF MDS. Currently the mobility units of the Mobility Air Force (MAF) have designed a very flexible maintenance support structure by separating the maintenance units from the operating units. MAF lift aircraft operate globally and, by their nature, are not tied to a location but move according to mission. This tends to create low densities of aircraft spread over many locations. The maintenance units are capable of servicing all the mobility MDS to more efficiently provide support under these conditions. The aircraft can get maintenance at the en route hubs, or maintainers can be deployed to needed locations. This is a unique arrangement in the USAF. The Combat Air Force (CAF) forces, whether at home or deployed, tend to operate from one location, so dedicated maintenance units collocated with operational units makes sense. A change to provide cross-MDS-trained maintainers probably would not copy the mobility forces because the CAF has more aircraft types and has a propensity to operate from one location. But it might be worth considering whether some cross-MDS training of some Fuels, Weapons, and some other maintenance tasks maintainers would allow the USAF to establish several MDS-agnostic turn sites.

The concepts considered in this report could be expanded to provide this additional cross-training, so it would exist as a distinct cross-training program if the USAF sees benefits in such capabilities.

Cross-Functional Training

Having considered cross-AFS maintenance training and cross-MDS maintenance training, we now consider cross-functional training: that is, training maintainers to defend and recover from

attacks. Currently, the USAF has forces that provide a variety of base protection and recovery capabilities. As footprints at operating locations become more lean, there will likely be situations where few or none of these forces are present. In those cases, what cross-functional training is necessary for maintenance and other forces? The Marines say that all marines are riflemen. The USAF does not have that mentality but certainly might wish for personnel in a position that could come under attack from ground threats to be trained to defend themselves.

Whether deployed forces should also be able to augment or replace security forces is a different question. It is not clear that the maintainer workload will provide much time for alternative support functions. Setting aside the disparate nature of the security and maintenance tasks,⁸⁴ this strategy might not be practical: An attacker would prefer to attack while aircraft are present so that they can damage the aircraft; however, that is when the maintainers will likely be conducting maintenance. They cannot be doing both simultaneously. If there is a ground threat, it is probably best countered with well-trained security forces, be they USAF, joint, or host nation, not with maintainers.

Alternatively, the forces could be trained in some recovery functions. As discussed above, the attacker can target many different airfield assets. Assuming that the Fuels experts will already be trained and equipped to recover from an attack on fuel storage, another recovery task that could benefit from additional manpower would be runway repair. This could provide some benefit to recovery speed; however, the extra manpower from maintainers is probably not the key ingredient to runway repair. Runway repair comes with substantial equipment and materials demands that would need to be in place, which, in turn, implies a fairly large detachment. Furthermore, it needs expertise in EOD and engineering that are not amenable to cross-training, but instead require strong expertise.

Thus, cross-functional training of maintainers is not obviously a potential benefit beyond providing self-defense instruction to those who will deploy to areas with increased ground threats.

⁸⁴ This brief discussion does not consider occupational analysis data, which can definitely determine which tasks are most amenable for cross-functional training.

References

- 359 Training Squadron and 372 Training Squadron Detachment 2918, “Combined Mission Brief,” delivered to RAND Corporation researchers during visit to Eglin Air Force Base, Fla., March 2019.
- AFI—*See* Air Force Instruction.
- Air Force Instruction 21-101, *Aircraft and Equipment Maintenance Management*, Washington, D.C.: Department of the Air Force, updated January 16, 2020. As of March 4, 2020: https://static.e-publishing.af.mil/production/1/af_a4/publication/afi21-101/afi21-101.pdf
- Air Force Instruction 36-2650, *Maintenance Training*, Washington, D.C.: Department of the Air Force, May 2, 2019. As of March 6, 2020: https://static.e-publishing.af.mil/production/1/af_a4/publication/afi36-2650/afi36-2650.pdf
- Air Force Instruction 36-2651, *Air Force Training Program*, Washington, D.C.: Department of the Air Force, updated November 20, 2019. As of September 4, 2019: https://static.e-publishing.af.mil/production/1/af_a1/publication/afi36-2651/afi36-2651.pdf
- Air Force Instruction 38-101, *Manpower and Organization*, Washington, D.C.: Department of the Air Force, updated August 29, 2019. As of September 12, 2019: https://static.e-publishing.af.mil/production/1/af_a1/publication/afi38-101/afi38-101.pdf
- Air Force Instruction 65-503, *U.S. Air Force Cost and Planning Factors*, Washington, D.C.: Department of the Air Force, updated July 13, 2018. As of September 3, 2019: https://static.e-publishing.af.mil/production/1/saf_fm/publication/afi65-503/afi65-503.pdf
- Air Force Personnel Center, Airman Extract Data Set, obtained on December 6, 2018, Not available to the general public.
- Air Force Personnel Center, *Air Force Enlisted Classification Directory (AFECD)*, April 30, 2019.
- Albrecht, Mark J., *Labor Substitution in the Military Environment: Implications for Enlisted Force Management*, Santa Monica, Calif.: RAND Corporation, R-2330-MRAL, 1979. As of April 2, 2020: <https://www.rand.org/pubs/reports/R2330.html>
- Arthur, Winfred, Jr., Winston Bennett, Jr., Pamela L. Stanush, and Theresa L. Mcnelly, “Factors That Influence Skill Decay and Retention: A Quantitative Review and Analysis,” *Human Performance*, Vol. 11, No. 1, 1998, pp. 57–101.

- Aspin, Les, *Report on the Bottom-Up Review*, Washington, D.C.: U.S. Department of Defense, October 1993.
- Bahrack, Harry P., “Maintenance of Knowledge: Questions About Memory We Forgot to Ask,” *Journal of Experimental Psychology: General*, Vol. 108, No. 3, 1979, pp. 296–308.
- Bowie, Christopher J., *The Anti-Access Threat and Theater Air Bases*, Washington, D.C.: Center for Strategic and Budgetary Assessments, 2002.
- Boyle, Edward, Stanley Goralski, and Michael Meyer, “The Aircraft Maintenance Workforce Now and in the Twenty-First Century,” *Air Force Journal of Logistics*, Vol. IX, No. 4, Fall 1985, pp. 3–5.
- Brauner, Marygail K., and Jean R. Gebman, *Is Consolidation Being Overemphasized for Military Logistics?* Santa Monica, Calif.: RAND Corporation, IP-103, 1993. As of August 15, 2019: https://www.rand.org/pubs/issue_papers/IP103.html
- Brown, Charles Q., Jr., Bradley D. Spacy, and Charles G. Glover III, “Untethered Operations: Rapid Mobility and Forward Basing Are Keys to Airpower’s Success in the Antiaccess/Area-Denial Environment,” *Air and Space Power Journal*, Vol. 29, No. 3, May–June 2015, pp. 18–28.
- Bureau of Economic Analysis, “GDP Price Index,” webpage, last updated February 27, 2020. As of March 4, 2020: <https://www.bea.gov/data/prices-inflation/gdp-price-index>
- Cepeda, Nicholas J., Harold Pashler, Edward Vul, John T. Wixted, and Doug Rohrer, “Distributed Practice in Verbal Recall Tasks: A Review and Quantitative Synthesis,” *Psychological Bulletin*, Vol. 132, No. 3, May 2006, pp. 354–380.
- Correll, John T., “Tradition and Change in ATC,” *Air Force Magazine*, Vol. 71, No. 12, December 1988, pp. 40–44.
- Custers, Eugène J. F. M., “Long-Term Retention of Basic Science Knowledge: A Review Study,” *Advances in Health Sciences Education*, Vol. 15, No. 1, 2010, pp. 109–128.
- Da Cunha, Mozer O., “NCOA Changes Curriculum and Eligibility Requirements,” Barksdale Air Force Base, webpage, November 4, 2014, updated November 5, 2014. As of August 1, 2015: <https://www.barksdale.af.mil/News/Article/634884/ncoa-changes-curriculum-and-eligibility-requirements/>
- Dahlman, Carl J., Robert Kerchner, and David E. Thaler, *Setting Requirements for Maintenance Manpower in the U.S. Air Force*, Santa Monica, Calif.: RAND Corporation, MR-1436-AF, 2002. As of August 15, 2019: https://www.rand.org/pubs/monograph_reports/MR1436.html

- DeBlois, Bradley, Thomas Light, Daniel M. Romano, Michael Boito, John G. Drew, Paul Emslie, Michael Kennedy, Kathryn O'Connor, and Jonathan William Welburn, *Options for Enhancing the Effectiveness of Maintenance Force Structure: Examining the Decline in KC-135 Availability*, Santa Monica, Calif.: RAND Corporation, 2020, Not available to the general public.
- Defense Intelligence Ballistic Missile Analysis Committee, *Ballistic and Cruise Missile Threat 2017*, Wright-Patterson Air Force Base, Ohio: NASIC Public Affairs Office, NASIC-1031-0985-17, June 2017.
- Director, Operational Test and Evaluation, *FY 2018 Annual Report*, Washington, D.C.: U.S. Department of Defense, December 2018.
- Drew, John G., Kristin F. Lynch, James M. Masters, Robert S. Tripp, and Charles Robert Roll, Jr., *Options for Meeting the Maintenance Demands of Active Associate Flying Units*, Santa Monica, Calif.: RAND Corporation, MG-611-AF, 2008. As of November 3, 2018: <http://www.rand.org/pubs/monographs/MG611.html>
- Everstine, Brian W., "PACAF Practices Rapidly Dispersing to Forward Bases," *Air Force Magazine*, April 23, 2019.
- Harrington, Michael Trent, "Rapid Raptor Moves JBER F-22s Closer to the Fight," Joint Base Elmendorf-Richardson, webpage, May 15, 2014. As of March 4, 2020: <https://www.jber.jb.mil/News/Commentaries/Display/Article/772210/rapid-raptor-moves-jber-f-22s-closer-to-the-fight/>
- Heginbotham, Eric, Michael Nixon, Forrest E. Morgan, Jacob L. Heim, Jeff Hagen, Sheng Tao Li, Jeffrey Engstrom, Martin C. Libicki, Paul DeLuca, David A. Shlapak, David R. Frelinger, Burgess Laird, Kyle Brady, and Lyle J. Morris, *The U.S.-China Military Scorecard: Forces, Geography, and the Evolving Balance of Power, 1996–2017*, Santa Monica, Calif.: RAND Corporation, RR-392-AF, 2015. As of March 4, 2020: https://www.rand.org/pubs/research_reports/RR392.html
- Hoffman, Robert R., Paul Ward, Paul J. Feltovich, Lia DiBello, Stephen M. Fiore, and Dee H. Andrews, *Accelerated Expertise: Training for High Proficiency in a Complex World*, New York: Psychology Press, 2013.
- Joint Chiefs of Staff, *Manual for the Operation of the Joint Capabilities Integration and Development System*, Washington, D.C., August 31, 2018.
- Lammers, Matthew, "56 FW LIGHTNING INTEGRATED TECHNICIAN (LIT)," briefing delivered to RAND Corporation researchers, Luke Air Force Base, Ariz., December 6, 2018.
- Layne, Mary, Scott Naftel, Harry J. Thie, and Jennifer H. Kawata, *Military Occupational Specialties: Change and Consolidation*, Santa Monica, Calif.: RAND Corporation, MR-977-

- OSD, 2001. As of November 3, 2015:
http://www.rand.org/pubs/monograph_reports/MR977.html
- Leonard, Russell L., Jr., George R. Wheaton, and Frances P. Cohen, *Transfer of Training and Skill Retention*, Washington, D.C.: American Institutes for Research, TR-76-A3, October 1976.
- Light, Thomas, Daniel M. Romano, Michael Kennedy, Caolionn O’Connell, and Sean Bednarz, *Consolidating Air Force Maintenance Occupational Specialties*, Santa Monica, Calif.: RAND Corporation, RR-1307-AF, 2016. As of August 15, 2019:
https://www.rand.org/pubs/research_reports/RR1307.html
- Lynch, Kristin F., John G. Drew, David W. George, Robert S. Tripp, Charles Robert Roll, Jr., and James A. Leftwich, *The Air Force Chief of Staff Logistics Review: Improving Wing-Level Logistics*, Santa Monica, Calif.: RAND Corporation, MG-190-AF, 2005. As of September 11, 2019:
<https://www.rand.org/pubs/monographs/MG190.html>
- Mattis, Jim, *Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Military’s Competitive Edge*, Washington, D.C.: U.S. Department of Defense, 2018.
- McGarvey, Ronald G., James H. Bigelow, Gary J. Briggs, Peter Buryk, Raymond E. Conley, John G. Drew, Perry Firoz, Julie Kim, Lance Menthe, Craig Moore, William W. Taylor, and William A. Williams, *Assessment of Beddown Alternatives for the F-35*, Santa Monica, Calif.: RAND Corporation, RR-124-AF, 2013. As of September 9, 2019:
https://www.rand.org/pubs/research_reports/RR124.html
- McKenna, Stephen P., and A. Ian Glendon, “Occupational First Aid Training: Decay in Cardiopulmonary Resuscitation (CPR) Skills,” *Journal of Occupational Psychology*, Vol. 58, No. 2, June 1985, pp. 109–117.
- Mills, Patrick, John G. Drew, John A. Ausink, Daniel M. Romano, and Rachel Costello, *Balancing Agile Combat Support Manpower to Better Meet the Future Security Environment*, Santa Monica, Calif.: RAND Corporation, RR-337-AF, 2014. As of March 4, 2020:
https://www.rand.org/pubs/research_reports/RR337.html
- Moore, Frankie D., “Air Force ICTs Make a Comeback,” Air Combat Command, webpage, February 11, 2019. As of March 4, 2020:
<https://www.acc.af.mil/News/Article-Display/Article/1754204/air-force-icts-make-a-comeback/>
- Munn, Trey G., “Blended Operational Lightning Technician (BOLT) Program Overview,” briefing delivered to RAND Corporation researchers, Hill Air Force Base, Utah, November 30, 2018, Not available to the general public.

- Office of the Assistant Secretary of Defense for Manpower and Reserve Affairs, Total Force Manpower and Resources Directorate, *Defense Manpower Requirements Report Fiscal Year 2018*, Washington, D.C.: U.S. Department of Defense, December 2017.
- Oliver, Steven A., *Cost and Valuation of Air Force Aircraft Maintenance Personnel Study*, Maxwell Air Force Base, Gunter Annex, Ala.: Air Force Logistics Management Agency, August 2001.
- Robinson, Elaine, “Rivet Workforce and the F-16 Block 40: The Convergence of Training Issues in the 388 TFW’s Conversion,” *Air Force Journal of Logistics*, Volume XIII, No. 3, Summer 1989, pp. 16–20.
- Schanz, Marc V., “Rapid Raptor Package,” *Air Force Magazine*, September 27, 2013.
- Shanmugam, A., and T. Paul Robert, “Ranking of Aircraft Maintenance Organization Based on Human Factor Performance,” *Computers and Industrial Engineering*, Vol. 88, October 2015, pp. 410–416.
- Shugart, Thomas, “Has China Been Practicing Preemptive Missile Strikes Against U.S. Bases?” *War on the Rocks*, February 6, 2017.
- Sitterley, Thomas E., and Wayne A. Berge, *Degradation of Learned Skills: Effectiveness of Practice Methods on Simulated Space Flight Skill Retention*, Seattle, Wash.: Boeing Company, D180-15081-1, July 1972.
- USAF—See U.S. Air Force.
- U.S. Air Force, “Regular Air Force Selective Retention Bonus Listing,” webpage, November 21, 2019. As of December 12, 2019:
https://www.afpc.af.mil/Portals/70/documents/14_RETENTION/FY20%20SRB%20Listing-20191121.pdf?ver=2019-11-20-122754-163
- U.S. Air Force, AFLCMC/EZJS, *LCOM Analysis Toolkit 5.0.1 User’s Manual Volume 3—Input Model*, Wright-Patterson Air Force Base, Ohio, July 2017, Not available to the general public.
- U.S. Department of Defense, *Quadrennial Defense Review*, Washington, D.C., September 30, 2001.
- U.S. Department of Defense, *Quadrennial Defense Review 2014*, Washington, D.C., March 4, 2014.
- U.S. Government Accountability Office, *F-35 Sustainment: DOD Needs a Plan to Address Risks Related to Its Central Logistics System*, report to congressional committees, Washington, D.C., GAO-16-439, April 2016.

- U.S. Government Accountability Office, *Military Personnel: Strategy Needed to Improve Retention of Experienced Air Force Aircraft Maintainers*, report to congressional committees, Washington, D.C., GAO-19-160, February 2019a.
- U.S. Government Accountability Office, *F-35 Aircraft Sustainment: DOD Needs to Address Substantial Supply Chain Challenges*, report to congressional requesters, Washington, D.C., GAO-19-321, April 2019b.
- Vineberg, Robert, *A Study of the Retention of Skills and Knowledge Acquired in Basic Training*, Alexandria, Va.: Human Resources Research Organization, HUMRRO-TR-75-10, June 1975.
- Wang, Xiaoqian, Eric Anthony Day, Vanessa Kowollik, Matthew J. Schuelke, and Michael G. Hughes, “Factors Influencing Knowledge and Skill Decay After Training: A Meta-Analysis,” in Winfred Arthur, Jr., Eric Anthony Day, Winston Bennett, Jr., and Antoinette M. Portrey, eds., *Individual and Team Skill Decay: The Science and Implications for Practice*, New York: Taylor and Francis, 2013, pp. 68–117.
- Watts, Barry D., *The Evolution of Precision Strike*, Washington, D.C.: Center for Strategic and Budgetary Assessments, 2013.
- Weisgerber, Marcus, “Pentagon Debates Policy to Strengthen, Disperse Bases,” *Defense News*, April 13, 2014.
- Wild, William G., Bruce R. Orvis, Rebecca Mazel, Iva S. MacLennan, and R. D. Bender, *Design of Field-Based Crosstraining Programs and Implications for Readiness*, Santa Monica, Calif.: RAND Corporation, R-4242-A, 1993. As of September 12, 2019: <https://www.rand.org/pubs/reports/R4242.html>
- Winkler, John D., and Paul S. Steinberg, *Restructuring Military Education and Training: Lessons from RAND Research*, Santa Monica, Calif.: RAND Corporation, MR-850-A/RC, 1997. As of September 12, 2019: https://www.rand.org/pubs/monograph_reports/MR850.html
- Wisher, Robert A., Mark A. Sabol, and John A. Ellis, *Staying Sharp: Retention of Military Knowledge and Skills*, Special Report No. 39, Alexandria, Va.: Army Research Institute for the Behavioral and Social Sciences, July 1999.



The U.S. Air Force (USAF) has a goal of reducing the life cycle operating and support (O&S) costs of the F-35A. Maintenance manpower is a significant driver of O&S costs, and consolidation and reorganization of maintenance career fields could reduce manpower and training costs. Such consolidations might also apply to other objectives, including reducing aircraft downtime due to maintenance, improving combat resiliency, and developing a maintenance workforce that can be employed in leaner, more-mobile adaptive basing concepts.

The authors of this report evaluate the costs and benefits of six F-35A maintenance manpower force structures that merge maintenance career fields in different ways, including two alternatives that are being explored by the USAF at the time of publication: the Blended Operational Lightning Technician (BOLT) and the Lightning Integrated Technician (LIT). In addition to quantifying impacts to O&S costs if merged Air Force Specialty (AFS) concepts are adopted, the authors discuss the applicability of such concepts to future basing concepts and identify implementation challenges.

The analysis finds that some—but not all—merged AFS concepts offer the potential to increase readiness through increased sortie-generation capability or lower O&S costs through manpower efficiencies, but significant barriers to implementation exist. If the USAF adopts merged AFS concepts, only those that are aggressive mergers of career fields—such as BOLT and LIT—should be pursued. Additionally, before adopting merged career field concepts, the USAF should further explore implementation barriers identified in the analysis, particularly those related to maintainer proficiency and training.

\$33.50

ISBN-10 1-9774-0534-7
ISBN-13 978-1-9774-0534-0



www.rand.org