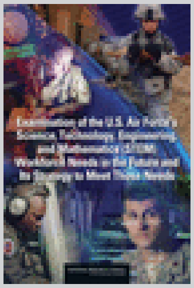
This PDF is available from The National Academies Press at http://www.nap.edu/catalog.php?record_id=12718



Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

ISBN
978-0-309-14197-0

176 pages
8 1/2 x 11
PAPERBACK (2010)

Committee on Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs; National Research Council

Add book to cart

Find similar titles

Share this PDF

Visit the National Academies Press online and register for...

- Instant access to free PDF downloads of titles from the
  - NATIONAL ACADEMY OF SCIENCES
  - NATIONAL ACADEMY OF ENGINEERING
  - INSTITUTE OF MEDICINE
  - NATIONAL RESEARCH COUNCIL
- 10% off print titles
- Custom notification of new releases in your field of interest
- Special offers and discounts

Distribution, posting, or copying of this PDF is strictly prohibited without written permission of the National Academies Press.
Unless otherwise indicated, all materials in this PDF are copyrighted by the National Academy of Sciences.
Request reprint permission for this book

Copyright © National Academy of Sciences. All rights reserved.

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

Committee on Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

Air Force Studies Board

Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

Copyright © National Academy of Sciences. All rights reserved.

THE NATIONAL ACADEMIES PRESS 500 Fifth Street, N.W. Washington, DC 20001

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This is a report of work supported by Grant FA9550-08-1-0253 between the U.S. Air Force and the National Academy of Sciences. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the organizations or agencies that provided support for the project.

International Standard Book Number 13: 978-0-309-14197-0
International Standard Book Number 10: 0-309-14197-4

Limited copies of this report are available from:

Air Force Studies Board
National Research Council
500 Fifth Street, N.W.
Washington, DC 20001
(202) 334-3111

Additional copies are available from:

The National Academies Press
500 Fifth Street, N.W.
Lockbox 285
Washington, DC 20055
(800) 624-6242 or (202) 334-3313
(in the Washington metropolitan area)
Internet, http://www.nap.edu

Copyright 2010 by the National Academy of Sciences. All rights reserved.

Printed in the United States of America

Copyright © National Academy of Sciences. All rights reserved.

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

www.national-academies.org

Copyright © National Academy of Sciences. All rights reserved.

Copyright © National Academy of Sciences. All rights reserved.

COMMITTEE ON EXAMINATION OF THE U.S. AIR FORCE'S SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS (STEM) WORKFORCE NEEDS IN THE FUTURE AND ITS STRATEGY TO MEET THOSE NEEDS

NATALIE W. CRAWFORD, The RAND Corporation, *Co-Chair*
GEORGE K. MUELLNER, American Institute of Aeronautics and Astronautics, *Co-Chair*
WILLIAM P. ARD, Point One, Inc.
JAMES B. ARMOR, JR., The Armor Group, LLC
EARL H. DOWELL, Duke University
RICHARD P. HALLION, National Air and Space Museum of the Smithsonian Institution
MICHAEL A. HAMEL, U.S. Air Force (retired)
RAY M. HAYNES, Northrop Grumman
LEON A. JOHNSON, United Parcel Service
LESTER McFAWN, Wright Brothers Institute
MICHAEL C. McMAHAN, Abilene Chamber of Commerce
DONALD L. PETERSON, U.S. Air Force (retired)
LEIF E. PETERSON, Advanced HR Concepts and Solutions
(resigned from the committee on July 14, 2009)
ALBERT A. ROBBERT, The RAND Corporation
PAULA E. STEPHAN, Georgia State University
TODD I. STEWART, Michigan Technological University
RONALD W. YATES, U.S. Air Force (retired)

Staff

JAMES C. GARCIA, Senior Program Officer (through January, 2010)
ROBERT KATT, Editorial Consultant
KAMARA E. BROWN, Research Associate
ZEIDA PATMON, Program Associate
MARGUERITE SCHNEIDER, Administrative Coordinator
URRIKKA WOODS, Program Associate (through February, 2010)

Copyright © National Academy of Sciences. All rights reserved.

AIR FORCE STUDIES BOARD

GREGORY S. MARTIN, GS Martin Consulting, *Chair*
PAMELA A. DREW, TASC, Inc., *Vice Chair*
MARSHA J. BERGER, New York University
THOMAS J. BURNS, SET Corporation
THOMAS DARCY, EADS North America Defense Company
KENNETH E. EICKMANN, U.S. Air Force (retired)
JOHN V. FARR, Stevens Institute of Technology
RAND H. FISHER, Aerospace Corporation
MICHAEL J. GIANELLI, Boeing Company (retired)
JACQUELINE GISH, Northrop Grumman Corporation
LESLIE GREENGARD, New York University
KENNETH C. HALL, Duke University
WESLEY L. HARRIS, Massachusetts Institute of Technology
PAUL G. KAMINSKI, Technovation, Inc.
LESLIE KENNE, LK Associates
LESTER L. LYLES, The Lyles Group
DEBASIS MITRA, Bell Laboratories
MATT L. MLEZIVA, Wildwood Strategic Concepts
GERALD F. PERRYMAN, JR., Raytheon Company
GENE W. RAY, GMT Ventures
MARVIN R. SAMBUR, Headquarters, U.S. Air Force (retired)
J. DANIEL STEWART, University of Tennessee

Staff

MICHAEL A. CLARKE, Director
JESSICA BROKENBURR, Financial Assistant
KAMARA E. BROWN, Research Associate
WILLIAM E. CAMPBELL, Senior Program Associate (through May 2010)
SARAH CAPOTE, Research Associate
LISA COCKRELL, Senior Program Associate (through August 2009)
GREGORY EYRING, Senior Program Officer
CARTER W. FORD, Program Officer
JAMES C. GARCIA, Senior Program Officer (through January 2010)
CHRIS JONES, Financial Manager
ZEIDA PATMON, Program Associate
MARGUERITE SCHNEIDER, Administrative Coordinator
DANIEL E.J. TALMAGE, JR., Program Officer
SHANNON THOMAS, Program Associate
URRIKKA B. WOODS, Program Associate (through February 2010)

Copyright © National Academy of Sciences. All rights reserved.

Preface

Technical capabilities have always been critical to the missions and roles of the U.S. Air Force in military operations, and these capabilities are rooted in science, technology, engineering, and mathematics (STEM). Airmen with such knowledge and skills have played significant roles in career fields across the Air Force, with the science and engineering (S&E) and acquisition career fields receiving the most obvious benefits.

For a variety of reasons, concerns have arisen over the future of both the military and civilian contingents of the Air Force's STEM workforce. Emerging mission areas, particularly in the space and cyber domains, as well as increasing use of technologically sophisticated systems, such as unmanned air systems, are expanding the need for new technical skills and expertise. Simultaneously, force reductions, ongoing military operations, and budget pressures are creating new challenges for attracting and managing the needed technical skills. Assessments of recent development and acquisition-process failures have identified loss of organic technical competence as an underlying problem. A growing percentage of science and engineering graduates in the United States are foreign citizens and thus ineligible for the security clearances that many jobs in the Air Force and in the aerospace industry require. The existing STEM workforce is aging, with many individuals nearing retirement. Women and minorities are underrepresented in most S&E educational pursuits at a time when they constitute the majority of college students and therefore the majority of the future workforce. The market for STEM-educated U.S. citizens is becoming much more competitive.

Anticipating this challenge, the Air Force Deputy Chief of Staff for Manpower and Personnel and the Deputy Assistant Secretary of the Air Force for Science, Technology, and Engineering asked the National Research Council (NRC) to examine the Air Force's STEM workforce needs in the future and its strategy to meet those needs. In response, the NRC formed the ad hoc Committee on Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs to conduct this examination. This report contains the results of the committee's work.

The committee acknowledges and appreciates the contribution of the members of the Air Force Studies Board (AFSB) of the National Research Council for developing the study statement of task in concert with the Air Force sponsor. The committee also thanks the many persons who provided information to the committee, including the guest speakers listed in Appendix B, their organizations, and supporting staff members; the many Air Force officer, enlisted, and civilian functional managers and career field managers who responded to the committee's inquiries; others, including The Honorable Claude Bolton, General John Corley, and Maj Gen David Eidsaune; and the Air Force study sponsor, Terry Jaggers, and his staff members, including Col Jim Fisher, Maj Dan Doyle, and Barb Hunter. The committee is also grateful to the NRC staff members who provided their dedicated support throughout the study.

Copyright © National Academy of Sciences. All rights reserved.

Finally, as co-chairs of the study committee, we extend special thanks to the committee members for the commitment and diligence that enabled us to complete the task successfully.

Natalie W. Crawford, *Co-Chair*
George K. Muellner, *Co-Chair*
Committee on Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

Copyright © National Academy of Sciences. All rights reserved.

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Beth J. Asch, RAND Corporation,
Robert J. Beichner, North Carolina State University,
Donald G. Cook, U.S. Air Force (retired),
Richard B. Freeman, Harvard University,
Allison A. Hickey, Accenture National Security Services,
Timothy C. Jones, Northrop Grumman Corporation,
Donald A. Lamontagne, Star Mountain Consulting, Inc.,
Robert H. Latiff, George Mason University,
Mark J. Lewis, University of Maryland,
William Maikisch, U.S. Air Force (retired),
Richard R. Paul, Boeing (retired),
Sharon B. Seymour, U.S. Air Force (retired),
Jan Eakle Terrell, Shippensburg University, and
Sheila Widnall, (NAE), Massachusetts Institute of Technology.

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Lawrence D. Brown (NAS), University of Pennsylvania, and Elsa M. Garmire (NAE), Dartmouth College. Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Copyright © National Academy of Sciences. All rights reserved.

Copyright © National Academy of Sciences. All rights reserved.

Contents

Copyright © National Academy of Sciences. All rights reserved.

Copyright © National Academy of Sciences. All rights reserved.

APPENDIXES

Copyright © National Academy of Sciences. All rights reserved.

Copyright © National Academy of Sciences. All rights reserved.

Acronyms

ABET	Accreditation Board for Engineering and Technology
ACAT	Acquisition Category
AEDC	Arnold Engineering and Development Center
AF/A1	Air Force Deputy Chief of Staff for Manpower and Personnel
AFDD	Air Force Doctrine Document
AFFTC	Air Force Flight Test Center
AFIT	Air Force Institute of Technology
AFMC	Air Force Materiel Command
AFOSR	Air Force Office of Scientific Research
AFPC	Air Force Personnel Center
AFPD	Air Force Policy Directive
AFRAMS	Air Force Rated Aircrew Management System
AFRL	Air Force Research Laboratory
AFROTC	Air Force Reserve Officer Training Corps
AFSB	Air Force Studies Board
AFSC	Air Force Specialty Code
AFSLMO	Air Force Senior Leader Management Office
AFSPC	Air Force Space Command
AIA	Aerospace Industries Association
AIAA	American Institute of Aeronautics and Astronautics
APDP	Acquisition Professional Development Program
ASC	Aeronautical Systems Center
AT&L	Acquisition, Technology and Logistics
BRAC	Base Realignment and Closure
BTZ	Below-the-Zone
CAP	Critical Acquisition Position
CASPAR	Computer-Aided Science Policy Analysis and Research
CONOPS	Concept of Operations
CSAF	Chief of Staff, Air Force
CSO	Combat Systems Officer
DAL	Developing Air Force Leaders
DAWIA	Defense Acquisition Workforce Improvement Act
DOD	Department of Defense
ESC	Electronic Systems Center
FFRDC	Federally Funded Research and Development Center
FMDC	Force Management and Development Council
GAO	U.S. Government Accountability Office
GATM	Global Air Traffic Management
GOMO	General Officer Management Office

Copyright © National Academy of Sciences. All rights reserved.

ICL	Institutional Competency List
IDEAS	Interactive Demographic Analysis System
IPA	Intergovernmental Personnel Act
IPZ	In-the-Promotion Zone
IT	Information Technology
LEAD	Leaders Encouraging Airmen Development
NPS	Naval Postgraduate School
NRC	National Research Council
NRPP	Non-Rated Prioritization Plan
NSF	National Science Foundation
NSPS	National Security Personnel System
O&M	Operations and Maintenance
OSD	Office of the Secretary Defense
OTS	Officer Training School
PBD	Program Budget Decision
PLTW	Project Lead the Way
R&D	Research and Development
RDT&E	Research, Development, Test and Evaluation
RMDSS	Rated Management Decision Support System
ROTC	Reserve Officer Training Corps
RPA	remotely piloted aircraft
S&E	science and engineering
SAF/AQ	Assistant Secretary of the Air Force for Acquisition
SAF/AQR	Science, Technology, and Engineering Directorate of the Office of the Assistant Secretary of the Air Force for Acquisition
SAF/AQXD	Air Force Director of Acquisition and Career Management
SE&I	Systems Engineering and Integration
SES	Senior Executive Service
SETA	Systems Engineering and Technical Assistance
SL	senior level
SMC	Space & Missile Systems Center
SOC	standard occupational classification
ST	scientific and professional [level]
STARBASE	Science and Technology Academies Reinforcing Basic Aviation and Space Exploration
STEM	Science, Technology, Engineering, and Mathematics
TTP	Tactics, Techniques, Procedures
USAF	U.S. Air Force
USAFA	U.S. Air Force Academy
USC	United States Code
VCSAF	Vice Chief of Staff of the Air Force

Copyright © National Academy of Sciences. All rights reserved.

Summary

The Air Force requires technical skills and expertise across the entire range of activities and processes associated with the development, fielding, and employment of air, space, and cyber operational capabilities. The growing complexity of both traditional and emerging missions is placing new demands on education, training, career development, system acquisition, platform sustainment, and development of operational systems. While in the past the Air Force's technologically intensive mission has been highly attractive to individuals educated in science, technology, engineering, and mathematics (STEM) disciplines, force reductions, ongoing military operations, and budget pressures are creating new challenges for attracting and managing personnel with the needed technical skills. Assessments of recent development and acquisition-process failures have identified a loss of technical competence *within* the Air Force (that is, in-house or *organic* competence, as opposed to contractor support) as an underlying problem. These challenges come at a time of increased competition for technical graduates who are U.S. citizens, an aging industry and government workforce, and consolidations of the industrial base that supports military systems.

STUDY APPROACH AND DEFINITION OF KEY CONCEPTS

In response to a request and task statement (see Chapter 1) from the Deputy Assistant Secretary of the Air Force for Science, Technology, and Engineering, the National Research Council (NRC) formed the Committee on Examination of the U.S. Air Force's Science, Technology, Engineering and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs. The committee conducted five fact-finding meetings at which senior Air Force commanders in the science and engineering, acquisition, test, operations, and logistics domains provided assessments of the adequacy of the current workforce in terms of quality and quantity. The committee also interviewed representatives of several Air Force major commands and commissioning sources. Air Force personnel and manpower databases were made available.

To address its tasks and report its findings and recommendations with reasonable clarity and rigor, the committee defined a number of key terms for describing Air Force personnel with STEM capabilities (Table S-1). Because an accepted and clear demarcation of the fields of study for an undergraduate major or post-baccalaureate degree that count as a STEM degree was not available either in Air Force documents or in the general literature, the committee developed a working list of STEM fields, building on work of the National Science Foundation. For purposes of this report, the committee developed a working definition of "STEM-cognizant," recognizing that the Air Force will need to consider the optimal level of STEM education appropriate for this designation (see Recommendation 2-2 below).

Copyright © National Academy of Sciences. All rights reserved.

TABLE S-1. Definitions of STEM Terms for the Air Force Workforce

Term	Description
STEM-degreed	Having an undergraduate or graduate degree in science, technology, engineering, or mathematics
STEM-cognizant	Lacking a specific degree in science, technology, engineering, or mathematics, but having a minimum of 30 hours of undergraduate course work in these subjects, training, or experience and being conversant in these subjects.[a]
STEM-assigned	Personnel assigned to a position that requires a STEM degree
STEM workforce	All STEM-assigned personnel in the overall Air Force workforce

[a] The assumption is that such individuals will have a foundation in the use of the scientific method in decision making. See rationale in chapter 1.

ROLE OF STEM CAPABILITIES IN ACHIEVING THE AIR FORCE VISION AND STRATEGY

The Air Force uses the STEM skills and expertise of its workforce today in key mission and functional areas across the service, including emerging requirements for STEM capabilities in the newer domains and mission areas. These domains include airpower, nuclear deterrence, space operations, unmanned air systems, operations in cyberspace, and force planning and operational employment/evaluation of integrated systems combining weapons platforms and information networks. Within the Air Force, STEM-degreed and STEM-cognizant personnel are found in all major commands. They work in all 26 of the officer career fields identified by Air Force Specialty Codes (AFSCs).

A particular focus of this study was the critical roles that STEM-degreed and STEM-cognizant Air Force personnel play in system acquisition. Their skills are applied across the entire acquisition life cycle of each system, from exploration of advanced technologies and definition of operational needs to the development, evaluation, and employment of tactical and strategic capabilities.

Only five Air Force officer career fields currently require a STEM degree—Weather (two-digit AFSC 15W), Civil Engineer (32E), Communications and Information (33S), Scientist (61S), and Developmental Engineer (62E). Even though all other officer career fields, such as pilot, navigator, air battle manager, maintenance, space and missiles, and program management, have no *stated requirements* for STEM education, a significant percentage of officers in these career fields do hold STEM degrees. For example, 45 percent of pilots have science or engineering degrees, and a STEM degree is one of the preferred educational backgrounds for candidates to the Acquisition Corps, in accordance with the Defense Acquisition Workforce Improvement Act (DAWIA) and the Air Force's Acquisition Professional Development Program (APDP).

Only three civilian occupational series in the Air Force require a STEM degree: Engineering, Physical Sciences, and Mathematics. However, as with STEM-degreed officers, STEM-degreed civilians work in many occupations that do not formally require a STEM degree.

Finding 2-1a. STEM-degreed and STEM-cognizant personnel are critical to operational missions and roles across the Air Force and to the entire life cycle of Air Force weapon systems, from basic through applied research, requirements determination, definition, concept development, technology and system development, and test, production, deployment, operations, and sustainment.

Copyright © National Academy of Sciences. All rights reserved.

Finding 2-1b. The ability to conceive, develop, acquire, operate, and sustain advanced weapon systems has been addressed in Air Force descriptions of its Technology-to-Warfighting core competency. However, the *Air Force Strategic Plan, 2006–2008* neither references this core competency directly nor includes a priority, goal, or objective that unequivocally supports the Air Force's current and future needs for STEM-degreed and STEM-cognizant personnel.

Recommendation 2-1. The Air Force should incorporate in its Strategic Plan as an eighth goal the ability to conceive, develop, acquire, operate, and sustain advanced weapon systems. The Strategic Plan should state that this goal is essential to maintaining and advancing the existing Technology-to-Warfighting core competency and the emerging core competency in Cyber Operations. The Strategic Plan should set out recruiting, developing, employing, and retaining STEM skills and experience as key enabling objectives for this goal.

Finding 2-2a. Assessments of future missions and the future operating environment suggest that Air Force missions will become more technologically intensive and will require a proportionally larger STEM workforce in many career fields across the Air Force.

Finding 2-2b. Most officer career fields include STEM-degreed personnel to varying degrees. However, only five military officer career fields have stated requirements for STEM education; other officer career fields have no stated requirements for STEM-degreed or STEM-cognizant personnel.

Finding 2-2c. As discussed in Chapter 1, the Air Force does not have a consistent definition of its STEM workforce. The baccalaureate majors and the fields of study for postbaccalaureate degrees that count for a STEM degree are not specified. Furthermore, there is no uniform concept corresponding to STEM cognizance as used in this report. The committee believes that it is essential that the Air Force identify those personnel with STEM degrees and those with STEM cognizance and identify what the Air Force's requirements are for STEM-degreed and/or STEM-cognizant personnel across all career fields.

Finding 2-2d. Only about 40 percent of the officers in the Acquisition Management career field have technical degrees, and fewer than 10 percent of civilians in the Business and Industry occupational series, which includes acquisition managers, have technical degrees.

Recommendation 2-2. The Air Force should review and revise as appropriate its current requirements and preferences for personnel with STEM capabilities in every career field and occupational series.

- The Air Force need not adopt the specific list of STEM majors/disciplines used by the committee, but an explicit demarcation of what counts as a STEM degree is necessary.
- The Air Force should define a level of STEM capability broader than having a STEM degree, similar to (albeit not necessarily identical with) the concept of STEM-cognizant used in this report.
- The Air Force should review, and revise or establish as appropriate, requirements and preferences for STEM-degreed and STEM-cognizant personnel in every career field and occupational series. Particular attention should be given to supporting the needs of the acquisition community and to developing such mission areas as intelligence and the emergent domains of space and cyberspace. This review should include identifying positions requiring STEM-degreed people and setting goals for appropriate numbers of

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

personnel in other positions to be STEM-cognizant (with appropriate education, training, and experience) throughout the officer career fields and civilian occupational series.

ISSUES FOR CAREER FIELDS AND CIVILIAN OCCUPATIONS CURRENTLY REQUIRING A STEM DEGREE

The committee believes that there are captain and field-grade manning issues in the STEM officer career fields, based on the committee's analyses of assignments versus authorizations, captain-to-lieutenant ratios, and field-grade officer manning in the five career fields that require a STEM degree. The implications of these analyses are supported by the assessments of Air Force commanders and supervisors interviewed by the committee that their communities have insufficient personnel with adequate experience to perform the technically demanding aspects of jobs that require STEM capability.

Civilian Air Force personnel in the occupational series that require a STEM degree are managed within three career programs, roughly paralleling the functional areas within which they are employed. An impending issue for this civilian STEM-degreed workforce is the imminent retirement of substantial numbers of employees with 20 to 30 years of experience, combined with smaller cohorts of employees with 10 to 19 years of service.

Finding 3-1. In some cases, the grade structures in officer career fields that require a STEM degree are not sustainable under the current legal and policy constraints. Additionally, in some cases, career fields requiring a STEM degree may have experienced below-average retention or promotion rates.

Finding 3-2. The workforce years-of-service profile (shown in Figure 3-1) indicates that a large proportion of the civilian STEM-degreed workforce will become eligible for retirement within the next 15 years.

Finding 3-3. Fill rates for field-grade officers in the Scientist and Developmental Engineer career fields, in the Acquisition Management career field, and in other career fields important to the acquisition life cycle, while responsive to the Air Force's Non-Rated Personnel Prioritization Plan, are well below 100 percent, which perpetuates the manning shortfalls in these career fields.

The committee's Recommendations 6-1 through 6-13, presented later in this summary, address the issues summarized in Findings 3-1 through 3-3.

STEM PERSONNEL IN THE ACQUISITION WORKFORCE

It is essential that the Air Force have a fully trained and qualified Acquisition Corps able to manage programs to deliver the complex warfighting systems needed to protect the nation. Air Force implementation of DAWIA requires that members of the Acquisition Corps have baccalaureate degrees *but does not specify that they must be STEM degrees*. Although specific educational requirements in STEM disciplines are not listed at the baccalaureate level, present Office of the Secretary of Defense (OSD) policy states that, for individuals serving in program management capacities at upper levels, a master's degree is desirable, preferably with a major in engineering, systems management, business administration or a related field.

Finding 4-1a. Although the *Air Force Acquisition Managers (63AX–1101) Career Field Education and Training Plan* states that a baccalaureate degree is required for Level 1 certification, neither a STEM degree nor STEM cognizance is required for that certification.

Copyright © National Academy of Sciences. All rights reserved.

Finding 4-1b. All Air Force product centers, air logistics centers, and test centers have significant shortfalls in assigned civilian STEM-degreed personnel.

Finding 4-1c. Some of the shortfalls in STEM capabilities in the acquisition workforce could be addressed by establishing criteria for STEM cognizance and applying those criteria to APDP certification requirements and other position requirements. Some acquisition positions already have requirements for STEM coursework that is less than a full major, such as positions that require 24 hours of STEM coursework.

Recommendation 4-1. The Air Force should lead the way in changing the OSD implementation policy of DAWIA by establishing STEM cognizance as a minimum requirement for program management certification. If OSD support for such a change is not forthcoming, the Air Force should unilaterally change its own implementing directives by specifying that STEM cognizance is a minimum requirement for acquisition program management certification.

Finding 4-2. DAWIA seeks to ensure that experienced personnel are engaged in running major programs. However, the experience criteria in DAWIA and Air Force directives are often waived for the senior ranks of the Air Force acquisition community. For example, general officers have often been placed in important acquisition positions—although not designated as critical acquisition positions (CAPs)—in Air Force Acquisition (SAF/AQ), the Air Force Materiel Command, and the Air Force Space Command, even when these officers have had little or no acquisition experience. Waiving these requirements runs counter to the basic intent of the legislation.

Recommendation 4-2. The Air Force should objectively review all general officer positions in the Air Force Materiel Command, Air Force Space Command, and SAF/AQ to determine which should be coded as CAPs. The Air Force should ensure that officers filling these positions meet the certification requirements.

Finding 4-3. While no specific "quality force" or retention-related data were provided for the committee's review, the presenters seemed to agree that, as a practical matter, STEM-degreed personnel in the acquisition, test, and logistics workforces should be given significant hands-on experience to develop their technical skills during the first five years of their careers. This experience would enhance their "smart buyer" capabilities and their ability to provide meaningful oversight of the contractor workforce. Air Force DAWIA requirements should be appropriately modified.

Recommendation 4-3. The Air Force should review its training and career development plan for the acquisition management career field/occupational series to strengthen the opportunities for STEM-degreed personnel to acquire hands-on experience to develop their technical skills during the first five years of their Air Force careers.

THE CURRENT AND FUTURE U.S. STEM-DEGREED WORKFORCE

To prepare for the Air Force's current and future STEM needs with realistic and effective actions, trends in STEM education and the STEM-degreed workforce in the United States must be considered, as well as issues that reflect policies, conditions, and trends internal to the Air Force. The challenges facing the Air Force as it seeks to acquire and retain STEM-degreed personnel include uncertainty about the adequacy of the future supply of STEM-degreed U.S.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

citizens, due to changing U.S. demographics and a more competitive career environment for U.S. citizens with STEM degrees.

In this context, women, Blacks, and Hispanics represent segments of the future U.S. workforce to which the Air Force must give attention, not just in its general commitment to diversity but also for its future STEM personnel needs. However, these three groups continue to be significantly underrepresented in STEM career fields. So there will be challenges in making the most of the resource they offer.

While there is uncertainty about the adequacy of future supply of STEM-degreed workers, there is also a wealth of documented programs that have been created to aid in increasing that supply. They range from programs focused on the kindergarten-through-secondary school (K-12) years to industry- or company-unique initiatives such as faculty and student internships and fellowships.

Finding 5-1a. There is reason for concern as to whether the supply of scientists and engineers who can obtain a security clearance will be adequate to meet the future needs of the Air Force. As an example, while the total of all S&E doctoral degrees awarded annually increased 8 percent from 2000 to 2005, the number of S&E doctoral degrees awarded to U.S. citizens and permanent residents decreased 5.5 percent over the same period. From 2002 to 2005, the number of U.S. citizens earning S&E doctoral degrees increased slowly but not enough to regain earlier levels.

Finding 5-1b. In light of the continuing substantial change in U.S. demographics, with women and minority groups constituting a growing segment of the target group for potential recruits, the Air Force is well positioned to take a proactive role in addressing the national shortfalls among middle and high school youth in math and science and, as a result, to work to create a more competitive U.S. workforce from which the Air Force can select its future STEM-degreed personnel.

Recommendation 5-1. The Air Force should create a vehicle to coordinate and evaluate existing STEM-related outreach, education, and training activities. Current activities of this type include Project STARBASE, the Falcon Foundation, Civil Air Patrol, and Junior Reserved Officer Training Corps, as well as its partnerships in such activities with the Air Force Association, American Institute of Aeronautics and Astronautics, and others. The charter for this group should include creating connectivity between such activities so that promising participants from across the entire demographic makeup of our nation have ready access to the next academic level or program that builds on the experience gained from interacting with the Air Force STEM-related outreach efforts. It seems suitable for the office having these responsibilities to be at the Air Staff level.

MANAGING STEM PERSONNEL TO MEET FUTURE STEM NEEDS ACROSS THE AIR FORCE

A key personnel management goal for the Air Force should be a process and a set of tools to ensure that its future STEM requirements can be filled by trained and ready personnel.

Finding 6-1. The Air Force does an excellent job of recruiting, managing, and developing officers and civilians in career fields that it values and considers mission essential. A paradigm example is the Air Force's training, management, and development of rated personnel. In the past, the Air Force had a robust supply of STEM-degreed and STEM-cognizant personnel and thus did not devote special attention to managing them. Because of the changing demographics of the American population and the increasing technical complexity of the Air Force mission, this

Copyright © National Academy of Sciences. All rights reserved.

approach will no longer work. To maintain the technical competency of the Air Force, active management of the STEM-degreed and STEM-cognizant workforce is essential.

Recommendation 6-1a. To manage the critical STEM-degreed and STEM-cognizant personnel assets for the future Air Force, two actions should be taken. First, the Air Force should establish a STEM Council to review policies and implementation and make recommendations on STEM accessions, utilization, and competencies across all Air Force missions, organizations, and career fields. This group should also determine what the minimum science, engineering, and mathematics educational requirements should be for STEM cognizance and determine which positions require STEM cognizance. This STEM Council should be a subcouncil to the Force Management & Development Council (FMDC).

Recommendation 6-1b. The Air Force should develop a decision support model, analogous to the Rated Management Decision Support System, to predict future requirements, inventory, and impacts of personnel policies and decisions, not only for specific career specialties but also for the aggregate needs of maintaining the technical competency of the overall Air Force.

Finding 6-2. Most Air Force functions have a designated advocate at the Air Force Headquarters level. This is an important step in managing a workforce. Since the Air Force has never managed STEM capability/functions as a distinctive entity across AFSCs and across major commands, STEM-degreed and STEM-cognizant personnel do not have a functional advocate.

- The Military Deputy to the Assistant Secretary of the Air Force for Acquisition is the one officer on the Air Staff who both sits on the FMDC and, through the Requirements Process, is close to both the acquisition workforce and the major commands. In the committee's view, this position is particularly appropriate as the designated advocate for STEM-degreed and STEM-cognizant personnel across the entire service.
- Currently, the Air Force Deputy Chief of Staff for Manpower and Personnel (AF/A1) is responsible for sustainment and use of career-force models for all current AFSCs. While many of these models were originally not developed in-house (i.e., the developer may have been a contractor or federally funded research and development center), the AF/A1 now has responsibility for their oversight and use. Thus, it is reasonable for oversight and use of a newly developed STEM decision support model to be under this official.

Recommendation 6-2. Overall functional management of STEM-degreed and STEM-cognizant personnel should be accomplished in a manner similar to management of flight-qualified officers through the Rated Management system. The Military Deputy to the Assistant Secretary of the Air Force for Acquisition should be the functional advocate for all STEM personnel, and the Deputy Chief of Staff for Manpower and Personnel (AF/A1) should oversee STEM decision support modeling, as well as recommending and implementing STEM personnel policies.

Issues in Retaining and Promoting STEM-Degreed Officers

Finding 6-3a. Multiple reductions in STEM-degreed authorizations and STEM-degreed personnel have had a negative impact on manning levels and morale and may be affecting the ability to recruit.

Finding 6-3b. Both promotion and experience are required for growing future acquisition leaders. As discussed in chapter 4, in recent history many senior acquisition leaders required waivers from DAWIA requirements for prior acquisition experience.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

Recommendation 6-3a. Promotion rates should be monitored to ensure that qualified acquisition officers are available at lower ranks to meet DAWIA requirements and experience needs for accessions to higher ranks.

Recommendation 6-3b. The Air Force should use a STEM management decision support model (see Recommendation 6-1) to understand long-term impacts of cuts in authorization or manning for career fields requiring a STEM degree and to ensure that the leadership understands all the likely impacts of such cuts.

Options for Meeting STEM Needs with the Existing STEM-Degreed Officer Workforce

Finding 6-4. The Air Force does not currently have a process in place to systematically review its allocation and utilization of STEM-degreed officers in light of changing requirements and priorities.

Recommendation 6-4. Under the direction and oversight of a STEM subcouncil of the FMDC (see Recommendation 6-1), the Air Force should establish a process to review systematically and (at least) annually the utilization of all of its STEM-degreed officers, with the goal of assigning these officers to the Air Force's highest-priority STEM and non-STEM requirements. This should be done in conjunction with a similar review of STEM-degreed civilians (see Recommendation 6-11). Note that this recommendation cannot be implemented without a clear definition of STEM requirements for each career field.

Finding 6-5. The Air Force has not assessed the potential for STEM-degreed officers in the Air Force Reserve and the Air National Guard to help meet the Air Force's requirements for STEM-degreed personnel.

Recommendation 6-5. Under the direction and oversight of a STEM subcouncil to the FMDC (see Recommendation 6-1), the Air Force, in collaboration with the National Guard Bureau and the Commander of the Air Force Reserve Command, should conduct an in-depth assessment of the potential for the Air Force Reserve and the Air National Guard to contribute to meeting the STEM capability needs of the Air Force, through either existing programs or new initiatives.

Finding 6-6. The Air Force Institute of Technology (AFIT) currently offers a number of degree, certificate, and short-course programs (and could potentially offer additional programs) that would increase the number of STEM-degreed officers available to meet Air Force STEM needs. In particular, the AFIT resident school offers graduate STEM education programs that address problems of unique importance to the Air Force; comparable programs are not available at civilian institutions.

Recommendation 6-6a. The Air Force should periodically access the capability of AFIT to help meet projected future requirements for STEM-degreed personnel by providing selected officers and civilians with educational opportunities leading to an award of a STEM degree. In addition, the STEM personnel decision support model (see Recommendation 6-1) should include a sufficient number of military and civilian AFIT student positions to enable use of these AFIT opportunities, in addition to modeling the STEM personnel required for direct mission support. Consideration should be given to the following educational options:

Copyright © National Academy of Sciences. All rights reserved.

- Graduate-level STEM education (both degree and certificate programs) at the resident school, through civilian institutions, or through on-line or other decentralized education modes; and
- Continuing education in STEM disciplines, to help STEM-degreed personnel remain current with changing science and technology. Again, these courses can be offered at the resident school, through civilian institutions, or through on-line or other decentralized education modes.

R**ecommendation 6-6b.** The Air Force should consider directing AFIT to develop modules of instruction to help increase the STEM cognizance of Air Force officers and civilians who are not STEM-degreed. These STEM-cognizance instruction modules can be delivered through various mechanisms such as professional military education, Acquisition Corps certification courses, base education offices, on-line courses, and other means. Such educational opportunities could significantly increase STEM cognizance across all officer career fields and civilian occupations.

Acquiring Additional Officer Assets

Finding 6-7. The U.S. Air Force Academy (USAFA) is a major source of new officers that are either STEM-degreed or STEM-cognizant.

Recommendation 6-7a. The USAFA should periodically review the core curriculum to ensure that graduates with non-STEM majors nonetheless are STEM-cognizant—that is, that they have an adequate appreciation of the impact of science and technology on the Air Force's ability to organize, train, and equip the forces required by combatant commanders in their respective areas of responsibility.

Recommendation 6-7b. The Air Force Chief of Staff should establish a goal for the minimum percentage of USAFA graduates with a STEM major, based on an assessment of requirements by the FMDC and recommendations from the Deputy Chief of Staff for Manpower and Personnel (AF/A1) and the USAFA leadership. The USAFA leadership, in collaboration with the faculty and staff, should identify and implement policies, procedures, and incentives to ensure that this goal is met.

Finding 6-8. The Air Force Reserve Officer Training Corps (AFROTC) is the source of the largest number of new commissioned officers. This program offers considerable potential for helping the Air Force to meet its requirements for STEM-degreed officers.

Recommendation 6-8. The Air Force should make full use of scholarships and other incentives to encourage AFROTC students to pursue degrees in STEM disciplines or, if they are not enrolled in a STEM-degree program, at least to take sufficient STEM courses to qualify as STEM-cognizant. In addition, Air Force officials should encourage the provost and faculty at institutions with AFROTC programs to include courses in the institution's undergraduate core curriculum that promote STEM cognizance.

Finding 6-9. The Officer Training School (OTS) gives the Air Force an important avenue to selectively access new officers who already possess specific STEM degrees.

Recommendation 6-9. The Air Force should establish annual goals for accessing STEM-degreed officers through OTS. These goals should be projected for the future 5-year period and reviewed and adjusted annually as appropriate. In recruiting candidates for OTS, the Air Force should

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

consider those undergraduate and graduate students pursuing a STEM field of study who were (or are) involved in research projects funded by the Air Force Office of Scientific Research or Air Force Research Laboratory. Officers accessed through OTS who do not possess a STEM degree should be afforded the opportunity to attend one or more short (continuing education) courses developed and offered through AFIT (or other institutions) to qualify these individuals as STEM-cognizant.

Managing and Retaining Existing Civilian Personnel Assets

Finding 6-10. Fill rates are an important indicator to the civilian workforce that their jobs are valued. Based on assessments from several Air Force leaders who briefed the committee (Chapter 4) and civilian vacancy rates in program management (Chapter 6), the hiring process for STEM-degreed civilians is not timely. In the committee's judgment, this contributes to a perception in the civilian workforce that the unfilled positions are not valued.

Recommendation 6-10. The Air Force should develop policies and devote resources to recruit STEM-degreed civilian personnel in a timely manner.

Finding 6-11. The Air Force does not currently have a process in place to systematically review its allocation and utilization of STEM-degreed civilians in light of changing requirements and priorities.

Recommendation 6-11. The Air Force should establish a process to assess systematically and (at least) annually the utilization of its STEM-degreed civilian workforce. This review should include accessing the need to offer additional incentives to encourage STEM-degreed personnel to compete for assignment to the Air Force's highest-priority STEM positions. This assessment should be done in conjunction with a similar review of assignments for STEM-degreed officers (see Recommendation 6-4).

Acquiring Additional Civilian Personnel Assets

Finding 6-12. At the Headquarters, Air Force organizational level, civilian pay is currently managed in a manner that hinders the employment and retention of STEM-degreed civilian personnel. Use of the operations and maintenance account (funding line 3400) for civilian pay, rather than the research, development, testing, and evaluation (RDT&E) account (funding line 3600), increases the variability and uncertainty in funding these positions from year to year. Consequently, employment planning is tenuous, and filling of positions that require a STEM degree is more difficult. In the committee's view, the funding uncertainty and variability also increase the difficulty of retaining valued STEM-degreed civilian personnel.

Recommendation 6-12. To address uncertainties in civilian workforce funding, and thereby improve employment and workforce stability, the Air Force should consider moving the acquisition workforce from the operations and maintenance funding line (Account 3400) to the RDT&E funding line (Account 3600).

Finding 6-13. It takes the Air Force far too long to fill civilian STEM positions. The Air Force cannot compete effectively with other government and nongovernment organizations that can recruit and hire the best-qualified STEM candidates much more quickly. This disadvantage negatively impacts both fill rates and the quality of the Air Force's STEM-degreed workforce.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

Recommendation 6-13. The Air Force should continue to look for ways to improve both the process of filling civilian positions (enabling legislation may be required) and the organizational issues that hinder the process. In particular, a means should be sought to make permanent the funding for civilian positions that require a STEM degree at the installations where these positions are located (or within the respective major commands).

Issues and Options for Contract STEM Support

Finding 6-14. Based on the personal experience of committee members who served in the acquisition workforce, the committee believes that contracting out inherently governmental tasks[1] can diminish the perceived value of the officers and government employees who perform similar tasks or who are assigned to oversee contractors. This negative effect on personnel morale and retention is in addition to the regulatory concerns when inherently governmental tasks are contracted out.

Recommendation 6-14a. The Air Force should reevaluate its contracting procedures and ensure that all inherently governmental tasks are performed by Air Force personnel.

Recommendation 6-14b. Significant portions of the STEM-degreed workforce now consist of contract personnel. The Air Force should consider converting contract dollars currently being used to pay for contracted engineering talent into funds that can be used to support additional civilian engineering authorizations to bring more of the required expertise in house. Senior Air Force leadership must, however, ensure that the dollars thus saved flow from the contracting accounts directly into the various civilian pay accounts. If adequate funds are not available in these accounts and if the authorizations are not forthcoming to support the previously contracted functions with governmental personnel, the potential consequences are risks to the capabilities of commanders and directors to carry out their missions.

THE NEED FOR ACTION

Over the past 20 years, the Air Force has elevated its capabilities and competencies in the development and employment of air and space power to an unrivaled level. It is essential that the Air Force maintain and enhance its technical competency—a competency provided by the Air Force's STEM-degreed and STEM-cognizant personnel. As the challenges to the future security environment grow, the Air Force must prepare to address these challenges fully and rapidly. This will require a wider range of technical skills and a technically competent workforce.

---

[1]Inherently governmental tasks are certain roles defined as such within the Federal Acquisition Regulations, including tasks covered by the Uniform Code of Military Justice or the Civilian Code of Ethics for government employees.

Copyright © National Academy of Sciences. All rights reserved.

1

Introduction

Technical capabilities have always been critical to the military missions and roles of the U.S. Air Force. These capabilities are rooted in science, technology, engineering, and mathematics (STEM). The Air Force's technologically intensive mission has historically been highly attractive to individuals educated in the STEM disciplines. Airmen with such knowledge and skills have played significant roles in career fields across the Air Force, with the science and engineering (S&E) and acquisition career fields receiving the most obvious benefits. The result has been a technically literate force capable of dealing with the development, fielding, operations, and sustainment of technology-intensive systems.

Yet for a variety of reasons, concerns have arisen over the future of both the military and civilian contingents of the Air Force's STEM workforce. One such concern is the growing technical complexity of both traditional and emerging capabilities required to fulfill Air Force missions. A second concern is that the environment in which the Air Force now must compete to recruit and retain STEM-educated personnel who are U.S. citizens is becoming much more competitive.

THE IMPORTANCE OF STEM CAPABILITIES TO THE AIR FORCE

The U.S. military's competitive edge depends on continuous investment in research and development (R&D); rapid fielding of enhanced capabilities; and rapid development of operational tactics, techniques, and procedures. Technical skills and expertise are critical across the entire range of activities and processes associated with the development, fielding, and employment of operational capabilities. All this is especially true for the Air Force. The *Air Force Strategic Plan 2006–2008*, for example, begins its section on Air Force Goals with the statement:

> To ensure we can execute our mission, today and always, we will build and sustain the world's foremost air, space, and cyberspace force. The Air Force will provide Joint Force Commanders the air, space, and cyberspace capabilities they need to conduct integrated interdependent combat operations (USAF, 2006a, pg. 9).

Both acquisition personnel and personnel in the receiving operational major command must acquire a deep technical understanding of the capabilities and limitations of the advanced systems and platforms on which the Air Force depends. The ability to define operational needs logically and quantitatively, to analyze alternative solutions and force structures that optimize systems and investment strategies, and to document the operational requirements and concepts that best meet these needs demands strong technical and operational skills and experience. The Air Force's acquisition workforce requires personnel who possess high levels of engineering skills and experience in technology R&D and the tasks and functions required to design, develop, produce, integrate, and test new systems, as well as to modify existing ones. Fielding new capabilities requires technical processes, extensive testing, and rigorous development and validation of tactics

Copyright © National Academy of Sciences. All rights reserved.

and procedures. As chapter 2 describes by domain and mission area, competence in STEM disciplines is critical to every domain in which the Air Force operates.

Over the past 20 years, the Air Force has elevated its capabilities and competencies in the development and employment of air and space power to an unrivaled level. The Air Force now possesses significant levels of STEM competence for conducting a full spectrum of missions and operational weapon systems for air superiority; precision strike; air mobility and refueling; special air operations; airborne intelligence, surveillance, and reconnaissance; and operational command and control. A deep level of expertise exists, along with the necessary infrastructure, for developing and testing systems, developing tactics, and employing these air capabilities and forces. Technically trained and experienced Air Force personnel have participated across the life cycle of system development, sustainment, and employment.

CONCERNS ABOUT THE FUTURE STEM WORKFORCE

The Air Force faces traditional demands that include supplying and sustaining new technologies and operational tactics for air and missile systems. In addition, new and evolving capabilities and operational domains—specifically, network-centric operations, unmanned air systems, and space and cyber operations—are placing extraordinary new technical demands on the Air Force. These will require unique skills and competencies to define, develop, field, and employ operational capabilities effectively.

The growing complexity of both traditional and emerging missions is placing new demands on education, training, career development, system acquisition, platform sustainment, and development of operational systems. Simultaneously, force reductions, ongoing military operations, and budget pressures are creating new challenges for attracting and managing the needed technical skills. Although the Air Force has generally been able to meet its accession goals,[1] these challenges come at a time of increased competition for technical graduates, an aging industry and government workforce, and consolidations of the industrial base that supports military systems.

Throughout the Air Force's history, its leadership has consistently and persistently enunciated the requirement for scientific, engineering, and technological competence. That requirement has been consistently linked with the importance of maintaining air and space supremacy, and more recently, cyberspace supremacy.[2] Concerns about how well the Air Force was doing in meeting its requirements for STEM competence have also been expressed over much of that history. As early as 1949, an Air University study team concluded that, "The United States Air Force is now dangerously deficient in its capacity to insure the long-term development and superiority of American Air Power." The study team further concluded:

> Personnel policies are not designed to support the specialized requirements for highly trained scientific and technical personnel for the R&D function.
>
> …Our personnel procurement program has not provided us with adequate numbers of scientifically trained personnel; we have not fully utilized those we do have; and our personnel policies have not been conducive to keeping those we have on the job or fully effective on the job (Anderson et al., 1949, p. G-17).

Appendix G discusses this 1949 study and the long history of such concerns in the context of the emerging military importance of air (and more recently, space) supremacy from World War I to the present.

---

[1]The term "accession" is used within the Air Force for the process for bringing new officers into the service; "recruitment" is typically used for enlisted airmen. In 2008 the Air Force was not able to meet its accession goals in several technical officer specialties.

[2]For a recent restatement of this linkage between STEM competency and maintaining air, space, and cyberspace supremacy, see USAF 2006, pages 12–20.

Copyright © National Academy of Sciences. All rights reserved.

Assessments of recent development and acquisition-process failures have identified a loss of technical competence *within* the Air Force (that is, in-house or *organic* competence, as opposed to contractor support) as an underlying problem. A 2003 joint study by the Defense Science Board and Air Force Scientific Advisory Board stated that the "government's capability to lead and to manage the space acquisition process has been seriously eroded, in part due to actions taken in the acquisition reform environment of the 1990s" (DSB-AFSAB, 2003). Acquisition reform initiatives and force-shaping have significantly reduced organic S&E force levels.[3] Many civilian S&E positions remain vacant for extended periods due to a slow and cumbersome hiring process. Unintended consequences of these actions are a highly stressed organic S&E workforce and overdependence on contractor technical support.

The Office of the Secretary of Defense and the other military Services have in the past regarded the Air Force acquisition system highly, but recent program and source-selection failures are eroding that confidence. Recent after-action reviews and Government Accountability Office (GAO) acquisition assessments have consistently identified loss of organic technical competence as a significant contributor to these failures.[4] The GAO (2008) found that program office decisions to use contractor personnel are often driven by such factors as civilian staffing limits and the shorter hiring time lines for contractors, rather than by the skills needed or the nature or criticality of the work.

These Air Force S&E management challenges are occurring at the same time that the United States faces the possibility of an impending shortfall of S&E personnel. In recent years, studies from the National Science Foundation and the National Academies of Science and Engineering have expressed concerns regarding the adequacy of the future U.S workforce in S&E (NAS, NAE, IOM, 2007). In January 2009, Norman Augustine, retired chairman and chief executive officer of Lockheed Martin Corporation and the chair of the 2007 National Academies study, stated that the shortfall in science and engineering graduates was contributing to "America's declining competitiveness" (Augustine, 2009). Moreover, for the Air Force, there is an additional problem: A growing percentage of science and engineering graduates in the United States are foreign citizens and thus ineligible for the security clearances required for many jobs in the Air Force and in the aerospace industry. Chapter 5 addresses these and other issues related to constraints on the future pool of STEM-degreed graduates available to the Air Force.

STATEMENT OF TASK AND COMMITTEE APPROACH

In a study request to the Air Force Studies Board of the National Research Council (NRC), the Deputy Assistant Secretary of the Air Force for Science, Technology, and Engineering noted that the Air Force lacks a strategic vision for employment of its STEM workforce over the next 25 years. After summarizing the reasons for and the importance of such a strategic vision, the Deputy Assistant Secretary asked the NRC to conduct a study focused on the following tasks:

Statement of Task

1. Assess the science, technology, engineering, and mathematics (STEM) capabilities the U.S. Air Force needs to meet the goals, objectives, and priorities in its strategic plan.
2. Determine whether the Air Force's current STEM workforce and strategy will meet those needs.
3. Identify and evaluate STEM workforce and strategy options to meet capability needs, including both resource-unconstrained and -constrained options. Address STEM

[3]In this report, "acquisition reform initiatives" refers to acquisition reforms by the Department of Defense (DoD) in response to the Federal Acquisition Streamlining Initiative Act of 1994, Public Law 103-355. "Force shaping" refers to Air Force activities to meet reduced end-strength requirements and is part of the force management development process.

[4]See, for example, DSB-AFSAB, 2003, and GAO, 2008, pp. 28–31.

Copyright © National Academy of Sciences. All rights reserved.

resource employment options, including mixes of Air Force military and civilian STEM workforces, federally funded research and development centers, technical support contractors, system prime contractors, and academia.

4. Address STEM capability needs, workforce, and options in terms of existing Air Force functional management areas.
5. Identify and evaluate options for the organization and management of the Air Force's STEM workforce to best balance and satisfy the needs of all functional areas and the Air Force as a whole, including any changes to the STEM workforce in the functional areas.
6. Recommend strategies that the Air Force should pursue to meet its STEM capability needs in the future.

In response to this request and task statement, the NRC formed the Committee on Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs. This committee conducted five fact-finding meetings, which brought forward representatives of the Air Force planning, personnel, education and training, science and engineering, acquisition, testing, and logistics communities. Senior leadership from all the product, test, and logistics centers provided the committee with information on the adequacy of their STEM workforces and indicated concerns about the future of STEM personnel in the Air Force. The committee also heard from representatives of several of the Air Forces' major commands.[5] Additionally, Air Force personnel and manpower databases were made available to the committee. Senior field commanders in the S&E, acquisition, test, operations, and logistics domains provided assessments of the adequacy of the current workforce in terms of quality and quantity. These inputs gave the committee the ability to access the existing STEM-degreed force structure and the current management process for these personnel, identify capability gaps, and evaluate accession options.

Assessment of Future Needs

Assessments of future needs were drawn from a Science Applications International Corporation study for the Air Force that provides targets for skills and workforce sizes for 2010, 2015, and 2025 (SAIC 2003). The study was provided to the committee by the Science, Technology, and Engineering Directorate of the Office of the Assistant Secretary of the Air Force for Acquisition (SAF/AQR). The committee further researched the additional STEM needs for the changing space and cyber environments. Assessments of options for meeting these future needs were provided for all the accession methods available to the Air Force, as presented in briefings and data from the U.S. Air Force Academy,[6] Holm Officer Accession and Citizen Development Center,[7] and the Air Force Institute of Technology.[8]

The committee limited the study to Air Force line officers and equivalent civilian positions.[9] While the Air Force's enlisted workforce must also be technically competent, the committee did not investigate its future recruiting challenges because of the limited time to conduct information gathering and the limited response received from recruiting personnel. Recruiting personnel did indicate that currently there is no reduction in the quality or quantity of recruits. Enlisted personnel typically receive technical training after entering the Air Force, rather than attending

[5]The Air Force major commands and their missions are defined in appendix B.

[6]Brig. Gen. Dana Born, Dean of the Faculty, U.S. Air Force Military Academy, briefing to the committee on December 4, 2008.

[7]Brig. Gen. Teresa A. Djuric, Commander, Holm Center, Air Education and Training, briefing to the committee on August 27, 2008.

[8]Brig Gen Paula Thornhill, Commandant, Air Force Institute of Technology, briefing to the committee on December 3, 2008.

[9]*Line officers* are those eligible to command a combat or combat support unit; the term excludes members of the chaplain, medical, and legal corps.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

college first. Armed Services Vocational Aptitude Battery test scores indicate that the technical aptitude of recruits continues to be adequate for them to enter Air Force technical training programs.

Definitions for Key Concepts

To address its tasks and report its findings and recommendations with reasonable clarity and rigor, the committee found it necessary to define a number of key terms, including "STEM workforce" for the Air Force context. The committee ascertained that the Air Force uses the term "STEM workforce" internally to refer to all and only those personnel who are assigned to a position that requires a STEM degree, and that usage is maintained in this report. Thus, an Air Force officer or civilian employee who has a STEM degree but is not assigned to a position that requires a STEM degree is not in the STEM workforce. The report uses "Stem-degreed workforce" to refer to all personnel who have a STEM degree at the baccalaureate or post-graduate level, whether or not they are assigned to a position requiring a STEM degree.

The committee did not find a satisfactory demarcation either from Air Force sources or in the general literature for what counts as having a STEM degree at either the baccalaureate or postgraduate level. For a baccalaureate degree, this means the "major field of study" for which the degree is awarded. For postgraduate degrees, it is the discipline in which the degree was awarded. Although the Air Force has a database that identifies personnel having a "technical" college degree, technical degrees appear to include degrees in management, business administration, history, and "other" disciplines. The Air Force's database of technical-degreed personnel was therefore too broad for the purposes of this study; many of the individuals in it are not qualified to fill Air Force positions requiring a STEM degree.

To delineate the specific undergraduate majors or postgraduate degree disciplines to be counted as a STEM degree, the committee leveraged the work of the National Science Foundation's Division of Science Resources Statistics.[10] From its WebCASPAR data system, the committee identified the majors/disciplines shown in table 1-1 as being significant to Air Force STEM needs.

As exemplified in the initial sections of this chapter and throughout Chapter 2, the committee tackled the fundamental issue of why and where the Air Force needs STEM capabilities in its organic workforce to accomplish its priorities, goals, and objectives as presented in the *Air Force Strategic Plan*. In this context, is STEM competence essentially the same thing as having a STEM degree—whether demarcated by Table 1-1 or by some roughly similar listing? Among the several arguments why "STEM competent" should not simply be reduced to "STEM-degreed," the following points most strongly support the committee's decision to broaden the concept of STEM competence:

---

[10]National Science Foundation, Division of Science Resources Statistics, Survey of Graduate Students and Postdoctorates in Science and Engineering, WebCASPAR Integrated Science and Engineering Resources Data System. Available online at http://webcaspar.nsf.gov/.

Copyright © National Academy of Sciences. All rights reserved.

TABLE 1-1 Significant STEM Disciplines for the Air Force

Academic Field	Major or Discipline	
Sciences	Astronomy	Natural science
	Chemistry	Biological and life sciences
	Physics	Earth, atmospheric, and ocean sciences
	Computer science	Oceanography
	Physical sciences	Other geosciences
Technology	Information	Electronics
	Computing	
Engineering	Aerospace, aeronautics, and astronautics engineering	Electrical engineering
	Chemical engineering	Computer engineering
	Industrial engineering	Civil engineering
	General engineering	Nuclear Engineering
	Materials engineering	Systems engineering
	Mechanical engineering	
Mathematics	Mathematics and statistics	Operations research and analysis

NOTE: Because specializations change rapidly across the STEM disciplines, no list can be truly comprehensive. Overall, these disciplines rely heavily on mathematics, the physical sciences, and the scientific method.

- The U.S. Air Force Academy (USAFA) annually graduates and commissions approximately a thousand officers. In recent years, both the number and percentage of officers graduating with STEM degrees (as defined by table 1-1) have been declining. Currently only about 41 percent graduate with a STEM degree. However, through its requirement that all cadets take a set of core science, mathematics, engineering, and technology courses, whatever their intended major field of study, the USAFA maintains a commitment to ensuring that all of its graduates have a basic level of STEM competence. It currently requires that all graduates must complete 45 hours of course work in science, technology, engineering, and mathematics. From time to time, this core set of STEM courses is revisited to ensure that it continues to meet evolving Air Force demands. Thus, the entire pool of USAFA graduates, irrespective of their majors, has a level of STEM competence that should not be ignored in a strategic vision to meet the future STEM needs of the Air Force.
- If graduates of other accredited institutions have attained a level of STEM competence roughly equivalent to that required by the USAFA, why should they not be considered to be of value in meeting Air Force STEM needs, whether or not they have a STEM degree (as defined by the accepted list of STEM majors)?
- For many of the STEM-related capabilities described in Chapter 2, an undergraduate STEM degree needs to be supplemented by work experience and professional development. Later chapters include recommendations for ensuring that young STEM-degreed officers and civilians receive the opportunities to acquire this essential experience. Thus, a STEM degree alone is only a condition of entry and needs to be supplemented with experience and training for some of the STEM capabilities the Air Force requires now and in the future.

Throughout this report, the committee has defined and used the term “STEM-cognizant” to refer to individuals who have acquired a sufficient foundation in the use of the scientific method in decision-making. The committee believes that the USAFA requirement for 45 hours of STEM coursework is more than adequate, although the minimum requirement, in course hours and subjects studied, is a matter for debate and decision within the Air Force (see Recommendations

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

2-2 and 6-1a for the committee's recommendations on this critical point). For purposes of this report, and to clearly distinguish "STEM-cognizant" from "STEM-degreed," while recognizing that the Air Force will need to consider the optimal level of STEM education appropriate for this concept, the committee agreed on 30 hours of STEM coursework as a minimum for STEM cognizance and adopted the following definition:

STEM-cognizant: Lacking a specific degree in science, technology, engineering, or mathematics, but having a minimum of 30 hours of undergraduate course work in these subjects or equivalent training or experience, and being conversant in these subjects.

For ease of reference, Table 1-2 explicitly summarizes key terminology used throughout this report to discuss STEM capabilities in the Air Force workforce.

TABLE 1-2. Definitions of STEM Terms for the Air Force Workforce

Term	Description
STEM-degreed	Having an undergraduate or graduate degree in science, technology, engineering, or mathematics
STEM-cognizant	Lacking a specific degree in science, technology, engineering, or mathematics, but having a minimum of 30 hours of undergraduate course work in these subjects, training, or experience and being conversant in these subjects[a]
STEM-assigned	Personnel assigned to a position that requires a STEM degree
STEM workforce	All STEM-assigned personnel in the overall Air Force workforce

[a]The assumption is that such individuals will have a foundation in the use of the scientific method in decision making.

ORGANIZATION OF THIS REPORT

Chapter 2 addresses task 1 of the committee's statement of task by accessing the STEM capabilities the Air Force will need to meet its goals, objectives, and priorities, as presented in the *Air Force Strategic Plan 2006–2008*, across its missions and domains. Chapter 3 responds to tasks 2 and 3 by characterizing the current STEM workforce—that is, the military and civilian personnel assigned to positions that require a STEM degree. Chapter 4 addresses tasks 3 and 4 by accessing needs for STEM capabilities in the acquisition workforce, including but not limited to positions that require a STEM degree. Chapter 5 describes the future competitive environment for recruiting and retaining STEM-degreed personnel and emphasizes the changing demographics of the U.S. workforce. These concerns are relevant to Tasks 3, 5, and 6. Chapter 6 responds to tasks 3 through 6 by evaluating options and making recommendations for strategies the Air Force should pursue to meet its needs for STEM-capable personnel in the future, across all missions and roles. The recommendations in Chapter 6 are intended to outline an integrated management approach to addressing the issues developed in all the preceding chapters. In Chapter 7, the committee explains why action is needed now to address these issues.

REFERENCES

Anderson, O.A., D.L. Putt, R.P. Swofford, Jr., and K.K. Compton. 1949. Research and Development in the United States Air Force. Air University, Maxwell Air Force Base, November 18.

Copyright © National Academy of Sciences. All rights reserved.

Augustine, N.R. 2009. America's Competitiveness. Statement Before the Democratic Steering and Policy Committee, U.S. House of Representatives, Washington, DC, January 7, 2009. Available at www.aau.edu/WorkArea/showcontent.aspx?id=8154

DSB-AFSAB (Defense Science Board; Air Force Science Advisory Board). 2003. Acquisition of National Security Space Programs. May 2003. Washington, DC: Office of the Secretary of Defense for Acquisition, Technology, and Logistics.

GAO (Government Accountability Office). 2008. Defense Acquisitions Assessments of Selected Weapon Programs. GAO-08-467S. March 2008. Washington, DC: Government Accountability Office.

NAS, NAE, IOM. 2007. Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future. Committee on Prospering in the Global Economy of the 21st Century, Committee on Science, Engineering, and Public Policy, The National Academies. Washington, D.C.: National Academies Press. Available online at http://www.nap.edu/catalog.php?record_id=11463.

SAIC (Science Applications International Corporation). 2003. Future Acquisition and S&E Workforce Requirements: 2010, 2015, and 2025. January 17, 2003. McLean, Virginia.

USAF (United States Air Force). 2006. Air Force Strategic Plan 2006–2008. Available online at www.airforcestrategynet.mil.

Copyright © National Academy of Sciences. All rights reserved.

2

Role of STEM Capabilities in Achieving the Air Force Vision and Strategy

Among the general public and across the service itself, the Air Force is seen as *the* high-technology branch of the military. Its people, missions, and systems are indeed among the most technically sophisticated anywhere in the world. There is, however, growing evidence that the foundation of this technological prowess has eroded and that current trend indicators give cause for concern about the future. Product, test, and logistics center commanders reported to the committee that it is becoming more challenging to hire and retain technically skilled (in the committee's terms, STEM-educated or STEM-cognizant,) military and civilian personnel.[1] Overall, the available pool of technically skilled and experienced personnel seems to be diminishing. As noted in Chapter 1, various studies from the National Academies, the Defense Science Board, the Government Accountability Office, and others have concluded that this situation has contributed to problems for development and acquisition across the Air Force (NAS, NAE. IOM, 2007; DSB-AFSAB, 2003; GAO, 2008).

This chapter first discusses how the Air Force uses the STEM skills and expertise of its workforce today in key mission and functional areas across the service, including emerging requirements for STEM capabilities in the newer domains and mission areas. It then describes the contribution of STEM-degreed and STEM-cognizant personnel in development, acquisition, and sustainment activities. The third major section focuses more specifically on STEM-degreed personnel–both officers and civilians—and their presence across the Air Force workforce, as well as in positions that currently require a STEM degree. The fourth section examines how all these roles for STEM capability relate to recent formal statements about Air Force core competencies and the priorities, goals, and objectives of the latest Air Force Strategic Plan. The chapter ends with findings and recommendations based on the entire chapter.

STEM NEEDS ACROSS AIR FORCE MISSIONS AND DOMAINS

Sustaining adequate STEM capability throughout the workforce is critical to the Air Force's priorities and goals across its missions. The following subsections highlight areas where STEM-degreed or STEM-cognizant personnel are of particular importance.

Airpower and Nuclear Deterrence

The Air Force must sustain its historical preeminence in airpower and nuclear deterrence. The weapon systems essential to accomplishing these missions—fighters, bombers, transports, intercontinental ballistic missiles, munitions—have undergone continued rapid technological advancement. F-22 and F-35 stealth aircraft are marvels of sophisticated technology that will

[1]Chapters 3 and 4 report the details of these comments and cite the briefers who made them.

Copyright © National Academy of Sciences. All rights reserved.

demand deep technical competence to master, in terms of sustainment as well as in tactics, techniques, and procedures (TTPs). New aircraft, such as a new tanker, and technology upgrades and modifications, as are necessary for all extended-life aircraft such as the venerable B-52 and C-5, will likewise demand technical competence for employment and sustainment. STEM-degreed or STEM-cognizant personnel are critical for this technical competence.

One current concern is Air Force management of its nuclear forces, both air-launched and intercontinental ballistic missiles, which came under criticism in 2008 because of missteps in nuclear operational and logistics areas. The Air Force is reviewing force-wide processes, procedures, systems, personnel training, and management and is taking significant action by refocusing the mission into a new command structure. The Air Force is also playing an important role in an ongoing national review of the role of new nuclear weapons and supporting infrastructures. In keeping with these developments, and in recognition of existing Air Force missions, there is no question that maintaining credible deterrence in an evolving environment requires robust STEM capabilities in the workforce.

Emerging Technologies

Since the end of the Cold War, the Air Force has evolved to be an expeditionary air warfare force capable of (1) projecting precise lethal force anywhere on the globe, (2) rapid mobility, and (3) continuous global monitoring and movement of information to enable joint operations. New operating concepts and missions have been achieved through innovative use of existing systems and technologies and through the introduction of new capabilities. The development of responsive and dynamic operational-level command and control capabilities has dramatically improved the planning and execution of theater air operations and the integration of joint operations. ”Reachback”[2] via satellite and other information links from lean in-theater forces to robust in-place resources in the continental United States has changed the nature of deployed operations. Today, airborne reconnaissance and strike missions are executed from thousands of miles away, telemedicine enables rapid stabilization and transport of casualties from the battlefield, and agile logistics and maintenance support allow forces to operate at a high tempo with a minimum “footprint” in theater. Optimal operation and sustainment of these still-emerging yet increasingly mission-critical capabilities require substantial STEM capabilities among the personnel involved.

Such dramatic new capabilities as unmanned air systems, day-night/all-weather operations, and the ubiquitous use of the Global Positioning System for precision operations across the battlefield have transformed Air Force forces and operations. These new systems and the missions they enable have demanded rapid advancement and new technical understanding in such areas as data links, anti-jam techniques, multispectral sensors, and low-light operations. Beyond developing these new technical operational capabilities, their real power is in using them effectively on the battlefield, which increasingly depends on STEM-degreed or STEM-cognizant warriors.

Space

In some ways, space operations may seem to be a simple extension of air flight. But space is a hostile environment in which physical conditions differ markedly from those within the atmosphere. These differences, in turn, have marked effects on the design and operation of systems that must operate in this domain. The Air Force has excelled in developing and operating military space capabilities from the earliest days of the space age, shepherding their rapid

---

[2]“Reachback” is the capability to communicate in real time to a distant location for rapid support.

Copyright © National Academy of Sciences. All rights reserved.

evolution from limited, short-lived, experimental prototypes to reliable, highly capable operational systems critical to modern military strategy.

Today, operational space systems primarily provide information sensing and transmission, but space control and new space applications are rapidly maturing. By their very nature, development and operation of such systems require high-level STEM capabilities. More recently, as both technology and needs have matured, the Air Force has emphasized integration of space capabilities and effects in joint operations and the deliberate, requirements-driven development and acquisition of future systems.

Individual Air Force space missions may be unique, but all are interconnected in some way. So, in 2001, the Air Force aligned all its space acquisition operations under a single major command, the Air Force Space Command (AFSPC), and began to coordinate leadership of these operations with other national security space organizations.

Space has historically been viewed as an "enabling utility" or as a "silent sentinel." Increasingly, as space is being integrated into joint military operations, it is becoming a key element of "finding, fixing, and finishing" targets on the battlefield. Unfortunately, as recent foreign antisatellite tests and electromagnetic attacks have demonstrated, space is also becoming a contested domain. Thus, while U.S. dependence on space in military operations is growing, potential adversaries are seeking to attack or disrupt use of it by the United States. All this suggests that the Air Force must treat space as it does the air and cyber domains, which require both warrior and technical (STEM-degreed or STEM-cognizant) skills.

Launch vehicles, satellite systems, mission payloads, ground control, mission processing, and surveillance sensors demand technical competence in many particular disciplines and specialties, such as astrodynamics, launch and space propulsion, attitude control systems, power and thermal control, data links, radars and optics, ground networks, and complex planning and control software. Further, because these often one-of-a-kind systems operate continuously (24 hours a day, 7 days a week), no system maintenance, upgrades, or new system launches can be allowed to affect ongoing operations and the systems must remain continuously compatible with users and their equipment. As emphasis on the integration and employment of space capabilities in joint operations has grown, so has demand for STEM-degreed and STEM-cognizant developers and operators3 to support the space users who deliver dynamic and responsive tactical support to warfighters on the battlefield.

Competitors and potential adversaries are also increasing their use of space. Air superiority is a key objective in all military campaigns and operations, and so must space superiority be. This objective demands increasing capabilities and investments for space situational awareness and defensive measures, much of which will incorporate new technical components and systems requiring STEM capabilities with a focus on the relevant advanced technologies.

All these realities point to the increased need for people who have STEM training at the appropriate level and in the necessary special areas. Many of these people will also require experience in the development, acquisition, fielding, and employment of future space forces. Although there are no stated requirements for STEM education in the space operations career field, the growing need for greater technical skills and experience across the space mission area, both in terms of acquisition and operation, is clear.[4] The necessary skills and experience can be

---

[3]In military parlance, an *operator* of a system or item of technology, whether the technology is an entire weapon platform or component weapon system, an entire information system or a station at a system node, etc., is the individual who uses (operates) that weapon or tool in its intended application(s).

[4]The space and missile career fields were combined in 1994 into Space and Missile Operations (13S). Prior to this time the Space Career Field (20XX) (Reference: AFR 36-1, Attachment 8, effective 30 April 1990) had specific and extensive educational requirements in mathematics, science, and engineering for all of the subsets ("shreds") of this career field. The current 13S career field educational requirements for entry are:undergraduate academic specialization in management, business administration, economics, mathematics, science, engineering, computer science, space

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

developed through formal education, focused systems and mission training, and deliberate career field management and leadership development.

Cyberspace

Cyberspace is distinctly different from the traditional domains of air, land, and sea. Some might think it does not even constitute a physical presence—yet it has direct and potent effects on our physical systems. Furthermore, the cyber domain depends on a human-made physical network of sophisticated workstations, communications links (including space resources), cables, switches, computers, software applications, databases, etc. All this hardware and software creates a virtual environment for the movement and processing of data, the transfer of information, and the creation of knowledge.

Cyberspace shares important characteristics with the space domain, especially in terms of the highly STEM-dependent nature of its systems, threats, and employment. That its nature is both physical and virtual, however, demands unique skills and thinking.

At the physical level, cyberspace consists of complex and highly interconnected computing, communications, networking, and software systems, most of which are commercial products and services with easy access and penetrability. The Defense Advanced Research Projects Agency originally created what is now the Internet for the Department of Defense as a science data-sharing network. Now, in the globally connected world of the 21st century cyberspace, this network has become ubiquitous as a part of global infrastructure. Dependence on cyberspace for commercial enterprise, governmental processes, and national security continues to grow exponentially. The skills to use the network have become widespread across the public at large and within the military in particular. Cyber capabilities are embedded in every area of military operations and maintenance.

Military forces and their operations and administration depend on commercial services and network systems, which demand increased protection and assurance measures. Hardware, software, connections, and protective measures undergo nearly continuous upgrades because of business decisions and in response to vulnerabilities and attacks. Likewise, exploiting and attacking the cyber systems of adversaries require highly sophisticated skills to penetrate, exfiltrate, and disrupt adversary use in both undetectable and acknowledged ways. The capability to protect critical U.S. cyber infrastructures against exploitation and attack is an increasingly important national security responsibility.

The Air Force has been developing its cyber capabilities for over a decade. It is currently formulating its organization, career field, training, equipage, doctrine, and tactics for cyberspace operations as a distinct force component (i.e., a numbered major unit or "air force") within the Air Force. Cyber operations include protecting friendly capabilities and exploiting or attacking hostile cyber systems. Such operations require sophisticated systems, techniques, and expertise. Further, the Air Force is one of many departments and agencies involved in cyber operations, and there is a growing need to integrate capabilities, share information, and leverage authorities for the successful execution of coordinated and joint cyber operations.

All these factors point to the need for an increased community of technically and operationally skilled "cyberwarriors" to execute the Air Force's mission. While the full scope of this mission and the organization to conduct it are still evolving, it is clear the Air Force will need more people having extensive cyber skills and competence to develop, field, and employ both defensive and offensive operations in cyberspace.

---

operations, or liberal arts two semesters of calculus and one semester of physics (Reference: Officer Classification Directory, AFOCD, 31 January 2010).

Copyright © National Academy of Sciences. All rights reserved.

STEM Capability in Other Air Force Domains

Other areas that value STEM-degreed and STEM-cognizant personnel include force planning, resource decision making, and operational employment and evaluation. These activities take advantage of operations research and other analytic skills. Developmental testing and operational testing of weapon systems require combined test forces consisting of large numbers of engineers, operators, and support personnel with STEM education and training. Moreover, significant numbers of technically trained and skilled personnel at the Air Force Warfare Center develop the TTPs for all operational weapon systems to ensure their optimal employment. Sustaining and maintaining complex flight systems and software, investigating mishaps and accidents, and implementing corrective actions all require strong technical skills across many mission systems and career fields.

Military operations today frequently require the integration of diverse platforms and systems with an ever-increasing reliance on sophisticated sensors, data links, processors, and command and control centers—often across joint, allied, and coalition forces. Advanced information technology enables this integration but also places a greater premium on technical competence and the qualifications of the developers, operators, and support personnel who must employ and leverage these powerful capabilities. Aside from its operational value, information technology has brought the same revolution in Air Force business management that it did to the private sector. Lean logistics, automated tests, geographic information systems, online personnel management and finance, network security, and numerous other advanced business applications have made literacy and basic competency in information technology necessary for all members of the Air Force.

STEM SKILLS AND EXPERIENCE IN THE ACQUISITION LIFE CYCLE

Although industry builds the Air Force's weapon systems, STEM-degreed and STEM-cognizant Air Force personnel play a critical role in weapon system acquisition. Their skills and competencies are applied across the entire life cycle of each system:

- exploration of advanced technologies;
- definition of operational needs and system solutions;
- development, fielding, maintenance, and sustainment of weapon systems; and
- development and employment of the full tactical, operational, and strategic capabilities and potential of the fielded systems.

Although the Air Force Materiel Command (AFMC) and AFSPC have the largest concentrations of STEM-degreed personnel among the major commands, STEM-degreed and STEM-cognizant personnel in the operational commands and in the Air Force Operational Test and Evaluation Center play crucial roles in defining requirements, testing systems for operational suitability, and operationally maturing TTPs for all Air Force weapon systems.

It is important to realize the importance of STEM-degreed *and operationally experienced* officers in the statement of operational requirements. Without the ability of operational users to translate operational needs into technical terms, the acquisition community is left to do that job on its own. This lack of operational input often results in flawed need statements and misdirects contractors in their bidding efforts. The iterative process of balancing operational requirements against technical feasibilities and financial imperatives is best accomplished by a team representing both the operational and acquisition communities, and this requires STEM capability on both sides of the team. Putting officers who are neither STEM-degreed nor STEM-cognizant in the highest management positions can also result in shortfalls in the oversight of important defense acquisition programs. Adept oversight of major acquisitions is crucial—for example,

Copyright © National Academy of Sciences. All rights reserved.

during the past seven years, 35 Air Force programs have experienced Nunn-McCurdy breaches: cost overruns that triggered a program review in accordance with the Nunn-McCurdy Amendment to the Defense Authorization Act of 1982 (10 USC §2433).

Concept Refinement and Requirements Definition

Engineers, operators, logisticians, and operations analysts in the AFMC and at Headquarters U.S. Air Force work closely with operators in the major commands to define and analyze the requirements for new weapon systems and for improving existing weapon systems, to analyze alternatives, and to translate these needs through a systems engineering methodology into concepts and technical requirements that industry can understand and eventually produce. This highly iterative process is the principal determinant of the total cost of a weapon system. Acquisition officers reported to the committee that the process is more efficient when operators have the critical reasoning and analysis skills associated with a STEM degree or STEM cognizance. These abilities allow them to communicate effectively and reach common understandings with the acquisition community.

Science and Technology Development

Scientists and engineers in the Air Force Research Laboratory lead the discovery and advanced development of technologies in all areas critical to the Air Force, including basic research, air and space vehicles, propulsion and power, sensors, materials and manufacturing, human effectiveness, information, munitions, and directed energy, as well as emerging technologies such as nanotechnology. This work leads to development of future weapon system concepts, collaboration with system acquirers on technology risk reduction for insertion into current and developmental weapon systems, and collaboration with both operators and system acquirers on quick-response solutions to urgent warfighter needs.

During system development and acquisition, engineers in the AFMC and AFSPC program offices conduct technology readiness assessments, identify the highest technology risk areas, establish technology risk-reduction plans, and actively evaluate the efforts of industry to ensure that the technology risk has been reduced or that lower-risk alternatives have been identified. Product center commanders, program managers, and retired senior acquisition officials interviewed by the committee all pointed out that having personnel with STEM skills provides greater understanding of the underlying technology and its inherent issues.[5] They possess the skills and experience necessary to analyze and interpret data and make recommendations. While engineers do the detailed work, program managers must make critical judgments and decisions based on the data and recommendations presented to them. A STEM degree, or at least STEM cognizance, enhances their ability to do this.

System Development and Demonstration

During this phase of acquisition, industry develops technical requirements, system designs, subsystem definitions, prototypes, and test plans and reviews them in coordination with Air Force developmental and operational test organizations. Program office engineers ensure the adequacy of the contractor's proposed design against performance specifications, prepare or review ground- and flight-test plans, and actively evaluate industry's progress. Technical expertise is needed across all key subsystems: structures, propulsion, sensors, flight control, etc. In addition, expertise

---

[5]Lt Gen Ted F. Bowlds, Commander, Electronics Systems Center, briefing to the committee on October 30, 2008. Maj Gen David J. Eichhorn, Commander, Air Force Flight Test Center, briefing to the committee on December 3, 2008. Col Art Huber, Commander, Arnold Engineering Development Center, briefing to the committee on December 3. 2008

Copyright © National Academy of Sciences. All rights reserved.

is needed in software development and systems integration, including system reliability and sustainability. Air Force test engineers work closely with program office engineers and their counterparts in industry to develop test plans, collect and analyze test data, and identify issues. All test pilots are STEM-degreed, which enables them to participate actively in test planning, execution, and data interpretation.

Production and Deployment

Air Force engineers skilled in manufacturing processes and logistics play a key role in weapon system production and deployment. Manufacturing issues inevitably arise, and Air Force engineers often lead integrated product teams: groups of experts gathered from across the Air Force, industry, and academia to solve these problems. Fielding advanced weapon systems involves building new facilities, deploying test and maintenance equipment, generating and validating procedures, and training personnel. All these activities depend on technically skilled and experienced government program personnel working with contractors, operators, and system maintainers.

Operations and Support

STEM-degreed or STEM-cognizant operators are especially valued in operational testing and development of TTPs for upgraded and improved weapon systems. Critical thinking skills, innovative ideas, and a technical understanding of weapon systems are essential to the constantly evolving play of employment of new technology and system capabilities against enemy systems and tactics.

Field and depot maintenance of weapon systems requires maintenance engineers able to analyze equipment failures, determine root causes, and recommend both immediate and long-term solutions. Because the Air Force aircraft fleet is aging, the need for these system-maintaining skills is increasing. Two recent examples that illustrate this need are (1) the grounding of more than half the A-10 fleet on October 3, 2008, due to wing cracks, and (2) the grounding of the F-15 fleet following the November 2, 2008, crash of an F-15 for longeron failure. In such situations, STEM-degreed experts in the Air Force Safety Center, depots, product centers, and Air Force Research Laboratory conduct incident analysis and accident investigation boards, all of which also require STEM-cognizant personnel to engage and interact effectively with the STEM-degreed experts.

STEM-DEGREED PERSONNEL IN THE CURRENT AIR FORCE WORKFORCE

The preceding sections of this chapter have argued for the pervasive value of STEM-degreed and STEM-cognizant personnel across Air Force missions and domains—with particular emphasis on the essential role that STEM capabilities play throughout the acquisition life cycle. This section focuses on current requirements for STEM-degreed personnel specifically and on the value of STEM-degreed personnel throughout the Air Force workforce, whether or not they are in a position that requires a STEM degree.

Current Occupational Requirements for a STEM Degree

Only five Air Force officer career fields currently require a STEM degree: Weather (15W), Civil Engineer (32E), Communications and Information (33S), Scientist (61S), and Developmental Engineer (62E). All other officer career fields, such as pilot, navigator, air battle manager, maintenance, space and missiles, and program management, have no stated requirements for STEM education, but a significant percentage of officers in these career fields

Copyright © National Academy of Sciences. All rights reserved.

do hold STEM degrees. For example, 45 percent of pilots have science or engineering degrees. While the committee found no direct data showing cause and effect, current and former Air Force officials who interacted with or were members of the committee believe the high degree of technical expertise among its pilots contributes significantly to the U.S. Air Force's operational and tactical excellence.[6]

STEM-Degreed Officers Across the Workforce

The Air Force has traditionally accessed technical workforce capacity and capability by tracking technical and nontechnical degree holders. Figure 2-1 shows the proportion of technical degree holders among key officer career fields of interest to this study for four promotion phase points between 1994 and 2009.[7] A caveat in interpreting this graph and others based on the Air Force's Personnel Database is that the definition of a technical degree in that database does not correspond exactly to the list of majors or fields of study in the committee's delineation of STEM degrees in Table 1-1. Nonetheless, the match is close enough to use these statistics, provided in Air Force briefings to the committee, as indicators of trends and issues.

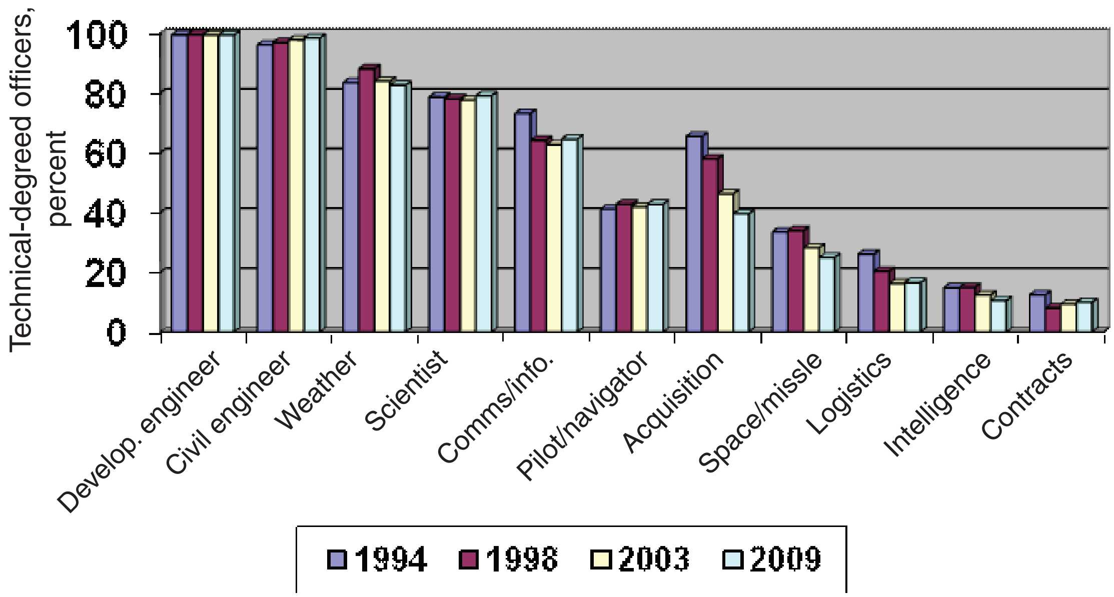


FIGURE 2-1 Officers with Technical Degrees in Career Fields with STEM Needs. Develop. engineer = developmental engineer; Comms/Info. = communications/ information officer; Space/missile = space or missile operations officer. SOURCE: Headquarters U.S. Air Force, Personnel Database, data extracted in September 2008.

The trends in Figure 2-1 highlight several areas of concern. First, while the proportion of technical degree holders has remained relatively constant in traditional technical fields such as

[6]Former Air Force officers on the committee who expressed this view, based on their years of service, include Ronald Yates (General, U.S.A.F., retired), who served as Commander of the Air Force Systems Command and Commander of the Air Force Material Command, and George Muellner (Lt. Gen. U.S.A.F., retired), who served as Deputy Chief of Staff for Requirements for Headquarters Air Combat Command, among other positions. Lt. Gen. John L. Hudson, Aeronautical Systems Command, also stated this view in his videoteleconference with the committee on October 30, 2008.

[7]A promotion phase point is the average number of years and months of active commissioned service completed when an officer in a particular competitive category advances to a particular grade.

Copyright © National Academy of Sciences. All rights reserved.

developmental engineering and civil engineering, technical degree holders in other career fields have declined notably over the past 14 years. Communications and information dropped 9 percentage points, and logistics dropped 10 percentage points. Of particular concern to this study is the large decline in acquisition and contracting from 65 percent to 40 percent. Incidentally, although they lack specific requirements for technical degrees, two career fields whose importance has increased recently also suffered rather large declines. The first is space and missiles, in which technical-degreed officers declined by 9 percentage points.[8] The second is intelligence, which has been facing sweeping challenges related to cyberspace and cybersecurity issues; the technical-degreed officers in this field declined by 4 percentage points from an already low level.

Figure 2-2 shows that the inventory of officers with technical degrees in the Air Force is not confined to the career fields requiring a STEM degree. Sizable populations that may qualify as STEM-degreed are present in other career fields.

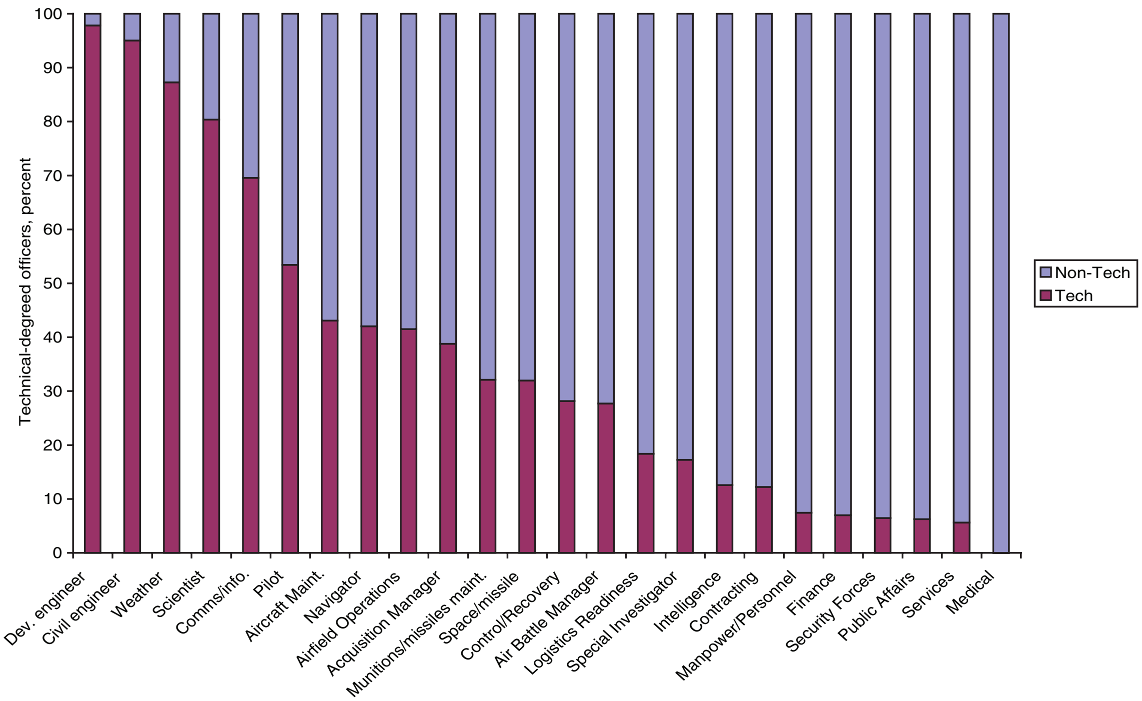


FIGURE 2-2 Percentage of Officers with Technical Degrees by Career Field. Note that not all technical degrees as defined by this source are STEM degrees. Dev. Engineer = developmental engineer; Comms/info = communications/information officer; maint. = maintenance; Space/missile = space or missile operations officer. SOURCE: Col. James D. Fisher, Chief, Engineering and Technical Management Division, SAF/AQRE, briefing to the committee on August 26, 2008.

[8]Point of information regarding decline in the space and missile career field: The 13S career field was created in 1994. All specific education requirements for specific STEM education were removed and replaced with less inclusive requirements.

Copyright © National Academy of Sciences. All rights reserved.

STEM-Degreed Civilian Personnel Across the Workforce

Only three civilian occupational series in the Air Force require a STEM degree: Engineering (0800), Physical Sciences (1300), and Mathematics (1500). However, as with STEM-degreed officers, STEM-degreed civilians work in many occupations that do not formally require a STEM degree. Figure 2-3 shows the percentage of civilians with technical degrees in a range of occupational series. Note that the caveat about the difference between "technical degree" and the committee's definition of a STEM degree applies here as well. Acquisition managers are included in the Business and Industry occupational series.

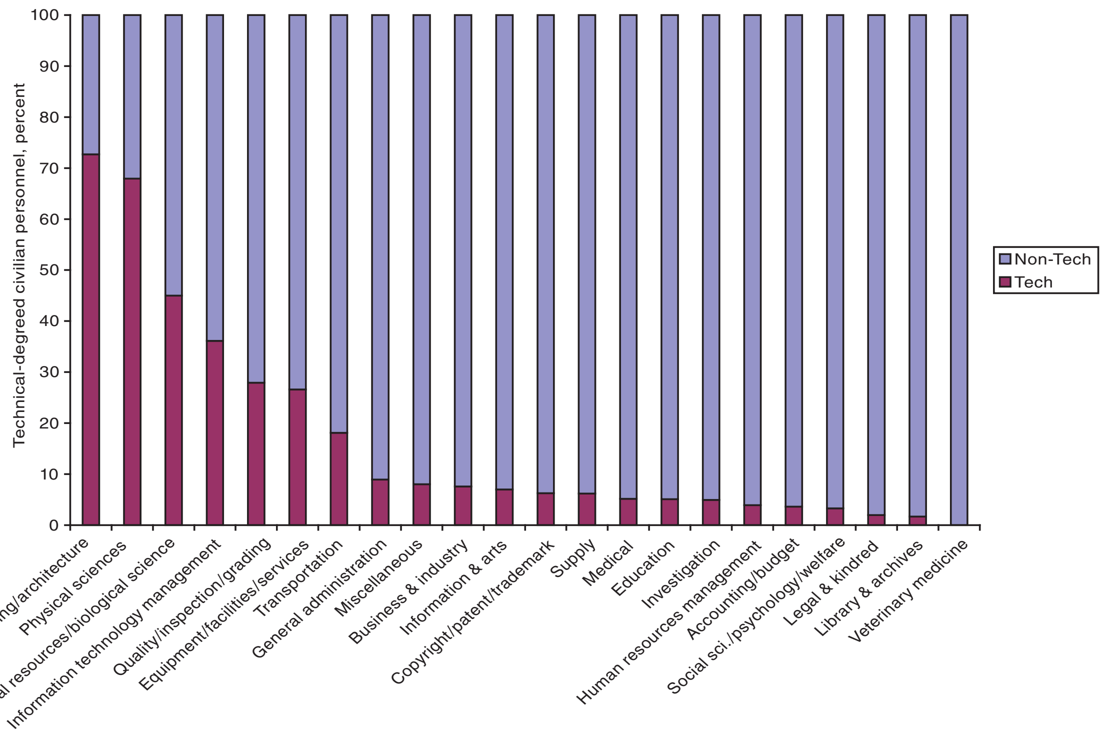


FIGURE 2-3. Percentage of Civilians with Technical Degrees by Occupational Series. Note that not all technical degrees as defined by this source are STEM degrees. SOURCE: Col. James D. Fisher, Chief, Engineering and Technical Management Division, SAF/AQRE, briefing to the committee on August 28, 2008.

PERCEIVED ROLE OF STEM CAPABILITY IN AIR FORCE CORE COMPETENCIES AND THE AIR FORCE STRATEGIC PLAN

Since 2003, the Air Force has had three formally established core competencies: Developing Airmen, Technology-to-Warfighting, and Integrating Operations. These three core competencies are described as "making possible" the Air Force's six "distinctive capabilities": Air and Space Superiority, Global Attack, Rapid Global Mobility, Precision Engagement, Information Superiority, and Agile Combat Support. (Jumper, 2003; Krisinger, 2003; USAF, 2009).[9] In his commentary on Air and Space Core Competencies for the Chief's Sight Picture of 15 January

[9]From about 1996 until 2003, these six distinctive capabilities had been described as Air Force core competencies (Krisinger, 2003; Tritten, 1997; Ryan and Peters, 2000).

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

2003, Chief of Staff of the Air Force (CSAF) Gen. John Jumper gave the following description of the Technology-to-Warfighting core competency:

> Our Air Force has a proud legacy of continually bringing cutting-edge technological capabilities to bear to confront threats to our nation's security. This legacy started a century ago with the dawn of aviation. It continues today, as our wielding of air power pushes the limits of not only the sky, but of outer space and cyberspace. We combine the tremendous technological advancements of stealth, global communications connectivity, global positioning, and more, to put cursors on targets and steel on the enemy. It is our unique ability to apply various technologies in unison so effectively that allows us to translate our air and space power vision into decisive operational capability.
>
> The Predator unmanned aerial vehicle is today's perfect example of this core competency in action. It combines the dynamics of manned aviation with the remote operation techniques of unmanned satellites and the information connectivity of networks into a single system capable not only of collecting and disseminating information, but of producing combat effects (Jumper, 2003).

Of the three 2003 core competencies, Technology-to-Warfighting is the one most clearly dependent on the STEM capabilities discussed earlier in this chapter, which extend across the operational domains of the Air Force and to every stage of the acquisition-to-employment life cycle.

Although the three 2003 core competencies are still cited on the Air Force's homepage to the global Internet community (USAF, 2009), the *Air Force Strategic Plan, 2006–2008* does not specifically mention them (USAF, 2006a). The only reference to core competencies occurs once, in Objective 1.3: "Develop cyberspace as an Air Force core competency." Otherwise, the Strategic Plan is couched in terms of three priorities, seven goals, and a range of objectives to support these priorities and goals. Another reference to cyberspace as an emerging Air Force core competency can be found in CSAF Gen. T. Michael Moseley's 2007 white paper, *The Nation's Guardians: America's 21st Century Air Force*: "We will continue to develop and implement plans for maturing cyber operations as an Air Force core competency" (Moseley, 2007, pg. 8).

There are a number of passages in the Strategic Plan that can be read as implying a need for STEM capabilities in the Air Force workforce. However, Gen. Jumper's 2003 description of the Technology-to-Warfighting core competency relates more clearly than the Strategic Plan to the STEM contributions to Air Force roles and missions described in this chapter. Similarly, the discussion of cyberspace in this chapter argues for the essential role that STEM capabilities will play in an emerging fourth Air Force core competency in cyber operations.

FINDINGS AND RECOMMENDATIONS

The preceding exploration of current and future Air Force missions and roles points to the Air Force's substantial needs for the technical skills and expertise provided by STEM-degreed or STEM-cognizant personnel in the development, operation, and sustainment of current Air Force systems and in the fielding and operations of new capabilities, including those in the emerging missions of the space and cyber domains, which are both technology intensive. These domains are on the innovative edge of global technology where actual and potential U.S. adversaries hope to reduce the asymmetric advantage of the United States and take advantage for themselves of the historical "sanctuary" provided in those domains. Consequently, it is essential that the Air Force maintain and enhance its technical competency—a competency provided by the Air Force's STEM-degreed and STEM-cognizant personnel.

While the Air Force sees itself as a "technical Service" and indeed develops, acquires, operates, and sustains some of the most sophisticated military systems in the world, its strategic

Copyright © National Academy of Sciences. All rights reserved.

vision, mission, and plan do not specifically identify these as core Service competencies. Based on the presentations to the committee, senior level Air Force assessments, and the national-level reports cited in Chapters 1 and 2, the committee concludes that the Air Force's continuing problems with acquisition of new systems are attributable in significant measure to the Service's loss of STEM skills and experience. In addition to sustaining historical missions of airpower and nuclear deterrence, new missions and emerging warfare domains, specifically space and cyberspace, will engender even greater demand for STEM skills and experience across the Air Force.

Within the Air Force, STEM-degreed and STEM-cognizant personnel are found in all major commands. They work in all 26 of the officer career fields identified by Air Force Specialty Codes (AFSCs).[10] However, only 5 of the 26 career fields have stated requirements for a STEM-degreed individual. Most STEM-degreed personnel who work in the R&D and acquisition specialties are found in the AFMC or AFSPC. Civil engineers and communications specialists are found in all of the major commands. Within the five career fields with stated STEM-degreed requirements, personnel are managed within their AFSC. Other STEM-degreed personnel within the Air Force are not managed as an entity.

Finding 2-1a. STEM-degreed and STEM-cognizant personnel are critical to operational missions and roles across the Air Force and to the entire life cycle of Air Force weapon systems, from basic through applied research, requirements determination, definition, concept development, technology and system development, and test, production, deployment, operations, and sustainment.

Finding 2-1b. The ability to conceive, develop, acquire, operate, and sustain advanced weapon systems has been addressed in Air Force descriptions of its Technology-to-Warfighting core competency. However, the *Air Force Strategic Plan, 2006–2008* neither references this core competency directly nor includes a priority, goal, or objective that unequivocally supports the Air Force's current and future needs for STEM-degreed and STEM-competent personnel.

Recommendation 2-1. The Air Force should incorporate in its Strategic Plan as an eighth goal the ability to conceive, develop, acquire, operate, and sustain advanced weapon systems. The Strategic Plan should state that this goal is essential to maintaining and advancing the existing Technology-to-Warfighting core competency and the emerging core competency in Cyber Operations. The Strategic Plan should set out recruiting, developing, employing, and retaining STEM skills and experience as key enabling objectives for this goal.

Finding 2-2a. Assessments of future missions and the future operating environment, suggest that Air Force missions will become more technologically intensive and will require a proportionally larger STEM workforce in many career fields across the Air Force.

Finding 2-2b. Most officer career fields include STEM-degreed personnel to varying degrees. However, only five military officer career fields have stated requirements for STEM education; other officer career fields have no stated requirement for STEM-degreed or STEM-cognizant personnel.

Finding 2-2c. As discussed in Chapter 1, the Air Force does not have a consistent definition of its STEM workforce. The baccalaureate majors and the fields of study for postbaccalaureate degrees that count for a STEM degree are not specified. Furthermore, there is no uniform concept

---

[10]A career field is a group of closely related Air Force specialties (or a single AFSC when there are not related specialties) requiring basically the same knowledge and skills (USAF, 2006b, pg. 63).

Copyright © National Academy of Sciences. All rights reserved.

corresponding to STEM cognizance as used in this report. The committee believes that it is essential that the Air Force identify those personnel with STEM degrees and those with STEM cognizance and identify what the Air Force's requirements are for STEM-degreed and/or STEM-cognizant personnel across all career fields.

Finding 2-2d. Only about 40 percent of the officers in the Acquisition Management career field have technical degrees, and fewer than 10 percent of civilians in the Business and Industry occupational series, which includes acquisition managers, have technical degrees.

Recommendation 2-2. The Air Force should review and revise as appropriate its current requirements and preferences for personnel with STEM capabilities in every career field and occupational series.

- The Air Force need not adopt the specific list of STEM majors/disciplines used by the committee (Table 1-1), but an explicit demarcation of what counts as a STEM degree is necessary.
- The Air Force should define a level of STEM capability broader than having a STEM degree, similar to (albeit not necessarily identical with) the concept of STEM-cognizant used in this report.
- The Air Force should review, and revise or establish as appropriate, requirements and preferences for STEM-degreed and STEM-cognizant personnel in every career field and occupational series. Particular attention should be given to supporting the needs of the acquisition community and to developing such mission areas as intelligence and the emergent domains of space and cyberspace. This review should include identifying positions requiring STEM-degreed people and setting goals for appropriate numbers of personnel in other positions to be STEM-cognizant (with appropriate education, training, and experience) throughout the officer career fields and civilian occupational series.

REFERENCES

DSB-AFSAB (Defense Science Board; Air Force Science Advisory Board). 2003. Acquisition of National Security Space Programs. May 2003. Washington, DC: Office of the Secretary of Defense for Acquisition, Technology, and Logistics.

GAO (Government Accountability Office). 2008. Defense Acquisitions Assessments of Selected Weapon Programs. GAO-08-467S. March 2008. Washington, DC: Government Accountability Office.

Jumper, John P. 2003. *Chief's Sight Picture.* 15 January 2003. Available online at http://leadership.au.af.mil/af/csaf_core_comps.pdf.

Krisinger, C. J. 2003. Who we are and what we do: The evolution of the Air Force's core competencies. Air and Space Power Journal. Fall 2003. Available online at http://www.airpower.maxwell.af.mil/airchronicles/apj/apj03/fal03/krisinger.html.

Moseley, T. Michael. 2007. The Nation's Guardians: America's 21st Century Air Force. CSAF White Paper, 29 December 2007. Available online at http://www.af.mil/shared/media/document/AFD-080207-048.pdf.

NAS, NAE, IOM. 2007. Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future. Committee on Prospering in the Global Economy of the 21st Century, Committee on Science, Engineering, and Public Policy, The National Academies. Washington, D.C.: National Academies Press. Available online at http://www.nap.edu/catalog.php?record_id=11463.

Ryan, Michael E., and F. Whitten Peters. 2000. The Aerospace Force: Defending America into the 21st Century. USAF White Paper. Available online at http://www.af.mil/shared/media/document/AFD-060726-029.pdf.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

Tritten, James T. 1997. Joint mission-essential tasks, Joint Vision 2010, core competencies, and global engagement: Short vs. long view. *Airpower Journal*. Fall 1997. Available online at http://www.airpower.maxwell.af.mil/airchronicles/apj/apj97/fal97/tritten.html.

USAF (United States Air Force). 2006a. Air Force Strategic Plan 2006–2008. www.airforcestrategynet.mil.

USAF. 2006b. Classifying Military Personnel (Officer and Enlisted). Air Force Instruction 36-2101. 7 March 2006. Available online at http://www.e-publishing.af.mil/shared/media/epubs/AFI36-2101.pdf

USAF. 2009. The Official Web Site of the U.S. Air Force: Welcome Available online at http://www.af.mil/main/welcome.asp. Accessed 25 March 2010.

Copyright © National Academy of Sciences. All rights reserved.

3

Air Force Career Fields and Occupations That Currently Require a STEM Degree

This chapter begins with a discussion of issues for the five officer career fields that require a STEM degree, followed by discussion of issues for the three civilian occupational series that require a STEM degree. A third section reports on perspectives of the adequacy of these two segments of the Air Force workforce, heard by the committee during presentations from several Air Force functional organizations.

ISSUES FOR OFFICER CAREER FIELDS REQUIRING A STEM DEGREE

Relative to its current authorizations for line officers, the Air Force remains overmanned in lieutenants and undermanned in captains, majors, and lieutenant colonels (Table 3-1).

TABLE 3-1 Line-Officer Manning, All Career Fields

	Lt.	Capt.	Maj.	Lt. Col.	Col.	Total
Assignments (A)	7,648	16,257	9,339	7,711	2,560	43,515
Authorizations (B)	5,948	17,898	10,924	7,962	2,555	45,287
Ratio, A:B	128.6%	90.8%	85.5%	96.8%	100.2%	96.1%

SOURCE: Headquarters Air Force Personnel Center, Directorate of Assignments, January 2009.

Assignments versus Authorizations

As of January 2009, the Air Force had a total of 43,515 line officers (excluding transients) assigned against 45,287 authorizations, for an overall manning level of 96.1 percent. Of these, 19,610 were field-grade officer assignments (majors, lieutenant colonels, and colonels), against 21,441 field-grade authorizations, resulting in overall field-grade manning of 91.5 percent. Company-grade manning (lieutenants and captains) was 23,905 assigned against 23,846 authorized (100.2 percent).

Table 3-2 compares assignments to authorizations in the five career fields that require a STEM degree. The table includes data for the Acquisition Management career field (63A) because field-grade manning in that field depends heavily on cross flow from the Scientist (61S) and Engineer (62E) career fields. The overall manning level in each of the five STEM-degree-

Copyright © National Academy of Sciences. All rights reserved.

TABLE 3-2 Manning in STEM-Requiring and Acquisition Management Career Fields

		Lt.	Capt.	Major	Lt. Col.	Col.	Total
15W	Assigns	129	187	119	96	16	547
Weather	Auths	94	229	141	75	15	554
	%	137.2%	81.7%	84.4%	128.0%	106.7%	98.7%
32E	Assigns	326	339	216	199	61	1,141
Civil Eng,	Auths	123	510	231	196	66	1,126
	%	265.0%	66.5%	93.5%	101.5%	92.4%	101.3%
33S	Assigns	686	1,109	656	391	110	2,952
Comm-info	Auths	177	1,206	819	460	117	2,779
	%	387.6%	92.0%	80.1%	85.0%	94.0%	106.2%
61S	Assigns	260	249	155	82	9	755
Scientist	Auths	105	367	202	92	11	777
	%	247.6%	67.8%	76.7%	89.1%	81.8%	97.2%
62E	Assigns	947	794	408	200	31	2,380
Dev. Eng.	Auths	427	1,177	532	257	37	2,430
	%	221.8%	67.5%	76.7%	77.8%	83.8%	97.9%
63A	Assigns	275	670	542	539	106	2,132
Acq. Mgt.	Auths	206	759	725	647	149	2,486
	%	133.5%	88.3%	74.8%	83.3%	71.1%	85.8%

SOURCE: Headquarters Air Force Personnel Center, Directorate of Assignments, January 2009.

requiring career fields is above the 96.1 percent total manning level for line officers. Assuming no change in authorizations, shortages of officers in these career fields could be corrected only by increasing overall officer strength in the Air Force or by imposing even greater shortages on other career fields.

Captain-to-Lieutenant Ratios

The ratio of assigned captains to lieutenants in the Air Force generally (see Table 3-1) is 2.1:1 (16,257 to 7,648) while the authorization ratio is 3.0:1 (17,899 to 5,948). Thus, the proportion of assigned captains (and therefore, of the more experienced level among company–grade officers) is less than desired by the authorization ratio. In the STEM-requiring career fields, as indicated in Table 3-3, the captain-to-lieutenant authorization ratios range from 2.4:1 to 6.8:1. Since these ratios, like those of most other career fields, are greater than the aggregate assigned strength ratio of 2.1:1, captain authorizations are very unlikely to be completely filled.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

TABLE 3-3 Captain-to-Lieutenant Ratios

		Lt.	Capt.	Ratio, Capt./Lt.
15W	Assigned.	129	187	1.4:1
Weather	Authorized	94	229	2.4:1
32E	Assigned.	326	339	1.0:1
Civil Eng.	Authorized	123	510	4.1:1
33S	Assigned.	686	1,109	1.6:1
Comm-info	Authorized	177	1,206	6.8:1
61S	Assigned.	260	249	1.0:1
Scientist	Authorized	105	367	3.5
62E	Assigned.	947	794	0.8:1
Dev. Eng.	Authorized	427	1,177	2.8:1
63A	Assigned.	275	670	2.4:1
Acq. Mgt.	Authorized	206	759	3.7:1

SOURCE: Headquarters Air Force Personnel Center, Directorate of Assignments, January 2009.

As indicated in Table 3-1, the average manning level for a line-officer career field is 128.6 percent for lieutenants and 90.8 percent for captains. All of the captain-to-lieutenant assigned strength ratios in the five STEM-requiring career fields are lower than the 2.1:1 Air Force average. Assuming a relatively level number of accessions from year to year, a career field with average retention would mirror this ratio. If the ratio is lower than 2.1:1, it is likely that the career field has experienced higher-than-normal attrition of captains, induced at least in part by the force reductions associated with Program Budget Decision 720.[1,2] In summary, the low manning levels for captains (compared to authorized numbers) in the 32E, 61S, and 62E career fields probably result from a combination of high attrition and nonsustainable authorized grade structures.

[1]A pattern of lower accessions followed by four years of higher accessions would also produce a lower-than-average ratio of captains to lieutenants. Since the Air Force generally accesses officers to a steady-state requirement, it is unlikely that such a pattern of accessions exists for the STEM career fields.

[2]Program Budget Decision 720, entitled "Air Force Transformation Flight Plan," was issued on December 28, 2005. by the Under Secretary of Defense (Comptroller). In it, the comptroller directed reductions in Air Force manpower from 2007 to 2011 totaling over 40,000 people, including active, Air National Guard, and Air Force Reserve civilian, officer, and enlisted personnel. Manpower reductions in specific career fields were not specified in the Program Budget Decision, but it was expected that the scientist, engineer, and acquisition manager career fields would experience significant reductions, as the budget decision reductions were allocated.

Copyright © National Academy of Sciences. All rights reserved.

Field-Grade Officer Manning

For the aggregate line-officer force, field-grade authorizations are 47.3 percent of total authorizations, while field-grade assigned strength is 45.1 percent of total (see Table 3-1). As indicated in Table 3-4, 15W and 32E field-grade authorizations are close to the line-officer aggregate figures, and their major, lieutenant colonel, and colonel manning levels indicated in Table 3-2 reflect this. In short, they are manned about as well as could be expected. The 33S career field has an above-average proportion of field-grade authorizations but a below-average proportion of field-grade officers assigned, consistent with the lower field-grade manning levels shown in Table 3-2. The 61S and 62E career fields have below-average proportions of field-grade authorizations but also have below-average proportions of field-grade strengths, probably reflecting some combination of low retention, low promotion rates, and migration of more experienced or tenured officers to the 63A career field. The shortage of field-grade assignments for the 63A Acquisition Management career field is discussed in Chapter 4.

TABLE 3-4 Field Grade as a Percentage of Total

		Field Grade	Total	Field grade, %
15W	Assigned	231	547	42.2%
Weather	Authorized	231	554	41.7%
32E	Assigned	476	1141	41.7%
Civ Eng	Authorized	493	1126	43.8%
33S	Assigned	1,157	2,952	39.2%
Comm-info	Authorized	1,396	2,779	50.2%
61S	Assigned	246	755	32.6%
Scientist	Authorized	305	777	39.3%
62E	Assigned	639	2,380	26.8%
Dev Eng	Authorized	826	2,430	34.0%
63A	Assigned	1,187	2,132	55.7%
Acq Mgt	Authorized	1,521	2,486	61.2%

SOURCE: Air Force Personnel Center, Directorate of Assignments

Career Path for Officer Scientists and Engineers

The Air Force has formally defined career paths for officers. Figures D-1 and D-2 in Appendix D show the career pyramids, which illustrate the formal career path, for officer scientists (61S) and engineers (62E). The pyramids appear to be identical to each other and differ from most other mission support officer career pyramids only at the company-grade officer level.

In practice, the committee believes that leadership opportunities for officers in these career fields would be somewhat limited, and therefore promotion rates to lieutenant colonel and colonel could tend to lag other career fields. This requires increased crossflow (or recoring) of these officers. The committee has been advised that the Acquisition Workforce Manager, SAF/AQXE, encourages significant crossflow of 62E officers into acquisition management (63A) positions.[3]

[3]Patrick Hogan, Director of Acquisition and Career Management (SAF/AQXD), briefing to the committee on December 3, 2008.

Copyright © National Academy of Sciences. All rights reserved.

Perceptions from the Air Force STEM Communities

In several presentations to the committee, representatives of various Air Force communities shared common concerns regarding the consequences of these manning conditions for officers in the five STEM-degree-requiring career fields.

- Manning in captain and field-grade ranks has been insufficient to meet authorizations.
- It has been difficult to retain technically qualified personnel, both military and civilians (as complementary components).
- There are gaps in the numbers of advanced STEM degrees and in the skill mixes degree holders need to have, both now and for anticipated future requirements.

In Appendix D, Figures D-3 to D-10, which were included in presentations from the Chief of the Force Management Division and the Headquarters Air Force Personnel Center, present additional perspectives on the current authorization structure and inventory for the five career fields that require a STEM degree and the Acquisition Management career field. The committee makes the following general observations based on the data presented in these charts:

- As shown in Figures D-3 through D-8, these six career fields except 33S share some sort of workforce "bathtub" for officers with 7 to 16 career years of service (CYOS). That is, in this range there are relatively fewer personnel at each year mark than in the years before and immediately after the low region. This window from roughly 7 to 16 years represents the time in officers' careers when their accumulated Air Force–wide and career-field experience and expertise are typically leveraged by the organization to obtain the greatest value. In addition, Air Force–wide levies on officer resources come into play during this interval, and the STEM-requiring career fields are expected to send mid- to senior-level captains and majors off to other duties (instruction, Reserved Officer Training Corps, recruiting, etc.). These levies accelerate the actual and perceived experience deficits in these career fields.
- As seen in Figures D-9 and D-10, both the 61S and 62E career fields absorbed significant drops in their authorizations (and consequently, their manning) from 2006 through 2008; this may be of concern because both career fields serve as feeders to the 63XX Acquisition Management career field.
- While the 61S career field absorbed significant drops in authorizations, as mentioned above, current and emerging mission requirements indicate a potential significant increase in requirements (both documented and undocumented) for scientists in the coming years.
- As indicated in Figure D-4, the 32E career field has demonstrated overmanning, in that assignments are consistently greater than authorizations. Extrapolations of contingency and deployment commitments, however, suggest real-world requirements that significantly exceed current assignments, further stressing the Civil Engineer officer workforce.

Conclusions on Officer Manning Issues

In summary, the committee believes there are captain and field-grade manning issues in the career fields that require a STEM degree. This judgment is based on the analyses above of assignments versus authorizations, captain-to-lieutenant ratios, and field-grade officer manning in these five career fields. The implications of the data analyses are supported by the perceptions of

Copyright © National Academy of Sciences. All rights reserved.

commanders and supervisors that their communities have insufficient personnel to perform the technically demanding aspects of jobs that require STEM capability.

Furthermore, efforts to redress these shortages and imbalances are hampered by the fact that field-grade authorizations in the aggregate line officer force are larger than permitted by legal constraints on assigned officer field-grade strengths and the fixed (by policy) phase point for promotion from lieutenant to captain. There are too few officers, and the experience distribution is too junior to provide the needed expertise. In addition, there are high demands on field-grade officers in the Scientist and Engineer career fields to deploy for ongoing and future contingency operations. The Air Force's manpower authorizations are inconsistent with both the total officer strength authorized for the Air Force and the grade structures established by law. Total strength is set in annual defense authorization acts. Field-grade strengths are set by law (originally promulgated as the Defense Officer Personnel Management Act) as a sliding-scale function of total officer strength. Officer promotions are managed so that actual field-grade strengths conform to these limits, but field-grade authorizations typically exceed these limits. As a result, overall field-grade manning is less than 100 percent. Similarly, total authorizations exceed allowable total strength, resulting in total manning less than 100 percent.

Despite recognition of the effects of these constraints on field grade manning in the career fields that require a STEM degree, improvements have not been easy to come by. Under the Air Force's Non-Rated Personnel Prioritization Plan, officer positions that are available to be filled are categorized as Must Fill, Priority, or Entitlement. The Must Fill and Priority categories are generally associated with joint-force assignments or assignments to the Combatant Commanders. The majority of positions in the product centers and test centers fall in the Entitlement category (see Figure D-11 in Appendix D). As reflected in Table 3-5, the respective manning percentages in the Scientist and Developmental Engineer career fields generally degraded between summer 2007 and summer 2008, exacerbating the manning imbalances discussed above. For example, the Non-Rated Prioritization Plan (NRPP) fill rate for lieutenant colonel engineers fell from 78 percent to 59 percent. For these STEM-degree-requiring fields and for the three acquisition-related career fields of Program Manager, Contracts, and Finance, the fill rates for captain, major, and lieutenant colonel positions are well below 100 percent, meaning there is an ongoing shortfall of experienced personnel in these positions. The fill rate for lieutenant colonel program managers fell from 42 percent to 31 percent, exacerbating manning issues discussed in Chapter 4.

TABLE 3-5. Entitlement Category Fill Rates for STEM-Degreed and Acquisition Career Fields under the Nonrated Prioritization Plan, Summer 2007 and Summer 2008[ab]

	Scientist[c]	Engineer[c]	Program Mgr.	Contracts	Finance
Lt Colonel	53%/50%	78%/59%	42%/31%	28%/22%	0%/13%
Major	68%/65%	79%/63%	66%/66%	35%/34%	39%/50%
Captain	34%/50%	58%/49%	77%/72%	66%/65%	39%/65%
Lieutenant	100%	100%	100%	100%	100%

[a]Fill rate percentages for 2007 and 2008 are shown as a 2007/2008 format.
[b]Fill rates are for the Entitlement category only. Must-Fill positions were filled 100 percent; Priority-category positions were 85 percent filled.
[c]Rate is for overall career field—fill rate may vary by discipline.
SOURCE: Patrick Hogan, Director of Acquisition and Career Management (SAF/AQXD), briefing to the committee on December 3, 2008.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

Captain manning is also generally problematic. Promotion from first lieutenant to captain is based on time in service (for line officers, four years). Thus, the ratio of captains to lieutenants is determined by the retention rate for captains (and the very limited attrition among lieutenants) and is unaffected by manpower authorizations.[4] The ratio of captains to lieutenants in manpower authorizations is greater than the ratio of captains to lieutenants in the officer population, resulting in persistent overmanning of lieutenant authorizations and undermanning of captain authorizations. Lieutenant and captain manning could be balanced by redistributing the grade authorizations, pumping up captain retention (e.g., by offering retention bonuses), or reducing the promotion phase point to less than four years.

CIVILIAN OCCUPATIONAL SERIES THAT CURRENTLY REQUIRE A STEM DEGREE

Table D-1 in Appendix D shows the distribution of the Air Force civil service workforce in the three occupational series that require a STEM degree: Engineering (0800), Physical Sciences (1300), and Mathematics (1500). These are all professional occupations requiring degrees corresponding to the series title. Personnel in these occupations are managed within three career programs, roughly paralleling the functional areas within which they are employed.

Aging of the Civilian Workforce in STEM Occupations

Figure 3-1 shows a bimodal distribution of experience (years of service) in the civilian workforce employed in occupations that require a STEM degree. Air Force civilians become eligible for retirement with full benefits after 20 years of service. The valley that extends from the 9th to the 19th year of service indicates that promotion to senior grades will, within the next ten years, begin to accelerate markedly for individuals in these year groups as the larger cohorts in the years just ahead of them begin to retire from their Air Force careers. For many civilians (and officers), retirement from the Air Force after 20 years is more of a job change than a full retirement from their working career; many go on to second careers in industry or academia.

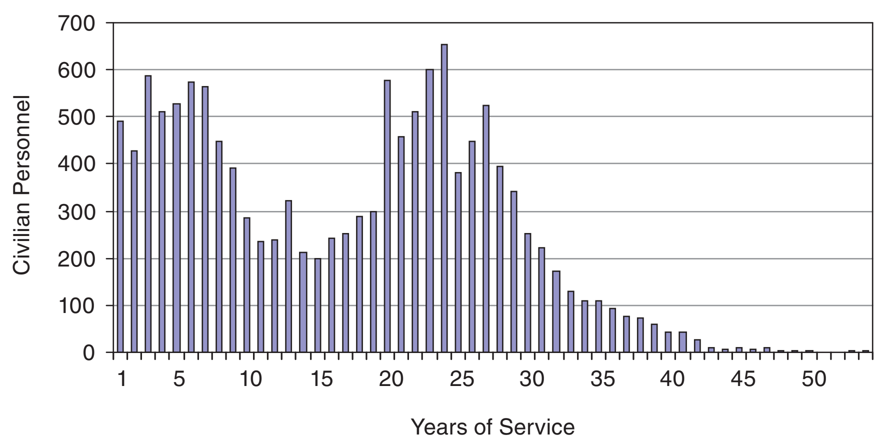


FIGURE 3-1 Civilian Workforce in Occupations Requiring a STEM Degree. SOURCE: AFPC Interactive Demographic Analysis System, December 2008.

[4]The length of technical training also affects this ratio for permanent party officer strengths. In the analysis below, the committee assumes permanent party strengths. Thus, the one STEM career field with lengthy technical training (33S—Communications and Information) would be expected to have a higher ratio than the other career fields.

Copyright © National Academy of Sciences. All rights reserved.

Civilian Scientist and Engineer Career Paths

The career management team for the civilian scientist and engineer career field envisions three career paths for its employees. The *technical expert* path is characterized by increasing depth in technical experience. Some on this path will progress to GS-14 or GS-15 civil service grades (or the equivalent National Security Personnel System [NSPS] band), and a few will reach the senior level (SL) or scientific and professional (ST) level. The *manager/leader* path concentrates on both technical expertise and technical management responsibilities. This path can lead to Senior Executive Service (SES) positions, although the preponderance of personnel on this path will peak at the GS-14 or GS-15 grade (or NSPS equivalent). The *senior leader* path grooms civilian employees for organizational leadership. Their assignments are expected to include career-broadening into areas such as program management. Most SES positions in scientist and engineering functions and organizations would be expected to be filled by individuals progressing through this path.[5]

The Civilian Technical Expert Path

Civilians may opt to continue on the technical expert path, leading to increased in-depth, technical experience. A few civilians on the technical expert path peak at the GS-14 or GS-15 grade level (or workforce project demonstration equivalent); even fewer make it to the SL or ST level.

Unlike the senior leaders and manager/leaders, the technical expert aspires to become an expert in a selected field recognized at the national or international level. Therefore, this path allows individuals to increase their technical expertise instead of moving into management. Technical experts tend to strive toward increasingly technical assignments, doctorates, and technical training rather than management and leadership assignments.

The Civilian Manager/Leader Path (to SES level)

Those who select the manager/leader path will concentrate on both technical expertise and technical management responsibilities. The scientist or engineer will be recognized as a technical expert in at least one discipline but will also accrue management experience through supervisory positions. Progression on this path, with its blend of technical expertise and management skills, can lead to SES positions, although the preponderance of those on the path will peak at the GS-14 or GS-15 (or workforce project demonstration equivalent).

The Civilian Senior Leader Path (to SES level)

The senior leader path is for scientists and engineers who choose to balance technical depth with breadth of alternative functional experience. Through communications and interactions with other career fields, organizational disciplines, and Air Force operations, the senior leader

[5]The Department of Defense has announced the establishment of the National Security Personnel System Transition Office and the selection of John H. James Jr. as its director. He will report to the Deputy Under Secretary of Defense for Civilian Personnel Policy and will lead the NSPS Transition Office in managing the development of the plan to transition employees from the NSPS to non-NSPS systems. The fiscal 2010 National Defense Authorization Act, Public Law 111-84, repealed authorities for the NSPS and mandated the transition of NSPS employees to appropriate non-NSPS civilian personnel systems. The NSPS Transition Office will oversee the design and implementation of an enterprise-wide performance management system, hiring flexibilities, and a DoD Workforce Incentive Fund, authorities for which were granted to the Secretary of Defense under the 2010 National Defense Authorization Act. (News Release, Public Affairs Office, Office of the Secretary of Defense, January 20, 2010).

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

becomes more of a strategist than a technical expert. Technical grounding, management experience, and leadership skills allow senior leaders to make the critical decisions that define organizational vision and focus.

LEADERSHIP ASSESSMENT OF CURRENT WORKFORCE ADEQUACY

This section conveys the main points in presentations to the committee from representatives of functional activities across the Air Force on the posture and status of the officer and civilian workforce in positions that require a STEM degree.

Air Force Personnel Center

From the Air Force Personnel Center (AFPC) perspective,[6] while the majority of the five career fields that require a STEM degree appear relatively healthy in the aggregate, there are shortages at the captain level. Electrical engineers understandably remain in high demand, especially in light of the computerization and information technology enablers to myriad processes and programs, with positions in the 32E, 33S, and 62E career fields all competing for quality technically based candidates in the pool of eligible accessions. The data presented show a specific shortage of electrical engineers in these three career fields. Further, the shortage at the captain level is accelerated by the current high operational tempo, especially within the 32E community, which raises retention concerns.

Air Force Space Command

Speaking from an operational perspective, the Air Force Space Command (AFSPC) representative expressed concerns about the adequacy of the workforce in positions requiring or desiring a STEM degree. [7] He pointed out that significant numbers of Air Force Specialty codes (AFSCs) within the space community require or desire STEM degrees. For example, the 13S (Space and Missile career field), 14N (Intelligence), and 15W AFSCs all *desire* a STEM-related degree as an accession requirement but do not require it, while 32E, 33S, 61S, and 62E AFSCs all *require* a STEM-related degree. Specifically, the command has 1,923 13S requirements, of which only 102 have any degree-related requirements. Further, to meet its needs, AFSPC seeks to use extensive crossflow from 61S and 62E to 63A (acquisition program manager) duties because it considers technical and scientific experience and background necessary to succeed in the program management role. However, the AFSPC representative emphasized that the majority of the billets do not specify education requirements (e.g., a specific degree or level).

Given AFSPC's assessment of its own STEM-related requirements, the representative offered the opinion that the Air Force may be paying too much for technical expertise because of how it is procured. He believes that requisite technical expertise has migrated to the private sector and that, because of its unique and highly technical nature, it is extremely expensive to acquire by contract. AFSPC Headquarters employs contract personnel at a cost of $55 million, and the amount is growing. Contract costs are running at $250,000 per full-time equivalent and higher. The AFSPC representative suggested, as did the Air Force Materiel Command representative (see

[6]Col Stan Perrin, Air Force Personnel Center, Director of Assignments, briefing to the committee on October 29, 2008.

[7]Doug Bell, Deputy Director, Manpower, Personnel, and Services, AFSPC, briefing to the committee on September 30, 2008.

Copyright © National Academy of Sciences. All rights reserved.

Chapter 4), that more technical expertise be brought back in–house—that is, the Air Force should increase the organic officer and/or civilian workforce with the requisite technical expertise.

Additional Perspectives from Senior Leaders and Managers

A representative[8] of the Air Force's scientist and engineer career field manager indicated that the Air Force faces the following broad problems in managing the workforce in positions requiring a STEM degree:

- STEM is not defined.
- STEM is not managed across the Air Force.
- Needs and effects are not characterized or understood within each of the 26 career fields.
- There is no clear Air Force STEM advocate (candidates are the Science and Engineering Functional Manager (SAF/AQR), Air Force Chief Scientist, Air Force Research Laboratory Commander (AFRL/CC), or others).

The concerns of the scientist and engineer career field manager include:

- captain and field-grade manning
- retention (military and civilian)
- advanced degrees (enough, the right mix, future requirements)
- civilian development into senior leadership
- Science and engineering role in the global war on terror
- STEM role, requirements and responsibilities.

The **Chief of the Air Force Force Management Division** (AF/A1PF) accessed overall manning, personnel tempo, and retention conditions in the five officer career fields that require a STEM degree.[9] He noted some personnel tempo issues but found no significant manning or retention issues. AF/A1PF did not access grade manning, as some other briefers did. However, in his presentation, he drew attention to the relative undermanning of captains and overmanning of lieutenants that is typical of many Air Force officer career fields.

The **Director of Assignments at the Air Force Personnel Center** (AFPC/DPA)[10] described manning gaps in selected AFSCs and grades:

- captains in AFSC 61S-A—operations research
- majors in AFSC 61S-B—quantitative psychology
- captains in AFSC 61S-D—physics, nuclear engineering, systems engineering.

[8]Col. James Fisher, Chief, Engineering and Technical Management Division, SAF/AQRE, briefings to the committee on August 26, 2008, The formally designated Science and Engineering Career Field Manager is SAF/AQR, the Deputy Assistant Secretary of the Air Force for Science, Technology, and Engineering.

[9]John Park, Chief, Force Management Division, Headquarters U.S. Air Force, briefing to the committee on October 30, 2008.

[10]Col. Stan Perrin, Director of Assignments, Headquarters Air Force Personnel Center, briefing to the committee on October 29, 2008

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

He noted that captain manning is generally low in most AFSCs, offset by high lieutenant manning. He also noted the heavy flow of field-grade officers from the 62E to the 63A career field.

The Air Force Director for Studies and Analyses, Assessments and Lessons Learned (AF/A9),[11] who serves as the career field manager for analysts in the Air Force, noted no manning gaps other than the familiar captain-lieutenant imbalance. Among other topics, she discussed the effects of the Program Budget Decision 720 force reduction on the analyst workforce, as well as the role that AF/A9's value model played in distributing the required reduction across officer career fields.

FINDINGS

Finding 3-1. In some cases, the grade structures in officer career fields that require a STEM degree are not sustainable under the current legal and policy constraints. Additionally, in some cases, career fields requiring a STEM degree may have experienced below-average retention or promotion rates.

Finding 3-2. The workforce years-of-service profile (shown in Figure 3-1) indicates that a large proportion of the civilian STEM-degreed workforce will become eligible for retirement within the next 15 years.

Finding 3-3. Fill rates for field-grade officers in the Scientist and Developmental Engineer career fields, in the Acquisition Management career field, and in other career fields important to the acquisition life cycle, while responsive to the Air Force's Non-Rated Personnel Prioritization Plan, are well below 100 percent, which perpetuates the manning shortfalls in these career fields.

The committee's recommendations related to these findings and to the issues discussed in this chapter are in Chapter 6.

[11] Jacqueline Henningsen, Director for Studies and Analyses, Assessments and Lessons Learned, Headquarters U.S. Air Force, briefing to the committee on December 3, 2008.

Copyright © National Academy of Sciences. All rights reserved.

4

STEM Personnel in the Acquisition Workforce

In Chapter 2, the committee reviewed the contributions made by STEM-degreed and STEM-cognizant personnel, both military and civilian, to the entire acquisition life cycle. As noted there, the operational commands play crucial roles in many phases of this life cycle, in addition to the essential roles played by the acquisition workforce per se. This chapter focuses on the officers and civilians with STEM capabilities who are considered part of the acquisition workforce. Many STEM-degreed officers and civilians in positions requiring a STEM degree (the focus of Chapter 3) are in the acquisition workforce. However, as Chapter 2 noted (see Figures 2-2 and 2-3), STEM-degreed officers and civilians are also in many acquisition positions that do not require a STEM degree. In addition, the acquisition workforce includes substantial numbers of both officers and civilians who are STEM-cognizant but not STEM-degreed. All these components of STEM capability are included in the scope of this chapter, although most of the hard data are limited to STEM-degreed personnel.

DEFINING THE ACQUISITION WORKFORCE

The civilian acquisition workforce can be defined as the personnel who are managed within the Acquisition Professional Development Program (APDP). The military acquisition workforce is less easy to define because many acquisition positions are in AFSCs outside the Acquisition Management (63A) career field, which includes military program managers who come under the APDP. In particular, many 61A (Scientist) and 62E (Developmental Engineer) positions are part of the acquisition workforce.

The Air Force Director of Acquisition and Career Management (DACM),[1] who is the Air Force's acquisition workforce manager, provided the data in Table 4-1 for fiscal year (FY) 2008, noting that the Air Force acquisition workforce is considerably smaller than those of other services. A search of the Air Force Personnel Center's Interactive Demographic Analysis System in December 2008 found 5,606 civilian personnel in the occupational series that require a STEM degree,[2] or 35 percent of the civilian acquisition workforce of 16,080 shown in Table 4-1. This percentage represents a lower bound on the STEM-degreed civilians in the acquisition workforce because, as noted in Chapter 2, some employees in other occupational series have STEM degrees.

[1]Patrick Hogan, Director of Acquisition and Career Management (SAF/AQXD), briefing to the committee on December 3, 2008.

[2]Results of this database search are shown in Table D-2, Appendix D.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

Table 4-1 Service Acquisition Workforce Numbers at End of FY 2008

	Civilians	Military	Total	Workforce fraction
Air Force	16,080	8,762	24,842	19.7%
Army	43,553	1,519	45,072	35.7%
Navy	36,467	4,218	40,685	32.2%
Other DoD	15,763	n/a	15,763	12.5%

THE ACQUISITION CORPS AND THE DEFENSE ACQUISITION WORKFORCE IMPROVEMENT ACT

The Acquisition Corps is intended to be a pool of highly qualified members of the acquisition workforce who are able to fill critical acquisition positions (CAPs). These individuals have met the grade, education, training, and experience standards prescribed by the Defense Acquisition Workforce Improvement Act (DAWIA) and the implementing regulations promulgated by the Office of the Secretary of Defense (OSD). They are admitted to the Acquisition Corps by the Service's designated Director of Acquisition Career Management, which for the Air Force is SAF/AQXD (USAF, 2008, pg. 20).

It is essential that the Air Force have a fully trained and qualified Acquisition Corps able to manage programs to deliver the complex warfighting systems needed to protect the nation. These programs must meet requirements and be completed on time and within budget. Congress passed the DAWIA to ensure that all the military Services had a fully trained and experienced acquisition workforce to competently acquire the complex war fighting equipment needed for national security. DAWIA covers several career fields beyond Program Manager (63A for officers) and includes positions for scientists and developmental engineers (61S and 62E, for officers).

The qualifications of the military officers selected for the Acquisition Corps are expected to be sufficiently high that *the promotion rate for this group should, on average, match* the rate for all Air Force line officers. This statutory requirement does not mean that members of the Acquisition Corps will be given special treatment but rather that the quality of their records must meet or exceed that of other line officers (USAF, 2008, pg. 20).

In addition to meeting all other Acquisition Corps requirements, new entrants must have achieved the rank of lieutenant colonel (select), GS-14 (or NSPS pay band equivalent), NSPS pay band 3, or above. Supervisory NSPS[3] pay band 2 personnel who meet Acquisition Corps requirements and are selected for assignment to a CAP will automatically be admitted to the corps. These individuals are eligible for Acquisition Corps membership after they have reached Level II APDP certification in any functional discipline (including acquisition management), accumulated four years of acquisition experience, and met all educational requirements.

Civilians assigned to GS-13 (or pay band equivalent) and above APDP coded positions must request a review and update for Acquisition Corps data elements once they have met eligibility requirements to enter the Acquisition Corps at the proper level.

[3]For more information see in Chapter 3 footnote 5 on NSPS.

Copyright © National Academy of Sciences. All rights reserved.

DAWIA Implementation Through the APDP

DAWIA was signed into law in November 1990 and updated in 2004. It requires the Secretary of Defense, acting through the Undersecretary of Defense for Acquisition, Technology and Logistics, to establish education and training standards, requirements, and courses for both the military and civilian members of the acquisition workforce.

The Defense AT&L Workforce Education, Training, and Career Development Program has implemented the objectives of DAWIA across the DoD components, mandated certification requirements for acquisition management positions, and established statutorily mandated assignment-specific education, training, and experience requirements for program managers, deputy program managers, and program executive officers. In the Air Force, DAWIA is implemented through the APDP. The Air Force APDP certification process reflects the education, training, and duty experience needed by the acquisition, technology, and logistics career fields through formal programs (USAF, 2008, pg. 19).

DAWIA and APDP Educational Requirements for the Acquisition Corps

Air Force implementation of DAWIA requires that members of the Acquisition Corps have baccalaureate degrees (*but does not specify that they must be STEM degrees*) in order to become an Acquisition Corps member (USAF, 2008, pg. 21). DAWIA specifies 24 semester credit hours (or the equivalent) from among the following disciplines: accounting, business finance, law, contracts, purchasing, economics, industrial management, marketing, organization and management, and quantitative methods.[4] An alternative is "24 semester credit hours (or the equivalent) in the person's acquisition career field and 12 semester hours from among accounting, business finance, law, contracts, purchasing, economics, industrial management, marketing, organization and management, and quantitative methods" (USAF, 2008, pg. 21).

Although specific educational requirements in STEM disciplines are not listed at the baccalaureate level, present OSD policy states that, for individuals serving in program management capacities at Level II, a master's degree is *desirable*, *preferably* with a major in engineering, systems management, business administration, or a related field (USAF, 2008, pg. 21, emphasis added).[5] However, DAWIA does require that program executive officers, program directors, and deputy program directors of major defense programs and significant nonmajor programs complete the Defense System Management College's program management course. DAWIA further directs that general officers in a CAP have 10 years of acquisition experience

APDP Level I Certification

APDP Level I certification in program management is granted after completion of mandatory training and accrual of one year of acquisition experience. In the Air Force, typical entry level (years 1–3) grades are GS-7/9/11 (or pay band equivalent) for civilians and O1/O2 for officers. However, a substantial number of civilians and officers with more seniority cross over to program management from other Air Force occupational series and specialties or from outside the Air Force, some with more acquisition experience (USAF, 2008, pg. 19). In the U.S. military services other than the Air Force, the vast majority of acquisition officers transfer into program management from a variety of operational or support backgrounds at O3/O4 levels.

[4]U.S. Air Force Academy graduates meet these criteria by completing the core educational curriculum.

[5]Acquisition Managers (63AX – 1101) Career Field Education and Training Plan, CFETP 63AX & 1101, Parts I and II, 2008 Edition, March 17, 2008, Department of the Air Force, Headquarters US Air Force, Washington DC 20330-1030, p. 21. .

Copyright © National Academy of Sciences. All rights reserved.

Initial acquisition management assignments should establish and build depth of knowledge and technical expertise within the career field. Commanders/supervisors are directed to provide ample opportunities to gain this experience while exposing new acquisition managers to the entire mission of the unit. Unit training tasks are focused on acquiring knowledge and beginning to demonstrate competency in a host of acquisition and program management areas. The Acquisition Managers (63AX–1101) Career Field Education and Training Program states that individuals should complete the initial assignment core requirements within their first acquisition assignment or 36 months (USAF, 2008, pg. 19).

APDP Level II Certification

APDP Level II certification in program management is granted after completion of mandatory training and accrual of two years of acquisition experience, at least one of which is in program management. At this intermediate level (years of service 4–10**),** acquisition managers should seek to gain additional depth in their field but may also begin to broaden their breadth of knowledge, experience, and expertise. Career-broadening opportunities should be considered to increase an acquisition manager's overall professional development and career progression through assignments in operational exchange tours (e.g., space, intelligence, maintenance) or related acquisition functional fields (e.g., test, systems engineering, financial management, contracting, logistics).

Opportunities are also given each year to officers and civilians for the Education with Industry program, a 10-month competitively selected nondegree program with industry-leading companies. In some cases, an acquisition manager may be placed in an operational capacity as a first assignment. Supervisors have input into whether additional career broadening is right. Two out of the first three assignments normally should be acquisition management assignments. Back-to-back career broadening assignments are strongly discouraged due to loss of currency and expertise (USAF, 2008, pp. 19–20).

APDP Level III Certification

APDP Level III certification in program management is granted after completion of mandatory training and accrual of four years of acquisition experience, two of which are in a program office and one in a position with cost, schedule, and performance responsibilities. At this level (beyond 10 years of acquisition experience), the acquisition manager is encouraged to continue broadening expertise through leadership and staff assignments. For CAPs available to lieutenant colonels or pay band 2 (or GS-14) civilians and above, there are additional statutory requirements in order to manage Acquisition Category (ACAT) I/II programs (USAF, 2008, pg. 19).

Acquisition Management Career Path and Training Flow

The Acquisition Managers (63AX–1101) Career Field Education and Training Plan outlines career path opportunities for acquisition managers and indicates when training is required for career progression within this specialty (see Figure D-12 in Appendix D). The plan also includes an extensive checklist of training requirements (USAF, 2008, pp. 24, 33–40).

Officer Manning Issues in the Acquisition Workforce

This section extends the discussion of manning issues, begun in Chapter 3, from the five officer career fields that require a STEM degree to the acquisition workforce. A key difference is

Copyright © National Academy of Sciences. All rights reserved.

that, as detailed in the preceding sections, the APDP certification levels do not require a STEM degree, although OSD policy includes a preference for a program manager's required baccalaureate degree to have "a major in engineering, systems management, business administration or a related field" (USAF, 2008, 21). Thus, an open question, which the committee addresses in Chapter 6, is whether some manning shortages of STEM capability in the acquisition workforce could be met by formal consideration of STEM cognizance as a position requirement or preference, in addition to evaluating which positions should require (or state a strong preference for) a STEM degree.

The discussion here includes the 61S Scientist and 62E Developmental Engineer career fields, as well as the 63A Acquisition Management field, for two reasons. First, as discussed at length in Chapter 2, a great many 61S and 62E officers have positions in the acquisition workforce, and the technical fields reflected in their STEM degrees are essential to the activities in the acquisition life cycle. Second, there is considerable crossflow from the 61S and 62E career fields into 63A, which helps in meeting 63A authorizations for field-grade officers but appears to exacerbate the shortages in the 61S and 62E grades from captain and above. The data on 61S, 62E, and 63A authorizations and assignments presented in this section are the same as in Tables 3-3 and 3-4. They are restated here for ease in following the committee's analyses.

Manning Ratio Issues

Table 4-2 contains the data on captain-to-lieutenant ratios from Table 3-3 for just the Scientist, Developmental Engineer, and Acquisition Management career fields. Whereas the assigned captain-to-lieutenant ratios for 61 S and 62E, at 1.0:1 and 0.8:1, are substantially less than the 2.1:1 average for Air Force line officers in aggregate (calculated from Table 3-1), the ratio for the 63A career field is just above the average at 2.4:1.

TABLE 4-2 Captain-to-Lieutenant Ratios, Scientist, Developmental Engineer, and Acquisition Management Career Fields

		Lt.	Capt.	Ratio, Capt./Lt.
61S	Assigned	260	249	1.0:1
Scientist	Authorized	105	367	3.5
62E	Assigned	947	794	0.8:1
Dev. Eng.	Authorized	427	1,177	2.8:1
63A	Assigned	275	670	2.4:1
Acq. Mgt.	Authorized	206	759	3.7:1

SOURCE: Air Force Personnel Center, Directorate of Assignments.

Table 4-3 contains the data on field-grade-to-total officer ratios from Table 3-4 for these three key career fields in the acquisition workforce. As noted in Chapter 3, the 61S and 62E career fields have below-average proportions of field-grade strengths, as well as below-average proportions of field-grade authorizations. Their below-average field grade strength probably reflects some combination of low retention, low promotion rates, or migration of more experienced and/or tenured officers to the 63A career field. The 63A career field, by contrast, has

Copyright © National Academy of Sciences. All rights reserved.

a high proportion of its assigned strength (55.7 percent) in the field grades. However, it also has a very high proportion of field-grade authorizations (61.2 percent), resulting in below-average field-grade manning because of the disconnect between the "required" strength and the available qualified inventory. Due to inadequate promotion rates from the company grades and/or migration to other AFSCs, sustainment of field-grade 63A officers has required migration from other career fields. It has benefited from high retention, better promotion rates, and/or crossflow from other career fields.

TABLE 4-3 Field Grade as a Percentage of Total Officer Strength

		Field Grade	Total	Field Grade, %
61S	Assigned	246	755	32.6%
Scientist	Authorized	305	777	39.3%
62E	Assigned	639	2,380	26.8%
Dev. Eng.	Authorized	826	2,430	34.0%
63A	Assigned	1,187	2,132	55.7%
Acq. Mgt.	Authorized	1,521	2,486	61.2%

SOURCE: Air Force Personnel Center, Directorate of Assignments

Senior Officer Preparation for Acquisition Leadership

In the Air Force Materiel Command (AFMC), Air Force Space Command (AFSPC) and Air Force Acquisition (SAF/AQ), general officers are sometimes assigned to important acquisition positions not designated as CAPs. Some of these individuals must be granted waivers from DAWIA requirements, but despite their lack of experience, they have far-reaching influence over the Acquisition Corps and over the acquisition process. Moreover, experience criteria for other leadership positions within the Air Force acquisition community are often waived.

The central purpose of DAWIA is to ensure that major acquisition programs are managed by experienced personnel. Thus, granting such waivers runs counter to the basic intent of the legislation. The committee concluded that waivers could be decreased by creating a larger pool of trained and experienced senior leaders and by providing earlier identification of potential candidates to allow pipeline training that would better fit with DAWIA and APDP intent.

CONTRACT LABOR FOR SYSTEM ENGINEERING, TECHNICAL ASSISTANCE, AND FFRDC SUPPORT

One of the recurring themes the committee heard from multiple Air Force leaders interviewed for this study was that the balance between organic workforce capabilities and contractors has tilted too far toward the latter. These leaders perceive this tilt as leading to an undesirable atrophy of necessary in-house technical skills. As one commander described it, insufficient in-house technical expertise makes the Air Force a "blind" buyer in the acquisition arena. He stressed that technical knowledge is key to understanding system limitations, defects, and lack of robustness in a planned operating environment. Technical knowledge of the system and broad experience is critical to challenging overly optimistic program assumptions. Two

Copyright © National Academy of Sciences. All rights reserved.

examples presented during the Air Force Flight Test Center (AFFTC) presentation[6] underscore this point:

Contractor personnel proposed testing the Global Air Traffic Management (GATM) system only in Texas. However, because of their experience, the government engineers on the project were concerned about the risks of such limited testing. Their concerns led to an alternative integrated test in GATM airspace that resulted in the development of more than 40 changes, many of which addressed interoperability deficiencies. Following the contractor proposal might have meant denial of the ability to operate in GATM airspace, which would have severe negative effects critical to warfighter support.

In the second instance cited by the AFFTC Commander, the contractor proposed a software upgrade to a fighter weapon system via a software change to the heads-up display. The contractor validated the software upgrade in a systems integration lab. Air Force engineers conducted an independent analysis in the AFFTC's Integrated Facility for Avionics Systems Test. This test revealed a host of errors, turning the proposed upgrade into a flight-safety issue requiring modification before the upgrade could be installed on the weapon system. The government engineers' action reduced the risk of an air-to-ground mishap.

From the AFFTC perspective, one overriding concern is the growing dependence on contractors for executing core mission requirements and longer-term sustainment functions. The AFFTC leadership also clearly perceives a direct connection between early identification of design and technology shortfalls in development programs, rigorous test and evaluation processes, and the government's inherent interest in early and effective discovery. AFFTC's leaders believe this early identification can yield cost avoidance factors as high as a 30-to-1 ratio (Figure D-13 in Appendix D). In their experience, the earlier any problems in design or technology are discovered and addressed, the less the changes cost over the long run. Accordingly, they believe a technically qualified organic workforce is vital in this discovery process.

The AFFTC commander stated that the test center has a good balance of civilian scientists and engineers in both numbers and education levels. He sees three major challenges: (1) building experience in development, test, and evaluation planning through repeated practice; (2) convincing Air Force customers of the value of government weapon system evaluations; and (3) recruiting, hiring, and developing the workforce. In the third challenge, the issues are in transferring knowledge skills, the lengthy delays in the hiring process, and the remote work location of the test center in an area with a high cost of living.

Another concern expressed by leaders in the acquisition community about the growth of the contractor workforce was the cost of the contracts themselves and the permanence of those costs. For example, an AFSPC representative stated that his center spends $55 million annually (and growing) on contract personnel, excluding federally funded research and development centers (FFRDCs), with the cost of contract labor averaging $250,000 for each full-time equivalent.[7] The contractor workforce is used to address workload increases. Within the Space and Missile Systems Center (SMC), 33 percent of acquisition resources are FFRDC; system engineering and technical assistance accounts for 15 percent; military, 25 percent; and civilian, 27 percent.[8] According to the presenter, the SMC needs approximately 300 additional organic personnel, evenly split between military officers and civilians, to support the center's known acquisition

[6]Maj Gen David J. Eichhorn, Commander, Air Force Flight Test Center, Edwards Air Force Base, briefing to the committee on December 3, 2008.

[7]Douglas Bell, Deputy Director, Manpower, Personnel, and Services, AFSPC, briefing to the committee on September 30, 2008.

[8]Pat Robey, Director, Manpower and Personnel, SMC, briefing to the committee on September 30, 2008.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

requirements.[9] Given the nature of the SMC's mission, a large portion of the additional personnel would need to be STEM-degreed.

Other AFMC activities reported the need for more personnel, including personnel with STEM capabilities. The Electronic Systems Center (ESC) estimates an authorized-to-assigned labor shortfall of 924 people, of which the contractor shortfall is 376 full-time equivalents (see Figure D-14 in Appendix D).[10] Contracted advisory and assistance services (from Jacobs Corp) and FFRDC support (from MITRE) make up 70 percent (evenly split between advisory and assistance services and FFRDC) of the ESC workforce. From the ESC commander's perspective, the key to optimizing the engineering team lies in clarity of roles between the various components of the workforce in their respective workforce components.

Voicing similar concerns, the commander of the Arnold Engineering and Development Center (AEDC), stated that AEDC's overall mix and numbers are adequate for today's mission but the government workforce is at an absolute minimum. Providing adequate oversight challenges its ability.[11] He shares the concern about the technical skill balance between its organic and much larger contractor workforce and told the committee that a stronger organic technical staff provides more-effective contractor oversight and makes AEDC a "smart buyer" when procuring contract services. This assessment was based on his observations of declining experience within the in-house workforce, with insufficient technical knowledge among the remaining civilian scientists and engineers. Figure D-15 in Appendix D presents an AEDC perspective on how technical excellence has been lost because of changes in the nature of the mission. Figure D-16 in Appendix D makes the argument that, over the years, there have been fewer opportunities to hone the technical skills of civilian scientists and engineers because the test base has gotten smaller. The AEDC commander added that these technical experts have also had to spend more time on program and contract management. Furthermore, thrusting new hires directly into program and contract management erodes their technical abilities by denying them a period of "apprenticeship," which should last perhaps five years. The AEDC commander believes three changes are needed: rebuild technical excellence (help build "smart buyers"), utilize their science and engineering talent better, and find new sources for this STEM talent (government and contractor).

ADDITIONAL LEADERSHIP ASSESSMENTS OF CURRENT ACQUISITION WORKFORCE ADEQUACY

The previous section summarized perspectives provided to the committee by leaders in the acquisition community who spoke specifically on the balance of military and in-house civilian scientists and engineers with contracted STEM support. This section summarizes key points from these and other leaders in the acquisition community concerning the general level of adequacy of STEM capability in the acquisition workforce. The committee carefully considered and evaluated these leadership perspectives in arriving at the findings and recommendations presented at the end of this chapter and in Chapter 6.

An Overview from the Director of Acquisition and Career Management

During the briefing in which the acquisition workforce statistics in Table 4-1 were presented to the committee, the DACM noted shortages in captain and field-grade officers as manning

[9]Note added in proof: The SMC need for 300 additional people was accomplished in CY2010.

[10]Lt. Gen. Ted F. Bowlds, Commander, Electronic Systems Center, AFMC, briefing to the committee on October 30, 2008.

[11]Col. Art Huber, Commander, AEDC, briefing to the committee on December 3, 2008.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

issues for the 62E and 63A officer career fields.[12] He also noted that the civilian workforce is not entirely able to compensate for these shortages, since there are a large number of open civilian positions. This contributes to shortages in STEM capability in the civilian component of the acquisition workforce and highlights the need to accelerate and/or improve hiring processes.

The DACM pointed out that, just as the flow of officers from the 62E to the 63A career field is beneficial to acquisition program management, he would like to see a similar flow of civil servants from engineering to higher-grade positions in the program management occupational series. However, it is difficult to convince engineers to make the move because the program management positions are filled using an occupational series that does not require a STEM degree, which many engineers consider a step down in status. The Air Force has led efforts to set defined certification requirements for the program management occupational series and fill such positions in accordance with the requirements. However, for several reasons, it has encountered resistance from the other Services. The reasons, he suggested, include competition for key technical talent, perceived grade creep, and the anticipation of other possible workforce inequities between the Services. The issue of grade creep arises because many acquisition positions require a higher grade than other line career fields. Workforce inequities among the Services arise because the Services have implemented DAWIA and the Goldwater-Nichols Act in different ways. In some of the Services, acquisition fields are rotational assignments that require little specific experience.

The DACM noted an ongoing effort to recore (i.e., change their permanent career field, as opposed to a duty assignment) many military engineers (62Es) into the acquisition management (63A) career field. He saw the need for a better definition of future scientist and engineer requirements, by discipline, in both the military and civilian workforces. He believes the Air Force needs a reliable and credible predictive manpower model for sizing acquisition staffs, mentioned past efforts to develop such a model, and indicated that the Air Force Manpower Agency is working to develop such a model. He noted that he would like to increase the proportion of project managers with technical degrees. An appropriate benchmark, in his opinion, would be about 50 percent of field-grade officers with technical degrees.

Headquarters AFMC

From the headquarters perspective,[13] AFMC recognizes that it is home to large numbers of requirements for which STEM capability is needed. Accordingly, it has developed a deliberate approach and methodology, reflected in Figure 4-1, as to where AFMC leaders envision placement and utilization of STEM-related specialties.

In applying this approach, and in recognizing the heavy concentration of civilian employees in its workforce, AFMC sees a potential shortfall in seasoned STEM-degreed workforce at the mid-senior level (Figure D-17 in Appendix D). These are the technically competent and experienced technical leaders who provide the oversight and management of key processes and programs, while also providing the mentoring and guidance perspective for the next generations of technical personnel.

[12] Patrick Hogan, Director of Acquisition and Career Management (SAF/AQXD), briefing to the committee on December 3, 2008.

[13] Jon Ogg, Headquarters AFMC, Engineering, briefing to the committee on August 27, 2008.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

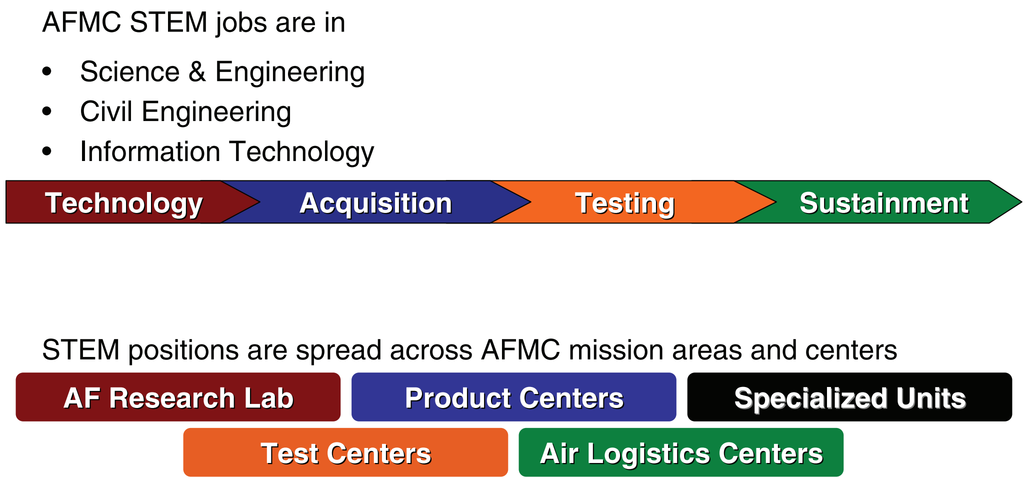


FIGURE 4-1 AFMC Approach to STEM Placement and Utilization. SOURCE: Jon Ogg, Headquarters AFMC, Engineering, briefing to the committee on August 27, 2008.

This shortfall in the more senior civilian cadre becomes of more concern, the AFMC presenter said, when compared to the comparable grades and structure in the military workforce. As Figure D-18 in Appendix D shows, the STEM-degreed military workforce shares a similar deficit in the more experienced, more senior field grades (major to colonel), with significant manning shortfalls present from the grade of captain up. The large numbers of lieutenants and accessions are the only available backfills to lessen these shortfalls. Consequently, the military and civilian STEM-degreed workforces do not have the capability to offset each other's manning and experience shortfalls.

Besides the relative dearth in the more senior civilian cadre, AFMC tracks the retirement-eligible population. As shown in Figure 4-2, AFMC has a potential bow wave of STEM-degreed civilians approaching retirement-eligible age in 6 to 15 years. This high proportion of personnel in older cohorts of the civilian STEM-degreed workforce is of even more concern given the "bathtub" (relatively smaller cohorts) that immediately follows.

AFMC Product Centers

The representatives from the AFMC product centers who were interviewed by the committee shared similar concerns. According to the commander of the Aeronautical Systems Center (ASC), his center uses multiple indicators to access the adequacy of the workforce, both in terms of quantity and skills type.[14] He recognizes that merely measuring overall manning is not sufficient, as he envisions a significant long-term drawdown caused by decreased manpower allocations and/or funding availability. In support of this perspective, he observed that ASC's STEM workforce has decreased by approximately two-thirds over the past 16 years, while the acquisition dollars at ASC have increased by about two-thirds in the same period (in inflation-adjusted dollars). As further evidence of this continuing decrease in STEM workforce, ASC has concluded that the increased number of support contractors to provide STEM capability means that ASC lacks sufficient organic STEM-degreed (or STEM-cognizant) workforce to perform

[14]Lt. Gen. John L. Hudson, Commander, ASC, AFMC, briefing to the committee during videoteleconference on October 30, 2008.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

current and future mission requirements. The number of contractors has increased almost 200 percent; they now comprise 15-20 percent of the ASC workforce with STEM degrees.

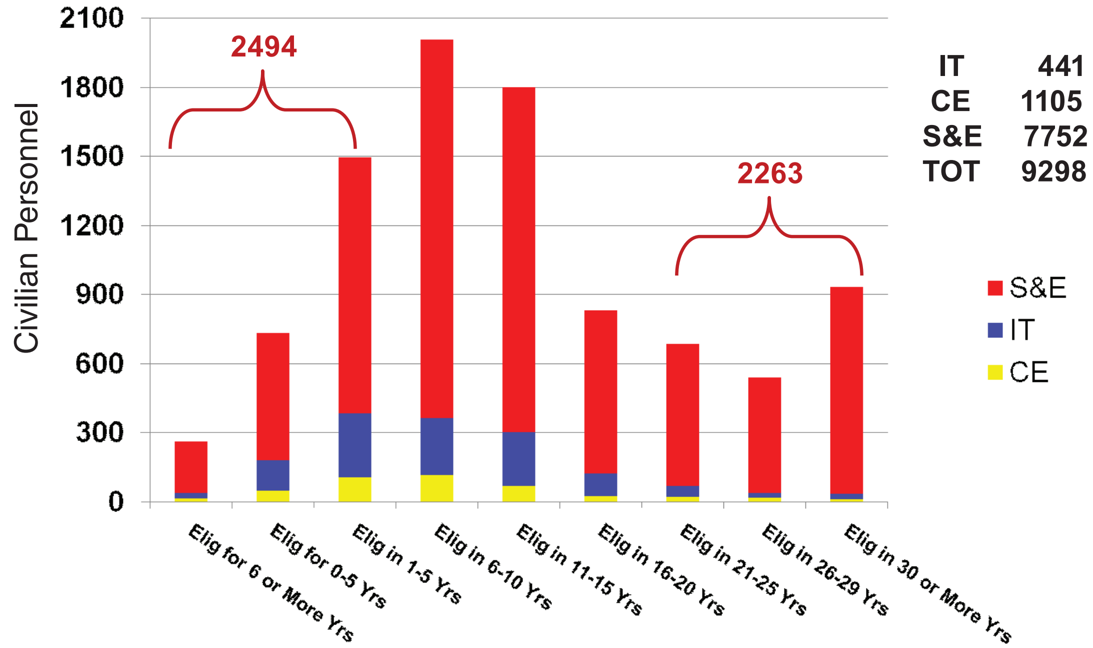


FIGURE 4-2 Retirement eligibility of AFMC STEM-degreed civilian personnel. IT = information technology, CE = civil engineering, S&E = science and engineering, TOT = total of IT, CE, and S&E. Elig = Eligible. SOURCE: Jon Ogg, Headquarters AFMC, Engineering, briefing to the committee on August 27, 2008.

As a result of these ongoing reviews, the ASC commander concluded that recent drawdowns have decreased mission capability and resulted in a long-term loss of experienced employees. Specifically, ASC authorized organic workforce strength has gone from nearly 12,000 in FY 1993 to under 7,000 in FY 2009, while the portion of the workforce in acquisition positions has dropped from 6,133 to 3,086 – literally cut in half. In the past four years, while the acquisition workforce authorized numbers dropped about 200, ASC estimates its requirements actually rose by 377. The ASC commander further predicted that shortages and imbalances will continue to increase as ASC's aging workforce gains eligibility to retire, with concomitant years of knowledge, skill, and talent quickly draining. Besides decreasing population strength, the ASC leadership further expects a bathtub of reduced experience in their force profile—generated in part by years of hiring freezes—to result in a significant experience shortfall in the future. The ASC commander already sees a clear loss of program-specific knowledge, creating lengthy talent gaps while new hires learn program areas. He also identifies numerous specific shortage areas, depending upon current workloads and priorities. Some examples are electromagnetics (including low observables, communications, and electromagnetic compatibility), structures, software, reliability and maintainability, and manufacturing engineers. Yet another problem is the loss of senior mentors or trainers of the less-experienced workforce, which can be seen as detrimental to the long-term success of ASC in performing its mission.

The commander of the Electronic Systems Center (ESC) expressed similar concerns, reporting that ESC sees the ability to reestablish an engineering leadership cadre of government

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

personnel at the center as a strategic priority.[15] He pointed out that there is a lack of government engineers to fill 80 critical engineering positions (CEPs), and appropriate CEPs are needed to do inherently government work, as well as operational safety, suitability, and effectiveness studies.

As noted in the discussion above of balancing the contract labor force and the organic workforce, the contractor workforce at ESC is 70 percent of the total, with 35 percent in advisory and assistance services and 35 percent in a FFRDC. The commander said that ESC desires to increase the government workforce, which currently is composed of 63 percent civilian and 37 percent military, above the current 30 percent of the total workforce. He observed that the outlook for military entitlements continues to be bleak, that one-third of the civilian workforce will become eligible for retirement in the next two years, and that the center had 40 civilian vacancies at the time of his presentation to the committee. To address these workforce-related issues, simply in terms of numbers, the commander believes ESC needs an increase of approximately 300 additional authorizations.

Air Force Research Laboratory and Arnold Engineering and Development Center

The Air Force Research Laboratory (AFRL) is predominately civilian; only13 percent of the science and engineering workforce is drawn from the military, while 46 percent are contractors and the remaining 41 percent are organic civilian personnel (Figure D-19 in Appendix D).[16] According to the Executive Director, AFRL like other AFMC organizations is facing an unprecedented loss of experience and expertise. Forty percent of the civilian scientist and engineering workforce are nearing the age of retirement eligibility (Figure D-20 in Appendix D).

Compounding the challenge for AFRL, the Executive Director continued, is the Base Realignment and Closure (BRAC) move of its directorates from San Antonio, Texas; Hanscom AFB, Massachusetts; and Mesa, Arizona; to Dayton, Ohio. He anticipates that only 10 percent of civilian personnel will move when their positions are moved, and that this will drive a need to recruit 400 civilian scientists and engineers. He cited the cumbersome hiring process, the conundrum between reactive and proactive planning, and the continuing loss of experienced talent through retirement as factors further compounding the challenge. On the positive side, he noted that AFRL does have some extensive and aggressive training and educational outreach programs (secondary schools and colleges) for its existing and planned workforce. AFRL is also using Section 852[17] funding for interns, co-ops,[18] skill- and competency-based occupation workforce planning, career broadening, rental allowances, and branding. As threats to AFRL's recruiting efforts, the Executive Director cited this unprecedented loss of experience and expertise, a projected surge in hiring needs of 680 civilian personnel related to BRAC activities, competition from the private sector and other government agencies competing for limited pool of candidates, and fewer hiring flexibilities for seasoned candidates.

---

[15]Lt. Gen. Ted F. Bowlds, Commander, ESC, AFMC, briefing to the committee on October 30, 2008.

[16]Joe Sciabica, Executive Director, AFRL, AFMC, briefing to the committee on October 30, 2008.

[17]Section 852 of the National Defense Authorization Act for Fiscal Year 2008 directed the Secretary of Defense to establish a "Department of Defense Acquisition Workforce Fund" to "provide funds, in addition to other funds that may be available, for the recruitment, training, and retention of acquisition personnel of the Department of Defense." The stated purpose of the fund was "to ensure that the Department of Defense acquisition workforce has the capacity, in both personnel and skills, needed to properly perform its mission, provide appropriate oversight of contractor performance, and ensure that the Department receives the best value for the expenditure of public resources." Section 852 defined "acquisition workforce" to mean personnel in positions designated as acquisition positions under U.S. Code Title 10, Chapter 87, Section 1721. To the extent that the Air Force's acquisition and STEM workforces overlap, the Section 852 Department of Defense Acquisition Workforce Fund can potentially help rebuild the base of the STEM workforce.

[18]A co-op is a university student who works part time at AFRL.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

As noted earlier in the section on balancing contractor and organic workforces, the AEDC commander stressed problems of declining experience and an insufficient technical base among AEDC's remaining civilian scientists and engineers.[19] Figure D-15 in Appendix D illustrates how, from the commander's perspective, technical excellence at AEDC has been lost because of changes in the nature of the mission. Figure D-16 shows that, over the years, there have been fewer opportunities for personnel to hone their science and engineering expertise and test their technical excellence because the test base (programs in development) has progressively declined. The commander said that one key source of talent is noncommissioned officers separating from the military. They offer a near-term and viable source of experienced technical talent with the potential to partially fill the shortage of scientists, engineers, and science and math educators. He sees a need to build skill requirements in experimental design, integrating math and science with test techniques, integrating ground and flight tests, and more cross-disciplinary expertise.

FINDINGS AND RECOMMENDATIONS

Finding 4-1a. Although the *Acquisition Managers (63AX–1101) Career Field Education and Training Plan* states that a baccalaureate degree is required for Level 1 certification (USAF 2008, pg. 21), neither a STEM degree nor STEM cognizance is required for that certification.

Finding 4-1b. All Air Force product centers, air logistics centers, and test centers have significant shortfalls in assigned civilian STEM-degreed personnel.

Finding 4-1c. Some of the shortfalls in STEM capabilities in the acquisition workforce could be addressed by establishing criteria for STEM cognizance and applying those criteria to APDP certification requirements and other position requirements. Some acquisition positions already have requirements for STEM coursework that is less than a full major, such as positions that require 24 hours of STEM coursework.

Recommendation 4-1. The Air Force should lead the way in changing the OSD implementation policy of DAWIA by establishing STEM cognizance as a minimum requirement for program management certification. If OSD support for such a change is not forthcoming, the Air Force should unilaterally change its own implementing directives by specifying that STEM cognizance is a minimum requirement for acquisition program management certification.

Finding 4-2. DAWIA seeks to ensure that experienced personnel are engaged in running major programs. However, the experience criteria in DAWIA and Air Force directives are often waived for the senior ranks of the Air Force acquisition community. For example, general officers have often been placed in important acquisition positions—although not designated as critical acquisition positions (CAPs)—in Air Force Acquisition (SAF/AQ), the Air Force Materiel Command, and the Air Force Space Command, even when these officers have had little or no acquisition experience. Waiving these requirements runs counter to the basic intent of the legislation.

Recommendation 4-2. The Air Force should objectively review all general officer positions in AFMC, AFSPC, and SAF/AQ to determine which should be coded as CAPs. The Air Force should ensure that officers filling these positions meet the certification requirements.

[19] Col Art Huber, Commander, AEDC, briefing to the committee on December 3, 2008.

Copyright © National Academy of Sciences. All rights reserved.

Finding 4-3. While no specific "quality force" or retention-related data were provided for the committee's review, the presenters seemed to agree that, as a practical matter, STEM-degreed personnel in the acquisition, test, and logistics workforces should be given significant hands-on experience to develop their technical skills during the first five years of their careers. This experience would enhance their "smart buyer" capabilities and their ability to provide meaningful oversight of the contractor workforce. Air Force DAWIA requirements should be appropriately modified.

Recommendation 4-3. The Air Force should review its training and career development plan for the acquisition management career field/occupational series to strengthen the opportunities for STEM-degreed personnel to acquire hands-on experience to develop their technical skills during the first five years of their Air Force careers.

REFERENCE

USAF. 2008. Acquisition Managers (63AX – 1101) Career Field Education and Training Plan, CFETP 63AX & 1101, Parts I and II. 2008 Edition, March 17, 2008. Washington, D.C.: Department of the Air Force, Headquarters US Air Force.

Copyright © National Academy of Sciences. All rights reserved.

5

The Current and Future U.S. STEM-Degreed Workforce

Chapters 3 and 4 explored issues for the Air Force's STEM-degreed workforce that results from policies, conditions, and trends internal to the Air Force. This chapter focuses on external conditions—specifically trends in STEM education and the STEM-degreed workforce in the United States—that must be considered to prepare for the Air Force's current and future STEM needs with realistic and effective actions. The challenges facing the Air Force as it seeks to acquire and retain STEM-degreed personnel are due in part to changing U.S. demographics and a more competitive career environment for U.S. citizens with STEM degrees. Some of these challenges relate to uncertainties about the adequacy of supply of STEM-degreed workers who can qualify for Air Force or aerospace positions. Other challenges relate to tapping the potential human resource in the growing numbers of women and disadvantaged minorities seeking college and postgraduate degrees. Fortunately, the Air Force is already involved in education-incentive programs that can be leveraged to help address these and other challenges in meeting future needs for STEM-skilled personnel.

For this discussion, the undergraduate majors or postgraduate fields of study that the committee counts as having a STEM degree are those listed in Table 1-1. The term "STEM-degreed workforce" will be used to refer to all individuals who have an undergraduate major or postgraduate degree in one of the STEM fields, whether or not they are currently working in a position that requires a degree in that field. Terms such as "scientist" or "engineer" are used to refer broadly to those working in the indicated professional occupation.

A FUNCTIONAL PROFILE OF A MEMBER OF THE STEM-DEGREED WORKFORCE

With respect to the future U.S. STEM-degreed workforce, desired traits are well documented in reports such as *The Engineer of 2020: Visions of Engineering in the New Century* (NAE, 2004) and *Educating the Engineer of 2020* (NAE, 2005) and in publications of the Accreditation Board for Engineering and Technology (ABET). ABET provides appropriate auditing and certification for more than 1,700 university programs nationwide. Evaluations are performed on-campus by members of professional societies such as the American Institute of Aeronautics and Astronautics (AIAA) for aerospace programs, American Society for Mechanical Engineers for mechanical engineering, and the Institute of Electrical and Electronics Engineers for electrical engineering, as well as by university faculty.

A significant component of ABET accreditation is the requirement that the program being evaluated demonstrate that its students attain a set of learning outcomes. The following set of 11 outcomes are those specified for graduates from an engineering program (ABET, 2008), but they also provide a functional profile applicable generally to all the STEM disciplines listed in Table 1-1 of this report. Taken together, these descriptors constitute a qualitative profile of the future engineer, and they are relevant to the other STEM disciplines as well:

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

a) an ability to apply knowledge of science, technology, engineering, and mathematics
b) an ability to design and conduct experiments, as well as to analyze and interpret data
c) an ability to design a system, component, or process to meet desired needs with realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
d) an ability to function on multidisciplinary teams
e) an ability to identify, formulate, and solve engineering problems
f) an understanding of professional and ethical responsibility
g) an ability to communicate effectively
h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
i) a recognition of the need for, and an ability to engage in, life-long learning
j) a knowledge of contemporary issues
k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice. (ABET, 2008, pg. 2)

The ABET process provides some degree of validation and consistency for engineering and technology coursework. Thus, it helps ensure that the quality of STEM-degreed personnel remains high. This view was reaffirmed by the perceptions of the senior Air Force commanders from the product, test, and logistics centers who briefed the committee, as reported in the perspectives and perceptions sections of Chapters 3 and 4.

WILL SUPPLY MEET DEMAND FOR THE U.S. STEM-DEGREED WORKFORCE?

The committee identified a number of arguments that have been advanced in one forum or another to support concerns that the United States may face an inadequate supply of STEM-degreed workers in the future.[1] For purposes of reviewing and commenting on such concerns in this report, these diverse arguments have been organized under six general issues: weaknesses in the pipeline of elementary and high school education that prepares students for success in STEM subjects in college, an apparent decline in student interest in science and mathematics, inadequate resources for the educational system, a decline in incentives to pursue a STEM career, slow growth or decline in the number of U.S. citizens or permanent residents earning advanced STEM degrees, and an aging STEM-degreed workforce. U.S. citizenship is an important workforce consideration because STEM-related positions in the Air Force require access to information that is either classified national security information or controlled unclassified information.[2] Access to such information is often a requirement for STEM-related work in the aerospace industry.

Concern about the Educational Pipeline

The gist of this concern is that, as a consequence of inadequate educational opportunities in elementary and high school, careers in science and engineering (S&E) become beyond the reach of students who might otherwise pursue a STEM degree. Although the reasons for this lack of preparation in precollegiate science and math are undoubtedly complex, there is straightforward evidence that U.S. children at the elementary and high school levels are lagging their peers not only in the developed world but even in many developing countries. In a 1999 comparison of 15-year-olds in 37 countries, U.S. youth ranked 19th in math and 18th in science (Mullis et al., 2000, exhibit 1.1; Martin et. al., 2000, exhibit 1.1). A subsequent comparison of U.S. students over time

[1]A recent example of an airing of many of the arguments summarized here was the Inside Aerospace 2008 international forum for the aerospace industry, sponsored by AIAA. See, for example, Chapter II, "The Issues: Attracting, Encouraging, and Inspiring Top Talent" in the formal report from the forum's organizers (AIAA, 2008).

[2]"Controlled unclassified information" includes information that comes under the International Traffic in Arms Regulations (ITAR) or other restrictions outside the formal national security classification process.

Copyright © National Academy of Sciences. All rights reserved.

found that the percentage of U.S. eighth graders meeting an international benchmark in advanced math achievement remained almost constant between 1995 and 2007 (Mullis et al., 2008), while the percentage that met the advanced benchmark in science declined (Martin et al., 2008).

Many voices have proffered solutions for this lag in the science and math preparation necessary for a competitive STEM workforce (AIAA, 2008). Improving the quality of kindergarten-to-12th grade (K-12) teaching of science and mathematics is often an essential component of such solutions. The first recommendation of a 2007 study of the future U.S. STEM workforce by a committee of the National Academies, which reported its findings and recommendations in *Rising Above the Gathering Storm*, was to "increase America's talent pool [in science and mathematics] by vastly improving K–12 science and mathematics education." The authors urged, as "the highest priority," three actions to implement this recommendation:

> **Action A-1:** Annually recruit 10,000 science and mathematics teachers by awarding 4-year scholarships and thereby educating 10 million minds….
>
> **Action A-2:** Strengthen the skills of 250,000 teachers through training and education programs at summer institutes, in master's programs, and in Advanced Placement (AP) and International Baccalaureate (IB) training programs….
>
> **Action A-3:** Enlarge the pipeline of students who are prepared to enter college and graduate with a degree in science, engineering, or mathematics by increasing the number of students who pass AP and IB science and mathematics courses. (NAS, NAE, IOM, 2007, pp. 5–6)

Declining U.S. Student Interest in Science and Mathematics

Compared with other developed nations, and particularly with the rapidly developing nations, relatively few U.S. students pursue undergraduate and graduate degrees in STEM fields. In testimony before a congressional committee in 2009, Norman Augustine, the chair of the study committee that wrote *Rising Above the Gathering Storm,* stated that the number of engineers and physical scientists graduated in the United States has declined by 20 percent. The number of U.S. citizens achieving Ph.D.s in engineering has declined by 34 percent, while two-thirds of the students who receive Ph.D.s in engineering from U.S. universities are non-U.S. citizens (Augustine 2009, pg. 2). The undergraduate program that is the single largest source of S&E doctoral students in the United States is Tsinghua University (in Beijing, China), while the second largest source of S&E doctoral students at U.S. universities is Peking University (Mervis, 2008). These trends do not bode well for the continued dominance of America's technological edge at the macro level or for the Air Force's needs for STEM-degreed personnel.

Inadequate State Resources to Invest in Education

During the economic recession that began in 2008, most states cut education budgets to deal with state budget deficits. The Center on Budget and Policy Priorities reported in February 2009 that 36 states had cut education or were proposing cuts because of the budget deficits from the recession (Johnson et al., 2009).[3] Some of the states hardest hit by this recession—e.g., California, Texas, and Florida—have had a strong aerospace workforce in the past. In California, the Department of Education's "Budget Crisis Report Card" warns that the $17 billion in cumulative cuts to education in that state "threatens to derail the progress students have made over the last several years" (California Dept. of Education, 2010).

Moreover, these three states have large and growing Hispanic communities, a group that has traditionally been underrepresented in science and engineering (Mellado and Yochelson, 2006).

[3] In an update to their 2009 report, Johnson et al. reported in May 2010 that 30 states and the District of Columbia had enacted cuts to K-12 education and 42 states had cut their budgets for higher education (Johnson et al., 2010).

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

Yet even with the pressures on state education budgets, selected states with large Hispanic populations have demonstrated the potential for success by providing role models plus lessons learned. For example, Texas has created the Texas Engineering and Technical Consortium, a statewide initiative that involves state and local collaboration with industry to address K-12 shortfalls (Grose, 2006).

Are Incentives to Enter STEM Careers Declining?

Science and engineering are challenging fields. The time it takes to complete a degree is often longer than in other fields, and compensation after acquiring a degree is not always commensurate with the amount of time required. Nor does the compensation in STEM careers relative to non-STEM careers make a STEM career appealing. The relative pay in STEM careers has fallen far short of the compensation in careers such as medicine, health care, law, and management/business (Hosek and Galama, 2008).

Speakers at the 2008 AIAA Inside Aerospace conference who expressed concern about the incentives to enter STEM careers included chief executive officers and human resource managers from the aerospace industry, representatives from the Aerospace Department Chairs Association (reflecting the perceptions of educators at the baccalaureate and higher levels), and senior advisors to Congress and to the Executive Office of the President, all of whom were dealing with aerospace workforce issues on a daily basis (AIAA, 2008). Among their concerns was a perception that scholarships and fellowships for students interested in pursuing a STEM degree, especially at the undergraduate level, are in short supply. They cited studies suggesting that the hardest hit students are those from low and/or middle income households. They described concerns among students in some fields, especially at the graduate level, that jobs may not be available when those students receive their degrees. Another concern was that, while jobs for STEM-degreed workforce entrants may be generally available, career opportunities that would generate excitement among recent graduates may be declining. Money is definitely a motivator, conference participants reported, but an increased number of college graduates appear to be more concerned with job satisfaction, quality of life, and making a positive contribution to society (AIAA, 2008).

In contrast to these factors viewed as decreasing STEM career incentives, recent economic events may be pushing in the other direction. The Wall Street collapse of 2008 has the potential to increase the incentives for choosing a STEM career through at least two factors. First, economic stimulus measures such as the America Recovery and Reinvestment Act of 2009 and the fiscal year 2009 omnibus appropriations bill have provided funds that can be allocated to supporting graduate students and postdoctoral fellows in STEM disciplines. Second, these incentives come at a time when careers in finance have lost much of their appeal, both monetarily and in terms of the social respect they command (Lohr, 2009).

National Science Foundation (NSF) indicators on S&E education and the S&E-degreed workforce do not yet show how strongly these and other factors will ultimately affect the S&E workforce of the future. On the scholarship/fellowship supply issue, for instance, NSF data on the primary source of support for all S&E graduate students show gradually increasing levels of research grants and a stable level of fellowship support over the period 1985–2005. Teaching assistantships as the primary source of S&E graduate student support did decrease from about 24 percent to 18 percent over this period, while self-support as the primary source increased from 30 percent to 34 percent (NSB, 2008, appendix table 2-7). For 2005, the NSF graduate student categories for All Engineering and Aerospace Engineering had higher levels of research grant support (41 and 42 percent, respectively) than All S&E (28 percent) and lower levels of self-support (28 and 24 percent respectively) than did All S&E (34 percent) (NSB, 2008, appendix Table 2-8).

Copyright © National Academy of Sciences. All rights reserved.

Tables 5-1 through 5-4 summarize NSF data on entering freshmen intending to major in a S&E field, bachelor degrees in STEM fields earned by U.S citizens or permanent residents, S&E graduate enrollments of U.S. citizens or permanent residents, and STEM master's degrees earned by U.S. citizens and permanent residents. The general picture from these four indicators is that the data for the Engineering category show a drop—a steep drop in some cases such as graduate enrollment in engineering or engineering bachelor degrees—sometime between 1985 and 2000. For All S&E and for Natural Sciences, the pattern up to 2000 is mixed. And most of the indicators show a flat or increasing trend from about 2000 to 2005, although in some cases the levels have not yet regained their previous peaks.

TABLE 5-1. Percentage of Freshmen Intending S&E Majors, 1985–2006

STEM Field	1985	1995	2000	2001	2002	2003	2004	2005	2006
All S&E	32.6%	32.4%	33.1%	33.5%	33.5%	32.6%	33.1%	30.9%	32.0%
Physical, computer, & math. sciences[a]	13.0%	15.4%	15.2%	14.8%	13.6%	12.8%	13.3%	12.9%	13.5%
Engineering	11.0%	8.1%	8.7%	9.1%	9.5%	9.3%	9.6%	8.4%	8.0%

[a]Includes physical sciences, mathematics/statistics, and computer sciences; excludes biological/agricultural sciences and social/behavioral sciences. All of these science areas plus engineering are included in "All S&E."
SOURCE: NSB, 2008, Vol. II, Table 2-15.

TABLE 5-2. Bachelor Degrees in STEM Fields Earned by U.S. Citizens and Permanent Residents, 1985–2005

STEM Field	1985	1995	2000	2001	2002	2003	2004	2005
All S&E	328,899	363,463	383,438	384,492	399,288	423,358	437,228	447,559
Natural Sciences	125,047	124,311	145,321	146,216	151,871	160,862	163,020	161,859
Engineering	71,381	58,561	55,003	54,839	56,372	59,498	60,128	61,396

SOURCE: NSB, 2008, Vol. II, Table 2-28.

TABLE 5-3. S&E Graduate Enrollment, U.S. Citizens and Permanent Residents, 1985–2005

STEM Field	1985	1995	2000	2001	2002	2003	2004	2005
All S&E	324,081	396,755	364,954	368,840	387,532	412,282	424,147	436,530
Natural Sciences	161,021	198,753	193,036	195,259	205,709	218,925	227,424	233,716
Engineering	67,187	71,717	56,711	56,971	61,362	67,393	66,456	66,638

SOURCE: NSB, 2008, Vol. II, Table 2-22.

TABLE 5-4. Earned Master's Degrees in STEM Fields Earned by U.S. Citizens and Permanent Residents, 1985–2005

STEM Field	1985	1995	2000	2001	2002	2003	2004	2005
All S&E	52,220	72,092	70,933	71,564	71,623	75,542	83,120	86,563
Natural Sciences	19,462	20,986	22,589	23,230	23,721	25,466	27,626	27,788
Engineering	15,241	18,931	15,913	15,522	15,463	16,330	18,252	19,219

SOURCE: NSB, 2008, Vol. II, Table 2-30.

Copyright © National Academy of Sciences. All rights reserved.

For the future Air Force STEM-degreed workforce, perhaps the principal long-term consideration is that the historical pattern of an ample supply of STEM-degreed graduates and young workers to meet both industry and military service demands cannot be taken for granted. Will the drops in college-level and graduate preparation for engineering careers, which occurred in 1985–2000, resume? Or will the stable-to-increasing trends since 2000 continue—and will they suffice to meet the needs of both the Air Force and the aerospace industry, if those needs increase substantially? In a competitive labor market, the Air Force will need to consider the incentives and disincentives it presents to students considering a STEM career and to recent graduates just entering the workforce with a STEM degree.

Uncertainties in the Number of U.S. Citizens Earning Advanced STEM Degrees

The number of graduate students earning advanced S&E degrees in the United States has continued to grow over the past decade. However much of this growth has come from foreign citizens who are here on temporary visas and are therefore ineligible for the security clearances and access to restricted information required for many jobs in the Air Force and the aerospace industry.

As Table 5-5 shows, the number of new S&E Ph.D.s increased by 8 percent from 2000 to 2005, with a slight decline in the first part of this period more than offset by the increase since 2002. However, the absolute number of new Ph.D.s who can get the clearances required for many of the positions in the Air Force or the aerospace and defense industry (U.S. citizens plus Permanent Resident visas) has decreased by 5.5 percent over this period, with the early strong decline only partially recovered since 2002. The concern is whether this recent uptick will continue or the longer-term downward trend will dominate.

TABLE 5-5. S&E Doctoral Degrees

Visa status	2000	2001	2002	2003	2004	2005	Change, '00-'05
All S&E	27,557	27,037	26,235	26,907	27,991	29,751	+8.0 %
U.S. Citizen	16,826	16,112	15.466	15,799	15,933	16,118	-4.0%
% of all S&E	61.1%	59.6%	59.0%	58.7%	56.9%	54.2%	-11.3%
Perm. Resident	1,484	1,338	1,238	1,157	1,076	1,189	-19.9%
U.S. Cit. +Perm. Res	18,310	17,450	16,704	16,956	17,009	17,307	-5.5%
% of All S&E	66.4%	64.5%	63.7%	63.0%	60.8%	58.2%	-12.3%
Temporary Res.	7,964	8,260	8,015	8,711	9,516	10,792	35.5%
% of All S&E	28.9%	30.5%	30.6%	32.4%	34.0%	36.3%	25.6%

SOURCE: Numbers of doctoral degrees are from NSB, 2008, Vol. II, Table 2-32. Percentages calculated by NRC staff.

In recent years, the number of master's degrees in S&E fields has grown more quickly than in 2000–2002 (Table 5-6). For the 5-year period from 2000 to 2005, the rate of growth for all S&E masters degrees was 25 percent. After slower growth in the number of U.S. citizens and permanent residents in 2000-2002, that rate has increased in recent years, and the percentage of new S&E masters earned by students eligible for a security clearance has held in the 70–72 percent range since 2001.

Copyright © National Academy of Sciences. All rights reserved.

TABLE 5-6. S&E Master's Degrees

Visa status	2000	2001	2002	2003	2004	2005	Change, '00-'05
All S&E	95,683	98,986	99,173	107,910	118,470	120,025	25.4%
U.S. Citizen	NR	NR	NR	NR	NR	NR	
U.S. Cit. +Perm. Res	70,933	71,564	71,623	75,542	83,120	86,563	22.0%
% of All S&E	74.1%	72.3%	72.2%	70.0%	70.2%	72.1%	
Temporary Res.	24,750	27,422	27,550	32,368	35,350	33,462	35.2%
% of All S&E	25.9%	27.7%	27.8%	30.0%	29.8%	27.9%	

SOURCE: Numbers of masters degrees are from NSB, 2008, Vol. II, Table 2-30. Percentages calculated by NRC staff. Numbers for U.S. citizens earning masters degrees were not reported (NR).

Aging of the STEM Workforce

The National Science Board has noted that the age distribution for the American workforce with STEM degrees is increasing. Whereas rapid increases in this workforce in the past resulted in a relatively young age distribution, that historical pattern is changing. Slightly more than a quarter (26.4 percent) of all S&E-degreed workers are now over 50 (NSB, 2008, pp. 3-43 to 3-45). This aging trend is even more pronounced in the aerospace and defense industry, where 58 percent of the workforce is over age 50. Although many workers with S&E degrees continue to work beyond age 50, the proportion falls with age, decreasing to 40 percent by age 65 (Hedden, 2008, pg. 73).

As with the Air Force's STEM-degreed civilian workforce (see Chapter 3 and Figure 3-1), the aerospace industry has a bimodal age distribution, with the highest percentages of workers (the modes of the distribution) being those in the early years of their careers and those over 40 years old (NRC, 2006, pg. 20). Within the industry, there are concerns about an imminent "silver tsunami" of retirements, although the retirement rate for those eligible to retire has been lower since 2005 than previously anticipated (Hedden, 2008, pg. 72; AIAA, 2008, pg. 3).

As the STEM-degreed workforce ages and moves into less than full-time employment and retirement, the challenge will be to fill vacant positions with newly trained scientists and engineers. The report from the 2008 Inside Aerospace conference warned that, "Atrophy of the U.S. aerospace workforce is a system-wide problem" because "[t]here are an insufficient number of students emerging from our educational system with [STEM] training to replenish the retirement of skilled people from the aerospace profession and meet the other national needs for engineers" (AIAA, 2008, pg. 3). Whether or not the supply of STEM graduates in general is sufficient to meet demand, the workforce recruitment challenge will be intensified for the Air Force, which must seek U.S. citizens who can gain a security clearance. At the time of the 2008 survey of the aerospace and defense industry, nearly 53 percent of the open job requisitions required U.S. citizenship (Hedden, 2008, pg. 74).

WOMEN AND UNDERREPRESENTED MINORITIES IN THE STEM-DEGREED WORKFORCE

For multiple reasons, women and disadvantaged minorities represent a valuable pool of potential workers that the Air Force cannot and should not ignore in planning for its future STEM-degreed and STEM-cognizant workforce. First, as an agency of the federal government, the Air Force is required to adhere to policies in hiring its own employees and in contracting with aerospace companies that are intended to rebalance historical trends now judged to have been unfairly discriminatory against these segments of the population. Second (but not second in importance), women and minorities represent an opportunity: a reservoir of talent and potential

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

expertise in STEM fields that can be tapped to meet the demand for workers with the STEM skills that both the Air Force and industry require. As discussed below, women and minorities already comprise the majority of college students and will constitute the majority of the future U.S. workforce.

Nonetheless, the Air Force—and the aerospace industry that both supports the Air Force with STEM capability and competes with it for STEM-degreed workers—will be challenged to make the most of this workforce opportunity. The data presented below show that women are still not pursuing STEM degrees in the disciplines most needed by the Air Force and the aerospace industry in numbers representative of their percentage of the population, of college graduates, or of the future workforce. By contrast, students from racial/ethnic minorities who pursue higher (post-secondary) education are earning bachelor degrees in S&E at rates generally comparable to—or even greater than—White students. The major issue for minorities other than those of Asian ethnicity,[4] is their lower participation rate (including both enrollment and retention/completion rates) in higher education, relative to the racial/ethnic profile for their age group.

Women and Minorities in the Current Workforce

To provide current workforce benchmarks against which to compare statistics on women and minorities now preparing to enter the workforce, the committee used standard occupational classification (SOC) data from the 2000 census to characterize the gender and racial/ethnic profiles for four engineering categories (aerospace engineers, civil engineers, electrical and electronic engineers, and mechanical engineers) and two scientist categories (atmospheric and space scientists and chemical and material scientists). These occupational profiles, detailed in appendix C, display the following general patterns:

- Fewer than 1 in 10 engineers is a woman except for civil engineers, where just about 1 in 10 is a woman. The science fields have more women: about 13 percent of atmospheric and space scientists and nearly a third of chemical and material scientists are women.
- More than 80 percent of engineers in these categories are non-Hispanic White. About 4 percent (3.3–4.6 percent across the four categories) are Hispanic, Another 8 to 9 percent are Asian, 3 to 4 percent are Black, and less than 0.5 percent are Native American.
- Among atmospheric and space scientists, 91 percent are White; none of the minority groups has more than 3 percent of the profile. Among chemical and material scientists, 74 percent are White and 14 percent are Asian. Blacks constitute 6 percent of this group and Hispanics 4 percent.

In 2000, the general population profile was about 63 percent non-Hispanic White, 12.5 percent Hispanic, 12.3 percent Black, 3.7 percent Asian, 0.9 percent Native American, and about 8 percent in another racial/ethnic group or belonging to two or more groups.[5] For the 18–64 age group, which can be taken as the working-age population, the 2000 census found that 49.7 percent were males and 50.3 percent were females.[6] Comparing these general population statistics with the committee's S&E profile, one can gauge the degree to which women and minorities (except Asian) are underrepresented in STEM fields currently most important to the Air Force.

---

[4]For ease of reference, this report includes in the "Asian" category those designated as "Asian/Pacific Islanders" in the text and appendix tables of *Science and Engineering Indicators 2008* (NSB, 2008).

[5]These percentages are approximate and were derived from Quick Table QT-P3, Race and Hispanic or Latino: 2000, available from the U.S. Census Bureau at www.census.gov.

[6]Percentages were derived from Quick Table QT-P1, Age Groups and Sex: 2000, available from the U.S. Census Bureau at www.census.gov.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

Increasing Women's Role in the Future STEM Workforce

In 2005, women comprised 48.8 percent of the U.S. population aged 20–24. By 2025, the proportion of women in that age group is projected to increase just slightly to 49.1 percent (NSB, 2008, appendix table 2-14). In 2006, just 27 percent of entering freshmen women said they intended to major in any S&E field, whereas 37.9 percent of freshmen men intended an S&E major (NSB, 2008, appendix table 2-15). Thus, even though more women than men have been going to college since 1982, fewer than half (47 percent) of freshmen intending an S&E major are women (NSB, 2008, pp. 2-18, 2-26). For STEM fields of particular relevance to the Air Force and aerospace, the gender gap in intended majors is often much greater: just 2.5 percent of freshmen women intended to major in engineering in 2006, compared with 14.5 percent of freshmen men. Just 1 percent of freshmen women intended to major in mathematics or computer science, compared with 4 percent of freshmen men (NSB, 2008, appendix table 2-15).

Women earned 58 percent of all bachelor degrees awarded in 2005 and 50.5 percent of the bachelor degrees in an S&E major (NSB, 2008, appendix table 2-27). They have earned about half of all S&E bachelor degrees since 2000 (NSB, 2008, pg. 2-26). The National Center for Education Statistics projects that undergraduate enrollment, while continuing to increase overall, will remain at roughly 57 percent women and 43 percent men through 2017 (NCES, 2008, pp. 14, 95). However, a substantial gender gap in STEM-degreed graduates still exists in some STEM fields of high interest to the Air Force. Only 1 in 5 bachelor degrees in engineering went to a woman in 2005 because only 1.6 percent of graduating women, compared with 8.7 percent of graduating men, were engineering majors. Just over a fourth (27 percent) of all bachelor degrees in math and computer science went to a woman because only 2.2 percent of women majored in these fields, versus 7.8 percent of men (NSB, 2008, appendix table 2-27).

Women earned nearly 60 percent of all master's degrees awarded in 2005, but only 44 percent of the degrees in an S&E field. They earned 22 percent of the master's degrees in engineering, 32 percent of those in math and computer science, and 37 percent of those in the physical sciences (NSB, 2008, appendix table 2-29).

Identifying and accessing the factors underlying the gender gaps noted above is beyond the scope of this report, but there are reasons to believe those factors are malleable. First, the number of S&E bachelor degrees awarded to women has been increasing since at least 1985, with notable increases in physical sciences. In chemistry, for example, women's share of bachelor degrees increased from 25 percent in 1985 to 42 percent in 2005 (NSB, 2008, pg. 2-26). Second, in 2006, the ratio of freshmen women to men intending to major in physical sciences was 71 percent—about the same as the 72 percent ratio for those intending to major in any S&E field. And in 2005, the number of bachelor degrees in physical sciences earned by women was 75 percent of those earned by men. If freshman women's interest in STEM fields with currently low proportions of women, such as engineering and computer sciences, can be shifted and then sustained through their college years, as historically has occurred in some physical sciences, the increase in degreed graduates in those fields would be substantial.

Increasing Minorities' Role in the Future STEM Workforce

For Blacks, Hispanics, and Native Americans, statistics on higher education suggest that interest in STEM careers among those entering and graduating from college is relatively high. The challenge will be to bring the numbers who are college-bound and college-degreed in line with their age-group profile, which is shown in the first row of Table 5-7.

Copyright © National Academy of Sciences. All rights reserved.

TABLE 5-7. Distribution of Earned Bachelor Degrees by S&E Field and Racial Ethnic Group, 2005, U.S. Citizens and Permanent Residents only

Population Segment	All Degrees	Black	Hispanic	Asian	Native American	Non-Hispanic White
All 20–24 year olds, 2005	--	14.8	17.3	4.3	1.1	61.6
All bachelor degrees, % of degrees	100	9.0	7.9	6.5	0.7	70.2
Any S&E degree, % of S&E degrees	100	8.8	7.9	9.6	0.7	67.3
Any S&E degree, % of group	32.4	31.3	32.1	47.5	33.1	30.8
Engineering degree, % of degrees	100	5.2	7.5	13.4	0.6	68.7
Engineering degree, % of group	4.6	2.5	4.2	9.1%	3.7	4.3
Physical sci. degrees, % of degrees	100	6.7	6.5	9.2	0.7	71.7
Physical sci. degrees., % of group	1.0	0.8	0.9	1.5	1.1	1.1
Math/computer sci., % of degrees	100	10.1	6.6	12.3	0.5	62.2
Math/computer sci., % of group	4.6	4.9	3.6	8.3	3.4	3.9

SOURCES: NSB, 2008, appendix table 2-28 for all degree-related data. Percentages for all 20–24 age groups except Native Americans are from NSB, 2008, appendix table 2-14. Percentage for Native Americans aged 20–24 calculated from appendix table 2-14 total for all groups and 2000 census data on Native Americans aged 15 to 19, from www.census.gov

The second and third rows of Table 5-7 show the racial/ethnic profile for all bachelor degrees and all S&E degrees, respectively, earned in 2005. For the three minority groups that are underrepresented, relative to their age-group profile—Blacks, Hispanics, and Native Americans—the profile for all S&E degrees mirrors the profile for all degrees. Asian and non-Hispanic White students are overrepresented relative to the age-group profile, with Asian students earning S&E degrees at more than twice their percentage in the age-group profile. Given the similarity in the profiles of the three underrepresented minorities with respect to all bachelor degrees and any S&E degree, the fourth row in the table is not surprising: the percentages of students within each group who earned an S&E degree are similar to each other (ranging from 31.3 to 33.1 percent) and to the percentage for the graduating population as a whole (32.4 percent). Each minority group earned S&E degrees in 2005 at a higher rate (percentage within their group) than did non-Hispanic Whites. Since 1995 at least, the percentages of S&E degrees awarded to both the underrepresented minorities and Asians has increased, while the percentage awarded to non-Hispanic Whites has decreased.[7]

The remaining rows of Table 5-7 show the distribution across racial/ethnic groups (first row of each pair) and the percentage of the group who earned degrees in that field (second row of each pair) for three S&E fields of high interest for Air Force and aerospace workforce needs: engineering, physical sciences, and mathematics and computer sciences. The underrepresentation of Blacks, Hispanics, and Native Americans is greater in these fields than it is for all S&E degrees.

[7]See Table 1 in appendix C for trends in S&E bachelor degrees from 1995 to 2004. Note that the percentages shown in that table include nonresident aliens, whereas Table 5-7 is for U.S. citizens and permanent residents only.

Copyright © National Academy of Sciences. All rights reserved.

In summary, women and the minority ethnic/racial groups currently underrepresented in the STEM workforce and among students earning STEM degrees are segments of the future U.S. workforce that the Air Force cannot ignore for its future needs for STEM-degreed personnel, but there will be challenges in making the most of these potential resources. The Air Force should continue to build on existing relationships and memoranda of understanding with groups whose membership reflects an intersection of these population groups with career interests in STEM fields important to the Air Force. Among such groups are Women in Aviation International, Tuskegee Airmen Incorporated, the League of United Latin American Citizens, Asian-American Engineers, Black Engineers, Hispanic Engineers, International Black Aerospace Council, and Shades of Blue, as well as many others. Finally, the Air Force should take a leadership position on coordinating these relationship-fostering programs with agencies in the Department of Defense or other federal agencies.

PROGRAMS TO INCREASE THE STEM-DEGREED WORKFORCE

While there is uncertainty about the adequacy of future supply of STEM-degreed U.S. citizens, there is also a wealth of documented programs that have been created to aid in increasing that supply. They range from programs focused on the K-12 years to industry- or company-unique initiatives that support university faculty and student internships and fellowships. There is certainly an awareness of the importance of addressing the pipeline issues. At this time, the principal issue may be increasing the number of STEM-degreed graduates—particularly those who can meet the requirements for access to classified or restricted information (Hedden 2008, pg. 74).

Programs Supported by Industry and Professional Organizations

Many programs are geared toward enhancing awareness of STEM subjects among K-12 students and preparing teachers to teach—and students to learn—about these subjects. These are potential models for replication, but in general, most of them as currently structured reach too few youth to have substantial impact on workforce outcomes. Other constraining factors include differing requirements imposed by many state agencies and local school districts. A 2008 inventory created by Boeing, for example, lists more than 80 such programs nationwide.[8] Reports by Raytheon in partnership with the Business-Higher Education Forum (Wells, et al., 2008) and by the Aerospace Industries Association (AIA) identify a significant number of programs trying to improve STEM-related education in grades K-12 (AIA, 2008).

Many professional organizations are working hard to develop more focus on sustainability and growth in the aerospace workforce as documented in the recent (AIA) report, *Launch into Aerospace* (AIA, 2008). One key call to action in that report was, “Each AIA company will designate a senior executive responsible for implementing the company’s commitment to workforce revitalization and accountable for measurable progress in revitalizing and growing the STEM workforce” (AIA, 2008, pg. 8). Considering that more than 300 companies are AIA members, this charge has potentially far-reaching implications.

Other organizations such as AIAA, the International Council on Systems Engineering, and the traditional engineering professional societies offer extensive training and education programs that are designed for skill-set enrichment, professional development, and certifications for existing industry and government employees. So, while aerospace workforce needs may in some degree remain unfilled, significant resources are being devoted to addressing both current and future requirements.

---

[8] Unpublished white paper on K-12 program inventory. Available on request from Terri Morse, terri.f.morse@boeing.com.

Copyright © National Academy of Sciences. All rights reserved.

Two Successful Programs with Air Force Sponsorship

To illustrate the opportunities and the challenges for the Air Force in joining with industry and academic partners to improve the STEM pipeline and foster interest in STEM career opportunities, the committee selected two programs that have been successful in providing STEM education to substantial numbers of students in the critical early years of their schooling: Project STARBASE and Project Lead the Way. These examples were selected because the Air Force is already involved in them and they were recommended as useful models by individuals involved in education and outreach activities who were interviewed by the committee. There are certainly many other successful programs and activities to enhance STEM education and student interest that are worthy of support.

Project STARBASE

In 1991, the Assistant Secretary of Defense for Reserve Affairs began sponsoring a program called Project STARBASE (Science and Technology Academies Reinforcing Basic Aviation and Space Exploration), which has been successful in addressing shortfalls in STEM education in elementary schools.[9] STARBASE is a partnership among the military, school systems, and communities. Its vision is "to raise the interest and improve the knowledge and skills of at-risk youth in science, technology, engineering, and mathematics, which will provide for a highly educated and skilled American workforce that can meet the advanced technological requirements of the Department of Defense."[10]

The program provides students with 20–25 hours of exemplary instruction, using a common core curriculum, and stimulating, real-world experiences at National Guard, Navy, Marine, Air Force Reserve, and Air Force bases across the nation. It introduces them to role models—military personnel with STEM backgrounds—with whom they would not otherwise come into contact. In 18 years, the program has reached over 450,000 youth and expanded from one site in Michigan to 34 states, the District of Columbia, and Puerto Rico. The program's website explains the program further:

> Students participate in challenging "hands-on, mind-on" activities in aviation, science, technology, engineering, math, and space exploration. They interact with military personnel to explore careers and make connections with the "real world....
>
> DoD STARBASE focuses on elementary students, primarily fifth graders. The goal is to motivate them to explore science, technology, engineering and math (STEM) as they continue their education. The academies serve students that are historically underrepresented in STEM. Students who live in inner cities or rural locations, those who are socio-economically disadvantaged, low in academic performance or have a disability are in the target group. The program encourages students to set goals and achieve them.
>
> The program engages students through the inquiry-based curriculum with its 'hands-on, mind-on' experiential activities. They study Newton's Laws and Bernoulli's principle and learn about the wonders of space and the properties of matter. Technology captivates the children as they use the computer to design space stations, all-terrain vehicles, and submersibles. Math is embedded throughout the curriculum and students use metric measurement, estimation,

---

[9]The committee's judgment on the success of Project STARBASE is based upon comments and recommendations heard from Dr. Ronald M. Sega, formerly Director of Defense Research and Engineering and Undersecretary of the Air Force and currently professor and Vice President of Applied Research at Colorado State University; Assistant Secretary of Defense for Reserve Affairs Dennis M. McCarthy; Gen. Kevin P. Chilton, Commander, U.S. Strategic Command; Gen. Victor E. Renuart, Jr., Commander, North American Aerospace Defense Command and U.S. Northern Command; Rear Admiral Joseph F. Kilkenny, Commander, Naval Education, and Training command; and MG Tod Bunting, Adjutant General, Kansas National Guard.

[10]See http://www.starbasedod.com/index.php.

Copyright © National Academy of Sciences. All rights reserved.

calculation and geometry to solve questions. Teamwork is stressed as they work together to explore, explain, elaborate and evaluate concepts.

The military volunteers apply abstract principles to real world situations by leading tours and giving lectures on the use of STEM in different settings and careers. Since the academies are located in different branches of the military this experience is highly varied. Students may discuss how chemical fires are extinguished, learn how injured are transported, explore the cockpit of an F-18 or the interior of a submarine.[11]

Teacher and student assessments of the program are conducted routinely and reported in the STARBASE annual reports, which are available on the program website. With respect to its ultimate impact on increasing interest in STEM careers and growth of the U.S. STEM-degreed workforce, STARBASE is a long-term investment, and more time will be needed to document its long-term consequences. Even so, the positive responses from educators, parents and students, documented in the participant assessments, indicate that STARBASE is having substantial positive impact. It would benefit the nation to expand the STARBASE program, with the goal of exposing a larger number of at-risk youth across the nation to math and science education, especially in inner cities where students' interests in STEM are low and their risk for dropping out of school is high.

Project Lead the Way

Another notable program, Project Lead the Way (PLTW), has a decade of experience and statistics documenting the merit of its approach to middle school and high school teacher training to better provide STEM learning in the classroom.[12] The PLTW program has five learning modules for middle school including one on "flight and space." At the high school level, there are eight courses including one focused on "aerospace engineering."

The PLTW approach/curriculum is endorsed by the AIAA, AIA, American Society for Engineering Education, National Defense Industrial Association, and many other professional organizations, plus U.S. corporations. The program has achieved the following milestones:

- In 12 years, it has expanded to 49 states and 2,000 schools.
- Approximately 10,000 middle and high school teachers have been trained.
- Over 200,000 students have completed PLTW modules.

The committee heard positive assessments of the effectiveness of PLTW from multiple sources outside the PLTW program itself.[13] According to these sources, high school graduates with PLTW certificates are more likely to attend and complete college and to do so in S&E fields.[14] The PLTW website reports the following results that support this claim:[15]

---

[11]"DoD Starbase: About Us." Available online at http://www.starbasedod.com/index.php?option=com_content&task=blogsection&id=6&Itemid=48. Last accessed May 6, 2010.

[12]Project Lead the Way website, www.PLTW.org.

[13]The committee discussed Project Lead the Way (PLTW) with Jon Ogg, Headquarters AFMC, as part of a discussion of AFMC/ASC outreach activities at the committee's first meeting in August 2008. More information on PLTW came from three representatives of Battelle Memorial Institute, who discussed education outreach activities by both the Air Force and the aerospace industry at the committee's second meeting (October 1, 2008). Individual members also heard evaluations of PLTW from Julie Albertson of the University of Colorado at the Inside Aerospace conference in 2008 (see AIAA, 2008, pg. 10) and from Richard C. Liebich at the 2009 Inside Aerospace conference. PLTW was highlighted as a model for successful outreach to K-12 students by Dr. Ronald Sega, former NASA astronaut and Under Secretary of the Air Force in his speech at the Space 2008 conference in San Diego.

[14]Rich Rosen, Vice President, Education and Philanthropy, Battelle Memorial Institute, presentation to the committee on September 30, 2008.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

- PLTW alumni study engineering and technology at 5 to 10 times the rate of non-PLTW students.
- PLTW students have a higher retention rate in college engineering, science, and related programs than non-PLTW students.
- 80 percent of PLTW seniors say they will study engineering, technology, or computer science in college whereas the national average in 32 percent.

The Air Force should consider becoming a sponsor of Project Lead the Way (PLTW) to enhance the knowledge base of middle and high school teachers.

FINDINGS AND RECOMMENDATIONS

Finding 5-1a. There is reason for concern as to whether the supply of scientists and engineers who can obtain a security clearance will be adequate to meet the future needs of the Air Force. As an example, while the total of all S&E doctoral degrees awarded annually increased 8 percent from 2000 to 2005, the number of S&E doctoral degrees awarded to U.S. citizens and permanent residents decreased 5.5 percent over the same period. From 2002 to 2005, the number of U.S. citizens earning S&E doctoral degrees increased slowly but not enough to regain earlier levels.

Finding 5-1b. In light of the continuing substantial change in U.S. demographics, with women and minority groups constituting a growing segment of the target group for potential recruits, the Air Force is well positioned to take a proactive role in addressing the national shortfalls among middle and high school youth in math and science and, as a result, to work to create a more competitive U.S. workforce from which the Air Force can select its future STEM-degreed personnel.

Recommendation 5-1. The Air Force should create a vehicle to coordinate and evaluate existing STEM-related outreach, education, and training activities. Current activities of this type include Project STARBASE, the Falcon Foundation, Civil Air Patrol, and Junior ROTC, as well as its partnerships in such activities with the Air Force Association, AIAA, and others. The charter for this group should include creating connectivity between such activities so that promising participants from across the entire demographic makeup of our nation have ready access to the next academic level or program that builds on the experience gained from interacting with the Air Force STEM-related outreach efforts. It seems suitable for the office having these responsibilities to be at the Air Staff level.

REFERENCES

ABET (Accreditation Board for Engineering and Technology). 2008. Criteria for Accrediting Engineering Programs: Effective for Evaluations During the 2009–2010 Accreditation Cycle. Baltimore, Maryland: ABET, Inc.

AIA (Aerospace Industries Association). 2008. Launch into Aerospace. September 2008. Arlington, Virginia: Aerospace Industries Association. Available online at www.aia-aerospace.org

AIAA (American Institute of Aeronautics and Astronautics). 2008. Inside Aerospace: An International Forum for Aviation and Space Leaders Working Together to Build the Aerospace Workforce of Tomorrow. Report and recommendations of a forum held in

[15]"Project Lead the Way: About Us." Available online at http://beta.pltw.org/about-us/impact, accessed May 6, 2010.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

Arlington, Virginia, May 13–14, 2008. Reston, Virginia: American Institute of Aeronautics and Astronautics.

Augustine, N.R. 2009. America's Competitiveness. Statement Before the Democratic Steering and Policy Committee, U.S. House of Representatives, Washington, DC, January 7, 2009. Available at www.aau.edu/WorkArea/showcontent.aspx?id=8154.

California Dept. of Education. 2010. Budget Crisis Report Card. Available online at http://www.cde.ca.gov/nr/re/ht/bcrc.asp. Accessed July 11, 2010.

Grose, Thomas K. 2006. Booting Up. ASEE Prism 16(1) September. Available online at http://www.prism-magazine.org/sept06/feature_tetc.cfm

Hedden, Carole R. 2008. A&D workforce in depth: Aviation Week workforce study results. Aviation Week and Space Technology. August 18, 2008. p.72.

Hosek, J., and T. Galama. 2008. U.S Competitiveness in Science and Technology. Santa Monica, California: RAND Corporation.

Johnson, N., P. Oliff, and J. Koulish. 2009. Most States are Cuting Education. Center on Budget and Policy Priorities. Updated February 10, 2009. Available online at www.cbpp.org/12-17-08sfp.htm

Johnson, N., P. Oliff, and J. Koulish. 2010. An Update on State Budget Cuts: At least 45 States Have Imposed Cuts that Hurt Vulnerable Residents and the Economy. Center on Budget and Policy Priorities. Updated May 25, 2010. Available online at www.cbpp.org/cms/index.cfm?fa=view&id=1214.

Lohr, S. 2009. New trends for college graduates. New York Times. April 12, 2009.

Martin, M.O., I.V.S. Mullis, E.J. Gonzales, K.D. Gregory, T.A. Smith, S.J. Chrostowski, R.A. Garden, and K.M. O'Connor. 2000. TIMSS 1999 International Science Report: Findings from IEA's Repeat of the Third International Mathematics and Science Study at the Eighth Grade. Chestnut Hill, Massachusetts: Boston College. Available online at http://timss.bc.edu/timss1999i/science_achievement_report.html.

Martin, M.O, I.V.S Mullis, and P. Foy. 2008. TIMSS 2007 International Science Report. Findings from IEA's Trends in International Mathematics and Science Study at the Fourth and Eight Grades. Chestnut Hill, Massachusetts: IEA TIMSS & PIRLS International Study Center.http://timss.bc.edu/TIMSS2007/sciencereport.html.

Mellado, Ray, and John Yochelson. 2006. The Fork in the Road. Great Minds in STEM website, September 28, 2006. Los Angeles, California: Great Minds in STEM. Available online at http://www.greatmindsinstem.org.

Mervis, Jeffrey. 2008. Top Ph.D. feeder schools are now Chinese. Science 321, 185.

Mullis, I.V.S., M.O. Martin, E.J. Gonzales, K.D. Gregory, T.A. Smith, S.J. Chrostowski, R.A. Garden, and K.M. O'Connor. 2000. TIMSS 1999 International Mathematics Report: Findings from IEA's Repeat of the Third International Mathematics and Science Study at the Eighth Grade. Chestnut Hill, Massachusetts: Boston College. Available online at http://timss.bc.edu/timss1999i/math_achievement_report.html.

Mullis, I.V.S., M.O. Martin, and P. Foy. 2008. TIMSS 2007 International Mathematics Report. Findings from IEA's Trends in International Mathematics and Science Study at the Fourth and Eight Grades. Chestnut Hill, Massachusetts: IEA TIMSS & PIRLS International Study Center. http://timss.bc.edu/TIMSS2007/mathreport.html

NAE (National Academy of Engineering). 2004. The Engineer of 2020: Visions of Engineering in the New Century. Washington, D.C.: National Academies Press.

NAE 2005. Educating the Engineer of 2020: Adapting Engineering Education to the New Century. Washington, D.C.: National Academies Press.

NAS, NAE, IOM. 2007. Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future. Committee on Prospering in the Global Economy of the 21st Century, Committee on Science, Engineering, and Public Policy, The National Academies.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

Washington, D.C.: National Academies Press. Available online at http://www.nap.edu/catalog.php?record_id=11463.

NCES (National Center for Education). 2008. The Condition of Education 2008. Report No. NCES 2008–031. Washington, D.C.: U.S. Department of Education, National Center for Education 2008 Statistics.

NRC (National Research Council). 2006. Issues Affecting the Future of the U.S. Space Science and Engineering Workforce: Interim Report. Committee on Meeting the Workforce Needs for the National Vision for Space Exploration. Washington, D.C.: National Academies Press. Available online at http://www.nap.edu/catalog/11642.html

NSB (National Science Board). 2008. Science and Engineering Indicators 2008. 2 volumes (volume 1, NSB 08-01; volume 2, NSB 08-01A). Arlington, Virginia: National Science Foundation.

Wells, B.H., H.A. Sanchez, and J.M. Attridge. 2008. Modeling Student Interest in Science, Technology, Engineering and Mathematics. Waltham, Massachusetts: Business-Higher Education Forum and Raytheon Company. Available online at http://www.bhef.com/publications/documents/raytheon_paper.pdf.

Copyright © National Academy of Sciences. All rights reserved.

6

Managing STEM Personnel to Meet Future STEM Needs Across the Air Force

This chapter discusses options available to the Air Force to meet its current and future needs for personnel with STEM capabilities, including both STEM-degreed and STEM-cognizant military officers and civilians. The final section addresses issues in using contractor personnel to meet needs for STEM capability. The committee's findings and recommendations are presented at the conclusion of major topics of discussion. Some recommendations draw on findings in Chapters 2 through 5, as well as on the findings stated here.

AN ACTIVE MANAGEMENT SYSTEM FOR STEM-DEGREED AND STEM-COGNIZANT PERSONNEL

The Air Force currently meets its requirements for STEM capabilities through a combination of organic and contracted personnel resources. Because the Air Force operates in a dynamic and somewhat uncertain environment, it needs authorities, policies and processes in place that provide the flexibility and agility necessary to adapt its mix of organic and contractor personnel resources to best meet changing needs, opportunities, and constraints.

With regard to whether an organic position requiring STEM capability should be staffed with a military officer or a civilian from the Federal Civil Service, the approach has generally been to fill the position with a civilian unless the requirement for a military officer is compelling. Examples of the latter include wartime/deployment requirements or a requirement for operational experience, especially as might be required to define or access operational requirements and capabilities of materiel to be developed, acquired, or tested. As an important exception to this general policy, the Air Force has selectively filled a number of junior technical positions—typically, within the Air Force Research Laboratory (AFRL)—with newly commissioned officers having STEM degrees. These young officers bring the latest technical skills, often in disciplines where the current state of the science is continually (and rapidly) evolving.

Thus, a key personnel management goal for the Air Force should be a process and a set of tools to ensure that its future STEM requirements can be filled by trained and ready personnel. The Air Force has four sources of STEM-degreed and STEM-cognizant personnel: members of the active-duty force, members of the Air Force Reserve Component, civilians, or contract labor. Determining the correct source for a particular STEM need involves answering three questions:

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

- Is the position either militarily essential[1] or inherently governmental?[2] If it is, a contractor cannot be hired to fill it.
- How much funding is available to support the position? Is the funding single or multiple year?
- How does the position relate to the roles and missions of the Service components—i.e., the total force approach?

The choice among the personnel sources is also influenced by statutory and policy (Office of the Secretary of Defense [OSD] and Air Force policies) constraints.

In the case of positions requiring STEM expertise, a further complication occurs because STEM requirements cross multiple Air Force Specialty codes (AFSCs), major commands, and functional areas. The committee determined that the current Air Force personnel management process, which is aligned by AFSC and function, is not adequate for managing STEM personnel. The absence of a clear definition of STEM and the inability to comprehensively measure the inventory of STEM personnel make the personnel management task considerably more complex.

Management Approaches Considered and Rejected

Among the many management approaches for STEM-degreed (and STEM-cognizant) personnel considered by the committee, two extreme alternatives were rejected as inadequate.

The committee considered a "STEM Corps" to be managed separately—and within which personnel would be promoted separately—from other segments of the Air Force workforce, i. e. non-line officers. Chaplains, Judge Advocates General, and medical personnel are managed this way. Although these career fields cross major commands, they do not reside in other Air Force specialties and functions. With each career field, independent actions can be taken that do not impact other AFSCs and functions. Additional motivation for a separate corps was the false perception that it would automatically result in a higher promotion rate. This is not true, as a separate corps does not automatically mean higher rates; in fact, promotion rates have been lower in some separate corps. In addition, if promotions within a corps were vacancy-based, a hard requirement must exist to justify promotion. For STEM capabilities in general, a defined requirement does not exist and inventory detail does not exist.

"Do nothing" was also considered as an alternative. The Air Force has not managed its STEM-degreed workforce in the past and could continue to just let STEM-degreed and STEM-cognizant personnel migrate naturally among the officer career fields and civilian occupational series. The Air Force has historically commissioned large numbers of officers with STEM degrees and let the large numbers migrate on their own to various areas. Because college education leading to a STEM degree was so pervasive, requirements were filled from the excess numbers of STEM-degreed personnel at each grade and specialty. There were always enough STEM-degreed personnel to fill the needs, stated or unstated. Therefore, there was no active management of the STEM-degreed workforce as an entity. Because the committee foresees a continuing decrease in the STEM-degreed population and a decreasing percentage of STEM-degreed graduates capable of obtaining security clearances (i.e., U. S. citizens, see Chapter 5),

---

[1]Militarily essential positions include those performing tasks that come under the Uniform Code of Military Justice and/or the Geneva Convention or are designated as militarily essential under the Status of Forces Agreements.

[2]Inherently governmental tasks are certain roles defined as such within the Federal Acquisition Regulations, including tasks covered by the Uniform Code of Military Justice or the Civilian Code of Ethics for government employees. The Government Accountability Office has held that, in some cases, inherently governmental positions were filled by contractors under the guise of acquisition reform, in violation of statutory and/or regulatory requirements (GAO, 2008a, 2008b).

Copyright © National Academy of Sciences. All rights reserved.

this past abundance of STEM-degreed personnel will not exist in the future. Doing nothing is therefore not a viable option.

The Need to Model Personnel Management Options

Unlike the "STEM Corps" and "Do Nothing" approaches to managing STEM-degreed and STEM-cognizant personnel, there were a range of other approaches on which the committee was unable to make definitive recommendations because data on which to access their outcomes were unavailable and unattainable without a suitable workforce model. These approaches were suggested by committee members, briefers, or others involved in the study, Examples are bonuses to increase retention in certain year groups, increased recruitment in Reserve Officer Training Corps programs, changes in initial assignments of STEM-degreed graduates of the U.S. Air Force Academy (USAFA), changes in promotion policy, creation of continuing education assignments, and creation of continuing education criteria for maintaining or acquiring a level of STEM capability.[3] A workforce model capable of simulating the consequences of such actions would not only allow leadership to determine the impact of Air Force policy options but could also be used to access the impact of external factors such as increases and decreases in civilian education and STEM pay in the private sector. A credible model would also help justify the expenditure required to implement policy changes.

How can such a model be built? Could it have credibility with the leadership of the Air Force, OSD, the Office of Management and Budget, and Congress? Is there a management system based on education rather than function that would be capable of managing a large force? Is there a management system that can prioritize both staff needs and critical operational capability? The answer to each of these questions is "yes." In fact the basis not only of such a workforce model but also of a workforce management system already exists in the Air Force. It is the personnel model and the associated management system used to manage the critical asset of rated personnel.

The Rated Management System as a Paradigm for STEM Management

U.S. Air Force aeronautical ratings are military aviation skill standards established and awarded by the Air Force for commissioned officers participating in aerial and space flight. The six categories of aeronautical ratings are Pilot, Navigator, Combat Systems Officer (CSO),[4] Air Battle Manager, Observer, and Flight Surgeon (USAF, 2009, pg.17). The Rated Management system is a personnel management system that tracks the education, currency of training, rank, and other attributes of each rated officer in the Air Force. This system allows senior Air Force leaders to identify and implement appropriate actions to ensure that requirements for rated categories of personnel, such as aircrews, are met (USAF, 1997). The requirements for each rated category vary a great deal, and there are multiple levels of rating within a category, but the common thread running through all the categories and levels is education and training.

The Rated Management system provides an inventory of rated personnel, with each individual's record having attributes such as education, currency of training, and rank that can be searched and documented. Maintenance of up-to-date records for rated personnel is a management priority. In addition, a complex taxonomy is used to identify needed staff,

---

[3]Once a person is educated in a field such as math, physics, engineering, or the other disciplines listed in Table 1-1, that person also gains a valuable set of general skills: critical thinking and how to apply the scientific method to problem solving. These general skills always stay with the person and constitute an essential part of the value in being STEM-degreed or STEM-cognizant.

[4]The older Navigator rating is being replaced by the CSO rating, and the Navigator career field is being phased out. After 2009, only CSOs are receiving ratings formerly awarded to navigators.

Copyright © National Academy of Sciences. All rights reserved.

operations, currency, and experience. Some of these workforce requirements are very specific; others are very generic. All requirements for rated personnel are periodically validated and prioritized by the leadership of the major commands and Air Staff. Thus, this system tracks these personnel independent of the AFSC they are currently filling.

During policy reviews of the ratings system and budget allocation reviews, a workforce model, called the Rated Management Decision Support System (RMDSS) (USAF 1997, pp. 22, 25) is used, with the Rated Management system's data as input, to simulate the impacts of alternatives such as the following:

- Should the number of pilots entering the Air Force be changed?
- Should the Air Force save dollars by cutting flying hours?
- Should a bonus be paid to encourage navigators/CSOs with 8–12 years of experience to remain in the Air Force to fill generic rated-personnel requirements at the colonel level?
- What is the impact of starting a new category of pilots that graduate from fixed wing training but are assigned to non-flying assignments in Remotely Piloted Aircraft (RPA)?

The impact of such decisions 5, 10, or 20 years in the future can be modeled with the RMDSS, and the projected consequences can be communicated to senior decision makers. Many times several policy or funding decisions must be made concurrently. There is a high probability that the combined effects of such decisions will produce outcomes different from implementing a single decision. Effective modeling can help mitigate this problem by allowing the interactions of the decision options to be simulated and projected forward. While it is true that not all alternatives can be modeled, the improved knowledge that the RMDSS provides helps senior leaders make difficult, expensive, long-lasting, and critical decisions on how to meet current and future needs for rated personnel.[5]

Most of the critical characteristics for the data input to enable the RMDSS to run simulations of rated management options are similar for personnel with STEM education and experience (that is, for STEM-degreed and/or STEM-cognizant personnel at any point in their Air Force career). For example, both rated-personnel management and STEM management must track by AFSC and by various aggregations or families of AFSCs. A look at parallels in taxonomy for a personnel record in the two management systems may help. A simple example is outlined below.

Rated Management
Specific training: pilot, navigator/CSO, air battle manager, etc.
Category: fighter, bomber, mobility, combat, search and rescue, special operations command, etc.
Utilization: line, first assignment instructor pilot, rated supplement, unmanned aerial vehicle, etc.

Stem Management
Specific education: electrical engineering, operations research, physics, etc.
Category: engineer, mathematician, optics specialist, scientist, etc.
Utilization: space operations, depots, acquisition, laboratories, etc.

In addition to these and other similarities, there are some significant differences. STEM personnel management includes civilian employee and contractor options; rated management does not. Unlike the rated operational positions (e.g., F-16, B-1, C-17 for different flight

[5]An in-depth review of both the Rated Management system and the model described here (also called the Air Force Rated Aircrew Management System) can be found in USAF AFI 11-412 *Aircrew Management.* Appendix F of this report more extensively describes parallels and challenges in using the model and the principles and organization applied to rated management that could be adapted as the basis for STEM personnel management modeling.

Copyright © National Academy of Sciences. All rights reserved.

platforms) that are large in numbers, many operational "weapon systems" STEM positions are presently small in number—for example, those in space and cyber operations. This increase in complexity of personnel attributes may require more specialized tools for specific needs. Experience identifiers that can be tracked (paralleling rated flying hours) will be a task for a STEM workforce management system and decision support model. The experience attributes analogous to the basic experience measure of flying hours for rated personnel may, in a STEM management system, need to be tracked by specific assignments, time in a particular AFSC, or other characteristics such as those included in the certification required under the Defense Acquisition Workforce Improvement Act (DAWIA) and discussed in Chapter 4.

By substituting specific educational background for specific rated training, one may begin to see how the Air Force can manage the important STEM-degreed and STEM-cognizant workforce for the future. Regardless of the differences in the comparative numbers of personnel, most of the inputs and products of the RMDSS would have close analogues in a STEM decision support model: Cumulative Continuation Rates, Total Active Rated Service(which in STEM could be called Total Active STEM Service), retention, professional military education, continuation training, entitlements, absorption capability, experience levels, promotions, retention, etc. Some of these rated-personnel attributes are used by many functional managers as basic tools for workforce management. Suitable STEM analogues should likewise be used for managing STEM-degreed and STEM-cognizant personnel. A difference is that the STEM-degreed and STEM-cognizant workforce needs to be aggregated and managed not only according to individual functions/AFSCs but also as families of functions/AFSCs based on education, experience, and past utilization.

STEM MANAGEMENT AND PRIOR OFFICER DEVELOPMENT INITIATIVES

This section discusses an organizational home within the Air Force for permanent STEM management. The recent history of officer development initiatives in the Air Force provides context for the committee's recommendation on this point. Beginning in 1999, General Michael Ryan, then the Air Force Chief of Staff, launched several initiatives to enhance the development of high-potential officers. Over the ensuing 5-year period, the Air Force established several new organizational entities dedicated to this purpose.

The Air **Force Senior Leader Management Office** (AFSLMO) was formed in 2000 by merging the functions then being performed by the General Officer Management Office (GOMO) and the Senior Executive Management Office. It later assumed responsibility for managing colonels, chief master sergeants, and GS-15s. AFSLMO was disbanded in 2005, and its responsibilities were redistributed much as they had been prior to its formation. GOMO and AFSLMO were active in promoting new force development constructs for the Air Force. A series of force development advisory committees, originally formed by GOMO in 1999, evolved into a full-time staff to support force development.

The **Developing Air Force Leaders** (DAL) office, established in 2001, had a high-level advisory committee chaired by the Vice Chief of Staff, Air Force with membership composed of vice commanders of the major commands and Air Staff deputy chiefs of staff or equivalents. When the DAL office was deactivated in 2003, the advisory committee continued to operate first as the Force Development Council and later as the **Force Management and Development Council** (FMDC). A representative of the Air Force Director of Force Development (AF/A1D1) described to the committee the roles of the FMDC, its subpanels, and the development teams

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

convened by functional managers.[6] Its role is prescribed in Air Force Policy Directive (AFPD) 36-26, *Total Force Development* (USAF, 2008).[7]

AFPD 36-26 also recognizes the responsibilities of functional authorities to promote effective development of workforces within their functional communities. Per this directive, functional authorities designate functional managers, who are senior leaders responsible for day-to-day oversight of development within their functional area, and career field managers, whose primary responsibility is to manage development and other career field issues. The directive also requires that functional authorities create development teams to guide the development of individual officer and civilian personnel to meet both functional and Air Force corporate leadership requirements (USAF, 2008).

Another product of the AFSLMO era was the publication of Air Force Doctrine Document (AFDD) 1-1, *Leadership and Force Development,* which articulates leadership and force development principles and tenets and provides a framework for measuring and developing them (USAF, 2004). It includes, as components of leadership, the Air Force's three core values (integrity, service before self, excellence) and its enumerated leadership competencies.[8]

The FMDC serves as a corporate body to provide an institutional perspective on Air Force–wide force development issues and to make recommendations to the Secretary of the Air Force and Chief of Staff, Air Force. The Air Force Assistant Secretary for Manpower and Reserve Affairs, Air Force functional authorities, vice commanders of the major commands, the Chief Master Sergeant of the Air Force, and appropriate Air Reserve Component and civilian representation make up the FMDC and provide a review of total force management. The Vice Chief of Staff, Air Force (VCSAF) chairs the FMDC (USAF, 2008, pg. 7). As Chapter 2 described in detail, STEM-degreed and STEM-cognizant personnel are dispersed throughout the Air Force, and their STEM-related capabilities are now and will continue to be of value across Air Force domains and missions. Thus, the FMDC, with its Air Force–wide scope of responsibility and representation, is the appropriate organization to provide oversight of a STEM management system.

Finding 6-1. The Air Force does an excellent job of recruiting, managing, and developing officers and civilians in career fields that it values and considers mission essential. A paradigm example is the Air Force's training, management, and development of rated personnel. In the past, the Air Force had a robust supply of STEM-degreed and STEM-cognizant personnel and thus did not devote special attention to managing them. Because of the changing demographics of the American population and the increasing technical complexity of the Air Force mission, this approach will no longer work. To maintain the technical competency of the Air Force, active management of the STEM-degreed and STEM-cognizant workforce is essential.

Recommendation 6-1a. To manage the critical STEM-degreed and STEM-cognizant personnel assets for the future Air Force, two actions should be taken. First, the Air Force should establish a

[6]Greg Price, Force Development Integration, AF1/A1D1, briefings to the committee on August 26, 2008.

[7]The FMDC is principally supported by the Director of Force Development (AF/A1D). Its development teams are principally supported by the Director of Assignments at the Air Force Personnel Center (AFPC/DPA). The FMDC has chartered panels to formulate policy recommendations for its consideration. These include an Officer Force Development Panel, Enlisted Force Development Panel, and Civilian Force Development Panel, Air Force Learning Committee, Expeditionary Skills Senior Review Group, and Nuclear Enterprise Advisory Panel (Buzanowski 2008).

[8]The list of competencies in the current version of AFDD 1-1 will eventually be replaced by an institutional competency list (ICL). *STEM-related skills are not specified as either competencies or subcompetencies in the ICL*, but they are sometimes represented in definitional statements. For example, "Utilizes innovation and technology in the employment of lethal and non-lethal force" appears under the subcompetency *operational and strategic art*. "Uses analytic methods in solving problems and developing alternatives" appears under the subcompetency *decision-making*.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

STEM Council to review policies and implementation and make recommendations on STEM accessions, utilization, and competencies across all Air Force missions, organizations, and career fields. This group should also determine what the minimum science, engineering, and mathematics educational requirements should be for STEM cognizance and determine which positions require STEM cognizance. This STEM Council should be a subcouncil to the Force Management & Development Council (FMDC).

Recommendation 6-1b. The Air Force should develop a decision support model, analogous to the Rated Management Decision Support System, to predict future requirements, inventory, and impacts of personnel policies and decisions, not only for specific career specialties but also for the aggregate needs of maintaining the technical competency of the overall Air Force.

Finding 6-2. Most Air Force functions have a designated advocate at the Air Force Headquarters level. This is an important step in managing a workforce. Since the Air Force has never managed STEM capability/functions as a distinctive entity across AFSCs and across major commands, STEM-degreed and STEM-cognizant personnel do not have a functional advocate.

- The Military Deputy to the Assistant Secretary of the Air Force for Acquisition is the one officer on the Air Staff who both sits on the FMDC and, through the Requirements Process, is close to both the acquisition workforce and the major commands. In the committee's view, this position is particularly appropriate as the designated advocate for STEM-degreed and STEM-cognizant personnel across the entire Service.
- Currently, the Air Force Deputy Chief of Staff for Manpower and Personnel (AF/A1) is responsible for sustainment and use of career-force models for all current AFSCs. While many of these models were originally not developed in-house (i.e., the developer may have been a contractor or federally funded research and development center), the AF/A1 now has responsibility for their oversight and use. Thus, it is reasonable for oversight and use of a newly developed STEM decision support model to be under this official.

Recommendation 6-2. Overall functional management of STEM-degreed and STEM-cognizant personnel should be accomplished in a manner similar to management of flight-qualified officers through the Rated Management system. The Military Deputy to the Assistant Secretary of the Air Force for Acquisition should be the functional advocate for all STEM personnel, and the Deputy Chief of Staff for Manpower and Personnel (AF/A1) should oversee STEM decision support modeling, as well as recommending and implementing STEM personnel policies.

MEETING FUTURE NEEDS FOR OFFICERS WITH STEM CAPABILITIES

The Air Force has two general approaches available to it for meeting its future requirements for STEM-degreed and STEM-cognizant officers. The first involves retaining the existing officer force. The second is to acquire new STEM-degreed and STEM-cognizant officers through accession. These approaches are obviously not mutually exclusive, and some optimal combination of options from both approaches will be needed. In this section, the committee discusses multiple options for retention first, then options for acquiring new officers. However, a STEM decision support model, as discussed in the previous section (see Recommendation 6-1b), will be needed to ascertain what practically feasible combination of options is most effective for achieving Air Force priorities, goals, and objectives.

Proper management of human capital is vitally important to the Air Force, especially when that capital is critical to mission accomplishment, in short supply, and difficult to recruit and retain. Moreover, continuous oversight is necessary because personnel requirements and

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

inventory are constantly changing. The difficulties involved in predicting future STEM needs and determining whether there are likely to be shortages in STEM-degreed and STEM-cognizant personnel are addressed elsewhere in this report. At present, however, it appears to the committee that the Air Force is able, with a few exceptions,[9] to meet its stated recruiting goals for STEM positions. Retention is another matter.

Retaining STEM-Degreed Officers

Retention is one of the primary challenges confronting managers of STEM-degreed personnel. This was a persistent theme expressed by product center and air logistics center commanders who briefed the committee (see leadership comments in Chapter 4). Retention problems within the Air Force have been exacerbated, in the committee's judgment, by recent decisions to decrease end strength.

Presentations at the Inside Aerospace conferences in 2008 and 2009 noted that, if people feel that they are valued within their organizations, they are less likely to leave. This was described as especially true for younger generations (AIAA, 2008; 2009). In the experience of committee members who worked with STEM-degreed personnel in the Air Force, another consideration is that, for government personnel, many times the "grass seems greener" on the other side—for example, if pay and benefits in the private sector are coupled with perceptions of long-term job availability in STEM-related careers. Furthermore, in the military, the door only opens one way; when experienced military personnel are lost to the private sector, they rarely return to military service. Even when military personnel do return via civil service,[10] their positions must be carefully managed to prevent their civilian counterparts from feeling that the potential for upward mobility has been reduced.

Among the primary contributors to the retention problem is a perception prevalent within the STEM-degreed workforce—especially among members of Generation X—of being undervalued. This perception was highlighted by several of the young professionals (less then 5 years in industry) at Inside Aerospace 2009 (AIAA, 2009) and was echoed by several STEM-degreed officers[11] who were released during the recent force-shaping initiatives, which released a significant number of STEM-degreed personnel. Such a perception can of course be changed, but not unless sustained actions are taken to counteract it.

Based on the presentations, described in Chapters 3 and 4, from commanders and staff of the Air Force product and logistics centers and on the committee's discussions with the chief scientists of major commands,[12] the committee identified several specific areas of concern for retention. Each is a problem in its own right and, in the committee's judgment and experience, contributes to the perception of being undervalued. In combination, they have had particularly negative effects on efforts to keep talented and capable individuals from seeking opportunities outside the Air Force.

First, placing lieutenants in an oversight position in acquisition without proper preparation and training seems, in the committee's judgment, likely to detract from their performance. Lack of performance leads to delayed promotion or to separation. Delayed promotion results in less responsibility and upward mobility. The overall result is lack of promotion of experienced personnel and an increase in experience waivers. The perception of the young officers or civilians

[9]In 2008, the Air Force was unable to meet its accession goals for six S&E career fields.

[10]The Air Force's civilian workforce comprises 22 percent former enlisted personnel and 6 percent former officers.

[11]Discussions with George Muellner, committee co-chair, at an AIAA Section Meeting in Dayton, Ohio.

[12]Dr. Janet S. Fender, Chief Scientist, Air Combat Command, briefing to the committee on December 3, 2008; Dr. Don Erbschloe, Chief Scientist, Air Mobility Command, briefing to the committee on December 3, 2008.

Copyright © National Academy of Sciences. All rights reserved.

is likely to be that there is a glass ceiling. They cannot see themselves moving up in the system, but instead see personnel from outside their career fields being assigned to or promoted into the leadership positions they should aspire to fill in the coming years. This diminishes their perceived value. In times of transition within a major command, when a major change in direction is required or desired, it is conceivable that the best option may be to choose a person for a leadership position because of his/her broad general background and demonstrated leadership skills in times of significant transition. When that is the case, the leadership making such a decision should make clear why such an assignment is being made.

A second area of concern to the committee is that large numbers of vacancies are a daily visible sign that a position is not valued enough to commit the time and resources to backfill. Unfilled vacancies lead to more work on remaining personnel, resulting in decreased performance and increased burnout, inability to attend training, and other negative impacts on personnel.

Assigning general officers without STEM qualifications to acquisition positions is a third practice that sends a strong message to colleagues in STEM-requiring career fields that their service and experience are not valued. Further, senior officers without domain knowledge of the many facets of the acquisition process cannot fulfill the important mentoring and role model responsibilities necessary to lead and inspire the next generation of acquisition leaders. It will be a particular challenge to develop this expertise in space operations, cyber operations, and other areas of growth for future STEM needs.

Finally, because of the shortage of STEM-degreed officers, there has been a rush to contract out some inherently governmental tasks, including CONOPS development and requirements generation on the operational side and some project management responsibilities and oversight on the acquisition side. In the committee’s judgment, this use—or misuse—of contracting affects the perceived value of an individual’s contributions and sometimes creates the impression that military officers are merely performing a contractor’s job without bringing any special attributes or viewpoints to the table.

These are four examples of areas where current practices contribute to perceptions of “not being valued”—and these perceptions may cascade into reality.

Assignment of STEM-Degreed Personnel

STEM-degreed personnel tend to be placed in either STEM-related or operationally focused assignments. Many STEM graduates are justifiably proud of their academic achievement and want to put their “extra” academic effort to work on meaningful projects. However, instead of being given assignments where they can apply these accomplishments, many times they are put in oversight positions where they are asked to supervise contractor personnel whose STEM knowledge, experience, and maturity exceeds their own. This lack of grooming often leads to frustration because the new graduates are not using their hard-won educational skills and they are not properly prepared for their supervisory roles. In contrast, if they were first afforded an opportunity to acquire knowledge of Air Force operations and apply existing skills, and then were transitioned to supervisory roles after they had received proper mentoring and training, the committee believes these young STEM-degreed officers would make more-substantial contributions, experience less job dissatisfaction, and add both real and perceived value for the Air Force mission.

Copyright © National Academy of Sciences. All rights reserved.

Military Promotions of STEM-Degreed Officers

Promotions have lasting, across-the-board impact. They affect not just job title and income but level of responsibility and sense of self worth. In the military, the symbols of rank are visible reminders to others of how one is valued by "the system."

Within the acquisition community, STEM-degreed personnel compete well for promotions at the lower ranks, but they do not compete as well for promotions to higher ranks.[13] Thus, the acquisition workforce is rich in STEM-degreed lieutenants and undermanned in STEM-degreed officers at every higher grade. Because of this, many highly qualified and experienced officers separate or seek early retirement. As of January 2009, authorized program manager positions at the level of colonel were only 71 percent filled (see Table 3-2 in Chapter 2). According to the Director of Acquisition and Career Management, the Air Force desires 50 percent of its field grade officers who are program managers to have a STEM degree; currently, only 30 percent have a STEM degree.[14]

However, statistics regarding officer promotions can also be misleading. The FMDC should review promotion rates both in the promotion zone (IPZ) and below the zone (BTZ). One can look at IPZ promotion board results and be content, but promotion to general officer is highly correlated with early promotion BTZ at the rank of lieutenant colonel or colonel. Therefore, to determine if a career field is viable in promoting enough officers to sustain it at the highest ranks, the BTZ promotion rates must be examined.

Finding 6-3a. Multiple reductions in STEM-degreed authorizations and STEM-degreed personnel have had a negative impact on manning levels and morale and may be affecting the ability to recruit.

Finding 6-3b. Both promotion and experience are required for growing future acquisition leaders. As discussed in Chapter 4, in recent history many senior acquisition leaders required waivers from DAWIA requirements for prior acquisition experience.

Recommendation 6-3a. Promotion rates should be monitored to ensure that qualified acquisition officers are available at lower ranks to meet DAWIA requirements and experience needs for accessions to higher ranks.

Recommendation 6-3b. The Air Force should use a STEM management decision support model (see Recommendation 6-1) to understand long-term impacts of cuts in authorization or manning for career fields requiring a STEM degree and to ensure that the leadership understands all the likely impacts of such cuts.

Options for Meeting STEM Needs with the Existing STEM-Degreed Officer Workforce

The committee identified three general options available to the Air Force to meet current and future STEM needs with existing officer assets. After describing each option in value-neutral

---

[13]This committee statement is based on (1) Air Force promotion data reviewed by committee members but not publically released, committee discussion with Air Force presenters from the acquisition community (see Appendix B), and the personal experience of committee members while serving in the Air Force acquisition community.

[14]Patrick Hogan, Director of Acquisition and Career Management, SAF/AQXD, briefing to the committee on December 3, 2008.

Copyright © National Academy of Sciences. All rights reserved.

terms, the committee discusses the challenges and issues it sees for implementing the option. Committee findings and recommendations are presented after all three options are discussed.

Option 1: Reallocate STEM-degreed officers who are currently serving in AFSCs that do not require a formal STEM education

Description. The Air Force currently has a significant number of active-duty, STEM-degreed officers currently serving in AFSCs (or positions within certain AFSCs) for which there is currently no formally established STEM requirement. Most notably, it has been estimated that approximately 45 percent of the pilots, 34 percent of navigators/CSOs, and 20 percent of air battle managers are STEM-degreed. Under this option, after establishing STEM requirements for all career fields, the Air Force could elect to selectively reassign STEM-degreed officers serving in positions that do not *require* those STEM capabilities to positions that require their STEM capability, if it judged the positions requiring a STEM degree to be a higher priority.

Challenges and Issues. This option has to be very carefully considered and executed with sensitivity to the potentially negative career impacts on the individual officers who are asked to make mid-career changes between career fields. Such reassignments should be career-enhancing where possible, recognizing that the needs of the Air Force come first. In considering its priorities for reassigning STEM-degreed military personnel, the Air Force also needs to bear in mind that it is an inherently technical service and there is value in having some STEM-degreed personnel in every career field.

Option 2: Use STEM-degreed Reserve and Guard officers

Description. A second option to meet STEM needs with the existing officer workforce is to use STEM-degreed officers from the Air Force Reserve and Air National Guard to help meet requirements for STEM-degreed personnel. Significant STEM-degreed capability (and by extension, STEM-degree requirements) resides in the Air National Guard and Air Force Reserve officer components. Table 6-1 shows the officer populations in both reserve components for the five career fields requiring a STEM degree and for the 63A Acquisition Management career field.

TABLE 6-1. Air National Guard and Air Force Reserve Officers in Fields Requiring a STEM Degree and in 63A Acquisition Management

	15W	32E	33S	61S	62E	63A	Total
Air National Guard	90	486	920	9	11	3	1,511
Air Force Reserve	59	378	520	66	342	190	1,555

SOURCE: AFPC IDEAS Personnel Statistics Database, January 9, 2009.

Conceivably, it would be possible to establish specialized Reserve or Guard units to provide STEM support to the Air Force. One attractive alternative would be to constitute these units in locations that are proximate to the product centers, AFRL locations, and other organizations having significant requirements for STEM-degreed personnel.

Challenges and Issues. In the near term, this option would have to be executed within the statutory and regulatory constraints that govern the Air Force Reserve and the Air National Guard. Policies and procedures would also have to be established to preclude any potential conflicts of interest that might arise for individual officers whose civilian employment was with a company competing for Air Force contracts.

Copyright © National Academy of Sciences. All rights reserved.

Option 3: Provide STEM education to existing officers through the Air Force Institute of Technology (AFIT) and Naval Postgraduate School (NPS)

Description. A third option for meeting STEM needs with the existing officer workforce is to provide selected active-duty officers with additional STEM education to make them fully STEM-degreed. This could be accomplished through AFIT, either at its resident school or in collaboration with selected civilian institutions. It could also be done in collaboration with NPS. This option is already routinely exercised to provide selected Air Force officers with graduate-level STEM education at both the masters and doctoral levels. These are usually officers who have earned an undergraduate degree in a STEM major, although not necessarily in the same STEM discipline in which they are pursuing a postbaccalaureate degree. The Air Force can also enroll selected officers who have earned a non-STEM undergraduate degree in particular STEM-related graduate programs—for example, in operations research.

This AFIT option could also be used to increase the number of STEM-degreed officers at the undergraduate level. For example, in the past, to meet the Air Force demand for electrical engineers, AFIT established a two-year program that granted a bachelor of science degree in electrical engineering to selected officers who met certain academic prerequisites. AFIT also offers technical continuing education courses for officers to take throughout their careers, to help them keep current on the latest technologies. Currently, AFIT provides continuing education opportunities in STEM areas through its School of Civil Engineering and Services and its School of Systems and Logistics.

Challenges and Issues. The primary challenge in expanding the use of AFIT and NPS is one of resources. Selecting an officer for an AFIT-managed educational assignment takes the officer "off line" for one to three years, exacerbating any personnel shortages that might already exist within particular AFSCs. Additionally, if AFIT programs are established to increase significantly the number of officers with STEM graduate (or undergraduate) degrees, additional funding and/or faculty resources would likely be required.

Findings and Recommendations on Managing the Existing Officer Workforce

Finding 6-4. The Air Force does not currently have a process in place to systematically review its allocation and utilization of STEM-degreed officers in light of changing requirements and priorities.

Recommendation 6-4. Under the direction and oversight of a STEM subcouncil of the FMDC (see Recommendation 6-1), the Air Force should establish a process to review systematically and (at least) annually the utilization of all of its STEM-degreed officers, with the goal of assigning these officers to the Air Force's highest-priority STEM and non-STEM requirements. This should be done in conjunction with a similar review of STEM-degreed civilians (see Recommendation 6-11). Note that this recommendation cannot be implemented without a clear definition of STEM requirements for each career field.

Finding 6-5. The Air Force has not assessed the potential for STEM-degreed officers in the Air Force Reserve and the Air National Guard to help meet the Air Force's requirements for STEM-degreed personnel.

Recommendation 6-5. Under the direction and oversight of a STEM subcouncil to the FMDC (see Recommendation 6-1), the Air Force, in collaboration with the National Guard Bureau and the Commander of the Air Force Reserve Command, should conduct an in-depth assessment of

Copyright © National Academy of Sciences. All rights reserved.

the potential for the Air Force Reserve and the Air National Guard to contribute to meeting the STEM capability needs of the Air Force, through either existing programs or new initiatives.

Finding 6-6. The AFIT currently offers a number of degree, certificate, and short-course programs (and could potentially offer additional programs) that would increase the number of STEM-degreed officers available to meet Air Force STEM needs. In particular, the AFIT resident school offers graduate STEM education programs that address problems of unique importance to the Air Force; comparable programs are not available at civilian institutions.

Recommendation 6-6a. The Air Force should periodically access the capability of AFIT to help meet projected future requirements for STEM-degreed personnel by providing selected officers and civilians with educational opportunities leading to an award of a STEM degree. In addition, the STEM personnel decision support model (see Recommendation 6-1) should include a sufficient number of military and civilian AFIT student positions to enable use of these AFIT opportunities, in addition to modeling the STEM personnel required for direct mission support. Consideration should be given to the following educational options:

- Graduate-level STEM education (both degree and certificate programs) at the resident school, through civilian institutions, or through on-line or other decentralized education modes; and
- Continuing education in STEM disciplines, to help STEM-degreed personnel remain current with changing science and technology. Again, these courses can be offered at the resident school, through civilian institutions, or through on-line or other decentralized education modes.

Recommendation 6-6b. The Air Force should consider directing AFIT to develop modules of instruction to help increase the STEM cognizance of Air Force officers and civilians who are not STEM-degreed. These STEM-cognizance instruction modules can be delivered through various mechanisms such as professional military education, Acquisition Corps certification courses, base education offices, on-line courses, and other means. Such educational opportunities could significantly increase STEM cognizance across all officer career fields and civilian occupations.

Acquiring Additional Officer Assets

The Air Force has (and will continue to have) three major avenues for accessing new STEM-degreed officers into the Air Force. These are the United States Air Force Academy (USAFA); the Air Force Reserve Officer Training Program; and the Officer Training School (OTS). Each of these accessing mechanisms has both advantages and disadvantages. As with the options discussed above for managing existing STEM-degreed officer assets, the initial description of each of these accession avenues is followed by the committee's assessment of challenges and issues in expanding the avenue to increase STEM-degreed and STEM-cognizant personnel. Findings and recommendations are presented after the discussion of all three avenues.

U.S Air Force Academy

Description. The USAFA in Colorado Springs, Colorado, is one of the nation's federally chartered academies for the undergraduate education and training of commissioned officers for the United States armed forces. Candidates are selected on the basis of academic, leadership, extracurricular, and physical fitness criteria. The academy has a four-year program—including summers—that is intended to expose the student (cadet) to the military lifestyle and culture while delivering a demanding academic education. Upon graduation, cadets are commissioned as second lieutenants. There are approximately 1,400 openings at the academy each year, of which

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

85 are reserved for active duty airmen. Upon completion of the four-year program, cadets receive a bachelor of science degree and a commission. The USAFA offers degrees in 32 majors.

Of the 41,000 line officers in the Air Force, over 9,500 graduated from the USAFA.[15] By virtue of their academy education, they are all STEM-cognizant under the committee's definition (see Table 1-2). Almost 1,800 of these 9,500 USAFA graduates currently serve in one of the five career fields that require a STEM degree or in the 63A Acquisition Management career field. Figure 6-1 depicts the rate of entry (first assignment) into a career field requiring a STEM degree for the USAFA graduating classes from 2000 through 2008. Figure 6-2 shows the distribution of these new accessions among the five career fields that require a STEM degree. Figure 6-3 shows the distribution from these same graduating classes into career fields that do not require a STEM degree, including Acquisition Management and Operations.

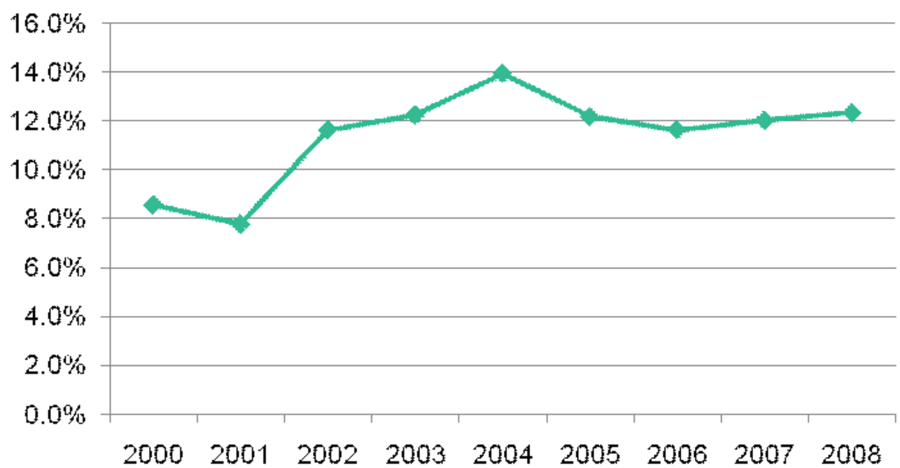


FIGURE 6-1. USAFA Graduates Entering a Career Field Requiring a STEM Degree as First Assignment, Classes of 2000 through 2008. SOURCE: Brig. Gen. Dana Born, Dean of the Faculty, USAFA, briefing to the committee on December 4, 2008.

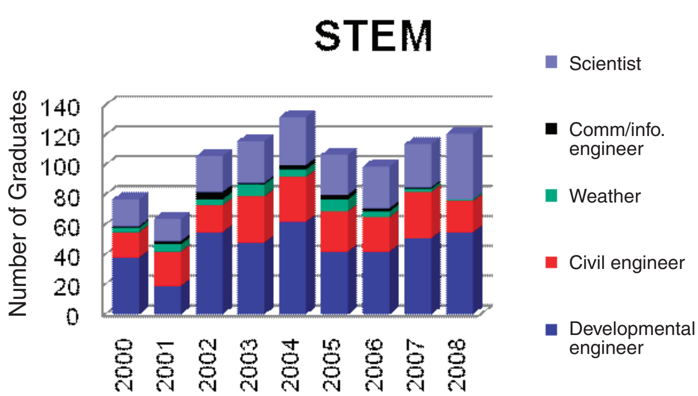


FIGURE 6-2. Distribution of USAFA Graduates, 2000 through 2008, among the Five Career Fields Requiring a STEM Degree. SOURCE: Brig. Gen. Dana Born, Dean of the Faculty, USAFA, briefing to the committee on December 4, 2008.

[15] Brig. Gen. Dana Born, Dean of the Faculty, USAFA, briefing to the committee on December 4, 2008.

Copyright © National Academy of Sciences. All rights reserved.

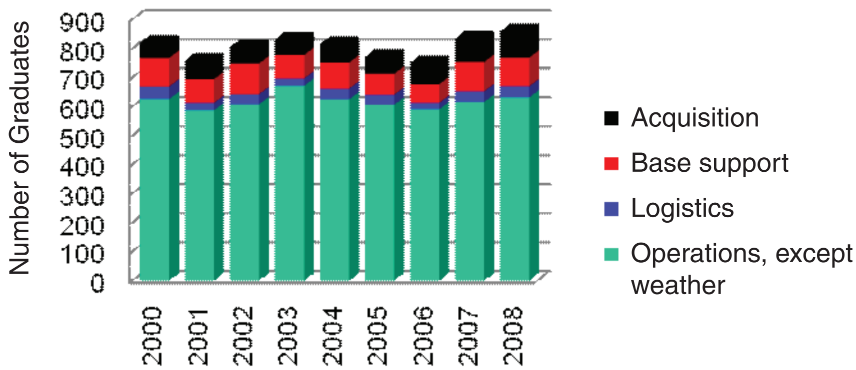


FIGURE 6-3. Distribution of USAFA Graduates, 2000 through 2008, among non-STEM-requiring Career Fields. Acquisition includes both 63A (Acquisition Management) and 64P (Contracting) AFSCs. Operations excludes 15W (Weather) AFSCs. SOURCE: Brig. Gen. Dana Born, Dean of the Faculty, USAFA, briefing to the committee on December 4, 2008.

The USAFA is already committed to ensuring that all graduates are at least STEM cognizant through its requirement that all cadets take a set of core science and technology courses, whatever their intended major field of study. From time to time, the USAFA leadership revisits this core set of courses to ensure that it continues to meet evolving Air Force needs.

The Air Force provides an avenue for enlisted airmen to attend the USAFA. The Leaders Encouraging Airmen Development (LEAD) Program delegates authority to unit and wing commanders to nominate highly qualified airmen to become Air Force officers via attending and graduating from the USAFA. Depending on a candidate's educational qualifications, a LEAD nomination may provide direct entry to the USAFA, entry to the USAFA Preparatory School, or referral to other programs.

Challenges and Issues. The USAFA annually graduates and commissions approximately 1,000 officers. Currently, about 41 percent graduate with a STEM degree. In recent years, the number and percentage of officers graduating with STEM degrees has been declining. Moreover, of this 41 percent, a significant number enter rated AFSCs or other AFSCs for which a STEM degree is not a formal requirement.[16] However, since the USAFA is an asset organic to the Air Force, the Air Force leadership has the option of directing the USAFA to require that a larger percentage of cadets pursue STEM degrees. The Air Force leadership can also influence curriculum content to some degree, subject to a number of constraints. For example, the committee determined that the Chief of Naval Operations recently directed the U.S. Naval Academy to have 65 percent of the midshipmen in the Class of 2013 graduate with a STEM degree (Harvey, 2007**)**. However, as this example illustrates, such a policy decision to increase the number and/or percentage of graduates with a STEM degree could take up to 4 years to achieve the mandated result.

[16]Brig. Gen. Dana Born, Dean of the Faculty, USAFA, briefing to the committee on December 4, 2008.

Copyright © National Academy of Sciences. All rights reserved.

Air Force Reserve Officer Training Corps

Description. The Air Force Reserve Officer Training Corps (AFROTC) delivers the largest number of officers to the military Services each year. AFROTC offers programs through more than 1,000 colleges and universities, including some with long-standing military traditions, such as Virginia Tech, Texas A&M, Norwich University, The Citadel, and Virginia Military Institute. AFROTC scholarships are widely available and are used to help meet specific academic requirements, as well as quantitative requirements, for officers. The availability of degree-focused scholarships has historically been the primary mechanism used to encourage AFROTC cadets to pursue academic programs leading to a STEM degree.

AFROTC cadets attend civilian colleges and may choose their majors, but they must take military-oriented courses throughout the period of their association with AFROTC. They also participate in structured military organizational activities and military drill, as well as a 4–6 week field exercise during one summer, to orient them to military organizations and bases and to help determine their career field, consistent with Air Force needs and their desires. Upon graduation, AFROTC cadets are commissioned as second lieutenants.

The Air Force also has a number of programs to encourage enlisted airmen to complete their undergraduate education and earn a commission through the AFROTC program. For example, the Airman Scholarship and Commissioning Program allows enlisted personnel to separate from active duty and receive scholarships while pursuing their commission through AFROTC. Scholarships are awarded in a variety of fields, including both STEM and non-STEM fields. Selections are based on Air Force officer production requirements.

The Technical Degree Sponsorship Program is intended to increase the accession rate of individuals with engineering and other technical degrees by allowing the Air Force Recruiting Service to recruit and place junior (no more than 24 months from graduation) and senior college students on (enlisted) active duty prior to college degree completion. This program also applies to graduate students no more than 24 months from graduation. The program's intent, which is consistent with its supporting resources, is to maintain 25 enlistees who are 24 months from graduation and 25 enlistees who are 12 months from graduation.

Challenges and Issues. The AFROTC program has the potential for producing the largest number of STEM-degreed (and STEM-cognizant) officers. The program is voluntary and depends primarily on the use of focused scholarships as an incentive to attract students enrolled in undergraduate STEM degree programs. Consequently, if the Air Force elected to invest significantly more in STEM-focused AFROTC scholarships, it would take 2 to 4 years to have a significant effect on the number of STEM-degreed officers entering the Air Force.

There is no current requirement that all students commissioned through the AFROTC program be at least STEM-cognizant. Thus, if acknowledging and managing STEM cognizance is recognized as part of the solution for meeting future STEM needs, establishing and implementing such a requirement for AFROTC scholarships would in time substantially increase the accession of STEM-cognizant officers. Because the curricula at the various academic institutions attended by AFROTC cadets are not under the direct control of the Air Force, measures to ensure that AFROTC graduates are at least STEM-cognizant and preferably STEM-degreed would necessarily be more nondirective than at the USAFA and may need to be achieved through incentives. For example, most colleges and universities operate under the principle of "shared governance," in which curriculum content and changes must be approved by the Faculty Senate or analogous faculty body. The senior military officer at an AFROTC detachment typically holds a faculty appointment and, directly or through his/her representative to the Faculty Senate, could make recommendations for changes in curriculum policy and content.

Copyright © National Academy of Sciences. All rights reserved.

Officer Training School

Description. OTS, the third major avenue for commissioning new Air Force officers, is the most flexible in terms of numbers of candidates accepted and commissioned and in the number and frequency of classes being trained. OTS is typically the shorter term cushion used to help adjust commissioning numbers during the year of execution, with the required number of officer candidates and skills recruited “off the street.” OTS Basic Officer Training is a 12-week course for college graduates (including some enlisted airmen) who wish to become officers. Candidates may have a degree in any field. However, those with STEM degrees typically have a better chance of acceptance. Selectivity tends to be extremely high, given the relatively small numbers selected each year for OTS.

Challenges and Issues. While OTS offers more flexibility and quicker response time for producing more STEM-degreed officers than do the USAFA or the AFROTC program, as a STEM option it would need to focus on candidates who already have an undergraduate STEM degree and are motivated to join the Air Force. Historically, OTS has produced relatively fewer officers than either the USAFA or AFROTC.

The Air Force Office of Scientific Research (AFOSR), a division of AFRL, annually funds hundreds of research projects at civilian universities. Collectively, these projects involve thousands of undergraduate and (especially) graduate students in STEM disciplines. In the process of working on their projects, these students are exposed to Air Force needs and opportunities for STEM capabilities. The committee is aware of instances where these students have applied for OTS and Air Force civil service positions as a result of their positive experience working on AFOSR-funded projects. These students represent a high-potential pool of OTS (and civil service) candidates that should be exploited by Air Force military and civilian recruiters.

Findings and Recommendations on Acquiring Additional Officer Assets

Finding 6-7. The USAFA is a major source of new officers that are either STEM-degreed or STEM-cognizant.

Recommendation 6-7a. The USAFA should periodically review the core curriculum to ensure that graduates with non-STEM majors nonetheless are STEM-cognizant—that is, that they have an adequate appreciation of the impact of science and technology on the Air Force’s ability to organize, train, and equip the forces required by combatant commanders in their respective areas of responsibility.

Recommendation 6-7b. The Air Force Chief of Staff should establish a goal for the minimum percentage of USAFA graduates with a STEM major, based on an assessment of requirements by the FMDC and recommendations from the Deputy Chief of Staff for Manpower and Personnel (AF/A1) and the USAFA leadership. The USAFA leadership, in collaboration with the faculty and staff, should identify and implement policies, procedures, and incentives to ensure that this goal is met.

Finding 6-8. AFROTC is the source of the largest number of new commissioned officers. This program offers considerable potential for helping the Air Force to meet its requirements for STEM-degreed officers.

Copyright © National Academy of Sciences. All rights reserved.

Recommendation 6-8. The Air Force should make full use of scholarships and other incentives to encourage AFROTC students to pursue degrees in STEM disciplines or, if they are not enrolled in a STEM-degree program, at least to take sufficient STEM courses to qualify as STEM-cognizant. In addition, Air Force officials should encourage the provost and faculty at institutions with AFROTC programs to include courses in the institution's undergraduate core curriculum that promote STEM cognizance.

Finding 6-9. The OTS gives the Air Force an important avenue to selectively access new officers who already possess specific STEM degrees.

Recommendation 6-9. The Air Force should establish annual goals for accessing STEM-degreed officers through OTS. These goals should be projected for the future 5-year period and reviewed and adjusted annually as appropriate. In recruiting candidates for OTS, the Air Force should consider those undergraduate and graduate students pursuing a STEM field of study who were (or are) involved in research projects funded by the Air Force Office of Scientific Research or Air Force Research Laboratory. Officers accessed through OTS who do not possess a STEM degree should be afforded the opportunity to attend one or more short (continuing education) courses developed and offered through AFIT (or other institutions) to qualify these individuals as STEM-cognizant.

MEETING FUTURE NEEDS FOR STEM-DEGREED CIVILIAN EMPLOYEES

As with military officers, the Air Force has two general approaches available for meeting its future needs and preferences for STEM-degreed civilian employees. The first involves managing the existing Air Force civilian workforce with an emphasis on retaining STEM-degreed personnel. The second approach is to hire new STEM-degreed civilian employees.

Managing and Retaining Existing Civilian Personnel Assets

The replacement of STEM-degreed civilians who leave the workforce is currently neither robust nor timely. In the past, the Air Force actively recruited STEM-degreed civilians and rewarded their service. As discussed in Chapters 3 and 4,[17] a large proportion of senior Air Force civilians in positions that require a STEM degree will become eligible for retirement during the next 15 years. Several leaders of logistics and product centers who discussed civilian workforce retention problems with the committee believe the Air Force is lagging the private sector in competing for STEM-degreed civilians and in training its existing civilian workforce to assume greater responsibilities in positions that require STEM capabilities.[18]

As is the case for military officer positions, fill rates are an important indicator of civilian job value. Based on committee members' experience, confirmed by discussions with Air Force presenters, the committee believes that if civilians see their colleagues leave and they are not replaced, this inaction sends a powerful message that those positions are not on the "A Team." Currently, the Air Force has a 15 percent vacancy rate in civilian STEM positions requiring a

---

[17]See text discussing Figure 3-1, as well as Finding 3-2, for STEM-degreed civilians in positions requiring a STEM degree and Figure 4-2 for STEM-degreed civilians in AFMC.

[18]Joe Sciaba, Executive Director, AFRL, AFMC, briefing to the committee on October 30, 2008. Patricia Robey, Director, Manpower and Personnel, Space & Missiles System Center, briefing to the committee on September 30, 2008. Lt. Gen. Ted F. Bowlds, Commander, Electronics System Center, briefing to the committee on October 30, 2008. Lt. Gen. John L. Hudson, Aeronautical Systems Command, videoteleconference with the committee on October 30, 2008.

Copyright © National Academy of Sciences. All rights reserved.

STEM degree.[19] And, against a goal of 50 percent of program managers having a STEM -degree, only 20 percent of civilian program managers currently have a STEM degree.[20] However, the real shortage may be much more acute. When force reductions due to budget shortfalls were necessary, the Air Force made a disproportionate share of the reductions from the STEM-degreed civilians in the acquisition workforce. The following year, the Air Force tried to rehire these same people but was largely unsuccessful.

The Air Force does have some limited ability to enhance the STEM capabilities of its existing civilian workforce. Within constraints (grade, geographic area, and qualifications), it can direct STEM-degreed civilians to move from positions that do not have a formal requirement for a STEM degree to positions having that requirement. It can also encourage STEM-degreed civilians to compete for those positions by offering incentives such as promotion and professional development opportunities.

The Air Force currently provides financial assistance to civilians who are interested in pursuing both undergraduate and graduate education in STEM (and non-STEM) programs. Limited numbers of Air Force civilians attend AFIT's Graduate School of Engineering and Management on a full-time basis, along with their officer counterparts. Air Force civilians also attend AFIT's continuing education schools (e.g., the School of Civil Engineering and Services and the School of Systems and Logistics) to maintain their technical proficiency and currency.

Finding 6-10. Fill rates are an important indicator to the civilian workforce that their jobs are valued. Based on assessments from several Air Force leaders who briefed the committee (Chapter 4) and civilian vacancy rates in program management (Chapter 6), the hiring process for STEM-degreed civilians is not timely. In the committee's judgment, this contributes to a perception in the civilian workforce that the unfilled positions are not valued.

Recommendation 6-10. The Air Force should develop policies and devote resources to recruit STEM-degreed civilian personnel in a timely manner.

Finding 6-11. The Air Force does not currently have a process in place to systematically review its allocation and utilization of STEM-degreed civilians in light of changing requirements and priorities.

Recommendation 6-11. The Air Force should establish a process to assess systematically and (at least) annually the utilization of its STEM-degreed civilian workforce. This review should include accessing the need to offer additional incentives to encourage STEM-degreed personnel to compete for assignment to the Air Force's highest-priority STEM positions. This assessment should be done in conjunction with a similar review of assignments for STEM-degreed officers (see Recommendation 6-4).

Acquiring Additional Civilian Assets

The second general approach for meeting the Air Force's requirements for STEM-degreed civilians is through the recruiting and hiring process. For purposes of this study, the committee focused primarily on the policies and processes by which the Air Force recruits and hires new STEM-degreed civilians.

[19] Patrick Hogan, Director of Acquisition and Career Management (SAF/AQXD), briefing to the committee on December 8, 2008.

[20] Patrick Hogan, Director of Acquisition and Career Management (SAF/AQXD), briefing to the committee on December 8, 2008.

Copyright © National Academy of Sciences. All rights reserved.

The Air Force draws on two major sources to meet its requirements for STEM-degreed civilian personnel. The first is STEM-degreed civilians who are employed outside the Federal Civil Service—for example, in the private sector or in nonfederal government organizations. The second source comprises college students who are completing an undergraduate or graduate STEM degree. In the latter case, the Air Force has the capability to offer scholarships or fellowships to students in exchange for a commitment for some minimum period of Federal Civil Service.

The Air Force can also use the authorities provided by the Intergovernmental Personnel Act (IPA) to meet temporary STEM requirements or as a temporary means of staffing permanent STEM positions that are difficult to fill. The IPA provides the Air Force with the authority to compete for the (temporary) services of individuals who might not otherwise be available at the compensation levels the Air Force is authorized to pay its permanent Civil Service employees. Under the IPA, an individual with particular STEM expertise who is an employee of another government organization (federal, state or local), a university, or other qualifying (nonprofit) organization can be assigned—in effect, "loaned"— to the Air Force for a period of up to 4 years. Under this arrangement, the Air Force is authorized to reimburse the "loaning" organization for the employee's salary and benefits.

The committee identified two major challenges to recruiting and hiring STEM-degreed civilian employees. The first is related to funding; the second relates to the lengthy process to recruit and hire new civilians who are not currently in the Federal Civil Service.

Funding New Civilian Hires

The funding of civilian pay continues to be a significant challenge to those in the Air Force recruiting STEM personnel. The committee heard this repeatedly from presenters and interviewees.[21] The issue is three-fold: operations and maintenance (O&M) funding versus research, development, testing, and evaluation (RDT&E) funding; timing; and predictability. A large portion of the Air Force STEM-degreed acquisition workforce is funded from the O&M budget (Account 3400). Other portions of the STEM-degreed workforce, such as AFRL, are funded from the RDT&E budget (Account 3600). O&M funding levels vacillate, sometimes significantly, from year to year. The appropriation for the 3400 line item is for one year only, and for the Air Force this funding line has been highly stressed by the challenge of the increased cost of sustaining aging aircraft. Thus, the Civilian Pay account under this same funding line gets perturbed significantly every year to balance the "must pay" O&M bills, creating workforce instability. The appropriation for the 3600 funding line, which is appropriated for multiple years, enjoys more stability.

This variability, coupled with late budget approvals from Congress, typically delays O&M funding until the end of the first quarter of each fiscal year. Although Continuing Resolution authority allows the federal government to operate in the absence of congressionally enacted appropriations for the current fiscal year, this authority typically limits operations to spending at the previous year's level (or some other restricted level). It does not permit new starts (e.g., new programs) and may include a specified or de facto hiring freeze. Moreover, an authorized O&M funding level can arbitrarily be further decremented (for example, from an authorized 97 percent to 92 percent) at the beginning of the fiscal year to offset other Air Force budget needs. This makes employment planning tenuous and filling of positions requiring a STEM degree more

[21]Patrick Hogan, Director of Acquisition and Career Management (SAF/AQXD), briefing to the committee on December 3, 2008. Lt. Gen. Ted F. Bowlds, Commander, Electronic Systems Center, AFMC, briefing to the committee on October 30, 2008. Lt. Gen. John L. Hudson, Commander, Aeronautical Systems Center, AFMC, briefing to the committee during videoteleconference on October 30, 2008.

Copyright © National Academy of Sciences. All rights reserved.

challenging than it would otherwise be. If additional money becomes available later in the fiscal year, often in the fourth quarter, it is too late to help the civilian employment program.

Hiring Time

Nearly every Air Force field location representative who briefed or communicated with the committee—including AFRL, air logistics centers, product centers (such as the Space and Missile Systems Center at Los Angeles), logistics centers, and test centers—said that one of their biggest challenges (if not the biggest challenge for some locations) is the length of time (nearly 180 days) it takes to fill civilian positions. The two major factors they typically cited were the process and the organizational structures established for this personnel management task. The slow response time adversely impacts the Air Force's ability to recruit STEM-degreed personnel in a timely manner, especially when the competition (e.g., private-sector companies) can make on-the-spot hiring offers.[22]

The process factor results from the procedures imposed by the Office of Personnel Management to comply with statutory and regulatory requirements such as veterans' preference, as well as from policies and procedures dictated by OSD and the Air Force.

The organizational factor results from the Air Force policy to centralize nearly all civilian personnel servicing at the Air Force Personnel Center (AFPC), located at Randolph Air Force Base, Texas. Although this centralization remains a policy goal of the Air Force, it has not been totally realized in the staffing of civilian positions for three reasons: (1) lack of adequate staff and expanding workload at AFPC, (2) the lengthy process for filling positions as noted above, and (3) AFPC's inability to fill positions in a timely manner. In response to many complaints from serviced locations, most notably those under the Air Force Material Command (AFMC), the Air Force returned most of the staffing processes, on an interim basis, to designated AFMC locations in late Spring 2008. Although resources were provided to AFPC in the 1990s to perform this work, no resources were provided back to AFMC when the work was returned in 2008.

While there are always open fills in the Air Force recruitment and hiring pipeline, positions that require a STEM degree can be some of the most difficult to fill. It is imperative for the Air Force (at large) to reduce the number of open fills in the STEM-degreed civilian workforce (1,079 as of January 2010[23]) to an acceptable level and to manage this workforce as a critical asset. A number of actions can be taken by the Air Force to help reduce civilian hiring time:

- Develop improved metrics related to civilian hiring time, especially for positions that require a STEM degree.
- Review career-field personnel business processes and civilian career program policies, processes, and procedures, with the goal of expediting recruiting and hiring.
- Participate in the Department of Defense (DoD) initiative for rapid improvement of staffing, with the objective of implementing a DoD enterprise staffing tool within the year.

Encourage customers to:

- Increase the use of standard position descriptions,
- Prioritize their fill actions,

[22]Appendix E provides a more in-depth description of the civilian hiring-time problem, including supporting data and related discussion.

[23]Michelle Lowe-Solis, Air Force Personnel Center, personal communication to Dr. Albert Robbert, committee member, January 22, 2010.

Copyright © National Academy of Sciences. All rights reserved.

- Project their requirements and release fill requests as early as possible, and
- Act promptly on selections after they receive a list of names.
- Insist that those providing these services meet their requirements for timeliness and for the quality of candidates.
- Ensure positions are properly classified. Anecdotal evidence indicates that classification specialists often do not appreciate the technical complexity of a position and the qualifications required to do the job effectively. This results in under-classification of the position and applicants being judged as unqualified by the hiring official.

Finding 6-12. At the Headquarters, Air Force organizational level, civilian pay is currently managed in a manner that hinders the employment and retention of STEM-degreed civilian personnel. Use of the O&M account (funding line 3400) for civilian pay, rather than the RDT&E account (funding line 3600), increases the variability and uncertainty in funding these positions from year to year. Consequently, employment planning is tenuous, and filling of positions that require a STEM degree is more difficult. In the committee's view, the funding uncertainty and variability also increase the difficulty of retaining valued STEM-degreed civilian personnel.

Recommendation 6-12. To address uncertainties in civilian workforce funding, and thereby improve employment and workforce stability, the Air Force should consider moving the acquisition workforce from the operations and maintenance funding line (Account 3400) to the RDT&E funding line (Account 3600).

Finding 6-13. It takes the Air Force far too long to fill civilian STEM positions. The Air Force cannot compete effectively with other government and nongovernment organizations that can recruit and hire the best-qualified STEM candidates much more quickly. This disadvantage negatively impacts both fill rates and the quality of the Air Force's STEM-degreed workforce.

Recommendation 6-13. The Air Force should continue to look for ways to improve both the process of filling civilian positions (enabling legislation may be required) and the organizational issues that hinder the process. In particular, a means should be sought to make permanent the funding for civilian positions that require a STEM degree at the installations where these positions are located (or within the respective major commands).

CONTRACT SUPPORT TO PROVIDE STEM-DEGREED PERSONNEL— ISSUES AND OPTIONS

For purposes of this study, organic STEM workforce positions are those positions that the Air Force believes must (or should) be filled by a STEM-degreed military officer or federal civil servant because one or more of the following conditions are met:

- The duties and responsibilities of the position are inherently governmental.[24]
- Adequate oversight of contracted activities requires in-house staff.
- The requirement for STEM capability is likely to be permanent.
- The Air Force believes that an organic capability is more cost-effective than contracted support.

[24] A technical definition of "inherently governmental" is included in footnote 2, Chapter 6, where this term is first used in the report.

Copyright © National Academy of Sciences. All rights reserved.

Conversely, a position that requires STEM capability is non-organic only if (1) the position is not inherently governmental, (2) the position is not permanent, and (3) it is more cost effective to contract for the capability than to establish an organic capability.

The Air Force relies extensively on contractor support for non-organic STEM positions. These external sources of STEM capability include systems engineering and technical assistance (SETA) contractors and federally funded research and development centers (FFRDCs).

SETA Support

While SETA contractors have long been an important component of the government's STEM capability, their roles and contributions in the Air Force have grown over the past decade. In significant measure, this growth has been necessary to replace manning and skills lost in the organic acquisition workforce and through personnel cuts at Headquarters, Air Force and in the major commands. In some cases SETA roles and support may have grown excessively, but in other cases SETA personnel provide unique and specialized skills essential to supporting Air Force program offices in executing their management responsibilities. Further, new Systems Engineering and Integration (SE&I) contracts are being established to assist the government in managing large-scale systems programs and complex system-of–systems procurements.

FFRDCs

FFRDCs such as the MITRE Corporation, Lincoln Laboratory, or the Aerospace Corporation are a special case of a contracted capability. While they are technically not-for-profit, nongovernment organizations, by law they essentially function as an organic (or quasi-organic) activity, providing essential STEM capability to the Air Force. Several FFRDCs were established to play an important role in Air Force development and acquisition by providing highly qualified STEM personnel with specific domain knowledge. These include MITRE and Lincoln Laboratory, which provide expertise in command, control, communication, intelligence, and surveillance sensors to the Electronic Systems Center, and The Aerospace Corporation, which provides expertise in space and missiles to the Space and Missile Center.

As private, not-for-profit corporations, FFRDCs have trusted oversight roles, free from the conflicts of interest that might arise with for-profit contractors, and with greater flexibility than the government in recruiting and managing personnel with a high degree of specialized STEM capabilities. FFRDC scientists and engineers perform across the entire acquisition life cycle, including planning and concept development, research and development, systems acquisition, integration and test, mission assurance, and on-orbit support. They provide independent technical assessment, advice on standards and best technical practices, and technical problem resolution input to government engineering and program managers, which is critical to program and mission success.

Appropriate Use of Contractor Support

As stated in the above definition of an organic STEM position, contractor support should not be used for work that is inherently governmental. This work should be accomplished by Air Force military or civilian personnel. Where the work is not inherently governmental, contractor support should be used when it is clearly more cost-effective than using Air Force organic resources, considering all life-cycle costs, fully burdened with salaries, benefits, support costs, hiring and termination costs, overhead and profit, etc. Perhaps the most common appropriate role for

Copyright © National Academy of Sciences. All rights reserved.

contractor support is work that is not inherently governmental and is temporary in duration—for example, projects or programs having a specified, limited duration.

The committee heard anecdotal reports of situations where more-costly contractor support was used because limited civilian personnel funding would not support hiring Air Force civil service personnel at grades that would attract fully qualified candidates, even though the comparable costs favored use of Air Force civilians. While the committee has no doubt that such situations have occurred (and continue to occur), this is clearly an inappropriate use of contractor support. Rather, this is a programming issue, where the appropriate action should be to reprogram sufficient funds from other sources into the civilian pay account to permit execution of the more cost-effective organic alternative. That said, the committee recognizes that such reprogramming actions are often very difficult and time consuming. Considering the excessive time currently required to recruit and hire civil service personnel and the time required to execute certain funding reprogramming actions, the temporary use of contractor support might be necessary to provide adequate mission support. However, pending execution of the preferred organic alternative whenever this option is more cost-effective, such use of contractor support should be used only as a temporary measure.

Finding 6-14. Based on the personal experience of committee members who served in the acquisition workforce, the committee believes that contracting out inherently governmental tasks can diminish the perceived value of the officers and government employees who perform similar tasks or who are assigned to oversee contractors. This negative effect on personnel morale and retention is in addition to the regulatory concerns when inherently governmental tasks are contracted out.

Recommendation 6-14a. The Air Force should reevaluate its contracting procedures and ensure that all inherently governmental tasks are performed by Air Force personnel.

Recommendation 6-14b. Significant portions of the STEM-degreed workforce now consist of contract personnel. The Air Force should consider converting contract dollars currently being used to pay for contracted engineering talent into funds that can be used to support additional civilian engineering authorizations to bring more of the required expertise in house. Senior Air Force leadership must, however, ensure that the dollars thus saved flow from the contracting accounts directly into the various civilian pay accounts. If adequate funds are not available in these accounts and if the authorizations are not forthcoming to support the previously contracted functions with governmental personnel, the potential consequences are risks to the capabilities of commanders and directors to carry out their missions.

REFERENCES

AIAA (American Institute of Aeronautics and Astronautics). 2008. Inside Aerospace: An International Forum for Aviation and Space Leaders Working Together to Build the Aerospace Workforce of Tomorrow. Report and recommendations of a forum held in Arlington, Virginia, May 13–14, 2008. Reston, Virginia: American Institute of Aeronautics and Astronautics.

AIAA. 2009. Inside Aerospace: An International Forum for Aviation and Space Leaders Working Together to Build the Aerospace Workforce of Tomorrow. Report and recommendations of a forum held in Arlington, Virginia, May 12–13, 2009. Reston, Virginia: American Institute of Aeronautics and Astronautics.

Buzanowski, J. G. 2008. Council addresses Airmen issues. November 18, 2008. Washington: Air Force News Service.

Copyright © National Academy of Sciences. All rights reserved.

GAO (Government Accountability Office). 2008a, Defense Acquisitions: DoD's Increased Reliance on Service Contractors Exacerbates Long-standing Challenges. GAO-08-621T. January 23, 2008. Washington, D.C.: U.S. Government Printing Office. Available online at http://www.gao.gov/products/GAO-08-621T.

GAO. 2008b. Defense Acquisitions: Assessments of Selected Weapon Programs. GAO-08-467SP. March 31, 2008. Washington, D.C.: U.S. Government Printing Office. Available online at http://www.gao.gov/products/GAO-08-467SP.

Harvey, J.C. 2007. Memorandum for Superintendent, United States Naval Academy (USNA); Commander, Naval Education Training Command (NETC), from Vice Admiral John C. Harvey, Jr. Subject: Academic Major Policy for Scholarship Midshipmen.

U.S. Air Force (USAF). 1997. Air Force Instruction 11-412, 1 August 1997, Flying Operations, Aircrew Management. Washington, DC: Department of the Air Force. 26 pp.

USAF. 2004. Air Force Doctrine Document 1-1, Leadership and Force Development. February 18, 2004. Headquarters Air Force Doctrine Center.

USAF. 2008. Air Force Policy Directive 36-26, August 27, 2008, Personnel Total Force Development. Washington, DC: Department of the Air Force.

USAF. 2009. Air Force Instruction 11-402, 25 September 2007, Incorporating Change 1, 10 July 2009, Flying Operations, Aviation and Parachutist Service, Aeronautical Ratings and Badges. Washington, DC: Department of the Air Force. 178 pp.

Copyright © National Academy of Sciences. All rights reserved.

7

The Need for Action

STEM training, whether it leads to a STEM degree or just to STEM cognizance, provides the foundation for the technical competence essential to the effective and efficient performance of the mission of the United States Air Force. This competence must reside in Air Force military and civilian personnel if they are to perform their Title X responsibilities. While FFRDCs and contractors can effectively augment STEM capability in the organic workforce, they cannot replace it.

Over the past 20 years, the Air Force has elevated its capabilities and competencies in the development and employment of air and space power to an unrivaled level. The Air Force possesses a significant inventory and critical mass of expertise for a full spectrum of missions and operational weapon systems for air superiority; precision strike; air mobility and refueling; special air operations; airborne intelligence, surveillance, and reconnaissance; and operational command and control. The U.S. military's competitive edge depends on continuous investment in research and development (R&D), rapid fielding of enhanced capabilities, and rapid development of operational tactics, techniques, and procedures. Technical skills and expertise are critical across the entire range of activities and processes associated with the development, fielding, and employment of operational capabilities.

The ability to logically and quantitatively define operational needs, analyze alternative solutions and force structures to optimize systems and investment strategies, and document operational requirements and concepts to best meet those needs demands strong technical and operational skills and experience. Maturing R&D-based technology and the normal tasks and functions involved in the design, development, production, integration, and test of new and modified systems require in-depth engineering skills and expertise in the acquisition workforce. Fielding new capabilities depends on extensive testing and the rigorous development and validation of tactics and procedures, all of which demand rigorous technical processes and deep technical understanding of systems capabilities and limitations within both the acquisition workforce and the receiving operational major commands.

Further, there has been a depth of institutional expertise and infrastructure for systems development and testing, tactics development, and employment for these air capabilities and forces. Technically trained and experienced people have participated across the life cycle of systems development, sustainment, and employment.

In addition to sustaining and inserting new technologies and operational tactics into air and missile systems, new emerging capabilities and operational domains—specifically net-centric operations, unmanned air systems, space operations, and cyber operations—place extraordinary new technical demands on the Air Force. These missions and domains require unique new technical skills and competencies to effectively define, develop, field, and employ operational capabilities in these mediums.

Copyright © National Academy of Sciences. All rights reserved.

All these considerations point to a substantial need for STEM-related skills and expertise in the development, operations, and sustainment of current Air Force systems and in the fielding and operations of new capabilities. Within the Air Force, STEM-degreed and STEM-cognizant personnel are found in all major commands and work in all Air Force career fields or Air Force specialty codes. This workforce permeates every fiber of the Air Force today. It is therefore essential that the Air Force maintain and enhance its technical competency—a competency provided by the Air Force's STEM-degreed and STEM-cognizant personnel.

To date, the Air Force has benefitted from having significant numbers of STEM-degreed personnel not only in the 5 officer career fields that require a STEM degree but also in the 21 other career specialties. In many instances, these personnel were attracted to the Air Force because of the technology-intensive nature of its mission. Though not specifically recruited or managed by the Air Force, STEM-degreed personnel have contributed significantly to the overall technical competence of its workforce.

Going forward, uncertainties about an adequate supply of STEM-degreed personnel who are U.S. citizens, together with the growing importance of mission domains that need advanced STEM capabilities, mean that the Air Force must actively manage the recruitment and retention of these valuable resources. As recommended in Chapters 4 and 6, it must establish appropriate recruiting and training requirements, develop competitive hiring practices, and provide viable career paths for all STEM-degreed personnel. The committee has further recommended that the Air Force define a functional level of STEM cognizance short of having a STEM degree (Recommendation 2-2), and that it should seek to recruit, retain, and provide career paths for STEM-cognizant personnel as well as its STEM-degreed workforce (Recommendations 4-1, 6-1a, 6-1b, and 6-2).

As the challenges to the future security environment grow, the Air Force must prepare to address these challenges fully and rapidly. This will require a wider range of technical skills and a technically competent workforce—this requires action by the Air Force now!

Copyright © National Academy of Sciences. All rights reserved.

Copyright © National Academy of Sciences. All rights reserved.

Appendixes

Copyright © National Academy of Sciences. All rights reserved.

Copyright © National Academy of Sciences. All rights reserved.

Appendix A

Biographical Sketches of Committee Members

Natalie W. Crawford, **NAE,** *Co-Chair*, is a senior fellow at the RAND Corporation, senior mentor for the USAF Scientific Advisory Board, and member of the National Academy of Engineering (NAE). Natalie Crawford has worked at RAND for more than 40 years. She served for nine years as vice president and director of RAND Project AIR FORCE from September 1997 to October 2006. She has deep, substantive technical and operational knowledge and experience in areas such as conventional weapons, attack and surveillance avionics, fighter and bomber aircraft performance, aircraft survivability, electronic combat, theater missile defense, force modernization, space systems and capabilities, and non-kinetic operations. She has been a member of the Air Force Scientific Advisory Board since 1988, and was its vice chairman in 1990 and cochairman from 1996 to 1999. In 2006, Mrs. Crawford received the OSD Medal for Exceptional Public Service and a Lifetime Achievement Award from the National Defense Industrial Association's Combat Survivability Division, as well as the RAND Medal for Excellence. In 2003 she received the Air Force Analytic Community's Lifetime Achievement Award and the Vance R. Wanner Memorial Award from the Military Operations Research Society. In addition, she received the Department of the Air Force Decoration for Exceptional Civilian Service in 1995 and again in 2003. Mrs. Crawford has a bachelor's in mathematics from UCLA where she also pursued graduate study in applied mathematics and engineering.

George K. Muellner, *Co-Chair*, is a fellow and president of the American Institute of Aeronautics and Astronautics, a fellow of the Society of Experimental Test Pilots, a fellow of the Royal Aeronautical Society, and serves on the board of directors of the Air Force Association. Mr. Muellner retired from the Boeing Company in February of 2008 where he served as president of Advanced Systems for the Integrated Defense Systems business unit with responsibility for developing advanced concepts and technologies, and executing new programs prior to them reaching the system design and development phase. Before this assignment, Mr. Muellner was vice president and general manager of Air Force Systems where he was responsible for all domestic and international Air Force programs. He was appointed to this position in July 2002. Before that, Mr. Muellner became president of Phantom Works, Boeing's advanced research and development unit. in June 2001, after serving as vice president and general manager. Before that, he served 31 years in the U.S. Air Force, retiring as a lieutenant general from the position of principal deputy for the Office of the Assistant Secretary of the Air Force for Acquisition in Washington, D.C. From 1993 to 1995, he served as director and program executive officer for the Joint Advanced Strike Technology program, now the Joint Strike Fighter program. In 1992, he became deputy chief of staff for requirements for the Headquarters Air Combat Command at Langley Air Force Base, VA. He later served as mission area director for tactical, command, control and communications, and weapons programs for the Office of the Assistant Secretary of

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

the Air Force for Acquisition. Mr. Muellner is a highly decorated veteran who spent most of his career as a fighter pilot and fighter weapons instructor, test pilot and commander. He flew combat missions in Vietnam and commanded the Joint STARS deployment during Operation Desert Storm. Mr. Muellner holds a bachelor's degree in aeronautical and astronautical engineering from the University of Illinois, a master's degree in aeronautical systems management from the University of Southern California, a master's degree in engineering from California State University and a master's degree in business administration from Auburn University. He also completed the Air War College and the Defense Systems Management College.

William P. Ard is senior vice president of the National Defense Division for Point One, Inc. He provides on-site senior level leadership and program support to the National Security Agency in the areas of corporate strategic planning, performance management, corporate governance processes, work role development, and alignment with intelligence community and Department of Defense processes and goals. Mr. Ard is currently involved in work supporting the national efforts to develop and employ cyber-related practices and resources. Before that, Mr. Ard served as the first director of workforce plans and resources for the Office of the Director of National Intelligence, helping to develop the workforce structure and attributes needed to enable and support the 16 federal agencies that make up the intelligence community. Mr. Ard is a retired Brigadier General from the United States Air Force and last served as the director of manpower and organization at Air Force Headquarters where he oversaw the Air Force manpower, organization, and corporate performance management processes. He served in manpower and personnel positions at all levels of the Air Force throughout his career, as well as multiple command billets, culminating in wing command and Air Force Forces command in a Joint Task Force. Mr. Ard received a master of science degree in management from Troy State University in Troy, Alabama, as well as a bachelor of science degree in public administration from Virginia Tech. He is also a graduate of the national security management course at the Maxwell School at Syracuse University and of the Industrial College of the armed forces.

James B. Armor, Jr. is currently owner and CEO of The Armor Group, LLC, VA, a consultant to industry and government for space systems development, operations, and strategic planning. Mr. Armor also serves on the Board of Integral Systems, Inc., and NAVSYS Corporation. He is an associate fellow of American Institute of Aeronautics and Astronautics. Major General Armor retired from the Air Force in 2008 as Director of the National Security Space Office (NSSO) of the Office of the Under Secretary of the Air Force in Washington, D.C., where he was responsible for integrating and coordinating defense and intelligence space planning, acquisition, and operational activities. Before serving with NSSO, he was director of signals intelligence systems acquisition and operations at the National Reconnaissance Office (NRO), vice commander of the Warner Robins Air Logistics Center at Robins Air Force Base in Georgia, and program director of the Global Positioning System (GPS) at the Space and Missile Systems Center at Los Angeles Air Force Base in California. General Armor was commissioned in 1973 through the ROTC program at Lehigh University in Bethlehem, PA. He served as a combat crew missile launch officer, laser signal intelligence analyst, satellite launch system integrator, and space program manager. Mr. Armor trained as a space shuttle payload specialist, and studied information warfare while a research fellow at the National War College. He also served at the Air Force Headquarters in the Office of the Deputy Chief of Staff for Plans and Operations and in the Office of the Secretary of the Air Force for Acquisition.

Earl H. Dowell, NAE, is an elected member of the National Academy of Engineering and a fellow of the American Academy of Mechanics, the American Institute of Aeronautics and Astronautics (AIAA), and the American Society of Mechanical Engineers (ASME). He is also an

Copyright © National Academy of Sciences. All rights reserved.

honorary fellow of the AIAA, a recipient of the Crichlow Trust Prize, and was named a Von Karman Lecturer. He is a recipient of the Spirit of St. Louis Medal from ASME and the Guggenheim Medal from the AIAA, ASME, AHS and SAE. He also served as vice president for publications and member of the executive committee of the board of directors of the AIAA; member of the United States Air Force Scientific Advisory Board; member of the Air Force Studies Board; member of the AGARD (NATO) advisory panel for aerospace engineering; president of the American Academy of Mechanics; chair of the US National Committee on Theoretical and Applied Mechanics; and chairman of the National Council of Deans of Engineering. Dr. Dowell currently serves on the boards of visitors of Carnegie Mellon University, Georgia Institute of Technology, Princeton University, the University of Illinois and the University of Rochester. He is an occasional consultant to government, industry and universities in science and technology policy and engineering education as well as his research topics. Dr. Dowell received his bachelors of science degree from the University of Illinois and his S.M. and Sc.D. degrees from the Massachusetts Institute of Technology. Before serving as Dean of the School of Engineering at Duke University, he taught at Massachusetts Institute of Technology (M.I.T.) and Princeton.

Richard P. Hallion is currently a Verville fellow in aeronautics for the National Air and Space Museum of the Smithsonian Institution. Before becoming a Verville fellow, Dr. Hallion was senior advisor for air and space issues in the Directorate for Security, Counterintelligence and Special Programs Oversight. Dr. Hallion holds a BA and PhD from the University of Maryland. He is also the author and editor of over fifteen books on aerospace technology, air war and air doctrine.

Michael A. Hamel is retired Commander, Space and Missile Systems Center for the Air Force Space Command at the Los Angeles Air Force Base in California. General Hamel was responsible for managing the research, design, development, acquisition and sustainment of space and missile systems, launch, command and control, and operational satellite systems. He was responsible for more than 6,500 employees nationwide and an annual total budget in excess of $10 billion. General Hamel was the Air Force program executive officer for space and was responsible for the Air Force Satellite Control Network; space launch and range programs; the space-based infrared system program; military satellite communication programs; the global positioning system; intercontinental ballistic missile programs; defense meteorological satellite program; the space superiority system programs; and other emerging transformational space programs. General Hamel was commissioned as second lieutenant through the U.S. Air Force Academy in June 1972.

Ray M. Haynes is director of university strategic alliances for the Northrop Grumman Corporation's Corporate Programs, Engineering and Technology Office. He works with 100+ universities worldwide to coordinate R&D funding totaling more than $50 Million annually and other strategic alliances across the broad university community. He is also Founding Dean for the NG SPACE University and chairs the NG Native American Caucus. Before his current assignment, Dr. Haynes served in a number of key engineering, executive and project management roles, including positions with RCA, TRW, Hewlett-Packard and the US Navy's Surface Warfare Center. For 15 years in the academic world, Dr. Haynes' positions have included adjunct professor at Arizona State University and TRW Chaired professor/director of the graduate engineering management program at California Polytechnic University at San Luis Obispo. During his career, Dr. Haynes has published and/or presented 100+ articles, case studies and papers on engineering management, service operations, systems engineering, university corporate relations and technology leadership. He has extensive advisory board participation with ASU

Copyright © National Academy of Sciences. All rights reserved.

Polytechnic, University of Arizona, Cal Polys, Cal Tech, LMU, MIT, Stanford, UC Riverside and UT Pan Am. Dr. Haynes is a frequent guest lecturer at these schools in addition to others like Michigan University, Naval Post Graduate School, Purdue University, UCF and US Air Force Academy. Service to the professional community includes ASEE (past PIC-V Chair/board, CMC director, CIP director, Diversity SIG), ABET (industry advisory council plus PEV), NSF (Corporate Alliance and proposal reviewer), NAE (GUIRR with CalTech, NRC-NASA Workforce Study and upcoming NRC-AF Workforce Study), and National Board service to EPICS and PLTW. Dr. Haynes is active in the diversity community with AISES (corporate advisory council, Executive Excellence Award-2006), HENAAC (industry advisory board), and NAMEPA (president's advisor) and is a lifetime member of MESA, SACNAS, and SHPE. As the chair of the ASEE CMC Diversity Special Interest Group, he has worked to ensure more communication and collaboration across the professional diversity organizations. Dr. Haynes' degrees include a BS in Aerospace engineering, an MBA from the University of Arizona, a MS in systems engineering from the RCA Computer Institute, and a Ph.D. in operations logistics from Arizona State University. His education was supported by an NSF Scholar Award, Rotary International, AiResearch Fellowship, RCA Fellowship, Native American Graduate Scholar and TRW Fellowship.

Leon A. Johnson is currently a manager and check pilot for United Parcel Service (UPS) flight operations. General Johnson retired from the U.S. Air Force with the rank of brigadier general after 33 years of service. During his Air Force career, General Johnson commanded an Air Force Fighter Squadron, Fighter Group, was the vice commander of 10th Air Force and served as the mobilization assistant to the Assistant Secretary of the Air Force for Manpower and Reserve Affairs. In that role he advised senior Air Force leadership on outreach, marketing, retention and recruiting initiatives. He also served as the chair of the Air Force Reserve Command (AFRC) Human Resources Development Council (HRDC). As the chair of the HRDC, General Johnson was the principal staff officer responsible for formulating and administering policies and programs and affecting AFRC people programs including outreach and retention initiatives, in concert with other Air Force Reserve Staff agencies,. He is a command pilot with over 3500 hours of flying time in the T-37 trainer, A-37 and A-10 fighter aircraft, including missions over Bosnia in support of Operation Deny Flight. Following the events of 9/11, the general served as a director of the Air Force Crisis Action Team in the Pentagon. General Johnson is a member of the Air Force Association, Military Officers Association of America, Military Order of World Wars, Veterans of Foreign Wars, Reserve Officers Association, League of United Latin American Citizens, Women in Aviation, the International Black Aerospace Council, Incorporated, and sits on the board of advisors of the Southern Illinois University School of Aviation. General Johnson is a member of the National Academies of Science and Engineering and the Naval Studies Board. He was also a committee member of a report titled, "Manpower and Personnel Needs of a Transformed Naval Force."

Lester McFawn is director of the Wright Brothers Institute in Dayton, Ohio. The Wright Brothers Institute enables world-class research, development and technology transfer in areas of high interest to the Air Force and the Dayton region. Before that he was a member of the federal government's Senior Executive Service, serving in key Air Force leadership positions in aerospace research, development and acquisition. Until January 2008 he was Executive Director of the Air Force Research Laboratory. In this position, he led the Air Force's $3.7 billion science and technology program; 10 R&D business units with global operations; and a workforce of 9,900 of the world's top scientists, engineers and support staff. He held director positions with responsibility for policy, strategic and organizational planning, manpower, and out-year budget development for the Air Armament Center, a $1.5 billion and 4,000 person enterprise; and the Air

Copyright © National Academy of Sciences. All rights reserved.

Force Materiel Command, a $45 billion and 78,000 person enterprise. As director of the Sensors Directorate of the Air Force Research Laboratory, he had responsibility for the Air Force's total science and technology program in sensors and electronics. Mr. McFawn holds a masters degree in computer, information and control engineering from the University of Michigan, and a masters degree in electronics engineering from Florida State University. He has received numerous awards including the Outstanding Civilian Career Service Award, Presidential Rank Award for Meritorious Executive, and Defense Acquisition Executive Certificate of Achievement.

Michael C. McMahan is the president and CEO of the Abilene Chamber of Commerce. His responsibilities include the development and promotion of the economy by expanding and retaining businesses and attracting outside investments. He is also responsible for the Industrial Foundation and Abilene Chamber Foundation. He is a member of the Abilene Advisory Board of Cisco Junior College and the West Central Texas Workforce Development Board. Mr. McMahan authored "Five Stages of Leadership," a presentation on change management of senior leadership. His background includes 32 years of service with the United States Air Force. He has been a commander five times and has had staff tours in the Pentagon and various headquarters at home and abroad. He has over 10 years staff and leadership experience in Air Force manpower, organization and personnel development. He is a native of Dallas, Texas and is a graduate of Texas Tech University with a degree in mechanical engineering. He has a master of science degree from the Air Force Institute of Technology at Arizona State University in the area of industrial engineering operations research.

Donald L. Peterson is retired from the US Air Force where he served as deputy chief of staff for personnel at Air Force Headquarters. He was responsible for comprehensive plans and policies covering all life cycles of military and civilian personnel management, including end strength management, education and training, compensation, and resource allocation. Following his retirement from active duty, he was selected to serve as the president and CEO of the Air Force Association for a five-year term. In 1966, Mr. Peterson graduated from Texas A&M University with a degree in finance. He completed pilot training in 1967 and later completed a masters degree in management from Auburn University. He participated in executive development programs at Carnegie-Mellon and Harvard Universities. He commanded a tactical fighter squadron, a tactical fighter wing, a flying training wing, and the North American Aerospace Defense Command and US Space Command at Cheyenne Mountain Operations Center. His staff assignments include the chief of U.S. Air Force operations assignments, a major command inspector general, the director of plans and operations at Air Education and Training Command, the director of plans at Air Force Headquarters, and assistant deputy chief of staff for Air and Space Operations at Air Force Headquarters. He is a command pilot, having flown more than 4,000 hours, including 597 combat hours.

Leif E. Peterson (Resigned 7/14, 2009) is managing partner for Advanced HR Concepts and Solutions. Before retiring in December 2007, Leif Peterson was a member of the Senior Executive Service and the director of Manpower, Personnel and Services for the Air Force Materiel Command at Wright-Patterson Air Force Base in Ohio. He provided executive management of the command's nearly 80,000 military and civilian professionals throughout the United States and overseas in research facilities, test sites, universities, and at product development, logistics and specialized centers. The function of the Directorate of Manpower of Personnel and Services was to shape the AFMC workforce to deliver war-winning expeditionary capabilities and provide oversight, direction and control for all personnel activities within AFMC. Mr. Peterson entered federal service in 1971 as a labor relations specialist at the U.S. Air Force

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

Headquarters. He held numerous positions as a civilian personnel officer, serving two tours at Eglin Air Force Base in Florida., and six years overseas. In 1983, Mr. Peterson became deputy director of civilian personnel for Air Force Systems Command at Andrews Air Force Base in Maryland. He later returned to U.S. Air Force Headquarters as chief of staffing of development and equal employment opportunity. For eight years he was director of civilian personnel at Tactical Air Command and Air Combat Command at Langley Air Force Base in Virginia. He was then assigned as director of civilian personnel and programs at AFMC. He was appointed to the Senior Executive Service in May 2004 assuming his previous position as deputy director of personnel.

Albert A. Robbert is director of manpower, personnel and training program for the RAND Project Air Force in Washington, DC. In this role he researches and develops policy alternatives regarding human resource and human capital development. He also coordinates and manages the manpower, personnel and training research agenda within Project Air Force. Before joining the RAND research staff in 1994, Dr. Robbert served for 27 years in the United States Air Force, having personnel management responsibilities at the Air Staff, the Air Force Personnel Center, and several major commands. Dr. Robbert holds a doctorate in public administration from the University of Alabama in Tuscaloosa, Alabama.

Paula E. Stephan is professor of economics of the Andrew Young School of Policy Studies at Georgia State University and a research associate of the National Bureau of Economic Research. Her research interests focus on the careers of scientists and engineers and the process by which knowledge moves across institutional boundaries in the economy. Dr. Stephan was recently appointed to serve a four-year term on the National Advisory General Medical Sciences Council of the National Institutes of Health, and currently serves on the advisory committee of the social, behavioral, and economics program of the National Science Foundation. She was a member of the European Commission High-Level Expert Group that authored the report *Frontier Research: The European Challenge*. She has served on National Research Council committees including the Committee on Dimensions, Causes, and Implications of Recent Trends in the Careers of Life Scientists, Committee on Methods of Forecasting Demand and Supply of Doctoral Scientists and Engineers, and the Committee on Policy Implications of International Graduate Students and Postdoctoral Scholars in the United States. Her research has been supported by the Alfred P. Sloan Foundation, the Andrew W. Mellon Foundation, and the National Science Foundation. Dr. Stephan graduated from Grinnell College (Phi Beta Kappa) with a bachelors degree in economics, and earned a masters degree and Ph.D. in economics from the University of Michigan. She has published more than 80 articles and book chapters. Her articles have appeared in journals such as the Science, American Economic Review, the Journal of Economic Literature, Economic Inquiry, and Social Studies of Science. She co-authored *Striking the Mother Lode in Science: The Importance of Age, Place and Time* and recently co-edited *Science and the University*. Dr. Stephan has lectured extensively in Europe. Periodically from 1992 to 1995, Dr. Stephan was a visiting scholar at the Wissenschaftszentrum Berlin fur Sozialforschung in Berlin, a visiting scholar at Katholieke Universiteit Leuven in Belgium in 2005, and in 2008, a visiting scholar at Politecnico di torino in Italy.

Todd I. Stewart was appointed to the position of director of the office of institutional partnerships at Michigan Technological University in September 2008. He is responsible for building partnerships between the university and government- and non-government organizations of all types. Before his current position, he served for six years as director of national security research and education programs at Ohio State University. At Ohio State, he was responsible for promoting research and study in all areas of national security, including defense, intelligence,

Copyright © National Academy of Sciences. All rights reserved.

foreign relations, international development and homeland security. He also served as the executive director of the National Academic Consortium for Homeland Security. Dr Stewart is an adjunct assistant professor of national security affairs with The John Glenn School of Public Affairs at Ohio State. In September 2006, the United States Senate confirmed President George W. Bush's nomination of Dr. Stewart to serve a four-year appointment as a member of the National Security Education Board. This group directs the National Security Education Program, establish in law in 1991 to promote national security through the study of international issues and languages. Before his appointment at Ohio State, he served for 34 years with the United States Air Force. His military career included numerous command and staff assignments in positions responsible for strategic planning, combat engineering and installation management, including infrastructure design and construction, installation operation and maintenance, and environmental protection at Air Force bases in the United States and around the world. While on active duty, he also served as an associate professor of management at the Air Force Institute of Technology. He retired from active service in April 2002 as a major general. General Stewart's academic education includes a bachelor of science degree in civil engineering from Michigan Technological University, a master of science degree in engineering administration from Southern Methodist University, and a doctor of philosophy degree in management from the University of Nebraska. He is also a graduate of the Air Force Squadron Officer School, the Air Command and Staff College, and the Air War College. He is a member of the Academy of Management, Michigan Technological University's Academy of Civil and Environmental Engineers, the Society of American Military Engineers and the Air Force Association.

Ron Yates is an independent consultant to the aerospace industry. He spent 35 years in the US Air Force. He is a combat fighter pilot and test pilot and has 5,000 flying hours in over 50 different types of aircraft. He has extensive experience in the acquisition business having served as program director of both the F-15 and F-16 system program offices. He was also a Test Wing Commander. He served as Air Force director of tactical programs in the Pentagon, and as deputy assistant secretary of the Air Force for acquisition. He was the Commander of both the Air Force Systems Command and the Air Force Materiel Command, where he was responsible for all Air Force research, development, acquisition policy and logistics. He is a member of the Society of Experimental Test Pilots; a commissioner for the National Research Council Commission on Engineering and Technical Systems; a member of the Ballistic Missile Defense Office Advisory Group; a member of the board of visitors of the National Defense University; and a member of the board of directors of the U.S. Air Force Academy's Association of Graduates. He is a graduate of the U.S. Air Force Academy and holds a Masters Degree in systems management from the University of Southern California.

Copyright © National Academy of Sciences. All rights reserved.

Appendix B

Meetings and Speakers

MEETING 1
AUGUST 26-27, 2008
THE NATIONAL ACADEMY OF SCIENCES BUILDING
WASHINGTON, D.C.

Co-Sponsor Discussion of Need and Vision for Study
Colonel James D. Fisher, Chief, Engineering and Technical Management Division, SAF/AQRE
Gregory Price, Deputy Chief, Force Development Integration Division, Headquarters U.S. Air Force

Air Force S&E Functional Manager Needs for STEM
Colonel James D. Fisher, Chief, Engineering and Technical Management Division, SAF/AQRE

Air Force STEM Needs
Gregory Price, Deputy Chief, Force Development Integration Division, Headquarters U.S. Air Force

Impact of Reduced U.S. STEM Manpower
Steven H. Kenney, Partner, Toffler Associates

STEM Workforce Demand and Supply
Brig Gen Alfred J. Stewart, Commander, Air Force Recruiting Service

STEM Workforce Demand and Supply
Jon Ogg, Director, Engineering HQ AFMC

Scientist and Engineer Summer Study, August 2002
Patrick F. Nolte, Senior Program Manager, Center for Gaming Excellence, SAIC
Ron St. Martin, Senior Gaming Consultant, SAIC

Air Force STEM Capability Needs, Strategy, and Workforce
Maj Gen Paul Selva, Director, Strategic Planning, Headquarters U.S. Air Force

STEM Workforce Demand and Supply
Colonel Teresa A. Djuric, Commander, Holm Center, Air Education and Training Command

Copyright © National Academy of Sciences. All rights reserved.

MEETING 2
SEPTEMBER 30-OCTOBER 1, 2008
THE ARNOLD AND MABEL BECKMAN CENTER
IRVINE, CALIFORNIA

Air Force Space Command STEM Needs
Douglas V. Bell, Deputy Director, Manpower, Personnel, and Services, Headquarters Air Force Space Command

SMC Perspectives - Air Force STEM Capability Needs, Strategy, and Workforce
Ms. Pat Robey, Director, Manpower and Personnel, SMC/A1

AFMC Perspectives - Air Force STEM Capability Needs, Strategy, and Workforce
Ms. Sherre Collier, Chief, Personnel Division, AFMC/A1K

Battelle's STEM Initiatives
Rich Rosen, Vice President, Education and Philanthropy, Battelle Memorial Institute

MEETING 3
OCTOBER 29-30, 2008
THE KECK CENTER OF THE NATIONAL ACADEMIES
WASHINGTON, D.C.

Air Force STEM Capability Needs, Strategy, and Workforce
Col Stan Perrin, Director of Assignments, AFPC/DPA

Sponsor discussion of study issues, background, charge and scope
Terry Jaggers, Deputy Assistant Secretary of the Air Force for Science, Technology, and Engineering, SAF/AQR

Discussion with Mr. Blaise Durante, SES
Blaise Durante, Deputy Assistant Secretary for Acquisition Integration, SAF/AQX

Discussion with Gen Bowlds
Lt Gen Ted Bowlds, Commander, Electronics Systems Center, AFMC ESC/CC

AFRL STEM Forecast Needs
Joe Sciabica, Executive Director of AFRL

Discussion with Mr. Park
Mr. John Park, Chief, Force Management Division, HQ USAF/A1PF

Discussion with Gen Newton
Lt Gen Dick Newton, Deputy Chief of Staff, Manpower and Personnel, AF/A1

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

MEETING 4
DECEMBER 3-4, 2008
THE KECK CENTER OF THE NATIONAL ACADEMIES
WASHINGTON, D.C.

Discussion with Patrick Hogan
Mr. Patrick Hogan, Director of Acquisition and Career Management, SAF/AQXD

Discussion with Drs. Janet Fender and Don Erbschloe
Dr. Janet S. Fender, Chief Scientist, Air Combat Command, Langley AFB, VA
Dr. Don Erbschloe, Chief Scientist, Air Mobility Command, Scott Air Force Base, IL

Discussion with Dr. Jacqueline Henningsen
Dr. Jacqueline Henningsen, Director for Studies and Analyses, Assessments and Lessons Learned, Headquarters AF/A9

Discussion with Col Art Huber
Col Art Huber, Commander, Arnold Engineering Development Center, Arnold AFB, TN

Discussion with Gen Paula Thornhill
Brig Gen Paula Thornhill, Commandant, Air Force Institute of Technology, Wright-Patterson AFB, OH

Discussion with Maj Gen David Eichhorn
Maj Gen David J. Eichhorn, Commander, Air Force Flight Test Center, Edwards AFB, CA

Discussion with Gen.Dana Born
Brig Gen Dana Born, Dean of the Faculty, United States Air Force Academy, CO

MEETING 5
JANUARY 13-15, 2009
THE ARNOLD AND MABEL BECKMAN CENTER
IRVINE, CALIFORNIA

(No speakers attending)

Copyright © National Academy of Sciences. All rights reserved.

Appendix C

Supporting Demographic Data

This appendix provides the following information to support topics discussed in Chapter 5:

- Ethnic definitions
- Data from analyses of female and minority employment in selected STEM career fields
- Table 1—Distribution of science and engineering bachelor's degrees by citizenship, race/ethnicity, and sex of recipients (1995-2004)

ETHNIC DEFINITIONS

The following definitions are from the U.S. Census website, www.census.gov :

- White refers to people having origins in any of the original peoples of Europe, the Middle East, or North Africa. It includes people who indicated their race or races as 'White' or nationalities such as Irish, German, Italian, Lebanese, Near Easterner, Arab, or Polish.
- Black or African American refers to people having origins in any of the Black racial groups of Africa. It includes people who indicated their race or races as 'Black, African-Am, or Negro,' or nationalities such as Nigerian, or Haitian.
- American Indian and Alaska Native refers to people having origins in any of the original peoples of North and South America (including Central America), and who maintain tribal affiliation or community attachment. It includes people who indicated their race or races by marking this category or writing in their principal or enrolled tribe, such as Rosebud Sioux, Chippewa, or Navajo.
- Asian refers to people having origins in any of the original peoples of the Far East, Southeast Asia, or the Indian subcontinent. It includes people who indicated their race or races as Asian Indian, Chinese, Filipino, Korean, Japanese, Vietnamese, or other Asian, or wrote in nationalities such as Burmese, Hmong, Pakistani, or Thai.
- Native Hawaiian and Other Pacific Islander refer to people having origins in any of the original peoples of Hawaii, Guam, Samoa, or other Pacific Islands. It includes people who indicated their race or races as Native Hawaiian, Guamanian or Chamorro, Samoan, or other Pacific Islander, or nationalities such as Tahitian, Mariana Islander, or Chuukese.
- Some other race was included in Census 2000 for respondents who were unable to identify with the five Office of Management and Budget race categories. Respondents who provided write-in entries such as Moroccan, South African, Belizean, or a Hispanic origin (for example, Mexican, Puerto Rican, or Cuban) are included in the "Some other race" category.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

- The term Hispanic is an ethnic category **not a racial category** for persons who identify themselves as being of Spanish origin. Unlike other Census Bureau designations, Hispanic denotes neither race nor color, and a Hispanic may be White, Black, or American Indian, as well as (1) Mexican Americans/Chicanos, (2) Puerto Ricans/Boricuas, (3) Hispanos (U.S. Hispanics who identify themselves as Spanish), (4) Cuban Americans, and (5) Latinos (Hispanics from countries other than those already mentioned). Terms other than Hispanic may be preferred. For example, many Mexican Americans prefer Chicano, Puerto Ricans may prefer Boricuas, while others may prefer the more general term, Latino.

ANALYSES OF FEMALE AND MINORITY EMPLOYMENT IN SELECTED STEM CAREER FIELDS

Committtee analysis of data from the 2000 census yielded the following profiles for four engineering disciplines (aerospace engineers, civil engineers, electrical and electronic engineers, and mechanical engineers) and two science fields (atmospheric and space scientists and chemical and material scientists) representative of science and engineering disciplines important to Air Force STEM needs and the aerospace industry.

- Aerospace Engineers (SOC 17-2011)
    - 91 percent Male and 9 percent Female
    - 81 percent White, 4.6 percent Hispanic, 3.1 percent Black, 0.2 American Indian/Alaskan Native, 9.4 percent Asian and the remaining 1.7 percent from 6 mixed racial groupings
    - 6.5 percent White Females, 0.5 percent Hispanic Females, 0.6 percent Black Females, 0.0 percent American Indian/Alaskan Native, 1.2 percent Asian Females and the remaining 0.2 from 6 mixed racial groupings
- Civil Engineers (SOC 17-2061)
    - 89.9 percent Male and 10.1 percent Female
    - 81.8 percent White, 4.3 percent Hispanic, 3.4 percent Black, 0.4 American Indian/Alaskan Native, 8.5 percent Asian and the remaining 1.6 percent from 6 mixed racial groupings
    - 7.5 percent White Females, 0.6 percent Hispanic Females, 0.6 percent Black Females, 0.1 percent American Indian/Alaskan Native, 1.1 percent Asian Females and the remaining 0.2 from 6 mixed racial groupings
- Electrical and Electronic Engineers (SOC 17-2070)
    - 91.5 percent Male and 8.5 percent Female
    - 81.8 percent White, 4.3 percent Hispanic, 3.4 percent Black, 0.4 American Indian/Alaskan Native, 8.5 percent Asian and the remaining 1.6 percent from 6 mixed racial groupings
    - 5.4 percent White Females, 0.4 percent Hispanic Females, 0.8 percent Black Females, 0.0 percent American Indian/Alaskan Native, 1.6 percent Asian Females and the remaining 0.1 from 6 mixed racial groupings
- Mechanical Engineers (SOC 17-2141)
    - 93.6 percent Male and 6.4 percent Female
    - 84.2 percent White, 3.3 percent Hispanic, 3.4 percent Black, 0.2 American Indian/Alaskan Native, 7.5 percent Asian and the remaining 1.4 percent from 6 mixed racial groupings

Copyright © National Academy of Sciences. All rights reserved.

    - 5.0 percent White Females, 0.2 percent Hispanic Females, 0.5 percent Black Females, 0.0 percent American Indian/Alaskan Native, 0.6 percent Asian Females and the remaining 0.1 from 6 mixed racial groupings
- Atmospheric and Space Scientists (SOC 19-2021)
    - 87.2 percent Male and 12.9 percent Female
    - 90.9 percent White, 2.4 percent Hispanic, 3.0 percent Black, 0.3 American Indian/Alaskan Native, 2.4 percent Asian and the remaining 1.0 percent from 6 mixed racial groupings
    - 11.5 percent White Females, 0.2 percent Hispanic Females, 0.4 percent Black Females, 0.1 percent American Indian/Alaskan Native, 0.5 percent Asian Females and the remaining 0.1 from 6 mixed racial groupings
- Chemical and Material Scientists (SOC 19-2030)
    - 67.7 percent Male and 32.4 percent Female
    - 74.4 percent White, 3.9 percent Hispanic, 5.8 percent Black, 0.3 American Indian/Alaskan Native, 14.1 percent Asian and the remaining 1.3 percent from 6 mixed racial groupings
    - 21.7 percent White Females, 1.6 percent Hispanic Females, 2.1 percent Black Females, 0.1 percent American Indian/Alaskan Native, 6.3 percent Asian Females and the remaining 0.5 from 6 mixed racial groupings

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

TABLE C-1 Distribution of bachelors degrees awarded in science and engineering, by citizenship, race/ethnicity, and set sex of recipients: 1995-2004

(Percent distribution)

Citizenship and race/ethnicity	1995	1996	1997	1998	2000	2001	2002	2003	2004
All recipients	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
U.S. citizens and permanent residents[a]	96.1	96.2	96.2	96.2	96.2	96.1	96.1	96.0	95.9
Asian/Pacific Islander	7.6	7.9	8.4	8.7	8.9	9.1	9.0	9.0	9.0
Underrepresented minorities	13.3	13.9	14.6	15.1	15.9	16.1	16.2	16.3	16.4
American Indian/Alaskan Native	0.5	0.6	0.6	0.6	0.7	0.7	0.6	0.7	0.7
Black, non-Hispanic	7.1	7.4	7.7	7.9	8.3	8.3	8.4	8.3	8.4
Hispanic	5.6	5.9	6.3	6.6	7.0	7.1	7.2	7.3	7.3
White, non-Hispanic	72.9	72.0	70.7	69.8	67.8	66.9	66.5	65.8	65.1
Other/unknown race/ethnicity	2.3	2.4	2.5	2.7	3.5	4.0	4.4	4.9	5.4
Nonresident aliens[b]	3.9	3.8	3.8	3.8	3.8	3.9	3.9	4.0	4.1
Male	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
U.S. citizens and permanent residents[a]	95.1	95.2	95.3	95.3	95.4	95.2	95.3	95.2	95.1
Asian/Pacific Islander	7.8	8.2	8.7	9.1	9.4	9.6	9.5	9.5	9.4
Underrepresented minorities	11.0	11.4	11.9	12.4	13.0	13.2	13.1	13.1	13.2
American Indian/Alaskan Native	0.5	0.5	0.5	0.6	0.6	0.7	0.6	0.6	0.6
Black, non-Hispanic	5.3	5.5	5.7	5.8	6.1	6.1	6.1	6.1	6.1
Hispanic	5.2	5.4	5.7	6.0	6.3	6.4	6.4	6.5	6.5
White, non-Hispanic	74.0	73.1	72.0	71.1	69.5	68.4	68.3	67.5	66.9
Other/unknown race/ethnicity	2.4	2.5	2.6	2.7	3.5	4.0	4.4	5.0	5.6
Nonresident aliens[b]	4.9	4.8	4.7	4.7	4.6	4.8	4.7	4.8	4.9
Female	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
U.S. citizens and permanent residents[a]	97.3	97.2	97.2	97.2	97.0	96.9	96.8	96.7	96.7
Asian/Pacific Islander	7.3	7.6	8.0	8.3	8.5	8.6	8.6	8.5	8.7
Underrepresented minorities	16.0	16.6	17.4	17.9	18.8	18.9	19.2	19.4	19.6
American Indian/Alaskan Native	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.8
Black, non-Hispanic	9.2	9.5	9.8	10.0	10.4	10.5	10.6	10.6	10.7
Hispanic	6.2	6.6	6.9	7.2	7.7	7.7	7.9	8.1	8.1
White, non-Hispanic	71.7	70.7	69.4	68.4	66.2	65.5	64.7	64.1	63.2
Other/unknown race/ethnicity	2.3	2.3	2.4	2.6	3.5	3.9	4.3	4.7	5.2
Nonresident aliens[b]	2.7	2.8	2.8	2.8	3.0	3.1	3.2	3.3	3.3

[a] Race/ethnicity categories are as designated on survey form. These categories include U.S. citizens and foreign citizens on permanent visas (i.e., resident aliens who have been admitted for permanent residency).

[b] Nonresident aliens include foreign citizens on temporary visas only. No race/ethnicity data are collected for this group.

NOTES: Detail may not sum to total due to rounding. Detailed national data were not released by the National Center for Education Statistics for the academic year ending in 1999. See appendix B for specific fields included in each category.

SOURCE: Tabulated by National Science Foundation/Division of Science Resources Statistics; data from Department of Education/National Center for Education Statistics: Integrated Postsecondary Education Data System Completions Survey.

Copyright © National Academy of Sciences. All rights reserved.

Appendix D

Air Force STEM Workforce

This appendix supplies a variety of details about the Air Force STEM workforce as shown in selected tables (Tables D-1 and D-2) and figures (Figures D-1 through D-20).

TABLE D-1 Civilian Personnel in Career Program Paths for Occupational Series That Require a STEM Degree.

Air Force Civil Service STEM Workforce				
	Career Program			
Occupational Series	Civil Engineer	Communications & Information	Scientist & Engineer	Total
0801 General Engineering	886		1662	2548
0803 Safety Engineering			4	4
0804 Fire Prevention Engineering	5			5
0806 Materials Engineering			285	285
0807 Landscape Architecture	8			8
0808 Architecture	129		2	131
0810 Civil Engineering	232		6	238
0819 Environmental Engineering	552		21	573
0830 Mechanical Engineering	174		648	822
0840 Nuclear Engineering			12	12
0850 Electrical Engineering	147		67	214
0854 Computer Engineering		142	196	338
0855 Electronics Engineering	5	341	4140	4486
0858 Biomedical Engineering			19	19
0861 Aerospace Engineering			1223	1223
0881 Petroleum Engineering			1	1
0892 Ceramic Engineering			1	1
0893 Chemical Engineering	2		45	47
0896 Industrial Engineering	11		91	102
1301 General Physical Science	231		143	374
1306 Health Physics	2		5	7
1310 Physics			265	265
1313 Geophysics			25	25
1315 Hydrology	4			4
1320 Chemistry	15	1	162	178
1321 Metallurgy			2	2
1330 Astronomy And Space Science			5	5
1340 Meteorology			122	122

Copyright © National Academy of Sciences. All rights reserved.

TABLE D-1 Continued.

1350 Geology	9			9
1370 Cartography	2		10	12
1372 Geodesy			2	2
1373 Land Surveying	1			1
1386 Photographic Technology		5		5
1501 General Mathematics			2	2
1510 Actuarial Science			1	1
1515 Operations Research		12	376	388
1520 Mathematics (1520)			80	80
1529 Mathematical Statistics			1	1
1530 Statistics			12	12
1550 Computer Science		230	406	636
Grand Total	2415	731	10042	13188

Source: AFPC Interactive Demographic Analysis System, December 2008.

TABLE D-2 STEM-Degreed Personnel in the Civil Service Acquisition Workforce

Occupational Series Requiring STEM Degree	Number
0801 General Engineering	1,344
0802 Engineering Technical	3
0803 Safety Engineering	26
0806 Materials Engineering	224
0810 Civil Engineering	22
0819 Environmental Engineering	30
0830 Mechanical Engineering	380
0840 Nuclear Engineering	1
0850 Electrical Engineering	41
0854 Computer Engineering	188
0855 Electronics Engineering	2,055
0856 Electronics Technical	2
0858 Biomedical Engineering	19
0861 Aerospace Engineering	927
0893 Chemical Engineering	30
0896 Industrial Engineering	21
0899 Engineering & Architecture Student	5
1301 General Physical Science	64
1310 Physics	142
1311 Physical Science Technician	1
1320 Chemistry	73
1330 Astronomy And Space Science	3
1340 Meteorology	4
1341 Meteorological Technician	1
TOTAL	5,606

SOURCE: AFPC IDEAS, as of December 2008

Copyright © National Academy of Sciences. All rights reserved.

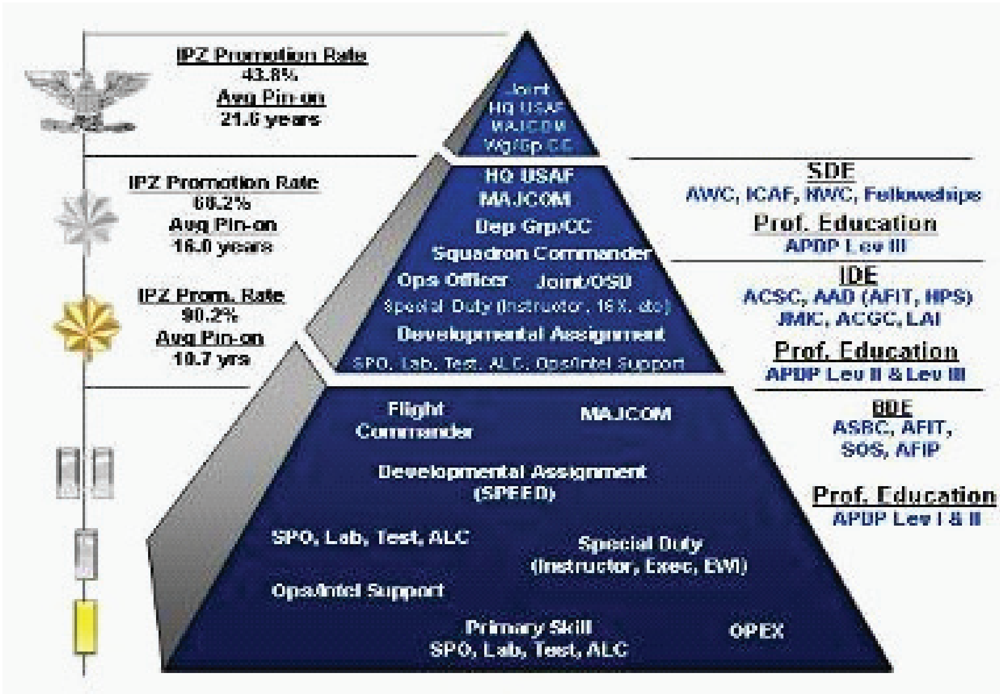


FIGURE D-1 Career Pyramid Illustrating the 61S Scientist Officer Career Path. SOURCE: "Msn Spt Officer Career Planning Diagrams," Air Force Personnel Center Website.

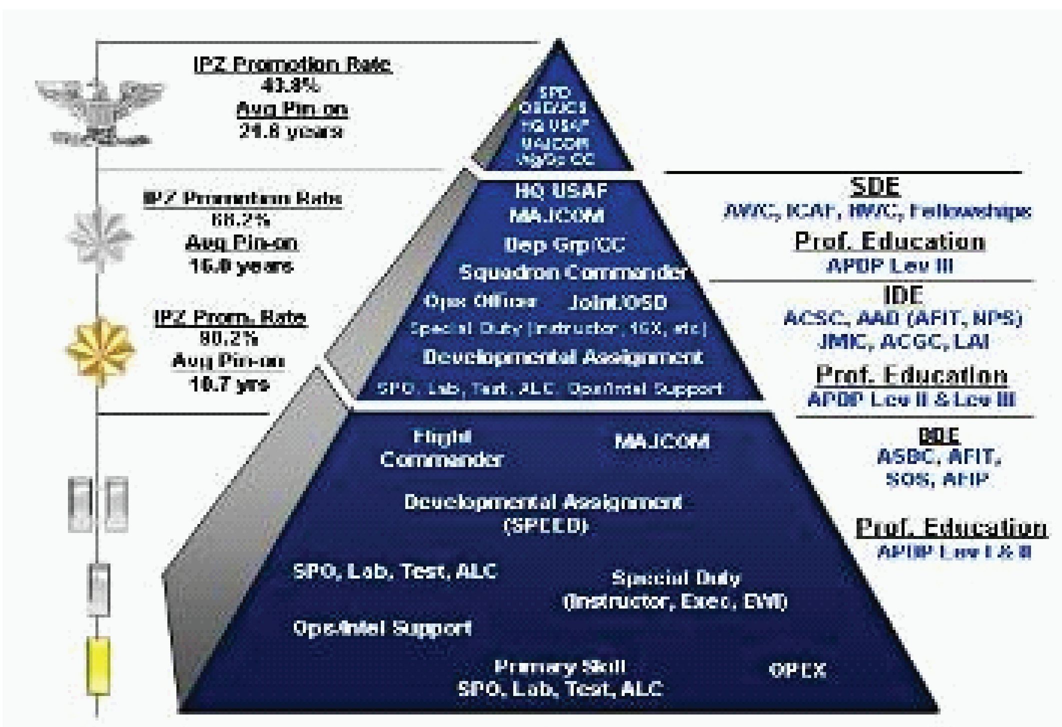


FIGURE D-2 Career Pyramid Illustrating the 62E Developmental Engineer Officer Career Path. SOURCE: "Msn Spt Officer Career Planning Diagrams," Air Force Personnel Center Website.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

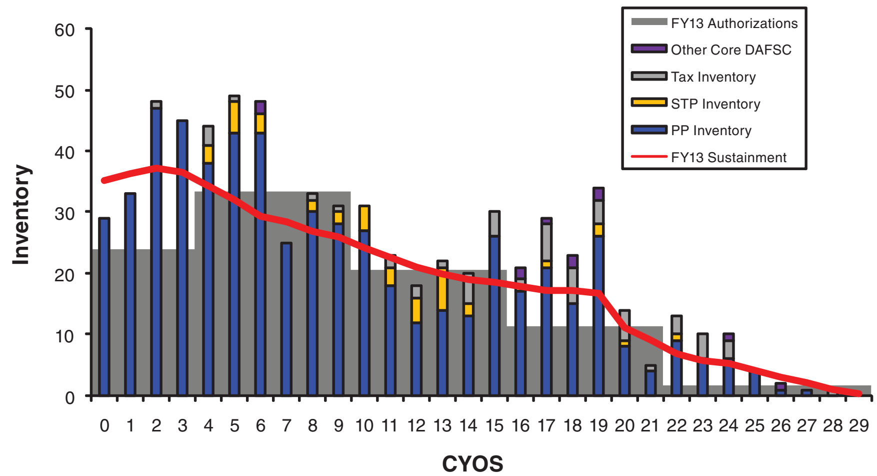


FIGURE D-3 15W Officer Inventory in 15W Career Field by Career Years of Service (CYOS). SOURCE: John Park, Chief, Force Management Division (HQ USAF/A1PF), briefing to the committee on October 30, 2008.

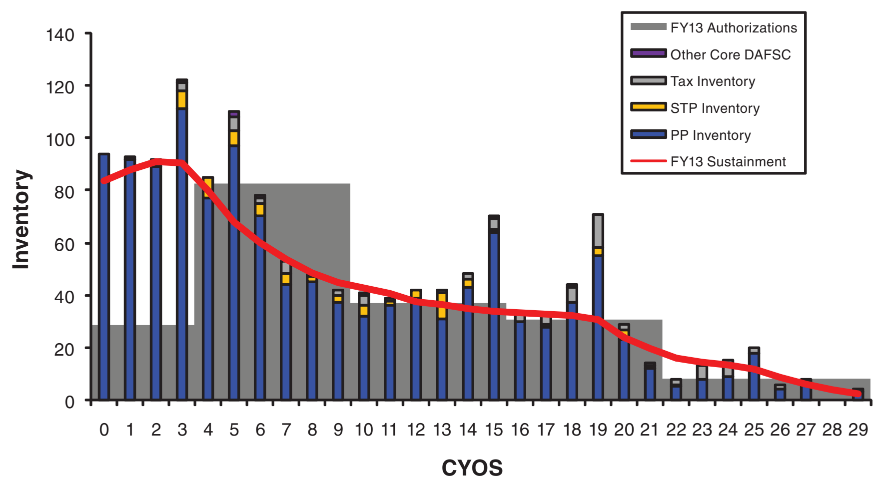


FIGURE D-4 Officer Inventory in 32E Career Field by Career Years of Service (CYOS). SOURCE: John Park, Chief, Force Management Division (HQ USAF/A1PF), briefing to the committee on October 30, 2008.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

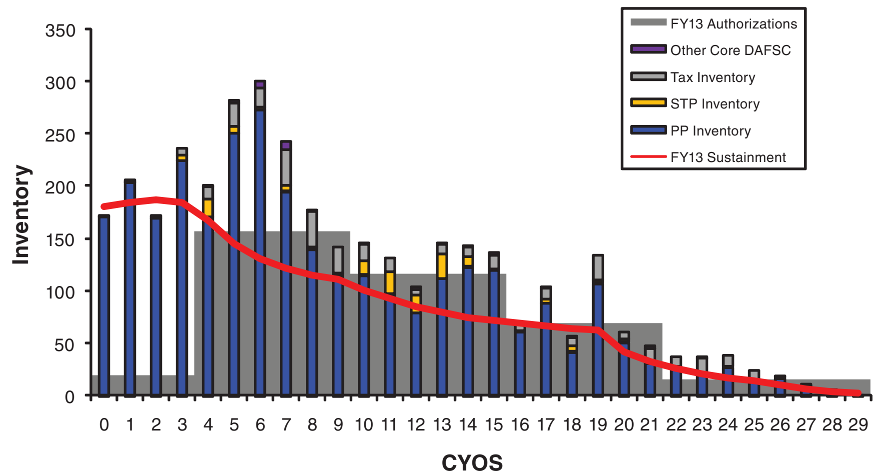


FIGURE D-5 Officer Inventory in 33S Career Field by Career Years of Service (CYOS). SOURCE: John Park, Chief, Force Management Division (HQ USAF/A1PF), briefing to the committee on October 30, 2008.

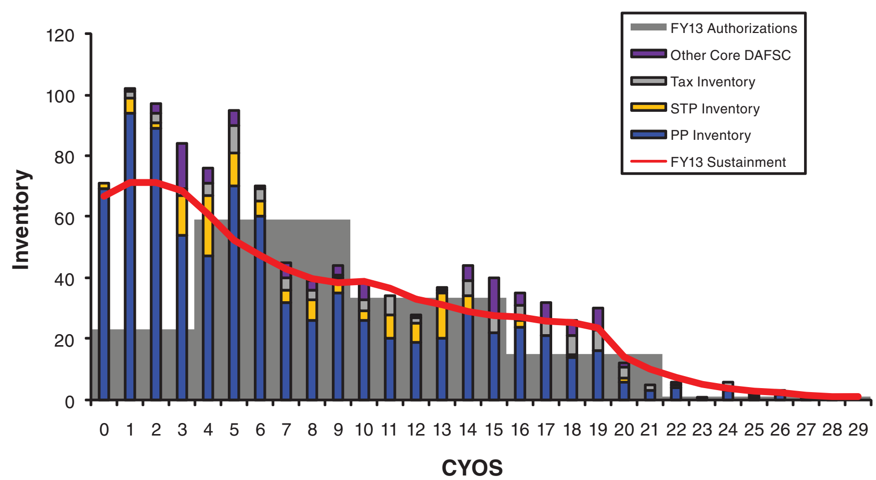


FIGURE D-6 Officer Inventory in 61S Career Field by Career Years of Service (CYOS). SOURCE: John Park, Chief, Force Management Division (HQ USAF/A1PF), briefing to the committee on October 30, 2008.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

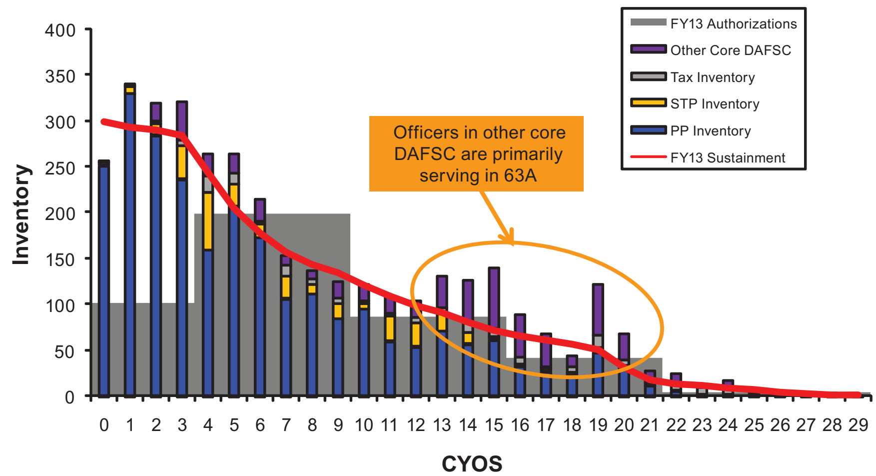


FIGURE D-7 Officer Inventory in 62E Career Field by Career Years of Service (CYOS). SOURCE: John Park, Chief, Force Management Division (HQ USAF/A1PF), briefing to the committee on October 30, 2008.

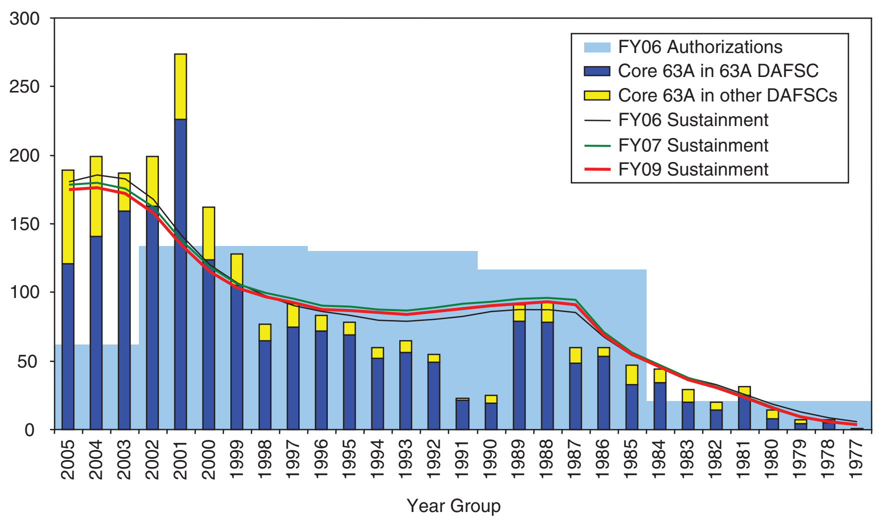


FIGURE D-8 Officer Inventory in 63A Career Field by Career Years of Service (CYOS). SOURCE: Pat Hogan, Director of Acquisition and Career Management (SAF/AQXD), briefing to the committee on December 3, 2008.

Copyright © National Academy of Sciences. All rights reserved.

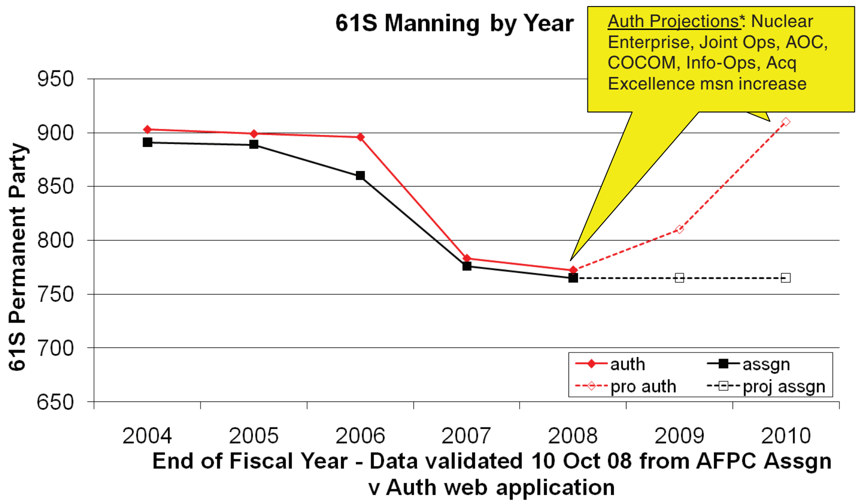


FIGURE D-9 61S Officer Authorizations and Assignments, 2004–2010. SOURCE: Col. Stan Perrin, Air Force Personnel Center, Director of Assignments (AFPC/PA), briefing to the committee on October 29, 2008.

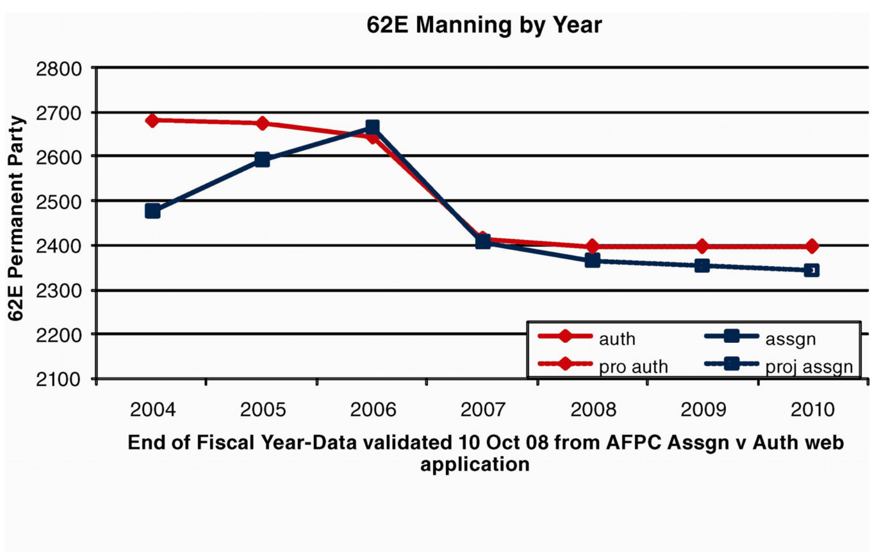


FIGURE D-10 62E Officer Authorizations and Assignments, 2004–2010. SOURCE: Col. Stan Perrin, Air Force Personnel Center, Director of Assignments (AFPC/PA), briefing to the committee on October 29, 2008.

Copyright © National Academy of Sciences. All rights reserved.

- **Must Fill - 100%**
    - **Air Staff (HAF, SAF, AFPEO)**
    - **Commander (C-prefix)**
    - **FOAs / DRUs**
    - **Green Door**
    - **Joint (JDAL only)**
    - **MDA**
    - **OS Short TOUR (< 18 mo)**
    - **Special Duty (16x, 8x, 9x)**
    - **AU, ROTC, Training Instructors,**
    - **Execs (Wg +), FAO, IG, etc…**
- **Priority Fill - 85%**
    - **Instructors - T-Prefix 6X & NRO**
- **Entitlement**
    - **AF Agencies**
    - **AFRL**
    - **Joint, Non JDAL**
    - **MAJCOM Centers/Wing/Sq**
    - **MAJCOM HQ**
    - **NAF**
    - **all others**

FIGURE D-11 Fill Priority Categories under the Non-Rated Prioritization Program.

Grade	Acquisition Experience	ACQUISITION MANAGEMENT TRAINING FLOW
	0 - 3 Months	Following base acculturation, attend AFFAM offered by AFIT (ACQ 101 equivalent)
	0 - 12 Months	Military officers must attend six-week Air & Space Basic Course (ASBC) when scheduled; civilian attendance is optional
	2 - 12 Months	Complete SYS 101 and the continuous learning modules CLB 007 and CLB 016 **
	12 Months	Apply for Level I Program Management certification
	1-36 Months	Complete all core unit training tasks and those non-core tasks required by supervisor
	18-24 Months	Complete ACQ 201A/B
	20-28 Months	Complete PMT 250 A/B, CON 110** and SAM 101** (in any order)
	24-28 Months	Apply for Level II Program Management certification
	30-36 Months	Complete IPM (PM 301) at AFIT
	37 Months – 10 Years	Complete operational level unit training tasks; accept supervisor/mentor roles
Capt / GS-12*		Complete Basic Developmental Education (mandatory for officers; recommended civilian attendance)
	4-8 Years	Complete SYS 202 **
Maj / GS-13*		Complete Intermediate Developmental Education
	8-10 Years	Complete PMT 352A. Complete PMT 352B. Apply for Level III PM certification
	Job specific	If assigned as ACAT III PM, complete PMT 403
Lt Col-Col / Pay band 2-3		Complete Senior Developmental Education; apply for PMT 401 nomination for development towards ACAT I/II PM/DPM positions.
	Job specific	If assigned as ACAT I/II PM/DPM, complete PMT 401 (prerequisites: Level III certification and completion of PMT 352); then PMT 402 (prerequisite: PMT 401, PMT 301, or PMT 302)
	Job specific	If assigned as materiel squadron commander, attend senior-level ALCP-II course

* Or pay band equivalent ** Certification requirement on/after 1 Apr 08

FIGURE D-12 Path Opportunities and Training for Career Progression in Acquisition Management. SOURCE: USAF, 2008, pg. 24.

Copyright © National Academy of Sciences. All rights reserved.

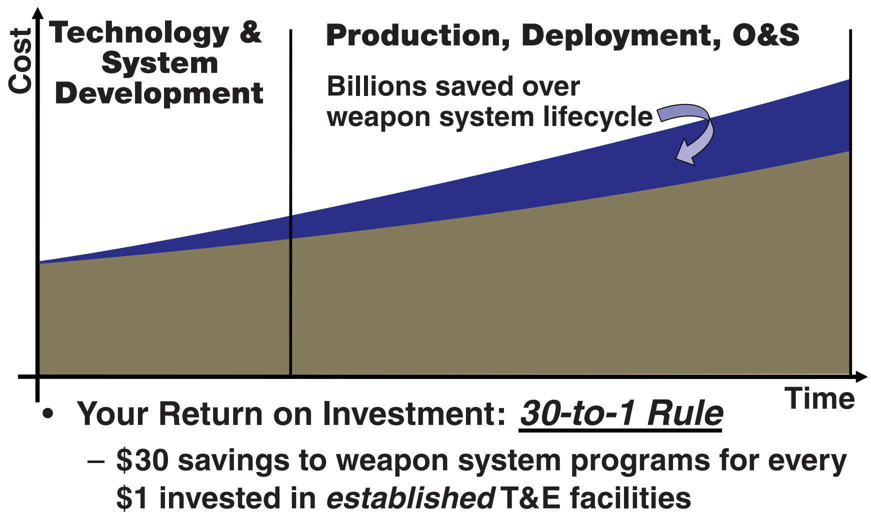


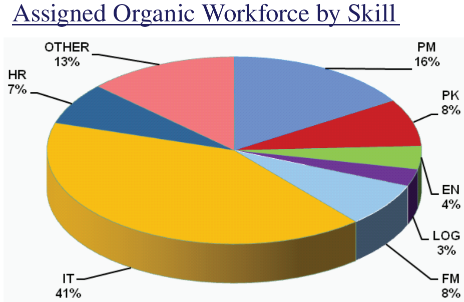
FIGURE D-13 Representation from the Air Force Flight Test Center of Savings from Early Identification of Design and Technology Shortfalls in Development Programs. SOURCE: Maj. Gen. David Eichhorn, Commander, AFFTC, briefing to the committee on December 3, 2008.

Demographics As of: 04 Oct 08

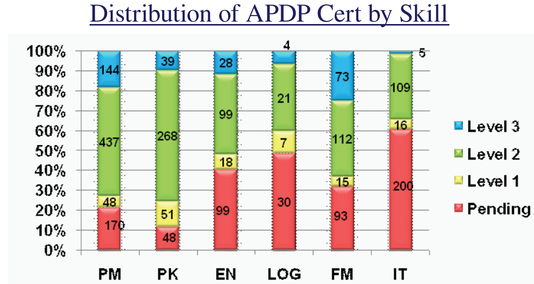
AF STEM Workforce

	CIV		ENL		OFF		CME		Total	
	AUTH	ASSN	AUTH	ASSN	AUTH	ASSN	AUTH	ASSN	AUTH	ASSN
HQ Staff	261	298	65	68	62	45	60	24	448	435
350 ELSW	351	295	24	30	257	208	703	682	1335	1215
551 ELSW	219	136	17	17	163	110	513	513	912	776
554 ELSW	1088	960	423	420	192	95	645	455	2348	1930
653 ELSW	695	548	140	149	168	144	994	1030	1997	1871
66 ABW	423	421	245	289	52	64	271	106	991	880
TOTAL	3037	2658	914	973	894	666	3186	2810	8031	7107

Assigned Organic Workforce by Skill



Distribution of APDP Cert by Skill



319 of 413 Critical Acquisition Positions are filled (77.24%)
258 of 319 assigned to CAPs are certified at appropriate level(80.8%)

FIGURE D-14 Demographics at the Electronic Systems Center. SOURCE: Lt. Gen. Ted Bowlds, Commander, Electronic Systems Center, AFMC, briefing to the committee on October 30, 2008.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

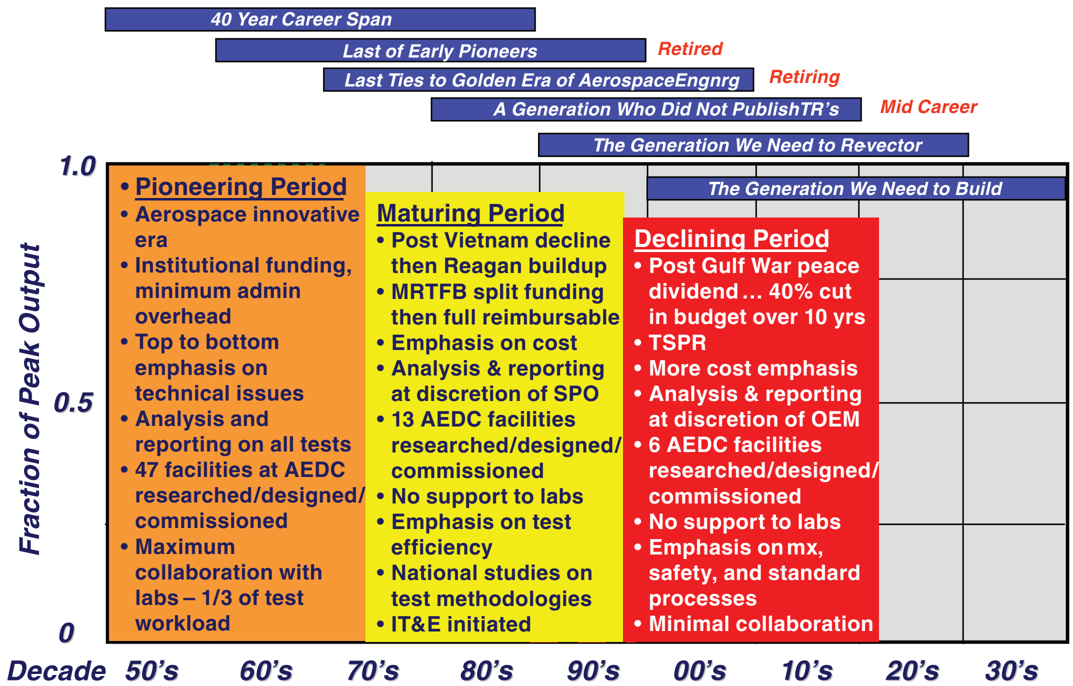
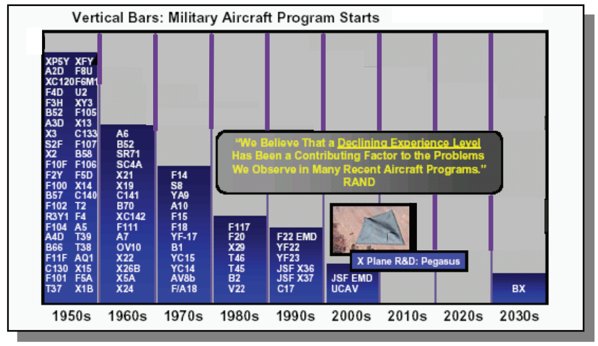


FIGURE D-15 AEDC Commander's Perspective on the Rise and Decline of Technical Excellence. SOURCE: Col. Art Huber, Commander, AEDC, briefing to the committee on December 3, 2008.

Copyright © National Academy of Sciences. All rights reserved.

Case studies* of five aircraft design programs ranging from 70s to 90s

- **Assessed aircraft and program performance metrics**
- **Defined IC metrics**



<u>Study Observations</u>

- **Strong linkage between intellectual capital and performance**
- **Current designers less experienced than predecessors – fewer opportunities**
- **70s-era design efforts outperformed those of 90s-era**
- **Test phase an important downstream indicator of design performance – test personnel understood design flaws through exposure to recurring problems**
- **Modern design tools graphically compelling, but reduced experimental experience has led to deficiencies**

***Eric Rebentisch "Managing Intellectual Capital for the Long Haul" Lean Aerospace Initiative Conference on Enterprise Value: The New Lean Horizon, March 27, 2002**

FIGURE D-16 Military Aircraft Program Starts by Decade, Actual (1950–2009) and Projected (2010–2039). Source: Col. Art Huber, Commander, AEDC, briefing to the committee on December 3, 2008.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

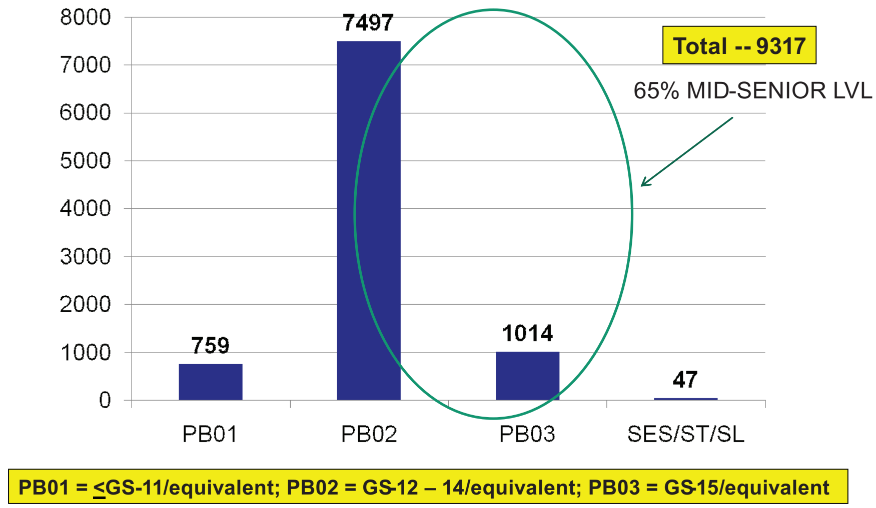


FIGURE D-17 AFMC Civilian Workforce in Occupations Requiring a STEM Degree (Science and Engineering, Civil Engineering, and Information Technology). SOURCE: Jon Ogg, Headquarters AFMC, Engineering, briefing to the committee on August 27, 2008.

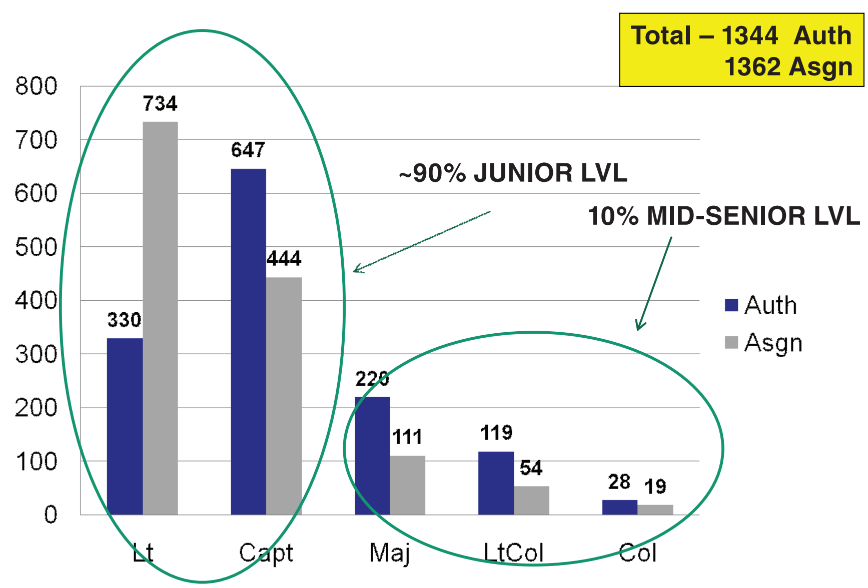


FIGURE D-18 Authorized and Assigned AFMC Officers, by Rank, in Science and Engineering, Civil Engineering, or Information Technology Positions that Require a STEM Degree. SOURCE: Jon Ogg, Headquarters AFMC, Engineering, briefing to the committee on August 27, 2008.

Copyright © National Academy of Sciences. All rights reserved.

	Employees	Civilian	Military	Contractor
Total	~10800	~4750	~1450	~4600
S&Es	~ 6750	~2800	~ 850	~3100

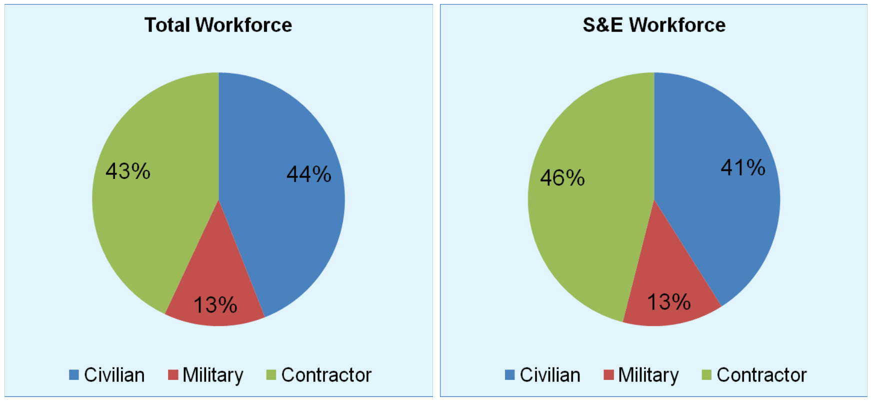


FIGURE D-19 Demographics of the AFRL Total Workforce and Science and Engineering (S&E) Workforce. SOURCE: Joe Sciabica, Executive Director, Air Force Research Laboratory, briefing to the committee on October 30, 2008.

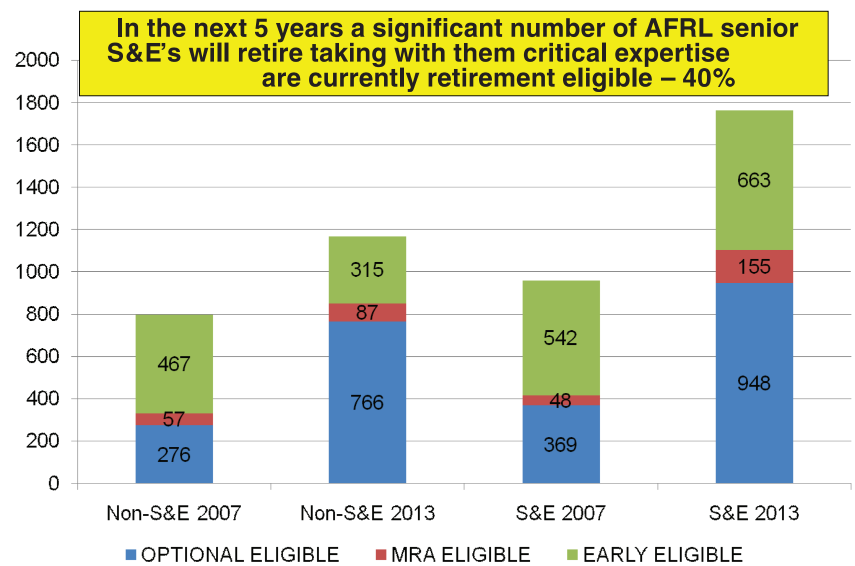


FIGURE D-20 Retirement Eligibility as of 2007 and 2013 for the AFRL Civilian Workforce: S&E = science and engineering occupations. SOURCE: Joe Sciabica, Executive Director, Air Force Research Laboratory, briefing to the committee on October 30, 2008.

Copyright © National Academy of Sciences. All rights reserved.

Appendix E

Length of Time to Fill Civilian Positions

The civilian timeliness data supporting the committee's findings and recommendations are shown in Figures E-1 through E-5.

1. The average number of days, Air Force wide, to fill a position by AFPC was 156 days in Nov 2007 rising to 170 days one year later. The latter figure is after AFMC servicing was returned to AFMC in the Spring of 2008. For AFMC positions still serviced by AFPC, typically at non-AFMC locations, the average time to fill a position as of Nov 2008 was 190 days. The days for AFSPC was 185 days.
2. Open fill actions at AFPC, AF wide, were 7885 in Nov 2007, rising to 9660 in April, dropping to 7775 the next month (reflecting transfer to AFMC), and ending the year period in Nov 2008 at 6740.
3. The staffing of civilian positions at the AFMC Air Logistics Centers and Wright-Patterson AFB has never moved to AFPC though it is the goal of Air Force to do so. The staffing of the remaining AFMC locations (Eglin, Hanscom, Edwards, Kirtland, and Arnold) were returned to AFMC in May of 2008. The average number of days for AFMC to fill a position was 71 days in Oct 2007 rising to 73 days one year later.
4. AFMC, as of Nov 2008 had 1474 open fills for engineering positions and 239 in the math and sciences. Though there are always open fills in the "pipeline" and these can be some of the hardest jobs in the Air Force to fill.

The committee's analysis shows that AFMC can fill its positions in less than half the time it has taken AFPC to do so. Though the AFMC trend is upwards since June 2008, this could be explained by the additive workload from the transfer of staffing in the Spring without additive resources, as well as civilian pay funding complexities (O&M, RDT&E, and working capital funds) and related timing issues.

Copyright © National Academy of Sciences. All rights reserved.

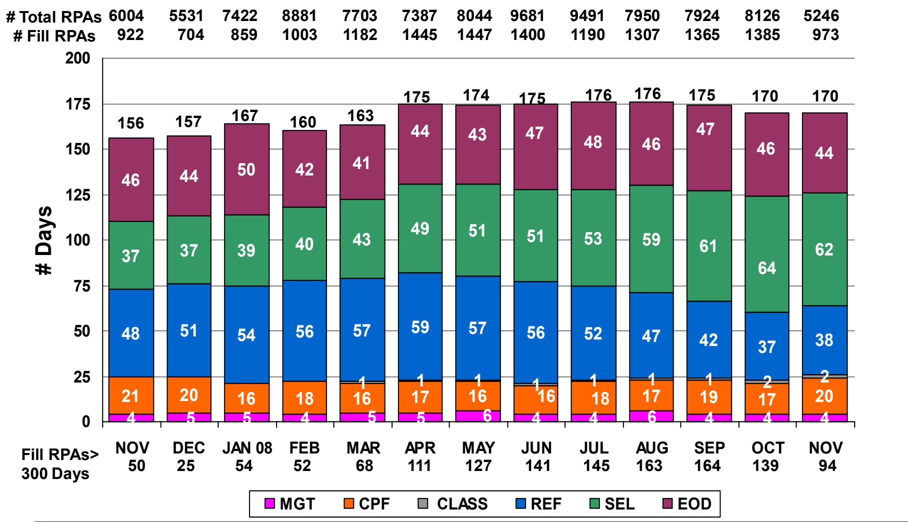


FIGURE E-1 DPI Closed Fills Average Days. SOURCE: Air Force RPA Tracker, December 1, 2008.

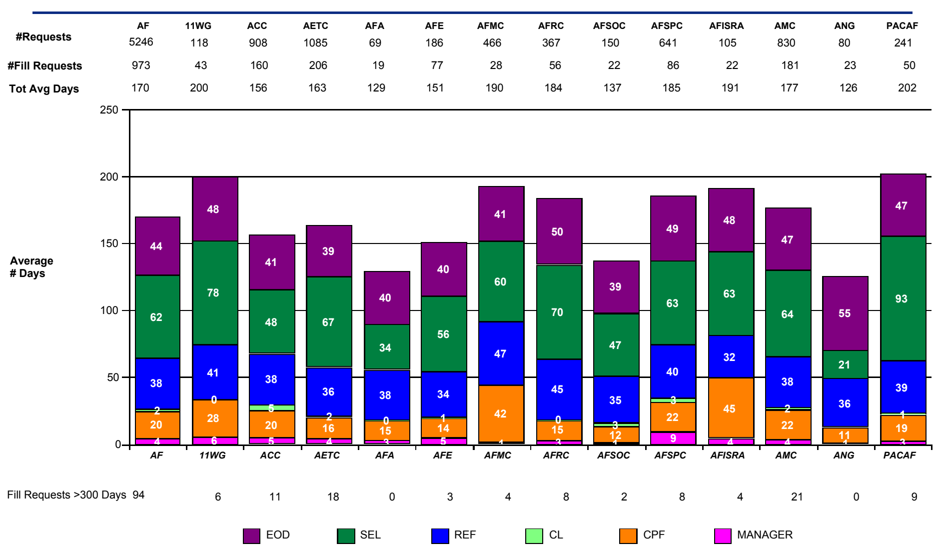


FIGURE E-2 DPI Closed Fills By Serving MAJCOM. SOURCE: Air Force RPA Tracker, December 1, 2008.

Copyright © National Academy of Sciences. All rights reserved.

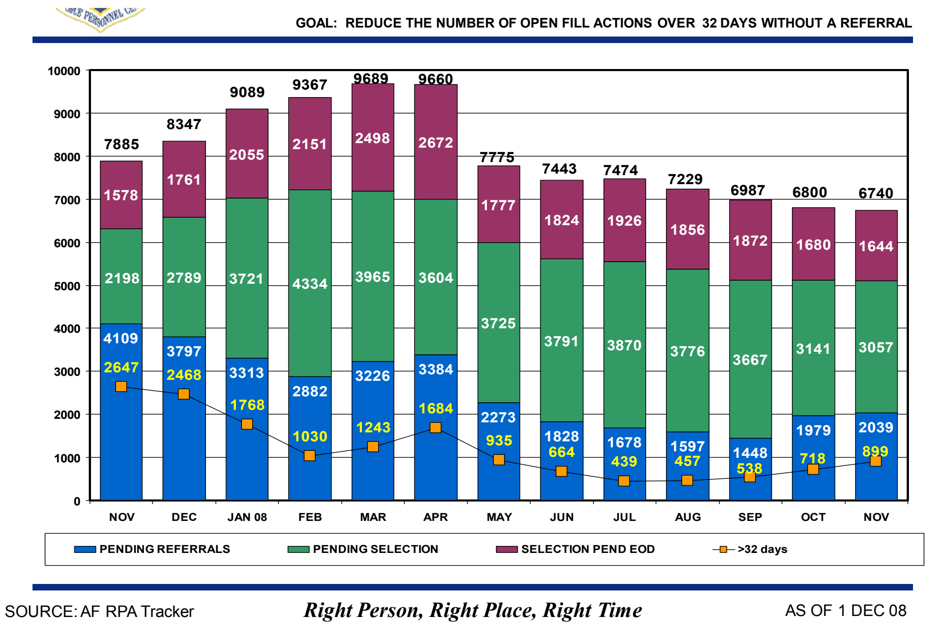


FIGURE E-3 DPI Open Fill Actions. SOURCE: Air Force RPA Tracker, December 1, 2008.

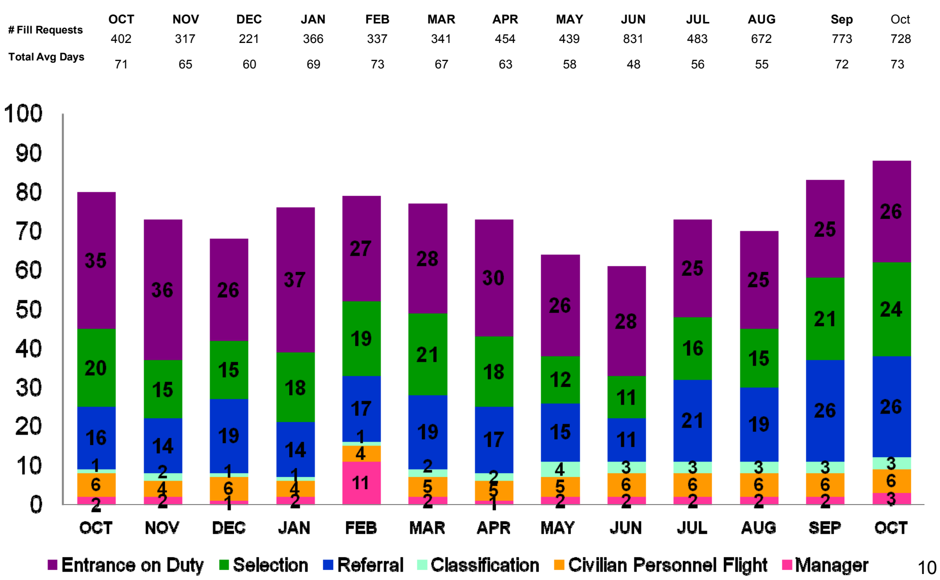


FIGURE E-4 AFMC Closed Non-AFPC Fill Actions. SOURCE: Air Force Materiel Command.

Copyright © National Academy of Sciences. All rights reserved.

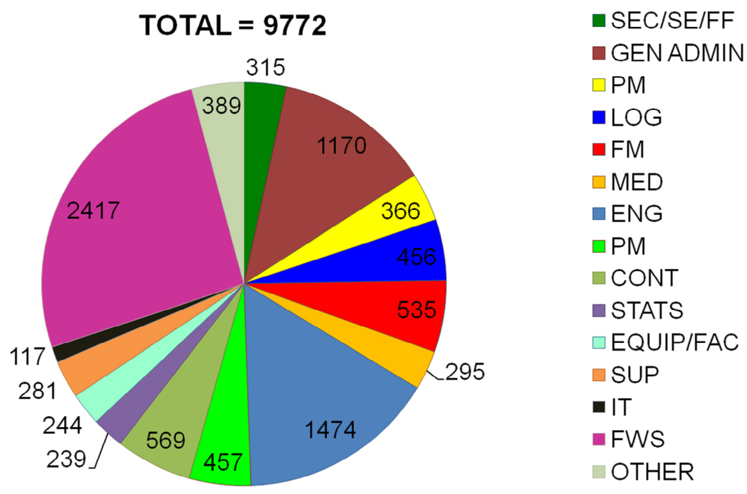


FIGURE E-5 AFMC Open Fill Actions by Occupational Series. SOURCE: Air Force Materiel Command.

Copyright © National Academy of Sciences. All rights reserved.

Appendix F

Applying Basic Rated Management Process and Model to STEM

The following is a discussion of how this basic rated management process and model could be applied to STEM. Many of the STEM processes have a direct correlation to rated management processes. See AFI 11-412 AIRCREW MANAGEMENT for full explanation of rated management within the Air Force.

This is not intended to be a comprehensive outline of STEM management, but instead is intended to show how many of the same principles of Aircrew management can be applied to STEM management.

STEM MANAGEMENT OVERVIEW

Purpose

This outline of management processes provides Air Force policy and guidance for the STEM workforce throughout the Air Force. It lays out an approach to STEM management, assigns responsibilities, and outlines processes and methodologies that might be used to manage STEM human capital capability.

STEM MANAGEMENT APPROACH

Objective

The overall STEM-management objective is to maintain a STEM-degreed force whose readiness and size enable it to effectively accomplish the Air Force's current and forecast mission.

Approach: Present - Sustainability Balance

Effective STEM management requires constant attention, specific incremental adjustments within a logical range/band, and fully coordinated actions that make sense for both the short and long term. To meet today's needs there will be many suboptimal solutions and actions taken. Each time a decision and action is taken that impacts future needs, an assessment and conscious decision must be made on this trade off of today vs. tomorrow. Whenever possible, modeling techniques should be employed to obtain the best understanding of potential impacts. Attaining the "size" aspect of the objective necessitates that sufficient numbers of STEM are accessed, produced, absorbed, and retained, and that a healthy inventory exits to support required overhead (Staff, Training, Instructors, etc.). The many facets and factors of STEM management are inextricably linked; changing one factor typically affects/changes several others. The litmus test

Copyright © National Academy of Sciences. All rights reserved.

for STEM management actions/decisions is whether they will improve combat capability, retention, and sustainment today and tomorrow.

Absorption

This is one of the most important and difficult factors in finding present sustainability balance for long-term health of STEM. The ability to retain quality STEM personnel depends on finding the right balance between short-term and long-term manning especially for the military component of STEM.

Absorption is the process of accessing new STEM accessions or cross-trained STEM personnel from other operational assignment by educational degree field (i.e., Electrical Engineer, Mechanical Engineer, Operations Research, Scientist etc) into STEM-required positions.

The Air Force's absorption goal is to balance the long-term need to sustain an inventory that meets requirements with the near-term goal of maintaining capability; i.e., to absorb the required number of new STEM personnel while maintaining at least the minimum capability (experience mix, average time on station, manning levels) required to meet taskings /commitments.

The primary absorption factors are:

- Total active duty requirements (i.e., force, training, staff, students, AFIT/PME and Transient)
- Active STEM prioritized requirement
- Programmed training (initial and continuation) to meet DAWIA, instructor, and advanced requirements
- Capability parameters (manning level, experience mix, and average time on station)
- Positions new STEM personnel can be assigned to become experienced ("absorbable billets").

Absorption calculations not only determine the number of inexperienced STEM to be assigned to organizations, they also provide the number of experienced and limited experience (LIMEX) STEM required

Additionally, the objective is to "experience" individuals during their first few STEM tours. Attempting to set absorption levels based on inventory overages or shortfalls is problematic and results in insufficient numbers of STEM and/or reduced capability. Regardless of retention/ inventory levels, organizations can only effectively absorb a set number of new STEM personnel.

STEM MANAGEMENT TENETS

- Optimize Absorption to sustain requirements within readiness parameters (Manning Level, Experience Mix, Average Time on Station)
- Size Accessions/Training (Production) based on operational needs
- Improve Retention through credible, congruent, long-term-focused policies and actions that facilitate force sustainability
- Set Manpower Requirements to provide sufficient line force positions to meet operational taskings and efficiently support (Training/Staff/Test/Other) operations
- Manage the STEM-degreed Force
    - Take actions that reflect Air Force priorities to include preservation of institutional culture

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

- Smooth incremental adjustments to get/keep the system in balance and operate within reasonable bands
- Fully coordinate actions that make sense for the short and long term
- Effectively use all available aircrew expertise/assets as required
- Use a Litmus Test: Will the decision/action improve mission capability?

STEM MANAGEMENT ROLES

Vice Chief of Staff of the Air Force (VCSAF)

VCSAF as chair of the Force Management & Development Council (FMDC) should oversee the STEM management function and should periodically convene summits to address STEM issues. This could be accomplished either as a single subject summit on STEM or as part of a larger FMDC review**.** FMDC serves as a corporate body to provide an institutional perspective on Air Force-wide FD issues and make recommendations to the Secretary of the Air Force (SECAF) and Chief of Staff, Air Force (CSAF). SAF/MR, Functional Authorities (FA), MAJCOM CVs, Chief Master Sergeant of the Air Force (CMSAF), and appropriate Air Reserve Component and civilian representation make up the FMDC and provide a review of total force management. The VCSAF chairs the FMDC.[1]

Military Deputy, Office of the Assistant Secretary of the Air Force for Acquisition

The Military Deputy to the Assistant Secretary of the Air Force for Acquisition should be the office of primary responsibility (OPR) for STEM management. This position develops strategy, policy, guidance, plans and processes/methodologies for managing the STEM force.

STEM Management Executive Council (SMEC)

At least annually, the Military Deputy to the Assistant Secretary of the Air Force for Acquisition should organize and chair a colonel/GS-15 SMEC conference whose attendees are STEM managers from the operations and personnel communities across the Air Force. The SMEC would assess the health of the STEM force by reviewing key STEM-degree-required force decisions/guidance and trends/issues/concerns, discussing improvement options, and developing proposals/tasking for further coordination/approval in the formal Air Force staffing process. Also, the SMEC would provide a forum for ensuring STEM managers have a sufficient and consistent understanding of STEM management. STEM issues normally discussed would include: experience mix, average time on station, manning levels, military, civilian, reserve, FFRDC, contract mix objectives; manpower requirements; absorption; training/production; distribution; retention; STEM allocation; requirements-inventory delta management; and any other issues or developments that may affect the STEM force.

STEM Training Management Subgroup (STMS)

The STMS would do the following: Facilitate/coordinate the Source of Commission (SOC), AFIT input - output to ensure entrance of STEM personnel are trained in required specialties and will enter STEM positions or STEM growth positions (including the identification, validation, consolidation, programming and resourcing of requirements); review Distribution Plans for sufficient numbers to accomplish the mission; reviews USAFA, AFROTC, OTS and Program

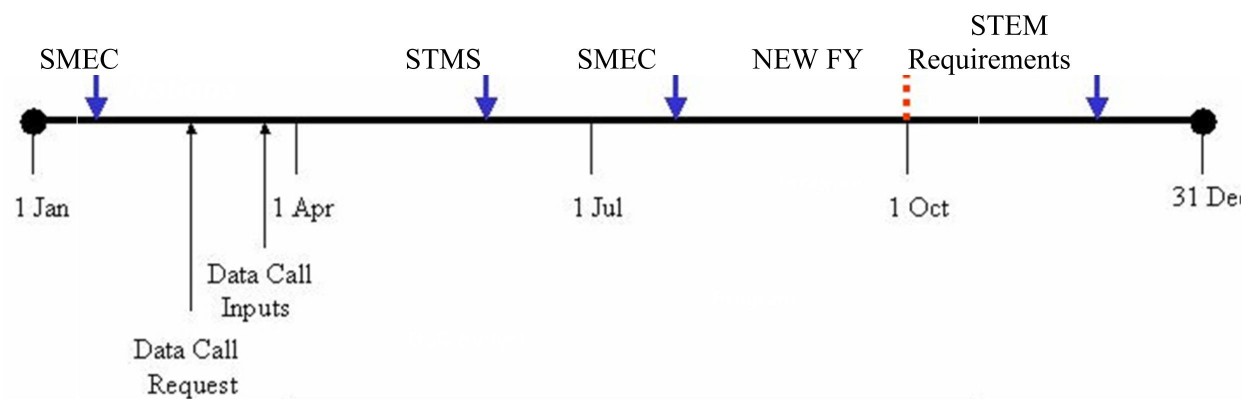
[1] Air Force Policy Directive 36-26, August 27, 2008, Personnel Total Force Development, p. 7.

Copyright © National Academy of Sciences. All rights reserved.

Requirements Documents and Programmed Funding Level are sufficient; identify any projected over/under-production, breaks in training, and other deviations that could adversely affect the Training and Force categories; and provide visibility into the pipeline training flow and management with an eye toward improving effectiveness/efficiency. Of particular importance is the creation of a sufficient pool of DAWIA-certified personnel to meet requirements. The STMS, normally an ‘AO-level’ group, would be responsible for keeping the SMEC apprised of its activities and progress.

At Figure F-1 is a STEM Management Timeline to guide timing of critical decisions to meet programming cycles.

Key organizations for day-to-day management would be Air Force DCS for Manpower and Personnel (A1), the Military Deputy, Assistant Secretary of the Air Force for Acquisition and Air Force Material Command (AFMC). Table F-1 is a chart of some of the major areas of responsibility of day-to-day management.



(STMC)STEM Management Executive Council
(STMS) STEM Training Management Subgroup
(FY) Fiscal Year

FIGURE F-1 STEM management timeline. SOURCE: Adapted from AFI 11-412, Attachment 6.

Copyright © National Academy of Sciences. All rights reserved.

TABLE F-1 Major Roles and Responsibilities

HQ USAF A-1	ASAF Acquisition	SAF / AQR
STEM Policy	STEM Requirements	
Compensation Incentive pay Bonus pay	Production requirements	
Inventory managers	Career Field Managers	Career field Manager
Publish STEM training Requirements Source of Commission Formal training	Establish training policy and requirements	DAWIA training requirements
Coordinate on waivers and exceptions to policy for STEM designation	Set policy / process for waivers	DAWIA waiver policy and approval
MODEL: Create and operate model for personnel management RL/BL	Set input – output requirements	
Model: Absorption create and operate	Establish Absorption Policy and parameters in conjunction with other MAJCOM and Agencies	

STEM REQUIREMENTS INVENTORY MODEL

Overview

To properly manage the STEM force for near term and long term it is necessary to model the interactions of: accessions; retention; changes in military, civilian contract mix; absorption capability; requirements by specific STEM education; generalized requirements by STEM education; adjustments to overhead; impact of adjusting entitlements; programmatic requirement changes; arbitrary changes in requirements; changes in acquisition programs; establishment of new classified programs; standup of new missions (space offense/ defense, cyber, optics etc.), just to name a few. Each of these changes and many more interact to have both short-term and long-term impacts. It is imperative to gain insight into the impact of decisions before implemented. It will NOT give a "20/20 crystal ball answers" to every question, but it can provide basic knowledge on which to base decisions on our most important asset, Air Force people.

Model

Figure F-2 is a flow chart of the existing Air Force Rated Aircrew Management System (AFRAMS) model input-output. It is followed by a table of terms that might be used to translate Rated to STEM (Table F-2) if this same type of model were developed for STEM management. The committee calls this the Air Force STEM Management System (AFSTEMMS). AFSTEMMS and Table F-2 were developed by the committee.

Copyright © National Academy of Sciences. All rights reserved.

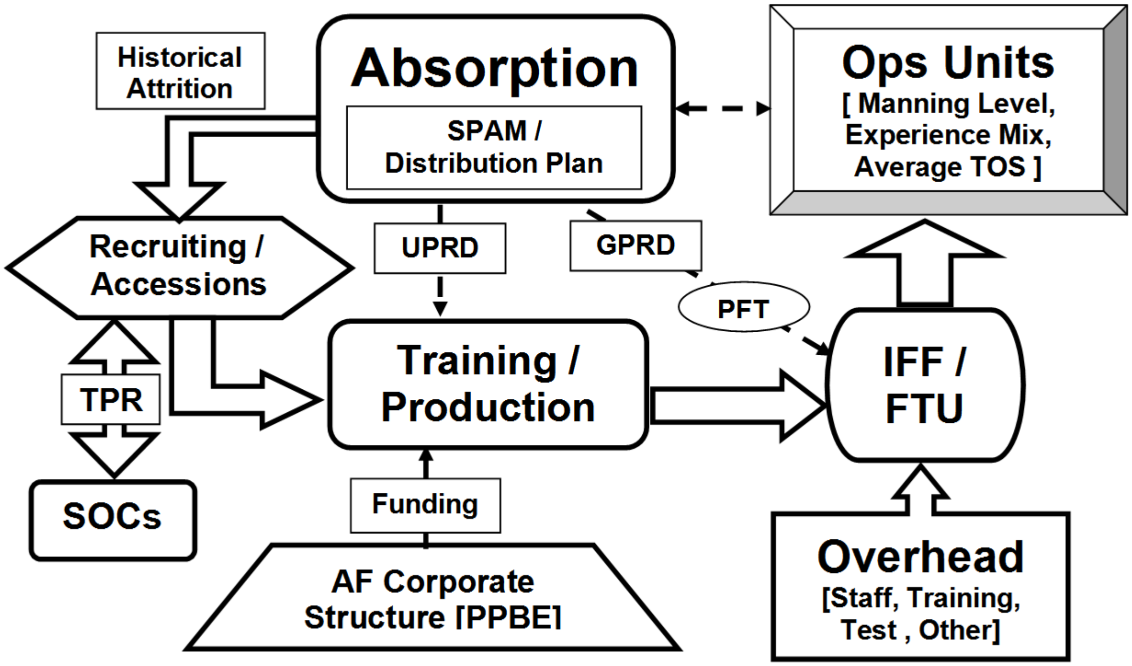


FIGURE F-2 AFRAMS model. SOURCE: (AFI 11-412 fig 4-1).

Copyright © National Academy of Sciences. All rights reserved.

TABLE F-2 Terms that Might be Used to Translate Rated to STEM

AFRAMS FACTOR	AFSTEMMS FACTOR
1. Ops Units (Manning levels, Experience mix, average Time on Station (TOS))	Requirements, present manning. STEM required manning levels in core STEM AFSCs, DAWIA required experience, time on station, acquisition continuity.
2. Overhead staff, training, test, other	Overhead staff, AFROTC, instructors, other to account for other than hard Air Force STEM requirements
3. Source of Commissions (SOC)	SOC: USAFA, AFROTC, OTS capacity, projected output ; add civilian recruiting ; Capability of FFRDC and contracting
4. Air Force Corporate Structure (PPBE) Programmed input for funding of programs	Air Force Corporate Structure (PPBE): mission and program changes requiring STEM personnel and changes in funding of existing programs
5. Funding	Actual funding or programs, civilian pay and any targeted contract costs
6. Absorption (distribution plan) from absorption capability model	Absorption (distribution plan) from STEM absorption capability model
7. Historical Attrition	Historical Attrition: Will need to track by areas STEM specialty and aggregate
8. Recruiting / Accessions	Recruiting / Accessions: AFROTC scholarships, USAFA policy, OTS objectives. May need to add concept of cross training from dated STEM-degreed operational assignments
9. Trained Personnel Requirements (TPR)	TPR: STEM training requirement based on SOC output skills and any refresher training into STEM positions from dated STEM-degreed operational assignments
10. Undergraduate Program Requirements Document (UPRD)	DAWIA / AFIT formal required training documents
11. Graduate Program Requirements Document (GPRD)	DAWIA / AFIT formal required training documents
12. Training Production	Training production
13. Program Flying Training (PFT) three year projected training requirement	Programmed STEM Training. Equivalent STEM is academic work in pre commissioning. May need to project out longer lead due to 4-5 years to produce change in USAFA and AFROTC.
14. Introduction to Fighter Fundamentals(IFF) / Flying Training Units (FTU) capability and capacity	Training pipeline capacity for all formal STEM

1. OPS Units / STEM-degreed requirements and inventory: The rated requirement is based on military only. STEM will need to account for DoD civilian contract and FFRDC capabilities. This will require some basic decisions on objective mix and definition of ability to deviate from this optimum mix. Contract and FFRDC can be used for long term "shock absorbers" of requirements, for "pop up" requirements or unexpected changes in the external environment. As stated elsewhere in the report, present mix may not meet long-term objectives and needs to be adjusted by the STEM management and reviewed at least annually.

Copyright © National Academy of Sciences. All rights reserved.

Requirements and required manning levels: Because there are true shortages in some specialties and overages in others it is important to understand impact of prioritization. Management of the whole is dependent upon prioritization and cross flow of talent. Some requirements can be filled with only specific experience and background, others need a general knowledge. For example sometimes there is a requirement for an electrical engineer (translate fighter pilot), sometimes it requires a generic engineering degree (translate any pilot), and sometimes it requires STEM cognizance (translate any rated). It will be critical to not game the system, but instead make the best estimate of the true requirement. It will also be important to not remove a true requirement for a specific position only because in the short term there is no person to fill the position. To do so, creates a spiral and masks the true requirement. Prioritization and trade-offs are required to obtain the best utilization of limited capabilities.

Experience mix objectives will need to be set for STEM positions. These objectives will have to be put into the model to see impacts on cross-flow, military/civilian mix, absorption etc. Historical attrition can be impacted by special pay, bonus and active duty service commitments, once the true requirement is identified and the model identifies gap analysis of requirement and inventory.

Time on station is important for experience, fairness and broadening. Not all assignments are desirable. Time on station may also be a factor as today's acquisition programs have long lives and need continuity. There will also have to be adjustments for requirements set by DAWIA.

2. Overhead staff, training, other: This area is a separate requirement to acknowledge a "tax" to run the Air Force. It normally does not acknowledge the wartime, temporary duty, and one-year assignments that almost all Air Force AFSCs support. It does acknowledge the many requirements the Air Force must fill and the realities of transients, patients and prisoners accounts. Some may decide not to include these requirements. Just as in any other AFSC this will result in "actual" shortages. To ignore this input only masks the true requirements and results in further shortages. For STEM this may be a place to account for the instructors at the USAFA and AFIT.

3. SOC: Standard USAFA, AFROTC, OTS, plus, with STEM sources of input, can be civilian recruitment and adjustments to FFRDC and contracts.

4. Air Force Corporate Structure (PPBE): Reflect changes in acquisition programs, civilian personnel funding levels, programmatic and arbitrary cuts in personnel authorization or funding, base structure, etc. All these areas impact the requirements and the mix of military/civilian/contractor. Acceptance of these decisions on rated model and management tools is well understood and accepted by Air Force Board decision makers. Education will be required for STEM input/output requirements for funding level and impacts of other programming decisions.

5. Funding: no significant differences (see 4)

6. Absorption (distribution plan): Capacity to absorb new STEM personnel as they gain experience through future assignments may be a limiting factor. Absorption may not be a limiting factor in the sense of "cockpit seats," but the challenges of identifying requirements that will provide challenges, productivity and utilize the talents of new STEM personnel is very important. Civilian absorption is also a factor. Some DoD civilians will come to a position with experience and some will enter the workforce though DoD. The use of this model may influence civilian target experience to alleviate absorption shortfalls.

7. Historical Attrition: Will need to track military and civilian. There is not a long record and history of impacts of incentive pays or bonuses in STEM areas. Will need to track by STEM-degreed area as well as aggregate STEM categories.

8. Recruiting /Accessions: USAFA, AFROTC and OTS are the military sources. However, the recruiting and accessions for STEM are even more important than for rated management. In STEM, the education prior to accession sets the skills for future functional assignments. Because

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

of this, the requirements may have to be established over 4 years ahead of actual accessions. OTS is the exception, but still requires lead time to actual production. To meet this required for USAFA and AFROTC university "degrees" this requirement may drive polices to encourage specific degree production. Because civilians, FFRDC, and contractors can be "recruited" with years of experience, there is potential for a feedback loop to "experience mix" that does not exist in the military. This may be the place to acknowledge the use of dated STEM-degreed operational assignments personnel (aircrew, space and other operational experienced personnel) to the STEM workforce.

9. TPR: similar to rated model, except as stated before, formal training may be less than rated, but not eliminated. Follow on training for operational assignments, advanced academic degrees and OJT/formal mentoring programs. Civilian programs must be included.

10/11. UPRD/GPRD: DAWIA and AFIT training for acquisition or other specialized pipeline training requirements for STEM.

12. Training Production: For STEM, many areas do not require lengthy formal training. As STEM requirements are defined for Space and Cyber operations, this may be an addition to the formal training requirement. If formal OJT or internships are required, this area could be used to model this requirement.

13. PFT (PST) Programmed STEM Training: This may be duplicative for STEM since primary training is accomplished at SOC. Equivalent. May need to project out longer lead time due to 4-5 years to produce change in USAFA and AFROTC.) see 3, 9, 11, 12.

14. Introduction to Fighter Fundamentals (IFF)/Flying Training Units (FTU) capability and capacity; **STEM Training Pipeline capability:** Training pipeline capacity for all formal STEM training required DAWIA education, advanced academic degree (AFIT etc) capacity to produce trained and ready STEM-degreed or experienced personnel. Includes civilian STEM internship or formal training courses.

STEM MANAGEMENT DOCUMENT (SMD)

STEM Management Document (SMD) is one of the primary documents used for planning and programming STEM personnel. This document is designed to include any materials Principal, Assistant Secretary of Air Force Acquisition deems appropriate to archive and might include: historical account of STEM management significant decisions/initiatives since the last SMD was published; SMEC briefings and background papers; operational unit experience, average time on station (TOS), and actual manning level data for the end of the fiscal year; requirements and inventory actual data for the end of the fiscal year; total and major organizational users of STEM requirements vs. inventory projections; retention statistics; SOC and AFIT planned and actual data; distribution planned and actual data; forecast allocation and actual data; and experience definitions, criteria, and mix. These parameters should be a product of the STEM management model and/or management decisions.

Copyright © National Academy of Sciences. All rights reserved.

Appendix G

Scientists, Engineers, and the Air Force: An Uncertain Legacy

Richard P. Hallion[1]
Smithsonian Institution

Air Forces, more than other military Services, are critically dependent upon science and technology. The nature of air and space power intrinsically dictates the use of systems and the projection of capabilities that demand mastery of the three-dimensional medium of flight, an environment vastly different than two-dimensional surface movement. Flight is a relatively recent human endeavor: ballooning appeared in 1783, with its application to battlefield observation just over a decade subsequently. The heavier-than-air airplane first flew in 1903, and the first use of the airplane for wartime reconnaissance and bombing came less than eight years later, in 1911. However crude, the use of the airplane as a primitive intelligence, surveillance, and reconnaissance system decisively influenced the outcome of the two great opening battles of the "Great War," the Battle of Tannenberg and the First Battle of the Marne, thereby dramatically transforming (indeed shaping) the subsequent nature of the war. The surprising value of aircraft converted even its critics. By 1916, French Marshal Ferdinand Foch, who before the war had thought aviation had "zero" military value, was writing "Victory in the air is the preliminary to victory on land."[2] By war's end, as British Prime Minister David Lloyd George noted afterwards, "Supremacy in the air" constituted "one of the essentials of victory."[3] Indeed, the combatant nation's technologists and airmen had evolved aircraft, doctrines, and tactics for virtually all subsequent military uses of the airplane, including strategic and tactical reconnaissance and bombardment, and maritime air operations.

The interwar years witnessed steady evolution of the airplane. By the end of the interwar period, the wood-and-fabric biplane had given way to all-metal highly streamlined monoplane fighters, bombers that could carry heavy payloads over hundreds of miles, and transports that could span continents and cross oceans. The power of the aircraft piston engine had increased over a hundred-fold since the time the Wrights flew at Kitty Hawk, and the speed of aircraft had increased over ten-fold in the same period, from 40 mph to over 400 mph. Already, far-seeing

[1]Dr. Hallion served on the study committee for this report and prepared this history at the committee's request.

[2]Handwritten comment on letter to Commander, troisième bureau, n. 6145 (23 Nov. 1916), in Bernard Pujo, "L'evolution de la pensée du general Foch sur l'emploi de l'aviation en 1915-1916," in Colloque air 1984 (Paris: Service historique de l'armée de l'air and Institute d'histoire des conflits contemporains, and the École militaire, Sep. 1984), p. 221

[3]David Lloyd George, War Memoirs of David Lloyd George, v. 2 (London: Odhams Press Ltd., 1938 ed.), pp. 1095 and 1588

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

innovators were forecasting the era of gas turbine "jet" propulsion, with routine flight speeds over 550 mph. The invention of the high-performance liquid-and-solid-fueled rocket, though itself then in its infancy, offered the promise of extending military striking power well beyond the range of conventional artillery, exceeding the speed of sound, and possibly reaching into space as well.

The Second World War made manifest the multifold capabilities of military aviation. In 1939, Nazi Germany's air-land forces swiftly overran Western and Northern Europe. England's salvation from possible Nazi subjugation came through the air, in the bitter Battle of Britain fought over Kent in the summer of 1940. At sea, maritime Allied air power—most of it projected by land-based aircraft—proved of crucial significance to winning the Battle of the Atlantic and defeating the menace of both surface raiders and the infamous U-boat. The Allies' Combined Bomber Offensive effectively constituted an aerial "Second Front" that forced Nazi Germany's leadership to redirect military priorities and acquisition goals from offensive to defensive systems and forces, in a futile attempt to protect the Reich from Allied air attack. When, in 1944, Allied invasion forces landed at Normandy, they did so under an umbrella of fighters shielding them from meaningful German air attack. Invasion commander General Dwight Eisenhower stated boldly "If I didn't have air supremacy, I wouldn't be here."[4] Overwhelming Allied air power denied German ground forces any ability to decisively intervene. "The enemy's air superiority has a very grave effect on our movements," German Field Marshal Erwin Rommel confided to his wife, noting "There's simply no answer to it."[5] A decade afterwards, Nazi Lieutenant General Bodo Zimmerman still vividly recalled "the unimaginable effects of the enemy's air supremacy," and "the impossibility of travelling along any major road in daylight without great peril."[6] The subsequent advance of Allied forces across the European Continent was so dependent upon Allied air power for its rapidity of movement and overall success that, at war's end, Nazi propaganda minister Joseph Goebbels confided in his diary that "Our whole military predicament is due to enemy air superiority."[7]

The Pacific war was won by the projection of three-dimensional attacks against Japanese forces. The synergistic interplay of submarine and air attack destroyed Japan's merchant and combat fleet, severed its lines of communication, and effectively made hostages of its deployed forces. In the China-Burma-India theater, air transport substituted for the lack of road and coastal access, keeping China's military forces supplied with critical weapons and materials. At war's end, fearsome bombing raids destroyed Japanese industrial and urban centers, culminating in the use of two atomic bombs that shattered any remaining will to resist among the Japanese military and civilian leadership. But even without the atomic bombs, the aerial destruction wrought upon Japan's homeland caused Japanese Premier Kantaro Suzuki to state afterwards "merely on the basis of the B-29s alone I was convinced that Japan should sue for peace."[8]

Having secured its birthright in the hot crucible of air combat, the United States Air Force emerged as a fully independent military service in September 1947, its creation greatly eased by the extraordinary record of accomplishment its airmen had established in a remorseless global air war. The triumphal fulfillment of a vision dating to the days of "Billy" Mitchell and the early service of Henry "Hap" Arnold, the Air Force was created amidst one of the most challenging

[4]John S. D. Eisenhower, Strictly Personal (Garden City, N.Y.: Doubleday and Co., 1974), p. 72.

[5]B. H. Liddell Hart, ed., with Lucie-Maria Rommel, Manfred Rommel, and General Fritz Bayerlein, The Rommel Papers (N.Y.: Harcourt, Brace, and Co., 1953) p. 491.

[6]Quoted in Seymour Freidin and William Richardson, eds., The Fatal Decisions (New York: William Sloane Associates, 1956), p. 215.

[7]Goebbels Diary, 21 March 1945.

[8]James Lea Cate and Wesley Frank Craven, "Victory," in Craven and Cate, eds., The Army Air Forces in World War II, v. 5: The Pacific: Matterhorn to Nagasaki, June 1944 to August 1945 (Chicago: University of Chicago Press, 1953), p. 756.

Copyright © National Academy of Sciences. All rights reserved.

periods in aeronautical history. Already, over the decade from 1935 to 1945, the speed of the fastest military aircraft had more than doubled, and the explosive energy of a bombers' payload had risen almost ten-fold for conventional bombs, and over ten-thousand fold for atomic ones. Now the mid-century turbojet and high-speed revolution, entwined with the onset of the atomic and computer ages, promised to transform it further still. For Air Force airmen, the recognition of the challenges and opportunities of this new era was accompanied by the uncomfortable realization that, for all of America's aeronautical excellence, its wartime triumphs had been (as Wellington remarked of Waterloo) "a close-run thing."

The authors of the United States Strategic Bombing Survey's *Summary Report* on the European and Pacific air war noted somberly that:

> Upon entering the war, we were deficient not only n numbers, but in quality of many of our aircraft types. We were forced thereafter into hasty and costly modification and technical development programs to raise the performance of our aircraft to acceptable standards. These programs could have been conducted more efficiently and economically during prewar years. . . . In the future, national security will depend to a large degree on technical superiority of weapons and on operating and maintenance proficiency of personnel. . . .expenditures for research and development in the order of one billion dollars annually may be required to assure an acceptable degree of national security.[9]

In the postwar era, of course, annual research and development appropriations for national defense eventually consumed far more, on average, than a billion dollars. But the authors of the USSBS *Summary Report* hinted more accurately at an essential and enduring truth: the critical importance of securing the services of well-trained and qualified scientific and technical personnel for maintaining and ensuring "Air Age" security.

Indeed, the need for scientific and technological competency historically was, arguably, the single most consistent and persistent requirement repeatedly enunciated by the airmen-leaders of the Army Signal Corps, the Army Air Service, the Army Air Corps, and, prior to establishment of the United States Air Force, the Army Air Forces. In contrast to European air forces, many of whose leaders were professional infantry or cavalry officers in background, the Army and Navy chose their air leaders from the graduates of West Point and Annapolis who were, in the interwar period, effectively all trained engineers. Many--Generals Henry H. "Hap" Arnold and James H. Doolittle foremost among them--were active in professional scientific and technological organizations such as the Institute of the Aeronautical Sciences (predecessor of today's American Institute of Aeronautics and Astronautics) and the National Advisory Committee for Aeronautics (NACA, predecessor of today's National Aeronautics and Space Administration), and thus intimately cognizant of the state of contemporary and future aeronautics. They formed close associations with leading aircraft industrialists, designers, government scientists, and academicians, individuals such as Donald Douglas, Glenn Martin, James Kindleberger, Jerome Hunsaker, George Lewis, Hugh Dryden, and Theodore von Kármán.

Repeated studies from the earliest days of the air service emphasized the significance of a science and technologically cognizant military and civilian workforce. As early as 1914, in the foundational period of American aeronautical engineering, the U.S. Army Signal Corps sent technical officers to the Massachusetts Institute of Technology to study aeronautics. In 1919, the Crowell Committee argued for establishment of both an independent air force, the importation of European aviation science and laboratory organization, and establishment of a national military-and-civil air academy to train air-minded officers and civil air leaders. The Army Air Service's need for properly trained scientific and technical officers triggered creation of the Air Service

[9]USSBS, Summary Report (European and Pacific War) (Maxwell AFB: Air University Press, Oct. 1987 ed.), pp. 111-112.

Copyright © National Academy of Sciences. All rights reserved.

Technical School, predecessor of today's Air Force Institute of Technology. Exposure to European (particularly German) aeronautical development caused air prophet (and gadfly) William "Billy" Mitchell to arrange the importation of study examples of modern European aircraft, and individuals as well, notably Russian émigré Igor Sikorsky, inventor of the first great intercontinental airliners and the practical helicopter. Successive investigations over the interwar period—the Lampert Committee, and the Morrow Board most memorably—stressed the necessity of adequately supporting the technical infrastructure and advancement of American aviation, and ensuring the quality of technical staffs. In partnership with American universities, and encouraged by Federal agencies such as the NACA and the military services, the private Daniel Guggenheim Fund for the Promotion of Aeronautics (1926-1930) effectively established professional aeronautical engineering education in universities, its greatest and most notable educational accomplishment being creation of the Guggenheim Aeronautical Laboratory at the California Institute of Technology (GALCIT) and securing Hungarian scientist Theodore von Kármán as its director. The establishment of GALCIT, an American equivalent to Ludwig Prandtl's world-renowned fluid mechanics research institute at Germany's Göttingen University, effectively led to a "special relationship" between the school, the American aircraft industry, and the military services, but particularly the Army Air Forces. Nurtured by the strong personal bonds and mutual respect existing between Arnold, Douglas, and von Kármán, Caltech became a leading center of government-industry sponsored research, and a vital adjunct (and occasionally cross-check) to the service's own laboratories and those of the National Advisory Committee for Aeronautics.

America's enthusiastic embrace of professional science and engineering training constituted, like mass-production and rational industrial organization, one of the distinctive hallmarks of its national aeronautical style. During the Second World War, when Sir Roy Fedden led a British technical mission to the United States, its members were most "impressed with the scale and size of the engineering staffs of the most important firms in America," Fedden's report noting "the general technical training and theoretical knowledge of the average aeronautical engineers" was "of a higher order" than Britain's, due, the mission believed, "to the excellent facilities at the various engineering universities for the training of aeronautical engineers."[10]

In the years between the Great War's Armistice and VJ Day, America's uniformed and civilian military aeronautical engineers contributed notably to the advancement of American aeronautical technology. Air Service, Air Corps, and Air Forces engineers achieved a number of significant "firsts" including:

- Derivation of the first American thick-wing section airfoils enabling design of high-lift cantilever monoplane aircraft. (Virginius Clark).
- The first discovery of transonic shock phenomena around a propeller tip, including drag divergence and loss of lift. (Elisha Fales and Frank Caldwell).
- Development of the world's first retractable landing gear low-wing high-performance fighter-type monoplane anticipating the "normative" fighter configuration of the Second World War by more than a decade. (Alfred Verville).
- Development of improved air-cooled cylinder configurations leading to the high-performance radial piston engine. (S. D. Heron).
- Development of the first American all-metal redundant aircraft structures for monocoque and cantilever design. (Charles Monteith and John Younger).

[10] Great Britain, Ministry of Aircraft Production, The Fedden Mission to America: Final Report (London: HMSO, 1943), 1A-1.24, p. 12, emphasis added, from the library of the Science Museum, South Kensington, London. I thank Dr. Andrew Nahum of the Science Museum for graciously arranging for my examining this report.

Copyright © National Academy of Sciences. All rights reserved.

- Development of the first understanding of structural loadings and deformations during maneuvering flight. (William Brown and James Doolittle).
- Development of blind-flying instrumentation and navigational aids. (Harry Diamond, James Doolittle, and Alfred Hegenberger).
- Development of the practical pressurized cabin (Carl Greene and John Younger).
- Development of the first practical configuration for a transonic and supersonic rocket-propelled research airplane, leading to the Bell XS-1. (Ezra Kotcher).

The service sent many officers to specialized training at civilian institutions; in 1938-39, for example, Wright Field sent seven officers to study at Caltech, Michigan, Stanford, and MIT.[11] The Air Corps Engineering School was very advanced in its course offerings; in the early 1930's, its student engineers in an aircraft design course, were already integrating such advances as all-metal monocoque and cantilever construction, controllable-pitch propellers, and retractable landing gears, at a time when such features were far from standard elements of the "normative" airplane.

However, the service did not possess an unblemished record in aeronautical achievement. Its engineers missed the significance of gas turbine propulsion, in part because the Air Corps, in the late interwar period, relied excessively upon other Federal agencies and industry for its scientific and technical expertise. When the NACA, the Bureau of Standards, the U.S. Navy, and the aero-engine industry all missed the significance of the jet engine, the Air Corps was not then in a position to contradict such technological conservatism. Air Corps chief General Hap Arnold, shocked to learn of British turbojet advances during a key 1941 visit to the United Kingdom, immediately recognized the necessity of importing Whittle engine technology to the United States, and from this sprang the first American jet airplane program, the Bell XP-59A. Missing the jet engine would be the strongest single goad driving Arnold to appointing his own scientific advisor (the eminent von Kármán), and ultimately for the Air Force to possess a Chief Scientist, a comprehensive laboratory system, and a Scientific Advisory Board.

The wartime encounters between American propeller-driven fighters and bombers, and German cannon-and-rocket –armed jet fighters, and postwar examination of the German aeronautical industry and research establishment (particularly its investment in high-speed swept-and-delta-wing design), offered mute evidence of the close nature of the Allied aerial victory. A shift of several years, a differing approach to physical sciences research, and a change in Nazi aeronautical research policies to more effective coordination and management, could have dramatically reversed the course of the war, with German aircraft and missiles carrying German atomic weapons at transonic and supersonic speeds well beyond the ability of Allied defensive forces to intercept and destroy them.

Arnold's enthusiastic, indeed driving, support of a robust science and technology establishment within the service is well-recognized by both practitioners and historians of American aerospace science. At his behest, in 1945, von Kármán headed a team that assessed German scientific and technical accomplishments. As well as recommending that the wartime practice of relying upon civilian expert consultants continue, and that the Air Force chief of staff have a special scientific advisory body reporting directly to him, their report, *Science, the Key to Air Supremacy,* recommended exchanges of military and civilian scientific and engineering personnel, and stressed the necessity for "the infiltration of scientific thought and knowledge throughout the Air Forces and, therefore, certain organizatory [sic] changes in recruiting

---

[11]Martin Clausen, Comparative History of Research and Development Policies Affecting Air Materiel, 1915-1944, Historical Study No. 20 (Washington: HQ USAAF, June 1945), pp. 43-45.

Copyright © National Academy of Sciences. All rights reserved.

personnel, in training, and in staff work."[12] It stated that "scientific ideas" must be introduced into day-to-day staff and command work, particularly long-range planning, management of research and development, intelligence, and operations. "The theory than an intelligent officer is able to direct any organization, military, technical, or scientific, is certainly obsolete," it argued, further noting:

> "Offices with engineering training on engineering duty must not be handicapped, as regards promotion, because of long tenure of the same assignment or time spent in acquiring advance education. The position and rank of officers responsible for research and development must be made commensurate with the importance of their work and achievement and must not depend on the size of the organizations under their command. The level of civilian personnel engaged in research and development work must be raised by authorizing the Air Forces to hire or dismiss civilian scientific personnel outside of the Civil Service. Also, methods of appointment, compensation, and management of civilian scientific personnel under the Civil Service must be freed from those restrictions of the Civil Service regulations which make the government service unattractive for first-rate scientists. In this connection, a separate branch of the Civil Service for scientific personnel would be of value."[13]

While not all of their broader objectives were actually achieved, the von Kármán reports set forth an agenda that drove much of subsequent Air Force investment in science and technology. As one consequence, from it sprang the Arnold Engineering Development Center, its creation triggered by discovery of the extensive German investment in supersonic and hypersonic wind tunnel facilities.

The recommendations and positions of the von Kármán reports, especially those emphasizing the significance of science and technology have echoed in the years since their initial enunciation. As the nation drew-down from one conflict and uneasily progressed towards even longer and more intricate one that followed, the "Cold War," science and technology assumed even greater significance. A particular concern then, and one apparent in various studies since, was the challenge of ensuring the availability of trained scientists, engineers, technologists, and technically qualified personnel sufficient to fuel the needs of postwar American industry, military Services, and government research laboratories. In 1947, the President's Scientific Research Board reported the Soviet Union increasing its engineering training programs to produce upwards of 140,000 trained engineers per year.[14] Alarmed by this and a growing shortage of scientists in academia, industry, and the government, Board members recommended formation of a National Science Foundation, and expanding scientific research and education in anticipation of driving competition over the next decade.[15]

Such concern resonated strongly within the aviation community, where wartime employment levels of science and engineering professionals had dropped precipitously. Production plummeted within the aircraft industry, and with it, numbers of engineering and technical personnel, manufacturing efficiencies (measured in terms of pounds of structure produced per worker per day). Senior industry executives testifying before the President's Air Policy Commission (the Finletter Commission) repeatedly complained of the declining numbers (and competency) of engineering and technical staffs, one terming it "a real hazard," and another judging it

[12]Letter. von Kármán to H. H. Arnold, 15 Dec. 1945, reprinted in Michael H. Gorn, ed., Prophecy Fulfilled: "Toward New Horizons" and its Legacy (Washington: USAF History and Museums Program, 1994), n.p.

[13]von Kármán et. al., Science, the Key to Air Supremacy (Washington: AAF Scientific Advisory Group, 1945), findings 14.9-14.11.

[14]John R. Steelman and The President's Scientific Research Board, Science and Public Policy: A Report to the President, v. 1: A Program for the Nation (Washington: GPO, 27 Aug. 1947), p. 6.

[15]Ibid.

Copyright © National Academy of Sciences. All rights reserved.

"alarming."[16] The Finletter report itself found lack of trained scientific and engineering personnel "The most serious bottleneck in the research and development picture," more, even, than the paucity of money and need for new and expanded facilities, recommending:

> that the Services offer every possible inducement for capable officers to enter aeronautical research and development work. They should be given opportunity to take graduate work in their specialty in the best civilian schools in the country at Government expense. They should be assured that they will be allowed to work in their special fields without interruption, and that their opportunities for advancement in rank will not be prejudiced as a result. Only by so doing will we be assured of the continuity of research leadership that we require.[17]

Vannevar Bush, wartime chief of the Office of Scientific Research and Development (OSRD) and President of the Carnegie Institution of Washington, added his own prestige to arguing the case for expanding scientific and technical education, in his influential *Modern Arms and Free Men.* "In a world where wars were crudely fought, with little relation to industry of the application of science, we could coast along fairly safely," he wrote in 1949, adding, "In a world where the prosecution of war or the avoidance of war demands that we be in the forefront in the applications of science . . . we can no longer afford to drift with a slow current."[18]

Ironically, even as industry and the professional science and engineering community argued the centrality of science and engineering to American aviation supremacy, the leadership of the Air Force, in the post-Arnold era, grappled uncertainly with the future of Air Force S&T. Despite Arnold's strong endorsement, and despite von Kármán's prestige and the evident lessons of the Second World War, science and engineering had a tough slog to incorporation within an Air Staff confronting many seemingly more pressing resource challenges. In October 1947, the same month that Air Force test pilot Charles "Chuck" Yeager ushered in the era of supersonic flight with the Bell XS-1 (an aircraft program conceived in 1944 by a Wright Field engineering officer), the Air Force leadership briefly entertained abolishing the Air Force Scientific Advisory Board, and a von Kármán assistant took time from his own doctoral studies at MIT to warn him "there seems to be considerable question as to whether or not the SB will continue to exist," noting that "the board is nowhere shown on the new organization charts."[19] It took the personal intervention of von Kármán, with his legendary persuasiveness, to convince Air Force Chief of Staff General Carl Spaatz to incorporate the SAB as a functional element of the Chief of Staff's office; otherwise it might never have existed to serve the nation over the next six decades.[20]

The SAB's travail matched the then-generally disorganized and fluctuating state of Air Force S&T, which itself reflected the precipitous decline of Air Force personnel strength and resources in the 1945-1950 era. Overall, the Air Force had less than forty percent of the authorized R&D personnel of the U.S. Navy, and less than sixty percent of the Army's, even

[16]Statements of Guy W. Vaughan, President, Curtiss-Wright Corporation, and Malcolm P. Ferguson, President, Bendix Aviation Corporation, in Aircraft Industries Association, Elements of American Air Power (Washington, AIA, 1947), pp. 94, 119.

[17]Thomas K. Finletter and the President's Air Policy Commission, Survival in the Air Age: A Report by the President's Air Policy Commission (Washington: GPO, 1 Jan. 1948), pp. 94, 96.

[18]Vannevar Bush, Modern Arms and Free Men: A Discussion of the Role of Science in Preserving Democracy (Cambridge: The MIT Press, 1968 ed.), p. 237.

[19]Letter. Major Theodore Walkowicz to Theodore von Kármán, 14 Oct. 1947, Papers of Theodore von Kármán, Box 31, Folder 31.38, Archives of the California Institute of Technology, Pasadena, CA. I thank the Caltech archives staff for their assistance in locating this and other materials.

[20]Re SAB troubles, see Michael H. Gorn, Harnessing the Genie: Science and Technology Forecasting for the Air Force, 1944-1986 (Washington, D.C.: GPO, 1988), pp. 46-47..

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

though both the Army and Navy had considerably smaller R&D budgets.[21] The number of engineering officers had fallen from 9,964 at the end of 1945 to less than half this (4,049) at the time of formation of the Air Force as an independent Service less than two years later.[22] (By the time of the Korean War, it had risen slightly, to 5,357).[23] Many believed themselves little utilized, with little prospect of advancement in a Service heavy with combat veterans, many quite distinguished. "Research laboratories and establishments will never be provided with inspiring technical leadership if *tactical* accomplishments become a primary requisite for assuming positions of *technical* leadership," one complained in an Air University research paper;

> In utilizing our technical personnel, the Air Force must realize that the technical man has become this nation's most vital asset and should be given proper recognition for the exhausting and laborious research and development, while another Air Force officer performs the glamorous and exciting job of shooting down enemy fighter aircraft.[24]

But higher commanders were more concerned than more junior officers might have suspected. Reflecting SAB concerns, General Donald Putt, Director of R&D within the DCS-Materiel at Headquarters Air Force, considered the numbers inadequate, noting in particular that "The shortage of high-ranking USAF R&D personnel compromised the effectiveness with which USAF R&D needs are presented."[25] Central to improving the position of Air Force S&T was the idea of forming a specialized air research and development command to separate R&D from production. In April 1949, Air Force Vice Chief of Staff General Muir Fairchild, acting on behalf of chief of staff Hoyt Vandenberg, asked the SAB to survey the state of Air Force research and development, during which he emphasized that the Air Force required:

> (1) Inspired and competent leadership for our technical activities
> (2) Adequate career opportunities for technically trained personnel, to provide incentives and to insure integration into the Air Forces high command of a sufficient number of men with sound technical backgrounds. [and]
> (3) The attraction of a sufficient number of young professional personnel each year into technical work.[26]

Out of this sprang a committee, chaired by Dr. Louis Ridenour of the University of Illinois, strongly endorsed creation of R&D within a single agency. As well, General Vandenberg directed that Air University form a study team under General Orville A. Anderson; it submitted its own report in November 1949. In his cover letter, General George C. Kenney, wartime chief of the 5th Air Force turned Air University commander, excoriated Air Force research and development,

[21]Memo, Lt Gen. Donald Putt to CSAF, re "Need for More Emphasis on USAF Research and Development Activities," 24 May 1949, Papers of General Muir S. Fairchild, Box 4 "R&D" file, Manuscript Division, Library of Congress, Washington, D.C. The assistance of the LC staff is gratefully acknowledged.

[22]USAF Statistical Digest, 1947, Table 19, p. 27, reflecting end of war drawdown.

[23]USAF Statistical Digest, 1949-1950, Table 22

[24]Maj. Earle W. Kelly, "Proper Utilization of Technicians and Scientists in the Air Force," Air Command and Staff Course, Air University, Maxwell AFB, Oct. 1948, Doc. 239.04348, "Kelly, Earle W. 1948," Archives of the Air Force Historical Research Agency, Maxwell, AFB. The assistance of the AFHRA staff in locating this and other documentation is gratefully acknowledged.

[25]Putt memo to CSAF, 24 May 1949, Fairchild Papers, Box 4 "R&D" file, LC. There is another version of this letter from the Military Director of the SAB to the CSAF on 24 May 1949 in v. 2 of the HQ ARDC, History of the Air Research and Development Command, 23 January 1950-30 June 1951, (HQ ARDC, USAF, 1951); copy in AFHRA archives. The assistance of the staff in locating this and other documentation is gratefully acknowledged. (Hereafter, annual histories of ARDC and its successors are referred to by organizational abbreviation, year, volume [if necessary] and page. The other version suggests that Putt decided to put his "horsepower" behind the memo to furnish greater support by sending it over his own signature, a measure of his concern.

[26]Stmt of Gen. Muir S. Fairchild to SAB, 11 July 1949, in Fairchild Papers, Box 4, "R&D" file.

Copyright © National Academy of Sciences. All rights reserved.

stating bluntly that "the Air Force is seriously deficient in providing for its own future strength, a strength which may well be of critical importance to the security of our country."[27] Kenney's words were more than matched by the Anderson committee, which had, as its first conclusion, the provocative statement that "The United States Air Force is now dangerously deficient in its capacity to insure the long term development and superiority of American air power;" and which went on to conclude "Personnel policies are not designed to support the specialized requirements for highly trained scientific and technical personnel for the Research and Development function, noting subsequently "Our personnel procurement program has not provided us with adequate numbers of scientifically and technically trained personnel; we have not fully utilized those we do have; and our personnel policies have not been conducive to keeping those we have on the job or fully effective on the job." The committee recommended establishing policies so that only scientific or technically qualified officers could hold management positions in research and development, and developing a long-range plan to ensure recruitment of adequate numbers of technically qualified personnel. Finally, it recommended "Immediate establishment of a Research and Development Command," noting "We cannot hope to win a future war on the basis of manpower and resources. We will win it only through superior technology and superior strategy."[28]

Thus, by the end of 1949, coincident with the shock of the Soviet Union exploding its first atomic bomb, the ground had been well-prepared, thanks to the one-two of the Ridenour and Anderson reports. In February 1950 ARDC stood up as an independent command.[29] Formation of ARDC did not automatically resolve the challenge of adequately supporting R&D and of finding and nurturing STEM-qualified officers in the Air Force. The Korean War, which broke out in June 1950, resulted in the Air Force withdrawing 250 officers from civilian institutions and returning them to active duty, most of whom had been destined for research and development billets.[30] General James Doolittle, himself a distinguished aeronautical engineer (and holder of one of the first earned doctorates in aeronautical engineering awarded in the United States) advised Chief of Staff Hoyt Vandenberg in April 1951 that:

> We cannot have better weapons tomorrow *without sacrifice* today. Everyone is for research and development, just as everyone is against sin. However very few people will sacrifice for it . . . ask [an Air Force officer] how many groups or how many good people he will give up today in order to have a better Air Force tomorrow and you get a measure of his belief.[31]

Doolittle went on to note that:

> The most serious single problem in the Air Force is the shortage of competent personnel. It will take time to solve this problem, but this task is a must and should have top priority. *The greatest deficiency both in numbers and in competence exists in the scientific and technical personnel categories.* There are some excellent people already in USAF research and development establishments, and some extremely competent technically-trained people now on other duty in the Air Force who should be with research and development activities [but] On the

[27]Letter., Gen. George C. Kenney to CSAF, 19 Nov. 1949, ARDC, 1950-51 Annual History, v. 2. The Anderson report is "Research and Development in the United States Air Force" (Maxwell AFB: AU, 18 Nov. 1949), and a copy is within the ARDC history as well. Anderson's other committee members were Maj. Gen. Donald L. Putt, HQ USAF; Brig. Gen. Ralph P. Swofford, Jr., AMC; and Col. Keith K. Compton, Air Proving Ground.

[28]Anderson, O.A., D.L. Putt, R.P. Swofford, Jr., and K.K. Compton. 1949. Research and Development in the United States Air Force. Air University, Maxwell Air Force Base, November 18. Page 1.

[29]ARDC, 1950-51 Annual History, v. 1, p. 58. The correspondence (orders, etc.) is found in the Fairchild Papers, Box 4, "R&D" file, LC

[30]"Report on the Present Status of Air Force Research and Development," 20 Apr. 1951, p. 8, copy in Papers of General James H. Doolittle, Box 29, "ARDC" file, Library of Congress.

[31]Ibid, p. 4.

Copyright © National Academy of Sciences. All rights reserved.

> whole, the more aggressive, ambitious, intelligent and generally competent young officers—even among those with technical training—prefer duty with operational or combat units, since that is where the opportunities for promotion, decoration and public recognition are greatest. . . .As a result, research and development activities now desperately need not only more technically trained officers but also additional aggressive and intelligent administrative officers, who have a constructive attitude toward research and development work and who have the drive to get a job done.[32]

As an individual intimately familiar with civilian scientific and engineering organizations, agencies, and personnel, Doolittle recognized that the Air Force could not simply rely upon its officer cadre to resolve the challenge of increasing the numbers of STEM-qualified personnel. Instead, he recommended that "competent civilians must be given authority, responsibility, and prestige commensurate with their capacity," including a position "high on the organizational chart," with "real responsibilities, the opportunity to produce, and official recognition," including social privileges including membership in Officers Clubs. He urged intensified recruitment of civilian and military engineers and scientists, with particular emphasis upon ROTC graduate recruitment. (In fact, ARDC went beyond this, securing Air Force waiver to directly commission engineering graduates into ARDC, whether they had any previous military or cadet training at all). Echoing Lt. General Putt's concerns previously, Doolittle noted:

> There has been some apprehension about the number of people in the Air Force assigned to R&D work. This apprehension is unwarranted. Actually the Air Force R&D establishment is far too small to meet even the minimum supervisory requirements in connection with the R&D workload, the major part of which is contracted out to industry. The Air Force R&D personnel deficiency is indicated by the facts that, with a smaller R&D program, the Army has more than half again as many people as the Air Force directly involved in R&D work, while the Navy has over twice as many people as the Air Force directly involved in tan R&D program of not appreciably greater magnitude that that of the Air Force.[33]

By the end of the Korean War, a period coinciding with the "Golden Age" of Air Force transonic and supersonic research and development, ARDC had a total officer, enlisted, and civilian personnel strength of 41,000. Of these, 6,900 were defined as "R&D professional and scientific," with a further 8,100 listed as "R&D technicians." Supporting this workforce were 3,400 contractor personnel at various centers such as Lincoln, Eglin, and Arnold.[34]

The Doolittle survey of Air Force research and development constituted a seminal document from an author of unquestioned integrity and authority, and, as such, it had great influence. Several years later, Doolittle again reviewed the subsequent work of the ARDC, this time as part of an SAB team, which noted approvingly that:

> Competent technical personnel were brought for the first time into the highest policy making and planning councils of the USAF. Long-range planning of future weapon systems was initiated by bringing together R&D personnel, war planners, and representatives of the operational commands, industry, and the scientific community. The scientific resources of the nation, particularly those in the universities, were brought to bear on critical USAF problems through the establishment of special contract development laboratories. R&D personnel, then in critically short supply and dispersed throughout the USAF, were gradually reassigned to the

[32]Ibid, p. 5, emphasis added.

[33]Ibid., p. 8. In particular, he singled out electronic specialists, noting that, in 1951, the Service had need of 1,200, but only had 110 "properly trained.' (p. 9). Finding electronics-competent personnel, even this early, appears repeatedly in STEM-related documentation as a particular concern.

[34]"HQ ARDC Total Personnel" chart, Doolittle Papers, Box 29, "ARDC" file, LC.

Copyright © National Academy of Sciences. All rights reserved.

> newly established R&D organizations, and plans were made to augment the future supply of R&D personnel and to insure their optimum utilization.[35]

But, again, the SAB noted that, for all ARDC's successes, "The career management of technical personnel of high intelligence and competence remains a major problem area in ARDC as evidenced by the difficulties fully reflected in data supplied to us of recruiting and retaining officers and civilians of desirable technical caliber." R&D officers, he stated, should be retained in R&D billets, and that "a few officers of exceptionally high caliber should be provided from systems development through testing to operations and training." Overall, it urged, "R&D officers and civilians should be promoted for their technical accomplishments in R&D, not for their operational abilities nor for their administrative experience. Promotion boards sitting on the promotion of R&D personnel should be made up mainly of R&D officers and civilians." Civilians, the report argued, should be

> given assignments 'in the line' which put them in direct charge of a unit. In general, civilians should be used in this way for activities most closely related to research and technical development while officers should predominate in systems development. In cases where it is not advisable or practical to place civilians 'in the line,' they should be designated as 'chief scientists' or 'scientific advisors,' not as 'technical directors' when they are not in fact directing anything.[36]

It recommended greater opportunities for civilian graduate technical training, perhaps as an adjunct to, or emulating, education grants from the National Science Foundation.

This second look at ARDC coincided with the onset of the *Sputnik* crisis, which rocked American science and confidence in American technical excellence. It was a crisis that involved more the National Advisory Committee for Aeronautics (soon to be reorganized as the NASA), the Navy (developing the *Vanguard* booster which spectacularly failed before an international audience just weeks after the Soviets had orbited their first satellite), and the Army's von Braun team which successfully (if belatedly) launched *Explorer I* in January 1958. The Air Force came under little criticism, for it had a full plate of advanced research and development initiatives, was in the midst of transforming its fighter force from a subsonic one to a transonic and supersonic force, and had as well as robust missile development program that would soon bear fruition. Although *Sputnik* dramatically reshaped America's attitude toward science and technology education and undoubtedly encouraged many to enter the new field of "aerospace," in a practical sense it may be argued that little changed in the short-term. Those scientists and engineers working within the government, military, and industry in 1957 were largely those who, over the next decade, led the crossing of the space frontier and the landing on the moon in July 1969.

Further, the concern over the national state of science and engineering education was one that predated the catalyzing shock of the "Red Moon." In April 1956, fearing that "as a result of our continuing shortages of highly qualified scientists and engineers we are running the danger of losing the position of technological pre-eminence we have long held in the world," the Eisenhower administration had appointed a national "Committee on Scientists and Engineers."[37] It sought, by "the stimulation of community action across the Nation" to use scientists and engineers more effectively, and undertake other initiatives including strengthening scientific and mathematics training in elementary and secondary schools, and to motivate students to enter the

[35]Draft document, n.d., pp. 1-2, Doolittle Papers, Box 8, "AF SAB" file. Document is after Sputnik.
[36]Ibid, p. 15.
[37]President's Charge to the Committee, in National Science Foundation, The National Committee for the Development of Scientists and Engineers, NSF-56-10 (Washington, D.C., National Science Foundation, May 1956), p. vii.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

science and engineering field.[38] At that time, as a group, scientists and engineers constituted approximately one-half of one percent of the American population, and, if seemingly small, even this represented the quadrupling of scientists and doubling of engineers over the previous twenty years, much of this increase due to the benefits of the G.I. Bill encouraging veterans to take up technical and scientific education. At a higher administration level, members of the President's Science Advisory Committee differed on the relative merits of "science" and "scientists" versus "engineering" and "engineers." In one February 1959 meeting, confronting evidence of a national decline in engineering enrollments and an even more disturbing ratio between those students securing bachelor's degrees and doctorates (only one student in fifty went on to earn a doctorate in engineering), members could not agree whether there was a problem. One remarked that "industry in general would prefer to hire well trained physicists rather than well-trained engineers" and another affirmed "good science was basically more important than good engineering."[39]

As Sputnik most dramatically indicated, the time period of the 1950's was one of tumultuous expansion of American investment in science and technology, and particularly aerospace. Federal expenditure for research and development increased by roughly 75% between the end of the Korean War and the onset of the *Sputnik* crisis, with industrial research and development in aviation expanding from approximately $758 million dollars annually to $2.1[40] billion per annum, unmatched by any other industry. Hidden within this were Air Force R&D developments that radically transformed American military capabilities: development of transonic area-ruled nuclear strike fighters such as the F-105; introduction of the Boeing B-52, an aircraft of immense potential, flexibility, and subsequent significance; development of the first jet tanker-transports and turboprop airlifters that revolutionized global and theater access and mobility; development of increasingly sophisticated "systems" aircraft beginning with the Air Defense Command's SAGE system and progressively more refined interceptors leading to the Mach 2+ F-106; development of the Atlas and Thor ballistic missiles, followed soon by Titan, and Minuteman; and the progressive expansion of the X-series to the hypersonic X-15, with a variety of other specialized X-craft developed as well. The science and technical cadre producing these advances was small; in 1955, for example, ARDC's total personnel strength was 37,616 military and civilian members. Of this, just 7,138—19percent--were engineering and scientific personnel.

Table G-1 shows the number of officers assigned to scientific research and engineering development at five years intervals coinciding with the immediate postwar drawdown, onset of the Korean War, the full-flowering of Air Force supersonic and high-speed research, and the beginnings of the drive into space; over this time, the locus of Air Force science and technology shifted from its Army roots in the interwar era at McCook and Wright Fields to a postwar orientation first at Wright, then in Baltimore, and finally (following creation of Air Force Systems Command) to Andrews AFB. (It would return in time to Wright-Patterson, following establishment of Air Force Materiel Command after the Gulf War. Along the way, organizations changed: from the wartime Air Technical Services Command (ATSC), to the postwar establishment of Air Materiel Command, in 1946, to the ARDC in 1950, and on to AFSC in 1961, with AMC renamed Air Force Logistics Command at the same time. (It would be these that would merge and return the locus of Air Force R&D once more back to Dayton, in the sweeping

[38]Letter., Howard L. Bevis, Pres. of Ohio State University and Chairman PCSE, to President Eisenhower, 26 Nov. 1957, Papers of the President's Scientific Advisory Committee (PSAC), Microfilm Reel 2, Manuscript Division, Library of Congress.

[39]Robert M. Briber, Ass't to the Special Ass't to the President for S&T, "Memo for the Record," 20 Feb. 1959, PSAC Papers, Microfilm Reel 1.

[40]"Research and Development Costs in American Industry, 1956: a Preliminary Report," in NSF Reviews of Data on Research & Development, NSF-58-10, n. 10, (May 1958), pp. 1-4.

Copyright © National Academy of Sciences. All rights reserved.

organizational reforms of the Secretary Donald Rice—Chief Of Staff General Merrill McPeak era).

TABLE G-1 AAF-USAF Scientific Research and Development Engineering Officers, 1945-1960

Year	Sci. & Eng. Officers	Total Officer Population	Sci. & Eng. Officer %
1945	9,964	164,004	6.1%
1950	5,357	57,577	9.3%
1955	3,640	132,484	2.7%
1960	4,282	129,192	3.3%

SOURCE: USAF Statistical Digest, 1947, Table 19, p. 27, reflecting end of war drawdown; USAF Statistical Digest, 1949-1950, Table 22; USAF Statistical Digest, 1955, Table 165 (Reflects new category of Research and Development); USAF Statistical Digest, 1961, Table 129.

Table G-2 continues the five-year cut of scientific and engineering officer assignments to these through the onset of the "Space Age," the "Hollow Force" of the 1970s, the Reagan build-up of the 1980s, and the post-Desert Storm establishment of AFMC, into the post 9-11 era and the Global War on Terror.

TABLE G-2 USAF Scientific Research and Development Engineering Officers, 1965-2005

Year	Sci. & Eng. Officers	Total Officer Population	Sci. & Eng. Officer %
1965	7,916	126,058	6.3%
1970	9,079	129,803	7.0%
1975	6,497	105,161	6.2%
1980	5,745	97,901	5.8%
1985	7,900	109,000	7.2%
1990	2,800	100,000	2.8%
1995	5,644	78,444	7.2%
2000	3,241	69,023	4.7%
2005	3,645	73,252	5.0%

SOURCE: USAF Statistical Digest, 1965, Table 110 (Reflects new categories of Scientific, R&D Management, and Developmental Engineering); USAF Statistical Digest, 1970, Table 90; USAF Statistical Digest, 1975, Table 86; USAF Statistical Digest, 1980, Table 79; USAF Statistical Digest 1992, Table D-2 (Reflects restructuring of data into a general "R&D" category, with rounding of entries); USAF Statistical Digest 1995, Table D-14; USAF Statistical Digest 2000, Table D-14; USAF Statistical Digest 2005, Table D-14.

Again this was an era of profound transformational change: early on, the cancellation of much-anticipated programs such as the XB-70A, F-108, and X-20; then the rapid adjustment to the war in Southeast Asia and its demands for new capabilities such as light STOL observation aircraft (the OV-10) and "Wild Weasel" SAM-killers armed with new electronic combat sensors and "hard-kill" anti-radiation missiles; the painful development of the F-111; maturation of space launch with the Titan III heavy launch family and its successors; development of a new second-generation global jet airlifter, the C-141; development of the large bypass engine and its enabling development of the C-5, another troubled but immensely useful system; development of the laser-guided bomb; development of GPS and a host of other military space systems; investment in new materials technology and in electronic flight controls; advances in sensor systems such as Pave Tack and LANTIRN; rebuilding the force with the aircraft and missiles of the 1970s-90s, the F-15, F-16, A-10, B-1, AWACS, J-STARS, SRAM, ALCM, and CALCM; and (in the 'black

Copyright © National Academy of Sciences. All rights reserved.

world") the F-117, B-2, and ACM. The Air Force scientists and engineers of the 1965-2005 era gave the United States Air Force the tools to wage overwhelming air war of the sort that won the Cold War and savaged the Saddam Hussein regime during Desert Storm, and again after 9-11.

Once more, one is struck by how small these numbers are in relation to what was accomplished. At the end of 1964, still early in the onset of the Vietnam-era "ramping up," but in the full-flowering of the national space program (to which the Air Force was heavily committed), Air Force Systems Command had 5,361 officers assigned to R&D functions, an "overage" of 109percent; civilian manning at the same time was 5,464, and might well have been lower except for the Federal Salary Reform Act of 1962 which had materially assisted AFSC in being able to attract and retain highly qualified civilian engineers and scientists.[41] Even so, such actions only enabled AFSC to keep up. Two decades later, in the early 1980's (the onset of the Reagan-era buildup and the height of post-Vietnam force restructuring, coinciding with the most challenging—and arguably most dangerous—days of the Cold War, AFSC was still experiencing shortages of scientists and developmental engineers. The engineer and science shortage at the time was endemic across the defense community, so much that the American Defense Preparedness Association (ADPA) had issued a summary report in 1981that called for reinvigorated recruitment of suitable candidates by the military Services. In response, Air Force Air Training Command stepped up its own activities, awarding the majority of AFROTC scholarships to science and technology officer candidates, and increasing technical officer generation via the enlisted training and commissioning pipeline, and engaging more aggressively in outreach and other activities such as campus visits. "Procuring additional engineers and scientists to help alleviate the Air Force shortage," ATC Commander General Thomas M. Ryan wrote the ADPA, "is a top priority for Air Training Command."[42] Indeed, by now, for AFSC, S&E officer manning, rather than characterized by overages (except a whopping 180percent overage for lieutenants!), was between 69 percent and 74 percent manned for Captains, Majors, and Lieutenant Colonels, and 90 percent manned for Colonels. Civilian manning concerns caused some AFSC and Air Staff scientist and engineering advocates to press for a centrally managed career program for USAF scientists and engineers, though this, of course, was not pursued either then or subsequently.[43]

Instead, the S&E community continued to limp along. At the end of the Cold War, at which point the total of Air Force civilian scientists and engineers numbered 16,109 (of which Systems Command possessed 7,976, and Logistics Command a further 4,904), a study of S&E civilian demographics by AFLC concluded that the "quality of the AF S&E work force is eroding;" it was aging (the average age being 42), and experiencing high attrition rates (a loss rate of approximately 10percent, yet an accession rate of at best only between 1percent and 3percent). The study came up with no better solution than suggesting "Devoting dollars to training seems to be the most economical answer."[44] AFLC merged shortly afterwards with AFSC to form Air Force Materiel Command (AFMC), essentially a return to the structure of the 1940s—and ironic given how Kenney, Anderson, Putt, Doolittle, and others had castigated the previous Air Materiel Command for its deficiencies in trying to fulfill both logistics and R&D.

Merger did not resolve the shortages and imbalances afflicting key elements of the new organization. Table G-3 shows AFMC's civilian and military Scientist (61S) or Developmental Engineering (62E) from its creation through 2005:

---

[41]AFSC, 1964-1965 Annual History, v. 1, pp. 62, 68; AFHRA archives.

[42]Letter., Gen. Thomas M. Ryan, Jr., ATC/CC to Gen. Henry A. Miley, Jr., USA (ret.), Pres. ADPA, 2 Oct. 1981, in AFATC, 1982 Annual History, v. 12, Doc. II 275; AFHRA archives.

[43]AFSC, 1983-1985 Annual History, v. 1, pp. 100-101.

[44]Philip P. Panzarella, "Demographics and Retention of the AF S&E Work Force," (Wright-Patterson AFB: AFLC, 1990); I thank the AFMC historians for locating this document.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

TABLE G-3 AFMC S&E Manpower Authorizations, 1992-2005

Year	Civilian	Military	Total
1992	10,613	3,481	14,094
1993	11,072	2,965	14,037
1994	10,285	2,636	12,921
1995	10,028	2,509	12,537
1996	9,799	2,323	12,122
1997	9,307	2,154	11,461
1998	8,978	2,066	11,044
1999	8,865	1,995	10,860
2000	8,183	1,996	10,179
2001	7,907	1,946	9,853
2002	7,671	1,498	9,169
2003	7,618	1,444	9,062
2004	7,862	1,402	9,264
2005	7,453	1,369	8,822

SOURCE: AFMC/EN, "S&E Manpower Authorizations" briefing chart for AFSC/CC (Dayton: Wright-Patterson AFB, 1995). Data for Authorizations with a Scientist (61S) or Developmental Engineering (62E) Air Force Specialty Code (AFSC). I thank AFMC/EN, and the historians of AFMC for locating this data.

Overall organizational strength declined, even as taskings grew, and as the age of the workforce continued to rise and increasing numbers of professionals approached retirement age.

Table G-4 shows demographics for officers and civilian scientists and engineers across the Service from the immediate post-Gulf post-*Global Reach-Global Power* strategic planning period through the present.

Again, roughly speaking, the percentage of Air Force officers remains remarkably consistent with the previous history of the Service from immediately after the Second World War.

In sum, a review of the history of the Air Force indicates those charged with responsibility for the technical maturation of the Service and the application of S&T to weapons development have repeatedly worried over the size of their personnel force, the relationship of those personnel to the Service, and even the Service's commitment to science and technology excellence itself. They have voiced continuous concerns about how to nurture, sustain, and grow a cadre of trained professionals to meet the constantly dynamic expansion of science and technology. Periodically they have called for centralized career management of such personnel. Practitioners have performed well, even occasionally brilliantly, while all-too-often perceiving with evident and oft-stated exasperation that their career opportunities are limited by the very nature of their working within a service devoted so thoroughly to operations. For example, for many military S&E officers, the road to a viable career is seen not in the laboratory or test center but, rather by transitioning from the 61S scientist or 62E engineer billet to a 63A acquisition program management AFSC, a career field where a STEM background, mandatory for a scientist or engineer, may be desirable, but not necessary.[45]

[45]See, for example, Major Montgomery C. Hughson, USAF, "The Future Role of the USAF Technical Officer," Research Report AU/ACSC/082/2000-04, Air Command and Staff College, Air University, Maxwell AFB, April 2000, p. 6.

Copyright © National Academy of Sciences. All rights reserved.

Examination of the U.S. Air Force's Science, Technology, Engineering, and Mathematics (STEM) Workforce Needs in the Future and Its Strategy to Meet Those Needs

TABLE G-4 Air Force Officer and Civilian Scientist and Engineer Demographics, 1994-2008

	Officer		Civilian	
Year	Total 61S/62E Officers[a]	Total USAF Officers[b]	Scientists and Engineers[a]	Total AF Civilian Workers[b]
1994	6,352	80,708	19,726	175,197
1995	6,153	78,170	18,885	164,328
1996	5,853	76,113	18,501	161,387
1997	5,331	73,710	17,861	157,350
1998	4,826	71,618	17,074	151,115
1999	4,518	70,046	16,391	144,455
2000	4,291	68,752	15,837	139,986
2001	4,111	67,371	15,508	140,470
2002	4,170	71,268	15,735	139,482
2003	4,447	73,197	16,044	138,041
2004	4,716	73,838	16,363	141,147
2005	4,975	72,979	16,655	142,335
2006	5,005	70,252	16,948	145,252
2007	4,705	65,436	16,775	141,573
2008	4,722	64,512	16,500	139,342

[a]Data provided by Air Force Personnel Center/DS/DSY dated August 26, 2010.
[b]Data drawn from "Officer Extract File" and "Civilian Extract File" annual demographics, from AFPC IDEAS Reporting System, HQ AFPC, Jan. 2009, covering FY 1994-FY 2008.

Given this, it may be said with some unintended irony that the relationship of the Air Force to science and technology and the people who pursue it has left a long-standing, synergistic, and powerful legacy, one confirming the wisdom and foresight of Arnold, von Kármán, Kenney, Anderson, Putt, Doolittle, and many of their successors who championed science and technology within the Service. But that legacy was more fortuitous and reflective of individual merit than organizational excellence. At heart, the issue is starkly simple: America projects global air and space power thanks to Air Force scientists and engineers. They and their predecessors helped create every single one of the major technical revolutions that led to the robust capabilities the Service now enjoys. However, if their accomplishments have been commendably consistent, the record is not one that is either untroubled, or one reflecting far-sighted planning and resource allocation. It is not a comforting record in the emergent era of air, space, and cyberspace warfare.

Copyright © National Academy of Sciences. All rights reserved.