

REPORT

AD-A278 635

Form Approved
OMB No. 0704-0188

(2)

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, reviewing existing information, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.



including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, reviewing existing information, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE

PORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE

AIRCRAFT BATTLE DAMAGE REPAIR for the 90s and Beyond

5. FUNDING NUMBERS

N/A

6. AUTHOR(S)

MAJ DARRELL H HOLCOMB, USAF

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

CADRE/PT
MAXWELL AFB AL 36112-5532

8. PERFORMING ORGANIZATION
REPORT NUMBER

AU-ARI-93-4

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

SAME as #7

10. SPONSORING/MONITORING
AGENCY REPORT NUMBER

N/A

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

PUBLIC RELEASE

DISTRIBUTION STATEMENT A
Approved for public release
Distribution Unlimited

12b. DISTRIBUTION CODE

A

13. ABSTRACT (Maximum 200 words)

DTIC
SELECTED
APR 29 1994
B

DTIC QUALITY INSPECTED 3

14. SUBJECT TERMS

15. NUMBER OF PAGES

55

16. PRICE CODE

no charge

17. SECURITY CLASSIFICATION
OF REPORT

UNCLAS

18. SECURITY CLASSIFICATION
OF THIS PAGE

UNCLAS

19. SECURITY CLASSIFICATION
OF ABSTRACT

UNCLAS

20. LIMITATION OF ABSTRACT

None

2

AIRCRAFT BATTLE DAMAGE REPAIR

DTIC
ELECTE
APR 29 1994
S B D

for the 90s and Beyond

Darrell H. Holcomb, Maj, USAF

DISTRIBUTION STATEMENT 1
Approved for public release
Distribution Unlimited

DTIC QUALITY INSPECTED 3

94-12924



REPRODUCED FROM
BEST AVAILABLE COPY



Research Report No. AU-ARI-93-4

Aircraft Battle Damage Repair for the 90s and Beyond

by

DARRELL H. HOLCOMB
Major, USAF

ARI Command-Sponsored Research Fellow
Air Force Materiel Command

Air University Press
401 Chennault Circle
Maxwell Air Force Base, Alabama 36112-6428

March 1994

DTIC QUALITY INSPECTED 3

DISCLAIMER

This publication was produced in the Department of Defense school environment in the interest of academic freedom and the advancement of national defense-related concepts. The views expressed in this publication are those of the author and do not reflect the official policy or position of the Department of Defense or the United States government.

This publication has been reviewed by security and policy review authorities and is cleared for public release.

Contents

<i>Chapter</i>		<i>Page</i>
	DISCLAIMER	ii
	FOREWORD	v
	ABOUT THE AUTHOR	vii
	ACKNOWLEDGMENTS	ix
1	THE IMPORTANCE OF AIRCRAFT BATTLE DAMAGE REPAIR	1
	Scope of the Project	2
	Background	3
	General Repair Philosophy	5
	Observations	6
	Notes	6
2	THE UNITED STATES AIR FORCE AIRCRAFT BATTLE DAMAGE REPAIR PROGRAM	9
	Aircraft Battle Damage Repair Program History	9
	Impact of Vietnam and the Rapid Area Maintenance Concept	10
	The Development of Combat Logistics Support Teams	11
	The Establishment of a Formal United States Air Force Aircraft Battle Damage Repair Program	12
	Aircraft Battle Damage Repair Organizations	14
	Role of Air Force Materiel Command	15
	The Aircraft Battle Damage Repair Program Management Office	16
	The Aircraft Battle Damage Repair Advanced Development Technology Program	16
	Combat Logistics Support Squadrons	17
	Operating Commands	18
	Training Organizations	19
	Comments	19
	Notes	20

<i>Chapter</i>		<i>Page</i>
3	ALTERNATIVE APPROACHES TO AIRCRAFT BATTLE DAMAGE REPAIR	23
	Israeli Air Force Aircraft Battle Damage Repair Program	23
	Basic Approach	24
	Yom Kippur Lessons Learned	26
	British Royal Air Force Aircraft Battle Damage Repair Program	27
	United States Navy Aircraft Battle Damage Repair Program	29
	Conclusion	30
	Notes	31
4	CHALLENGES TO THE CURRENT AIRCRAFT BATTLE DAMAGE REPAIR PROGRAM	33
	Technological Challenges	33
	Advanced Composite Structures	34
	Transparencies	36
	Large-scale Repairs	38
	Subsystems and Components	38
	Programmatic Challenges	41
	Comments	43
	Notes	43
5	CONCLUSIONS AND RECOMMENDATIONS	45
	Illustrations	
<i>Figure</i>		
1	Effect of ABDR Capability and Aircraft Attrition Rates of 1-2 Percent	1
2	Israeli Aircraft Battle Damage Repair Results	5
3	Israeli Air Force Squadron-Level Maintenance Organization	25
4	Effect of Wire Identification on Damage Repair Time	40

Foreword

The primary objective of the USAF's Aircraft Battle Damage Repair Program is to return damaged combat aircraft to operational status with at least some degree of combat capability in time to affect the ongoing battle. The plethora of new technologies being incorporated into modern combat aircraft coupled with the dramatic downsizing and restructuring of the military has combined to make this task both more difficult and more important. Major Holcomb's study clearly demonstrates the necessity of maintaining a viable battle damage repair capability and proposes new techniques which will improve the USAF's ability to provide this crucial service to operational commanders.



ROBERT M. JOHNSTON, Colonel, USAF
Director
Airpower Research Institute

Accession For	
NTIS GRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution	
Availability Codes	
Dist	Avail and/or Special
A-1	

***About the
Author***



Maj Darrell H. Holcomb

Maj Darrell H. Holcomb graduated from Cumberland College in 1979 with a BS in mathematics and was commissioned through Officer Training School in 1980. He then attended the Air Force Institute of Technology where he earned a BS in aeronautical/astronautical engineering in 1982. Following graduation, he worked at the Aeronautical Systems Division as an engineer responsible for airframe/engine compatibility for numerous systems, including the C-17, T-46, B-2, V-22, and other advanced technology vehicles.

After earning his MS in systems engineering, Major Holcomb was assigned to the San Antonio Air Logistics Center. While there, he was chief of the Aerodynamics and Performance Section, where he conducted aircraft mishap investigation, performance analysis, and aerodynamic studies. He was subsequently assigned as deputy chief of the Resources Management Division, where he was responsible for the manpower and personnel programs, depot facilities, and a budget of over \$720 million. Major Holcomb was also the lead engineer for the Aircraft Battle Damage Repair Program providing global C-5 battle damage engineering support.

Air Force Materiel Command sponsored Major Holcomb's research while he was assigned to the Air University Center for Aerospace Doctrine, Research, and Education, Airpower Research Institute, Maxwell Air Force Base, Alabama.

Acknowledgments

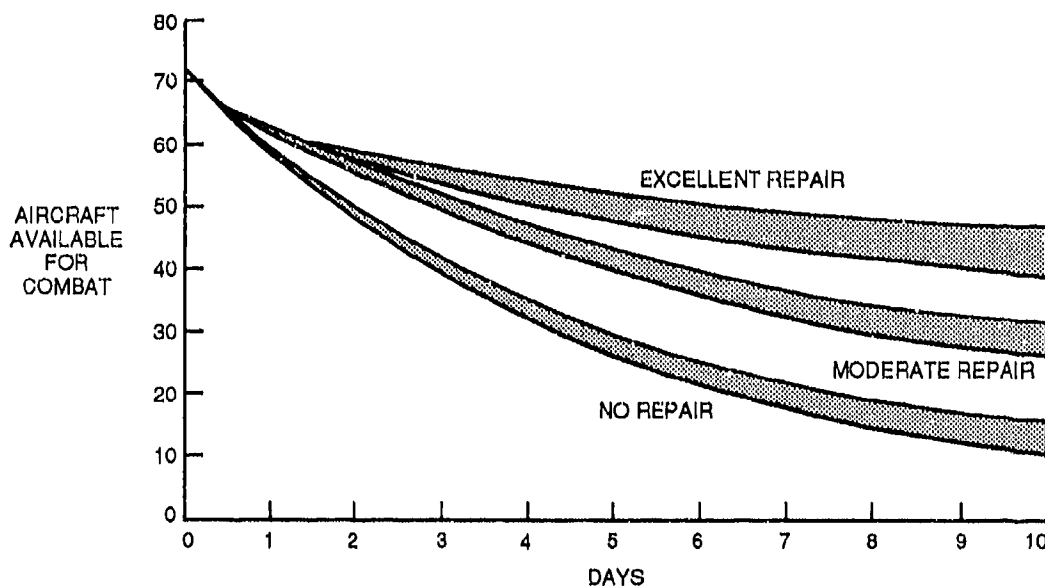
I gratefully acknowledge the research and editorial assistance of Ms Emily Adams and Dr Richard Muller. I also would like to thank Col Glenn Easterly and Lt Col Tom Nowak for their support and help throughout the year. My wife Joyce deserves special recognition for her unfailing help and encouragement during a very busy year. But, most of all, I thank God for all his blessings, which allowed me to complete this project.

Chapter 1

The Importance of Aircraft Battle Damage Repair

Combat aircraft that are damaged and sitting on the ground are completely useless to air component commanders. The goal of the United States Air Force's Aircraft Battle Damage Repair (ABDR) Program is to rapidly restore these damaged aircraft to some level of combat capability. To be effective, the repairs must allow the aircraft to return to combat in time to affect the outcome of the battle. Effective battle damage repair capability can truly be a force multiplier. Figure 1 shows that an excellent repair capability (defined as returning 50 percent of the damaged aircraft to combat in 24 hours and 80 percent in 48 hours) can quadruple the number of available aircraft after only 10 days of combat.¹

This research project suggests methods to improve the Air Force's ability to provide this critical service to operational field commanders. Recent changes



Source: Donald W. Snull, Edward D. Simms, Jr., and Raymond A. Schaible,
Battle Damage Repair of Tactical Weapons: An Assessment,
Report RE801R1 (Bethesda, Md.: Logistics Management Institute, August 1989), 4.

Figure 1. Effect of ABDR Capability and Aircraft Attrition Rates of 1–2 Percent

to the way the Air Force accomplishes its mission necessitate improvements to the ABDR Program. New technology, defense downsizing, and the introduction of composite wings all affect the Air Force and consequently its aircraft battle damage repair philosophy. A comprehensive review of the current ABDR Program with emphasis on areas of improvement is therefore in order.

This study begins with a review of the ABDR Program and is followed by a brief historical background of battle damage repair, an outline of the current USAF program status, and a description of basic repair techniques and philosophies. Next is a comparison of different approaches to ABDR by other military services including the Israeli Air Force, the British Royal Air Force, and the United States Navy. The study then identifies both technical and programmatic challenges which the program must address to remain viable. The final chapter contains conclusions, recommendations for improvements, and highlights of areas requiring further research.

Scope of the Project

Although battle damage repair applies to all types of combat vehicles, this project addresses fixed-wing aircraft only. Tanks, ships, and helicopters all have specific programs which address the need to repair them rapidly. However, these techniques do not necessarily apply to the repair of fixed-wing aircraft and are not considered here. This paper uses a generalized approach to aircraft-specific battle damage repair and places particular emphasis on the ABDR process.

To focus this study on the ABDR process, a number of peripheral issues are not addressed. These issues include:

1. a detailed cost analysis of the ABDR Program including repair techniques, training, and repair kits;
2. actual solutions to complex technical challenges posed by advanced materials, manufacturing techniques, or new technology; and
3. lengthy discussions on aircraft design for repairability or specific changes to the aircraft acquisition phase.

Further, the ABDR Program is huge and involves numerous commands. Headquarters Air Force, Air Combat Command, Air Mobility Command, US Air Forces in Europe, Pacific Air Forces, Air Training Command, and Air Force Materiel Command (AFMC) all play an active part in the overall program. This research concentrates on AFMC's role in providing this critical combat support. Specific issues this paper addresses include the training and policy-making role of the ABDR Program office at Sacramento (Calif.) Air Logistics Center (formerly the Sacramento Air Materiel Area) and the technical support provided by the Advanced Development Technology Program at Wright Laboratory, Ohio. Also of interest is the support provided to the

operational commands by the 11 combat logistics support squadrons located at the five air logistics centers and Wright-Patterson Air Force Base, Ohio.

Background

During peacetime operations, damaged aircraft are repaired in accordance with specific Air Force technical orders, commonly referred to as the -3 (dash three) series. These technical orders, generally written by the airframe manufacturer, provide repair techniques intended to return the aircraft to original design specifications. These techniques require that repairs are performed to retain design factors of safety, aerodynamic contours, and general appearance. Typically these repairs are lengthy operations which demand numerous spare parts as well as specialized tools and equipment. The stress and pressure of combat operations usually preclude this type of repair—thus, the advent of ABDR.

The primary purpose of ABDR is to "enhance the wartime repair capability of aircraft maintenance activities . . . by assessing and/or repairing damaged aircraft in sufficient time to contribute to immediate wartime requirements."² This purpose implies that a substantial number of damaged combat aircraft will be able to return for repairs. Historically, between three and five aircraft are damaged for every aircraft destroyed for tactical air missions.³ Analyses of hypothetical future conflicts indicate that the ratio of damaged to destroyed aircraft could be as high as 15 or 20 to 1.⁴ The Persian Gulf War clearly demonstrated this phenomenon. As many as 70 of the 144 A-10s deployed to the Persian Gulf were damaged, but only five were destroyed.⁵ This large number of damaged aircraft highlights the need for an effective ABDR Program.

Many other differences between combat and peacetime operations indicate a serious need to conduct repair activities differently. Combat operations are usually conducted at forward operating locations far from the depot maintenance facilities and large spare parts inventories. Even though attrition aircraft may not be available, combat operations must continue. There will also be a limited number of aircraft maintenance technicians on hand. In many cases, the repairs must be made in hostile environments, possibly even under actual combat conditions. In these situations, an expedient alternative to depot-type repair is the answer.

This alternative repair plan seeks to return the damaged combat aircraft to operational status with at least some degree of combat capability in time to affect the ongoing battle. Many times this plan isn't possible. In these instances, a secondary objective is to repair the aircraft enough to allow a one-time flight to a rear area where more extensive repair capability is available.⁶ Generally, these repairs need only to restore sufficient structural strength to accomplish the required mission with reduced emphasis on aerodynamic efficiency and without regard to aesthetics.

The idea of battle damage repair goes back as far as aerial combat. The first recorded cases of actual ABDR date back to World War I. In that war, airmen used discarded parts from French farm machinery to keep their early airplanes flying.⁷ The effect of air power was limited during this war. However, air power still made major contributions to several campaigns and provided a small glimpse of its effectiveness in future wars.

In World War II, the British used ABDR techniques extensively against the numerically superior German Luftwaffe. In fact, a retired British air vice marshal said:

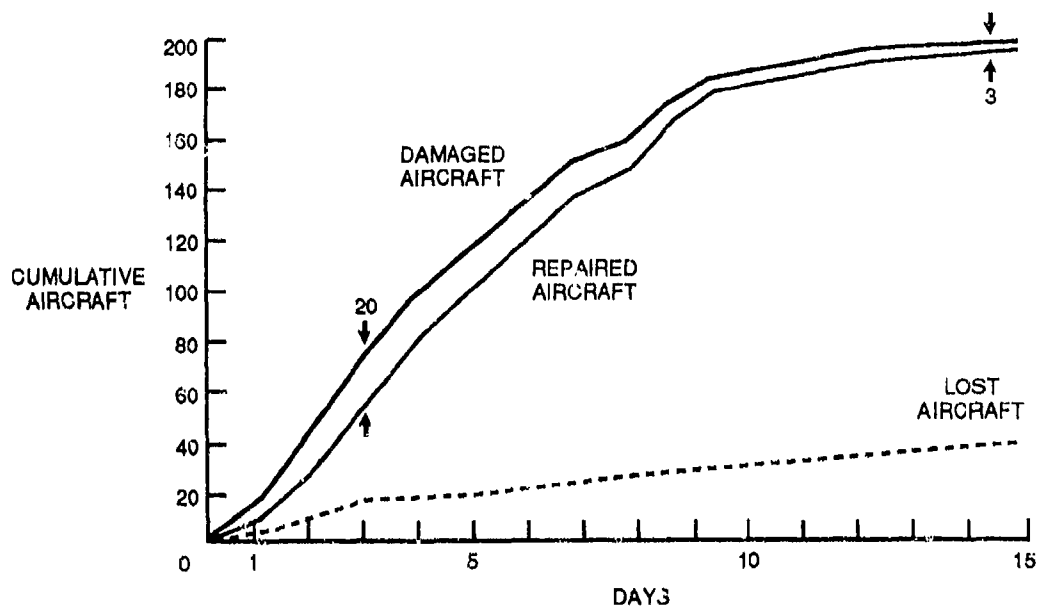
During the Battle of Britain every garage and workshop was called in to carry out repairs. All over the south of England damaged aircraft parts were being rapidly restored by a makeshift organization that paid little attention to normal service procedure. From this improvisation grew an enormous machine that was able to cope with the vast need of the Royal Air Forces.⁸

The German Luftwaffe took a different approach to battle damage repair and logistics in general. Prior to the war, the Germans defined specific damage categories and the corresponding organizations responsible for repair. Aircraft which suffered significant damage (more than 40 percent) were disassembled, boxed, and sent by rail back to the original production facility—a cumbersome and lengthy process.⁹ Aircraft with less than 40 percent damage were left with the local maintenance organizations for repair. Luftwaffe field commanders indicated a desire to completely separate logistics from operations. In fact the Luftwaffe's chief of staff, Gen Hans Jeschonnek, felt that logistics and technical functions were simply necessary burdens to military field commanders.¹⁰

In modern warfare, the Israeli Air Force developed much of the current philosophy regarding battle damage repair including many of the rapid repair techniques. An excellent example of the importance of effective battle damage repair methods is the Israeli experience in the 1973 Yom Kippur War. Figure 2 shows the importance of rapid repair for sustained operations for a particular set of Israeli aircraft.¹¹ Using rapid, temporary repair techniques, the Israelis were able to return 72 percent of their damaged aircraft to combat within 24 hours.¹² In fact one ABDR expert said, "Without effective rapid repairs, the Israeli Air Force would have been out of business by the eighth day of the conflict."¹³

Clearly, the ability to sustain combat operations is absolutely essential during armed conflict. ABDR is a key element in maintaining high sortie rates, especially considering the likelihood of long supply lines, limited spares, and fewer replacement aircraft. Several countries including Great Britain, Israel, Canada, Germany, and France have active ABDR programs which include research and information exchange.¹⁴

The US Army Air Corps operated more than 50,000 aircraft simultaneously in World War II and over 15,000 aircraft in Vietnam.¹⁵ Today, the active duty fleet has fewer than 6,200 aircraft, including over 1,400 trainers.¹⁶ Certainly our modern aircraft are far more capable than their predecessors, but this drastic decrease in numbers highlights the fact that each aircraft represents a



Source: Donald W. Snull, Edward D. Simms, Jr., and Raymond A. Schable, *Battle Damage Repair of Tactical Weapons: An Assessment*, Report RE801R1 (Bethesda, Md.: Logistics Management Institute, August 1989), 2.

Figure 2. Israeli Aircraft Battle Damage Repair Results

much larger percentage of our fighting force, further emphasizing the need to keep each and every aircraft combat-ready.

General Repair Philosophy

Many factors combine to distinguish battle damage repair from regular flight-line maintenance, intermediate-level maintenance, or even depot repair. Austere repair facilities, great emphasis on speed, nonavailability of sophisticated equipment, and shortage of personnel all exacerbate the problem of repair. Dealing effectively with these problems requires specialized repair techniques, training, and equipment. ABDR programs are specifically designed to meet these challenges.

One of the first steps toward meeting these challenges is the development of specific ABDR repair techniques. The techniques must be safe, reasonably quick, and require no special tools or equipment. Experienced engineers and technicians develop most of the repairs by applying sound engineering judgment to existing permanent repair procedures.¹⁷ These ABDR repairs are temporary. Peacetime maintenance technicians can accomplish the permanent repairs after the conflict has concluded. The procedures restore sufficient strength to accomplish the required mission while avoiding unnecessary or cosmetic repairs.

The ABDR personnel performing these repairs require special training and education to be proficient during actual combat. These technicians are similar to "cut men" in boxing—they can temporarily repair damage and quickly return the "patient" to the fight.¹⁸ The repair technicians are generally highly skilled in non-ABDR repairs and have completed additional training in the temporary repairs required for ABDR. Ingenuity is the key since aircraft damage is unpredictable and training cannot possibly cover all types of combat damage.

Generally, damaged aircraft will recover at the nearest airfield controlled by friendly forces. Rarely will these airfields have fully stocked maintenance facilities. The repair crews must be highly mobile and able to provide their own equipment. Their equipment typically consists of —

1. structural repair tools, equipment, and materials;
2. mechanical fasteners (rivets, nuts, bolts, and high-strength fasteners);
3. electrical systems repair equipment (wires, connectors, tape, and plugs);
4. pneudraulic systems repair equipment (hoses, clamps, and connectors);
5. assessment aids (flashlights, mirrors, paper, and pencils).¹⁹

Special repair techniques, training, and equipment are essential elements of a successful ABDR program. These elements cannot become stagnant. They must continue to evolve and improve to meet the challenges of new weapon systems, high technology, and a changing force structure.

Observations

The ability to repair combat-damaged aircraft and return them to the battle rapidly could prove decisive in future conflicts. Although the US Air Force currently has a viable ABDR program, improvements are necessary to meet the challenges of new technology and force restructuring. This paper closely examines the program and offers suggestions to improve the present program.

The following two chapters provide a detailed look at the USAF program and a broader view of the programs of other military services for comparison purposes. Chapter 4 highlights the challenges to the current USAF program due to technological improvements and force restructuring. Finally, chapter 5 gives specific conclusions and recommendations for the program; it also highlights areas requiring additional research.

Notes

1. Donald W. Srull, Edward D. Simms, Jr., and Raymond A. Schaible, *Battle Damage Repair of Tactical Weapons: An Assessment*, Report RE801R1 (Bethesda, Md.: Logistics Management Institute, August 1989), 2.
2. AFR 66-8, *Equipment Maintenance: Aircraft Battle Damage Repair*, 5 February 1992, 1.
3. Donald W. Srull, D. Jerry Wallick, and Bruce J. Kaplan, *Battle Damage Repair: An Effective Force Multiplier* (Bethesda, Md.: Logistics Management Institute, September 1991), 2.

4. Ibid., 3.
5. Breck W. Henderson, "A-10 'Warthogs' Damaged Heavily In Gulf War But Survived to Fly Again," *Aviation Week & Space Technology*, 5 August 1991, 32.
6. Lt Col Richard S. Greene, "Aircraft Battle Damage Repair: A Force Multiplier," lecture, Air War College, Maxwell AFB, Ala., 3-5 March 1980, 4.
7. Donald Voys, "Historical Background on Battle Damage Repair," unpublished, 1.
8. Maj William F. McDonald, "Aircraft Battle Damage Repair Capability, A Key to Combat Sustainability," lecture, Air War College, Maxwell AFB, Ala., 28 February-2 March 1983, 4.
9. Williamson Murray, *The Role of German Battle Damage Repair in the Luftwaffe's Conduct of the Second World War*, Report RE602P1 (Bethesda, Md.: Logistics Management Institute, February 1988), 2.
10. Ibid., 1.
11. Srull, Simms, and Schaible, 2.
12. Maj Mark S. Peacock, USMC, "Modern Aircraft and Antiquated Battlefield Repair Techniques," *Marine Corps Gazette*, May 1991, 48.
13. Srull, Wallick, and Kaplan, 1.
14. Peacock, 48.
15. Voys, 2.
16. "Air Force Almanac," *Air Force Magazine* 75, no. 5 (May 1992): 34.
17. AFWAL-TR-88-3011, *Evaluation Procedures for Aircraft Battle Damage Repair (ABDR) Techniques*, vol. 1, March 1988, 2.
18. Capt Queenie A. Byars and Maj Anthony J. Epifano, "In A 'Class' By Themselves," *Citizen Airman* 41, no. 3 (July 1989): 23.
19. Maj Robert G. Sloan, "Prepositioning Aircraft Battle Damage Repair Kits in Europe," Report 86-2330 (Maxwell AFB, Ala.: Air Command and Staff College, April 1983), 32-40.

Chapter 2

The United States Air Force Aircraft Battle Damage Repair Program

A thorough understanding of the current Aircraft Battle Damage Repair (ABDR) Program is important for several reasons. First, planners need an understanding of the capabilities of the present program to identify challenges presented by technological advances and USAF force structure changes. Next, this program gives them a baseline for comparing and contrasting the battle damage repair programs of other services and countries. Finally, planners must fully comprehend the current program to reach meaningful conclusions or identify potential process improvements.

To understand the current program, one must first comprehend the circumstances and events leading to its creation. The first section contains a brief history of the Air Force's ABDR Program including a short account of aircraft battle damage repair from World War I to the present, with emphasis on the Vietnam War and the USAF's experience with the primarily civilian repair and combat logistics teams. An explanation of the important events leading to the formation of a formal USAF ABDR program follows. The last section outlines the responsibilities of the key organizations tasked with implementing the ABDR Program. Of primary emphasis is the role of the Air Force Materiel Command, but the duties and responsibilities of other contributing groups and how they interface with AFMC are included as well.

Aircraft Battle Damage Repair Program History

As early as World War I military aviators recognized the importance of rapidly repairing combat-damaged aircraft and returning them to battle. However, the US military did not embark on a formal program to develop this rapid repair capability until the Vietnam War. Even today some observers would argue that ABDR is simply an extension of unscheduled maintenance, but most military practitioners and industry experts would agree that battle damage repair is a separate discipline and should be treated as such. This section briefly traces the development of the ABDR Program in the USAF and points out major influences on the current program.

Both world wars, but especially World War II, clearly demonstrated that the rapid and effective repair of combat aircraft could help to offset the numerical superiority of an adversary. In these wars, the United States and

its allies were not able to decisively establish air superiority early in the conflict due to German and Japanese technical and numerical superiority. This inability forced the Allies to rely heavily on rapid repair techniques to keep their aircraft combat-capable and industrial mobilization to increase aircraft production. The United States amassed a huge number of aircraft, over 50,000, by the end of World War II.¹ The combination of rapid repair and national industrial mobilization played a major role in allowing the Allies to combat the combined German and Japanese air threat effectively.

Just a few short years after World War II, the United States engaged in armed conflict in Korea. Unlike the world wars, this war had limited objectives and took place within a restricted combat area. The United States established air superiority quickly with an air force superior in both numbers and technology. Antiaircraft defenses were not extremely effective; US aircraft losses were relatively small, and aircraft spare parts and replacement aircraft were readily available. These facts, coupled with the lack of available repair data from the conflict, combined to lessen the impact of this war on modern ABDR doctrine.

The next major US military conflict, the Vietnam War, vividly demonstrated our inability to repair our air assets rapidly. This operational shortfall led to the development of organizations which were the precursors of our modern aircraft battle damage repair forces.

Impact of Vietnam and the Rapid Area Maintenance Concept

The United States became involved in the Vietnam Conflict as military advisors in January of 1955 and remained in Vietnam as combatants from 1965 to 1975.² During this time, information-gathering teams documented over 11,800 incidents of combat damage to fixed-wing aircraft.³ The first recorded incident of aircraft battle damage occurred in March of 1961, when a USAF C-47 returned from a mission with structural damage.⁴ As the war escalated in 1964, the Viet Cong began their attack on US Air Force bases and during the course of the war damaged or destroyed hundreds of aircraft on the ground.⁵ Data collected by Air Force Systems Command indicates that approximately 56 percent of the aircraft assigned to the Southeast Asia (SEA) area of operations sustained combat damage of some form.⁶ Further, Pacific Air Forces (PACAF) studies showed that the damage to destroyed ratio for F-4s, the primary fighter in Vietnam, was approximately four to one.⁷

By the mid-1960s the loss of large numbers of combat-damaged aircraft was having a significant adverse effect on operational readiness. Until 1965, contract field teams from Dynalectron, Lear Seigler, Lockheed, and Air Asia (civilian contractor firms with aircraft maintenance expertise hired by the US government) provided the only in-theater depot-level maintenance and battle damage repair capability.⁸ But, in April of 1965, PACAF requested additional crash/battle damage repair support from Air Force Logistics Command (AFLC) to repair two crash-damaged F-105 fighter aircraft.⁹ Officials at the

Sacramento (Calif.) Air Materiel Area (AMA), the depot responsible for system support and item management of the F-105, suggested sending "mobile teams of highly skilled AMA workers . . . to accomplish specific maintenance or modification work that was beyond the capacity or capability of USAF operational forces" to answer this request.¹⁰ AFLC headquarters approved this suggestion and authorized the formation of the first rapid area maintenance (RAM) teams.

Sacramento AMA took the lead in forming, organizing, and deploying the RAM teams to Southeast Asia from 1965 to their final deployments in 1975.¹¹ These teams were responsible for providing depot-level support to combat units. Generally speaking, if estimated aircraft repair times exceeded five days, then the RAM teams were called in for assistance.¹² Their duties included repair of combat-damaged aircraft and heavy maintenance activities which were beyond the capability of operational maintenance units. These teams also performed depot-directed modifications and upgrades to aircraft in the Southeast Asia theater of operations.

The teams consisted of highly skilled aircraft maintenance technicians and engineers. Some team members were military, but most were civilian. Team members included sheet metal workers, mechanics, electricians, hydraulic/pneumatic technicians, carpenters, machinists, and aeronautical engineers. They were deployed from all of the AMAs (Sacramento, San Antonio, Oklahoma City, Ogden, Warner Robins, and Mobile) as well as Griffis and Wright-Patterson Air Force Bases.¹³ Working conditions ranged from normal industrial facilities to flight lines at operating bases under direct enemy fire.

Frequently, aircraft were damaged so severely that they could not return to combat. When possible, the RAM teams prepared these aircraft for a single flight to a main operating location or contractor facility with the available repair capability. If this were not possible, the RAM teams disassembled the aircraft and shipped it to an AMA in the United States for depot-level repair.

Despite the austere working conditions and the fact that most of the RAM team members were noncombatant civilians, these teams repaired or modified over 1,000 aircraft during the course of the Vietnam War.¹⁴ These rapid area maintenance teams provided vast amounts of battle damage information and repair experience. They are the historical precursors of our current aircraft battle damage repair teams.

The Development of Combat Logistics Support Teams

As the US involvement in Southeast Asia grew, so did the requirement for diverse types of logistics support. To address this requirement, AFLC established and deployed additional teams of specialists similar to the RAM teams. These teams provided supply, packaging, and transportation support to both the USAF and the South Vietnamese Air Force.

Beginning in 1965, AFLC deployed scores of rapid area supply support (RASS) teams to the Southeast Asia theater of operations. These teams, recruited and trained at the AFLC air materiel areas, provided the expertise "to help establish workable accounting, inventory, storage, and issue procedures at USAF bases."¹⁵ They deployed to bases in South Vietnam, Taiwan, Thailand, Korea, the Philippines, Okinawa, and Guam. Over 3,000 civilian and military personnel traveled to SEA to provide this valuable service to the air bases in the Vietnam effort.¹⁶

In addition to the supply specialists in the RASS teams, the air bases needed experts in packaging and transportation. AFLC provided this expertise in the form of rapid area transportation (RATS) teams, also recruited and deployed from the air materiel areas. These technicians provided essential services, such as designing specialized containers for fragile parts requiring transportation and efficiently packing entire cargo aircraft shipments. Like the RAM and RASS teams, most RATS team members were USAF civilian employees.

Sending large numbers of civilians to combat areas presented many problems. First, the cost was excessive. Civilians traveled on temporary duty status and therefore received a per diem allowance in addition to travel costs and regular salary. Also, most team members worked long hours requiring a great deal of overtime pay. Next, the duty locations were often in hazardous areas and often under direct enemy attack. Many team members suffered serious injury, and several noncombatant civilians were killed. Finally, as the conflict persisted, fewer civilians volunteered for duty and many absolutely refused to join the teams.

AFLC had to address the concern of having large numbers of noncombatant civilians in the combat areas and yet still provide the essential logistical services. To remedy this situation, the command decided to establish new military organizations to provide this support. So, in June 1967, AFLC announced the creation of five new combat logistics support squadrons (CLSS) to perform the functions of maintenance, supply, and transportation.¹⁷ AFLC later formed six Air Force Reserve CLSS units and stationed them with the five active duty units at the AMAs and Wright-Patterson AFB—AFLC headquarters.

The Establishment of a Formal United States Air Force Aircraft Battle Damage Repair Program

Although the US Air Force developed both the RAM teams and the combat logistics support squadrons in the 1960s, the USAF ABDR Program did not begin until 1981. What prompted the USAF to initiate the ABDR Program in the first place? Many factors contributed to the eventual formation of a separate, formal ABDR Program. US experience in Vietnam, numerous academic studies, the development of the A-10 close-air-support aircraft, and

the combat performance of certain allies all led to the development of the USAF ABDR Program.

The Vietnam Conflict exposed a serious lack of combat maintenance capability including the capacity for timely and effective aircraft battle damage repair. Even with the assistance of the AFLC RAM teams, the repair times for the numerous incidents of combat damage were painfully long. Also, the US maintained air superiority throughout the conflict, operated from relatively secure airfields, and possessed sufficient attrition aircraft and spare parts—luxuries that may not exist in a future conflict.

After the conclusion of the Vietnam Conflict, reports and conferences sponsored by numerous government and industry sources advocated the development of new and streamlined repair procedures to increase aircraft availability rates. Probably the most influential of these was a 1978 Surge Sortie Rate Conference conducted by Headquarters United States Air Force (USAF). This conference studied the extensive data collected during the conflict including damage extent and location, repair times, and maintenance and repair capability of field units. The conferees concluded that the use of rapid repair techniques could increase combat sortie rates greatly.¹⁸ It recommended that AFLC develop a program to augment field organizational maintenance units in time of crisis. These reports were instrumental in encouraging the US Air Force to develop a comprehensive program to examine rapid repair techniques.

Another factor influencing the creation of an organic rapid repair capability in the USAF was the development and testing of the A-10 close-air-support aircraft. The acquisition of the A-10 focused attention on aircraft survivability and subsequently damage repair methods. The A-10 contained many revolutionary characteristics which improved its ability to absorb punishment and continue to complete its mission. Features specifically designed to improve aircraft survivability included

1. engine locations protected from ground fire,
2. a titanium "bathtub" to protect the pilot from shrapnel and small arms fire,
3. the ability to operate the flight controls manually, called manual reversion, if hydraulic pressure is lost,
4. oversized twin vertical tails providing redundancy in flight controls,
5. "beefed up" wing structure capable of absorbing tremendous punishment,
6. dual hydraulic systems,
7. flight control disconnects allowing separate operation in case of control surface jamming, and
8. self-sealing fuel bladders.

These features spawned numerous studies and reports regarding battle-field survivability and damage repair capability. In the late 1970s, the A-10 System Program Office along with Air Force Systems Command recom-

mended the "development of a quick-turn battle damage repair technical order, creation of a depot team for ABDR, and establishment of battle damage kits to include spares, engines, and auxiliary power units for the A-10."¹⁹

Finally, the positive results of certain allies using the rapid repair techniques attracted the attention of several USAF leaders. The USAF repaired 59 percent of the aircraft damaged in Vietnam in 48 hours or less.²⁰ However, with aircraft of comparable technology, the Israelis were able to repair about 72 percent of their combat damaged aircraft in 24 hours or less in the 1973 Yom Kippur War.²¹ This improvement translates to a substantial increase in combat power. The British Royal Air Force also had a viable battle damage repair program. In 1978 a group of European countries formed a working group to promote the exchange of ABDR information and techniques. The group included the United Kingdom, West Germany, Belgium, Denmark, the Netherlands, and Canada.²²

In 1979 the USAF formed its own working group to "provide general guidance on the employment of USAF resources to accomplish aircraft battle damage repair."²³ This group developed the plan for the USAF ABDR Program and in April 1980 drafted the "U.S. Air Force Concept for Aircraft Battle Damage Repair." AFLC assigned the program to the Sacramento Air Logistics Center in July of 1981.²⁴ Sacramento was the choice for ABDR Program management responsibilities for two primary reasons. First, engineers at Sacramento developed the ABDR prototype technical order which outlined rapid repair techniques, necessary materials, and the types of repairs allowable using rapid repair methods. Also, Sacramento provided weapon system management, logistics support, and depot-level repair to the A-10 weapon system.

USAF headquarters issued the Program Management Directive (PMD) for Aircraft Battle Damage Repair (PMD L-Y 2036-1) in December of 1981 with AFLC as the implementing command. The PMD charged the ABDR Program Management Office with developing ABDR technical orders, tools, training, and repair kits. It also tasked the program management office to establish an ABDR research effort and incorporate ABDR considerations into the design of new aircraft acquisition programs.²⁵ With this PMD the Air Force officially embraced the concept of ABDR and provided the means to implement ABDR practices into the fleet.

Aircraft Battle Damage Repair Organizations

Many different organizations within the Air Force, the Department of Defense (DOD), and other service components are involved in ABDR. The programs addressing battle damage repair concerns are numerous, often crossing command and organizational lines. The following sections explain the duties of the primary organizations and the interrelationships between organizations. However, the primary focus is on the Air Force Materiel Com-

mand organizations which perform the daily program management tasks, direct the research and development efforts, and provide the actual combat logistics support to the operating units.

Presently, a great deal of interest abounds throughout DOD on the subject of battle damage repair. In fact, DOD has joint organizations with members from all three services which promote ABDR concepts and fund research and development activities. Probably the best known joint organization involved in ABDR is the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS), a component of the Joint Aeronautical Commanders Group. This office, formed in 1971, provides the services with a forum for exchanging ideas, technology, and techniques in the fields of ABDR and aircraft survivability.²⁶ It oversees research and development efforts in the DOD insuring minimal duplication of effort among the separate services. Computer simulation models predicting the aircraft damage and survivability comprise one of the major efforts of the JTCG/AS.

At the Air Force level, the responsibility for ABDR-related programs belongs to the deputy chief of staff for logistics, USAF/LG. This organization, actually a subordinate unit—USAF/LGMM—provides "overall program policy and guidance to include coordination of and advocacy for all USAF ABDR activities within the Air Staff, Secretariat, Department of Defense, and among the Major Commands."²⁷ LGMM issues and revises the program management directive and works budget and funding issues; it also assists in the procurement of training aircraft for field units and helps to determine the future direction and priorities of the program. This office is not, however, responsible for the day-to-day management of the program—that responsibility rests with the ABDR Program Management Office in Sacramento.

Role of Air Force Materiel Command

Air Force Logistics Command was designated the implementing command for the USAF ABDR program. Now, when the Air Force Logistics Command and the Air Force Systems Command (AFSC) merged to form the Air Force Materiel Command, AFMC inherited the responsibilities of both commands.

As the successor of AFLC, AFMC is now responsible for the ABDR Program Management Office, all the combat logistics support squadrons, and the ABDR engineers. AFMC is responsible for providing necessary manpower and resources to the ABDR Program Management Office to ensure timely, effective management and execution of the program. AFMC also authorizes and provides the manpower necessary for the augmentation forces, including CLSS assessors, technicians, and trained aeronautical engineers.

AFMC performs the technical and acquisition-related elements of the program which were primarily the responsibility of AFSC before the merger. These duties include conducting battle damage repair research, developing new repair techniques and assessment aids, and disseminating design and acquisition guidance for new weapon systems. AFMC also oversees the creation of appropriate repair databases, facilitates technical exchange and infor-

mation sharing, and implements the guidance outlined in the new acquisition regulations.²⁸

The Aircraft Battle Damage Repair Program Management Office

The actual responsibility for the day-to-day management of the ABDR Program rests with the ABDR Program Management Office (PMO) at the Sacramento Air Logistics Center. The ABDR PMO is the single focal point for the daily operations of the program. Its responsibilities cover the entire spectrum of ABDR-related tasks, including

1. developing and coordinating training requirements for the technicians, assessors, and engineers assigned to the program;
2. creating, publishing, and disseminating technical orders, military specifications, and related technical information;
3. hosting technical meetings, review conferences, and interservice/international technical exchanges;
4. including ABDR requirements in wartime planning documents;
5. managing and allocating training aircraft requirements;
6. providing annual status reports to USAF and AFMC;
7. coordinating numerous research and development projects with the JTCG/AS and the ABDR Advanced Development Technology Program at the Wright Laboratory;
8. validating new repair techniques, and
9. formulating tool and material requirements.²⁹

The PMO, assigned to the Technology and Industrial Support Directorate, works closely with the composites office also located in Sacramento in developing repairs for composite materials. The PMO also coordinates with the combat logistics support squadrons and the ABDR engineers assigned to the other air logistics centers regarding new technology, repair techniques, technical meetings, and equipment standardization.

The Aircraft Battle Damage Repair Advanced Development Technology Program

The ABDR Advanced Development Technology Program (ADTP) works closely with the ABDR PMO in the day-to-day management of technology-related issues. The ADTP is staffed by engineers, both military and civilian, with extensive experience in aircraft repair and survivability issues. The office is located at Wright-Patterson AFB and assigned to the Flight Dynamics Directorate of the Wright Laboratory. The primary objectives of the ADTP are to "perform the research and development necessary to enhance our capability to rapidly return battle damaged aircraft to a combat ready status and to support the USAF ABDR program."³⁰ To meet these objectives, the ADTP conducts in-house research and directs contractor efforts in a wide range of repair-related technical areas.

The ADTP is currently working on a number of projects aimed at improving the state of the art in battle damage repair. These projects include

1. battle damage assessment aids to include video probes for inaccessible areas and computerized wiring assessment aids,
2. transparency repair techniques,
3. high-pressure hydraulic repairs,
4. turbine engine repairs,
5. large-scale structural damage repair,
6. fiber-optic cable repairs,
7. low observable material repair, and
8. integral fuel tank repair.

Additionally, this office is directly involved in the Joint Live Fire Program sponsored by JTCG/AS. The Joint Live Fire Program evaluates the damage inflicted on real weapon system components and subsystems by subjecting them to actual ballistic and explosive damage using current weapon systems employed by prospective enemies. The ADTP is also the USAF representative on several technical coordinating groups involving industry, other services, and our allies.

Finally, the ADTP oversees the Survivability and Vulnerability Information Analysis Center (SURVIAC) located at Wright-Patterson Air Force Base. SURVIAC provides information, analysis, and technology assessments on numerous subjects including ABDR and aircraft survivability. In its ABDR library, SURVIAC houses one of the largest collections of aircraft battle damage information in the entire country.

Combat Logistics Support Squadrons

As previously mentioned, the units which provide the manpower to actually accomplish the repairs to battle-damaged aircraft are the combat logistics support squadrons. These squadrons were formed during the Vietnam War to provide operating units a military team capable of performing ABDR, supply, packaging, and transportation duties. The primary mission of these squadrons, according to an early AFLC concept of operations, was "to provide highly trained, worldwide deployable military teams to accomplish aircraft battle damage repair and combat supply and packaging operations in support of USAF contingency operations."³¹ There are currently 11 CLSSs (five active duty and six reserve units). Each of the five air logistics centers (Sacramento, San Antonio, Ogden, Warner Robins, and Oklahoma City) has both an active and a reserve squadron, and Wright-Patterson—AFMC headquarters—has a reserve squadron.

The squadrons are highly mobile and capable of deploying in short periods of time to virtually any location worldwide. They are self-sufficient, providing their own tools and equipment in modular, easily transportable containers. The squadrons are organized into teams which provide critical logistics support in the three crucial skills. ABDR teams include assessors, technicians,

and engineers—all working together to comprise a highly trained, elite maintenance force. They rapidly assess the battle damage, perform the necessary repairs, and place flight restrictions on the aircraft as necessary. The supply teams augment existing operational supply units by providing expertise in inventory control, storage, and parts accounting. Finally, the packaging and transportation teams provide packaging, crating, warehousing, and distribution skills to deployed units.

Presently, the ABDR teams consist of separate engine and airframe teams. Each team is dedicated to specific aircraft. ABDR engineers specially trained in aerodynamics and structures and capable of designing repairs for aircraft damaged beyond ordinary technical order limits augment the teams. The teams are responsible for the aircraft serviced by their particular ALC. The CLSSs assigned to the ALCs are responsible for the following aircraft:

<i>Air Logistics Center</i>	<i>Assigned Aircraft</i>
Sacramento	A-10, F-111, F-117
Ogden	F-4, F-16
Oklahoma City	A-7, KC-135
San Antonio	C-5, B-52
Warner Robins	F-15, C-130, C-141
Wright-Patterson	F-16, C-130 (not an ALC, reserve unit only)

There are currently 76 aircraft repair teams (31 active duty and 45 reserve) with over 1,700 personnel assigned.³² Also, the engine repair teams number 102 (55 active duty and 47 reserve) with just over 200 personnel assigned.³³ Engine repair team members are assigned to the squadrons headquartered in Oklahoma City and San Antonio. These combat logistics support squadrons make up the bulk of the ABDR augmentation forces.

Operating Commands

Although this research focuses on the role of Air Force Materiel Command in the USAF ABDR Program, many other commands play a major part in the implementation and execution of the program. In particular, the operating commands make important contributions to the successful accomplishment of the ABDR mission.

All the operating commands, including the Air Combat Command, US Air Forces in Europe, Air Mobility Command, Pacific Air Forces, Air Force Reserves, and Air National Guard, have ABDR programs. In fact, each operating command is required to "develop an effective unit-level ABDR capability for each type of assigned aircraft likely to be damaged during combat operations."³⁴ The combat logistics support squadrons cannot provide the required ABDR support for a major conflict by themselves. Also, since the CLSSs are not normally assigned to the operational units, a time delay always occurs during their deployment. An early 1980s PACAF study highlighted the need for immediate ABDR support, concluding that ABDR "had the greatest

influence of all factors on sortie surge capabilities during the first five days of a conflict."³⁵

Additionally, the operating commands provide tools, materials, equipment, and training to support their organic ABDR capability. These commands have designated focal points which work closely with the Air Force Materiel Command, the ABDR PMO, and the CLSSs. The operating command ABDR units are an integral part of the ABDR Program and will most likely be the first to perform battle damage repair in a conflict.

Training Organizations

The other major contributors to the ABDR mission are the Air Force Training and Education Command (AFTEC) and its subordinate unit, the Air Force Institute of Technology (AFIT). These organizations work closely with the ABDR PMO to develop the courses for the technicians, assessors, and engineers responsible for performing the battle damage repairs. Additionally, AFTEC assists the PMO by developing training aids and technical documentation.

AFTEC field training detachments located throughout the Air Force teach courses for both technicians and assessors. The technician course, requiring seven days, offers basic ABDR procedures and theories including structural repair and patch design. The course instructions explain and demonstrate quick repairs for hydraulic, electrical, and fuel systems.³⁶ The assessor course enables technicians to determine the extent of the damage and recommend repairs. This course takes three days to complete and is often geared to a specific aircraft type.

AFIT developed and teaches a two-week course for the ABDR engineers. This course serves as a refresher in many cases, since the engineers all have degrees and are required to complete both the technician and assessor courses. The course focuses on structural repair theory, including structural load determination, stress, fatigue, crack propagation, and vibration analysis. Also included is a brief review of aerodynamic principles and material science.³⁷ The trained engineer provides the capability to perform repairs to damage outside the prescribed technical order limits to allow flexibility and additional support.

Comments

In the few short years since the Vietnam War, the US Air Force has developed a functioning aircraft battle damage repair program. The USAF ABDR Program is unique and is based on the experience and needs of the US Air Force. Many of the techniques and methods used in the USAF ABDR Program were borrowed from our allies. The experience of others continues to

present an abundant source of information which improves and refines the existing Air Force ABDR Program. The following chapter describes the development of battle damage repair programs currently used in other countries and services.

Notes

1. Donald Voyle, "Historical Background on Battle Damage Repair" (Unpublished personal notes), 2.
2. John Schlight, *The War in South Vietnam: The Years of the Offensive, 1965-1968* (Washington, D.C.: Office of Air Force History, 1988), 2.
3. AFWAL-TR-86-3064, *Aircraft Battle Damage and Repair: Vol 1. A Survey of Actual Combat Experience*, August 1986, 2.
4. Voyle, 3.
5. Roger P. Fox, *Air Base Defense in the Republic of Vietnam, 1961-1973* (Washington, D.C.: Office of Air Force History, 1979), 32.
6. Lt Col William R. Foster II, "Aircraft Battle Damage Repair (ABDR) 2000: Will ABDR Become the Logistics Center of Gravity by the Year 2000?" Defense Analytical Study (Maxwell AFB, Ala.: Air War College, May 1989), 7.
7. Ibid.
8. Steven Diamond and Dr Craig W. H. Luther, *The RAM Team Experience in Vietnam, 1965-76: Rapid Area Maintenance on USAF Aircraft, 1965-1975*, Sacramento Air Logistics Center Oral History #7 (McClellan AFB, Calif., Office of History, Sacramento Air Logistics Center, September 1991), xv.
9. Voyle, 3.
10. Diamond and Luther, xv.
11. Ibid.
12. Capt Robert H. McMahon, *Analysis of the Training Requirements for Effective Aircraft Structural Battle Damage Repair* (Dayton, Ohio: Air Force Institute of Technology, Wright-Patterson AFB, December 1986), 12.
13. Diamond and Luther, xvi.
14. Ibid.
15. Ibid., xiv.
16. Ibid.
17. Voyle, 2.
18. TIQ Report, *Functional Management Inspection of USAF Aircraft Battle Damage Repair Program*, Report PN 86-611 (Air Force Inspection and Safety Center, 20 December 1985), 2.
19. Maj William F. McDonald, "Aircraft Battle Damage Repair Capability, A Key to Combat Sustainability," lecture, Air War College, Maxwell AFB, Ala., 28 February-2 March 1983, 6.
20. Maj Mark S. Peacock, USMC, "Modern Aircraft and Antiquated Battlefield Repair Techniques," *Marine Corps Gazette*, May 1991, 48.
21. Ibid.
22. McDonald, 6.
23. HQ USAF/LEW, *U.S. Air Force Concept for Aircraft Battle Damage Repair*, April 1980, 1.
24. Gen Bryce Poe II, AFLC commander, to SM-ALC/CC, letter, subject: Aircraft Battle Damage Repair Program Manager Assignment, 28 July 1981.
25. *Concept for Aircraft Battle Damage Repair*, 2.
26. Lt Col Tony L. Dedmond, "Joining Forces to Survive Tomorrow's Battles," *Aerospace America*, August 1992, 37.
27. AFR 66-8, *Equipment Maintenance: Aircraft Battle Damage Repair*, 5 February 1992, 2.
28. Ibid.
29. Ibid., 3.

30. Minutes of the 1992 US Air Force-wide Aircraft Battle Damage Repair Conference, March 1992, 2-2.
31. Air Force Logistics Command, *Operational Concept for Combat Logistics Support Squadrons* (Wright-Patterson AFB, Ohio: Headquarters, Air Force Logistics Command, 1983), 1.
32. HQ AFMC/LG, CLSS Strength Report, July 1992.
33. Ibid.
34. AFR 66-8, 1.
35. McDonald, 10.
36. Jeffery P. Rhodes, "Improvise, Adapt, Overcome," *Air Force Magazine* 71, no. 12 (December 1988): 73.
37. Capt Robert L. Feiler, *Analysis of the USAF Aircraft Battle Damage Repair Engineer Qualification Program* (Dayton, Ohio: Air Force Institute of Technology, Wright-Patterson AFB, September 1989), 27.

Chapter 3

Alternative Approaches to Aircraft Battle Damage Repair

As outlined in the previous chapters, the US Air Force has developed a workable, reasonably mature aircraft battle damage repair program. The unique organization, doctrine, and experiences of the USAF have determined the present state of its ABDR Program. The current program addresses concerns brought about primarily from significant in-theater maintenance shortfalls experienced during the Vietnam War. Since the USAF structure, organization, size, funding, and primary threat are all changing at a staggering pace, the ABDR Program must evolve to meet both present and future needs.

One method of facilitating this change examines the programs of other air forces to capitalize on their lessons learned. Many other countries, including Israel, Great Britain, France, Canada, Germany, and Russia, have ABDR programs—some more mature than our own. This chapter examines the programs of three different services—the Israeli Air Force, the British Royal Air Force, and the United States Navy. It describes the basic approach of each service, highlights applicable innovations, and evaluates strengths and weaknesses of each program. Finally, it presents recommendations adopting specific techniques and methods which will improve the USAF ABDR Program.

Israeli Air Force Aircraft Battle Damage Repair Program

Since Israel's formation by the United Nations in 1948, the country has been plagued by war with its Arab neighbors. This constant state of readiness, peculiar geographical conditions, fiscal constraints, and military policies have led Israel to develop a unique self-defense force. The Israeli Defense Forces (IDF) consist of a small active duty force augmented annually by 40,000 to 50,000 conscripts, who enlist for a three-year term.¹ This trained reserve force, when fully mobilized, accounts for another 500,000 personnel.²

One of the primary functions of the active duty force is to delay any attack against Israel until the large reserve force can mobilize. This heavy reliance on reserve forces, driven primarily by the enormous cost of a large standing army, places a great deal of burden on the Israeli Air Force (IAF). During

wartime, the IAF is a major contributor in the strategy of "buying time" for the reserves to mobilize. This strategy calls for maximum combat air power applied against the enemy, often for sustained periods. Since maximum combat power requires maximum combat aircraft availability, an effective ABDR program is essential to the Israeli national defense effort.

Basic Approach

Because of the constant threat of warfare in the Middle East, the IAF has developed a mature and sophisticated aircraft battle damage repair program. The Israeli ABDR program, developed in the 1960s and 1970s, received its most demanding test during the 1973 Yom Kippur War. The 1973 war was a watershed for the entire field of battle repair and resulted in techniques and procedures emulated today by many countries around the world.

The Yom Kippur War caught the Israelis completely by surprise, resulting in terrible initial losses. The Egyptian and Syrian forces attacked simultaneously on two different fronts inflicting heavy losses on both ground and air forces before the reserves could be mobilized. In fact, the IAF lost over 30 percent of its total fighter force during the first 18 days of the war, most losses being sustained in the first five days.³ The Israelis made the conscious decision to use air power for close air support without having established air superiority, which greatly exacerbated their losses. Experts in the field of battle damage repair have said that "without effective rapid repairs, the Israeli Air Force would have been out of business by the eighth day of the conflict."⁴ To say that ABDR was important to the IAF is a tremendous understatement.

The rapid repair employed by the Israelis enabled the IAF to slow the initial enemy ground offenses. During this conflict, the goal of the Israeli ABDR program "was to be able to repair as many damaged aircraft as possible in a short period of time at the field level."⁵ The emphasis on field level repair marks one of the major philosophical differences between the IAF and USAF concerning aircraft battle damage repair. the Israeli approach was effective—they repaired 72 percent of the damaged IAF aircraft in 24 hours or less compared to a 59 percent repair rate requiring 48 hours for the USAF in Vietnam.⁶

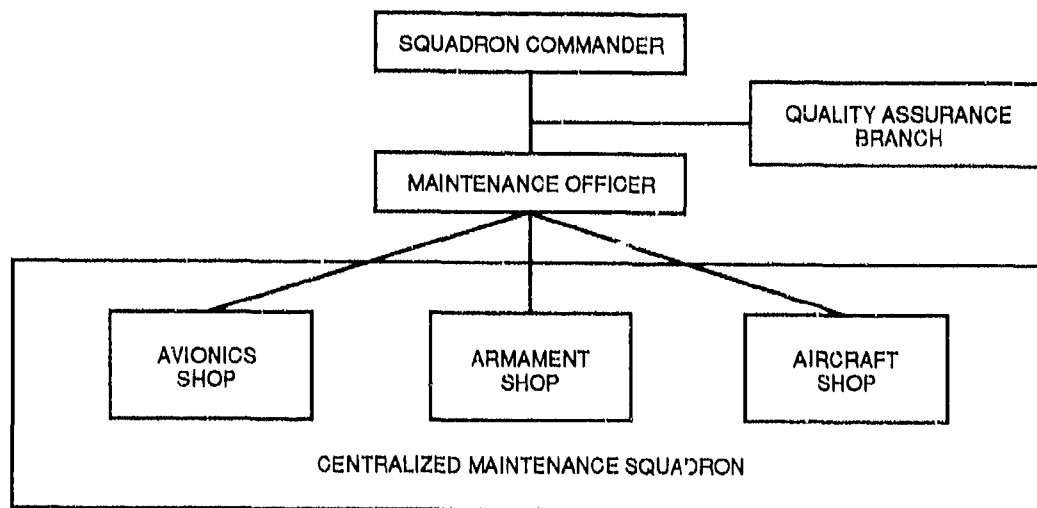
The Israelis operated many of the same weapon systems during this war as the United States military used during the Vietnam conflict. However, many significant differences contributed to the development of vastly different repair philosophies. First, Yom Kippur was an all-out war for the Israelis, requiring a total effort from both the military and society. Next, the Israelis were not fighting a technologically inferior foe. Both Egypt and Syria possessed large numbers of modern weapons. The Israeli logistical system was stressed proportionally far greater than was the US system during the Vietnam Conflict. In fact, the United States mounted a large-scale resupply effort to assist the Israelis during this war. The Israelis did not operate from secure

bases far from the actual battle area. Finally, neither the Israeli society nor its economy could support a prolonged, high-intensity conflict.

These important differences, coupled with the proximity of the Israeli population and industrial centers to the battle areas, led to the development of a unique battle damage repair philosophy. To minimize the repair times, the IAF moved the majority of its maintenance activities, including depot activities and personnel, into the field. The depot personnel were integrated into the organizational maintenance units—not separated as were their US counterparts during Vietnam.

Figure 3 shows a typical IAF squadron-level maintenance organization. Note its similarity to a USAF combat-oriented maintenance organization, even though it has some important differences. First, the Israeli maintenance organization is subordinate to the squadron commander, like the USAF structure in its reorganized operational units—objective wings. Second, the maintenance personnel are more highly qualified and less specialized, thus requiring fewer personnel. Israeli maintenance officers generally come from the enlisted ranks and are technically competent in the maintenance and repair areas, unlike USAF maintenance officers who may have no technical expertise in any maintenance discipline.⁷ Third, the crew chief and crew are dedicated to specific aircraft, instilling a sense of pride and responsibility. Fourth, “the centralized maintenance squadron has very skilled communications, navigation, flight control, and propulsion system specialists who can function on more than one type of aircraft.”⁸

In addition to the differences in the maintenance personnel, the Israelis also approach the issues of equipment and repair facilities in a unique way.



Source: Air Force Systems Command, "ABDR Experience and Planning in the Israeli Air Force" (U), May 1982, 6. (Secret) Information extracted is unclassified.

Figure 3. Israeli Air Force Squadron-Level Maintenance Organization

They have integrated quick combat turns (refueling, rearming, and minor maintenance actions) with the aircraft battle damage repair function and perform both in specially-equipped maintenance shelters using the same maintenance personnel. These shelters contain special tools, equipment, and repair modules which allow front-line maintenance units to perform intermediate and even depot-level repairs.⁹ Their support equipment is simple, durable, and designed for easy repairability. The Israeli spares kits are well-equipped, containing dedicated emergency repair kits and major structural modules based on combat damage simulations.

Studies conducted by Air Force Logistics Command analysts indicated that the "ABDR spares are critical in the Israeli's ability to generate sufficient wartime sorties" during the Yom Kippur War.¹⁰ Their wartime spares policies stress that "combat operations are not an expansion of peacetime conditions."¹¹ They recognize that combat operations are vastly different from peacetime maintenance by requiring different spares and equipment. The combat spares analyses consider the following variables not found in peacetime analyses:

1. Failure rate changes due to combat mission demands.
2. Launch window based on threat.
3. Attrition rate.
4. Battle damage/loss ratio.
5. Battle damage repair time.
6. Percentage not repairable.¹²

Another difference between the Israeli ABDR program and the USAF program concerns the actual mechanics of the repair. Engineering personnel assess battle damage and also assist in the subsequent repair. Almost all repairs performed are permanent in nature and conform to existing IAF technical orders or are approved by engineering.¹³ Engineering groups deploy with repair teams to all necessary bases and work in conjunction with the normal unit maintenance troops. Finally, the ABDR personnel and major structural units are centrally controlled and assigned work on a priority basis from a headquarters level—emphasizing the need for constant and reliable command, control, and communications networks.

Yom Kippur Lessons Learned

The Israelis stressed four key lessons learned from the Yom Kippur War ABDR experiences.

1. Skilled ABDR teams must be available from the beginning of the conflict.
2. Rapid and thorough battle damage assessment is the key to a successful ABDR program—assessors must be highly experienced and possess extensive structural knowledge.
3. Each instance of battle damage is unique, requiring creativity, skills, and experience from the ABDR team members.

4. Major modular replacement spares were critical and many repairs could not have been performed without them.¹⁴

Finally, the Israeli ABDR program in the Yom Kippur War was successful, but the policies and procedures that ensured success had to be in place before the war began. Prior planning for sustained ABDR operations is essential.

British Royal Air Force Aircraft Battle Damage Repair Program

The British paid close attention to both the US experiences during the Vietnam conflict and the ABDR experiences in the Yom Kippur War. Also, in the late 1960s and 1970s the North Atlantic Treaty Organization (NATO) strategy was changing from a predominately nuclear focus to a flexible response strategy emphasizing the use of combat aircraft in a more conventional role. This strategy increased the likelihood of aircraft combat damage during close air support, air superiority, and interdiction missions. These factors were the primary motivators which convinced the British Royal Air Force (RAF) to develop its own ABDR program.

The British led the development of aircraft battle damage repair for the western/NATO alliance. Taking elements from both US and Israeli experiences, the RAF developed its first formal ABDR program in 1976. Even though the British had used rapid repair techniques in World War I and extensively in World War II, 1976 marked the beginning of the first formal peace time program. The RAF leadership recognized that battle damage repair and combat maintenance were disciplines distinct from routine peacetime maintenance activities.

To address this separate discipline, the RAF formed specialty trained ABDR repair teams. The teams are led by senior noncommissioned officers (NCO) who also performed the duties of battle damage assessors. These senior enlisted members must complete advanced ABDR training courses covering such topics as ABDR techniques, aircraft structural design, and aircraft subsystem operational repair.¹⁵ The other team members, who function as the actual repair technicians, are also specially trained in ABDR techniques and procedures. The techniques are subdivided into four basic categories: structural, electrical, avionics, and weapon system specialists.¹⁶ The assessors receive ABDR training at an RAF depot, while the technicians train for their specific weapon system at the local base level.¹⁷

The RAF deployment philosophy augments the field-level maintenance units with an ABDR team at each operational unit. Time permitting, the ABDR teams are prepositioned and integrated into the operational maintenance units. The weapon system specific teams generally consist of six members, but larger, more general teams are also available.¹⁸

In combat conditions, either the senior NCO or the maintenance/engineering officer can decide to use ABDR techniques to repair damaged aircraft. Unlike

the Israelis, the RAF approach is to perform temporary repairs which are not designed to restore original structural strength to the damaged components. The RAF stresses speed and simplicity in its ABDR repairs. Thus, its philosophy is that "repair times must not be extended because of repair techniques employing unnecessarily high standards of workmanship."¹⁹

Repair techniques and damage limitations are clearly delineated in the extensive battle damage repair technical orders. The RAF developed these technical orders by using military researchers, operational maintenance personnel, and aircraft manufacturers. The technical orders are succinct and geared toward the senior NCOs who perform the battle damage assessment. The technical orders contain repair criteria and formulas which generally determine whether a given damage is repairable. Damages outside the repair criteria aren't usually repaired. However, the maintenance officer, almost always an engineer with a degree, may intervene with a suggested repair.

The first combat test of the British ABDR capability came during the 1982 Falklands War. During this war, the Harrier, a vertical takeoff and landing aircraft, flew most of the combat missions. Aircraft battle damage was commonplace—"every Royal Air Force GR Mk-1 Harrier committed to fight had to be repaired at least once."²⁰

As a result of this conflict, the RAF compiled and presented the following list of 14 principles learned regarding aircraft battle damage repair:

1. Future aircraft should be designed for survivability.
2. Manuals are for guidance only.
3. Initiative and ingenuity count for a lot.
4. Some documentation is still important.
5. Go/No Go lists are important.
6. Additional spares are necessary to support ABDR.
7. Access holes need to be cut for assessment and/or repair.
8. Robbing from damaged aircraft is very much a part of ABDR.
9. Kits are essential for land operations.
10. Transparency (canopy) repair methods are lacking.
11. Repairs should be the best possible in the time available.
12. Self-sealing fuel tanks are needed.
13. The pilot is not always aware that damage has occurred.
14. Assessment is very important—the assessor is the key man.²¹

During Operation Desert Storm, the RAF deployed seven ABDR teams to bases in the theater of operations, six were six-man weapon system specific teams, and one was a 17-man general ABDR team.²² All teams deployed prior to the initiation of hostilities. The teams successfully performed repairs on Jaguar, Tornado, and C-130 Hercules aircraft, significantly increasing the combat power of the RAF forces.

The Royal Air Force remains at the leading edge of aircraft battle damage repair technology. The RAF, in conjunction with aircraft/engine manufacturers and allies including the United States, continues to conduct substantial ABDR research. Damage simulation and modeling, structural repair techniques, subsystem repairs, and composite repairs are all subjects of research

sponsored by the RAF. The entire ABDR community has benefitted from the research and leadership supplied by the Royal Air Force.

United States Navy Aircraft Battle Damage Repair Program

The US Navy paid close attention to the British efforts during the Falklands War. The British fought this war using primarily naval surface and air forces. The logistics and repair efforts required to support such an effort left an indelible impression on US Navy war planners. This conflict, along with the ABDR efforts of the US Air Force and the Israeli Air Force, convinced the US Navy that rapid battle damage repair techniques performed in-theater should be considered as an alternative to their current methods of repairing battle-damaged aircraft. Their current method was to transport damaged aircraft via ship or cargo aircraft to a depot repair facility and deploy civilian depot personnel and aircraft manufacturing contractor representatives to the repair facilities to perform the depot-level maintenance/repairs. The cost and delays of such a battle damage repair philosophy are prohibitive.

So in May of 1984, the Navy convened a working group to research existing ABDR programs and make recommendations regarding a viable ABDR program for the Navy.²³ The working group completed its study and recommended specific actions to implement the program. The commander of the Naval Air Systems Command (NAVAIR) developed an operational concept for ABDR and submitted it to the chief of Naval Operations (CNO) in January of 1985.²⁴ The CNO subsequently approved the ABDR concept and the US Navy began developing its own organic ABDR capability that same year.

The Navy's original ABDR program was an ambitious effort to develop, in a series of three separate phases, a fully organic aircraft battle damage repair capability within seven years. The first phase of the program was to use existing resources and technology to develop an initial ABDR capability, establish a research and development effort, develop assessment and repair time planning factors and develop follow-on requirements. This phase, lasting two years, was to be followed by a second phase lasting up to three more years. In this second phase, the Navy planned to develop and publish ABDR manuals for specific aircraft, procure and distribute tools and materials, and implement the Navy training plan.²⁵ This initial effort was similar in scope to the current USAF program and would have given the Navy a substantial ABDR capability by the early 1990s. However, the Navy did not follow through on this effort and their ABDR program lost priority as time passed.

Since then, the Navy ABDR program has undergone substantial restructuring, followed by downsizing, and implementation delays—due primarily to austere budget conditions and diminished superpower competition.²⁶ In 1990 the Navy restructured its program to include “not only wartime battle damage

but also peacetime damage caused by negligence, lack of concentration, corrosion, lack of training, engine foreign object damage, and bird strikes.²⁷ Again, the Navy lost momentum on this program and never fully implemented it.

In February 1991 the Department of Defense published two regulations (DOD 5000.1, *Defense Acquisition*, and DOD 5000.2, *Defense Acquisition Management Policies and Procedures*) requiring that battle damage repair be considered in the development and acquisition of DOD weapon systems. These two regulations have breathed new life into the Navy program. As a result, the Navy has embarked on a rescope ABDR effort whose stated purpose is to

enhance the capability and capacity of Navy/Marine operational units to accomplish rapid repair of battle damaged aircraft that will increase aircraft availability, sortie generation and continued capacity to fight in wartime and in the long term, increase the capability of technicians to accomplish any repair on the aircraft.²⁸

The Navy again plans a phased implementation of this program beginning with accomplishing the programmatic issues required to sustain the program. The phases attempt to meet the near-term, midterm, and long-term requirements from immediate fleet needs to plan for future acquisition and new technologies. Implementation plans include the development of both generic and aircraft specific technical publications, the formation and in-house training of Naval Reserve and civilian personnel, and procurement of ABDR specific tools and equipment. Technical and engineering support continues to come from the civilian depot engineers and contractor representatives. This program is an ambitious one, which should provide the Navy with a more capable and timely repair process.

Conclusion

The United States Air Force clearly has no monopoly on good ideas regarding the rapid repair of battle damaged aircraft. Both the Israelis and the British have greatly influenced the philosophy and development of the USAF ABDR Program. Although the USAF is significantly larger than either force, it could use many of the techniques pioneered by these countries. Also, the USAF would benefit greatly from adopting more of the ABDR methods of Israel and Great Britain.

Although addressed in more detail in chapter 5, the USAF should strongly consider adopting the following:

1. the Israeli policy of computing spare part requirements considering both peacetime replacements and ABDR requirements,
2. the Israeli practice of extensively using engineers and making repairs permanent,

3. the British practice of requiring that maintenance officers be degreed engineers, and

4. the British approach to technical repair manuals which are user friendly and contain specific repair criteria and damage limitations.

These practices combined with the current USAF program would create a more capable and cost-effective ABDR program.

In light of the staggering changes taking place within the Air Force and Department of Defense, the development of a streamlined, efficient ABDR program is absolutely essential. Numerous technical, organizational, and financial challenges face the current program. The following chapter addresses many of these challenges, and recommends specific courses designed to overcome several of the recognized and potential program deficiencies.

Notes

1. *Encyclopedia Americana*, 1991 ed., s.v. "Israel," by Nadav Safran and Davis Pollock.
2. Ibid.
3. Capt George S. Maxwell, *Israeli Defense Force Logistics in the Yom Kippur War* (Dayton, Ohio: Air Force Institute of Technology, September 1986), 45.
4. Donald W. Srull, D. Jerry Wallick, and Bruce J. Kaplan, *Battle Damage Repair: An Effective Force Multiplier* (Bethesda, Md.: Logistics Management Institute, September 1991), 1.
5. Capt Robert H. McMahon, *Analysis of the Training Requirements for Effective Aircraft Structural Battle Damage Repair* (Wright-Patterson AFB, Ohio: Air Force Institute of Technology, December 1986), 14.
6. Maj Mark S. Peacock, USMC, "Modern Aircraft and Antiquated Battlefield Repair Techniques," *Marine Corps Gazette*, May 1991, 48.
7. McMahon, 16.
8. Air Force Systems Command, "ABDR Experience and Planning in the Israeli Air Force" (U), May 1982, 6. (Secret) Information extracted is unclassified.
9. Ibid., 7.
10. Air Force Logistics Command, "Israeli F-4 Aircraft Battle Damage Repair Data Analysis II" (U), July 1990, 1. (Secret) Information extracted is unclassified.
11. "ABDR Experience," 5.
12. Ibid., 10.
13. "Israeli F-4," 1.
14. Capt Robert L. Feiler, *Analysis of the USAF Aircraft Battle Damage Repair Engineer Qualification Program* (Wright-Patterson AFB, Ohio: Air Force Institute of Technology, September 1989), 17-18.
15. Flt Lt E. Bittel, Flt Lt W. A. Brown, and P. F. Jowitt, *Aircraft Battle Damage Repair Studies* (Farnborough, U.K.: Royal Aircraft Establishment, June 1981), 4.
16. 1992 US Air Force-wide Aircraft Battle Damage Repair Conference Minutes, March 1992, 4.
17. Ibid.
18. Ibid.
19. Bittel, Brown, and Jowitt, 4.
20. Peacock, 48.
21. ABDR AD HOC Committee Meeting Minutes: Aircraft Battle Damage Repair, 20-21 February 1985.
22. 1992 US Air Force-wide Aircraft Battle Damage Repair Conference Minutes, March 1992, 4.
23. ABDR AD HOC Committee Meeting Minutes.

24. Lt Cmdr Charles R. Duncan, *Repair Support for Naval Aviation During War* (Newport, R.I.: Naval War College, June 1988), 10.
25. ABDR AD HOC Committee Meeting Minutes.
26. Peacock, 48.
27. Ibid., 47.
28. Cmdr N. G. Eiben and F. T. Furlough, "Aircraft Battle Damage Repair," address to Worldwide ABDR Conference, Monterey, California, 21 July 1992.

Chapter 4

Challenges to the Current Aircraft Battle Damage Repair Program

Change is universal—and the pace of change in today's world is absolutely staggering. The global community, the United States, and the entire defense establishment are undergoing change at an unprecedented rate. Shifting political and military alliances, technological advances, new forces deployment strategies, and significant budget reductions all contribute to the increased tempo of change confronting nearly every organization. The USAF Aircraft Battle Damage Repair Program is certainly not exempt from the changes running rampant throughout the Department of Defense and the individual services.

With change come challenges which any organization or program must address to remain viable. This chapter identifies several of the most demanding challenges which currently face the ABDR Program or will face it in the near future. It also briefly describes these challenges and their significance to the ABDR Program. Finally, this chapter, along with the following chapter, makes specific recommendations regarding methods of addressing these challenges.

The challenges identified in this chapter fall into two broad categories—technical and programmatic. Challenges identified under the technical category include the repair of nonmetallic structures, large-scale damages, transparencies, and various aircraft subsystems. The programmatic challenges include the effect of composite wings, budgetary constraints, and alternative maintenance concepts. Although the challenges listed are not all encompassing, they represent some of the major issues the current ABDR Program must address.

Technological Challenges

Although the USAF ABDR Program is relatively young, technological advances in aircraft design and production techniques have outpaced the program's ability to develop sufficient repairs. The current program has developed repair techniques for Vietnam-era aircraft. Today's aircraft are considerably more complex than the 1960s-1970s technology aircraft in operation during Vietnam. Those aircraft were basically all-metal structures with mechanical control systems containing simple hydraulic and electrical subsys-

terms. In contrast, the development of lightweight, high-strength materials coupled with the sophistication of modern electronics and aircraft subsystems have radically increased the complexity of the current generation of aircraft.

The current and future generations of aircraft require the development of new battle damage repair techniques and procedures. Those aircraft will fight tomorrow's conflict—complete with their composite structures, low observable (stealth) technology, computer-intensive avionics and subsystems, and fiber optic controls. Certainly these are more capable aircraft, but each aircraft represents not only a substantial monetary investment but also a significant percentage of available combat power—considering their limited numbers. This monetary investment makes developing modern repair techniques for these aircraft even more crucial. This section highlights some of the most critical repair shortfalls identified to date.

Advanced Composite Structures

One of the most publicized shortcomings of the current ABDR Program is its inability to assess and repair damaged advanced composite structures. Advanced composites are defined by the Rand Corporation as "a particular and very small subset of reinforced plastics . . . generally distinguished from other reinforced plastics by the use of high-stiffness and high-strength fibers."¹ (This paper uses the terms *advanced composites* and *composites* interchangeably.)

These composite materials offer many advantages over current metal technology. Because of increased stiffness of composites, significant weight savings are possible. Some existing combat aircraft structures are up to 30 percent lighter than equivalent metal structures.² Plus, by aligning the stiffening fibers to resist the primary applied load, a composite structure can be tailored to a specific application requiring even less material. Composites are also virtually transparent to radar, a feature which lends itself to radome applications. Additionally, this characteristic reduces an aircraft's electromagnetic signature and is used extensively with other stealth technologies. Finally, certain composite materials retain greater strength at elevated temperatures than do existing aluminum aircraft structures. This property makes composites particularly suitable for high-speed applications where aerodynamic heating is a problem for typical metallic structures.

Because of these many advantages, the use of composites is increasing with each succeeding generation of aircraft. Advanced composite structures are already quite common among the current USAF and US Navy aircraft fleets. Today, the F-14, F-15, F-16, F-18, F-111, AV-8B, and B-1B all make extensive use of composite structures. Also, the aircraft currently under development—the C-17, B-2, and the F-22—use composites for secondary, and sometimes primary, aircraft structures. In addition to widespread use on new aircraft, many replacement parts manufactured from composite materials are used to replace aging parts on existing aircraft. These replacement parts offer increased reliability and lower weights.

This proliferation of composite structures on nearly all types of modern combat aircraft means that combat damage to these types of structures is a virtual certainty which the battle damage repair community must address. Present ABDR techniques call for metallic patches fastened over the damaged composite structure with such mechanical fasteners as rivets or bolts. This technique has proved adequate for the current secondary structures which are relatively flat and thin-skinned, but there is little data available on the strength restored by this type repair.³ The next generation of composite structures, however, will contain highly contoured and primarily load-bearing structures. These metallic patches will not be sufficient since patch strength is unknown, and metallic patches do not lend themselves to the repair of complex contours.

Current peacetime composite repairs fall into two general categories, bonded and cured repairs. Bonded repairs use an advanced adhesive material to fasten a patch onto the remaining parent structure. The patch can have either metal or composite construction, as can the parent structure. The other common composite repair technique is a cured repair. This repair technique consists of some form of advanced composite matrix and fiber material saturated with a resin. This combination is fitted onto the existing damaged area and cured in place. The matrix and fiber material composition varies greatly, depending on application, and takes different forms—from preimpregnated fiber and matrix cloth to separate dry fibers.⁴

Although these bonded and cured repair techniques are now available, they present a number of challenges—especially in an ABDR environment. Surface preparation is a major consideration for these type repairs since the effectiveness of a repair is dependent on the bond strength between the remaining structure and the patch. To ensure a good bond, the structures must be thoroughly cleaned, sanded, and smoothed. Sometimes this is a lengthy process which may require the removal of additional undamaged material, further weakening the parent structure.

Another factor affecting bond strength is the moisture content of a damaged composite structure. Composite structures absorb moisture from the air—up to 2 percent of their total weight in high-humidity environments.⁵ The residual moisture degrades the strength of the epoxy matrix materials, thus, the structure must be dried and repaired in a temperature and humidity-controlled environment.

Clearly, present cured and bonded repairs require a great deal of additional support equipment. Autoclaves or heating blankets are needed to provide the elevated temperatures necessary for good quality bonding and curing. Vacuum bags and pressure equipment are needed for the high-pressure, evacuated environment these repairs require. Also, refrigeration units for storage of resins, epoxies, and certain fiber matrix materials are necessary. This support equipment is not part of the normal ABDR kit deployed to an austere operating location, so these techniques greatly increase the logistics support required for an ABDR team.

These shortfalls with current repair methods for composite structure damage are exacerbated by the limited shelf-life of many of the necessary materials and the serious lack of empirical data available regarding these repairs. Many of the commercially available epoxies, resins, and fiber matrix materials are useful for only a short time after manufacture, making them unsuitable for prolonged storage in ABDR repair kits. Additionally, the current allowable depot-level repair of damaged composite structures is limited. For example, the F-15 and F-16 technical orders restrict peacetime repairs of composite structures to damages up to only 3.25 inches when using accepted bonded repair techniques.⁶

Finally, composite structures present yet another challenge—how to determine the extent of damage to composite structures. The extent of physical damage to metal structures is relatively easy to determine by means of a simple visual inspection. This however is not the case with composite structures, where the damage may extend well beyond what is visually discernible. When composite structures are ballistically damaged, the various layers will often separate, or delaminate, in the areas surrounding the visibly damaged location. Delamination in the composite material greatly weakens the structure and degrades its load-carrying capability, so the delaminated areas are usually removed and replaced with a patch. These delaminations are not detectable visually, and assessors must employ more sophisticated non-destructive inspection (NDI) techniques to determine the extent of the damage. Common NDI techniques used for composite delaminations include x-ray examinations, ultrasonic examinations, and acoustic response tests (commonly called tap tests). Both the x-ray and ultrasonic examinations require expensive, bulky equipment and additional training for assessors—again increasing the necessary support equipment for ABDR teams. The tap test uses the principle of sound resonance to locate delaminations by tapping the structure and listening for different noise responses from the damaged areas. Although this method is inexpensive and easy to learn, it is highly unreliable and does not identify exact damage locations.

These problems must be solved for ABDR repairs of composite structures to become a reality. There are many ongoing research efforts sponsored by the Air Force, the Navy, the Department of Defense, and the aircraft manufacturers to address these concerns. However, this deficiency continues to be the most important shortcoming of current ABDR technology.

Transparencies

Another area requiring the attention of those in the ABDR community is the quick, effective repair of damaged aircraft transparencies in a combat environment. Advances in transparency (canopy) technology allows the construction of exceedingly tough, impact resistant transparent structures designed to protect pilots from bird strikes at high-speed conditions.

The current generation of transparencies incorporates both material improvements and manufacturing advances to provide high-performance aircraft with lightweight, strong canopies. Modern transparencies are generally constructed from high-strength acrylics and polycarbonates (advanced plastics with high-impact resistance and elevated softening temperatures). The transparencies are generally either cast in a mold or stretched into the desired shape. They consist of either a single thick layer of advanced plastic (monolithic) or several layers of thin material bonded together (laminated). But whatever the construction, transparencies present a major technological challenge to the ABDR team in the field.

The current approved ABDR method of repair is simply to bolt a sheet of aluminum over the damaged area.⁷ Although this technique is sufficient to avoid windblast and reduce wind noise, it does not allow the damaged aircraft to return to combat. This type of metal repair prohibits cabin pressurization due to leaks and insufficient strength, thereby severely restricting aircraft operating altitude. Further, this repair can limit pilot visibility and field of view again, depending on damage location, making it unsuitable for a combat aircraft. These severe restrictions cause this repair to be suitable only for ferry flights, thus violating the primary tenet of ABDR—to return the aircraft to combat quickly.

This metal repair has additional shortcomings which further limit its utility in a combat environment. Many of the modern fighter aircraft have transparencies that are highly curved with complex multidimensional contours. This greatly complicates the fabrication of a metal patch which can match these contours. These nonflush patches also increase aerodynamic drag and can create unwanted shock waves at high speeds, which could degrade aircraft stability and control, performance, and handling qualities. Finally, these metal patches expand at a different rate than the transparency during temperature changes, causing poor fit and degraded structural integrity.

Both the military and the aircraft industry have examined alternative methods of transparency repair. The Air Force has tested methods, including bonding acrylic and polycarbonate patches to damaged transparencies, using both thermal fusing and adhesive-bonding techniques.⁸ These techniques have had limited success. The thermal-fusing technique requires preformed patches and additional support equipment for heating. This technique caused thermal shrinkage and cavitation in the stretched acrylic transparencies and was basically unsuitable for this type of material. Further, it resulted in an opaque bondline, which exacerbated visibility problems. The adhesive-bonding technique exhibited some problems as well including fairly extensive surface preparation and additional heating equipment to accelerate repair times.

The ABDR community needs a repair technique which can quickly restore an aircraft to combat status with a minimum of operational limitations. This means a fast repair with little additional support equipment which can restore sufficient structural strength to allow pressurization and not restrict visibility.

Large-scale Repairs

Aircraft battle damage repair teams are currently limited regarding the size of repairs they are able to accomplish. According to the Air Force's ABDR Program Office, "the present repair capability is limited to flat metallic structure with damage sizes of six inches in diameter."⁹ Considering the lethality of the modern battlefield, this restricted repair capability is definitely not sufficient.

The threats to aircraft grow more ominous with each conflict. Large-caliber antiaircraft artillery, surface-to-air missiles, air-to-air missiles, and a plethora of advanced technology weapons—directed energy weapons and kinetic energy weapons—are all capable of inflicting large-scale damage to aircraft. However, this damage is not always catastrophic. This damage was certainly evident during the Persian Gulf War, where many aircraft suffered damage to structural members measuring several feet in diameter but returned safely to their operating base.

These large-scale damages present many unique difficulties to the ABDR teams. In fact, this type of damage is challenging to even the peacetime depot repair teams requiring lengthy repair times, special material, equipment, tools, and repair facilities—which are all unavailable to the ABDR teams operating from austere combat airfields. Additionally, many large-scale damages involve highly contoured structures which are particularly difficult to repair, especially if the material is thick or rigid. The repair material available to the ABDR teams, generally thin sheets of aluminum and stainless steel, is quite difficult to form into these highly contoured shapes.

The Air Force is, however, sponsoring research into this problem of repairing large-scale damages. The ABDR Advanced Development Technology Program has awarded contracts to investigate the development of composite patches, shaped on the damage location on a similar airplane, which would be suitable for repairing these large-scale damages.¹⁰ Additional research is needed to resolve this repair deficiency and make large-scale damage repair a reality.

Subsystems and Components

In addition to the difficulties encountered in the repair of aircraft structures, contemporary aircraft subsystems and components also present quite a challenge to ABDR teams. As the performance and capability of aircraft subsystems improve, their design complexity often increases causing repair to become more difficult. Simple mechanical systems are being replaced by high-technology electrical, fiber-optic, and hydraulic/pneumatic systems. Of particular concern to the ABDR team are fuel systems, high-pressure hydraulic/pneudraulic systems, electrical subsystems (particularly electrical wire bundles), aircraft engines, fiber optics, and low observable (stealth) coatings and structures.

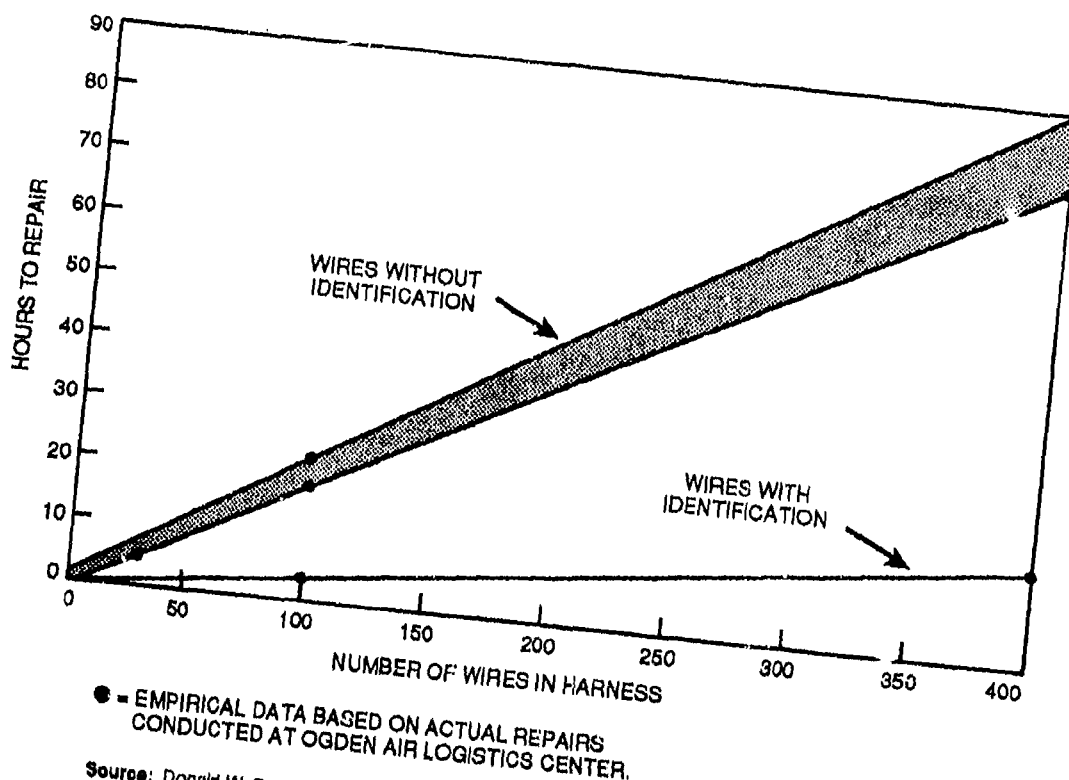
The first subsystem of interest is the aircraft fuel system. Modern aircraft fuel systems are highly complex subsystems consisting of multiple fuel tanks,

bladders, fuel lines, metering devices, connectors, and control systems. The fuel tanks and surrounding structure are particularly susceptible to damage because of the adverse effects of hydraulic ram. (The hydraulic ram process occurs when a penetrator enters a fluid-filled cavity. The fluid absorbs the energy of a penetrator as it travels through the fluid and imparts this energy in the form of pressure and shock waves to the surrounding structure, often resulting in severe damage.)¹¹ Damage to integral fuel tanks and lines is particularly challenging to repair, due to the inaccessibility of the damaged areas, the internal bladders, and the requirement to make the repaired area and fuel lines leakproof. Rapid repairs to fuel tanks are therefore especially difficult and certainly warrant further research.

Another critical subsystem which continues to increase in performance and complexity is the aircraft's hydraulic system, which is used to activate control surfaces, landing gear, and a variety of aircraft systems. In an effort to decrease aircraft weight and correspondingly improve aircraft payload and performance, advanced hydraulic systems use much higher pressures. These high-pressure systems operate at pressures up to 8,000 pounds per square inch compared to current fielded systems which usually operate at around 3,000 psi.¹² These new systems require hydraulic lines, hoses, and couplings which differ from the replacement spares in the ABDR toolkit and from repair techniques. Currently, commercial vendors are examining this ABDR shortfall with promising results.

Repair of electrical wiring associated with various aircraft subsystems is another major problem area facing ABDR teams. Aircraft manufacturers generally group large numbers of wires together to run through the airframe structure—typically called a wire bundle. This practice makes the aircraft wiring process easier and provides to individual wires the added strength of being surrounded by additional wires. However, this practice can cause great repair difficulty if this wire bundle is damaged in combat. With dozens of severed wires to repair, the matching and repair processes can be lengthy and laborious. This observation is especially true when the individual wires are not properly labeled for quick matching. Figure 4 shows the adverse effect of not having identification on individual wires. This marked increase in repair time for unmarked wire bundles can be avoided with proper identification at frequent intervals and some type of assessment aid outlining the purpose of the individual wires—since it is often unnecessary to repair all damaged wires, only those critical to the operation of needed subsystems. This wire identification procedure should become common practice for all new aircraft and subsystem designs.

A shortfall which has plagued the rapid repair of aircraft since World War I is the inability to repair engines which have been structurally damaged in combat. Aircraft engines are extremely complex and sophisticated systems incorporating the latest developments in materials technology and aerodynamics. Although the ABDR teams have highly trained engine repair technicians, their ability to effect repairs to a damaged engine or component is limited. Even the depot repair of aircraft engines is a laborious and time-



Source: Donald W. Snull, D. Jerry Wallick, and Bruce J. Kaplan, *Battle Damage Repair: An Effective Force Multiplier* (Bethesda, Md.: Logistics Management Institute, September 1991), 8.

Figure 4. Effect of Wire Identification on Damage Repair Time

consuming process, requiring extensive and expensive repair equipment and test facilities. There is no short-term solution to this shortfall, yet the Department of Defense and government contractors continue to expend considerable effort to develop this capability.

To reduce weight and decrease susceptibility to electromagnetic effects, the use of fiber-optic cables to replace conventional electric wiring is becoming more popular. These fiber-optic cables can transmit significantly more information than common electrical wires at a fraction of the weight and volume. Also, since these cables use digital pulses of light instead of electromagnetic signals, they are resistant to electronic jamming or the electromagnetic pulse effects of a nuclear detonation. As their use increases, quick repairs which do not optically distort the digital signals must be developed.

Finally, with the increasing number of aircraft taking advantage of the stealth technologies, repair techniques are needed for the repair of the observable structures and coatings. Such aircraft as the B-2, F-117, and F-22 rely heavily upon their ability to operate virtually undetected by the enemy. But, damage to the radar absorbent material which allows this stealth operation could dramatically increase their radar cross-section, thus allowing enemy radars to acquire and potentially destroy these high-value aircraft. Repairs which retain these low observable characteristics are desperately needed for

both structures constructed from these materials and for the coatings used on more conventional structures to impart this stealth capability.

Programmatic Challenges

In addition to the many serious technical challenges listed above, another broad category of challenges, mostly programmatic in nature, confront the ABDR Program. These challenges are primarily due to ever-changing global political situation, domestic economic concerns, and internal restructuring of the Air Force and Department of Defense. In many respects these programmatic considerations are more formidable than even the technical shortfalls, considering their pace of change and the potential impact they could have on the ABDR Program. However, the programmatic as well as the technical challenges must be overcome for the ABDR Program to remain a viable force multiplier.

Of immediate concern to the ABDR Program and virtually every Air Force program is the shrinking defense budget and dwindling manpower pool. Although few Air Force personnel actually perform ABDR-related tasks on a full-time basis, the cost of the program is not insignificant. Personnel costs include the salaries of full-time personnel at both the ABDR Program Management Office at McClellan AFB and the ABDR Advanced Development Technology Program at Wright Laboratories as well as the focal points at Air Force Materiel Command Headquarters and the combat logistics support squadrons. Additionally, there are costs associated with technical manual publications, ABDR exercises, technical development programs, and recurring training for engineers, assessors, and technicians.

It would seem unreasonable to assume that the shrinking defense budget and military drawdown would affect the ABDR Program funding and manpower. Air Force leadership should therefore anticipate budgetary and personnel reductions and plan for them accordingly by examining downsizing options. (Although discussed in chapter 5, certain recommendations are outlined in this chapter.) As a start, the Air Force should minimize or preferably eliminate redundancies to use both money and personnel wisely. Like most other large programs, some redundancy and overlap of responsibility occur in the ABDR Program, especially between the ABDR PMO and the ABDR ADTP. Combining these organizations into one unit helps to save money and eliminate some personnel overlaps. Also, training costs could be lowered by doing more training in-house and less frequently.

Besides the budget and manpower cuts, the Air Force is currently experiencing unprecedented change in structure and organization. The traditional wing structure, comprised of squadrons of aircraft of the same type and mission, is being replaced with composite wings combining different types of aircraft in the same unit. Also, the wing command structure and organization are being further revised into the new objective wings, replacing the traditional

tri-deputy configuration. Finally, to reduce maintenance and repair costs, the Air Force is testing a two-level maintenance concept, effectively eliminating the intermediate level of maintenance. These changes to the Air Force's ABDR Program are likely to range from small to significant.

The composite wing is likely to have the most significant effect on the ABDR Program. These composite wings are structured along more mission-oriented lines than traditional wings to improve combat effectiveness. These wings will contain several types of aircraft, including fighters, bombers, refueling, and transports. These wings will emphasize deployment mobility and rapid response. This concept of having multiple types of aircraft in the same organization may change the current approach of AFMC ABDR support. Currently, the CLSS ABDR teams and their supporting depot engineers train primarily to repair the aircraft supported at their respective depots. Although the teams get some generalized training, which would be applicable to many types of aircraft, the subsystems and aircraft structures are unfamiliar to most repair personnel. This problem could be addressed by the deployment of teams for each type of aircraft, but this method would probably be cost-prohibitive. A preferred solution would broaden ABDR team training to encompass a broader variety of aircraft with a few specialists for each aircraft. Another possible solution would shift even more of the battle damage repair burden to the operational maintenance units—an option which would degrade repair and heavy maintenance capability.

Another organizational change of significance in the Air Force is the transition to the objective wing concept. An objective wing is "organized to give the wing commander and the squadron commanders more control over those elements which contribute to or affect operational mission of the wing."¹³ This wing structure clarifies command lines with the one-base, one-wing, one-boss concept—where the wing commander is also the installation commander. The three deputy wing commanders (operations, maintenance, and resources) are replaced by two commanders—operations group and logistics group. This objective wing structure applies equally to composite or homogenous wings. The most significant change to the ABDR community is the realignment of the flight-line maintenance troops from a single deputy commander for maintenance to reporting directly to the respective squadron commanders. The supporting maintenance troops (intermediate level or "backshops") will report to the wing logistics group commander. This organizational change should have little effect on the AFMC support provided to operational wings—simply a change of command lines.

The final organizational change affecting the ABDR community is the implementation of the two levels of maintenance concept. Currently the Air Force has three levels of maintenance—organizational, or flight line; intermediate, performed at the operational base; and depot, generally performed at an air logistics center or contractor facility. In this concept, much of the intermediate-level maintenance (that maintenance too complex or time-consuming

to be performed on the aircraft or flight line) would be removed from the operational base and given to the supporting depot. This concept could impact the ABDR support AFMC provides to operational wings. AFMC would now be responsible for both intermediate- and depot-level maintenance as well as ABDR augmentation—using many of the same personnel. Further, “the two-levels of maintenance ground rules mandate no increase in actual spares in the inventory.”¹⁴ This potential shortage of spares at the operational bases coupled with the work load increases at the supporting depots could adversely impact AFMC's ability to provide timely and adequate ABDR support in a contingency situation.

Comments

Like most military programs in this postcold war environment, the Air Force's ABDR Program is facing changes not only in technology but also in economic priorities and defense reorganization. To remain viable, the entire ABDR community—not just the US Air Force—must address these challenges of technology, funding, and organization. The days of multiple organizations performing the same function independently are drawing to a close.

The USAF ABDR Program must consolidate its efforts and work closely with industry, the other military services, and allied air forces to avoid duplication of effort. It must also address the technical concerns mentioned in this chapter, especially in the areas of structural repair of composites, transparencies, and aircraft subsystems. The following chapter provides specific recommendations regarding the future direction of the Air Force's ABDR Program.

Notes

1. Curt Rogers, *Advanced Composite Materials: The Air Force's Role in Technology Development*, Rand Report N-3503-AF (Santa Monica, Calif.: The Rand Corporation, 1992), 1.
2. *Ibid.*, 5.
3. USAF Aircraft Battle Damage Repair Program Management Office, *Requirements for USAF Aircraft Battle Damage Repair Involving Composites* (McClellan AFB, Calif.: Sacramento Air Logistics Center, February 1992), 2.
4. William M. Cavitt, *Aircraft Battle Damage Repair of Advanced Composite Structures* (Monterey, Calif.: Naval Postgraduate School, March 1988), 94–95.
5. *Ibid.*, 72.
6. *Requirements for USAF Aircraft Battle Damage Repair*, 2.
7. 2Lt D. A. Crocker, *Battle Damage Repair of Birdstrike Resistant Laminated Transparencies* (Wright-Patterson AFB, Ohio: Air Force Flight Dynamics Laboratory, June 1984), 27.
8. Susan S. Saliba, *Aircraft Battle Damage Repair of Transparencies* (Wright-Patterson AFB, Ohio: Air Force Materials Laboratory, April 1990), 3.
9. USAF Aircraft Battle Damage Repair Program Management Office, *1992 U. S. Air Force-wide Aircraft Battle Damage Repair (ABDR) Conference* (McClellan AFB, Calif.: Sacramento Air Logistics Center, March 1992), 2-4.

10. Ibid., 2-5.
11. Cavitt, 52-53.
12. 1992 U. S. Air Force-wide Aircraft Battle Damage Repair (ABDR) Conference, 2-1.
13. Lt Col William L. Egge, *Logistics Implications of Composite Wings* (Maxwell AFB, Ala.: Air University Press, February 1993), 20.
14. Ibid., 81.

Chapter 5

Conclusions and Recommendations

In the 1980s, the US Air Force developed an aircraft battle damage repair program to meet the needs of the eighties. But, technological improvements, the changing global political situation, and defense organizational restructuring have combined to create a vastly different military/political environment to which the ABDR Program must adjust. The ABDR Program must adapt to the shrinking defense budget, dwindling military manpower, high-tech materials, and the new Air Force organizational structure. It must eliminate managerial duplication, consolidate research and development efforts, interact and learn from sister services and allies, and demonstrate relevancy in the peacetime Air Force.

The current structure of organizational maintenance units trained in ABDR techniques supplemented by both active and reserve combat logistics support squadrons is feasible but expensive. An ABDR philosophy incorporating some of the advantages pioneered by the British Royal Air Force and the Israeli Air Force will better serve the USAF. The following recommendations are offered to help the ABDR Program remain viable throughout the 1990s and beyond.

1. Operational maintenance units must continue to perform ABDR. The US Air Force should maintain the capability to augment these organizational units with personnel trained in heavy maintenance/depot-level repair. The combat logistics support squadrons can serve this purpose and should be retained in some form.

2. In keeping with the current Air Force philosophy of single, consolidated leadership, all facets of the ABDR Program should be combined into a single organization. This organization would be responsible for the daily management of all aspects of the ABDR Program including training requirements, technical publications, research and development activities, interservice/international technical exchanges, ABDR wartime planning, and coordination with air logistics center ABDR units. This organization would replace both the ABDR Program Management Office in Sacramento Air Logistics Center and the ABDR Advanced Development Technology Program at Wright-Patterson Air Force Base. Additionally, this organization would assume certain highly technical training functions and interface directly with the focal points at the Air Force Materiel Command headquarters.

3. Considering the shrinking defense budget and the rising cost of aircraft maintenance and repair, the Air Force should seriously consider the Israeli

practice of making ABDR-type rapid repairs permanent. Although this practice is not advocated on a wholesale basis, selected ABDR repairs could replace expensive depot repairs if aircrew safety is not compromised.

4. USAF wartime spares planners should consider project ABDR requirements as well as accelerated peacetime replacements when computing wartime spares requirements.

5. Both the ABDR training exercises and training aircraft need updating. The training scenarios should be realistic and actual supported aircraft, or a reasonable substitute, should be made available for ABDR training. (Example: C-5 ABDR teams should not train on Vietnam-era fighters.)

6. The classroom technical training given technicians, assessors, and engineers ought to be relevant and taught on a level commensurate with the educational level and skill of the students. (Example: The engineering training taught by the Air Force Institute of Technology is too theoretical and of limited use in actual field situations.) The curriculum should be relevant to ABDR-type repairs and taught by trained ABDR engineers instead of a graduate-level engineering mechanics course taught by college professors.

7. More emphasis should be placed on repairs to high-technology structures and subsystems. In particular, composite structures and high-technology materials need workable repair techniques suitable for field conditions.

8. Design for battle damage repairability must be institutionalized among both the aircraft manufacturers and the government acquisition community.

9. The ABDR Program should clarify the roles of the ABDR engineers and make more extensive use of its engineering talent.

10. Finally, the ABDR technical publications need to be written at a level commensurate with the technicians and assessors using them. These publications should be logically constructed and generally self-contained, with minimal reference to other manuals which may not be available.