History of US Air Force Aircraft Battle Damage Repair (ABDR)

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This essay chronicles the evolution of the specialized military discipline dedicated to rapidly restoring damaged aircraft to combat capability, the US Air Force's Aircraft Battle Damage Repair (ABDR). It traces ABDR's progression from informal "field fixes" during the World Wars to the establishment of a formal doctrine during the Vietnam War with the creation of Combat Logistics Support Squadrons (CLSS). The modern USAF program adopted a hybrid philosophy in the late 1970s, blending the British RAF's model of rapid, temporary repairs with the Israeli Air Force's engineering-intensive, permanent-repair approach, a strategy successfully validated during Operation Desert Storm. The essay further details the organizational shift from large CLSS units to smaller, more specialized Expeditionary Depot Maintenance (EDMX) flights and addresses the new complexities of repairing advanced stealth aircraft. The essay concludes that despite changes in technology and organization, the core mission of ABDR as a critical force multiplier remains essential for sustaining air superiority in modern conflict.

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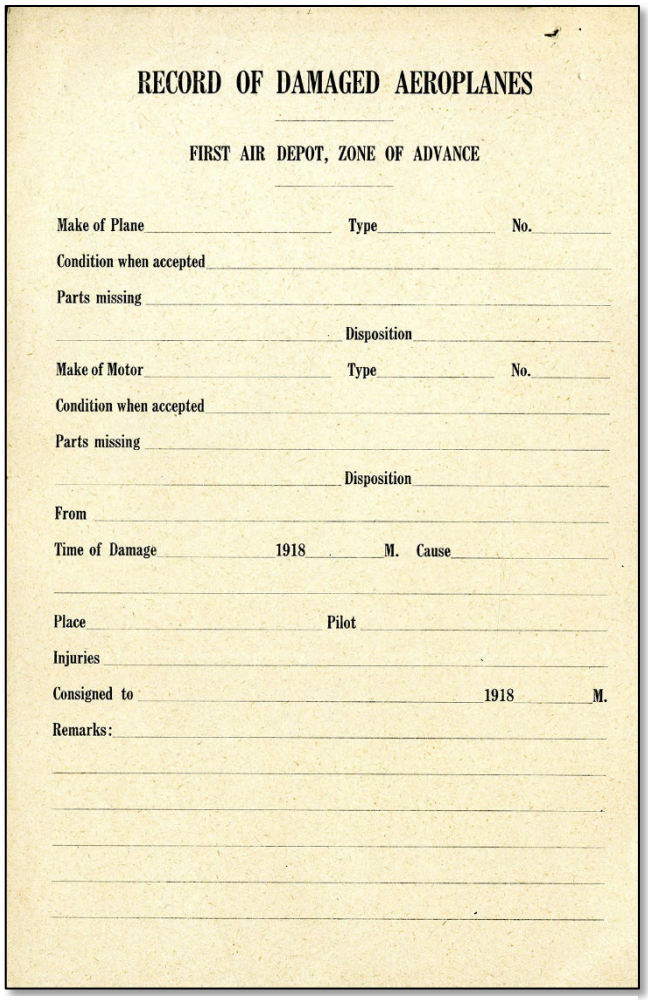
The strategic necessity of maintaining a robust aerial combat force is predicated not only on the initial procurement of advanced airframes but, more critically, on the ability to sustain those assets during the attrition-heavy environment of high-intensity conflict against a near peer. Aircraft Battle Damage Repair, or ABDR, represents a specialized military discipline designed to rapidly restore combat capability to an airframe that has sustained damage from hostile fire, structural fatigue, or austere environmental conditions. The core objective of the United States Air Force ABDR program is to return damaged assets to operational status with at least a sufficient degree of capability to influence the ongoing battle, distinguishing itself fundamentally from peacetime maintenance by prioritizing speed and mission urgency over long-term structural perfection. ABDR philosophy has often described as a "hospital triage" system for aerospace assets. This approach requires a radical departure from standard peacetime maintenance protocols governed by a series of Technical Orders (T.O.'s), which focus on returning an aircraft to its original design specifications. In contrast, ABDR operates under a different series of technical guidance, which allows for temporary, semi-permanent, or "fly-to-fight" repairs that prioritize immediate functionality and mission safety over aesthetic or long-term considerations. These repairs are conducted under austere conditions characterized by limited tooling and a lack of standard spare parts, emphasizing improvisation and "engineering judgement."

The conceptual framework of ABDR is built upon the recognition that in modern warfare, a damaged aircraft sitting on a flight line is a liability to the air component commander, occupying space and resources while contributing nothing to the warfighter. Historically, the ratio of aircraft damaged to those destroyed in combat has remained consistently between three-to-one and five-to-one. Without a formalized mechanism to address this high volume of repairable damage, the operational effectiveness of an air force would rapidly degrade during a sustained campaign. This is where ABDR steps in. Theoretical models suggest that a mature ABDR program – one capable of returning 50-percent of damaged aircraft to the fight within 24 hours and 80-percent within 48 hours – can effectively quadruple the available fighting force after 10 days of high-intensity combat. As the total inventory of the USAF has decreased over the decades, from over 50,000 aircraft in World War II to roughly 6,200 by the mid-1990s to just over 1,250 combat-coded fighter and attack aircraft today, the relative value of each individual airframe has increased, making the ability to resurrect damaged airframes an existential requirement – the then cost of a DH-4 in 1919 was roughly $11,250 with today's F-35A flyaway costs roughly $81.1 million.



RECORD OF DAMAGED AEROPLANES

FIRST AIR DEPOT, ZONE OF ADVANCE

Make of Plane _____ Type _____ No. _____

Condition when accepted _____

Parts missing _____

_____ Disposition _____

Make of Motor _____ Type _____ No. _____

Condition when accepted _____

Parts missing _____

_____ Disposition _____

From _____

Time of Damage _____ 1918 _____ M. Cause _____

_____

Place _____ Pilot _____

Injuries _____

Consigned to _____ 1918 _____ M.

Remarks: _____

Figure 1: World War I Record of Damage utilized by the First Air Depot to identify damage to airframes.

World War I and "Field Fixes"

The institutionalization of ABDR within the USAF is a relatively recent phenomenon. While mechanics performed miraculous "field fixes" during the World Wars, these were largely the result of individual ingenuity rather than a centralized doctrine. World War I presented several issues concerning the repair of aircraft, the lack of "seasoned" mechanics and materials for repairing said aircraft. The US's late entry into the war put it behind on recruitment of men not only with the proper skills to repair aircraft but recruitment of instructors to train them how to make repairs. During World War I, aircraft repairs conducted in the field were commonly referred to as "field fixes." These early repair efforts were not governed by a centralized military doctrine or a formal ABDR program. Instead, they were largely the result of the individual mechanics performing the work in austere locations on the battlefield. Because the discipline had not yet been institutionalized, these "miraculous" repairs were performed without the specialized technical guidance or standardized procedures that define modern combat maintenance. The practice of repairing aircraft in the field during this era represents the informal roots of what would eventually become a scientifically grounded military discipline. Specialist of the salvage section were tasked with dismantling and hauling wrecks across cratered terrain like that at the Somme battlefield and across the dreaded no-mans land. Airmen and engineers utilized heavy ropes, timber skids, horse teams, and sometime brute strength to drag airframes through mud and over barbed wire back to friendly lines for repair. If an airframe could not be repaired in the field and needed further repairs or was salvageable, it was then sent to the nearest depot, or as they were called then, mobile parks – a depot that served one to three groups that could move in 24 hours but limited in the degree of what they could accomplish as they could not be burdened with having heavy repair equipment to move.

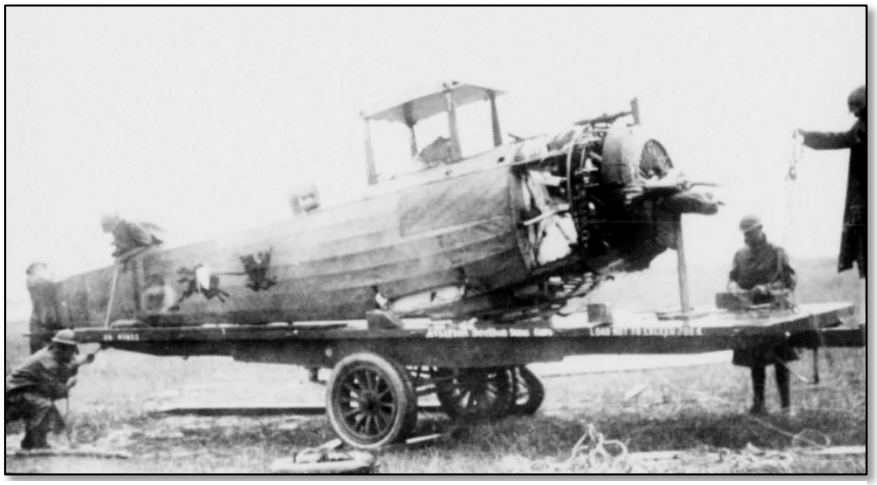


Figure 2: A de Havilland DH-4 being recovered near the from by AEF personnel wearing protective gear to protect them against gases.

World War II

During the early combat stages and remote theaters of World War II, aircraft repair was a matter of survival that often fell to the flight crews themselves due to a lack of service personnel. In the Pacific, mechanics would utilize "ingenious improvisations," such as flattening out tin cans to patch holes and using

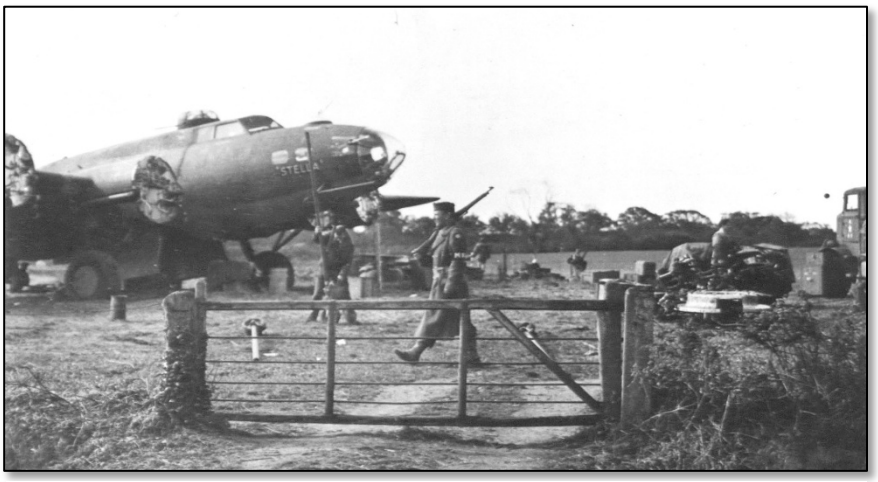


Figure 3: A Boeing B-17F Flying Fortress forced landed in a field near Poole in April 1943. The 8th AF Mobile Repair Unit deployed and repaired over 9 days and built a temporary steel-mesh runway.

baling wire for fasteners. In North Africa, "tin from flimsies" (Gasoline containers) was utilized as aluminum for patching holes. As the war progressed, the Army Air Forces (AAF) developed specialized mobile organizations to handle repairs beyond the capacity of combat units but too urgent for distant base depots. These units, equipped with a truck, jeep, and trailers, were designated to reach crash-landed aircraft at the site of the landing with their primary goal to make "on-the-spot" repairs sufficient to allow the aircraft to fly back to the depot,[1] rather than being disassembled for ground transport. In Europe, service groups were split into mobile "teams" that moved with combat groups to continental airfields in France and Germany where they performed the majority of battle-damage repairs. By early 1944, they were so efficient that they were repairing 50-percent of battle-damaged heavy bombers within twenty-four hours. In the Pacific Theater, where land-based facilities were slow to develop, under the top-secret program, Operation IVORY SOAP, the AAF

Figure 4: Mechanics repair a bullet hole in the vertical stabilizer in a Marianas-based Boeing B-29 suffered during a raid on an aircraft factory near Kobe, Japan.

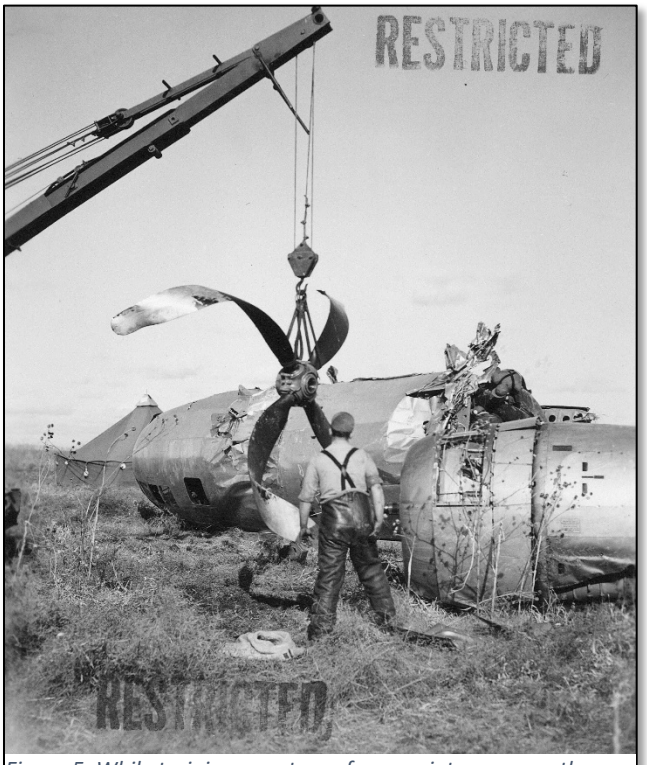


Figure 5: While training men to perform maintenance on the Boeing B-29 at Tinker, a mobile repair function was developed and utilized on downed aircraft.

utilized Liberty ships as floating depots to support combat units with third and fourth echelon maintenance. In some cases, extreme battlefield repair took place, as an example when a Boeing B-29 *Superfortress* forced landed in China due to a mechanical. After Japanese aircraft knocked out two engines while it was on the ground, mechanics and parts were flown into the site, still within range of enemy airfields. Chinese laborers jacked the plane out of the mud and built a runway of railroad ties, allowing the stripped-down bomber to escape after repairs. To meet the rising rate of damage, the AAF instituted special training for sheet-metal workers as Eighth Air Force had seen nearly 30-percent of all heavy bomber sorties result in reparable damage, necessitating large teams of these specialists at strategic European depots.

[1] In the European Theater, there were two depots set up in England at RAF Burtonwood, known as Base Air Depot 1 (BAD 1), and Warton Aerodrome, known as Base Air Depot 2 (BAD 2).

Korean Conflict

While the formal organizational structure of ABDR still had not been developed, the Korean War kicked off in the early 1950s and saw a high demand for rapid repair capabilities due to severe aircraft battle damage and an initial shortage of airframes in-theater. Maintenance units during this period served as a precursor to the specialized teams that would be formalized in later years to handle high-intensity combat attrition. Squadron mechanics, on the flight-line working directly from the dirt or pierced-steel planking (PSP) runways of K-sites (Korean airfield), focused on minor fixes like patching small shrapnel holes and swapping out broken components to keep turnaround times minimal. The base-level maintenance shops handled the heavier repairs with the heavily damaged aircraft being either flown or shipped to the rear depot at Tachikawa Air Base on the Japanese mainland.

Figure 4: Mechanics repair damage from a rough landing.

A specially organizational maintenance squadron from the 452d Maintenance and Supply Group in May 1951 remained behind at Miho Air Base[2], on the western coast of Japan, performed major periodic inspections and repairs on aircraft returning from Korea on scheduled intervals, which in turn increased the mission capable (MC) rate from 57-percent in July to 82-percent in November. During this same period, the 3d Bombardment Wing moved to Kunsan attempted to perform maintenance under field conditions but saw the rate of their Martin B-26 *Marauders* fall from 78-percent to 65-percent; however, the B-26s were already in poor condition. In 1953, Air Depot Wings, like the 75th from Kelly Air Force Base, Texas, dispersed between various operating locations – both in the rear in Japan and as well as five different locations in Korea – to repair aircraft on the flightline to either return to the fight or fly back to the rear for further repairs.

During the early periods of Korea, leadership developed a system of rear-echelon maintenance with aircraft returning to units set up at Tsuiki, Itazuke, and Miho on mainland Japan who were charged with performing battle-damage, structural, engine, and other aircraft maintenance repairs. However, many combatant commanders objected to this system due to the time lost ferrying aircraft to the rear as well as the required skilled maintenance personnel in the rear, depriving lesser-skilled men at the tactical squadrons. By late 1951, this concept morphed into an organization known as rear-echelon maintenance combined operations or REMCO. REMCOs were organizations consisting of maintenance units of several wings that flew the same type of airframe and co-located at a base in Japan, in the rear of operations. Under the REMCO system, aircraft maintenance was performed in two ways, either on the flightlines in Korea under combat conditions or in the rear on bases in Japan. Those personnel in Korea took care of the aircraft pre- and post-flight as well as

[2] The host wing, 452nd Bombardment Wing, was forward deployed at Pusan-East Air Base (K-9). Miho Air base is present day Yonago Kitaro Airport.

performed minor repairs. Those personnel back in Japan performed the 100-hour inspections and repaired aircraft unfit for combat.

Vietnam War

The modern ABDR program largely emerged from logistical shortfalls during the Vietnam War. Following the August 1964 Tonkin Bay incident, U.S. operations in Southeast Asia rapidly intensified, leading to a sharp rise in aircraft battlefield damage. Initially, the civilian contractors absorbed the new workload, but their limited facilities soon became saturated with HQ's Air Force Logistics Command (AFLC) looking at ways to support PACAF's aircraft repair needs. In December, personnel from AFLC and Sacramento Air Materiel Area (AMA) met at McClellan AFB to discuss the issue and develop a way forward with four COAs: establishment of mobile maintenance teams, development of mobile shop vans similar to the PACVAN Program[3], conversion of mothballed Navy carriers as floating repair docs, and, creation of depot level maintenance squadrons in the areas. After considering these, the team decided to develop the mobile team concept with completion of "AFLC Aircraft Maintenance Mobile Repair and Crash/Battle Damage Recovery Plan" in April 1965. This plan outlined the procedures developed by the Command for the organization, equipping, and the deploying of the Rapid Area Maintenance teams, or RAM teams, to Southeast Asia. The plan identified the equipment the teams would need to accomplish their mission and the maximum number of workdays/man-hours to repair a specific type of damage at a particular location. In coordination with the RAM teams, AFLC established the Rapid Area Supply Support (RASS) teams that were specialized, mobile military logistics units designed to provide urgent, depot-level packaging, supply, and distribution operations in a combat zone or forward operating area. RASS teams were intended to aid in the "elimination or reduction of base work backlogs in 'normal' assigned mission functions caused by temporary or continuing shortages of personnel assigned to accomplish such assigned functional workloads." It was shown that with each base that the RASS team visited, it substantially reduced the previous backlogs and restored order to the base supply functionality; however, once the team left, most of the bases regressed to their previous unmanageable workload predicament with inadequate manning and the heavy flow of material to the new and expanding bases the key indicator. An example of this was on 20 April, PACAF notified AFLC that it needed help with the repair of two crash-damaged Republic F-105 *Thunderchiefs,* which were still economically reparable, with Sacramento AMA sending a team of 18 civilians to Tan Son Nhut Air Base to conduct a preliminary support plan for recovery; the preliminary plan called for a number of RAM teams (consisting normally of 18 individuals – group leader, an aeronautical

Figure 5: The 2952nd CLSS, Ogden ALC, repair a McDonnell F-101 Voodoo in Vietnam.

[3] PACVAN was a program in the early 1960s developed for PACAF for forward maintenance activity in Southeast Asia for areas absence of the capability. These were mobile aircraft field maintenance vans in forward areas, capable of moving over unimproved roads and transportable by air and provided bench check and minor repair capability that reduced the reparable flow of aircraft and equipment spare parts back to main bases.

engineer, and maintenance and repair technicians) to deploy to support recovery efforts.

By 1967, the success of the concepts developed by the RAM and RASS teams as operations grew in Vietnam led AFLC to create a more permanent organizational structure. On 1 December 1967, the Combat Logistics Support Squadrons (CLSS) were activated with the intent to provide the Air Force with organic, mobile depot capability to sustain the fighting power of combat aircraft to not only repair battle damaged airframes specific to the platforms managed by the depot they were assigned to. The CLSS's were structured around the five major Air Logistics Centers (ALC), each supporting airframes their ALCs supported: the 2951st CLSS (later 652nd) based at Sacramento; the 2952nd CLSS (later 649th) based at Ogden; the 2953rd CLSS (later 654th) based at Oklahoma City; the 2954th CLSS (later 655th) based at San Antonio; and the 2955th CLSS (later 653rd) based at Warner-Robins. Personnel within these units underwent rigorous, non-standardized training and, unlike traditional units where technicians were stovepiped into specialties, CLSS Airmen were often cross trained to allow smaller teams of four or five individuals to address comprehensive damage that would normally require a much larger footprint. Training emphasized operating in degraded environments, such as practicing repairs in full Mission Oriented Protective Posture (MOPP) gear. These units frequently worked under hazardous and austere conditions, often within hostile environments far from home station performing emergency repairs on aircraft like the Boeing B-52 *Stratofortress* and McDonnell-Douglas F-4 *Phantom II* with their readiness exemplified by the unofficial motto, "Have Tools, Will Travel." Following the Vietnam War, the CLSS squadrons became the Air Force's primary organic depot logistics support organization and envisioned as the "Green Berets of AFLC," these were highly mobile, autonomous units capable of performing complex field repairs.

Following the post-Vietnam era, the British Royal Air Force (RAF) and the Israeli Air Force (IAF) developed distinct ABDR philosophies that represented two different approaches to combat sustainability in the 1970s. The British prioritized speed and simplicity, while the Israelis focused on permanent field-level restoration and engineering integration. The RAF formalized its ABDR program in 1976, emphasizing the maximization of sortie generation above all else. The British philosophy dictated that repairs should be temporary and intended only for immediate combat needs. They believed that "repair times must not be extended because of repair techniques employing unnecessarily high standards of workmanship." The senior Non-Commissioned Officer (NCO) was identified as the "key man" or accessor within the process and trained to make rapid "Go/No-Go" decisions using succinct technical orders containing formulas to determine if damage was repairable with the technical manuals viewed as guidance only, encouraging technicians to use initiative and ingenuity to perform the best possible repair in the specific time available for the mission.

Israeli Air Force and the 1973 Yom Kippur War

Now considered a foundational model for modern combat maintenance, the Israeli Air Force (IAF) utilized a highly sophisticated and integrated Aircraft Battle Damage Repair (ABDR) process during the 1973 Yom Kippur War. Their approach focused on maximizing aircraft availability at the field level to sustain high sortie rates during intense conflict. The IAF radically changed from the traditional models by moving the majority of its technical expertise directly to operational bases with depot-level personnel and structural engineers integrated directly into organizational maintenance units rather than being separated at distant facilities. This allowed the engineers to perform immediate assessments and designed custom, permanent repairs on-site, rather than sending data back to a distant depot. These structural engineers played a pivotal and integrated role, serving as a cornerstone within the successful ABDR strategy during the Yom Kippur War. They were able to: be integrated into the front-line operational bases, allowing for immediate technical support; responsible for on-the-spot assessment and design of custom, permanent on-site repairs that were the key philosophy of the IAF's ABDR

with engineers approving repairs based upon existing technical orders or used their "engineering judgment" to design and approve custom fixes that exceeded standard limits; and, engineers worked in close conjunction with unit maintenance troops and depot technicians in a collaborative environment to ensure that complex repairs could be executed rapidly and often simultaneously with "quick combat turns" like refueling and rearming. The maintenance units were subordinate to the squadron commander to ensure that repair priorities aligned with immediate operational needs, and Israeli maintenance officers often rose from the enlisted ranks and were technically competent with the repair processes. Technicians were highly qualified and less specialized than their counterparts in other air forces, allowing fewer people to handle a wider variety of complex tasks. The Israel process was designed for maximum efficiency through the integration of combat turns and battle damage repair with the utilization of specially equipped maintenance shelters. These shelters allowed repairs to be conducted while also handling refueling and rearming, allowing technicians to work on damage while simultaneously other turnaround tasks were performed, minimizing unproductive downtime. These shelters also contained specialized tools and repair modules that allowed front-line units to perform complex intermediate and even depot-level repairs on-site.

Unlike some of the earlier ABDR doctrine that favored rapid, temporary patches, this IAF process favored permanent repairs that conformed to existing technical orders with engineers assessing the damage, directly assisting in design, and approving fixes on the spot. The IAF utilized dedicated combat spares kits that were based on combat damage simulations rather than just amplified peacetime inventories with the kits including major modular replacement components that were critical for rapid restorations. While repairs were executed locally, the overall management of ABDR personnel and major structural units was centrally controlled at the headquarters level to assign work based on theater-wide priorities. Using this process, the IAF successfully returned 72-percent of their battle-damaged aircraft to combat within 24 hours with assessments suggesting that without these effective rapid repairs, the IAF would have been grounded by the eighth day of the war. Following this experience from the Yom Kippur War, the IAF identified four critical lessons: Immediacy – skilled ABDR teams must be available from the very start of the conflict; Assessment – rapid and thorough assessment was the linchpin of success with accessors having extensive structural knowledge; Ingenuity – every battle damage instance was unique, technicians must possess high levels of creativity and experience; and, Modular Spares – major modular replacement parts were essential for completing many types of combat repairs.

British RAF Philosophy – Speed and Simplicity

The British Royal Air Force (RAF) program, established in 1976, prioritized maximizing sorties over long-term airworthiness. The key characteristics of the British approach were, unlike traditional maintenance, to perform fixes intended only for immediate combat needs, under the mantra that repair times should not be extended by "unnecessary high standards of workmanship." They also developed succinct technical orders geared toward senior Non-Commissioned Officers that provided specific repair criteria and formulas to quickly determine if damage was repairable as well as identified the assessor as the "key man" in the process.

The 1982 Falklands War[4] served as a crucial validation for the RAF's doctrine on ABDR with the USAF watching closely. The RAF reported that every Harrier GR Mk-1 committed to the fight had to be repaired at least once, proving that a robust ABDR capability could keep a small, high-value fleet operational despite 100-percent damage rates. This reinforced the USAF's view of ABDR as a strategic force multiplier essential for modern, high-

[4] A 74-day conflict between Argentina and the United Kingdom over sovereignty of the Falkland Island, South Georgia, and the South Sandwich Islands.

intensity conflicts. Out of the 74-days of conflict, the RAF compiled and presented fourteen principles they learned regarding ABDR. First, future aircraft needed to be designed for survivability during conflict as it was discovered that access holes were frequently needed in airframes to facilitate thorough assessment and repairs as well as the technical manuals needed to be utilized for guidance rather than being restrictive. Next, they discovered that having individual creativity and the ability to improvise in the field were critical to successful repairs but maintaining some level of documentation was important as well as clear criteria was essential for rapid decision-making on whether an aircraft was fit to fly. It was discovered that standard peacetime inventories were insufficient with additional spares specifically for ABDR support necessary; however, cannibalization of parts from non-repairable aircraft became vital and integral parts of ABDR. They identified having specialized repair kits as essential for supporting land-based operations along with technicians striving to perform the best possible repairs within the specific times allotted. They discovered that there was a lack of an effective method for repairing damaged aircraft canopies and a critical need for self-sealing fuel tanks to mitigate combat damage. They identified early that pilots were not always aware that their aircraft had suffered damage during the mission but that rapid and accurate assessments were the most critical stage of the process, making the assessor the "key man" within the ABDR team – this would significantly influence the USAF's thoughts with the role adopted to streamline triage of combat-damaged aircraft and become the cornerstone of the USAF's formalized ABDR doctrine.

Comparison of 1970s ABDR Philosophies		
Feature	**British RAF Philosophy**	**Israeli IAF Philosophy**
Primary Goal	Maximize Sortie Rate	Maximize Aircraft Availability
Repair Nature	Temporary/Rapid	Permanent/Engineering-based
Lead Personnel	Senior NCOs (Assessors)	Structural Engineers & Depot Techs
Work Standards	Simplified; avoid "unnecessarily high standards"	Conforms to original technical specifications
Key Enabler	Succinct, user-friendly manuals	Modular spares and integrated shelters

US Air Force and ABDR Program, late 1970s

The USAF formalized its modern ABDR program in the late 1970s by strategically blending the rapid, temporary repair (speed and mission urgency) philosophy of the British RAF with the permanent, engineering-oriented (permanent and full-capability) approach of the Israel Air Force as well as various lessons learned during the Vietnam War. This hybrid doctrine, characterized as "fly-to-fight" or "hospital triage" system, allowed the Air Force to pivot its maintenance strategy based on the intensity of the conflict. There were numerous reports and conferences sponsored by various government and industry organizations post-Vietnam that looked at how to increase aircraft availability rates with perhaps the most influential of them all, the 1978 HAF Surge Sortie Rate Conference. This conference looked at the extensive data from the Vietnam War – extent of damage and location, repair times, and maintenance and repair capability of field units – and concluded that the utilization of

rapid repair techniques could in fact increase sortie rates. It then recommended that Air Force Logistics Command develop a program to augment field organizational maintenance units in times of crisis. This and the other reports were instrumental in encouraging the USAF to develop a comprehensive ABDR doctrine that utilized the strength of both the RAF and the IAF as well as the lessons learned from Vietnam.

Figure 6: 2952 CLSS crews from Ogden ALC repair an F-101 during an ABDR exercise.

With this information in hand, the Air Force developed the initial ABDR doctrine in the late 1970s understanding that during high-intensity combat, when the immediate need for sorties is critical, the USAF would adopt the British style, prioritizing rapid, temporary patching to return aircraft to the fight within 24 to 48 hours. Once the threat environment relaxed, the Air Force would shift to the Israeli style, performing permanent, full-capability repairs to preserve the long-term health of the fleet. The USAF's specialized "-39" series technical manuals (T.O. 1-1H-39) were influenced by the RAF's user-friendly, succinct guidance as they moved away from restrictive peacetime data and towards generalized techniques – like "scabs," "doublers," and "patches" – that allow technicians to apply innovative fixes in the field without waiting for distant depot approval. While adopting the RAF's speed, the USAF also adopted the Israeli practice of integrating structural engineers directly into field repair teams. These engineers provide the "engineering judgment" necessary to design permanent, safe repairs that exceed the limits of standard manuals, ensuring the aircraft is truly combat-ready. The USAF also adopted the British concept identifying the assessor as the "key man" in the repair team. This role, typically filled by a senior NCO or experienced technician, was responsible for the rapid "hospital triage" of damaged aircraft to determine which could be fixed quickly and which had to be evacuated or cannibalized. In the USAF model, the accessor was responsible for a structured ten-step process that included: aircrew interviews, methodical inspections, disposition decisions, and prioritization. Also, due to the accessor having to possess extensive structural knowledge and "engineering judgment" to make rapid decisions without standard technical data, the USAF adopted high standards for this role: SNCOs selected, dedicated assessor courses, and integrating structural engineers into the teams. The USAF adopted the Israeli policy of including major modular replacement spares in its combat kits. This allows for the rapid swapping of large, damaged sections – a key enabler of the Israeli approach – rather than relying solely on piecemeal temporary patches. This blended approach was operationally validated during Operation DESERT STORM, where it allowed the Fairchild Republic A-10 *Thunderbolt II* fleet to maintain a 95.7-percent mission-capable rate – higher than its peacetime average – by quickly resurrecting airframes that would have been permanently grounded under standard protocols.

Operation DESERT STORM

Figure 7:Fairchild Republic A-10 Thunderbolt II being repaired by ABDR teams during Operation DESERT STORM.

Operation DESERT STORM in 1991 was the ultimate test for the ABDR program; however, only the 2951st CLSS from the Sacramento ALC was tasked to the combat environment during the conflict. The *Thunderbolt II's,* or *Warthogs* as they are commonly referred to, sustained the highest volume of battle damage during the war with approximately 70 of the 144 deployed airframes suffering battle damage with nearly 20 of the damaged airframes suffering significant enough structural damage that would have permanently sidelined them under standard peacetime maintenance protocols. The 2951st CLSS successfully returned all but two damaged aircraft to combat, allowing the *Warthog* fleet to maintain a 95.7-percent mission-capable rate, the highest of any USAF aircraft in the conflict and 5-percent higher than its peacetime average; this high availability allowed the deployed *Warthogs* to fly a total of 8,775 sorties. The ABDR teams utilized the specialized "hospital triage" philosophy, prioritizing speed and mission urgency over long-term perfection when repairing the *Warthogs*. Technicians quickly patched massive holes caused by Iraqi 23-mm and 57-mm anti-aircraft fire, often preforming these repairs on-site at forward locations using limited tooling and improvised techniques allowed under ABDR technical guidance. An added benefit to the teams was the inherent survivability of the *Warthog*, including its redundant flight controls, that played into the ABDR teams' ability to perform rapid, on-aircraft structural repairs, allowing jets to return to the fight within days rather than being sent back to stateside depots. To sustain this effort, the squadron deployed over 150 maintenance, supply, and transportation personnel to the Middle East. While their efforts centered on the *Warthog*, members also performed maintenance on General Dynamics F-16 *Fighting Falcon* and McDonnel Douglas F-4 *Phantom II* airframes during the conflict. The success reinforced the value of the "force multiplier" concept, as the team effectively did the work of a force twice its size.

Figure 8: ABDR trailer first deployed to Operation DESERT STORM.

ABDR in the 2000s and Beyond

By the early 2000s, the remaining active-duty squadrons were the 649th CLSS at Hill, the 653rd CLSS at Robins, and the 654th CLSS at Tinker; however, by the late 2000s, this would change. In 2008, Air Force leadership

directed a force-shaping initiative that resulted in the decision to inactivate these three CLSSs with the primary rationale to reallocate the military manpower authorizations from the specialized squadrons to other high-priority needs within the Air Force. The inactivation of the CLSS's represented a significant strategic choice by the Air Force. It prioritized the reallocation of military personnel to other missions over maintaining a dedicated, uniformed cadre of deployable maintenance experts. While this met the force-shaping goals of the Air Force, it also marked the end of a long and storied history for the Combat Logistics Support Squadrons, which had provided critical, rapid-response maintenance support in every major conflict from Vietnam to Iraq and Afghanistan during Desert Storm. The inactivation was not an abrupt event but was a carefully managed, phased process that took place between 2008 and 2010 with the 654th CLSS at Tinker, the first to be inactivated on 27 February 2008. In late 2009, the 653rd CLSS at Robins was inactivated and in 2010 the final CLSS at Hill was inactivated. However, the inactivation's did not eliminate the *need* for deployable maintenance capabilities but changed *how* that need was met. The mission of providing on-site, depot-level maintenance and repair was transitioned to two other organizations.

Figure 9: ABDR members from AFMC deployed to the 379th Air Expeditionary Wing in 2013 forward deploy to a forward operating base in Afghanistan for reclamation and demilitarization of a C-130J Super Hercules*, recovering 250 components totaling more than $20 million.*

Figure 10: An ABDR repaired Lockheed Martin C-130J Super Hercules *that suffered severe shrapnel damage from a mortar strike at Bagram AB, Afghanistan while it was taxing out for take-off.*

The first was a Depot Field Team, or DFT. These teams, composed of civilian depot artisans, were tasked with performing the same kind of on-location repairs that the CLSS had previously handled with the DFT becoming the primary mechanism for deploying depot-level expertise. The other was the Contract Field Teams, or CFT. In situations where organic depot expertise was not available or practical, the Air Force could turn to contractor-provided teams to perform the necessary maintenance and repair tasks.

However, in the early 2010s, smaller flights known as Expeditionary Depot Maintenance (EDMX) were activated at each of the depots – 402nd EDMX at Warner-Robins, 309th EDMX at Hill, and 76th EDMX at Tinker – to meet the ABDR and depot level maintenance requirements in the field. This transition was driven by a shift in the nature of combat as officials noted that the high-volume of battle damage seen in previous wars, like Korea and Vietnam, had not manifested in the same way during recent conflicts, like Afghanistan and Iraq, where the US maintained complete air superiority, meaning hostile fire incidents and resulting damage were significantly rare than in previous eras. As aircraft became more technically advanced, the specific battle damage repair services provided by the squadrons were simply not required as frequently. AFMC determined that closing the large squadrons – which were often over 300 personnel – and transferring their workload to established depot

repair lines would be a significant manpower-saving measure. By distilling the massive CLSS capability into specialized EDMX flights of approximately 25 to 56 personnel, the Air Force was able to: reduce overhead, utilize manpower better, and integrate support between Maintenance Groups and Aircraft Maintenance Squadrons. Under the EMDX model, requests for battle damage repairs were first routed through standard aircraft maintenance squadrons with the specialized EDMX flight only called upon if those units could not accept the workload. Despite the reduction in size and the change in name, Air Force officials emphasized that the core mission and capability of performing major field repairs and ABDR remained. The EDMX flights continued to serve as "heavy hitters," composed of senior crew chiefs and structural technicians who maintain the specialized expeditionary skills required to deploy and perform miracles in contested environments. Besides contested environments, the teams provided repair capability beyond field unit's capability, returning between 1997 to 2004 over 1,454 aircraft to the fight.

Figure 11: ABDR War Wagon, a concept dating back to the 1940s, contains materiel to support initial repair of damaged airframes.

Today, and Tomorrow…

The introduction of the Lockheed Martin F-22 *Raptor* and the F-35 *Lightning II* fundamentally altered ABDR as these aircraft have carefully tuned electronic signatures and any damage that would be "minor" on legacy airframes could render a fifth-generation fighter vulnerable to radar. Low Observable (LO) technology relies on airframe shape and specialized radar-absorbent materials (RAM) with repairs having to be perfect. LO technicians must painstakingly remove RAM to allow for mechanical repairs and then restore afterwards. There has been innovation within composite repairs with the USAF pioneering new material science for field repairs, such as Ultraviolent (UV) Cure Resin Systems. These resins can be applied as patches and cured instantly with light, bypassing the need for complex thermal bonding equipment that is difficult to use on large metallic airframes. Furthermore, the *Lightning II* program has demonstrated major modular reconstruction and demonstrated the use of portable factory jigs known as Mobility Maintenance Systems (MIMS).

Figure 12: Members of the 76th Aircraft Maintenance Group's Expeditionary Depot Maintenance Flight inspect repairs completed by the ABDR team, allowing the KC-135 to fly back to Tinker to complete repairs.

The primary goal with repairs is to restore sufficient flight capability of the affected aircraft to return to the fight or fly to a more permanent location for lengthy repairs. The evolution of the USAF ABDR Program reflects the changing nature of air warfare, evolution from ad hoc field fixes during World War I into a highly specialized discipline integrating material science, digital tools, and advanced

manufacturing. While organizational structures have shifted from large squadrons to lean dedicated teams of professional maintainers and engineers, the core mission remains unchanged: ensuring that combat airpower is not lost to the inevitable attrition of combat. As the USAF prepares for the future, a paradigm shift has elevated ABDR to a critical pillar of deterrence, establishing rapid combat repair as a decisive capability in sustaining air superiority that could evolve where every Airman is a force multiplier of the ABDR process to fly, fight, and win against a near-peer adversary.

Figure 13: 309 AMXG/EDMX at Hill AFB.

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