Repair Types, Procedures – Part II

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ABSTRACT

US Air Force typical aircraft battle damage repair-type temporary and repairs for structures, mechanical systems, fuel systems, pneudraulic systems, and electrical wiring are discussed in broad terms with an emphasis on approach rather than specific instructions for repair.

1.0 INTRODUCTION

US Air Force (USAF) established procedures for typical aircraft battle damage repair (ABDR) are outlined in published ABDR technical guidance. These general repairs can be applied to any aircraft for damage to metallic structures, mechanical systems, fuel systems, pneudraulic systems, and electrical wiring and connectors. Simplified descriptions of these temporary repairs are presented in this document. The USAF ABDR program employs ABDR-trained assessors to develop or design the repair for implementation by trained repair technicians.

It is extremely important to note that the repair procedures described in this document are highly simplified and do not constitute complete repair instructions. Actual repairs should only be conducted using validated and verified published technical guidance by properly trained repair technicians. ABDR repairs such as those presented here are temporary in nature and should only be applied during combat operations when degraded aircraft capability is acceptable in light of heightened threat conditions. These repair techniques may be used by aircraft structural engineers in unusual cases, such as for a one-time ferry flight to a depot repair facility. These repairs are not alternatives to routine maintenance actions.

2.0 METALLIC STRUCTURAL REPAIRS

2.1 Repair Philosophy

ABDR repairs are performed to restore the strength of damaged aircraft components based on material ultimate loading (MUL) criteria, and not to assure adequate strength for aircraft performance requirements, which would constitute design ultimate loading (DUL) criteria. DUL repairs are the most accurate and least wasteful of repairs in terms of materials and aircraft performance; however, they require access to manufacturers design data and demand thorough and complex engineering analyses. An engineer must design DUL repairs. MUL repairs constitute a straight-forward reverse-engineering approach. MUL repairs are relatively easy to conduct and only require knowledge of the size and constitution of the damaged aircraft structural materials. MUL repairs can be conducted with or without an engineer present, depending on the extent of the damage and the complexity of the repair.

2.2 Skin and Structural Repairs

Skin and structural ABDR repairs can be conducted in the following sequence of typical steps:

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2.2.1` Remove Damaged Material

The first step in ABDR is to clean away damaged material until all that remains is viable, undamaged material and a cleaned-up hole. Torn and jagged material should be completely removed, usually with a hand-held cutting or grinding tool. Warped or buckled material should be repaired, but the damaged material can be left in-place to provide additional strength to the repair. Decisions to leave damaged material in-place should consider the benefit of the damaged material to the final repair and whether the damaged material will aid or interfere with the implementation of the repair.

When removing damage for clean-up, care should be taken to avoid increasing the size of the original damage. It is easy to remove more material than necessary by accident or neglect. Even small increases in the size of damage can take a reparable damage to beyond reparable limits.

To avoid stress concentrations in cleaned-up damage, internal corners of damage cut-outs should have the following minimum internal radii: 2.0 inch/5.1 cm or more for high-stress or primary structures; 0.25 inches/7 mm or more for other structures.

2.2.2 Select Repair Materials

In general, repair material should be identical to the damaged material. If identical material is not available, repair material should match the damaged material as closely as possible in terms of both strength and stiffness. Material substitution charts are available to aid in this action. Strength alone should not be the deciding factor in material substitution because distinct differences in stiffness can alter the load path in a structure considerably. In general, materials with higher stiffness will bear a greater portion of the load in a structure. As a secondary consideration in material substitution, understand the impacts of galvanic corrosion in choosing substitution materials for repair. If the repair is intended to stay in place for the duration of the ongoing conflict, some effort should be made to minimize the impacts of corrosion.

Once an appropriate material is selected, a sheet of appropriate thickness should be selected. Repair patch or strap thicknesses should be equal to or one gauge thicker than the damaged material. Repair material thicker than one gauge risks altering the load path as described above for stiffer material. If the damaged material is thicker than available repair materials, multiple stacks of fastened repair materials can be stacked to create the appropriate thickness. When applying a stacked repair comprised of varying thickness sheets, the thinnest sheet should be applied directly to the damaged material with the thickest sheet furthest from the damaged material

2.2.3 Repair Dimensions and Fastener Selection

With repair materials selected, the repair material dimensions must now consider fastener pattern and spacing to determine the appropriate size of repair to replace the missing strength and form. The first step in this process is to determine the size of fasteners necessary. In general, the fastener diameter should be three-times the thickness of the thickest repair sheet. The fastener length is determined by the type of fastener chosen and the total thickness of material it must bind. Fastener layout is described further in the next step.

Typically, non-countersunk, self-plugging fasteners, namely blind “Cherrymax” rivets or “Jo-Bolts” are preferred. Countersunk fasteners are only used on flush patches applied to critical aerodynamic areas. Hole size is critical when using blind rivets or Jo-Bolts because the installed fastener must completely fill the hole to realize the maximum strength of the fastener.

2.2.4 Fastener Layout

Determining the appropriate fastener layout is the last step in determining the repair dimensions. If available, use weapon system specific repair manuals to determine the best fastener layout for the damage in question. Otherwise, duplicate existing fastener patterns on the aircraft to the maximum extent possible. This approach requires removal of existing fasteners adjacent to the damaged area and replacing them with longer fasteners to include the thickness of the repair. Repair fasteners are applied in multiple rows, usually two or three, which will often require drilling additional fastener holes to existing fastener patterns to achieve the necessary fastener layout.

General rules for fastener layouts consider maintaining material bearing and buckling strength as well as optimizing the load transfer from original material to the repair material and back via fasteners. Fastener edge-distance (ED), which is the distance measured from the center of the fastener hole to nearest material edge, must be two to four times the fastener diameter (D) (ED = 2D – 4D). ED to the edge of the damage clean-up must be at least twice the fastener diameter (2D). Fastener pitch (P) is the spacing between fasteners in the same row. P must be four to ten times the fastener diameter (P = 4D – 10D), though 6D – 8D is preferred. Row Spacing (RS) is the spacing between multiple fastener rows and should be 75% – 100% of the pitch (RS = 0.75P to P). Unless specified differently by engineering or published technical guidance, a minimum of two rows of fasteners per edge should be applied.

2.2.5 Repair Procedures

With the damage cleaned-up, the repair dimensions determined, and the fastener layout loosely defined, the final step is to apply the repair to the aircraft. The standard USAF ABDR approach is to use transparent, flexible plastic sheet as a template to simulate the repair patch. Place the plastic template over the aircraft damage to include the adjacent, existing fastener patterns and pilot drill the fastener locations on the template.

Next, use the plastic template to transfer the fastener layout to the repair material 'patch'. Transfer any new fastener locations to the template from the patch using pilot-drilling. Place the template over the aircraft damage and use "Clecos" in the existing fastener holes to secure it in place. While holding it firmly in place, final drill the patch fastener layout onto the aircraft. Remove and discard the template and clean the repair area of all debris.

With the repair fastener layout drilled into both the repair patch and the aircraft, affix the repair patch firmly in place using Clecos and begin installing fasteners. Once all fasteners are installed, inspect the final repair for good fit and to assure proper fastener installation. Sealant may be applied to smooth the repair edges for enhanced aerodynamics and to prevent water intrusion into the repair.

For patches in pressurized fuselage or fuel cell skins, fay and seal the repair patch to the existing skin and apply sealant around each fastener.

2.2.6 Internal Structure Repair Procedures

Internal structures require the same principles and techniques already described. If repairing damage to a bulkhead, rib, or ring structure, ensure a minimum of four good fasteners tie the repair to the existing structure beyond the damage to properly transfer loads. Three fasteners are acceptable only if at least one undamaged flange remains in the existing internal structure. Sandwich repairs using extrusions or formed parts are better choices than simple straps to restore stiffness and buckling resistance. Beware of interfering with moving parts when installing any internal repair.

3 MECHANICAL SYSTEM REPAIRS

Aircraft mechanical systems reparable by USAF ABDR techniques include push-pull control rods, control cables and pulleys, and levers and bellcranks. Torque transfer shaft repairs are not discussed here. Most mechanical systems will require locking out the system before conducting repair to prevent injury due to moving parts; ensure all proper precautions for repairing these systems are undertaken before beginning the repair. For all internal repairs, beware of creating interference with necessary range of motion of the repaired part or other moving parts.

3.1 Push-Pull Control Rod Repairs

Push-pull control rods are two-force members (purely axially loaded) used to transfer load from actuators, levers, or bellcranks to other levers, bellcranks, or moving components such as control surfaces, landing gear bay doors, etc. Repair of damaged control rods requires simple restoration of axial load carrying strength. This can easily be affected by bridging the damage with two L-angle extrusions fastened together through undamaged portions of the existing rod to form a 'splint' over the damage. The L-angle splint should extend beyond the damage far enough to install two bolts or rivets at 90° to one another on each side of the damage. If the damaged control rod is completely severed, a similar repair can be affected using a smaller piece of solid stock or steel tube stock inserted between the ends of the severed rod and fastened into place in a similar manner as described above.

Severely damaged control rods can be completely replaced by fabricating a new rod from appropriately sized tube stock. If no single length of available tube stock is adequate to match the original control rod span, a single long tube can be fabricated from two lengths of different diameter tube stock. The tubes should be sized such that one has an inner diameter roughly equal to or slightly larger than the outer diameter of the other allowing the smaller diameter rod to fit into the other without excessive room for movement. Determine the required pin center to pin center length of the rod and clamp or hammer the ends of the repair tube to form flat ends. Drill pin holes in the flat ends and install the repair rod using original hardware. If tube stock is not available, repair can be made with solid stock of appropriate stiffness measured and drilled to the appropriate length.

3.2 Control Cable Repairs

Control cables connect system actuators to the systems themselves, namely flight controls to control surfaces. With the exception of throttle system cables, most control cables can be repaired if damaged or severed; throttle cables should always be replaced and never repaired.

Unsevered and severed cables are repaired in similar fashion. Cut a piece of 'splice' cable of equal or greater strength to extend 2.5 inches/6.5 cm beyond the cable damage on both sides. Secure the splice cable to the original cable using two nicopress swages or U-bolts on each side of the damage.

If the cable damage is near a bulkhead/rib pass-through or a pulley, cut the splice cable of sufficient length to move freely through the pass-through or over the pulley for the full-range of required motion without contacting the splice components.

3.3 Cable Pulley Repairs

Generally, cable pulleys should be replaced and not repaired. Properly functioning pulleys are critical to flight controls, so any damage that affects the free movement of the flight control system or may allow the cable to slip off of the pulley require replacement of the pulley.

Replacement pulleys can be fabricated from any round stock of appropriate size. One method to fabricate a new pulley is to cut two 0.25 inch/7 mm thick pieces of round stock and bevel the edges at 45° angles. Fasten the two pieces together with fasteners spaced 1 – 1.25 inches/2.5 – 3.2 cm apart with the bevels oriented inward to create a cable track.

An alternative method involves cutting a piece of round stock to an appropriate thickness to accommodate the cable in questions and sandwiching it between two round sheets of larger diameter sufficient to create a track capable of retaining the cable on the pulley. The end sheets should be fastened to the round stock with fasteners spaced 1 – 1.25 inches/2.5 – 3.2 cm apart.

3.4 Control Lever and Bellcrank Repairs

Control levers and bellcranks can be fabricated from a number of available materials, including plywood, phenolic, layered sheet metal, or other suitable stock. Simply fabricate the levers and bellcranks to match the holes and rough geometry of the original damaged parts and insert appropriately sized metal tubing as bushings in the holes.

4 FUEL SYSTEM REPAIRS

Damaged fuel systems can require repair of internal 'integral' fuel tanks or external fuel tanks, fuel cell bladders, and fuel lines. Every fuel system leak must be evaluated as a potential flight hazard. For example, even a small leak which may seem suitable to leave unrepaired may cause engine fuel ingestion during flight posing the risk of engine fire or explosion. Small leaks which freely flow out of the aircraft on the ground may accumulate within the internal structure when the aircraft is in a different attitude during flight. Fuel system damage should be repaired whenever possible and all fuel system repairs should be checked for leaks prior to flight. Personnel conducting fuel system repairs should use all proper precautions to prevent personal exposure to and inadvertent ignition of fuel vapors.

4.1 Integral and External Fuel Tank Repairs

Fuel tank repairs should be conducted in a similar manner to general metallic structural repairs previously discussed. In the case of fuel systems, edge distance should equal twice the repair fastener diameter and pitch and row spacing should both equal four times the fastener diameter to help assure a fuel-tight fit of the repair. Patches should be installed with faying surface seal at the interface and the entire patch should be coated with a fuel-resistant sealant.

4.2 Bladder Fuel Cell Repairs

Rubber fuel bladders with damage less than 3 inches/7.6 cm can be repaired in a manner similar to patching tire inner-tubes using Buna-N-Rubber liner sheet. The patch can be applied on the inside or outside of the bladder, depending on access, though internal repairs are preferred. The patch dimensions should extend 2 inches/5 cm beyond the damage in every direction. The patch should be applied and completely coated with fuel resistant sealant. Ensure the aircraft structure surrounding the patched area of the bladder is repaired to provide adequate support and prevent further damage to the bladder.

4.3 Fuel Line Repairs

Damaged fuel lines can be repaired a number of ways depending on the extent of the damage. For completely severed or severely damaged fuel lines, cut away the damaged section and use a piece of fuel-resistant rubber hose with an inner diameter equal to the existing fuel line outer diameter to replace the damaged section. Ensure the repair hose extends far enough on each side of the damage to accommodate two hose clamps, oriented 180° from one another. Flare the ends of the existing fuel line to improve the seal and prevent leakage. Coat the ends of the repair with fuel-resistant sealant.

If the fuel line has a single-sided penetration damage of less than 0.75 inches/2.0 cm diameter, it can be repaired with a simple patch repair. Clean up the damage and blend out the hole to assure minimum internal radii of 0.25 inch/7 mm. Using the same type and thickness of material as the damaged fuel line, cut a patch large enough to extend at least 0.5 inches/1.4 cm beyond the fuel line damage in every direction. Coat the entire faying surface of the repair with fuel-resistant sealant. Install the patch and secure with a single hose clamp on either side no more than 0.5 inch/1.4 cm from the damage. Coat all edges of the patch with fuel-resistant sealant.

If the fuel line has double-sided penetration or damage greater than 0.7 inches/2.0 cm, begin the repair as described above with a separate patch over each damage. Before installing the hose clamps described on the repair above, apply sealant over the entire surface of the repair extending at least 2 inches/5 cm beyond each side of the patch. Wrap sheet metal around the damaged area of the fuel line at least 1.5 times and secure with three evenly spaced hose clamps; the outer clamps should be no more than 0.5 inches/1.3 cm from either the edge of the repair patch beneath the sheet metal or the sheet metal itself. Apply fuel-resistant sealant over the seam and coat the edges at least as far as the hose clamp bands.

5 PNEUDRAULIC SYSTEM REPAIRS

Pneudraulic systems include any system operating with pressurized fluid, to include hydraulic systems, life-support oxygen systems, and engine bleed-air systems. The repairs described here are not for life-support or oxygen systems of any kind. Pneudraulic systems should be depressurized in the affected region prior to their repair; ensure all proper precautions for maintenance of these systems are undertaken before beginning the repair. In general, replacement of damaged pneudraulic tubes and hoses is preferred over repair. Standard procedures for fabrication and installation of pneudraulic tubes are not covered in this document. All pneudraulic system repairs should be leak and pressure checked prior to flight.

5.1 High, Medium, and Low Pressure Tubing Insertion Repairs

For insertion repairs, ensure all repair components are rated to meet or exceed the working pressure of the damaged system. Cut out the damaged tube section and install appropriate flared or flareless fitting to the ends of the remaining existing tube. If the removed section is no longer than a union or bulkhead length, simply bridge the gap using connector pieces as necessary. If the removed section is longer than a union or bulkhead length, bridge the gap using a manufactured length of hose or tube between connectors.

5.2 Low Pressure Tubing and Hose Repairs

If the damaged system is rated at 90 psi/625 kPa or less, the following repair is suitable. Cut out the damaged tube section. If the damage exceeds 8 inches/20 cm in length, install two of the described repairs with a length of manufactured tube between. Use a permanent marker or “Sharpie” to mark 2 inches/5 cm from the ends of the existing damaged tube ends. Slightly flare the existing tube ends, if possible, to improve seal and prevent leakage. Cut a length of appropriate pressure hose with inside diameter equal to the outside diameter of the tubing and at least 4 inches/10 cm longer than cut out section. Place 4 hose clamps on repair hose and slide over existing tube ends such that hose ends line up with marks on existing tubes. Secure the hose to the tube with two clamps on either side of the damage rotated 180° from one another with a minimum spacing of 0.25 inch/7 mm from the tube flare and end of the hose and 0.5 inch/1.4 cm between clamps. If the ends of the remaining damaged tube are offset, the offset shall not exceed 0.0625 inch/2 mm or 3° between tube centers at the ends.

5.3 H-Fitting Tubing Repair Repairs

This repair is suitable for tubes rated at 3000 psi/20.7 MPa or less with an inner diameter of 0.25 – 1 inch/7 – 25.4 mm and a damage or gap of 0.250 in/6.4 mm or less. Clean-up tube ends. Wrap a single layer of tape 0.550 inches/1.4 cm from one cut end of tubing and use a Sharpie to apply a 0.25 inch/7 mm long mark starting 1.15 inch/2.9 cm from the other cut end. Position H-Fitting components with nut and slide (rounded end toward cut-out) on taped side of damage and union and coupling on Sharpie-marked side. Position union over the damage/gap until it contacts the tape and the far edge of the coupling is aligned with Sharpie mark. Keeping the coupling held stationary, tighten the nut onto the coupling until a significant torque increase is felt. Back off the nut and inspect the joint: the slide and coupling should be bottomed against the union shoulder, the union should contact the tape, and the edge of the coupling should intersect with the Sharpie mark. If this all is correct, retighten nut to coupling and check for leakage before flight.

5.4 Bleed-Air Duct Repairs

This repair is suitable for bleed-air ducts operating at 500°F/260°C or less with a damage diameter of 2 inches/5 cm or less. First, remove sufficient insulation from duct to access the full extent of damage plus 2 inches/5 cm on either side. Clean-up the damage. Clean the exposed duct surface of all debris and insulation. From a 0.016 – 0.032 inch/0.4 – 0.8 mm thick annealed stainless steel sheet, cut a section wide enough to extend 2 inches/5 cm beyond each side of the duct damage and long enough to wrap completely around the duct without overlapping. Wrap the stainless steel piece around exposed duct with the seam positioned on the opposite side of duct from the damage. Up to a 0.25 inch/7 mm gap between the stainless steel edges at the seam is acceptable; overlap is not acceptable. Wrap the entire area with Teflon tape, tucking the tape ends under the wrapped tape to prevent unravelling. Install a minimum of five hose clamps to secure the repair, taking caution to not crush the duct. Leak and pressure check the repair prior to flight; replace the duct if leakage is discovered.

6 ELECTRICAL REPAIRS

Electrical wiring and connector repairs can be affected using a variety of ABDR techniques. Wire/system identification on each wire is a tremendous assistance to ABDR efforts as identifying individual wires is the most time consuming effort in ABDR. Empirical data from one USAF repair depot shows that the time required to repair unmarked wires in harnesses of 50 or more wires is four to five times greater than the time required to repair marked wires. Common wire identification schemes are available. Marked or not, there are a number of ABDR wire repair options, including in-line splices, terminal lug splices, solder splices, alternate wire repairs, shielded cable repairs, coaxial and triaxial cable repairs, and connector repairs.

6.1 In-Line Splice Repairs

In-line splice repairs are a common wire repair, though not generally allowed for aircraft maintenance in normal circumstances. To affect an in-line splice, strip 0.25 inches/7mm of insulation from the ends of the wires to be spliced and insert into an in-line splice ‘barrel’ connector, crimp, and insulate with shrink tubing, flexible transparent tubing, or insulating tape.. If multiple splices are required in a single wire bundle, as is often the case, offset barrel connectors by using jumper wires between splices.

6.2 Terminal Lug Splice Repairs

Similar to the procedure described above, terminal lug splices use terminal lugs instead of in-line splice connectors. Strip the wires to be spliced as described above and find a terminal lug with a barrel diameter sufficient to insert both wires at once. Cut off the terminal lug tongue flush with the insulation, insert one wire into each end of the barrel, crimp, and insulate with shrink tubing, flexible transparent tubing, or insulating tape.

6.3 Solder Splice Repairs

Strip 1.5 inches/4 mm of insulation from the ends of the wires to be spliced. Place stripped ends side by side and twist one around the other four times. Solder wire turns using 60/40 tin/lead rosin core solder and insulate with shrink tubing, flexible transparent tubing, or insulating tape.

6.4 Alternate Wire Repairs

As a last-resort when connectors are unavailable or mission needs are truly time-critical, the “twist-method” can be used to splice wires. This technique is similar to the solder method, but no solder is used on the wire turns. Instead, the exposed wires are placed side by side and end to end on the same side, one wire is then twisted around the other, and then the twisted wire bundle is bent back against the wire and secured with shrink tubing, flexible transparent tubing, or insulating tape.

Terminal lug bolting can be used for large wire repairs. Strip the ends of the wires to be spliced as usual, insert the stripped ends into separate terminal lugs, bolt the terminal lugs together, and insulate with shrink tubing, flexible transparent tubing, or insulating tape.

6.5 Shielded Cable Repairs

Select the proper sized grounding sheath. Strip 0.5 inches/1.4 cm of insulation from inner conductors and remove the outer cable jacket to expose 1 inch/2.5 cm of shielding. Attach a grounding sheath connector to one end of the severed cable's shield and slide a grounding sheath connector onto the other end, but do not crimp it. Join the inner conductors with an in-line or terminal lug splice repair. Connect the grounding sheath wire to loose connector and crimp. Insulate with shrink tubing, flexible transparent tubing, or insulating tape.

6.6 Coaxial and Triaxial Cable Repairs

Coaxial and triaxial cables should generally be replaced; repair should only be conducted as a last resort. If repair is required, an experienced electrician should conduct the repair due to the complexity of repair. Begin a coaxial cable repair by stripping away 1.5 inches/3.8 cm of outer insulation from each cable end, fold the shielding braid back, and strip 1 inch/2.5 cm of inner conductor insulation from each cable. Install an appropriate sized plug on one cable and a matching jack on the other. Connect and lock the plug into the jack and insulate with shrink tubing, flexible transparent tubing, or insulating tape. Triaxial cable repairs are conducted in a similar manner.

6.7 Connector Repairs

Connector repairs are determined by the extent of the connector damage and the availability of spare pins in the connector. If sufficient functional spare pins exist in a connector with broken pins, simply rewire broken pins into spare pins. If there are insufficient spare pins in the connector, simply splice the necessary wires around the connector using a jumper wire outside of the connector. Protect the splice with shrink tubing, flexible transparent tubing, or insulating tape.

In the case of a connector being damaged beyond use, cut away the damaged connector and prepare pigtails for replacement connector ensuring different lengths for staggered splices with the shortest pigtail being at least 6 inches/15 cm long. Solder, crimp, and pot pigtail wires as required into new connector and splice the pigtails to the existing wire bundle using one of the splice techniques discussed earlier in this section. Protect the splices with shrink tubing, flexible transparent tubing, or insulating tape.

7.0 CONCLUSION

USAF ABDR manuals outline a number of common system repair techniques, as discussed in this document. ABDR techniques are presented here for structural, mechanical system, fuel system, pneudraulic system, and electrical temporary repairs.

8.0 REFERENCES

This paper draws extensively the USAF ABDR technical manual, TO 1-1H-39, as well as my own personal experience. As such, there are no specific references annotated in the body of text for the reference below.

[1] United States Air Force. Technical Order 1-1H-39. *Aircraft Battle Damage Repair.*15 Sep 2002