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Original article

New challenges and technologies related to aircrafts' battle damages

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ABSTRACT

The authors of the article present the idea of the maintenance of aircrafts' battle damages. The aim of the paper is to discuss the issue of the field maintenance of aircrafts. The process of evaluating damages and recommendations regarding verification of airframe structure elements and its equipment damaged by an enemy's impact has been addressed. The paper demonstrates the changes in dealing with the issue of battle damages of aircrafts, which have occurred over the period of several decades. The new challenges faced by personnel servicing the modern aviation constructions in a contemporary battlefield have been subjected to the evaluation. Concepts regarding the new maintenance methods of an airframe construction of military aircrafts have been outlined.

KEYWORDS

battle damages, damages assessment, aircrafts damages maintenance

1. Introduction

During peacetime, the fact the military aircrafts will execute combat tasks in armed conflicts areas and will be exposed to damages caused by an enemy's impacts is often forgotten. Therefore, the aim of the present paper is to draw attention to the crucial problem that is maintenance of aircrafts' combat damages. Additionally, the article presents the authors' own observations and conclusions related to changes which should be implemented both in the training process of the personnel conducting the assessment and the maintenance of battle damages and the organizational and logistic issues associated with the question.

Aircraft Battle Damage Repair (ABDR) that is the maintenance of aircrafts' battle damages can play a significant role on the contemporary battlefield. The pace, quality and effectiveness of the repair is of crucial importance as far as the recreation of the technical and combat readiness of aircrafts is concerned. Bearing in mind the limited access to spare parts in combat conditions, the well-structured ABDR system is decisive in terms of the execution of air missions under those conditions. Restoration of 72%-airworthiness of damaged aircrafts within 24 hours [Bartholomeusz et al. 2002] during Yom Kippur War in 1973 constitutes an example of the effective application of the aircraft battle damage repair system by the Israeli Air Force. Battle damages are characterized by the unpredictability of the aircraft constructional elements, which can be destroyed or damaged. Figure 1 presents the pictures of the A-10 aircraft battle damages during the Iraqi War.

Fig. 1. Battle damages of A-10 aircraft during 'IRAQI FREEDOM' operation.
Source: Own study based on [2951st Combat…].

The modern military aircrafts are constructed in a way which assures their survivability rate as high as possible. The A-10 aircraft can serve as the example of a construction designed for achieving the best parameters within the combat sustainability. The aircraft is characterized by the constructional features that increase its survivability during execution of air missions at the theater of military operations [2951st Combat…]:

- mounting engines providing cover against ground fire,
- a titanium plate providing cover for a pilot against fractions and small arms fire,
- possibility to pilot an aircraft even in the case of losing pressure in the hydraulic system,
- a twin (double) rudder,
- two hydraulic systems,
- a reinforced wing framework,
- self-tightening fuel tanks.

For that reason, the complete destructions of aircrafts during the execution of combat missions are a mere 5% [2951st Combat…; Technical Order 1-1H-39 2014]. The airframe and, as the analysis show, particularly wings and flight control surfaces are the most significantly exposed to damages caused by small arms projectiles and missiles' fractions in military aviation. The airframes strength structures of contemporarily used military aircrafts and helicopters are designed in such a way that the direct hit by 20-30 mm caliber projectile does not cause damage to the aircraft strength structure. Therefore, most of damages occurring in combat conditions do not inflict catastrophe of an aircraft or a helicopter and can be repaired at an airbase or air component maintenance level.

2. Categories of an airframe structure

According to the regulations included in the corrective maintenance documentation of the US Air Force, the airframe structure is divided into 5 categories in order to facilitate the assessment of this type of repair by technical personnel, and they are as follows [MIL-PRF-87158B 1996]:

– Category No I – Primary Structure – it covers the airframe elements, which carry the main loads of the aircraft and are strictly necessary for maintaining the structural cohesion of the airframe. Usually, any damage to one of those elements triggers the damage of another element of the aircraft structure and results in losing the aircraft as a consequence. For the above reasons, the damages of those elements are subjected to the special strength and rigidity criteria. The following elements fall within this group: booms, frames, spars, ribs, torsion boxes, fabric covering carrying the loads and constructional elements carrying the loads between the remaining elements of the structure.
– Category No II – Secondary Structure – these are the elements of the structure which serve for transferring the loads on 'force' elements of the airframe. They include: less strained panels, intermediate ribs, longitudinal booms, bracings and other profiles.
– Category No III – Tertiary Structure – this category contains the elements which neither serve for carrying the loads nor are used to improve the aerodynamics of the airframe. The examples of them include: the aircraft's external hardpoint and pylons.
– Category No IV – Aerodynamic Components – the elements which do not influence the cohesion of the airframe structure but have the significant impact on aerodynamic parameters and flying qualities of the aircraft. The repairs of these elements rather consist in restoration of their aerodynamic shapes than in restoration of their strength and rigidity. The covers of radiolocation stations and pods are examples of such components.
– Category No V – Non-Reparable Using ABDR – the components of the structure which incorporate the mechanically treated or forged, including irregular shapes, ducts or angles complex elements. The accepted damages of these elements are limited to minor-size nicks, grooves or scratches in permitted spots which permit cleaning, polishing or possibly drilling in order to stop further cracking. Normally, they are subjected to the replacement.

3. Types and the characteristics of battle damages

The battle damages of the aircrafts in the US Air Force are divided according to the classes, which are used by the personnel conducting the assessment of damages. The personnel establish the maximal limits of damages in compliance with adopted criteria in order to schedule the scope and the type of maintenance or decide to postpone it. This permits to elastically schedule the maintenance during the execution of air missions [Technical Order 1-1H-39 2014].

– Class A Damage – Degraded Capability – the maximum damages which can remain unrepaired not affecting the execution of in types of combat tasks by the aircraft are identified;
– Class B Damages – Repairable Damage – the maximum damages which can be repaired with ABDR techniques and which enables restoring the aircraft FMC (Full Mission Capable) status are identified;
– Class C Damages – Acceptable Damage – are defined as the maximum damages, which can remain unrepaired and simultaneously the execution of the air missions is possible without limitations;
– Class E Damages – Engineering Disposition – the damages exciding Class B which require the engineering assessment by the aircraft's producer. Typically, these are the critical damages of the primary airframe structure.

The battle damages of the aircrafts are characterized by the fact that they are entirely distinct from those occurring during normal usage. Therefore, manufacturers' technical documentations do not incorporate the information regarding the technology of their repair. By virtue of the geometry and the character, battle damages are divided into types, which are addressed below [Lewitowicz and Kustron 2003].

3.1. Entry damages

In most cases of the battle damages caused by a projectile, the entry hole constitutes the first visible sign of the accident. This damage can appear in any external surface of the airframe such as: fabric covering, antennas covers, engine compartment or cabin glazing. The majority of entry damages triggered by single projectiles, result in appearing of the circular or oblong inlets. The shape of the inlet indicates the angle of the projectile impact. The retarded ammunition can additionally cause secondary damages, whose effects are similar to the damages caused by the ammunition that exploded during the strike. Then, the damages take the form of the extensive damage with various inlets of irregular shapes or one large of an irregular shape. The personnel evaluating the damages are obliged to inspect the area surrounding the inlet in order to assess the impacts of the destructive agent. Despite the visible damages in the form of the inlets, the effects of the use of combat means can also cause the bulges of the fabric covering, cut or damaged joints, delamination and dye penetrations of the external coat which can indicate acting of fire or high temperature.

3.2. Exit damages

A projectile striking an aircraft can also cause visible exit damages. The analysis of the damages demonstrates that not all damage will be associated with creation of the outlet. In some cases, the internal equipment of the airframe will rapidly decrease the velocity of a projectile, hence the exit hole will not occur, thus complicating determination of the projectile' trajectory and creating difficulties in assessing the damages. However, if an element of the projectile will pierce the airframe then the damages in the form of the hole appear which is of more oblong shape than the inlet due to distortions of the projectile and its circular motion. In such the case, the internal damages will be located close to the projectile trajectory. In the case of the bursting of the projectile, both various outlets and trajectories of fragments appear which can cause subsequent internal damages. In a situation when the damage is the effect of the internal explosion of a projectile, a significant number of small exit holes prompted by the projectile's fragments or the single large outlet caused by the explosion of the powder charge occur. This type of situations generates difficulties in internal damages defining due to the hundreds of possible trajectories of the projectile and the elements of airframe systems.

3.3. Internal damages

The internal systems of an aircraft are exposed to the impact of a destructive agent differently than the elements hit directly. Fragments and damaged elements of the equipment can cause collateral damages of electrical wiring, elements of the airframe systems and the wires themselves. The internal damages of the aircraft caused by the impact of a single projectile depend on the type of projectile, strike angle, projectile velocity and the type of hit component of the aircraft. Certain element of the airframe structure such as: casted basic mechanical elements, main airframe attachment points or some system joints can entirely stop the projectile while becoming destroyed or heavily deformed. The greater is the projectile striking velocity, the lower the probability of stopping the projectile and the greater probability of the ricochets and subsequent damages. Certain elements e.g. electrical wiring can stop the projectile or its fragments without leaving visible traces of damages.

3.4. Internal damages caused by explosion

Damages caused by the heavy explosion of the charge can take various forms: from bulges or minor damages caused by fragments to extremely broad deformations of the material with tears and punctures of the airframe. The main, the so-called force elements of the airframe's structure trigger ricochets of projectiles and fragments. The damaged elements of the equipment, owing the power of the explosion, can also cause additional damages. Contrary to single projectiles, the exploding ammunition can lead to damages in places theoretically not associated with the impact area of the penetration element. The electrical wirings that as result of the explosion are subject to deformation in the form of stretching and come to the original state hiding previously sustained damages constitute such the example. The influence of fuel located in fuel tanks can serve as an example of the secondary damage. The fuel as liquid can hydrodynamically force the walls of the tank causing its damage or the damage of internal systems of the tank despite the lack of visible traces of the projectile's impact. While analyzing the inlet and possible detonation area (symptoms of sooting and/or carbonization of the material) the original trajectory of the projectile can be identified. Other traces surrounding the entry point allow for determining the directions of fragments movement and consequently areas, which require additional inspections. The assessment of damages where fragments of the elements of the equipment puncture the structural components of the airframe such as ribs, spars and secondary fragments falling into the difficult-to-reach compartments of the airframe, triggers the significant number of problems. The evaluation of the damage can require removing additional panels or cutting-out a structural element of the airframe

3.5. Damages of joints

The strike of the projectile and its explosion can inflict the damages of rivet and glue joints of the airframe. In the majority of cases these kinds of damages will refer to the area of the direct contact of the projectile with the striking point. Occasionally, the vast 'cut' of the joints over the large surface is observed.

3.6. Dents and delamination

The structure of the airframe may be punctured by each type of projectile. Some of them may cause only dents and bulges of the fabric covering, iron ducts and collectors. In addition, the cracks are possible to appear in the area of the influence of a projectile or detonation ammunition. Their quantity can be assessed using the non-destructive research method.

Delamination occurs for composite materials or sandwich structures and consists in compartmentation of the cover from a core. Conducting the so-called 'tap test' that is tapping the cover with an iron hammer constitutes the simplest method of this damage verification. The area without the delamination will generate 'clean' metallic sound, whereas the delaminated area will generate the dead, low sound.

3.7. Damages caused by a flame or a high temperature

In most cases, the damages caused by a flame are characterized by appearing color changes of protective coats of individual components of an aircraft. It is possible to verify such damages by using the non-destructive research method including measurement of conductivity or hardness of the material. The short-term fire performance (less than 30 s) results in bubbles' appearing on protective surfaces and typically does not trigger critical changes in structural elements of the airframe, but can cause the damages of certain elements of the airframe's systems, which can be manifested by dye penetrations. The changes of the color constitute the symptoms of the oxidation process of the surfaces, which can serve for the assessment of the temperature affecting the particular surface. Normally, the protective coats are dye penetrated prior the material under them is significantly damaged. Table 1 presents the impact of the temperature on the color of the protective coats of the F-16 aircraft. Typically, aluminum and certain steels lose their mechanical properties under the influence of the long-term temperature exciding 300°C. Other materials such as corrosion resistant steel or titanium are characterized by higher residence to temperatures. Thereby, any dye penetrations require conducting the electrical conductivity or hardness tests to verify whether negative flaws in the tested element occurred.

Table 1. Colors of the protective coats affected by high temperatures

MMax. temp. [°C]	**Primer MIL-P-23377**	**White paint MIL-P-81352 MIL-P-23377**	**White polyurethane paint MIL-C-83286 MIL-P-23377**	**Light grey paint MIL-C-83286 MIL-P-23377**	**Mid-grey paint MIL-C-83286 MIL-P-23377**	**Dark grey paint MIL-C-83286 MIL-P-23377**
3149	Light dye penetrations	Light dye penetrations	White	Light grey or grey	Mid-grey	Dark grey
3176	Yellowish redish-brown	White-grey	White	Light grey	Mid-grey	Dark grey
4204	Redish-brown	Light white redish-brown	Broken white	Light darkening	Light dye penetrations	Light darkening
4232	Light brown	Light grey Redish-brown	Light Redish-brown	Light darkening	Mid-grey blue	Light darkening
5260	Mid-brown	Light redish-brown	Grey-green Redish-brown	Light grey	Mid-grey darkening	Light darkening
5287	Dark grey-brown	Mid-grey Redish-brown	Light brown	Light brown	Mid-brown-grey	Light dye penetrations
6315	Dark brown	Mid-brown-grey	Mid-brown	Mid-brown	Mid-brown-grey	Light dye penetrations
7371	–	–	Black	Black	Light brown-grey	Light dye penetrations

Source: Study based on [Technical Order 1-1H-39 2014].

Overheating constitutes another substantial issue. For example, the cadmium coats exposed to the temperature exciding 320°C melt and coagulate in the form of a drop on the cadmium surface. The other changes refer to e.g. a primer that despite the lack of the dye penetration caused by the temperature converts into powder and is easy-wear. Typically, this situation occurs in the temperature above 371°C.

In order to assess the degree of deterioration of mechanical properties of the material exposed to the fire or high temperature it is essential to conduct the electrical conductivity or hardness tests. Table 2 presents the exemplary values of the conductivity or hardness for the materials applied in the aviation. As for aluminum alloys, the result of the conductivity test should be comparable to the value of the undamaged element. The hardness measurement is much reliable while assessing the damaged elements.

Table 2. Change of the mechanical properties of the materials

Material	Maximum Ultimate tensile strength UTS [MPa]	Hardness [Rockwell]	Conductivity [% IACS]	Minimal Temperature affecting UTS [°C]
4130	689	86-93Rb	–	676
301-A	758	91-91Rb	–	1010
302-A	620	80-87Rb	–	1010
2024T3	441	62-72	38-40	196
2024T4, T42	427	51-72Rb	37-39	196
6061-T6	289	40-47Rb	41-45	182
7049-T73	455	50-48Rb	39-40	171

Source: Study based on [Technical Order 1-1H-39 2014].

When the temperature acting on the particular element accounts approximately 196°C, the strength and hardness can increase, but the corrosion resistance of the material deteriorates. The results of the hardness measurements significantly exciding data included in the table can manifest the decreased material plasticity and increased shortness.

While most of the elements of the airframe structure are covered with protective coats enabling the identification of the elements damaged by the high temperature, the elements of the airframe systems present lack of these features. The elements of the structure can 'resist' the increased temperature, whereas the components of the systems cannot. The rubber components of the installation that are carbonized or become frangible in the increased temperature constitute the example of the above-mentioned features. The high temperature can cause burnt, melt or increase the frangibility of the electrical wiring.

3.8. Damages of the cinematic elements

Conducting operational tests of individual systems can facilitate identification of the damaged components difficult to detect during visual inspections. For example: by conducting the verification of the aircraft's flight control surfaces the lack of the displacement of the surface with the relevant angle which can manifest e.g. the damage of the quill or the bearing in the steering system caused by the lack of the concentricity of certain elements can be detected. Therefore, the attention of the personnel conducting the operational tests of the particular elements of the aircraft should be drawn to any anomalies in functioning of the relevant cinematic elements, which can make the identification of damages.

4. Aircrafts' battle damages assessment

The assessment of the aircraft's battle damages covers also the evaluation criteria of the functionality of the airframe systems. Pursuant to the guidelines embedded in the maintenance documentation prevailing in the American operation system, the functionality level is divided in the following manner [Technical Order 1-1H-39 2014]:

- Full Capability (FC) / Essential (E) – appears when the essential component of the aircraft is absolutely necessary for the safe execution of a combat mission e.g. operative altimeters or on-board radio stations;
- Degraded Performance (DP) / Desirable (D) – occurs when the equipment of the aircraft which has the impact on the effectiveness of the execution of the combat task by is not essential for its fulfillment is damaged. They include: radiolocation stations, electronic warfare systems, etc.;
- Not required (NR) / Non-Essential (N) – appears when the equipment which is not required to conduct combat missions is damaged. However, occasionally, conducting the appropriate securing of them on the aircraft or electrical bypasses of the damaged system is required. The collision warning system constitutes such the example.

In order to conduct the adequate assessment of the scale of damages, the personnel involved in this activity must be able to diagnose the effects of the enemy's destructive agent. The analysis of the inlets and outlets enables identification of the type of projectile, which strikes the airplane. For example, if the entry and exit holes are of similar sizes and shapes, it can be assumed that the damage was caused by the armor-piercing projectile or by the blind projectile. However, when the single inlet is observed with the various smaller or a single large outlet the situation might have been caused by the ammunition containing the explosive charge that exploded inside the airframe structure. Small entry holes without the outlet can indicate the small projectiles of relatively low velocity. Any type of combat means will leave in the airframe structure visible traces of influence both on the metal and composite elements in the form of: splinters, scratches, breaches, jagged holes and delamination. The nature of the damage of both the structure and the airframe system can provide valuable suggestions. The personnel assessing the level of damages can use these traces for determination of both the trajectory of the projectile and secondary damages caused by the impact of the specific combat means. The element detached of the structure causing damages of the hydraulic system can serve as the example of such the activities. The traces of the projectile's burst allow for determining the areas, which require the verification from the perspective of the occurrence of possible additional damages. It is not recommended to conduct the assessment only within the movement path of the penetrator between the inlet and the outlet since the majority of combat agents are subjected to ricochets additionally destroying the elements inside the airframe [Holcomb 1994].

5. Conditions of conducting repairs in ABDR system

The battle damage appears when the entire or partial destruction of the aircraft, the crack, dent, deformation and material breaches of its systems, subsystems or parts of the aircraft caused by the impact of the combat means is observed [Lewitowicz and Żyluk 2009]. During the execution of combat missions, aircrafts are exposed to numerous types of damages among which only few lead to irreversible loss of such an aircraft. Taking into consideration the reason of the occurring, the damages can be divided into several categories:

– damages by a projectile – result in the occurrence of holes, structure decrements, splinters, breaches, grooves, cracks, fiber covering expansion and deformations,
– damages by the shock wave and high pressure – cause the deformation of the airframe' structure, locking of the parts, lack of centricity, displacements which lead to tearing the joints and the structure deformation,
– high temperature – the acute impact of the high temperature on the elements of the airframe structure can lead to attenuation of the material, especially aluminum alloys, and additionally cause fusions and burns of the material,
– secondary damages – appearing in the damaged and consequently loaded structure of the airframe, which cracks and deforms.

During armed conflicts, immediate repairs are crucial in order to maintain operational capability of the aircrafts engaged in the air missions or to relocate them to maintenance works in order to return them to technical and operational readiness. The ABDR system under consideration aims at restoring a damaged aircraft to its initial tensile strength with the application of the all the technological capacities available in the area of operation.

Decreasing the durability ratio of the construction constitutes the fundamental difference between conducting peacetime and ABDR system repairs. During peacetime, the durability ratio of the repaired element should be equal to the durability of the construction. Whereas the criteria formulated for the repairs of battle damages can be defined as follows [Bartholomeusz et al. 2002]:

– restoration of the initial durability for the period of 100 flight hours meaning that the repair is carried out with the static durability taken into account and the fatigue process and the issue of the durability of the repair is considered as less important question,
– the pace of the repair plays the role of a decisive factor,
– the repair technology should be relatively simple and feasible in the airbase conditions,
– the technological process is expected to be projectable with the use of simple analytical tools or intuitional computer system,
– materials applied for the repair must not lose their utility properties under the long-term storage conditions at room temperature,

- tools, materials and the maintenance equipment should be easily transportable and the possibility of delivering them to the aircraft should be granted,
- the ABDR system ought to be treated as the interim maintenance system and conducted repair must not cause subsequent secondary damages of the structure and should be realized in the way which enables quick dismounting of the repair block in order to conduct the permanent maintenance.

Depending on the type and the size of the damage, the repairs can be subdivided into several categories [Greenwell 2010]:

1. Full repair in the basing place conducted by the personnel of the airbase. This type of repair is feasible if the personnel of the engineering-aviation branch is capable of removing the damage with the use of the available technical documentation, spare parts, tools and the service equipment. The status of the aircraft after the repair – FMC Fully Mission Capable – i.e. airworthy without limitations.
2. Full repair in the basing place conducted by the personnel of maintenance works. The status of the aircraft FMC. This type of repair requires the personnel, maintenance equipment, tools and materials unavailable in the base and delivered to the damaged aircraft location.
3. Partial repair at the spot conducted by the specialized personnel. This type of repair is carried out by the personnel specializing in battle repair technology. The type of interim repair enabling rapid restoration of the aircraft to the PMC status (Partially Mission Capable), that is airworthy with the limitations. The maintenance allows for the execution of certain types of combat tasks e.g. dropping bombs only from the level flight or relocating to the nearest repair works.
4. Lack of the possibility to conduct the maintenance at the spot but with the ability to regain the aircraft with the use of the specialized experts. The aircraft is qualified to the above-mentioned category if the equipment, tools or maintenance facilities are not available at the place or the physical possibility of delivering them to the aircraft parking area does not exist. Typically, these are the aircrafts, which landed in the terrain site. In such a case, the partial dismounting of the aircraft is required in order to transport it to the repair location.
5. Lack of the possibility to conduct the maintenance or costs of the repair are economically unjustified. This situation occurs when the repair costs excide the value of the aircraft and when the aircraft sustained many severe damages requiring costly maintenance or a crucial element was damaged and its replacement or maintenance are uneconomic. The main longeron of the aircraft fuselage or the center wing constitutes the example of such the category.

The requirement for restoration of the initial endurance and utility properties for the defected aviation construction constitutes the basic criterion of the effective execution of the repair. Currently, when the aircrafts are used in a limited number during local conflicts, there is the additional requirement to certify the repairs (most frequently by the aviation authorities of the states which produce the aircraft or more seldom – operate it). To satisfy this criterion, the US Air Force adopted following solutions:

- repair of the damaged structure is thoroughly described in the maintenance documentation of the aircraft (e.g. Structural Repair Manual or Technical Manual Structural Repair F-16C and F-16D Aircraft) [To TRN1F-16CJ-3-4 2005], which was previously approved by the appropriate aviation authority – in the case of the United States – Federal Aviation Administration (FAA). Such the solution refers to the aircrafts whose repair efficiency (conducted strictly pursuant to the guidance incorporated in the maintenance documentation) of the selected elements was previously confirmed by the adequate research and whose operating data confirming the efficiency of repairs were collected. The cooperation between the United States Armed Forces and the Sandia National Laboratories in terms of the research projects related to the aviation structures repair efficiency constitutes the example of this kind of solution [Roach 1998]. The positive results obtained due to conducting this type of projects represent the basis for the repair certification by the Federal Aviation Administration (FAA):
- repair of the damaged structure is not embedded in the aircraft maintenance documentation whereas the repair was previously carried out on the aircraft and was accepted (certified) by the reliable authorities or repair commissions,
- repair of the damaged structure is not included in the maintenance documentation and was not previously conducted and approved by the appropriate aviation authorities. Conducting the repair in this situation depends on the type of damaged element of the aircraft (e.g. certain force elements of the airframe affecting its endurance are not subject to the repair) and the type and size of the damage. When the repair is executed outside the combat area the adequate aviation authorities or services validating such the repair approve the maintenance project and technology. In the case of repairs conducted in specific situations e.g. during combat operations, the maintenance must be accepted at the unit level by a qualified engineer,
- the last solution represents a specific challenge for the technical personnel operating the aircrafts in specific conditions. In such case the qualifications of the group conducting the repair and the experience of the personnel projecting the repair is important. General recommendations related to the repair of the damaged structure in the field conditions include the guidance regarding the possibility of conducting the repair conditioned by the reduction of the coefficient of damaged element operability to the level not exciding 1-2 [Joint Airworthiness… 1994].

6. New technological challenges in ABDR system

The modern construction of the airframes of military aircrafts based on light and high-strength materials combined with the sophisticated avionic equipment and aircraft flight control systems of fly-by-wire type have radically increased the level of complexity of the new generation airplanes. For this reason, it is necessary to change the battle repair procedures and technologies concerning aircrafts. For example, the construction of the F-16 aircrafts (Fig. 2) and the materials used for their manufacture enable obtaining the light and strength construction of the airframe. The airplane's fuselage is covered with the metal fabric covering which is braced with frames and longerons. The main longerons, spars and booms are made as integral during the mechanical treatment process. The aircraft's flight control surfaces, leading and trailing edges, a rudder and an elevator, flaperons, fences and aerodynamic covers are made of composite materials such as: e.g. graphite-epoxide.

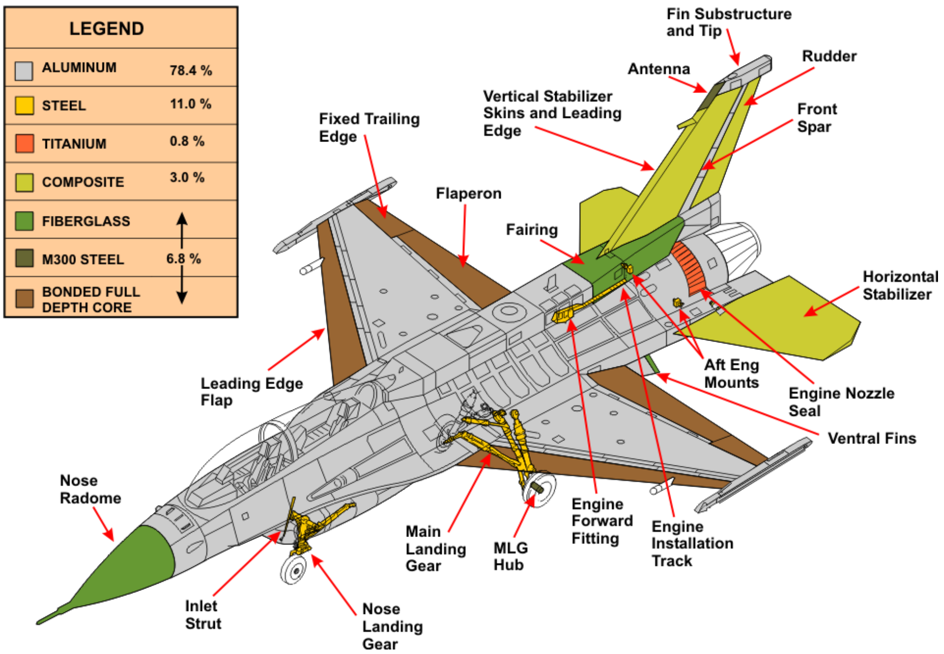

Fig. 2. Materials used for the production of F-16 aircraft
Source: Own study.

Currently, the conventional ABDR idea is based on the usage of metal patches mounted to the airframe with mechanical joints. However, this type of repair results in the necessity of additional weakening of the material by the supplementary number of holes for mechanical joints. Frequently, the element is entirely damaged during the repair process. What is more, the above-mentioned activity prevents conducting permanent repair at a later point as the material is damaged to such extent that the replacement of the defected structure is required. By contrast, the glued composite patches enable repairs not causing collateral damages, as the additional holes for the mechanical joints are not required. Moreover, the possibility of conducting repairs with the use of metal patches is limited to flat surfaces due to the difficulties appearing during the forming process of them. The composite materials are relatively easy to form which allows for their application for the complex shapes of the aircraft surfaces. In this regard, the repairs based on the use of the metal patches mechanically mounted to the elements of the airframe are insufficient. Apart form the additional holes, which are to be made in already weakened construction the quality of the repair is relatively low due to the poor strengthening of the damaged structure. In addition, the repair of the airframe's structure with complex shapes can be complicated or even unfeasible in the field conditions due the lack of adequate workshop equipment for precise forming of the metal patches. Hence, the repairs with the application of composite materials and glue joints (adhesive) have been increasingly used.

However, repairs with the use of the composite materials require changes in the organizational and logistic system. It is necessary to have at the disposal the appropriate logistic and technical potential enabling this type of repairs. Conducting the repair necessitates possessing at a base the specialized equipment such as: a stand and a device for performing a glue joint, equipment for precise connection of adhered components, working machines, vacuum pumps, furnaces and heating mats. The personnel should be equipped with the personal protective kits enabling work with the dangerous materials. The access to a clean room with the controlled temperature and humidity, with the adequate power supply and the compressed air is essential. The materials vital for conducting the repair, such as polymer pre-pregs, glues, cellular fillers, vacuum bags and sealants, have to be stored in low temperatures. Certain glues and composites require being stored in airtight containers and in the temperature of -18°C in order to maintain the period of validity and properties. The access to the comprehensive technical and logistic resources determines the pace and the quality of the necessary repairs.

Conclusions

Both currently operated and future generations' aircrafts necessitate the works on the development of technologies and procedures regarding the repairs of battle damages. The lack of capabilities to conduct adequate repairs by the personnel of an airbase during the execution of air missions at the theater of operation will shortly lead to the insufficient number of available aircrafts and consequently to the loss of operational capabilities of a given air component.

Reassuming the aforementioned considerations, it is to be stated that in order to assure the continuity of the execution of air missions in the area of engagement providing the efficient system of conducting the battle repairs of the aircrafts is of the significant importance. To achieve this, resolving numerous issues seem to be essential. Creation of the appropriate organizational structures that facilitate the fulfillment of field repairs is indispensable. The US Air Force established the special teams ("Combat Logistics Support Squadrons and ABDR Engineers") consisting of the engineering-aviation personnel trained to conduct field repairs of the aircrafts operated by the USAF. The lack of the training system for the engineering-aviation personnel related to field repairs and consequently the lack of the trained personnel able to assess the damages, engineers validating the proposed repairs and the experts carrying out the necessary maintenance activities constitute the further problem. The shortage of the technical documentation enabling the selection and execution of the adequate repairs creates the consecutive issues. Nevertheless, gaining the required logistic potential is to be perceived as the most serious and crucial issue. Shortage in appropriate workshop equipment, tools, disposable materials, modern composite-repair structures and the necessary maintenance resources can determinate the combat potential of an air component at a theater of operation.

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Author contributions

All authors contributed to the interpretation of results and writing of the paper. All authors read and approved the final manuscript.

Ethical statement

The research complies with all national and international ethical requirements.

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