Engine and Wiring BDAR Experience and Continued Airworthiness Processes and Tools

Mr. Kevin Rotenberger
Aviation Engineering Directorate (AED)
Redstone Arsenal, AL USA

Kevin.rotenberger@us.army.mil

ABSTRACT

The Aviation Engineering Directorate (AED) is the Army Airworthiness Authority for all US Army rotary and fixed wing assets. Assessing damage to aircraft in the field and making appropriate decisions on the reparability, making repairs at the lowest repair level possible and evaluating airworthiness of subsequent repairs is critical to the US Army maintaining its force projection capability. This paper will examine the experience of engines and wiring systems as part of Battle Damage Assessment and Repair program. The paper will also examine current processes and procedures for Battle Damage Assessment (BDA) including BDA tools recently developed. The paper will describe and analyze the echeloned approach of battle damage assessments employed including embedded field maintenance engineers, centralized functional expertise and depot capability at RESET locations. The paper will also describe the processes for assuring airworthiness throughout the repair process. The paper will use examples of aircraft damage from OIF and OEF in describing the practices and procedures for conducting BDAR assessments and repair. The BDA assessments will encompass primary aircraft structure, secondary structure, engines and electrical wiring system. Design tools have been developed that allow for quick assessment of field damage by analyzing vulnerable regions of the aircraft in advance with damage limits and repair concepts defined for typical damages. That design tool will be explained and examples provided where efficient BDA and repairs have been affected.

1.0 INTRODUCTION

Airworthiness is a fundamental element of the design, production and maintenance of all air vehicles flown in the US Army. Dealing with the effects of battle damage on aircraft in the field is afforded the same rigorous airworthiness process for the determination of repairs and service duration of those repairs. This paper will overview the airworthiness process, identify the unique features of airworthiness for battle damage and how it is implemented in the US Army and provide some process and technology advancements that are aiding the safe and effective maintaining of aircraft in theatre.

2.0 AIRWORTHINESS PROCESS

In the US Army, the airworthiness of aircraft and helicopters is a program conducted independently from both the war fighters and the material developer of the aircraft system. That independence necessarily separates the missions and functions of war fighter operations, material acquisition and airworthiness certification. The process is applicable to all life cycle stages of an aircraft program including design, production and fielding. Assessing and repairing battle damage on aircraft is clearly an airworthiness concern as part of the continuing airworthiness phase of any aircraft program.

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14. ABSTRACT

The Aviation Engineering Directorate (AED) is the Army Airworthiness Authority for all US Army rotary and fixed wing assets. Assessing damage to aircraft in the field and making appropriate decisions on the reparability, making repairs at the lowest repair level possible and evaluating airworthiness of subsequent repairs is critical to the US Army maintaining its force projection capability. This paper will examine the experience of engines and wiring systems as part of Battle Damage Assessment and Repair program. The paper will also examine current processes and procedures for Battle Damage Assessment (BDA) including BDA tools recently developed. The paper will describe and analyze the echeloned approach of battle damage assessments employed including embedded field maintenance engineers, centralized functional expertise and depot capability at RESET locations. The paper will also describe the processes for assuring airworthiness throughout the repair process. The paper will use examples of aircraft damage from OIF and OEF in describing the practices and procedures for conducting BDAR assessments and repair. The BDA assessments will encompass primary aircraft structure, secondary structure, engines and electrical wiring system. Design tools have been developed that allow for quick assessment of field damage by analyzing vulnerable regions of the aircraft in advance with damage limits and repair concepts defined for typical damages. That design tool will be explained and examples provided where efficient BDA and repairs have been affected.

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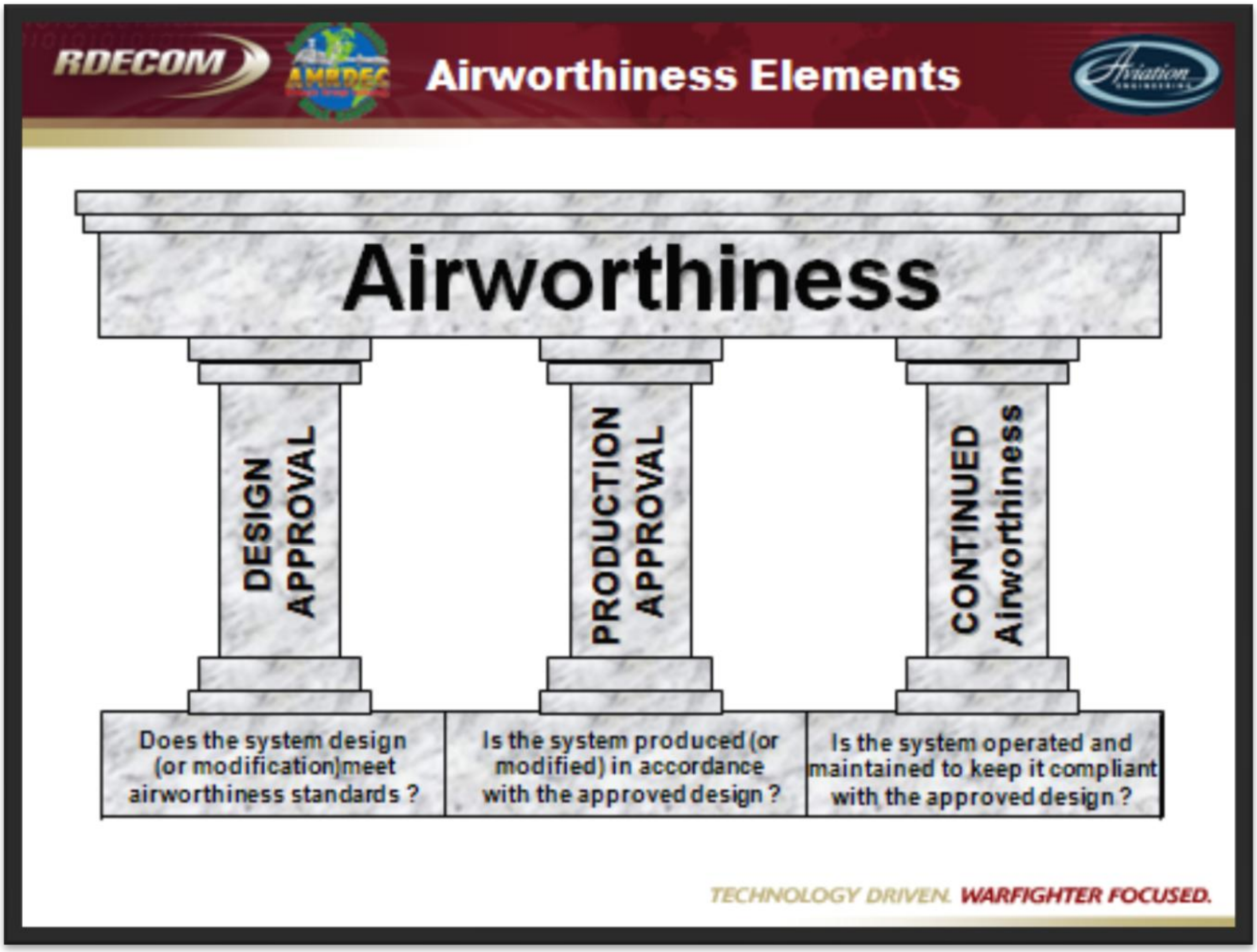

Figure 1: Airworthiness elements

2.1 Airworthiness: A Definition

The broad definition of airworthiness in the US Army is a demonstrated capability of an aircraft to perform its intended functions within prescribed limits. The three key phrases in this definition are “demonstrated”, “intended functions” and “within prescribed limits”. The demonstrated capability is a common requirement regardless of the phase of the program. It applies equally to development aircraft type certification, continued airworthiness during service use, maintenance of the systems and aircraft damage assessments. The airworthiness program is a data driven process that requires sufficient analysis, test, demonstration or inspection data to substantiate the airworthiness of the intended certification function. It is the data driven process that makes the program robust and repeatable and produces accurate results. The other two elements of the program, within prescribed limits and perform its intended function, are more variables in the dynamic environment of aircraft battle damage assessment. The type and severities of the damage encountered in wartime operations span the spectrum and not all damage can be repair to full capability condition. Another variable in battle damage assessment is the criticality of the assets to the mission and the time and schedule for replacement of the damaged asset. These entire variables are in the trade space of the military service commanders in determining the actions to be taken on damaged aircraft. Elements of the airworthiness process are also variables in that process. The intended function of the repair aircraft may be acceptably reduced and the airworthiness assessment would be conducted to the reduced capability level. An example of that would be the desire to repair the asset only to the extent that the asset can be returned to a depot facility out of theatre for further repairs. The functional capability of the damaged system may be consciously reduced to keep the asset in service. Many times repair are made knowing the long term durability of the repair is lacking yet that reduced capability provides a necessary capability to the commander. Again the airworthiness evaluations would be conducted to that reduced set of functional capability.

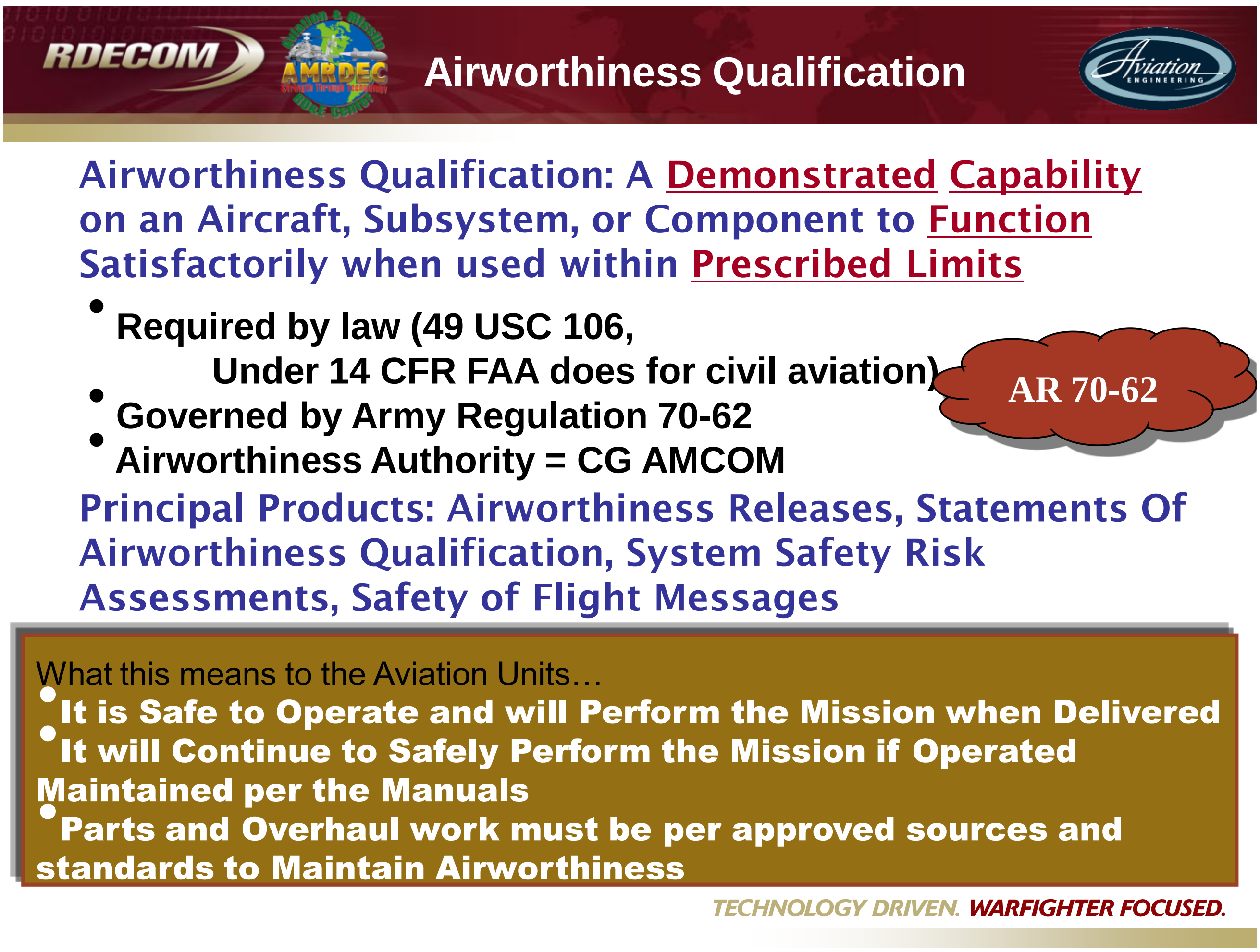

Figure 2: Airworthiness Definition

2.1 The Airworthiness Process

In the US Army, a centralized independent organization administers airworthiness assessments of all fielded aviation assets in the fleet. That organization is the Aviation Engineering Directorate based in Huntsville Alabama in the same location as the acquisition and program managers of the aircraft fleets. The organization contains all analysis and simulation capability necessary to assess the broad array of flight sciences with functional expertise in structures, materials, aeromechanics, dynamics, aircraft performance, mass properties, electronics, electromagnetic's, man-machine interface, propulsion, drive systems, hydraulics, pneumatics, and software. Also based in the Huntsville is the Army Aviation test capability which is leveraged for test determination of airworthiness or for the generation of airworthiness test data for functional engineer's assessment.

2.1.1 Organizational Construct

The AED has an organizational construct that provides both aircraft systems level expertise and detailed functional area expertise. As you can see in the organizational diagram in Figure 1, the organization is divided in two distinct elements, along air vehicle platforms on the left side of the organization and along functional expertise areas on the right side of the organization. The system support part of the organization provides direct program office support and coordination of all airworthiness activities in support of each aircraft system. They provide expertise in the specific aircraft systems and lead the systems engineering trade space and system integration functions for each specific aircraft. The functional experts provide detailed assessments and evaluations in specific functional expertise areas. The functional engineers have the technical authority over there functional expertise. The systems engineers are the integrating function for all airworthiness matters for all issues on a given aircraft system. When it comes to airworthiness support to field problems such as battle damage, another critical element of the airworthiness construct is introduced, that is the field liaison engineer. Each aviation battalion in the US Army has an AED field liaison engineer embedded in the organization. The principal function of this position is to provide boots on the ground maintenance engineering expertise to provide assessments and authorizations for repairs or modifications to aircraft that are not authorized in documented aircraft maintenance procedures. These individuals are the airworthiness eyes and ears in the field and are the first line of support to commanders in the field dealing with real world aircraft damage and repair issues. These liaison engineers are empowered to support the field with on the spot repair authorizations for anything he is capable of assessing himself. The efficiencies of this construct are clear and obvious. For any repair authorization beyond the individual capability of the specific liaison field engineer, he has reach back capability to the full depth and breadth of the capabilities of the central AED expertise in Huntsville. This organizational construct has proven to be invaluable to the efficient and effective repair of damaged aircraft and maintaining continued airworthiness for aircraft throughout their fielded life.

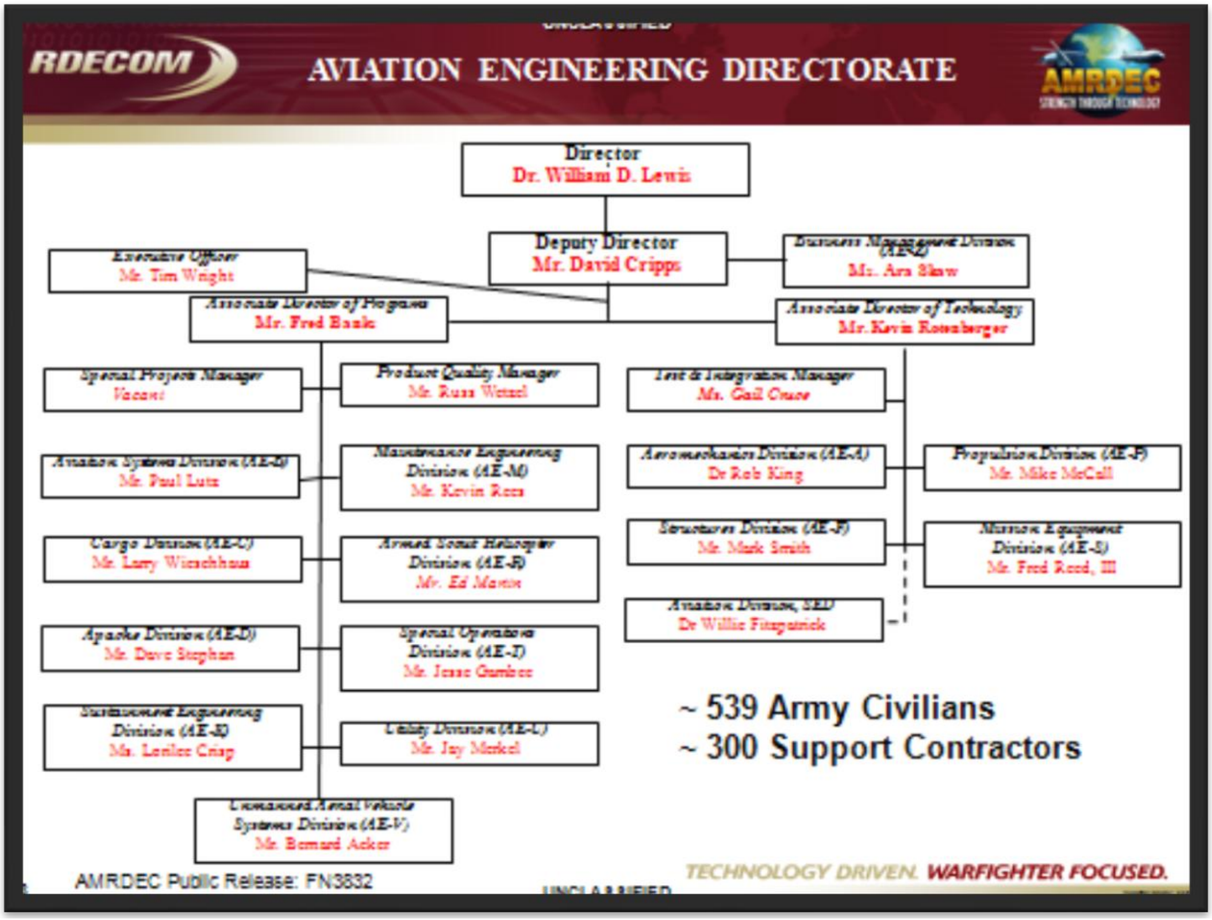

Figure 3: AED Organizational Diagram

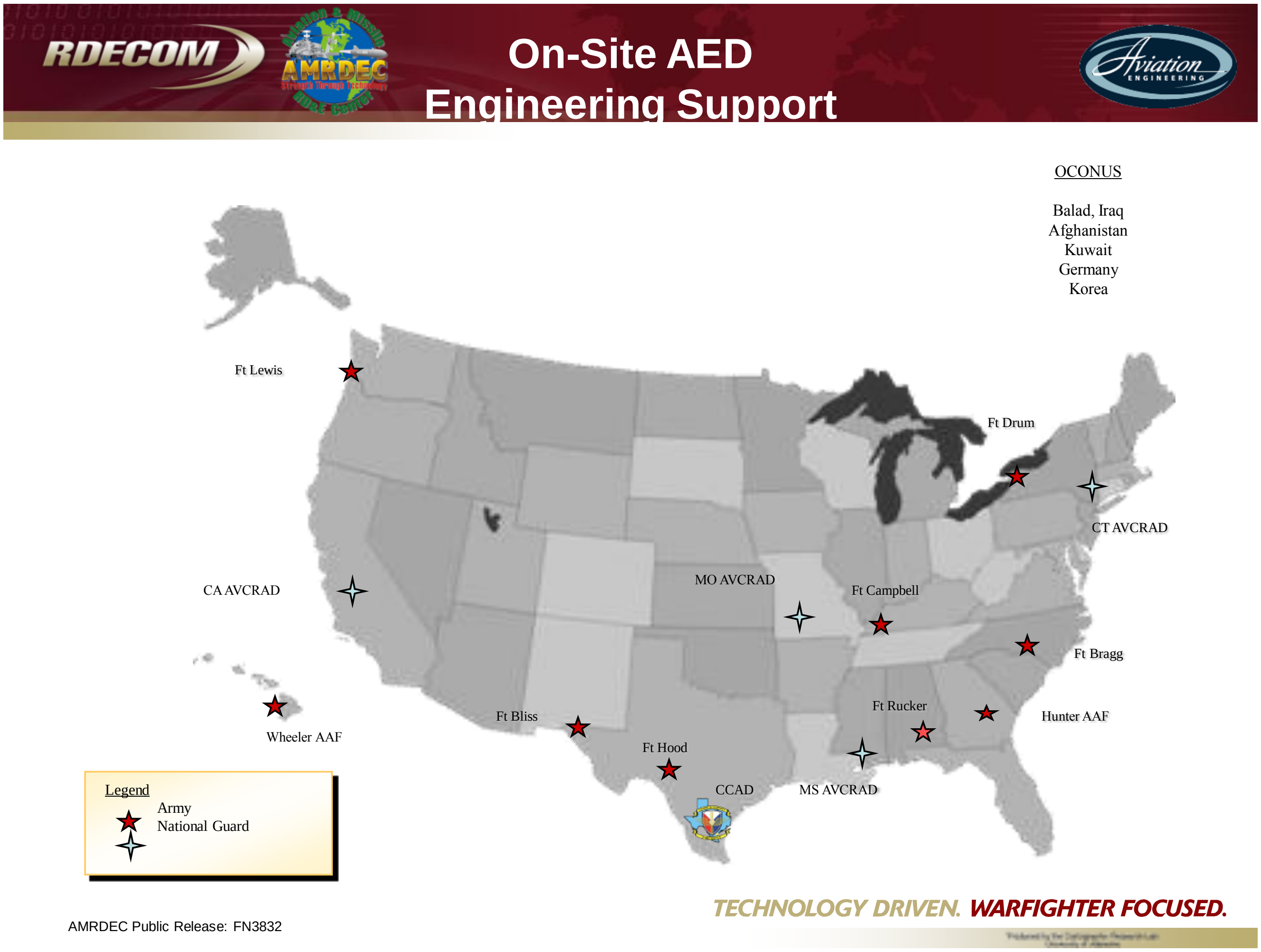

Figure 4: AED Liaison Engineering Locations

2.1.2 Metrics of Success

The recording mechanism for all actions taken to authorize maintenance outside the established procedure are Maintenance Engineering Calls (MEC's) As you can see in Table 1, the number of MEC's written in support of deployed forces have risen dramatically since 2003 in support of both OIF and OEF. The field MEC's would represent all maintenance calls made at non-deployed base location both CONUS and OCOCUS. This also shows a dramatic increase in field engineering calls. This construct of embedded field engineers has evolved and grew during the period and once included only select CONUS locations with large aircraft populations. We have been building the construct since 2003 and now have field engineer positions in every Combat Aviation Brigade. The program is a key enabler of responsive battle damage assessments of all fielded aircraft.

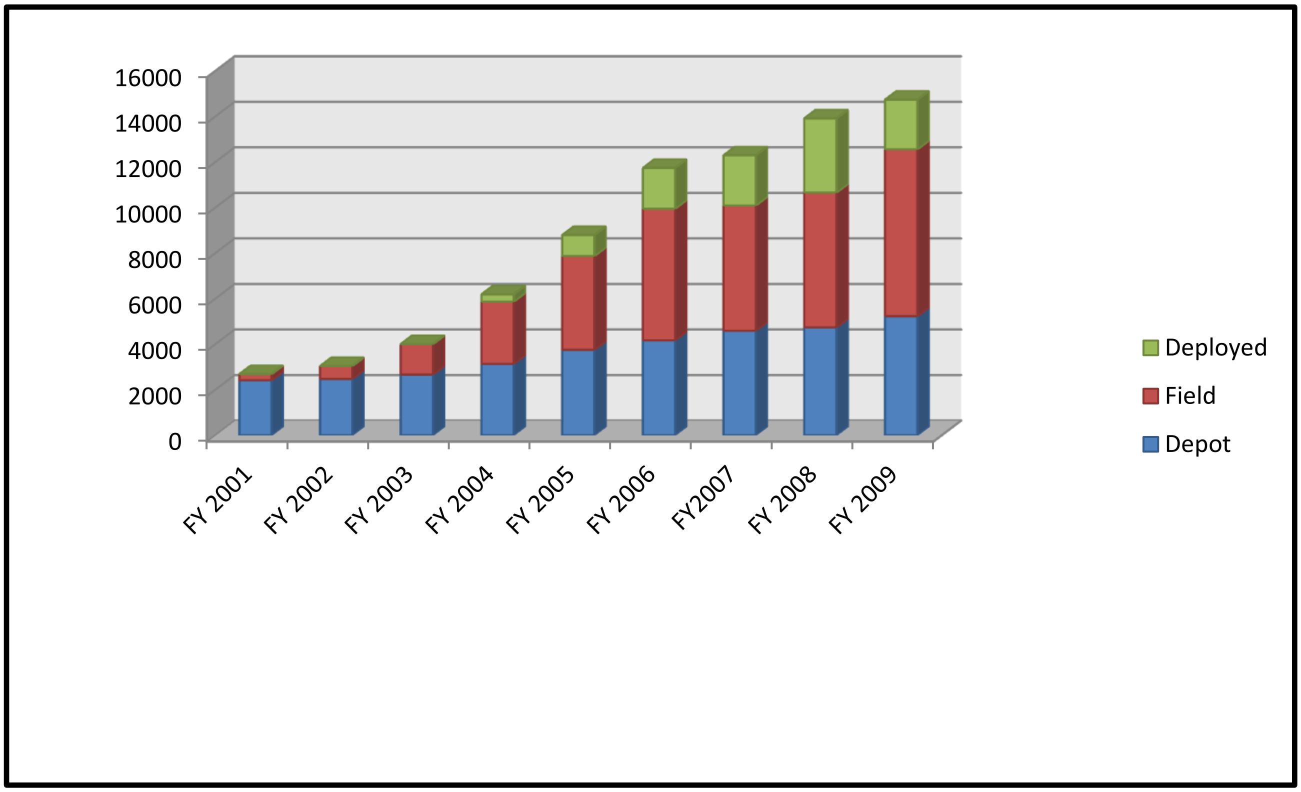

Figure 5: MEC Rates: The Metric of Success

3.0 ENGINE BDAR EXPERIENCE

Battle Damage impacts to engine systems are significant from the OIF/OEF theatres of operation. However, Battle Damage repairs to engines or significant components repairs are very limited in a theatre due to the modular design nature of most modern turbine engines. The T700 family of engines is used on AH-64's and UH-60's and is a modular design engine. The field maintenance is is primarily troubleshooting that leads to removal and replacement of modules of the engine and returned to DEPOT for repair. The T55 engine is an older design with less built in modularity but the unit level maintenance is still troubleshooting problems and remove and replace engines if not repairable. Other engines like the 250-C30 used on OH-58's are contractor maintenance and logistic support above unit level and engines are removed and replaced in theatre for faults or lack of power. The US Army has a DEPOT forward engine repair capability to conduct some engine repairs in Kuwait through the AVCRAD. At the AVCRAD they generally have Flexible Engine Diagnostic Systems (FEDS) or Mobile Engine Test Stands (METS) that allow for DEPOT level repair and dynamic balancing of the engine.

The environments that engines are operated at in the current theatres are characterized by heat, sand, and dust. All these environmental factors contribute negatively to engine on-wing performance. As seen from the engineering review board data for the T700 engine in Figure 6, the single largest cause of engine returns is low power or torque. The principal causal factor for engines returned for low power is directly or secondarily related to erosion. The direct effects of sand erosion can be seen in the components such as compressor blades, power turbine nozzles, and gas generator blades. There are also secondary effects from operations in sand environment that effect engine performance. The most significant of these is interrupted cooling processes in the engine. The effects of plugged cooling passages result in blade creep, fatigue, blade buckling, burns and oxidation. The most prominent result of these problems is inability to produce power resulting in engine removal and return to depot for repair. There are also potential for non-benign failure modes to develop as a result of cooling interruption such as blade fatigue failures that would result in in-flight engine failures and potential catastrophic results. Examples of engine erosion and cooling problems are illustrated in Figures 7and 8.

The overall effect of the conditions in the current theatres of operations can be directly measured by on-wing engine time. Figure 9 shows the data for T700, T55 and 250C30 engines comparing CONUS vs. OIF/OEF engine on-wing time. The comparison shows great disparity on the T700 performance and no effect at all on the 250 engine series used on the OH-58 aircraft. The T55 engine used on the CH-47 shows an impact of on-wing time but not as dramatic as the T700. There may be factors influencing this data. One difference in the various engines is the dust filtration systems. The T700 series engine has an integral Inlet Particle Separator (IPS) were the 250C30 engine has a inlet barrier filter system. It may be that the barrier filter is much more effective at eliminating sand and dust and the resultant erosion and power loss problems. Equally as probable a factor is that logistics support arrangement in place. The 250C30 engine has in-country contractor logistics support where as the T700 is logistically supported through the US Army logistics system. There may be an attempt by Rolls Royce to provide greater repair support to the 250C30 in theatre as opposed to sending the engine back to Depot for repair.

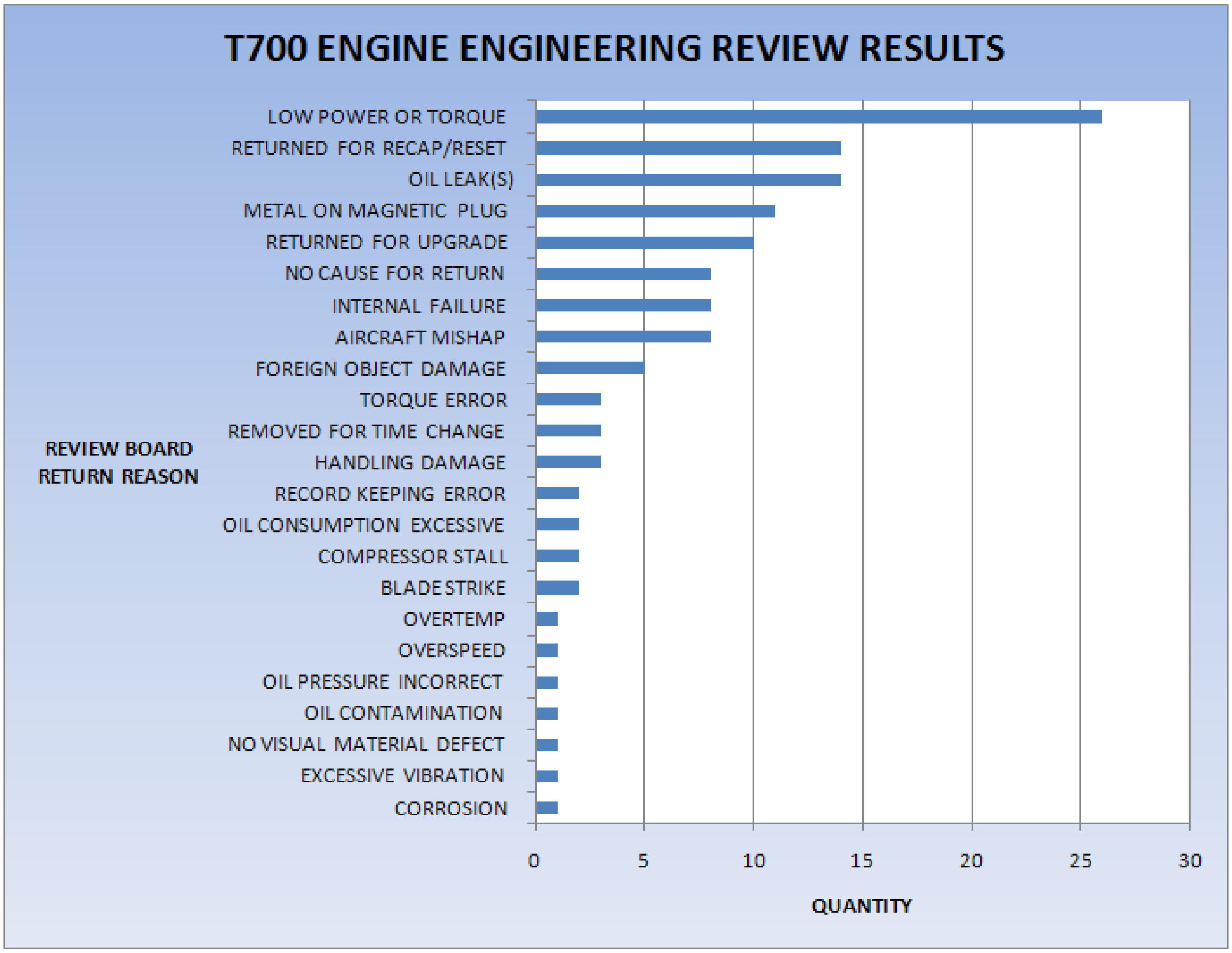

Figure 6: T700 Reason for Return

Figure 7: Erosion on T700 1st Stage Blisk

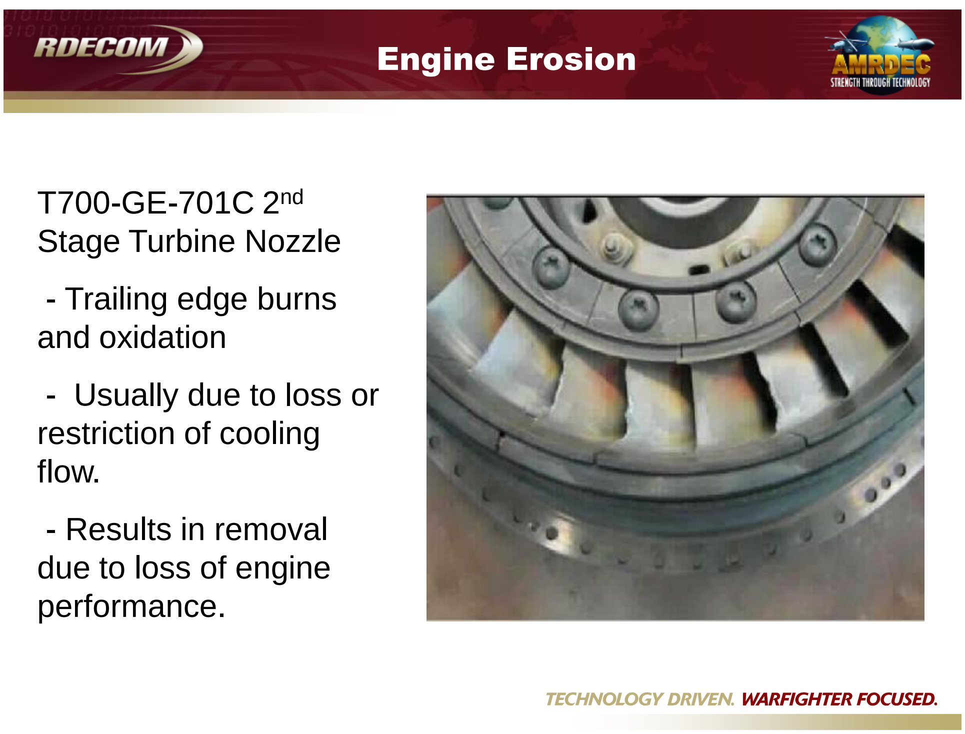

Figure 8: Erosion on T700 2nd Stage Nozzel

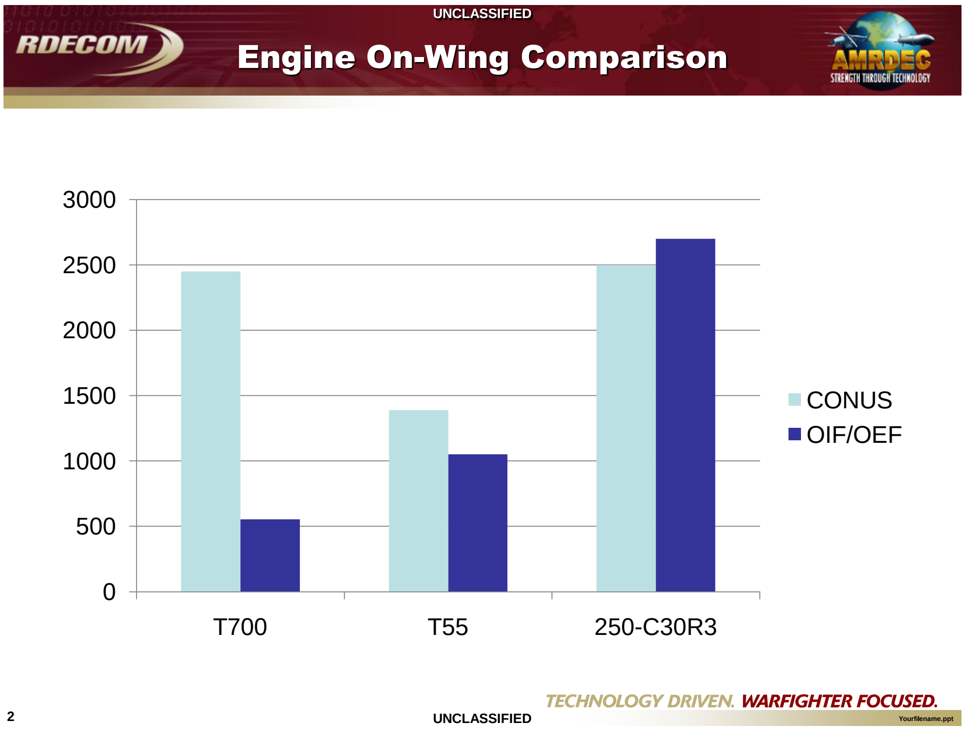

Figure 9: ENGINE ON WING TIME COMPARISION oif/oef VS CONUS

4.0 DESIGN PRACTICES FOR BDAR REPAIRS OF WIRING

Repair of electrical wiring and cables associated with rotary wing aircraft systems and subsystems is a major BDAR problem for timely aircraft return to action or evacuation from the battlefield. Aircraft designers and manufacturers generally group large numbers of wires together in a “bundle” to run together though common places in the airframe. This process makes the wiring practice simpler and provides added strength of the wires surrounding each other. The use of wiring bundles can make both BDAR and normal operational repairs difficult, tedious, and time consuming, especially to a damaged wiring bundle from combat.

4.1 Current Electrical and Wiring BDAR Procedures in Effect

When aircraft, rotary wing or fixed wing, receives battle damage, the repairs on the wiring and electrical systems can be some of the most time consuming and meticulous work. Couple damage with the battlefield environment and the repair task becomes difficult if not impossible to execute. With dozens to even hundreds of severed wires to repair, the matching process of which wire connects to which can be extremely lengthy and laborious. The difficulty is magnified when one or more wiring harnesses sustain damage. It is even more of a problem with inadequate or improperly labelled wires and cables. Figure 10 shows the adverse effects of improper or inadequate wire labelling and identification. Additional complications can arise when dealing with “shielded” or Electro-Magnetic Interference (EMI) protected wires and cables.

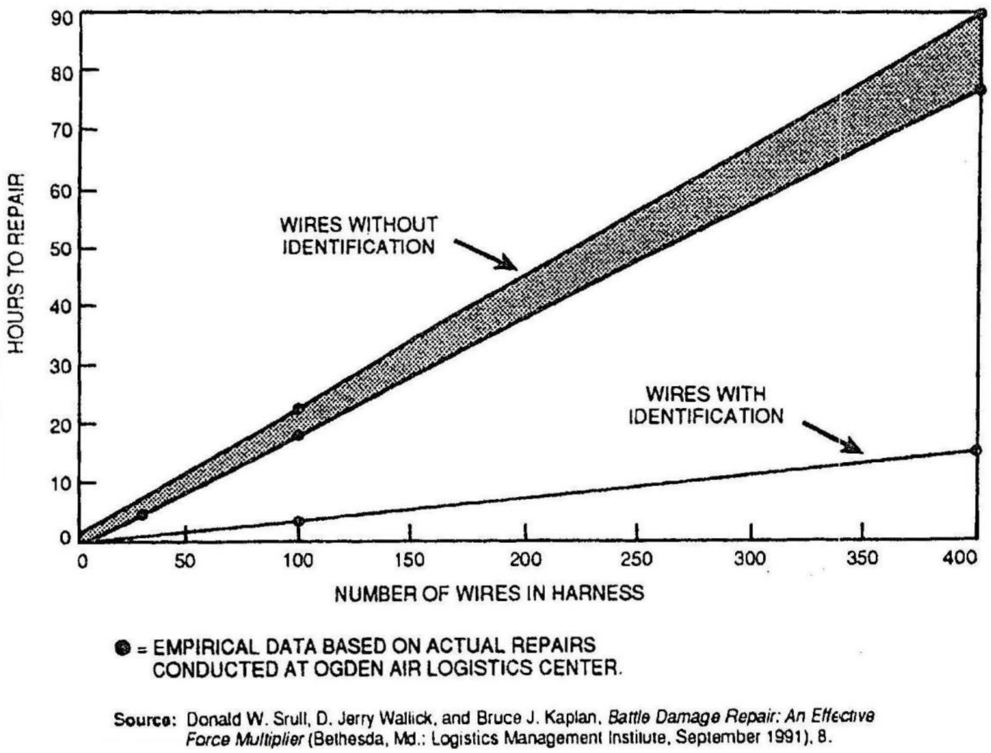

Figure 10: Repair Time of Identified vs. Unidentified Wires

The shielding may not be available, for BDAR repairs, or due to rerouting, impossible to install. As a general rule of thumb, the BDAR assessment must quickly identify whether to repair a wire or cable, replace the wire or cable, or replace the harness as a whole. Magnify that when a whole bundle is damaged. Figure 11 shows BDAR on and AH-64D Longbow Apache where a wire bundle was damaged and repair wires were rerouted.

Figure 11: AH-64 Apache Electrical BDAR Damage and Repair

4.2 Recommendations for Improved Electrical and Wiring BDAR

Due to the intricate nature of wiring, quick, effective and timely BDAR is difficult at best. Rotary wing aircraft have thousands of wires running throughout all areas of the airframe, some vital and critical, some non-essential and superfluous. There are many ways to improve the wiring in helicopters to facilitate not only BDAR but less time critical repairs as well. Such standardizations and recommendations include:

- Procure and supply the BDAR field units with assessment tools that have the ability to rapidly identify individual wires/cables by systems affected and wire number.
- Color code wires/cables to identify critical, essential and non-essential systems.
- Standardize and improve wire/wire bundle/cable marking in all aircraft.
- Improve the current BDAR kits with the ability to splice wire bundles.
- Develop and implement splices for highly sensitive data bus wires.
- Use fiber optics to reduce weight and protect against EMI.

5.0 ADVANCED TOOLS

The dynamic nature and unpredictability of battle damage makes it difficult to plan in advance for support and conduct airworthiness assessments. Most damage events are specific with unique location information and require specific detailed analysis. However, some pre-analysis and prepositioning can be done to aid and shorten the response time of assessments. This paper will examine two of the preplanning tools and kits that have been developed.

5.1 BDAR Kits

During the early timeframe of OIF, it was recognized that standard repair kits were lacking for field maintainers to deal with typical damage to the current fleet of aircraft. A quick reaction kitting was developed, filled and deployed to all maintenance companies. The Kit contents are shown in Figure 12. One of the significant problems with battle damage on modern aircraft is severed wire. As aircraft continue to evolve to be more electronic aircraft, the repair of wire bundles and connectors becomes a significant activity for battle damaged aircraft. Another element in the kit is fuel cell repair material. Modern fuel cells are difficult to repair in the field due to the self-sealing features of the cell. Most repairs cannot restore the self sealing capability but field repairs are possible with the reduced functional capability of the system.

Battle Damage Assessment and Repair System (BDAR)

DESCRIPTION:
Transportable and expeditious means to assess combat damage, defer repair, and /or repair Army helicopters in a battlefield Environment.

BLOCK I: (Fielding complete)
- (1) Electrical Main Kit
- (3) Electrical Consumables Kits
- (1) Electrical Heat Gun Kit
- (2) Fuel Cell/Skin Repair Kits
- (1) Borescope Kit
- (1) Low Pressure Fluid Line Kit
- (1) High Pressure Fluid Line Swaging Tool Kit
- (1) High Pressure Fluid Line Swaging consumable Kit

BLOCK II:
Composite Repair (In development)

BASIS OF ISSUE (BOI)	
AMC	One (1) set per flight company supported
ASC	Two (2) sets per
AVCRAD	One (1) per
Total	380

Figure 12: BDAR Kit

5.2 DENT Program

Another tool that has been developed to aid in rapid response of battle damage assessments is the Damage Evaluation and Notification Tool (DENT) on the AH-64 Apache. DENT is a product developed by Boeing for the Army that models the airframe structure of the Apache and allows for concise identification of damage identification, automated reporting procedures, linkages to automated analysis tools and an archiving of all damage events and disposition instructions. This tool greatly enhances and speeds the process of defining necessary fixes to field with precise airworthiness definition of the repair. Below, the paper examines the core elements of the DENT Program.

5.1.1 DENT Reporting Tool

The DENT reporting tool is a laptop based tool resident with the Aviation unit maintainer. It allows for concise definition of damage location and severity. It has a drilldown Graphic User Interface that provides models of the sectional properties of all structural members. As you see in Figures 13-15, you drill down in a menu until you identify the specific damage on exact detail structural members. The reporting system allows you to interactively highlight damaged areas on pre-modeled sectional views as seen in Figure 16. The maintainer interface allows for text input to describe the damage and photograph upload to capability for further clarity. The reporting tool also has all the automated features for storage, disposition request and progress tracking. The reporting tool also incorporates dynamic storage with search and sort capability for future analyses and comparisons.

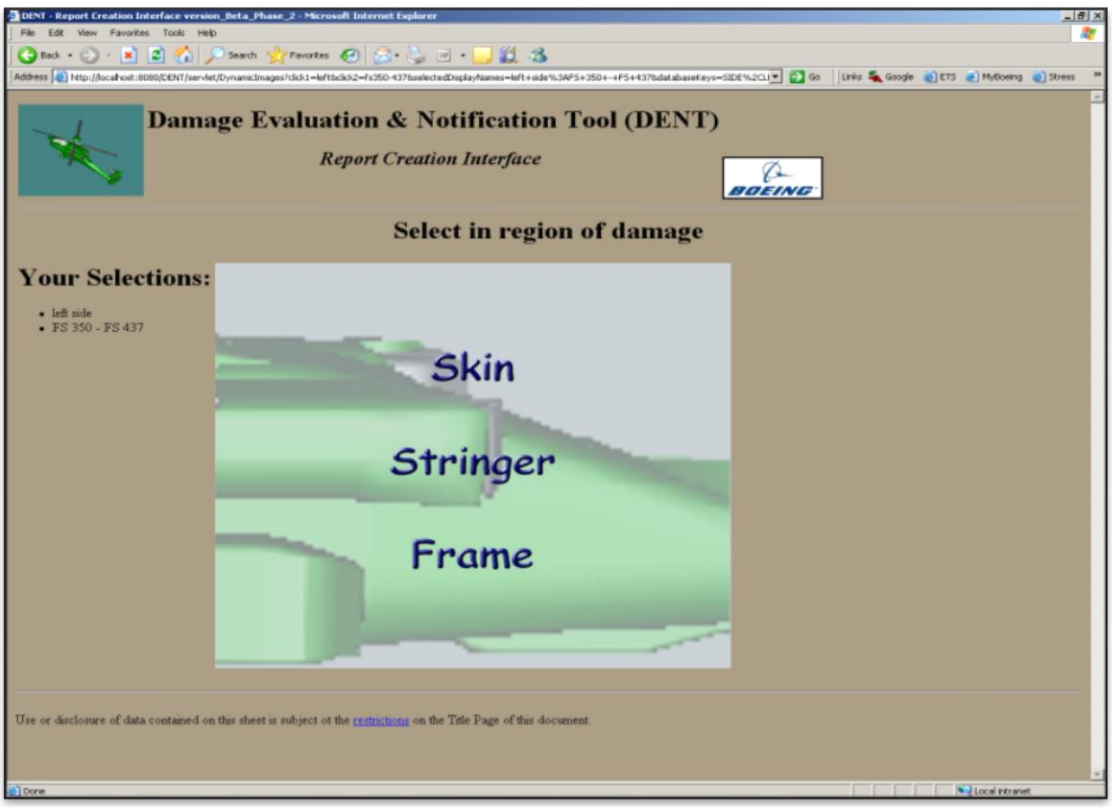

Figure 13: Identification that a frame is damaged

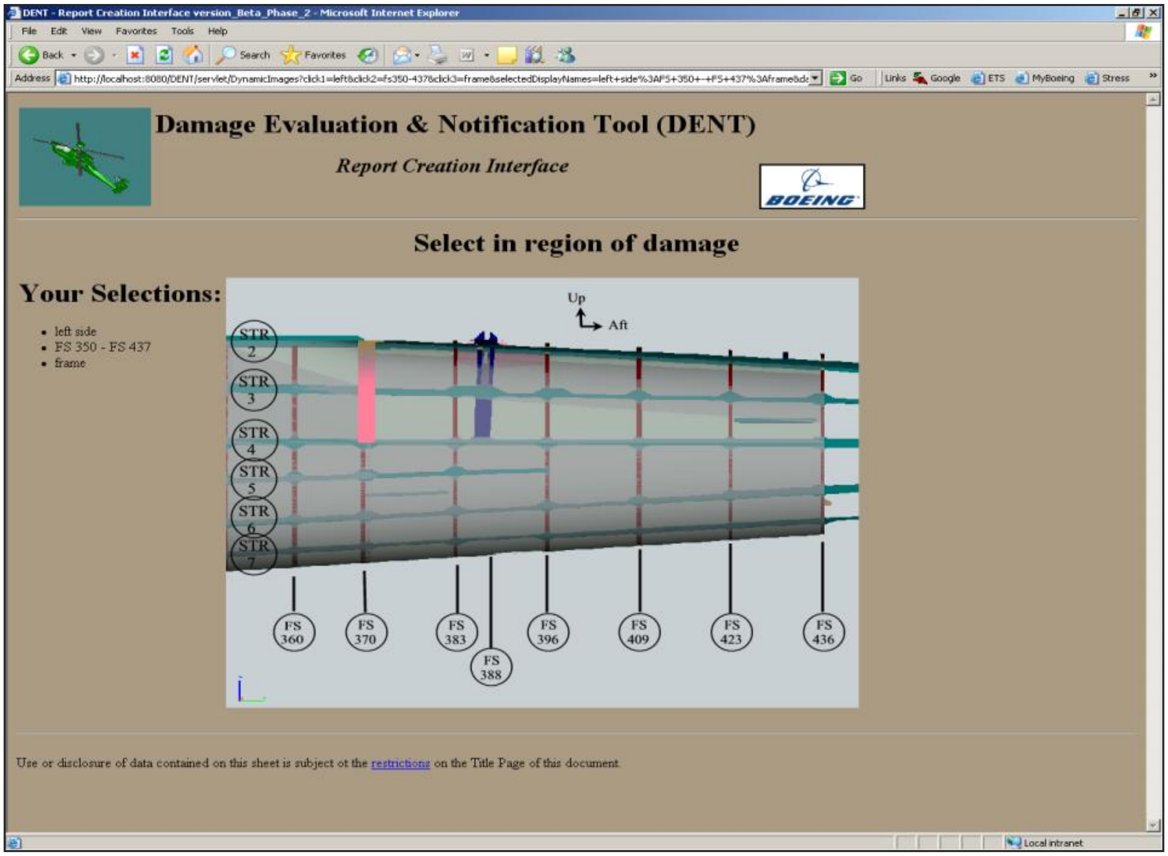

Figure 14: Identification of Damage in the 2nd Frame, Aft of the Tail Rotor Support Bracket (FS 409.9)

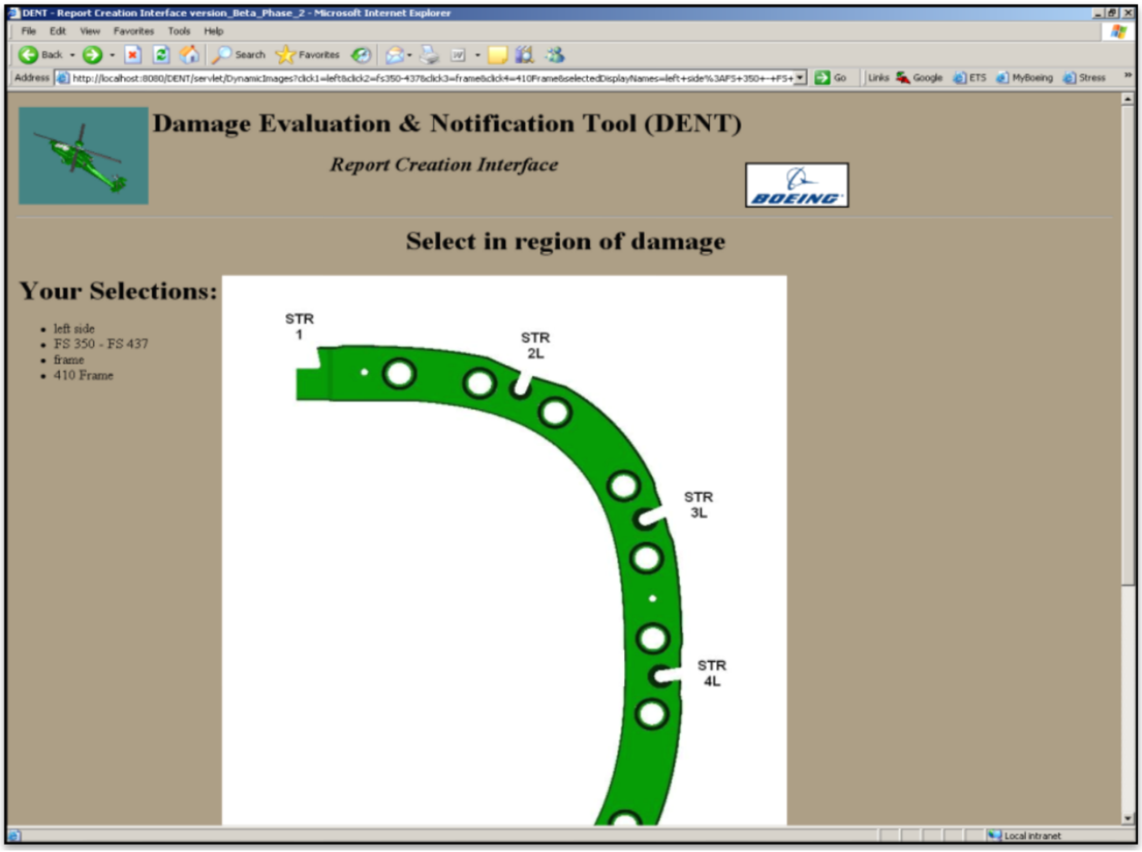

Figure 15**: Identification that the Frame Cap is Damaged**

Outboard of the Lightening Hole Between Stringers 3 and 4.

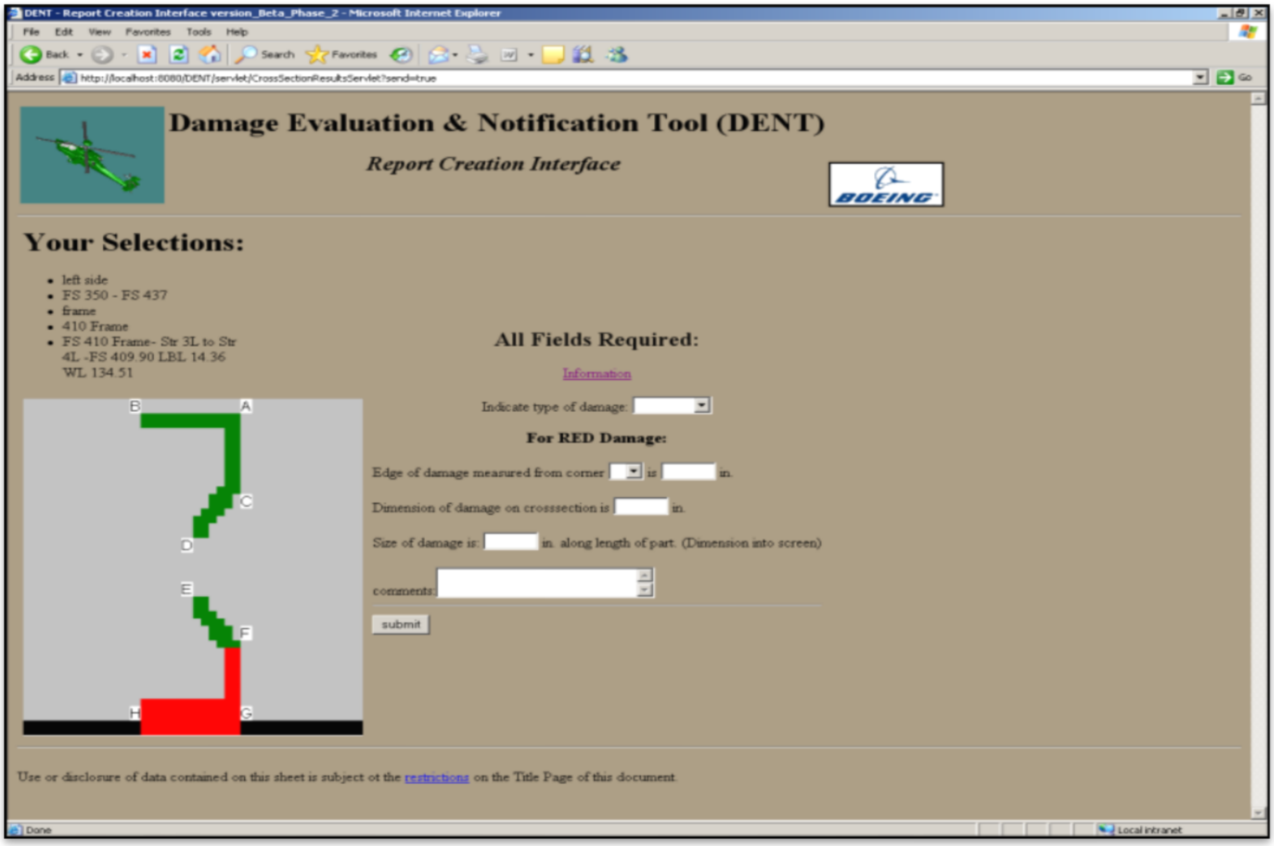

Figure 16: Highlighting the Extent of Damage in the Section Properties.

5.1.2 Link to Automated Analysis

The automated damage reports generated in the dent program have a direct interface back to existing airframe analysis model. The report generating sectional properties are directly from the airframe NASTRAN model for the Apache. The reporting data directly sets up the inputs for updated model runs to calculate internal loads and conduct all strength, stability and margin checks on the structure. Through a series of iterations, repairs can be identified and evaluated for acceptability against the desired criteria for return to service. Those criteria could be a full capability repair with no limitations or a limited exposure repair (100 hours for example) with further disposition and repairs when the aircraft returns for depot repair.

5.1.3 Electronic File Cabinet

The last feature of the DENT program is the retrievable file feature of the system. With all damage report and the dispositions of damage repairs in a central retrievable database many analyses or reports can be generated to enhance the overall continued airworthiness picture. Reports can be generated evaluating the types of damage sustained. The types of repairs employed and the standardization of those repairs can be evaluated. Repairs that have been instituted can be tracked with time to evaluate the long term durability effects of the employed repairs.

5.1.4 DENT Program Benefits

The DENT program has provided many benefits to the Aviation Commanders, the aircraft maintainers and the engineers providing airworthiness support to the field. The program has provided improved accuracy of battle damage reporting from the field. It provides for a more accurate identification of the damaged structure. It aides in identifying the information to the right personnel through the engineering interfaces and it allows for worldwide employment. The program has allowed for reduced repair disposition times and increased aircraft readiness rates due to the automated analysis suite and the access to historical aircraft repairs. The standardized data storage and retrieval system has reduced field and depot repairs due to immediate access to historical repairs and improved visibility of regular occurring damage.

6.0 SUMMARY AND CONCLUSION

The processes and procedures for assessing battle damage and assuring repaired aircraft and components maintain airworthy status have been discussed. The airworthiness organizations construct and the forward locating of maintenance engineers to guide that battle damage assessment process has been presented. The effects of current operations on engine on-wing time and the principal causes for engine removals have been discussed. The difficulties of conducting BDA on wiring systems were also presented. Many advanced tools are being developed that speed the process and increase the accuracy of BDA's. The very successful Boeing Program call DENT was presented in detail.