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ECONOMICAL VALIDATION OF A NEW REPAIR CONCEPT FOR CF-THERMOPLASTICS BY ITS COMPARISON WITH AN ONGOING REPAIR PROCESS (E.G. CF-THERMOSETS)

Chet.K.Sunar[1*], M. Kaden[1]

[1]*Institute of Structure and Design, German Aerospace Center, Stuttgart, Germany*
**chetsunar@gmail.com, markus.kaden@gmx.de*

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ABSTRACT

The goal of any commercial aircraft maintenance and repair crew is the safe return of aircraft to service in limited time. Especially in view of the fact that cost in lost revenue of an unscheduled aircraft on ground is on average $100,000 per day. This is becoming a hectic moments for all OEMs, airlines and MROs thinking that how composite repair can be made faster and reliable. Considering that the average composite permanent repair, as permitted in SRM takes roughly 15 to 16 hours according to CACRC.

With the help of the required process steps to perform a hot bonded repair, a new repair concept for carbon fiber reinforced thermoplastics is compared with an ongoing repair process (e.g. carbon fiber reinforced thermoset). For both repair processes, the several steps are estimated regarding time as a basis for an approximated cost calculation. It is approximated from some literatures, experiences and theoretically that about 10 hours earlier an aircraft can be dispatched back to service with the help of new repair concept. By the use of this time, cost estimation is done in terms of labor cost and the aircraft downtime cost.

1. INTRODUCTION

Aircraft producers are introducing more percentages of advance composite materials in primary and secondary structures of an aircraft. The reason behind is that, use of lightweight composite materials can reduce considerable weight of an aircraft in compare to the conventional metals. In the battle to win number of orders from airlines, use of lightweight composite materials is increasing. This has direct impact on the reduction of fuel consumption which account almost 50 percent of an airline's operating cost.

In the competitive airline industry direct operating cost (DOC) are keys to airline profitability. DOC covers the entity like ownership costs, flight and cabin crew costs, fuel costs, maintenance cost and other cost. Main parameters of DOC as fuel cost as well as maintenance cost are directly affected by the structure of an aircraft. Structural weight of an aircraft plays vital role in determining the expenses that occur during the operation of an aircraft. As structural

weight is directly proportional to the fuel consumption that contributes almost 50% of aircraft operation cost [1]. The fuel cost is like skyrocketing which is becoming a pivotal problem for any aircraft operating bodies. At the same time to meet the requirement of safety factors assigned by the regulatory bodies the structural integrity of an aircraft structures are equally considered. Original Equipment manufacturer (OEMs) and operators are concerned about reducing the structural weight of aircraft including the structural integrity with the fulfillment of the safety factors. Equally, OEMs, MROs (maintenance, repair and overhaul) and operators concern is to find the effective repair options of advance materials structures. If they can do this an in-service aircraft can be dispatch back into service in mean time to save the cost that an airline would have to suffer when a plane is grounded for a day or two or more depending on the nature of damage.

2. Important factors

The term "continued airworthiness" is often used to monitor the safety of an aircraft when it enters the service. MROs and OEMs plays important role to take the aircraft back into service and maintain airworthiness of an aircraft. Either providing the maintenance, repair and overhaul service or providing the required spare parts respectively. Cost, revenue, performance and technology are key problems that the airlines and MROs, as they deal with emerging market, supply chain and growth opportunities.

Introduction of composite structures to the aircraft have led OEMs and operators to think about finding out types of inspections and effective repair options. To keep repair and maintenance cost low is the prime concern to the MROs, operators and regulatory bodies. The economic advantages step primarily from time savings in the repair and reducing in-service aircraft downtime. A prominent example with approximately 10,000 aircraft in the U.S. commercial fleet, reduced aircraft downtime may represent greatest potential for cost savings, if a plane is grounded for a day the revenue loss for aircraft downtime can be upwards of dollar 100,000 per day [2]. Looking at this fact, it can be concluded that faster a grounded aircraft can be dispatch back into service lesser the depreciation of the cost would incur to an operating bodies. Here, the amount of time plays vital role in determining the revenue loss to an airline. Time as an important factor which has direct impact on cost of operating bodies, different approach to repair of damaged composite structures is being highlighted in this paper. Time required to complete the repair processes steps provided in source documentations as structural repair manual (SRM) provided by OEMs is calculated. With this basis, cost that an operating body can save will be calculated. This time estimation is made only possible with the comparison of two different repair options to specified composite structures as conventional repair option (e.g.- thermosets) and new repair concept (e.g. - CF-Thermoplastics).

3. Typical repair processes

Repair of composite structures was first considered by National Aeronautics and Space Administration (NASA) and US Air Force in the late 1970s [3]. It was during these early days that the ground rules for composite repair were defined. The repair must restore the functional requirements such as aerodynamics, the repair must have negligible weight penalty, the repair must be performed with limited tools etc. The basic composite repair remains largely the same regardless of where they are used or how they are made. One example of foreign object damage caused by bird strikes is shown in **Figure 1.**

Figure 1.Aircraft damaged due to bird strike

OEMs provides specific repair manual to operators and MROs to perform the repair to any damaged composite structures. Different processes steps for the execution of specific permanent bonded repair are mentioned as per the requirements. These processes cover; Damage assessment and mapping, Damage removal, Drying(moisture or fluid removal), Scarfing out the damaged area, Surface and repair area preparation, Repair material preparation, Layup of repair plies, Installation of the vacuum bag and thermocouples, Cure cycle and in-process cure data monitoring(i.e. temperature and vacuum), Post-repair inspection and Surface protection system restoration. In the conventional repair approach all the processes steps are followed. Considering that the average composite permanent repair, as permitted in SRM takes roughly 15 to 16 hours according to CACRC. This time exposure was confirmed by the MRO Company HAITEC GmbH based at airport Frankfurt Hahn. As per the information provided by HAITEC GmbH the most time consuming repair steps are removal in combination with scarfing out the damaged, drying of the processed area and the cure cycle. These steps take comparatively longer time during repair cycle.

In case of new repair concept time taken to complete the necessary repair processes steps were estimated from the experimental, theoretical knowledge gained during research at German Aerospace center (DLR). This concept can save tremendous amount of time with the introduction of Scanner supported laser machining tools and inductive heated steel-sheets for the cure cycle. This time calculated showed that a grounded aircraft can be dispatched back to service almost about 10 hours earlier with new repair concept. This is discussed in detail in following chapter

4. New repair concept

Different advance composite material like CFRP, GFRP, AFRP, and BFRP are used in the aircraft primary and the secondary structures. Apart from fiber reinforced Thermosets, use of high performance thermoplastics resins like PPS (polyphenylene sulphide), PEEK (polyetheretherketone) are widely reported. Among thermoplastics, carbon fiber reinforced polyetheretherketone (CF/PEEK) is emerging for the use in aircraft applications because of its good physical properties that meets the engineering applications in aircraft. In the new concept repair approach different high performance thermoplastics matrices can be explained. But, one of the typical repair materials is taken here to explain is with PEEK. Here, the conventional repair approach refers to the all existing repair applied to the existing composite materials system used in the aircraft structures especially carbon fiber reinforced thermosets materials. One of the peculiar physical properties of CF/PEEK is that, the material can be re-melted and remolded into any shape. CF/PEEK material normally does not absorb moisture which is next peculiar

properties and in terms of cost as well it can be beneficial to the OEMs and MROs. Because of the weld ability characteristics of CF/PEEK, it has great advantages during repair.

In conventional repair processes damage removal to scarfing out of the damage area is done manually. This might lead to thermal damage and increase the surface roughness of the repair area. Also, prepregs used in the conventional repair process need to be preserved and might not be available in the required place and in time. During the cure cycle the patch integration is done using the vacuum consolidation technique. Source of heat is heating blanket. It takes tremendous amount of time during the compaction of the repairing laminate in conventional repair. Normally, it is not necessary to reach temperatures over 250°C during the compaction of thermosets material. The cure cycle takes longer time to heat up and to cool down because of the matrix systems used in conventional repair. But same heat source is not enough for the processing of high performance thermoplastics resins like PEEK used in new repair approach. The processing temperature for CF/PEEK is nearly 400°C. The cure cycle completes comparatively faster.

In case of new repair approach materials properties are advantageous and the scanner supported laser machining is used to remove damage as shown in **Figure 2**.

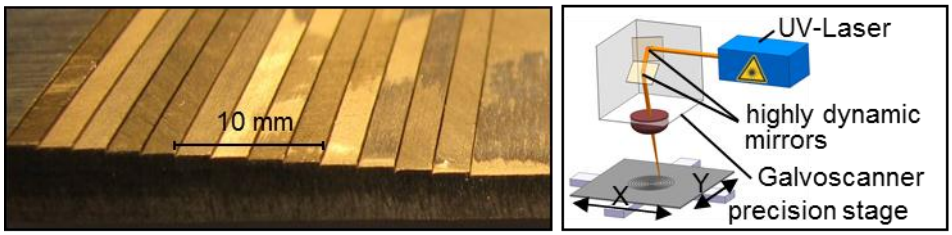

Figure 2. Scanner supported laser machining setup and steps treated by laser system [4]

This provides the advantage of smooth surface and not any possibilities of damages in the repair patches. The stepped-lap repair technique is used to repair laminate. If this is to be done manually it might take considerably longer time to repair. With the scanner supported laser machining, scarfing out of the patches steps can be done in limited time and with limited power supply. Similarly, preservation of the repair patches (Prepregs) is not required. Thermoplastics matrix like PEEK used in the new repair approach normally do not absorb moisture and drying is normally not required. This saves tremendous amount of time and cost. During the compaction of the repair patches the installation of the vacuum bagging is done but the source of heat is used as the inductive heated steel-sheets as shown in the **Figure 3**. This can provide the high temperature around 400°C, which is required for the patch integration of material system used in new repair approach. Due to the weld ability feature it's not necessary to use the adhesive in between the layers during compaction. The cure cycle completes very fast in the new repair approach, this saves noticeable time compared to conventional repair system.

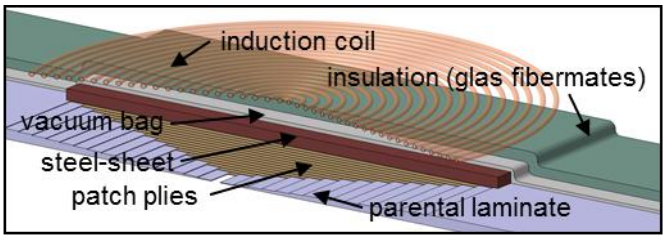

Figure 3. Simplified buildup of new repair concept using inductive heated steel-sheet [4]

5. Time calculation

SRM steps	Conventional repair time (hour)	New repair concept time (hour)
Damage removal /scarfing out damage area	3 hour (scarfing steps, 2 to 3days manual)	2.4 hour (with the average beam power of around 75 watt the volume of 67 cm^3)
Drying(moisture and fluid removal	3 to 4 hour approximate	null
Surface and repair area preparation	40 minute to 1 hour	5 to 10 minute
Repair material preparation	1.30 hour to 2 hour	30 to 45 minute
Layup of repair plies	1 hour (if not available 1-2 hour to prepare fresh adhesive)	15 to 20 minute
Installation of vacuum bag and thermocouples	1 to 2 hour	1 to 1,30 hour
Cure cycle and in process data monitoring	4 to 5 hour	1 hour to 1.30 hour
Post repair inspection/surface protection system restoration	1 hour to 1.45 hour	30 minute to 1 hour
Completion of the repair process Total time (approx.)	17 to 19 hours	5.5 to 7.5 hours

Table 1. Time data collected from different sources and practice

Apart from routine check downtime there are number of damages that occurs on an operating aircraft because of which schedules aircraft are compelled to take out of service. So, aim of this report is to focus on reducing downtime of an aircraft to reduce the economic impact to an airline. Now every OEMs and MROs concern is how to minimize the cost of re-pair as well as minimize ground time of a scheduled aircraft. Definite size of the damage is taken to be as big as 20 mm, the damage is considered to be small dent due to foreign object impact during landing or take off of an aircraft as shown in **Figure 4**. It is already mentioned that, the main aim is to calculate time take to complete the repair processes steps for bonded repair technique provided in the source documentation. Source document refers documentation provided by SRM or the OEMs to repair specific structure constructed from specific materials systems. It is already discussed as conventional repair approach refers to most prominent technique that is in practice today and specifically for Carbon fiber reinforced Thermosets materials. New repair approach is dedicated to the repair technique used for the carbon fiber reinforced thermoplastics.

Figure 4. Damaged laminate [4]

Then with this time basis, Aim is to calculate the cost that incurs to airline operators. This time calculation is based on the approximation of repair time data collected from different sources (SRM and HAITEC GmbH) and from the theoretical knowledge and some practical knowledge during the preparation of laminate from CF-Thermoplastic material at German Aerospace center (DLR). Main sources to calculate time required completing the conventional repair steps was SRM and HAITEC GmbH. For the new approach it is theoretical knowledge and practical knowledge gained at DLR during master's thesis research for the economical validation.

The approximated value of the time taken to complete conventional repair is calculated. The time taken to repair ranges from 17 to 19 hour which is almost similar to the time provided by SRM to complete the repair. This data seems to be promising and comparable.

Similarly, in new repair concept the time taken ranges from 5.5 to 7.5 hours, here it can be witnessed the time difference between two repair approaches. This can be acknowledged that introduction of the carbon fiber reinforced thermoplastics matrix components to aircraft structures can be beneficial from different perspectives.

6. Cost calculation

Controlling operating cost is very essential in any business. Unlike other industries, aircraft operators face tremendous amount of springing costs that comes in the form of airworthiness directives promulgated by the aviation authorities and service bulletins. Cost, revenue, performance and technology are key problems that the airlines and MROs, as they deal with emerging market, supply chain and growth opportunities. Airline operators are driven to have unnecessary expenditure out of maintenance. This spending can be the least of the maintenance costs. Aircraft downtime is often more costly than work done during non-earning periods. Cancellation and delay due to flawed maintenance can cost huge sums. Maintenance choices are re-examined in light of new economic pressures. This can mean giving more attention to the traditional practices, redefining best practice that fits to this new economic environment or adopting new techniques.

Extra different kind of cost are classified primary delay and cancellation or secondary delay or cancellation) and in the countries like USA where more than 10,000 aircrafts are flying due to one cancellation of delay an airline suffers huge loss ranging from $75000 and above. In worst case the downtime cost would range around $100,000 thousand and above in a day. The maintenance cost covers almost 20% of an airline operating cost for example the chart shown in **Figure 5** illustrates the breakdown of DOC of B737[5]. The latest data shows that the MRO is a $50 Billion industry. It can be noticed how big role does a maintenance cost plays in any airlines to dispatch an aircraft back to service and in time. In this industry the major cost goes to the Maintenance Staff which covers 70% of Maintenance cost is illustrated in **Figure 5** [6].

Labor cost is the main parameter that is taken into consideration. This also indicates that labor hour's plays vital role in calculation of operating cost. Different labor hours cost is illustrated for the maintenance staff around the world according to the region. It shows that it is paid most in Europe ranging $50 - $100.

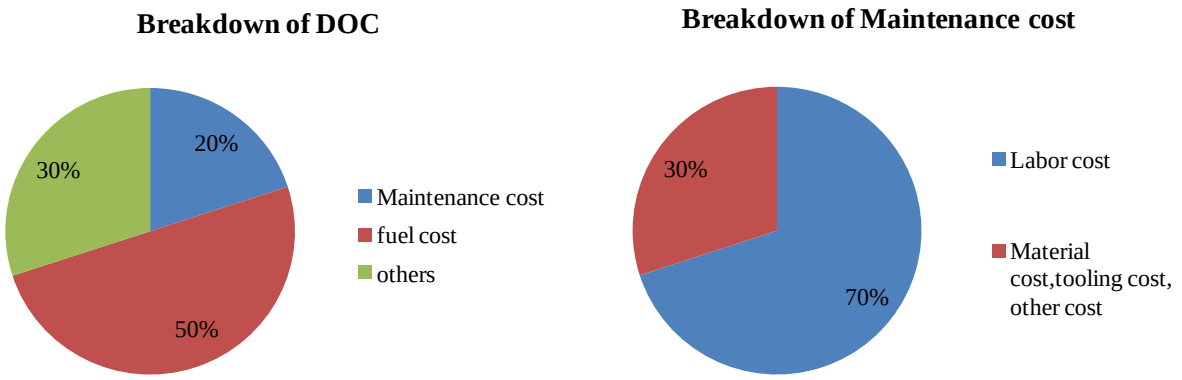

Figure 5. Illustration of breakdown of DOC of B737

In conventional repair technique the number of maintenance labor as maintenance engineers, quality assurance staff, materials and logistics specialists etc. are required at maintenance base. It is shown in **Table 2**, which maintenance labor cost per hour in Europe ranges from $50 to $100 per hour. In new repair concept, certain man hour is required but also the automated repair technique is used to prepare the repair area which saves tremendous amount of time. For example with the laser based repair approach for CFRP components the running cost for removal and scarfing out of damage would cost very low about $1.378- $4.13 per hour [7]. When automated laser tool is used it enhances the bonding strength almost by 20%, total repair cost is reduced approximately by 60%.at the same time it is highly reliable, no human error factor.

Region	Labor Cost range (Per hour)
Europe	$50 - $100
North America	$40 - $50
Asia and Latin America	$30

Table 2. Maintenance labor cost per hour according to the region [7]

The main parameters considered for cost calculation are maintenance labor cost paid per hour and the aircraft downtime cost that an airline would have to suffer when a plane is grounded for time being. According to the source provided from HAITEC GmbH, to carry a repair generally two maintenance staff gets involved for smaller damages. This can be made in due time to take back the plane into service in conventional repair process. Based on this fact the labor cost is calculated. In case of downtime cost, it is discussed earlier that when a plane is grounded in a day the cost incurs is around $100,000 and above. Taking this amount literally for 24 hours of ground time, the average of this cost per hour is taken to estimate roughly to compare the cost that can be saved in two different approach of repair.

Literally, the average dollar paid for a staff in Europe is approximated to be $80 per hour. Based on this fact the labor cost in two different approaches is calculated. Similarly, the Aircraft downtime cost per hour is approximated to be around $4,165 per hour. From **Table 1**, the amount of time taken to complete the repair processes steps is taken. For conventional repair approach it is taken to be 17 hours to complete the repair processes and in new repair approach the damage of the similar nature can be repaired in approximately 6 hours. Taking this time the cost that incurs when a plane is damaged is calculated and is compared in the graphs below. It is

noticed that almost 10 hours earlier an aircraft can be dispatched back to service with the application of new repair concept.

The graphs shown in **Figure 6** illustrates the amounts that an operating bodies can save by implication of new repair concept and the use of high performance thermoplastics materials as a components of aircraft structures. The main cost parameters as labor costs and the downtime cost that incurs to an airline when aircraft have a nominal damage are compared in the form of conventional repair approach and new repair concepts. The total labor cost that an operating body can save is approximately calculated to amount of $1,760 with the implication of new repair concept. When the downtime cost is compared an operating body can save almost $45,815 with the introduction of new repair concept. With the new repair approach almost 64 % of the labor cost and the downtime cost can be saved.

So far this paper has taken labor cost and the downtime cost as a major cost that affects the operating cost in gross amount. But also there are number of factors like material cost, tooling cost etc. further research work can be carried in detail to evaluate the cost to compare the different approach. So far the new repair concept proves to be astonishingly beneficial to any operating bodies as tremendous amount of cost can be saved to generate revenue.

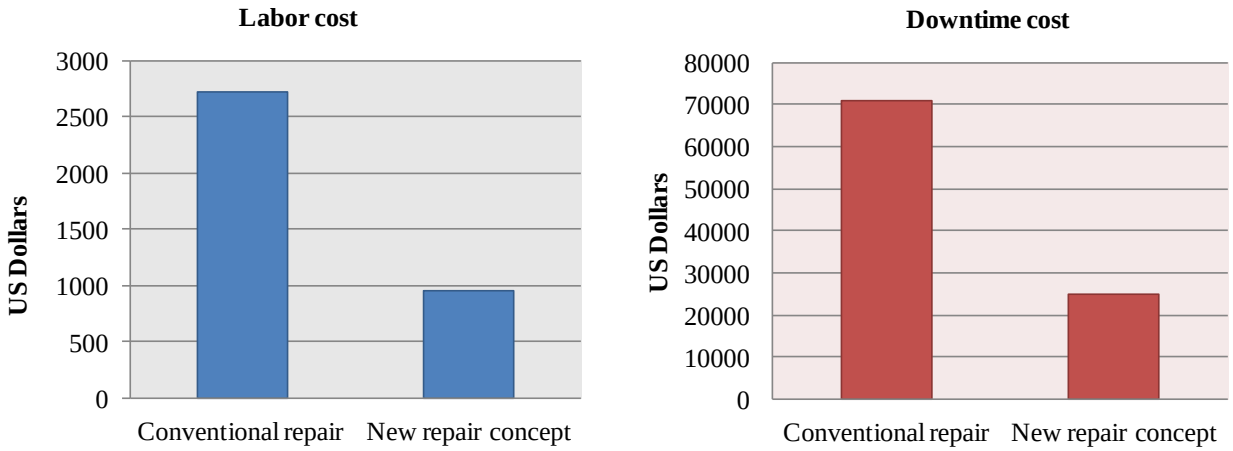

Figure 6. Comparison of labor cost and comparison of downtime cost

7. Conclusion

This report dealt with the different repair process steps approved by SRM. The time taken to repair damage structures in conventional repair technique is compared to new repair concept. The result is shown in **Table 1**. These times calculation is based on the approximation of the repair time from different sources and from the theoretical knowledge. With the new repair concept many hours can be saved in compare to the conventional repair. It is concluded that the time taken to perform permanent hot bonded repair of composite materials with thermoset matrix system using conventional repair techniques is around 17 to 19 hours. In new repair concept, structures with a thermoplastic matrix system it takes around 5.5 to 7.5 hour to complete the permanent repair. Tentatively the **Table 1** indicates about 10 hours can be saved in the new repair concepts with the use of automated repair. With this time basis two main parameters as labor cost out of maintenance cost and downtime cost are calculated. With the help of new repair approach almost one third of time can be saved and almost 64% of the labor cost and the downtime cost can be saved. This concludes the promising result.

Finally, Use of carbon fiber reinforced composite material is skyrocketing in aircraft industry. Further work can be done to measure the time value and the cost value of an airline taking this repair time into consideration. Such as material cost, machine cost, tooling cost etc, can be compared to get a detail idea how an operating cost can be saved in this fast growing industry.

8. References

[1] "The Economic Cycle and Aviation", 2009, QFINANCE

[2] Roach,D Patrick, Rackow,Kirk A, "Development and Validation of Bonded Composite Doubler Repairs for Commercial Air-craft", 2007, Sandia National Laboratories

[3] S.H.Myhre, J.D. Labor," Repair of advanced composite structures", 1979, Journal of Aircraft, Vol.18, No.7

[4] M.Kaden, R.Keck, H Voggenreiter, "Developing a repair concept, using the advantages of carbon fibre reinforced plastics", 2011, SAMPE Conference

[5] "MRO ready for transformation", 2011, IATA.

[6] H. Canaday, "Cost control over time", 2005, Aviation Week

[7] Product information,"CFRP Laser Repair Tool", Clean LASER