Certification Concept and Development of a Bonded Eurofighter Airbrake Flight Demonstrator

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ABSTRACT

The joining of composite aerostructures is a key element which can influence the weight as well as the complete design of a structure. Due to current airworthiness regulations in civil aerospace industry in primary structures design features are used to stop a potential debonding. It is required in order to prevent non-systematic failures in the bondline (i.e. basically weak bonds). In the military aircraft industry similar airworthiness regulations apply for MALE (medium altitude long endurance) RPAS (remotely piloted aircraft systems). Therefore, the main objective of the R&T work presented in this paper was to develop and demonstrate a more robust and reliable secondary bonding process by adding several components such as additional surface treatment by plasma and additional process control specimen testing. The approach of the developed process has been applied to a Eurofighter Typhoon military aircraft part, the airbrake. A military certification concept has been developed and proposed. The complete qualification process has been conducted according to the building block approach. The certification concept has been presented, discussed and agreed by the German military airworthiness authorities.

The next step consists in flight testing. The approach is expected to be transferred by a step-by-step approach to primary composite aerostructures for military and civil application in close cooperation with military and civil airworthiness authorities in the next years.

1.0 INTRODUCTION

Composites offer several advantages over metallic aerostructures in civil as well as in military aircraft industry including reduced weight, less maintenance costs due to corrosion-free composites and a superior fatigue behaviour compared to aluminium. One of the major aspect for every aerostructure is the assembly and joining technology. Structural bonding of composites offers several advantages over mechanical means of fastening including higher stiffness, more uniform load distribution, cleaner aerodynamic surfaces, and no holes in adherends (with stress concentrations and reduced load-bearing area), and reduced manufacturing costs. Figure 1 shows an overview of criteria for applicability of bolting and bonding joints.

Condition	Bolting	Bonding	
Lightly Loaded, Thin (<0.10 in. [2.5 mm])		X	Main advantage for bonding
Highly Loaded, Thick (>0.10 in.[2.5 mm])	X	X	
High Peeling Stresses	X		
Honeycomb Structure		X	
Dry and Clean Adherend Surfaces	X	X	
Wet and/or Contaminated Adherend Surfaces	X		
Sealing Required	X	X	
Disassembly Required	X		
Restore Unnotched Strength		X	Main advantage for bonding

Source: MIL- Handbook 17-3F, Chapter 8

Figure 1: Criteria for application of bolting and bonding joints

Furthermore, bonding is considered a major enabler for advanced and disruptive structural concepts. The drawbacks of bonding in primary structures are related to higher costs linked to process control and quality assurance driven by certification issues. A key element in this context is the adherend surface preparation which is critical to structural integrity of bonded joints. Inadequate surface preparation, environmental effects, possible peel ply chemical contamination, and other mechanical or chemical factors may prevent proper adhesion thus resulting in interfacial, adhesion failures. These failures may occur at loads well below those of properly bonded joints that fail cohesively. Other interfacial failures may occur over time in service as joints are exposed to harsh environments, including elevated temperature and humidity. The overall objective of the technology activities presented in this paper is to support increased application in future military aircraft developments. Furthermore, it shall increase the confidence in bonded structures as well as to achieve future certification of structural bonding in primary composite aerostructures without design feature to prevent disbonding (or extremely reduced fasteners if used).

1.1 Actual Certification and Airworthiness regulations

The Advisory Circular (AC) No. 20-107B “Composite Aircraft Structure” sets forth an acceptable means, of showing compliance with the provisions of Title 14 of the Code of Federal Regulations (14 CFR) parts 23, 25, 27, and 29 regarding airworthiness type certification requirements for composite aircraft. This applies also to the STANAG4671 for the airworthiness certification of fixed-wing military UAV Systems with a maximum take-off weight between 150 and 20,000 kg that intend to regularly operate in non-segregated airspace. The mentioned advisory circular gives the guidelines for substantiating the primary composite airframe structures for bonded joints as follows:

(a) For any bonded joint the failure of which would result in catastrophic loss of the airplane, the limit load capacity must be substantiated by one of the following methods:

(i) The maximum disbonds of each bonded joint consistent with the capability to withstand the loads must be determined by analysis, tests, or both. Disbonds of each bonded joint greater than this must be prevented by design features;

or (ii) Proof testing must be conducted on each production article that will apply the critical limit design load to each critical bonded joint;

or (iii) Repeatable and reliable non-destructive inspection techniques must be established that ensure the strength of each joint."

According to AC 20-107B, these options do not supersede the need for a qualified bonding process and rigorous quality controls for bonded structures. According to AC 20-107B, fail safety implied by the first option is not intended to provide adequate safety for the systematic problem of a bad bonding process applied to a fleet of aircraft structures. Instead, it gives fail safety against bonding problems that may occasionally occur over local areas (e.g., insufficient local bond contact pressure or contamination).

Critically examining these means of compliance in the context of production of military aircraft, for example such as Medium Altitude Long Endurance remotely piloted air systems (MALE RPAS) reveals that currently the only feasible measure is the limitation of the maximum disbond size, which is the first option mentioned above. Proof testing (ii) is cost-prohibitive when scaled to higher production volume and non-destructive techniques (iii) have not yet the capability and maturity to measure or correlate bonding strength to date and therefore to detect weak bonds.

1.2 State of the art

Different possibilities and options apply in order to manufacture and assembly composite aerostructures. Besides conventional fastening, the main composite-related joining methods are co-curing, co-bonding and secondary bonding, as illustrated in Figure 2.

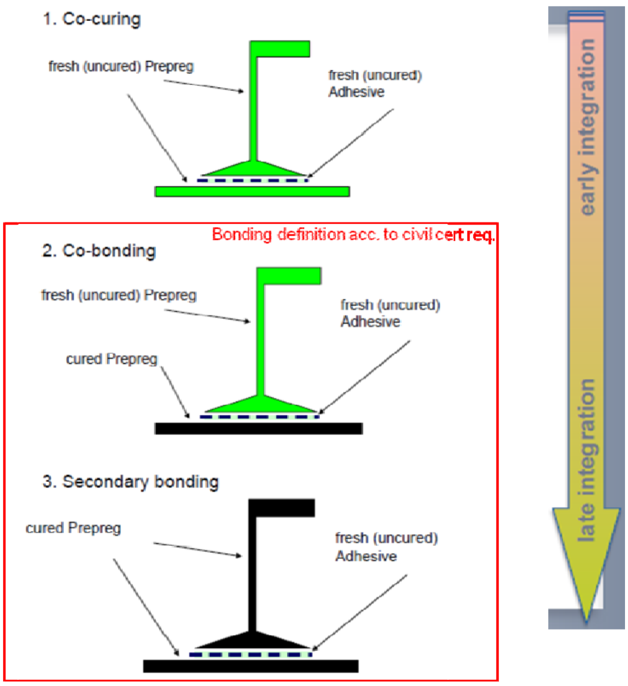


Figure 2: Composite manufacturing and assembly joining technologies

In the co-curing technology, different parts and/or subassemblies are cured together in the autoclave with temperature and pressure. In general large and complex structural parts are manufactured using this technology. The toolings are in general expensive and rather complex. An additional drawback is that process induced flaws or deviations have to be reworked or repaired which is time consuming and expensive, in the worst case the part has to be scrapped. According to the certification guidelines, the co-curing technology is not considered as a structural bonding technology, since the joining mechanism is not driven by adhesion.

Another possibility of joining composite parts is the secondary bonding technology. According to this technology smaller and less complex parts are cured separately and bonded after curing in a separate process using a film or a paste adhesive. The benefits are in terms of reducing the number of complex toolings and therefore costs as well as rather scrap small and cheap components if during the manufacturing deviations should occur. The single parts may also be manufactured using different manufacturing technologies (e.g. pultrusion for profiles) and joined after curing.

Structural bonding, as co-bonding, is used in aeronautics industry. However, the actually applied bonding technology is usually limited to rather low stressed areas such as stringer/skin joints (Figure 3) or bonded doublers. In primary structures disbonds of each bonded joint must be prevented by design features using additional fasteners. Furthermore, bonding is used as assembly aid in manufacturing without structural purpose.

Bonding is also used for repairs. These repairs can be performed by means of co-bonded patches with the requirement that the surrounding structure is still able to carry design limit loads without the repair patch in place. This usually results in small repairs with a typical initial damage size limit of approx. 5 cm. Larger damages will be structurally repaired using titanium or CFRP patches which are bolted onto the structure. The bolts, however, require a minimal skin thickness to accommodate the bolt head leading to an overall penalty for the initial design. The consequences are twofold. A visibly large repair as indicated by Figure 4 on an aircraft might lead to mistrust by the passengers and reduced reselling value is not acceptable for operators.

Figure 3: A350 skin panel with co-bonded stringer

Figure 4: Bolted fuselage repair

Table 1 shows a brief overview of the state of the art and the limitations of different technologies for bonding for as initial design and bonding for repairs.

Technology	State-of-the-Art	Limitations
Joining initial design (CFRP, FML, hybrid)	Stringer/skin connections; usage of film adhesive for co-bonding. Certification based on fasteners at intersections with ribs or proof testing.	Low load transfer joints (e.g. Skin/Stringer)
Repair considerations in initial design	Thickness and geometric edge distance provisions for potential bolted repairs.	No large bonded repair certified.
CFRP structural bonded repair	Soft patch co-bonded repair	Small repairs with limit load capability in case of patch off, damage tolerance capability determined by repair material.

Table 1: State of the art and Technology limitations today

1.3 Technical concept and Approach in R&T

As highlighted in the previous chapters, repeatable, robust and reliable bonding processes are considered key enablers for the certification of the structural bonding technology, for bonding as initial design for new aerostructures as well as for large, bonded structural repairs. The concept adopted in order to achieve this goal consists in the 4 following steps, according to the well know building block approach, illustrated in Figure 5:

1. Development, specification and demonstration of the bonding process on coupon level → TRL4 achievement
2. Application, Testing and Demonstration on critical detail element level → TRL5 achievement
3. Demonstration on full scale component level → TRL6 achievement
4. Achieve certification by German Military Airworthiness Authorities (German "Luftfahrtamt der Bundeswehr") and flight testing

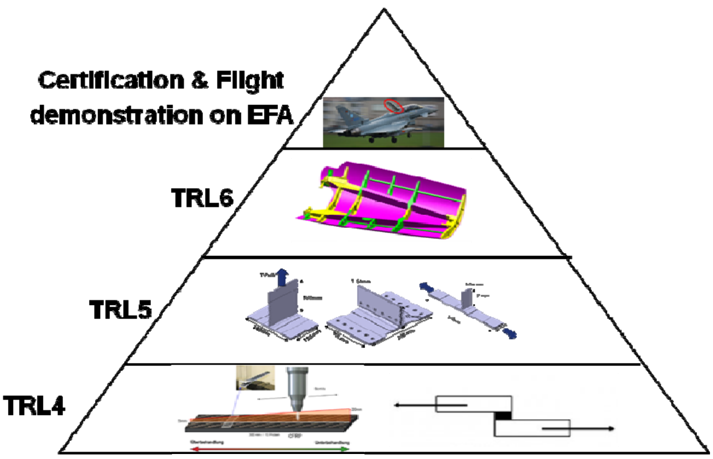


Figure 5: Approach for development, qualification and certification of structural bonding technology

In order to perform these R&T activities for structural bonding, an Eurofighter Typhoon component, the airbrake, has been selected, as shown in Figure 6. The main structural concept of the series airbrake has been retained. The main difference is consisting in changing the manufacturing technology for the main stiffener elements / beams from co-curing to secondary bonding (Figure 67).

Figure 6: Eurofighter Typhoon (EFA) with deployed airbrake

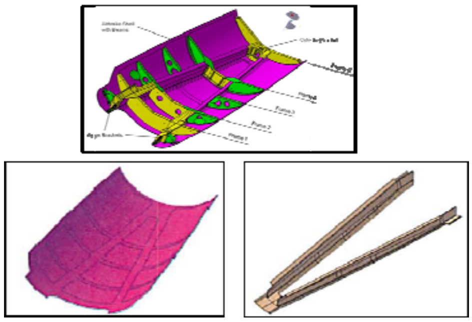


Figure 7: Structural concept and bonded components of EFA airbrake

2.0 SPECIFICATION AND DEFINITION OF MATERIALS AND PROCESSES

In this subchapter the R&T developments are presented concerning the development, specification and demonstration of the bonding process. In order to achieve repeatable, more robust, reliable secondary bonding processes the following main points have been considered:

- application of improved and more detailed surface analysis methods (SEM, XPS…) within the process qualification
- selection, definition and application of specified and controlled materials, adhesives, peel plies relevant for bonding system
- no human touch approach
- application of an additional surface cleaning and activation process including adequate quality assurance steps
- controlled bonding process (restricted processing parameters and additional process control specimen)

A complete process for qualification of the bonding process has been developed. One of the crucial point here is that ancillary materials such as peel plies are considered and treated as structural materials including the check of certificate of conformity and incoming inspections. After manufacturing of the composite adherends including process control specimen different destructive tests are performed such as interlaminar shear stress, single lap shear (Mode II), and GIC (Mode I) tests. A geometrical measurement of the adherends is to be performed next. The geometrical measurement can also be used for estimation of bondline thickness. Prior to bonding the adherends have to be dried back in order to avoid moisture induced voids and porosity in the bondline which may appear during curing of the adhesive. After peel ply removal the surface will be activated by atmospheric plasma treatment. The assessment of the appropriate plasma process parameters will be presented next. Once bonded the appropriate non-destructive testing using ultrasonics and the testing of the process control specimen have to be performed.

As mentioned before, a systematic parameter study has been performed in order to specify the process parameters for the surface treatment with atmospheric plasma. Here the influence of the plasma nozzle distance and the nozzle velocity on the surface treatment has been investigated based in GIC specimen, as illustrated in Figure 8.

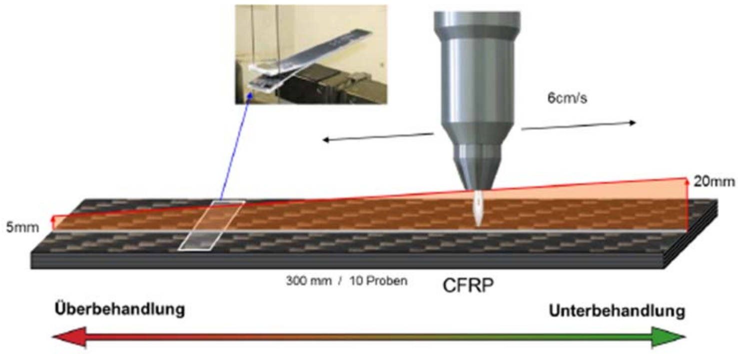


Figure 8: Experimental approach for definition of robust process windows for plasma treatment

Figure 9 shows the influence of nozzle distance on GIC energy release rate as well as on the failure mode for the selected film adhesive.

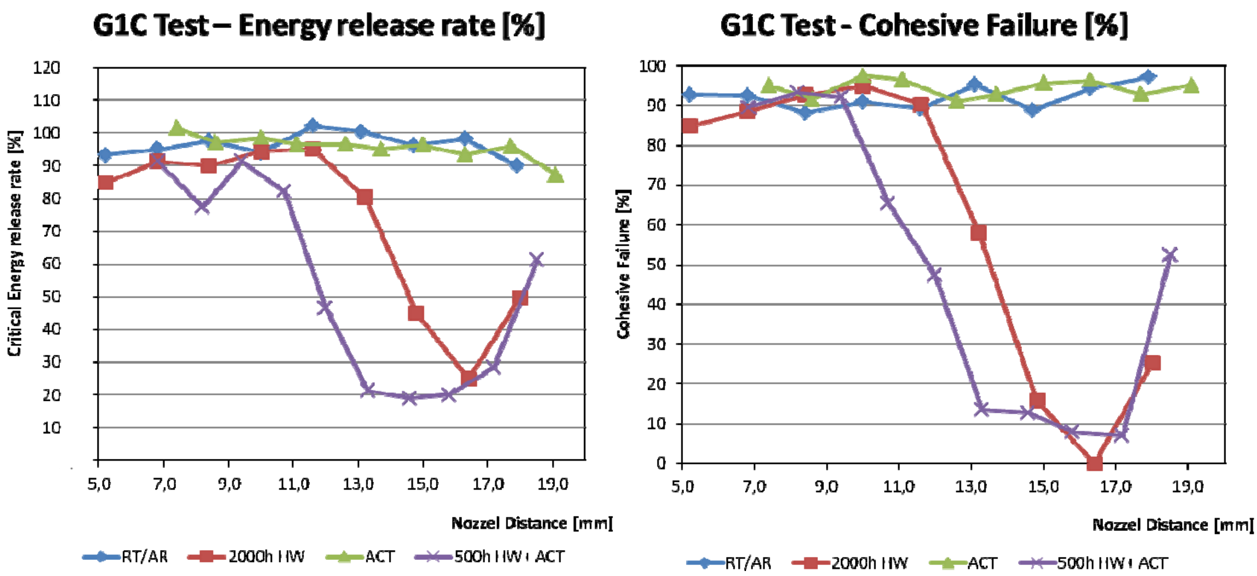


Figure 9: Influence of plasma nozzle distance for the selected film adhesive on energy release rate Mode I (GIC)

After successful definition of the specification for the bonding process which has been defined on the basis of coupon specimen, the next step was to verify and validate the process on the next level of the building block approach – the critical detail test level, which will be highlighted in the next chapter.

3.0 VERIFICATION AND VALIDATION ON CRITICAL DETAIL TESTS

In order to verify the developed bonding process and highlighted in the previous chapter different tests and test conditions have been selected. Figure 11 shows an overview of the test matrix performed. According to the bonding procedure defined, T-profiles have been joined to skin panels in a secondary bonding process. Three different load cases have been applied in a so called T-Pull, T-Shear and T-Tension test, as illustrated in Figure 11, in order to cover Mode I and Mode II loading modes. The tests have been performed at room temperature, but also at -55°C and at hot wet condition, which means hot wet conditioning and testing at 100°C.

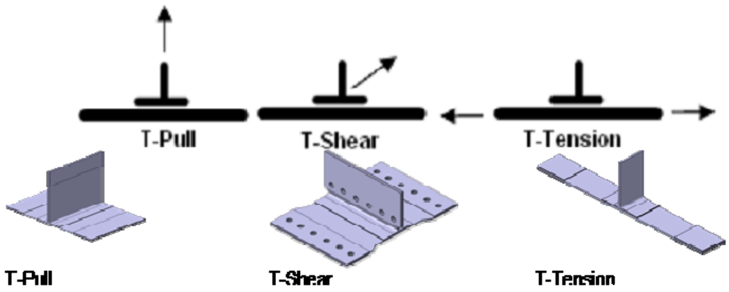


Figure 10: Critical detail specimens

ID	Detail	Test	Environmental condition			Remarks
			CTD	RTD	ETW	
C1	T-Pull	Static	X	X	X	
C2		Fatigue+ Residual Strength		X		
C3.1		Manufacturing defects		X		Fatigue damage on critical area
C3.2		Damage Tolerance + Residual Strength		X		Fatigue damage on critical area
C4	T-Shear	Static	X	X	X	
C5		Fatigue + Residual Strength		X		
C6.1		Manufacturing defects		X		Fatigue damage on critical area
C6.2		Damage Tolerance + Residual Strength		X		Fatigue damage on critical area
C7	T-Tension	Static	X	X	X	
C8		Fatigue + Residual Strength		X		
C9		Damage Tolerance + Residual Strength				no impact possible

CTD: cool temperature (-55° C), dry (as received)
RTD: room temperature, dry (as received)
ETW: elevated temperature (100° C), wet
wet: conditioning at 70° C/85% r. h. until saturation (1,2% weight gain)

Figure 11: Overview of test matrix performed

Prior to bonding a bondline thickness measurement using the verifilm technique has been performed. Figure 12 shows exemplarily the comparison of measured bondline thickness by the verifilm technique (i.e. prior to bonding) and after bonding (by micrographs) along one of the 1.5 meter long critical detail specimen for T-Pull testing.

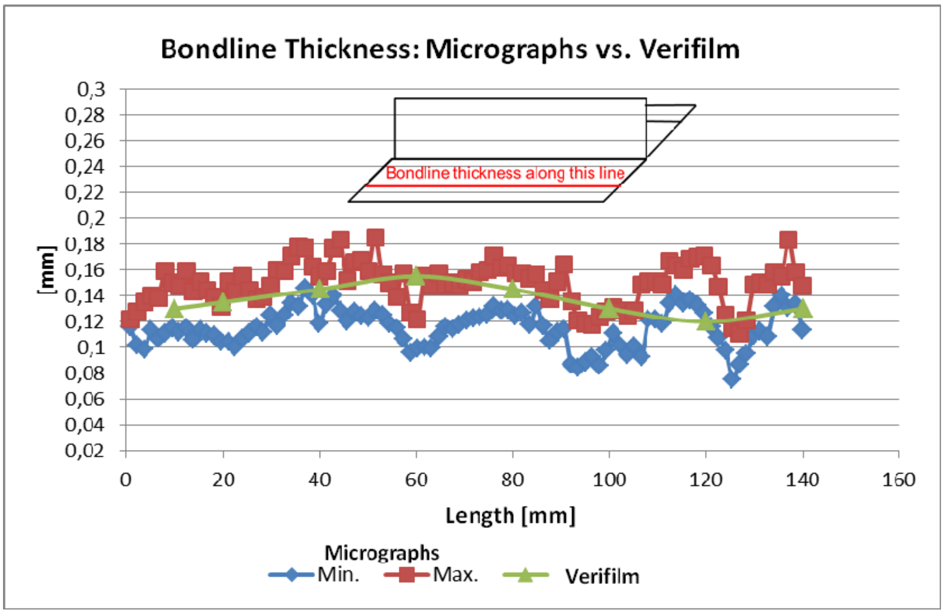


Figure 12: Bondline thickness: Micrographs vs. Verifilm

The specimen have been tested on pure static as well as on fatigue loading including impacted specimen as well as specimen with artificial damage, which consisted in the lamination of a 16 x 16 mm Teflon foil in the bondline to simulate a debonding. Figure 13 shows three typical failure modes of the T-pull specimens. Depending on temperature and humidity conditions the specimen failed next to the filler, in the radius area, as well as delaminating below the filler or starting at the edge. All failure modes were driven by pure composite failure rather than failure in the bondline. No interfacial, adhesion failure have been observed in any test case.

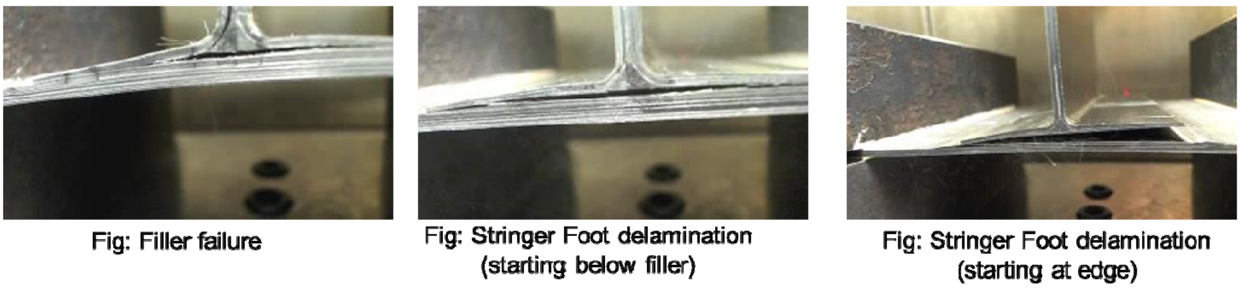
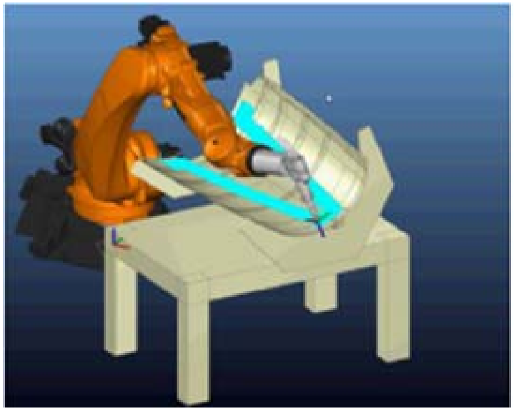


Figure 13: Failure modes of T-Pull specimen

4.0 DEMONSTRATOR MANUFACTURING, QUALIFICATION AND CERTIFICATION OF FULL SCALE COMPONENT

Once the process has been demonstrated successfully also on critical detail level, the next step consisted in the demonstration on a full component level including full certification by German Airworthiness Authority and flight testing. As mentioned in the introduction of this paper, the airbrake of the Eurofighter Typhoon military aircraft has been selected as demonstrator part (Figure 6 and Figure 7).

The surface treatment of the airbrake demonstrator prior to bonding has been performed by automatic atmospheric plasma treatment with a robot as illustrated in Figure 14.



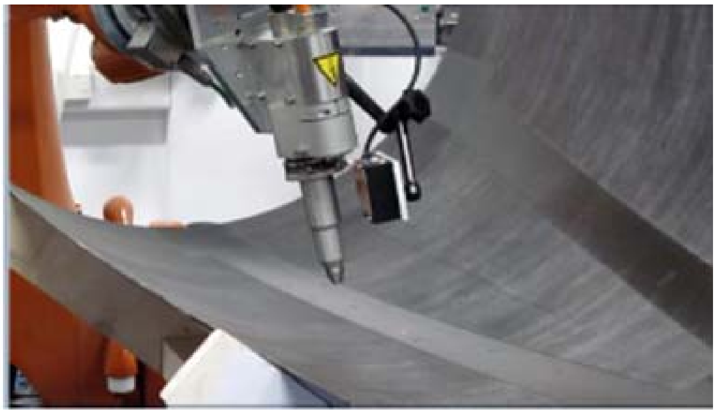


Figure 14: Automatic plasma treatment prior to bonding

The design and manufacturing of the bonding tooling has been performed at the German Aerospace Center (DLR) in Braunschweig. The tooling for bonding has also been used for lay-up and cure of the outer airbrake shell. The tooling system features four frames for positioning and fixing the spars to be joined by secondary bonding. Figure 15 illustrates the complete tooling system.

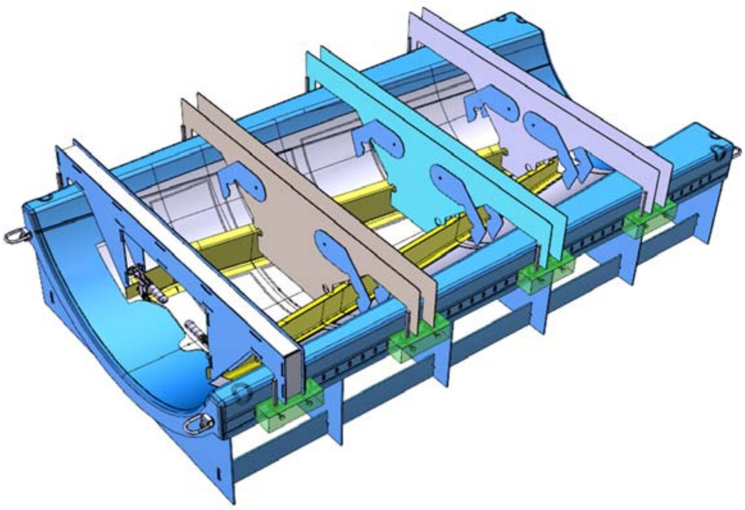


Figure 15: Tooling for secondary bonding of the spars to the airbrake skin (Source DLR FA Braunschweig)

After bonding non-destructive testing has been performed by means of ultrasonic inspection. The left hand side of Figure 16 illustrates the outer shell with the spars after bonding. Finally, the airbrake demonstrator has been assembled and is now ready to fly.

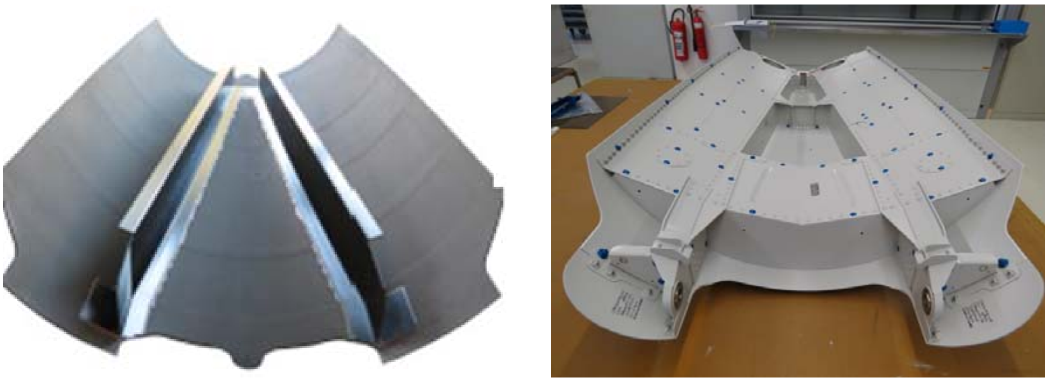


Figure 16: Outer shell with bonded spars (left) and Airbrake demonstrator after final assembly (right)

5.0 SUMMARY AND OUTLOOK

The joining of composite aerostructures is a crucial element which can influence the weight as well as the complete design of a structure. Due to current airworthiness regulations in civil aerospace industry in primary structures design features are used to stop a potential debonding. It is required in order to prevent non-systematic failures in the bondline (i.e. basically weak bonds). In the military aircraft industry similar airworthiness regulations apply for MALE (medium altitude long endurance) RPAS (remotely piloted aircraft systems). Therefore, the main objective of the R&T work presented in this paper was to develop and demonstrate a more robust and reliable secondary bonding process by adding several components such as additional surface treatment by plasma and additional process control specimen testing. The approach of the developed process has been applied to a Eurofighter Typhoon military aircraft part, the airbrake. A military certification concept has been proposed. The complete qualification process has been conducted according to the building block approach. The certification concept has been presented, discussed and agreed by the German military airworthiness authorities

Next step is first flight. This approach is expected to be transferred by a step-by-step approach to primary composite aerostructures for military and civil applications in close cooperation with military and civil airworthiness authorities in the next years.