R&T activities on composite structures for existing and future military A/C platforms at Airbus DS, Military Aircraft

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ABSTRACT

This paper gives a short overview on the state of the art in composite aerostructures for civil and military aircraft. Major challenges are highlighted in this context and the requirements from military aircraft point of view are illustrated, derived from existing and future military aircraft perspectives.

The main objective of the paper is to present the R&T activities in the aerostructure research program called FFS, advanced aerostructures. The activities range here from structural bonding, advanced radomes, new thermoplastic composite technologies and new materials and structures for low observability purposes. A brief insight is given to each of the topic highlighting the challenges and approaches, finishing with a summary of future trends and emerging technologies.

1.0 INTRODUCTION

Composites offer several advantages over metallic aerostructures in civil as well as in military aircraft industry including reduced weight, less maintenance effort and costs due to “corrosion-free” composites and a superior fatigue behaviour compared to aluminium. The thermal expansion is much less and the material waste (“buy to fly ratio”) is more advantageous compared to aluminium structures. However, these advantages come along with higher material and manufacturing costs. For the prepreg technology for example the material has to be stored at -18°C, energy and investment intensive autoclaves are necessary and for quality assurance 100% non-destructive testing (NDT) is required in contrast to aluminium structures. The notch sensitivity, the hot/wet behaviour, (impact) damage detectability and poor electrical conductivity are additional drawbacks of composite aerostructures. Therefore the application of the most appropriate material has to be evaluated very properly during trade-offs taking into account the requirements. Decision on application must therefore target the best match of materials (characteristics) with design drivers including best match of materials choice with manufacturing technology.

In contrast to civil aerostructures, military aircraft structures have to fulfil additional requirements such as low observability and often higher in-service temperature in the case on supersonic aircraft. Military fighter aircraft are primarily designed for high agility manoeuvre performance throughout their flight envelope for a defined usage life and spectrum. Structural weight of the aircraft is minimized using advanced design principles, highly integrated structures and high strength materials. Compared to civil aircraft structures designed usage life is comparatively short while the stress spectrum is more severe. A basic difference consists also in the production rate. As the aircraft civil industry produces more than 40-50 aircraft (A/C) per months, in the military industry in Europe the production rate lies in the lower single digit region per month.

The objective of this paper is to give an overview on the R&T activities performed recently and partially still ongoing at Airbus Defence and Space, Military Aircraft division in Germany in the framework of the R&T progam FFS – Advanced Aerostructures. These activities cover a wide range from advanced joining technologies such as structural bonding, multiband lightweight radome, novel thermoplastic one-step manufacturing technologies, additive layer manufacturing and low observability materials and structures.

1.1 State of the art in composites

The military aircraft industry was an early adopter of composites in secondary as well as primary structures. Development of composites for aerospace use was both costly and potentially risky, therefore initial development was performed by military who had relatively large development budget and where the mission performance were key compared to the civil side. On the civil side composite development was restricted to non-structural applications first. The A310 was the first production aircraft to have a composite fin box; the A320 was the first aircraft to go into production with an all-composite tail; about 13% by weight of the wing on the A340 is composed of composite materials [1]. The ATR 72 was the first civil aircraft in production with composite outer wing boxes. The maiden flight of the ATR 72 was completed in October 1988 and the aircraft entered into service in October 1989. Figure 1 shows an overview of composite structural weight in different civil and military aircraft in the last 40 years. The latest military A/C developments such as Eurofighter Typhoon, A400M and F35 JSF are in the range of 36 – 40 % of composite structures related to the overall structural weight. The latest civil A/C programs such as Boeing B-787 and Airbus A-350 XWB are even in the range of 50-53 % composite.

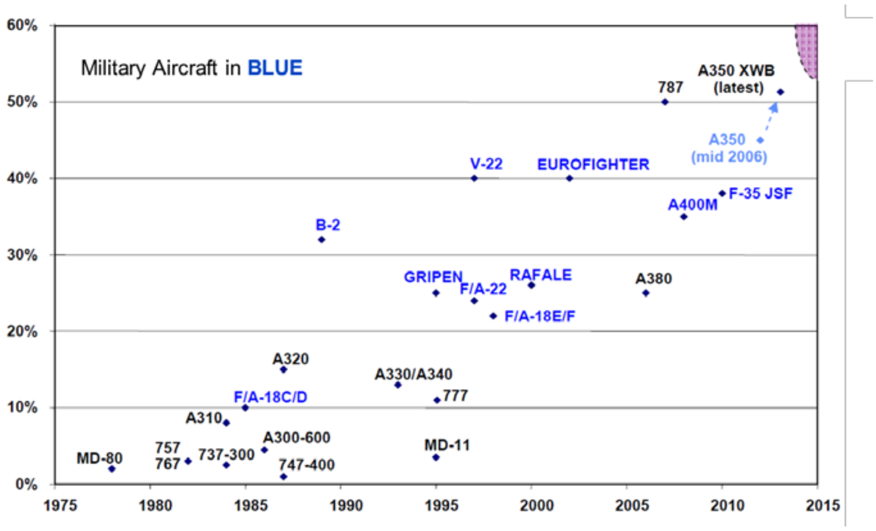

Figure 1: Composite structural ratio in different military and civil A/C programs [2]

Of course composite structures a not a panacea. In fact they have their advantages but also disadvantages and weaknesses. An overview based on a “Strength-Weaknesses-Opportunities-Threats” (SWOT) analysis of today’s composites is illustrated in Figure 2. This analysis is also the main basis for the definition of research and technology (R&T) and research and development (R&D) programs.

STRENGTH
- Specific properties (stiffness & strength)
- Excellent corrosion resistance
- Superior fatigue strength
- Less thermal expansion
- More complex part shapes possible
- Tailored properties
- Reduced material waste (buy to fly ratio better than for aluminum)

OPPORTUNITIES
- Fuel economy and reduced emissions (together with improved engines)
- Less maintenance costs
- Innovation and Automation in manufacturing (OoA, Higher Lay-up deposition rates…)
- Further part integration and integration of additional functions / Smart & Functional materials
- Legislation (e.g. environmental regulations, ACARE & Flightpath 2050)
- Cost of oil → Fuel economy

WEAKNESSES
- High material and manufacturing costs
- Notch sensitivity
- Hot/wet behavior
- Damage tolerance and damage detectability
- Fridge storage (Prepreg)
- Higher costs in quality assurance (100% NDT)

THREATS
- Innovations in competing materials (new aluminum alloys and Alu joining techniques, ALM)
- Carbon fiber availability together with possible price rise
- Single sourcing in material supply
- Reuse and Recycling Issues
- Legislation (e.g. REACH)
- Cost of oil → material production

Figure 2: Strength-Weaknesses-Opportunities-Threats (SWOT) Analysis of today's composites

Most of the civil as well as military composite aerostructures are based today on the prepreg technology using thermoset resin systems and autoclave curing. In the Eurofighter program co-curing is largely used in order to manufacture complex, lightweight high performance composite parts. In the civil A350 XWB program co-bonding with film adhesive and design features to prevent damage growth in bondline according to accidental damage, as currently required by the civil certification requirements is used. The lay-up is performed by prepreg automatic tape laying (ATL) and automated fiber placement (AFP) in order to reach cost efficiencies and achieve high production rates. An emerging composite thermoset technology, which does not require an autoclave ("Out of autoclave") is the dry fiber / dry textile infusion technology with curing in oven. Here dry fiber placement as well as non-crimp fabric (NCF) textiles are used. Another emerging trend today is the thermoplastic technology. This technology is rather limited today to small components and secondary structures, such as clips and cleads, which are manufactured from pre-consolidated organo-sheets by hot-stamping / press technologies. Different thermoplastic matrix systems such as PPS and PEEK are used here.

1.2 Existing and future military Aircraft platforms – Driver of R&T programs and innovations

Every R&T program has to be defined in order to support existing products for maintenance, repair and overhaul (MRO), to perform modifications, updates and upgrades on the one side and to prepare the technology basis for the development of new products on the other side.

Existing military A/C in Airbus Defence and Space, Military Aircraft range from combat aircraft such as Tornado and Eurofighter Typhoon to the Military Transporter, A400M, the light and medium transport aircraft such as C-212, CN-235 und C-295 and the Multi-Role Tanker Transport Airbus A330 MRTT.

In May 2015, France, Germany and Italy declared their intention to conduct a definition study in order to prepare the development of an European MALE RPAS (Medium Altitude Long Endurance Remotely Piloted Aircraft System) [3]. Spain became the fourth participating member a little later. In July 2017 MALE RPAS completed an initial 10-month definition process, with a basic configuration agreed among the partner companies and nations. The official development phase is due to begin in 2019, with a prototype first flight in early 2023 and delivery of the first system in the 2025 timeframe. In the much longer timeframe a successor of the Tornado A/C and of the Eurofighter Typhoon, a new military aircraft development, is supposed to be the main driver for R&T developments. Under consideration of the needs of existing and potential new developments, the R&T program FFS (advanced aerostructures) has been defined as a long term collaboration between Airbus Defence and Space, Military Aircraft Germany, the German Aerospace Center (DLR), the Bundeswehr Research Institute for Materials, Fuels and Lubricants (WIWeB) and the Airbus Central R&T. Some of the activities will be highlighted in the next chapter.

2.0 RESEARCH AND TECHNOLOGY (R&T) ACTIVITIES

2.1 Structural bonding

The joining of composite aerostructures is a key element which can influence the weight as well as the complete design of the 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 today 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 in the advanced aerostructures program 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, Figure 3, by changing the manufacturing concept of the series airbrake from co-curing to secondary bonding for the flight demonstrator (Figure 4). A military certification concept has been developed and proposed. The complete qualification process has been conducted according to the building block approach.

Figure 3: Eurofighter Typhoon (EFA) with deployed airbrake

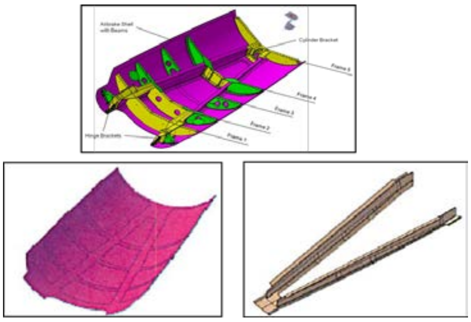

Figure 4: Structural concept and bonded components of EFA airbrake

In order to achieve repeatable, more robust, reliable secondary bonding processes the following main contributors 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 key aspect consisted in the development of process parameter for surface treatment by plasma. Figure 5 shows the plasma treatment of the outer shell of the Eurofighter Typhoon airbrake which has been performed at Airbus Central R&T in Ottobrunn in an automate way, by a robot.

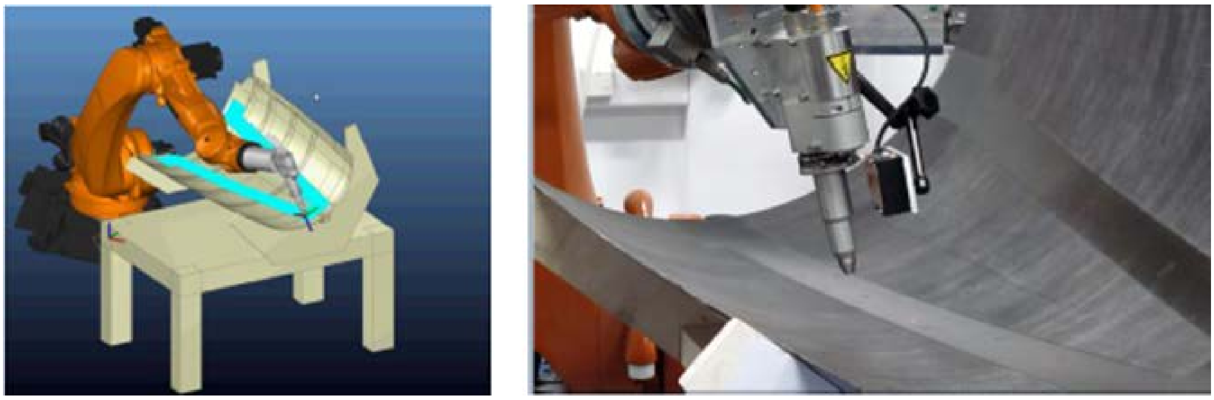

Figure 5: Automatic plasma treatment prior to bonding

Finally the complete manufacturing and final assembly of the bonded airbrake has been performed in order to achieve certification by the German Military Airworthiness Authorities (i.e. in German: Luftfahrtamt der Bundeswehr – Aviation agency of the federal armed forces).

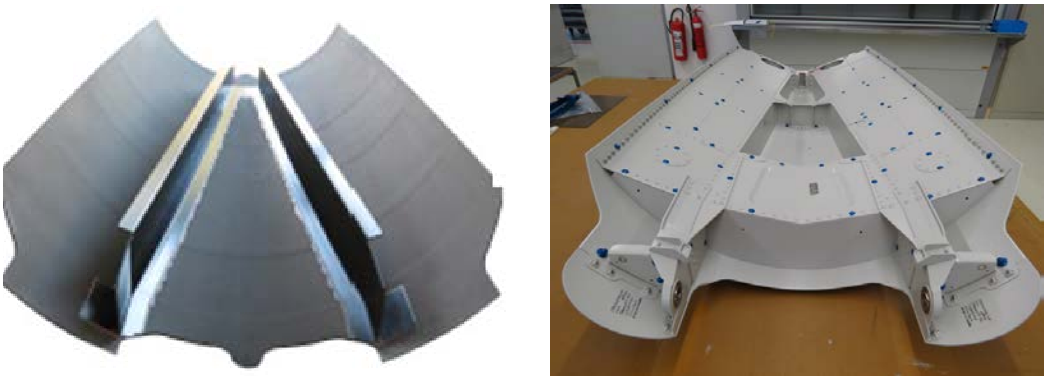

Figure 6: Outer shell with bonded spars (left) and Airbrake demonstrator after final assembly (right)

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.

2.2 Multiband lightweight radomes

The operational scenarios for future remotely piloted aircraft systems (RPAS) define challenging requirements with respect to data transmission systems. The central tasks of these systems consist essentially in the transmission of command and control data, navigation-relevant information and the transmission of sensor data such as SAR (Synthetic Aperture Radar) data, data from infrared sensors or the data of electro-optical sensors. The large amount of information require data transmission systems with high frequency bandwidth in order to ensure fast and efficient data transmission to other platforms or ground stations and thus to ensure fast data processing.

As a consequence, far-reaching demands for electromagnetically highly transparent behaviour as well as parallel coverage of different frequency bands (multiband requirement) also result for the associated radome structures (radome = radar dome).

Other main requirements for future RPAS radomes include:

- Mechanical robustness and damage tolerance, in particular resistance to bird strike
- Low weight
- Low production costs
- Processability of the materials used
- Resistance to weather conditions, in particular against lightning strike, rain and hail strike
- Inspectability, maintainability and reparability

In order to create a solid technological basis for future radome developments, new radome technologies are being developed and tested. Here, a generic typical SATCOM radome is defined as a representative target structure as the basis for technology development, Figure 7.

Figure 7: The SATCOM radome of a future MALE RPAS platform

In the beginning of the technology project several potential radome design concepts have been evaluated including an A-sandwich and a C-sandwich design (Figure 8).

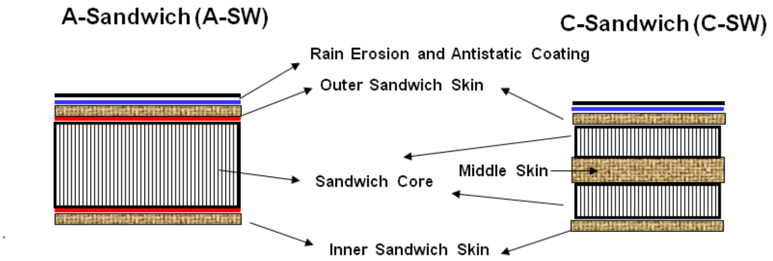

Figure 8: Sandwich radome structural radome concepts

Essential criteria in the selection of the materials used in the radome were high electromagnetic transparency, high strength, temperature stability and general resistance to environmental influences as well as availability. Finally, the following materials are used in the manufacture of the radome:

- Quartz-Glass / Epoxy prepreg
- Stabilized NOMEX honeycomb as sandwich core,
- Film adhesive for stabilizing and connecting honeycomb with fiberglass skin,
- Splice adhesive for bonding the core segments

In addition, lightning diverter strips are used as lightning protection system. Figure 9 shows the tooling for forming the honeycomb core (on the left side) and the glass fiber reinforced autoclave tooling for curing the radome.

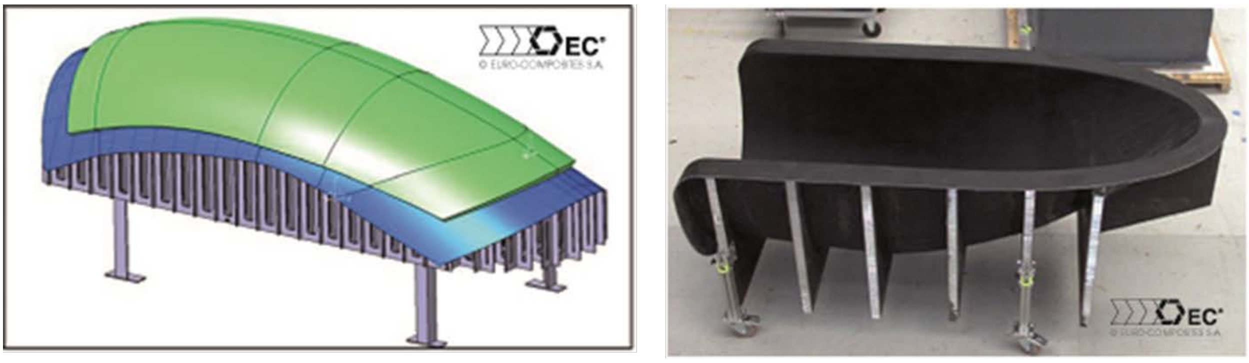

Figure 9: Outer shell with bonded spars (left) and Airbrake demonstrator after final assembly (right)

Finally a full scale radome demonstrator has been manufactured with an external supplier based on the built to print principle. In order to achieve the TRL (technology readiness level) different tests have to be performed on the radome demonstrator which consist of subsequently measuring the electro-magnetic transparency, a lightning strike test and a bird strike test. It is planned to achieve TRL6 by May 2018.

Detailed information on these developments can be found in [4] – [6].

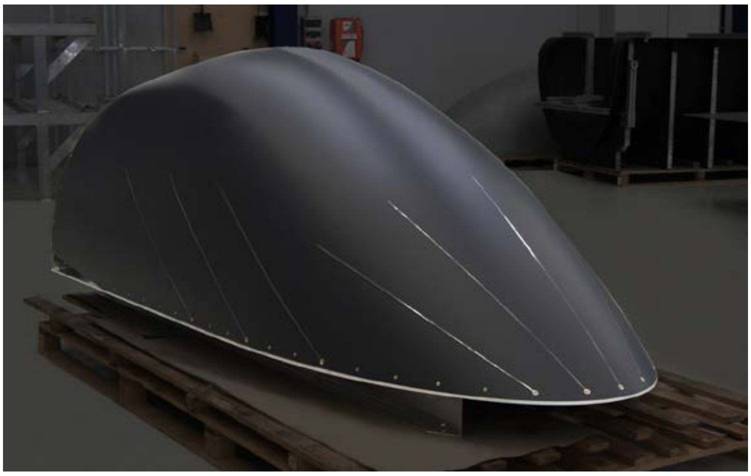

Figure 10: Full scale SatCom radome demonstrator

2.3 Thermoplastic composites

Thermoplastic materials offer several advantages compared to thermoset materials, such as improved mechanical properties, better impact resistance or unproblematic shelf-life. Unfavourable are, however, the relatively high material costs and the processing technology which is still not completely matured yet. Although the tape placement technology for thermoset and thermoplastic systems is known for many years, only the processing of thermoset systems has been established today on an industrial scale. The fiber placement and tape laying technology using thermoplastic matrix systems such as low-cost and low-melting point PPS and high performance PEEK and PEKK has made big progress in the last couple of years. Especially the development of high-performance and controlled laser heating technology is a main contributor and enabler of the thermoplastic tape placement technology, on the manufacturing facilities side.

Figure 11 shows the basic design of a thermoplastic tape laying head for in-situ consolidated laminates.

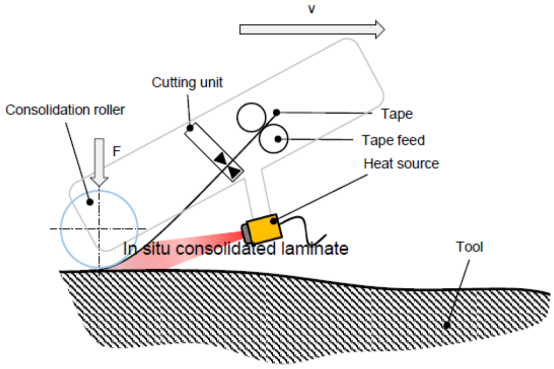

Figure 11: Basic design of a tape laying head

After placement of the composite lay-up the thermoplastic laminate can be consolidated by vacuum in oven (2 step process). In order to save lead time and manufacturing costs the main goal is to perform the consolidation “in-situ” that means without any additional consolidation step in oven, autoclave or press. The development of such an “in-situ” consolidation 1-step process is therefore the main objective of the R&T activities. The main challenge is to achieve good laminate quality (i.e. porosity content, surface quality, interlaminar strength, process induced geometrical deformations, etc.). This starts with the tape quality, i.e. of the raw tape material before laying up. In the case of in-situ consolidation, 1-step process, the requirements for the tape quality are much higher since no additional consolidation step, which in general reduce the porosity and increase the laminate quality takes place. Figure 12 shows the facility available at DLR Stuttgart and used in the project for investigations on process parameters. The basic fiber placement head is mounted on a state of the art industry robot.

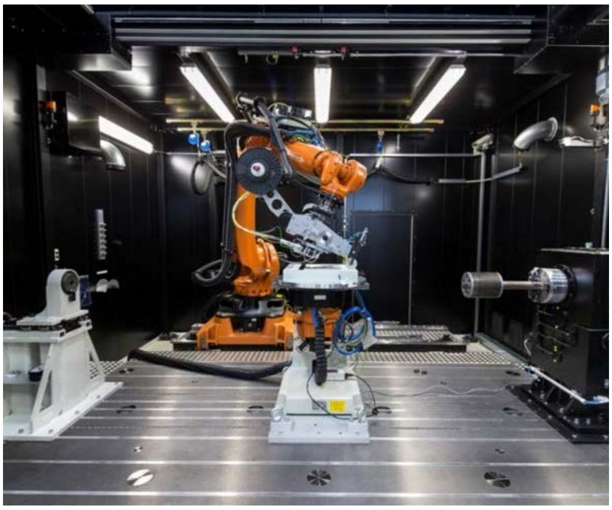

Figure 12: Automatic thermoplastic tape laying facility at DLR Stuttgart

The in-situ consolidation, 1-step thermoplastic process using fiber placement or tape laying has a TRL of 4 today. Since the process for production is not mature yet several basic research is ongoing for the definition of the process parameters and the appropriate passive or active feedback control. One of the basic tests here is the mode I test (Figure 13, right) in order to evaluate the interlaminar strength which is a basic property that is determined by the consolidation method.

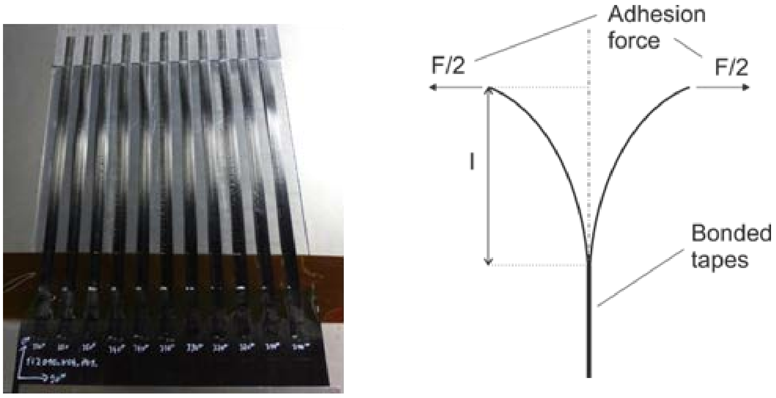

Figure 13: Manufacturing trials using the thermoplastic in-situ consolidation technology and experimental testing of adhesion force for evaluation of the consolidation quality

2.4 Low observability materials and structures

Materials and structures for low observable (LO) aircrafts pose specific challenges for manufacturing technologies. For LO designs a precisely defined electrically conductive surface structure with locally applied radar absorbing materials and structures is required. Compared to conventional manufacturing, additional challenges are:

- High precision manufacturing at affordable cost is required to achieve:
    - Small steps and gaps between different skin panels or around doors are required as seen in Figure 14, as each discontinuity of the surface impedance causes additional radar scattering.
    - Precise thickness control of multi-material layered structures is necessary, as the spacing between layers has an influence on the radar return interference pattern caused by the multilayer design.
    - Precise control of the material composition of a composite is required, as a change of the volume content of the constituents, e.g. a reinforcement fibre, changes the dielectric constant of the material and thereby the relation between physical thickness of a layer and the wavelength in the material.
    - Precise thickness of paint layers is necessary.
- Integration of different materials into one structure is a key challenge for multi-material layered structures, as the different coefficients of thermal expansion can cause excessive thermal stress and deformation both during manufacturing and during operation.
- Repair and maintenance

Thus, manufacturing technology is an integral aspect of LO design, which is reflected in multiple ongoing technology programs. Details however are classified.

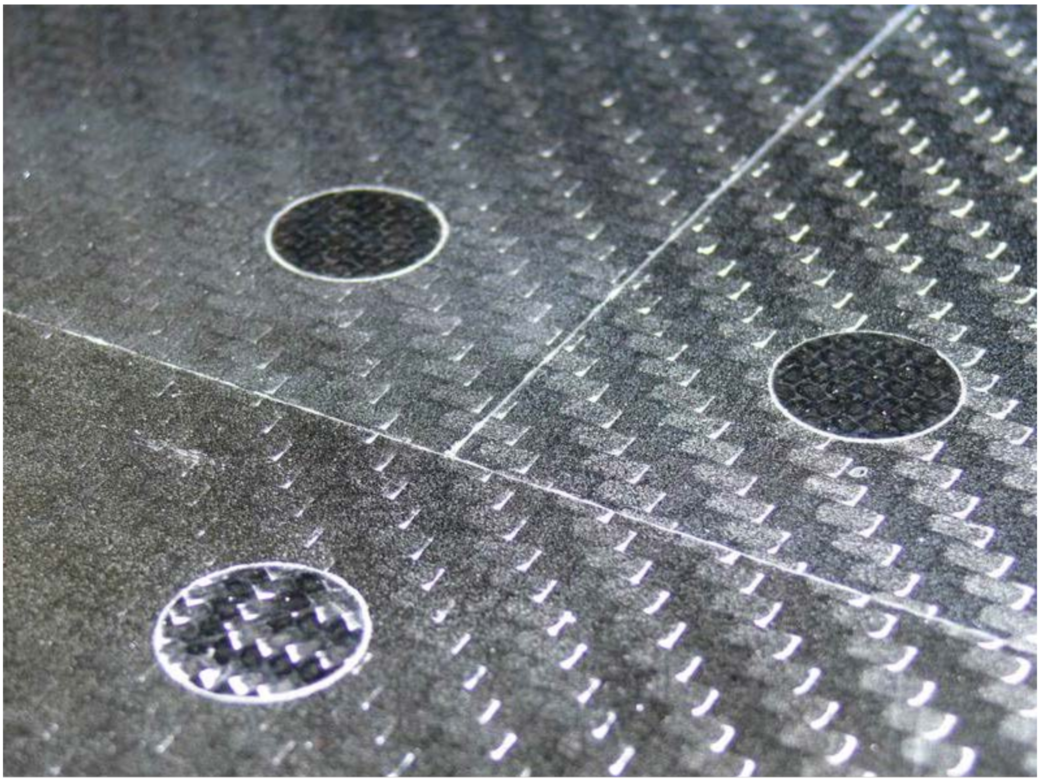

Figure 14: High precision joint between composite panels with hidden fasteners on an LO test component.

3.0 SUMMARY AND OUTLOOK

The composite technology has found the way into primary aerostructures for civil and military applications for many decades already. Especially driven by the civil aerospace industry, the main developments consisted of increased automation for high rate manufacturing and further evolution of the existing prepreg thermoset technology on a very high level, rather than disruptive new concepts or technologies. One of the main trends in thermoset technology is the OoA dry fiber and textile technology using injection and infusion technologies and oven curing. The dry textile and infusion technology is driven today by a lot of manual work, such as the lay-up of dry textiles. Automatic deposition of dry fiber tows is a major field of research and technology these days, basically driven by the civil aerospace industry for high rate manufacturing. An emerging technology is the development of advanced joining technologies such as structural bonding in order to reduce fasteners or even eliminate them completely. Thermoplastic composites are limited today in the aerospace industry to rather small, secondary structure parts using the hot-forming, press technology. Automated fiber placement and tape laying with thermoplastic pregregs and in-situ consolidation (“1-step” process) is considered as an emerging technology also of high interest in the military aircraft industry where the number of parts is rather less compared to civil aircraft.

In the Airbus Defence and Space, Military Aircraft division several emerging structure technologies are evaluated, assessed and developed for application in existing (for upgrades, modifications and repair and overhaul) and future military aircraft programs. Some of them are addressed in the R&T program FFS (advanced aerostructures) and presented in this paper.

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