Automated Manufacture of Fibre Metal Laminates to Achieve High Rate of Production

Fibre metal laminate made from glass fibre prepreg and thin aluminium sheets is an alternative material for aircraft fuselage. It has advantages over monolithic aluminium used so far and over other composite structures. Premium AEROTEC is developing solutions for automating and reducing the current supply chain, creating the basis for the introduction of fibre metal laminate at high rates of production.

Authors

DR. HILMAR APMANN is Head of Core Technologies at Premium AEROTEC in Varel (Germany).

MATTHIAS BUSSE is Member of the Core Technologies Team at Premium AEROTEC in Varel (Germany).

JIA-YANG DU is Member of the Core Technologies Team at Premium AEROTEC in Varel (Germany).

PATRICK KÖHNKE is Member of the Core Technologies Team at Premium AEROTEC in Varel (Germany).

Advantage and Challenge of Laminates

The proportion of composite components in the aerospace industry is growing steadily and poses a challenge for the design of aircraft, as some of the structures that need to be manufactured are very large. One important area of application for fibre metal laminates (FML) – previously known as glass laminate aluminium reinforced epoxy (GLARE) – in aircraft construction is the manufacture of sections of the fuselage for the Airbus A380. GKN Fokker and Premium AEROTEC manufacture a total of 27 skin sections for the A380 from FML, Figure 1.

The primary reasons for the use of this laminate are the advantages of the material compared with the monolithic aluminium

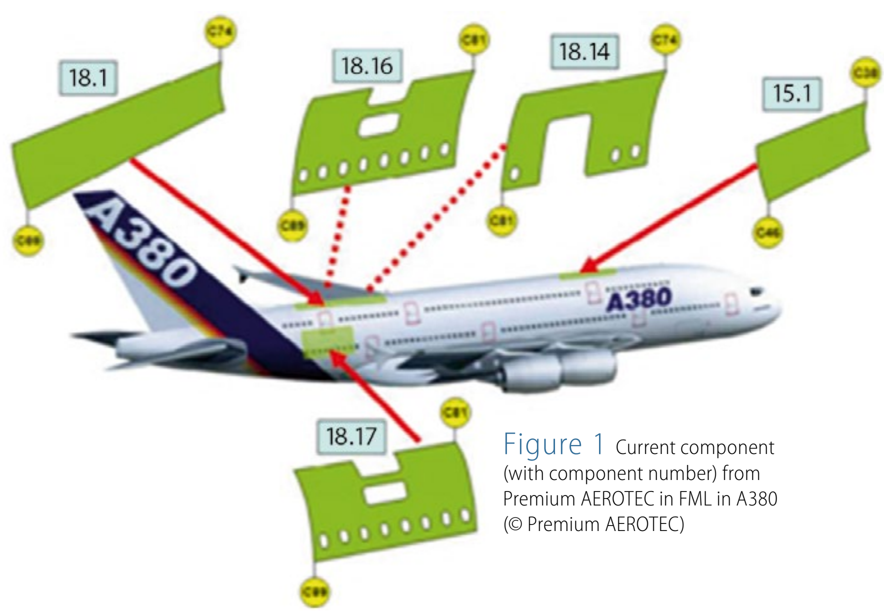

Figure 1 Current component (with component number) from Premium AEROTEC in FML in A380 (© Premium AEROTEC)

materials that are currently used. In addition to a lower density accompanied by high stiffness, these include above all high damage tolerance. This results in an important field of use, especially for large structural components. These weight savings, especially in aircraft construction, lead to greater fuel economy and a longer range, meaning lower costs for the operator, and ultimately, for passengers. Initial design calculations for the use of this FML material in so-called single-aisle programmes (Airbus 320 or Boeing 737 structure) indicated weight reductions of well in excess of 15% compared with the materials currently deployed.

However, experience from the A380 at Airbus programme points to the need for improvements in design, the combination of materials used, costs and process chain if a high output rate is to be achieved for FML.

For this purpose, a development project was set up three years ago in which the required automation steps for the manufacture of FML have been introduced. The basis for implementation is the automated construction of laminate from thin aluminium sheets and glass fibre prepreg. Furthermore, it is also necessary to integrate the stringers and required adhesive film strips into the automated process. Premium AEROTEC has been working with its partners Airbus, GKN Fokker and Stelia for around three years to meet the challenges of the automated manufacture of FML for the high rates of production in aircraft construction.

This article summarises a number of different concepts and results from the last few years. A further focus of the developments is on the industrialisation of FML manufacture for future aircraft programmes with a high output rate.

Current Production Process

In the current production process, virtually all the FML skin sections of the A380 are manufactured in mostly manual process steps [1], Figure 2. The aluminium sheets – with a maximum thickness of 0.4 mm, maximum width of 1.5 m and maximum length of 5 m – are cut and milled mechanically. The sheets then undergo chemical pre-treatment and receive a coat of primer. They are then ready for the laminate to be built up. They are inserted into the curing unit by hand. The prepreg strips are first cut to size and also inserted by hand [2]. Adhesive film, doublers as well as the stringers are also integrated manually. The use of laser projection equipment provides significant assistance to the operators. The laying process therefore needs logistical support to enable the right strips to be laid in the correct location. The concluding process step in laying up the laminate involves creating a vacuum, which is also performed almost completely manually.

After the initial curing process in an autoclave, the skin sections undergo non-destructive testing (NDT). The skin sections are then placed in the curing unit to allow further assembly with doublers and stringers. The second curing process in the autoclave is then performed. After an NDT process and surface protection, the skin section is then released for the further assembly process. The manual process steps lead to low productivity. This means that these rates of productivity will have to be increased considerably for additional and future applications in the aerospace field.

> Rates of productivity need to be increased significantly for further applications in the aerospace field.

One possible approach to achieving much higher rates of production is to use automated laying processes for fibre metal laminate made from thin aluminium sheets and glass fibre prepreg. Furthermore, the requirements of positioning precision for aerospace must be met. In this connection, automation technology is used to perform reproducible processes that are more productive than the previously adopted processes while meeting the exacting demands of the aerospace industry.

Research and development into handling, positioning, measuring and control is being conducted to this end, with special automa-

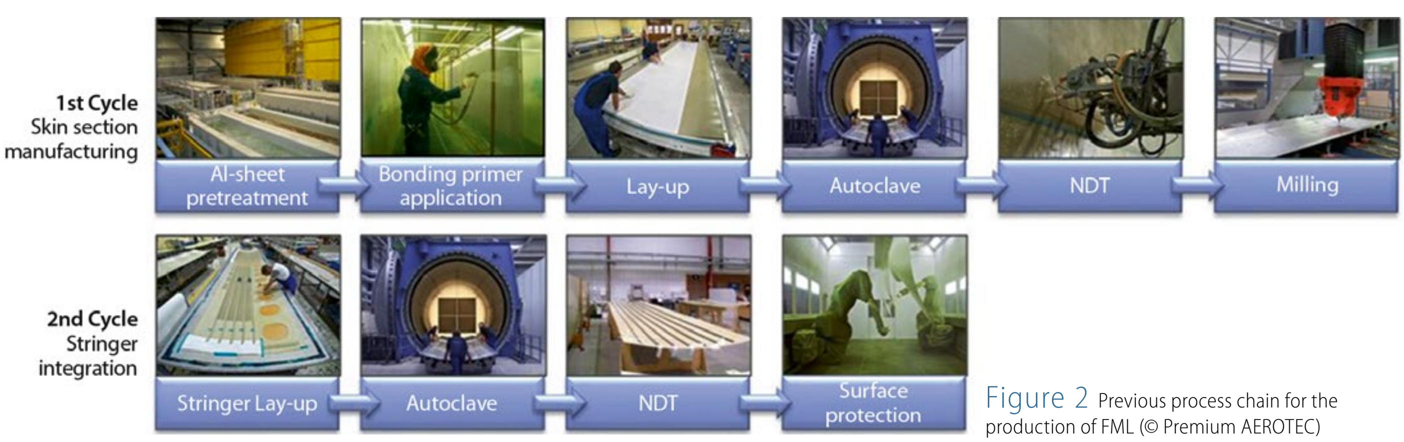

Figure 2 Previous process chain for the production of FML (© Premium AEROTEC)

tion processes for use in the FML area being developed [3]. Besides the technical challenge, it will also be necessary to adapt the design to the manufacturing process and to optimise the process chain.

Concept for Automation

Premium AEROTEC began developing an automatic tape laying (ATL) head more than five years ago that is capable of laying a 230 mm wide tape. This was the first step in testing the possibilities for a production rate approaching that of series production using an automated laying process. Following initial studies and tests, the laying head was further developed for a laying width of 460 mm. This allowed a normal roll of prepreg from series production to be integrated into the laying head. The laying head was affixed to a standard robot, Figure 3. Here, the prepreg material is fed through the laying head and laid in the curing unit by a draping unit with adjustable pressing force. The backing paper used to hold the prepreg is then peeled off as a separate roll following the laying process. For this purpose, a complete roll with glass fibre prepreg is inserted into the end effector. At the same time, the end effector is attached to a robot in order for it to be deployed flexibly, Figure 3. The prepreg is guided by guide rollers in the end effector to the draping unit, where the material is pressed onto the jig or onto the laminate with a defined force. The backing paper is wound onto a winding roll and remains in the end effector while the prepreg remains in the component. The draping unit is divided into narrow rollers that can be adjusted flexibly and individually in order to be able to follow the contours of the jig and hence the component. Geometries of down to 1600 mm in radius can be covered by the draping unit.

The draping forces used guarantee the high quality of the laminate that is required during the laying up process. Two ultrasonic cutters are used to cut the prepreg longitudinally and laterally, allowing the prepreg layers to be cut to match the specified design. The cutters can also create geometries like corners or any type of free-form cut, allowing cylindrical as well as spherical geometries to be laid up using the end effector.

> Initial design calculations indicated weight reductions of far in excess of 15 %.

The data required for the laying up process are input into the control system directly from the CAD model and define the position, travel path and contour settings for the prepreg end effector. The direct connection of design and production thus also guarantees simple quality management (QM) processes, since quality, position, fibre direction and overlap or gap of the prepreg layer can be monitored during the laying up process and stored in the QM system.

An additional end effector is also required to insert the thin aluminium sheet in order to produce the FML laminate. The thin sheets are made available on a flat table on which sensors are used to register the position and orientation of the sheet. These data are transferred to the control system so that the sheet can be picked up according to its position and laid to match the contours. For this purpose, it is possible to adjust the end effector via the geometry adjusting unit to match the laying jig, Figure 4. This principle can be used to produce any required geometry and thus forms the basis for producing FML laminates at high production rates in aircraft construction.

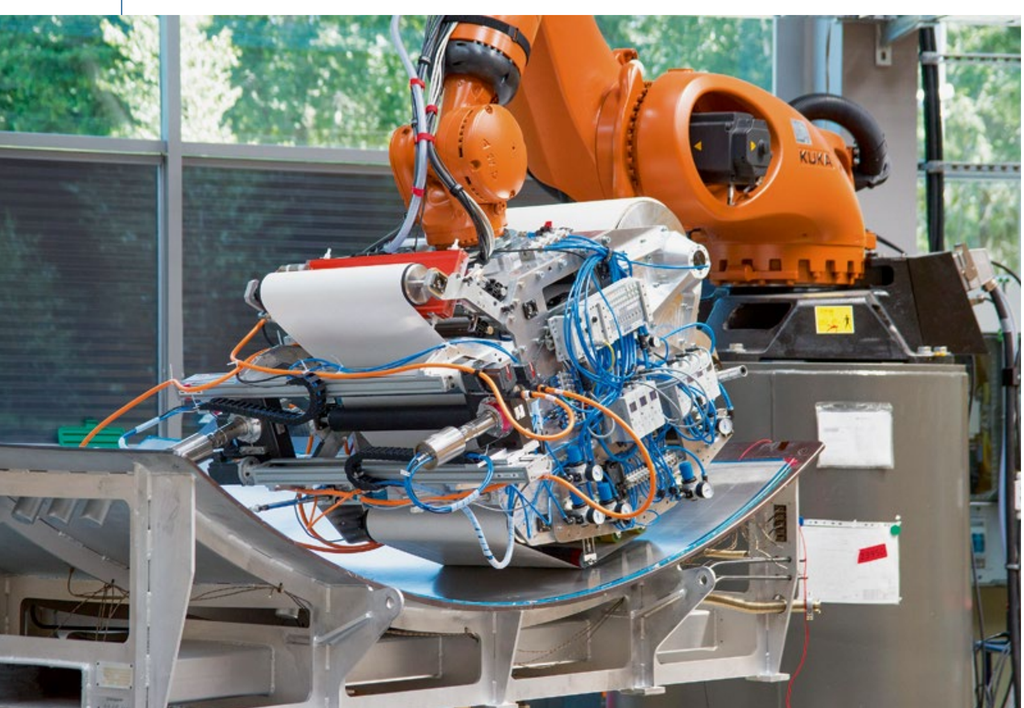

Figure 3 Laying head for glass fibre prepregs in FML (© Premium AEROTEC)

Initial Series of Tests

An initial series of tests was performed in order to demonstrate the feasibility of using ATL and picking-and-placing, producing cylindrical demonstrators measuring 2 m x 2 m with a skin structure consisting of 4/3 laminate – four layers of thin aluminium sheets and three double layers of prepreg. The design provided for joints on the sheet – so-called splices – in different locations.

The second milestone was the demonstration of the feasibility of the technology on spherical geometries with the same size of 2 m x 2 m. In this case, the geometry to be laid is far more complex than that of the cylindrical demonstrator, with 1600 mm as the minimum radius that is possible to be produced. Both geometries were taken from a component in the current aircraft programme in order to allow for a realistic demonstration. In both cases, it was possible to demonstrate that automated construction of the laminate is possible using end effectors and also that the required quality standards can be met.

Demonstration for Series Production

Following the successful laying of the first demonstrators, each measuring around 2 m x 2 m, the next step in the development of the technology was decided upon in the project. To this end, the manufacture of a further demonstrator measuring approximately 2 m x 6 m was planned. The aim was to completely automate the laying up process of the laminate with thin aluminium sheets and glass fibre prepreg as well as the application of the adhesive film and the integration of the stringers in order to produce a panel. Instead of the processes that had previously been automated, the picking-and-placing process for laying the sheet and the prepreg was chosen to be used. This was to be a significant step towards the introduction of automation technology for series production in the manufacture of FML panels. The dimensions and the geometry of the planned demonstrator panel were taken from a current component in a series production programme of Airbus and represent the most complex geometry of the fuselage. The intention of this was to demonstrate the potential of series production with regard to manufacturing times, costs, throughput time and quality compared with the current production of FML.

A new test cell was set up in the technology centre at Premium AEROTEC's site in Nordenham. The test cell was set up within just over three months in cooperation with its existing project partners and new partners FFT and IFAM from the Fraunhofer Society in Stade. Figure 5 shows an overview of the test cell in the technology centre for the automated laying of glass fibre prepreg, thin aluminium sheets, adhesive film and stringers. The test cell consists of a total of two robots and five end effectors. One robot travels on a linear unit using the end effectors to integrate all the elements of the laminate assembly. The second robot is stationary and supports the process with the integration of the stringers in a cooperative control system together with the first robot.

The design of the demonstrator panel corresponds to the most curved component with regard to longitudinal and lateral curvature in the fuselage of an airliner from the Airbus family. It has a double-curved geometry. In terms of FML design, the panel has lateral splices, i.e. aluminium sheets are inserted that meet and are glued in the transverse direction of the panel. As a result, the aluminium sheets are not much larger than 1.3 m x 2 m. They are then preformed and thus double-curved. The glass fibre prepreg has a maximum width of 460 mm and a maximum length of 6 m. The prepreg is inserted both longitudinally (max. 6 m) as well as laterally (max. 2 m). The adhesive film is laid in the vicinity of the splice below the stringer using a separate end effector. Furthermore, two cooperative robots with two

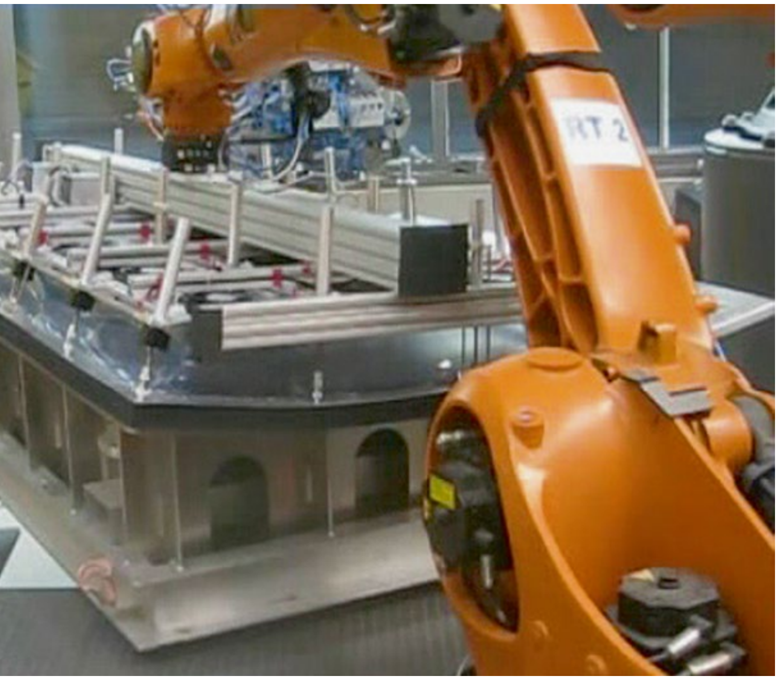

Figure 4 End effector for laying up aluminium sheets in cylindrical geometries (© Premium AEROTEC)

Figure 5 Test cell for the automated lay-up of FML (© Premium AEROTEC)

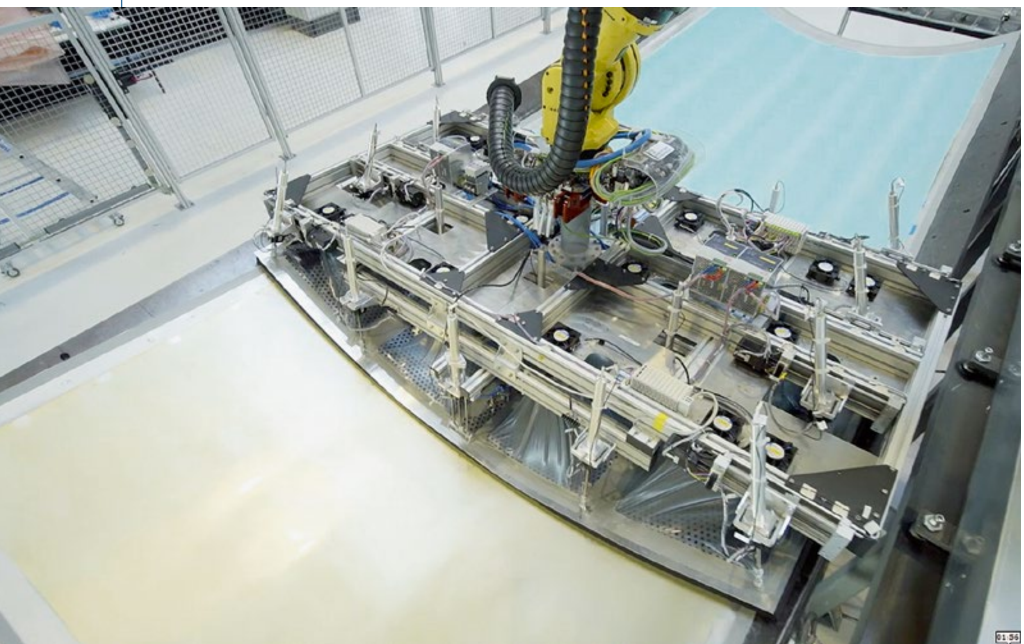

Figure 6 Laying up thin aluminium sheets for FML (© Premium AEROTEC)

additional end effectors are used to integrate a total of 14 stringers of up to 6 m in length.

For the special design devised for the FML demonstrator, all parts of the test cell must show that all demonstrator components can be built up at a series production level. The five end effectors required for this purpose were developed and manufactured by different partners. IFAM developed the end effectors for laying the adhesive film and integrating the stringers. Premium AEROTEC realised the end effectors for handling and positioning the sheets and the prepregs. As the integrator, FFT assumed responsibility for the control system for the cell as a whole and collaborated with the other partners to develop and implement the automated laying and integration processes.

> The demonstrators meet the lay-up tolerances of ± 1 mm.

Premium AEROTEC developed end effectors for handling and positioning the aluminium sheets and glass fibre prepregs based on the same principle. One of the end effectors measures approximately 1.6 m x 2.1 m and is used both for integrating the sheets and laying the lateral (90° direction) prepreg strips. The prepreg strips are taken up by a staging area and inserted into the curing jig. The pre-formed aluminium sheets are picked up in a staging device before being positioned in the curing jig. The end effector can change the geometry via linear adjustment axes in order to ensure the prepreg strips to match contours correctly. The end effector for the up to 6 m long longitudinal prepreg strips (0° direction) is approximately 0.6 m wide and 6.3 m long and also takes up the prepreg strips from a flat surface to then integrate them in the demonstrator component in accordance with the required geometry. Linear axes are also used the set the contours for the end effector. Both end effectors operate according to the same principle. The contour is controlled by linear axes seated on a supporting frame. Handling is effected by means of a vacuum generated by fans and realised with a sturdy perforated plate and foam on the underside of the end effector. This principle allows sheets and prepregs to be handled and positioned. Figure 6 shows the end effectors in operation.

FFT worked with Fraunhofer's IFAM to develop end effectors used to integrate the stringers based on a principle currently used in the series production of the A350. The stringers are held by at least two robots, with one of the robots travelling the length of the stringer, fixing it to the component at regular intervals using an infrared heating process. A special end effector was developed by partner IFAM to integrate the adhesive film and is able to lay the 25 mm wide adhesive in the component. The adhesive film is provided on a roll. It is unrolled on the end effector together with backing paper and laid and fixed in the component by means of a thermal process. The adhesive film can be cut to length during the process. The backing paper is rolled up and subsequently disposed of. The end effectors are shown in Figure 7.

The end effectors and processes for the automated laying of FML panels were developed, implemented and tested within a period of about three months. The demonstrator panels were constructed in a fully automated process in the test cell of the technology centre after a total development time of six months. The demonstrators produced meet the lay-up tolerances familiar in the aerospace industry of less than ± 1 mm and also fulfil the demands for laying speed and automation. The quality of the components matches that of series production in the A380 programme, which is today almost exclusively performed manually. In addition to the automated manufacturing process for laminates, the single-shot process was also developed to enable the skin (sheets and prepregs) as well as doublers and stringers to be produced in one curing process. Combining the single-shot process with the automated laying process reduces manufacturing costs considerably.

Next Steps

In the future, a demonstrator panel in an uninterrupted serial process step at an accepted process laying speed is planned to

Figure 7 Laying up glass fibre prepregs for FML (© Premium AEROTEC) (© Premium AEROTEC)

be manufactured. This will demonstrate process times with a target pick-up and laying time of around 1 min for each strip and sheet. It will reflect the process times currently assumed for the business case and support implementation of the automated process approaching that of series production. Furthermore, additional design variants (for example, longitudinal splices and flat sheets) was demonstrated in an automated process in the test cell by summer 2017. This will involve comparisons between various designs and the resultant production times and costs in order to achieve optimum implementation for series production. The test cell will be extended from autumn 2017 in order to be able to set up the next development step for demonstrator panels measuring 4 m x 12 m. The geometry will reflect the largest components in the fuselage of short- and medium-range aircraft in the Airbus family. These demonstrators are planned to be manufactured in the technology centre from summer 2018.

Conclusion and Outlook

Premium AEROTEC and its partners Airbus, GKN Fokker Aerostructures and Stelia Aerospace, together with other partners in the AutoGlare LuFo project, are collaborating closely in the field of automated manufacture for large FML components. The goal is a significantly higher rate of production for FML components for aircraft bodies. Besides shortening the process chain, the principal development approaches involve the automated manufacture of laminates and panels. The milestones and project outcomes achieved so far have shown that the automated manufacture of FML components enable significantly higher rates of production to be achieved. The next milestone in summer 2018, the automated manufacture of an FML demonstrator measuring 4 m x 12 m, is planned to show that fuselage structures made from FML can be produced efficiently and cost-effectively. This would then be the prerequisite for the manufacture of FML structures in current or future series production programmes of aircraft manufacturers like Airbus.

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Thanks

This paper is based on the long years of collaboration between partners Airbus, GKN Fokker Aerostructures and Stelia Aerospace in the development of manufacturing processes for fibre metal laminates (FML) for the aerospace industry. The authors would also like to thank the people responsible for aerospace research funding at the Federal Ministry for Economic Affairs for their substantial support. Partners Airbus, Premium AEROTEC, the Fraunhofer Society, DLR and AirbusGroup Innovation are collaborating on the "AutoGlare" LuFo-V-2 to further develop the material FML.