Production of a Full Scale Demonstrator-Structure within the FP7 Project “Maaximus”

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1. Introduction

According to [1], the main objectives within the EU FP 7 project “Maaximus - More Affordable Aircraft through eXtended, Integrated and Mature nUmerical Sizing” are as follows:

Highly-Optimised Composite Fuselage:

- Enable a high-production rate: 50% reduction of the assembly time of fuselage section
- Reduce the manufacturing and assembly recurring costs by 10% compared to the ALCAS equivalent reference
- Reducing weight by 10%, compared to best available solutions on similar fuselage sections.

Faster Development:

- Reduce by 20% the current development timeframe of aircraft composite structures from preliminary design up to full-scale test
- Reduce by 10% the non-recurring cost of aircraft composite structures from preliminary design up to full-scale test (ALCAS reference)

Right-First-Time Structure:

- Reduce the airframe development costs by 5% compared with the equivalent development steps in an industrial context

As demonstrator and validator structure a side shell with a pax door was chosen (see picture 1). The design refers to an actual aircraft with a wide body fuselage.

Within the project phase 2, the German Aerospace Center (DLR) as work package (WP) leader is responsible for the WP 7.6 “Manufacturing & Assembly”. Figure 1 shows the major contributors and the parts, for which they are responsible. The large stringer stiffened skin incl. its curing as well as the C73 frame in the door surround structure belong to the scope of DLR. The present paper is concentrated on the way of manufacturing of these two components.

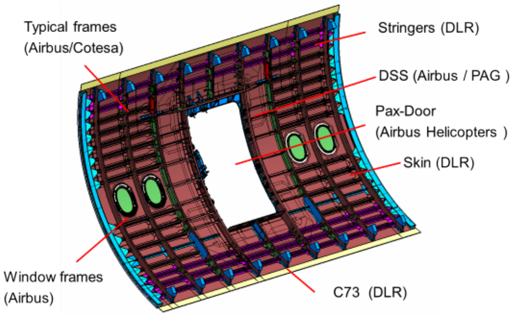

Figure 1: CAD-model of the Maaximus physical demonstrator with part supplier

2. State of the art

Some major tasks while producing a side shell are the lay-up of the skin, the manufacturing of all longitudinal and cross-sectional stiffeners.

With state of the art technology, the skin lay-up is done by fully automated fiber placement (AFP) machines, consisting of one lay-up head mounted on a gantry system. Due to the gantry concept, only some meters of additional space are needed around the part as it is visible in Figure 2.

Figure 2: Production of an A350 crown panel (Source: Airbus)

Another type of machine which is often used for fuselage panel production is shown in Figure 3.

This floor-mounted machine is able to place up to 32 individual tows or slit tape to produce a variable bandwidth "on-the-fly". But like the gantry mounted machine, only one head is in service at one part.

Figure 3: CNC Fiberplacement machine Viper 6000, Source: Fives Cincinnati

Male toolings are used as well as female toolings. Especially in the door area, lots of reinforcement patches have to be placed. These door surround patches are actually manufactured with a separate lay-up machine and feeded by hand or by robots with grippers.

The stringers as well as the differential type typical frames are manufactured on male toolings out of thermoset prepreg materials. Some long range aircrafts with a primary structure mostly made of CFRP, are equipped with a metallic door surround structure. Newer developments using a CFRP solution, placed by robot mounted AFP-heads.

The assembly is a very time consumptive process due to the differential approach. With the stringer stiffened skin as the masterpiece, all the smaller parts were riveted together with a high amount of hand drilled holes for the rivets.

3. Maaximus approach

With the side shell from the running production of a state of the art - aircraft as the reference, a lot of new technologies are chosen and used for the Maaximus demonstrator.

In WP 7.4 a complete new stacking sequence and ply book was developed. Instead of the door surround patches, a new ply book with integrated reinforcements around the door cut out was used. The latter could be applied by the same fiber-placement-head, which was used to apply fibers to the other areas of the skin. Beside the benefits in the mechanical performance, this solution saves a lot of production time and costs. The only drawback is a slightly higher effort for programming the pathes of the fiber placement machine. But the time savings due to the integrated door surround reinforcements are such high, that the higher effort for programming will be amortized rapidly.

The skin lay-up is done by a completely new and unique lay-up machine – the GroFi-plant of the DLR, which is described in detail in the references [2] and [3]. In a nutshell, the concept consists on up to eight industrial robots from KUKA, which were equipped with endeffectors to apply fibers. The robots are mounted on track guides carriers. The robot/carrier combination with its control and all the necessary equipment to carry and apply fibers is called "platform" within the further text.

To avoid downtime due to refilling of the endeffectors or maintenance of the complete platforms, the track system was divided in a production loop and a maintenance area. The production loop surrounds two vertically mounted toolings. Thus, a simultaneous processing of two larger parts in one machine is possible.

Both, the production loop and the maintance area, are linked via turning tables. These turning tables allow the platforms to move on every chosen position within the track system. This simple but effective solution is shown as a CAD-model in Figure 3.

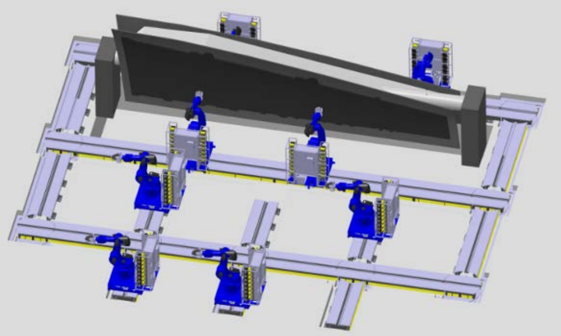

Figure 4: CAD model of the GroFi-Concept

On each long linear track or axis, up to four platforms are working together on one part.
With the above mentioned two-side tooling scenario, up to eight platforms are working on two parts in one machine.

Futhermore the GroFi concept allows a combined lay-up with several tape laying and fiber placement heads working simultaneously together on one task.

Up to now, a coordinated processing of a ply book with two platforms was demonstrated. A theory to distribute a lay-up task on three or more platforms is developed, implemented and tested by simulations. A large wingcover-tooling (18 m length), which provides enough space to demonstrate the coordinated lay-up with three platforms will be mounted by the end of 2015.

Besides Prepreg- layup, an automated preforming cell, as part of the EVo RTM-production line [4] is used for a near net shape preforming of two specific frames. This automated process consists of the sub processes ply preparation, robotic draping, local binder activation consolidation and preform fine-trimming to net shape.

Individual plies of woven carbon fabrics get trimmed on a cutter and handled by an array of coanda grippers. Their exact position on a transition table is detected by a camera and picture analysis software and forwarded towards the draping robot.

Figure 5: Draping gripper for Z-shaped frames

It's two-part draping gripper collects the ply from the table and drapes it into its three dimensional shape. Each additional ply will be locally fixed to the one below by an electrical resistance heating [5], before it gets transferred to the next station, the consolidation press. This infrared heated membrane press will activate the binder globally and consolidate the preform into a stiffer state. This is necessary for the final fine trimming of the preform to net shape by an ultrasonic-knife.

Figure 6: Preform-fine trimming to net shape

This ensures that the preform will fit exactly into the RTM-mold in order to achieve a stable injection process.

4. Manufacturing of the stringer stiffened skin

Besides some smaller demonstrator parts to prove the fiber-placement and tape-laying platforms, the demonstrator of the EU FP7-project "Saristu" was the first full scale structure, which was manufactured in the GroFi-Plant. Figure 4 shows the lay-up of the skin in 2014.

Although the Saristu-demonstrators ply book and stacking sequence was simple in comparison to the ply book of the Maaximus demonstrator, it was a very good exercise on the way to Maaximus.

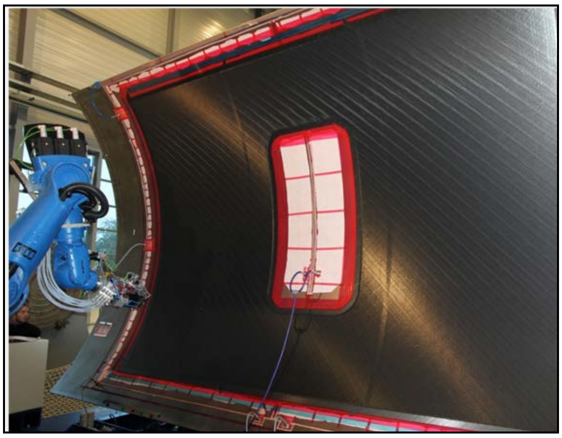

Figure 7: Skin lay-up of the "Saristu" demonstrator within the DLR's GroFi-plant

With its more than 200 different patches and full plies, the Maaximus skin was a real challenge. Due to the complexity of the Maaximus demonstrators ply book and the high cost and time risk, a safer single head solution was used for the skin lay-up.

During the development and computation phase of the demonstrator structure within WP 7.4, some earlier versions of the ply book were provided to DLR. This ply books or cut outs of the ply books were tested in respect to their processability with simulations and lay-up trials. The results and experiences were feeded back to WP 7.4 and considered in a newer version of the CAD-Model until the design freeze point was reached.

Within this adjustment loops it turns out, that the existing tooling has to be prolonged. Due to two additional full-length-stringers, one at the upper and another at the lower end of the shell, the remaining space for accelerate and decelerate the fiber-placement head was too small. Thus, the CAD-model of the tooling was modified at DLR.

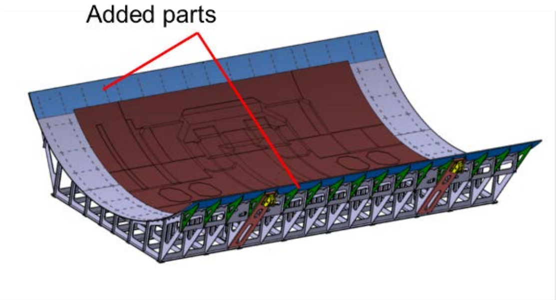

Figure 8: Modified CAD-model of the tooling

Furthermore, some calculations were carried out, to check the deformation and stresses within the structure of the tooling under critical load cases.

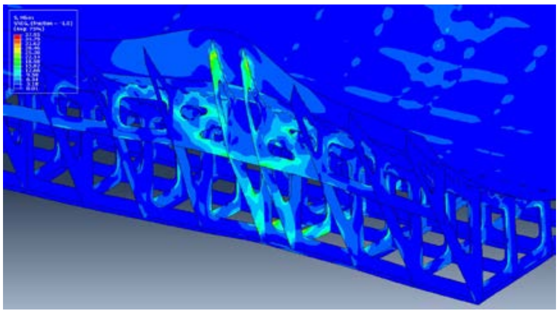

Figure 9: Strain distribution while lifting the tooling by a crane

During the physical modification of the tooling by an external partner, the design ply book was transferred into a manufacturing ply book. This step was necessary, because the tooling was designed and built with a warpage correction in its geometry.

Afterwards, the manufacturing ply book was translated into a CNC-programm by a CADCAM-software. This step was followed by reachability simulations to find the ideal position of the tooling within the GroFi-machine. Additionally, some simulations were performed to be sure, that no collisions occur during the whole skin lay-up process.

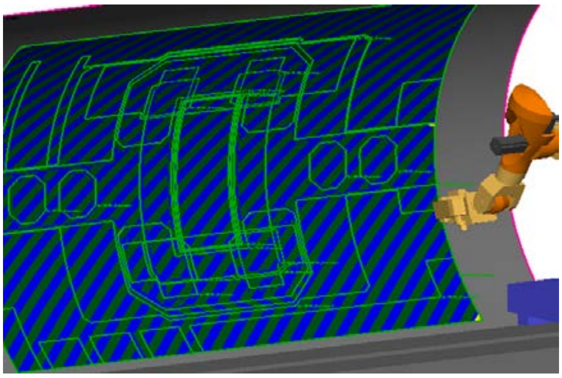

Figure 10: Simulation of the lay-up process

Keeping in mind, that the value of the used prepreg material is in a range of a 6 digit number of euros, some further studies were carried out. Due to the unfreezing of the prepreg material and the resultant application of the first ply, the counter of shop life time of the material runs inevitably towards zero. Thus, a critical failure while the lay-up, which takes some days to fix, can result in a total loss of the applied material up to this point. As shown before, a very critical part of the lay-up process was the very complex stacking sequence and ply geometry of the door surround area.

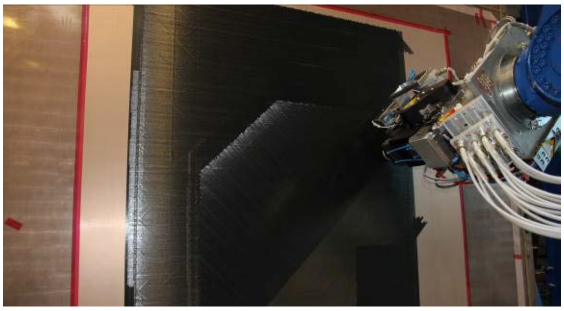

Figure 11: First lay-up studies of the door surround area on a flat plate

This said, a cut-out of the ply book in the door surround area was projected on a vertical mounted flat plate by using Catia CAD. The flat plate was choosen, because the Maaximus-tooling was at this time in the machining process.

The above mentioned range of functions - starting from the CADCAM programm and ending by the last applied ply – was then successfully tested on this first demonstrator part, which is shown in Figure 11.

Parallel to all this activities, another team was manufacturing a complete set of stringers. This was necessary due to the co-bonding process, in which a cured part was bonded with a uncured part. Typically, the stringers are choosen as the cured part. Thus, there was a strong need that the complete set of stringers was cured, machined and checked by NDT straight ahead of the skin lay-up process.

The lay-up was done by hand on existing invar toolings, followed by a curing cycle in the large DLR autoclave. After a first NDT-check, the cured stringers were machined and tested a second time according Airbus manufacturing standards

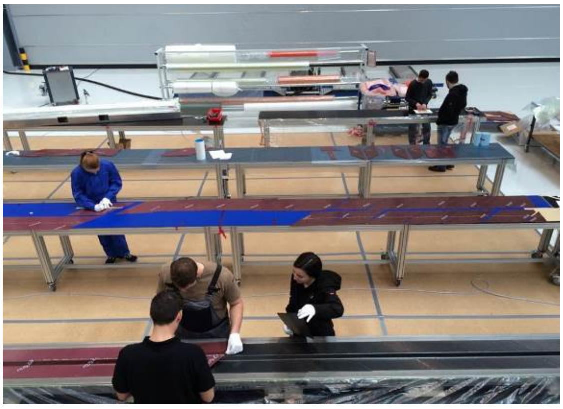

Figure 12: Stringer production by hand lay-up

Finally, after mounting the prolonged Maaximus tooling in the GroFi-plant and the measuring of its geometry, the lay-up of the Maaximus demonstrator has begun in mid of August 2015. During the lay-up process, the time of the AFP head in operation, the time for maintanence as well as the time for fixing different types of failures was counted. By doing this, it was possible to gain a first estimation the average lay-up rate as well as the reliability of the machine.

Figure 13: Lay-up process of the Maaximus demonstrator

The fixing of the pre-manufactured and cured stringers on the wet skin will be done with a new and innovative inductive heating device. This solutions is up to 10 times faster, the usual “smoothing iron like” heating device. The prototype is given in Figure 14. An early version of this principle was used first time to fix the stringers of the Saristu-shell.

For the maaximus shell, an improved version with integrated thermal sensors and control was developed.

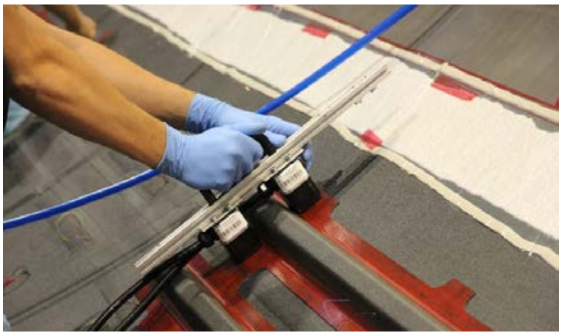

Figure 14: inductive heating device for stringer fixation

Curing of the stiffened skin was done in the large research autoclave of DLR. The latter is equipped with many sensors. Temperature distributions on the parts surface are measured with a combination of a water cooled infrared camera inside of the autoclave and classical thermo-sensors.

The degree of curing was monitored by dielectrical sensor system - which was developed in WP 7.7 - as well as ultrasonic-sensor-unit. Furthermore the autoclave system offers a lot of plugs for pressure sensors.

Figure 15: Large research autoclave system at DLR Stade.

All the collected process data were provided to other work-packages like WP 7.8 to compute the demonstrator structure “as-built”.

To examine the potential of dry textile technologies in combination with resin-infusion or injection-processes, some parts of the door surround structure were chosen. Thus, the C 74 doorframe was built in a dry fiber lay-up process and a following infusion process by Premium Aerotec. The z-type C73 was produced in a fully automated and near netshaped preforming process within the DLR’s EVo-plant, which was described in section 3.

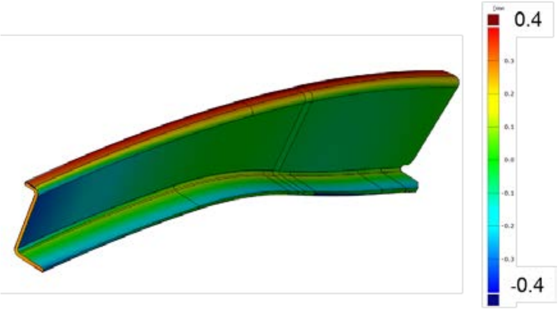

Figure 16: C73-frame with calculated distortion [mm] after curing without spring-in compensation

A challenge while using a mass production plant in a research institute is the high effort to produce for the preforming and RTM toolings.

Especially the RTM toolings in aerospace production are typically made out of rare and expensive invar steel. Due to the limited budget of the project and the fact, that not more than a few umpteen parts should be produced, a much cheaper solution was necessary.

The RTM injection process for the C73 was performed by Airbus Helicopters. The company was experienced in using aluminium as material for RTM toolings. It is obvious, that the process induced distortions within the final part are much higher due to the high thermal expansion coefficient of aluminium. Thus, some computions of the warpage of the part while curing were carried out prior to the manufacturing of the toolings in WP 7.6. With the results of this simulation, a spring-in compensation could be applied in the RTM-toolings. The same sping-in compensated geometry was used for the preforming tools at DLR. The latter could be realized as inserts to an existing tooling of another z-type frame. This saves a lot of money and time.

5. References

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6. Acknowledgement

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