DEVELOPMENT OF A NEXT GENERATION COMPOSITE ANNULUS FILLER FOR ROLLS ROYCE JET ENGINES

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ABSTRACT
There is an on-going trend in aerospace engineering to investigate the opportunities to replace metallic components with fibre reinforced composite parts. Within the CleanSky funding scheme of the European Framework Programme 7, the replacement of an aluminium annulus filler for Rolls Royce jet engines with a full composite solution has been studied. Several design concepts are evaluated concerning their application under high centrifugal forces and potential impact situations. Finite element methods are used for dimensioning and optimization of the structure; critical geometries are manufactured as subcomponents and tested in experiments. Simultaneously, different manufacturing concepts are analysed and the Resin Transfer Moulding (RTM) process is simulated to guarantee complete filling of the part and prevent from manufacturing issues. Eventually, the component is produced and tested under real life conditions. Further development will now focus on final structural optimisation and serial production for future engines.

INTRODUCTION
To meet upcoming thrust-to-weight ratio targets, the development of high-performance composite fans can offer advantages. Within Europe's Sustainable and Green Engine (SAGE) effort, funded under the Clean Sky program, the ALPS (Advanced Low-Pressure System) demonstrator is being built to prove the feasibility of such a fan (ref. 1). Within the composite fan system, there is an opportunity to develop an advanced annulus filler.

Composite components on the fan will help reduce weight on the overall structure. The material allows structurally efficient designs to be developed. A further advantage lies in the nature of the material during a severe impact event. In the unlikely event a composite annulus filler should detach from the rotor hub, it will engage with casing. The filler will then break up in such a way as to distribute the kinetic energy across the casing. This facilitates the optimisation of the casing design, thus saving weight (ref. 1).

FILLER DOWN SELECTION

The annulus filler covers the gap between the individual blades and ensures an optimal aerodynamic profile. The aluminium filler used today is mounted directly onto the fan disc, using hooks enganged by inserting the filler downwards and backwards between the blades. Different concepts for a composite filler have been evaluated (Figure 1): bridged fillers (attached to nose cone and rear seal), fillers bonded onto the blade or connected to the fan disc. The latter have several advantages: they are mostly retro-fitable on current fan discs, the modifications to adjacent components are minimal, and no structural bonding is required.

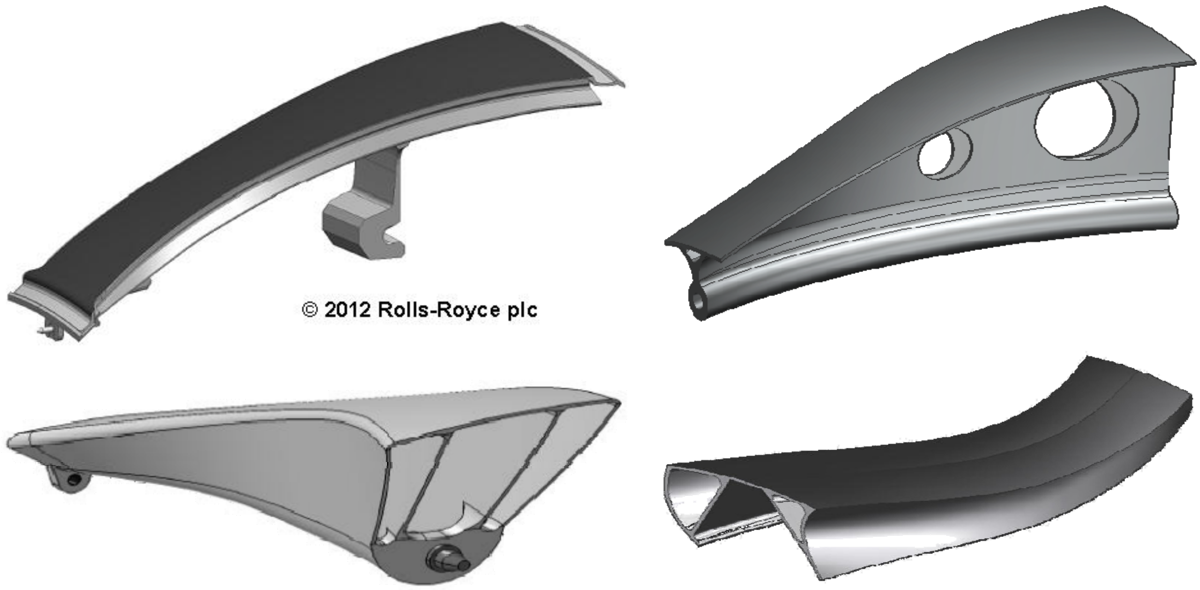


Figure 1: Filler concepts (upper left: Rolls Royce aluminium filler; upper right: dovetail filler connected to fan disc; lower left: bridged filler; lower right: bonded to blade, suction side and pressure side)

Some of the concepts are realised as rapid prototyping parts in 1:2 scale. From a total of 12 concepts, 3 are selected to be evaluated in detail:

- *Hooked filler*, to be mounted using hooks similar to the existing aluminium filler
- *Dovetail filler*, to be mounted using a dovetail feature of the fan disc (similar to the dovetail used for the fan blade)
- *Bonded filler*, bonded directly onto the fan blade

The evaluation of the proposed filler design is done in several categories:

- Finite element simulation of mechanical properties (deformation, stresses, impact) of the structure, using low cycle fatigue and ultimate load criteria
- Experimental validation (coupon-tests and subcomponents)
- Selection and evaluation of manufacturing & processing techniques, including process simulation
- Material selection based on processing & availability
- Handling, mountablility, maintenance
- Cost effectiveness
- Time schedule of program

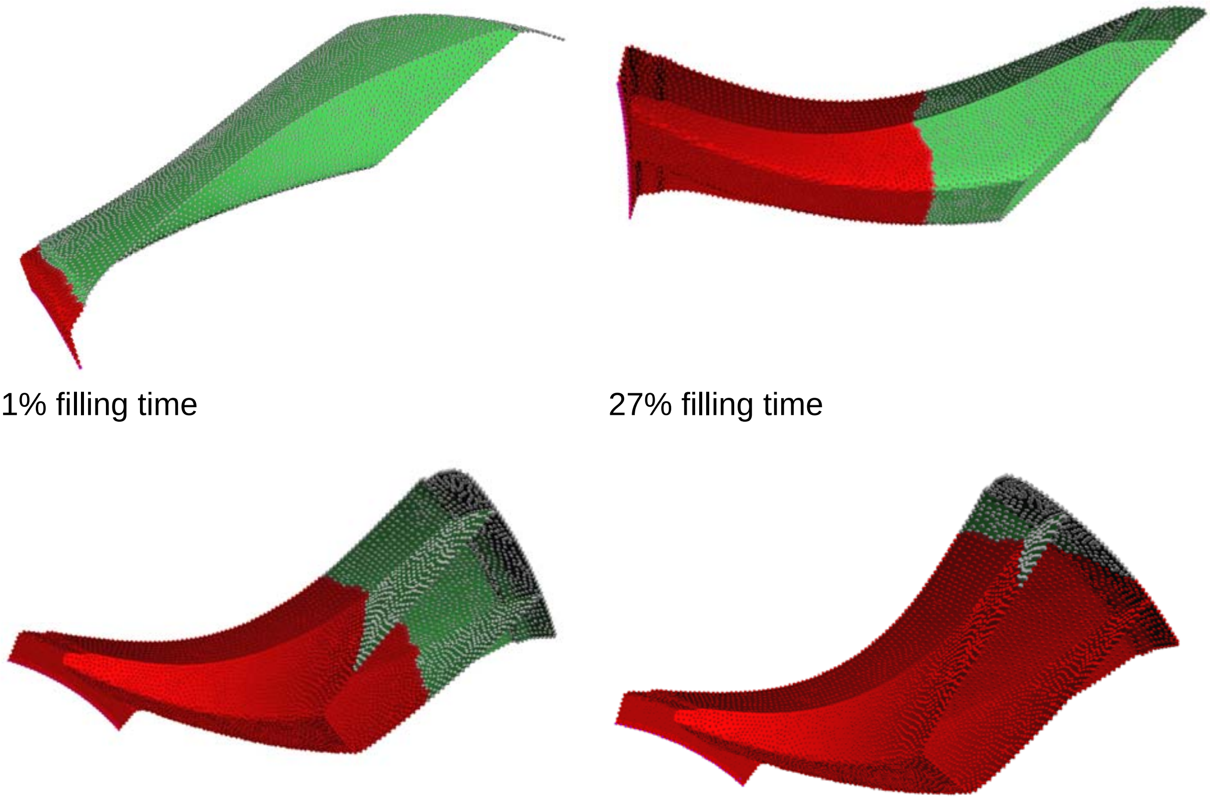
DESIGN PROCESS

Within the design process, several concepts are prepared and all aspects as noted above are considered to select a final solution.

Structural optimisation

The programme timescales precluded the development of the bond-on filler, at an acceptable level of risk.The addition of a second dovetail feature to the fan disk might cause stress concentrations. Thus, the retro-fitable hooked filler is chosen as best alternative.

As impact (hail strike, bird strike) is an important load case, a quasi-isotropic woven fabric is preferred. Finite element optimisation is done with Ansys ACP based on a layered shell model. Cross-comparison in NASTRAN confirms the results. Whereas in-plane stresses are well below critical values, interlaminar shear and through thickness tensile stresses require optimisation of the geometry to ensure proper safety margins. This optimisation is done parallel in ANSYS ACP and in NASTRAN, and supported by subelement testing (ref. 2). Based on the deformation field, the unrun shape is calculated to match the optimal aerodynamic profile for cruise speed.



1% filling time | 27% filling time

60% filling time | 90% filling time

Figure 2: Fill simulation with myRTM of moulded shape; relative fill time with front-to-rear injection strategy

Process simulation

Due to the shell like geometry and the size of the filler, resin transfer moulding (RTM) is identified as suitable manufacturing process. Several injection strategies are therefore simulated (Figure 2) using myRTM (ref. 3). The moulded part shape contains allowances along the edges, all cut-outs are machined after demoulding. The hollow geometry requires the use of a demouldable core.

Experimental work

To support numerical optimisation processes, subcomponent tests are done for selected geometries, in particular the U-channel (hook) and the T-joint (ref. 2). In addition, compression after impact tests (CAI) are carried out to compare different potential material systems.

Manufacturing costs

The estimation of total manufacturing costs is based on a internal FACC cost model. Prepreg autoclave, out-of-autoclave infusion and resin transfer moulding (RTM) are considered as feasible manufacturing processes. A set of 18 fillers is required for every engine, thus piece number is higher than for typical composite parts. It can be shown that for these numbers, RTM is the most cost effective process – for lower numbers, prepreg processes are better suited.

TOOLING

The hollow design of the filler consist of several individual preforms that are combined (Figure 3).

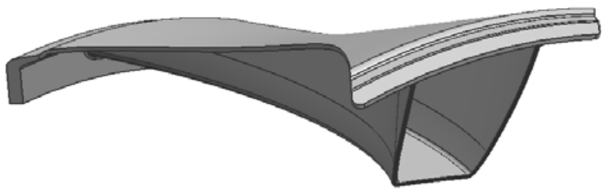


Figure 3: Preform and moulded shape of filler

To be able to easily demould the filler, a multi-material tool is proposed (Figure 4); lower and upper die consist of invar, the cores are made from aluminium. The thermal expansion during mould cooling will enable the separation of of the filler from the core (ref. 4). Due to the geometry of the filler rear seal (undercut), a split core with 3 parts is necessary. The cores are screwed together (using guidance bushings), joint faces and hence screws are sealed against resin. Figure 5 illustrates the completed tool with lower die, upper die and core.

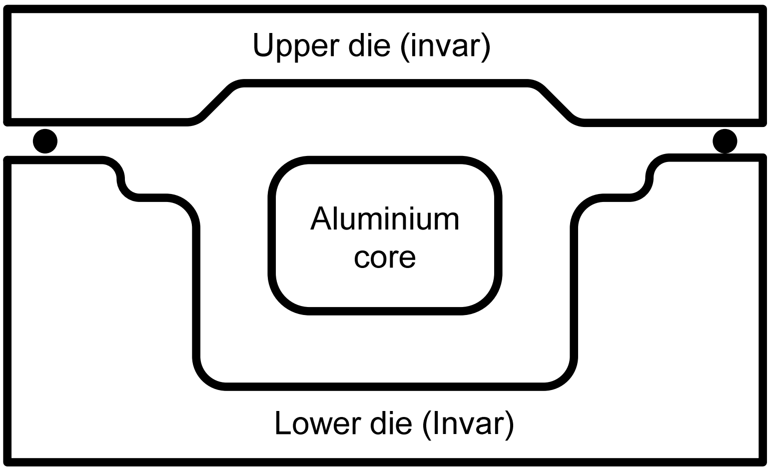


Figure 4: Tooling concept

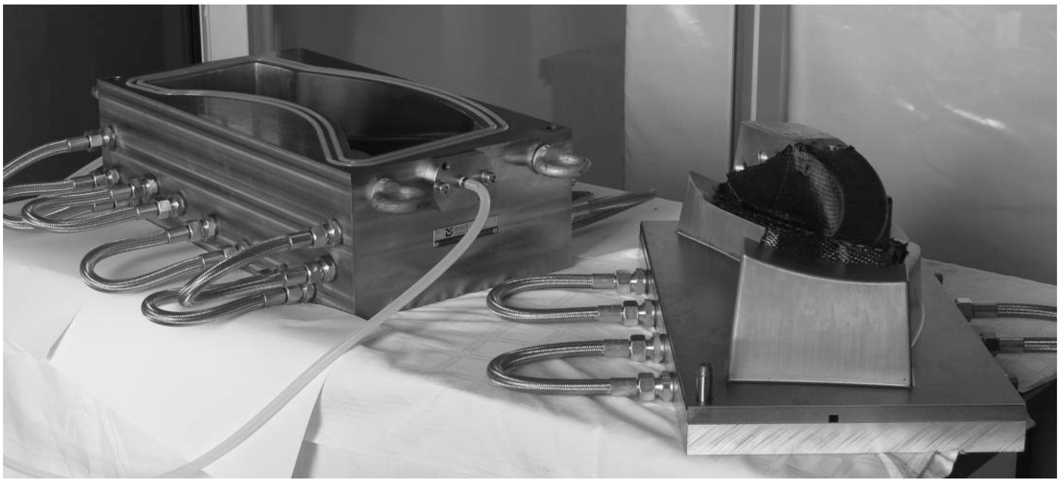


Figure 5: RTM tool (left: lower die; right: upper die with preform and core)

MANUFACTURING

The manufacturing process is based on the injection strategies derived by the simulations. The chosen process has proven to be very robust, as none of the manufactured fillers (Figure 6) shows dry spots and only minor resin rich areas or air entrapments are present.

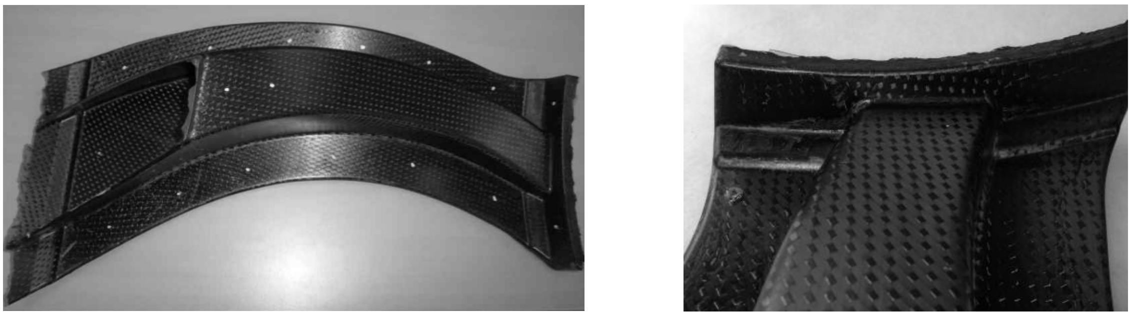


Figure 6: Demoulded filler (left: bottom view; right: front detail)

RESULTS AND OUTLOOK

Based on the results of the design process, a robust manufacturing process has successfully been implemented. The produces components meet all requirements: fibre volume content is within the expected range of 55-60%. Due to the positioning of the core, variations along the axial direction might occure. This will be corrected by a better core positioning in future tools. Porosity is extremely low in all samples, generally around 0.2%, maximum 0.85%. First (static) mechanical testing have shown adequate safety margins even on relatively low quality fillers.

A first batch of fillers will now be produced for a complete engine set. After investigations in a spin test rig, evaluation in the flying testbed will take place in 2014.

ACKNOWLEDGEMENTS

This work was granted under the JTI Clean Sky (JTI-CS-2010-1-SAGE-03-001) within the European Framework Program 7. The authors gratefully acknowledge the support by Clean Sky and the European Commission.

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