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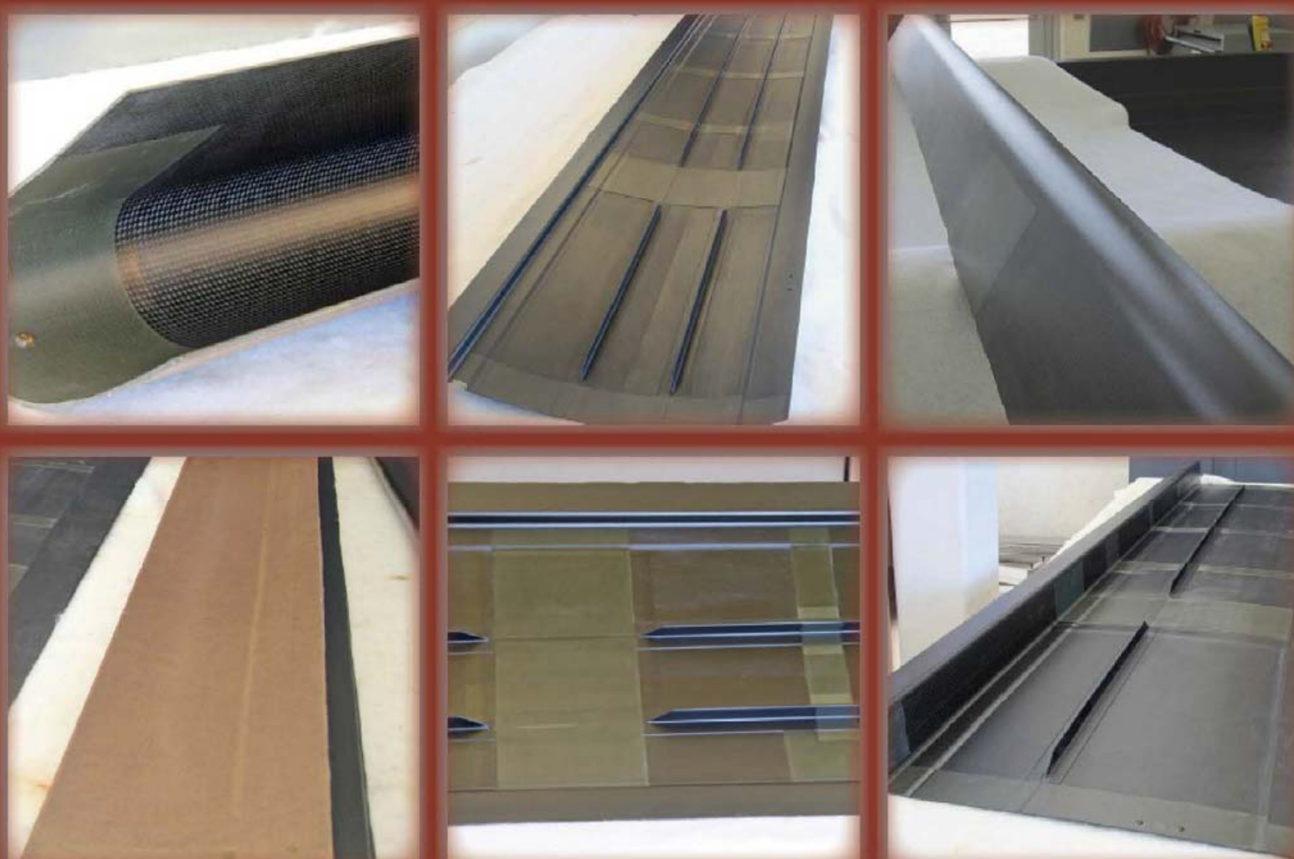
Resin Infusion/ Liquid Molding Technologies



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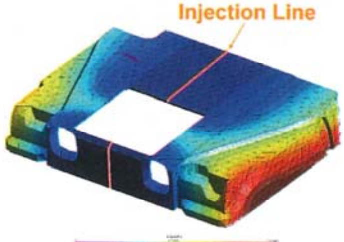

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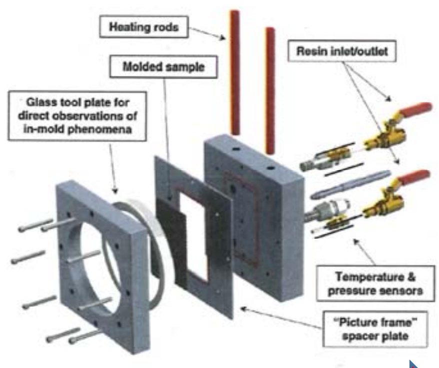

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About the Cover

SQRTM (Same Qualified Resin Transfer Molding) process developed by Radius Engineering Inc. (Salt Lake City, UT) used by Sonaca S.A. (Gosselies, Belgium) to produce these high quality resin infused wing sections, nose, trailing edge and skin panels as shown in the cover photos. Photos courtesy of Sonaca.

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Evolution in Composite Injection Moulding Processes for Wing Control Surfaces

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Abstract

Since 2010, Sonaca is engaged in R&D projects, with the support of Radius Engineering and Coexpair, aiming to design, develop, manufacture and test monolithic CFRP flap structures made from the conventional 8552 resin prepreg system and the newest SQRTM process ('Same Qualified Resin Transfer Moulding') in order to assess several additional benefits of this process over the conventional RTM process, amongst which the use of already qualified tough prepreg materials and the ease combination with automatic deposition and preforming techniques of UD-tapes. Following advantages were also considered during the initial trade-off analysis for the technology selection of such wing control surface structure having very stringent requirements in terms of structural performance, weight optimisation, aerodynamic quality and cost:

- *Strong control on thicknesses,*
- *Strong control on the geometry (radii, plies conformity),*
- *High surface and internal laminate qualities,*
- *Robust process generating less scraps and non-conformities,*
- *High level of part integration possible.*

Introduction

Sonaca is producing today, in serial production, hybrid slat structures on the A350 program. The concept resulted from an important R&D project ('Newslat') running from 2003 till 2010 and consisting finally in the assembly of a metallic nose skin with a composite rear structure produced from a closed mould RTM process based upon the RTM6 epoxy resin and carbon fabric/ carbon non-crimp fabric reinforcements, allowing very high product dimensional characteristics together with very good internal and surface quality. This concept demonstrates now in serial production to be very efficient in terms of part quality and robustness but the use of the dry fabrics and dry non-crimp fabrics do not allow automation of the lay-up deposition.

In 2010, Sonaca decided to launch an extensive research and development programme ('Ecotac') to develop the newest SQRTM (Same Qualified Resin Transfer Molding) process for application on wing control surface components and, followed in 2013, by another programme with the final aim to bring the technology up to TRL9 for use on flaps of an actual regional aircraft project (Figure 1). Today, Sonaca can be considered as the first European company having introduced this advanced technology in production.

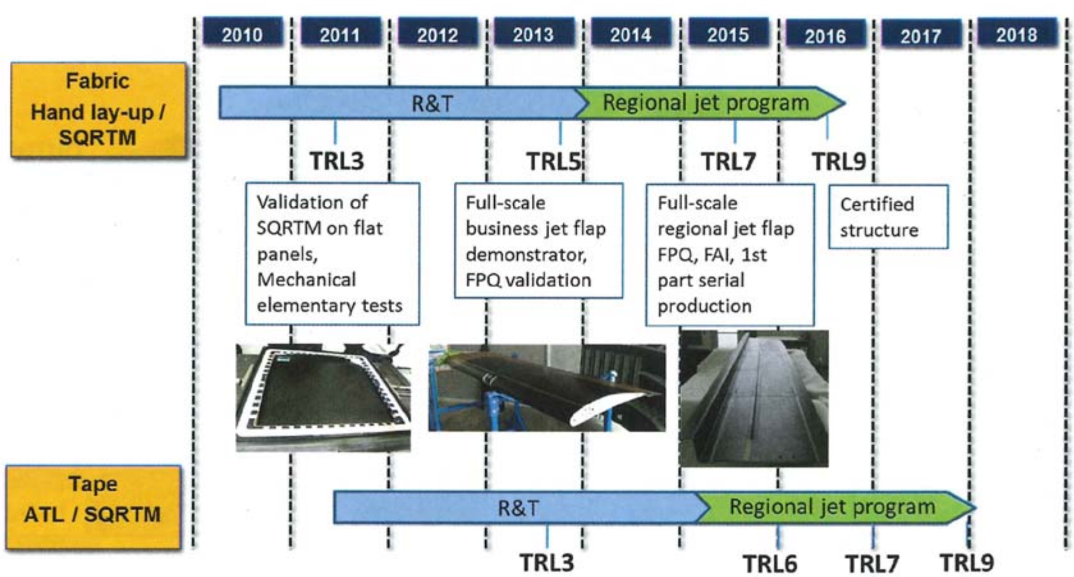


Figure 1. SQRTM TRL Road Map at Sonaca.

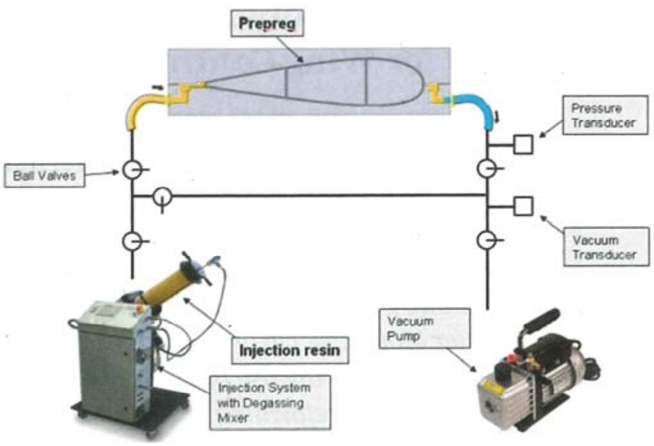


Figure 2. SQRTM process principle.

SQRTM process involves prepreg material cured in a closed mold. The pressure inside the mold is applied by a small quantity of prepreg resin (to be available in bulk form) that is injected to fill the tool cavity around the edges of the part and maintained until the gel of the prepreg material. The process combines advantages from prepreg materials (use of high tough resins and ease combination with automatic deposition and preforming techniques of UD-tapes) and RTM process (dimensional and surface qualities). Following advantages were also considered during the initial trade-off analysis for the technology selection of such wing control surface structure having very stringent requirements in terms of structural performance, weight optimisation, aerodynamic quality and cost:

- Strong control on thicknesses,
- Strong control on the geometry (radii, plies conformity),
- High surface quality,
- Robust process generating less scraps, less non conformities and repairs,
- High level of part integration possible,
- Faster NDT inspection (less scatter at the part surface due to the better surface roughness),
- Automation possible with the use of UD reinforcements (AFP or ATL) and it can be pushed further than autoclave (no vacuum bag, more repeatable process).

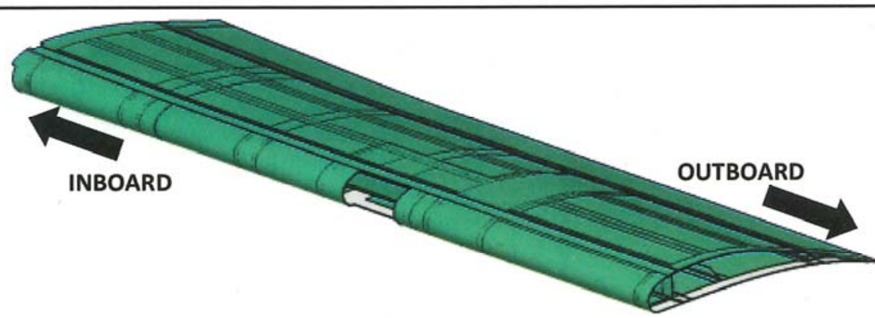
The main injection/curing steps are (Figure 2):
-Putting the resin inside the injector, degassing and heating it to the specified resin injection temperature,
-Applying vacuum to the mold having the prepreg lay-up placed inside,
-Heating-up the tool to the specified injection temperature,
-Opening the injection line and adjusting injection pressure or resin flow,
-Shutting-off vacuum port valves on tool when resin appears,
-Ramping tool temperature to the curing temperature,
-Shutting-off the resin injection,
-Holding the curing temperature/time.

SQRTM Composite Flap R&D Project

SQRTM Flap Demonstrator Part and Tool Concepts

The demonstrator (Figure 3) has been designed to be composed of only four main elements: a lower skin with an integrated front spar, an upper skin with an integrated rear spar, a D-nose and a trailing edge. Selected raw material was 8552 resin with AGP193 fabric and AS4 UD-tape carbon reinforcements as well as expanded copper foil 3 CU 7-125 on the outer surface of the skins, D-nose and trailing edge. Fabric material

Figure 3. SQRTM flap demonstrator.



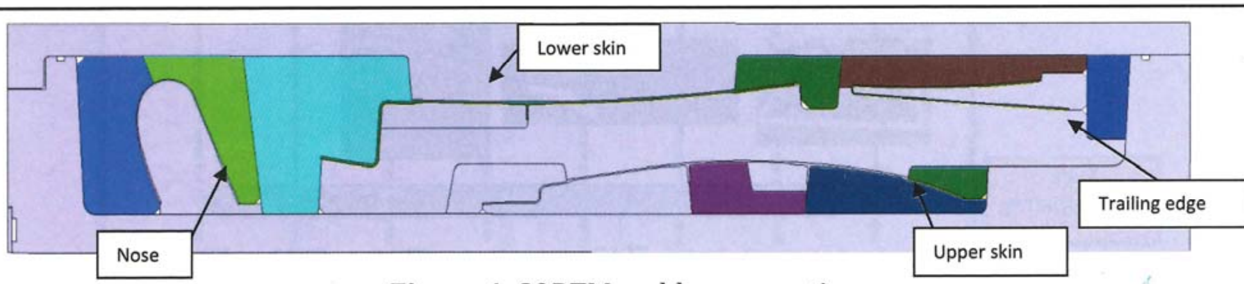


Figure 4. SQRTM mold cross-section.

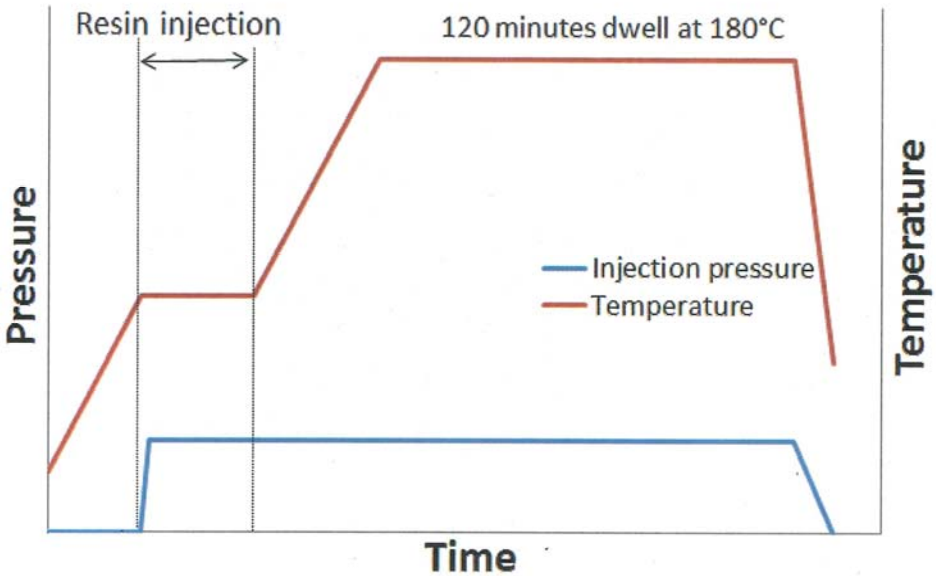


Figure 5.
Typical SQRTM curing cycle.

was chosen for the skins while tape has been used for the co-cured stringers.

The tool was designed to be able to manufacture the four composite parts in one single mould/injection. A cross-section of the tool is showed Figure 4.

Demonstrator Manufacturing Results

After ply cutting-off and laying-up of the pre-formed plies, the mandrels were positioned on the tool and the mould was closed before its installation in the SQRTM press. The parts were injected with 8552 resin and cured with the cycle shown in Figure 5.

After cooling and de-moulding, a visual inspection of the cured parts revealed a really exceptional part quality as shown by Figures 6a through 6d.

Dimensional inspection was performed based upon ultrasonic measurements and micrographics. Over more than 150 thickness control points selected, no value was found out of the allowed +/-8% tolerance around the nominal thickness.

Furthermore, the micrographic cuts analysis has confirmed that the demonstrators presented a very good level of internal quality (skin, stringers, spar and joggle areas) as shown in Figures 7a through 7d:

-No delamination,

-Good compaction of the plies (even at difficult areas such as radius in spars, stringers, joggles, ...)

-Good filling of the stringers with the noodle fillers,

-Good filling of the joggles with the fillers,

-Thicknesses compliant with the requirements,

-Spar radii and stringers radii compliant with the requirements,

-No internal ply waviness.

The C-scan US NDT reports have confirmed the fully satisfactory internal quality of the produced parts for what concerns porosity and inclusion.

Figure 6a. Lower skin quality.

Figure 6b. Upper skin quality.

Figure 6c. D-nose quality.

Figure 6d.
Trailing edge quality.

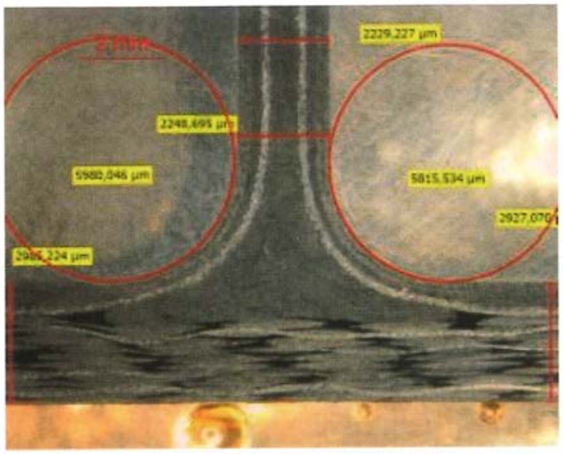


Figure 7a. Lower skin stringer radius.

Figure 7b. Lower skin front spar radius.

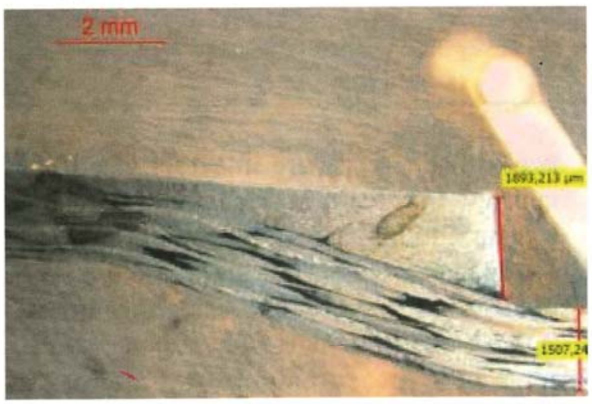


Figure 7c. Upper skin joggle area.

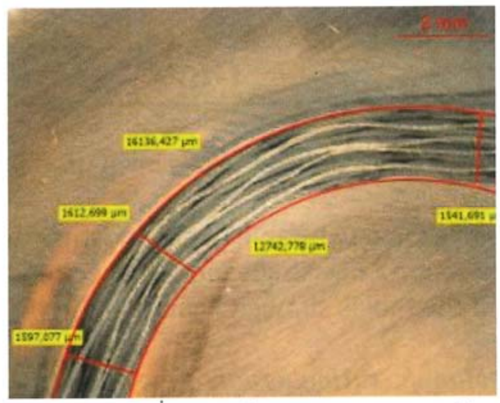


Figure 7d. Upper skin rear spar radius.

Material Characterization Programmes

In order to validate the mechanical characteristics of the 8552 fabric and tape materials as processed by SQRTM and confirm the design allowable values used for the sizing of the parts, a large characterization test programme has been performed at two levels: from samples directly taken out the demonstrators and from separate flat panels.

Results from Specimens Sampled Out of the Demonstrator Skin Parts

From test results (porosity, Tg measurements and mechanical properties) obtained on samples extracted from upper and lower skin demonstrator parts (Table 1) and consisting in specific part lay-ups, it can be seen that all SQRTM specimen properties are above minimum design requirements on one hand and that all SQRTM mechanical test results are above equivalent results obtained from a same part produced by mean of the conventional autoclave process on the other hand. This effect seems to be due to the better control of the ply thicknesses, of the FVF ratio and of the ply waviness (for compression properties mainly) brought by this SQRTM process.

Results from Specimens Sampled Out of Separate Flat Panels

An even more extensive mechanical property comparison was done on the 8552/AS4 UD-tape material on the basis of test specimens extracted from flat panels either processed by SQRTM or by autoclave. In this case, the lay-ups were unidirectional for tensile, compression and ILSS material characteristics and quasi-isotropic for open hole tension, open hole compression, compression after impact and bearing characteristics. For all investigated properties (Figure 8), the mechanical results of the SQRTM processed 8552 tape material are above the specification requirements and equivalent or above those same properties for the same material processed by autoclave.

Risk Reduction Phase and Full-Size Aircraft Flap Components

The aim of this second project was to develop full scale SQRTM skin components for the inboard flap of a regional aircraft. To reach the high level of quality required for actual aircraft parts within a very short time period, Sonaca conducted, in a first phase, a risk mitigation plan with a building blocks approach (Figure 9).

Table 1. Comparison of AGP193/8552 fabric material properties from equivalent demonstrator part lay-ups processed by SQRTM or by autoclave.

	Definition	Unit	SQRTM cured part		Autoclave cured part		Req. (min.)	Status
			Mean	Min.	Mean	Min.		
Lower skin sample test results	Void Content	Vol%	0	0	0.3	1.5	< 2	OK
	ILSS	MPa	76.3	72.6	73.4	71.3	51	OK
	Tg dry (onset)	°C	199	200	197	190	190	OK
	Tensile Strength	MPa	550	520	519	503	359	OK
	Compression Strength (2 lay-ups tested)	MPa	666	657	599	562	435	OK
		MPa	592	540	491	443	396	OK
Upper skin sample test results	Void Content	Vol%	0.9	1.4	0.9	1.1	< 2	OK
	ILSS	MPa	77.1	76	68	65.4	51	OK
	Tg dry (onset)	°C	197	200	209	209	190	OK
	Tensile Strength	MPa	440	419	426	405	301	OK
	Compression Strength	MPa	575	556	471	431	396	OK

The plan consisted in developing a highly curved skin integrated Z-spar for spring back compensation definition and a 5.7 m long flat demonstrator panel with integrated stiffeners.

The second phase of the project consisted in the full size inboard flap part design, tool design and manufacture, in the process parameter definition as well as in the manufacturing of first parts qualification.

For this SQRTM development, thanks to the previous R&D work and above risk mitigation steps, Sonaca succeeded in producing directly first parts qualification right.

Economical Potential of the SQRTM Process

Major recurring cost (RC) benefits shall come from the process automation and the higher integration of parts allowed by SQRTM. Although RC drawbacks of the technology are related to the injection resin, some right away cost savings could be obtained from:

–The near net-shape design which allows material reduction of up to 5%,

–The disposal of bagging and associated ancillary materials, cost of which is estimated at about 1% of the "flying" materials,

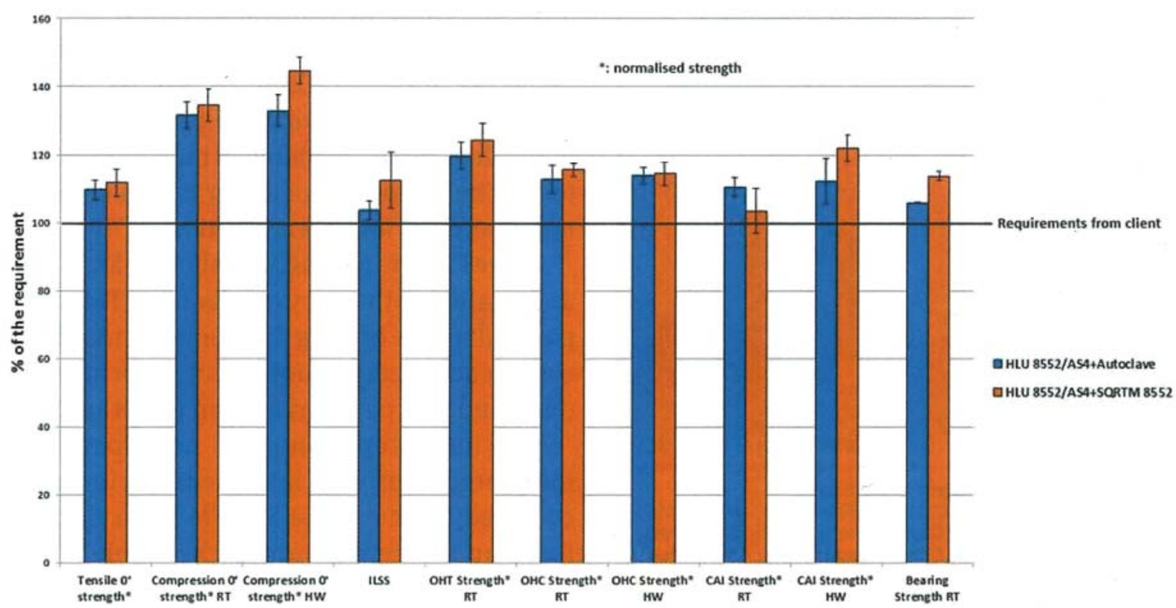


Figure 8. Comparison of AS4/8552 RC34 AW194 UD-tape material properties from flat panels (Unidirectional and Quasi-Isotropic) processed by SQRTM or by autoclave.

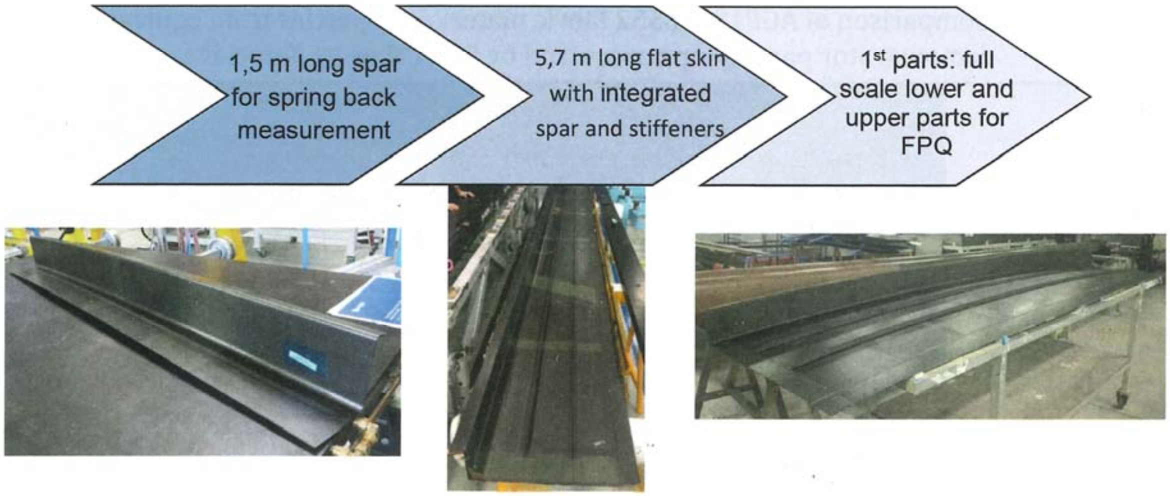


Figure 9. Risks mitigation plan and final FPQ parts.

-The scrap rate and the time spent for non-conformities, both divided by a factor of 2 with respect to the rate and time of equivalent autoclave processed parts,
-The assembly costs leading to a reduction of about 5% on the global cost of the part, thanks to the reduction of the needed assembly shimming due to closer tolerances brought by this SQRTM process,
From development point of view, there is no significant cost, nor technical challenge for the OEM's to accept SQRTM due to the robustness of the process and the use of already qualified autoclave prepregs (only a material equivalency demonstration will be needed).

Conclusion and Further Technology Validation Steps

In the past years, lots of out-of-autoclave technologies have been developed as attractive alternatives to autoclave process but most of these induce huge costs and technical challenges that stand in the way of serial production. SQRTM process is the only one to combine a very good control of process key parameters from closed mould capability and the use of same autoclave qualified materials having high material characteristics (including those related to toughness such as BVID properties). SQRTM offers a large potential for diversification and is compatible with various types of reinforcements (UD, fabric) and resins (ex: 8552, 977-2, M21E, 3900-2, BMI 5250-4); all these latter cases having the prepreg resin (or almost equivalent resin) available in bulk or unreinforced film form. The possibility of integration also presents great opportunities for diversification.

Above R&D programs have allowed Sonaca developing and qualifying this very efficient SQRTM process for the particular case of wing flap components. Part produced easily exceeded requirements in terms of quality on one hand and performance on the other.

As a next step, Sonaca is now focusing on more integrated flaps with intermediate ribs, spar and skin co-cured in one single SQRTM cycle. Sonaca will also focus on the automation of the whole manufacturing cycle: from automated tape laying (ATL) of UD-tapes through hot forming, automated transfer of parts between operations before the SQRTM process itself.