ACCUBLADE

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List of abbreviations

AGF	Active Gurney Flap
CTE	Coefficient of Thermal Expansion
NDT	Non Destructive Testing
TGA	Thermo Gravimetric Analysis
TM	Topic Manager

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1. INTRODUCTION

One of the most challenging research areas, leaded by the Green Rotorcraft Consortium within the Clean Sky Program, is the development of Active Rotor Technologies as the Active Gurney Flap (AGF) system, which enables a helicopter to operate with a reduced tip speed of its main rotor whilst preserving the current flight performance capabilities.

The validation of innovative AGF systems requires the manufacturing and testing of small scaled model blades in wind tunnel tests before their implementation at full scale. The incorporation of the AGF mechanism into small scaled model rotor blades (a scheme is shown in figure 1) implies the need for a very accurate and robust processing of the model blades in order to allow the AGF mechanism to be accurately assembled to perform efficiently.

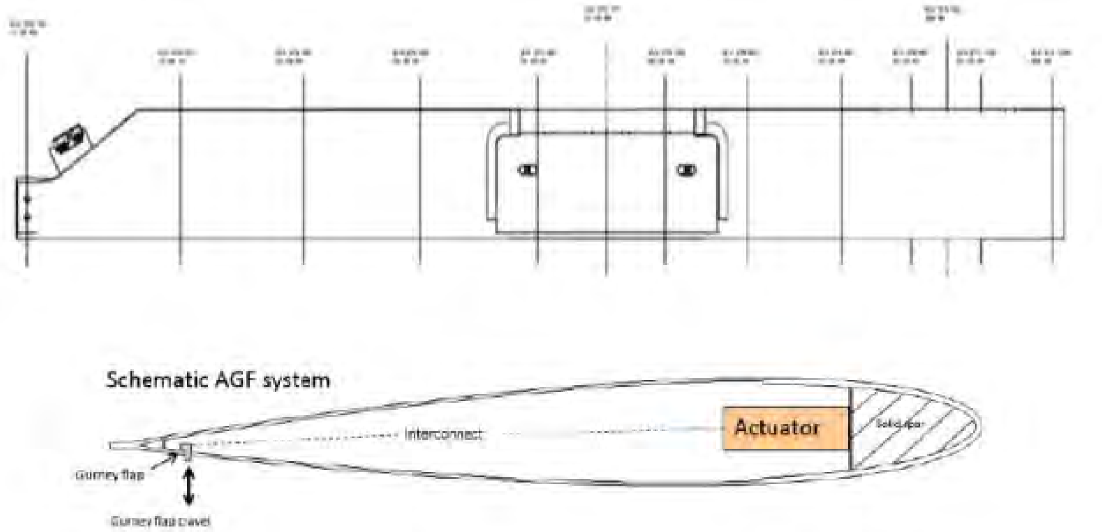

Figure 1 Scheme of rotorcraft model blade with AFG system

Due to the small dimensions of the model rotor blades, the dimensional requirements for the manufacturing are very tight, less than +/- 0,1mm on the aerodynamic profile, which is very difficult to achieve with the state-of-the-art prepreg technology.

In order to fulfill those tight tolerances for the manufacturing of the model blades with the AGF, not only the mould must be machined with high precision means, but also the cavity design must be defined with special consideration for minimizing any shape distortion that may appear during the process.

2. PROJECT OBJECTIVES

The general objective of the ACCUBLADE project was the development of a low cost and highly accurate moulding process for manufacturing rotorcraft model blades incorporating an AGF mechanism that will be used for the assessment of functional performances in Wind Tunnel Tests.

The main innovation is that the design of the mould has been based on process simulations, in order to develop a "right-first-time" methodology, avoiding the need for expensive and long lasting design modifications to fulfil tolerance requirements.

For that purpose, CIDAUT has developed an innovative methodology of design, based in laboratory material characterisations and process simulations, which has enable an optimised design of the tooling for the accurate processing of the model rotor blades.

The standard prepreg moulding process and the alternative SQRTM technology are being compared by the TM in terms of quality and costs using the same moulds for the manufacturing of the model rotor blades that will incorporate the AGF mechanisms. For the control of the process and validation of the simulations, in-mould sensors were incorporated in the moulds.

3. WORK PERFORMED AND ACHIEVEMENTS

Project activities were divided in five work packages:

- WP1: Tooling Preliminary Design
- WP2: Tooling Design Optimization
- WP3: Tooling Manufacturing and Inspection
- WP4: Tooling Validation
- WP5: Management and dissemination

The duration of the project was 26 months, according to the following schedule:

ACCUBLADE PROJECT SCHEDULE	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24	M25	M26
WP5: Management and dissemination	WP5																									
WP1: Tooling Preliminary Design	WP1																									
1.0 Analysis of Requirements Specifications																										
1.1 Preliminary Design of suite of tools and Methodology for optimization																										
WP2: Tooling Design Optimization									WP2																	
2.1 Thermal Optimization																										
2.2 Resin Flow Optimization																										
2.3 Final Design of suite of tools																										
WP3: Tooling Manufacturing and Inspection															WP3											
3.1 Tooling Manufacturing																										
3.2 Tooling Inspection																										
WP4: Tooling Validation																			WP4							
4.1 Production of validation articles																										
4.2 Non destructive and destructive Analysis																										
4.3 Tooling corrections and supply																										
4.4 Final report																										

Figure 2 ACCUBLADE project activities schedule

- **WP1: Tooling Preliminary Design**

It included the analysis of the model blade design and specifications, and the definition of process and mould concepts valid for the alternative processing technologies.

During the first months of the project, we worked on the definition of the process simulation methodology for the optimization of the tooling design, including thermal simulations and impregnation simulations, both considering the geometrical features of the model blades to be manufactured and the conceived manufacturing process.

Thermal simulation models were created to predict the main process induced distortions that are expected to happen when processing composite parts. These are related to warping and spring-in effects:

- Warping effects that are caused by unbalanced or unsymmetrical lay-ups.
- Spring-in effects which happen in curved composite parts even with a balanced and symmetric lay-up due to the different shrinkage between the in-plane and through-the-thickness directions.

Material laboratory characterisations were carried out to identify the material parameters for the simulation models including the curing of composite samples, as illustrated in Figure 2, with different layup configurations and process parameters and the measurement and correlation of warping and spring-in distortions.

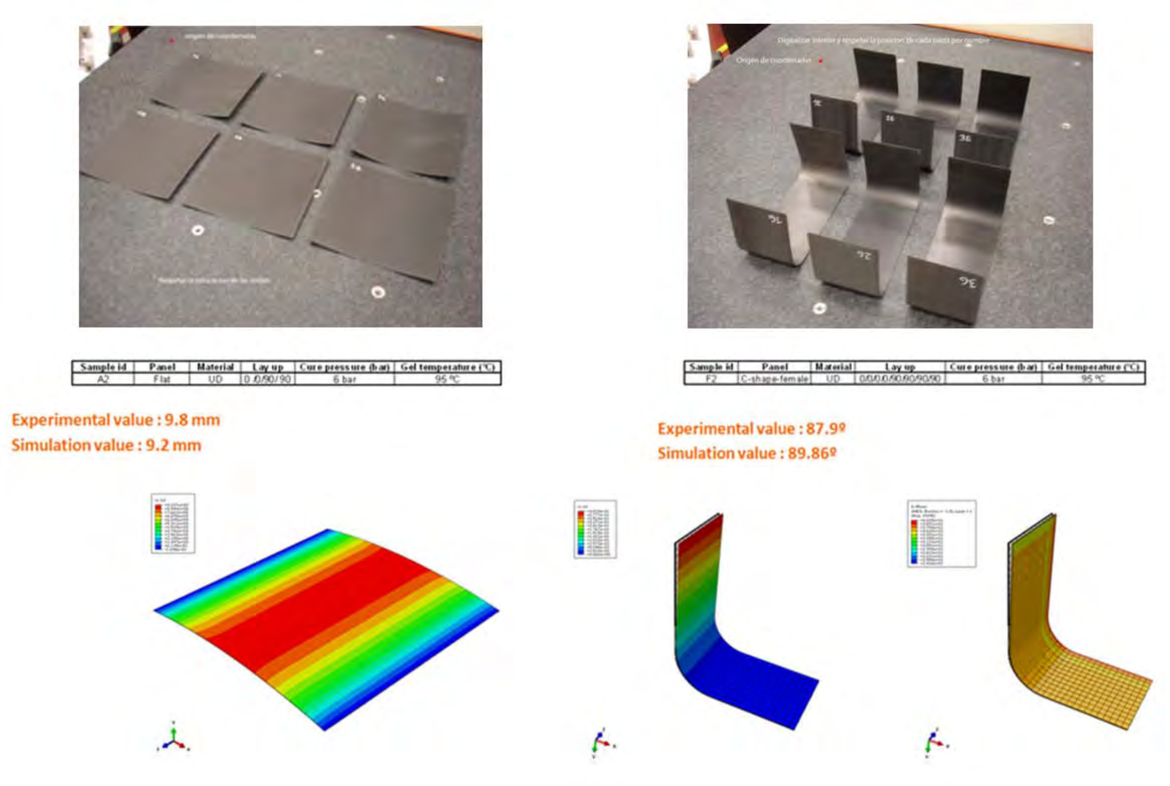

Figure 3 Analysis of process induced distortions: warping and spring-in phenomena

Considering the processing alternatives and the design of the model blades, a preliminary design of the suite of tools was conceived, in agreement with the preferences and capabilities of the TM. For the preliminary design, several trade-off analyses were carried out in order to identify the optimum features related to material, clamping and heating systems.

- **WP2: Tooling Design Optimization**

During the optimization stage, thermal simulations were carried out for the prediction of shape distortions and temperature gradients inside the mould.

Heat transfer simulations were carried out to optimize the distribution of the heating elements of the mould for an even distribution of temperatures. An example is shown in figure 4. Hot and cold zones in the surface of the tools were predicted in order to locate the sensors for the monitoring of the heating and cooling processes.

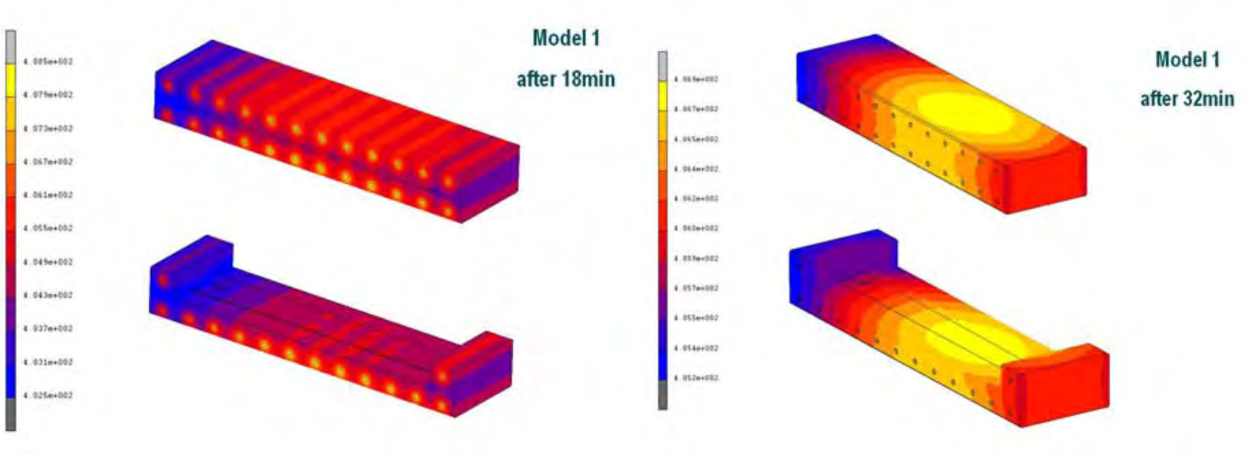

Figure 4 Heat transfer simulation for the optimization of the heating system

Also process simulations were carried out for the prediction of the expectable distortions induced during the manufacturing of the model blades, using the material parameters identified by the characterisation tests carried out in WP1. An example is shown in figure 5.

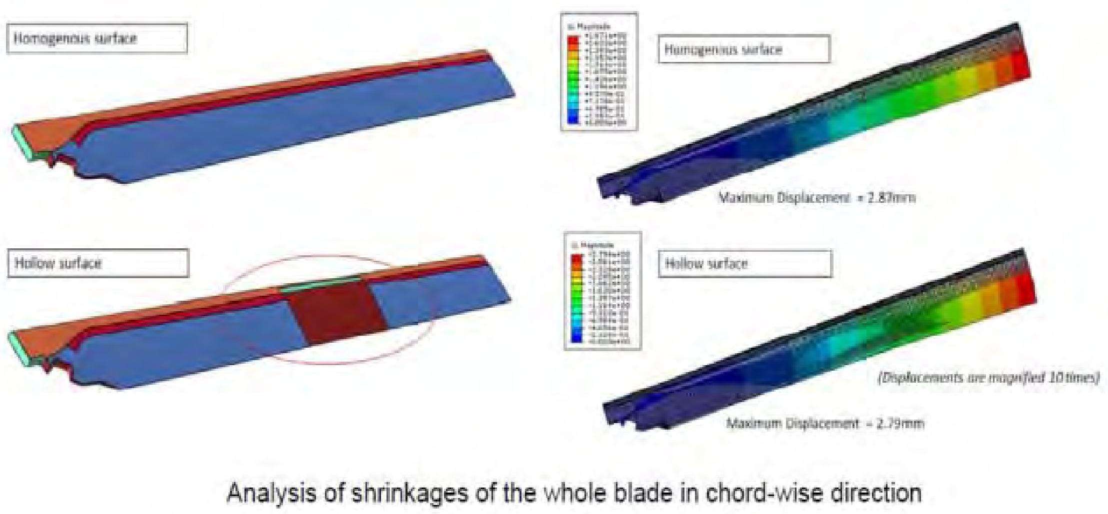

Figure 5 Prediction of process induced distortions in the model blades

The process simulation models were used to predict the levels of distortion expectable due to the curing and cooling process of the D-spar and model blades, and to identify the compensation measures that were considered in the design of the moulds, such that any deformations of the manufactured blades were minimised.

After several rounds of design optimization, the CAD design of the moulds was realized including the update in the design of the cavity surfaces and the optimum details related to alignment, sealing and demoulding features.

- **WP3: Tooling Manufacturing and Inspection**

According to the approved design of the moulds, the manufacturing operations were carried out at CIDAUT's workshop, specialized in the development of moulds and tools. The manufacturing activities included the high precision machining of the mould and the hand polishing of the surfaces of the cavity that was carefully carried out in order to achieve the very tight tolerances required for the contour surfaces. Finally, the assembly of oil heating system of the Blade Skin mould was done to complete the manufacturing.

After the manufacturing of the tools, we carried out the inspection and verification of critical performances of the manufactured tools as:

- Dimensional control of the mould surfaces to analyse the deviation of contour profiles in the cavity.
- Verification of the proper functioning of the alignment and closure systems.
- Vacuum integrity test.
- Thermal tests to check the oil heating system and temperature homogeneity.

The dimensional control of the cavity surfaces was carried out at using a coordinate measurement machine, as shown in figure 6.

Figure 6 Dimensional control of the tools

The thermal tests carried out at CIDAUT were useful to verify the proper functioning of the heating system, proving good temperature homogeneity in the cavity. In the following figure we show one of the temperature recordings with carried out with the model blade main mould.

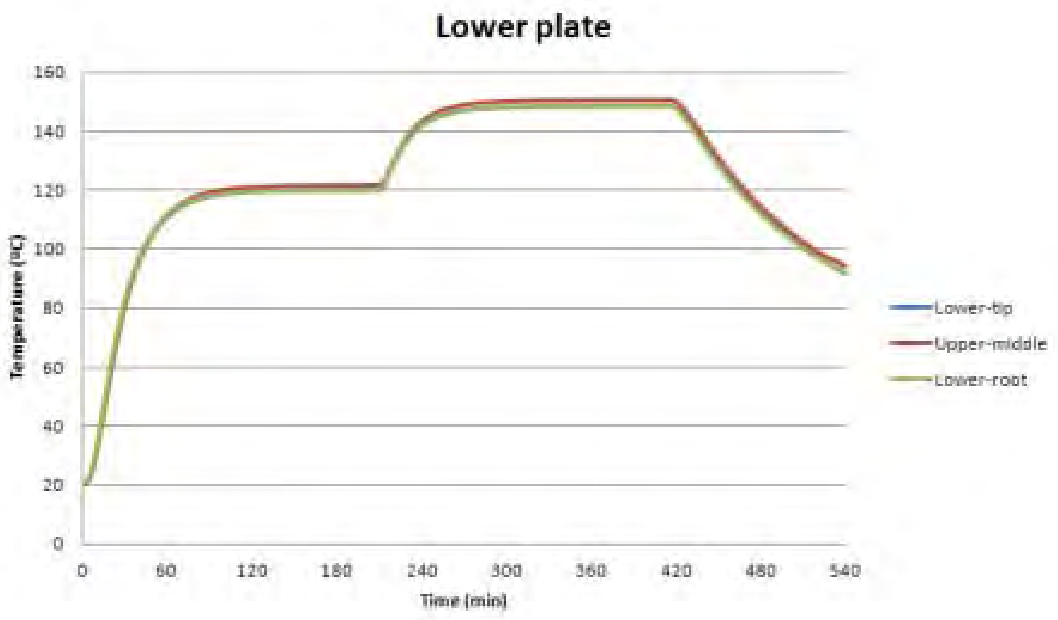

Figure 7 Temperature recordings during the heating system verification tests

- **WP4: Tooling Validation**

After the development and delivery of the suite of tools required for the processing of the rotorcraft model blades with AGF mechanisms, in the last stage of the project several validation articles were produced and inspected with the objective of validating the process and tooling design according to the specifications defined by the GRC and to analyse the correlation of results with the predictions from the process simulation models.

This phase included the processing of validation articles by the selected alternative processes to demonstrate the functionality of the tools and to validate the design methodology. In-mould sensors enabled the monitoring of the process parameters that were used for the control of the process and the validation of the simulation models.

Figure 8 Rotorcraft model blade. First validation article produced

The inspection plan included destructive and non destructive tests with the manufactured model blades like dimensional control, NDT (ultrasonic inspection) and optical microscopy (as shown in figure 9) and fibre content analysis of different cross sections in order to asses the fulfilment of the requirements previously defined.

Figure 9 Optical microscopy analysis of a D-spar cross section

The inspection tests were helpful for the optimization of the manufacturing process and the identification of potential improvements to be incorporated in the simulation models.

4. SUMMARY OF FINAL RESULTS AND CONCLUSIONS

The main goal achieved by the ACCUBLADE project was the development of a very accurate and robust moulding process for the manufacturing of composite model blades incorporating Active Gurney Flap systems. The main innovation was the development of process simulation models which helped us to anticipate and solve process related issues from the early design stage of the project in order to efficiently define an optimised moulding process and tool design, avoiding the need for expensive and long lasting trial and error experimental procedures to fulfil the requirements specifications.

The developed process simulation models included thermal and impregnation simulations that were used for the analysis and optimization of critical process related issues, such as shape distortions caused by the different CTE of the materials, temperature gradients, or potential resin flow defects. Laboratory characterisation tests were carried out with the composite materials defined for the model blades, in order to determine the required input data for the modelling of the most relevant causes of distortions in composite materials processing, including the warping and spring-in phenomena. Simulation models were well correlated with experimental results obtained through the processing of flat and C-profile coupons with different layups and curing conditions.

Based in the results and conclusions taken from the process simulations, all aspects of the mould were optimized at the design stage, including the selection of the optimum material, alignment and clamping system, efficient and even heating and cooling system and sensors.

With the aim of evaluating potential improvements in the manufacturing process of rotorcraft blades, in terms of quality and costs, the mould was designed and manufactured to allow the evaluation two alternative processes, both aimed at producing the same net model rotor blade product: conventional molding of prepregs and SQRTM.

After the manufacturing and inspection activities, a complete suite of tools were delivered to the TM for the processing of the model blades. The first model blades produced were used for the validation of the process and tooling, and subjected to destructive and non-destructive inspection tests with very successful results.
As summary, the following outcomes were achieved in the project:

- An optimized composite moulding process was developed for the processing of very tight tolerance model blades to incorporate AGF systems.
- The tool design optimization methodology was based in process simulations accounting for distortions (due to the different thermal coefficients of the composite materials) that were predicted by computer simulations.
- Required input material properties for the process simulations were characterized at the laboratory and simulation models were correlated with experiments related to warping and spring-in distortion phenomena.
- A reduction of development costs and lead-times was achieved by using process simulations compared to the usual times for aeronautic composite parts.

5. IMPACT, DISSEMINATION AND USE OF PROJECT RESULTS

The ACCUBLADE project has developed a green manufacturing route for the tooling leading to lower materials wastes and energy consumptions, with beneficial environmental effects in line with the topic impact. It is expected that the know-how acquired in the project and the developed methodology for the prediction of process induced distortions by simulation shall be useful for future research and development programs of very tight tolerance composite parts.

As part of the dissemination activities, a dedicated webpage was created with general information about the project objectives, activities and final results (http://www.cidaut.es/accublade-project/).