"Panel Liquid Infusion Technology"

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(Grant agreement number 323541)

Final Report

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1.0	20/02/2015	Vicente, Alberto	First release, V01
2.0	06/03/2015	Vicente, Alberto	Final release, V02, including amendments received from the TM

1. EXECUTIVE SUMMARY

In the Clean Sky JTI, new technologies for green manufacturing have been studied in the frame of both GRA (Green Regional Aircraft) and ED (Eco-Design) ITDs with the objective of producing low weight/eco-friendly aircraft components with competitive manufacturing costs. In order to achieve this purpose ALENIA AERMACCHI, Leader of the GRA ITD and Member of the ED ITD, has conducted several studies and launched various initiatives aimed at the development, optimization and industrialization of Liquid Resin Infusion (LRI) processes. Specifically, ALENIA AERMACCHI steered the Liquid Resin Infusion (LRI) process executed "Out-of-Autoclave" (without pressure) for the one shot manufacturing of wing box stiffened panels in composite material, with the aim of reducing impact on weight, on the environment and on life cycle costs, enabling synergies between GRA and ED ITDs, through the support of Clean Sky Members and Partners, selected by the Call for Proposals.

LRI processing is one of the most promising technologies for application in the aeronautic sector as it should provide good properties within an acceptable cost range also reducing the manufacturing risk of large complex structures. It consists in infusing the liquid resin in a pre-shaped dry fabric preform. The preforms (e.g. skin and stringers) are supported by specially shaped moulds and fairing bars, and positioned with special templates. The resin is heated and injected into a vacuum bag using special means. The cure cycle results then in a fibre reinforced structure. The LRI is an alternative to other similar processes like the Resin Film Infusion (RFI) in which the resin is pre shaped in film sheets, interlayed between the fabric layers or placed between the mould and the preform; the Controlled Atmospheric Pressure Resin Infusion (CAPRI); the Resin Transfer Moulding (RTM) and others. All the Infusion techniques compete with the well known and largely used autoclave curing of pre-preg composites.

The PLIT project, launched in the GRA "Low Weight Configuration" domain (Topic Manager SICAMB), arises under these initiatives contributing to provide a scientific approach to the physics of the LRI process by the creation and validation of a numerical simulation model to study the resin flow during the impregnation stage. This model shall be used to identify possible causes for non uniform distributions of resin flow that may cause dry spots, poor saturation of the pre-form, partially filled composite parts, defects, etc.

The activities of the PLIT project were developed by a consortium led by the CIDAUT Foundation (Spain), together with ITRB (Cyprus) and PBLH International Consulting (Belgium) in close communication with the Topic Manager (TM) SICAMB. The main innovation achieved in this project was the development of an optimized numerical approach for an accurate and efficient simulation of LRI processes for big parts such as stiffened wing panels. Another important achievement of the project was the development of an innovative test bench, that was designed starting from Members indications, and built for the manufacturing of stiffened wing panels at the TM site to validate the simulation results. Laboratory characterizations of key material parameters such as permeability and viscosity for the selected materials were key factors for achieving a good correlation between experimental and simulation results.

2. PROJECT OBJECTIVES

The main objective of the PLIT project***, carried out by the Consortium led by The CIDAUT Foundation (Spain) together with ITRB (Cyprus) and PBLH International Consulting SPRL (Belgium),*** was to provide a scientific approach to the physics of the LRI process, applied in aeronautics for the cost-efficient and clean manufacture of large high quality stiffened wing panel composite structures, by a "numerical process simulation model", to study the resin flow during the impregnation.

In particular, the scientific approach to the physics of the LRI process, has been implemented thanks to a numerical simulation model for studying the resin flow during the impregnation stage avoiding filling defects and improving the robustness of the process.

Two main technical objectives were addressed in the PLIT project:

- the development of an optimized simulation methodology for the LRI process, especially suited for the analysis of large parts and stiffened wing skin panels,
- and the generation of an in-depth understanding of the flow phenomena with more experimental data and experience.

For the development of the numerical model it was needed to fully understand the most significant phenomena in flow processing and to develop laboratory methodologies to characterize the key material parameters of carbon reinforcements, epoxy resins and distribution media (DM) that affect the resin flow in LRI processes.

Another implicit objectives of the project were that the LRI simulation models should be developed with a parametric approach using a suitable and affordable commercial software and that they could be managed by process engineers without needing a high degree of computing knowledge and with the capability of easily modifying the key materials and process parameters to analyze alternative impregnation strategies.

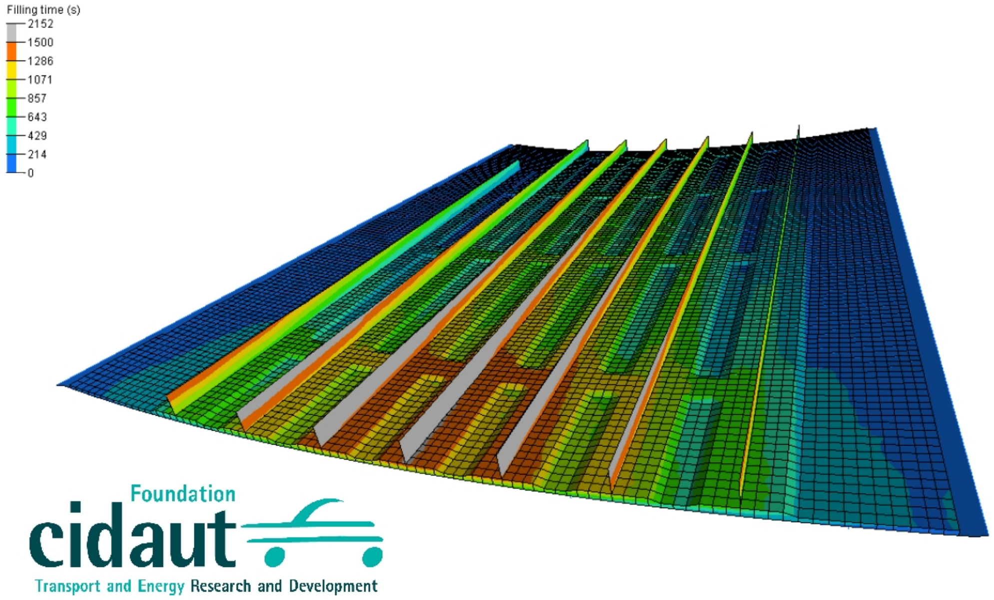

Figure 1 Example of filling time results for a stiffened wing panel

3. WORK PERFORMED AND ACHIEVEMENTS

The project activities were classified in four main WPs:

- **WP1: LRI simulation model**

  The objective of this WP was to investigate on the LRI technology with the aim to develop an advanced finite element model (FEM) for the analysis of resin flow in LRI processing of large stiffened wing panels. WP1 activities included:

  - Set up the physics of the LRI process and the optimized numerical approach.
  - Selection of viscosity model and laboratory characterization of resin parameters.
  - Laboratory characterization of key parameters of porous materials, including in plane and through-the-thickness permeabilities of carbon fibre pre-forms and distribution media.

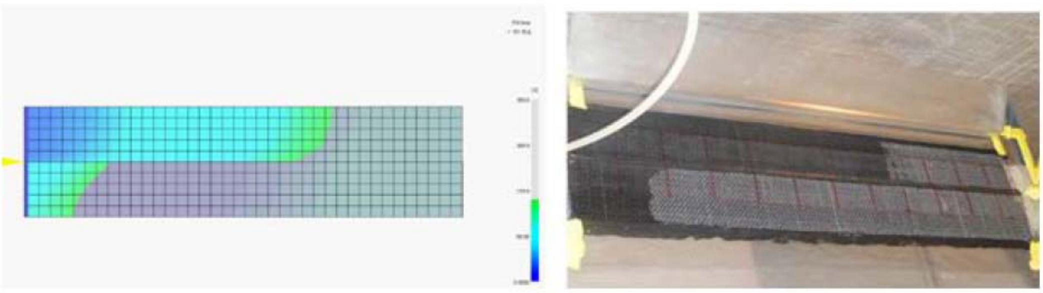

Figure 2 Correlation between simulation and laboratory tests to determine permeabilities

  - Creation of the LRI simulation models based on the geometry and laminate data of the upper and lower stiffened wing panel demonstrators.

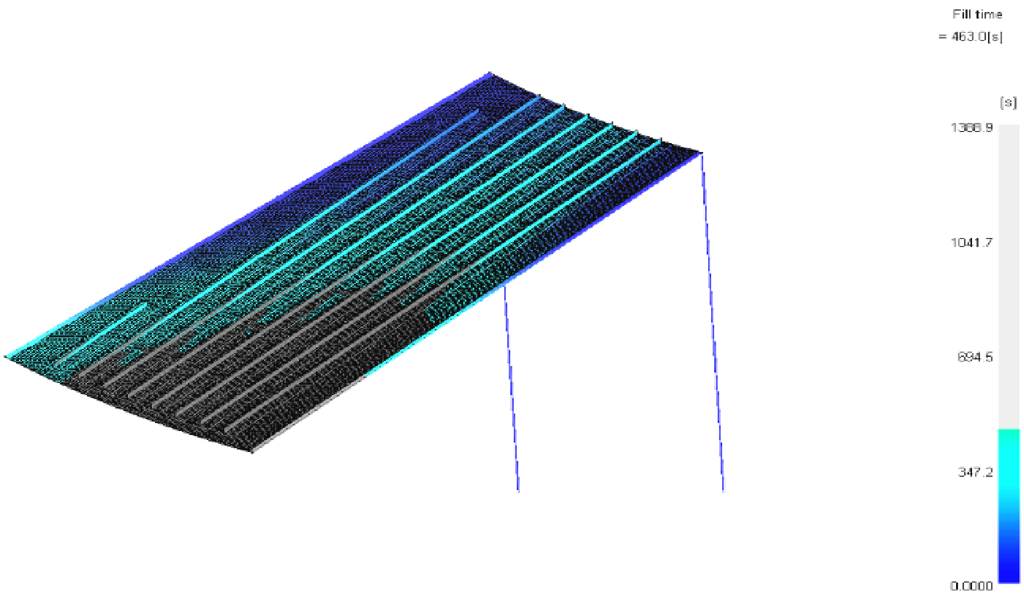

Figure 3 LRI simulation of stiffened wing panel

- Verification of the numerical model.
- Experimental validation LRI tests.

- **WP2: Test Bench design and manufacturing**

  The objective of this WP2 was to conceive and develop an innovative test bench for the validation of the LRI simulation model developed in WP1. The activities included were:
  - Selection of Tools materials (trade off steel-composite-aluminum).
  - Concept design of the Test Bench tools (upper and lower wing panels' main moulds, preforming tools, positioning tools…).Figure 4 shows the baseline concept design of the Test Bench.

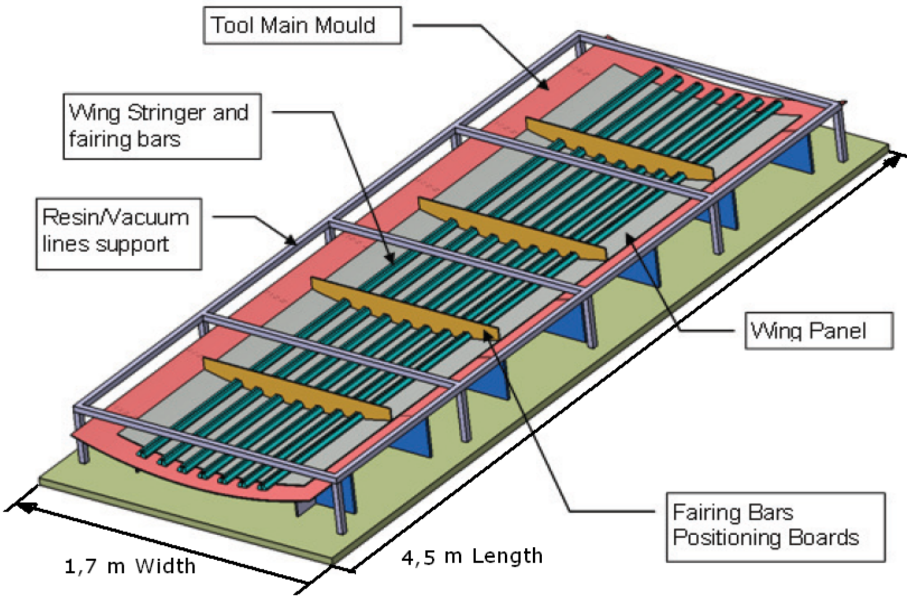

Figure 4 Test Bench concept design

  - Tools detailed design based on the geometry of the geometry and layup of the upper and lower wing panel demonstrators.
  - Tools manufacturing and control.

- **WP3: LRI model validation**

  The objective of this WP was to provide support to the TM during the final LRI model validation while processing the upper and lower stiffened wing panel demonstrators with the Test Bench. Technical support was given to the TM for the analysis of the correlation between experimental and simulation results.

  Alternative impregnation strategies were analyzed using the LRI simulation models both for the upper and lower stiffened wing panel demonstrators, verifying the optimum process setup (number and location of inlet and outlet pipes, distribution media, temperature…). Figure 5 shows one of the demonstrators processed by ALENIA AERMACCHI and SICAMB applying the LRI technology.

Figure 5 Stiffened wing panel made by LRI (Courtesy of ALENIA AERMACCHI and SICAMB)

- **WP4: Project coordination**

  The objective of this WP was the coordination of all project activities coping with the responsibility of carrying out on time all the tasks involved in the project and the dissemination of the project results.

4. SUMMARY OF FINAL RESULTS AND CONCLUSIONS

The PLIT project provided a scientific approach to the physics of LRI processes by producing a numerical simulation model to study the resin flow during the impregnation stage. The model is useful to efficiently identify the optimum LRI process setup, reducing leading times and high materials and labour costs associated with trial and error test procedures. The simulation model is able to predict the possible causes for non uniform distribution of resin flow that may cause dry spots, poor saturation of the pre-form, partially filled composite parts and other defects.

The main innovation achieved in this project was the development of an optimized numerical simulation model based in an accurate and cost-efficient physical approach to the LRI process. Compared to a full 3D computation of the resin flow, generally used for the analysis of infusion processes, the optimized numerical model leads to significant reductions in computation times still considering the resin flow from the DM through the thickness of the laminate. The models are parametric and easy to use even for process engineers without a high level of FEM skills. Different case studies for alternative impregnation strategies can be parametrically created by modifying all the parameters of the process, key material parameters and the number, location, diameter and length of the inlet and outlet pipes, location of DM, sequential fillings, etc. The simulation models were numerically verified and experimentally validated by means of the correlation between simulation and experimental LRI tests. The laboratory characterization of key material parameters such as permeability and viscosity for the selected materials is critical for achieving a good correlation between experimental and simulation results.

Another important achievement of the project was the development of an innovative Test Bench that was designed starting from Members indications, manufactured and delivered to the TM, for the processing of stiffened wing panels demonstrators to validate the simulation results and to develop the LRI technology.

5. IMPACT, DISSEMINATION AND USE OF PROJECT RESULTS

The activities undertaken within the PLIT project have contributed to a successful development of the LRI technology that will lead to shorten fabrication times and reduced energy consumptions in the manufacturing of large stiffened wing panels in composite material. This implies a reduction of the CO_2 emissions, which is one of the main goals of ACARE and CleanSky.

As part of the dissemination activities, from the very beginning of the project a dedicated webpage was created with all relevant, non sensitive, information about the project objectives, main activities and final results (http://plitproject.org).

It is expected that the know-how acquired during the project and the developed methodology for the simulation of LRI processes shall be useful for future research and development programs related to the LRI technology, for instance, within the Cleansky2 initiative.