1. Final publishable summary report

1.1 Executive summary

Today, advanced composites use either layers of plies impregnated with resin (pre-pregs) to form a laminate, or Liquid Composites Moulding (e.g. RTM) of dry textiles. Prepreg composites give superior mechanical properties due to toughened resins and high fibre content, but suffer from high material costs, limited drapeability, complex, expensive and time consuming manufacturing, and limited materials shelf life. Infusion technologies can overcome these limitations, but are not fully industrialised and rely on costly prototype testing due to the lack of simulation tools. Current infusion simulation technologies are approximate and really only suited to small scale components based on adaptations of Resin Transfer Moulding simulation; they are not accurate for large, thick and complex aerospace composites, where one sided tooling and vacuum membranes cause complex 3D heat/flow processes.

The INFUCOMP project will develop the full simulation chain from preform design to manufacture (infusion), process/part optimisation and final part defects/mechanical performance prediction with a focus on the infusion step. The project covers all popular Liquid Resin Infusion (LRI) methods currently used in the Aerospace industry. Although focus is on aerospace applications, the work will be very relevant to other industries. The proposed technologies will allow economical manufacture of high performance, integrated, large scale composite structures; thus, positively contributing to their increased use. Benefits include lower cost, improved performance, greater payloads and fuel/emissions reductions.

A team of four aircraft manufacturers, a materials manufacturer, university and industry researchers, and a commercial software specialists; all with a recognised track record in this field; one partner is an SME.

1.2 Summary description of project and objectives

To date, manufacture of advanced composites in the Aerospace industry mostly uses pre-impregnated composite materials, tape laying technologies and autoclave curing for the production of large, high performance structures and components. These combined technologies allow toughened resins to be uniformly dispersed in a well-controlled fibre system with a high fiber content, producing excellent mechanical stiffness, strength and fatigue resistance properties. However, there are drawbacks, including high material costs, limited shapeability, complex, expensive and time-consuming manufacturing, and short materials shelf life. As a consequence alternative manufacturing methods are being sought based on Liquid Resin Infusion (LRI) technologies in which the resin is infused only after all dry textiles are assembled to form the final composite component configuration. This assembly, prior to infusion, is called a preform. The advantages are lower material and material storage costs, indefinite shelf life (for the textiles) and the ability to manufacture integrated structures having complex geometries only limited by shapeabilty of the dry preforms.

Currently, LRI of large composite structures require 'trial and error' testing and considerable experience on the part of designers and manufacturers to get the correct set-up. The high cost and risks involved will often lead to overly conservative infusion designs with associated cost and performance penalties; or may lead to alternative, less competitive, manufacturing technologies and materials being adopted.

Infusion of dry fabrics may be undertaken using a variety of processes. The first popular method is Resin Transfer Moulding (RTM) which is widely used for the manufacture of small to medium sized components and is especially suited to automation and the manufacture of relatively high production volumes. High injection pressures can be used to reduce infusion time, but is in practice limited by stability of the tooling and effects such as porosity and fibre distortion which may occur especially in the vicinity of the injection ports. The main limitations are high cost and size (weight) of the two part tooling, and relatively long cycle times needed to cure the resin before the part is sufficiently stable to be extracted from the mould. The key steps in RTM are shown in Figure 1 below and involve shaping the preform, extraction and trimming of the preform, and resin infusion in sealed matched (usually metal) tooling.

As mentioned some limitations of RTM are high cost, weight and complexity of tooling. Liquid Resin Infusion can overcome these problems and requires only one sided tooling, which may be significantly lighter and therefore cheaper. Figure 1 below shows the essential features of LRI. A dry fabric is laid up in the tooling, usually with a low permeability flow medium to aid infusion, and a peel ply and/or release ply to help separation of the final composite and flow medium after curing of the final part. The complete setup is sealed in a vacuum bag that prevents air entering the system; vacuum is applied at one location (outlet port) and draws resin from an inlet port through the dry fabric. Large complex parts invariably need a system of inlet and outlet ports which may use synchronised opening and closing to enable complete infusion of the large volume. Also shown in Figure 2 is an intermediate stage of the infusion of an aircraft composite fairing.

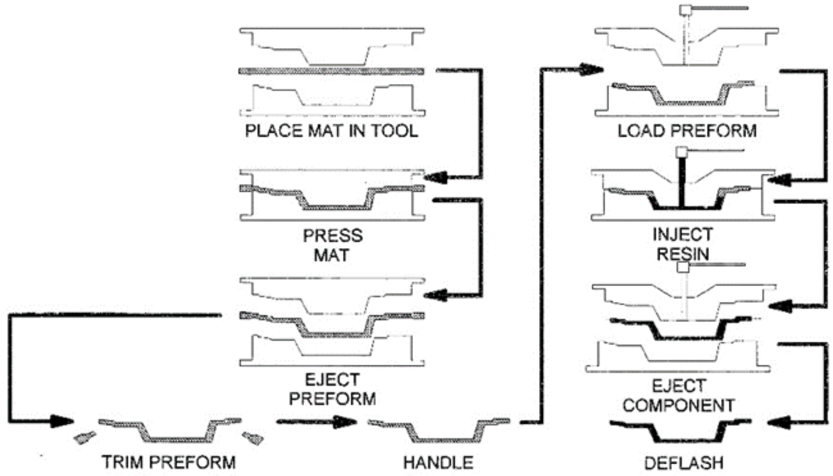

Figure 1: Steps in pre-forming and RTM infusion (Rudd, et al. 1997).

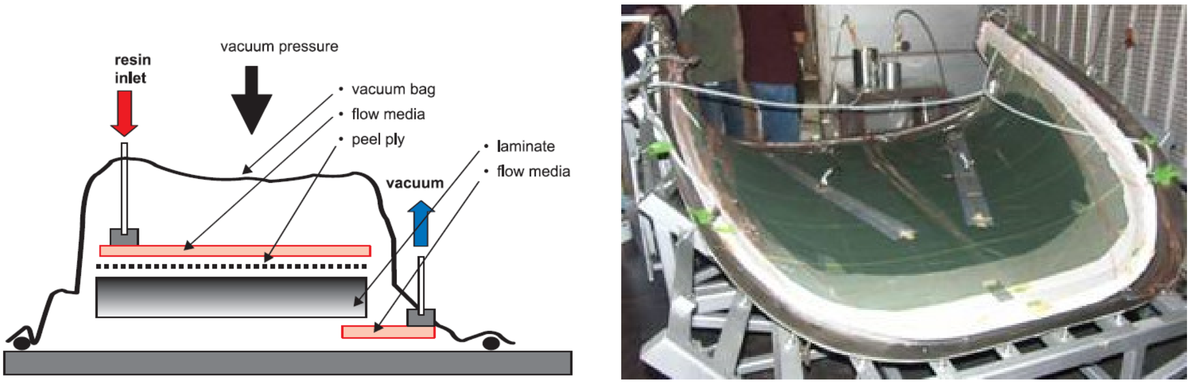

Figure 2: The LRI infusion set-up and an industrial example (Courtesy IAI)

The scientific aim of the CEC INFUCOMP project was to provide a full simulation chain for LRI manufacture of large aerospace composite structures dedicated to solutions required by the European Aircraft industry. Extensive materials testing for a range of dry fabrics and permeability characterisation was conducted from which new constitutive laws were developed. Software developments were implemented into an existing infusion code PAM-RTM^{TM} which has essentially been developed for Resin Transfer Moulding (RTM) processes. Some other specific developments included process optimisation, cost analysis and predictive tools to characterise imperfections such as porosity and residual stresses. One major software development was extension of current scalar computing capabilities so that advantage may be taken of State-of-the-Art massive parallel computers; this has allowed a step change to full 3D infusion modelling involving tens of millions of elements. The new capabilities were validated on a series of demonstration studies of representative parts using the different infusion technologies actively used at the four industrial partners sites.

The consortium was led by a software company (ESI) who have developed further the existing PAM-RTM software code, based on scientific contributions from university, materials and research partners. An important aspect of the project was development of a series of demonstrator parts undertaken by the industrial partners; this has helped validate and industrialise the new software developments.

In detail the consortium included:

- Four aircraft manufacturers: Bombardier Aerospace, Belfast (UK), Piaggio Aero Industries S.p.A (Italy), Daher Aerospace (France) and Israel Aerospace Industries (Israel).
- One material manufacturer: Hexcel (France).
- One simulation software supplier: ESI Group (France) and ESI GmbH (Germany).
- An infusion sensor specialist INASCO (Greece).
- Four academic partners: Cranfield University (UK), University of Patras (Greece), Ecole des Mines de Douai and Saint-Etienne (France), and Katholieke Universiteit Leuven (Belgium).
- Two institutes: The Institute for Aircraft Design, IFB (Germany) and SWEREA SICOMP (Sweden).

The overall project objectives included:

- A validated series of industrial studies on various Liquid Resin Infusion (LRI) processes.
- Successful application of the new software to show it may be efficiently and reliably used to model LRI processes.
- A new LRI software adapted to DMP computer architecture, so that 3D models having tens of millions of finite elements may be performed and results efficiently post-processed.
- New test methods and data to characterise draping and compaction of fabrics.
- New material models to predict fabric draping and compaction.
- New test data and constitutive laws to characterise resin viscosity specifically suited to infusion processes.
- Solutions to resolve known computational stability problems at the flow media-to-fabric interfaces.
- New work and progress in modelling manufacturing defects of LRI composites, including residual stresses, porosity and surface finish.
- Validated methodologies for costs modelling and optimisation of LRI processes.