



Project no. 605583

EU 7<sup>th</sup> Framework Programme  
THEME [AAT.2013.1-2. AAT.2013.4-3.]  
[Aerostructures Production]

## **Final Report**

Project co-funded by the European Commission within the 7<sup>th</sup> Framework Programme

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## 1. Introduction

The purpose of the CANAL project is to develop new Non-Conventional composite laminate configurations using Dry Fibre Placement (DFP) and the establishment of the engineering tools for the design of efficient structures made of these new configurations. The project integrates laminate design, manufacturing and structural design to ensure the industrial applicability of the technology in the aerospace industry and other industries, such as automotive, that can benefit from rapid and cost effective production of complex shaped and high-performance composite parts.

Recent advances made in two different technology areas are combined in the proposed CANAL project to push the state of the art in design, optimization, and production of advanced composite structures for aircraft application and increase the technology readiness level of the two areas towards a successful transitioning to industrial application.

The first area is the result of a recent EU project called AUTOW (Automated Preform Fabrication by Dry TOW Placement) during which Automated Fibre Placement technology is combined with the Liquid Composite Moulding process for rapid and cost effective production of complex doubly curved composite parts. The combined process allows fabrication of complex preforms through fibre placement followed by resin injection using liquid composite moulding process. Besides the weight and cost reduction that is achieved using automated composite manufacturing, the combined process has the added benefit of material cost reduction through the use of dry fibres instead of more costly prepregs, and time and cost savings through Liquid Composite Moulding instead of costly autoclave curing.

The second area is the development of Non-Conventional Laminates. Whereas up to now composite laminates usually consist of only 0,  $\pm 45$  and 90 degree layers, the development of Automated Fibre Placement technology has opened possibilities to divert from this limiting step in design and manufacturing. A form of Non-Conventional Laminates is the Variable Stiffness laminates with steered fibre paths that showed an improvement in buckling performance and natural frequencies for both panels and cylinders through optimal tailoring. A new form of Non-Conventional Laminates, called AP-PLY, has recently been introduced and experimentally demonstrated to have improved impact damage tolerance performance. The AP-PLY is a construction, which can be fabricated using Automated Fibre Placement or Automated Tape Laying machines, that creates a multi-directional weave pattern for a composite laminate.

## **2. State of the art – Background**

With the ever increasing percentage of composites in aircraft structures aiding weight and fuel reduction, so is the level of automation expanding rapidly. One of the most notable being Automated Fibre Placement (AFP) offering high lay-up rates combined with several other advantages of which unlimited fibre angles is one of the most promising. Another manufacturing method being used more and more is often referred to as Liquid Composite Moulding (LCM). The advantages of this process are that it is possible to use cheaper materials and simpler tooling. It also enables cheaper processing, tight tolerances, part integration, reducing assembly costs. The preceding EU project AUTOW laid the foundation for the CANAL project in successfully developing Dry Fibre Placement (DFP) enabling the cost effective, automated manufacture of dry preforms required for further successful implementation of LCM in aircraft and other transport vehicles.

Although Automated Fibre Placement offers an unlimited range of fibre angles and even steering, current design practices are still based on using only a limited number of angles mainly 0,  $\pm 45$ , 90 degrees resulting in sub-optimal quasi-isotropic laminates. To obtain further weight and cost reduction and increase the performance of composite structures, designers will need to move away from this and be able to exploit the full potential composites offer and manufacturing techniques such as AFP enable.

## **3. Objectives**

The AUTOW project was first of its kind, and successfully performed the initial development and demonstration of the two essential elements of the current project, namely Dry Fibre Placement (DFP) and Non-Conventional Laminates (NCL). Currently, no Non-Conventional Laminates (NCL) are known to be implemented in industry, though research has shown promising results through simulation and coupon testing.

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#### 4. Description of work

To achieve the CANAL objectives a multi-disciplinary approach is required. Partners will be developing new Non-Conventional Laminate concepts, which will firstly be manufactured and tested at coupon level in order to obtain the basic mechanical and physical properties. The test data will be coupled to modelling of the NCL made with DFP to predict the in-service behaviour but also the manufacturing characteristics such as permeability of real size structures. Changing the design from conventional lay-ups to NCLs in combination with DFP offers advantages, but there are some hurdles to overcome before it can be successfully integrated. Besides the investment cost, there is a learning curve. In CANAL engineering knowledge and tools will be developed that enable designers to create optimal composite structures that are integrated and compatible with DFP software. This will require engineers to learn the fundamentals of automated fibre placement and how it works with the design, while machine operators must be trained to use the new materials and processes. In CANAL the partners will validate the new technology, by performing the complete cycle of design, analysis, fabrication and testing for the representative components which are generic, but “full-scale” and sufficiently detailed to illustrate the capability of NCLs and DFP.

#### 5. Work performed in M37-48 and results achieved

The work in CANAL continued in the 3rd period with engineering and manufacturing of the conventional benchmark and NCL coupons and test articles.

The two main aerospace grade Dry Fibre Placement materials are HiTape from Hexcel and TX1100 from Cytec. NLR, Dassault and Airbus are the main responsible partners for manufacture of the preforms, test panels and coupons. The partners are investigating RTM and VARTM. Especially VARTM of DFP preforms has required development work. NLR continued the fine tuning of the bagging and infusion approach in the final period and completed the basic panel activities by fibre placing the NCL panels followed by infusion.

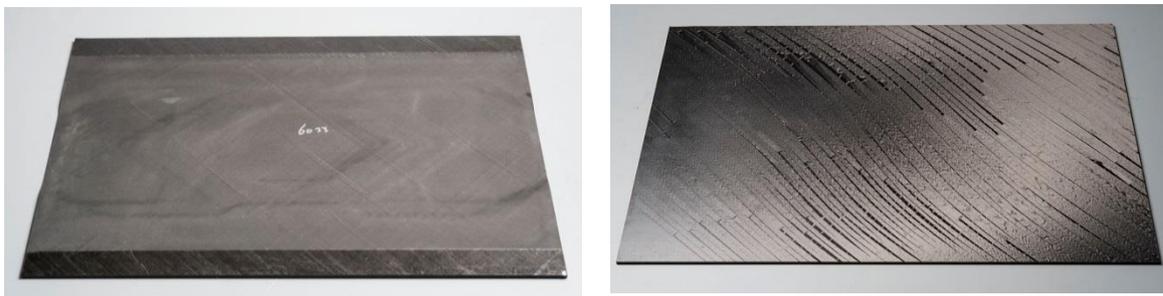


Figure 1: Example of NCL test panels designed by TUDelft and ONERA and manufactured using DFP and VARTM [NLR]

The conventional lay-up benchmark Spar was provided to VZLU for testing. However, the NCL version of this spar consisting of steered plies proved to be too challenging to programme and fibre place within the available time. For the IAI stiffened skin panel the partners managed to develop the conventional and NCL version. For the NCL version it was clear that steering considering the stiffener pitch was not an option, therefore a dispersed laminate design was developed. Both versions were tested successfully at VZLU.



Figure 2: Manufacturing the IAI Stiffened Panel – Dry Fibre Placed & Hot Draped U-stringer [NLR] and Infusion at IAI

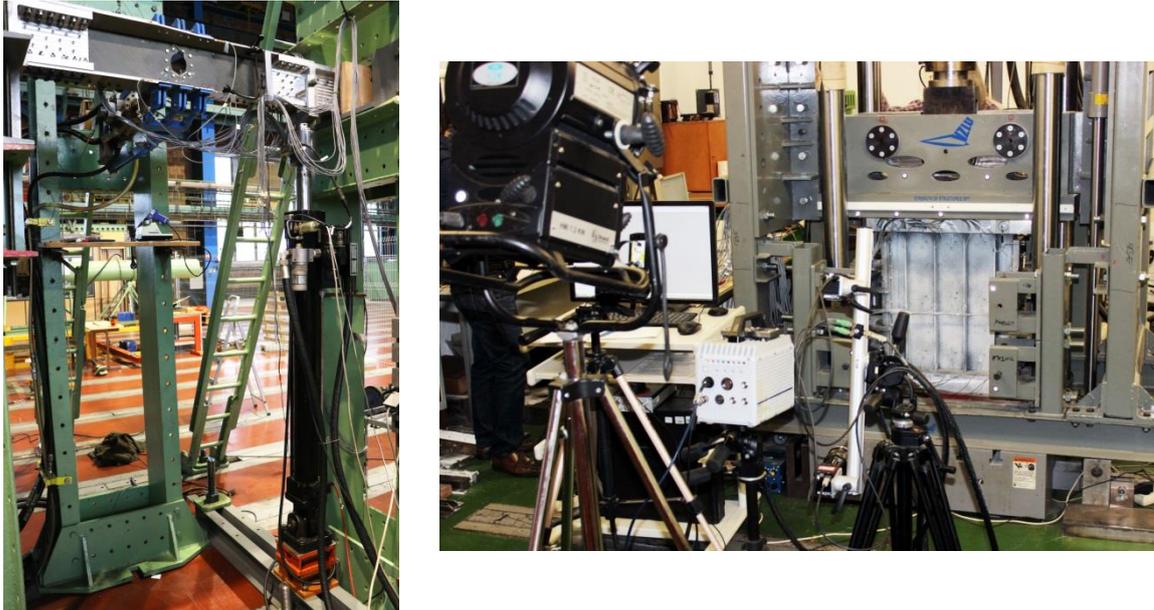


Figure 3: Testing of the Dassault Spar and IAI Stiffened Panel at VZLU

## 6. Results

CANAL aimed at pushing the boundaries of the research and technology demonstration on DFP and NCL composite structure in several areas. The end goal of the project was to generate knowledge and experience on the best combination of NCLs and DFP for various application cases and capture these in engineering tools and approaches. The use of NCLs in theory can result in startling improvements, being weight reduction, increased performance, etc. In CANAL a number of manufacturing constraints, such as minimum steering radius, was taken into account in the modelling and development of NCL concepts. For the stiffened skin panel using a dispersed NCL architecture this proved that increased structural performance can be achieved readily without weight increase. In case of AFP, an optimised fibre orientation of e.g.  $37^\circ$  instead of conventional  $45^\circ$  has no effect on the lay-up rate and hence manufacturing time and costs. However, not all NCLs can be implemented as readily and easily. For the Dassault NCL spar using steered fibres, the concept to AFP programming chain proved to be far more challenging and could not be completed in time. The conclusion is that although the basic combination of DFP and NCL proves feasible, more effort is required to demonstrate this technology on real components and for various NCL architectures especially variable stiffness requiring fibre steering.

## 7. Potential impact, main dissemination activities and the exploitation of Results

Many European aerospace industries not only develop and produce component for Airbus but also for Embraer, Bombardier, Dassault or even Boeing in a globalised market. To keep their competitiveness on this market, the European industry is now deploying the industrial capacity to supply state of the art composite structures.

Massive insertion of composites is thus one of the solutions to meet the top-level objectives of the Vision 2020 of the European aeronautics majors which is implemented by the strategic research agenda of the Advisory Council for Aeronautics Research in Europe (ACARE). In terms of structures, the statement "...towards a more affordable, safer, cleaner and quieter aircraft..." can be reformulated as:

- Towards structures with a reduced development cost, manufacturing cost and life cycle cost, that will make future aircraft and air-traffic more affordable
- Towards more automated manufacturing routes and net-shaped products for manufacturing cost-efficiency and reproducibility
- Towards the inclusion of strong environmental constraints in the early design phase
- Towards a reduced time-to-market that will allow for rapid insertion of more affordable, cleaner, high quality products
- Towards lighter structures (optimized design, better confidence in the capacity to sustain significant damage – i.e. damage tolerance) that will help decreasing the fuel consumption
- Towards high-performance structures (new materials, optimized design, in-situ monitoring, ...) with improved quality and reliability for a safer aircraft.

These concepts are indeed present in the FP7 under the form of selected topics which translate the strategic objectives in more technical terms.

The six items listed here above give very clear objectives to today's structure designers and engineers. Concurrent objectives have to be achieved (e.g. minimum weight, maximum performance, minimum cost), which have a particular meaning in terms of creating composite structures using the fibres in the most optimal way stepping away from the current, conventional laminate build-up; both design and manufacturing wise.

CANAL addressed the specific issues of cost-efficiency, performance and reliability of Non-Conventional Laminates, using the approach as described previously. CANAL thus brings knowledge, techniques and methodologies that will help the European Aeronautics Sector meeting them in the near future.

The first results of the CANAL project are the advanced concepts and technologies for increased and optimised use of composite and multi-functional materials in primary structures with a potential to reducing greenhouse gas emissions. Moreover, the potential for significant weight reduction (15%) for key structural items in a wingbox structure was demonstrated, as a result of advanced design, materials and processes usage. Jointly, these results will lead to the reduction of airplane weight, fuel consumption and greenhouse gas emissions.

The reduction in weight and cost supported by novel design and manufacturing approaches as used in CANAL will further facilitate and speed up the introduction of composite lightweight structures in aerospace and other transport industries. Lightweight composite structures contribute directly to reducing fuel consumption and hence GHG emissions of aircraft and other transport vehicles, Moreover weight reduction also allows for reduced power system requirements in turn facilitating electrification.

Composites become more attractive when they can be produced as a single, integrated, "one-shot" structure. The approach followed in CANAL creating dry preforms of skin panels and spars using a combination of NCL and DFP allows a high level of part integration when these are integrally infused using LCM techniques such as (VA)RTM. The high level of integration of composite structures achieved using LCM reduces or even completely eliminates fasteners or other joining elements.

Dry Fibre Placement is a further development of the highly automated manufacturing technique Automated Fibre Placement reducing production lead time through high material output. In CANAL industrial experience and guidelines were generated.

Manufacturing cost reduction is obtained mainly thanks to the automation of the deposition and the integral "one shot" manufacture, when compared to the current design (metal) and even to the state-of-the-art (manual lay-up NCF or prepreg hand lay-up). Additional cost saving will be obtained through optimization of the part thanks to use of UD material and steering (reduced quantity of material and minimum waste), combined with the green "closed loop", out of autoclave LCM technology. A target of 20% reduction of recurring costs is predicted for the considered primary components such as spar and skin panel compared to the current technology.

State-of-the-art is manual lay-up of dry fibre fabrics (NCFs) which are supplied in rolls with standard widths. Obtaining the individual plies for part lay-up and manufacture is sub optimal and results in a material scrap rate of 40-50% for standard sections to even higher percentages for more complex, large parts. With Automated Dry Fibre Placement this waste can be reduced to 5 to 10%, which is a significant reduction in the use of carbon fibre which is an expensive, and energy intensive to manufacture material.

### **Societal and environmental impact**

The use of CFRP structures for airframe structures brings immediate weight savings, if the parts can indeed be joined with confidence, hence reducing the aircraft fuel consumption with a direct impact on environment. Insertion of composites is thus driven by the quest for lighter aircraft. Nevertheless, the large adoption of- and the confidence in high-performance primary composites structures and the associated environmental impact will become a reality only when the costly, high performance fibres are used optimally and CFRP structures reach the same level of maturity and confidence as that already observed for metallic aircrafts.

A lack of knowledge and the tendency to fall back on existing knowledge, experience and data might lead to the adoption of conservative solutions, or even to the rejection of the composite solution. The adopted solutions are then not optimum from the standpoints of performance, cost and mass, i.e. solutions which do not meet the important requirements of Vision for 2020 of the majors of the European aeronautics sector. With respect to societal impact, health and welfare of employees in the composite industry should also be considered. In many composite industries and even in aerospace it is still common practice to use the manual wet lay-up process. Basically the liquid resin is poured over the dry fibre fabrics and rolled to ensure complete wetting of the fibre and removal of air bubbles. The apparent advantages of this method are that it is simple, low cost and no requirement for highly skilled labour. The disadvantages are that it is not suited for strength or weight critical primary structure as the fibre orientation and local resin content cannot be well controlled. But most critically for the involved composite mechanic, the wet lay-up also has health and safety issues because low molecular weight resins can be harmful. The development in CANAL will enable advanced, cost-effective closed mould manufacturing processes replacing these harmful open mould techniques in the composite industry.

Reducing the environmental impact is not only achieved through weight reduction and the consequently lower fuel consumption, but in CANAL also to a large extent due to application of Automated Dry Fibre Placement. State-of-the-art is manual lay-up of dry fibre fabrics (NCFs) which are supplied in rolls with standard widths. Obtaining the individual plies for part lay-up and manufacture is sub optimal and results in a material scrap rate of 40-50% for standard sections to even higher percentages for more complex, large parts. With Automated Dry Fibre Placement this can be reduced to **5 to 10%**, which is a significant reduction in the use of carbon fibre which is an expensive, and energy intensive to manufacture material.

Pre-preg is a term for "pre-impregnated" composite fibres in which the matrix material, in aerospace often an epoxy is already present. The fibre reinforcement is usually a fabric (weave) or uni-directional. Pre-pregs already contain an amount of the matrix material used to bond them together and to other components during manufacture. The resin is applied by the material manufacturer and is only partially cured; this is called B-Stage material and requires cold storage to prevent complete curing. B-Stage pre-preg is always stored in cooled areas (typically -18°C) since complete polymerization is most commonly done by heat. Even then the storage life is generally limited to 6 to 12 months. The composite part manufacturer lay-ups and cures the part with an oven or autoclave to finish the complete polymerization. So the manufacture of composite parts using prepregs is a two-step approach requiring energy and resources for the manufacture of the

basic prepreg. In contrast Liquid Composite Moulding technique is a direct manufacturing process resulting in a near net-section part and eliminates the intermediate step by directly combining the reinforcing fibres and the matrix in one manufacturing step by the composite part manufacturer itself.

Another energy saving aspect is that Out-Of-Autoclave technology such as Liquid Moulding requires much less energy than an autoclave process.

Dissemination and exploitation took place in several ways. The CANAL partners published various papers, which were presented at conferences. Also two workshops were held at NLR highlighting the potential of the technology developed in CANAL. Finally the commercial exploitation will become clear within the very near future, when some of the CANAL partners will be allowed to publish their further developments on Dry Fibre Placement, Infusion and NCL architecture. Due to confidentiality reasons, these cannot be disclosed yet.

