



AUTOW:

Automated Preform Fabrication by Dry Tow Placement

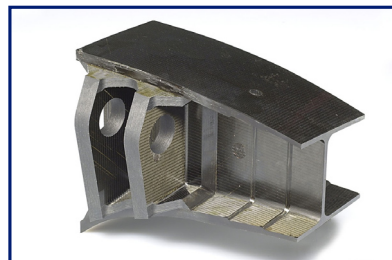
Background

The percentage of fibre reinforced materials (composites) in primary aircraft structures continues to grow. With this growth comes demand for continuous improvements in manufacturing technology. The most common manufacturing technology for composites used today involves manual stacking of pre-impregnated sheets of material followed by cure in an autoclave. It uses complex tooling and precludes a high level of part integration, increasing assembly effort. Hand lay-up of cut prepregs are labour intensive and a highly trained technician can place just about over 1 kg per hour. With AFP this could be increased to 6.5 to 11 kg/hour for complex tools and for cylindrical parts even up to more than 20 kg per hour. The capital investment of few hundred thousand to several millions Euro for AFP machinery can be more than compensated by this increase in lay-up rate, whereas the costs of labour will only increase in future. Combined with other advantages of AFP over hand lay-up such as very precise ply thickness control, in-process compaction, high consistent quality, low void content (typically < 1%), unlimited fibre angles (tow path optimisation) and low material scrap rate (5 to 20%). To summarize the above, the Boeing 787 would not have been built without the development of AFP.



Example of AFP manufacturing. Thermoplastic tape placement of skin [ALCAS]

Another novel manufacturing method, often referred to as Liquid Composite Moulding (LCM), uses dry fabric which is pre-formed into the component shape, placed in a mould, subsequently injected with resin and cured. The advantages of this process are that it is possible to use cheaper materials and simpler tooling. It also enables cheaper processing and part integration, reducing assembly costs. Examples of advanced aerospace composite structural components with tight geometrical tolerances manufactured using LCM and matched metal tooling are shown below.



Composite beam with integrated bracket and composite drag brace [Ref. 2]

So far, the potential advantages of LCM could not be fully exploited, because preforming is either a manual process or else an automated process with limited scope, such as weaving or braiding.

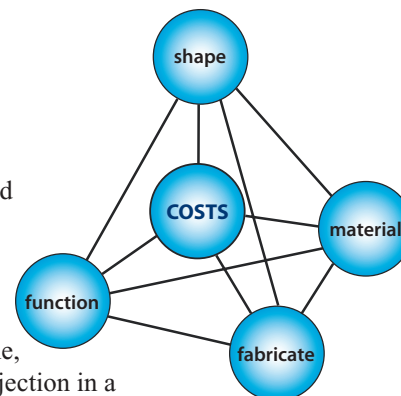
An innovative technology for the automated fabrication of complex preforms developed would overcome these problems and could enable cost savings of up to 40% in comparison with current technology, due to cheaper part manufacturing, less scrap, reduced assembly and increased accuracy. The basis of this innovation is dry tow placement using AFP technology.

Objectives

The aim of the project is the development of manufacturing technology for automated preforming, with a parallel development of a design capability to match. The AUTOW project will develop the technology by adapting existing automated deposition capability for pre-impregnated materials (prepregs) with the capability to deposit dry fibre tows, allowing the fabrication of complex preforms. These can then be injected with a cost-efficient, automated LCM process. The complexity of the challenge to develop this new technology is in the multi-disciplinary approach required to adapt, develop and explore:

- machine capability,
- material format,
- process window,
- an integrated design engineering approach.

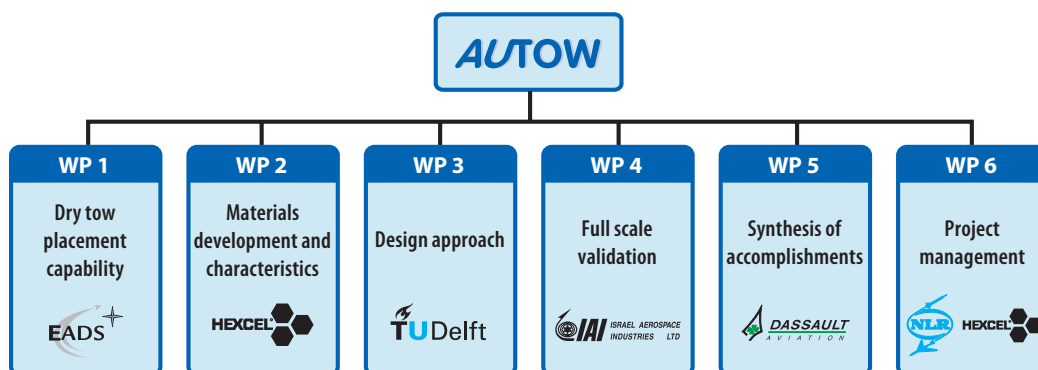
As shown in the right figure all aspects need to be addressed to achieve the final goal of cost reduction.



Critical areas that will be developed are:

- Advanced machine and materials expertise to develop a material that is compatible with the machine, will stick to the mould or substrate and allow resin injection in a subsequent LCM-process.
- Aerospace expertise to determine the scope and constraints of the new fabrication capability with respect to preform shapes, fibre trajectories and processing parameters for relevant applications.
- Expertise in materials modelling, process simulation, structural analysis and optimisation to obtain an integrated design engineering approach for the design of components to be made with the new fabrication capability.

A schematic overview of the project Work Packages and responsible Work Package Leaders is given in the figure below.



Organisation of the AUTOW project showing the 6 Work Packages and WP Leaders

In this presentation the focus will be on the active Work Packages 1, 2, 3, 4 and 6. Considering the relatively small size of the AUTOW consortium, it has been decided to limit the number of work packages, tasks, subtasks etc. In AUTOW each WP also has a limited number of tasks.

This presentation will inform the reader on the background and objectives of the AUTOW project and the technical progress achieved to date. It should be noted that considering the innovative nature of AUTOW related IPR issues not all technical details can be presented.

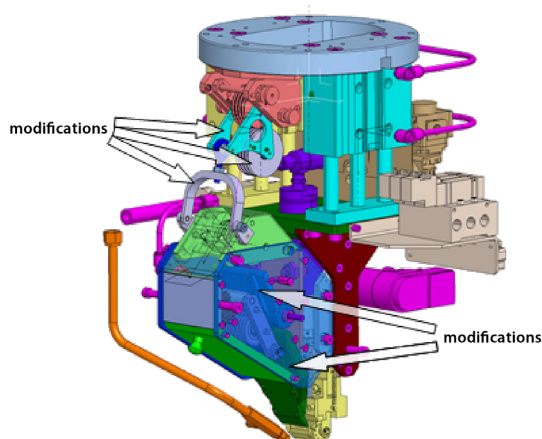
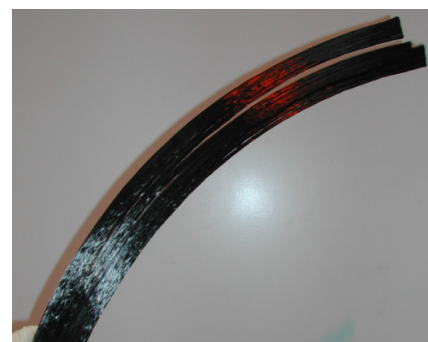
WP1 Dry Tow Placement Capability

Objectives of WP1 are:

- To develop fabrication capabilities to deposit dry carbon fibres on a defined laying-up tool by automated tow placement
- To obtain process windows for the new preforming method by fabricating generic preforms.

To achieve these objectives a number of issues need to be dealt with. The AFP machines used within the consortium are not laid out for placing dry tows and need to be modified. This implies the specification, conception, design, fabrication, assembly and instrumentation of the adaptations to the machines.

In the first year EADS-IW, DAV and NLR worked in parallel on their FP machines experimenting with the dry tow fibres supplied by Hexcel. In order to deposit the dry tow fibres successfully on the tooling, the dry tow fibres first need to be guided through the FP machine and head appropriately. The partners involved have successfully developed and implemented machine modifications to enable this and overcome problems encountered such as fraying at the compaction roller and fraying and winding of the tows around the pinch rollers. But also tuning the flow of the gas torch to prevent the fibres from being blown apart was investigated.



*Fraying at the compaction roller,
example of steering radius trials and
location of machine modifications*

Once the machines have been properly adapted to placing dry tows, which happens in close co-operation with WP2 Material Development & Characterisation, the work can start on investigating the process windows for the new capability. This implies the identification of configurations of interest, and the specification of the features to be investigated, such as fibre trajectories-steering radius, minimum access areas, and limits for concave and convex curvatures, as well as the development of innovative lay-up tooling. Finally a range of these configurations have been determined and these generic preforms are currently being manufactured.

WP2 Materials Development and Characterisation

Objectives of WP2 are:

- To develop one or more material configurations, consisting of dry tow material provided with binder.
- To determine the material properties and process parameters, by fabricating and testing specimens.

In the first year Hexcel was able to develop and manufacture a dry tow fibre configuration after discussing the performance and processing requirements with EADS-IW, DAV and NLR. These partners in turn investigated these dry tow fibres with binder on the compatibility with the machine, and the tackiness. This finally resulted in successfully depositing dry tow fibres onto a flat mandrel and injecting this dry preform with RTM.



Dry fibre placement on generic preform and the injected preform

Although the dry tow fibres with binder powder can be processed well, the partners have expressed the need for a material with higher toughness to achieve further impact characteristics improvement. HXL proposed to explore thermo-plastic (TP) veils. At the end of the first year the first two creels with the new veiled tows have become available and have been tested in the second year.

WP3 Design Approach

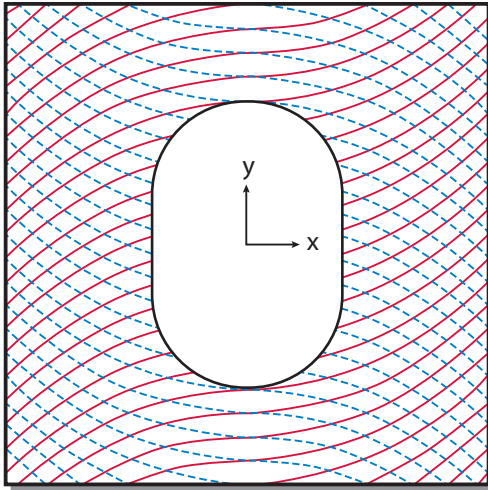
Objectives of WP3 are:

- Support fabrication with a design capability
- Develop integrated design engineering approach for dry tow placement:
 - optimise designs for compatibility with manufacturing constraints, as well as design requirements.
 - make use of new capabilities, notably fibre steering, to improve performance.

This work package supports the new fabrication capability with the development of an integrated design engineering approach. For this purpose, use is made of models and software, which are either commercially available, or of which the development was largely carried out in other EU-projects, such as Catia, Nastran, TOWPOP and AuTowTex. The interaction between them will be established, and a fibre path optimisation module is developed to guide the design process. This approach is needed to efficiently adapt an initial design to comply with manufacturing constraints, while still satisfying the design requirements, and optimising fibre paths.

In AUTOW all design aspects are linked. For example the stacking sequence can influence the permeability and this needs to be predicted. For this purpose ONERA developed a set of generic preforms and is working on predictive model(s) of fibrous materials (preforms) permeability both analytical as well as 3D FE. In this KULeuven also offers expertise. On micro level input is required on the ply properties, which KULeuven supplies. On the other side the limits of the fibre placement machine need to be taken into account in the design and the output format for the fibre placement programming.

In AUTOW IFB is responsible for linking all these different design steps and related software packages. So when an optimal lay-up is created by the TUDelft, this lay-up with varying fibre orientations will need to be checked in FE Nastran but also in the Fibre Placement Programming software and the Permeability model and feedback of results should be possible.



Panel with hole and varying fibre orientation laminate design

As mentioned one of the most promising advantages of advance fibre placement machines is fibre steering. Research has shown that buckling loads of composite panels can be improved significantly by allowing the laminate stiffness to vary locally. This variable stiffness approach results in improvement of buckling performance in excess of 100% compared to quasi-isotropic laminates. The TUDelft is working on optimizing laminates tailoring the local stiffness properties of a composite panel. An example of an alternative panel with hole laminate design is given in the left figure, clearly showing the varying fibre orientation and thereby changing laminate stiffness over the panel area.

Within WP3 an alternative design of a beam with a flat web will be created using the above described approach, whereas in WP4 the more traditional lay-up orientations $[0, \pm 45, 90]$ will be used to design, manufacture and test a sine wave beam.

TUDelft and KULEuven have published papers that describe in much more detail the work performed in WP3.

“Permeability of Textile Reinforcements: Simulation; Influence of Shear, Nesting and Boundary Conditions; Validation”, B. Verleye, R. Croce, M. Griebel, M. Klitz, S.V. Lomov (KULEuven), G. Morren, H. Sol, I. Verpoest and D. Roose, *FPCM-9 (2008), The 9th International Conference on Flow Processes in Composite Materials Montréal (Québec), Canada*

“Design of Composite Structures for Advanced Fibre Placement Technology”, Samuel T. IJsselmuiden, Mostafa M. Abdalla and Zafer Gürdal, *TUDelft, 2nd SAIAS Symposium, 14-16 September 2008, Stellenbosch, South Africa*

“Design of Variable Stiffness Panels for Maximum Buckling Load Using Lamination Parameters”, Samuel T. IJsselmuiden, Mostafa M. Abdalla, Shahriar Setoodeh, Zafer Gürdal, *TUDelft, pre-print sent to AIAA Journal*

Also the TUDelft presented a poster **“Retrieving Variable Stiffness Laminates from Lamination Parameters Distribution”**, at the Engineering Mechanics Symposium in Lunteren.

WP4 Full Scale Validation

Objectives of WP4 are:

- To qualify the new capability by performing a trade-off study versus traditional technology for five structural components
- To validate the new technology, by performing the complete cycle of design, analysis, fabrication and testing for a representative component – a component which is generic, but “full-scale” and sufficiently detailed to illustrate the new capability.

Changing to AFP offers advantages, but there are some hurdles to overcome before it can be successfully integrated. Besides the investment cost, there is a learning curve. Designers will have to learn to design composite structures that work and integrate or in other words are compatible with AFP software, requiring 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 equipment [Ref. 3]. In WP4 this learning curve is part of the validation of the new technology.

To focus this Trade-Off study and Work Package, five components were already defined in the Description of Work each of which are suitable candidates to be fabricated with the new technology, and incorporate features which are specifically achievable with dry tow placement. These components are: a centre wing box fitting, a sine-wave beam with access hole, an angled wing panel, a landing gear component and a wing nose rib. All partners evaluated these components on several issues such as manufacturing (AFP, LCM), design & optimization, testing using their expertise. After a joint meeting and evaluation, the sine wave beam was selected as the full scale validation part.

A concept Business Jet Wing Sine-Wave Rib design with Central Hole being representative for a rib of a Business Jet Wing was designed and stressed by IAI, with a machined aluminium rib as benchmark.

This concept design provided a good starting point for discussions on manufacturability and design/stress. One of the major issues is the definition of the fibre orientation. What is defined in the Patran-Nastran model certainly does not always match with what can be programmed in FPM and can be placed using the AFP machine. For example very basically the partners need to agree on the definition of 0deg orientation in the rib flange. Also the wave length and depth are partly determined by the capabilities of the AFP machine and need to be considered in the design.

Eventually NLR/EADS-IW/DAV will manufacture the dry preform of the sine wave rib, which IAI will inject this vacuum assisted with single sided hard tooling. The rib will then be tested at VZLU.

WP6 Project Management and exploitation

Objectives of WP6 are:

- To carry out project management and administrative aspects
- To provide overall co-ordination of the scientific and technical work within the project
- To carry out exploitation management

Hexcel has been appointed as Exploitation Manager by the partners to manage all of the Exploitation Tasks for the project. Hereby Hexcel is responsible for the co-ordination and production of all publicity and exploitation material and information for the project as a whole. Another important issue in AUTOW is Intellectual Property Rights. One of the major expected results of AUTOW is an aerospace quality, carbon fibre dry tow material configuration suited for AFP and LCM which is developed by Hexcel. As a developer and manufacturer of advanced materials, Hexcel has ample knowledge and experience on IPR issues and also therefore is the most suited party to safeguard IPR issues.

For successfully managing a project and achieving the objectives, communication is of crucial importance. This is very common knowledge, but much more difficult to actually put into practice. While communication is a two way lane, the project manager will have to start it and keep it going. Especially within EU projects with partners scattered all over Europe, this is quite a challenge. In AUTOW the partners are not only from different countries, but also have different backgrounds complicating matters even more.

For example in AUTOW the universities are mainly involved in WP3 where they can work rather independently. The challenge is then to make them interact with the other Work Packages. Not uncommon in EU projects and also the case with AUTOW, it is facing a major delay and project extension duration is required. However universities often allocate Post Graduates for a limited number of years that work mainly on one EU project like AUTOW and independent of the general progress of the project they can plan

and use the complete Person Months. It requires quite some flexibility from the universities to adjust to the project overall progress and duration.

In AUTOW, like many EU projects, Small and Medium Enterprises are involved for whom research and development is important but the day to day routine and 100% paid contracts are vital. The key issue is to keep these parties motivated and informed. This means a lot of phone-calls, because e-mails just cannot be read in time.

For the big enterprises, these are not any different, for them too day to day is very important and here competitiveness plays an important role. Often the major companies (materials, parts, assembly) already have a lot of knowledge and experience but cannot share all of this freely because of non disclosure agreements with other parties.

Finally for laboratories with research in composites booming, the main problem seems to be that there is just too much work with too few people to do the job.

Based on the experience in AUTOW the conclusion is that proper project management involves a lot of e-mailing, talking, negotiating, reporting, meeting, etc. and this is generally more time consuming than planned at the project conception. However working on AUTOW project is very rewarding with enthusiastic partners that share a mutual interest in solving technical challenges in a multi-disciplinary way.

Expected end results

The project will result in:

- A new capability for automated preform fabrication for LCM processes.
- An aerospace quality, carbon fibre dry tow material configuration:
 - that can be handled by the machine;
 - will stick to the mould;
 - and is sufficiently permeable to allow resin injection will be developed.
- Processing windows for fabrication and options and limitations with respect to component shape and tow trajectories
- An integrated design engineering approach with software capabilities for design of components using dry tow placement
- A validated fabrication capability for the complete design-analysis-fabrication-test cycle for representative component.

The proposed research will contribute to realise a validated fabrication technology for automated preform manufacture with advanced dry tow placement machines, which, in combination with automated liquid composite moulding and cure, enables building composite structures for aerospace vehicles in a fully automatic way. This will result in considerable cost and time savings. The possible cost reduction will strengthen the competitiveness of the European Aerospace industry and is in line with the European Vision for 2020.

References

- [1] AUTOW Annex I – “Description of Work”
- [2] Developments of Resin Transfer Moulding Technology at NLR, H.G.S.J. Thuis, NLR-TP-2003-567
- [3] ATL & AFP: Signs of evolution in machine process control, Jeff Sloan, High-Performance Composites, September 2008-12-08

AUTOW		List of participants:			
Participant Role		Participant name , business activity and RTD Role in project	Participant short name	Major PoC	Country
CO	1	National Aerospace Laboratory	NLR	Ronald Klomp – de Boer	The Netherlands
CR	2	Dassault Aviation	DAV	Mourad Chohra	France
CR	3	EADS Innovation Works	EADS-IW	Catherine Duval	France
CR	4	Hexcel Reinforcements	HXL	Esteban Villalon	France
CR	5	Office National d'Études et de Recherches Aérospatiales	ONERA	Bertrand Laine	France
CR	6	Katholieke Universiteit Leuven	KUL	Stepan Lomov	Belgium
CR	7	University of Stuttgart – IFB Institute for Aircraft Design		Klaus Drechsler	Germany
CR	8	Delft University of Technology	TUD	Zafer Gürdal	The Netherlands
CR	9	Vyzkumny a zkusebni letecky ustav (Aeronautical research and test institute)	VZLU	Vaclav Kafka	Czech Republic
CR	10	Israel Aircraft Industries	IAI	Herman Leibovich	Israel
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