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Composite landing gear components made with Resin Transfer Moulding (RTM)

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ABSTRACT

Composite materials are used in aircraft structures because of weight and cost benefits. These components are mostly shell structures. For helicopters, weight savings are even more important than for fixed wing aircraft. Hence, components other than shell structures, which can be made of composite materials, are being considered. A project is described, focused on the development of the fabrication technology for selected composite landing gear components. The project is being carried out by a Dutch consortium: landing gear supplier SPa&vs, aerospace research centre NLR, software company MSC.Software and preform supplier Eurocarbon. The Composites Group of Twente University is involved with software developments. The components considered are a pair of torque links and a trailing arm, baselined on the NH-90 helicopter. The torque links were fabricated and tested successfully. A trailing arm has been fabricated with the over-braiding technique, and will be tested later in 2004.

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Abstract

Composite materials are used in aircraft structures because of weight and cost benefits. These components are mostly shell structures. For helicopters, weight savings are even more important than for fixed wing aircraft. Hence, components other than shell structures, which can be made of composite materials, are being considered. A project is described, focused on the development of the fabrication technology for selected composite landing gear components. The project is being carried out by a Dutch consortium: landing gear supplier SPa&vs, aerospace research centre NLR, software company MSC.Software and preform supplier Eurocarbon. The Composites Group of Twente University is involved with software developments. The components considered are a pair of torque links and a trailing arm, baselined on the NH-90 helicopter. The torque links were fabricated and tested successfully. A trailing arm has been fabricated with the over-braiding technique, and will be tested later in 2004.

Introduction

The use of polymer matrix, fibre reinforced composite materials for aircraft structures has become quite common, even for civil aircraft. The primary advantages of the material are the weight savings that can be achieved compared to metal structures, and the potential for lower fabrication costs as a result of significant part integration. The composite components in use today are mainly shell structures, with distributed load introduction and in-plane stress conditions. They are often wing, fuselage or stabiliser panels and substructure, made with the prepreg/autoclave technique.

For helicopters, weight savings are even more important than for fixed wing aircraft. Hence, structural solutions for components other than shell structures, to be made of composite materials, are being pursued. Typical candidates are components for landing gears. Today, such components are often metal parts made with the expensive forging process, followed by an elaborate machining route. The components are different from shell structures in that they are thicker and have more complex shapes as well as concentrated load introduction points, and may carry out-of-plane loads.

For composite landing gear components, other benefits than just weight and cost reduction can be achieved as well. Such advantages are improvement of fatigue and corrosion properties, simplified production techniques with shorter lead times, and possibly improved crashworthiness capabilities [1,2]. The enabling technology for this type of components is the resin transfer moulding (RTM) technique. This technique allows the formation of heavy “lug-type” load introduction points, the incorporation of metal inserts, and offers a larger freedom towards more complex geometries.

“SP aerospace and vehicle systems” (SPa&vs) is a company, located in the Netherlands, which develops and manufactures landing gear components, as well as other aircraft and vehicle products. In conjunction with its partners, this company was awarded a national project in 1996, to develop the technology for the design, manufacturing and analysis of composite landing gear components. The partners in the project are the National Aerospace Laboratory (NLR), Eurocarbon and MSC.Software. The project is co-funded by the Ministry of Defence, the Ministry of Economic Affairs, and by the partners themselves.

The project is focused on the design, fabrication, testing and analysis of selected composite landing gear components, baselined on the NH-90 helicopter, for which SPa&vs has the design responsibility. In the project, SPa&vs carries out the overall design and the validation tests. NLR develops the composite fabrication technology (RTM), and fabricates composite components and parts. Eurocarbon is an innovative Small Enterprise, which has developed the “over-braiding” technology to braid fibre architectures on a mould. In the project, Eurocarbon provides over-braided

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pre-forms. A development branch of MSC.Software, located in the Netherlands as well, develops analysis methods and conducts design analyses.

The objective of the project is firstly to demonstrate the technical and economical feasibility of the use of composite materials for the fabrication of selected composite landing gear components. For this reason, the composite parts were made to satisfy all the requirements imposed on the baseline configurations, and to fit within the existing interfaces and operating space of the NH-90 helicopter, well known to SPa&vs, in order to allow the actual mounting on the helicopter. However, the certification proc ess, needed for the products to be actually operated on the NH-90 is not part of the project. The partners also have their individual R&D objectives to improve their core competences, in line with the strategies of the respective companies.

The components selected are the torque links and the trailing arm of the NH-90 main landing gear (figs. 1-3). The torque links were developed first, an activity, which served as a pilot project, because a number of the important issues related to pin-loaded composite parts are present on a relatively small scale. Presently, the trailing arm development has passed its first "technology development" phase and is entering its second "validation" phase. The work is being carried out in five tasks, focused on design, analysis, fabrication development, prototype fabrication and prototype testing. The present paper provides an overview of the work carried out, and the results achieved so far.

As one of the major technological research centres in The Netherlands, NLR has a mission to support the universities in their effort to supply innovations to the industry. During the project, NLR identified two areas of interest, not covered by the project, which still required a significant effort. These areas both pertain to the modelling of the fabrication process. Hence, a contract was signed with Twente University to co-fund the work of two Ph.D. students, focused on these topics. The subjects of their studies are the modelling of the fibre architecture as a function of the parameters of the braiding machine, and the modelling of the permeability of the resulting fibre structures to support flow simulations of the RTM-process. The preliminary capabilities of the tools to be developed are also presented in the present paper.

The torque links

Although the torque links of the main landing gears are relatively light components, and weight savings are therefore limited, they are interesting components, as they contain a number of issues related to pin-loaded composite parts, as is the case for the trailing arm, but on a smaller scale. Apart from that, the major objectives of this part of the project were to find a solution that would give improvements on both fabrication costs and weight. Cost benefits were pursued by developing a fabrication concept, in which both upper and lower torque links can be made within the same mould, while at least six components can made within the same cycle as one product, to be separated easily afterwards. A closed moulding concept was chosen to produce near net-shaped products (fig. 4).

The materials used were HTA carbon fabric (Lyvertex G808 of 220 gram/m², with 90% fibres in warp direction, 10% in weft direction), and RTM-6 epoxy resin. Optimisation for minimum weight was carried out on the basis of a finite element model with NLR's optimisation code B2000/B2OPT, which resulted in minimum ply-thickness. Subsequently, a detailed finite element analysis was carried out with MSC.Marc, using 8-noded brick elements. MSC.Marc's automated contact algorithm was used to describe the contact between the pins and the holes, to check the stresses (fig. 5).

Six torque links were tested in a static test programme, each applied with two 30 J impacts, resulting in barely visible impact damage (BVID). All torque links failed beyond Design Ultimate Load, with margins of safety ranging 1.40 – 1.45. The masses of the baseline aluminium torque links are approximately 180 gram, while the masses of the composite torque links are 125 gram, i.e., a weight reduction of 30%. The fabrication method resulted in components with a fibre volume percentage of 58%. A more detailed description of the torque link project can be found in [3].

The braiding process

Eurocarbon developed the over-braiding process already before the project was initiated. In this process, the braid, which is being produced by the braiding machine, is positioned on a mould, which serves later as the inner mould or "core" during the subsequent RTM process. For this purpose, the core is mounted on a traverse, which can be moved relative to the braiding machine (fig. 6). As part of the project, a numerical process control unit was developed, which continuously adapts the braiding speed and the relative velocity of the traverse to the position on the component where the fibres are being deposited.

The trailing arm consists of four carbon/epoxy components (fig. 7): two pre-fabricated cylinders, one at each end of the trailing arm at the locations of the pintle axle and the wheel axle, a lug assembly and the arm itself. The arm itself is made by the over-braiding of the core. The core was initially made of a metallic alloy with a low temperature melting point. In a later phase of the project, the core was made of polyurethane foam. Before the over-braiding was carried out, the cylinders were bonded to the core. The braiding process resulted in a 3-axial (0º, ±45º) fibre structure. However, due to the non-prismatic nature of the arm, the actual fibre orientation is somewhat different, depending on the location on the arm. The resulting thickness is 15 to 30 mm.

Development of numerical capabilities and stress analysis

The complexity of the trailing arm in terms of geometry, thickness (large number of layers), fibre angles (varying along the component) and fibre structure (3-D braided fibre structure) presented the need for capabilities which were not yet available in the MSC.Marc code. For this purpose MSC.Software developed various models. In the first place, because of the large number of plies in the trailing arm, a routine was developed to derive "homogenized material properties", by carrying out and evaluating "numerical tests" on a representative unit cell [4]. To carry out the actual determination of these properties, fibre angles were determined by visual observation of the outer plies. The angles of the inner layers were assumed to be similar. This limitation indicated the need for an algorithm, which computes these angles on the basis of component geometry and braiding machine parameters: one of the subjects, which are meanwhile under study at Twente University.

As the presence of (impact) damage is often governing the design of composite parts, a capability to compute the onset of failure was also developed [5]. The progressive damage in the layers of the composite material is represented by the reduction of the corresponding stiffness values. To eliminate the dependence of the predicted damage propagation on the mesh size, a length scale was implemented in this damage model [6]. The capabilities that were developed were applied to the numerical stress and strain analysis of the torque links [7,8], a sub-component of the trailing arm including the lugs [9], and the complete trailing arm [10]. The test results corresponded well with the strain results of the f.e. calculations (fig. 8,9). So far, failure predictions could not be compared due to lacking experimental data; the full-scale trailing arm has not yet been tested.

The trailing arm

The conceptual design of the trailing arm was partly based on proven technologies, available at NLR at the time. The trailing arm is basically a bending beam, supported on one end by the pintle axle, and loaded at the other end by the wheel axle. The strut is reacting the load halfway. The two axles are contained in metal bushes, which in term are contained in two pre-fabricated composite cylinders. These cylinders are made with the prepreg/autoclave process. To allow the positioning of the trailing arm at either side of the helicopter, lugs are provided both at the upper and the lower sides of the trailing arm. The lugs are part of a stitched, woven carbon preform (stabilised with binding powder), and moulded in one shot, together with the main, over-braided component.

On the basis of this concept, a finite element model was made with B2000 [11], (NLR's in-house code for the development and evaluation of new features related to structural mechanics). The optimisation routine of this code, B2OPT, was used to minimize the ply thickness for minimum weight, considering maximum strain constraints. Subsequently, the outer mould was designed, which includes the positioning of the resin supply channels as well as the vent holes. To check the validity of the resin infiltration strategy, in terms of the proper resin impregnation at all locations, flow simulations were carried out with RTMWorx, see figure 10. The simulation did not indicate any problems, but it was recognized, that the input for the programme, i.e., the permeability characteristics, were crudely represented. This deficiency is presently being resolved by one of the studies undertaken by Twente University.

Before fabricating the entire trailing arm, a subcomponent was defined, containing what was thought to be the most critical part of the trailing arm: the centre section including the lugs. A section of the main tube was braided, of prismatic cross section, the lug preform was added, and after injection and cure, metal bushes were inserted in the lugs. A test programme was carried out (fig. 11) with strain gauge instrumentation, which proved the concept. Strain predictions were accurate (fig. 12)

The results of the sub-component project were taken into account when finalising the design of the trailing arm. After manufacturing of the metal cores, the over-braiding of the cores, and the manufacturing of the outer mould, a series of three trailing arms was manufactured. This time it was experienced that the large volume of the low temperature melting metallic alloy resulted in a lack of homogeneity of the alloy, and difficulties were experienced in dissolving the core during the post-cure of the components. A new core concept was developed, based on the use of polyurethane foam. Six more trailing arms were manufactured successfully, and are currently being prepared for full scale testing by SP.

The modelling of the fabrication process

As mentioned above, during the project several problems were encountered, where trial and error had to

be used to generate a successful design. In particular, the lack of a capability to predict the exact fibre angle at each location of the trailing arm, and the lack of a capability to predict the permeability of the corresponding 3-dimensional fibre architecture, as well as a flow analysis capability for this type of 3-dimensional impregnation, were topics of sufficient interest for the Composites Group of Twente University
A new algorithm was developed to simulate the over-braiding process on cores (or 'mandrels') of arbitrary geometry. Accurate predictions of the braiding angles can be found by using a geometrical approach, in which zero fibre interaction is assumed before the fibres touch the mandrel and maximum interaction (in other words: a stick condition) once the fibres are in contact with the mandrel [12]. Currently, a standard FE mesh can be used to represent the mandrel geometry (fig. 13). The resulting algorithm is fast, suited for process optimisation procedures by which the braiding parameters will be determined to achieve a desired fibre distribution for a start. By including micro mechanics, also the stiffness distribution and the component stiffness can be used subsequently as a target for process optimisation.

The three-dimensional permeability of fibre pre-forms is studied both experimentally and numerically. Experiments were performed to determine both the in-plane and out-of-plane permeability's. A 'K_z'-measurement device was developed for the latter purpose [fig.14]. Flow simulations at the microscopic scale are used for permeability predictions. Fast multi-grid solvers are developed to take into account the variations in the micro-geometry, which are expected to correlate with the scatter inherent to permeability measurements. The predicted fibre orientation from the braiding process simulation will be used in conjunction with the validated permeability model in order to predict the permeability distribution of the over-braided pre-forms.

Outlook

In parallel to the project described here, the feasibility of the use of composite materials for landing gear applications has been demonstrated in another project. SPa&vs and NLR developed a composite drag brace for the F-16 main landing gear, which was flight-tested successfully (Fig. 15). Currently, a new phase is underway, with the objective to achieve actual certification of composite landing gear components.

Conclusions

A project has been described to develop the technology to design and manufacture composite landing gear components. A Dutch consortium, consisting of an aircraft component supplier, an aerospace research centre, a supplier of composite pre-forms and a software house, carried out the project. In parallel, a university has supported the development. The work was partly funded by the Dutch government.

In a pilot phase, torque links were successfully fabricated and tested, to evaluate the effect of point load introductions for components made with the RTM technology. The torque links have shown potential, in particular for helicopter applications, because significant weight and cost reductions can be achieved.

An innovative "over-braiding" process was enhanced with a system for numerical process control, which contributes to the development of a fully automated fabrication capability for pre-forms. New analysis capabilities for damaged composite components were developed and demonstrated. Software is being developed to simulate the fabrication process, with respect to fiber architecture and permeability characteristics.

The capabilities developed were used to design, fabricate, and analyse a heavily loaded trailing arm. A test programme is underway. As the baseline configuration is a steel forging, followed by an extensive machining route, a decrease of fabrication costs will be the major benefit. It is expected that a weight reduction of 20 % can be achieved as well.

Although the potential for composite trailing arms must still be proven, new capabilities were already demonstrated in a project to develop an F-16 landing gear component.

The project demonstrated the benefits of a government sponsored, multi-disciplinary project carried out by a national consortium, with a unifying role for the Dutch national aerospace research centre.

Acknowledgements

The support of the project by the Ministry of Defence and the Ministry of Economic Affairs is greatly appreciated, as is the co-funding of the student projects by the Twente Institute of Mechanics.

References

1. Barquet, F,. and Sarlin, P., "The development of a crashworthy composite fuselage and landing gear", 48th forum of the American Helicopter Society, 1992.

2. Cronkhite, J.D., and Mazza, L.T., "Bell ACAP full-scale aircraft test and KRASH correlation", 44th forum of the American Helicopter Society, 1988.

3. Thuis, H.G.S.J., "Development of a composite torque link for helicopter landing gear applications", 12th International Conference o Composite Materials, Paris, France, 1999, also NLR TP 99026.

4. Oudendijk, M.G.N.M., "Analytical determination of braided material properties", Technical Report MTR-0101, MSC.Software, 2001.

5. Oudendijk, M.G.N.M., "An anisotropic continuum damage material model for composite materials", Technical Report MTR-9909, MSC. Software, 1999.

6. Oudendijk, M.G.N.M., "Mesh independent anisotropic continuum damage material model for composite materials", Technical Report MTR-0201, MSC.Software, 2001.

7. Vosbeek, P.H.J., "Analysis of upper and lower composite torque link", Technical Report MTR-9803, MSC.Software, 1998.

8. Oudendijk, M.G.N.M., "Analysis of final design of upper and lower composite torque link", Technical Report MTR-9910, MSC.Software, 1999.

9. Oudendijk, M.G.N.M., "Analysis of composite trailing arm mid-section", Technical Report MTR-9902, MSC.Software, 1999.

10. Oudendijk, M.G.N.M., "Composite trailing arm analysis", Technical Report MTR-0102, MSC.Software, 2002.

11. Arendsen, P., "The B2000-optimisation module: B2OPT", NLR TP 94116L, 1994.

12. Kessels, J.F.A. and Akkerman, R., "Prediction of the yarn trajectories on complex braided performs", Composites: Part A 33 1073–1081, 2002

Figure 1. NH-90 helicopter.

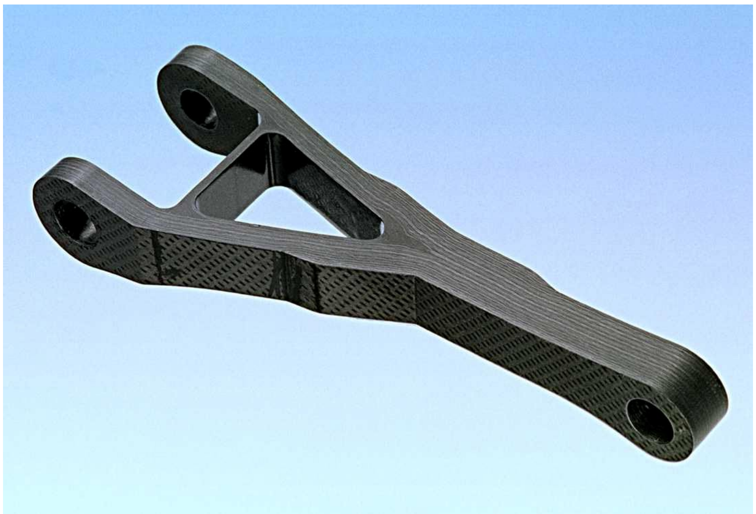
Figure 2. Torque-link.


Figure 3. Trailing arm.

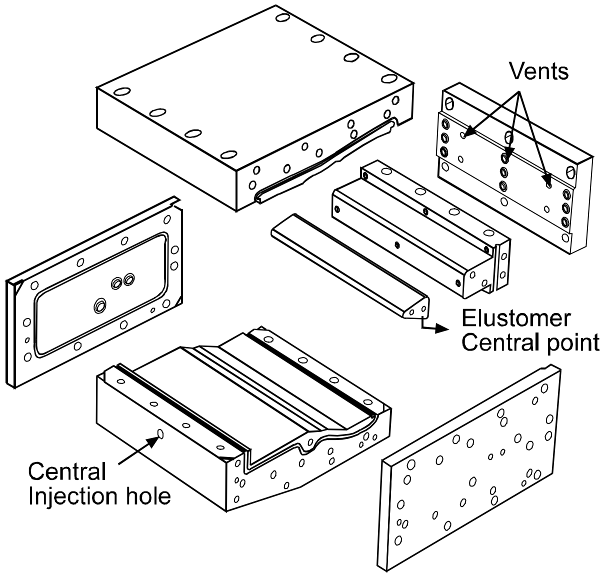

Figure 4. RTM mould concept for six torque links.

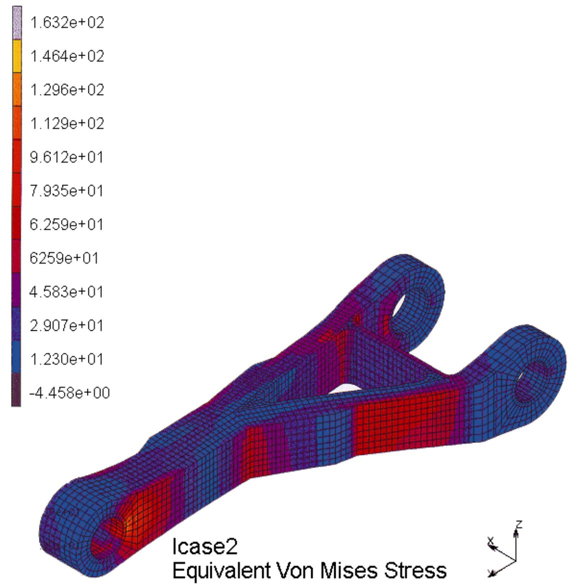

Figure 5. Equivalent von Mises stresses in torque link under tension at ultimate load (Marc).

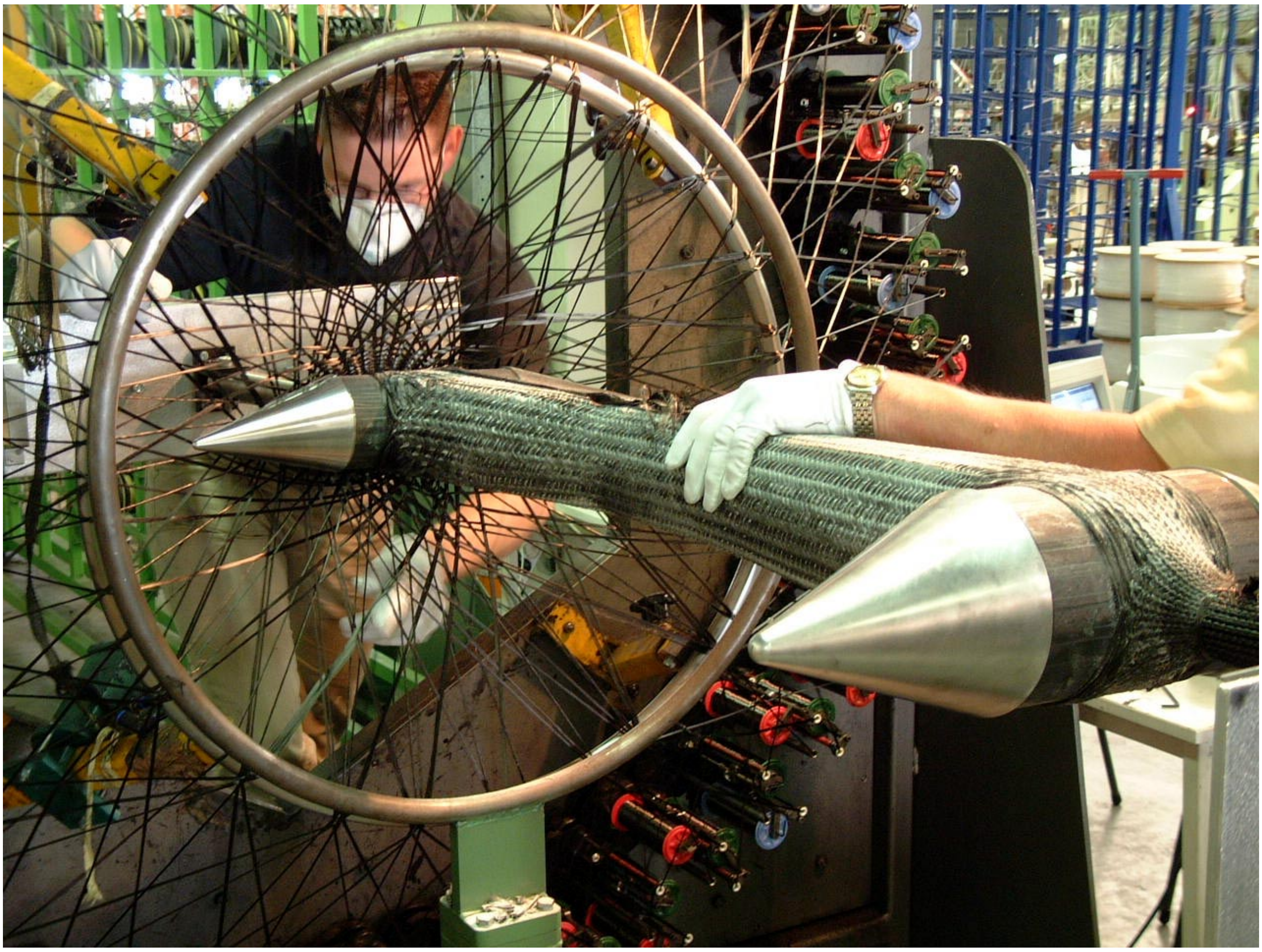

Figure 6. Pre-form for trailing arm on braiding machine.

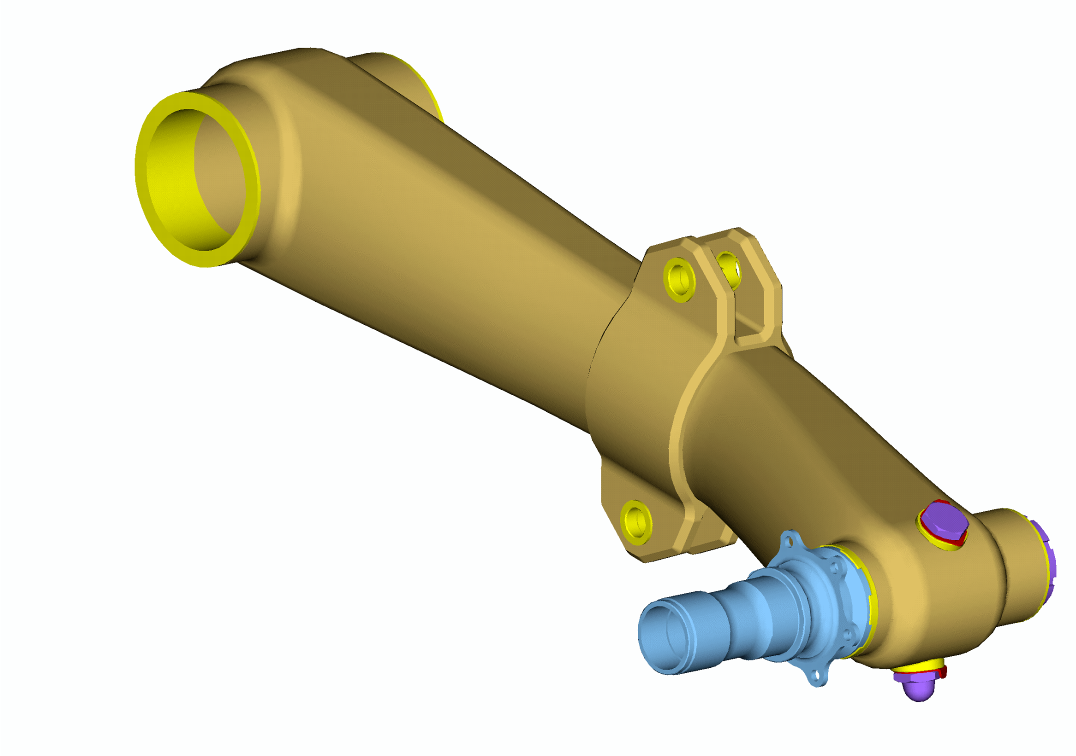

Figure 7. Trailing arm assembly.

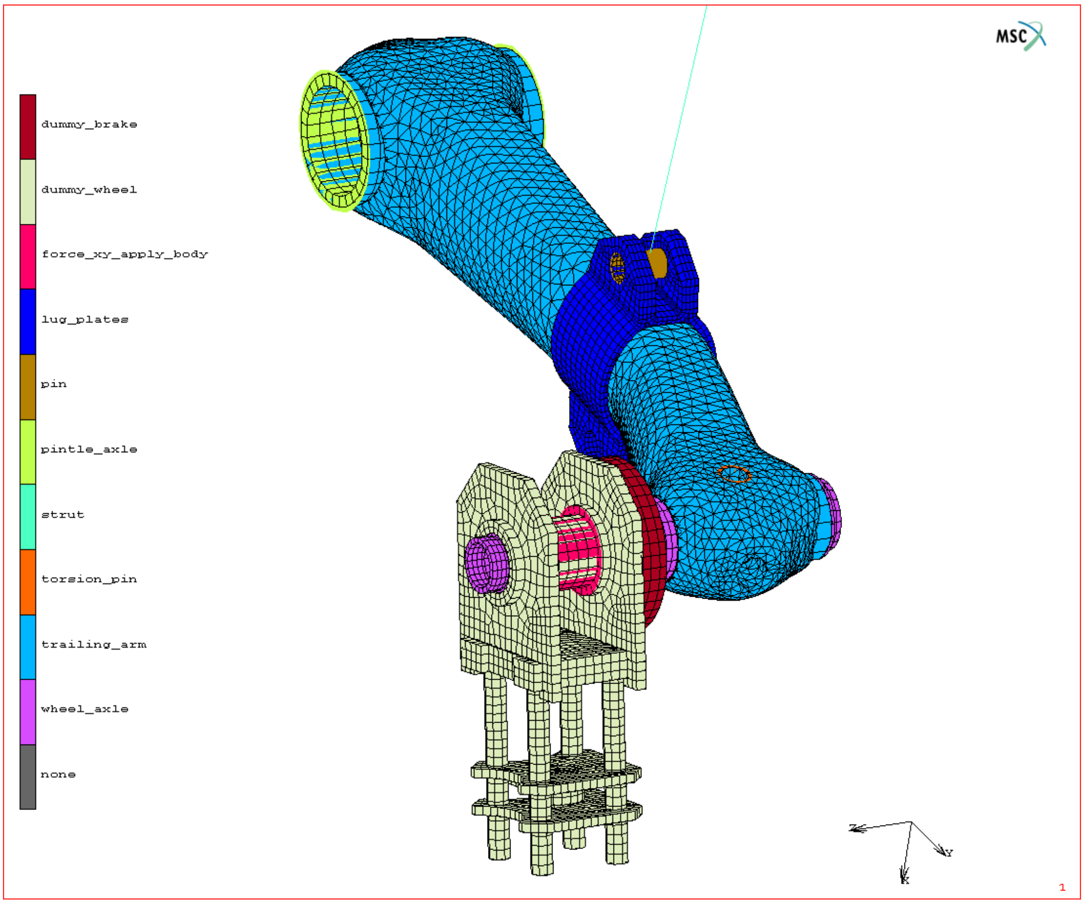

Figure 8. Finite element model (Marc) of the composite trailing arm as tested.

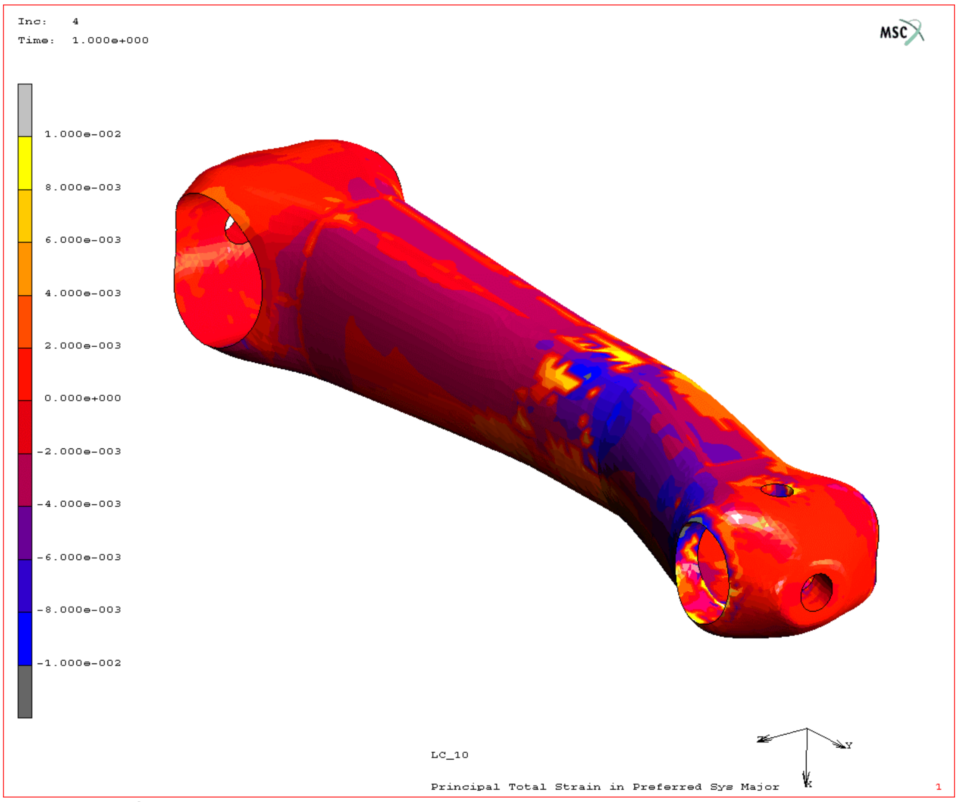

Figure 9a. Strains in the over-braided component.

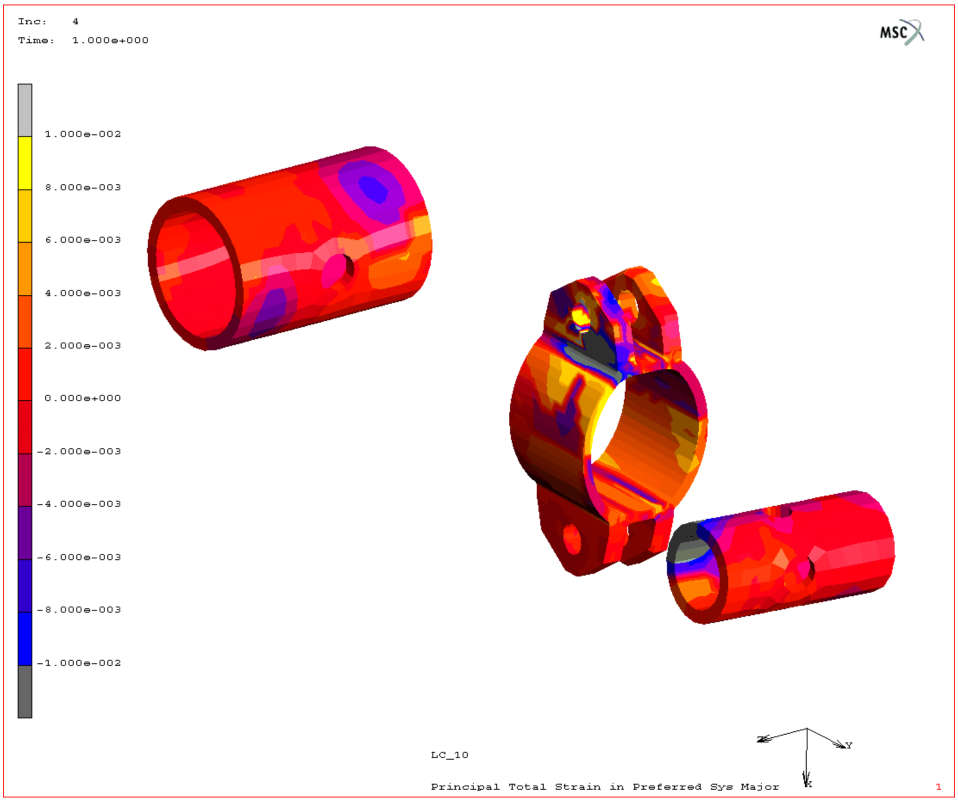

Figure 9b. Strains in the other components.

Figure 9. Strain results for the trailing arm (Marc), for load case 10.

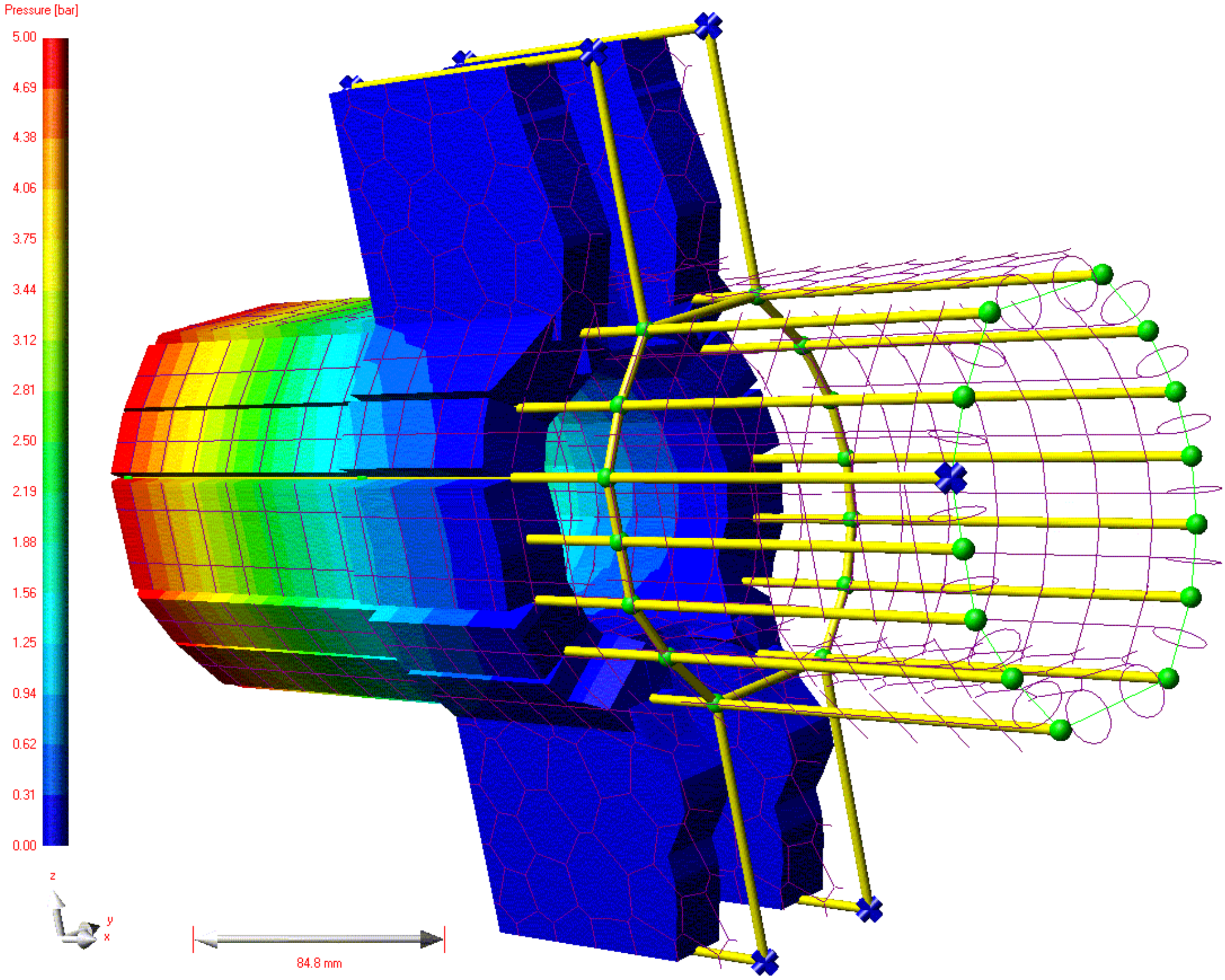

Figure 10. Flow simulation of trailing arm (RTMWorx).

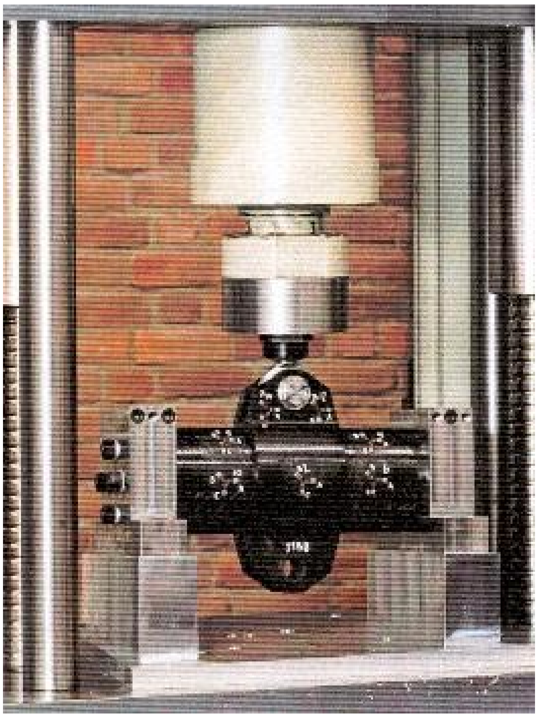

Figure 11. Test of trailing arm centre section.

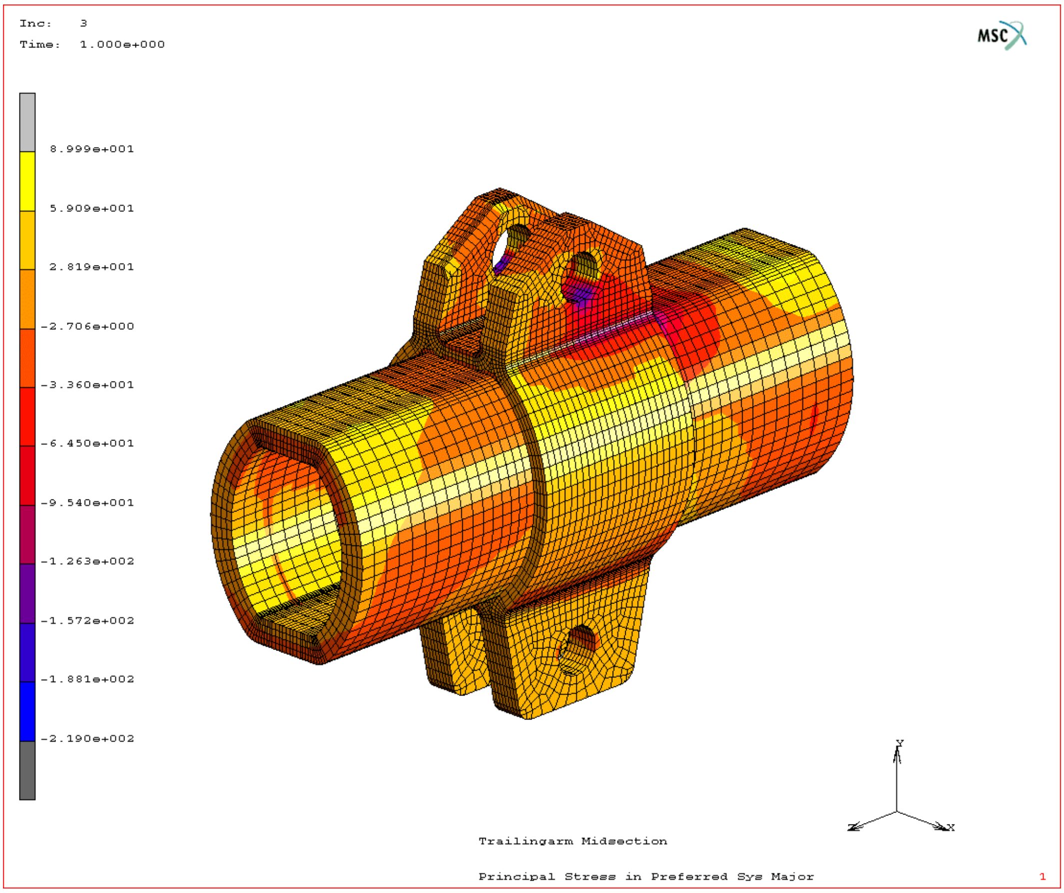

Figure 12. Analysis of trailing arm centre section.

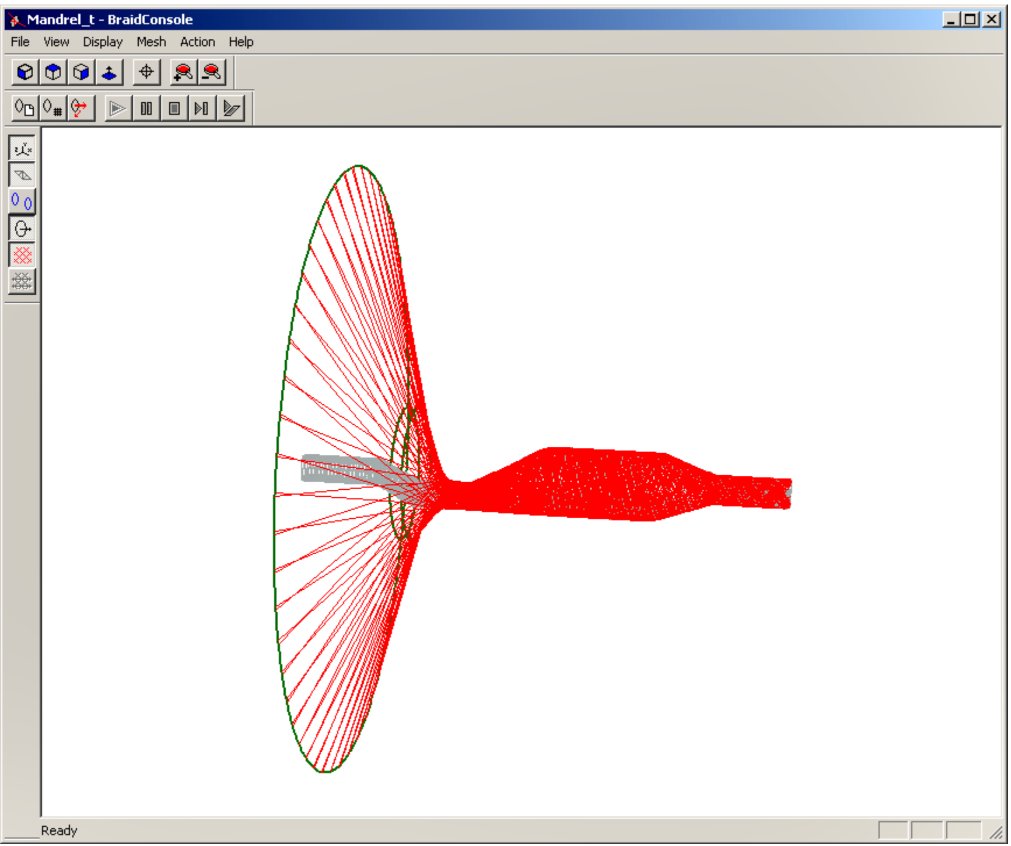

Figure 13. User interface of the braiding simulation program.

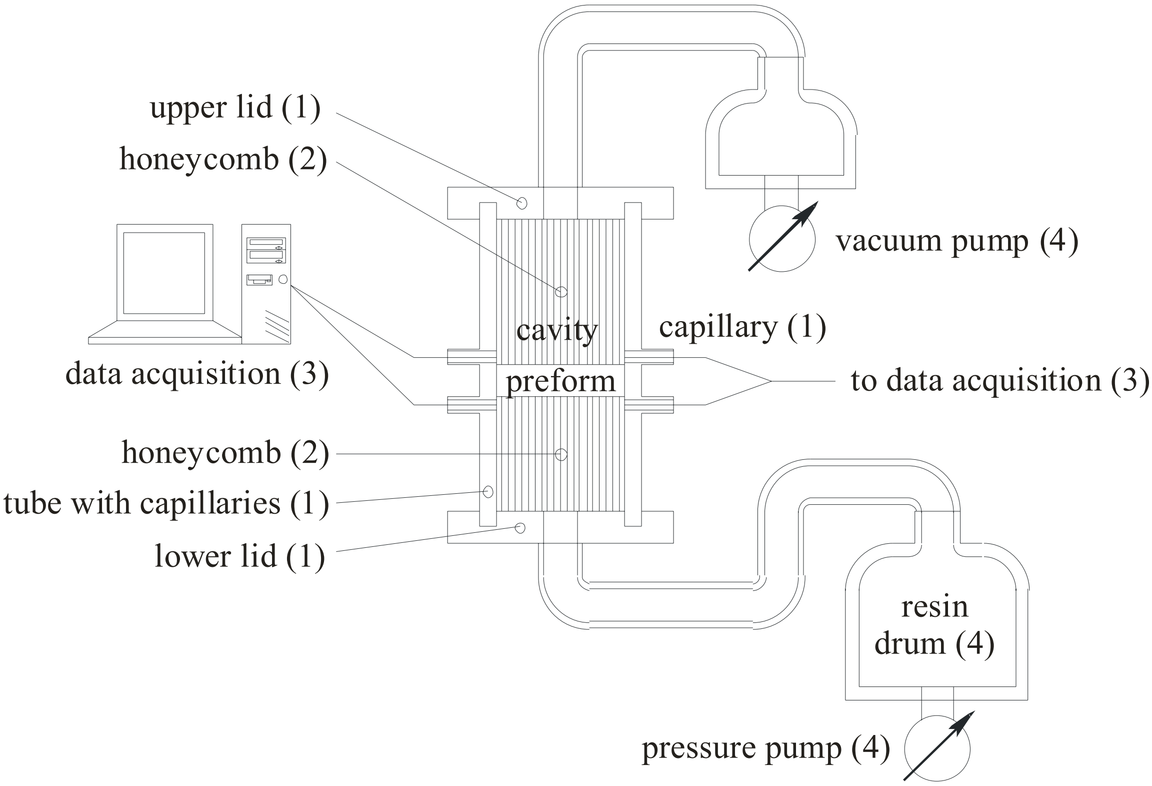

Figure 14. Measurement device for the transverse permeability of thick fibre pre-forms.

Figure 15. Composite trailing arm on F-16.