FAST DESIGN AND MANUFACTURING OF MULTILAYER GLASS AND CARBON TEXTILE PREFORMS FOR LCM

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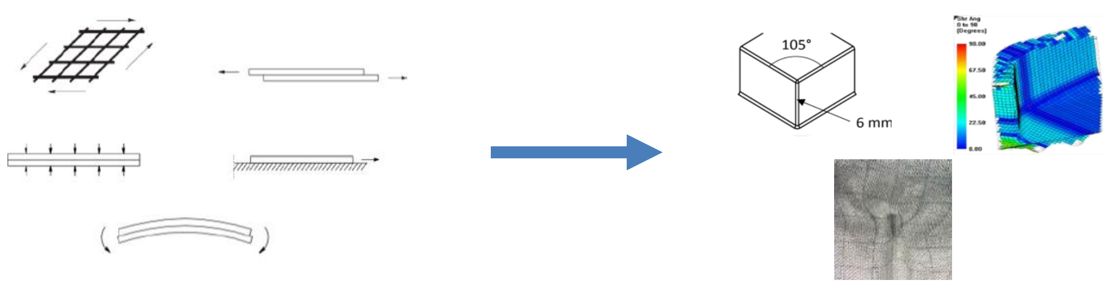
ABSTRACT

This work is concerned with the design and manufacturing processes for complex non-structural aerospace liquid composite moulding (LCM) textile preforms featuring lap joints between multiple patterns, which may be further cut or darted to improve draping coverage. The work aims primarily at streamlining and hastening the preform design process. The work also aims at documenting the process, ultimately leading to improvements in manipulation efficiency, preform reproducibility and fibre volume fraction consistency in composite parts manufactured from the preforms, the latter being achieved through reduction and elimination of potential resin rich zones via preform design instead of dedicated interventions by technicians.

Draping, shear, bending, and friction properties of dry fabrics are highly dependent on fabric construction and on the geometry of the preform and part to be designed and made. Pattern development, fabric orientations, positioning of joints, cuts and darts as well as the sequence in which patterns are laid down all depend on these properties and on part geometry. Despite ample industrial practice and know-how, the process of determining efficient preform designs featuring limited numbers of patterns and leading to reproducible, fast and economically competitive manufacturing remains challenging.

This work characterises dry fabrics in shear, bending, inter-ply friction, and stability. Tests are performed on portable equipment with some comparison with standard testing methods. Based on this characterisation, an evaluation method is developed that determines how a given fabric behaves when preformed to specific geometric features. The evaluation method is validated with experimental trials. The characterization work and evaluation method are combined in an algorithm that displaces preforming simulations and trial work to databases populated prior to the analysis of a specific geometry. Examples show that the algorithm achieves the objectives of lowering preform design and manufacturing times.



Dry fabrics characterization

Draping behavior

Figure 1: Dry fabrics characterization towards preform design

1 INTRODUCTION

Aspects of the bidding process relating to the preforming and draping of dry fabrics involve a level of uncertainty and can be time-consuming. The development of methods and tools for understanding and predicting the behaviour of dry fabrics aims at enabling the selection of appropriate materials as well as pattern and process design, reducing uncertainty and delays associated with the submission process.

The work led to the development a numerical tool for predicting rapidly the draping behaviour of dry fabrics over complex parts, assisting in predicting costs towards RFQ / RFI (Requests for Quotes / Information). This tool facilitates the development of cutting patterns by selecting the best fabric and its preferred fibre orientation, and determining patterns by locating cuts and joints for the draping of complex geometries.

Current software for the prediction of draping can produce flattened 2D shapes from a 3D geometry to be draped. In most cases of complex parts, a complex geometry cannot be flattened in one piece due to limitations brought by the geometry of the part. Most cases of complex geometries involve designing and draping several distinct patterns to cover the whole geometry adequately; typically, additional cuts must be made in each pattern to impart mobility to the draped fabric. Furthermore, the equations and boundary conditions implemented in current software sometimes limit draping ability when compared with what may be achieved on the shop floor. Typically, a user must make some allowances and use the results as information in an iterative design process that remains largely manual and requires high levels of expertise.

The numerical tool consists of a spreadsheet that assists in determining draping parameters from a breakdown of a complex geometry into several base geometries. The user identifies base geometries from a list, and then positions and parametrizes them, specifying quantities such as lengths, angles and radii. Base geometries were identified by studying an array of existing Hutchinson Montreal parts so that any complex geometry may be deconstructed whilst capturing its features - any complex geometry may be decomposed into a number of base geometries. Within this framework, the draping prediction tool includes a fabric database which aims at differentiating fabrics based on different characteristics that impact draping, namely their behaviour in shear, flexion, friction and stability. Similarly to the fabrics database, the base geometries database includes a characterization of the difficulties associated with each geometry and related to the same characteristics as the fabrics.

2 DRAPING PREDICTION

2.1 Draping analysis

The behavior of a fabric during draping on a mould is affected by the behaviour of the dry fabric as well as by the geometry of the mould on which the fabric is draped. The behaviour of the dry fabrics is defined by considering aspects that relate to the draping: shear, flexion, friction and stability [1]. The geometry to be draped also has a strong impact on the draping, but different aspects of the behaviour of the fabric will have more or less importance on the process depending on the geometry; and so, the geometry affects the selection of the best suited fabric. Some characteristics of dry fabrics will have more impact on draping prediction results than others. For example, the compaction of a dry fabric is important in the absolute in terms of consolidated composite parts, but its effect of the draping process is limited hence this characteristic, like others, is disregarded in this work [2].

Several geometric features of existing moulds and parts were identified and quantified at Hutchinson Montreal. These typical features were labelled base geometries and inventoried into a database. Using parametrized and positioned base geometries, a complex geometry may be deconstructed into several basic geometries. This, in turn, may be used in hastening the analysis as the difficulty associated with draping the base geometries will have been analysed prior and been made available through the geometry database. Analyzing the behavior of dry fabrics over base geometries renders it possible to know if a given fabric will drape over a certain combination of base geometries, and to quantify the difficulty associated with the operation. To do this, the behaviour of the fabrics must be quantified, also prior, in order to know the effects of the aforementioned characteristics involved in draping a given base geometry. This information is contained in the textile database.

Base geometries are quantified according to geometric parameters defining them and influencing the draping, such as the radius and angle of an outside single corner for example. The difficulty of draping each parameterized base geometry must be characterized considering the same characteristics of fabric behaviour: shear, flexion, friction and stability. Having pre-quantified knowledge of the specific aspects of difficulty associated with the base geometries, and of the capacity of the fabrics with regards to each characteristic, it is possible to determine the plausibility of draping a specific complex geometry using a given fabric. This comparison method can differentiate the ease of draping of different fabrics on a complex specific geometry and identify which aspects of the process may be more problematic.

The characteristics influencing the drapability were identified and selected by completing several physical draping trials using Hutchinson Montreal production moulds and parts, for an array of fabrics. Base geometries were also identified for these moulds and parts. Such characterization can quickly determine which fabric may be used depending on the geometry of the mould or part, the orientation of the fibers, and the mechanical restrictions imposed on the composite part. This characterization can also be used to determine a draping production time. The results are then associated with base geometries and used in documenting the geometry database, and they may be used again with other complex geometries that will only differ in the combination of base geometries into which they are deconstructed.

2.2 Dry fabrics characterization

Three fabrics were characterized; a plain weave glass, an 8 harness satin glass and a 5 harness satin carbon with binder powder on both sides. The three fabrics enabled comparisons to be made. Each fabric was evaluated in shear, flexion, friction and stability. A ranking was given for each fabric and each characteristic, based on quantified results. These rankings ranged from 1 to 10 where 10 is the highest score and 1 is the lowest score. Table **1** shows results for the three fabrics characterized, for each characteristic. The characterisation was performed using portable equipment; some comparative results were confirmed with those obtained from standard methods.

When comparing the shear characteristic rankings presented in Table 1, the plain weave is more appropriate in terms of its shear behavior with a score of 6 where the 8 harness satin and 5 harness satin both return an equal score of 4. Hence, for a complex geometry where high shear capability is needed, the plain weave would be selected over any of the satins. The plain weave would also be selected over the satins in the case of complex geometries where good capabilities in flexion are required. Conversely, because of the binder powder present in this specific fabric, the 5 harness satin causes difficulties in terms of flexural capability, scoring lowest.

Interply friction, defined as the friction between two plies of dry fabrics as they undergo linear relative motion, is an important characteristic when draping multiple layers of fabrics. The plain weave has the highest friction capacity, meaning that this fabric is easier to manipulate when using multiple layers: plies will tend to stay together and deform jointly when draped, as opposed to moving relatively one to another with one ply staying mostly fixed relatively to a mould and the others moving differently. On the other hand, the 8 harness satin showed the lowest level of interplay friction between its layers; therefore difficulties in draping may be expected such as slipping of plies, defects in the lower plies, and so forth.

Stability is defined as the capacity of a textile to stay in place when positioned and draped on a mould. This characteristic is useful in the case of net shape manufacturing scenarios as these typically involve that the fabric is subject to lower deformation levels. Depending on the complexity of the geometry and on process specifications say net shape or anchored moulding, for example, the impotence given to each characteristic will change. For example, for a complex geometry where a pattern is anchored and undergoes high shear, the plain weave is preferable at shear = 6 & flexion = 7. On the other hand, in the case of a pattern of simple geometry draped net shape the 5 harness will be preferable at stability = 8.

2.3 Basic geometry decomposition and characterization

Every basic geometry was characterized by considering the parameters that have the largest impact on drapability, based on trials conducted using available Hutchinson Montreal moulds. The geometries were characterized through identified parameters. The characterization was completed using both simulations and in mould draping. Simulations were used for quantifying shear characteristics of the base geometries, whilst physical trials on moulds were used to for quantifying flexion, friction and stability characteristics.

Table **2** shows an example of characterization of 3 different base geometries. Geometry A is a complex geometry where high shear and high flexion capacities are required of the textile. If a textile accommodates these requirements poorly, the pattern made from it will have to be cut and darted. For this geometry, the plain weave is the best fabric choice considering its capabilities. Geometry B is a simple geometry with low shear and low flexural difficulties, where net shape properties and limited movement of the fabric are required. For this geometry, the 5 harness satin carbon is the best choice as its capabilities fulfill the requirements of the geometry; in fact, the 5 harness satin carbon is the only fabric which is capable of meeting the stability requirement. Geometry C is a geometry of average difficulty where shear and flexural requirements are relatively low and the stability requirement is relatively high. For this geometry, the plain weave offers low stability and the 5 harness satin offers low shear and flexural capabilities. Therefore, the 8 harness satin is best choice in this latter case.

Table 1: Dry fabrics characterization table

Fabrics	Shear	Flexion	Friction	Stability
Plain weave glass 	6	7	8	2
8 harness glass 	4	4	3	6
5 harness carbone (binder) 	4	1	5	8

2.4 Draping prediction numerical tool

The draping prediction tool is implemented in spreadsheet form. The spreadsheet compares the dry fabrics characterization database to the base geometries characterization database. The user of the spreadsheet must first breakdown the complex geometry into base geometries, and indicate the thickness required for the final composite part. Next, the user must quantify each base geometry according to geometric parameters influencing the draping behaviour. The x, y and z coordinates as well as the orientation of the basic geometries are also specified in the prediction tool. Once the base geometries are quantified and entered, the spreadsheet will interact with both databases. The spreadsheet compares the draping difficulty of each feature for the base geometries with the capabilities of each fabric. Links between the base geometries are also quantified according to the magnitude of each characteristic and the distance between these geometries. Therefore, the spreadsheet makes it possible to determine, for each fabric, whether it is possible to drape the base geometries or not. Figure **2** shows a flowchart of the functionality of the draping predictive tool.

Table 2: Base geometries characterization table

Geometries	Shear	Flexion	Friction	Stability
Basic geometry A	5	5	2	2
Basic geometry B	2	2	2	7
Basic geometry C	3	3	1	5

Base geometries are identified from the CAD file. The geometries are analysed in the predictive tool and the difficulties of the base geometries are compared with the capabilities of the fabrics, using the databases. The predictive tool identifies the most appropriate fabric to be used, with its preferable fibre orientation and the localization of any cuts. These results are entered in the commercial unfolding software, and the cutting patterns are generated.

The spreadsheet is able to determine the position of any cuts as a function of the fabric used by comparing the shear difficulty associated with the base geometries with the shear capability of each fabric. The positioning of the joints is determined as a function of the extent of the links between the geometries, which are also quantified. Too strong links need to be cut to facilitate draping. The friction and stability of the draping are two characteristics evaluated as global factors influencing the difficulty of draping. These global factors depend on the number of base geometries and on the difficulty associated with them. For each base geometry, a preferable fibre orientation is assigned in order to determine which orientation is preferable for draping the complex preform. A weighted average of draping difficulties is calculated according to the orientation on the complex geometry, and the orientation returning the lowest difficulty is chosen. The number of plies used is determined according to the thickness and mechanical properties required for the resulting composite. Draping times are determined as a function of the difficulty associated with each base geometry. Finally, a ranking is given to each fabric in relation to the difficulty associated with draping. The fabric with the best score will be the easiest fabric to drape for a given complex geometry. The selection of the fabric to be used for a given part is carried out according to the qualification of the diverse characteristics, to the mechanical restrictions required of the part, and then according to the draping behaviour.

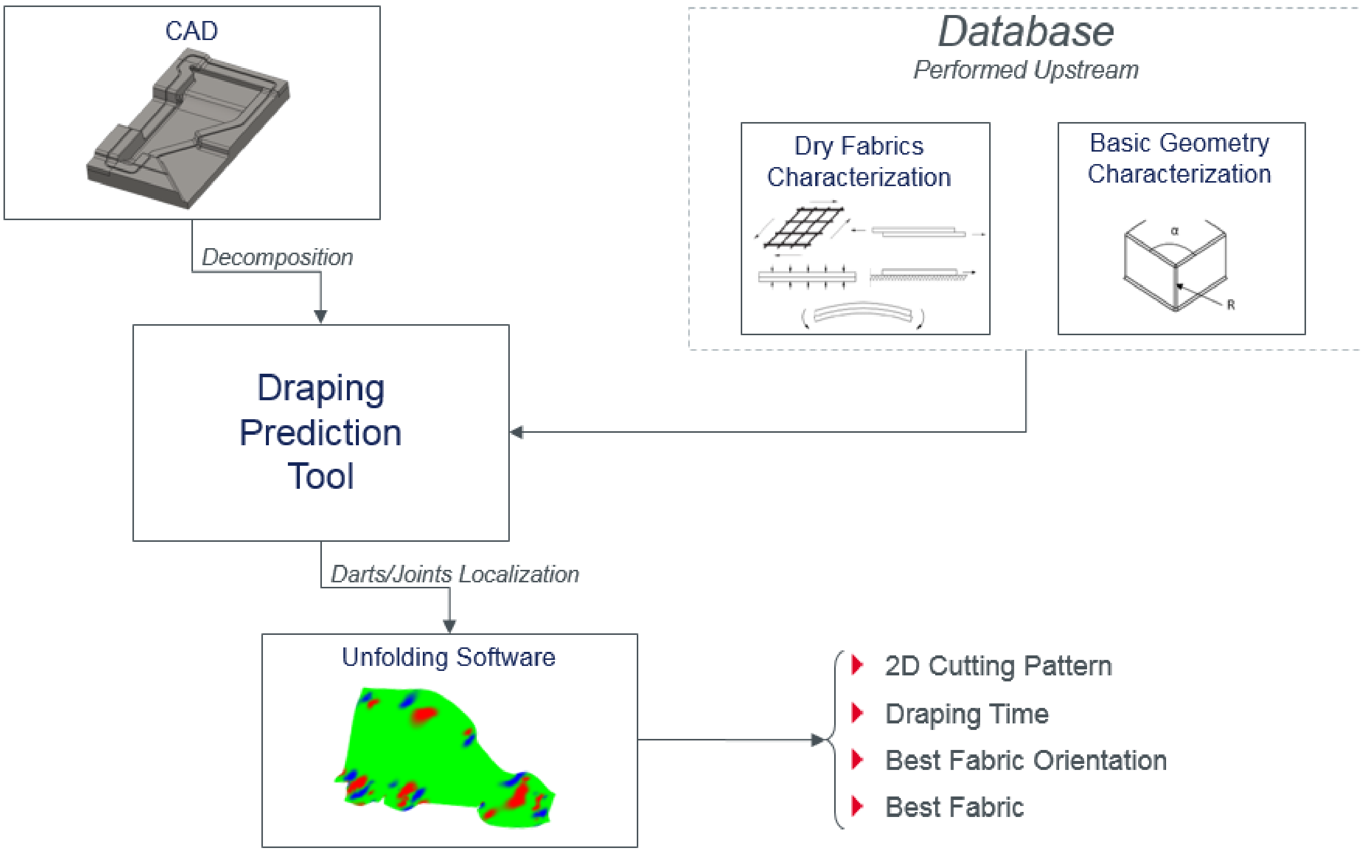


Figure 2: Predictive tool operation flowchart

Figure **3** shows cutting pattern development before and after implementation of the predictive tool. Before implementation of the predictive tool, many iterations were required prior to obtaining functional cutting patterns. After implementation of the predictive tool, cutting pattern definition is typically close to final at the first iteration. This results in valuable time savings during the bidding process. Therefore, the spreadsheet constitutes a fast and effective tool for support at the time of bidding, for preforming and draping processes.

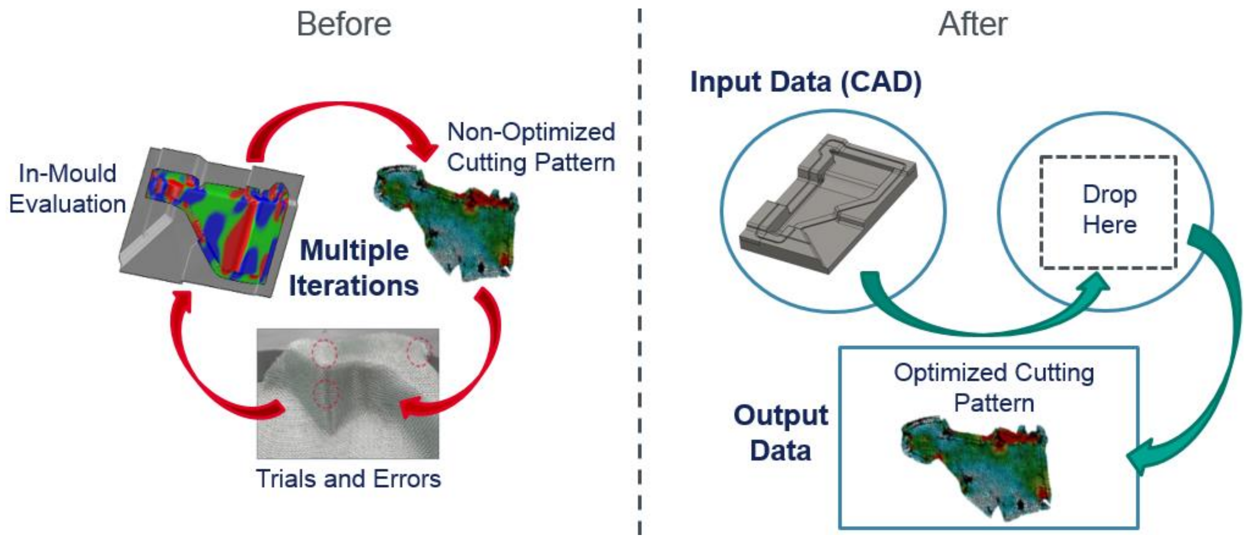


Figure 3: Cutting pattern development before and after the numerical predictive tool

3 CONCLUSION

This paper presents a numerical tool aiming at predicting dry fabric behavior upon draping over complex geometries, considering all relevant draping characteristics of the fabrics and geometry for cases of preforms made of multiple patterns. The predictive tool compares the drapability of different characterized fabrics to assist selection of the most appropriate to a given geometry. Fabrics are characterized in terms of shear, flexion, friction and stability. Base geometries are identified and characterized with regards to the same characteristics and the difficulty associated with each aspect of fabric behaviour. A database of dry fabrics characterization data and a database of base geometries characterization are compared in determining how a specific fabric will behave over a given geometry. The predictive tool concatenates the information from the geometry and databases through a spreadsheet. The numerical tool enables reduced bidding times, reduced cutting pattern development times, reduced draping times and reduced part rejection rates by assisting with the selection of the best suited fabric, best suited fibre orientations, and correct localization of cuts and joints for patterns. Work is ongoing for all aspect of the predictive tool beyond the first version presented herein.

4 REFERENCES

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