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# COMPUTER AIDED DESIGN OF COMPOSITE SHELLS

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**SUMMARY**: During the design of composites structures in which continuous fibre reinforced materials are applied, computer assistance is more then just useful. The designer needs are reviewed: freedom of shape, production processes & material properties. From these the demands for a useful design tool are outlined. One typical aspect of continuous fibre reinforced composites is the dependency of the material properties, and therefore the component properties on the applied production process.

**KEYWORDS: Composites, design, computer, software, fabric, UD, core, CAD, FEM.**

## INTRODUCTION

A designer has more freedom in shaping and materials when he/she applies composite materials into the design. How this freedom can be used to improve products is not straight forward. Support of computer programs during shaping (CAD programs) and structural analysis (FEM programs) are often needed. For FEM programs the material properties are of major importance. When fabrics are applied on double curved shapes the properties will vary locally. Using FEM programs in these cases will be very tedious in this case. So special programs for the design of composite structures are needed to limit the amount of time spend. DRAPE, an example of such a program, is discussed in this paper.

## DESIGNER NEEDS

A designer of light weight structures does not design with a specific material in mind, he just designs and depending on the requirements and wishes of the design and the experience of the designer (and company possibilities) the design will contain metal parts, composite parts or both. During this design the following aspects need to be covered.

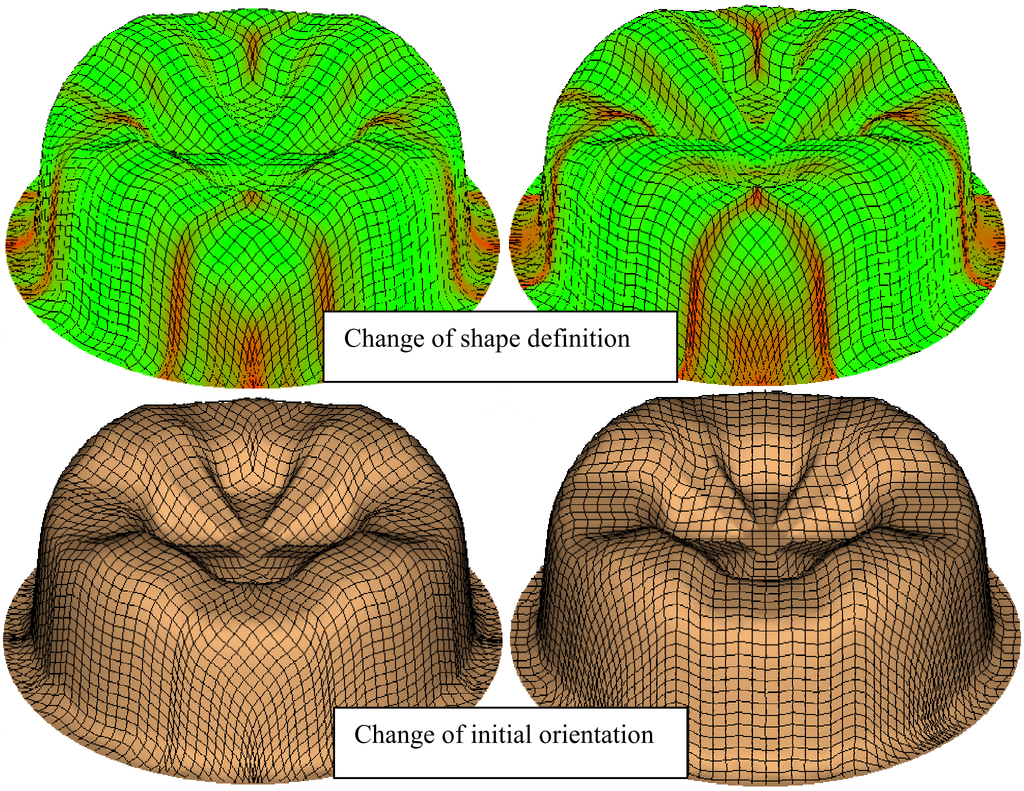
*Freedom of shape*
Many composite structures are created from non-rigid based materials (fibres and matrix) into a rigid product by curing (thermosets) or consolidation (thermoplastics). Because of the non-rigid shaping of the material into the final shape, the shaping is often limited by process aspects such as temperature and product size, not by the force needed (as is the case with metal sheets). For the designer this is very advantageous. This freedom of shaping can be used to create double curved areas which are stiffer than flat areas, and therefore often more desirable. The precise definition of the double curved shape is, however, much more difficult than the definition of flat shapes. Design software (CAD) exists which help the designer to define the shape he needs. So the definition of the shape of the product is not a major problem for the designer, it just takes computers and finances (which can be a problem of course). Therefore, the freedom of shape will not be discussed in this paper any further.

*Production processes*
For continuous fibre reinforced sheet materials several production methods exist. Depending on product size, process experience, required production rate, batch size, etc. several production processes are possible. Examples of processes are Hand Lay-Up, Press Forming and Resin Transfer Moulding. In all these processes two main stages can be found in general:

- Placement of the reinforcement in the position as needed.

- Curing or consolidating the composite into the final product.

If the second stage cannot be fulfilled, i.e. it is not possible (RTM: too much time needed for resin flow) or too expensive (Press forming: too much pressure needed for consolidation, so an expensive press), the design should be rejected. This second stage can therefore be seen as a go or no go stage. For a designer the first stage of a process is of much more interest than the second stage. The second stage must of course be fulfilled, but this is often not depending on the orientation of the fibres. In the fibre placement stage it must become clear whether the fibres can be placed into the direction the designer wants them to be in. This depends on the materials, the




product shape and the processes applied.

Figure 1 The shape and the initial orientation have a large influence on the reorientation of the fibres

*Material properties*

The product properties depend on the material properties of the fibres and resin used and the shape of the product. The amount of applied fibre and resin rule the mechanical properties of the product. The designer can often choose both fibre and resin. The shape of the product dictates the reorientation of the fibres after forming. It has to be clear to the designer what the fibre orientations are after forming. The designer can obtain the product properties he needs by for instance changing the product shape, the initial orientation of the reinforcement or the amount of reinforcement (figure 1). One of the effects of the reorientation of the reinforcement is that locally different fibre orientations will occur. Shearing of fabric occurs when double curved surfaces are used. When preimpregnated reinforcement (Press forming) is used the thickness of the product will vary locally. When dry reinforcements are used (RTM based processes) the fibre volume fraction after the resin flow will vary locally. The permeability will also vary locally since sheared fabric is tighter than non-sheared fabric. This makes it impossible for the designer to predict with simple engineering rules the properties of the product within reasonable accuracy.

Important aspects derived from this section are:

- Materials properties vary locally
- The type of fibre and resin have a major influence of mechanical properties
- The change of thickness caused by deformations is important
- The change of fibre volume caused by deformations is important
- The change of permeability is important for resin flow simulations

**THE DESIGN TOOL**

From the previous section it is clear that Finite Element calculations are needed to predict mechanical properties of the product. The material options in the current available FEM programs do not know fabric styles, which means that the fabric properties need to be translated into for instance UD layers, since FEM programs can handle these. Especially the undulation of woven fabrics can have a considerable influence on the mechanical properties of the product (10% for a plain weave). Different weave styles (figure 2) will have different mechanical properties, and these properties are often not balanced. In reality this means that the stacking sequence is very important for thin walled shell structures.

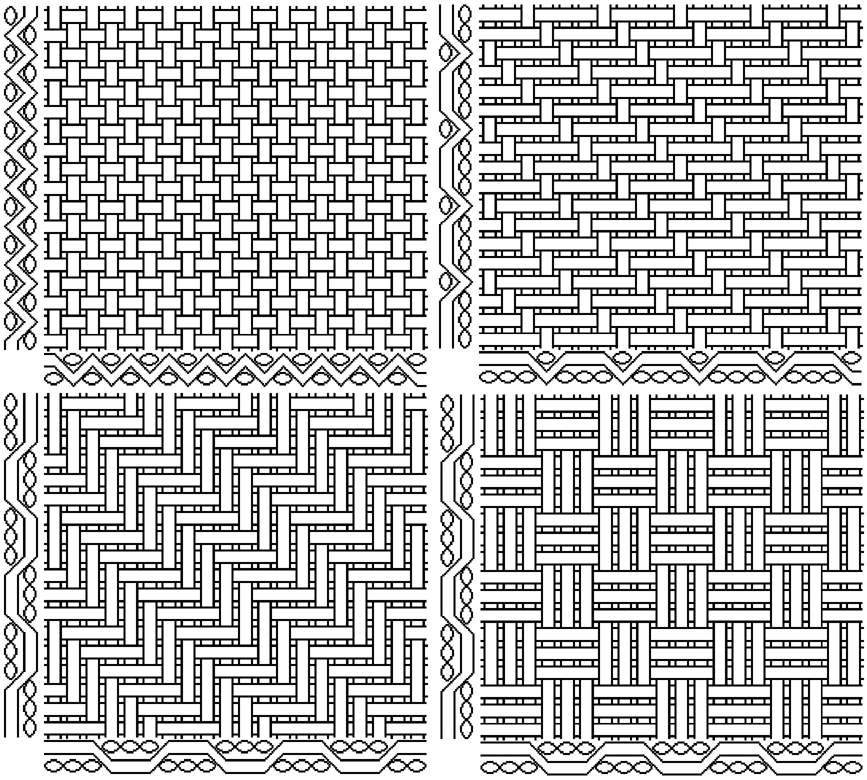


Figure 2 Different weave types have a different amount of undulation.

From the designer needs it is clear what the designer needs for a useful tool:

- *Connection with programs by which the product shape is defined.*
  To comply to this demand it was decided that the tool must be able to read and write from several finite element programs, and that it should not be to difficult to extend this to other finite element programs as well. Supported FEM programs will be: Patran, Marc, Ansys, Abaqus, Nastran.
- *Possibility to shape reinforcement before placement on the product shape.*
  This demand originates from the Hand Lay-Up process, but also for the Press Forming it can be useful. Therefore it was decided that for all processes this option must be possible to use. By

using a small 2D drawing grid the size and shape can be defined (figure 3). The initial orientation of the reinforcement must be given (how the material is cut from the role), so a unique placement on the product shape becomes possible.

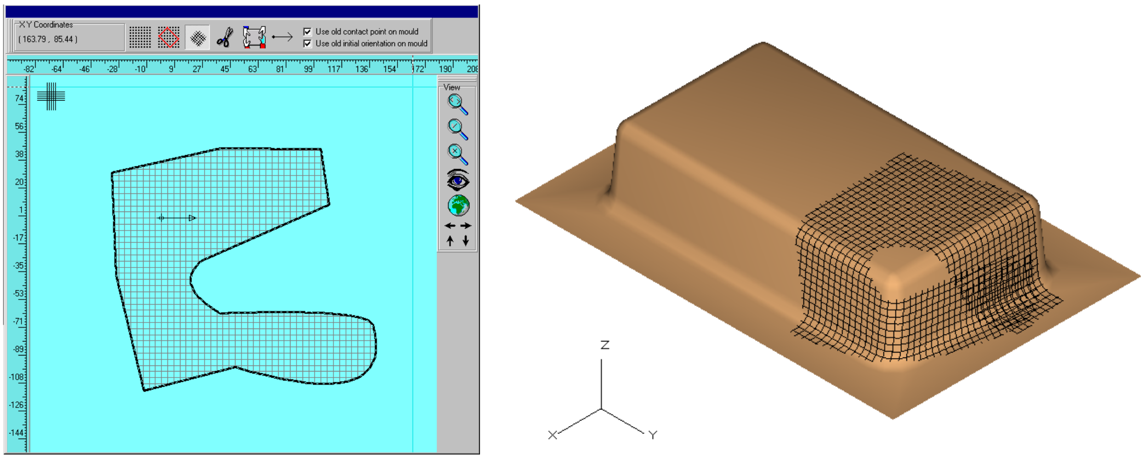



Figure 3 The predefined fabric can be placed on the product by pointing out a reference point and a reference direction

- *Possibility to put multiple layers of reinforcement on the product, using RTM, press forming, hand lay-up or even other processes.*
  In the tool it is possible to create as many layers of reinforcement as needed (figure 4). Layers, however, can not interact with each other. This seems a drawback, but in reality the interaction is not something a designer is looking for. To fulfil this demand even better it was decided that the product shape can be divided into smaller parts. On every part multiple layers of reinforcement can be placed, so the designer has a large freedom in placing reinforcement wherever he/she likes.

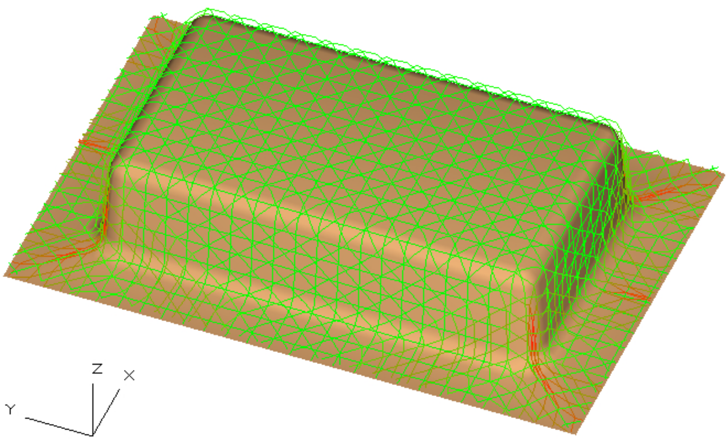



Figure 4 multiple layers of reinforcement can be applied

- *Prediction whether a product can be formed with these reinforcements.*
  Whether reinforcement can comply to a product shape depends on the shape and the deforming process (figure 5). Forces of the process on the reinforcement steer the reinforcement on the product shape. The locking angle of a fabric (the limit of the amount of possible shear) still dictates whether the reinforcement can comply to a surface or not [1,2]. Reinforcements that need to deform more then the locking angle allows will not comply in a decent way to the product shape. By using a relatively simple geometrical model for calculating the deformations of the reinforcement, the expected deformed reinforcement can be found and a check can be done on the occurrence of angle smaller then the locking angle. The deformation pattern of the reinforcement is calculated with the strategy model of the author [3]. This geometrical model

is developed for deformations of woven fabrics. For stitched UD material the flowing of the fibres is limited in the same way as for a fabric. Therefore, this model can also be applied for stitched UD materials. Since the strategy model gives the user freedom of placement of the reinforcement, different processes can be modelled.

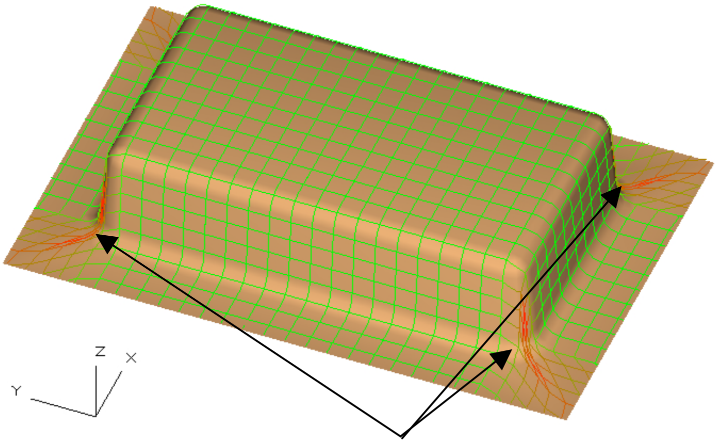



Figure 5 At positions where to much shear is required the fabric won't comply to the product shape

- *Connection with a finite element program to evaluate mechanical properties of the product considering: different fibres and resins, reorientation of the reinforcement, thickness change, fibre volume change and undulation of fabrics.*
  The influence of different fibres and resins are simple to incorporate into a FEM program. The properties of the structure mainly depend on these. The main effort for the connection with FEM programs is the implementation of the reorientation of the reinforcement. Since the orientation of the fibres differ locally and the amount of layers need not be the same on all places of the product it was chosen to define a material for every element. There are several ways to tell FEM programs what the mechanical properties of an element are. A first way is to calculate the so called ABD matrix of the whole laminate and define that as the "material". A second way is to give the mechanical properties of every layer. A disadvantage of the first method is that interlaminar problems can never be found. A disadvantage of the second method is that programs expect engineering constants instead of ABD matrices. When the B matrix is a non zero matrix (as is the case for many fabrics) coupling effects will occur. These effects can not be taken into account when the option of layers is chosen, which can be a major disadvantage if for instance elastic tailored wings must be designed.
  The thickness change which occurs during the press forming process can be estimated. A first order approach follows from the preservation of volume:

$$t(\alpha) = \frac{t(90)}{\sin(\alpha)}$$

  This change in thickness is only accounted for when preimpregnated materials are used. An example is shown in figure 6. In the Hand Lay-Up stage of the RTM, dry reinforcements are used, which lead to a change in fibre volume. An expression for the expected fibre volume is not as straight forward as the expression for the thickness change. It depends on certain properties of the fabric (how tight is the weave woven), and on the process, with two moulds there is a fixed thickness!

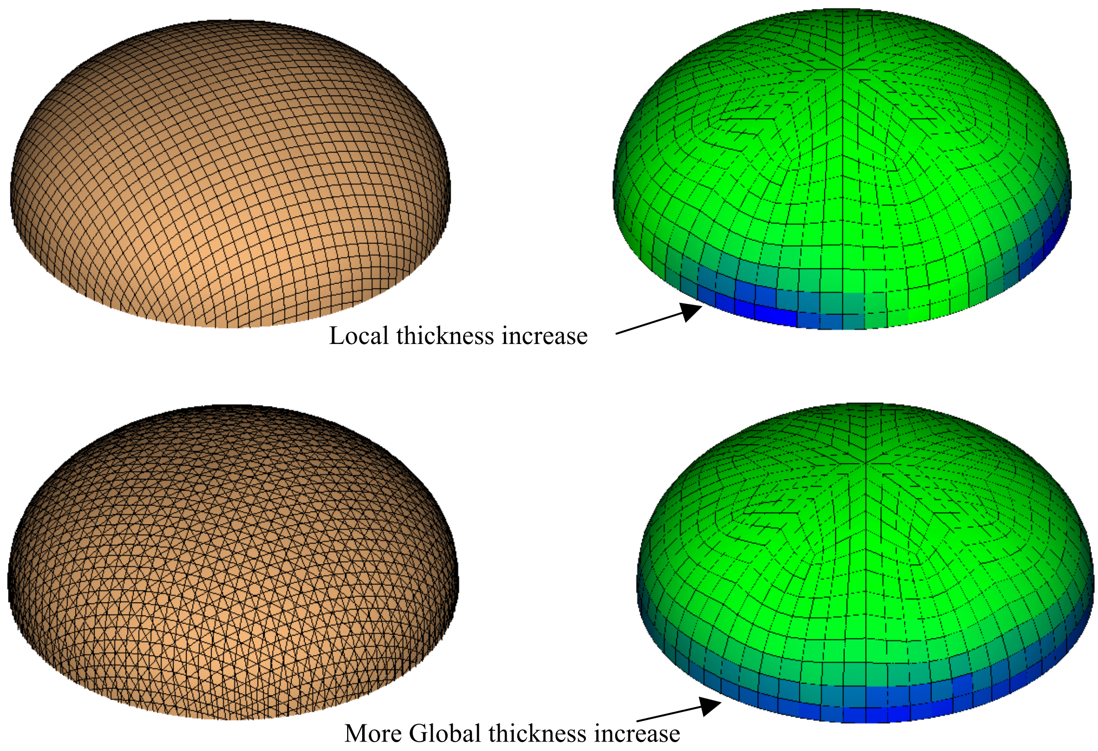



Figure 6 A ellipsoide cover with one layer of fabric (top) gives a local thickness increase in the sheared area near the bottom of the ellipsoide. When covered with two layers (bottom) the thickness increase is more global at the bottom of the ellipsoide.

The other effect of using weaves is the undulation of the fibres in the fabric (figure 7). It is depending on the fibre bundle (yarn) geometry. Flat bundle do not suffer to much from undulation, while round bundles show much more effects. For engineering properties an averaged fibre bundle geometry is used, so the undulation of different weave can be estimated. The effects can be found in the ABD matrix of the laminate.
It should be noted that since finite element programs only know UD, the use of other weave types takes a lot of effort. In the future development of weave models in finite element programs are therefore recommended.

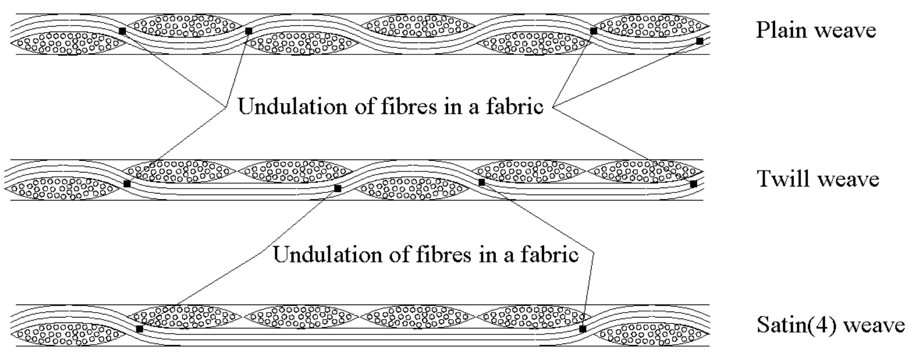



Figure 7 The undulation of a fabric as sketched for different fabric weaves.

- *Connection with resin flow simulation programs for RTM.*
  For the designer of RTM products it is important to extract information regarding the change of permeability of the reinforcement. Some work is already done in the field of estimating and predicting the influence of reinforcement deformation on permeability, but some work must still be done before a reliable translation of deformation data can be made into permeability data. At this stage it was decided that this is a project for the near future.

## EXAMPLE

An example of the usage of the drape program is shown in figure 8. This example deals with the design of a composite dome shape, which should carry high compression loads. During the design it became clear that carbon fibres as the material were needed, and that the thickness of the product should be about 2.5 cm. Since the production process involved a RTM kind of process with two moulds, the thickness of the reinforcement became important. Since the thickness increases in sheared areas the size of each layer should vary with such an amount that the gap width between the closed moulds was constant. With the drape program several blank sizes were generated, and after cutting they fitted well on the mould. With some typical process techniques the blank could be placed and mould closed, after which the resin was added.

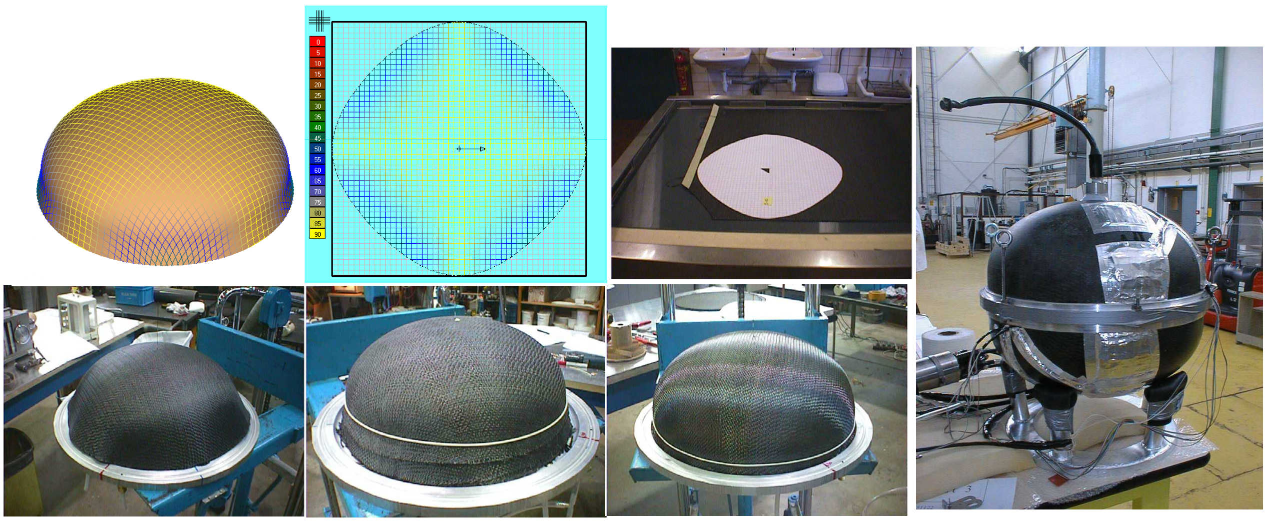


Figure 8 The example of a dome design with the aid of the drape program

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