Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

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Development of a composite cargo door for an aircraft

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Nowadays, aircraft manufacturers are not only looking for ways to reduce the structural weight of their aircraft but they are also searching for structural concepts that will lead to a cost reduction. One way to realize a cost reduction is to design a component with a high level of part integration since this will lead to a reduction in labor intensive trimming and assembly costs. By using composites in combination with new fabrication concepts this part integration becomes feasible. One of these new fabrication concepts is Resin Transfer Moulding (RTM) with pre-pregs. In traditional RTM processes, dry fiber pre-forms are positioned in a mould cavity. After the mould is closed, resin is injected into the mould and the fibers are impregnated. In the RTM process described in this paper, parts of the dry pre-form are replaced by pre-preg. After closure of the mould, the mould is heated and the resin in the pre-preg starts to melt. Then RTM resin is injected into the mould. The pressure of the RTM resin is used to pressurize the pre-preg. The main advantage of this fabrication concept is that sub-preforms can be made very easily in pre-preg that would be very difficult to make with dry fabric due to the lack of tack. Another advantage is that the RTM process time is reduced, because only a small quantity of resin has to be injected. In order to demonstrate the feasibility of this fabrication concept, a hat stiffened cargo door concept was developed. Two doors were made. The doors were tested by applying a pressure difference to the door of 0.12 MPa. Both doors did not fail during the tests.

Keywords: Resin Transfer Moulding, Composite Cargo Door.

INTRODUCTION

In the framework of the BRITE EURAM project: Advanced PRImary COmposite Structures (APRICOS), structural components for a composite fuselage of an aircraft were developed. The components ranged from discrete stiffened fuselage panels, beams, frames and a cargo door (see fig. 1). The main goal of the program was to achieve a cost reduction of at least 20% by using composites instead of metals. The National Aerospace Laboratory NLR was responsible for developing a fabrication concept for a composite cargo door. The paper presents a description of the cargo door. The mould and fabrication concept developed for producing the door is presented in detail, followed by a brief description of the test program and a presentation of the test results.

DESCRIPTION OF THE DOOR

The door represents an inwards-opening generic cargo door for an aircraft category like the Airbus A320. The purpose of the program was to develop a cost effective fabrication concept for this category of fuselage doors. Since only two doors had to be produced as deliverables of the program, it was decided not to develop a curved door but a non-curved door in order to limit tooling costs. However, the fabrication and tooling concept developed, had to be valid also for producing curved doors.

During flight conditions the door will only be loaded by the pressure difference between the pressure in the fuselage and the atmospheric pressure. This means that Design Limit Load for the door is 0.06 MPa. Design Ultimate Load is 2.0 x 0.06 = 0.12 MPa.

The cargo door concept is based on an outer skin that is stiffened by a lattice of hat stiffeners, integrated pin-locks, door-stops and two hinge points (see fig. 2). Figure 3 shows a cross section of a cargo door with a schematic presentation of the door-stops and the pin-locks (note that the cargo door in the figure has a curvature, whereas the door described in this paper is flat).

Inside the lattice of hat stiffeners a foam core is present. This foam core is only present for fabrication purposes and was not taken into account in the strength analyses. Each intersection of two hat-stiffeners is reinforced with four corner reinforcements (see fig. 2). Ten aluminum inserts are incorporated in the door. After curing the door, these metal inserts will be machined to form respectively door-stops and pin-locks (see fig. 2).

The finite element code B2000 (ref. 1) was used to design the door. B2000 is NLR's testbed for Computational Structural Mechanics. The finite element model comprised half a door and was composed of 753 nine noded QUAD elements (see fig. 4). The optimization module B2OPT (ref. 2) within B2000 was used to optimize the door for minimal weight with maximum values for the stresses as constraints. In order to facilitate the optimization, the following nine laminate design variables were defined (see fig. 2):

1. The thickness of the 0^0 plies in the skin
2. The thickness of the 90^0 ply in the skin
3. The thickness of the $\pm 45^0$ plies in the skin
4. The thickness of the 0^0 ply in the hat stiffeners
5. The thickness of the $\pm 45^0$ plies in the hat stiffeners
6. The thickness of the $\pm 45^0$ ply in the corner reinforcements

Not only design variables but also the following side constraint was defined: The thickness of both the optimized skin and optimized hat-stiffeners had to be at least 1.4 mm each, in order to allow a repair with counter sunk fasteners in case the door will be damaged.

The Tsai-Hill criterion was used as a failure criterion. The optimum design was found after 13 optimization cycles.

In order to minimize milling, drilling and assembly costs it was decided to fabricate the door (including the metal inserts) in a single fabrication cycle. Due to the complexity of the door, the Resin Transfer Moulding (RTM) fabrication concept was selected, since making the door with pre-preg in the autoclave would become very cumbersome. However, injection of a component of this size and this complexity would become very risky with the traditional

RTM as fabrication process:

- The injection time would probably expand the pot life of the RTM resin at injection temperarture.
- Reproducibility in impregnating every spot of the pre-form during the RTM process would be difficult to guarantee.

Therefore it was decided to make the hat-stiffeners and corner reinforcements from pre-preg and use the pressure of the RTM resin during the RTM process to pressurize the pre-preg. In this way injection time is dramatically reduced because the hat-stiffeners and corner reinforcements are already impregnated and the risk of dry spots in the cured door is nearly eliminated.

The next paragraphs describe the different elements that compose the door: the foam core, the metal inserts, the skin, the lattice of hat stiffeners, and the corner reinforcements.

THE FOAM CORE

Figures 5 presents an overview of the foam core for which Rohacell 71 WF was used. This foam was selected because it has a low density and is able to withstand a pressure of 0.4 MPa. This is very important since during the RTM process a resin injection pressure of 0.4 MPa was used. The total weight of the foam core was 1400 gram.

THE METAL INSERTS

Figure 5 presents the location of the aluminum inserts in the assembled foam core. After curing the door, these metal inserts were machined to form door stops and pin locks. In order to reduce the weight of the aluminum inserts, holes were drilled into these inserts. After drilling, these holes were filled with Rohacell 71 WF. The weight of the metal insets was 5750 gram.

THE SKIN

The skin was composed of dry carbon fabric Lyvertex G808 220 gram/m^2. This fabric has 90% of its fibers in the warp direction and 10% of its fibers in the weft direction. The lay-up of the skin pre-form was [+45 –45, 0, 90, 0, -45, +45] with a total thickness of 1.4 mm. The size of the skin pre-form was 900 mm x 900 mm. A pre-form of dry fabric of this size is very difficult to handle due to the lack of tack of the single layers. Therefore the skin pre-form was stabilized by stitching the edges of the skin pre-form with a 2 x 40 tex Kevlar stitching fiber. The RTM-6 epoxy resin was used to impregnate the skin pre-form.

THE HAT-STIFFENERS

The hat stiffeners were composed of Fiberite HMF carbon 977-2A-35-6KHTA-5H-370-T2 pre-preg fabric. This pre-preg was selected because tests on interlaminar shear specimens, made of RTM-6 resin and carbon fabric and the 977-2A-35-6KHTA-5H-370-T2 pre-preg, demonstrated compatibility between these two systems. The lay-up of the hat-stiffeners was: [+45, 0, 90, -45]. The thickness of the hat stiffeners was 1.4 mm.

THE CORNER REINFORCEMENTS

The corner reinforcements were composed of Fiberite HMF carbon 977-2A-35-6KHTA-5H-370-T2 pre-preg fabric. The lay-up of the corner reinforcements was: [+45, 0, +45]. The thickness of the corner reinforcements was 1.0 mm.

THE MOULD CONCEPT

As mentioned before the RTM fabrication concept was used to fabricate the door. The goal was to develop a stand alone tooling concept (with no need for an oven or an autoclave) in which the door could be produced with tight (reproducible) outer dimensional tolerances. For example, the tolerance on the thickness of the different elements (skin, hat stiffeners and corner reinforcements) was 0.1 mm. In order to make these tight tolerances feasible a stiff two-side mould had to be developed since the pressure used during the RTM process was 0.4 MPa. By incorporating electrical heating elements into the mould, no oven or autoclave was needed. This resulted in a mould concept with the following elements:

- A steel bottom frame.
- An aluminum bottom plate (see fig. 6). The bottom plate had an injection circuit at the edges of the plate and one vent located at the center of the plate. This radial injection strategy was selected to minimize injection time. Holes were drilled in the mould in which electrical heating elements were inserted before the RTM cycle.
- A composite top mould with integral electrical heating wires (see fig. 7). It was technically not necessary to use a composite top mould since the top mould could also be made of metal. However, the composite top mould was developed in order to gain insight in the behavior of composite moulds for RTM with internal electrical heating wires. The experiences gained with this composite mould will be not be presented in this paper.
- A steel top frame. Figure 6 presents a picture of the metal top frame and the aluminum bottom plate. The picture provides a good insight in the size of the mould.

THE FABRICATION CONCEPT

Two doors were made. Each door (including its metal inserts) was made during a single RTM fabrication cycle. During this fabrication cycle the following steps were distinguished:

- Laminating the hat stiffeners with pre-preg on laminating blocks and pre-compacting the laminates under vacuum for at least 10 minutes.
- Laminating the corner reinforcements with pre-preg on laminating blocks and pre-compacting the laminates under vacuum for at least 10 minutes.
- Preparation of the dry fabric skin pre-form by stitching the edges with a Kevlar stitching wire.
- Positioning of the pre-preg corner reinforcements in the composite top mould.
- Positioning the pre-preg hat stiffeners in the composite top mould.
- Positioning the dry fabric skin pre-form in the aluminum bottom mould.
- Assembly of the top and bottom mould.

- Assembly of the steel bottom and top frames.
- Applying vacuum to the mould for three hours.
- Heating the assembled mould to 120 ^{0}C by heating the electrical heating wire in the composite top mould and by heating electrical heating elements inside the aluminum bottom mould.
- Injection of RTM-6 resin into the bottom mould with a pressure of 0.4 MPa. The pressure of the RTM-6 resin will pressurize the pre-preg. The total injection time was approximately 25 minutes.
- Heating the mould to 160 ^{0}C after the skin was impregnated with resin.
- Curing the pre-preg and the skin laminate at 160 ^{0}C for 4 hours.
- De-moulding the cured product.
- Machining the metal inserts and the corners of the door.

The weight of the machined door including the foam core and the metal inserts was 13.47 kg.

Figure 8 presents one of the two doors after being machined. Figure 9 presents a detail of a machined pin-lock.

At this moment the cost comparison between a metal and the composite cargo door has not been made yet.

TESTING THE DOORS

The main goal of testing the doors was to demonstrate sufficient load carrying capability. In order to facilitate the tests on the doors a pressure box was designed and fabricated. Before being tested, the doors were mounted to the pressure box and all gaps between the door and the pressure box were sealed. Then the pressure inside the pressure box was gradually increased. The maximum pressure difference applied was 0.12 MPa. During the tests the displacement of the skin was measured at three locations (see fig. 10) by linear displacement transducers.

Both doors were tested according to the following test program:

- **Test no.1**
  Test on door no. 1 to Design Ultimate Load (0.12 MPa pressure difference). The door did not fail at this load level.
- **Test no. 2**
  Test on door no. 2 to Design Ultimate Load (0.12 MPa) pressure difference).
- Applying two impact damages to door no. 2: a 30 Joule impact in the skin resulting in a Barely Visible Impact Damage (dent depth of 0.9 mm) and a 30 Joule impact in the skin under a hat stiffener resulting in a puncture.
- **Test no. 3**
  Test on door no. 2 to failure. Failure occurred at 1.2 bar pressure difference (Design Ultimate Load), hence demonstrating the damage tolerance of the door.

Table 1 presents the measured displacements at maximum load of the doors during these tests.

Test	Pressure Difference: (Mpa)	Displ. 1 (mm)	Displ .2 (mm)	Displ. 3 (mm)
1	0.119	3.4	7.2	2.3
2	0.118	3.5	7.4	2.4
3	0.118	3.4	9.7	2.7

CONCLUSIONS

A fabrication concept for producing a composite hat stiffened door was developed successfully by combining dry fabrics with pre-preg during the RTM process.

Two doors were fabricated and tested. The tests not only demonstrated a sufficient load carrying capability of both doors but also damage tolerance of the doors. The cost evaluation will be carried out later.

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2. Arendsen, P.; *The B2000 Optimization Module: B2OPT*, NLR-Report TP 94116 L, National Aerospace laboratory, Amsterdam, April 1994.

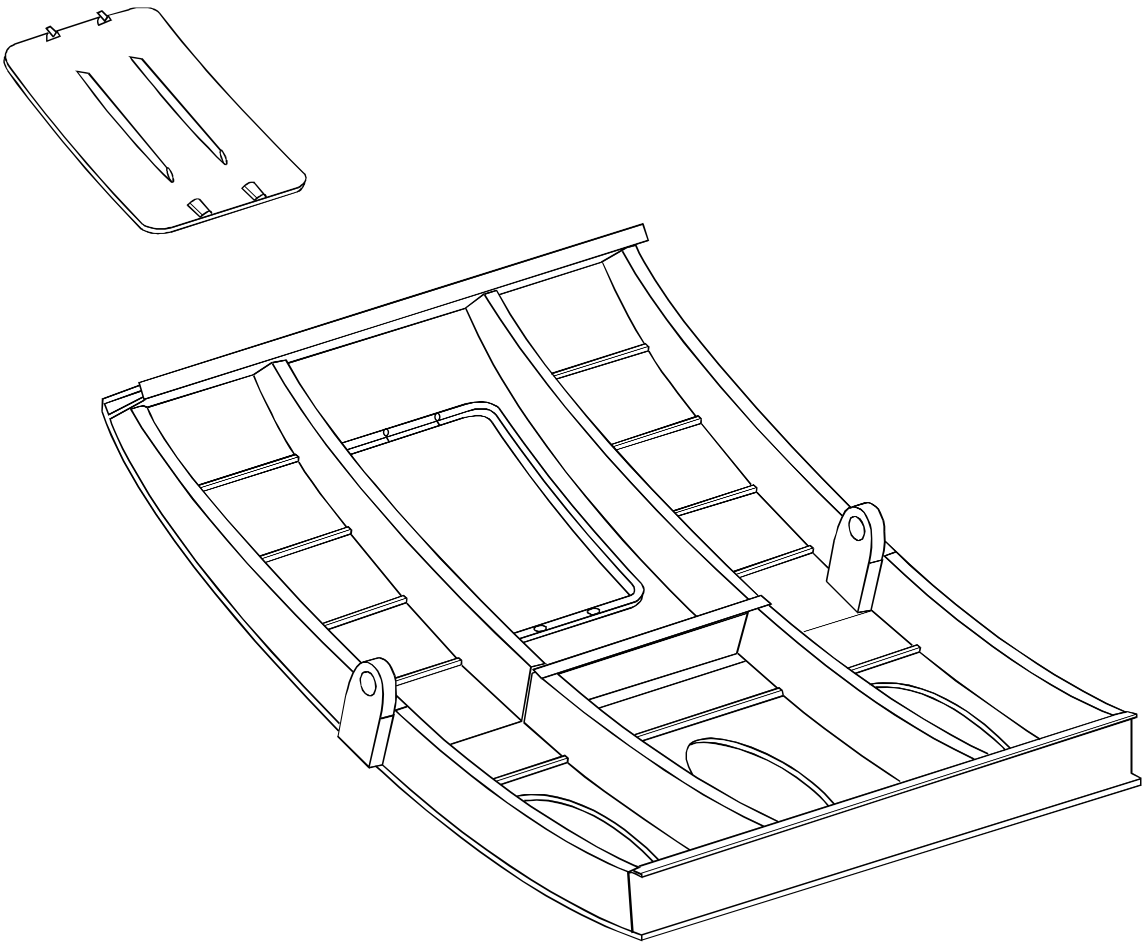
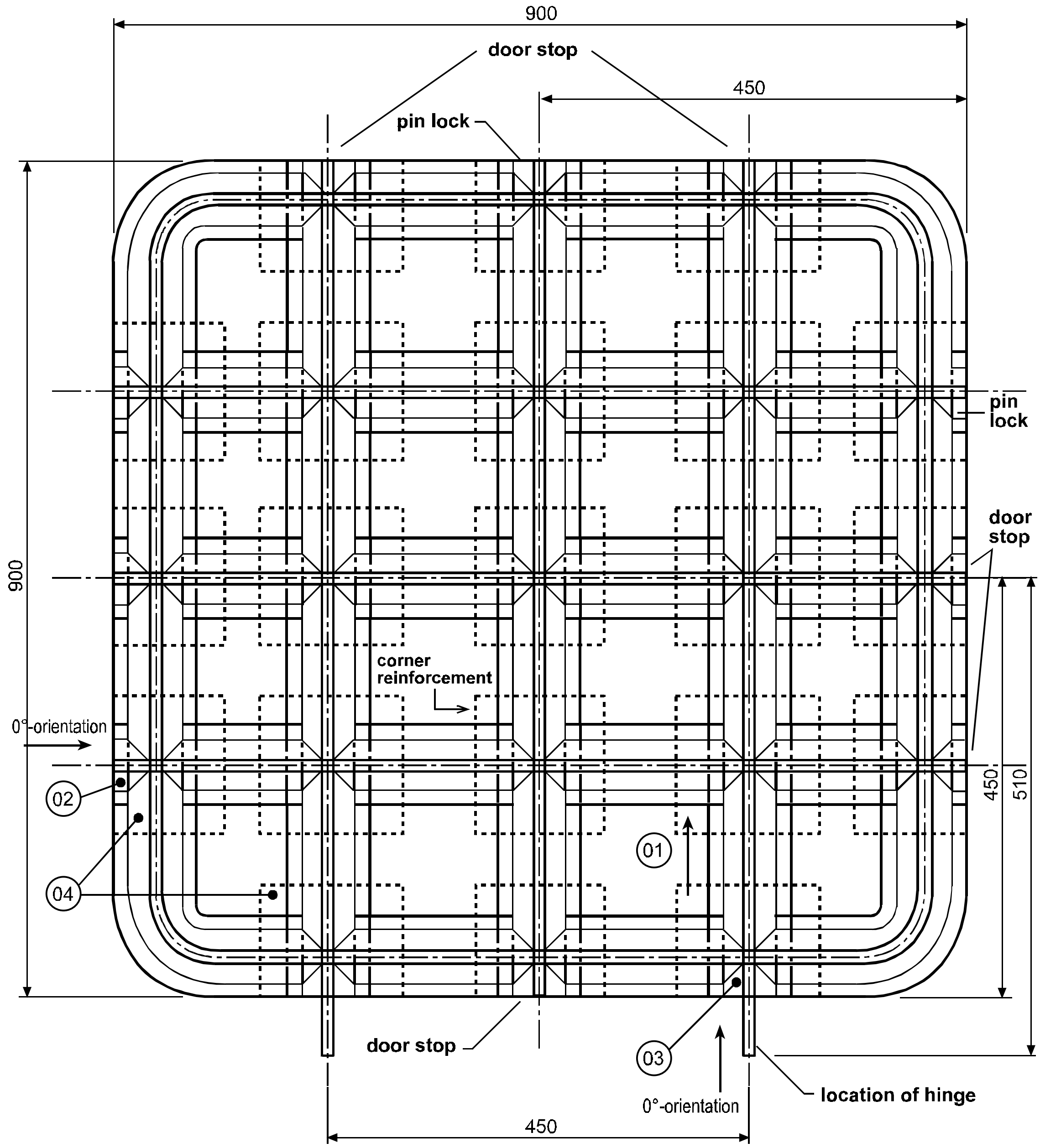


Fig. 1 Composite fuselage demonstrator



Skin laminate: [45,-45,0,90,0,-45,45] t = 1.4 mm
Hat-stiffener laminate: [45,0,90,-45] t = 1.36 mm
Corner reinforcement laminate: [45,0,45] t = 1.0 mm

01 = skin
02 and 03 = hat-stiffener
04 = local reinforcement
0°-orientation equal to skin laminate

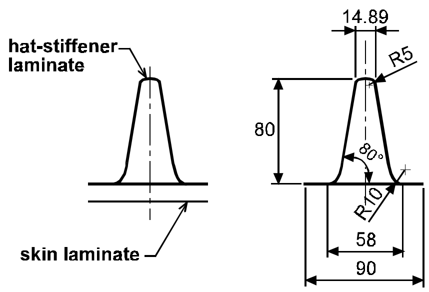


Fig. 2 Drawing of the door concept

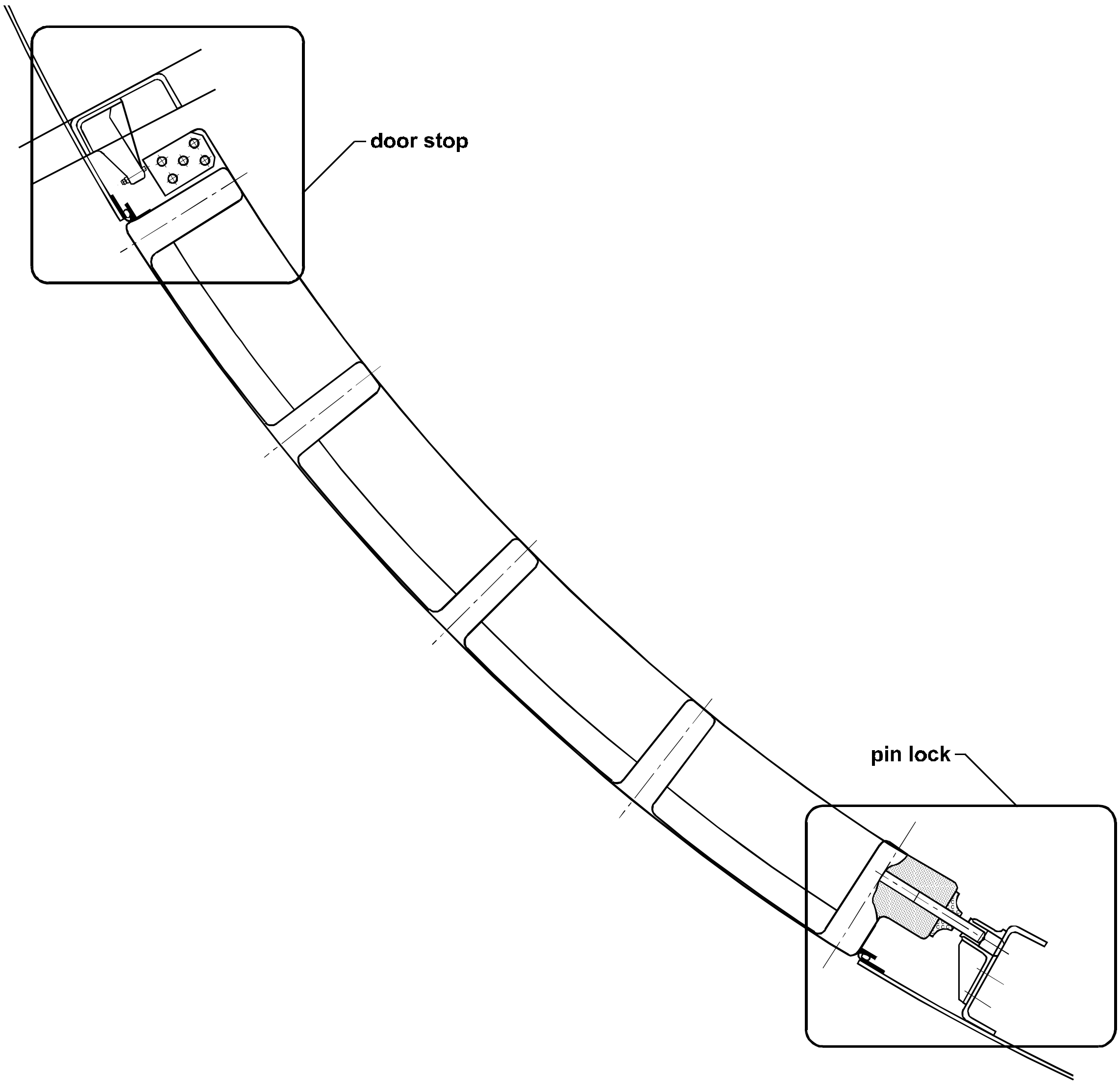
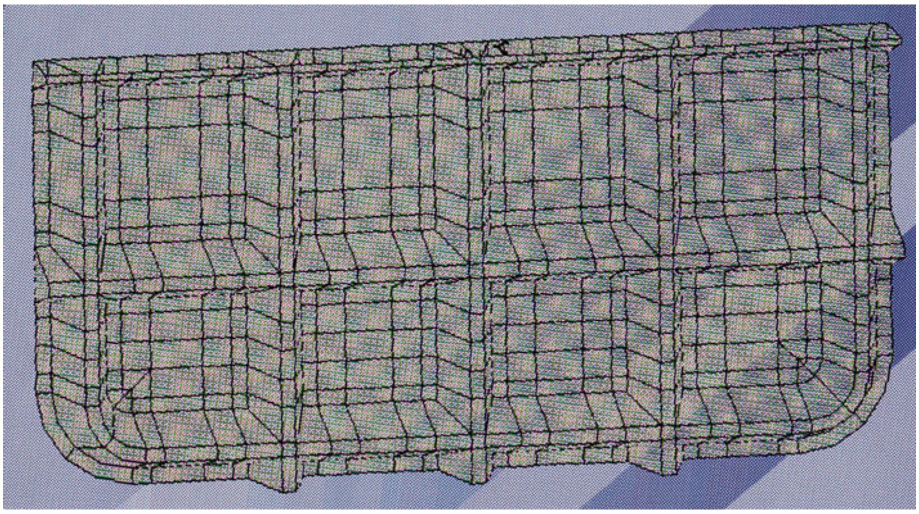


Fig. 3 Schematic cross section of the hat stiffened door with pin locks and door stops

- Element type: nine nodes QUAD
- Number of elements: 753
- Total degrees of freedom: 16563
- Material: composite
- Load case: Pressure: $2 \times 0.597 = 1.194$ bar



B2OPT Model

Fig. 4 Finite element model of the hat stiffened door

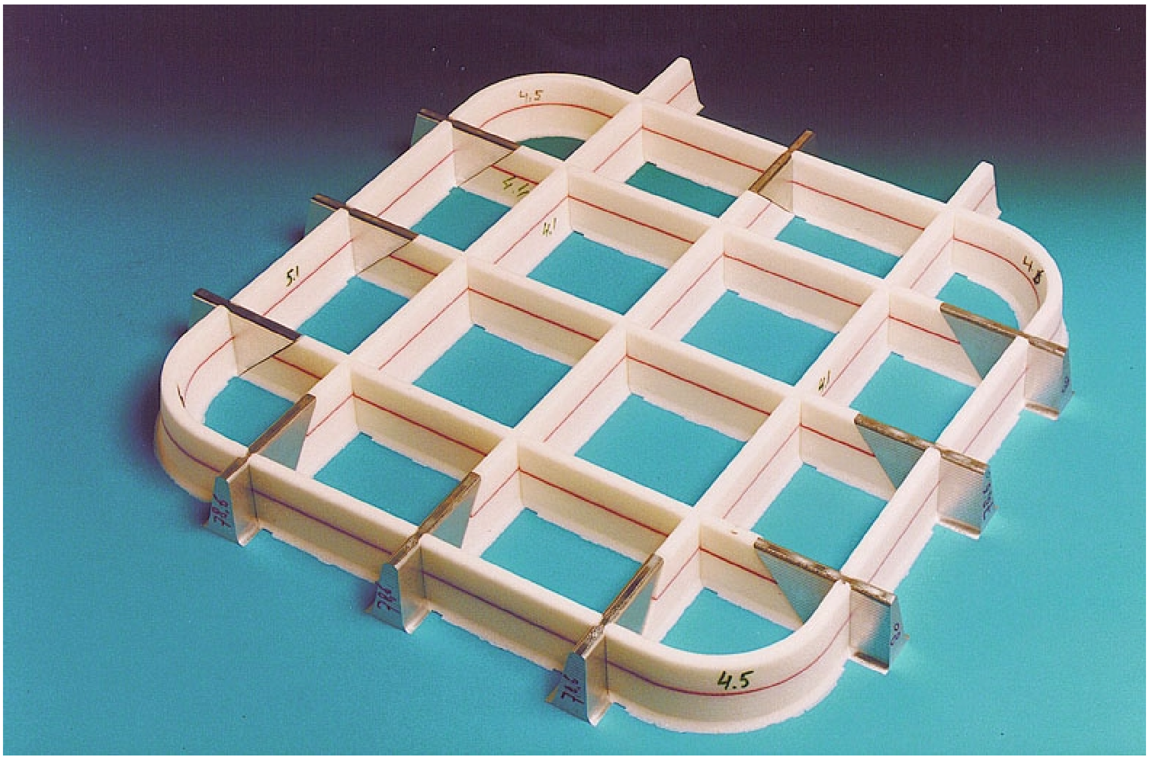


Fig. 5 Overview of Rohacell 71WF foam core and metal inserts

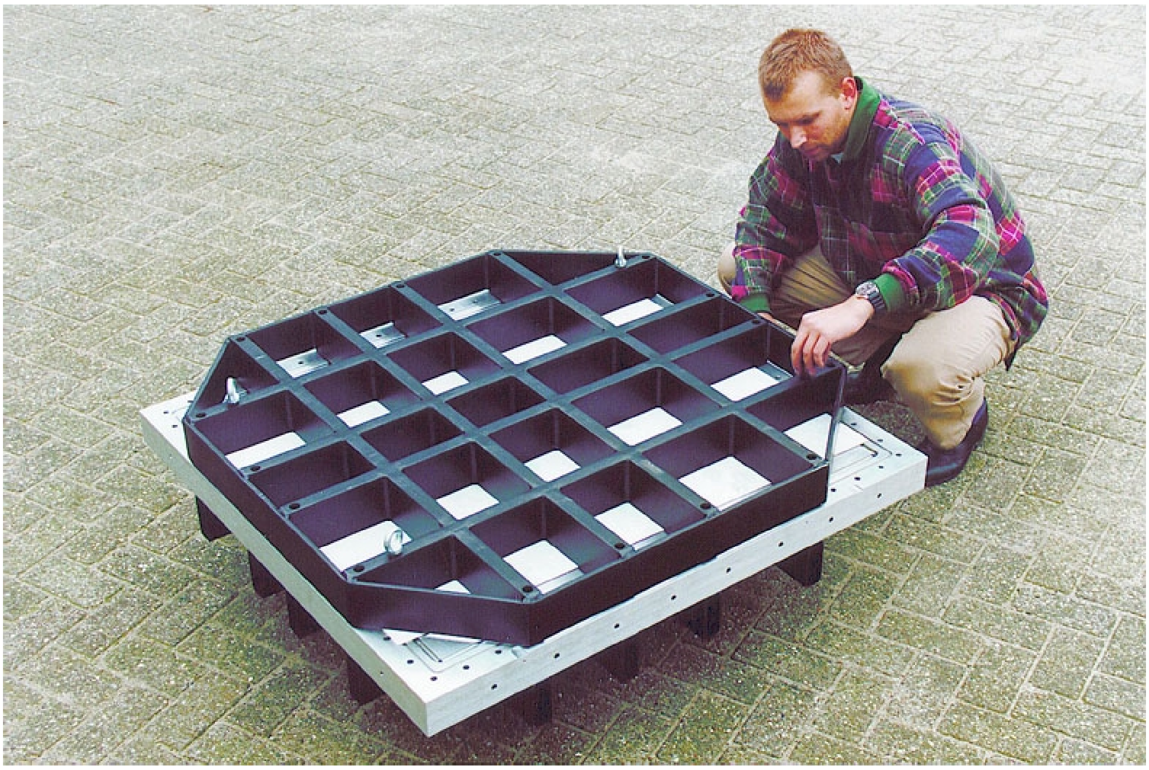


Fig. 6 Aluminium bottom plate and steel top frame

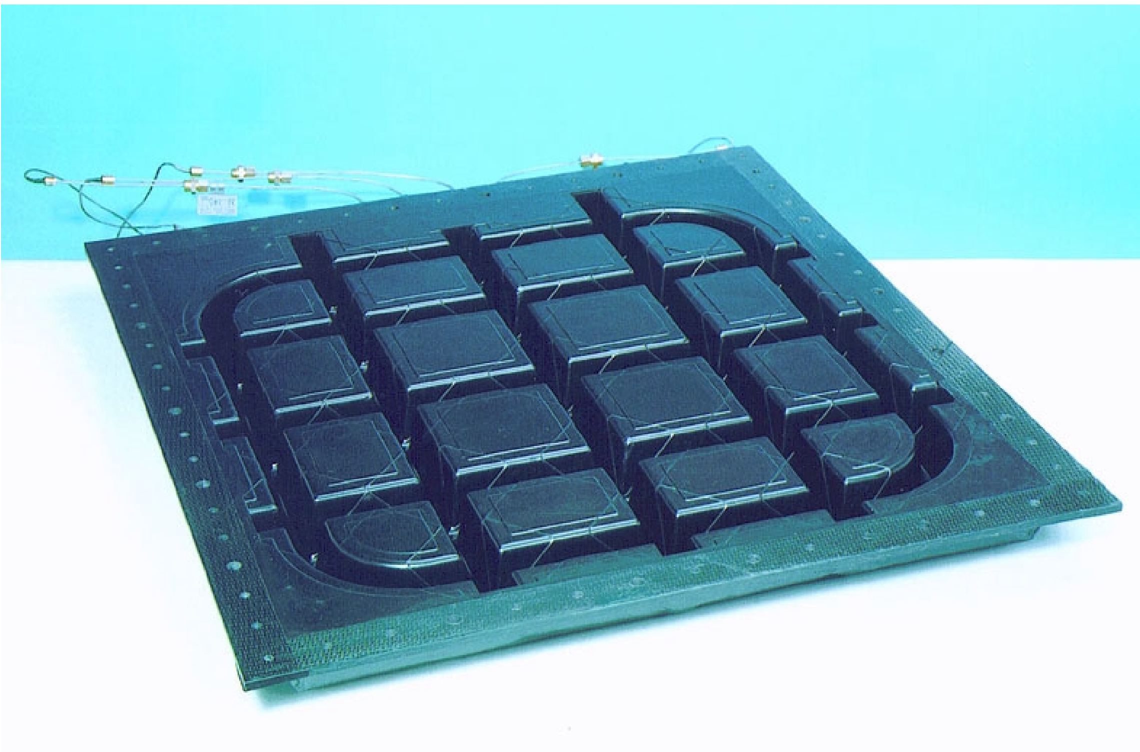


Fig. 7 Composite top mould with internal electrical heating wires

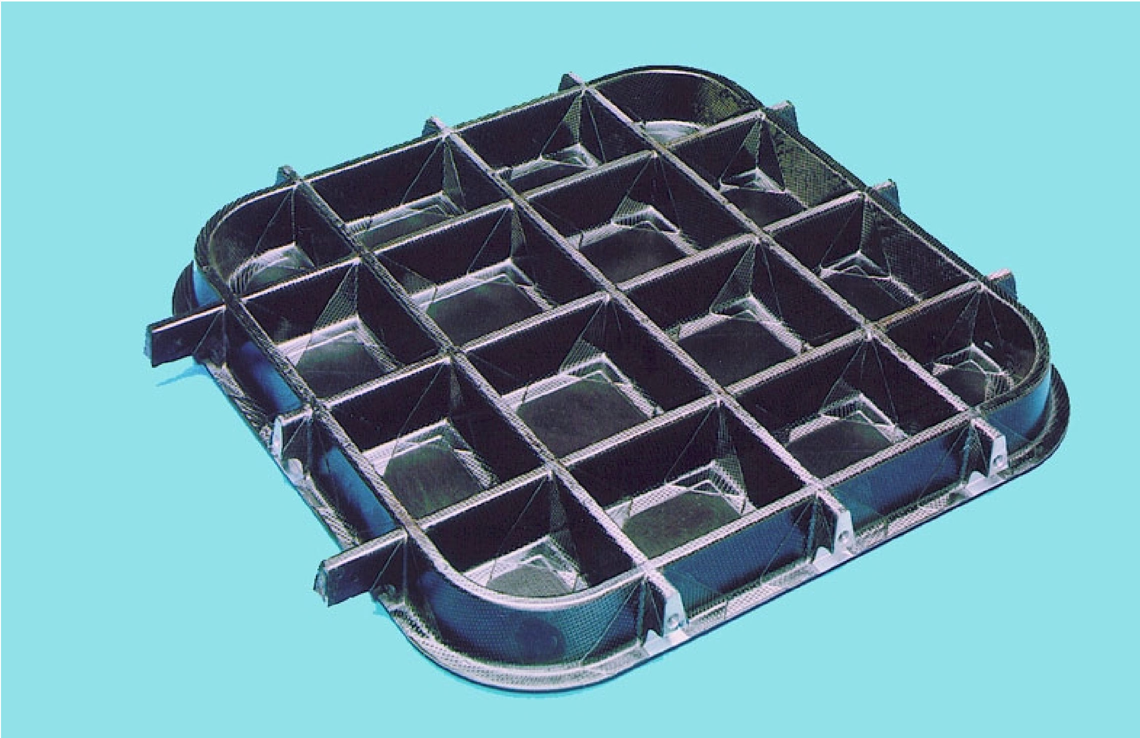


Fig. 8 Composite cargo door after machining

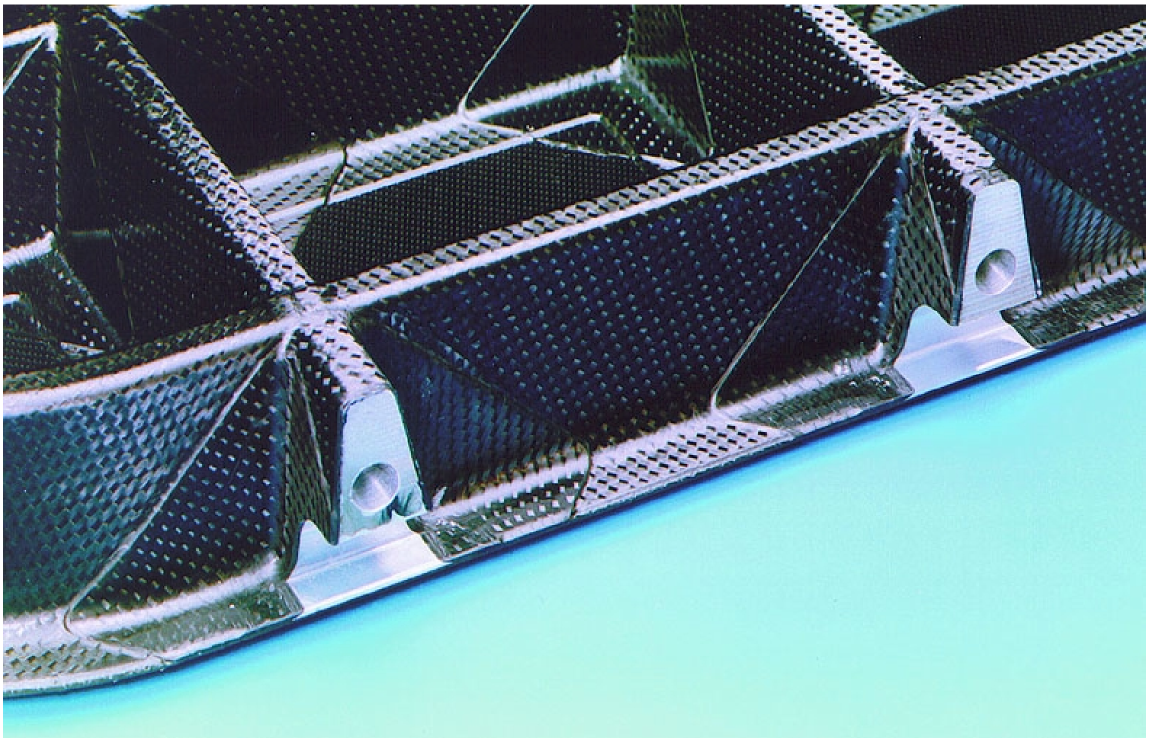


Fig. 9 Detail of a machined pinlock

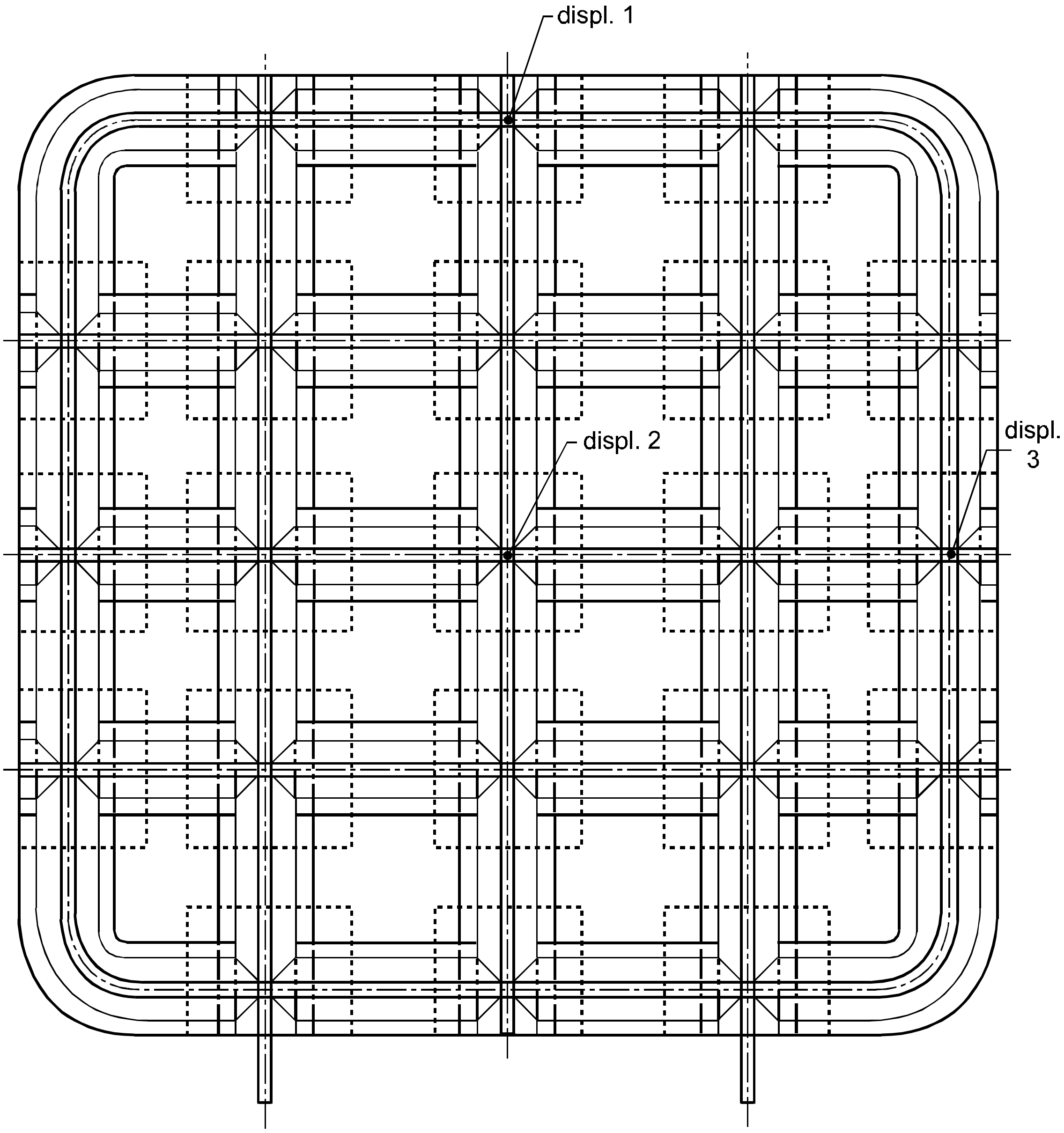


Fig. 10 Location of the displacement transducers