COMPUTERISED THERMO-MECHANICAL SIMULATION for Jean Louis Etienne's '*Mission BANQUISE*' survival capsule

'Mission Banquise'

'Mission Banquise' was a scientific and educational expedition undertaken by Jean Louis Etienne between April and July 2002.

It was a crossing of the Arctic Ice Ocean from the North Pole to the north east of Greenland lasting three months using the POLAR OBSERVER, an observation module born along by the transpolar drift current of the ice pack.

All the observers are unanimous; the ice pack is undergoing an unprecedented regression. In four decades, its extent has been reduced by 6% and its average thickness has come down from 3.1 metres to 1.8 metres, i.e., nearly a 40% reduction in thickness.

For millions of years, natural ecologic upheavals, such as meteorites, volcanoes and glaciers, have left their marks on the history of this planet and its inhabitants. Today, however, it comes as no surprise to anyone that our economic and industrial revolutions bear heavily on the world's ecological future. As a leading element in this sharp upturn, humankind has become the source of a new ecological upheaval that has turned the geological timescale on its head. In less than two centuries, mankind has taken over the evolution of Earth's species and their living conditions. As at today, evolution is no longer counted in eras but in generations!

For this expedition, Jean Louis Etienne undertook a thorough programme of observations and measurements from the **POLAR OBSERVER**. This was the name of a capsule made from composite materials specially designed for this Arctic expedition by *CRITT MECANIQUE et COMPOSITES* of TOULOUSE. It had to be a habitable module, capable of meeting the mechanical, climatic and energy conditions of this hostile environment. Its shape had to give it the stability to float on open water in the event of the ice pack breaking up.

The Polar Observer, with its six vision ports, was totally independent. Its conical living compartment was 3.7 metres high and 3.5 metres wide. It generated its own energy supplies (from solar panels and a fuel cell) and it was loaded with measuring equipment, probes and communications systems.

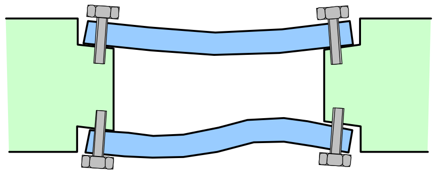
POLAR OBSERVER was designed and built in several detachable parts so that it could be transported to the North Pole. Each major item had to be able to fit through the 2x2 metre doors of an Antonov 75 aircraft in order to reach the Russian base at Barneo.

The selection and importance of adhesive bonding for the POLAR OBSERVER

The POLAR OBSERVER was an assembly of composite parts (compartments, bulkheads, dome, deck, bunk, worktops) surrounded by a metallic structure for transport by helicopter. These parts, like all composites, were thus made up of various materials bonded together. The designs and structural calculations for these parts were provided by *CRITT MECANIQUE et COMPOSITES* of Toulouse.

One of the major adhesive bonding problems concerned the vision ports.
The ports consisted of two panes of polycarbonate arranged either side of the composite structure on flat rebates.

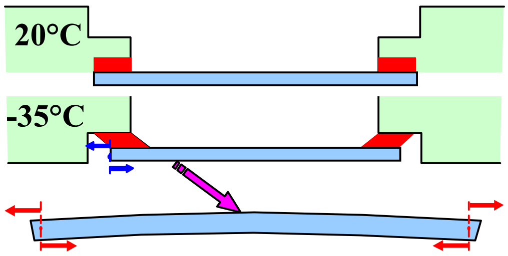
Adhesive bonding was the natural choice for several reasons, sealing, insulation, mechanical strength and the low level of mechanical stress risers. In comparison with, for instance, threaded fasteners, adhesive bonding offered several advantages.
The use of a dry-clamped gasket seal calls for very tight manufacturing tolerances. These are difficult to achieve between metallic mouldings given the possible faults with composite parts (shrinkage, creases, bubbles, etc). Any surface roughness or defects would become a source of leaks. During the bonding process, however, as the adhesive passes from the liquid to the solid state, it covers over these defects to ensure a seal, whilst also holding the sheet in place (no need for screws, drillings, thread inserts, etc).
Screw fastening assembly often leads to distortion of the parts by deforming the more flexible part (the pane). The less rigid part shapes itself to match the defect of the more rigid part. During an assembly by bonding, the adhesive flows around the defect and prevents the imposition of additional forces upon the various elements (apart from any shrinkage of the adhesive).



In the case of the POLAR OBSERVER, the differential contraction between the two materials (between their assembly at 20°C and their use at –35°C) drove the selection of adhesive bonding. The use of screws would have led to cracking of the polycarbonate pane or the tearing out of the thread inserts from the composite.

The use of adhesive bonding absorbs part of the forces of differential contraction whilst ensuring a seal, strength and a division of the forces within the mechanical connection.

Even so, we detected warping of the pane at –35°C caused by a difference in the tension across the two surfaces of the pane. The adhesive prevented shrinkage in one of the surfaces: the bonded surface was in a state of tension with respect to the other surface.



Warping of the pane

<u>Thermo-mechanical simulation and dimensions of the vision port seals</u>

<u>Simulation of the bonded joints:</u> a review of the problems based on a simulation of the bonded joints:
Simulations with thin materials:
Disproportionality between the 3 dimensions of each part.
Effects of edges and interfaces
Wastage from the finished parts, etc.
Simulation of forces at the interfaces.
Simulation of anisotropic materials in the linear and non-linear domains.
Thermo-mechanical simulation of visco-elastic adhesives.
Design of joint shapes that would distribute stresses and enable reliable installation.

In the case of the Polar Observer, the main mechanical stresses in the adhesive joint and its neighbouring materials were related to:
The differential expansion that caused dimensional variations of several millimetres and, in particular, a constant force across the joint (static fatigue).
The partial vacuum between the two panes (related to the temperature difference between their manufacture and use).

As a function of the adhesive and the form of the joint, the deflection of the vision pane could be as much as several millimetres. Such deflection alters the loadings on the joint, which may be summarised as:
In shear (differential expansion).
In cleavage (induced deflection).

To begin with, we carried out tests of adhesive and thermo-mechanical properties in order to find the right adhesives for the interfaces between the materials chosen (adhesion) and to calibrate the simulation (linear domains, transitions, ruptures).

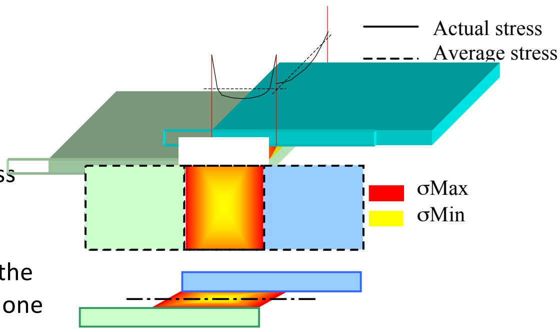
The thermo-mechanical characteristics of the materials used were established with the help of a **rheometer** in all three directions at one degree intervals across the range -60°C to +60°C. These were then reincorporated into the thermo-mechanical simulation in order to define the limits of stress and deformation approximating to reality.

We should like briefly to look at two themes affecting this simulation.
The evening out of stresses: the design of the joint.
The extent of the adhesive's thermal expansion.

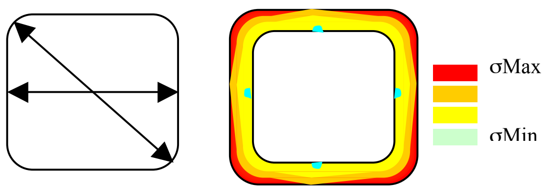
Evening out stresses.

The shear force stresses in a bonded joint are not distributed evenly.

The deformation of the materials and the direction of the shear loads cause uneven stresses across the width of the joint (the dimension at right angles to the load) and the length of the joint (the dimension in line with the load). The stresses across the width of the joint are close to the average shear stress. Along the length of the bonded area, stress accumulations are seen at the edges of the joint.

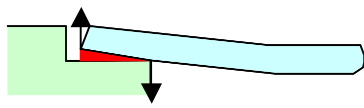


We can even see unevenness within the depth of the joint. As well as the edge effects, the deflection causes a shift of the neutral fibre towards one of the interfaces as a function of the rigidity of the substrates and their thickness. In the case of the Polar Observer's vision ports, the stresses accumulated at the interface with the composite.



Shear stresses on the expansion axes

In our case, the shear loadings were due to the effects of differential expansion. Since the expansion varies with the length available for expansion, so the shear stresses also vary with the length of expansion and thus the induced shear stresses vary all around the vision port's edge.



The deflection of the vision port (differential shrinkage across the surfaces of the pane) and the inter-pane partial vacuum (-60°C) lead to cleavage. At its external edge, the joint experiences a tearing tension load whilst, at its furthest internal edge, it is in compression.

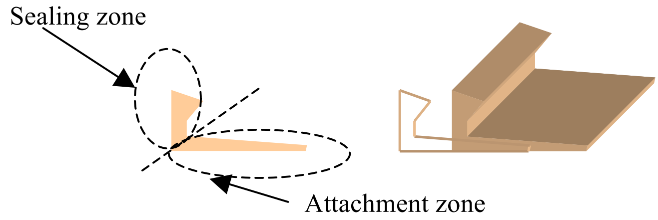
Shear stresses within the joint

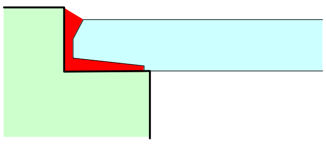
MPa

The deformation of the materials, the direction of differential expansion and the dimensional changes around the perimeter all lead to an accumulation of shear stresses at the exterior boundary of the joint, in particular, at the corners (the greatest expansion lengths).

In order better to even out the stresses, one of the solutions worked on consisted of identifying, for every point, a joint thickness that would provide a suitable average stress value.

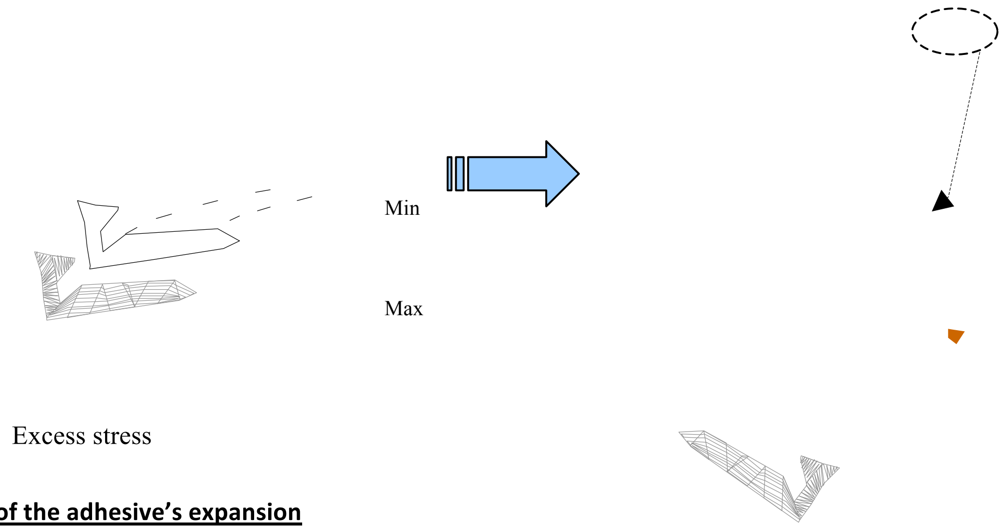
The proposed joint consisted of two zones: an attachment zone working in shear and a sealing zone working in light tension.





For a given fillet profile, the thickness varies gradually in each zone in order to align the stress value with the average stress.

Reduction of shear stresses by changing the joint thickness



Evening out and reduction of stresses

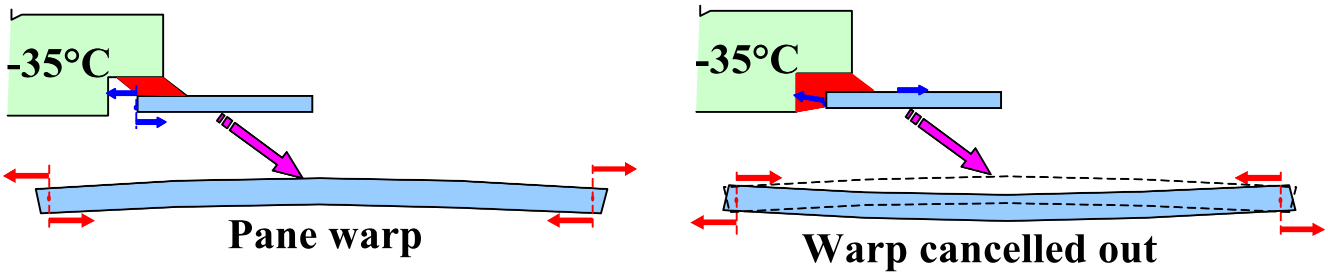
Effect of the adhesive's expansion

The properties (mechanical and thermal) and the shape of the joint can be used to influence the deflection or even reverse it. The cleavage load is then reduced if not cancelled out.

ARALDITE 2024 adhesive from VANTICO is a methacrylate glue. It was one of the adhesives chosen for the Polar Observer's vision ports, partly because of its ability to withstand a continuous force (a high resistance to rupture) and partly because of its suitability for diminishing the effects of differential expansion (a high deformation property). One of its more remarkable properties is its high expansion coefficient ($125x10^{-6}$ °C^{-1}).

Pane deformation as a function of the adhesive's expansion coefficient

The high shrinkage of ARALDITE 2024 and the design of the joint result in a moment acting against that caused by the differential shrinkage across the two surfaces of the pane.



The warping is cancelled out. The cleavage loads are therefore almost non-existent and the total stresses in all three directions (von Mises yield criterion) are reduced. The joint is thus made to work primarily in shear since the majority of the loadings now run across the plane of the seal. Excess stresses are significantly diminished (-50%) and the shrinkage forces from the adhesive around the pane express themselves mainly in shear. The average shear stress for the joint is thus significantly increased (+20%).

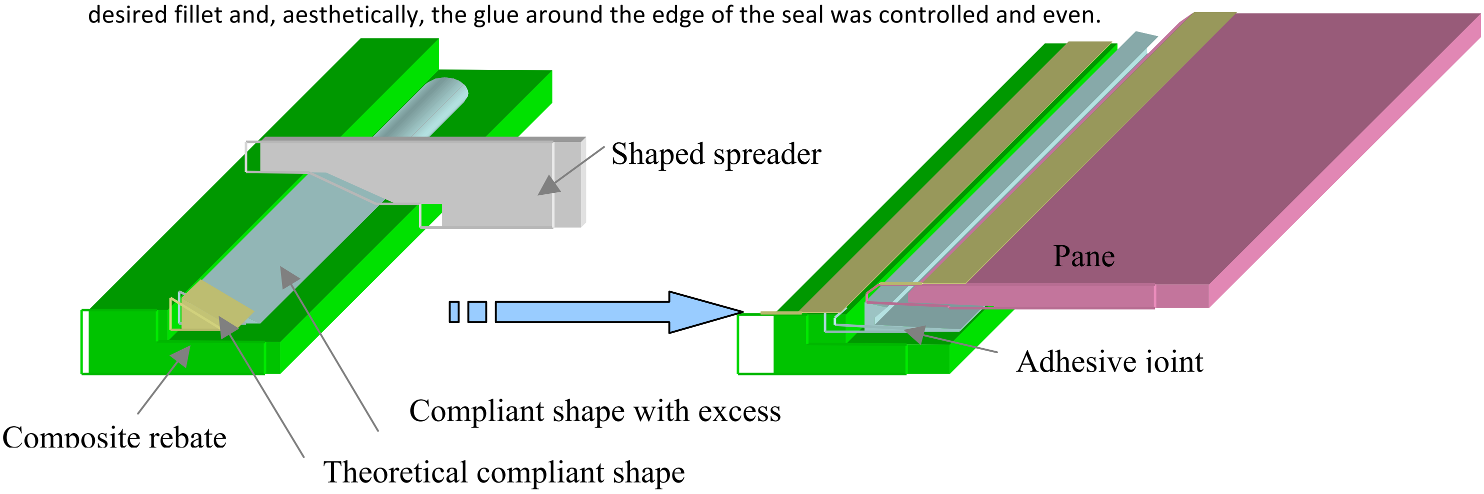
Any change to the depth of the joint as a function of the stress limits will have an extremely significant influence in lowering the average stress levels. It must, however, also take account of the adhesive's thermal characteristics, as these will have serious repercussions on the direction, value and distribution of the forces.

The importance of the bonding method

The bonding method (or any other assembly technique) is the means of guaranteeing the proper functioning of the finished product since it is this that ensures that the design shape and the properties of the bonded joint comply with its design requirements.
A number of operations are necessary to manufacture a bonded joint. They should not be seen as being issues relating only to adhesive bonding. Every assembly technique imposes its own limitations during implementation. Accordingly, actions such as de-scaling before brazing or tacking before welding have become automatic procedures in the world of mechanical engineering.

In the case of adhesive bonding, the operations affecting the implementation are as follows:
Managing the placement: (as for other assembly techniques).
Managing the surface condition: (as for other assembly techniques).
Managing the workspace: temperature, absence of dust
Managing time: Depending on the adhesive being used, the bonding operator must manage several operations. The manufacturing process is tightly linked to the minimum and maximum times required for each step of the bonding process. These steps include the working time or 'pot life' (to extrude, mix, deposit and complete the assembly), the cleaning off time, the handling time and the waiting time before use.
Managing the shape of the joint has serious repercussions on both mechanical performance and the aesthetics of the joint. The joint is dimensioned as a function of both the size of the fillet and the intrinsic properties of the adhesive. Complete filling of the joint is therefore important. The application of the adhesive and the presentation of the parts must be done without introducing any air bubbles that might affect the mechanical behaviour of the adhesive. In our case, we used a shaped spreader to pre-form the joint that, during its spreading, forced the

adhesive towards the outside of the part (to be accessible for trimming). Pre-forming allowed moulding of the desired fillet and, aesthetically, the glue around the edge of the seal was controlled and even.



=>The development of adhesives and bonded products is on the increase because of the numerous possibilities that such technology offers. The tooling and skills being developed today allow swift and effective joint designs. The numerous advantages of adhesive bonding were used to satisfy the requirements of the Polar Observer.

ARTICLE from ‘COLLAGE ACTUALITE’ released by Créacol (www.creacol.fr)