BEHAVIOUR OF AN AERONAUTIC COMPOSITE PANEL SUBMITTED TO AN IMPULSIVE LOAD.

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Abstract

The "Centre d'Etudes de Gramat (C.E.G.)" is working on the modelling of the behaviour of double wall aeronautical structures submitted to impulsive loading. These structures are made of a composite lining panel, on which the pressure loads apply, and an alluminum alloy skin. The lining panel and the skin are both attached on frames which separate them (figure 1).

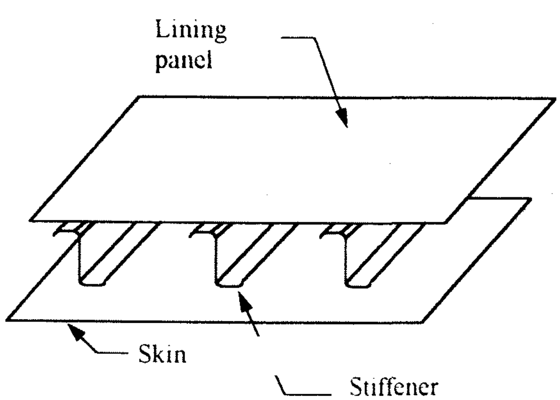


FIGURE 1 : Double Wall Structure

The object of the study is to develop a lining panel simplified modelling element (Finite Element method from ABAQUS explicit code) for predicting the dynamic behaviour of double wall structures made of several thousand elements. The work is part of a wider research project backed by the "Direction Générale de l'Aviation Civile" in the aircraft fuselage vulnerability assesment area.

Introduction

The effort profile that applies to the skin depends on one hand, of the stiffener and skin responses and, on the other hand, of the liner deterioration by delamination as well as skins and core failures.

Preliminary studies were realized in order to investigate the main liner failure mechanisms and to propose the basis for a classic liner modelling element by only considering the lining panel simply supported. The analytical approach reported here uses the ABAQUS Finite Element software to model the structure of an aircraft liner subjected to dynamic pressures. It is supported by a set of static and dynamic experimental studies. The liner modelling allows an approach, in a qualitative way, to the response of the liner as observed experimentally.

Study Structure

The study structure is described in figure 2 : the distance between two consecutive stiffeners is 530 mm and the support width is about 20 mm. Two liner surfaces are considered : 400 mm x 2000 mm and 1500mm x 1500mm.

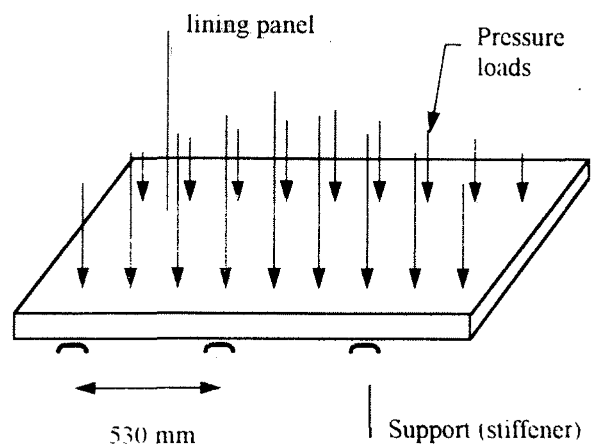


FIGURE 2 : Simply supported Liner

Technical data

The nature and technical data of the liner components are detailed below.

Liner design

The lining panels are manufactured by bonding two composite skins over a cardboard honeycomb core. Each skin is covered with a thin aluminum alloy sheet. The sandwich section geometry is given in figure 3.

Behaviour laws

In a first analysis, the behaviour law of the different components of the lining panel is defined without considering the effect of the strain speed : The dynamic laws are classed as quasi static ones.

- **Honeycomb**

The honeycomb is defined as an orthotropic material.

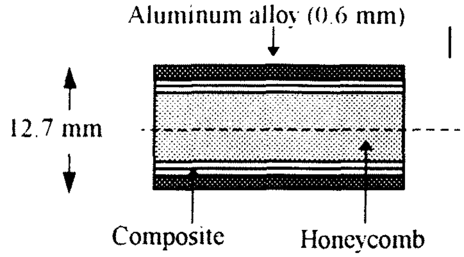


FIGURE 3 : Lining Panel Section

- **Aluminum alloy**

The aluminum alloy is described by an elastoplastic law that takes into consideration the material softening beyond the failure stress. The plasticity criterium is a VON MISES' criterium with isotropic hardening.

- **Composite**

The composite is two - ply woven consisting of resin matrix reinforced by glass fibres. The fibre directions are 0 et 90°. It is described by a linear orthotopic behaviour law.

Process

Shell elements are required to model the lining panel for cost and time savings. This modelling must take into account the shearing and compressive influences of the core on the lining panel global response.
The process used to model the lining panel consists of studying :
a) The linear static behaviour of lining panel strips under bending loads in order to determine the bending elasticity modulus of the lining panel components and to estimate a shearing adjusment factor.
b) The dynamic behaviour of the lining panel, first clamped on its edges to estimate the core crush and shear effects, then simply supported in order to characterize the effort profile transmitted to the stiffeners by the lining panel.

Static behaviour of the lining panel

The aim of the study is to adjust the elastic constants of the lining panel components by comparing the deflections calculated by means of volumic and composite shell models to the experimental ones.

Trials

Four-point bending quasi static tests are performed on strips of 508 mm long by 76 mm wid. The test specimens were cut in the fibre directions 0 and 90 ° as well as in the direction 45° (figure 4).
The analysis of the experimental results shows the linear character of the lining panel response until the core failed by shearing.

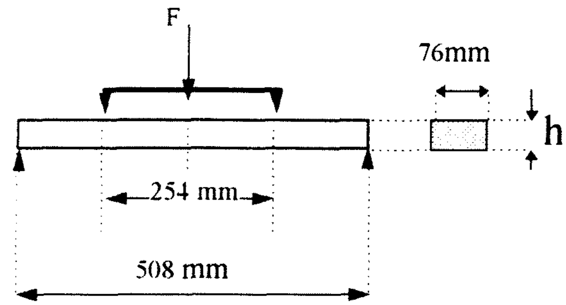


FIGURE 4 : Four-Point Bending Experiment

Computations

The numerical simulations are led with the volumic and composite shell elements.
Two stages are considered :
a) The mechanical data used in the volumic modelling are adjusted to lead to the same results as those obtained during the experimentations.
b) By considering the volumic model as a reference, the previous material properties are adjusted again in order to restore the test specimen response with the composite shell elements. The core transverse shear effect is introduced in the shell modelling with an adjustment factor determined from [1, 2].

Results

The shell model is validated for bend loads because the differences between the measured and the calculated deflection at the center and under the loading application points are less than 10 %. This doesn't allow the shear adjustment factor to be validated because the shearing effect is too weak.

Dynamic behaviour of the lining panel

The lining panel is considered either clamped on its four edges or simply supported. It is subjected to blast pressure whose profile is described in figure 5.
The pressure loads are calculated by means of an aerodynamic code. The pressure characteristics vary in space and time : the rise time is equal to 0 and the peak overpressure varies from a few bars to several tens of bars. The shock wave diffraction on the lining panel sides is neglected.
To determine the dynamic lining panel response, first requires a model of its transverse shear and crush behaviours [3].

Crushing behaviour

The honeycomb crushing effect is investigated by modelling the lining panel with volumic elements as figure 6 shows. For the dynamic loading levels considered here, the crushing stresses that are induced within the core are lower than the buckling loads.

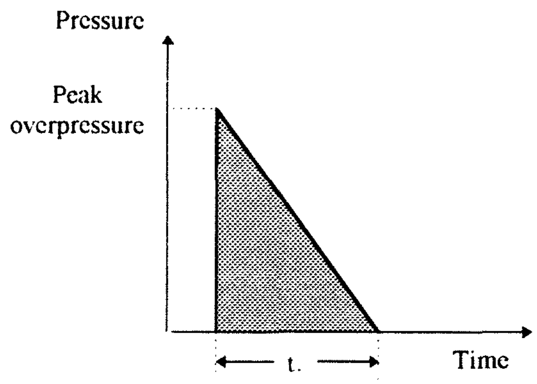


FIGURE 5 : Pressure Profile

In other respects, the results of crush tests realized on experimented lining panels don't reveal any modification of the crushing modulus. The core crushing effect on the lining panel behaviour will be neglected in further studies.

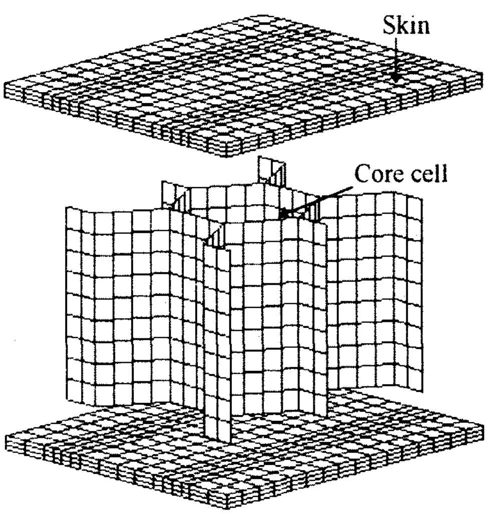


FIGURE 6 :Core Crush Model

Shearing behaviour

New computations are realized with a sandwich panel clamped on its four edges and impacted by weak pressure loads. The transverse shear effect introduced in the static phase is adjusted by comparing the lining panel deflection calculated with the shell model to the one calculated with the volumic model.

Computation description

The computation scheme may be viewed in figure 7. The values of the material elastic characteristics defined in the static phase are used to predict the dynamic response of the lining panel.

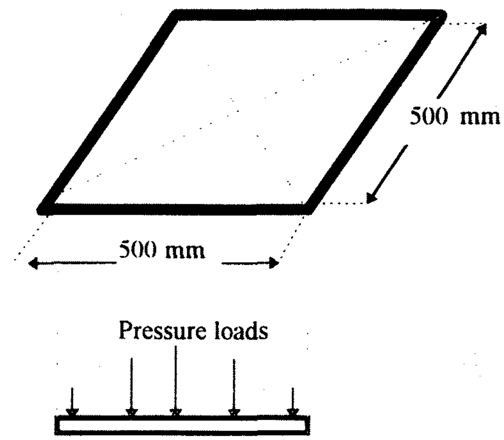


FIGURE 7 : Computation Scheme

Results

Figure 8 outlines the transverse shear effect on the displacement profile of the lining panel when shell elements are used.

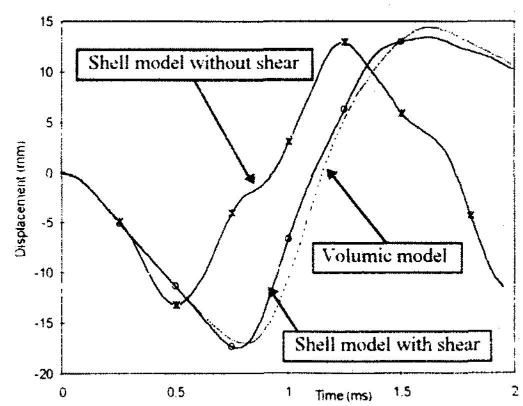


FIGURE 8 : Panel Central Deflection with and without Tranverse Shear

The transverse shear, by reducing the global stiffness of the lining panel, modifies the effort profile transmitted to the skin by the frames and might decrease the effort levels. Moreover, notice should be taken of the good correlation between the shell and the volumic modelling results : the adjustment factor will be used to estimate the dynamic response of the simply supported liner.

Simply supported lining panel experiments

Two kinds of trials were performed according to the level loading required to either preserve the integrity or generate severe damage of the panel.

Experimental device

The experimental device is presented in figure 9. It must allow the study of the influence of the lining panel response on the effort profile transmitted by this panel on its support. The lining panel is attached on the support in the same manner as in the aircraft. The support consists of 6063 T5 aluminum alloy I-beams whose dimensions are 100 mm x 100 mm x 10 mm. Two plates, made respectively of foam and rubber, separate the support from the concrete paving : these plates are flexible enough that of to suppose that their response time is larger than the support.

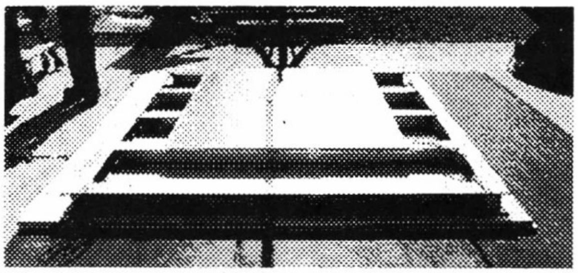


FIGURE 9 : Experimental Device

Weak loading trial results

Two lining panel dimensions were experimented : 1585 mm x 1440 mm and 2080 mm x 375 mm. The tested panels show, around their attachment points, small residual deformations of the metallic skin, cracks through the thickness of the lining panel and a delamination area.

High loading trial results

The experimented lining panel, of 2080 mm x 375 mm, was badly damaged (figure 10). The maximum residual deflection is about 100 mm. The interface between the skins and the core has failed over a large part of the lining panel. No crushing of the core is observed.

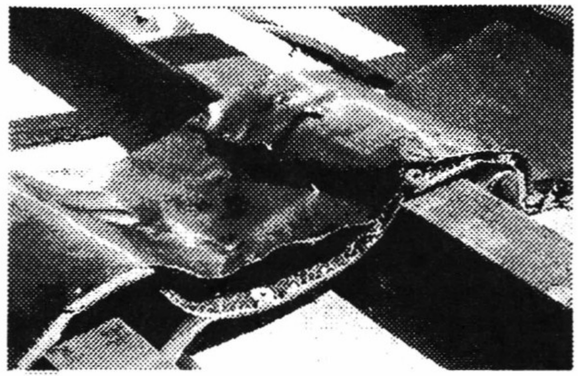


FIGURE 10 : Residual deformation of the lining panel sujected to high dynamic loads

Trial synthesis

A first analysis of the above mentioned experiments shows the requirement to model :

- The out of plane shear response of the core because it contributes to reduce the global stiffness of the lining panel and the effort levels transmitted to the stiffeners.
- The wrenching of the interface between the skins and the honeycomb.
- The contacts between the lining panel and the beams supporting it that may modify the effort distribution at the supports.
- The sandwich panel damping on the global structure response.

Numerical computations of the dynamic tests

The core crush effect is neglected according to the numerical results obtained at the time of the clamped lining panel study and the experimental one concerning the simply supported lining panel tests. The materials are described by quasi-static behaviour laws. The coupling between the structure and the fluid as well as the diffraction of the shock wave at the lining panel edges are not considered. The lining panel support is free of supporting conditions because of the plate flexibility. The damping is represented with a pressure that is opposed to the movement : the damping factor is such that :

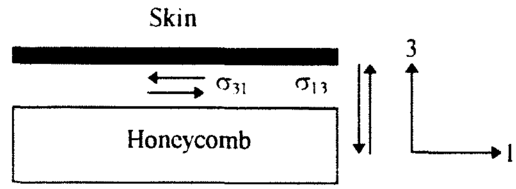
$$\mathbf{f} = 0.01 \times (\rho.\mathbf{E})^{1/2} = 10^{-4}$$

The disbonding of the lining panel is presumed to be caused by the shearing rupture of the interface skins-honeycomb as shown in figure 10. This behaviour mode is approximated with membrane elements linking the inner composite skin to the core (figure 11) : the tensile rupture stress of these elements is equivalent to the shearing rupture stress of the interface.

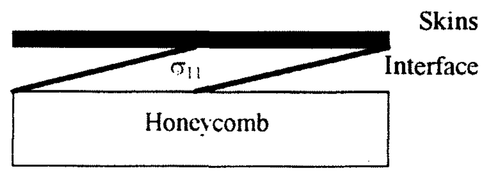
Then : $\sigma_{31}{}^{r}.b.l.S_{colle} / S_{totale} = \sigma_{11}{}^{r}.b.h$ (1)

$\sigma_{11}{}^{r} = \sigma_{31}{}^{r}.l\,(S_{colle} / S_{totale})\,/.h$ (2)

where l, b and h are the length, width and thickness of a membrane element and S is the core surface that is in contact with the composite skin.



a) Interlaminar stress in the lining panel



b) Tensile stress within the membrane element

FIGURE 11 : Delamination Modelling

If membrane element deformation is much smaller than the skin deformation, then, the following equations may also be written :

$\sigma_{11}{}^{r} / E_{11} << \sigma_{alu} / E_{alu}$ (3)

and $E_{11} >> \sigma_{11}{}^{r} . E_{alu} / \sigma_{alu}$ (4)

The characteristics of the membrane element can be determined from equations 1.2 and 4.

Numerical simulations

Only one quarter of the structure is modelled because of the existence of two symmetry planes.

Comparison between computations and trials

Weak loading

The calculations overestimate the strain levels in the I-beams supporting the lining panel but make a good estimation of the lining panel damage.

High loading

No strain gages were mounted on the support of the lining panel. For that reason, only qualitative comparison was made between the experiment and the computations. The numerical residual deformation of the lining panel (figure 12) is quite similar to the experimental one (figure10).

Double wall structure dynamic response

The lining panel model was applied to predict the response of a cylindrically curved lined fuselage panel submitted to impulsive loads. The skin, frame and rivet data has been extracted from a set of tests and numerical computation programs conducted by CEG on different kinds of fuselages. A good correlation was found between the experiments and the computation results in terms of fuselage skin strain levels and damage types generated to the metallic structural elements of the fuselage panel. New work will have to be undertaken in order to improve our knowledge of the lining panel rupture mechanisms and to be able to forecast the fuselage panel damage levels.

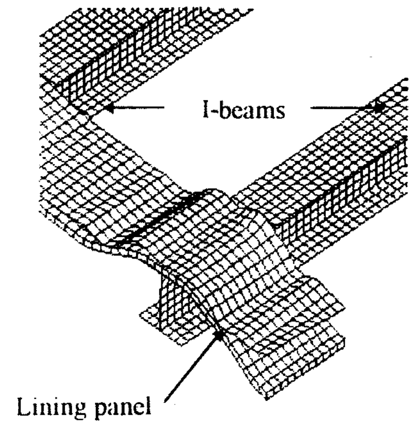


FIGURE 12 : Numerical residual deformation of the lining panel

Conclusion

The preliminary studies allowed the forecast of the experimental results in a qualitative manner. The work herein described shows that classical shell elements are not really suitable for modelling the lining panel behaviour and the effort profile transmitted to the stiffeners. It also shows the necessity to improve our knowledge of the failure modes and levels of the lining panel.
Future topics will be to :

- identify the failure modes and levels of the lining panel submitted to loads of which rise times can vary from 0 to several ms by realizing static and dynamic tests instrumented correctly.
- develop a specific detailed model of the damage mechanisms defined experimentally.
- develop a simplified model of the lining panel behaviour to be used to calculate the response of aeronautical structures made up of several thousand elements.

References

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