BIRD IMPACT ON AN AIRCRAFT LEADING EDGE

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ABSTRACT

Bird impact on an aicraft leading edge is a primary safety issue and a major consideration affecting the design of the nose of this component. Historically, CASA has assessed most of their designs purely on the basis of physical experiments. In this particular occasion, though, numerical calculations have been used prior to experiments in order to provide fast and inexpensive support to the design activities.

This paper describes a series of analyses carried out with ABAQUS/Explicit in order to investigate the performance of a new aircraft leading edge when subjected to a postulated bird impact event.

The two bird impacts described correspond in both cases to bird masses of about 1.90kg and 145m/s of relative velocity. The numerical predictions are discussed in detail and are shown to compare well with the available experimental results. In particular, the modes of failure are in very close agreement.

1. INTRODUCTION

Bird impact on an aircraft leading edge is a primary safety issue and a major consideration affecting the design of the nose of this component. This problem can be very expensive; both in terms of the potential loss of the aircraft of inadequately designed for this accident and in terms of the expense of testing required to prove it will meet the design and certification requirements.

Traditionally the design of leading edges to sustain bird impacts was based either on the use of empirical formulae derived from simple tests on plates to provide the penetration velocity, or on correlations supported on the considarable body of experimental data obtained in physical simulations of the event.

In this particular occasion, numerical calculations have been used to provide fast and inexpensive support to the design activities. Though certification requirements impose the necessity of a physical test to assess the final design, there is no doubt that the development of validated non-linear computer modelling techniques enables optimizing the design of leading edges and drastically reducing the number of verification tests.

2. DESCRIPTION OF THE PROBLEM

The proposed problem consists of evaluating the performance of a new aircraft leading edge when subjected to a postulated bird impact event. The leading edge had actually been tested before the analyses were carried out; however, the results were not communicated to the analysts. In this fashion, the results are true predictions rather than "postdictions". CASA utilized this comparison in order to assess the reliability of numerical calculations prior to enlisting them in supporting new design activities.

The specimen, depicted in figure 1, has a length of 2500 mm and 500 mm width; the depth is variable, reaching a maximum of 400 mm approximately. The leading edge is made of an aluminum nose of 3.20 mm thickness, which is joined to a largeron of the same material; the largeron is placed transversally to the chord plane and has a depth of 240 mm and a thickness of 1.20 mm. There are two panels, upper and lower, with thicknesses of 15 and 10 mm, respectively; both are made of a glass fiber composite. The panels are braced with a diagonal aluminum largeron 0.80 mm thick. The sides of the specimen are stiffened by two diaphragms aluminum of 1.2 mm thickness.

The two impacts considered are defined by the following parameters:

- Impact I

  Mass of the bird: 1.820 kg (4.01 lb)

  Velocity: 147.2 m/s (286.8 knots)

  Incidence angle: 5.94°

  Impact location: 833 mm from the left diaphragm, at the chord plane elevation

- Impact II

  Mass of the bird: 1.909 kg (4.02 lb)

  Velocity: 143.9 m/s (280.0 knots)

  Incidence angle: 5.94°

  Impact location: 575 mm from the right diaphragm, 70 mm above the chord plane

The incidence angle is the angleformed by the bird trajectory and the normal to the leading edge at the chord plane. The two impact locations are shown in figure 2.

3. METHODOLOGY

3.1 General

The numerical simulation has been carried out using ABAQUS/Explicit (HKS, 1993).

Explicit integration procedures are specially well suited for analyzing the effects of impacts on structures and solids in general. Impact problems typically involve major non-linearities and take place in a very short time period. The main advantage of explicit procedures is that it is not neccesary to solve coupled systems of equations to obtain the system response. Storage and computational effort increase only linearly with problem size and duration. Also, it becomes fairly easy to deal with aspects which are difficult to handle with other procedures, such as contacts, singularities, softening, etc.

The main disadvantage is that the time integration scheme is only conditionally stable. Stability requires using time steps shorter than the highest eigenperiod. However, this is not a major drawback in problems which naturally have a very short duration.

3.2 Geometric idealization

Due to the short duration of the impact event, 2 or 3 msec, the relevant structural effects are mainly local. The reason is that the only natural periods in that order of duration are local modes of the nose of the leading edge; global structural modes have much longer responses. Hence, the discretization has been oriented to represent adequately a local failure mode, such as a tearing of the nose shell close to the impact locations.

Figure 3 shows an isometric view of the mesh adopted . As it was previously justified, the mesh is specially refined in the areas where the impacts will take place.

The leading edge has been modelled with shell elements S4RF (HKS, 1993). The connection of the nose with the largeron and that of the largeron with the panels have been carried out modelling the rivets as short beam elements (B31). The section properties have been chosen in such a way that the force capacity per unit length coincides with real value.

The bird has been represented as a sphere made of solid elements (C3D8R). Figure 4 depicts the modelization adopted. The radius of the sphere has been obtained by considering the mass of the bird and the density of water.

The possibility of interaction between different structural components during the impact event has been taking into account. With this aim SURFACE CONTACT definitions have been used for contacts between the bird and the nose and for contacts between the nose and the transverse largeron.

The global mesh generated has 5696 nodes and consequently 32901 degrees of freedom.

3.3 Material characterization

The aluminum has been characterized as an elastoplastic material with Von Mises yield criterion and isotropic strain hardening. A potential hardening law has been adopted with the following form.

$$\sigma = \sigma_0 \varepsilon^m$$

where σ_0 = 694.96 MPa

m = 0.14996

The rivets are also made of aluminum with a yield stress of 276 MPa. An elastoplastic constitutive model with ductile failure was adopted in order to represent the possible rupture of the rivets.

The glass fiber composite material has been modelled as an elastic material.

With respect to the representation of the bird, the behaviour during impact events which take place at several hundreds of kilometers per hour can be modelled adequately by an equivalent mass of water. Several reasons justify this assumption:

- Firstly, viscous forces, and in general all the forces associated with the internal structure of the bird, are negligible in comparison with the inertial forces generated. However, it is important to represent the mass of the bird correctly because it plays a major role in the generation of inertia forces.

- Second, other parameter which could play some role in the generation of forces is the compressibility of the bird. Adopting the compressibility of water is conservative; if the air voids were included in the model, the effect would be reducing its stiffness and, very sligthly, increasing the duration of the impact as well as reducing the magnitude of the forces. The effect would only be small, because the duration of the event is governed by the time taken for the plane to travel the bird's dimension, rather than by elastic propagation times.

The constitutive model adopted corresponds to that of a perfect fluid, with a finite volumetric stiffness but without any capacity for generating deviatoric stresses. The mathematical idealization has been carried out by means of a linear equation of state of the form:

$$p = K \varepsilon_v$$

where K is the bulk modulus

ε_v is the volumetric strain

The bulk modulus adopted is 2 GPa, which corresponds to that of water. Similar approaches have been found in (Wray, 1990) and (Lawson, 1990).

4. RESULTS

The first postulated impact corresponds to that of a bird with a mass of 1.820 kg impinging the nose of the leading edge at a velocity of 147.2 m/s. The impact occurs at the chord plane elevation and 833 mm from the left diaphragm. Figure 4 depicts the configuration immediately prior to the impact showing both the structure and the water sphere representing the bird.

Figure 5 shows a sequence of the deformed configurations of the leading edge from 0.2 ms to 2.6 ms at 0.4 ms intervals. As it was expected, the effects are mainly local; the most notable manifestation is the local sinking of the leading edge nose around the point of impact.

As a consequence of the large relative rotations experienced at the connection between the nose and the transverse largeron, many rivets fail leading to a separation of the nose and the largeron. The separation, which occurs along the upper and lower panels, is presented in a more detailed view in figure 7. Rivet failure filters the transmission of forces and moments from the nose to the largeron, in this sense, the rivets act as real mechanical fuses.

In order to assess of the level of structural damage produced as consequence of the impact event, an analysis has been carried out of the intensity and distribution of the effective plastic strains. It is conventionally assumed that ductile failure takes place in metals when the level of effective plastic strains reaches a given threshold; the necessary data are obtained from uniaxial tension tests on the same material. Figure 6 shows the contours of effective plastic strains at 2.6 ms. It is important to point out again the localized nature of the strains. The higher values correspond to the lower area of the nose, with maximum plastic strains around 21%. The available technical literature (Bolton, 1990) seems to indicate that the ultimate strain is about 18% for this type of aluminium. Under these circumstances, it can probably be concluded that the nose will undergo localized tearing in its lower region.

The criterion adopted for ending the analysis was based on the component of the kinetic energy corresponding to momentum in the initial direction of the bird velocity. When this value is less than 1% of the initial kinetic energy, the analysis was considered complete.

Similar results have been obtained for the second impact configuration which corresponds to a bird with a mass of 1.909 kg and a velocity of 143.9 m/s. The impact occurs on the nose 70 mm above the chord plane and 575 mm from the right diaphragm.

Figure 8 shows the initial configuration immediately prior to the impact event. Various deformed configurations are depicted in figure 9, spanning from 0.2 to 2.2 ms at intervals of 0.4 ms. Finally, the contours of effective plastic strains at 2.2 ms are presented in figure 10; the maximum values, around 15%, do not predict a local failure of the nose shell.

5. CONCLUSIONS

Some conclusions can be drawn as a result of the numerical investigations conducted:

- The structural effects of both impacts are very local. These effects consist mainly in a distortion of the nose in the area of the impact and in the failure of rivets connecting the nose and the transverse largeron. Rivet failure results in separation of the nose shell and the largeron, thus "filtering" the transmission of forces and moments and reducing the potential damage to fiberglass composite panels.

- The maximum levels of effective plastic strain are 21% and 15% for the first and second impacts, respectively. The probable ultimate strain for the aluminum alloy of the nose is on the order of 18%. Under these circumstances, it can be probably be concluded that the nose will undergo some tearing in its lower area during the first impact.

- The results of the numerical simulations are in close agreement with the experimental results. The visual inspection of the specimen subjected to experimentation has confirmed that the existence of a local tearing of the nose as a consequence of the first impact. The calculated distortions, as well as, the failure of rivets, compare very well with the available experimental results.

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Lawson, M. (1990). "Engine Structural Dynamics for Aircraft Safety on the CRAY". Science and Engineering on Supercomputers. Computer Mechanics Publications.

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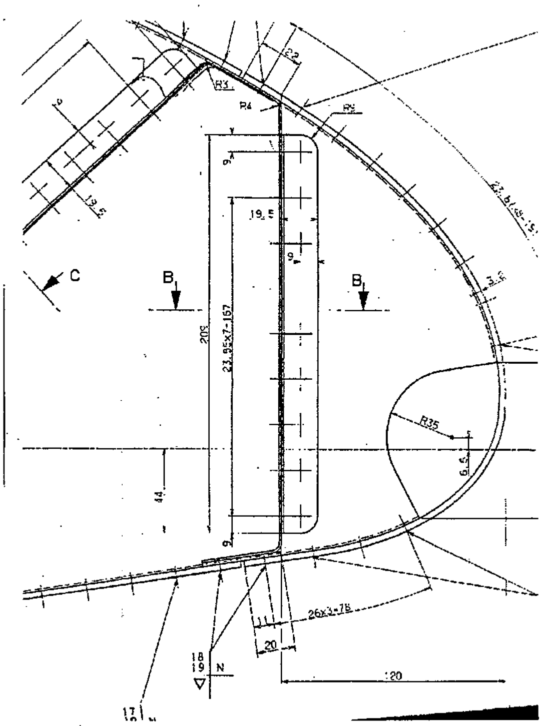

Figure 1. Leading edge geometry.

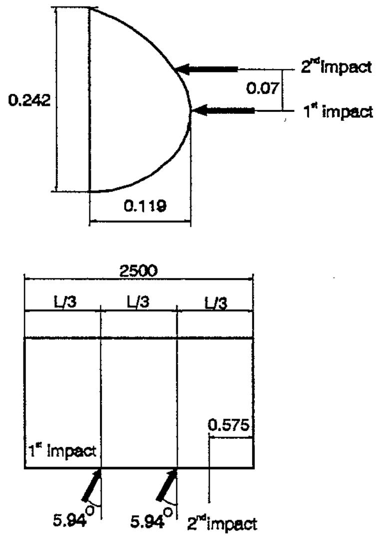

Figure 2. Test set up.

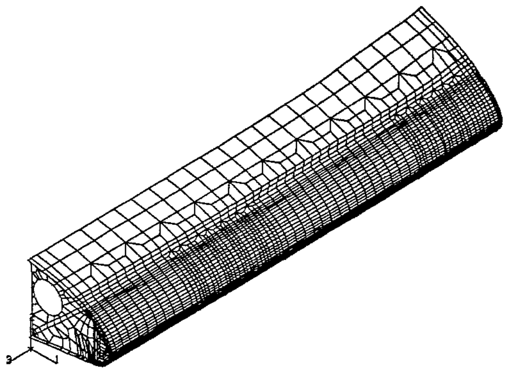

Figure 3. Isometric view of the mesh.

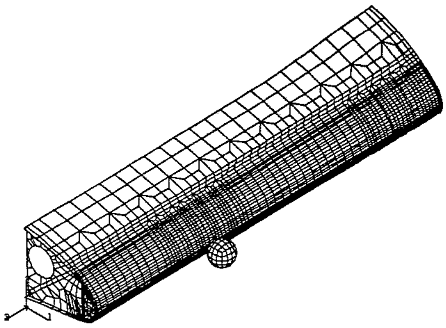

Figure 4. Configuration prior to the impact I event

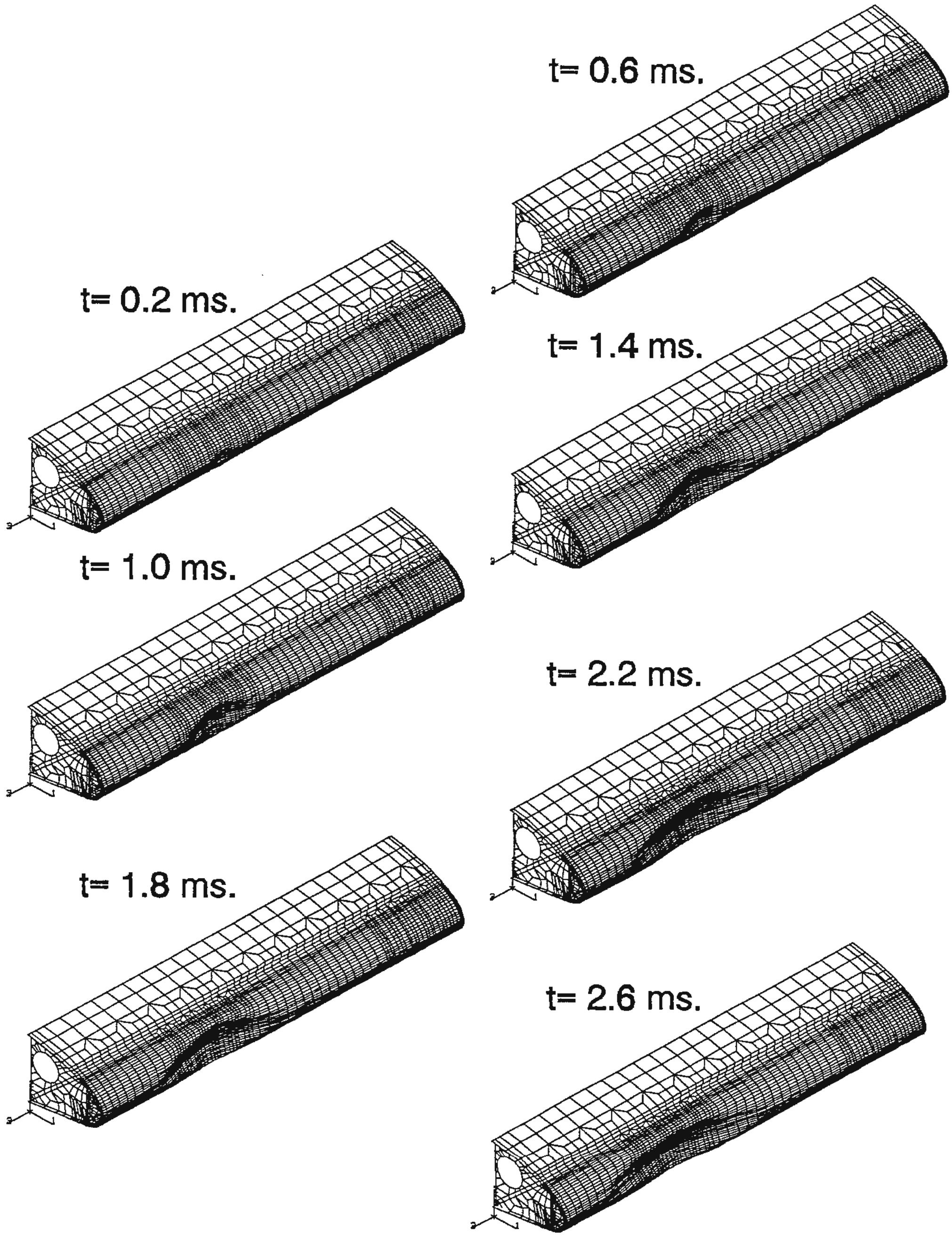

Figure 5. Sequence of deformed configurations.

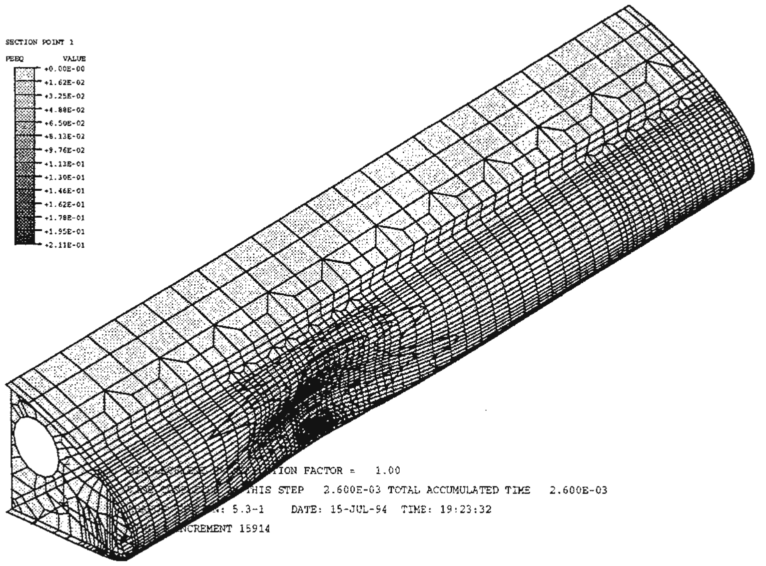

Figure 6. Contours of effective plastic strain at 2.6 ms.

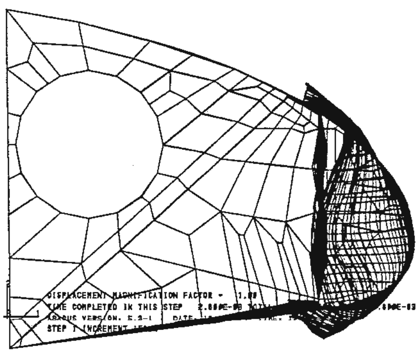

Figure 7. Deformed configuration at 2.6 ms. Lateral view.

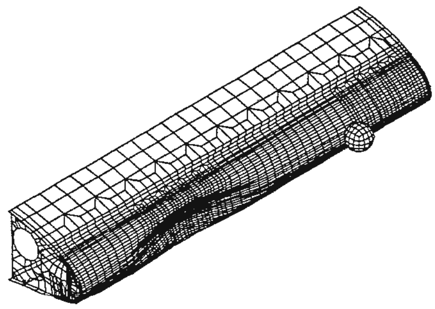

Figure 8. Configuration prior to the impact II event.

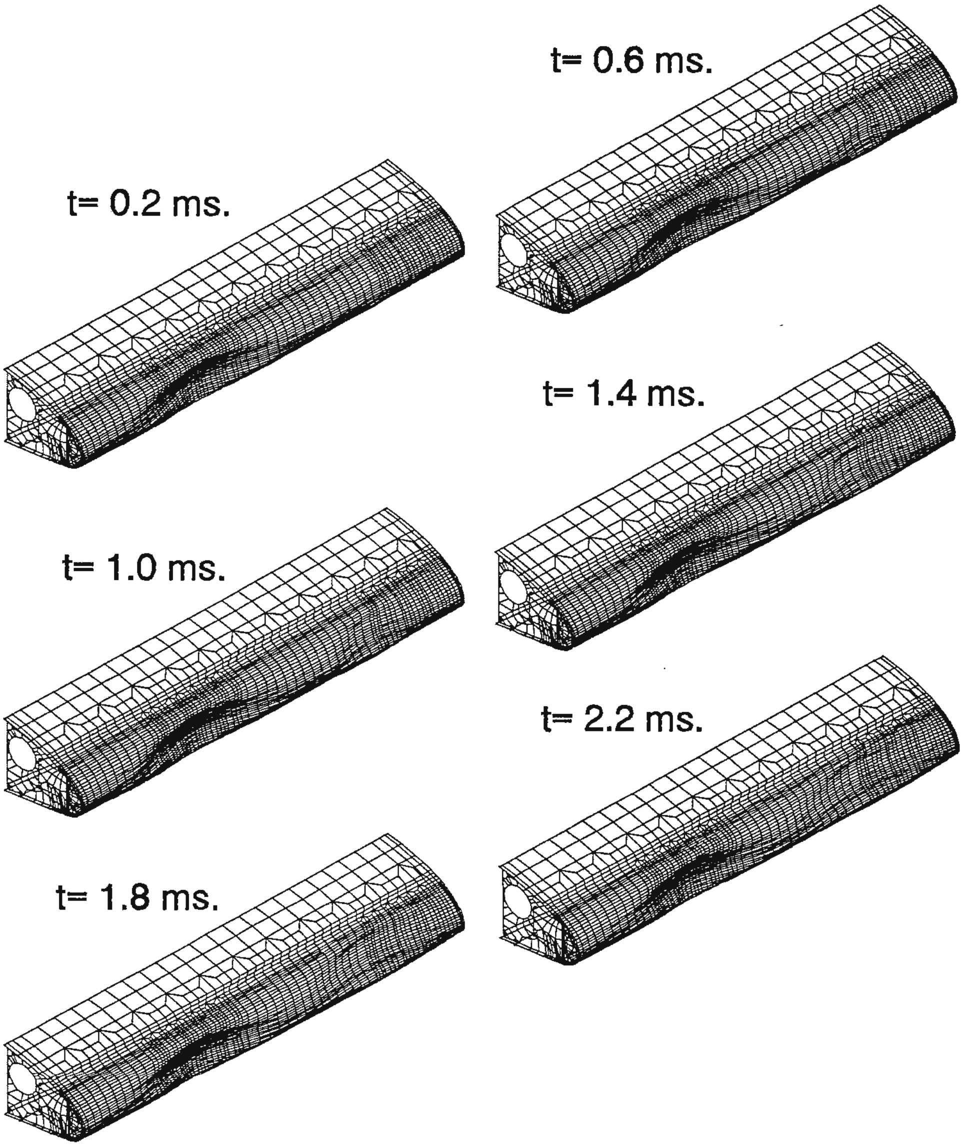

Figure 9. Sequence of deformed configurations.

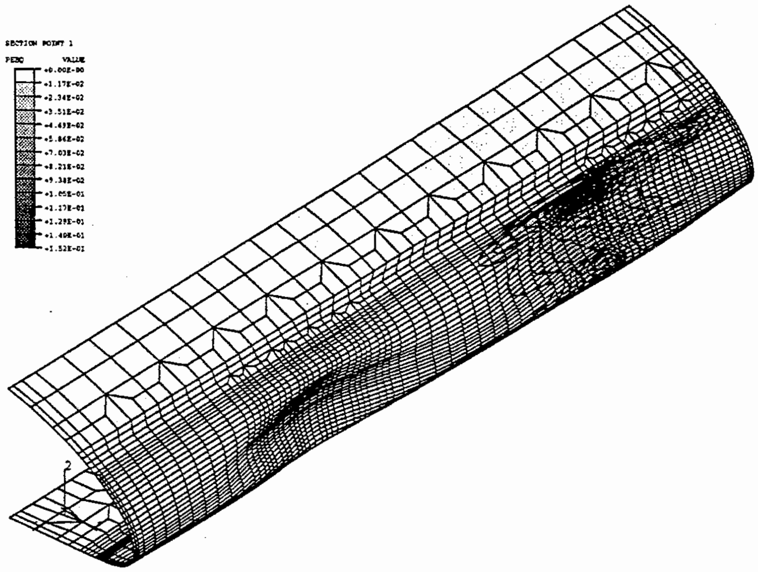

Figure 10. Contours of effective plastic strain at 2.2 ms.