Mechanics Research Communications 38 (2011) 72–76

Contents lists available at ScienceDirect

Mechanics Research Communications

journal homepage: www.elsevier.com/locate/mechrescom

Development of an efficient numerical model for hail impact simulation based on experimental data obtained from pressure sensitive film

Marie-Anne Lavoie [a], Manouchehr Nejad Ensan [b,*], Augustin Gakwaya [a]

[a] Department of Mechanical Engineering, Laval University, Cité Universitaire, Québec, QC, Canada
[b] Institute for Aerospace Research, National Research Council Canada, Ottawa, ON, Canada

ARTICLE INFO

Article history:
Received 26 May 2010
Received in revised form 22 June 2010
Available online 7 August 2010

Keywords:
Hail impact
Pressure sensitive film
SPH method
Experimental validation

ABSTRACT

Aircraft are subjects to a number of unpredictable loadings that can seriously affect their performance. In the spirit of ever increasing the safety of passengers, hail impact has been studied. This paper shows the progress that has been made using pressure sensitive film to measure the hail impact event. Moreover, the smooth particle hydrodynamics (SPH) method in LS-DYNA is used to create a numerical model in order to validate the numerical hail model so that it can be used in future advanced simulations of hail impact on components of aircraft. Results show that the SPH method can be effectively used to create a numerical hail model and that pressure sensitive film is a simple and inexpensive tool to capture the experimental data.

1. Introduction

Soft bodies impacting on aircraft are of concern to the aviation industry since they are unexpected events that threaten the structural integrity of the aircraft, and thus the safety of the passengers. Soft bodies include projectiles such as bird and hail which are highly deformable upon impact and flow over the structure. In previous work [1], bird impact has been studied and carbon gages were used to measure the pressure impulse imparted to a flat plate. This simple set-up allows validation of the numerical representation of a bird projectile developed mainly using theoretical considerations.

Recently, more tests were performed, this time using hail and pressure sensitive films. Although the range of application of the films requires that the pressure be maintained for a few seconds, experience has shown that a much shorter duration can provide valid data. Thus, it became interesting to investigate this simple and relatively inexpensive way of measuring the pressure. Moreover, hail was chosen as a projectile to broaden the current expertise in soft body impact.

Although hail is an easier projectile to manufacture when compared to a gelatine bird [1], very little theory and experimental data is found in the literature as to the expected behaviour during impact. One interesting piece of information is that in general, the density of hail is lower than that of ice. The nominal density of fresh water ice is 917 kg/m^3 whereas the average density of hail is 846 kg/m^3 [2–4]. Moreover, aircraft are more susceptible to encounter hail when they are stationary since hail storms during flight can usually be avoided by modifying the flight path. In such instances, the velocity of impact is approximately of 25 m/s [5], which is the velocity of free fall for a 0.04 m hail ball. Therefore, a minimal velocity for hail impact would be set around 25 m/s or more for storm conditions, but there is no need to use the cruising velocity of aircraft.

The following communication explains the preliminary results that were obtained in connection with hail impact tests and the numerical model that can be created from the information found in the literature and the newly acquired data. The purpose is to eventually perform reliable hail impact simulations on complex aircraft structures. The information is divided as follow: experimental tests with the pressure sensitive film, numerical simulations using the SPH method, and conclusion.

2. Experimental tests

The hail projectile was made by using snow and compressing it so that it turns into ice. This allows a better control of the density and it is easier to obtain the proper shape. The concept of the device used to compress the snow is shown in Fig. 1. The correct density is reached when the mass of the projectile is the same as that calculated for the same volume with the hail. Projectiles can be preserved over a period of time by keeping them in a freezer. When the tests are performed, the hail is inserted in a sabot made of an empty paint can filled with Styrofoam. The isolating properties of

* Corresponding author.
E-mail address: Manouchehr.Nejad@nrc.gc.ca (M. Nejad Ensan).

0093-6413/$ – see front matter Crown Copyright © 2010 Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.mechrescom.2010.07.014

Fig. 1. 0.04 m die to create hail.

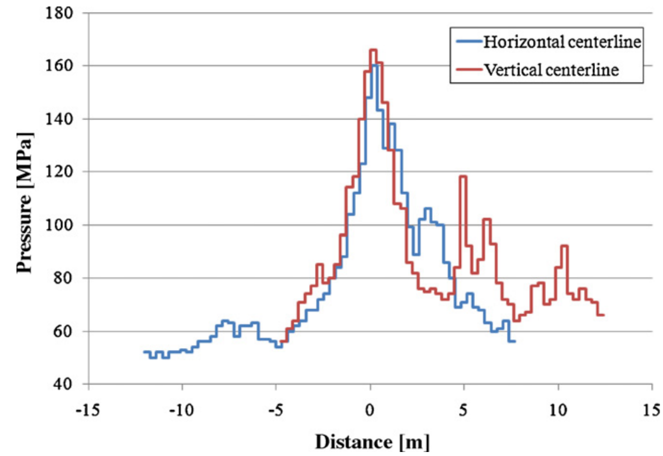

Fig. 3. Distribution of pressure along horizontal and vertical centerlines.

the Styrofoam are very useful to prevent the hail from melting as it is being inserted in the gun prior to each test.

The hail impacts on a flat panel of 200 mm by 200 mm and 6.35 mm thick. The panel is made of aluminum and is clamped along the edges. Such a simple set-up makes it possible to study the behaviour of the hail only and create an accurate numerical hail model. Impacts on aircraft structures will come at a later date.

The high pressure sensitive film used to measure the impact. Microballoons containing dye explode at a given pressure and the coloration concentration indicates the pressure reached. Only one pressure is obtained for the whole event and it is assumed to correspond to the peak pressure of the impact. The pressure is determined by comparing the color concentration over an area of 0.3 mm by 0.3 mm to the calibration curve provided by the manufacturer [6].

Additionally, a high speed video camera was used during the tests. Issues encountered with the digital camera made it impossible to present results of the hail impacting. This was mainly due to the lack of resolution of the camera used. It was nevertheless possible to observe that the hail is brittle upon impact and does not spread the way gelatine does [1].

Pressure results are shown for a 35 g hail projectile impacting the plate at a velocity of 45 m/s. Fig. 2 shows, on the left, the actual pressure sensitive film after impact and on the right, the dye concentration measured by the computer. It is interesting to note that the zone of impact for which a pressure is captured by the pressure film is less than the diameter of the projectile. For the various tests, the diameter of the area of impact varied between 18 mm and 23 mm which can be compared later with the numerical results. The pressure along the horizontal and vertical centerlines is plotted in Fig. 3.

3. Numerical simulations

The smooth particle hydrodynamics (SPH) method was chosen to create the hail model in LS-DYNA [7]. Combined with the proper material model, SPH is appropriate to model the brittle nature of the hail which shatters upon impact. Limited information is available regarding the physical properties of hail, so the properties provided by Anghileri et al. [4] were used for an isotropic elastic material model that includes failure (material 13 in LS-DYNA). The properties are listed in Table 1 and a parametric study could be performed in the future to determine the validity of the parameters used.

As for the target, it is made of aluminum and modeled with solid brick elements. Since the target does not sustain any permanent damage during the impact, a simple elastic material model is sufficient to represent its behaviour (material 3 in LS-DYNA) and the

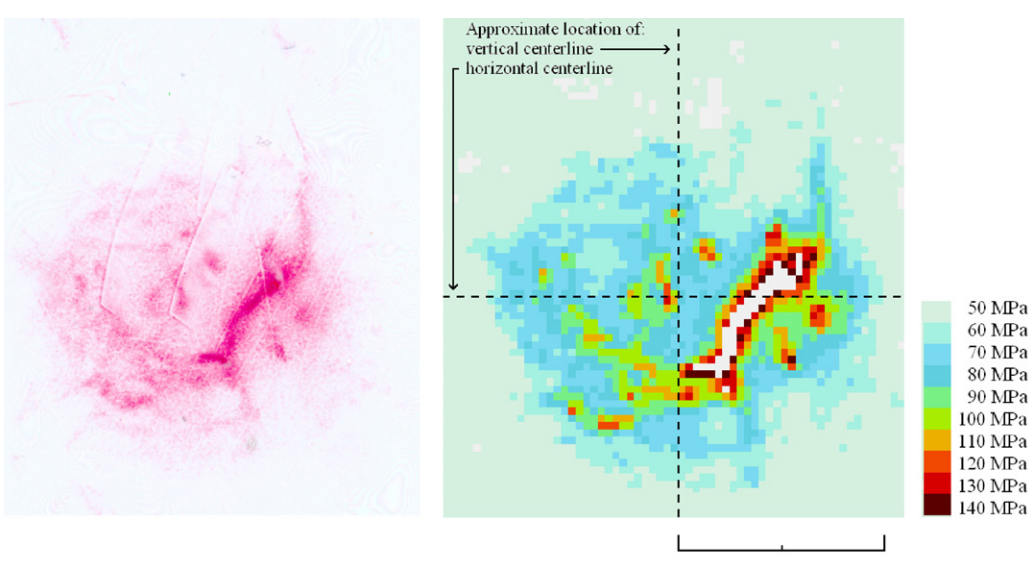

Fig. 2. Pressure sensitive film and measurement.