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Numerical and experimental study of impacts on an aircraft

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Abstract

This study concerns the development of an aeronautical structure reinforced against avian shock. The objective of the work carried out is to define and characterise an innovative concept of absorbent composite material. In order to make the mechanical characteristics of the structure more reliable and optimise them during high-energy impacts, work is performed to develop an experimental study methodology and a numerical simulation model. The objective of the simulation is to have a predictive tool validated by correlation with real tests. The lack of knowledge of the non-linear behaviour of the composite material at high deformation and at different speeds, as well as of the damage and failure mechanisms, are obstacles to the development of the concept. The lack of a dedicated experimental matrix presents a difficulty for the characterisation and sizing of the absorbent material. The work focuses on the study of the mathematical, mechanical, numerical and computer aspects of the problem. The three components of the study, i.e. the bird, the absorbent material at the scale of a specimen and the concept of the bulkhead are studied. For this purpose, different application cases are carried out. After the development of experimental studies, the new concept is validated by correlation with a numerical simulation methodology. The results of the study highlight the analysis and development of an interesting concept. This project also includes two complementary studies concerning other critical aeronautical impact cases: multiple impact of hailstones and tyre debris. These cases are considered following the lessons learned from the previously conducted study.

Keywords: applied mathematics, numerical simulation, aeronautics, transient dynamics, composite, avian impact, experimentation, nonlinear analysis.

1 Introduction

A major concern for aeronautics is the search for high-performance materials that lighten the structure to minimize kerosene consumption and absorb impact energy. Composite materials offer interesting perspectives. But the variability of their mechanical properties, due to environmental conditions, or to their impact behaviour is a brake on their development.

The statistics on the avian risk to civil aviation are alarming. More than 87,000 impacts were recorded between 1990 and 2008. Since 1988, 262 deaths and 247 aircraft destroyed have been reported [1-3]. The annual cost of avian shock to civil aviation is estimated at 1.28 billion US$ [4] and could be responsible for up to 69,000 hours of flight lost per year [1-3].

The nose structure of an aircraft is designed to ensure continued flight and a safe landing after a collision with a 4-pound bird. Impacts can occur at aircraft speeds exceeding 500 km/hr. The duration of an impact can be less than 10 milliseconds. At present, a high-performance aluminum alloy honeycomb is commonly used to absorb mechanical energy during impact [5-6].

In the first instance, we consider impacts due to avian shock. The objective of this study is, on the one hand, to develop for the aeronautical sector, in the context of bird strike, an original bulkhead structure with a new absorbent material, and on the other hand, to theoretically and experimentally validate this structure and the numerical simulation method used. Consequently, the method implemented and this new structure will be validated by correlation with the experimentation.

The avian impact is a transient dynamic phenomenon and leads to a highly non-linear mathematical model; it is therefore difficult to predict its effects on the structure of an aircraft. Moreover, experimentation is very costly and does not in any case allow all impact positions to be tested. The difficulty for aircraft manufacturers lies in carrying out virtual tests. Another objective of the work carried out is to combine experimental and numerical studies in order to reduce development costs.

Following on from the knowledge acquired for bird strike, two other impact cases were treated: the impact of hail and the impact of tire debris. Thus, we no longer consider the impact of a single projectile, but the impact of a set of projectiles that are not necessarily simultaneous.

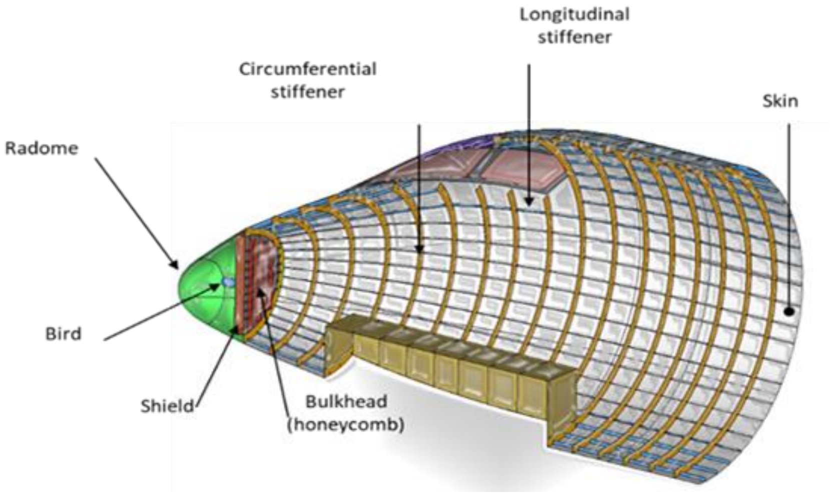

Figure 1: Aircraft nose with bird strike shield

2 Methods

The method consists of developing a mathematical model describing the impact. This model can then be used to perform numerical simulations to predict the effects of impacts. For this purpose, the parameters of the numerical simulation are determined. To determine these parameters and validate the structure, experiments are carried out. To this end, the three components of the problem, i.e. the projectile, the absorbent material and the bulkhead are studied.

2.1 Mathematical model

The behaviour of the structure is described by the dynamic equilibrium equation [7]. Due to the impact, geometric non-linearity [8], material non-linearity [9-10] and contact non-linearity [8, 11, 12, 13] are considered. To simulate the behaviour of the structure, the finite element method is used. For the bird, we use the Smooth Particle Hydrodynamic formalism which allows to represent large deformations and fragmentation [14-17]. Time integration is performed using the Newmark explicit scheme adapted to high speed impact problems [18, 19, 20].

2.2 Experimental and numerical study of the impact of a bird on a target

The objective is to determine the parameters of a numerical simulation model of the bird and the impact that efficiently represents a shock, in comparison with the experimental results.

2.3 Experimental and numerical study of the absorbent material

The objective is to determine a new material absorbing a high level of energy at impact in order to preserve the aircraft. The geometric and physical parameters of the material are determined from the analysis of the results of a bird strike simulation model on a reference aircraft.

An experimental test plan is defined to characterize this material at different impact speeds. Another objective is also to define a macroscopic numerical model of the material correlated with the test results, with a view to its integration into the numerical model of the new bulkhead.

2.4 Numerical and experimental study of the bird shock on the bulkhead

The bulkhead is defined using numerical simulation; the numerical models previously defined for the bird and for the absorbent material are used. In contrast to the two previous experimental and numerical studies, the simulation model is used to verify and optimise the structure, but also to define the final experimental test plan that corresponds to a bird strike on the aeronautical structure.

2.5 Additional study of impacts on an aircraft

Following on from the knowledge acquired for bird strike, we have also studied multiple impacts of hail and tyre debris.

3 Results

3.1 Experimental and numerical study of the impact of a bird on a target

For the SPH projectile, we choose for the geometry a cylinder with hemispherical ends and a spatial distribution of the SPH particles in the form of a centered cubic network. The particle discretization pitch and the smoothing length are determined, as well as the artificial viscosity parameters. The penalty method is used to study the interpenetration between the projectile and the target. The optimum value of the penalty parameter is fixed at a value given in the literature.

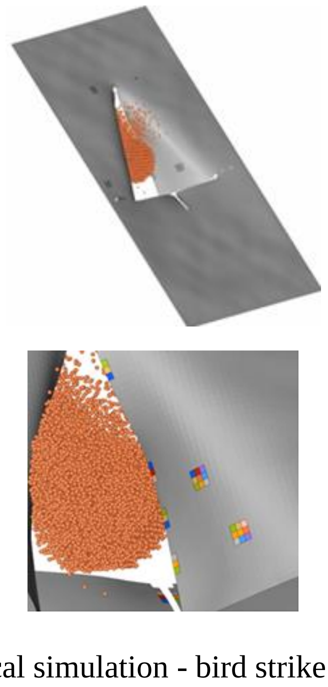

Figure 2: Numerical simulation - bird strike on a simple target

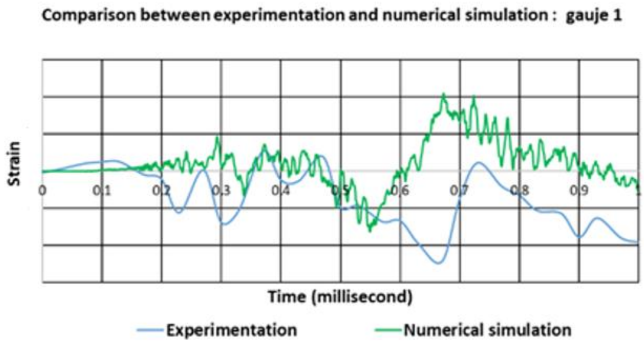

Figure 3: Comparison between experiment and simulation - bird strike on a single target - strain gauge 1

3.2 Experimental and numerical study of the absorbent material

The analysis of the results of the simulation model of the reference structure allows to distinguish the impact scenario, the damage of the structure and the energy absorbed by the different components.

Different analyses made it possible to define the geometrical and performance parameters of a new material. Thanks to the experimental design, quasi-static tensile, shear and dynamic compression tests at different speeds were carried out. A law of quasi-static and dynamic behaviour of the material is defined. This law models damage, fracture and the velocity influence.

The macroscopic numerical simulation model of the behaviour of the material in dynamic compression impact defined is predictive and represents the main results of the experiment; it can be used for an industrial application case.

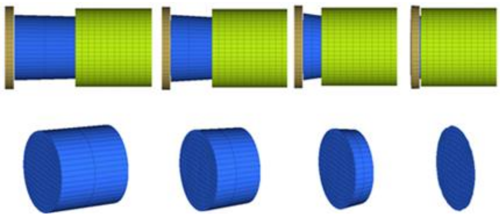

Figure 4: Numerical model of the dynamic test at specimen scale

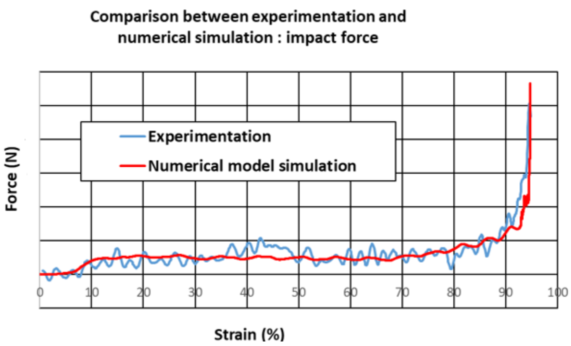

Figure 5: Comparison between experimentation and simulation - impact force

3.3 Numerical and experimental study of the bird shock on the bulkhead

The impact simulation model was used to verify the strength of the structure, to optimize its mass, to define the critical impact position and finally to develop the test plan in an optimal way. Thus, the characteristics and location of the sensors were determined. The calculation time was reduced by parallelization on several cores.

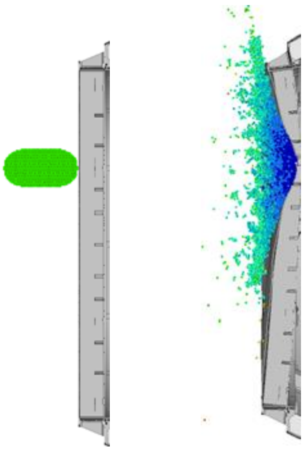

Figure 6: Numerical model of impact at scale of bulkhead - SPH bird

The real test validates the aeronautical structure. Experimental results are consistent with those obtained by simulation. We observe areas of permanent deformation and fracture which are detected by the simulation model.

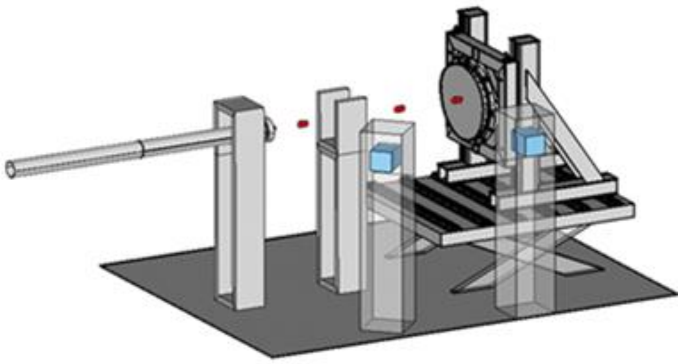

Figure 7: Experimental equipment for avian impact

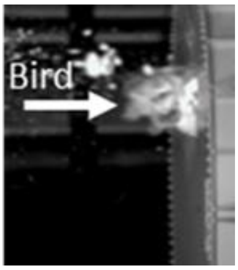

Figure 8: Bird impact at the scale of the bulkhead

3.4 Additional study of impacts on an aircraft

For the simulation of hail impact, a good correlation can be observed between the results obtained by simulation and experimentation. Concerning the simulation of tyre debris impact, the work carried out has made it possible to verify the strength of the structure.

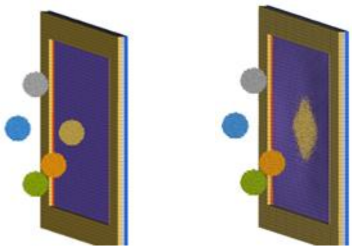

Figure 9: Multiple impacts of hail

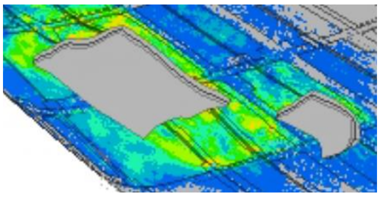

Figure 10: Multiple impact of tire debris

4 Conclusions and Contributions

The work carried out took into consideration a mathematical modelling which made it possible to perform rigorous numerical simulations and also to analyse at a lower cost the behaviour of an aeronautical structure subjected to a bird strike. This modelling deals with the high deformation of the structure, the non-linearities allowing to model the material and the phenomena of interpenetration of the projectile in the mechanical structure.

The numerical results could be confronted with experimental results and a good correlation between the two types of approach can be observed. The test results confirmed an interesting behaviour in terms of performance of the aeronautical structure.

The originality of the study lies in the deployed numerical simulation methodology based on the absorption of mechanical energy, but also in the choice of an innovative absorbent material and the bulkhead for the industrial application case. The development of the aeronautical structure was therefore essentially based on a predictive numerical simulation model. The method deployed to extract the numerical simulation parameters of the bird, the impact and the materials is therefore validated. With the two additional studies, the majority of the impacts that could occur on an aircraft were treated in this way.

The absorption capacity of the material developed for bird impact constitutes an interesting shielding solution for other types of impacts. In the continuity of the knowledge acquired, the numerical simulation of the impact of lightning strike on an aeronautical structure is the next step to be carried out. Moreover, this type of study is possible for other industrial sectors. Indeed, the numerical simulation method and the absorbing material can be implemented in the fields of defence and space.

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