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Study of medium velocity impacts on the lower surface of helicopter blades

Florian Pascal[a], Pablo Navarro[a]*, Steven Marguet[a], Jean-François Ferrero[a], Julien Aubry[b], Sandrine Lemaire[b]

[a]*Université de Toulouse, Institut Clément Ader – 3, rue Caroline Aigle, 31400 Toulouse France*
[b]*Airbus Helicopters, Blade Design & Analysis – Aéroport Marseille P., 13725 Marignane France*

Abstract

This work focuses on the study of oblique medium velocity impacts (~70m/s) on the lower surface of helicopter blades. The blade is assimilated to a composite sandwich panel with a thin woven composite skin stabilized with a foam core. A numerical study is performed through the use of a specific Finite Element formulation developed to model the behavior of the woven composite skin during an impact. Numerical and experimental results are compared. The proposed modelling strategy well correlates the tests. The modelling is then used to study the influence of the curvature of the blade and of the centrifugal load on the impact response.

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1. Introduction

This article deals with the modeling of impacts on the lower surface of helicopter blades made up of a thin woven composite skin (two or three plies) and a polyetherimide (PEI) foam core. This work focuses on the development of a specific Finite Element Modeling (FEM) capable of predicting the damage mechanisms of the woven skin under low and medium velocity impact loading.

* Corresponding author. Tel.: +335-61-17-11-62;
E-mail address: pablo.navarro@univ-tlse3.fr

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In the field of transport (aeronautics in particular), the slightest weakness in a part of the structure can have serious consequences. Thus, computational methods capable of predicting the structural integrity of composite structures under impact are required.

Many works concern the modelling of impact and damage of composite structures. Comprehensive reviews by Abrate [1, 2, 3] discuss impact failure mechanisms and summarize impact modeling approaches, based mainly on analytical models. Even if these analytical models provide a very good approximation of the damage level, more precise prediction of the damage in more complex composite structures is sometimes needed, in order to predict the post-impact behavior or to analyze with more accuracy the impact behavior, for instance.

In the specific field of impacts on woven fabric composites, five main modeling strategies can be highlighted. The first one consists in developing analytical modeling based mainly on the balance between the impact energy, the dissipated energy and the post-impact kinetic energies [4, 5]. The second one consists in using FEM with customized damageable energy based material laws [6, 7, 8]. In these models, the woven fabric is represented using homogenized shell elements. In the third main strategy, the developed woven composite models are based on continuum properties calculated from a deforming unit cell. This unit cell can be a very detailed three-dimensional pattern of the woven fabric [9] or it can be represented with a specific truss structure [10]. These last three strategies rely on the assumption that at an appropriate scale, the woven fabric behaves homogeneously and thus it can be approximated as a continuum. This assumption is no longer available when damage occurs. Thus, a fourth strategy based on FEM, presented by Johnson & al. [11] consists in modeling each woven lamina with a three-dimensional damaging non-linear orthotropic material connected with cohesive elements. This strategy provides good prediction of delamination area and contact force-time history for low velocity impacts. Finally, a fifth strategy has been proposed [12] which models impacts with higher velocities. It is based on experimental observations of medium velocity tests [13]. When the resin is totally damaged, the woven fabric behaves like a discrete truss structure. Finite Element modeling that takes into account the discrete state of the woven composite material has been investigated. A semi-continuous approach, where specific shell elements are coupled with rod elements, was developed. This strategy provides a very good representation of the damage mechanisms, but only for thin composite structures.

Here, this strategy is extended to thicker woven composite skins with different ply orientations. The woven composite plies are connected using specific interface (or cohesive) elements that are able to take into account the bending behavior of the shell "woven fabric" elements. In this proposed "shell-to-shell" interface element, the rotational degrees of freedom of the specific woven elements are accounted for with the introduction of virtual nodes located on the real surface of the composite plies which represent the physical thickness of each ply.

First, the modeling of the woven composite skin is described. Then the accuracy of the modeling is checked by comparing the experimental and numerical results of four medium velocity oblique impacts tests. Finally, the numerical results are used to analyze the damage mechanisms of the woven skin when impacted.

2. Modelling of the composite skin

2.1. Modelling of the woven fabric ply

A semi-continuous Finite Element Modelling has been suggested in [12] to represent the specific rupture of the woven composite skin under impact loading. The idea is to build a model which can represent the behavior of the undamaged woven skin (a continuous panel) as well as that of the damaged skin (non-stabilized bundles). The woven ply is modeled at the woven pattern scale. The fibre bundles are represented with rod elements stabilized by specific shell elements, which have been fully developed (Figure 1). For the membrane loading, the stiffness of the woven skin is represented by both the rods and the 2D shell elements. However, for the bending and transverse shear loading, the rods do not have any influence. Thus, the membrane and bending stiffness are decoupled in the 2D element. This element is damageable. It has been implemented in Radioss FE software.