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ScienceDirect

Transportation Research Procedia 28 (2017) 164–172

Transportation Research Procedia

www.elsevier.com/locate/procedia

International Conference on Air Transport – INAIR 2017

Application of Numerical Methods in the Improvement of Safety of Aeronautical Structures

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Abstract

The application of numerical methods in the improvement of safety of aeronautical structures has been demonstrated in this work through examples in which advanced numerical methods have been used in the structural analyses. The work presents the various research areas and engineering applications which have been performed at the Project Laboratory for Numerical Modelling of Damage in Aeronautical Structures at the University of Zagreb. The numerical methodology is based on the Abaqus/Explicit software where the ability to implement additional damage and failure models through user subroutines is used to extend the capabilities of the numerical framework. The results presented in this work illustrate the robustness of the methodology and the ability to accurately model the structural response of aeronautical structures in highly nonlinear loading conditions.

Peer-review under responsibility of the scientific committee of the International Conference on Air Transport – INAIR 2017.

Keywords: Simulation, bird strike, high-velocity impact, impact damage, crashworthiness

1. Introduction

Application of numerical analyses in various phases of the structural design is currently a standard approach in the design of new aircraft. Although the numerical testing is not expected soon to completely replace experimental testing in the certification phase, the maturity of the numerical approaches presents a great asset in the design phases allowing a considerable reduction of the number of experimentally tested structural configurations.

This work is focused on the application of numerical methods and approaches in the structural analyses of aeronautical structures.

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2352-1465
Peer-review under responsibility of the scientific committee of the International Conference on Air Transport – INAIR 2017.
10.1016/j.trpro.2017.12.182

The scientific research and engineering activities presented in this paper started as collaboration with the national operator “Croatia Airlines”. The aim of the research activities within the Technology project has been the development of an advanced numerical methodology aimed at the prediction of the realistic in-service foreign object damage (FOD) incidents in the operational aeronautical structures. The methodology has been intended to assist the maintenance process by providing additional information for engineering solutions to the FOD induced damage incidents in which the repair procedure has not been specified by the Structural Repair Manual of the particular aircraft type. Examples of these incidents include cases in which the FOD damage causes damage to the interior structure in addition to the externally visible damage.

The main focus has been set on two frequent sources of FOD: low velocity impact in the fuselage structure during ground handling activities and the bird strike damage as the high-velocity impact case. The bird strike problem is especially interesting from the scientific point of view since it is an always present threat to the safety of aircraft operations. The numerical methodology developed for the bird strike modelling is described in section 2. The numerical codes and constitutive models, developed for the bird strike simulations, have been also employed in the aircraft crashworthiness problems, as discussed in section 3. The analyzed problems included the ground impact of a small aircraft structure according to CS 23.562 and the ground-impact of a helicopter floor structure.

As to improve the damage modelling approach of aeronautical composite structures at the high-velocity impact, the multiscale approach has been developed and implemented into the numerical procedure. The aim of this technique is to apply a numerical approach in which the complex problem of damage modelling in the heterogeneous composite material is applied at the constituent level in the structural scale high velocity impact analyses. In order to enable this approach in the transient dynamic numerical analyses, the computational efficient reformulated High Fidelity Generalized Method of Cells (HFGMC), developed in Bansal and Pindera (2005) has been used to perform the microscale computations. A novel approach in which this computationally efficient micromechanical methodology has been applied in structural scale analyses is presented in section 4. Finally, section 5 illustrates the application of numerical methods in the high velocity perforation of aeronautical structures.

The damage events discussed in this work are highly nonlinear numerical problems, which include sophisticated contact conditions as well as complex failure and damage models. Consequently, the transient dynamic Finite Element Analysis (FEA) using Abaqus/Explicit has been employed as to simulate these problems due to its robustness and the ability to include specific constitutive and failure models. This is achieved by employing user subroutines which greatly extends the capability of the methodology.

Nomenclature

A	static yield stress [Pa]
B	hardening parameter [Pa]
C	material parameter which defines the strain rate effects [-]
$\mathbf{C_d}$	damaged elasticity matrix [Pa]
D	damage variable [-]
D_{CS}	material parameter in the Cowper-Symonds model [-]
df	fiber damage parameter [-]
ds	shear damage parameter [-]
dm	matrix damage parameter [-]
m	parameter which accounts for the temperature dependent softening of the material [-]
n	hardening parameter [-]
p	material parameter in the Cowper-Symonds model [-]
T	temperature [K]
T_0	transition temperature [K]
T_{melt}	melting temperature [K]
$\dot{\varepsilon}$	equivalent strain rate [s^{-1}]
$\dot{\varepsilon}_0$	referent strain rate [s^{-1}]
$\dot{\varepsilon}_{pl}$	plastic strain rate [s^{-1}]
σ_T	dynamic yield stress [Pa]