Numerical simulation and design of extruded integrally stiffened panels (ISP) for aeronautic applications subjected to blast loading: Sensitivity analyses to different stiffener configurations

Diogo Cardoso, Robertt Valente, R.M.F Paulo

YIC2013
Second ECCOMAS Young Investigators Conference
2–6 September 2013, Bordeaux, France

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D. Cardoso*, R.M.F. Paulo, R.A.F. Valente

GRIDS Research group, Center for Mechanical Technology and Automation, Department of Mechanical Engineering, University of Aveiro, Campus de Santiago 3810-193, Aveiro, Portugal
*diogocardoso@ua.pt

Abstract. *Protection of structures against explosions due to terrorism actions or accidents is a growing concern in the current times. The need for engineers to understand the structural mechanics during blast load events motivated the research leading to this work. This paper investigates the structural response of integrally stiffened panels, with different stiffener configurations, subjected to blast loading conditions through a set of finite element analyses (FEA) carried out using LS-Dyna commercial code. The numerical models developed in this work are validated by comparing the results to two small-scale blast loading experiments presented in the literature. The influence of different parameters, such as, numerical (i.e. element type, element size) and geometrical parameters, with respect to the accuracy of the finite element results are investigated. It is concluded which numerical parameters present the more accurate results with reduced computational effort and which stiffener configuration results in a more stable behaviour for the structure.*

Keywords: integrally stiffened panels; blast loading; structural behaviour.

1 STATE-OF-THE-ART REVIEW

Fuselage panels in aircraft applications are reinforced structural parts subjected to strong buckling effects under normal flight loads. These loads are typically in-plane compression and in-plane shear solicitations, leading to complex buckling behaviors [1]. The ability of a structure to survive non-typical loads, i.e. blast loading from a terrorist attack or an incidental explosion has also became a major concern. The detonation of an explosive material in the air generates an expanding shock front of finite amplitude moving supersonically [2]. The space and conditions between the point of detonation and the encountered obstacles, affect the propagation and magnitude of the pressure wave, resulting in a complex transient structural load [3, 4, 5]. Advanced numerical techniques, such as the finite element method, can be used and so, contribute to the understanding of the influence of the blast load and the resulting dynamic structural response in detail. However the reliability and stability of the finite element results must be validated with experimental data.

Analysis of the dynamic response of plates subjected to different kinds of impulsive loads has been an area of active research over the last decade [6, 7]. More recently, Spranghers *et al.* [2] presented a experimental and numerical study of aluminum plates under blast loading where is showned some numerical considerations adopted in the present work. Also, Kumar *et al.* [8] presented a study on the response of aluminum plates under blast loading and the effect of the plates curvature on the structural response. Nurick *et al.* [9] presented an experimental study on the deformation an tearing of blast-loaded stiffened square steel plates. In addicion, Nurick and Shave [10] and Teeling-Smith [11] performed experiments on plates attached to a ballistic pendulum under impulsive loads and presented an experimental study on the deformation and tearing of thin circular plates subjected to blast loading, respectively. Neuberger *et al.* [12, 13] measure the deflection of the central point of a circular plate subjected to free air blast loading and detonations of buried charges, obtaining a good agreement between numerical simulations predictions and test results. Finaly, Ramajeyathilagam *et al.* [14] and Chan-Yung Jen *et al.* [15] both present studies of the dynamic behaviour of rectangular plates and stiffened panels, respectively, subjected to underwater shock loading.

In this study, the finite element method was used to analyze the structural response of integrally stiffened panels (ISP) subject to a blast loading from a Composition C4[1] explosive material. For this purpose, two approaches were made in the development of the numerical models. The first approach corresponds to the validation of the numerical model. In this approach, 4 types of models were developed being divided by 2 groups: (i) type of elements used in the model (shell or solid); (ii) complexity of the models, the simplified model only considered the thin aluminum plate (target) while the complete model considered the set used in the experimental setup (steel frame, aluminum clamp and plate). This part of the work rests in what was already developed and studied by Spranghers *et al.* [2], serving only as a basis for the rest of the numerical study. The numerical validation of the models will be made through the comparison of the center point displacement of the aluminum plate and x-axis and y-axis cut view in three time instances, 0.24, 0.48 and 0.72 ms. The second approach corresponds to a sensitivity analysis of different stiffener profiles and configurations. For this study, 4 stiffener profiles were initially used, I shaped, L shaped, T shaped and Trapezoidal shaped stiffeners.

The numerical models developed presented accurate results when compared to the experimental data provided by Spranghers *et al.* [2]. The complete model with solid elements presents the more accurate results in the other hand it's CPU time, when compared to the shell element model, is much higher. Both analysis, central displacement and profile views in three instances, presented good results with led us to conclud that the model is valid but the numerical model with the stiffeners doesn't present any experimental data to compare, so the conclusion are still theoretical. From the different stiffener profiles studied, the T shaped stiffener presented the best results with an optimized geometry of $L = 90$ mm and $b = 60$ mm.

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[1] C4 is cyclotrimethylene-trinitramine (C3H6N6O6), commonly called RDX. The additive material is made up of polyisobutylene, the binder, and di(2-ethylhexyl) sebacate, the plasticizer. It also containsa small amount of motor oil and some 2,3-dimethyl-2,3dinitrobutane (DMDNB).

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support given by Science and Technology Fundation (FCT), Ministry for Science, Technology and Higher Education (FCT-MCTES), Portugal, under the Grant PTDC/EME-PME/113835/2009.