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Sensitivity analysis of blast loading parameters and their trends as uncertainty increases

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Abstract

A sensitivity analysis of blast loading parameters is performed to determine which of the parameters' uncertainties have the greatest effect on the maximum deflection of a clamped aluminum plate subjected to a blast load. A numerical simulation using the Monte Carlo method is used to obtain the ensemble averages of the probabilistic runs, with random variables given uniform distributions. The first loading model has an instantaneous rise with an exponential decay, represented by the modified Friedlander equation. The second loading model has a linear rise with an exponential decay. Both of these models are simulated with three different scaled blast loads, giving a total of six different cases. In addition, the deflection trends due to increases in loading uncertainties are quantified. Probability density functions for the maximum deflections are estimated. The probabilistic results and trends are also explained using deterministic methods. It is concluded that response is most sensitive to loading duration time.

1. Introduction

Due to the rise of terrorism, the commercial aviation industry has a great need to understand the effects of an on-board explosion in order to improve the designs of luggage containers and aircraft. It is also important to locate the areas of the aircraft that are most vulnerable to an explosive load. Knowing these locations and the amount of loading needed to cause critical failures provides a baseline for explosive detection technologies. In order to obtain these data, many costly and time consuming experiments are being performed. As an alternative, finite element codes can help analyze the response of structures to given loading. However, these codes can be rather time consuming. Therefore, an accurate simplified model of the response of an aircraft structure subjected to a blast load would be of great use to the aviation industry.

Aside from a simplified response model, an accurate loading model is needed. Many experiments have been performed to analyze different types of explosives. During these complex and costly blast experiments, a variety of sensors and devices are used to capture the loading on the structure. The positioning of the sensors

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and the accuracy of the devices generally lead to uncertainty of loading measurements, exclusive of the random characterization associated with the explosives.

In this paper, sensitivity analyses of blast loading parameters are performed to determine which blast model parameter uncertainties has the greatest effects on the maximum deflection of a clamped aluminum plate. In addition, we quantify how the deflection trends as a result of parameter uncertainties. Such results can be used to determine beforehand which experimental parameters must be measured most precisely in order to capture the fundamental behavior of the blast loading and structural response. This will help experimentalists in deciding which instrumentation and setup will collect the best set of data. Also the number of dangerous, expensive and time consuming experiments that are needed can be reduced.

For instance, consider an experimentalist who would like to obtain an accurate pressure profile of a particular explosion in order to study how that size explosion affects a structure. The experimentalist may want to perform numerous, identical blast experiments and use the average of all the experiments as the final, "accurate" pressure profile. During the experiment there are a number of instruments and equipment that need to be designed and/or chosen. Even the placement of the instrumentation has a key role in obtaining proper data. The experimentalist sets up the experiment in a way to obtain the most accurate result. However, what if the experimentalist had to choose between measuring a certain parameter more precisely verses another parameter? For example, one can choose an instrument that has a more precise pressure reading than some other instrument, but does not take the readings as often. This instrument will have less uncertainty to the pressure reading, however, it will increase the uncertainties of duration time and rise time. This sensitivity analysis will help determine which of the parameters should be more accurately measured in order to reduce the amount of uncertainty in the measurements.

We use approximate analytical models to numerically model a clamped, thin aluminum plate, representative of a fuselage section, subjected to a simplified blast load and calculate the maximum transverse deflection occurring at the plate's center. We then randomize the various loading parameters to see how their uncertainties affect the plate's maximum deflection. We define sensitivity as the difference between maximum deflections of the randomized model and the deterministic model.

2. Literature review on blast loading

There have been a few books dedicated to explosive loading. Kinney and Graham wrote the comprehensive book, "Explosive Shocks in Air" [1], which explains many different aspects and characteristics of explosive loads. Another extensive book on blast loading is "Explosions in Air" [2] by Baker. Aside from an overview of explosive loading, this book includes a compilation of experimental equipment and data, as well as some computational methods. A much cited book that deals with explosive loads is "Explosion Hazards and Evaluation" [3] by Baker, Cox, Westine, Kulesz and Strehlow. This book has an extensive compilation of experimental work.

In addition to books, there have been a number of review papers. Florek and Benaroya [4] provide an extensive review on pulse-loading effects on the deflection of structures. In addition, they summarize efforts that try to reduce or eliminate these pulse shape effects, which can be done for many rigid-plastic geometries under a uniform load. A detailed description is provided of research on pressure-impulse isodamage curves along with some background on the sensitivity of the structural response due to various loading models.

Beshara [5] provides an extensive review of the analysis of unconfined blast loading due to different sources for above ground rigid structures. He discusses the use of TNT equivalency and blast scaling laws, as well as the differences between overpressure, reflective pressure and dynamic pressure. Reviewing the available unclassified literature, Beshara concluded that "precise loading information is hard to obtain and may be not justified because of the many uncertainties involved in the interaction process between the blast wave and the structure and the ideal gas assumption in the derivation of relevant relations …". He adds that the way a blast load affects the response of a structure does not only depend upon the magnitude of the load, but also on its duration, rise time and general shape. The implication is that a good blast loading model is important, but its effects are very sensitive to small changes in these characteristics.

Chock and Kapania [6] review blast scaling, particularly the Hopkinson–Cranz and the Sachs blast scaling. They then compare two methods for calculating the loading profiles of explosive blasts in air. One method is