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# Impact damage detection in laminated composites by non-linear vibro-acoustic wave modulations

A. Klepka [a], L. Pieczonka [a], W.J. Staszewski [a], F. Aymerich [b,*]

[a] Department of Robotics and Mechatronics, AGH University of Science and Technology, Al. A. Mickiewicza 30, 30-059 Krakow, Poland
[b] Department of Mechanical, Chemical and Materials Engineering, University of Cagliari Piazza d'Armi, 09123 Cagliari, Italy

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ABSTRACT

The paper presents an application of nonlinear acoustics for impact damage detection in composite laminates. Two composite plates were analysed. A low-velocity impact was used to damage one of the plates. Ultrasonic C-scan was applied to reveal the extent of barely visible impact damage. Finite element modelling was used to find vibration mode shapes of the plates and to estimate the local defect resonance frequency in the damaged plate. A delamination divergence study was performed to establish excitation parameters for nonlinear acoustics tests used for damage detection. Both composite plates were instrumented with surface-bonded, low-profile piezoceramic transducers that were used for the high-frequency ultrasonic excitation. Both an arbitrary frequency and a frequency corresponding to the local defect resonance were investigated. The low-frequency modal excitation was applied using an electromagnetic shaker. Scanning laser vibrometry was applied to acquire the vibro-acoustic responses from the plates. The study not only demonstrates that nonlinear vibro-acoustic modulations can successfully reveal the barely visible impact damage in composite plates, but also that the entire procedure can be enhanced when the ultrasonic excitation frequency corresponds to the resonant frequency of damage.



## 1. Introduction

Composite materials are more and more widely used in advanced engineering structures due to high specific strength, light weight, resistance to fatigue/corrosion and flexibility in design. Application examples of composite materials can be found in many industries including transportation. Composites are particularly attractive for aircraft and space applications. Despite of all these benefits, the susceptibility of composite materials to incur impact damage is one of the major concerns related to structural design and maintenance. In aerospace, low velocity impacts are often caused by bird strikes, tool drops during manufacturing and servicing or runway stones during take-off. Such impacts may result in various forms of damage such as indentation, delamination, or fibre/matrix cracking, leading to severe reduction in strength and integrity of composite structures. Although structures designed with safe-life principles can withstand in theory catastrophic failures, impact damage detection is an important problem in maintenance of aircraft and space structures. While visible damage can be easily detected and repair action taken to maintain structural integrity, the major concern to end-users is the growth of undetected, hidden damage caused by low velocity impacts and fatigue. This hidden damage is also known in aerospace applications as the Barely Visible Impact Damage (BVID). It is well known that reliable detection of BVIDs will be a task of major importance when damage-tolerant principles are used in design of composite structures.

Various methods have been developed for impact damage detection in composite structures over the last few decades. This includes different Non-Destructive Testing (NDT) techniques based on visual inspection, ultrasonic testing, acoustic emission, X-rays or vibrothermography [1–3]. Although major efforts have been put to automate inspection, current NDT techniques used for damage detection are still labour-intensive, time-consuming and often expensive. Structural Health Monitoring (SHM), based on sensors that are integrated with structures and used to assess structural health, can offer a solution to this problem. Recent years have shown a range of different SHM techniques developed for damage detection in composite structures. Guided ultrasonic waves [4,5] are particularly attractive due to their ability of inspecting large structures with a relatively small number of transducers. Nonlinear vibration- and acoustic-based techniques have been also used for damage detection for many years [6–11]. The majority of these investigations are related to fatigue crack detection in metallic structures. Applications to composite structures are still limited

* Corresponding author. Tel.: +39 070 6755706; fax: +39 070 6755727.
*E-mail addresses:* andrzej.klepka@agh.edu.pl (A. Klepka), lukasz.pieczonka@agh.edu.pl (L. Pieczonka), w.j.staszewski@agh.edu.pl (W.J. Staszewski), francesco.aymerich@dimcm.unica.it (F. Aymerich).

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