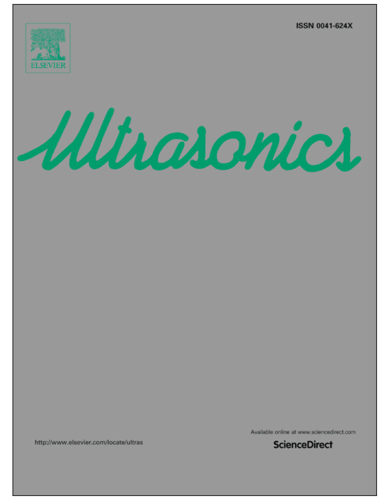
Accepted Manuscript



Nonlinear Elastic imaging of barely visible impact damage in composite structures using a constructive nonlinear array sweep technique

Gian Piero Malfense Fierro, Michele Meo

PII: S0041-624X(17)30180-4
DOI: https://doi.org/10.1016/j.ultras.2018.05.016
Reference: ULTRAS 5758

To appear in: *Ultrasonics*

Received Date: 21 February 2017
Revised Date: 23 November 2017
Accepted Date: 31 May 2018

Nonlinear Elastic imaging of barely visible impact damage in composite structures using a constructive nonlinear array sweep technique

Gian Piero Malfense Fierro and Michele Meo
University of Bath, Materials Research, Department of Mechanical Engineering, Claverton Down, Bath, UK

Abstract
Linear and nonlinear ultrasound imaging methods highlight different damage features: the linear method detects large stiffness changes, while the nonlinear technique identifies small impedance mismatches, such as microcracks or closed delaminations. Typically, nonlinear ultrasound techniques detect damage/defects in materials by measuring higher order harmonics. These harmonics can be difficult to measure due to low magnitude and signal to noise ratios (SNR): hence large excitation amplitudes are needed, which can further complicate the reliability of these methods as equipment nonlinearities can be generated. To overcome these issues, exciting at specific frequencies, known as local defect resonances (LDR), produce a much larger displacements at the damaged regions. However, estimation of LDR is time-consuming, complex and not an easily automated process.
A coupled baseline-free linear and nonlinear ultrasonic imaging approach is proposed, using a Constructive Nonlinear Array Sweep excitation and an image subtraction method for identifying damage in layered materials. The signal sweep method uses a narrow band frequency excitation to increase the probability of detection of a LDR frequency. The novel imaging approach was employed using laser vibrometry measurements in various complex composite structures to assess barely visible impact damage, critical for the aircraft industry. The results showed better estimation of impact damage when compared to classical linear or nonlinear ultrasonic methods leading to improved reliability of aircraft inspections.

Keywords: Nonlinear Ultrasound, Phased Array, Laser Vibrometer, Composite, Baseline-Free, Local Defect Resonance

1.1. Introduction

Carbon fibre reinforced plastic (CFRP – composite) materials are currently being used across a wide range of engineering fields, the selection of these types of materials are generally due to good strength to weight capabilities. These materials have inherent weaknesses such as susceptibility and difficulty in impact damage evaluation, which can lead to large reductions in the strength of components and can ultimately lead to failure. Evaluation of impact damage in composites becomes difficult under low velocity impact damage, as there may be very little surface flaws but large areas of subsurface delamination which can significantly reduce material strength. These types of damage are generally referred to as barely visible impact damage (BVID), and can be caused during the manufacturing process as well as during the service life of the component. Due to the difficulty of detection, BVID may be undetected and lead to catastrophic failure of key structures. BVID is classified as significant internal damage that is undetectable by visual inspection. Due to the hidden nature of BVID, composite materials must be regularly inspected and due to the ever increasing size of these structures inspection should be quick and cover large areas. There is significant interest within industry for non-destructive testing and evaluation (NDT/E) systems due to their ability to rapidly and accurately detect cracks and other defects in structures [1].
Aircraft structures can be subjected to numerous BVID sources which can be broadly categorised into two groups of damage: those that involve high-mass, low-velocity and wide area impact known as blunt impact (such as collisions with ground vehicles) and low-mass, high-velocity impact (hail, birds and tire fragments). Many locations of aircrafts are exposed to these sources of BVID damage such as the fuselage, nacelles, wing surfaces and control surfaces. Thus there is a high need for BVID NDT/E