Inspection Options for Detecting Various Types of Impact Damage in Composite Structures

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Abstract

Aircraft structures made from polymer-matrix composites are vulnerable to damaged created by impact from ground vehicles/equipment, as well as from events such as hail and bird strikes. These impacts can create internal damage that is not visually detectable and thus of great concern from a damage tolerance and safety standpoint. The focus of this study is on the detection of damage stemming from a variety of impact types and the relationship between inspection capabilities and the damage resistance of carbon/epoxy tape laminates. Panels of varying thicknesses were impacted with a variety of impactors (hardened, hail, bumpers) where the input energy was derived from both high velocity-low mass and low velocity-high mass scenarios. Impact location was also varied in order to study the effect on substructure elements. Different nondestructive inspection (NDI) methods were applied to damage stemming from impacts in the vicinity of the failure threshold energies (FTE) of these composites. FTE is defined as the minimum amount of energy required to create initial delamination damage in the structure. Relationships between failure threshold velocity and the ratio of panel thickness to impactor diameter were determined and the sensitivities of multiple nondestructive inspection (NDI) methods were intercompared. NDI testing included both hand-held A-scan or meter response methods, as well as wide area C-scan mapping techniques. Rapid, "Go/No-Go" NDI devices were assessed to establish the viability of using gate-check inspections on in-service aircraft to identify damage of concern. The inspection portion of this impact study seeks to determine the ability of conventional and advanced NDI to detect hidden impact damage that is at or below the level referred to as Barely Visible Impact Damage (BVID). This study will allow flaw detection to be adequately judged based on the effects of impact on the structural integrity of composites. It will aid maintenance engineers in assessing whether an incident could have caused damage to a structure, and if so, what type of inspection technique should be applied to resolve the extent of damage.

Inspection Options for Detecting Various Types of Impact Damage in Composite Structures

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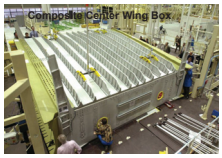
Program Motivation - Extensive/increasing use of composites on commercial aircraft and increasing use of NDI to inspect them

Composite Structures on Boeing 787 Aircraft

- Carbon laminate
- Carbon sandwich
- Fiberglass
- Aluminum
- Aluminum/steel/titanium pylons



Program Goals: Assess & Improve Flaw Detection Performance in Composite Aircraft Structure

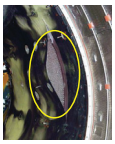
Sources of Damage in Composite Structure

One airline reports 8 composite damage events per aircraft (on avg.) with 87% from impact; cost = $200K/aircraft

Lightning Strike on Thrust Reverser

Bird Strike

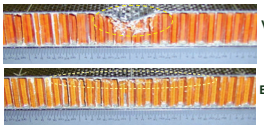
Disbonding at skin-to-honeycomb interface



Towing Damage

Inspection Challenge – Hidden Impact Damage

Backside fiber failure from ice impact

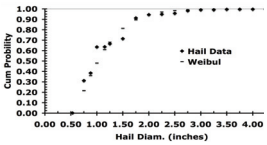


Visible Impact Damage – external skin fracture

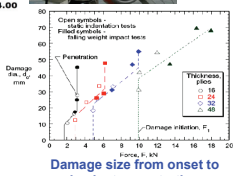
Backside Damage – internal skin fracture & core crush

Damage from ground vehicle

Impact Damage Formation & Inspection in Composite Aircraft Structures



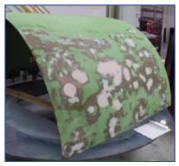
- Damage thresholds vs. laminate design; allowable limit
- Damage Threshold Energy
- Inspection for cause – self evident event vs. self evident damage



Damage size from onset to laminate penetration

Composite Impact Study - Background

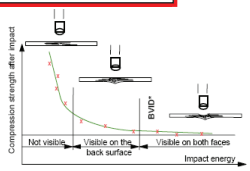
- Identify key phenomena that govern impact damage & relate them to damage initiation
- Correlate parameters (impact energy, stiffness) to assess threat level of an impact event → aid maintenance decisions
  - ➢ Panel geometry/design, impact energy & orientations, material of impactor (metals, bumpers, ice)
- Create damage associated with Failure Threshold ~ BVID range & evaluate sensitivity of NDI methods to detect and size the damaged area (reliable, sensitive, cost effective)



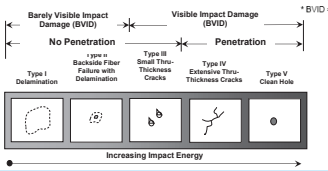
Hail Ice Impact – Low Mass, High Velocity

Effects of Impact on Composite Structures

Challenge: hidden damage in composite structures can be difficult to detect visually and/or require special equipment to be detected

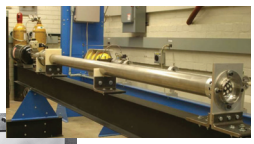


* BVID = Barely Visible Impact Damage

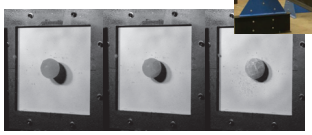


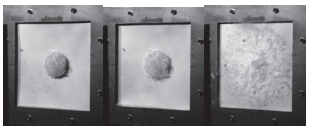
Backside fiber failure from ice impact

Imparting Hail Impact Damage



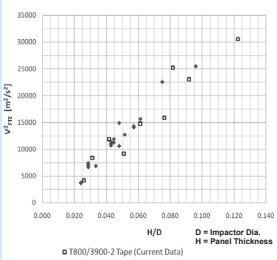
High Velocity Gas Gun



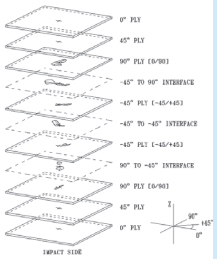


Still Images from 61 mm Ice Impact on 8 Ply Carbon Panel at 72 m/s

Damage in Composite Laminates from Ice Impact

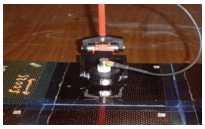


Failure Threshold (Energy) Velocity

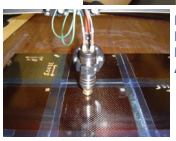


Impact-Induced Damage Morphology for 8 Ply Panel; 42.7 mm Ice at 120.4 m/s (267 J)

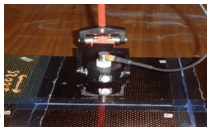
Composite Impact Damage – Inspection Methods Deployed



Pulse-Echo Ultrasonics



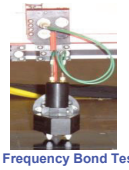
MAUS & V95 Mechanical Impedance Analysis



MAUS Resonance

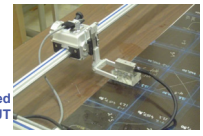
Composite Impact Damage – Inspection Methods Deployed

Thermography



Low Frequency Bond Test

Damage Check Device (Pulse-Echo UT)



Omniscan Phased Array UT

Inspection Results from 24 Ply Panel

TC-24-11

Impact Energy (J) - 704 & 819

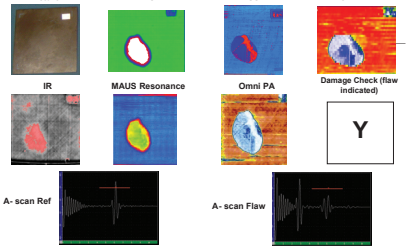
Flaw Size MAUS PE (mm²) - 8708

Flaw Size Omniscan PE (mm²) - 9030

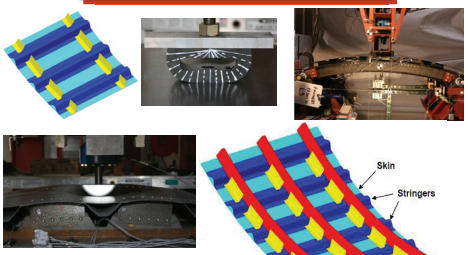
Flaw Size TTU UCSD (mm²) - n/a

Impact Velocity (m/s) - 151 & 163

Projectile Size (mm) - 50.8

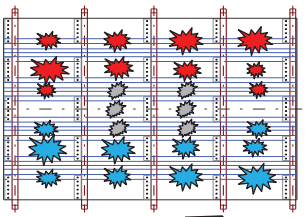


Inspection of Full Scale Panels with Low Velocity-High Mass Impacts

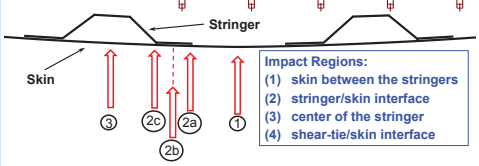


2' X 3' and 4' X 6' Panels With Substructure Elements

Impact Damage

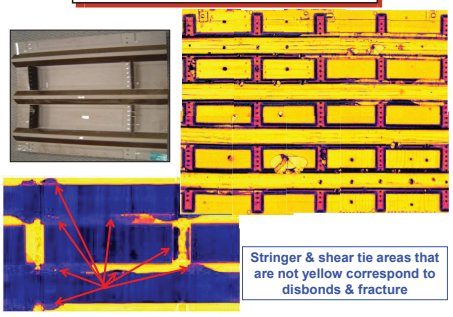


- Drop Weight (hardened) Impact
- Quasi-Static Impact
- Ice Impact



Impact Regions:
(1) skin between the stringers
(2) stringer/skin interface
(3) center of the stringer
(4) shear-tie/skin interface

Inspection of Full Scale Panels with Low Velocity-High Mass Impacts



Stringer & shear tie areas that are not yellow correspond to disbonds & fracture

Conclusions – Inspection of Composite Structures

- Engineering and economic benefits of composites will continue to expand its use
- Impact damage is a primary concern (hidden subsurface damage)
- Composite Impact Study is:
  - ➢ Identifying impact scenarios of concern
  - ➢ Identifying key parameters governing impact damage
  - ➢ Characterizing FTE & overall impact threat
  - ➢ Relating damage threat to capabilities of NDI
- NDI ability to detect impact damage was assessed in FTE ~ BVID range → sensitivity, sizing, procedures, deployment
- Multiple impact parameters must be studied – hardness of impactor, low mass-high velocity impact, high mass-low velocity impact, angle of impact, surface demarcations & visual clues, panel stiffness