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Simulation of Impact Damage in a Composite Plate and its Detection

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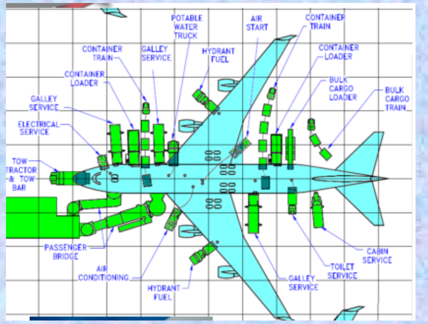
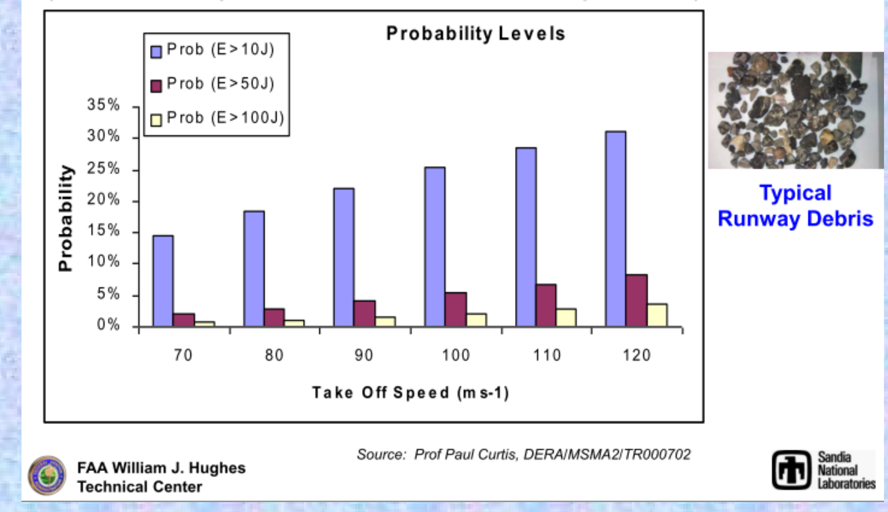
Introduction: Problem of Impact damage of Aircraft Composite Strucures

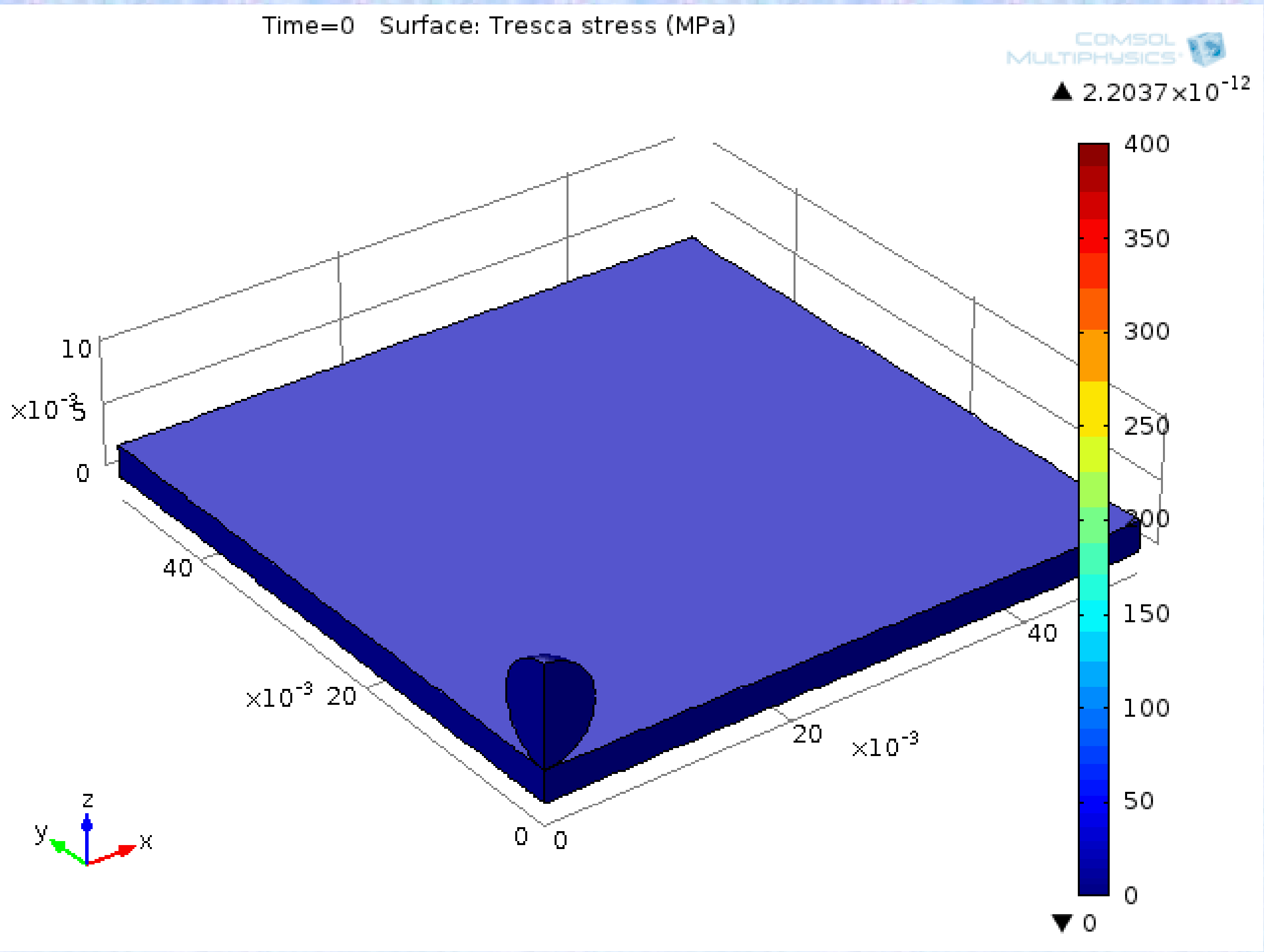
Denis Roach, Randy Duvall. Detection of Hail Impact Damage in Composite Structures at the Failure Threshold Energy// Sandia National Labs, FAA Airworthiness Assurance Center.





Javis Bayandor and all. Impact Damage Modeling of Composite Aerospace Structures Subject to Bird-Strike.// ICAS2006 (676) 12pp.

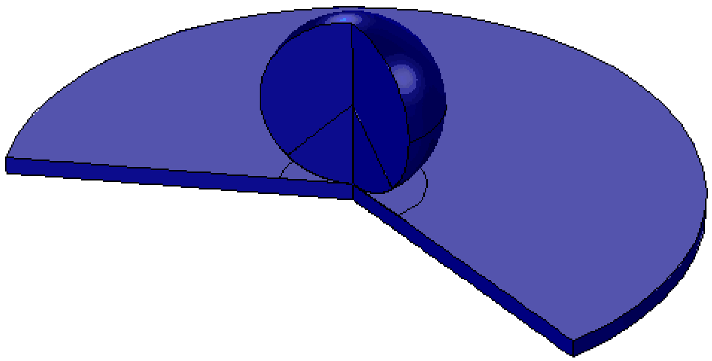
Example: 2.5x100x100mm GFRP with large orthotropy E1/E2=4.2 (Record duration 100 mks)



The goals of this research:

1) More details investigation of the dynamic stress-strain state and the destruction features of the long fiber thin-walled composite with polymer matrix at low-velocity impact by the rigid body with spherical contact surface
2) Some possible rational versions of the technology of the impact effect prediction to structural component damage and its estimation of its severity
3) Investigatation of some basic properties of Lamb wave interaction with delamination of long fiber thin-walled layered composite by computational simulation
4) Define that feature of LW is the most rational and sencitive for delamination detecting
5) Investigation of piezoelectrical transducer shape and technology of effective detecting of composite delamination

Impact simulation of a round plate with the fixed contour



The special simulation was done for definition of valid limits of model at investigation of low-velocity impact of the laminate composite plate. For comparison the result of impact test of 2 mm thick GFRP round plate (76.2mm diameter) described in [3] was used. The tests were performed using a free-fall drop dart machine: the maximum impact energy is limited by the fixed mass 20 kg, of the impactor and the falling height. As a results, the impact energy was varied in range from 20 to 54J.

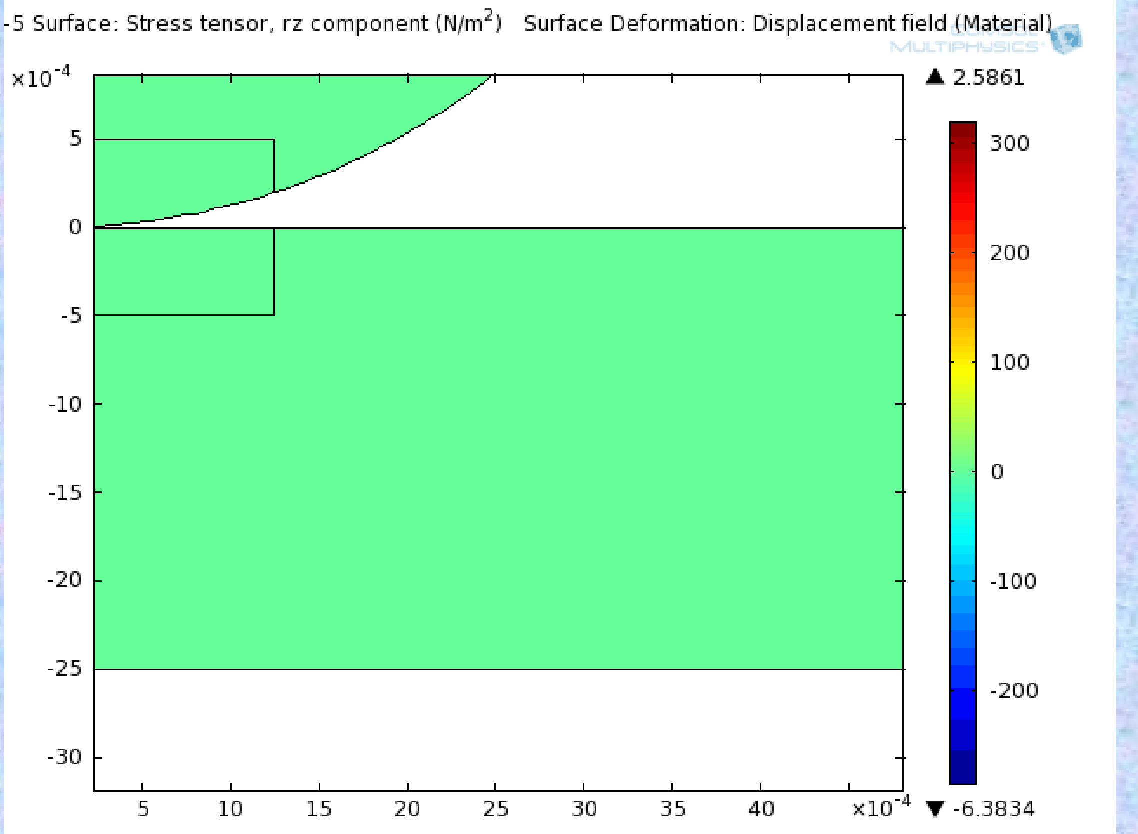
Three cases were realized:

- Free fall, stop, rebound of impactor;
- Free fall and impactor stop;
- Free fall and perforation.

Ball diameter, mm	20
Impact velocity, m/s	1.4-2.4
Impact energy, J	20-54

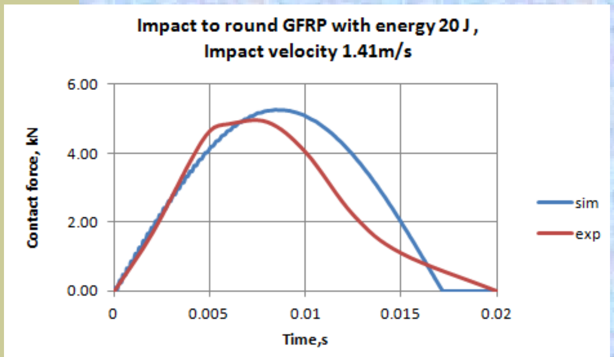
Giovanni Belingardi*, Roberto Vadori, Low velocity impact tests of laminate glass-fiber-epoxy matrix composite material plates// International Journal of Impact Engineering 27 (2002) 213–229

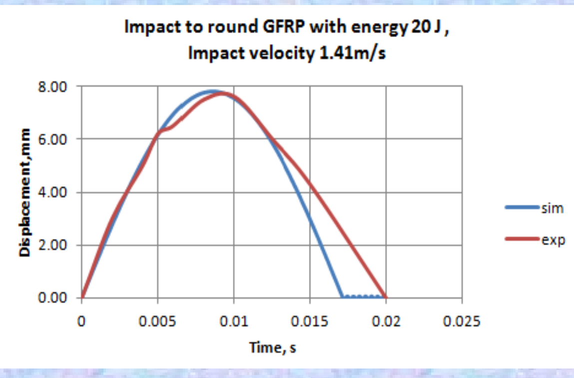
Impact simulation: Shear stress in-plane (record duration 100 mks)

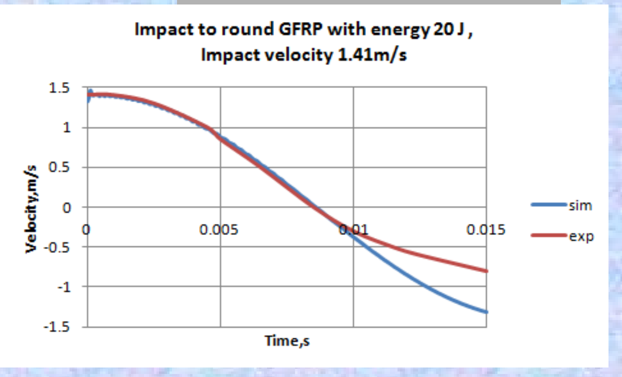


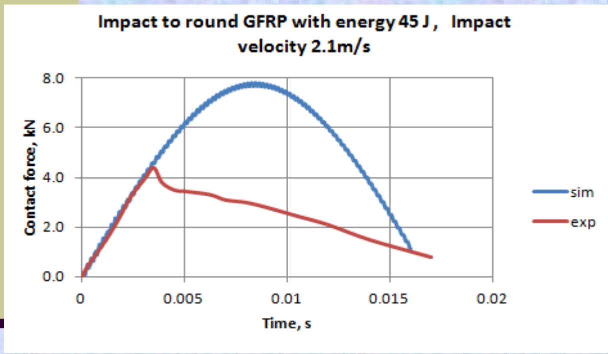
Ball diameter, mm	8
Impact velocity, m/s	20
Impact energy, J	0.42

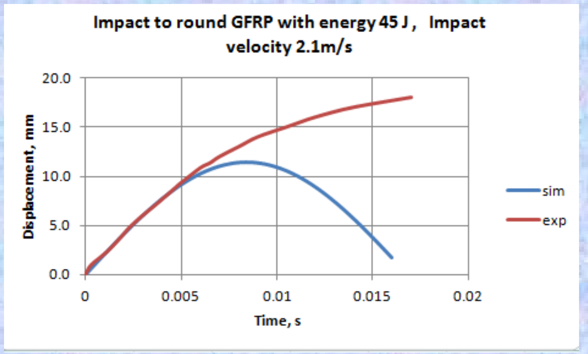
Comparison of simulation results with test

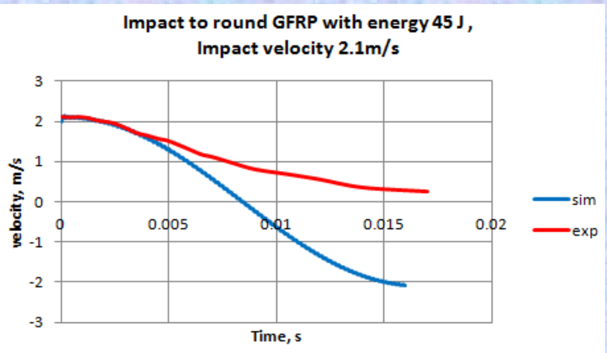


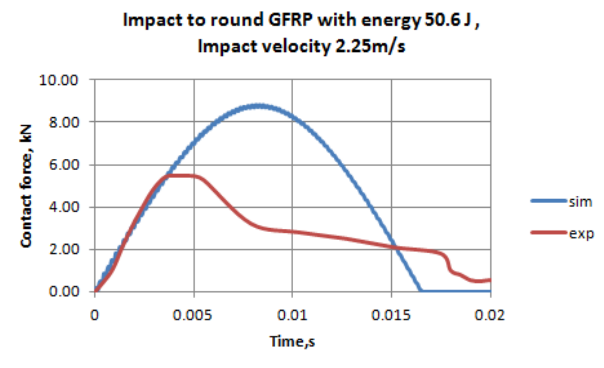


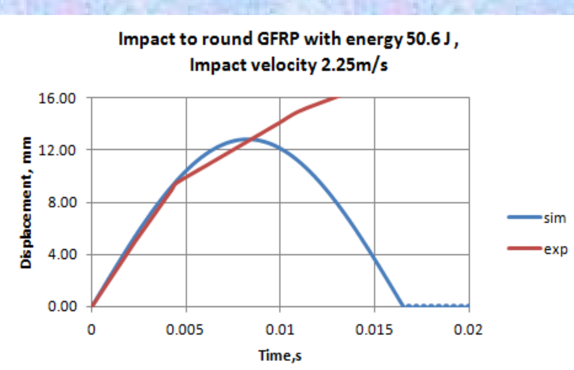


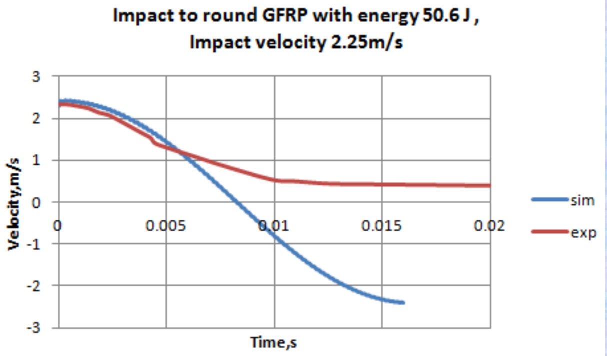












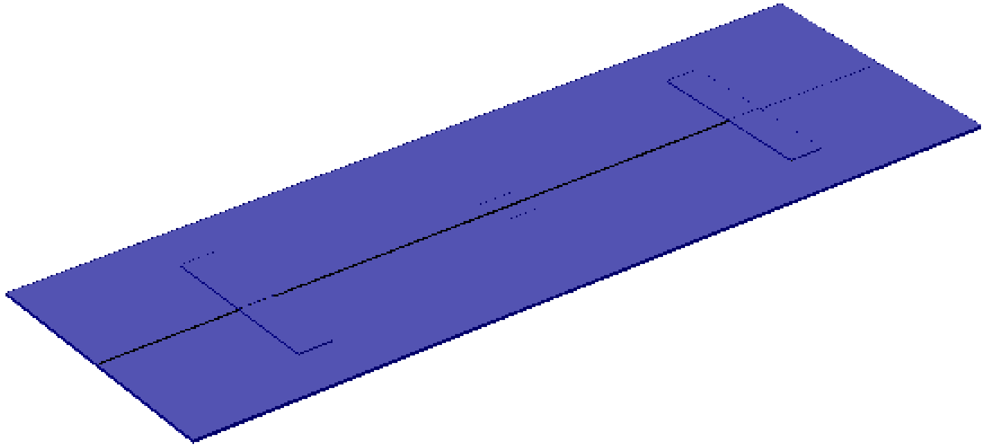
3D simulation of Lamb wave propagation in a layered composite plate with the 10x10mm delamination

The simulation of A-scan and C-scan (Figure 4) procedures using ultrasound Lamb wave technology was performed. The GFRP plate 1x80x240mm instrumented by two piezoceramics transducers was modeled by COMSOL software.

The basic frequency of excitation……250 kHz.

The phase velocities:

- S_0 mode…… 5310 m/s
- A_0 mode ……1820 m/s



Simulation results:

- o Both transmitted and reflected signals (A-scan) practically do not have any changes in comparison with non-damaged plate.
- o The C-scan shows that the transverse displacement up delamination is very well detected.

2D problem of Lamb wave propagation in composite layer and its interaction with delamination

The sizes of a sheet, delamination and sensor:

Thickness .... t =1 mm

Length.. L =1000 mm

Delamination width 0.1 mm and length..... d =1-15 mm

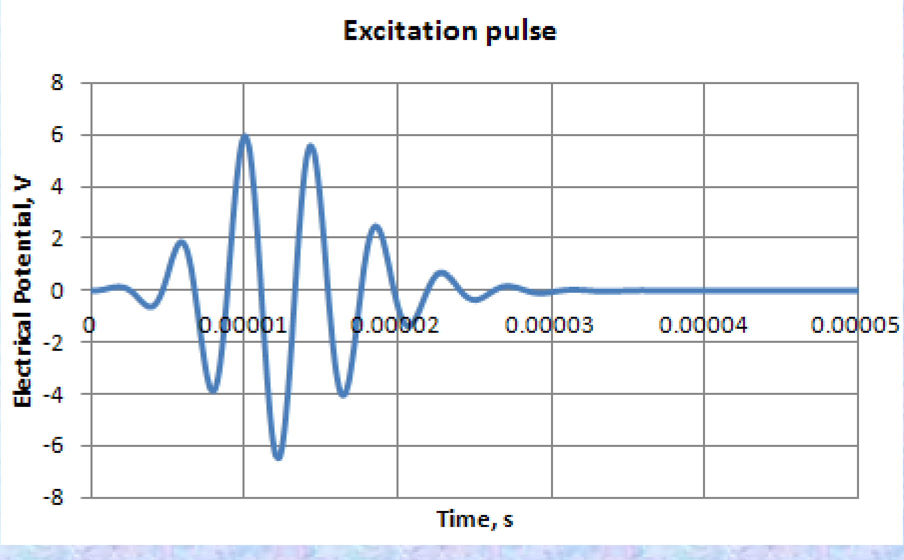
Sensor cross-section sizes............................ 0.5x10 mm

The wave was generated by the burst of sine function modulated by the error function.

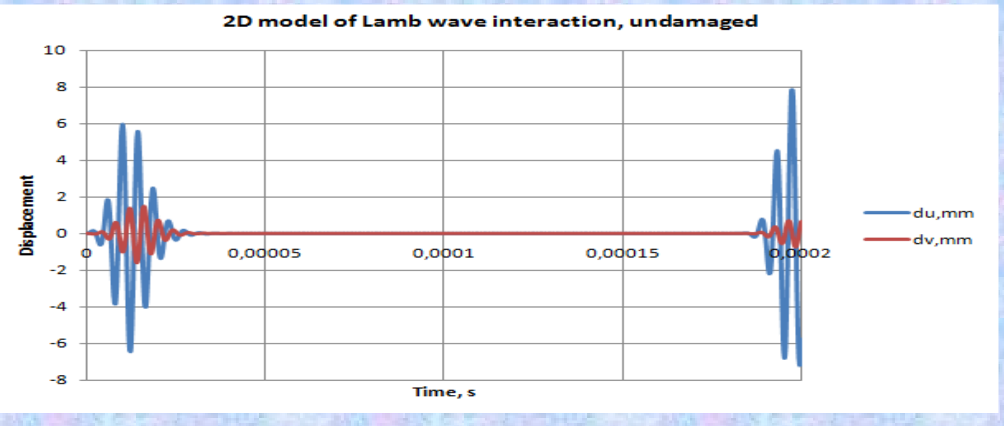
$$E(t) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{t-t_0}{\sigma}\right)^2} sin\omega t, \qquad (1)$$

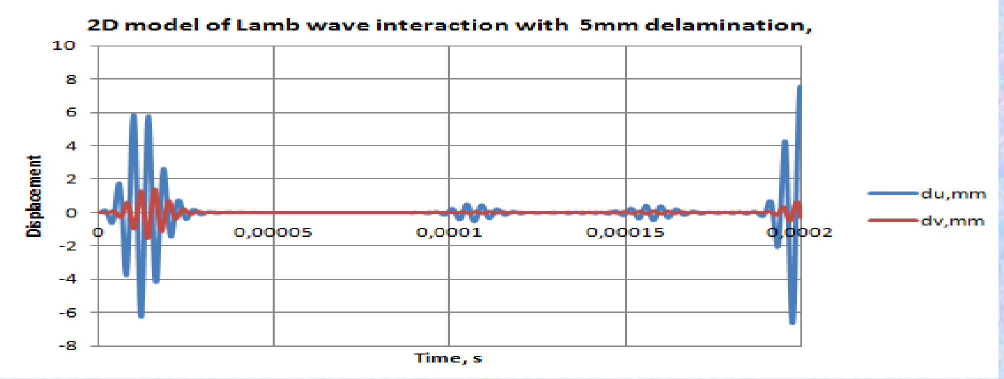
where $\omega = 2\pi f$, f is basic frequency of excitation, $t_0 = 3\sigma$, $\sigma = \frac{\pi n}{3f}$, and n is number of sine waves in the burst.

The basic frequency of excitation was equal 250 kHz. The phase velocities of S_0 and A_0 modes of Lamb wave propagation are equal to 5310 and 1820 m/s respectively.



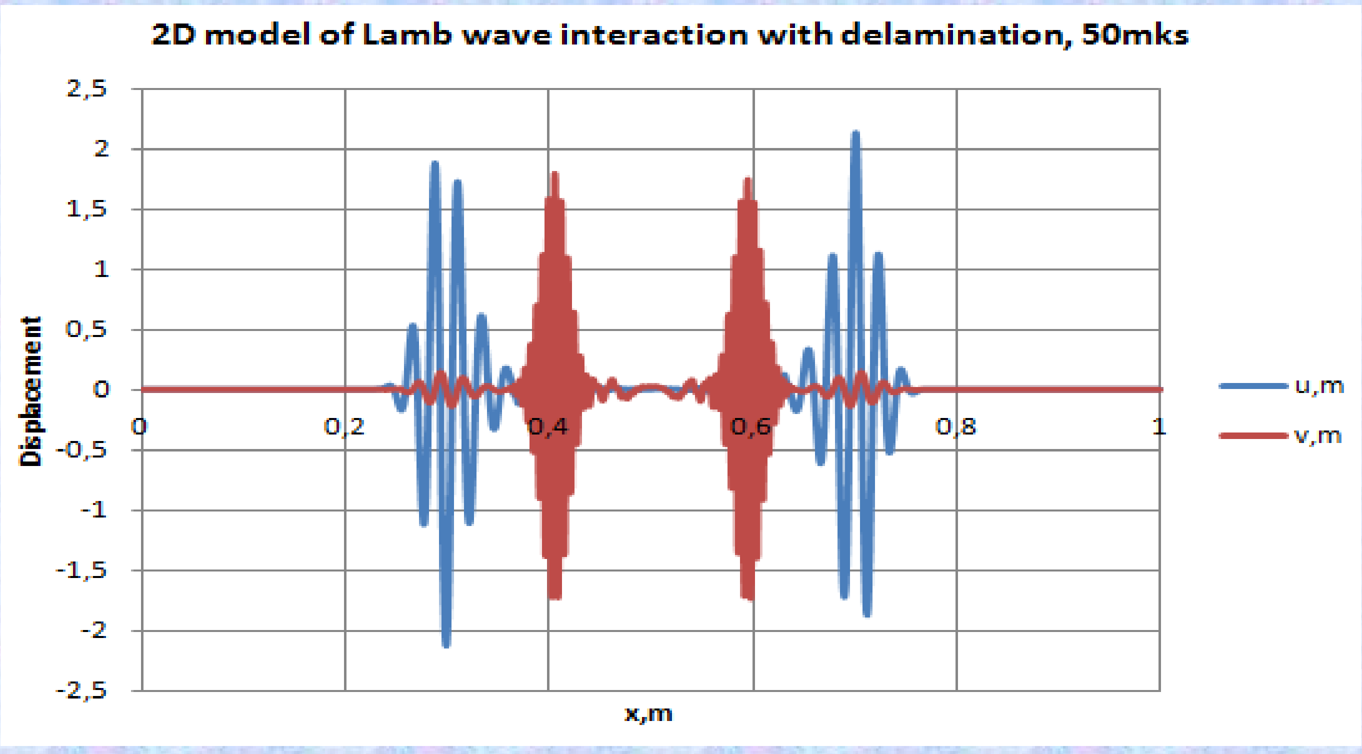
Time-history of Lamb wave propagation: undamaged state and the plate with 5mm delamination



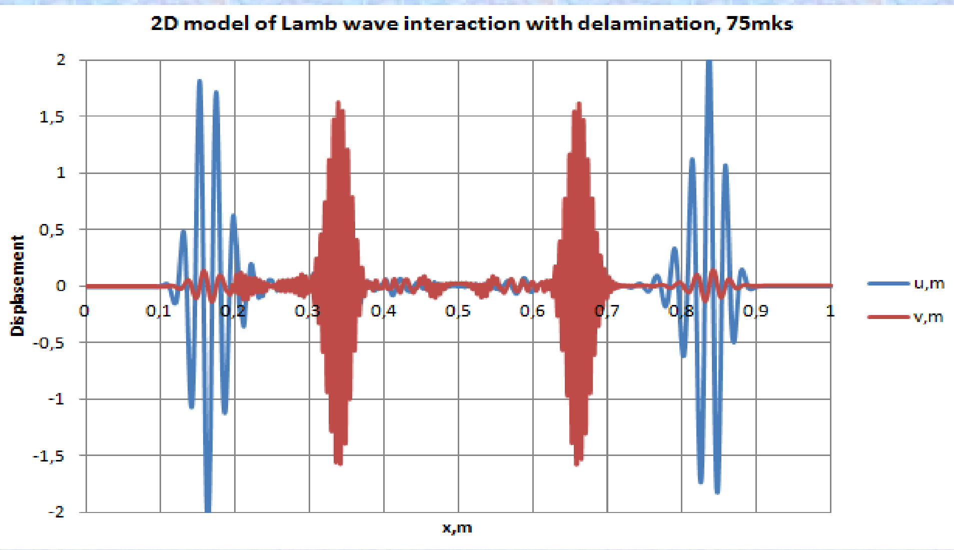


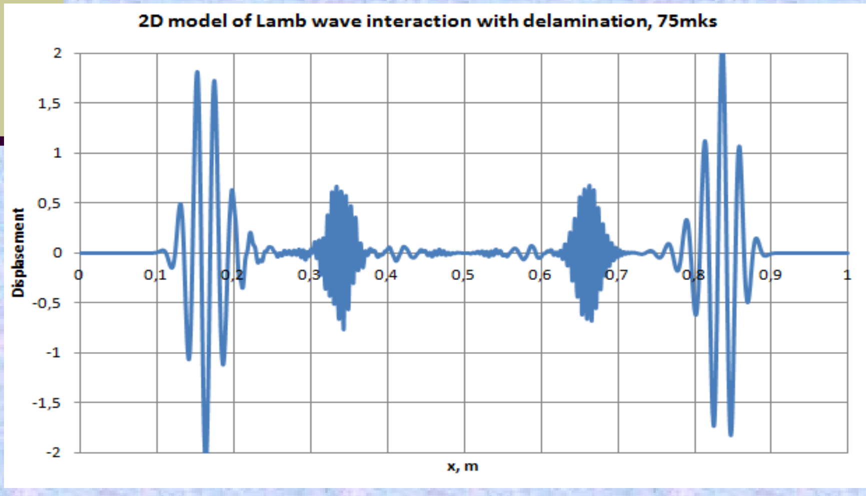
It can see the two weak signals were received by sensor before occurrence of the S0 mode reflected signal. It is reaction to delamination in composite.
First of them is the result of the S_0 mode interaction with delamination, but second is also the S0 mode as a conversion of A_0 mode to symmetrical one. Of course these signals could be used for health monitoring of structure, but the probability of detection is low.

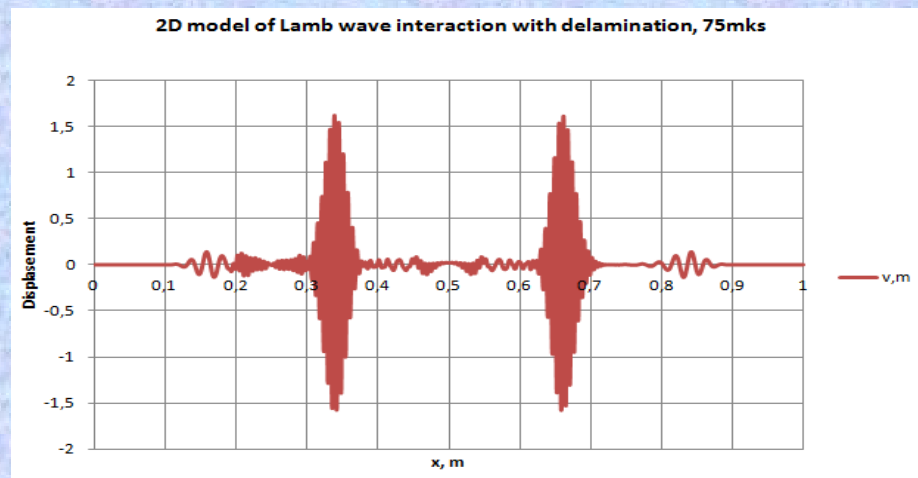
Step-to-step of time-history of Lamb wave propagation: initial stage



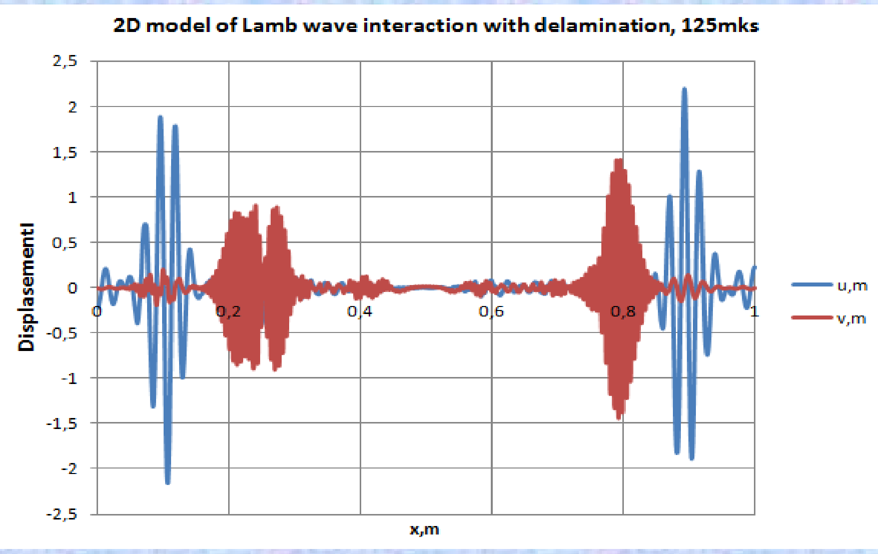
Step-to-step of time-history of Lamb wave propagation: S0 first interaction with delamination



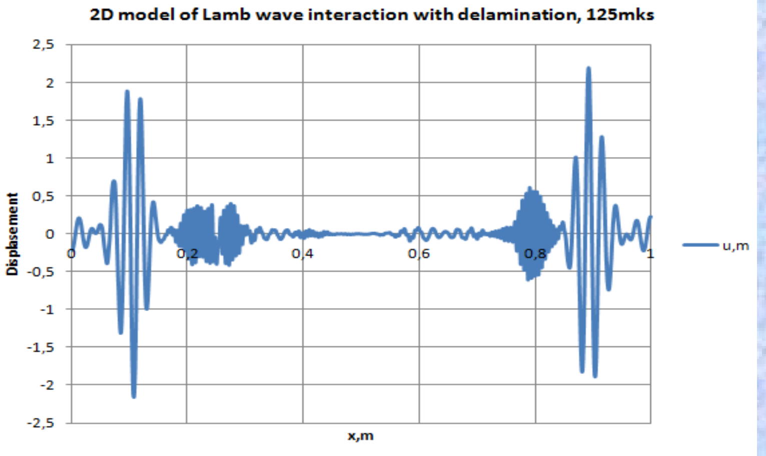


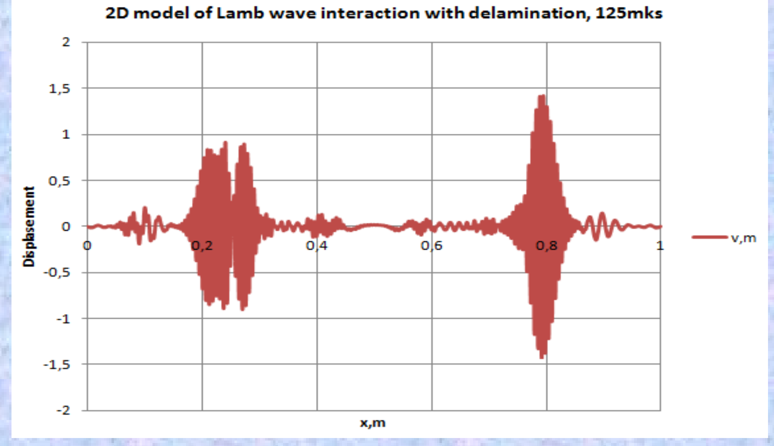


Step-to-step of time-history of Lamb wave propagation: A0 first interaction with delamination

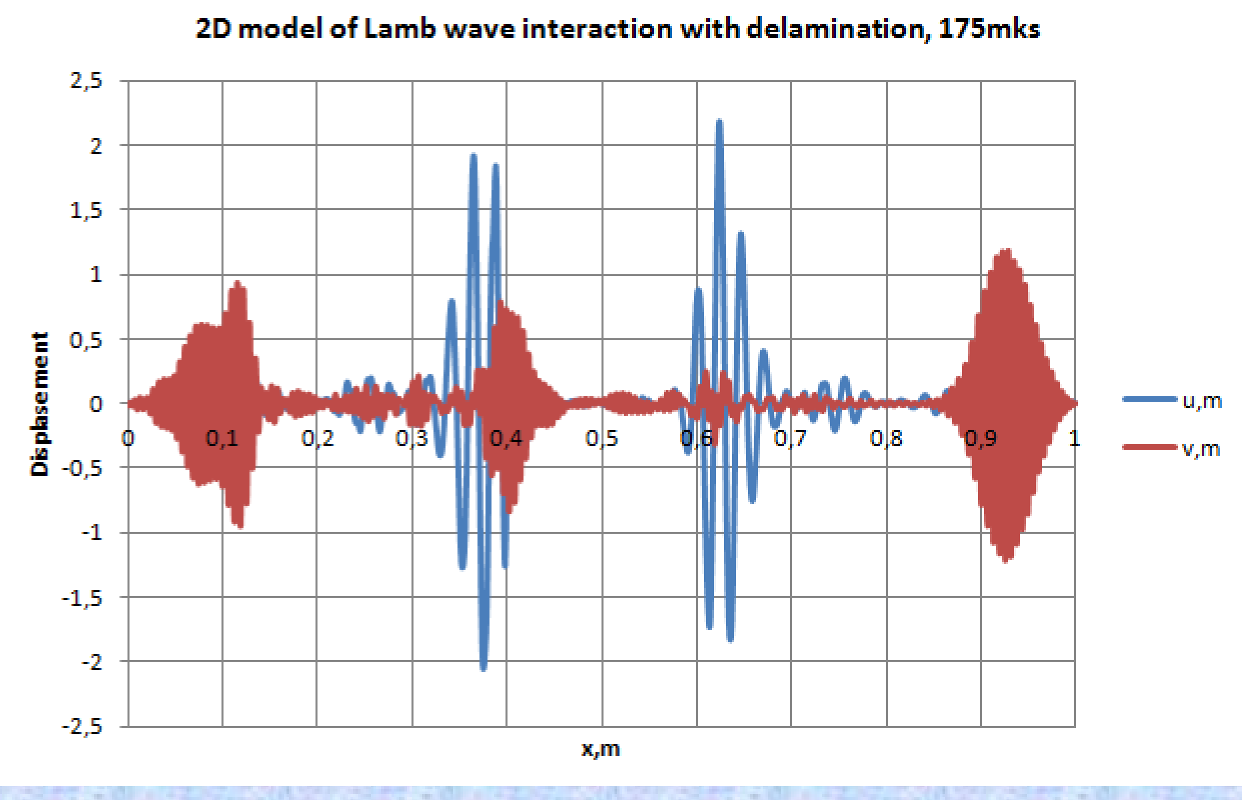


The reflected signal of A_0 mode is much more and can be used for detection of the damage





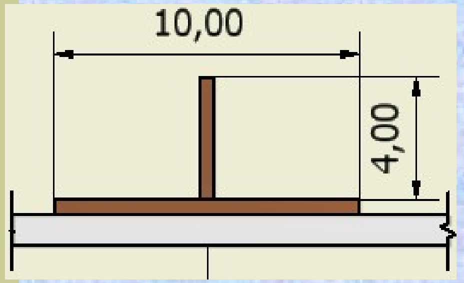
Step-to-step of time-history of Lamb wave propagation: Final stage

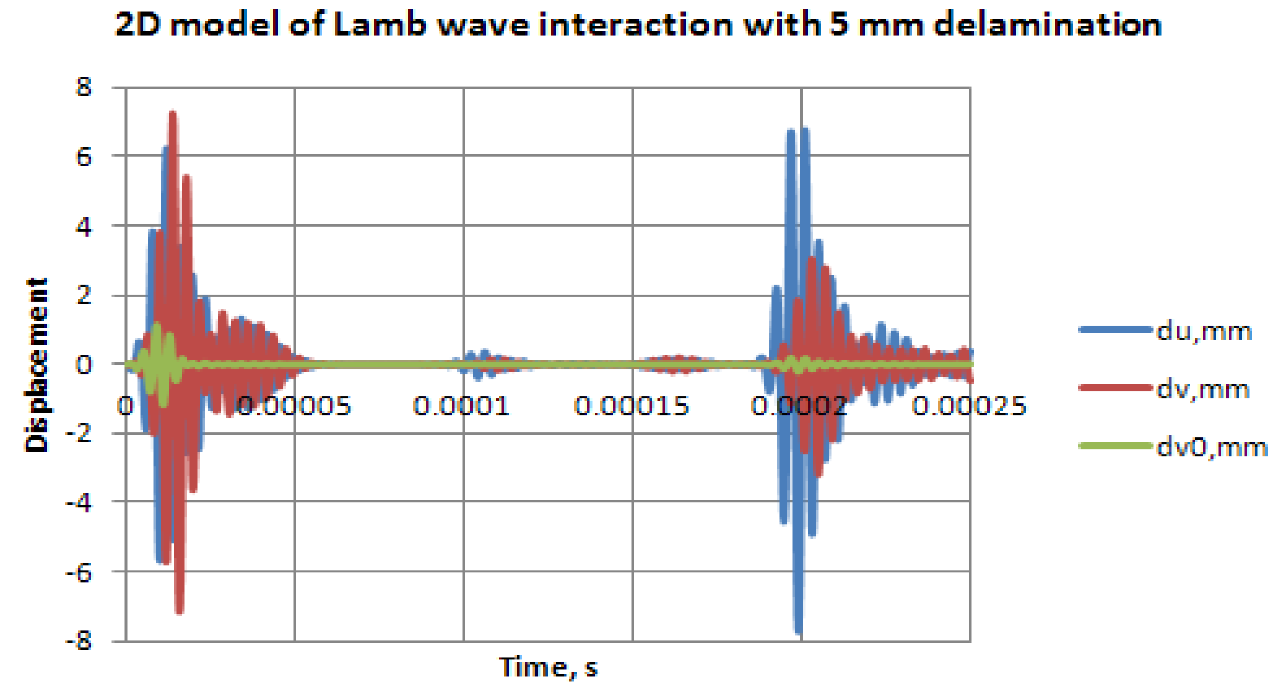


The corresponding additional transducer or its specific form should be used for effective health monitoring of composite with delamination. Possible shape of combined transducer that is tuned to receiving of the S_0 mode as well as A_0 mode is presented in Figure 5,a. The height of vertical part of transducer is calculated by follow formula:

$$h_1 = \frac{L_1}{2} = \frac{c_2}{2f} \ ,$$

Time-history of Lamb wave propagation as the response of a modified transducer





du defines the S_0 mode of reflected signal (blue line), dv defines the A_0 mode of signal that reflected from damage (red line), and $dv0$ defines the A_0 mode of a wave at initial shape of transducer (yellow line) without vertical part.

Conclusions

General conclusion: COMSOL Multiphysics software is effective tool for simulation and solution of actual problems of SHM of composite parts of aircraft

Partial conclusions:

1. Simulation of low-velocity impact of thin-walled laminate using linear model combined with adequate criteria of strength is sufficient for prediction of first stage of impact damaging (to maximal contact force)
2. The S_0 mode interaction with delamination is relatively weak and insufficient for reliable evaluation of this kind of damage.
3. The A_0 mode interaction with delamination induces conversed S_0 mode that also has small amplitude.
4. The reflected A_0 mode is significantly more than mentioned ones. But for its effective detection the separate transducer is needed.
5. Special combined transducer could be good solution for delamination detecting.

Acknowledgement

- The research leading to these results has received funding from the European Community's Seventh Framework Program [FP7/2007-2013] under grant agreement n°212912. The authors are grateful to European Commission for financial support and all partners for scientific and technological collaboration.

Thanks you for your attention!