Significance of Low Energy Impact Damage on Modal Parameters of Composite Beams by Design of Experiments

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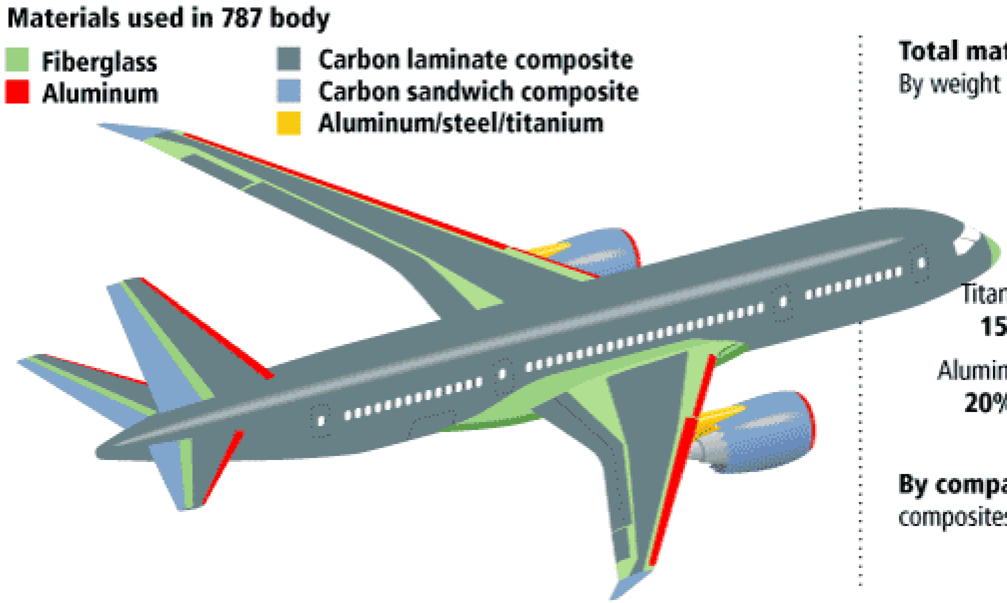
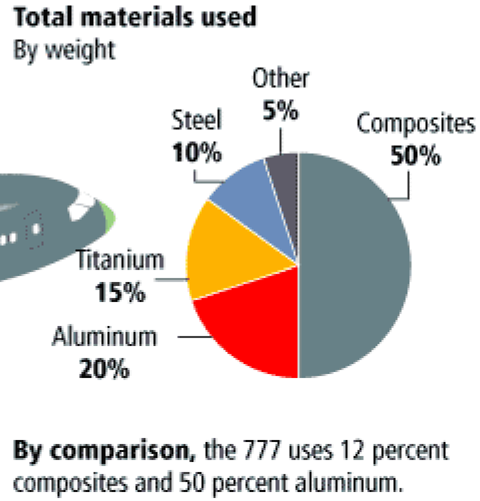
SHM in Smart Structures (Composites)





Boeing 787

50% of Structure made of Composite

➢ Aim of Using Composites

- ✓ Increase the specific stiffness and strength
- ✓ Reduce the weight

➢ Damage in Composites

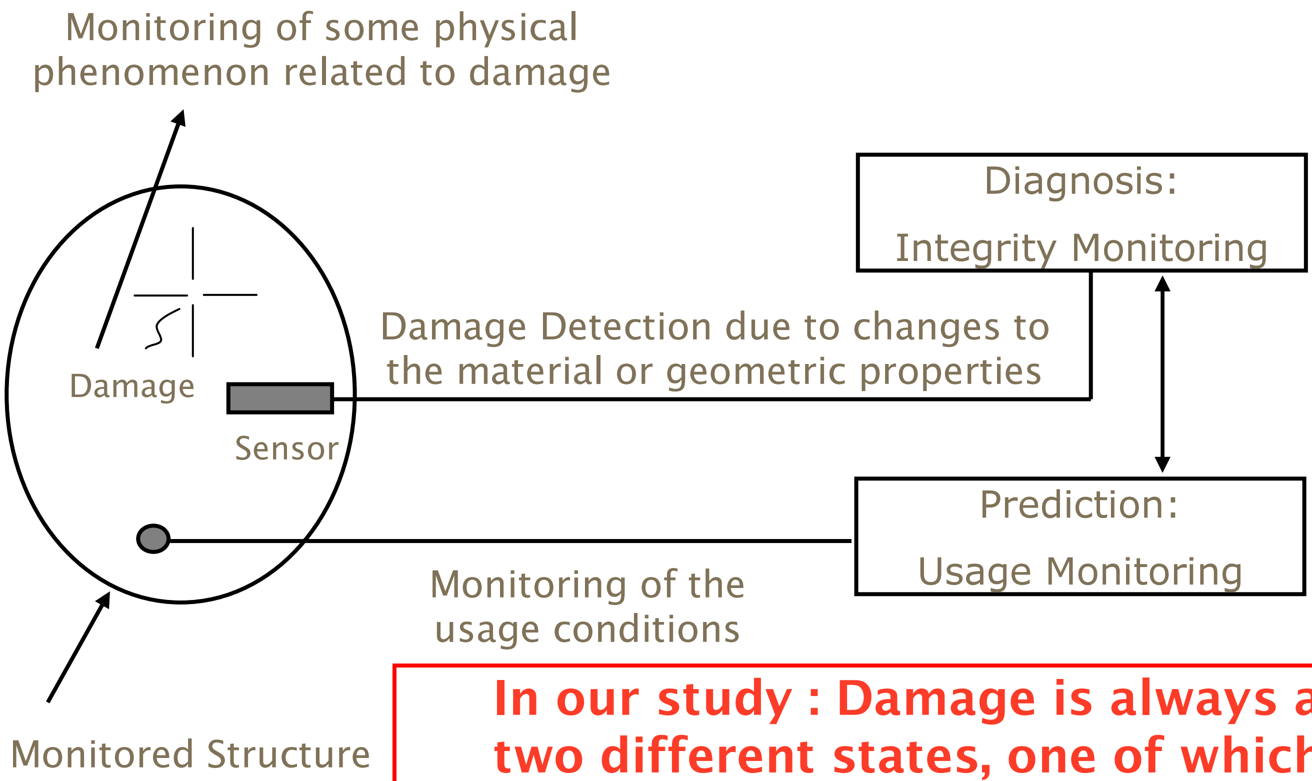
- ✓ fabrication stress
- ✓ environmental loadings
- ✓ handling and foreign object impact damage

Goals

- Better understanding of performance of composites beams versus LOW ENERGY impact damages (foreign objects, bird strikes, ice …) around BVID (Barely Visible Impact Damage).

- Correlate modal parameters shifts with damage density and level
  - ✓ High Quality vibration tests and drop weight (impact) tests
  - ✓ Results of preliminary works on laminates composites [SHM09]
  - ✓ Extent to 4 edge clamped BC for impact test (damage zone more important for same energy of impact == pole shift more sensitive)

Damage Detection Philosophy



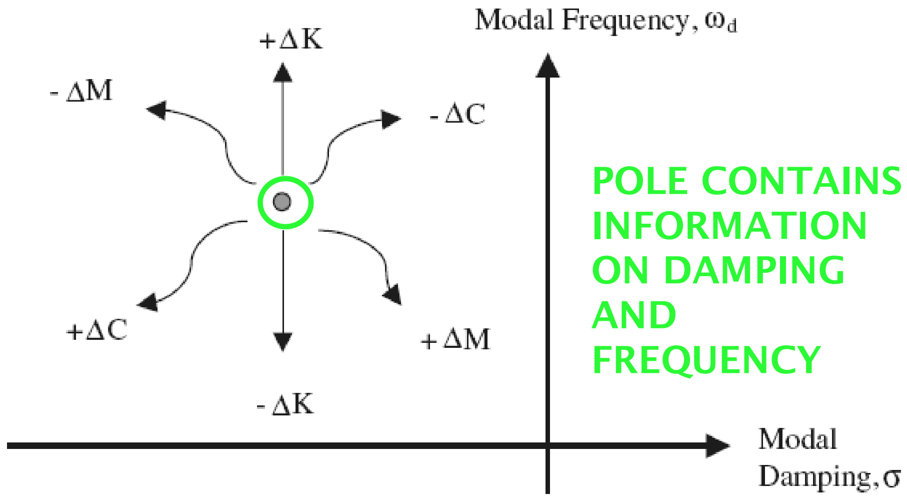
In our study : Damage is always a comparison between two different states, one of which is assumed to represent baseline or undamaged state

Validation of experiments using statistical tool (DOE)

No diagnosis, all variables are supervised (impact energy, localisation ….)

Choice of SHM Detection Techniques

- Ultrasonic testing
- Radiography
- Eddy current testing
- Liquid penetrant testing
- Infrared thermography
- Visual testing (optical)
- Vibration testing



Purpose of vibration based damage detection

Damage in a structure changes the modal parameters in the following way:

- ✓ Decrease in natural frequency
- ✓ Increase in damping ratio

Outlines

1. Vibration Tests
2. Impact Tests
3. Significance of damage by shifts in modal parameters
4. General Conclusion

Scheme of Presentation

1.Vibration Tests

2. Impact Tests

3. Significance of damage by shifts in modal parameters

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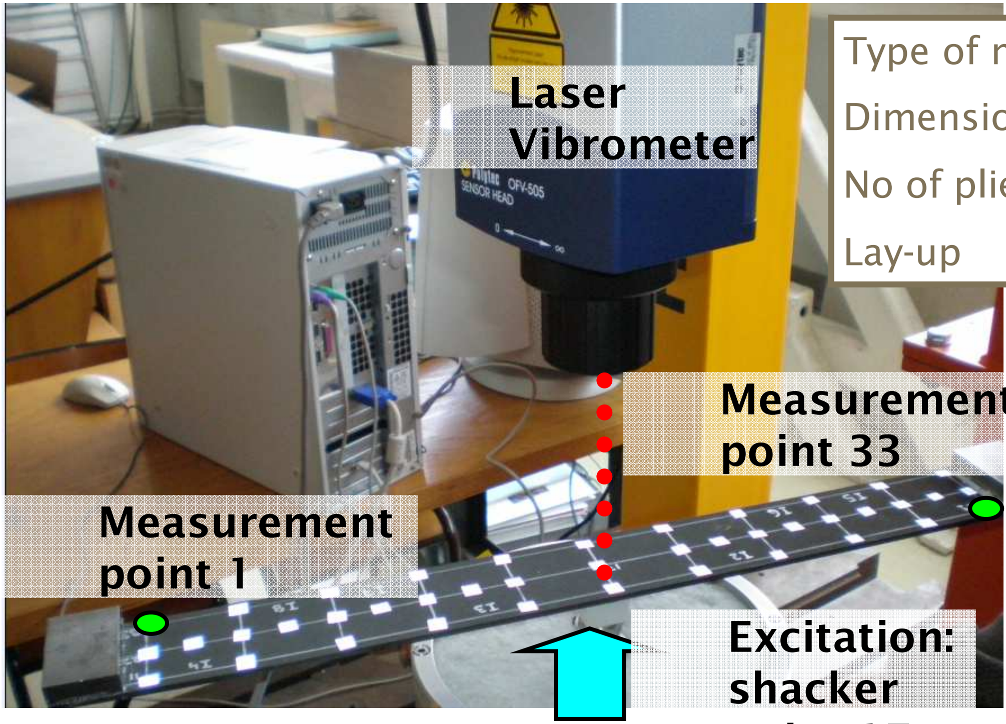
Vibration Tests: Testing Methodology

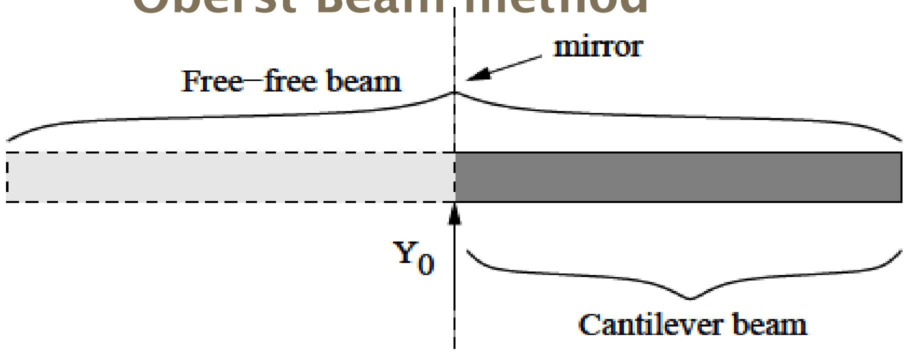


Type of material	T300/914
Dimensions of the beam	480 x 50 x 3 mm
No of plies	24
Lay-up	[0/90/45/-45]3s

➢ Acquisition Parameters for both BR and SD excitations)

- ✓ Frequency Resolution = 0.25Hz
- ✓ Excitation level = 1N
- ✓ Same number of measurement points for each beam (33 symmetric points)
- ✓ As the damages are symmetrical, We can compare the sum of FRF

Vibration test based on Oberst Beam method



Damping Estimation difficult ?

Use 2 Modal Parameter Estimators as previous study show us damping **is difficult to estimate** (Frequency is reliable)

- ✓ **POLYMAX** (frequency domain – LMS– Burst random)
- ✓ **POLYREFERENCE** (time domain –B&K – Sine Dwell take into account NL)

Both algorithms are based on least-squares optimization on 33 FRFs

Aim is to calculate the best optimum value of pole for each mode

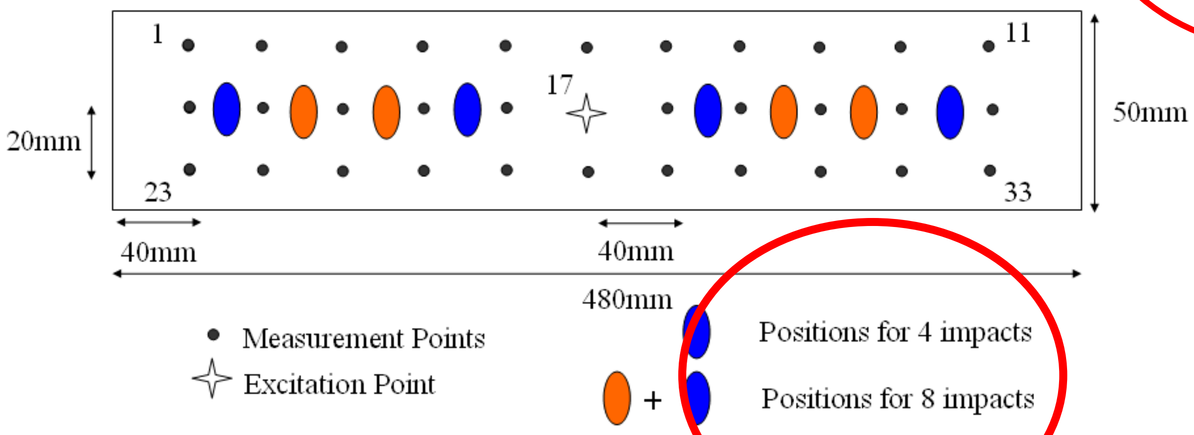
Experiments on 5 identical composites beams

➢ Modal Test Parameters

Type of Excitation	Burst Random
Resolution	0.25 Hz
Frequency bandwidth	0-1600 Hz
Modes of interest	First four bending modes

➢ Impact Test Parameters

Beam No	Energy of Impact (J)
1	6
2	8
3(BVID)	**10 (0.55mm)**
4	12
5	14



Parameters of the 5x2 Full Factorial DOE

Vibration tests carried out after each of the three states i.e., Undamaged (UD), Damage at 4 points (D1) and at 8 points (D2)

Scheme of Presentation

1. Vibration Tests

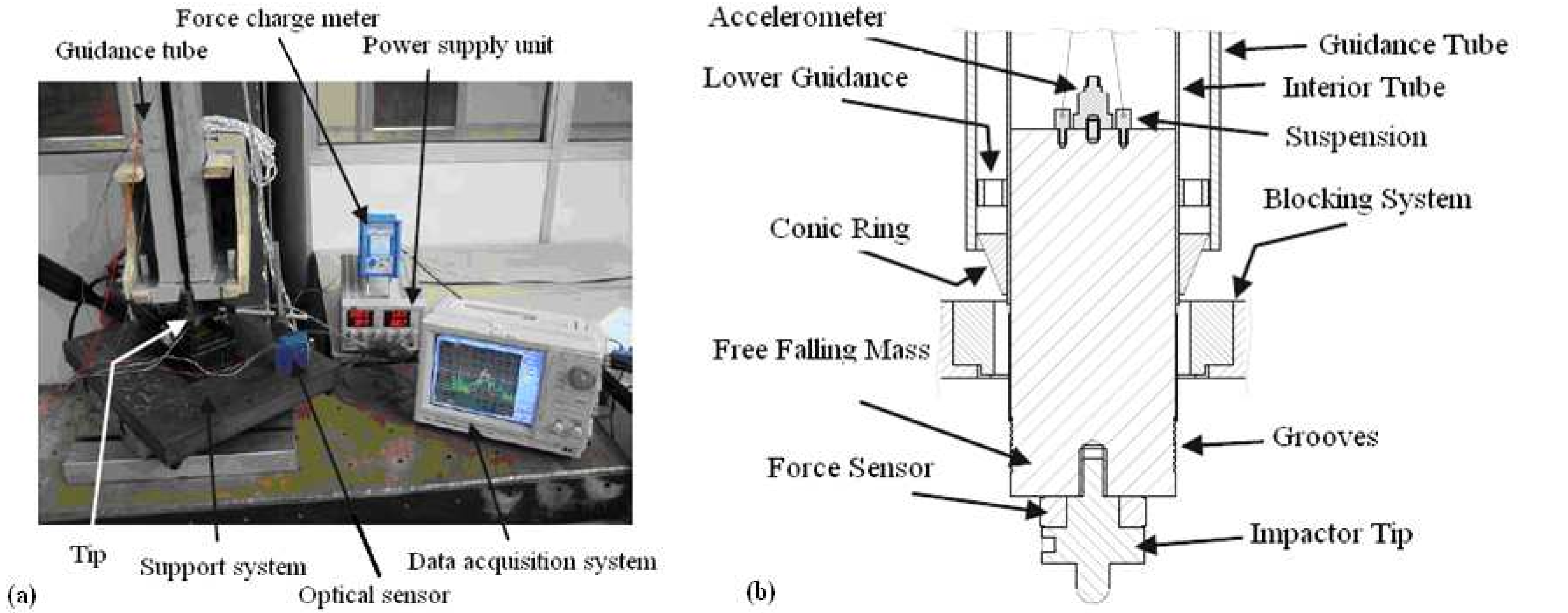
2. Impact Tests

3. Significance of damage by shifts in modal parameters

4. General Conclusion

Impact Tests

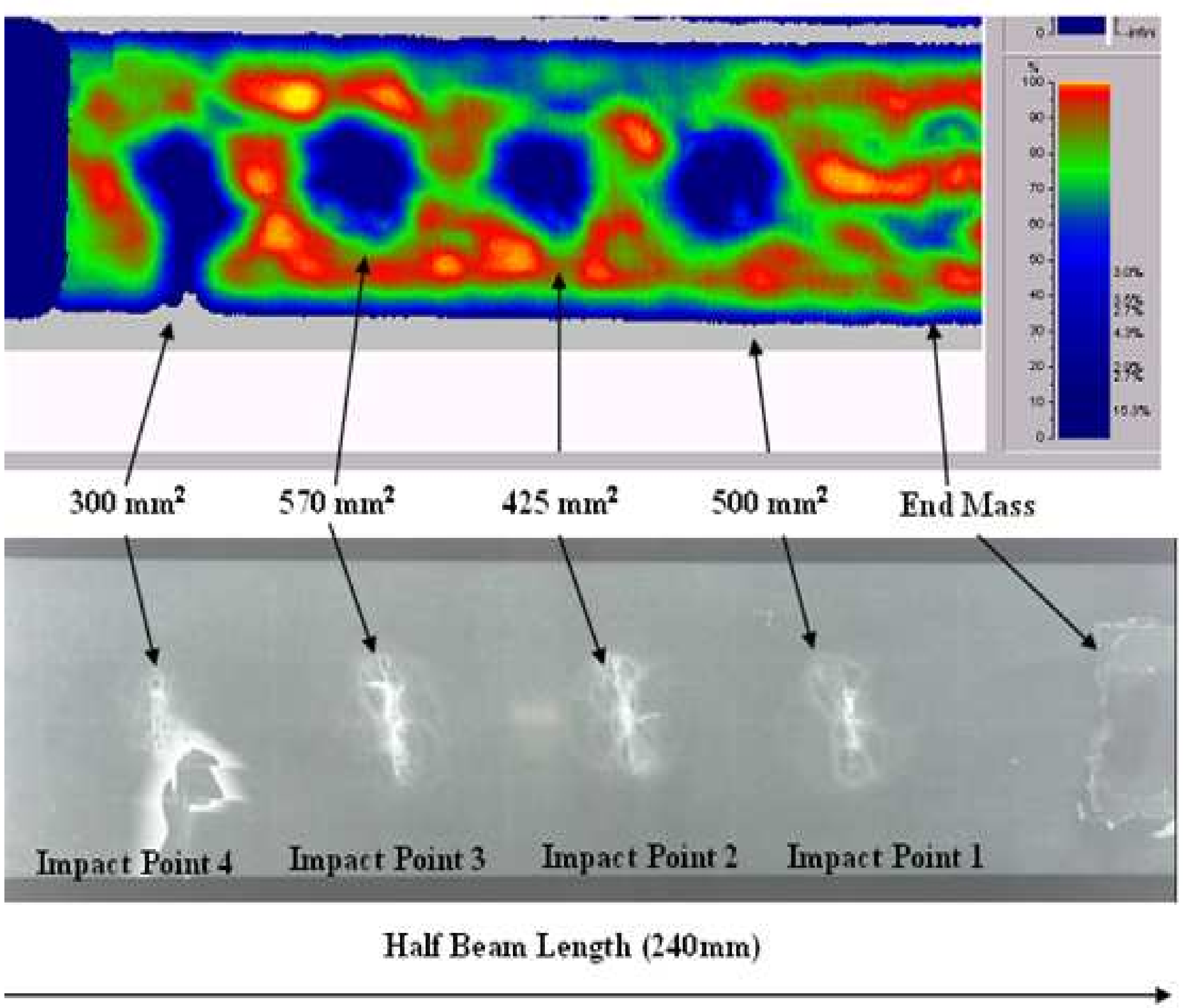
- Impact tests are carried out by a drop test machine
- Impactor has a hemispherical head with a radius of 12.7mm
- Beams are clamped at four ends during impact



Impacts carried out around the BVID limit

0.5-0.7mm of indentation depth just after impact

NDT results for impact tests (repetitivity)



C_SCAN

Damage zones:
local loss of rigidity
(decrease in frequency)
and
increase the surface of friction
(increase in damping)
due to delamination

RADIOSCAN

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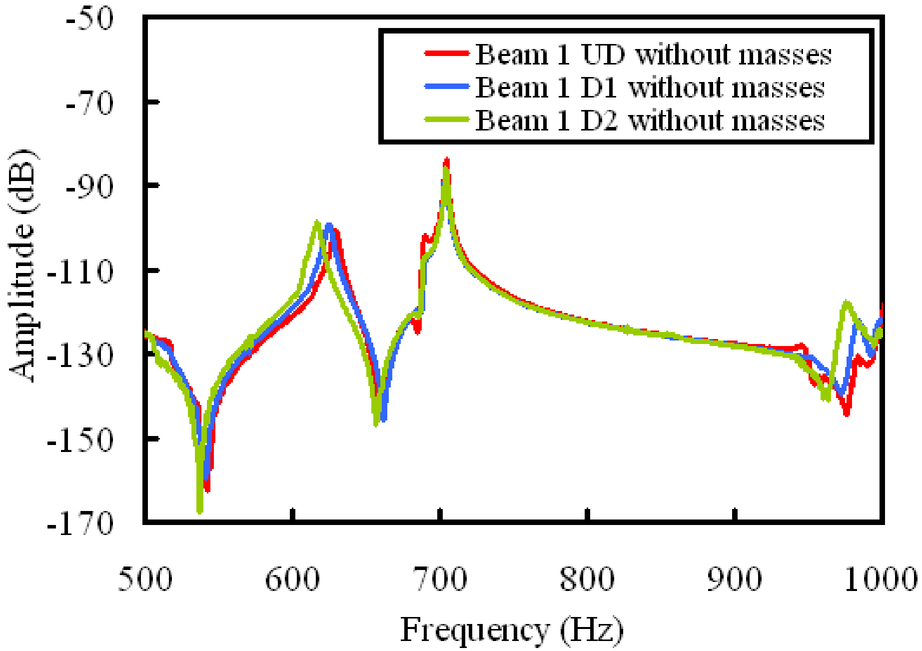
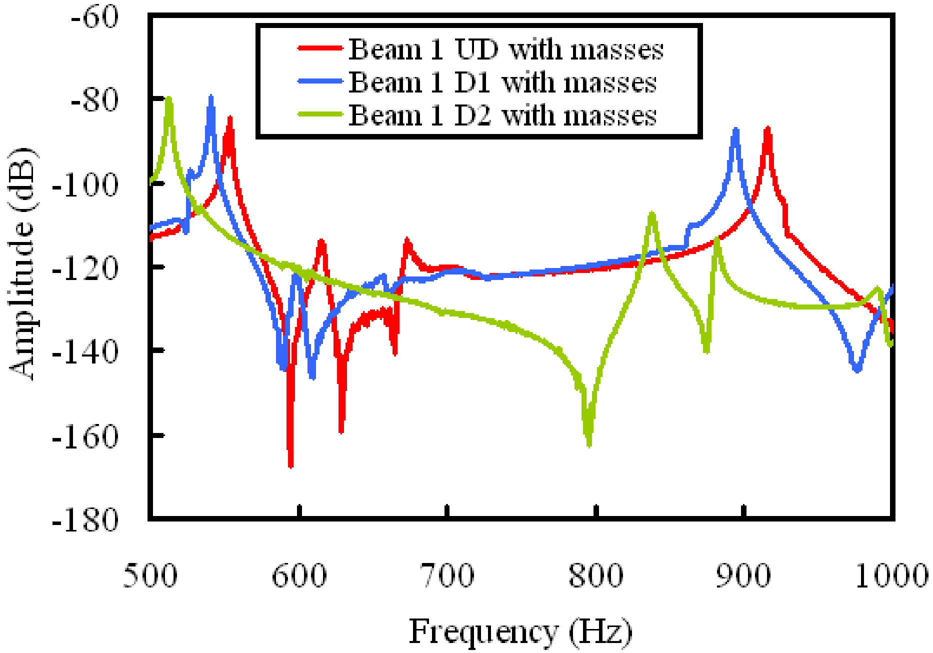
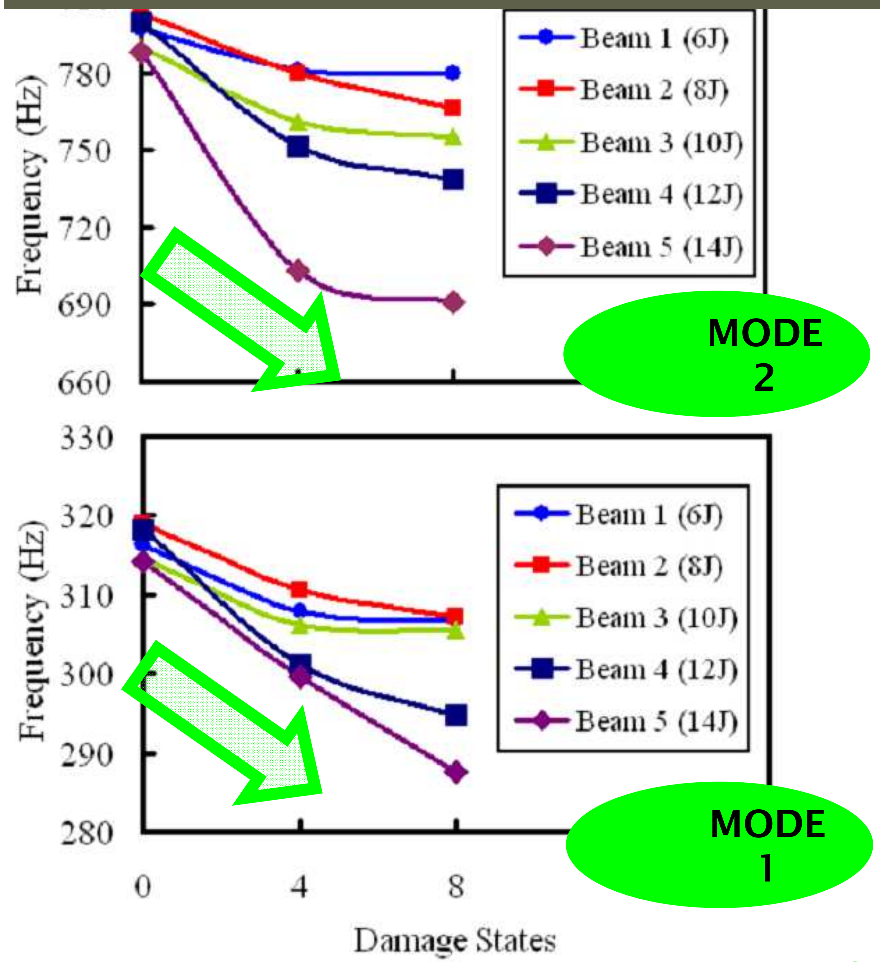
Significance of End-Masses

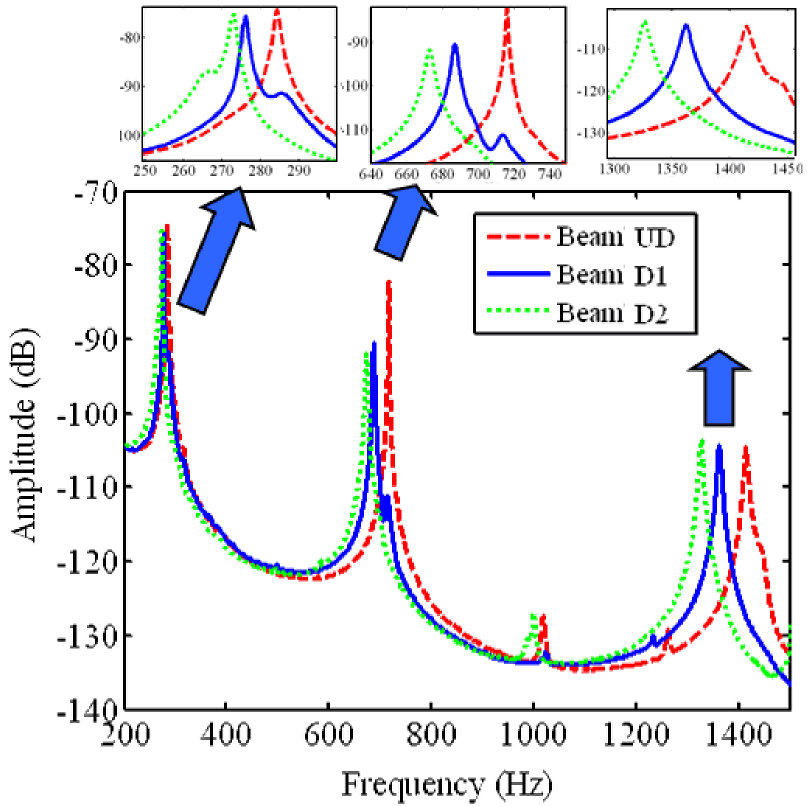




Shift in modal parameters is enhanced with end-masses (add shearing effect)

Shifts in Natural Frequency



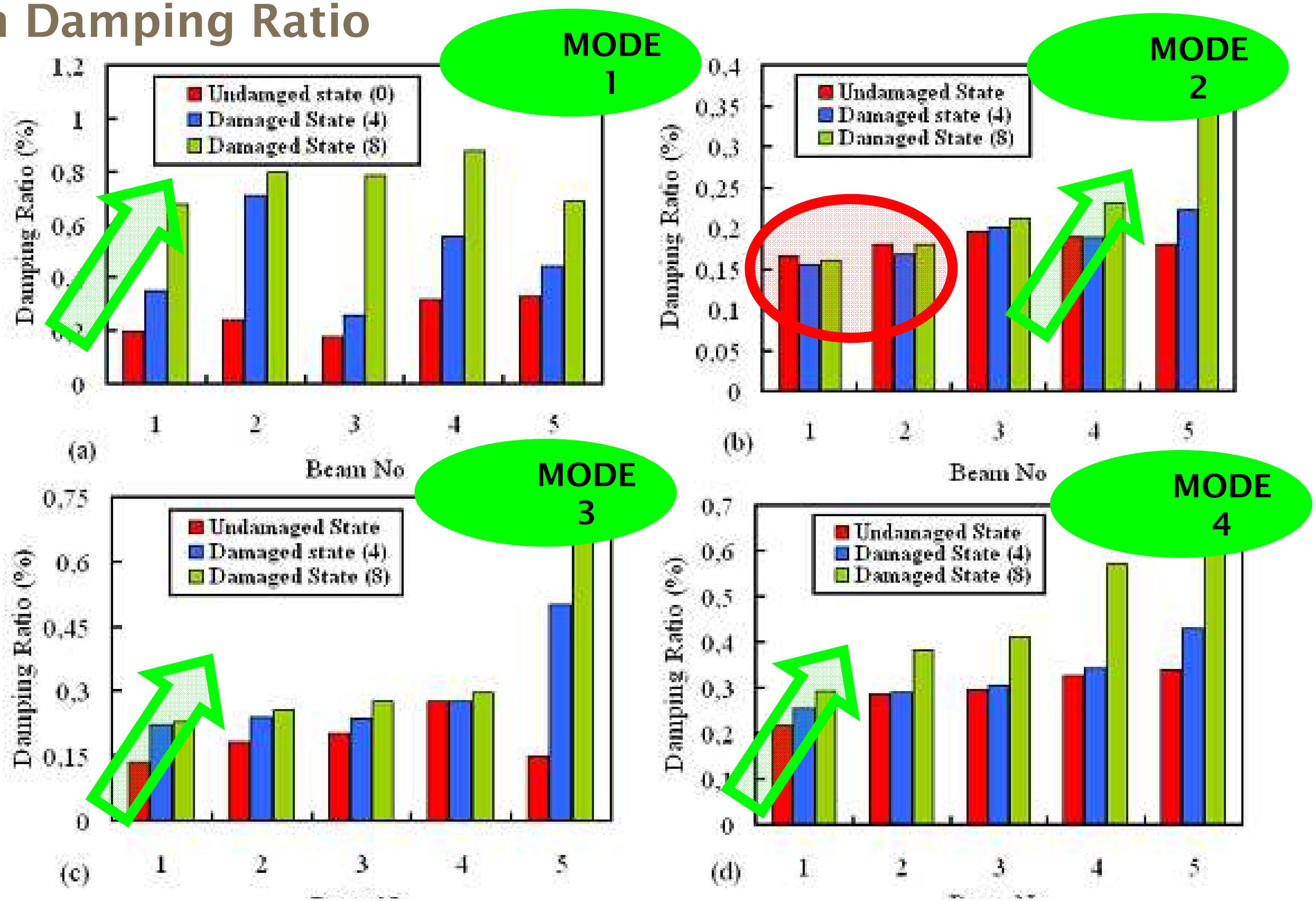


For all modes: Decrease in frequency increases with damage

Shift in frequency is higher for higher modes

Composite Laminates

➢ **Shift in Damping Ratio**



Generally damping increase with damage but sometimes not consistent with damage

Better results with Sine Dwell excitation (non-linearity effects)

DOE: influence of key parameters
2 factors : energy of impact and density of damage

- **Which Modal Parameter is more sensitive to damage ?**
  - ✓ Change in natural frequency = Less than 12%
  - ✓ Change in damping ratio = Up to 200 %

- **Which Design Factor is more sensitive to modal parameters ?**

Design of Experiments

- ✓ Energy of Impact = 6J to 14J
- ✓ Density of Damage = 0 (UD), 4 (D1) and 8 (D2)

By comparing the t-ratios it was found that Energy of Impact is Globally (2nd, 3rd, 4th mode) the more sensitive to the response (modal parameters frequency and damping ratio)

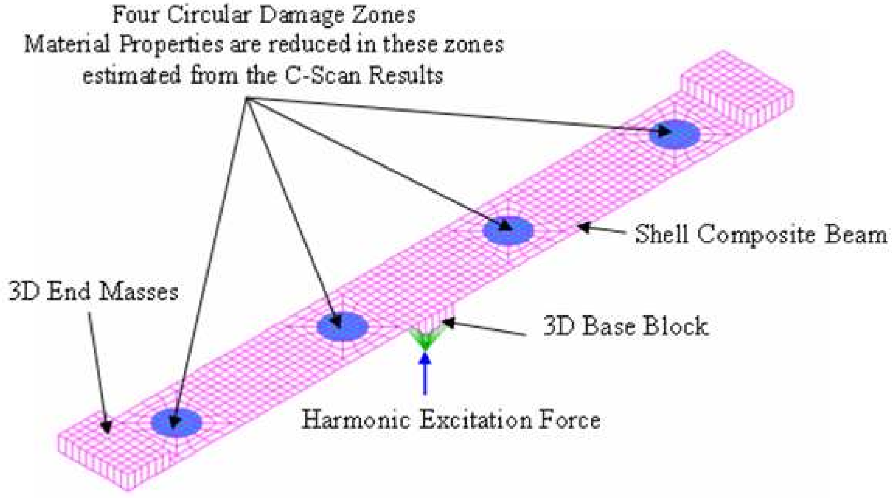
Composite Laminates impacted around BVID

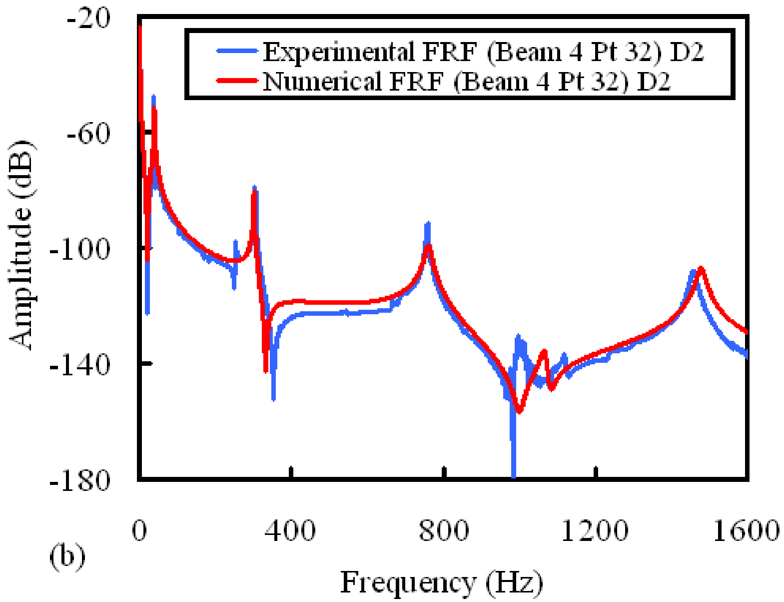
➢ Conclusion

Natural Frequency decreases and damping increases with damage

- ✓ Decrease in frequency consistent with damage unlike damping
- ✓ Damping more sensitive to damage
- ✓ Energy of impact more sensitive to the response (modal parameters)

FEM updating tool (done)

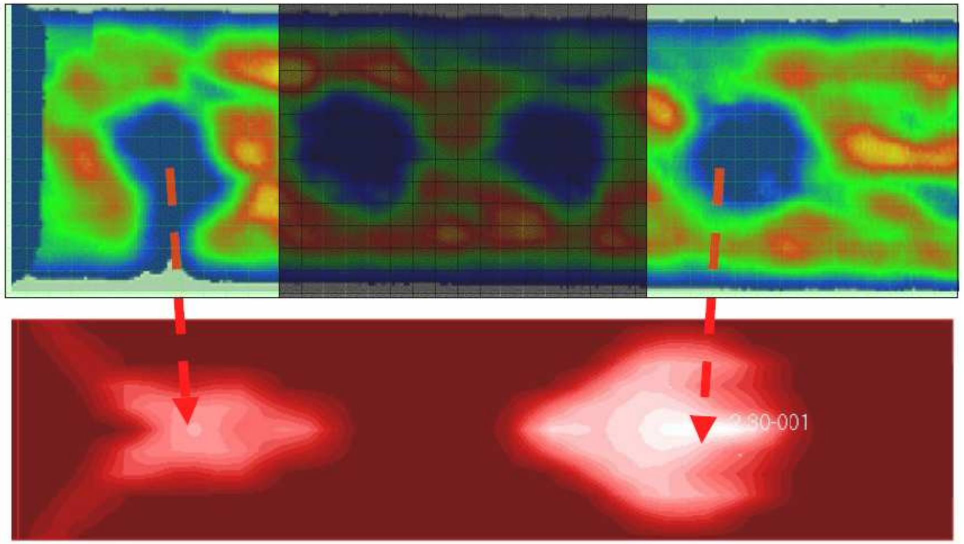


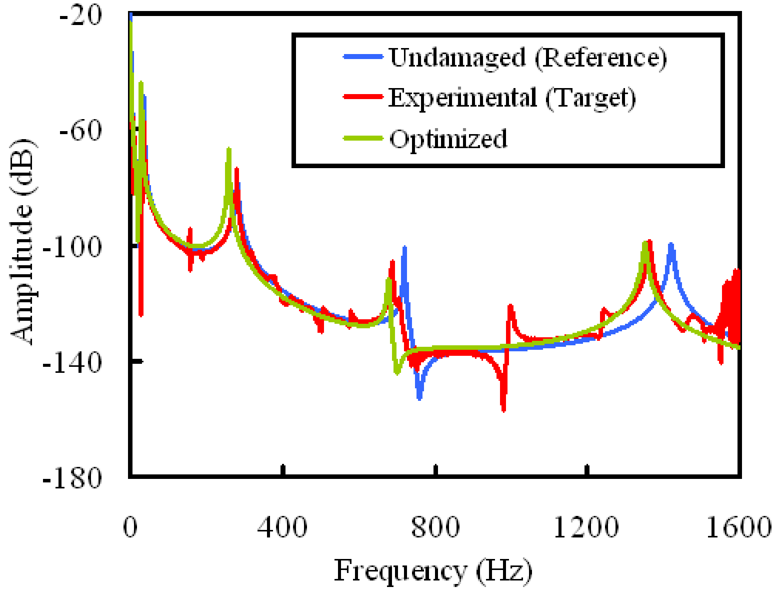


(b)

Future Works

➢ Damage localization using topology optimization (done)

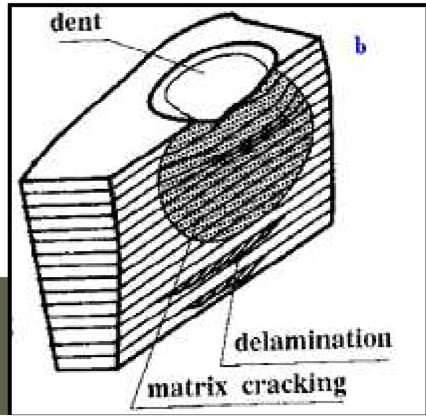




➢ **Vary the impacts: non-symmetric impacts, different shapes of impactor heads to study the effect of different types of damage on modal parameters**

➢ **Precise local modelling of the damage phenomenons**

(ply by ply, shape of the delamination, , matrix cracking etc).



Application: impact detection, localisation and energy estimation on aircraft specific structure (door panel)