AESDO Group
LAQ-AERMEC laboratory

Research activities overview

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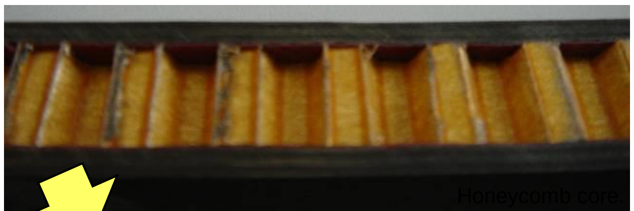
Research topics and experimental facilities

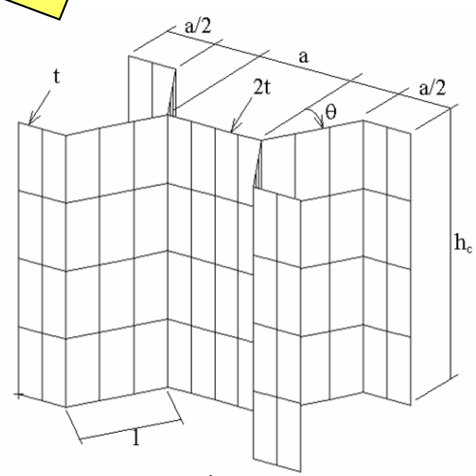
- ❑ Innovative materials characterization
- ❑ Modeling of composite structures
- ❑ Impacts simulation
- ❑ Optimization and probabilistic design
- ❑ Shape sensing and Structural Health Monitoring
- ❑ Experimental facilities (LAQ-AERMEC laboratory)

Innovative materials characterization

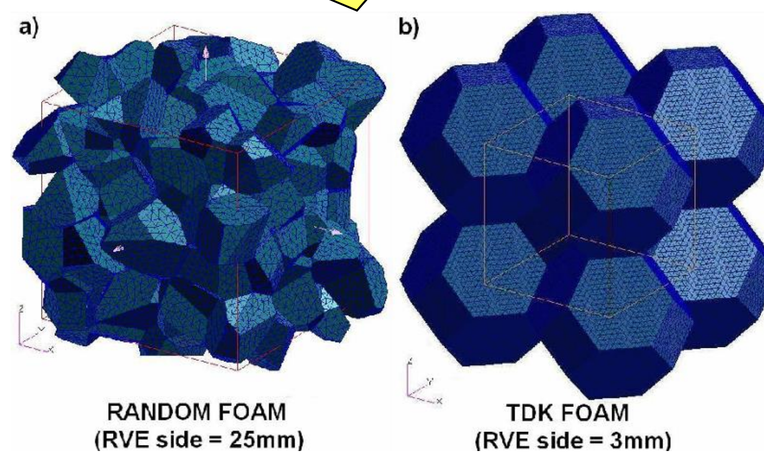
- ❑ Numerical characterization of honeycomb and corrugated cores, metallic foams and other innovative materials

Honeycomb core





Closed cells metallic foam



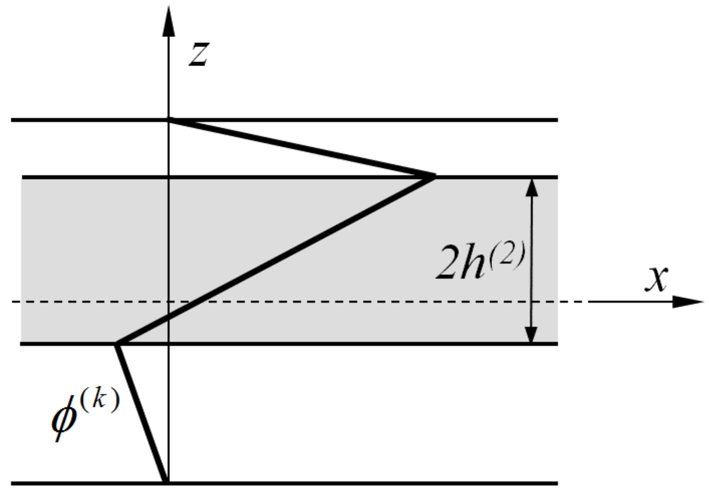
Homogeneous orthotropic lamina.
Equivalent properties through analytical / numerical models

Modeling of composite structures

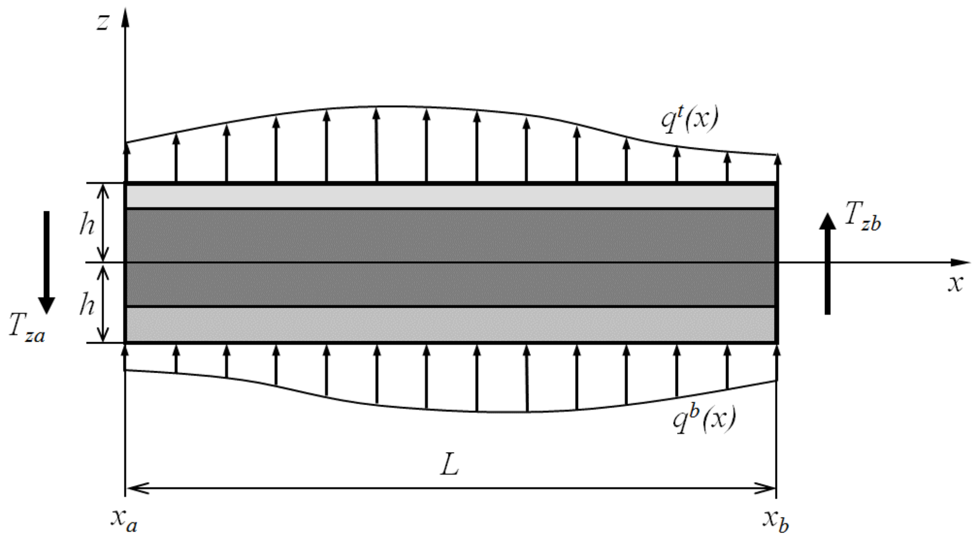
❑ Refined Zigzag Theory (RZT) for beams

$$u_x^{(k)}(x,z) = u(x) + z\,\theta(x) + \phi^{(k)}(z)\psi(x)$$

$$u_z(x,z) = w(x)$$

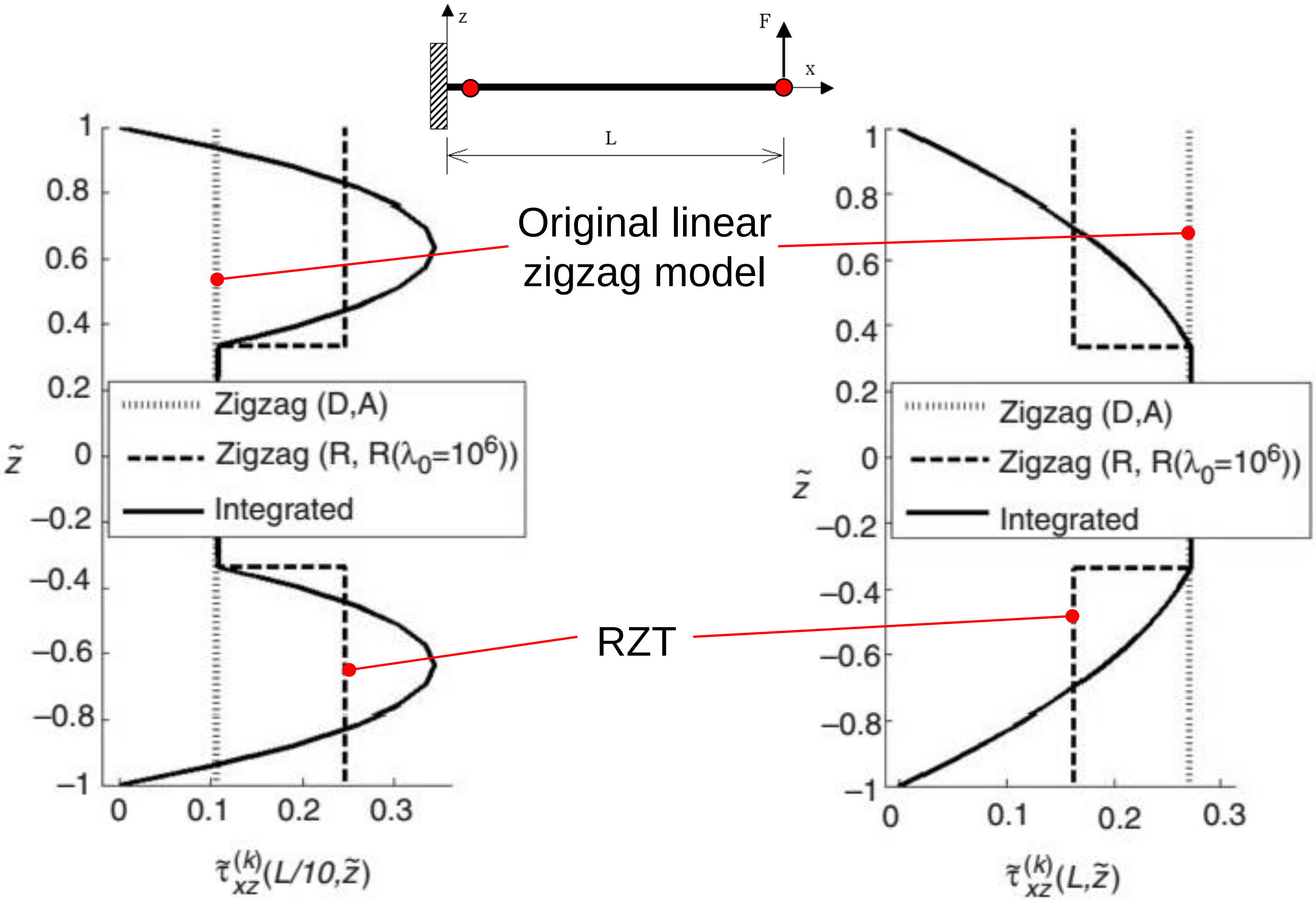


- Based on original linear zigzag model
- One additional kinematic variable w.r.t. linear zigzag model
- Zigzag function from the partial continuity of transverse shear stress and vanishing on top and bottom laminate surfaces
- No anomalies of transverse shear quantities
- C^0 continuity of shape functions for easier finite elements development



❑ Results (RZT exact)

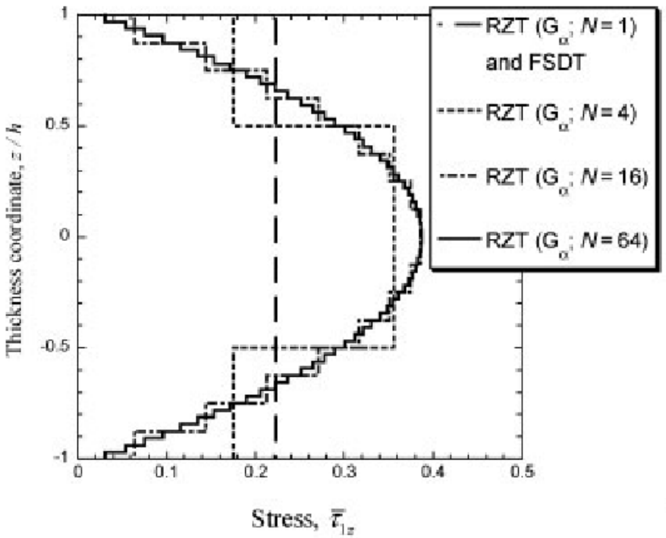
- CF beam, tip transverse load, L/2h=5, symmetric sandwich lay-up



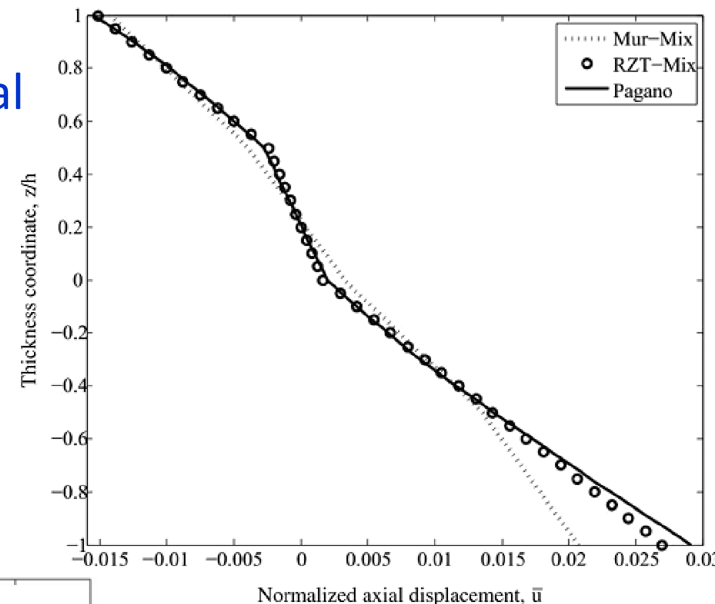
Modeling of composite structures

❑ RZT naturally extended to particular material lay-ups

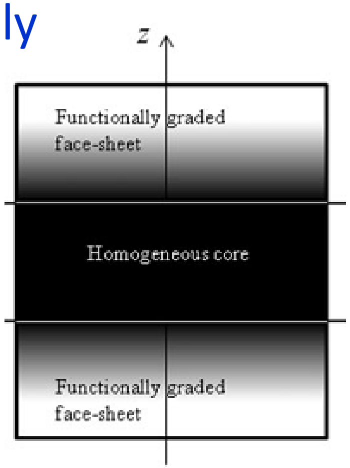
- Single-layered



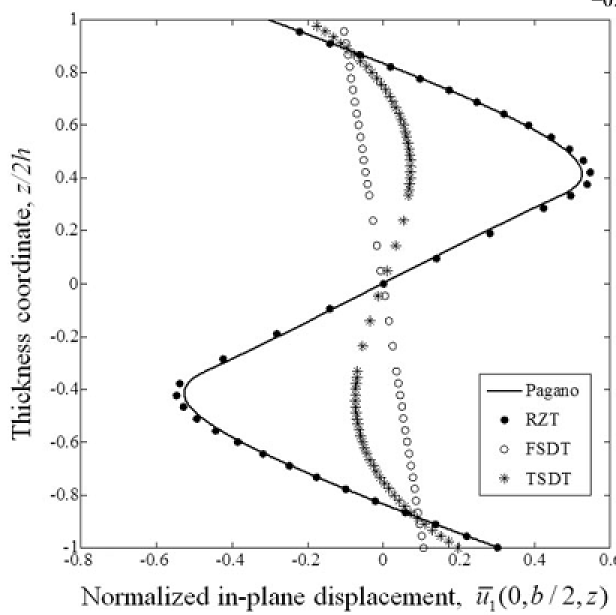
- External weak layers



- Functionally graded materials

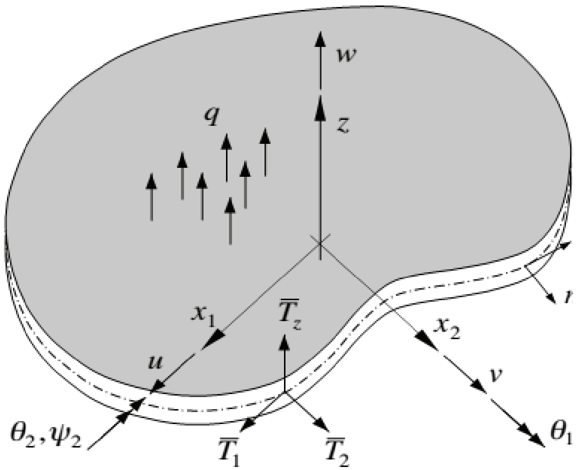


- Angle-ply laminates



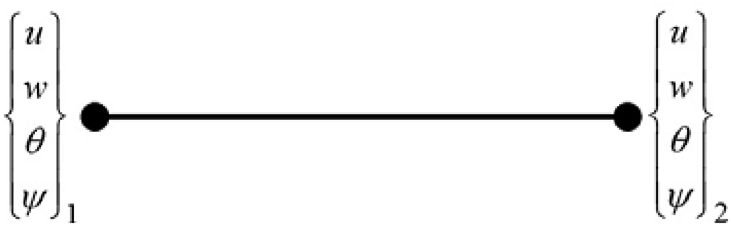
Modeling of composite structures

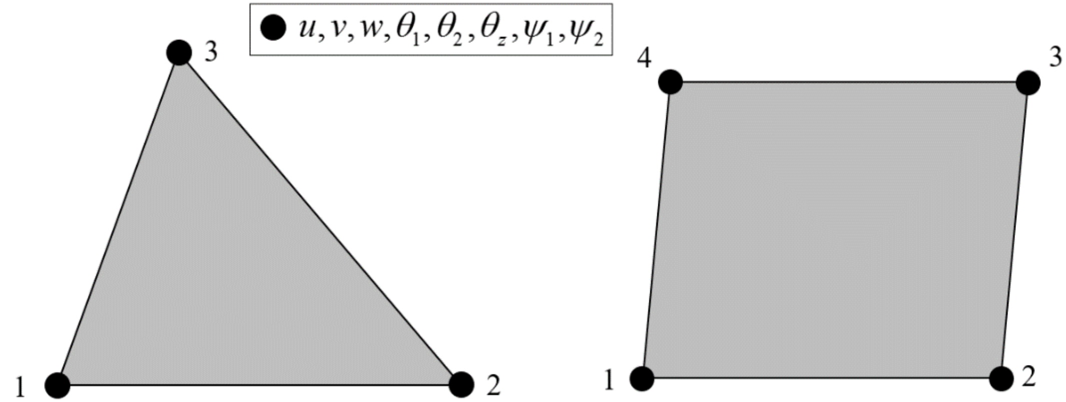
- ❑ RZT for plates



- ❑ Finite elements (beams, plates and shells)

  - Special shape functions to eliminate shear-locking, improve accuracy and reduce computational cost





Modeling of composite structures

❑ Experimental assessment

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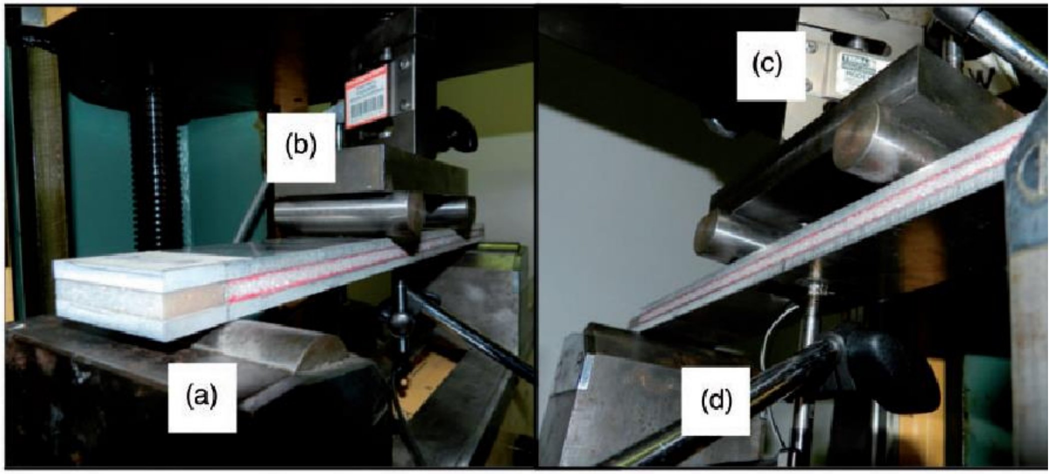
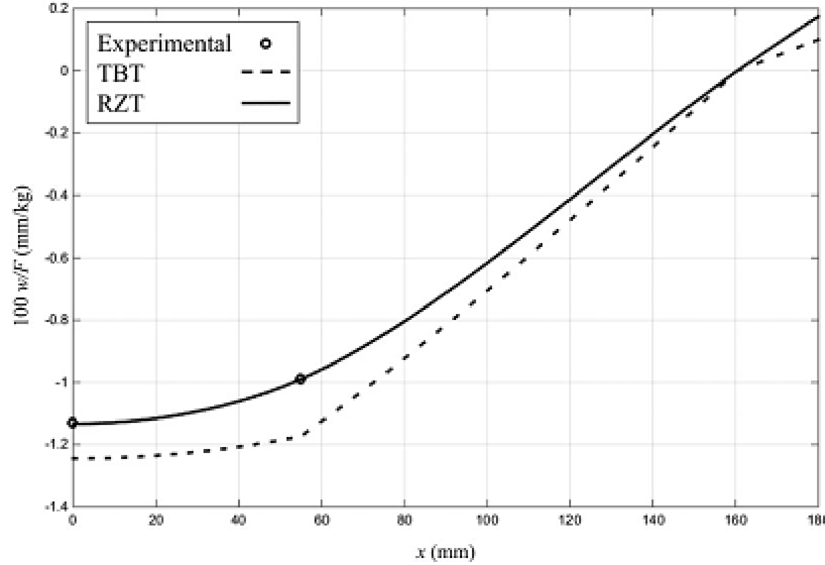
- Static (4PB SS sandwich beams)





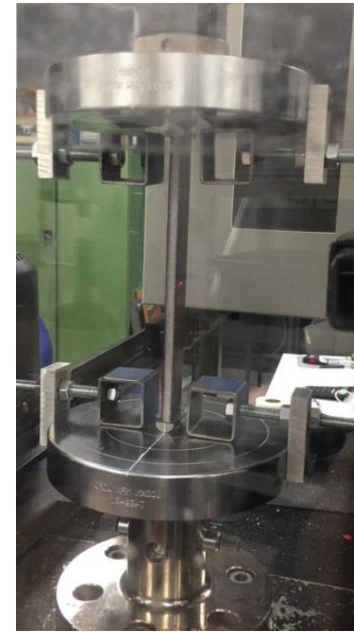
- Dynamic (free vibrations of CF sandwich beams)

Mode	Experimental (Hz)	RZT (%)	TBT ($k^2 = 1.1074 \times 10^{-3}$) (%)
1	83.9	−5.0	−22.1
2	331.5	−7.2	−41.0
3	772.0	−3.9	−53.3
4	1409	−0.3	−62.6
5	2254	1.8	−69.0

Modeling of composite structures

❑ Experimental assessment

RMIT UNIVERSITY



▪ Buckling (sandwich beams)

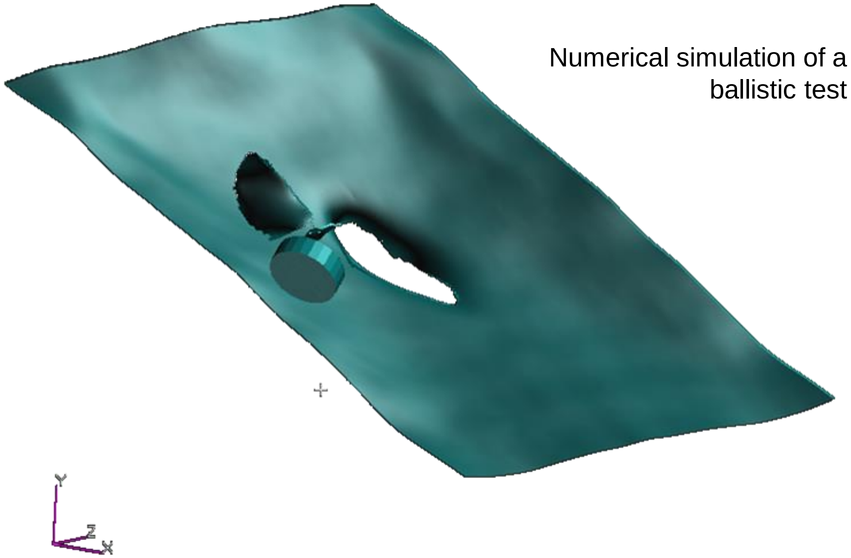
Beam	L	h_c	h_f	EXP (N)	RZT (%)	TBT (%)
WF-1-L1	443	20.00	0.68	24,831	-6.30	-6.31
WF-1-L2	427	20.00	0.68	24,929	0.50	0.49
IG-2-L1	160	5.40	1.45	3,188	1.13	-11.89
IG-4-L1	230	5.00	3.40	11,297	-5.33	-37.50
IG-4-L2	230	5.00	3.40	12,374	-7.88	-38.44

▪ Dynamic (free vibrations of sandwich oil-pan)

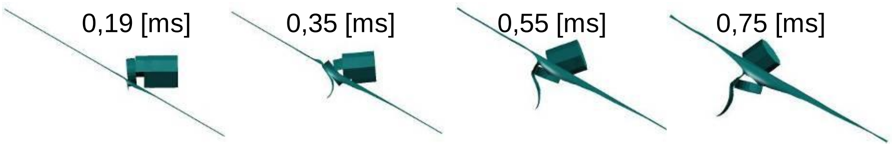
Mode	Experimental	RZT (shell elms)	MSC/NASTRAN (QUAD4 elms)
1	1.00	0.96	0.65
2	1.37	1.41	0.79

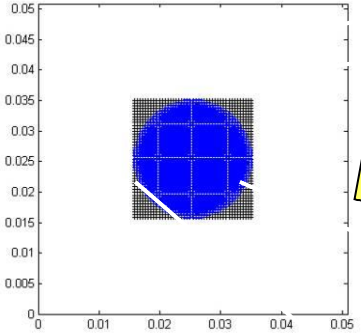
Impacts simulation

- Mid/high velocity impacts - numerical simulations of ballistic tests for the evaluation of containment properties of metallic materials
- Low velocity impacts - analysis of multilayered composite and sandwich structures quasi-statically indented by rigid impactors (evaluation of the contact area and of the pressure distribution)

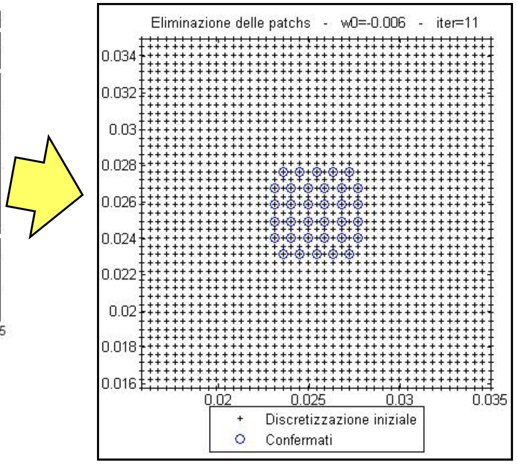


Numerical simulation of a ballistic test





Contact area computation between a rigid spherical indentor and a composite multilayer plate



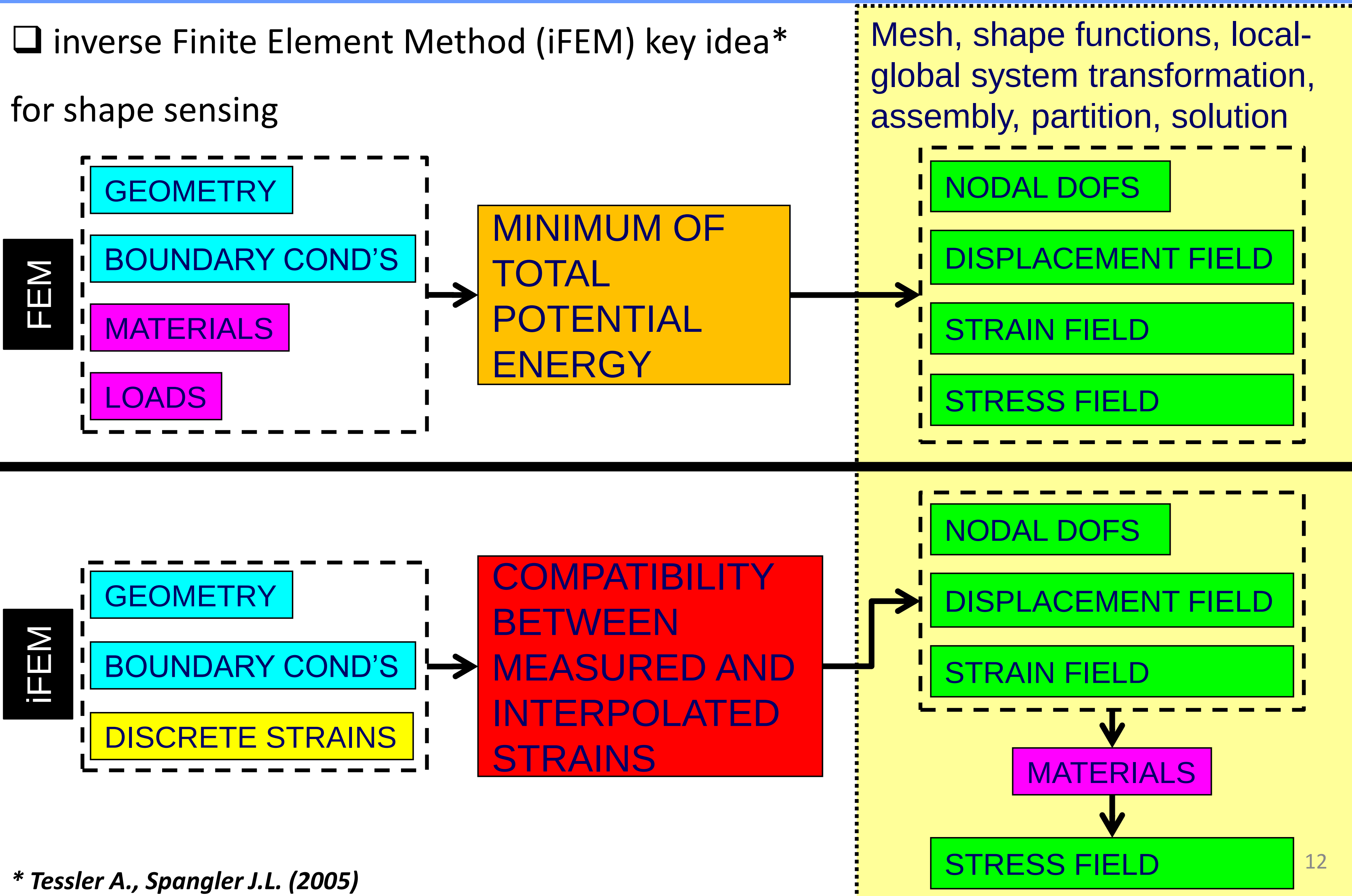
Optimization and probabilistic design

- Design space exploration techniques (DOE, Monte Carlo Simulation)
- Optimization methods based on genetic algorithms
- Multi-objective and multi-disciplinary optimization methods that allow taking into account stochastic variation of design parameters (Reliability Robust Design)
- Optimization of complex engineering systems

Shape sensing and Structural Health Monitoring

- ❑ inverse Finite Element Method (iFEM) key idea*

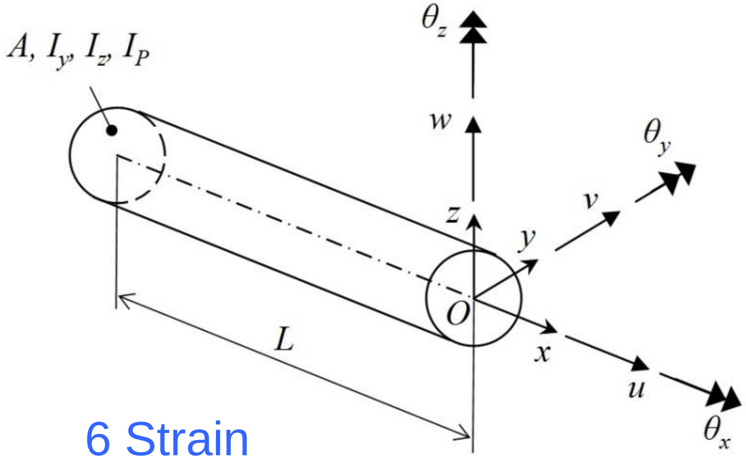
for shape sensing



** Tessler A., Spangler J.L. (2005)*

❑ iFEM for beam and frame structures

- Timoshenko kinematics



6 Strain measures

$$\mathbf{e}(\mathbf{u}) = \begin{Bmatrix} \varepsilon_{x0} \\ \kappa_{y0} \\ \kappa_{z0} \\ \gamma_{z0} \\ \gamma_{y0} \\ \alpha_0 \end{Bmatrix} \equiv \begin{Bmatrix} u_{,x} \\ \theta_{y,x} \\ -\theta_{z,x} \\ \theta_y + w_{,x} \\ -\theta_z + v_{,x} \\ \theta_{x,x} \end{Bmatrix}$$

- Finite element approximation

$$\mathbf{u}(x) = \mathbf{N}(x)\mathbf{q}^e$$

$$\mathbf{e}(\mathbf{u}) = \mathbf{B}(x)\mathbf{q}^e$$

$$\begin{Bmatrix} u \\ v \\ w \\ \theta_x \\ \theta_y \\ \theta_z \end{Bmatrix}_1$$

$$\begin{Bmatrix} u \\ v \\ w \\ \theta_x \\ \theta_y \\ \theta_z \end{Bmatrix}_2$$

❑ iFEM for beam and frame structures

- Least-squares functional to be minimized

$$\Phi^e \equiv w_\varepsilon^e \Phi_\varepsilon^e + w_{\kappa_y}^e \Phi_{\kappa_y}^e + w_{\kappa_z}^e \Phi_{\kappa_z}^e + w_{\gamma_z}^e \Phi_{\gamma_z}^e + w_{\gamma_y}^e \Phi_{\gamma_y}^e + w_\alpha^e \Phi_\alpha^e$$

$$\Phi_\varepsilon^e \equiv \frac{L^e}{2n}\sum_{i=1}^{n}\left[\varepsilon_{x0}(x_i) - \varepsilon_{x0}^{\varepsilon i}\right]^2$$

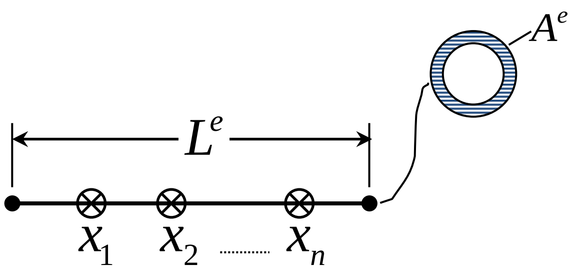
$$\Phi_{\kappa_y}^e \equiv \left(\frac{J_y^e}{A^e}\right)\frac{L^e}{2n}\sum_{i=1}^{n}\left[\kappa_{y0}(x_i) - \kappa_{y0}^{\varepsilon i}\right]^2$$

$$\Phi_{\kappa_z}^e \equiv \left(\frac{J_z^e}{A^e}\right)\frac{L^e}{2n}\sum_{i=1}^{n}\left[\kappa_{z0}(x_i) - \kappa_{z0}^{\varepsilon i}\right]^2$$

$$\Phi_{\gamma_z}^e \equiv \frac{L^e}{2n}\sum_{i=1}^{n}\left[\gamma_{z0}(x_i) - \gamma_{z0}^{\varepsilon i}\right]^2$$

$$\Phi_{\gamma_y}^e \equiv \frac{L^e}{2n}\sum_{i=1}^{n}\left[\gamma_{y0}(x_i) - \gamma_{y0}^{\varepsilon i}\right]^2$$

$$\Phi_\alpha^e \equiv \left(\frac{J_p^e}{A^e}\right)\frac{L^e}{2n}\sum_{i=1}^{n}\left[\alpha_0(x_i) - \alpha_0^{\varepsilon i}\right]^2$$



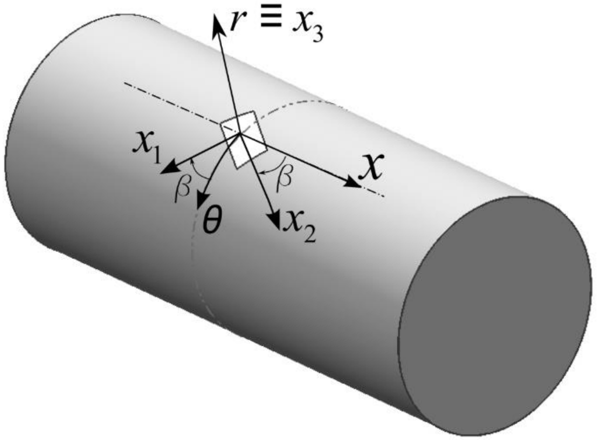
n = number of locations along the beam length where the strain measures are available

$$\frac{\partial \Phi^e}{\partial \mathbf{q}^e} = 0 \quad \Rightarrow \quad \mathbf{a}^e \mathbf{q}^e = \mathbf{b}^e$$

Shape sensing and Structural Health Monitoring

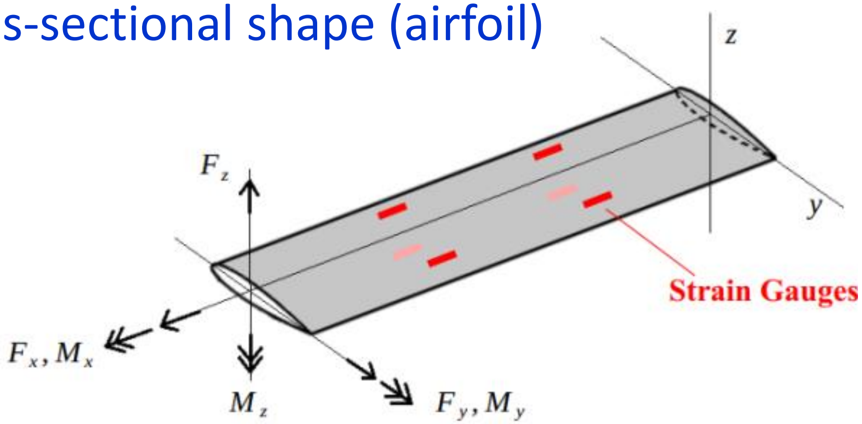
- iFEM for beam and frame structures

  - Strain measures from surface strain measurements (circular cross section)



$$
\begin{aligned}
\varepsilon_2\left(x_i,\beta,\theta\right) = & \left(\cos^2\beta - \nu\sin^2\beta\right)\underline{\varepsilon_{x0}\left(x_i\right)} + \\
& +\left(\cos^2\beta - \nu\sin^2\beta\right)R_{ext}\sin\theta\,\underline{\kappa_{y0}\left(x_i\right)} + \\
& +\left(\cos^2\beta - \nu\sin^2\beta\right)R_{ext}\cos\theta\,\underline{\kappa_{z0}\left(x_i\right)} + \\
& +\left(\cos\beta\sin\beta\right)\cos\theta\,\underline{\gamma_{z0}\left(x_i\right)} + \\
& -\left(\cos\beta\sin\beta\right)\sin\theta\,\underline{\gamma_{y0}\left(x_i\right)} + \\
& +\left(\cos\beta\sin\beta\right)R_{ext}\underline{\alpha_0\left(x_i\right)}
\end{aligned}
$$

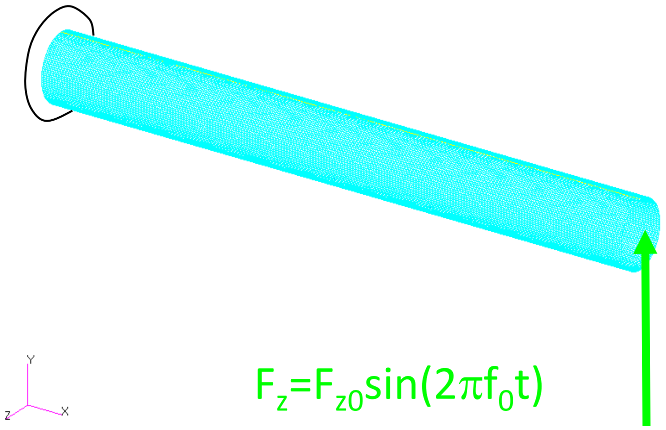
  - Extension to more complex cross-sectional shape (airfoil)



Shape sensing and Structural Health Monitoring

❑ Results

- CF beam, thin-wall cross section, tip harmonic force

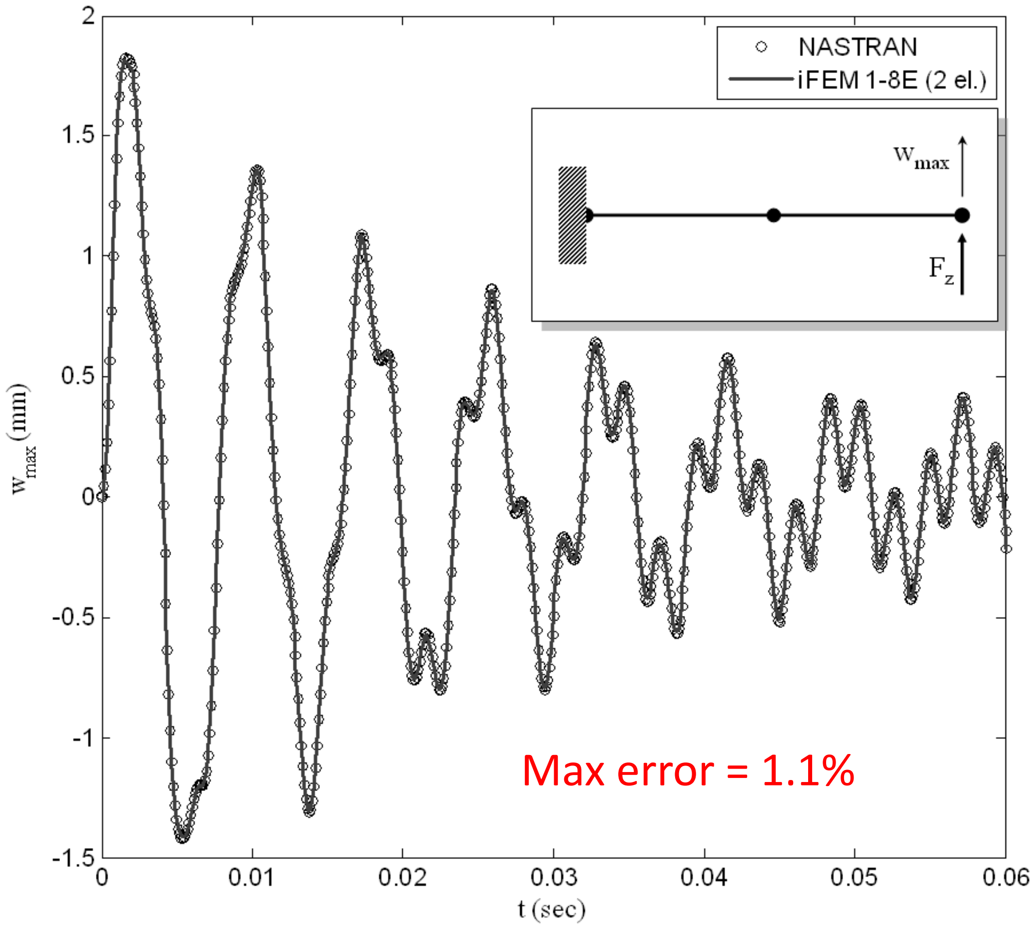


Viscous damping 5% with respect to the critical value at each frequency

f_0=450 Hz (about halfway between 1F and 2F modes)

2 beam inverse elms

16 strain gauges



Shape sensing and Structural Health Monitoring

❑ Experimental results (static)

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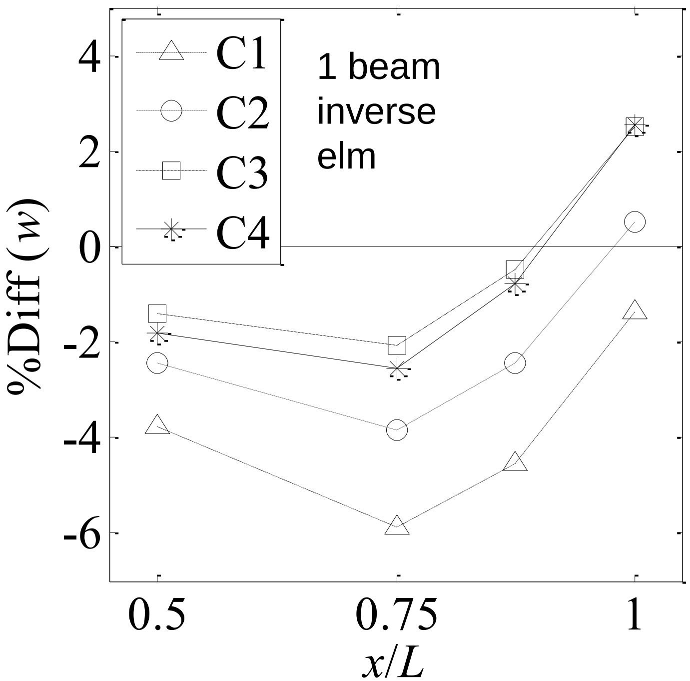
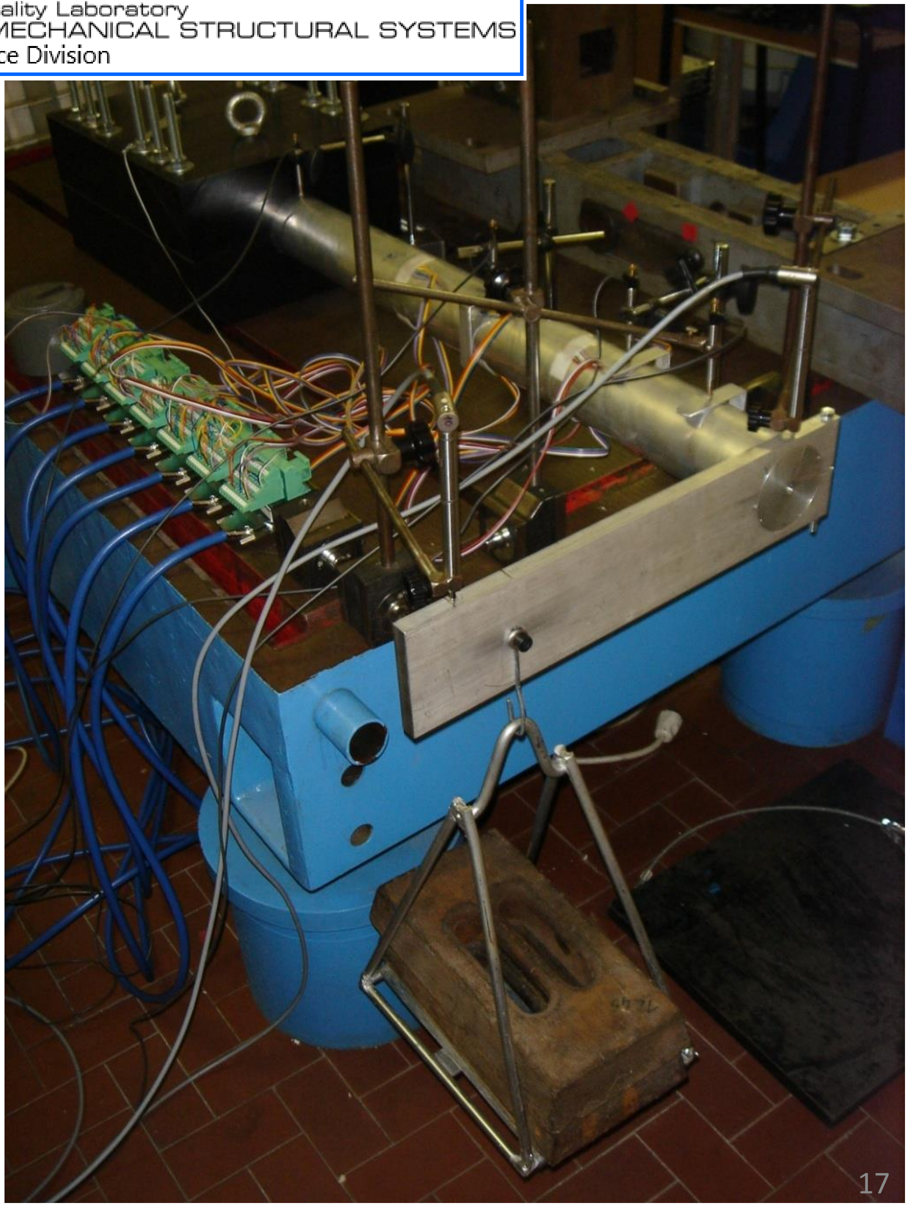
- CF beam, thin-wall cross section
- Several tip load configurations
- Strain rosettes and displacement transducers
- Several strain rosettes configurations (C_1, C_2, C_3, C_4)





Shape sensing and Structural Health Monitoring

❑ Experimental results (dynamic)

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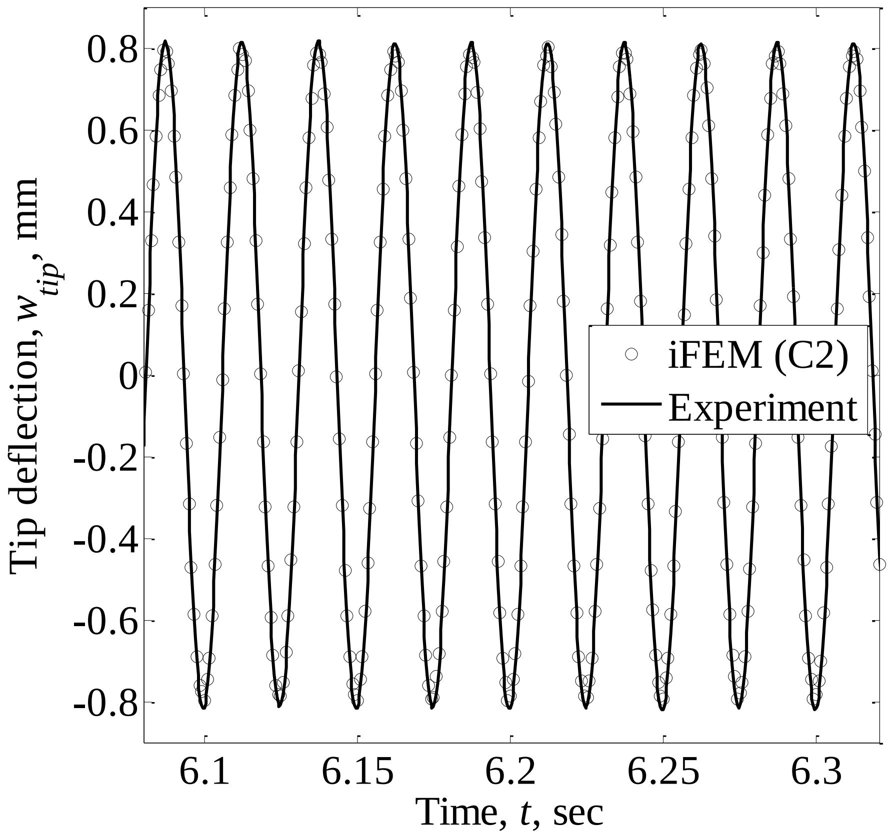
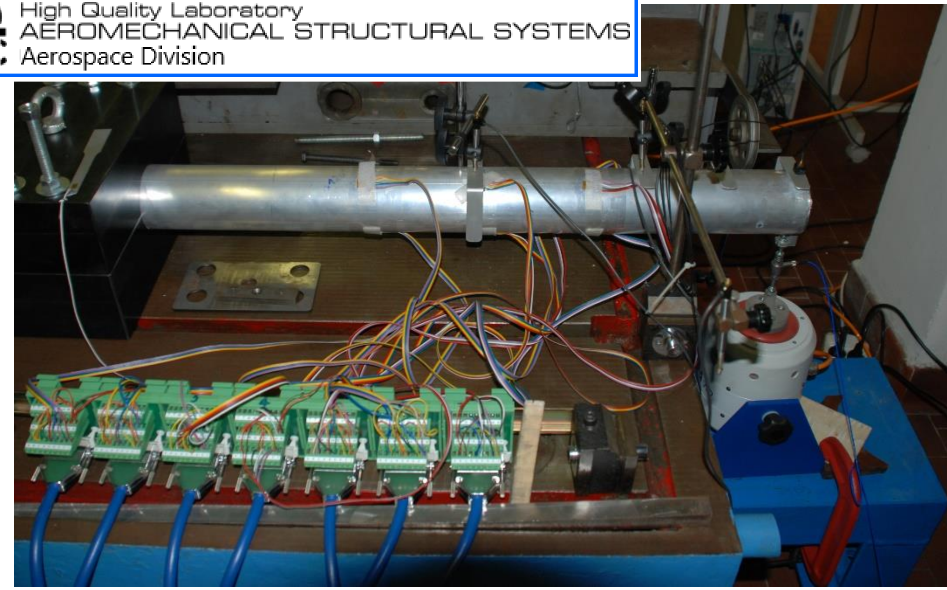
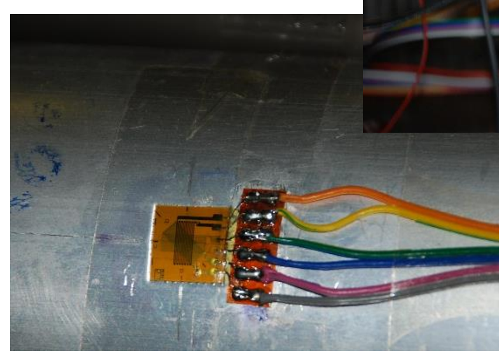
- CF beam, thin-wall cross section
- Tip harmonic force (80 Hz)
- Strain rosettes and one accelerometer
- Several strain rosettes configurations





1 beam inverse elm



Shape sensing and Structural Health Monitoring

❑ Experimental results (static)

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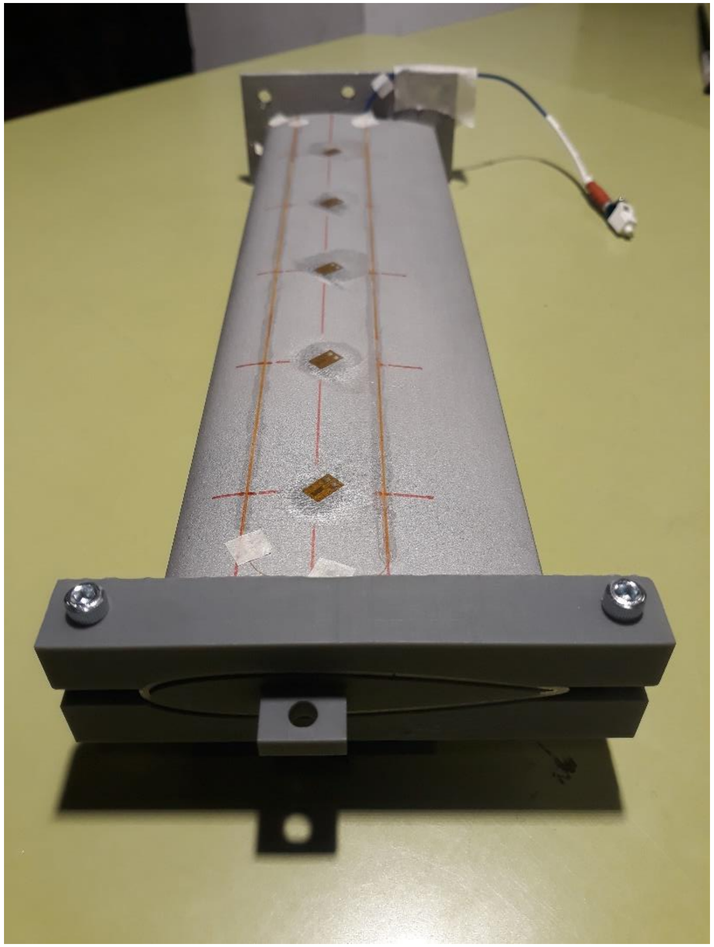
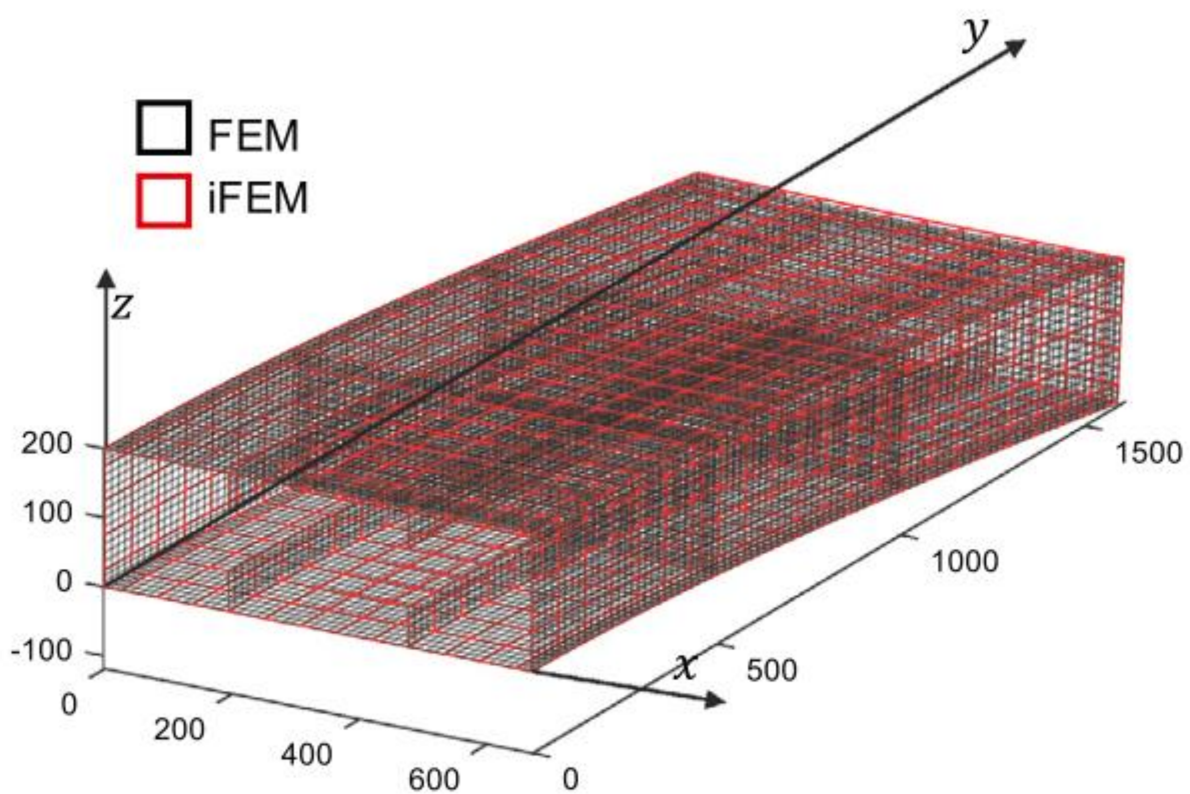
- On-going experimental campaign on 3D printed airfoil beam (with fiber optical sensors and strain gauges)



Shape sensing and Structural Health Monitoring

❑ iFEM for plate and shell structures

- Numerical application to composite wing boxes



Shape sensing and Structural Health Monitoring

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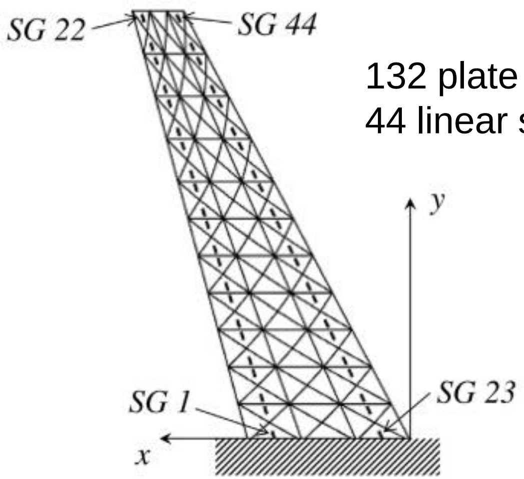
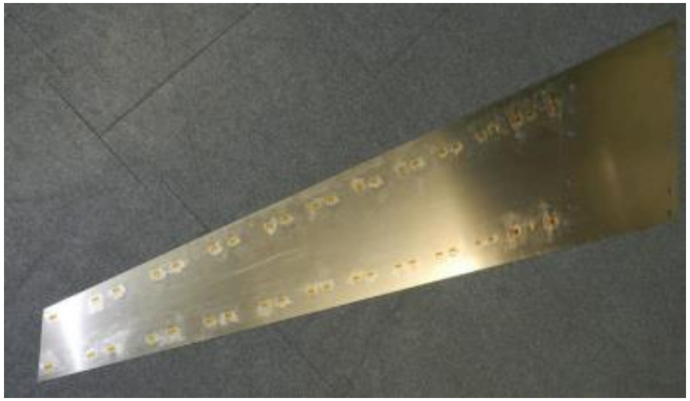
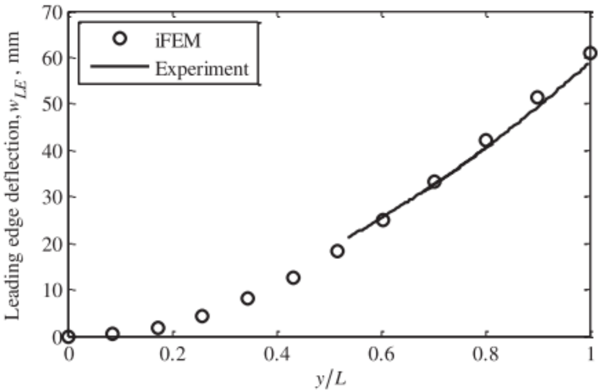
❑ iFEM for plate and shell structures

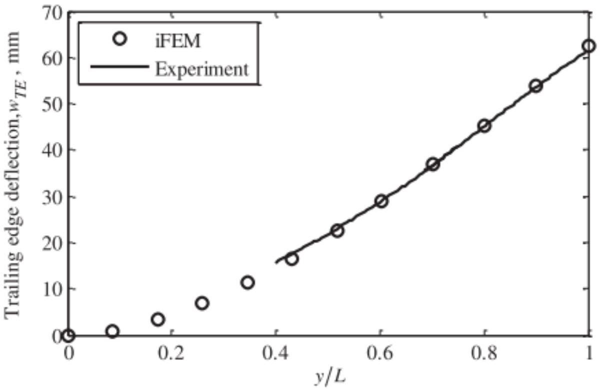
- Experimental results (static)
- Wing-shaped plate (own weight)
- Linear strain gages



132 plate tria inverse elms
44 linear strain gages







Shape sensing and Structural Health Monitoring

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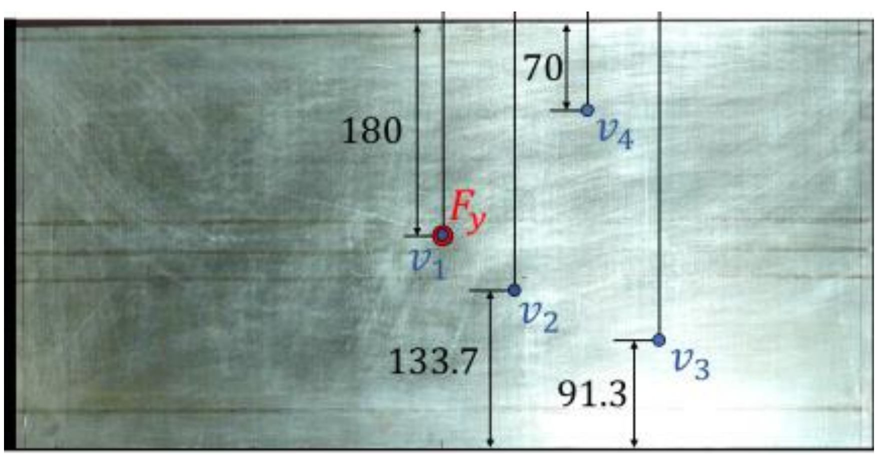
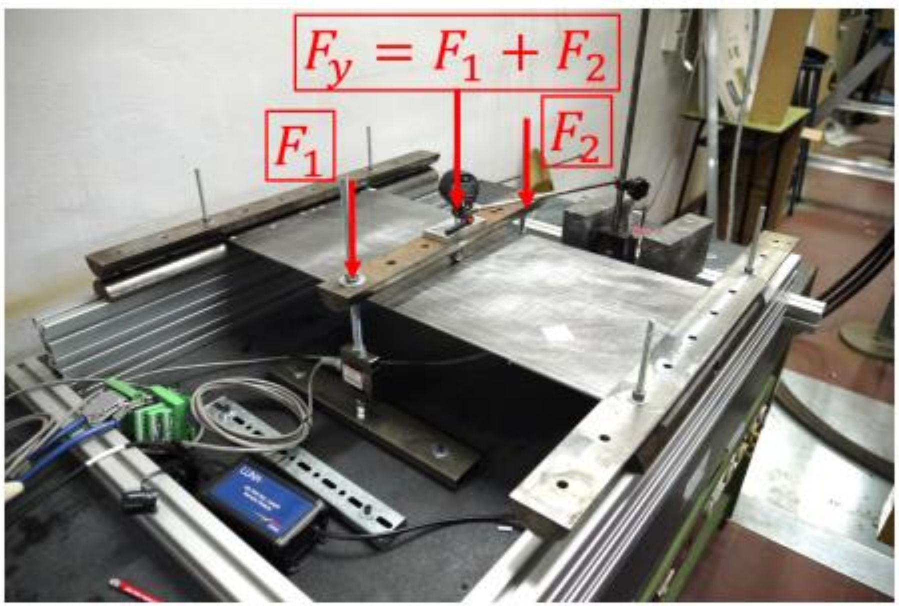
❑ iFEM for plate and shell structures

- Experimental results (static)
- Stiffened plate (concentrated force)
- Fiber-optic strain sensors

	2-step	MM [1-22]	MM [1, 2, 3, 8, 12]	iFEM
$\%\overline{Err}_{F_y}$	2.0%			
$\%\overline{Err}_{v_1}$	6.0%	3.9%	2.8%	1.6%
$\%\overline{Err}_{v_2}$	7.7%	7.0%	3.8%	0.6%
$\%\overline{Err}_{v_3}$	6.4%	0.9%	2.3%	1.4%
$\%\overline{Err}_{v_4}$	2.3%	31.2%	7.9%	2.2%
$\%\overline{Err}_{v}$	5.6%	10.8%	4.2%	1.5%



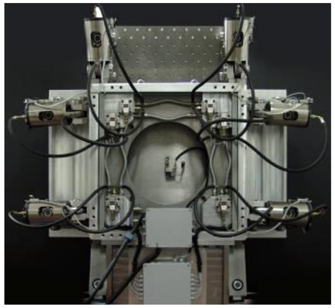


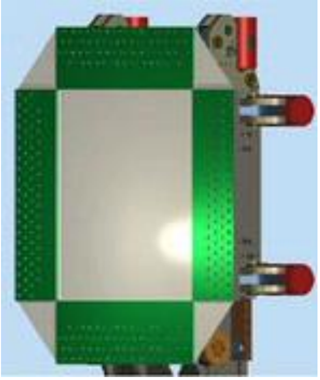
Experimental facilities (LAQ-AERMEC laboratory)

❑ Multi-purpose testing facility

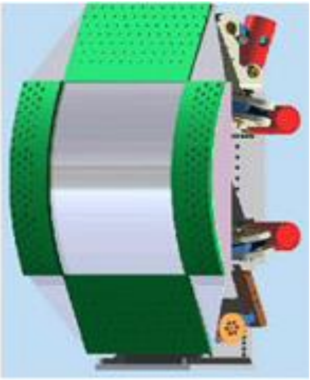
- possibility to test flat and curved panels
- six loading axes (maximum load, static and dynamic, 300 [kN]) whose action is independent)
- possibility to simulate pressurization effects (up to 1.5 [bar])

	Overall dimensions [mm]	Effective test dimensions [mm]	Curvature radius [mm]
Flat panels	1600 x 1600	1000 x 1000	-
Curved panels	1600 x ~1900	1000 x ~1000	1500





Flat panel configuration.



Curved panel configuration.

Experimental facilities (LAQ-AERMEC laboratory)

- ❑ Gas-gun ballistic facilities

- systems composed by a tank, a barrel and by a shooting system based on an electrical-resistance
- velocity is measured by means of three laser emitters and three photodiodes
- a digital camera with a flash lamps unit system allow getting some images of the projectile while it approaches the target and when the impact occurs.)

GAS-GUN #1
- ✓ Maximum tank pressure: 50 [bar]
- ✓ Barrels length: 4 / 6 / 10 [m]
- ✓ Barrels inside diameter: 4 / 6 / 8 [in]

GAS-GUN #2
- ✓ Maximum tank pressure: 16 [bar]
- ✓ Barrels length: from 1.5 to 4 [m]
- ✓ Barrels inside diameter: 38 [mm]

Experimental facilities (LAQ-AERMEC laboratory)

❑ Experimental modal analysis

- Complete set of sensors, actuators and acquisition systems to perform EMA – Experimental Modal Analysis on small-to-mid size structures
- Data acquisition system LMS SCADAS III + Testlab (16 input channels for AC-DC-IEPE sensors, 2 output channels for sine, random, shock, burst, closed loop actuator control)
- IEPE miniature accelerometers
- IEPE force transducers
- Impact hammer
- Modal shakers (10 [N], 50 [N], 100 [N])
- Dynamic Exciter TIRA TV 56280 LS (8000 [N])
- Signal conditioning devices