Presentation PhD Student XXXV – **Azzara Rodolfo**

∟ Department of Mechanical and Aerospace Engineering – Politecnico di Torino

PhD research theme

The development of advanced theories for the linear and nonlinear static and dynamic analysis of aerospace structures.

Supervisor ***Prof. Erasmo Carrera***

Collaborations with companies

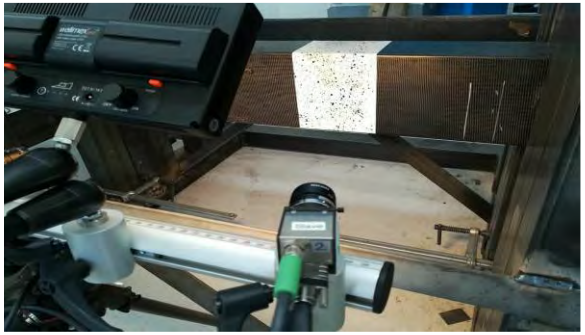
Static and dynamic experimental analysis of a full-composite VLA aircraft.

September 24, 2020
Turin

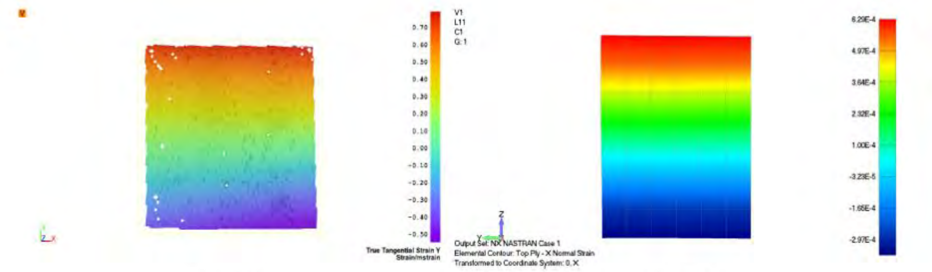
Static Test and Dynamic Test

∟ Digital Image Correlation (DIC)

∟ Operational Modal Analysis (OMA)



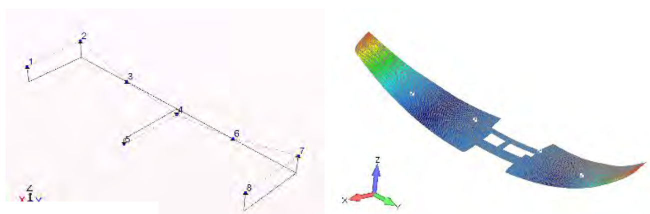
Test area after superficial treatment and during image acquisition.



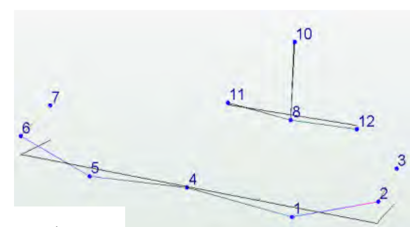
(a) DIC (b) FEM

Aspect was suspended with dedicated springs.

Preparation for GVT



Mode 1



Mode 6

Pagani, A., Azzara, R., Carrera, E., Zappino, E., “Static and dynamic testing of a full-composite VLA” (2020), submitted.

Numerical Dynamic analysis

∟ Target and formulations

- <u>Target</u>: comprehensive and efficient tool for flexible-aircraft analysis.

- Formulations:
  - ❑ CARRERA UNIFIED FORMULATION (CUF)

    $$\boldsymbol{u}(x,y,z;t) = F_\tau(x,z)N_i(y)\boldsymbol{q}_{\tau i}(t)$$

  - ❑ NEWMARK METHOD

    $$\dot{\boldsymbol{q}}_{t+\Delta t} = \dot{\boldsymbol{q}}_t + [(1-\delta)\ddot{\boldsymbol{q}}_t + \delta\ddot{\boldsymbol{q}}_{t+\Delta t}]\Delta t$$

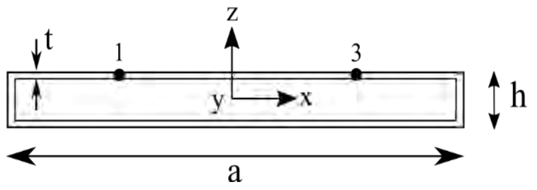
    $$\boldsymbol{q}_{t+\Delta t} = \boldsymbol{q}_t + \dot{\boldsymbol{q}}_t\Delta t + \left[\left(\frac{1}{2}-\alpha\right)\ddot{\boldsymbol{q}}_t + \alpha\ddot{\boldsymbol{q}}_{t+\Delta t}\right]\Delta t^2$$

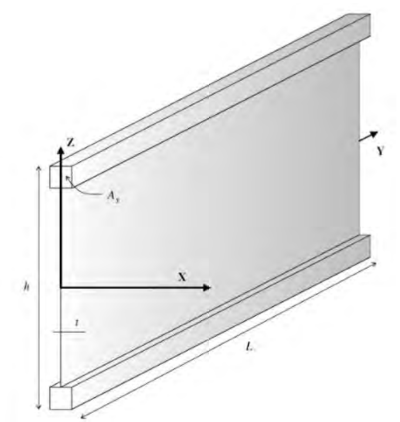
  - ❑ MODE SUPERPOSITION METHOD

    $$\boldsymbol{q}^m(t) = \sum_{i=1}^{m}\boldsymbol{\Phi}_i x_i(t)$$

  - ❑ LAPLACE FORMULATION

    $$\boldsymbol{F}(s) = \mathcal{L}\{\boldsymbol{f}(t)\} = \int_0^\infty e^{-st}\boldsymbol{f}(t)dt$$

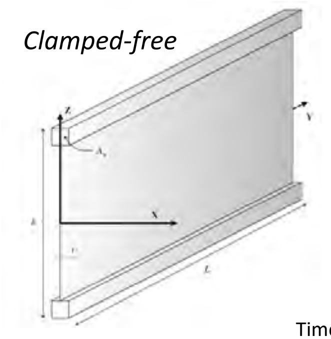


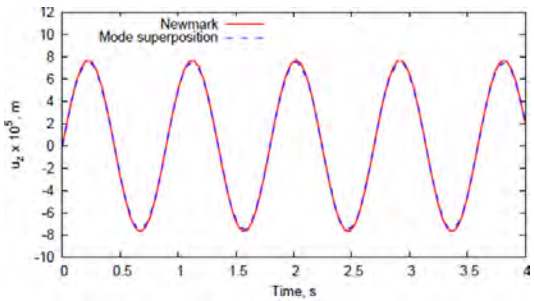


Two-Stringer spar and Complete NACA wing

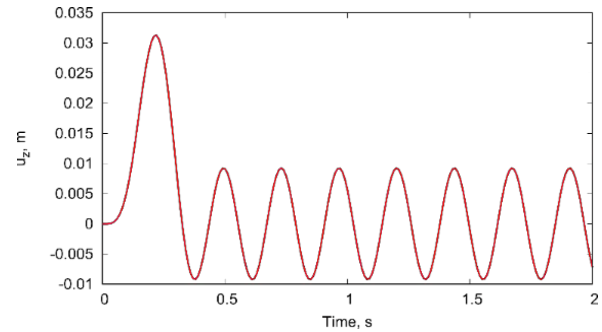
- Sinusoidal load
- Gust response analysis

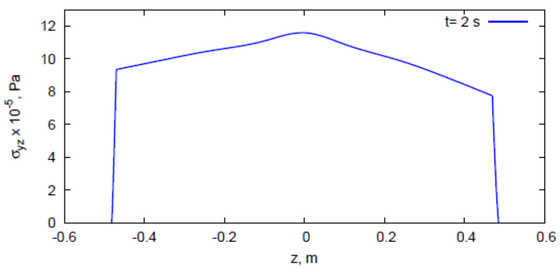
Clamped-free

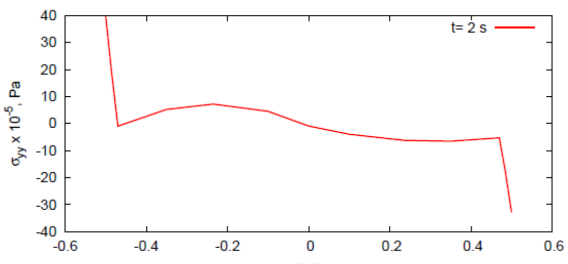


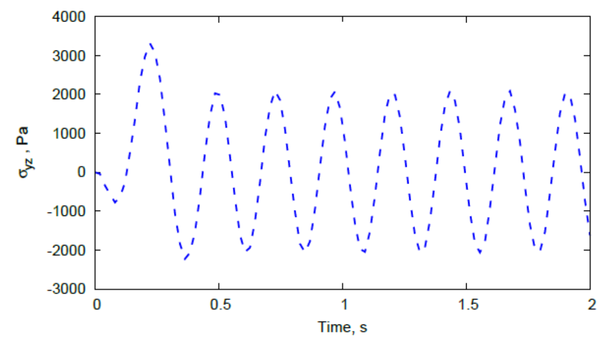


Time-dependent transverse displacement at mid-span. Comparison between the Newmark method and the mode superposition method. L9 beam model.









Time-dependent transverse displacement and stress at the trailing edge of the NACA wing tip. Mode superposition method.

Azzara, R., Carrera, E., Filippi, M., Pagani, A., “Time response stress analysis of solid and reinforced thin-walled structures by component-wise models” (2020), submitted.

Nonlinear Static analysis

∟ Target and formulations

Target: Accurate stress distributions of thin-walled isotropic and composite structures in the large displacement field via two-dimensional unified *shell* models.

- Formulations:
  - ❑ 2D CARRERA UNIFIED FORMULATION (CUF)

$$\boldsymbol{u}(\alpha,\beta,z) = F_\tau(z)N_i(\alpha,\beta)\boldsymbol{q}_{\tau i}$$

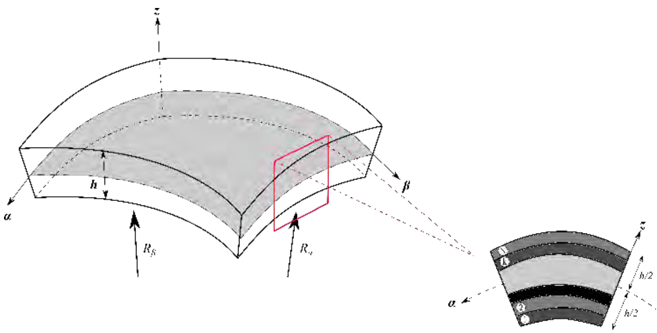
  - ▪ *Geometrical Nonlinearity*

$$\boldsymbol{\varepsilon} = \boldsymbol{\varepsilon}_{\boldsymbol{l}} + \boldsymbol{\varepsilon}_{\boldsymbol{nl}} = (\boldsymbol{b}_{\boldsymbol{l}}+\boldsymbol{b}_{\boldsymbol{nl}})\boldsymbol{u}$$

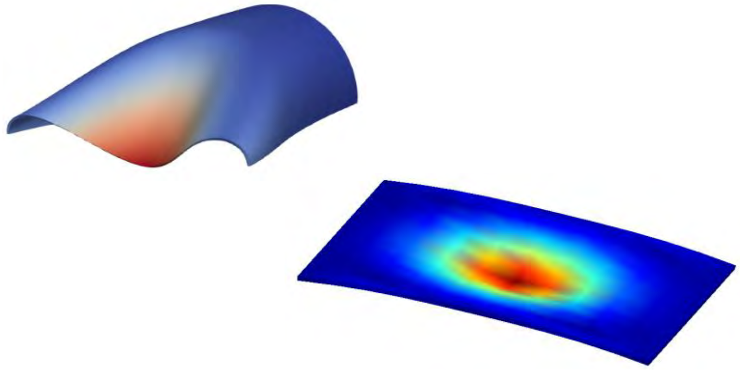
  - ❑ NEWTHON-RAPHSON METHOD

$$\begin{cases} \boldsymbol{K}_T\delta\boldsymbol{q} = \delta\lambda\boldsymbol{p}_{ref} - \varphi_{res} \\ c(\delta q, \delta\lambda) = 0 \end{cases}$$

using the *arc-length path-following* constraint scheme.



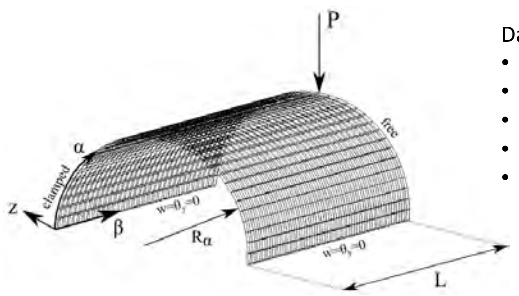
Geometry and reference system of a generic laminated doubly-curved shell.



K. Y. Sze, X. H. Liu, and S. H. Lo. Popular benchmark problems for geometric nonlinear analysis of shells. Finite Elements in Analysis and Design, 40:1551-1569, 2004.

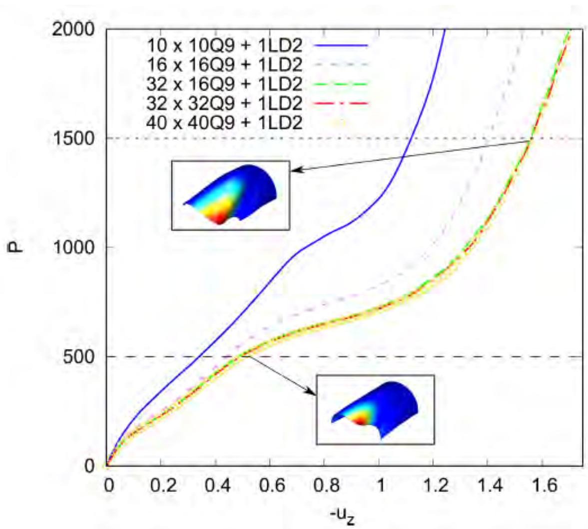
Numerical Results

Pinched cylindrical shell *isotropic*

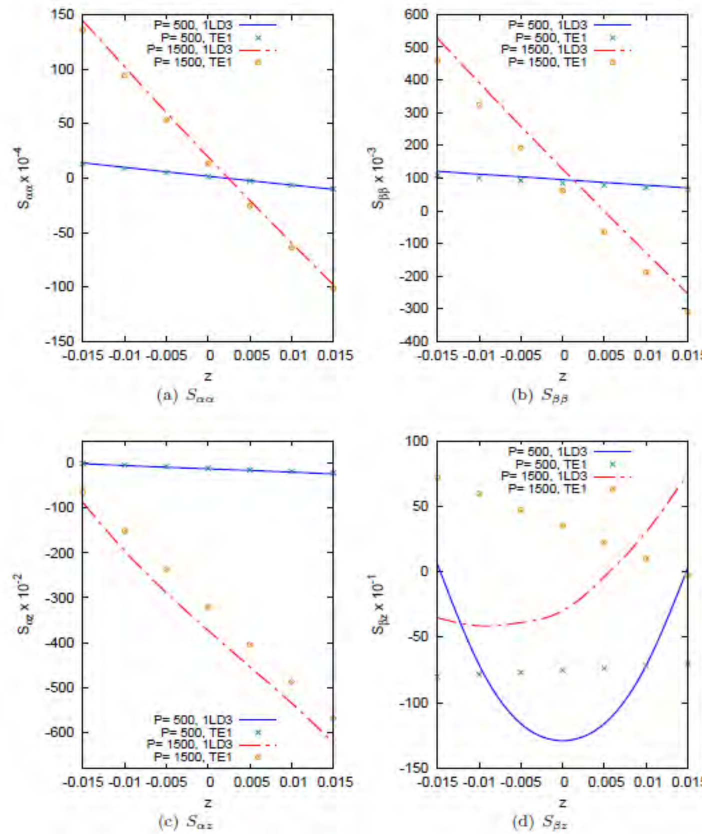


Data:

- L= 3.048
- $R_\alpha = 1.016$
- h= 0.03
- E= 2.0685x10^7
- v= 0.3



Convergence analysis of non-linear response curves for the isotropic pinched semi-cylindrical shell. Comparison of different in-plane mesh numbers.



Through-thickness distribution of PK2 stresses for different loads at α= 1.59512, β= 1.524. 32 x 32Q9 + 1LD3 model.

Pagani, A., Azzara, R., Augello, R., Carrera, E., Wu, B., “Accurate through-the-thickness stress distributions in thin-walled metallic structures subjected to large displacements and large rotations” (2020), submitted.

Pagani, A., Azzara, R., Augello, R., Carrera, E., “Stress states in highly flexible thin-walled composite structures by unified shell model” (2020), submitted.

Future works

- Introduction of aerodynamic and non-structural mass in gust load analyses.
- Coupling geometrical nonlinear analysis and dynamic formulations.
- Introduction of damping formulations in static and dynamic analyses.
- Coupling flight mechanics and structural formulation to perform aeroelastic analyses.

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