Vibrations des structures & acoustique
TP1 : modélisation
- modèles système
- problèmes directs et inverses

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ENSAM/PIMM, SDTools

http://savoir.ensam.eu/moodle/course/view.php?id=2158
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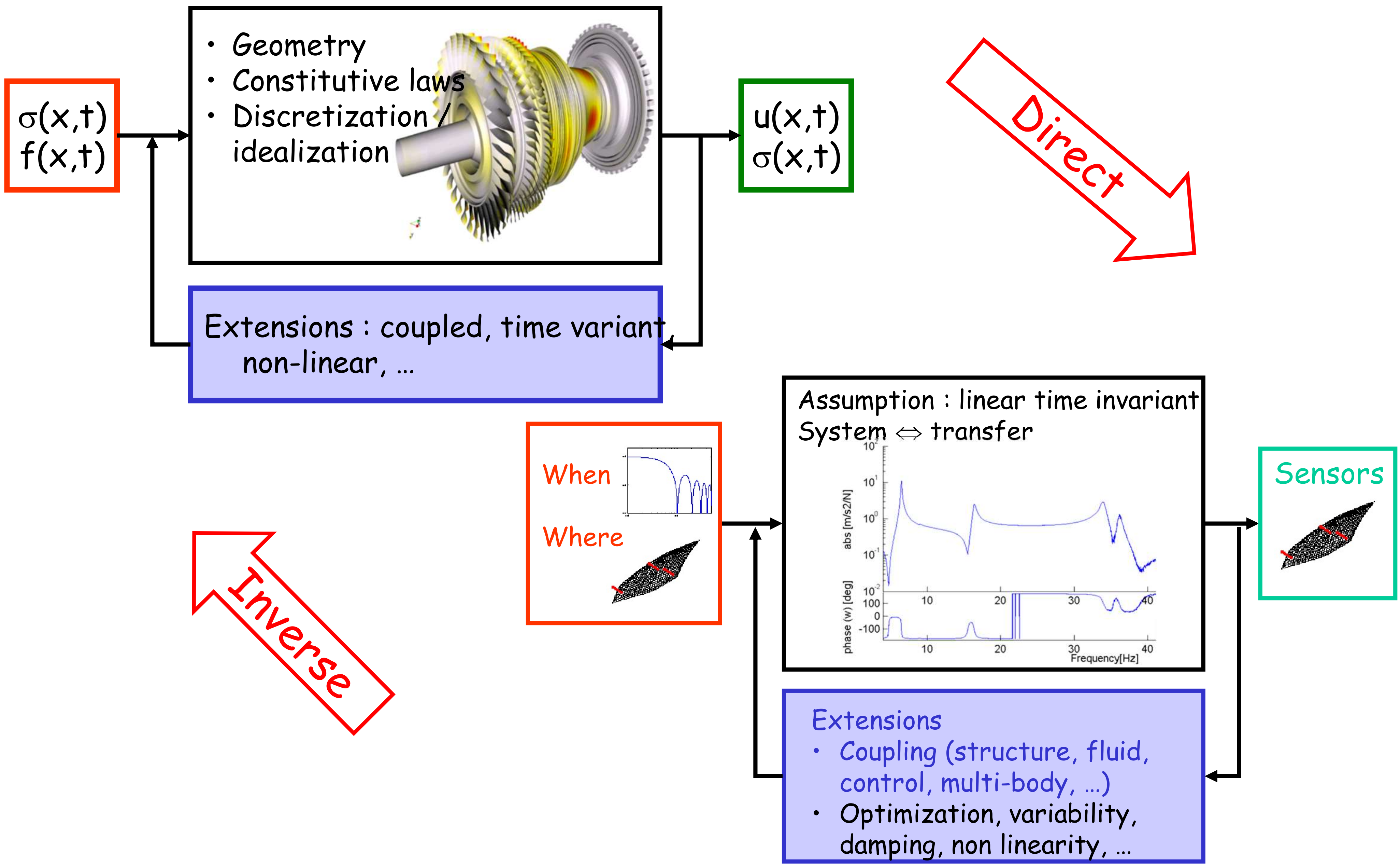
FEM model / system model



Lab work outline

- How are modes measured
  - What is a transfer
  - Identification
  - Content of modal test report
- Test and FEM modes
  - What is a FEM/test mode
  - MAC (modal assurance criterion)
- How are modes predicted
  - Data needed for mode computations
  - Transfers, observability, commandability
- Further steps
  - Damping
  - Sensitivity of frequencies

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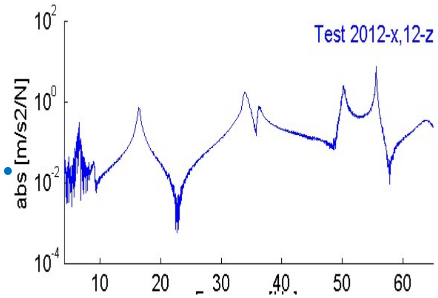
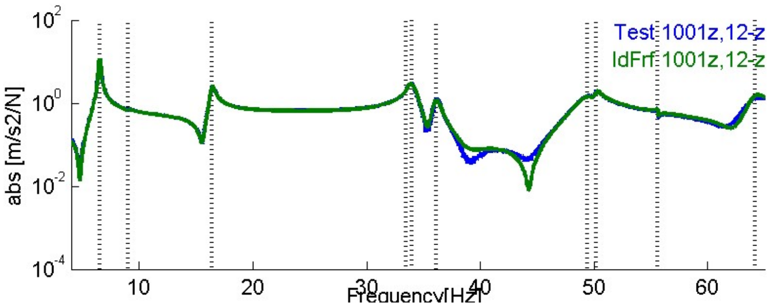
Experimental modal analysis: an inverse problem

Data
- Transfer
- Hankel mat.

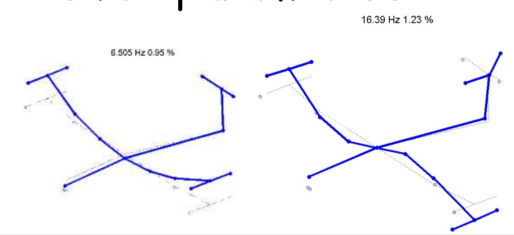


Objective H_{test}-H_{id}



Optimization

Result : parameters



Family of models

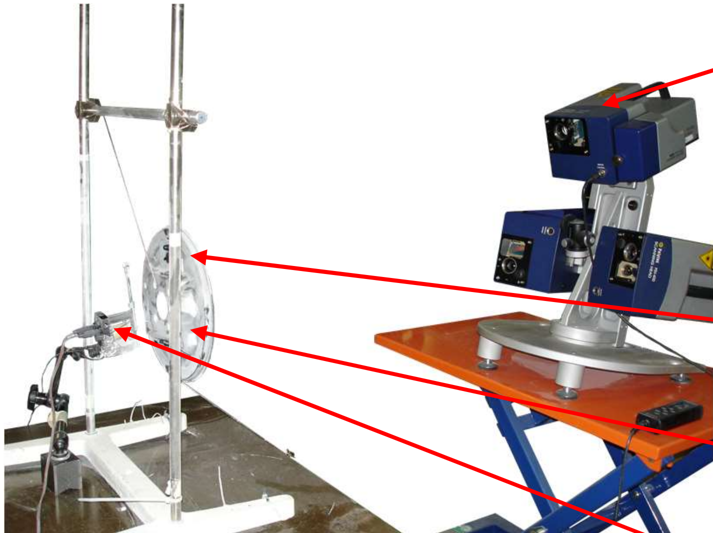
SVD $\sum_i \left\{ \begin{matrix} U_i \\ \downarrow \\ sensors \end{matrix} \right\} \{a_i(t) \;\; \rightarrow \;\; time\}$

State space $\{\dot{x}\} = [A]\{x\} + [B]\{u\}$

Pole residue $\sum \frac{[R_j]_{NS \times NA}}{s - \lambda_j}$

Rational fraction, modal model, second order …

Experimental modal analysis : measurements

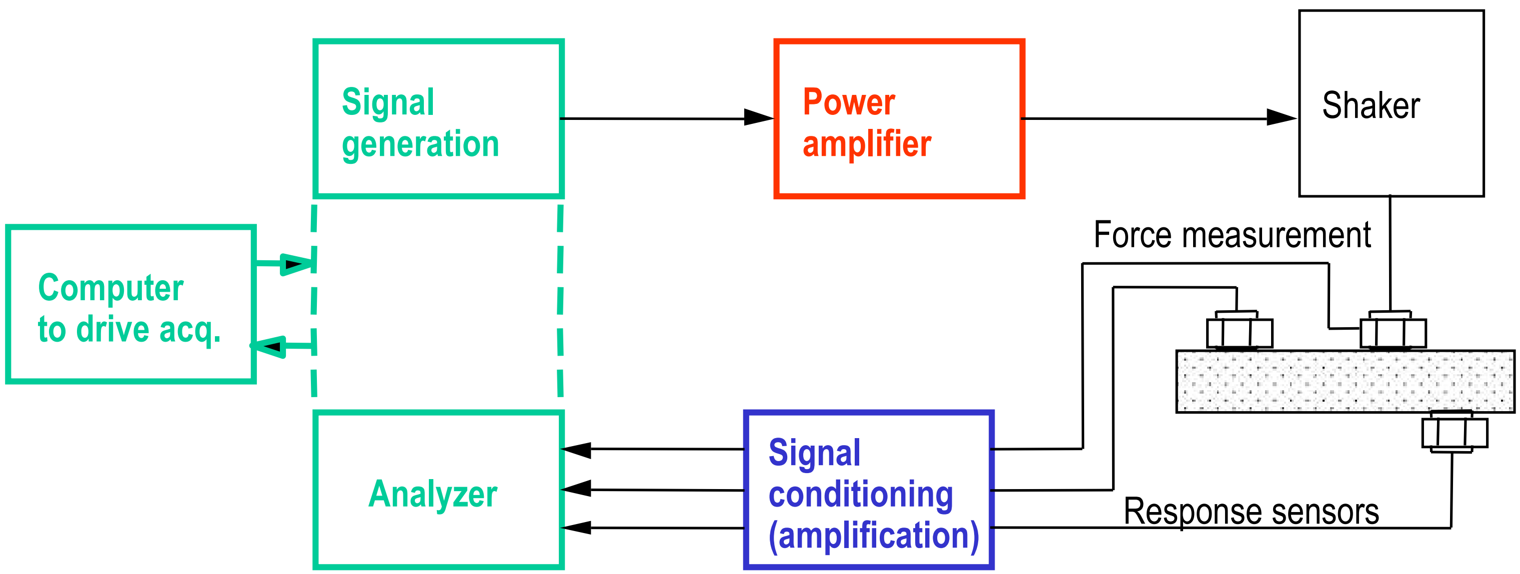


Laser vibrometer (measure)

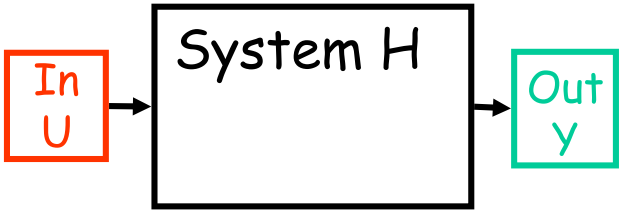
Measurement point

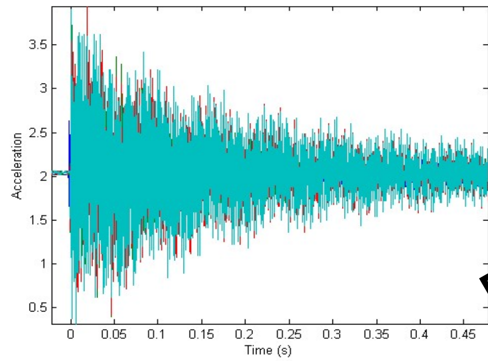
Plate

Shaker (excitation)



Modal analysis : transfers



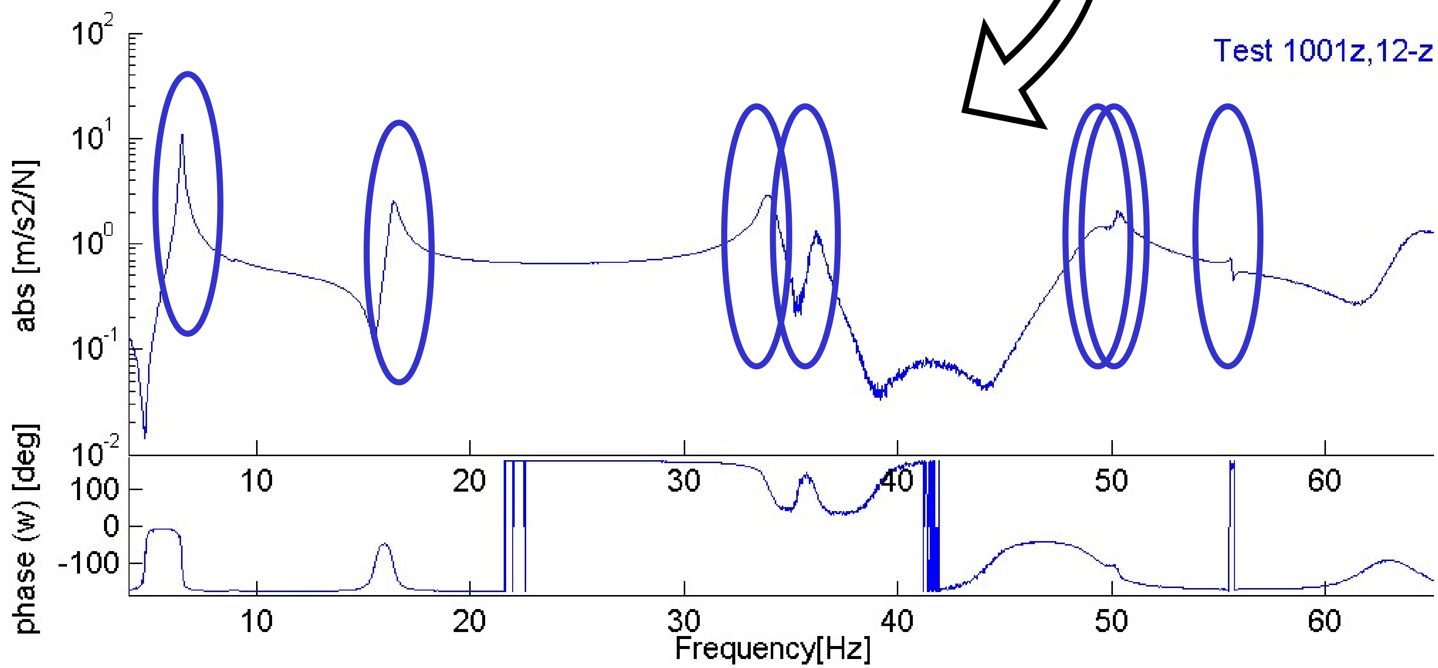


Transfers estimated from time response

ONE input

ONE output

{Y(ω)}=[H(ω)]{U(ω)}

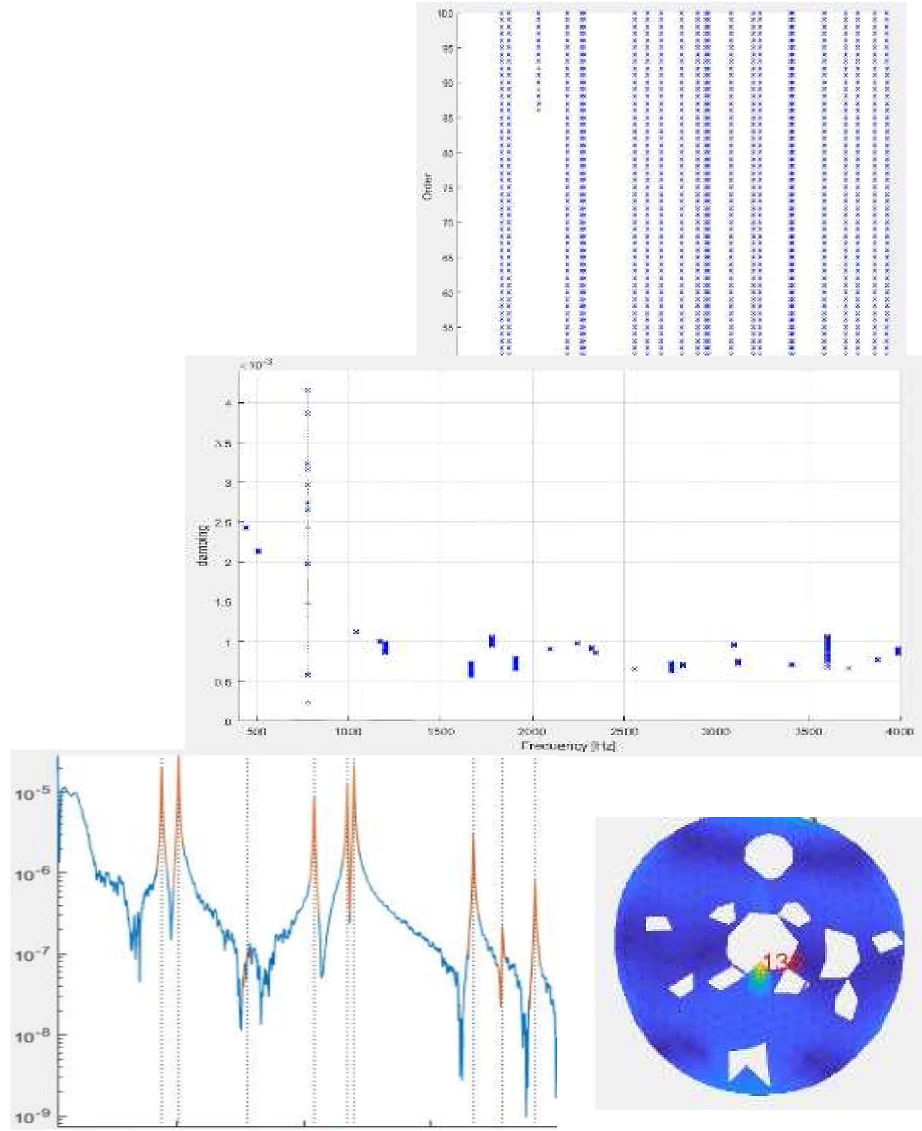


MANY resonances

Bode plot : visualization of transfer function

Identification phases

- Initialization pick from :
  - Single pole estimate [1]
  - Stabilization diagram [2]
- Estimate by band (why ? [1,3])
- How can problems be detected ? [3-4]
- Re-optimize poles (why ?)



[1] E. Balmes, « Frequency domain identification of structural dynamics using the pole/residue parametrization », IMAC 1996

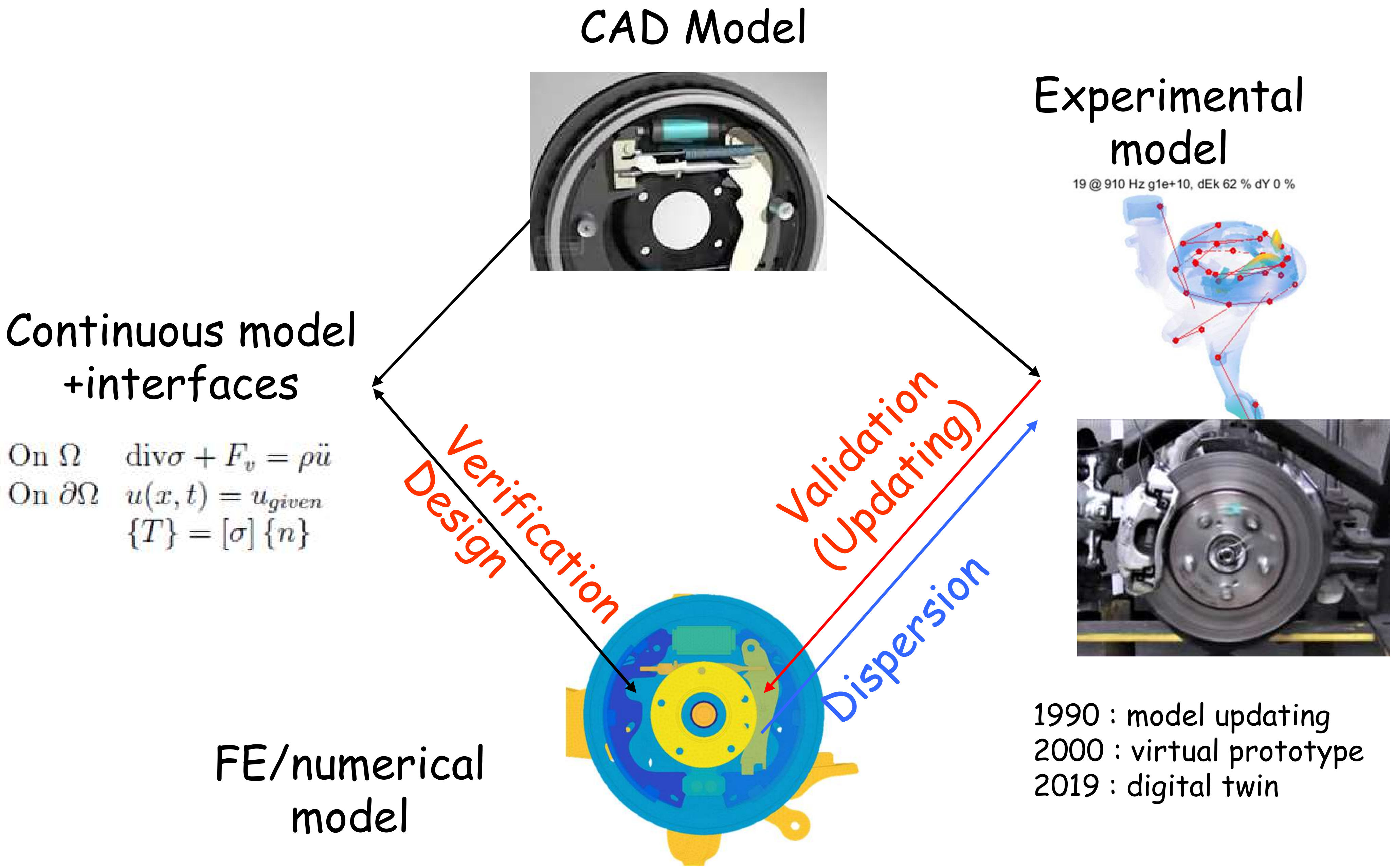
[2] P. Verboven, « Frequency-domain system identification for modal analysis », Ph.D. thesis, 2002.

[3] G. Martin, « Méthodes de corrélation calcul/essai pour l'analyse du crissement », Ph.D. CIFRE SDTools, Arts et Metiers ParisTech, Paris, 2017

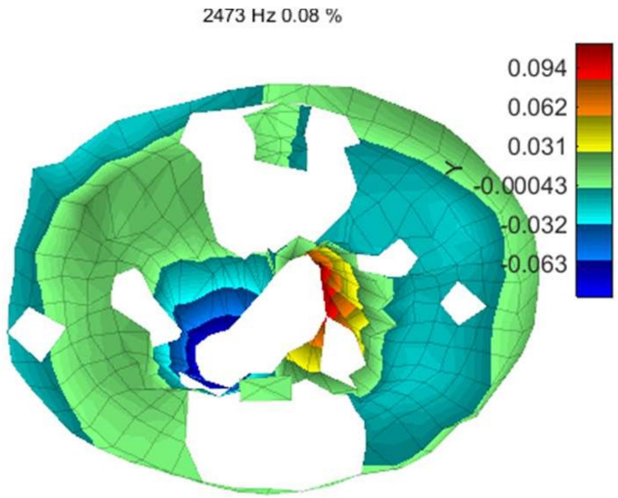
[4] G. Martin, E. Balmes, et T. Chancelier, « Characterization of identification errors and uses in localization of poor modal correlation », MSSP 2017.

Outline

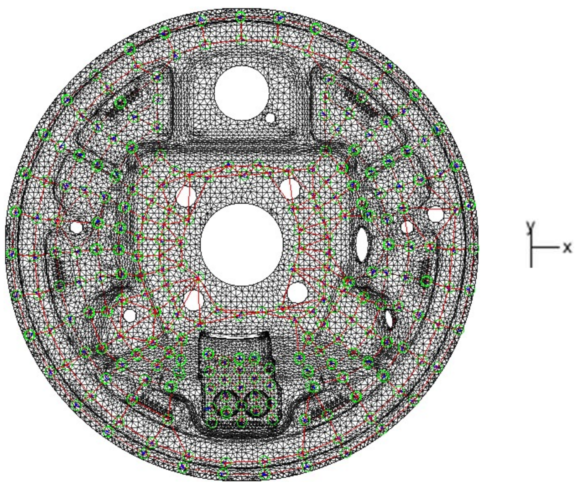
Model validation and verification



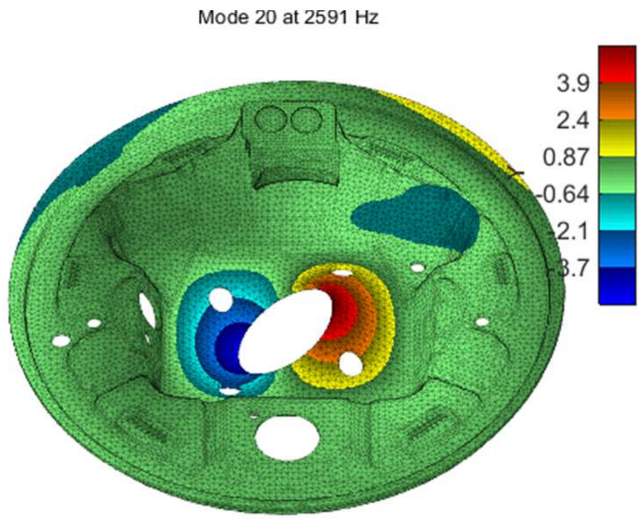
Comparing test & FEM



Identification
known @ sensors



Topology correlation
= observe FEM @ sensors



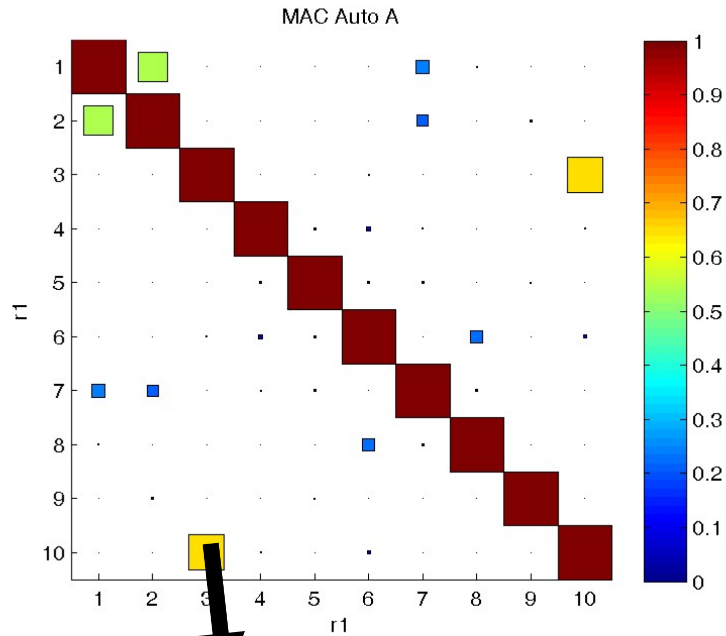
FEM known @ nodes

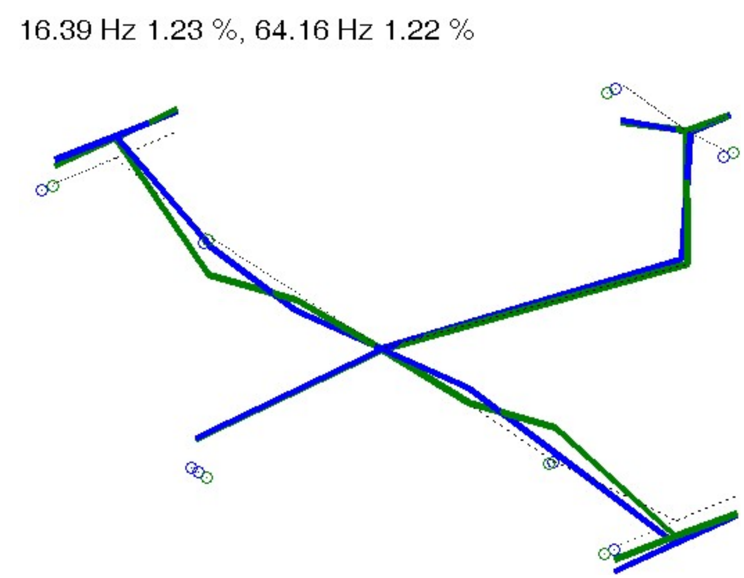
{y(t)} = [c] {q(t)}

MAC : comparing shapes

Shapes are compared through correlation coefficient (Modal Assurance Criterion)

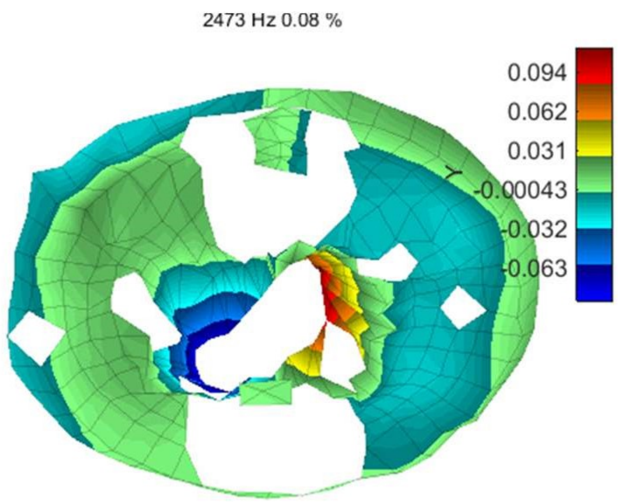
$$\mathrm{MAC}(U,V) = \frac{|\{U\}^H\ \{V\}|^2}{|\{U\}^H\{U\}||\{V\}^H\{V\}|}$$



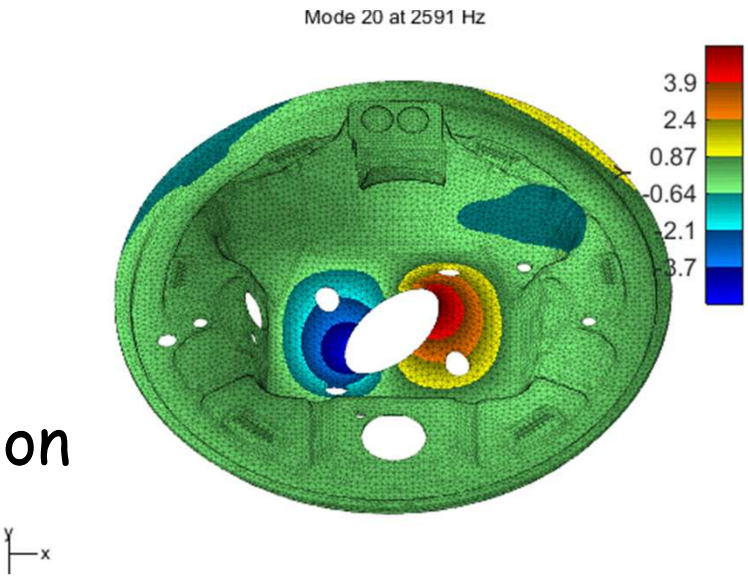


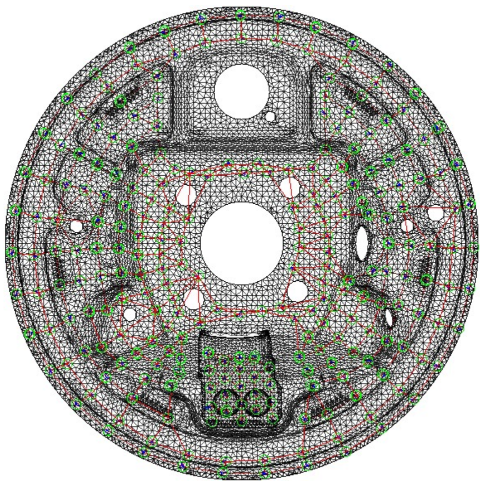
Next step : modal updating (*recalage*) = use correlation to correct model parameters

Where is the error?



Topology errors
- sensor/act position
- matching



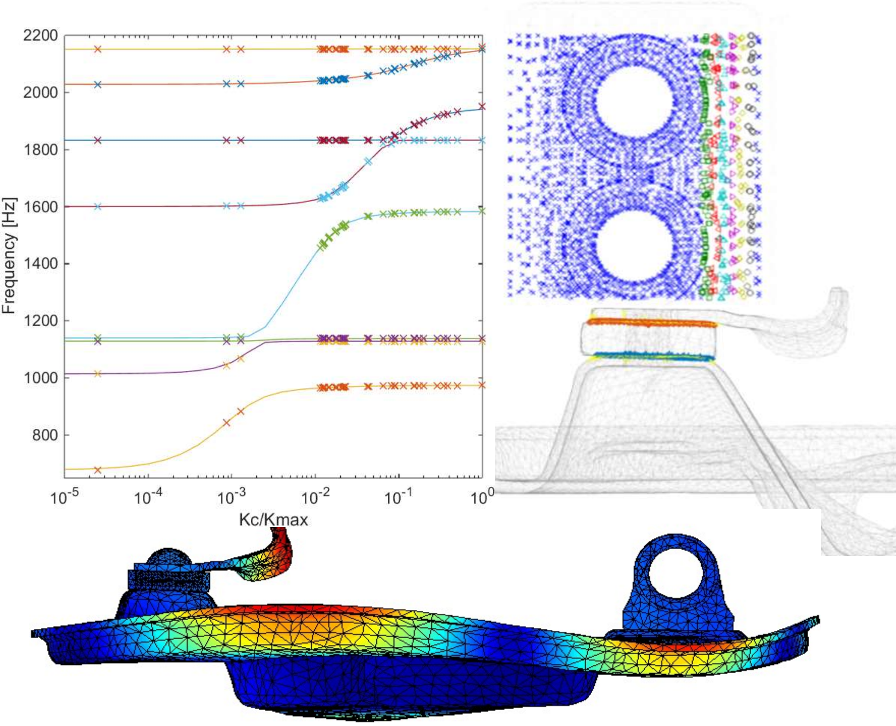


Identification error
- Noisy measurements
- Identification bias
- NL, time varying, …

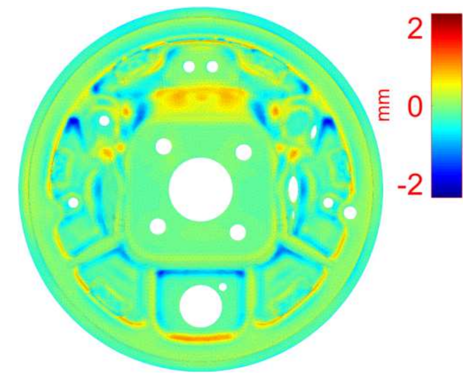
FEM error
- Geometry
- Material parameters
- Contact properties

Parametrization

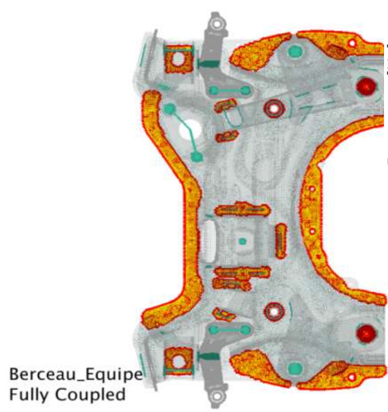
- Variable contact surface, contact, sliding

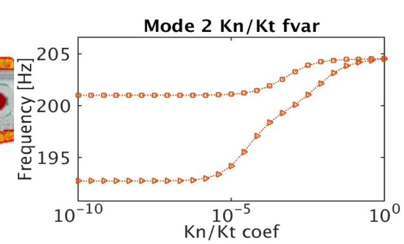


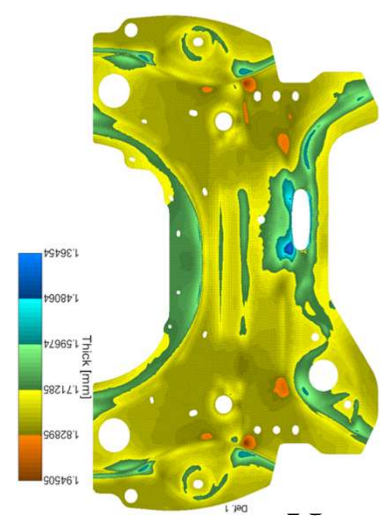
Chassis Brakes International
Eurobrake 2014



Variable geometry





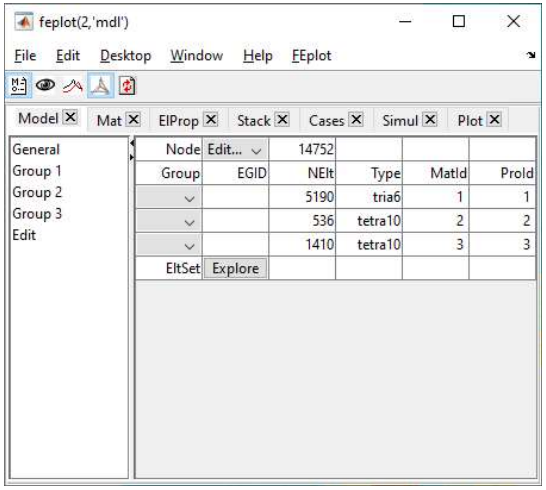


Balmes, ISMA 2016

Outline

What is a model

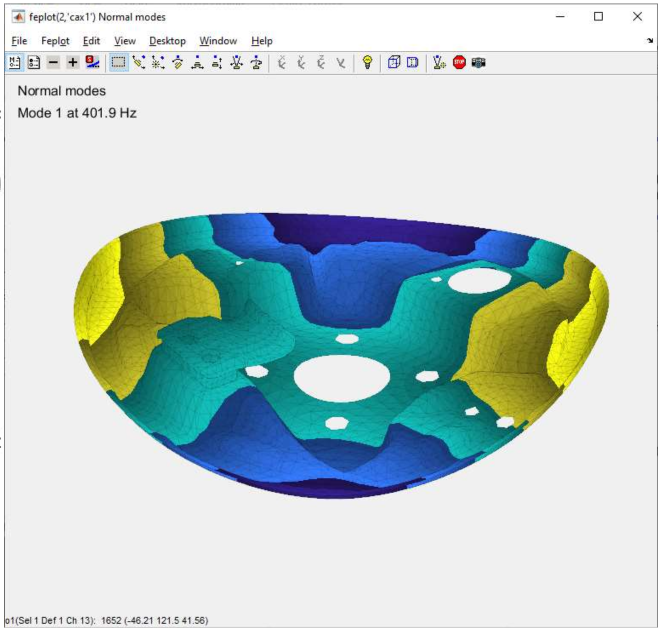
- within the domain Ω, one verifies the PDE $\rho A \frac{\partial^2 u}{\partial t^2} - \frac{\partial}{\partial x}\left(EA\frac{\partial u}{\partial x}\right) = f_v(x)$. This requires
  - a description of the domain (typically FEM geometry)
  - a problem formulation (you have seen : compression, bending, torsion, continuous mechanics = 3D solid, possibly plate/shell)
  - constitutive parameters to represent the material



- on the edge of the spatial domain $\partial\Omega$, one verifies *boundary conditions* in displacement (clamped), force (free or point load), or combination (added spring). You should remember that boundary conditions provide sufficient data to compute power flow : displacement or force but not both. Or a function that gives force as a function of displacement (constitutive law on edge).
- on the edge of the time domain, one talks about *initial conditions.*

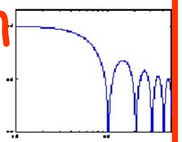
Thus one can compare the equations needed in the strong and weak forms

	strong/local	weak/PVW
On Ω	$\rho A \frac{\partial^2 u}{\partial t^2} - \frac{\partial}{\partial x}\left(EA\frac{\partial u}{\partial x}\right) = f_v(x)$	$\int_\Omega \left(\rho A u^* \ddot{u} + u^*_{,x} EA u_{,x} - u^* f_v\right) = 0$
On $\partial\Omega$		
- Right fixed	$u(x_R) = 0$	$u(x_R) = 0$
- Right free	$F_x = EAu_{,x}\vert_{x_R} = 0$	– (not needed since no work)
- Right loaded	$F_x = EAu_{,x}\vert_{x_R} = F_{ext}$	$P_e xt = [b]\, F_{ext}(t) = u^*(x_R) F_{ext}(t)$
- Spring at right	$EAu_{,x}(L) - ku(L) = 0$	$\int_\Omega \ldots + ku(L)^* u(L) = F_{ext}$

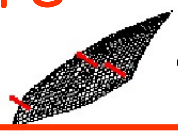


How are transfers predicted ?

When

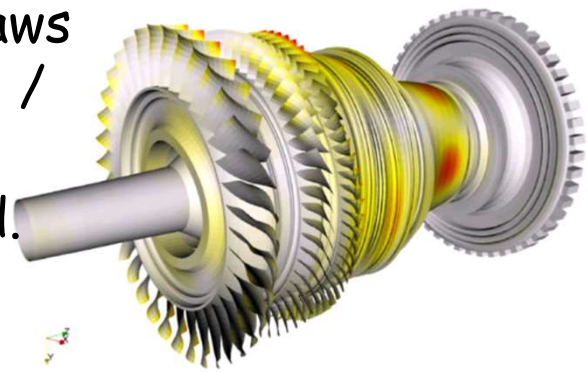


Where



System (FEM)

- Geometry
- Constitutive laws
- Discretization / idealization
- Boundary cond.



- DOFs {q}
- Mass M and stiffness K matrices

Outputs

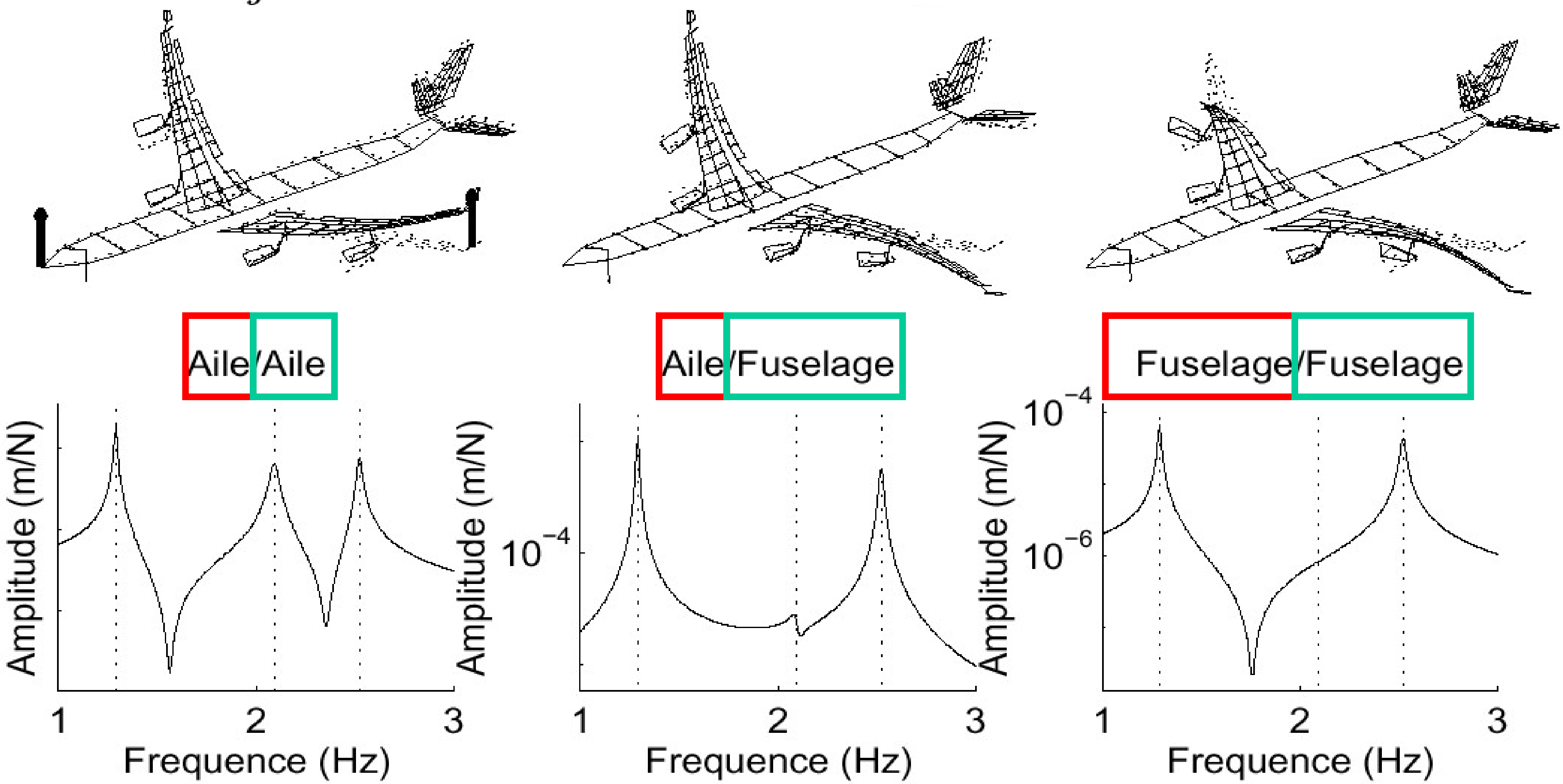
$u(x,t)$
$\sigma(x,t)$

Inputs (when)
- Unbalance : harmonic at Ω
- Aerodynamic loads ($n\Omega$)
- Rotor/stator contact

Inputs (where)
- Point mass
- Distributed pressure
- Blade tip

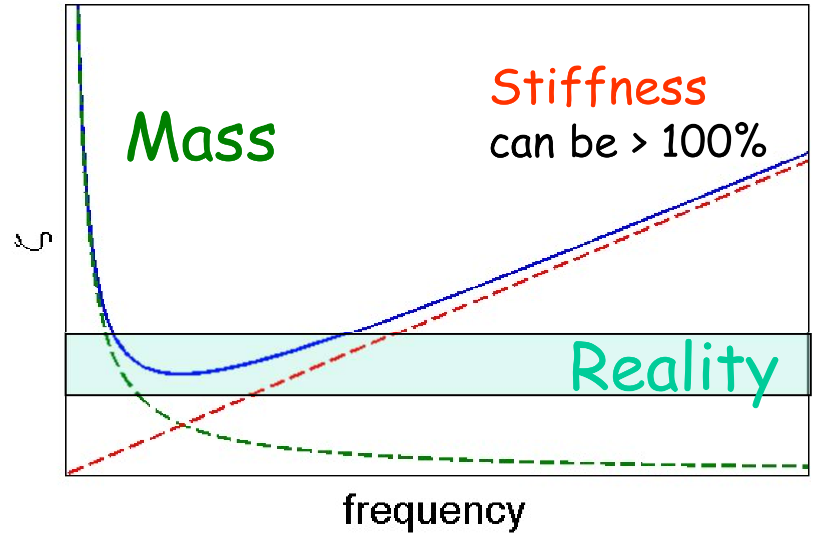
Observability/controlability

$$H(s) = \sum_{j=1}^{N} \frac{[c]\{\phi_j\}\{\phi_j\}^T[b]}{s^2 + 2\zeta_j\omega_j s + \omega_j^2}$$



Rayleigh damping (CM2)

- Rayleigh damping:
  - Physical domain $[C] = \alpha[M] + \beta[K]$
  - Modal domain $$\zeta_j = \frac{\alpha}{2\omega_j} + \frac{\beta\omega_j}{2}$$



Stiffness perturbation in modal coord. (CM4)

- Stiffness perturbation

$$[M]\{\ddot{q}\} + [K + \Delta K]\{q\} = [b]\{u\}$$

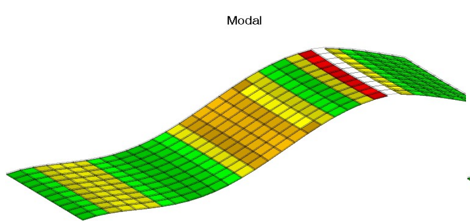
- Modal coordinates reanalysis $\{q\} = [\phi]\{q_R\}$

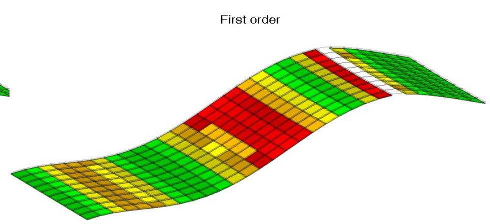
$$[I]\{\ddot{q}_R\} + \left[\left[\backslash\, \omega_j^2 \,\backslash\right] + \phi^T \Delta K \phi\right]\{q_R\} = [\phi^T b]\{u\}$$

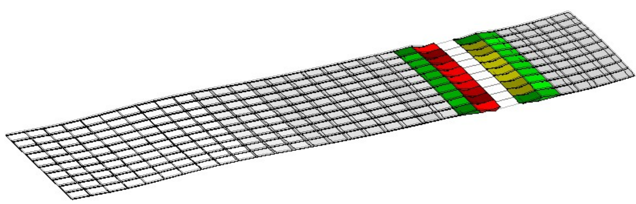
- Sensitivity on frequency (TD4 question 5)

$$\frac{\partial \omega_j^2}{\partial p} = \{\phi_j\}^T \left[\frac{\partial K}{\partial p} - \omega_j^2 \frac{\partial M}{\partial p}\right]\{\phi_j\}$$

- Need to know :
  may be significantly wrong without residual terms/static correction







Procédure COVID

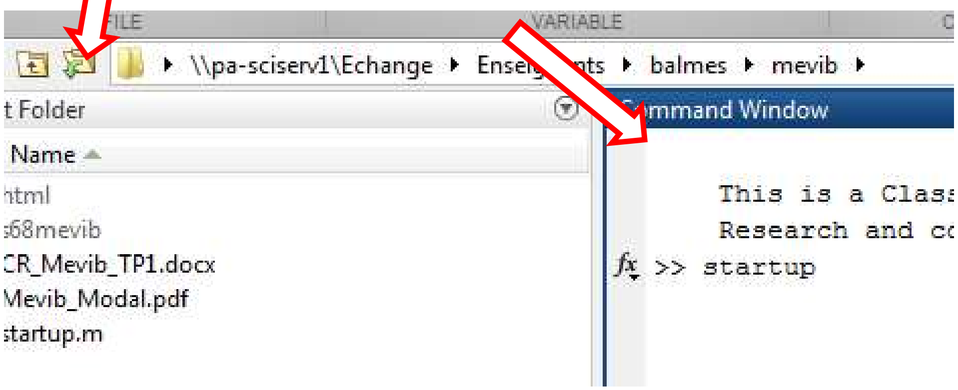
1. Copie slides Mevib_TpModal.pdf
2. Sujet PDF avec lien vers les films parties SujetTpModal.pdf
3. Posez des questions dans le chat de la réunion
4. Trame de compte rendu

Vous pouvez utiliser Office365 ou google-docs
pour partager la rédaction par binôme.

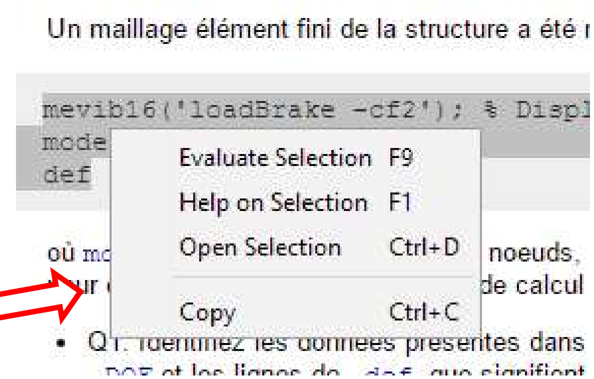
Compte rendu = élément de notation (délais un semaine au plus) :
etienne.balmes@ensam.eu

Ouverture sujet dans Matlab

1. \\intram\paris\Echange\Enseignants\balmes\Mevib
   (ou peut être X:\Enseignants\balmes\Mevib)
2. startup



3. Sélection + F9 (evaluate)



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