Course 7 : Reduction for reanalysis

- Reanalysis : section 10.4
- Start with motivation
- Then on blackboard
  - Parameter, nominal model selection
  - b_p residual vector columns of ΔK or $\Delta K T_0$
  - Complex modulus example
  - Residue iteration
  - Issues with reduction
- Back with a few illustrations

SDTools
VIBRATION SOFTWARE & CONSULTING

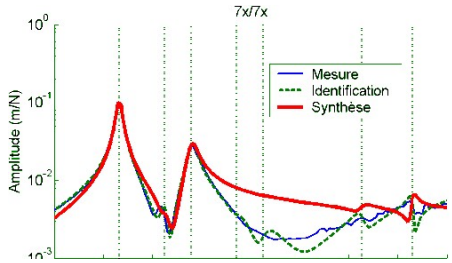
Arts et Métiers Institute of Technology

MS2SC http://savoir.ensam.eu/moodle/course/view.php?id=1874
PROVIR http://savoir.ensam.eu/moodle/course/view.php?id=490

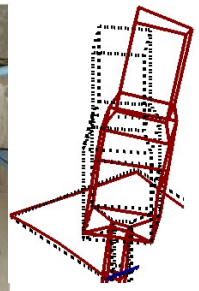
Reanalysis : model 1 config -> prediction other

In

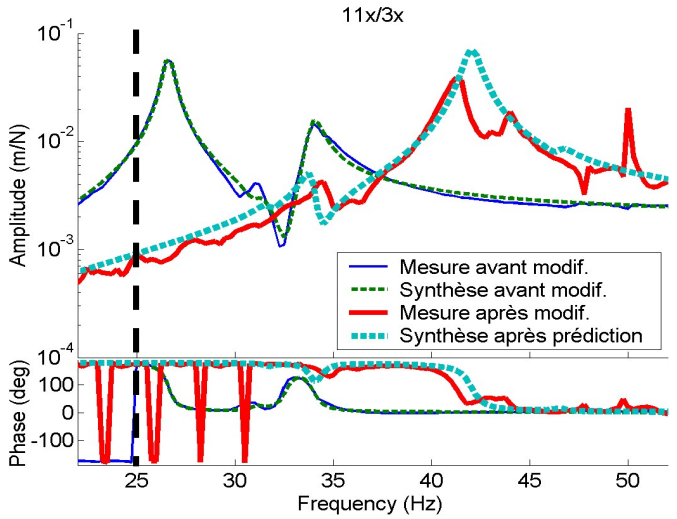
System : identified



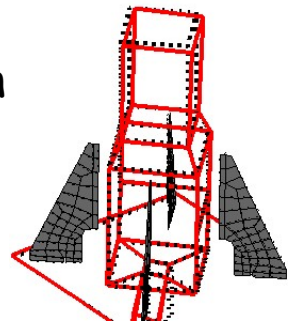




response



Feedback : modification



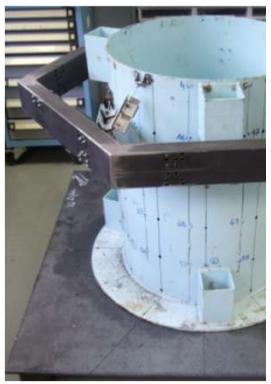
CENTRALE PARIS

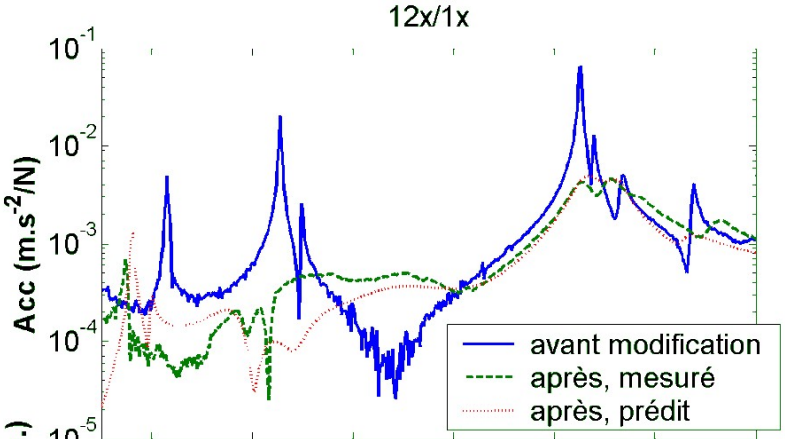
EDF Electricité de France

Test : example

SDM : structural dynamics modification

- distributed mass, stiffness or damping modifications
- Restricted to low frequency global modes

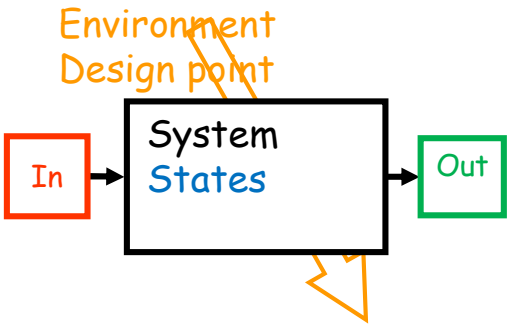


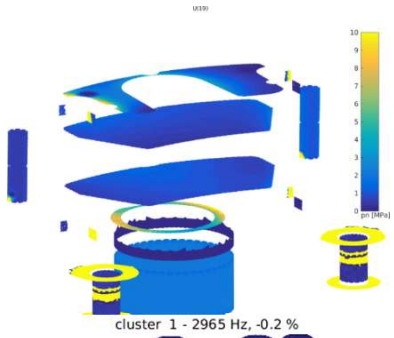


Reanalysis : computational example

Squeal applications

- 8-15 components
- Multiple interfaces/parameters
- 300-600 modes



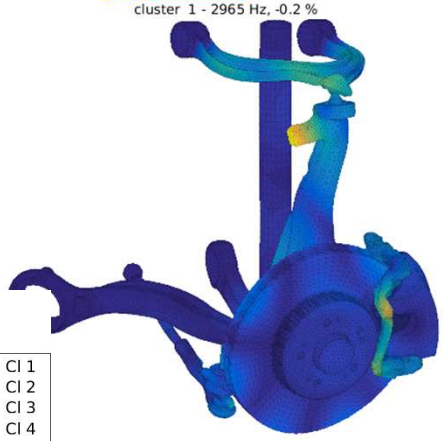


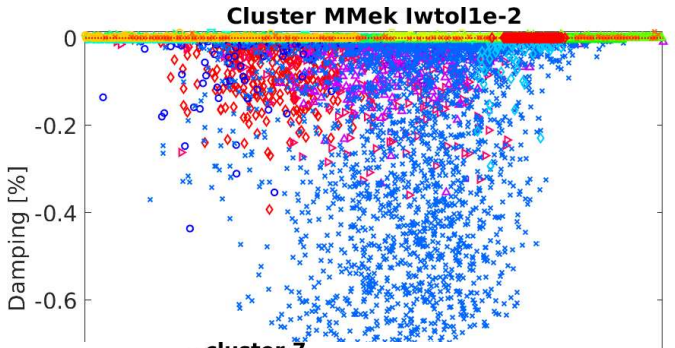
Design exploration 1000 points

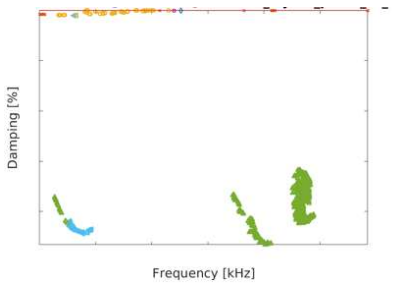
- Full 80 days CPU, 22 TB
- CMT a few hours off-line learning, <1h exploration

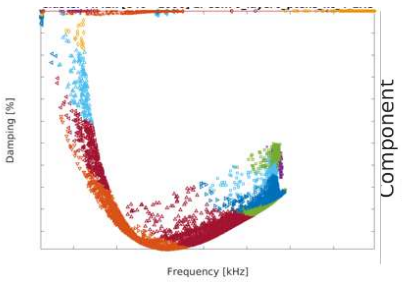
Exploitation

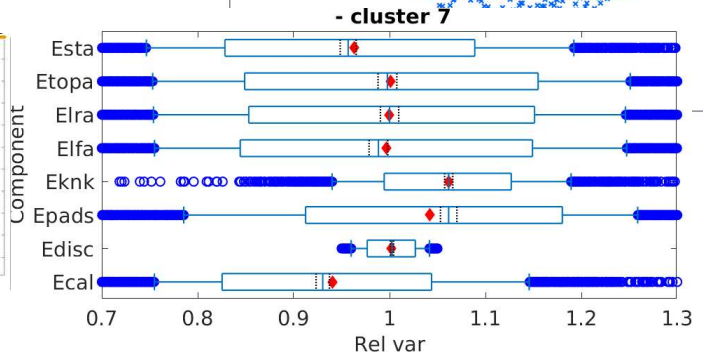
- DOE : basic edges, LHS
- Clustering & parameters

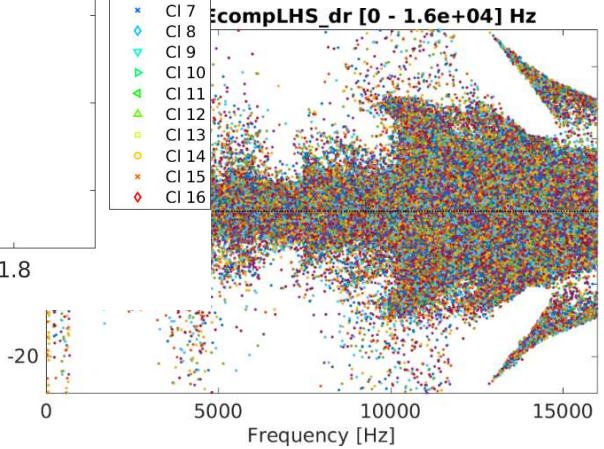






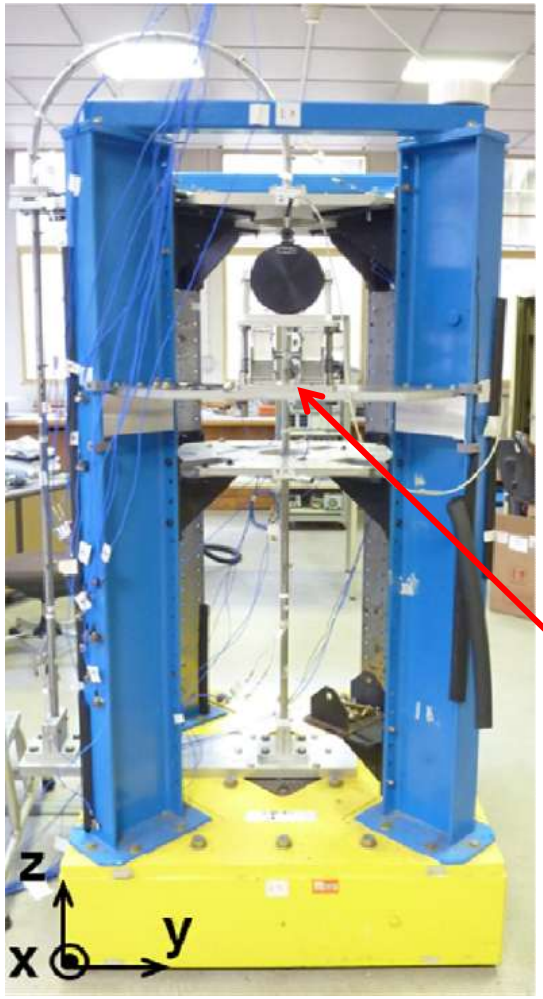


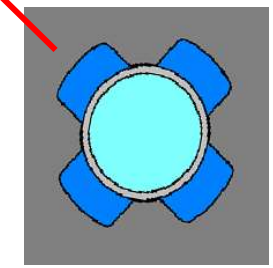




Energy coupling & NL system

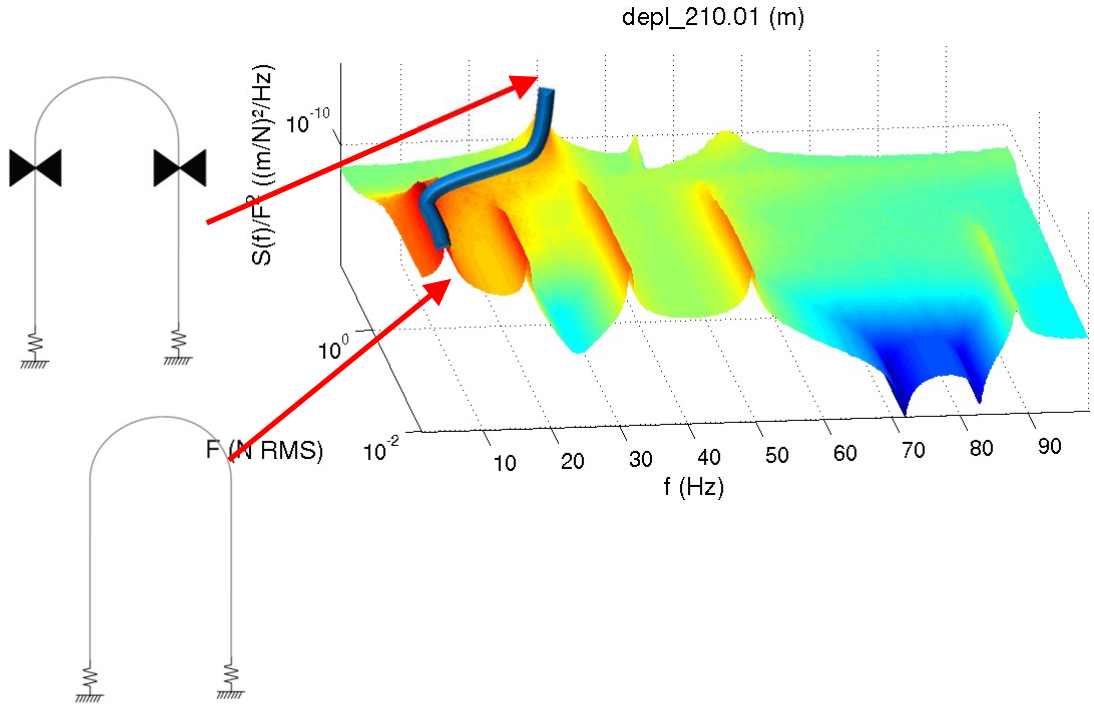
Bending beam with gap & contact
Apparent damping with pure contact

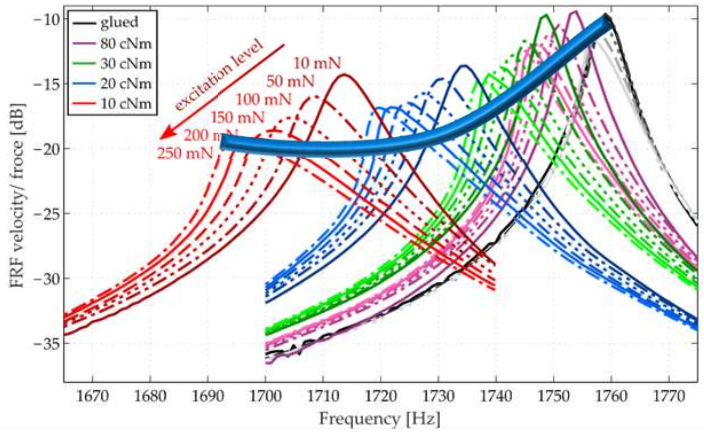




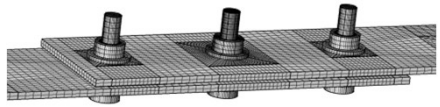
PhD. Thénint 2011

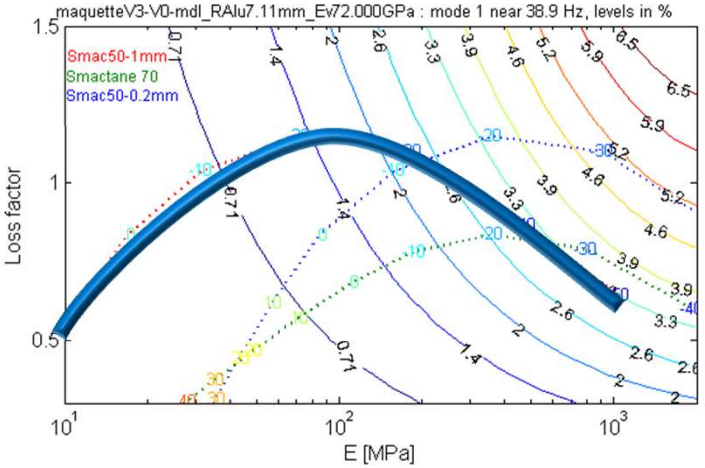
Damping occurs in the transition





FEMTo-ST Orion Testbed









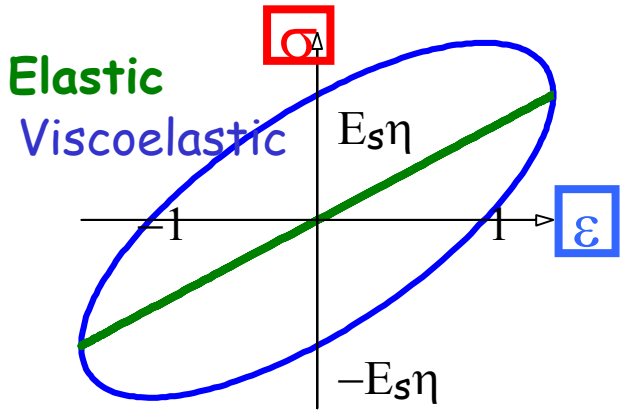
Transition

- Contact with broadband excitation level
- Friction : amplitude/normal force dependence
- Viscoelasticity : temperature/frequency dependence

ENSAM/PhD. Hammami 2014
Hammami/Balmes/Guskov, MSSP 2015

Dissipation models : viscoelasticity

- Viscoelasticity (Bolzmannian material)
- Stress function of strain history
  independent of amplitude
- Time convolution $\sigma(t) = \int_{-\infty}^{t} C(\tau)\epsilon(t-\tau)$
- Frequency complex modulus $\sigma = E(\omega, T, \epsilon_S)\epsilon$

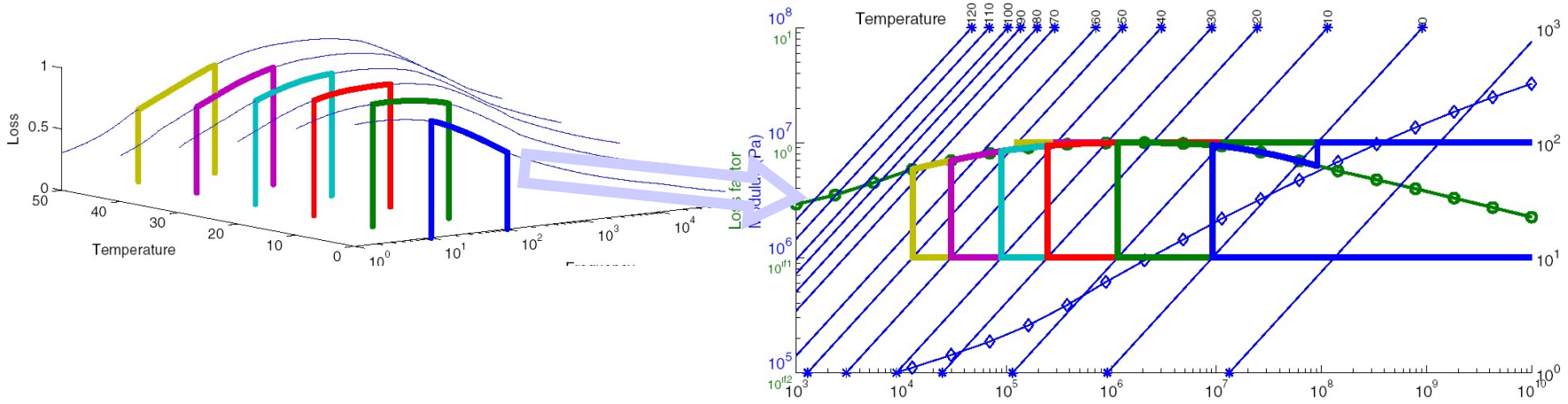


$$E = E'(1 + i\eta)$$

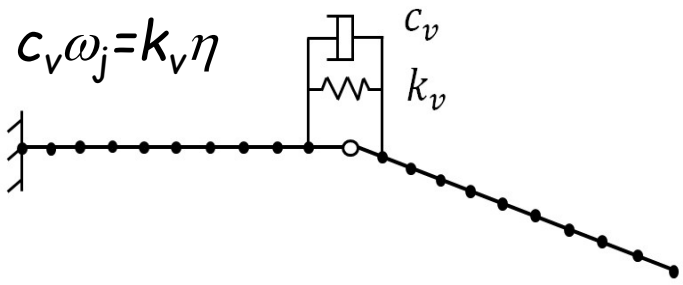
E' storage modulus, η loss factor

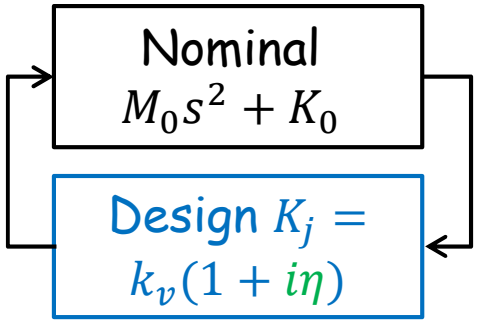
- Temperature/frequency equivalence

$$E(\omega, T, \epsilon_S) = E(\omega\alpha(T, \epsilon_s))$$



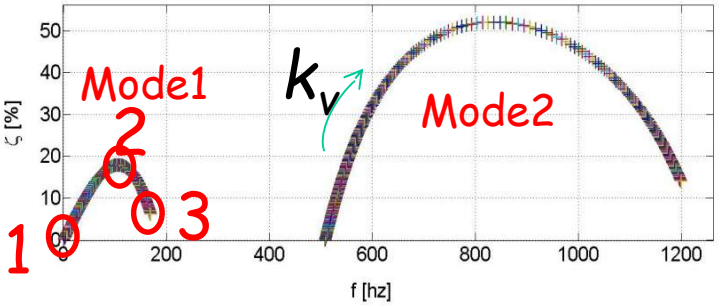
A mechanical root locus (coupling)

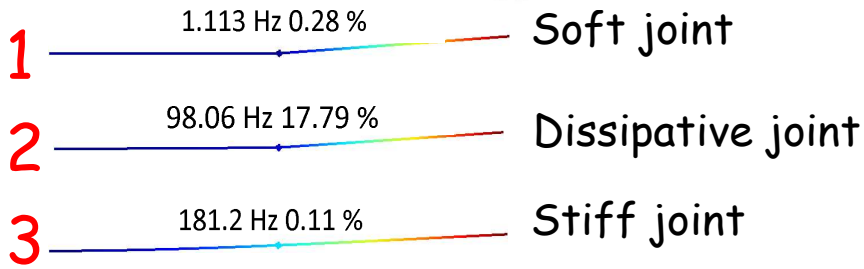




k_v variable, $\eta=1$ constant loss

Output : $f(k_v,\eta)$ $\zeta(k_v,\eta)$





Damping can only exist if joint is « working »

⬇

Energy fraction in joint must be « sufficient » (depends on k_v)

Related ideas : electro-mechanical coupling coefficient, pole/zero distance, modal strain energy

On blackboard

- Parameter, nominal model selection
- b_p residual vector columns of ΔK or $\Delta K T_0$
- Complex modulus example
- Residue iteration
- Issues with reduction

Related but not perfectly matching : section 5.4

Families of reduced models

p	physical parameters (geometry, constit.)
$Z(p,s)=[M(p)s^2+K(p)]$	finite element model
$Z_R(p,s)=T^T Z T$	reduced dynamic model
$T(p)=[\phi_1 \dots \phi_{NR}\ K^{-1}b]$	modal model
$\{y\}=[H]\{u\}$	transfer functions

Kinematic reduction $\Leftrightarrow$ choice fixed Ritz basis $\{q\} = [T]\{q_R\}$

Response surface / reduction

All predict I/O relation but

Response surface methodologies

- no knowledge of internal state

PGD (higher dimension variable separation)

- time and space are coupled

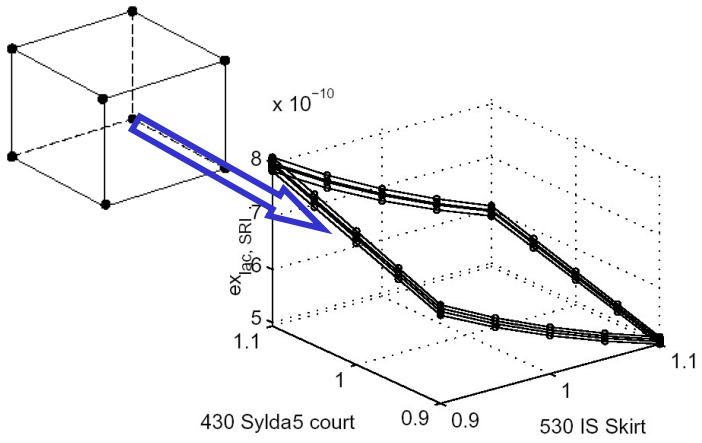
Fixed basis reanalysis

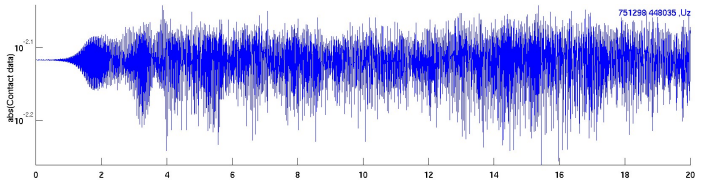
- Response surface for system matrices

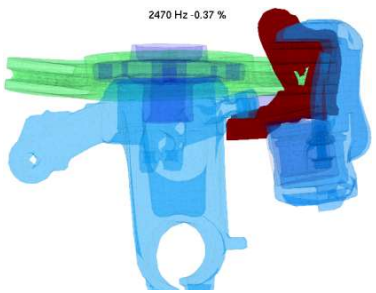
$$T^T Z(p) T \approx f(p, T^T M_i T)$$

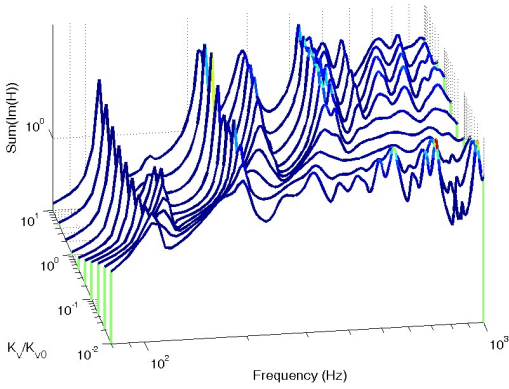
But

- still dynamic model
- restitution $\{q\}=[T]\{q_R\}$
  knowledge of all internal states









First order enhancement to MSE

$[Z(E(s),s)]\{q\} = \{F\}$ Damped viscoelastic resp. rewritten as

$$[Z(E_o,s)]\{q\} = \{F\} - \left[\sum (E(s)- E_o)/ E_o [Im(Z-Z_o)]\right]\{q\}$$

Tangent system, internal loads

Basis contains

- Modes to represent nominal resonances
- Flexibility to viscoelastic loads associated with nominal modes

$$T = \left[\phi_{1:NM} \quad K_o^{-1} \left[Im(Z-Z_o)\right] \phi_{1:NM}\right]$$

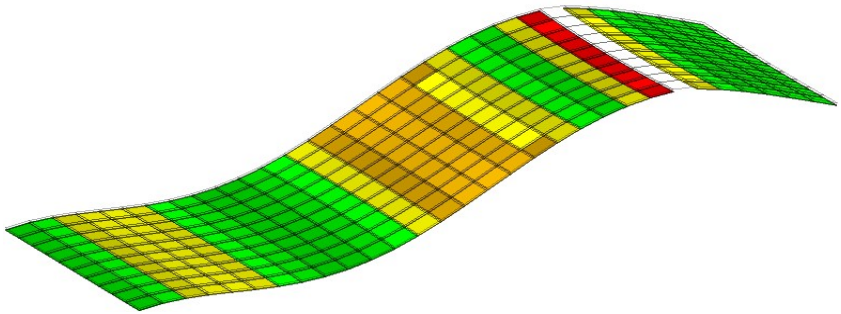
Modes MSE

static response to unit load

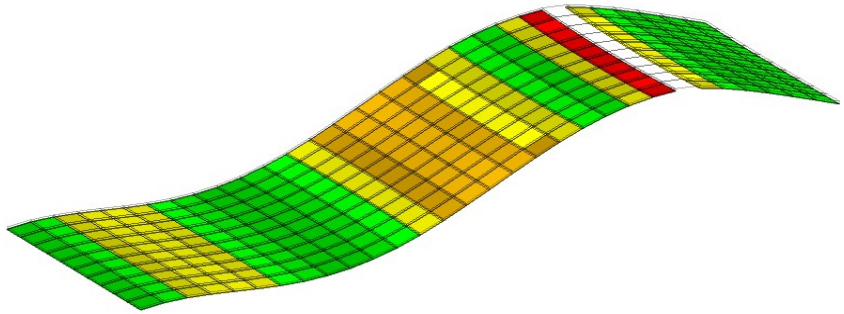
Principle of reduction (assumptions on excitation space & freq) unchanged

Non proportional damping model

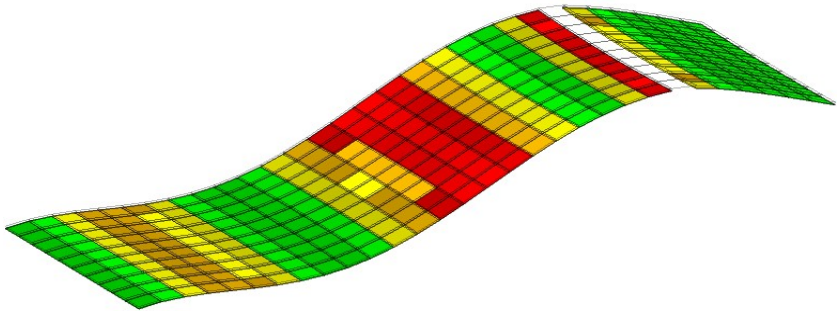
Modal



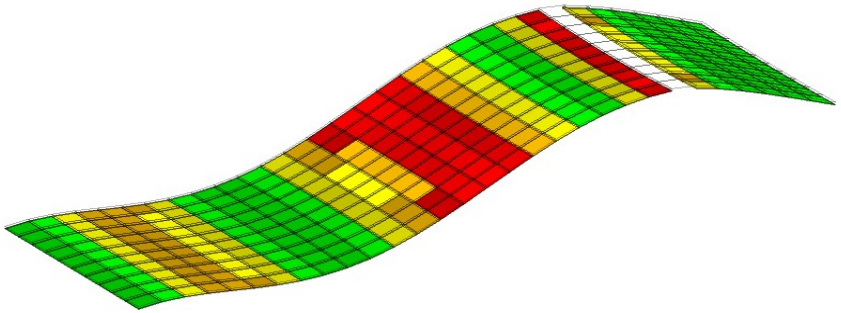
MSE



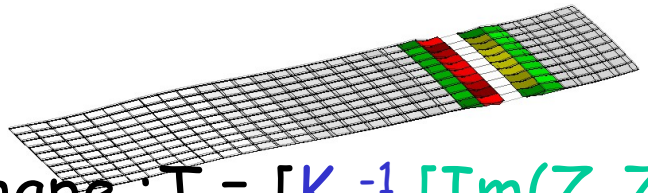
First order



Exact



- Forced response around a resonance



First order shape : $T = [K_o^{-1} [Im(Z-Zo)] \phi_4]_{orth}$

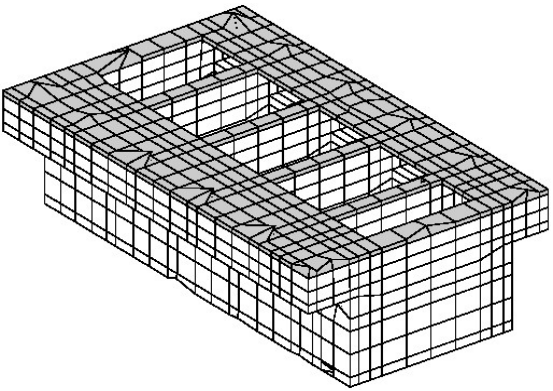
Reanalysis

Reanalysis

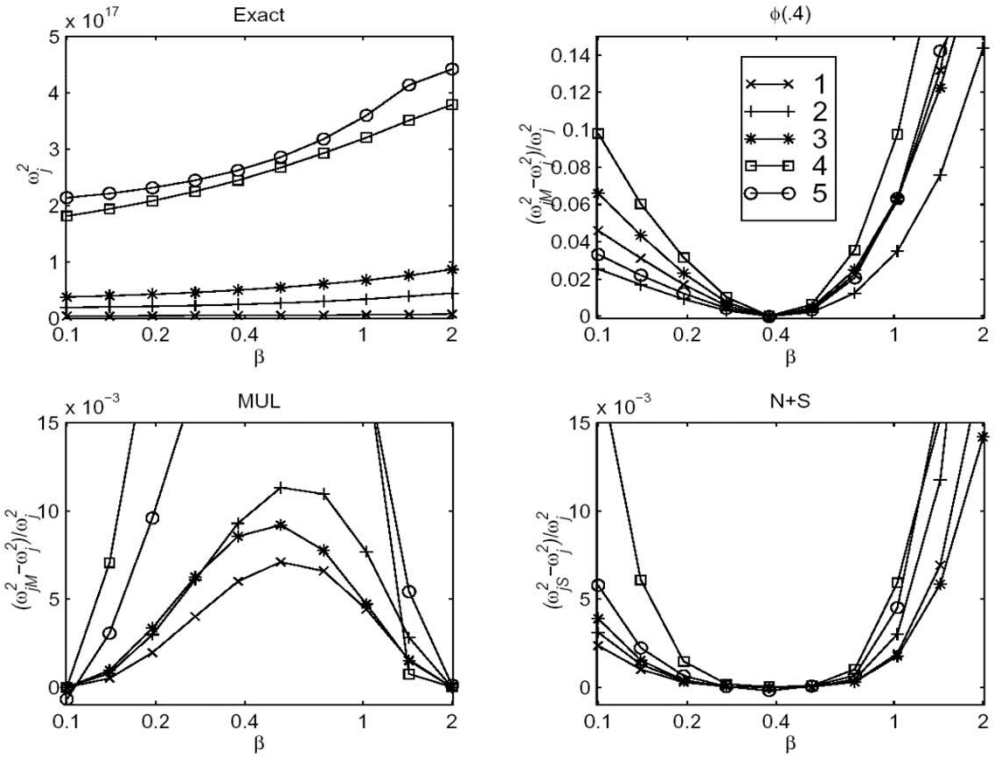
Multi-model bases

$$\left[\left[T^T K(p) T\right] - \omega_{jR}^2(p)\left[T^T M(p) T\right]\right]\{\phi_{jR}(p)\} = \{0\}$$

- Modes $T=[\Phi(p_0)]$
- Multi-model $T=[\Phi(p_1)\ \Phi(p_2)]$
- Modes + sensitivities $T=[\Phi(p_0)\ \partial\Phi(p_0)/\partial p]$

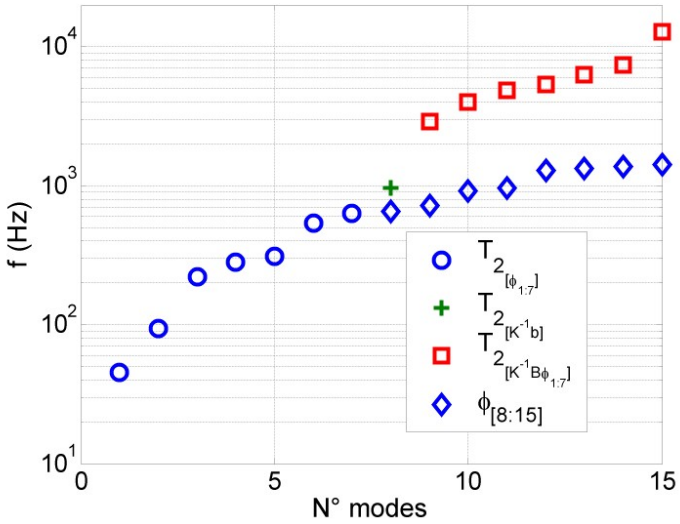


Frequencies



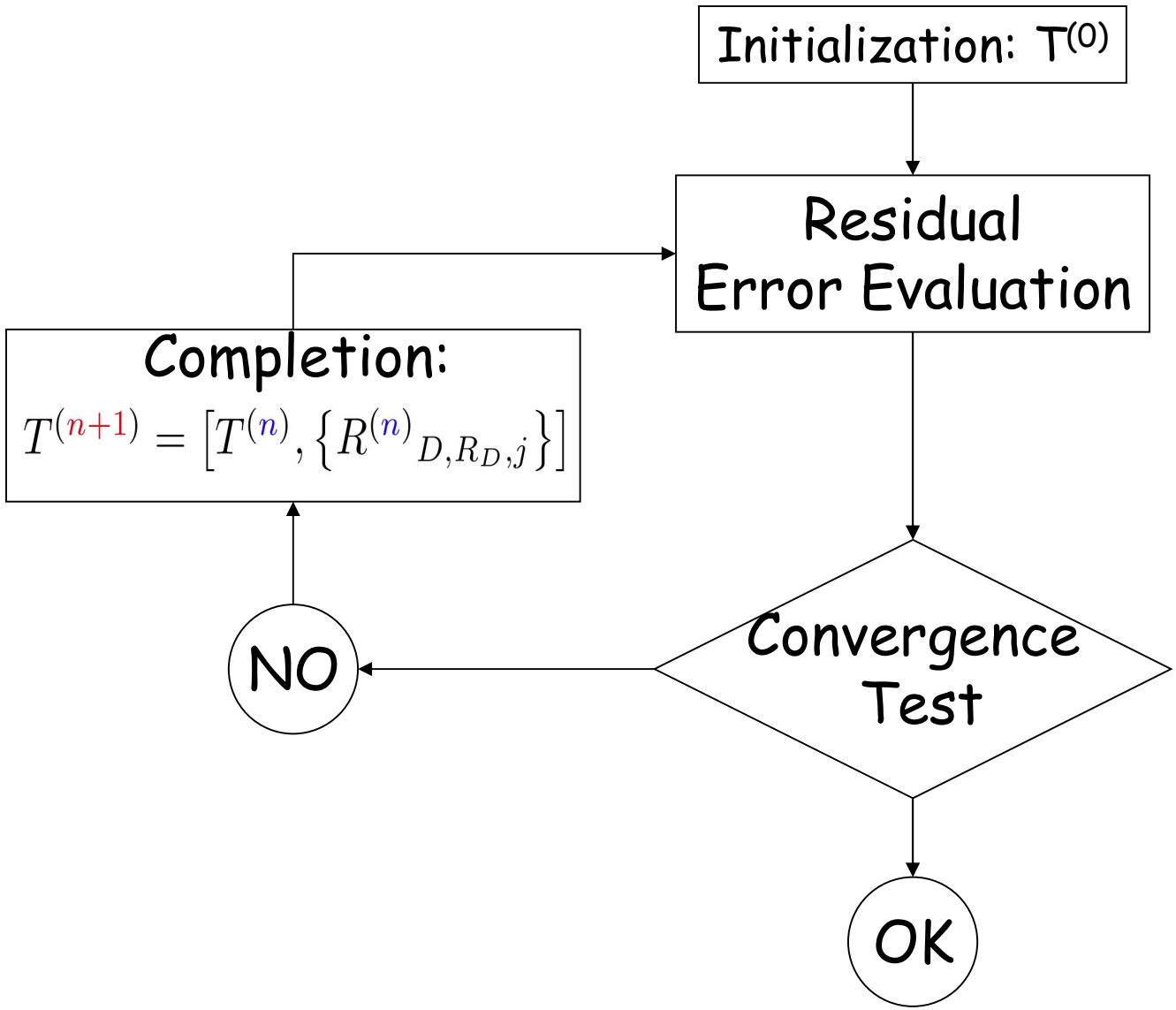
Reduction Bases/Starting Point

- Modal $T=[\Phi(p_0)]$
- Modal + static Responses to input $T=[\Phi(p_0)\ K^{-1}b]$
- Modal + static responses to representative loads $T=[\Phi(p_0)\ K^{-1}[b\ R_j]\ \Phi(p_k)]$



- Frequencies of corrections ☐ differ from modes ♦ : the added information is VERY different

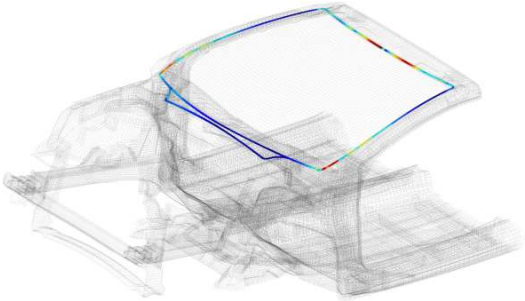
Iterative Procedure

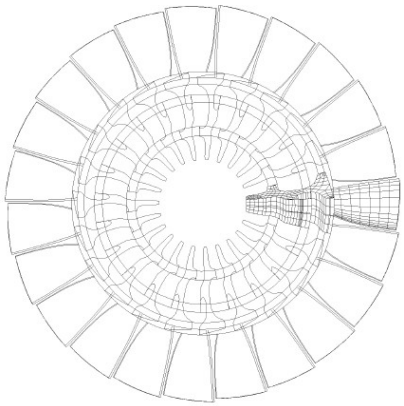


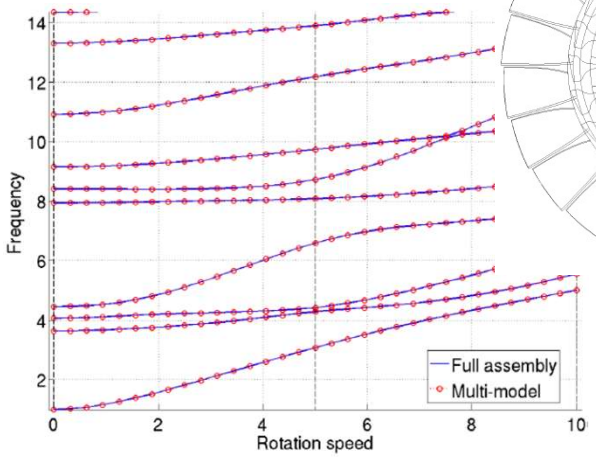
Fixed basis : enormous cost reduction

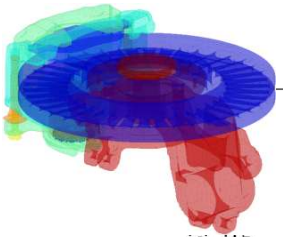
- Windshield joint complex modes at 500 design points for $\frac{1}{2}$ cost of direct solver
- Campbell diagram : 200 rotations speeds for the cost of 4.
- Squeal instabilities as function of pressure : few pressures sufficient for interpolation

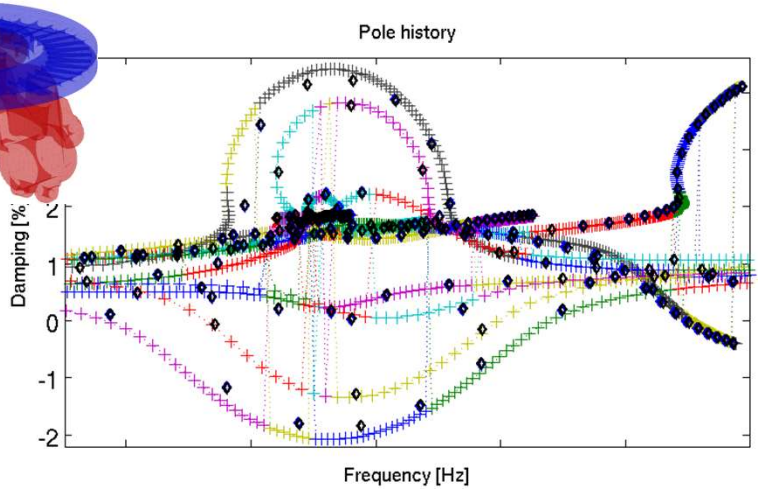
Ψ,λ	SOL107	2200s
Φ,ω	SOL103	300s
Ψ,λ Reduced	First order Error <4%	490s
Ψ,λ(500*T)	SOL107	~ 12 days
Ψ,λ(500*T) reduced	First order Error small	~1000s







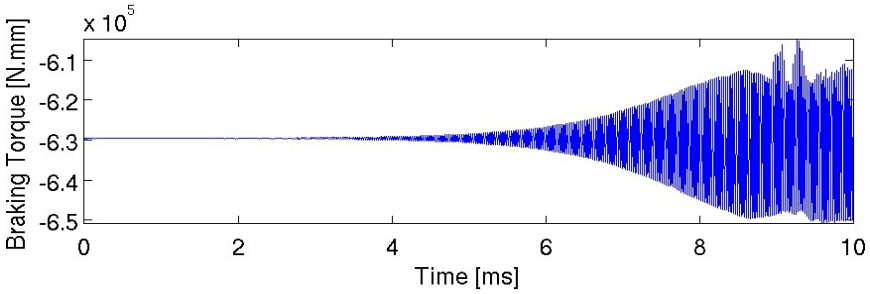


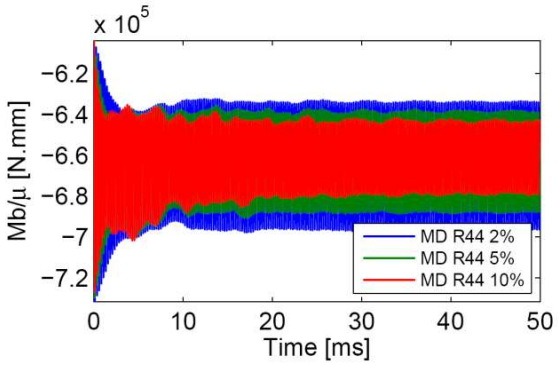


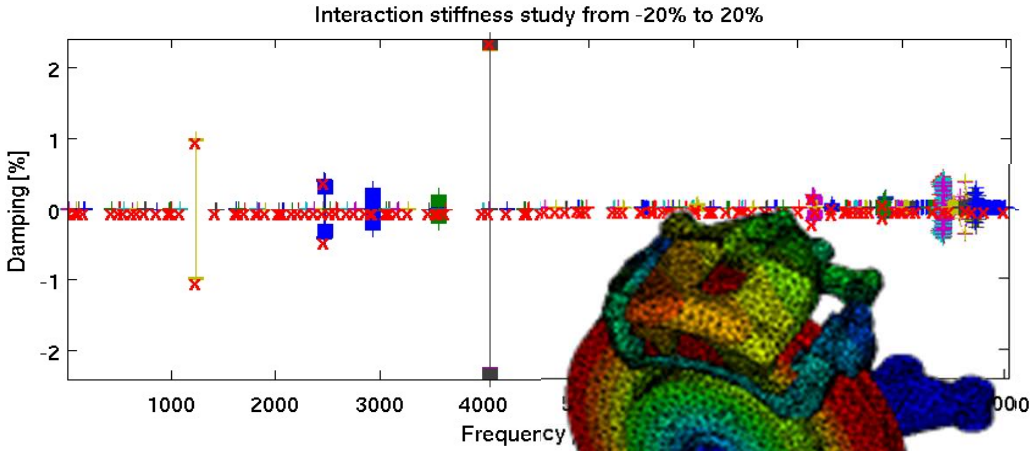
Reanalysis : squeal example

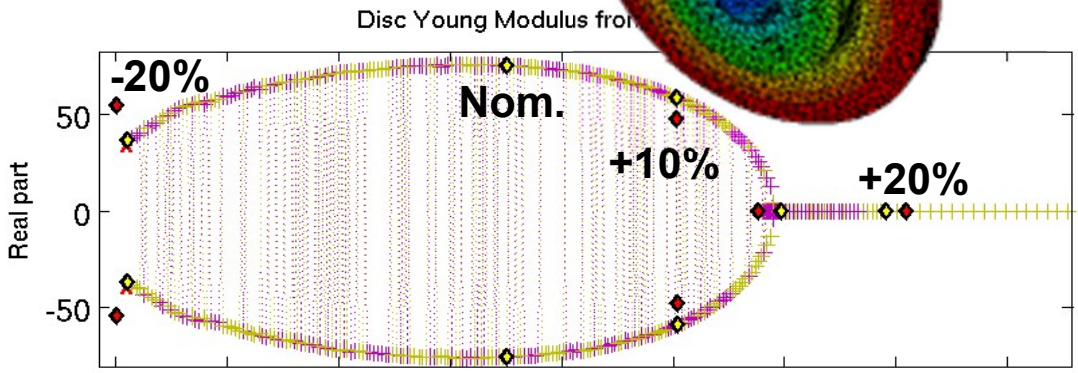
Objectives:

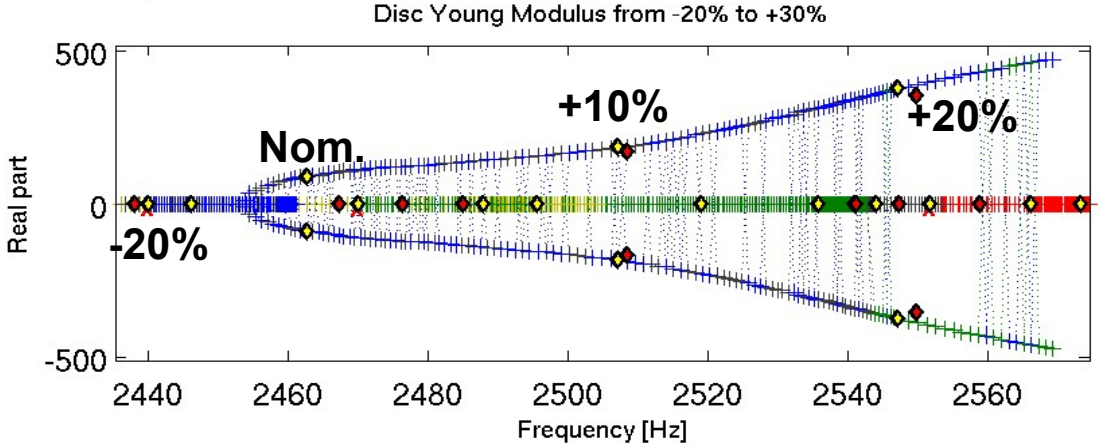
- complex mode stability
- Transient simulation











Other applications

- Multi-stage cyclic symmetry (SNECMA).
  - Which stage, which diameter, …
  - Mistuning (which blade)
- Damping design (PSA)
  - Fixed system modes, component redesign

