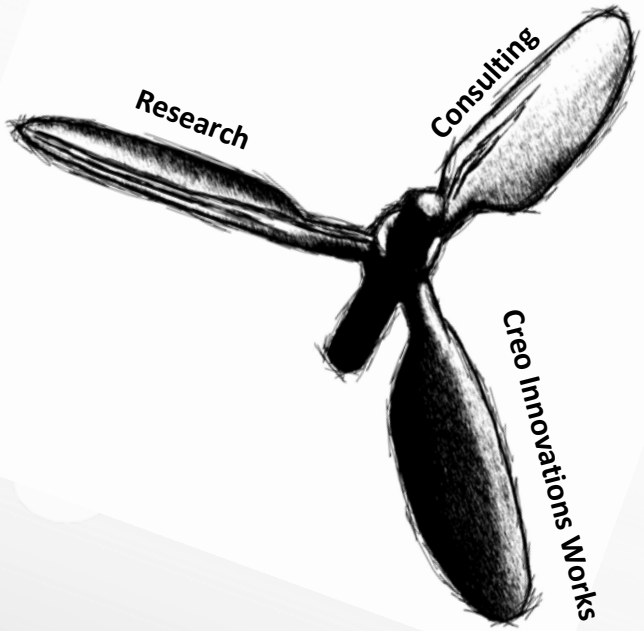
A reduction method for the vibro-acoustic problem including poroelastic material using interface-dependent Lanczos vectors

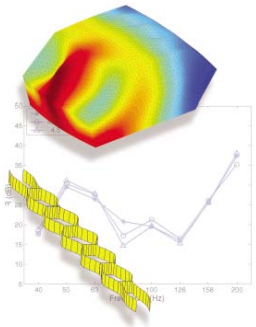


SAPEM 2014, STOCKHOLM

Peter Davidsson, Creo Dynamics AB
Göran Sandberg, Lund University

proud part of VINNGROUP

Introduction

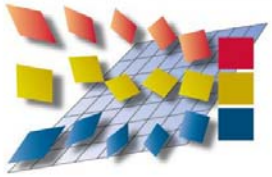


STRUCTURE-ACOUSTIC ANALYSIS; FINITE ELEMENT MODELLING AND REDUCTION METHODS

PETER DAVIDSSON

Structural Mechanics

Doctoral Thesis

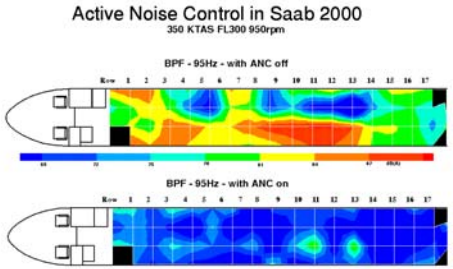


CALFEM

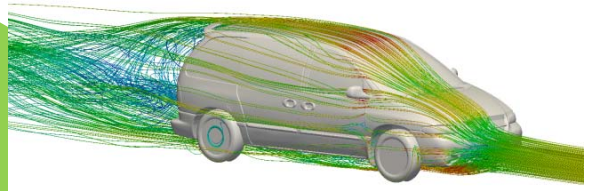
A FINITE ELEMENT TOOLBOX

Version 3.4

P-E AUSTRELL, O DAHLBLOM, J LINDEMANN, A OLSSON, K-G OLSSON, K PERSSON, H PETERSSON, M RISTINMAA, G SANDBERG, P-A WERNBERG



Active noise control

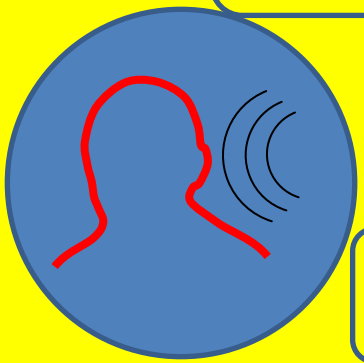


Aero-acoustic CFD

Propeller/engine noise

Flow induced noise

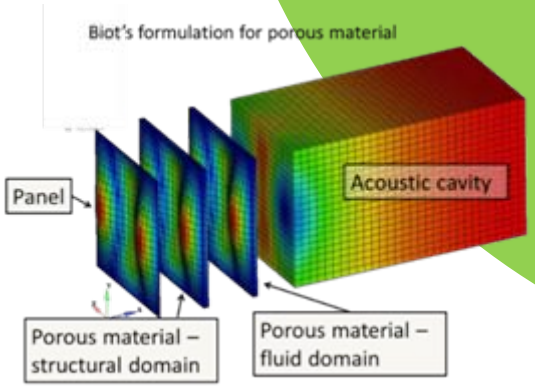
Transfer path



Advanced materials

Sound absorbing material

Vibro-acoustic simulations



Analysis & optimization of lightweight structures

Creo Dynamics – Competences

Acoustics

Fluid mechanics

Smart structures

Active noise control

Structural Dynamics

Measurements and correlation

Vibro-acoustic simulations

Aero-acoustic CFD

External flow, internal flow, heat transfer, combustion etc.

Open source CFD methodology

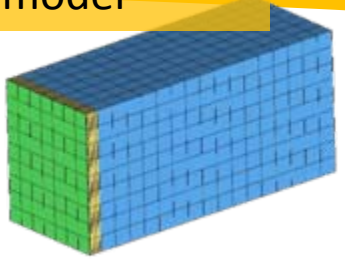
Structural Health Monitoring and NDT methods

Analysis & optimization of lightweight structures

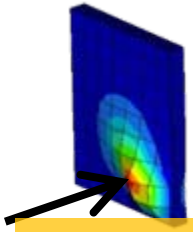
Building intelligence into composite structures

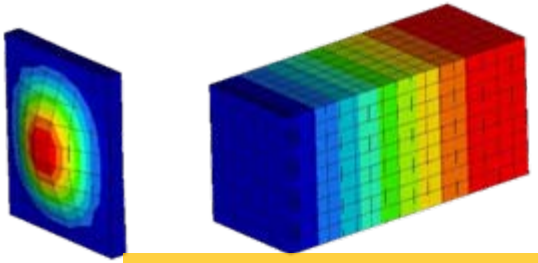
Analysis procedure

Generate model



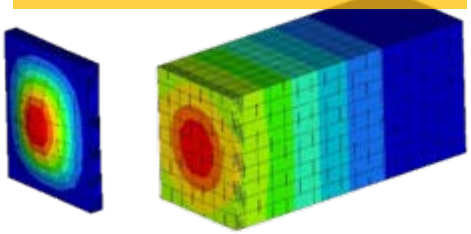
Generate excitation



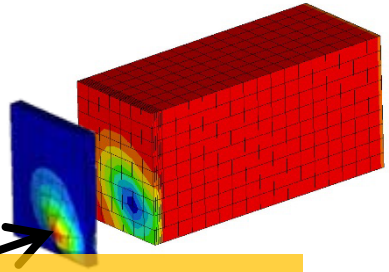


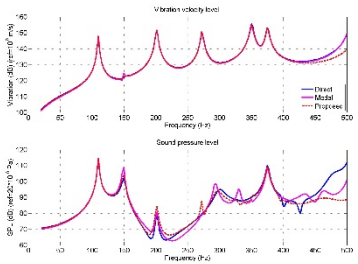
Calculate normal modes for each domain up to frequency limit

Derive extended modal base using interface dependent start vectors



Perform frequency response analysis





Evaluate results

Structure-acoustic analysis

- Vibro-acoustic problem

$$\begin{bmatrix} -\omega^2\mathbf{M}_s + \mathbf{K}_s & -\mathbf{H} \\ -\omega^2\mathbf{H}^T & -\omega^2\mathbf{M}_p + \mathbf{K}_p \end{bmatrix} \begin{bmatrix} \mathbf{d} \\ \mathbf{p} \end{bmatrix} = \begin{bmatrix} \mathbf{f}_s \\ \mathbf{f}_p \end{bmatrix}$$

- Porous material using $\mathbf{u}/p$ formulation

$$\begin{bmatrix} -\omega^2\mathbf{M}_{ss} + \mathbf{K}_{ss} & -\mathbf{C}_{sp} \\ -\omega^2\mathbf{C}_{sp}^T & -\omega^2\mathbf{M}_{pp} + \mathbf{K}_{pp} \end{bmatrix} \begin{bmatrix} \mathbf{d} \\ \mathbf{p} \end{bmatrix} = \begin{bmatrix} \mathbf{f}_{bs} \\ \mathbf{f}_{bp} \end{bmatrix}$$

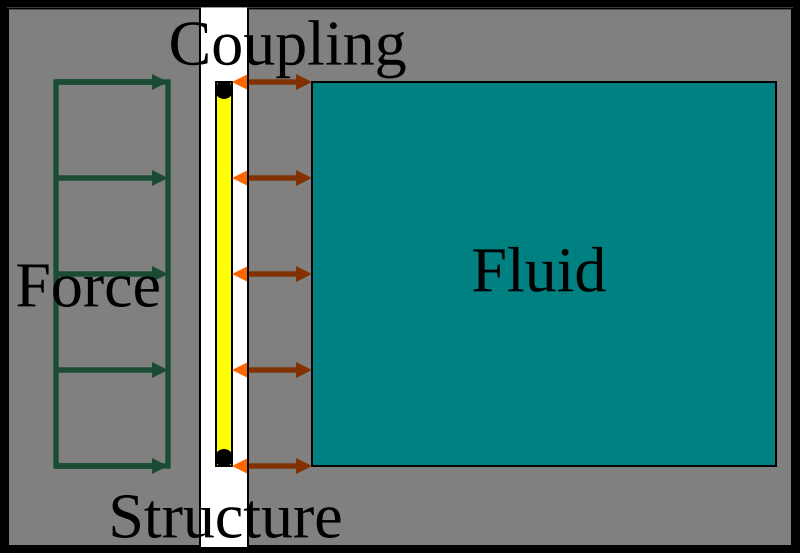
- Coupling force terms

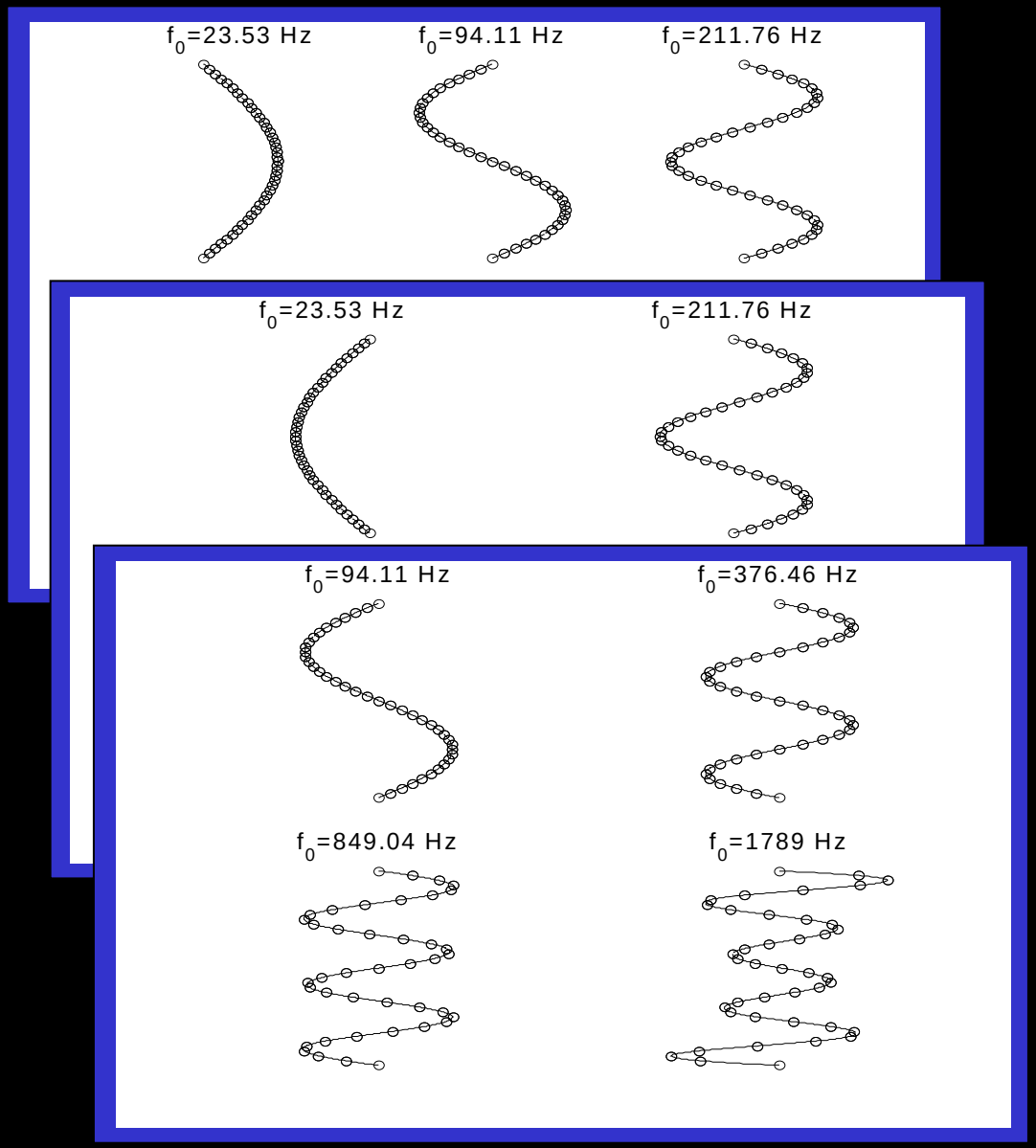
$$\mathbf{f}_{p->s} = -\mathbf{H}\mathbf{p} \qquad \mathbf{f}_{s->p} = -\mathbf{C}_{sp}\mathbf{p}$$

$$\mathbf{f}_{s->p} = -\omega^2\mathbf{H}^T\mathbf{d} \qquad \mathbf{f}_{s->p} = -\omega^2\mathbf{C}_{sp}^T\mathbf{d}$$

Lanczos vectors

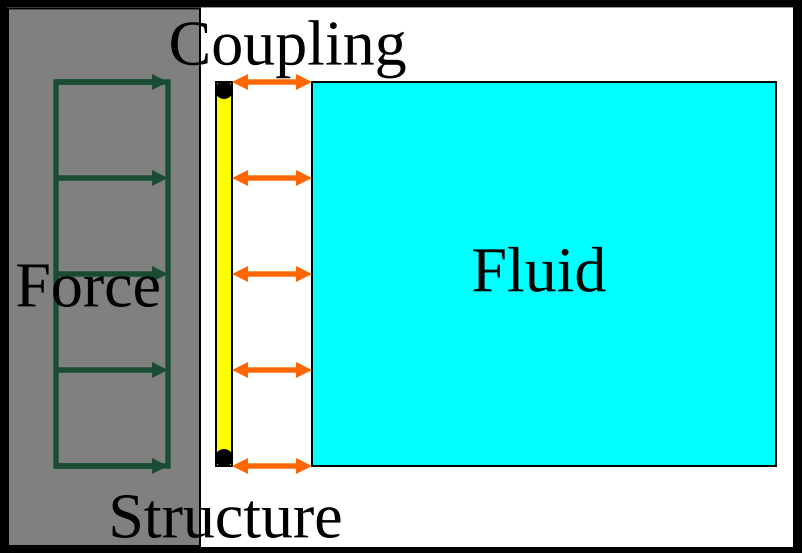
- Load dependent start vector in eigenvalue analysis
  - Random force → all modes
  - Actual force → important modes





Lanczos vectors

- Calculate the start vectors for each domain from
  - the pressure distribution of the fluid domain at the interface boundary
  - the displacement of the structure at the interface
- Where to get this information?



Analysis procedure

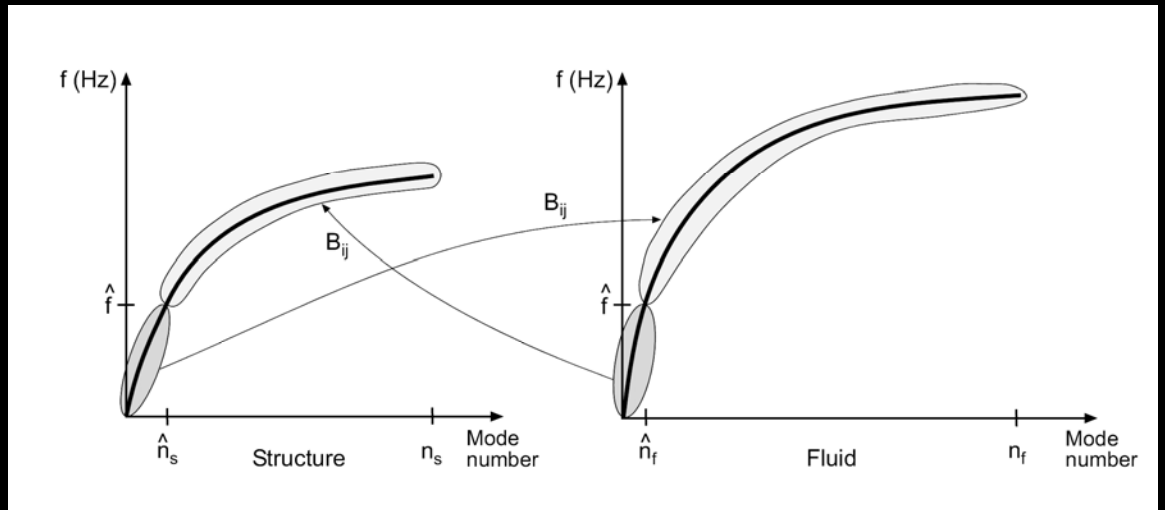
- Calculate the uncoupled modes up to the frequency limit of interest

$$\langle \hat{\Lambda}_S, \hat{\Phi}_S \rangle \qquad \langle \hat{\Lambda}_F, \hat{\Phi}_f \rangle$$

- Calculate the interface vectors

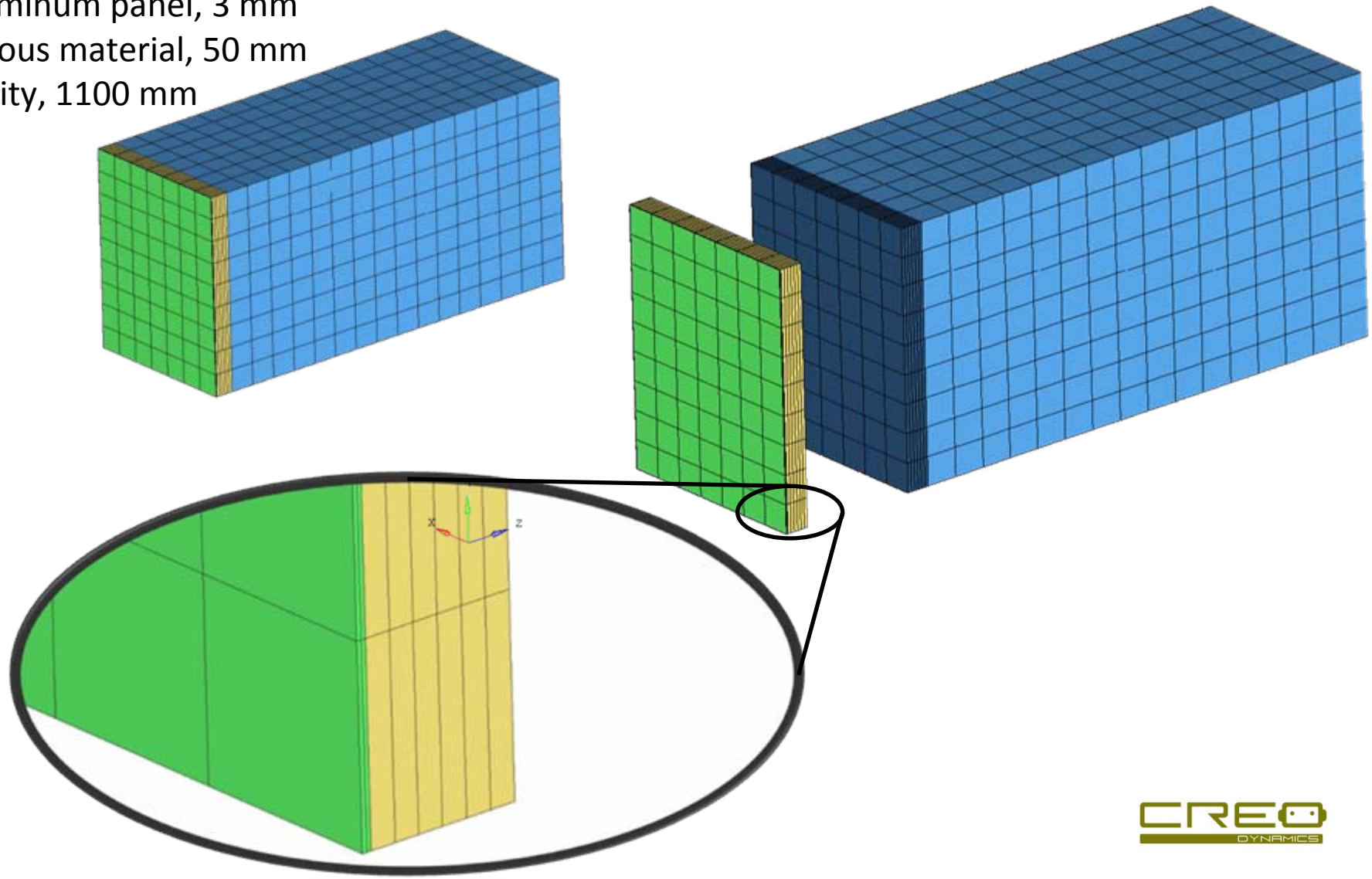
$$\mathbf{r}_F = \mathbf{H}_{SF} \hat{\Phi}_F \qquad \mathbf{r}_S = \mathbf{H}_{SF}^T \hat{\Phi}_S$$

- Derive a number of Lanczos vectors for each interface vector

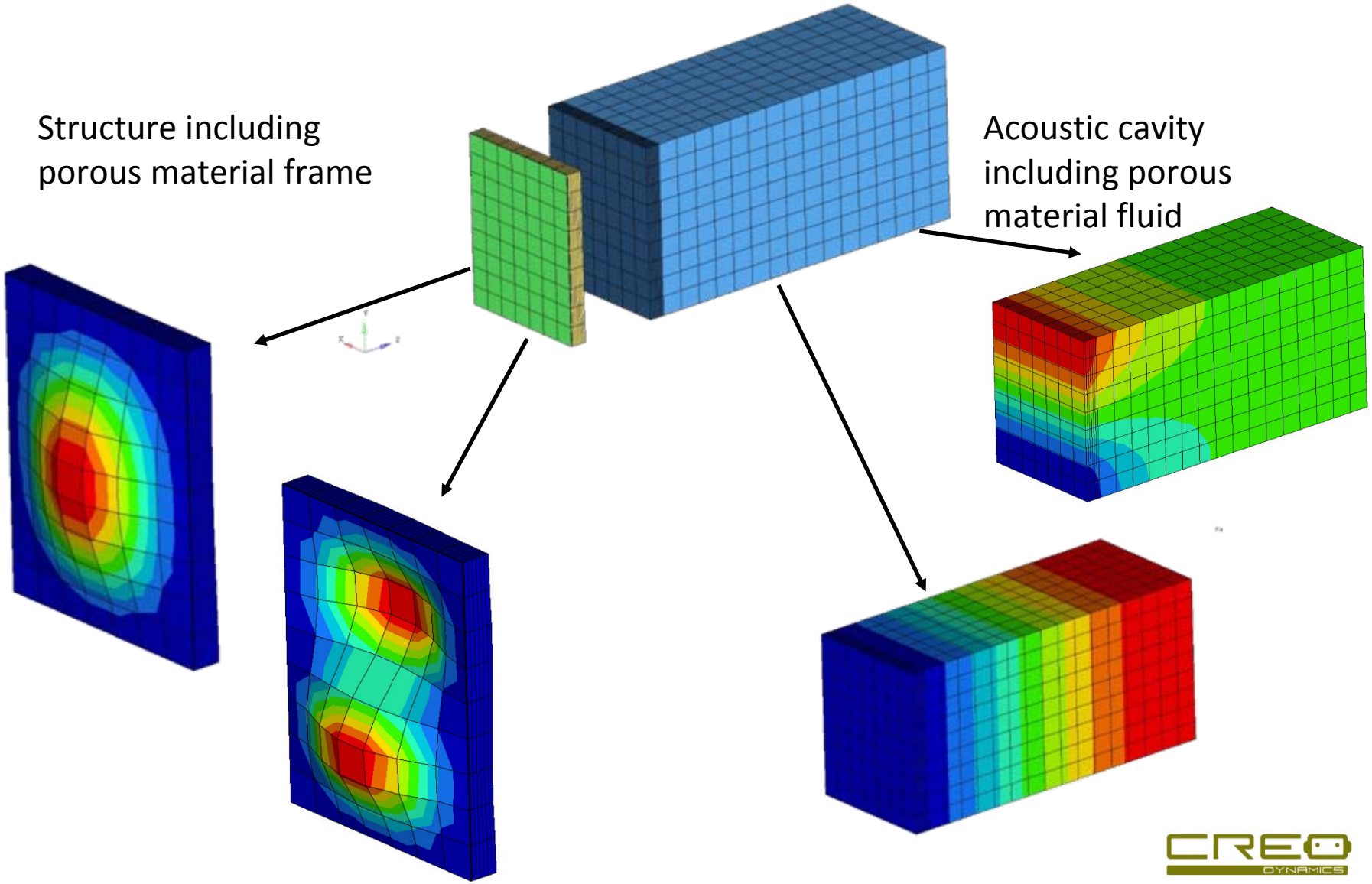


Box model

Aluminum panel, 3 mm
Porous material, 50 mm
Cavity, 1100 mm

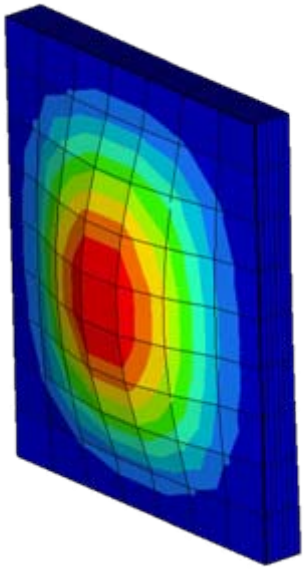


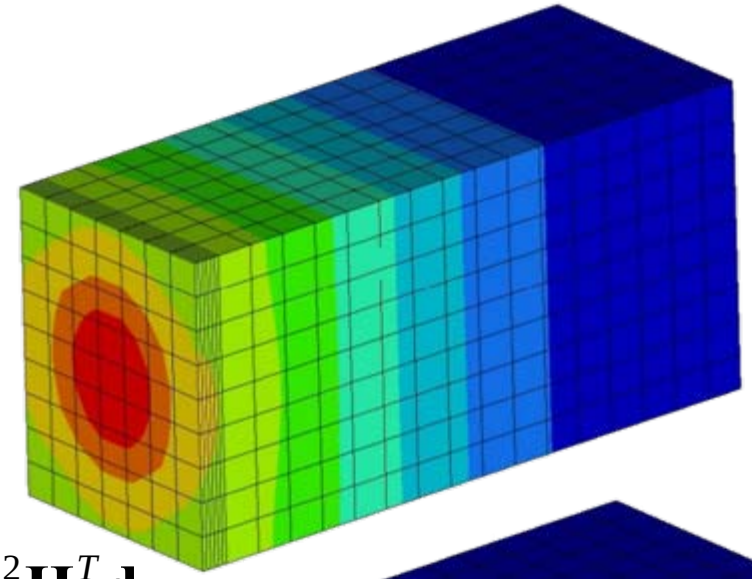
Uncoupled modes



Start vectors

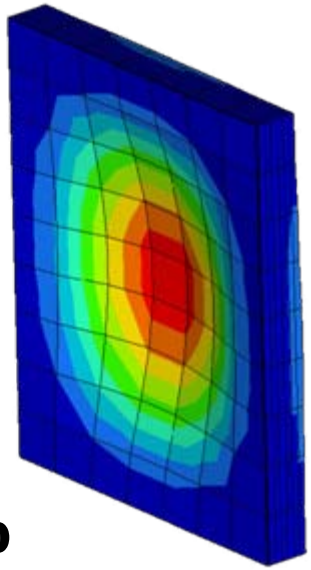
$$\mathbf{f}_{p->s} = -\mathbf{H}\mathbf{p}$$



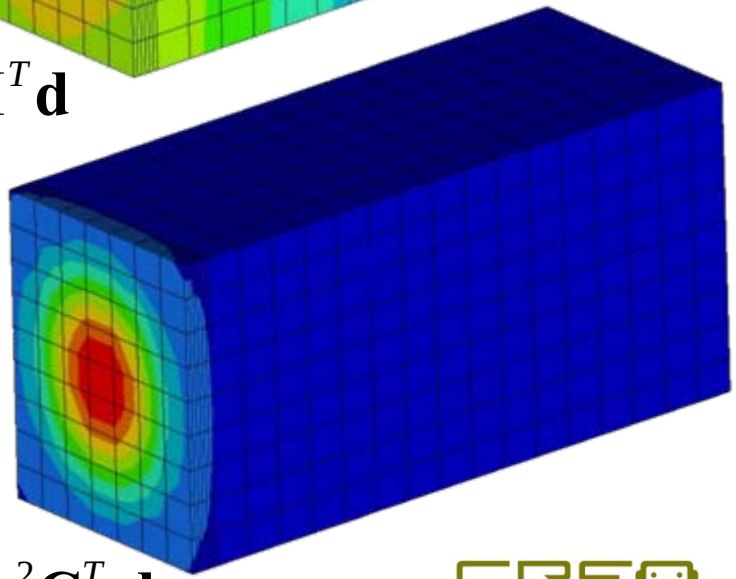


$$\mathbf{f}_{s->p} = -\omega^2 \mathbf{H}^T \mathbf{d}$$

$$\mathbf{p} = \mathbf{\Phi}_f \boldsymbol{\xi}_f$$



$$\mathbf{d} = \mathbf{\Phi}_s \boldsymbol{\xi}_s$$



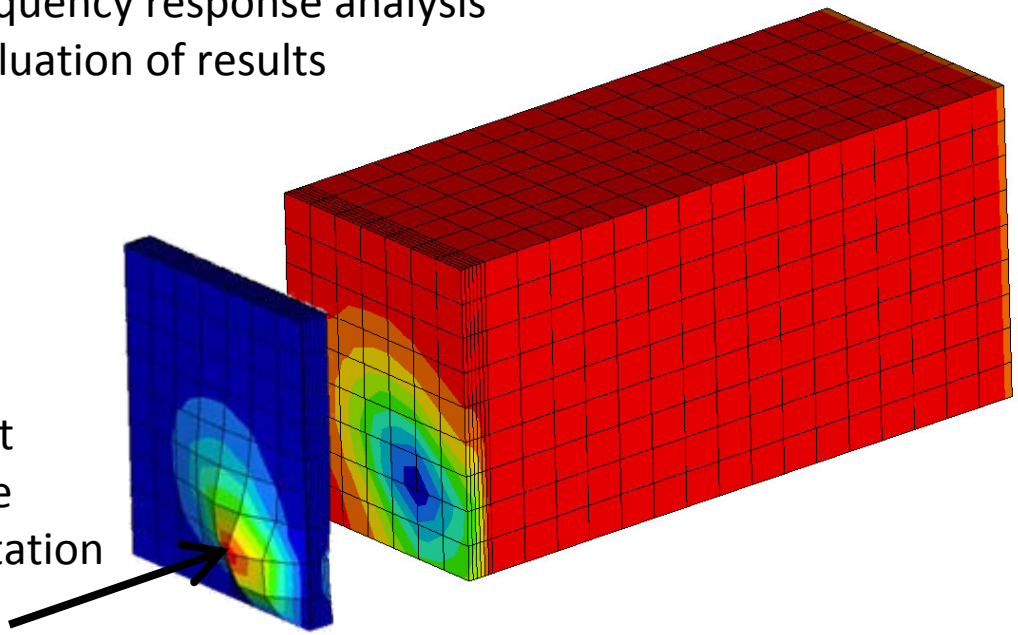
$$\mathbf{f}_{s->p} = -\mathbf{C}_{sp}\mathbf{p}$$

$$\mathbf{f}_{s->p} = -\omega^2 \mathbf{C}_{sp}^T \mathbf{d}$$

Frequency response analysis

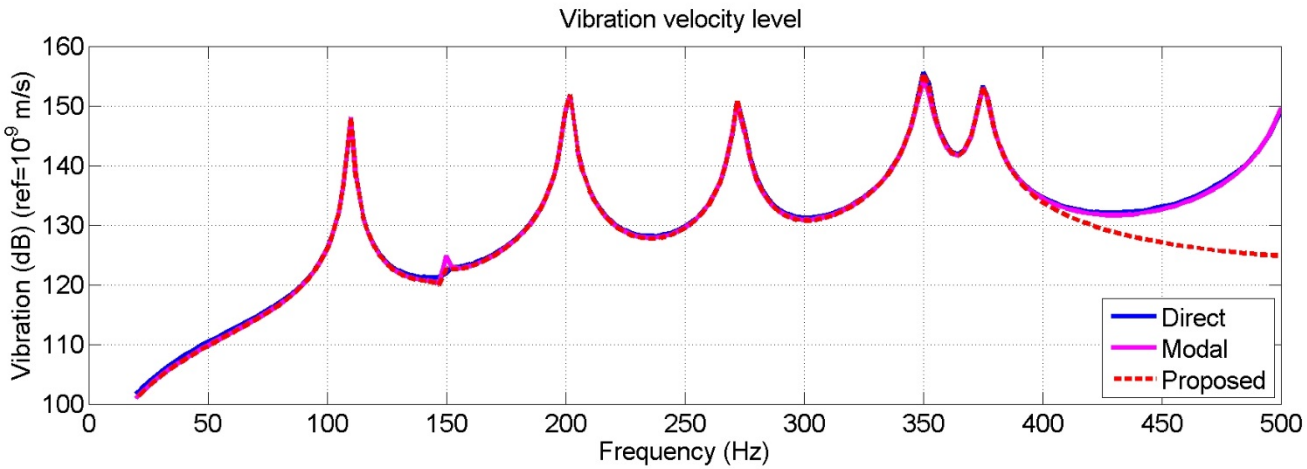
Procedure:
- Uncoupled modes
- Start vectors
- Interface dependent Lanczos vectors – extended modal base
  - Derived in iterative procedure based on the start vectors
- Modal reduction of the vibro-acoustic problem.
- Frequency response analysis
- Evaluation of results

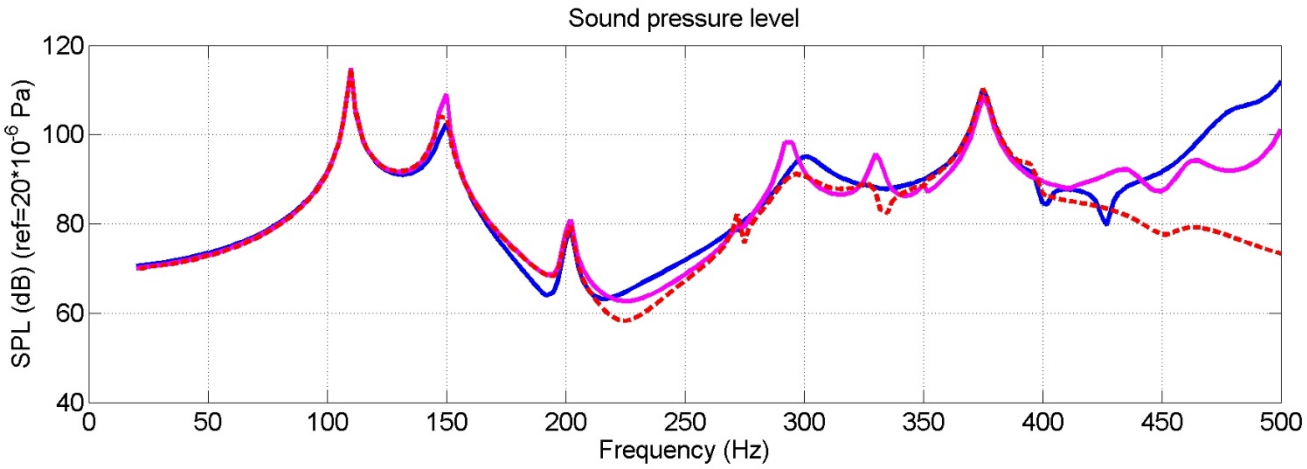
Results derived using:
- Direct solution (Direct)
- Modal reduction using uncoupled modes up to twice the frequency range of interest (Modal)
- Modal reduction using extended base with interface dependent Lanczos vectors (Proposed)



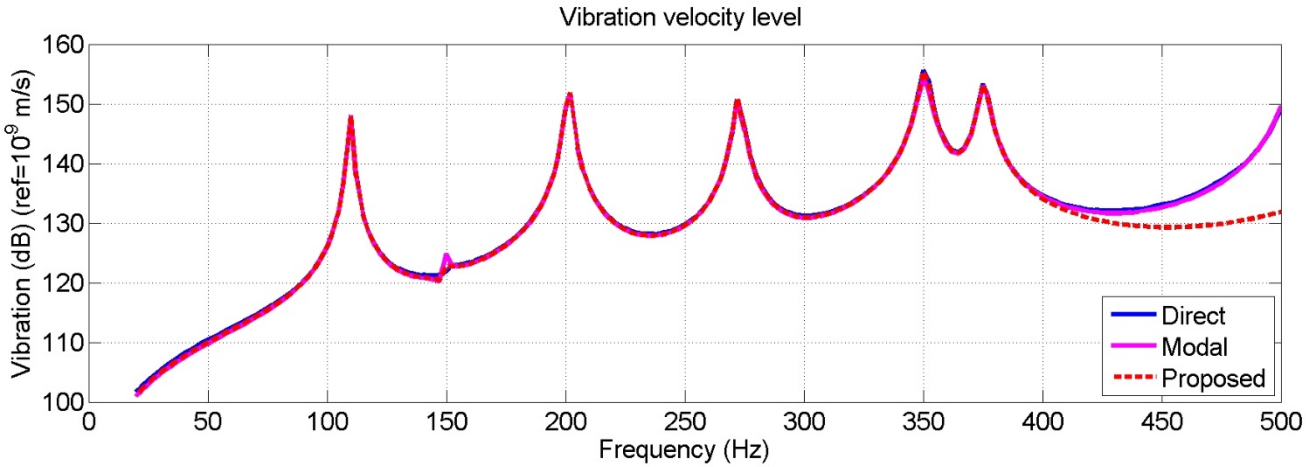
- Frequency sweep: 20 –500 Hz
- Evaluate:
  - Mean vibration level
  - Mean SPL

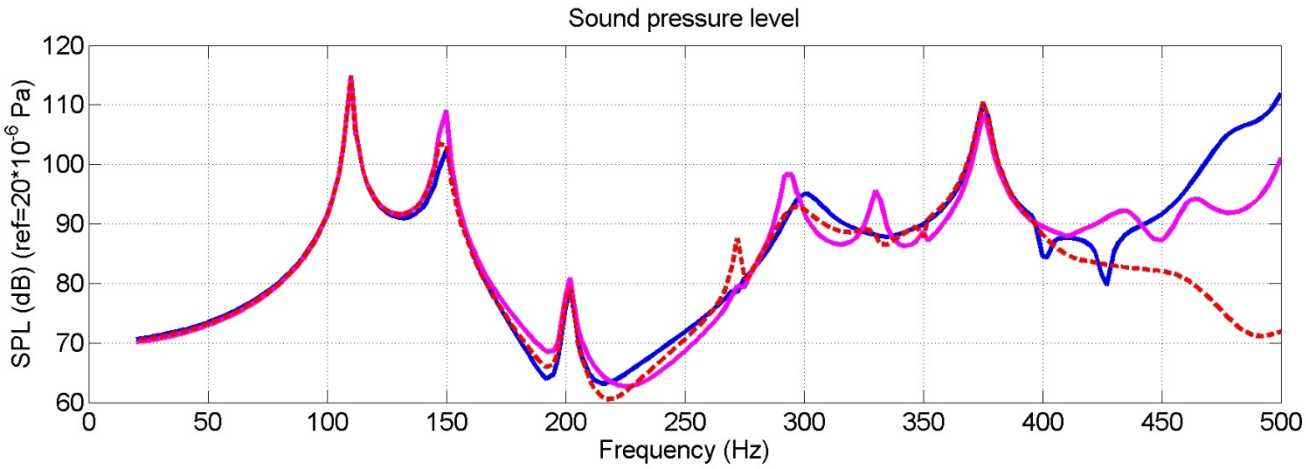
Frequency response result, One iteration



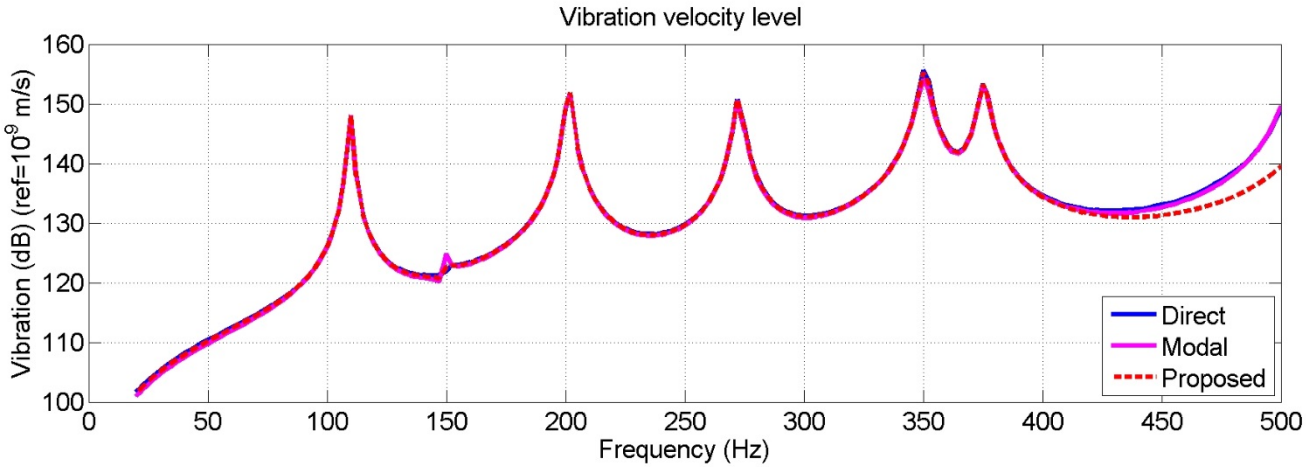


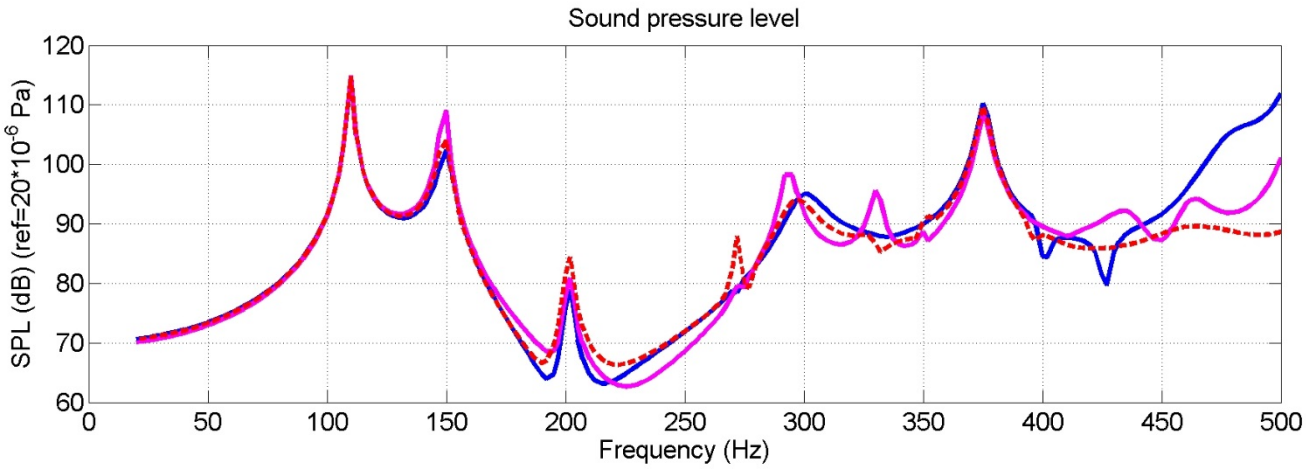
Frequency response result, Two iterations



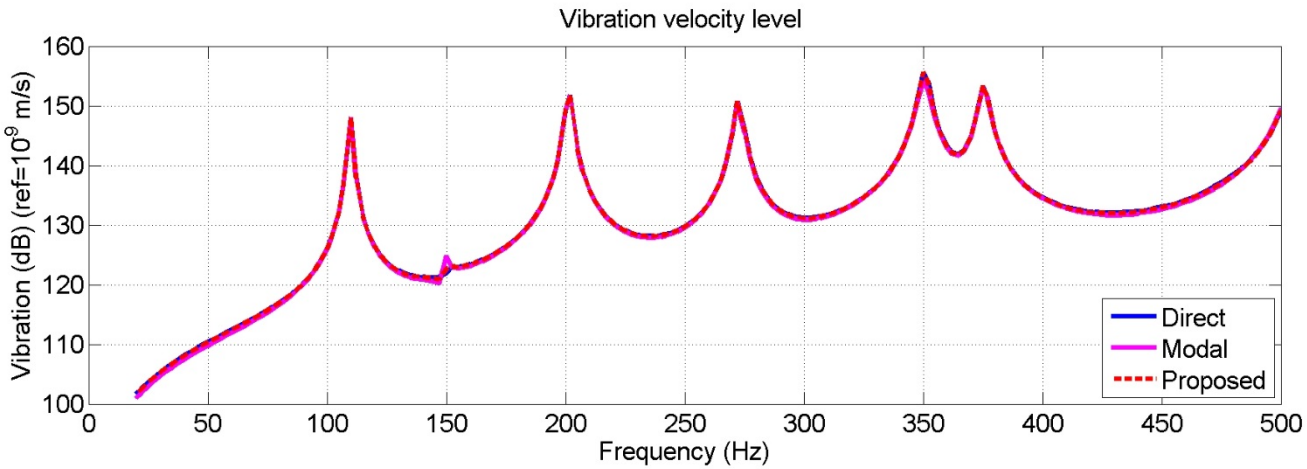


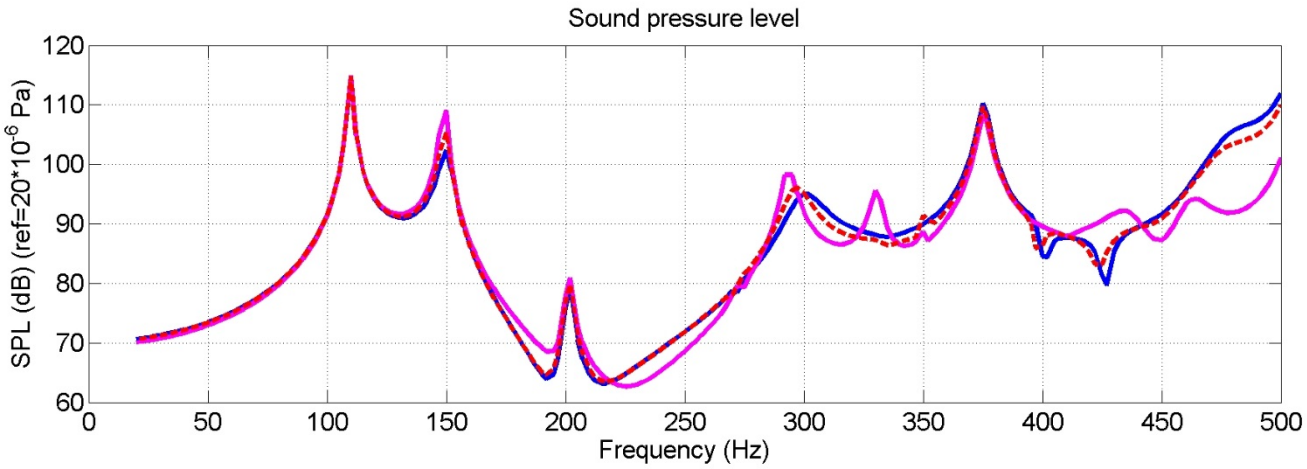
Frequency response result, Four iterations





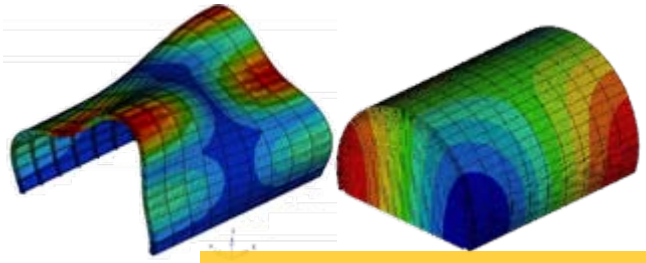
Frequency response result, Eight iterations



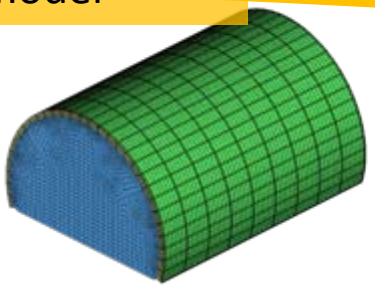


Analysis procedure, Small “industrial” problem

Strutural dofs:~500 000
Acoustic flud dofs: ~180 000



Generate model

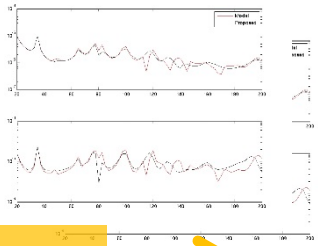


Generate excitation

Calculate normal modes for each domain up to frequency limit

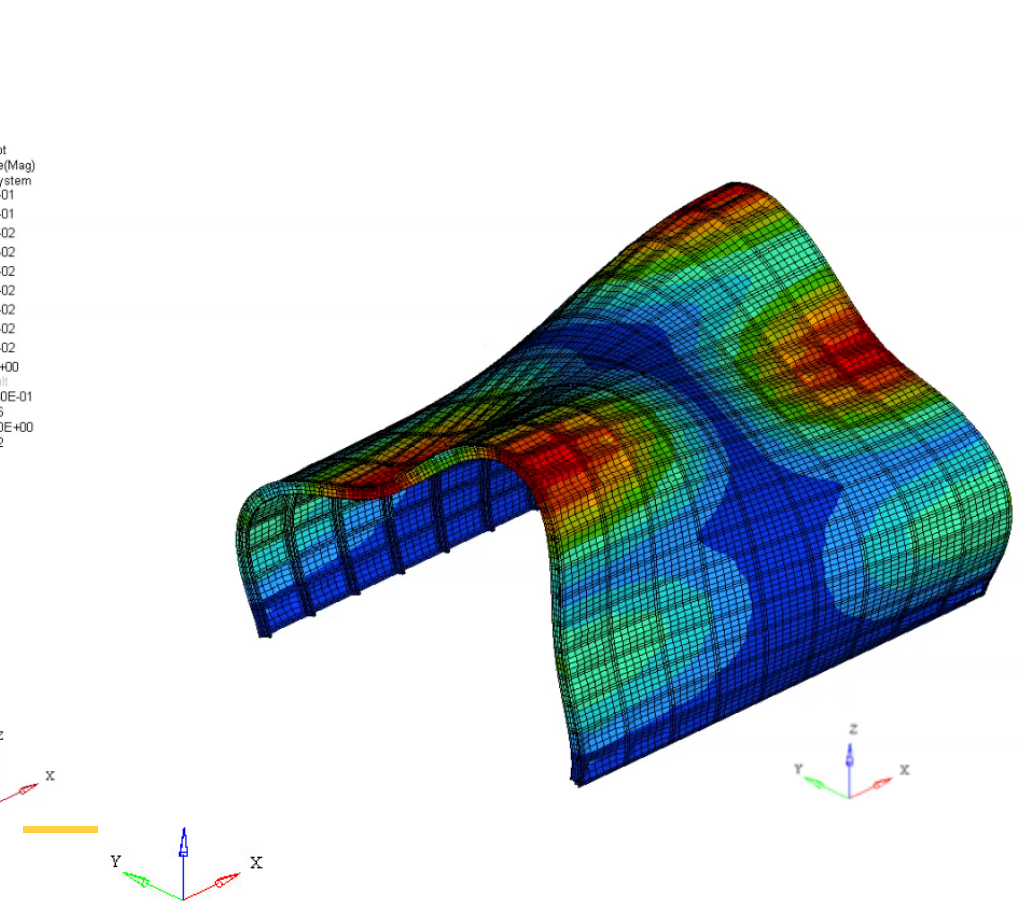
Derive extended modal base using interface dependent start vectors

Perform frequency response analysis



Evaluate results

Analysis procedure , Small “industrial” problem

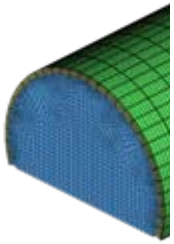


Response analysis

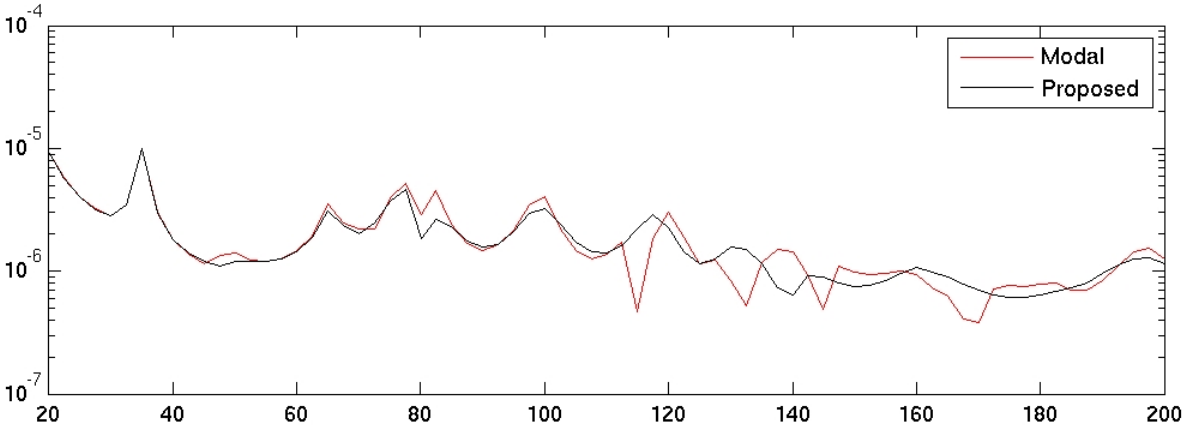
Evaluate results

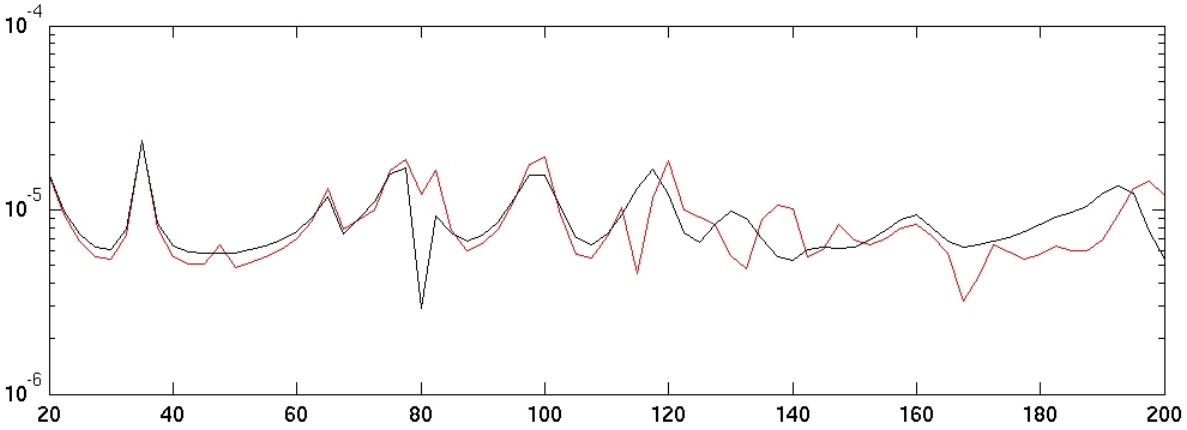
Analysis procedure , Small “industrial” problem

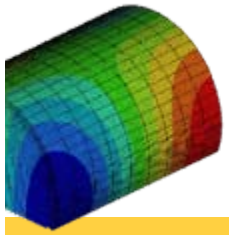
Generate model



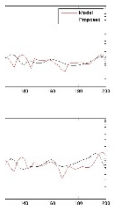
Derive ext
modal bas
interface c
start vecto







normal
each
to
limit



Conclusions

- Simulation using normal modes works well for this vibro-acoustic problem
- Box problem gives converging results with increased number of modes
- Typical small industry type of vibro-acostic problem needs further evaluation, but first results are promising

Creo Dynamics contacts

Research
Pushing technological barriers every day

Consulting
Providing cutting-edge knowledge to customers

Innovation
Creating competitive advantages through groundbreaking ideas

Creo Dynamics | Pioneering Solutions

Linköping
Westmansgatan 37A
SE-582 16 Linköping
Sweden
info@creodynamics.com

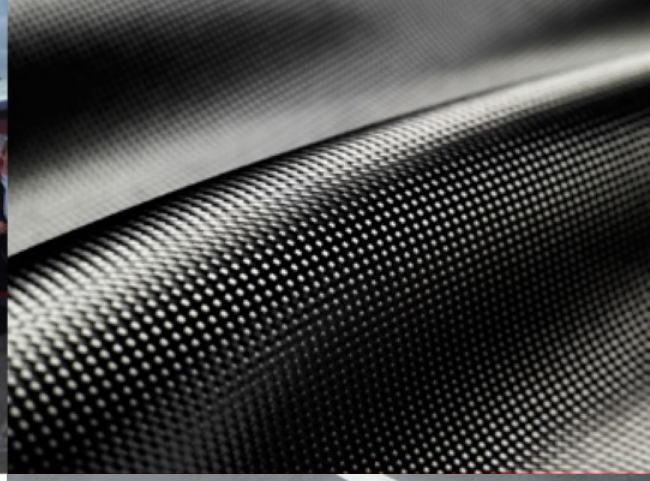
Lund
IDEON Gateway
Scheelevägen 27
SE-223 63 Lund
Sweden

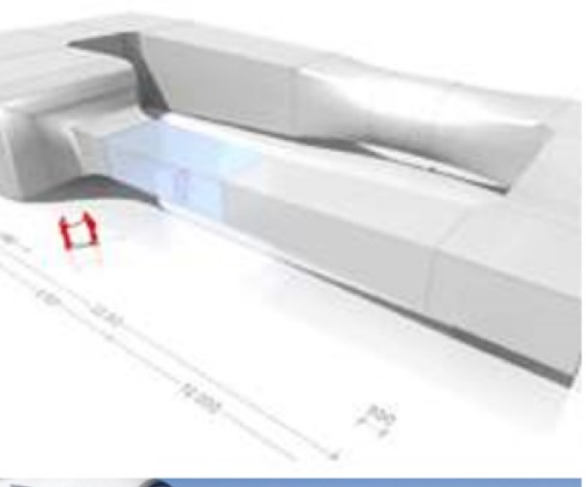
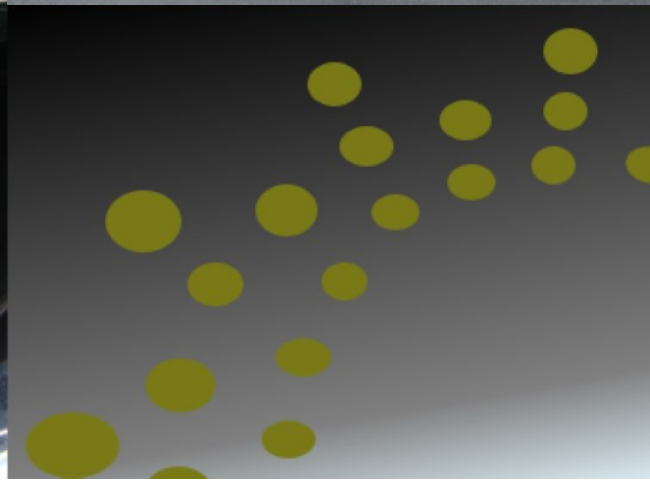
Urban Emborg, CEO
urban.emborg@creodynamics.com
+46 (0) 72 222 05 57

PETER DAVIDSSON

peter.davidsson@creodynamics.com
+46 (0) 72 222 05 55

CREO DYNAMICS





CREO DYNAMICS