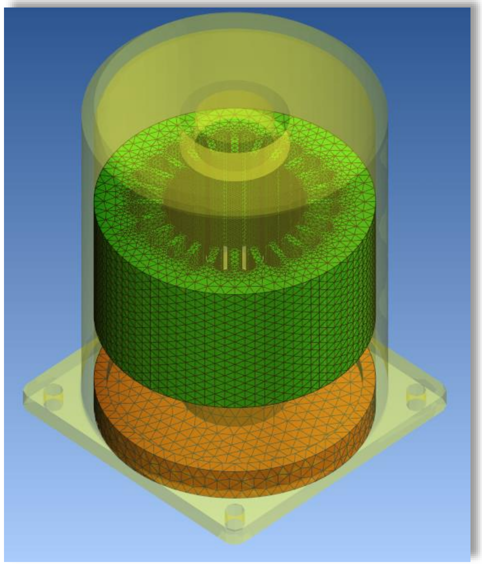
From Electromagnetic Forces To Acoustics

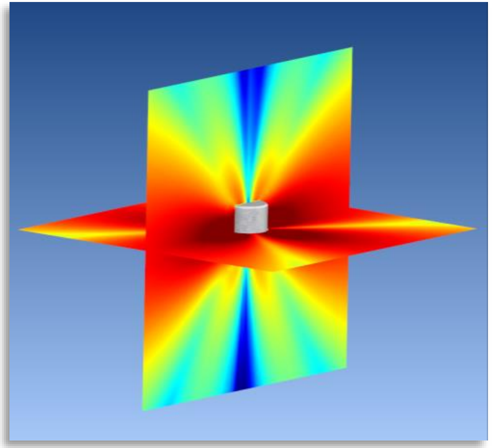
Full Chain Analysis for Vibro-Acoustic Studies with Electromagnetic Excitations

Presented By: Debbie Reeves, PhD
October 27, 2015

Content

- Objectives
- Introduction
- Radiated noise simulation in Actran
- Case study: electromagnetic motor noise
  - Actran model
  - Results
- Conclusion





Objectives

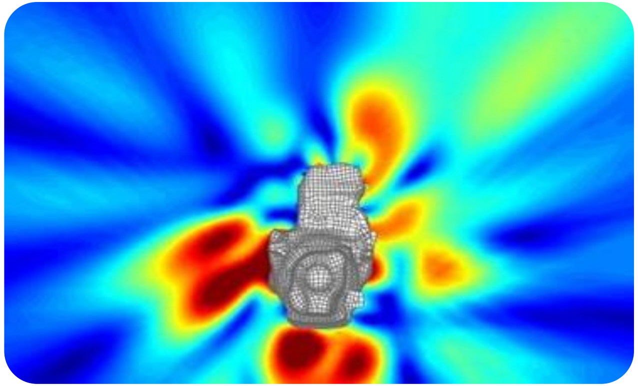
- Show chained simulation between Infolytica MagNet, MpCCI FSIMapper, MSC Nastran, and MSC Actran
- Predict the noise radiated from an electric motor due to electromagnetic forces

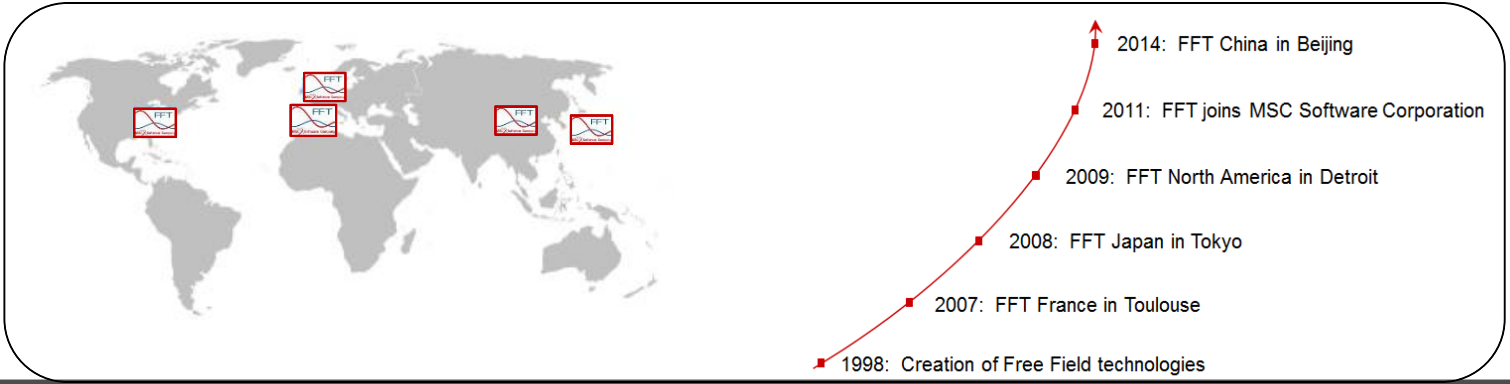
Introduction

Free Field Technologies & ACTRAN

Introduction

- **Free Field Technologies Founded in 1998**
- **Joined MSC Software in 2011**
- **Headquartered in Brussels, Belgium**
- **Activities:**
  - Development of the Actran software
  - Services support, training, consulting & technology transfer
  - Research in acoustic CAE and related fields
- **More than 300 industrial customers worldwide**

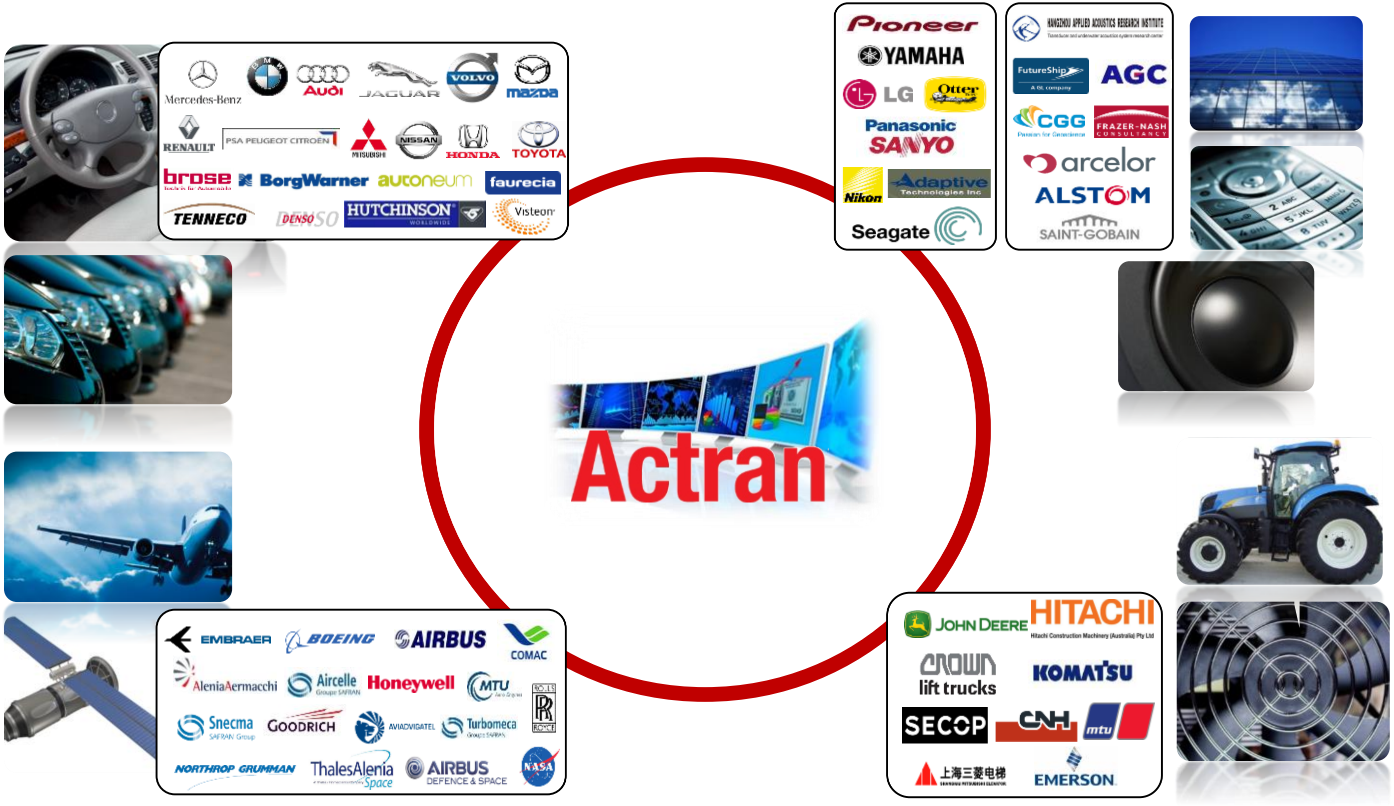




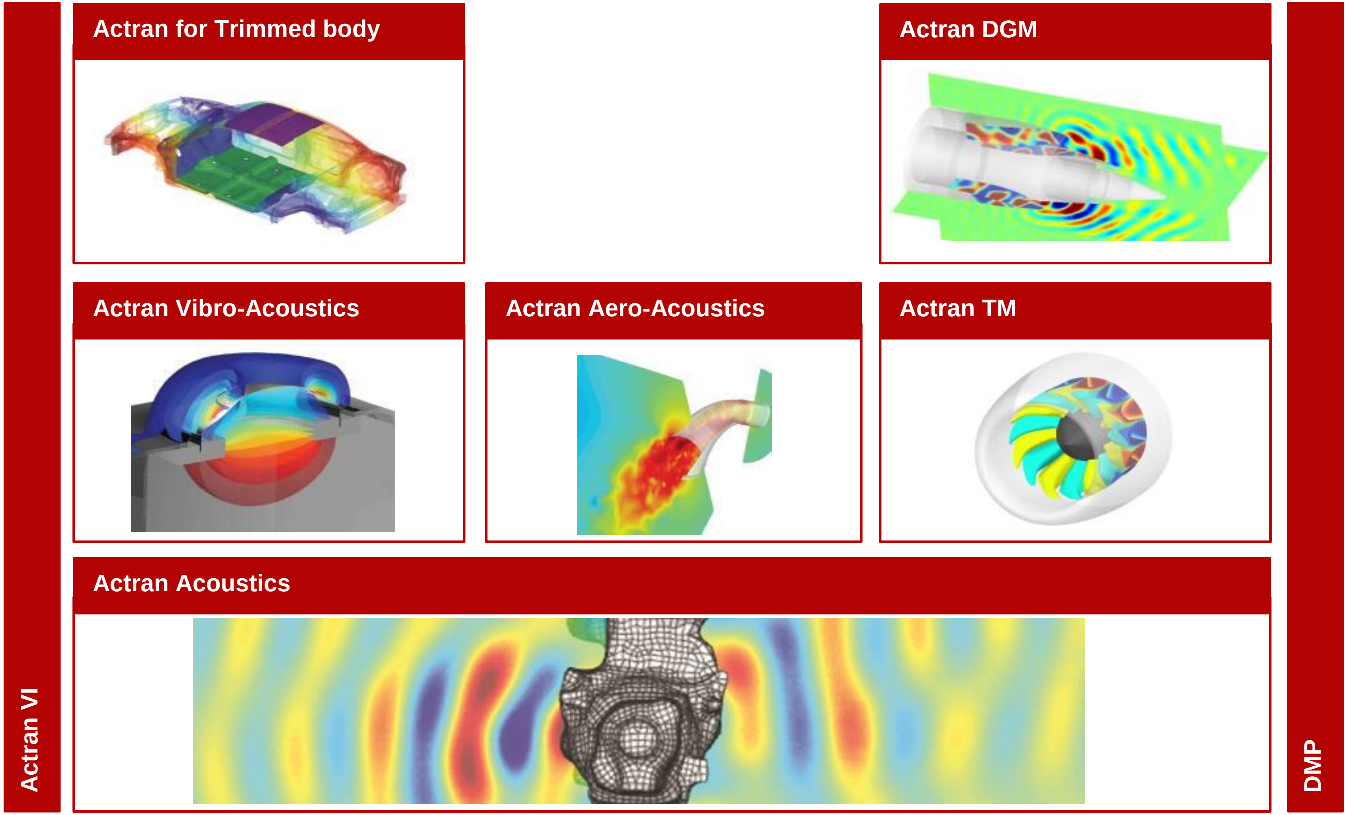
Why acoustics?

- **Noise needs to be studied to (among others):**
  - Accommodate for ***stringent standards***
    - The standards are becoming more and more restrictive
  - Improve ***comfort***
    - Acoustic comfort (car or aircraft) is a marketing argument today: Airbus A380
  - ***Prevent damages***
    - In the design of spatial structures, a high level of noise can lead to damages or break-down of the structure
- **Increasing need for simulation**
  - Prototypes are costly and involved too late in the development cycle
  - Simulation at the early design phase lead to reduce the development cost

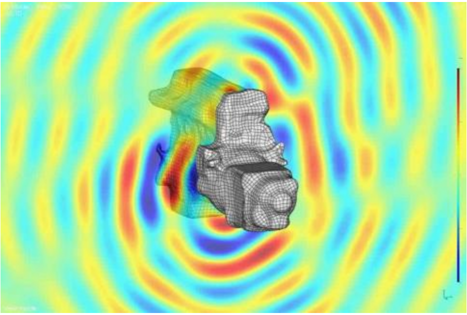
Actran Across Industries



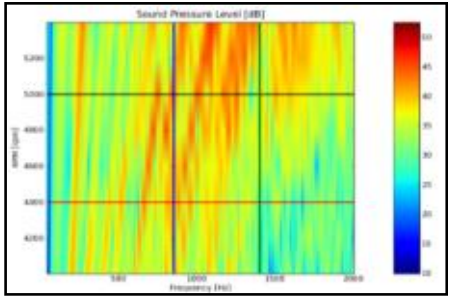
The Actran Software Suite



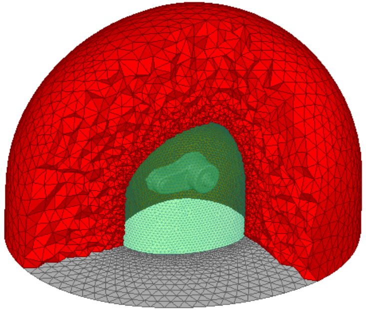
Actran Acoustics Features



- **Acoustic near field and far field propagation, with convection**
  - Acoustic finite elements, infinite elements, APML, time domain solver
  - Convected wave propagation (flow + temperature)
- **Excitations imported from MSC Nastran or others**

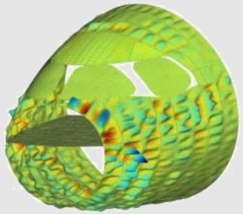


- **Results provided (among others)**
  - Acoustic pressure, intensity and power
  - Power distribution and radiation efficiency
- **Applications**
  - Engine: power train and auxiliaries (oilpan, manifold, exhaust, …)
  - Engine compartment insulation
  - Any vibrating / radiating component

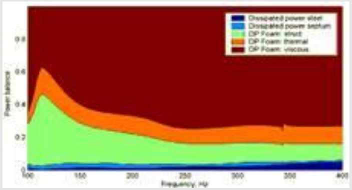


Actran Vibro-Acoustics Features

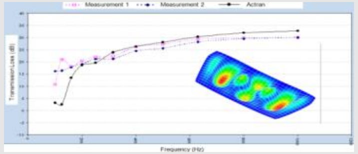
- **Structure elements**
  - Visco-elastic solid, shell, beam, stiffener
  - Poro-elastic elements
  - Rigid body, spring, point mass
  - Piezo-electric elements
- **Porous elements to model foam, rock, fibers: based on Biot model**
- **Perforated sheet model**
- **Coupling with fluid**
  - Strong coupling: fluid and structure interact together
  - Weak coupling: no retroaction of fluid on structure
  - Support of non-congruent meshes
- **Import Nastran structural models into Actran**
- **Example of results provided:**
  - Structural displacement, acceleration, force, stress
  - Energy dissipated in each layer or each material
  - Energy balance statements
  - Insertion Loss



Vibrations computed by Actran on an aircraft cockpit



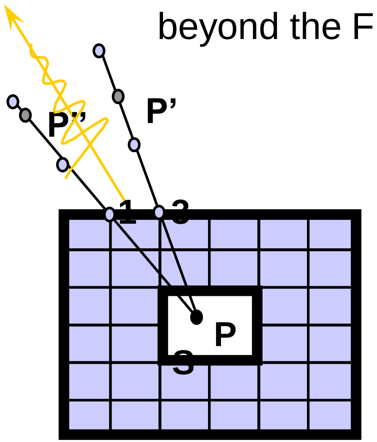
Dissipated Energy in each layer of a multi-layer material

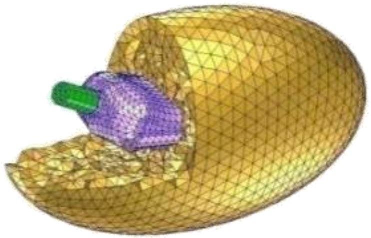


Transmission loss of a windshield

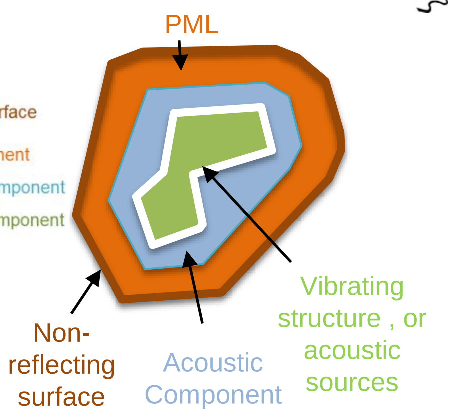
Infinite Elements and Perfectly Matched Layers (PML)

- **Infinite elements:**
  - Simulate unbounded domain
  - Appropriate high order shape functions in the radial direction
  - Ensure no wave reflections at the FE/IE interface
  - Provide accurate acoustic results beyond the FE domain



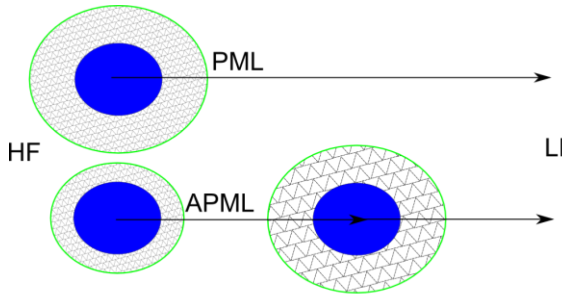


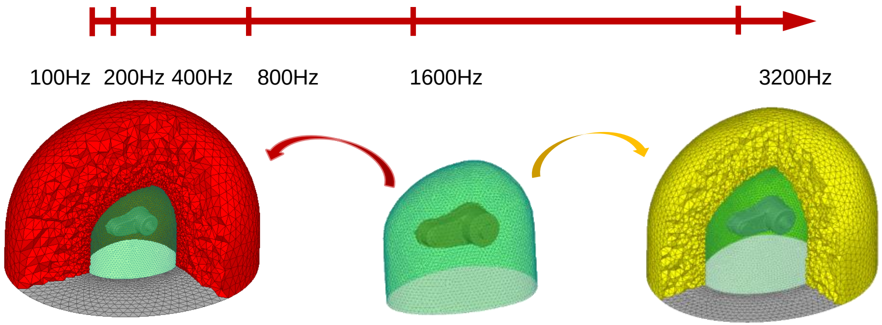
- **Perfectly Matched Layers**
  - Alternative/complement to infinite elements for the radiation in free field
  - Extra-layer of used to progressively damp the acoustic wave and non-reflecting boundary condition
  - Far field solution using automated FWH solver



Adaptive Perfect Matched Layer (APML)

- **For handling multiple frequencies in a single computation, the PML method has two opposite constrains:**
  - At lower frequencies, the PML layer should be thick enough to absorb acoustics with longer wavelength
  - At higher frequencies, the element size within the PML should be small enough to capture the shorter wavelengths
- **APML automates the PML mesh creation, adapting to different frequencies**
  - Reduced meshing effort for modeling sound radiation problems
  - Optimized computation time for the each desired frequency
- **Actran can generate different adaptations of PML layers for each frequency band**
- **Gain of calculation time by adaptive mesh**





APML for 400Hz ~ 800Hz

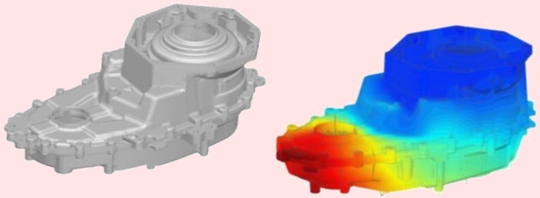
APML for 800Hz ~ 1600Hz

Radiated Noise Simulation in Actran

Radiated Noise Simulation in Actran

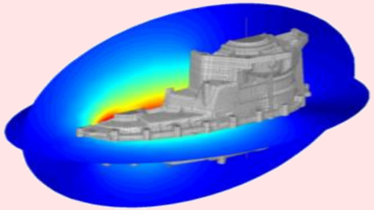
- **Overview of radiated noise simulation process**

1. Structural Analysis: MSC Nastran, Adams/Flex, Marc, Actran, etc.



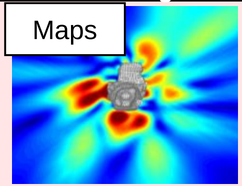
Structure surface vibration

2. Acoustic radiation: Actran in Frequency or Time Domain

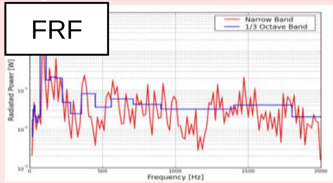


3. Post Processing and Analysis: Actran

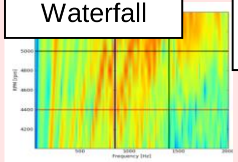
Maps



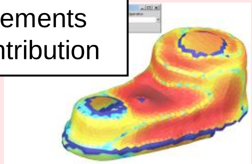
FRF



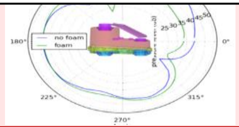
Waterfall



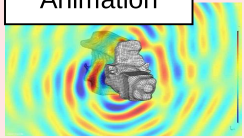
Elements contribution



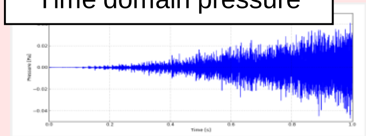
Acoustic directivity



Animation



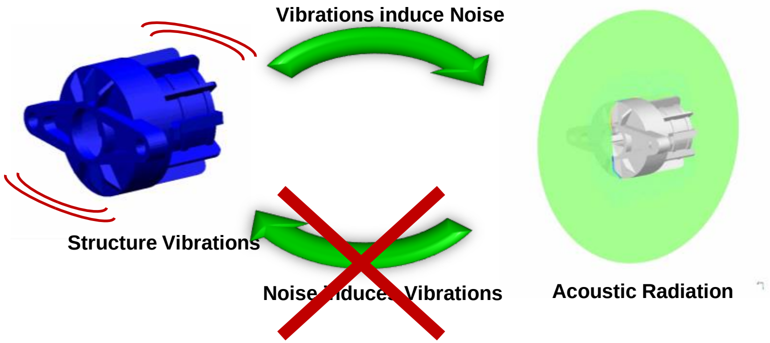
Time domain pressure



Sound file

Acoustic Radiation Analysis Strategies in Actran (1)

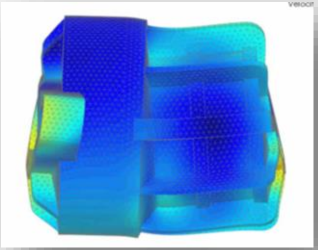
- **Two strategies to do acoustic radiation simulations in Actran:**
  1. **Fully coupled computation**
     - Structural vibrations create acoustics and acoustic field alter the behavior of the structure
     - Both fluid and structure are modeled in Actran
  2. **Weakly coupled computation**
     - Acoustics does not alter the behavior of the structure
     - Actran is used to model the acoustic part only
     - Vibration of the structure is analyzed in other FEA tools (e.g. MSC Nastran, Ansys, etc)
     - FEA results (e.g. surface displacements, velocities) are used as the excitation in the acoustic analysis
     - The FEA results are applied as boundary condition



- **Weakly coupled strategy was used in this case study**

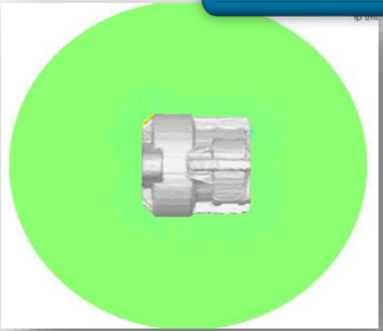
Acoustic Radiation Analysis Strategies in Actran (2)

- **Structural response**

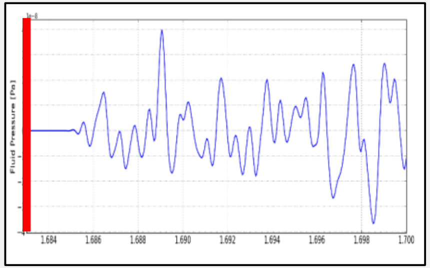


Boundary Condition
(BC MESH)

Acoustic Radiation



- **Dedicated features for efficient noise radiation calculations**



- **Results**

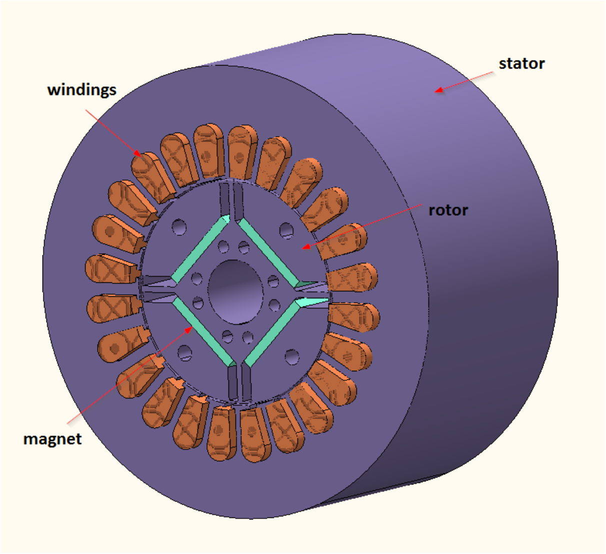
Post-Processing

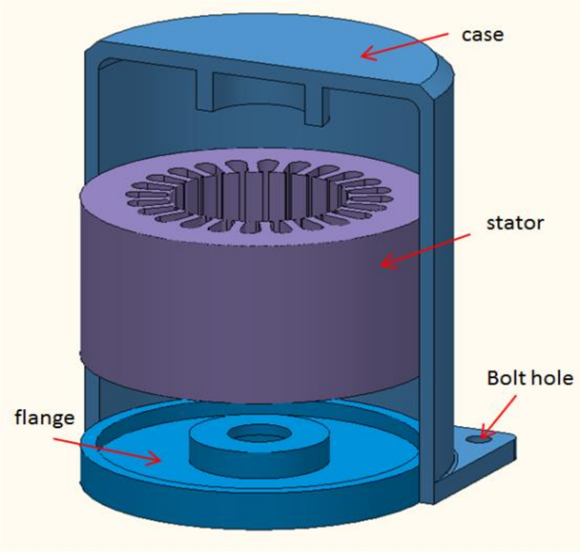
Case Study

Electromagnetic Noise

Example Case

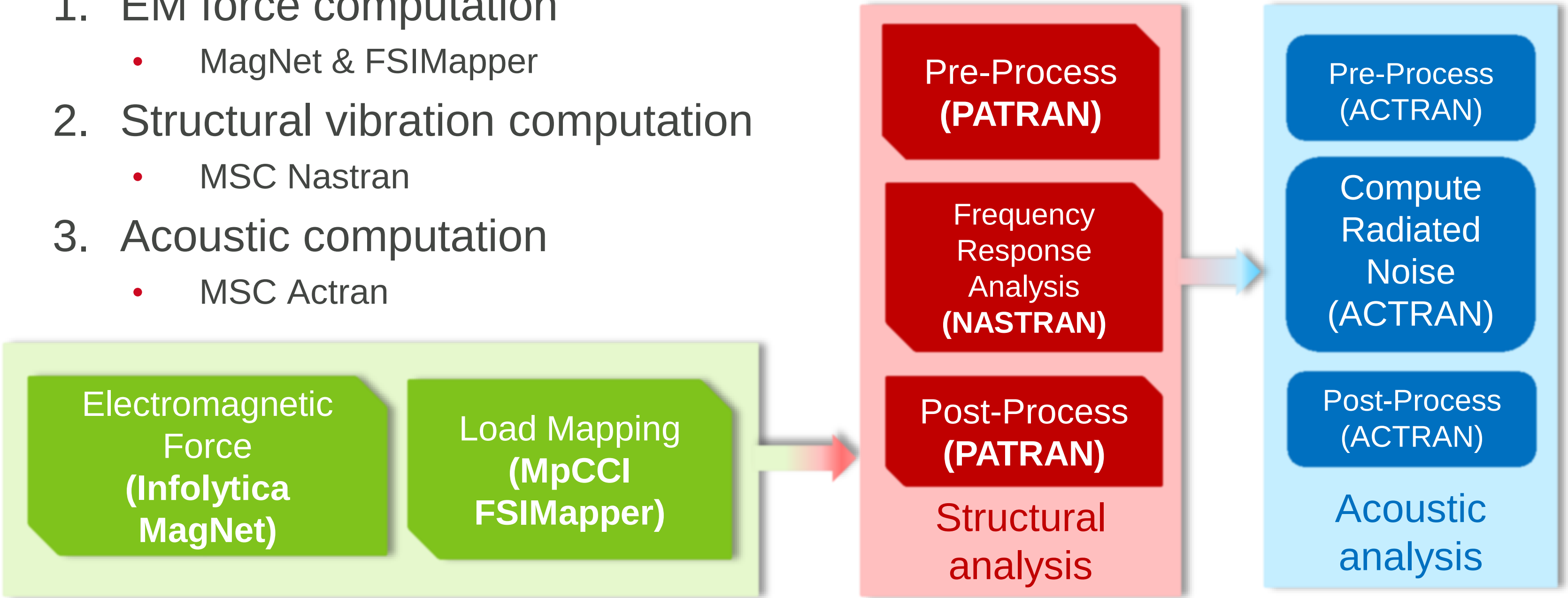
- Electromagnetic noise from 4-Pole 24-Slots Motor
- Rotation speed = 1800 RPM = 30 Hz





Chain Analysis of Vibro-Acoustic Study

- **Chain analysis process**
  1. EM force computation
     - MagNet & FSIMapper
  2. Structural vibration computation
     - MSC Nastran
  3. Acoustic computation
     - MSC Actran



Actran Acoustic Model (1)

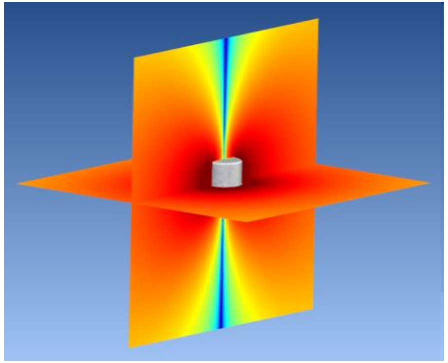
- **BC Mesh procedure**

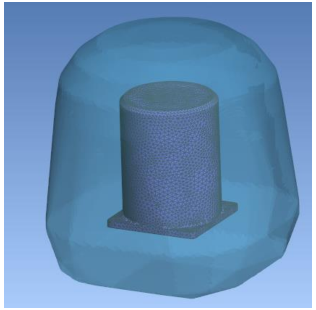
MSC PATRAN / NASTRAN

- Structure surface mesh +
- Surface velocities

ACTRAN (BC Mesh)

Acoustic Radiation





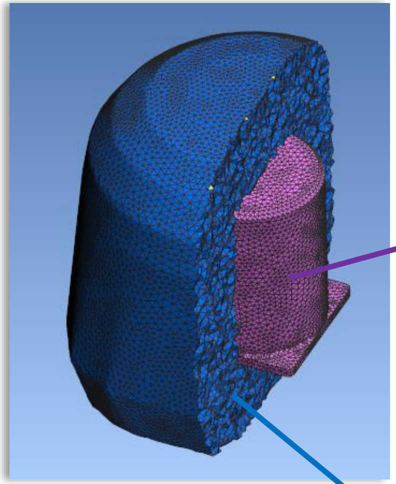
MSC ACTRAN

Acoustic mesh:

- FE mesh for fluid (3D)
- FE mesh for non-reflecting BC (2D)
- Coupling surface (2D)

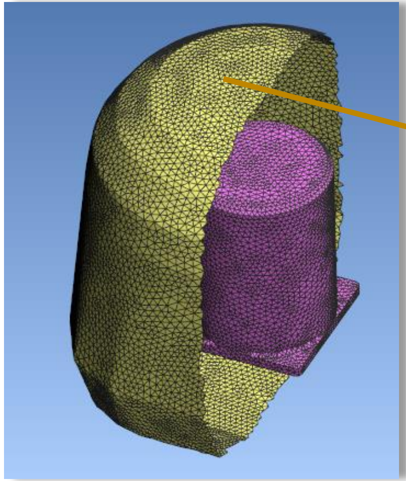
Actran Acoustic Model (2)

- Acoustic radiation model requires an acoustic mesh



Coupling surface

Acoustic fluid

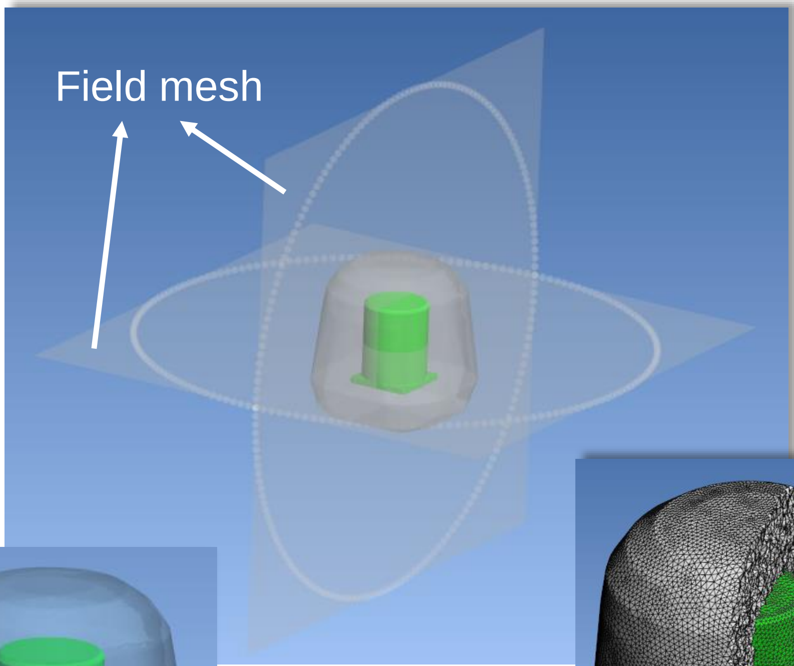


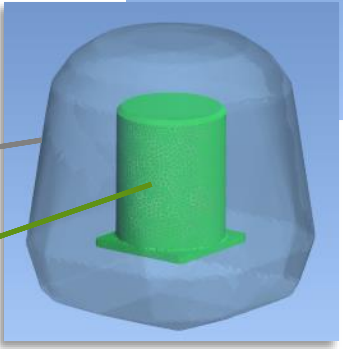
Non-reflecting Boundary Condition (NRBC) surface

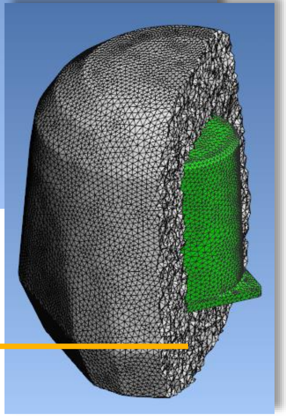
- Ensure there are no wave reflections
- Provide accurate acoustic results beyond the FE domain

Actran Noise Radiation Model

- **Two main modeling strategy for free-field radiation:**
  1. “Manually” create fluid mesh surrounding the structure
  2. Actran automatically creates fluid mesh
     - Fluid mesh is created in the background during solving stage
     - Reduce meshing effort

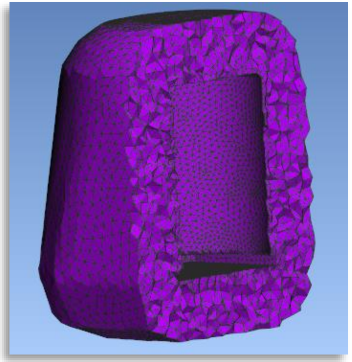






Fluid Mesh for Radiation Calculation

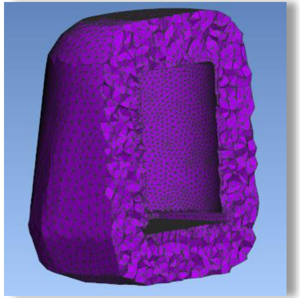
- “Traditional” acoustic radiation calculation



- One mesh is designed for the highest frequency solved
  - Small element size
  - Mesh is used for all frequencies
- ➢ Computation time is the same for all frequencies

- “Adaptive” acoustic radiation calculation

Low frequency mesh



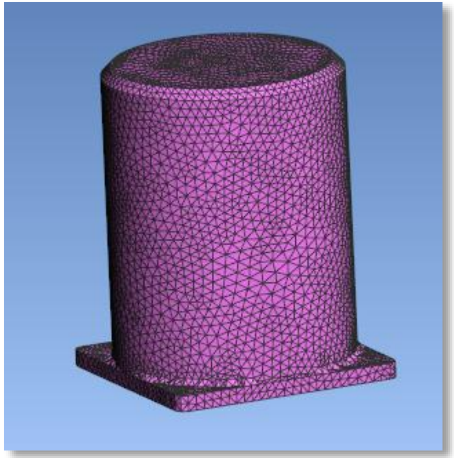
High frequency mesh

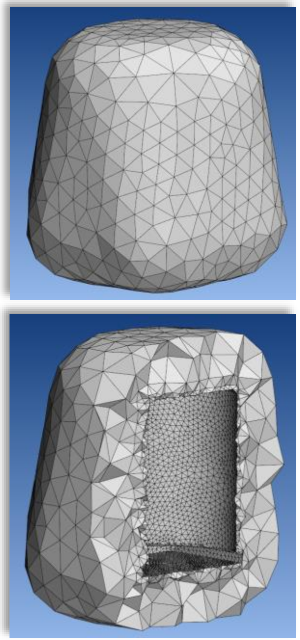
- The complete calculation frequency range is divided into smaller frequency bands
  - One mesh is created for each frequency band
- ➢ The computation time is reduced for low frequencies

Automatic Fluid Mesh

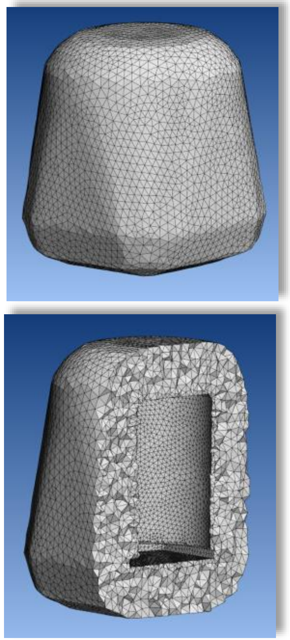
- *Exterior Acoustic* method
- Automatically creates acoustic domain in the framework of acoustic radiation in far field

Surface mesh as the base to create acoustic mesh





114 Hz – 2.1 kHz

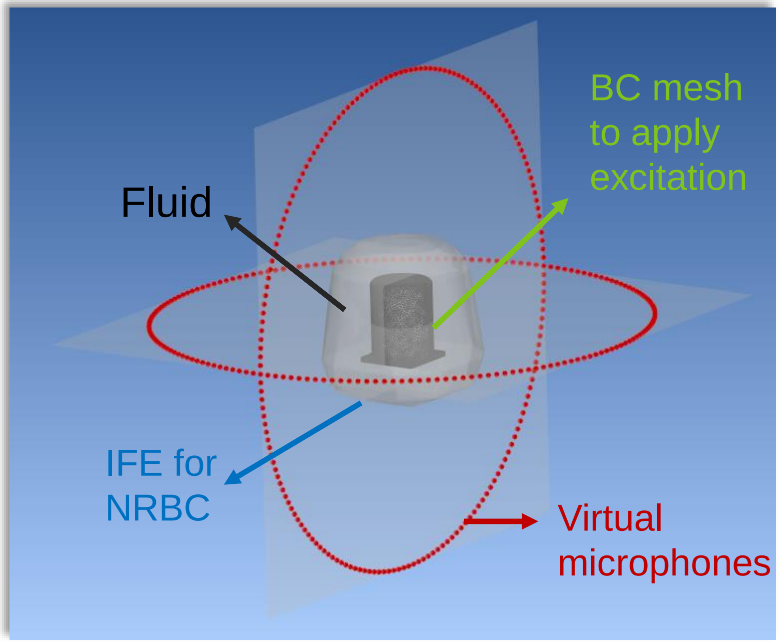


5.3 – 6.3 kHz

Automatically created fluid meshes

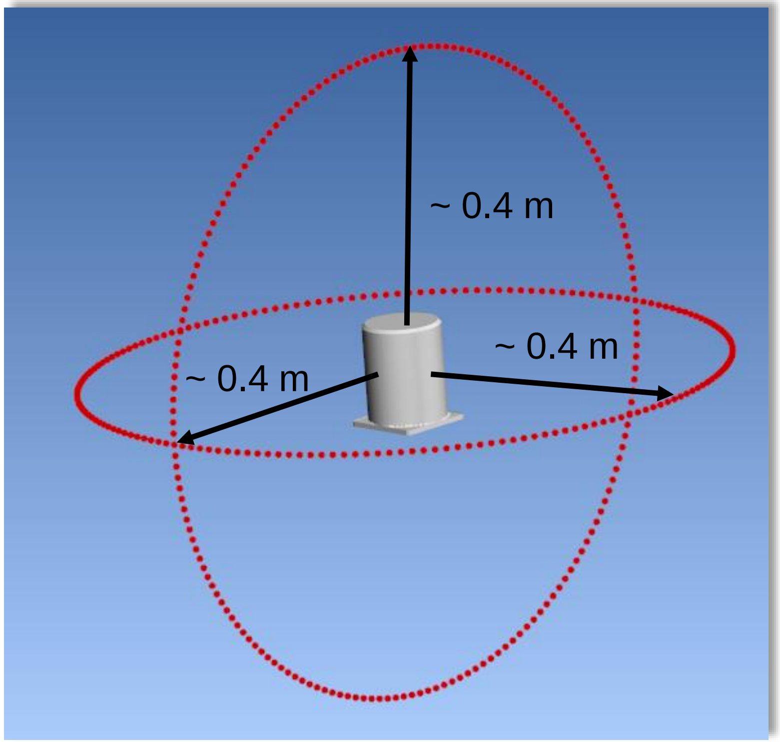
Actran Model Setup

- **Model setup process**
  1. Build fluid mesh (2D and 3D)
  2. Define material properties
     - Air: c = 340 m/s, ρ = 1.225 kg/m^3
  3. Define fluid components (domains + material properties)
  4. Define non-reflecting boundary condition (NRBC)
     - Infinite element: 2D skin of acoustic domain
     - Enable wave propagation into free-field
  5. Define excitation
     - Use Nastran results (OP2 format)
     - Apply excitation using BC mesh
     - Use of coupling surface to map structural results into acoustic mesh
  6. Define field points
     - To obtain output quantities



Field Points for Post-Processing

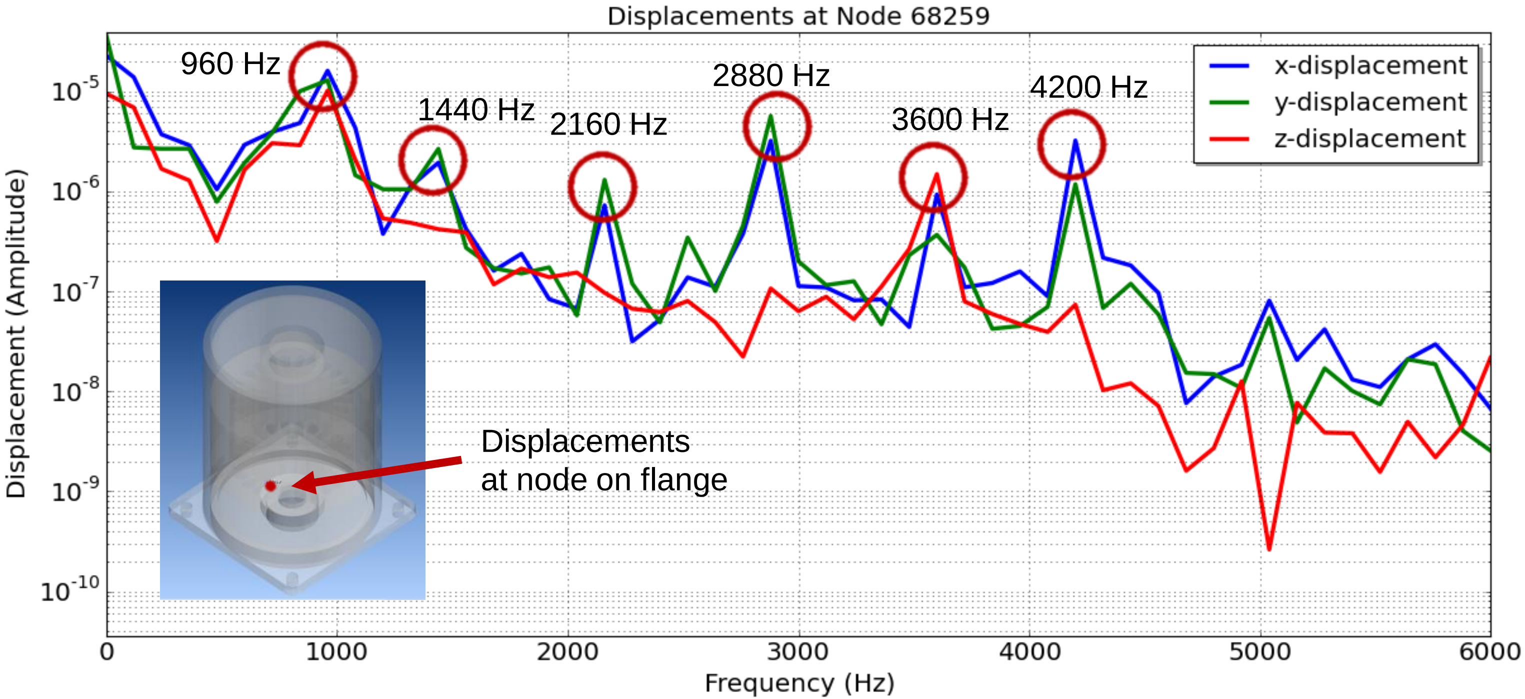
- **Field points distances from structure surface**
- **Field points in horizontal and vertical planes**
  - Can be used to generate directivity plots
- **Sound Pressure Levels (SPL) computed at virtual microphones**
- $$\boldsymbol{SPL = 20 \times \log_{10}\left[\frac{\sqrt{Fluid\ pressure^2}}{Ref\ pressure}\right]}$$
  - Fluid pressure in Pascal
  - Reference pressure = 2e-5 Pa



Results

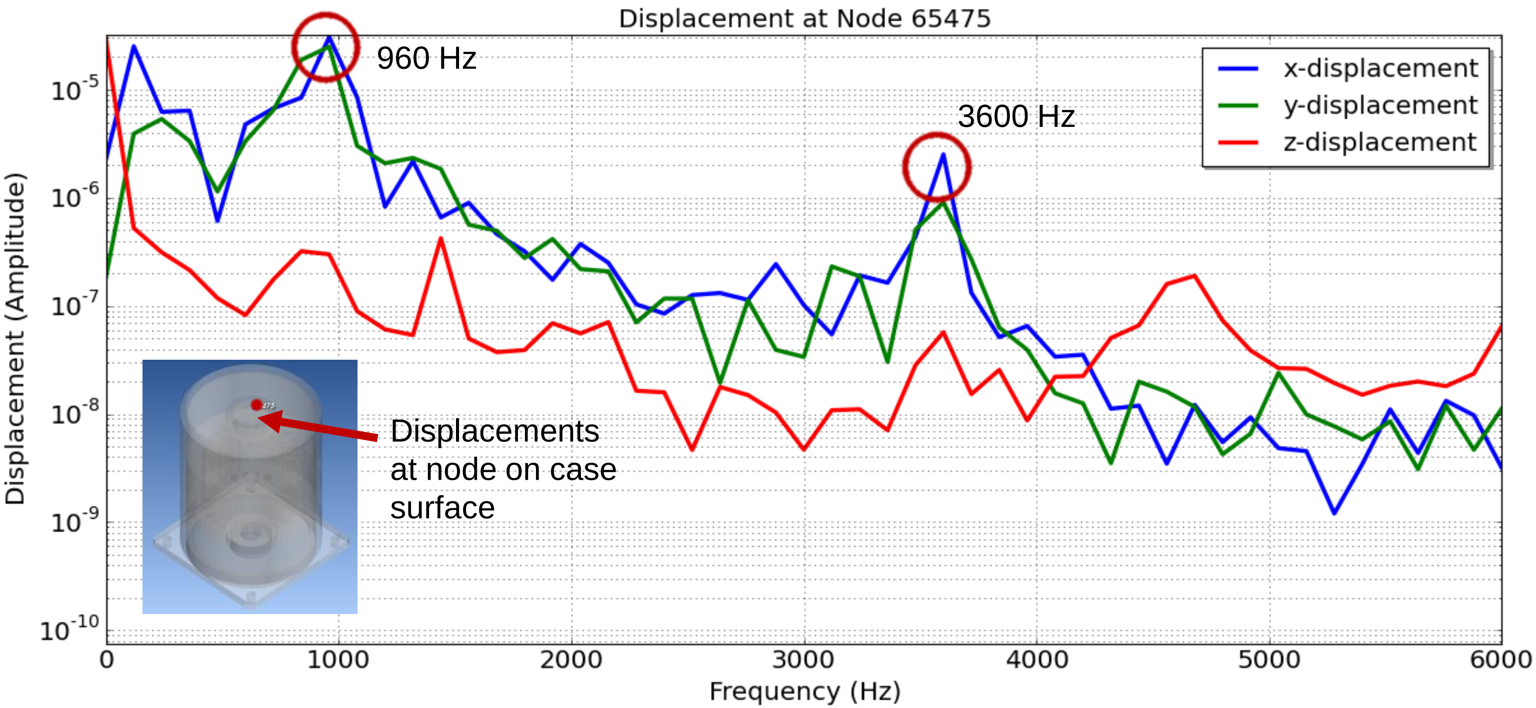
Structural Results (1)

- Plots of displacement at a node on the flange



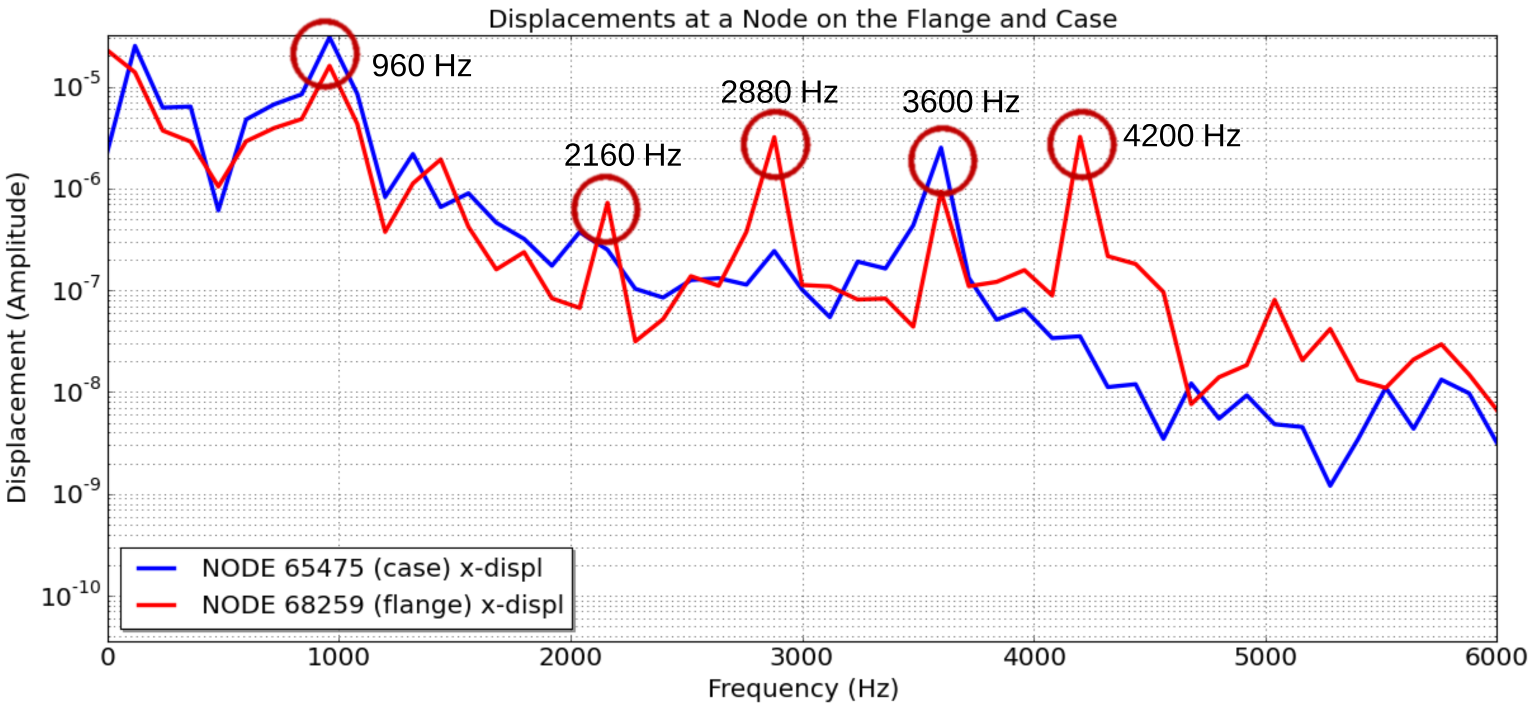
Structural Results (2)

- Plots of displacement at a node on the case



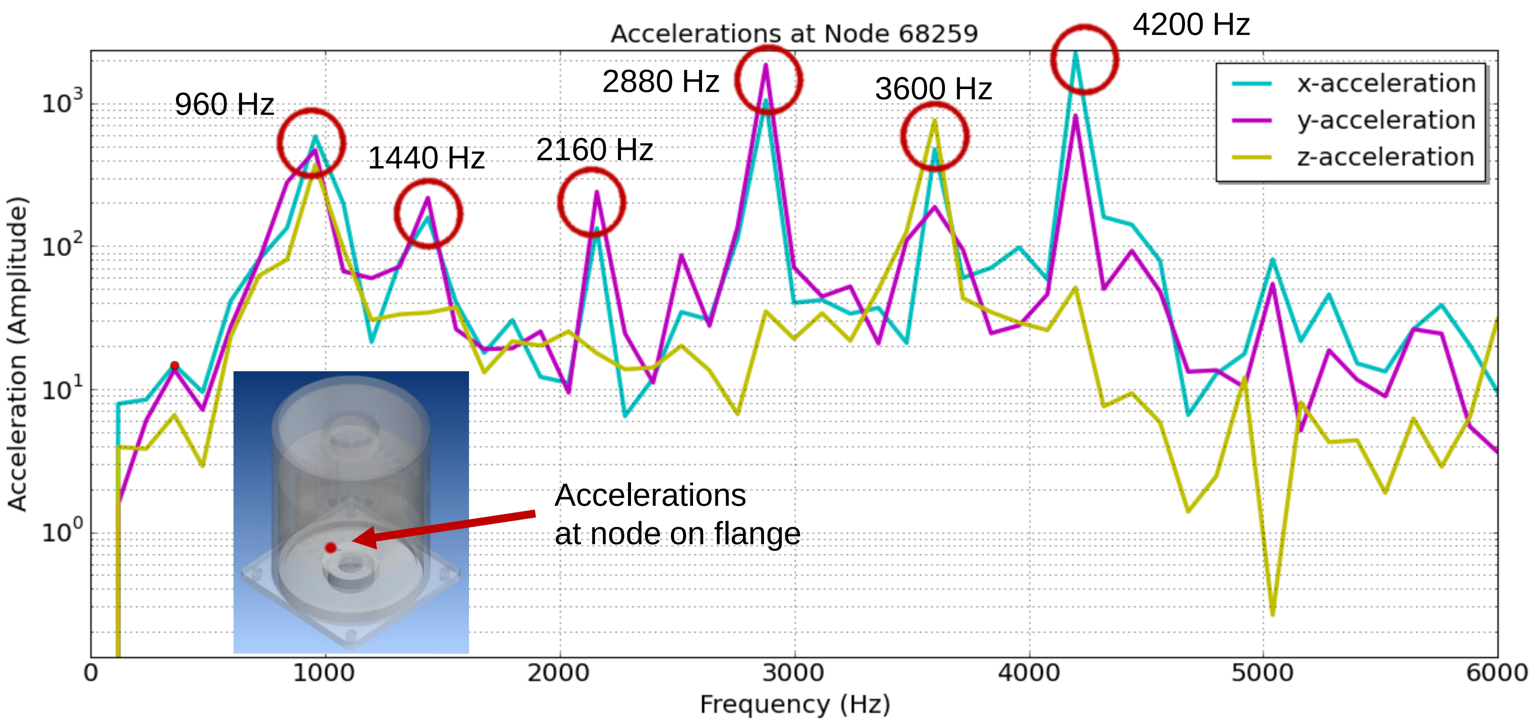
Structural Results (3)

- Comparison of displacements at nodes on the flange and the case



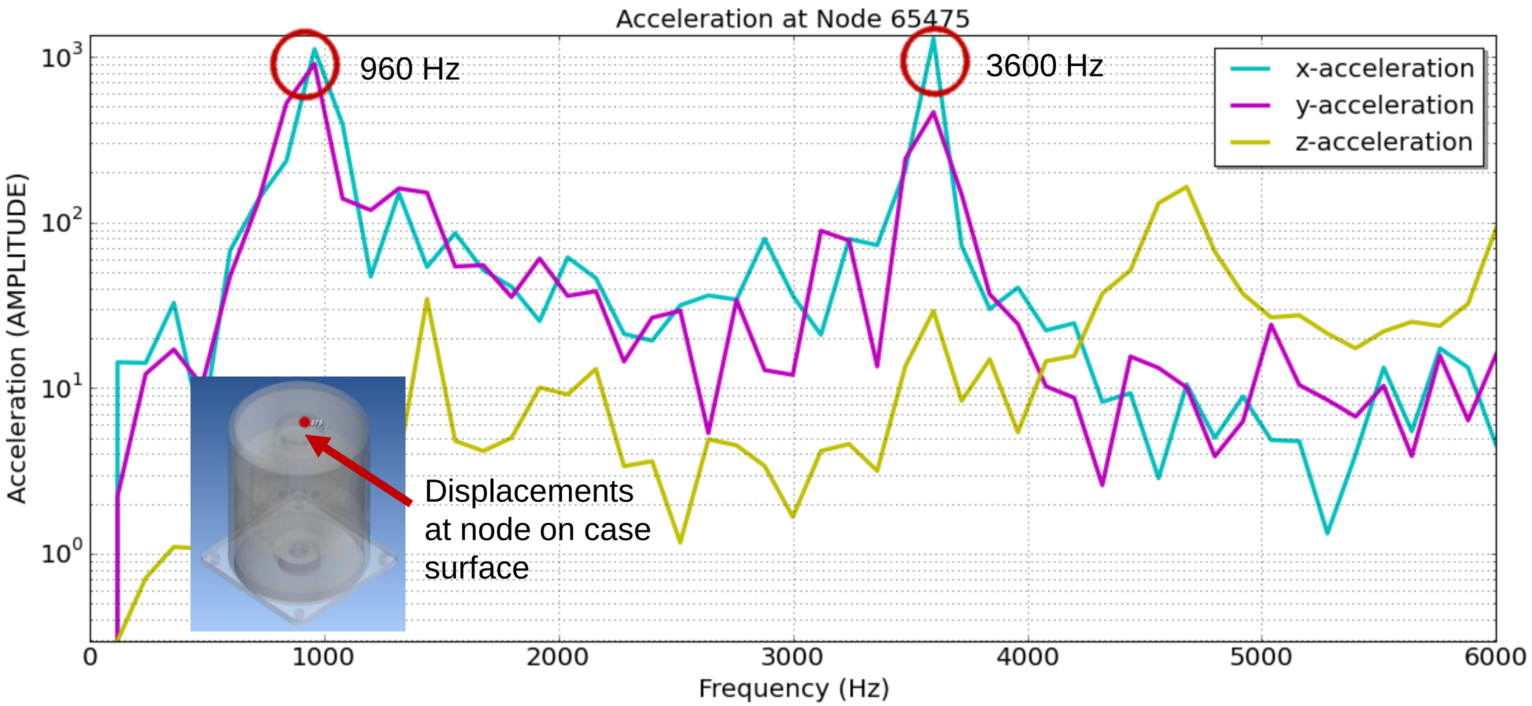
Structural Results (4)

- Plots of acceleration at a node on the flange



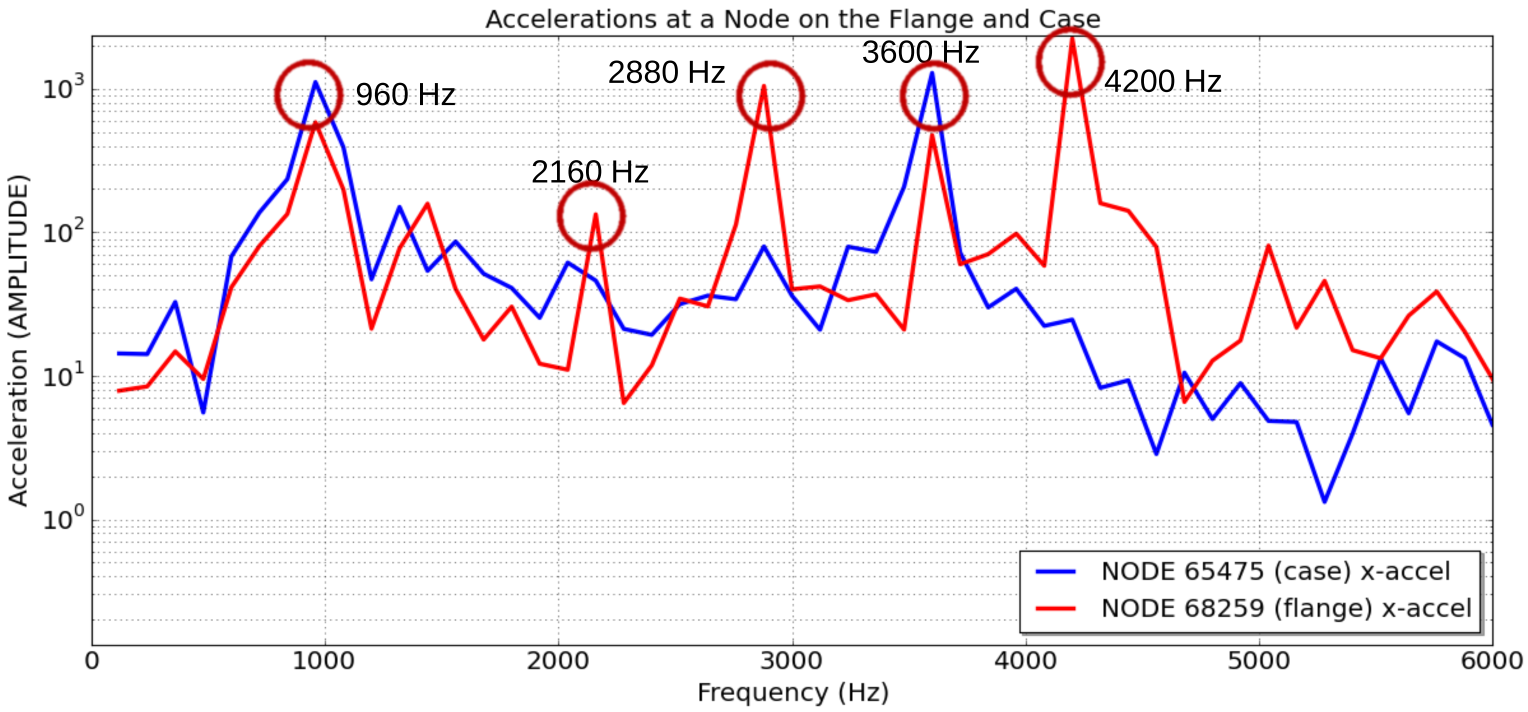
Structural Results (5)

- Plots of acceleration at a node on the case



Structural Results (6)

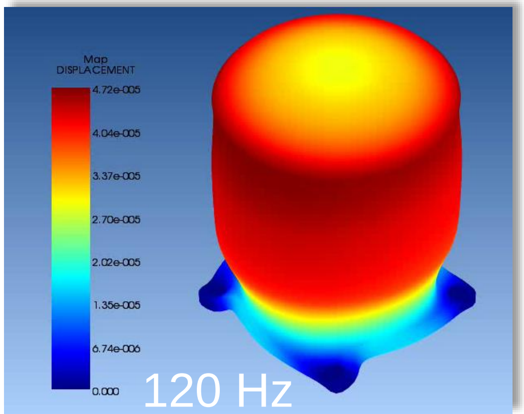
- Comparison of accelerations at nodes on the flange and case

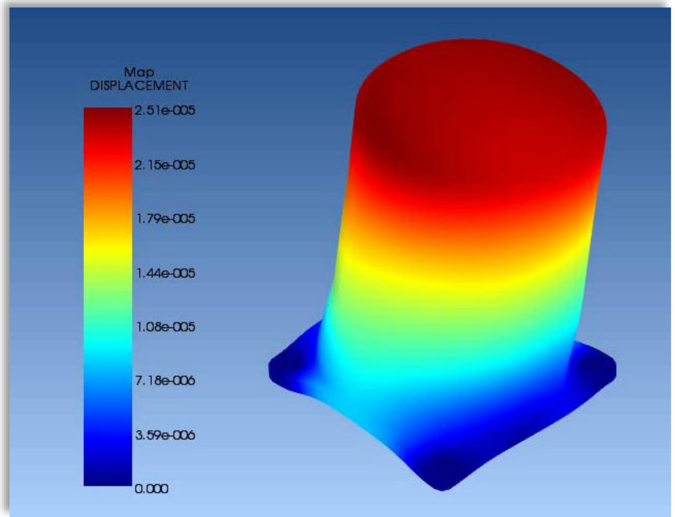


Structural Results (7)

- Animation of displacement output

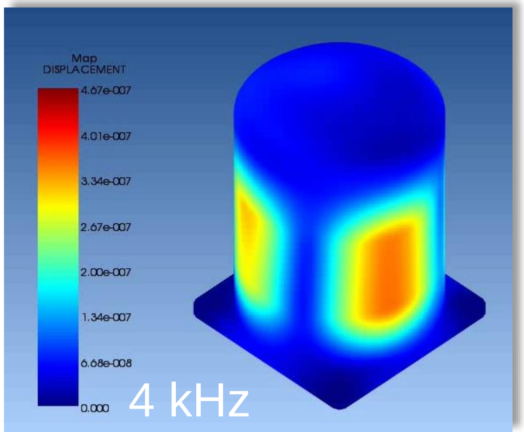
Color and deformation map at 120 Hz





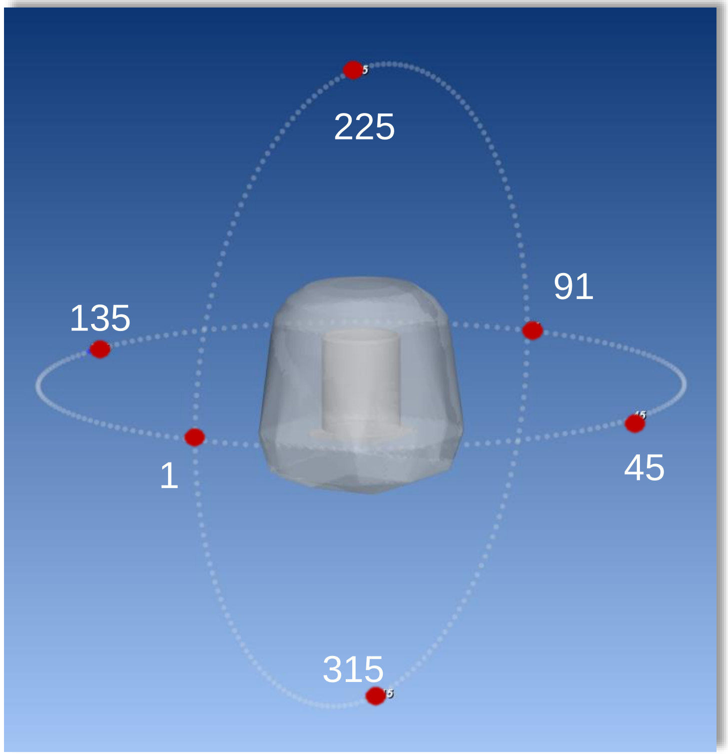
Color and deformation map as a function of frequencies

Color and deformation map at 4000 Hz



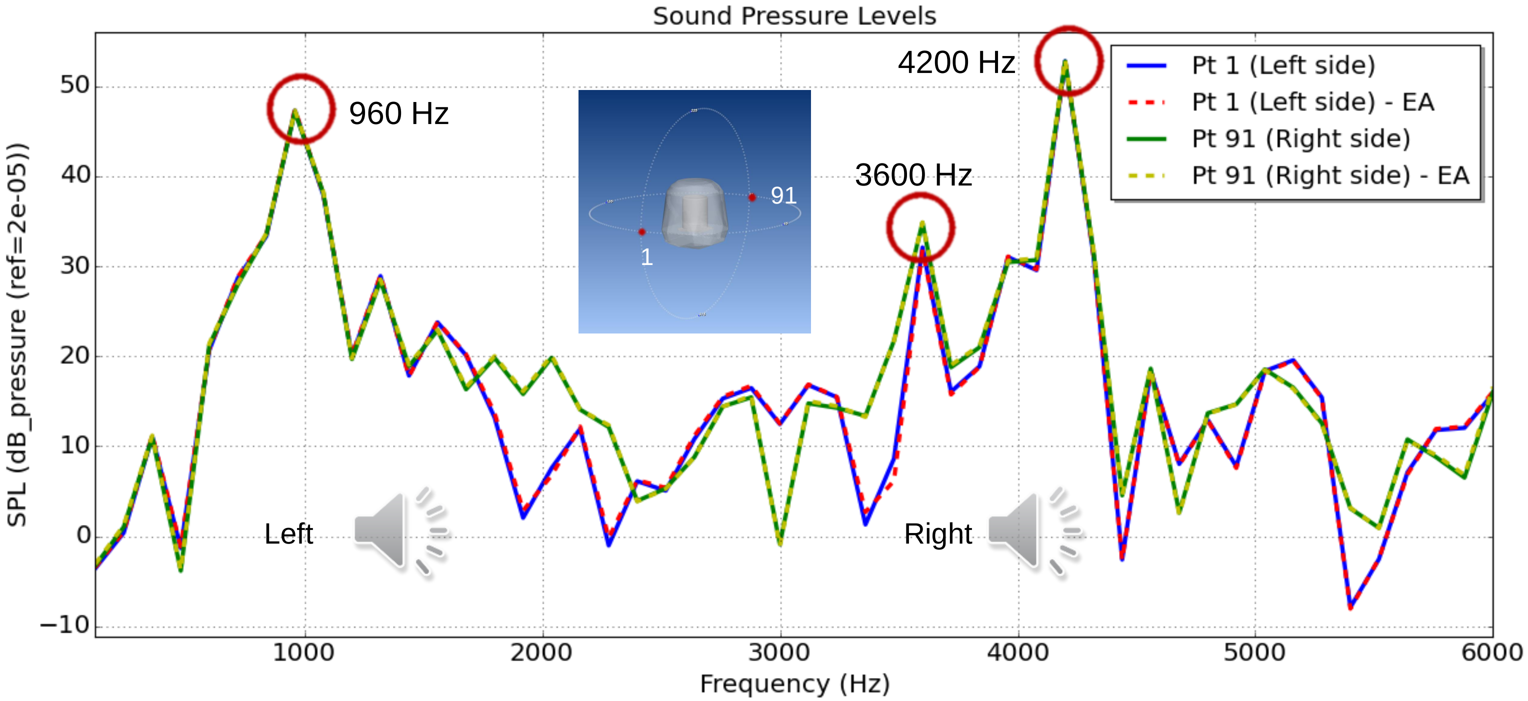
Acoustic Results (1)

- Virtual microphones IDs and locations
- Use PLTViewers to plot results



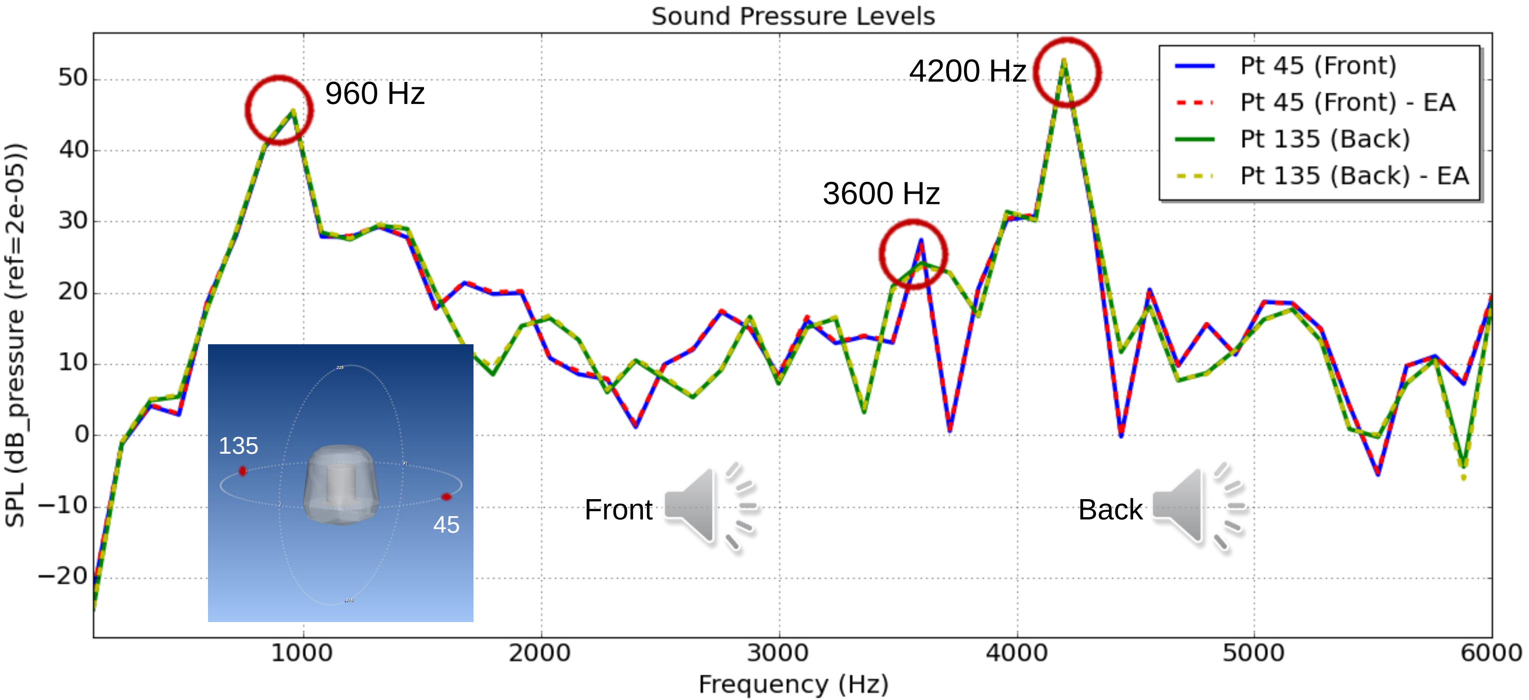
Acoustic Results (2)

- Sound Pressure Level (SPL) at left and right microphones



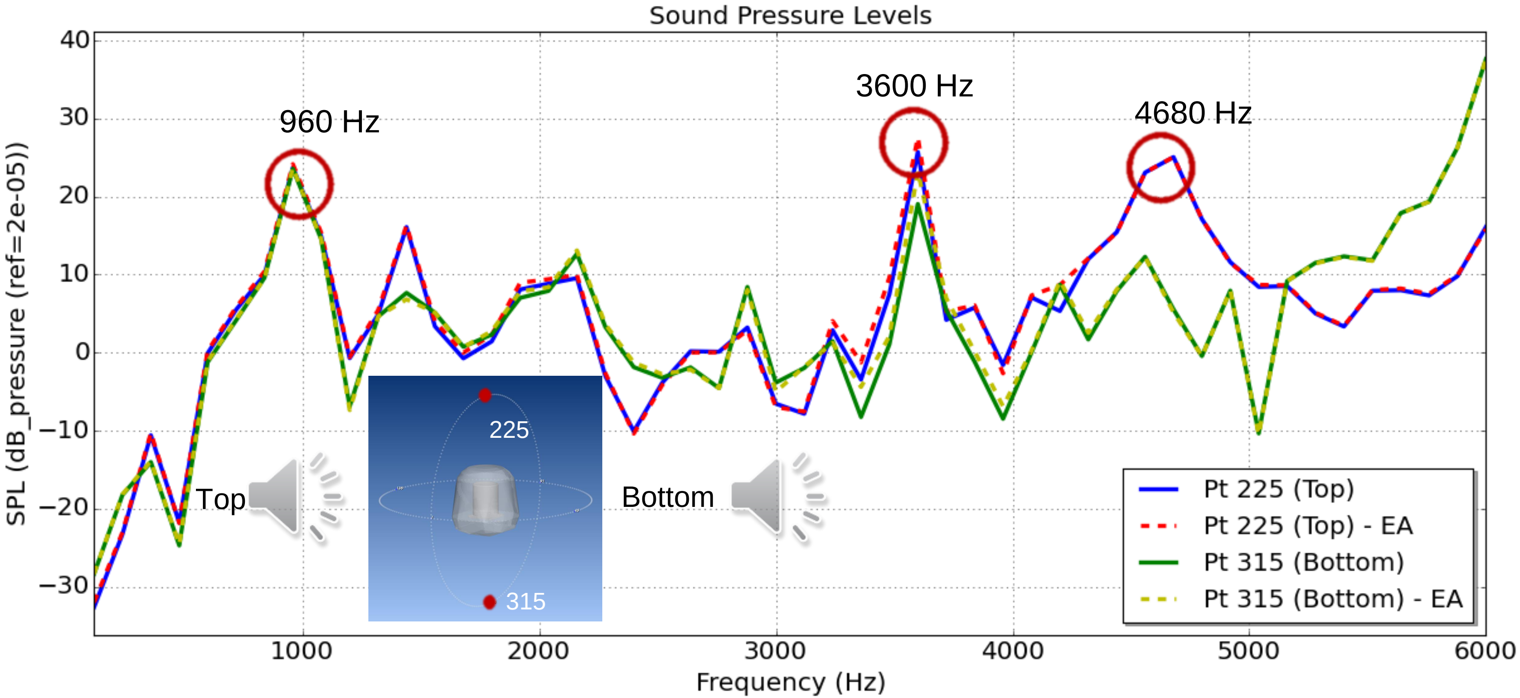
Acoustic Results (3)

- Sound Pressure Level (SPL) at front and back microphones



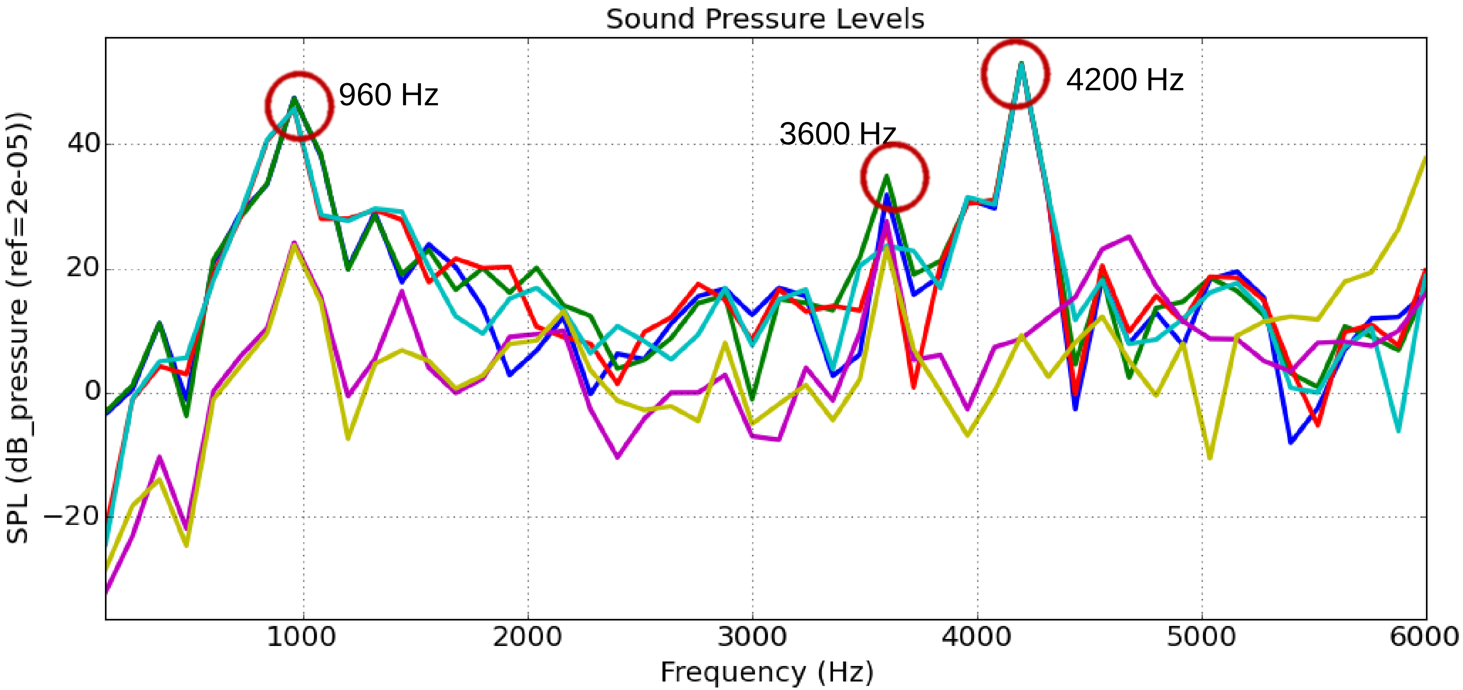
Acoustic Results (4)

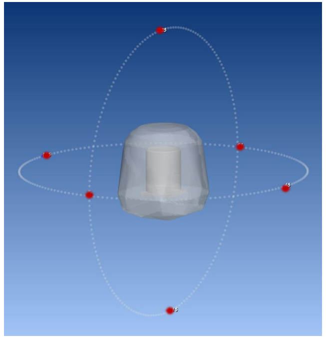
- Sound Pressure Level (SPL) at top and bottom microphones



Acoustic Results (5)

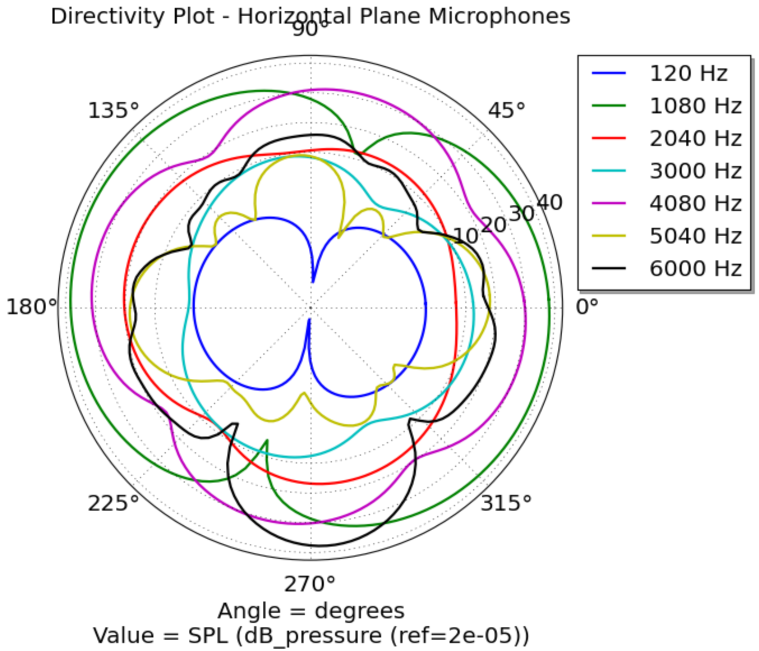
- Comparison of SPL from various microphones

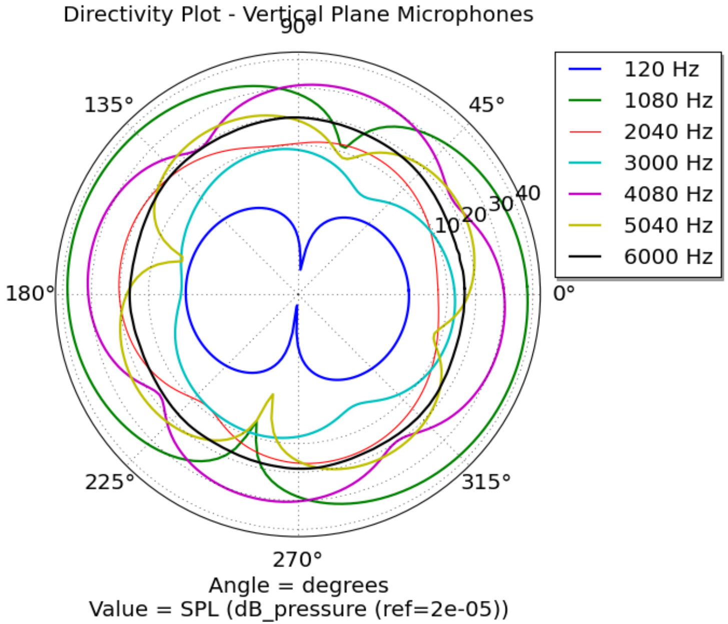




Acoustic Results (6)

- Directivity plots on horizontal and vertical planes



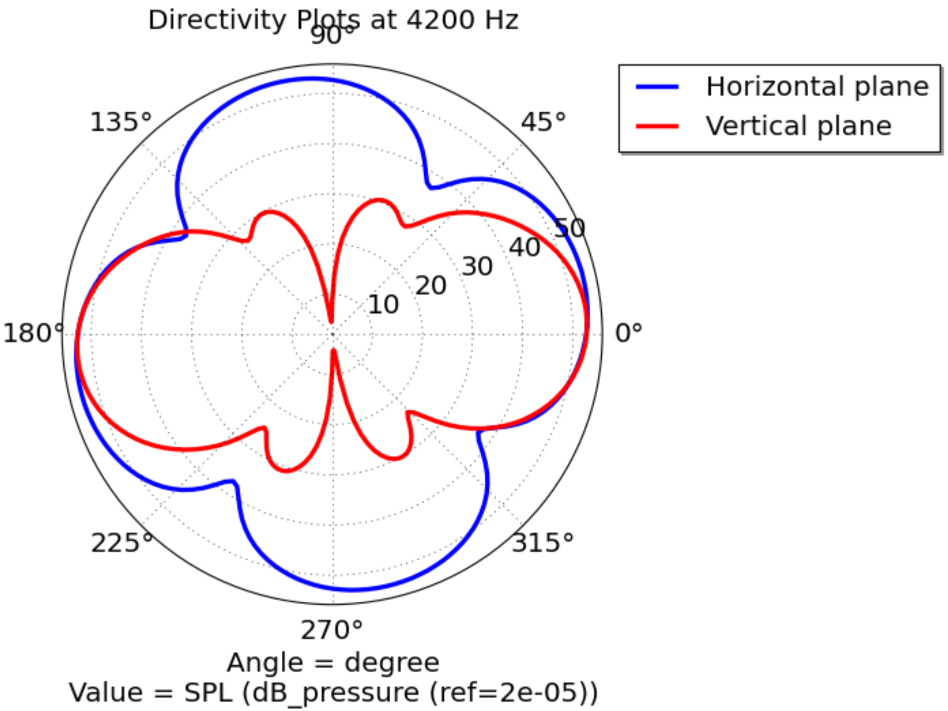


Acoustic Results (7)

- **Source directivity influences the overall SPL heard by observer**

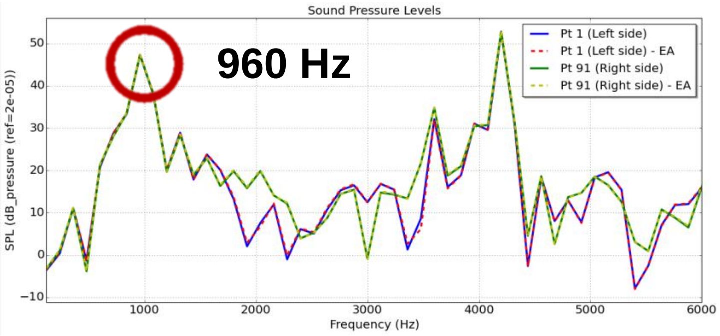
Mic on horizontal plane (front mic)

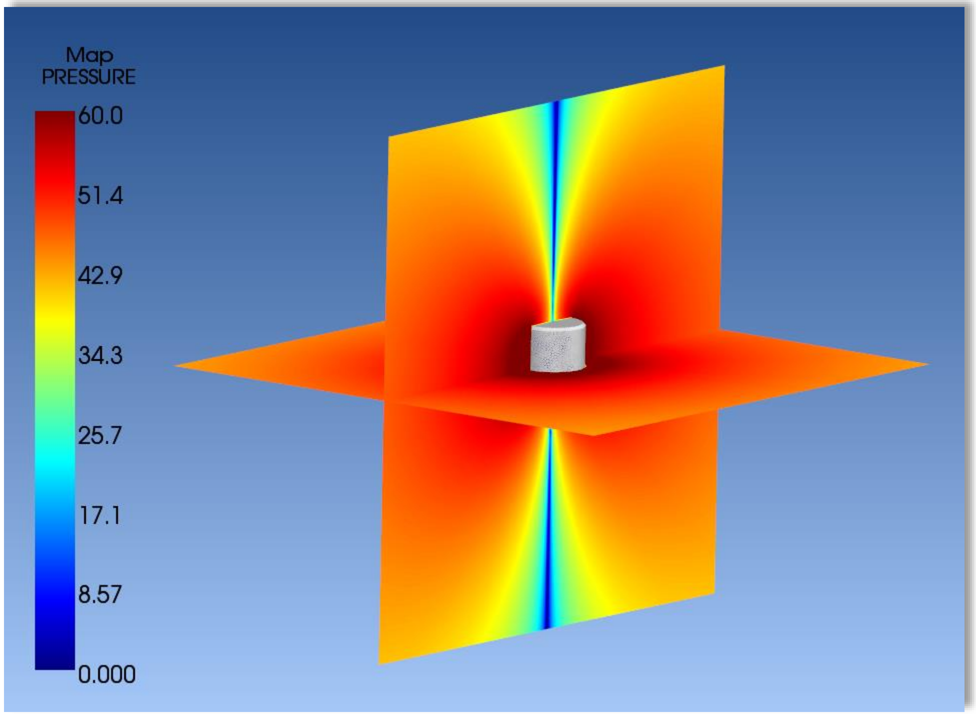
Mic on vertical plane (top mic)



Acoustic Results (8)

- Sound pressure map at a discrete frequency
- View radiation pattern at a certain frequency

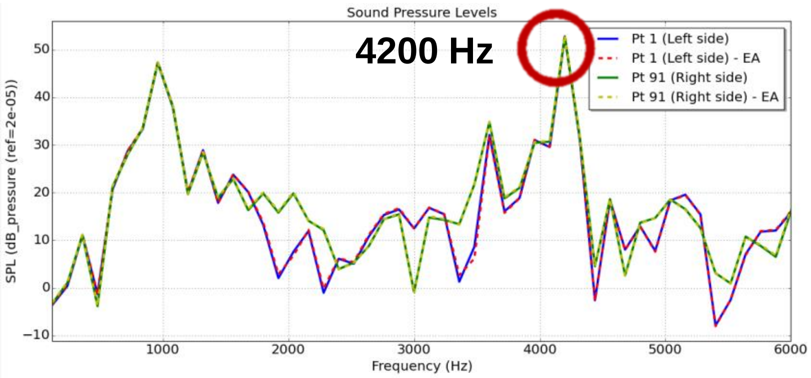


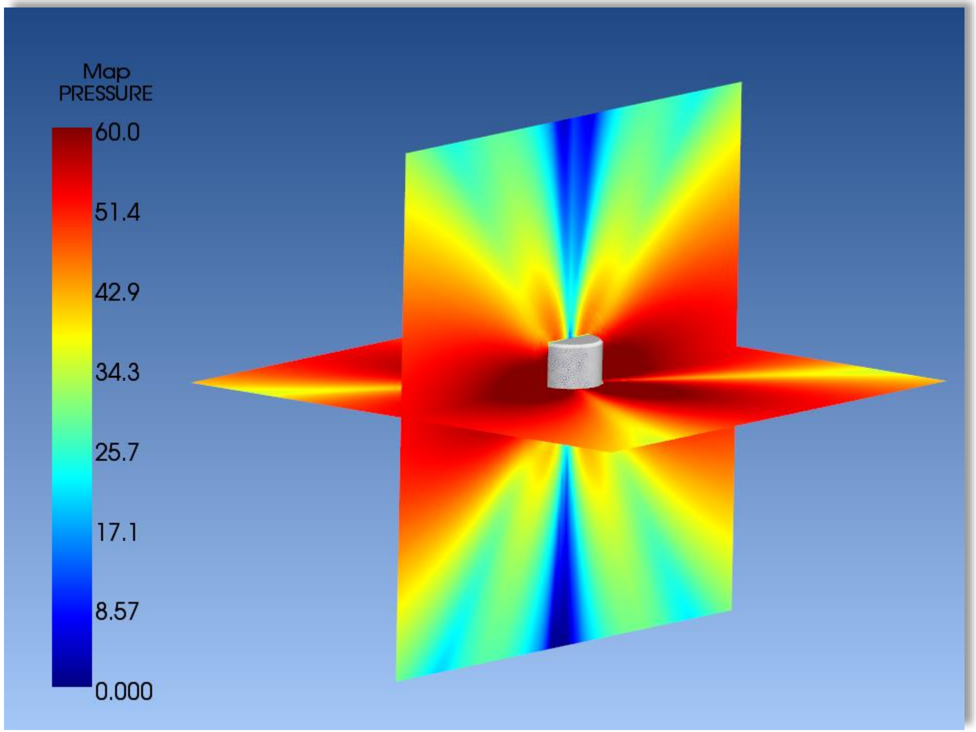


Sound pressure map at 960 Hz

Acoustic Results (9)

- Sound pressure map at discrete frequency
- View radiation pattern at a certain frequency

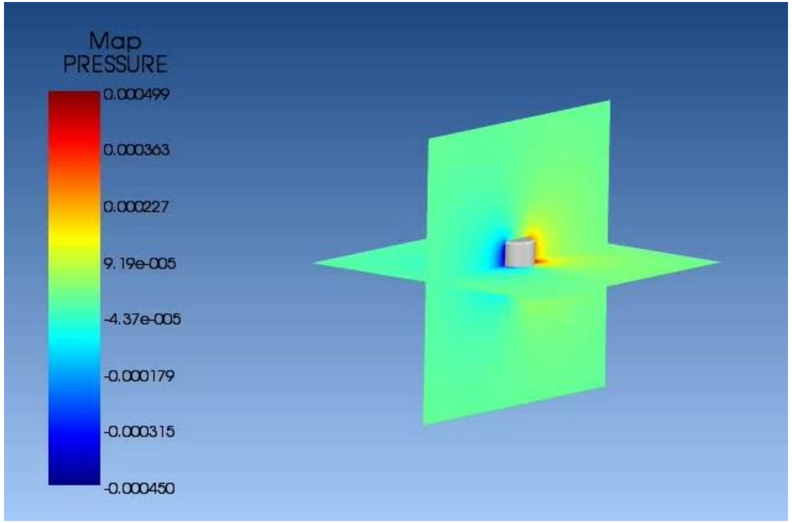




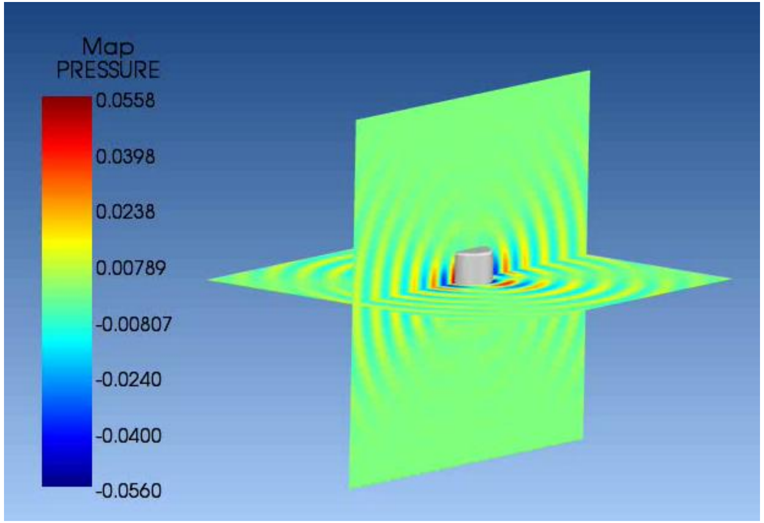
Sound pressure map at 4.2 kHz

Acoustic Results (10)

- Animation of pressure field around structure



Pressure map as a function of frequencies

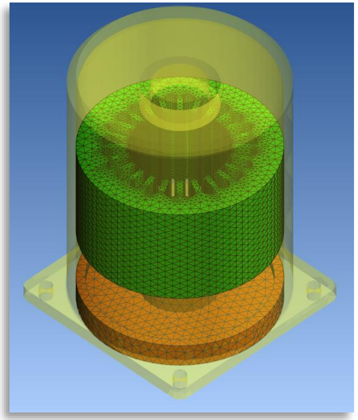


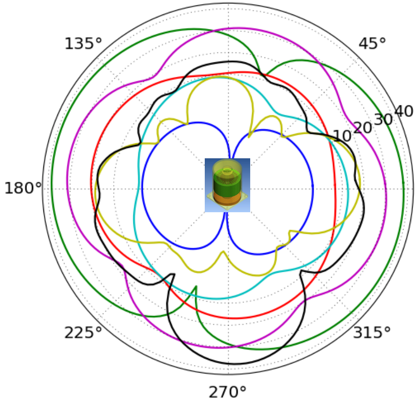
Pressure map at f = 4210 Hz

Conclusion

Conclusion

- ACTRAN has powerful capabilities to efficiently and accurately predict the sound radiated by vibrating structures
- ACTRAN can be used as a part of chained analysis with MagNet and FSIMapper to compute the radiated noise by electromagnetic
- Existing NASTRAN structural models can be used
- Can listen to predicted EM noise





Thank You

MSC Software