<table>
<thead>
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<th>Title</th>
<th>NOVI - Advanced functional solutions for Noise and Vibration reduction of machinery, Deliverable D2.3 Virtual cabin model</th>
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<tbody>
<tr>
<td>Author(s)</td>
<td>Siponen, Denis; Lehtinen, Antti; Uosukainen, Seppo</td>
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<td>VTT (2014), 49 p.</td>
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NOVI - Advanced functional solutions for Noise and Vibration reduction of machinery

D2.3 Virtual cabin model

Authors: Denis Siponen, Antti Lehtinen, Seppo Uosukainen
Confidentiality: Public
## Summary

<table>
<thead>
<tr>
<th>Project name</th>
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<td>Advanced functional solutions for Noise and Vibration reduction of machinery</td>
<td>71902–1.1.2 / NOVI-SP2</td>
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<th>Keywords</th>
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<td>Cabin modelling, virtual testing</td>
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**Summary**

A vibroacoustic model for Valtra cabin T888 M has been constructed. Cabinet interior and steel + glass + chassis structure model is valid up to 400 Hz with and without the inner roof. Wool is modeled with Biot’s model and the inner roof is modeled as solid and as porous Biot material. Modes of empty cabin, the response to an internal loudspeaker, the response to structure-borne sound, the response to external diffuse sound field excitation, and parametric studies for inner roof properties have been simulated. Enhancing material models, increasing frequency range above 400 Hz, virtual testing of different materials, and model auralization are the most important targets for future.

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Espoo 19.12.2013

Written by Seppo Uosukainen
Senior Scientist

Reviewed by Hannu Nykänen
Principal Scientist

Accepted by Johannes Hyrynen
Technology Manager
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- Introduction
- Vibroacoustic model
- Simulation results
- We have now
- Future work
Introduction

Goals

✓ Preparing the cabin geometry (dead-line 23.6.2011)
✓ Acoustic eigenfrequency analysis (dead-line 31.8.2011)
✓ Acoustic sound field analysis (dead-line 30.9.2011)
✓ Model with inner roof element included (dead-line 31.10.2011)
  ○ Sound field analysis with different roofs
○ Model with additional absorbents / resonators included (dead-line 30.11.2011)
  ○ Sound field analysis with different absorbents / resonators
✓ (2012)
  ○ Vibroacoustic model with cabin walls and windows included
  ○ Vibroacoustic model for airborne sound from exterior to cabin
  ○ Sound field analysis: parametric study for the inner roof
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- Vibroacoustic model
  - Acoustic model of the cabin interior
  - Cabin geometry
  - Mesh
    - Empty cabin
    - Total cabin
  - Modeling parameters
Acoustic model of the cabin interior (1)

- Cabin interior has been divided in 4 parts:
  - Lower airspace + HATS
  - Inner roof
  - Inner roof wool
  - Upper airspace
- The inner roof and the wool can be flexibly removed from the model
- Inner roof and wool modeled as solid or with Biot’s model
Acoustic model of the cabin interior (2)

- Three different geometries has been provided by Valtra
  - Only one of them was valid for modeling purposes
- Geometry of the airspace of the cabin (up to inner roof) is simplified in Ansys
- This geometry is then exported into Abaqus, where various steps were made to get final geometry:
  - Creating geometry of airspace between inner roof and top roof
  - Creating geometry of HATS
  - Creating final geometry (lower airspace + upper airspace – HATS)
Cabin geometry (1)

- Created geometry of the inner roof
  - 8 mm thick instead of real 10 mm, this is because of defective cabin geometry
- Original geometry of the cabin body is not included, as it was too defective to be usable
  - Tried to repair geometry with Ansys Design Modeler and Space Claim (with support from Medeso staff) with no success
- Zone tempered glasses in lower air space
- Various other improvements
  - Simplified upper side of the lower air space
  - Simplified upper air space
Cabin geometry (2)
Mesh of empty cabin

- Mesh was done in Ansys
  - Nodes: 180 k
  - Elements: 1 M
  - Max element size: 30 mm
  - Acoustic, quadratic elements

- Mesh valid up to ~ 3000 Hz
Mesh of total cabin

- Improving the mesh of the cabin
  - Improved mesh around head of HATS
  - Inner-roof meshed with multizone method to achieve more precision along thickness
    - Mesh of the inner-roof is not conformal with other meshes
  - 113 k nodes
  - Quadratic elements
    - Mesh valid up to 400 Hz
### Modeling parameters

- **Global damping:** imaginary part of complex sound speed
  \[ \tilde{c} = c(1 + j\xi) \quad \xi = \frac{\eta}{2} \quad \eta = \frac{2.2}{fT} \quad (1) \]

- **Inner roof:** solid
  - Young’s modulus 75 MPa
  - Poisson’s ratio 0.2
  - Solid density 316.5 kg/m³

- **Wool:** solid or default Biot rockwool
  - Flow resistivity 75 kPAs/m²

- **Windows:** thin shell, 5 mm thick default glass

- **Body:** thin shell, 3 mm thick default steel

### Table

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<th>( T30 ) [s]</th>
<th>( \xi )</th>
<th>( \xi_c )</th>
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<td>0.695</td>
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(1):  
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- Simulation results
  - Modes of empty cabin
  - Response to internal loudspeaker
    - Sound field distributions
    - Sound field in the ears of HATS
  - Response to structure-borne sound
  - Response to external diffuse sound field excitation
  - Parametric study for inner roof properties
Calculated modes of empty cabin (1)

- Calculated in Abaqus and Actran
- Methods used: AMS (Automatic multi-level substructuring) and Lanczos algorithm
- All modes in 0 – 2000 Hz frequency range
Calculated modes of empty cabin (2)

<table>
<thead>
<tr>
<th>mode n.</th>
<th>Abaqus</th>
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<td>2</td>
<td>121.4Hz</td>
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<tr>
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<tr>
<td>15</td>
<td>273.6Hz</td>
<td>273.9Hz</td>
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</table>
Measurement setup, camera positioning
Response to internal loudspeaker (1)

- Method: steady-state dynamic, modal
- Sound field distributions
- Sound field in ears of HATS
- Empty cabin
- Effects of inner roof, windows and chassis
- Comparison with measurements
Response to internal loudspeaker (2)
Empty cabin, cross section at the level of ears, 1/3 oct.

Model

100 Hz

Measurements
Response to internal loudspeaker (3)
Empty cabin, cross section at the level of ears, 1/3 oct.

Model

Measurements

125 Hz
Response to internal loudspeaker (4)
Empty cabin, cross section at the level of ears, 1/3 oct.

Model
160 Hz
Measurements
Response to internal loudspeaker (5)
Empty cabin, cross section at the level of ears, 1/3 oct.

Model 200 Hz Measurements
Response to internal loudspeaker (6)
Response in ears of HATS
Measurement vs. calculated globally damped empty cabin

Sound pressure level in left ear in driver’s position

- **Sound pressure level** [dB]
- **Sound pressure level in left ear in driver’s position**

- Measurement
- All air, complex speed of sound
Response to internal loudspeaker (7)
Cabin with inner roof
Measurement vs. calculated globally damped cabin with inner roof modeled as solid, wool as porous (Biot’s model)
Response to internal loudspeaker (8)
Effect of window vibrations in cabin with inner roof, calculated
Globally damped cabin with inner roof as solid, wool as porous (Biot’s model),
windows as 5 mm thick default glass, edges of windows fixed

![Sound pressure level in left ear in driver’s position](image)

- **Map PRESSURE**
  - 130.
  - 126.
  - 121.
  - 117.
  - 113.
  - 109.
  - 104.
  - 100.

100 Hz
Response to internal loudspeaker (9)
Empty cabin, windows and steel chassis included, calculated
Globally damped empty cabin vs. globally damped empty cabin with windows as 5 mm thick default glass, body as 3 mm thick of default steel, edges of windows fixed
Response to internal loudspeaker (10)

Inner roof, windows and steel chassis included

Measurement vs. calculated globally damped empty cabin with inner roof as solid, wool as porous (Biot’s model), windows as 5 mm thick default glass, body as 3 mm thick of default steel

Sound pressure level in left ear in driver’s position

100 Hz
Response to internal loudspeaker (11)
100 Hz 1/3 octave band, ear level, calculated

without inner roof

with inner roof
Response to internal loudspeaker (12)
100 Hz 1/3 octave band, ear cross section, calculated

without inner roof

with inner roof
Response to internal loudspeaker (13)
125 Hz 1/3 octave band, ear level, calculated

without inner roof

with inner roof
Response to internal loudspeaker (14)
125 Hz 1/3 octave band, ear cross section, calculated

without inner roof

with inner roof
Response to internal loudspeaker (15)
160 Hz 1/3 octave band, ear level, calculated

without inner roof

with inner roof
Response to internal loudspeaker (16)
160 Hz 1/3 octave band, ear cross section, calculated

without inner roof  
with inner roof
Response to internal loudspeaker (17)
200 Hz 1/3 octave band, ear level, calculated

without inner roof

with inner roof
Response to internal loudspeaker (18)
200 Hz 1/3 octave band, ear cross section, calculated

without inner roof

with inner roof
Response to internal loudspeaker (19)
Inner roof, windows and steel chassis included, calculated
Inner roof as solid, wool as porous & developed inner-roof material and MEL as wool
Response to internal loudspeaker (20)

- Calculated field distributions rather similar to measured ones
  - Amplitudes do not agree very well
- Inner roof affects the calculated response most towards the measured one
  - Glasses and chassis do not affect that much
- Inner roof
  - Reduces sound pressure levels
  - Affects sound field distributions
Calculated response to structure-borne sound (1)

Excitation at front vibration isolator

Sound pressure level in left ear in driver's position

- Front left
- Front right

Sound pressure level [dB] vs. Frequency [Hz]
Calculated response to structure-borne sound (2)

Excitation at back vibration isolator

Sound pressure level in left ear in driver's position

- Back left
- Back right
Calculated response to structure-borne sound (3)

Excitation at all vibration isolators, different phases

Sound pressure level in left ear in driver's position

- Red: All in phase
- Green: Front 90 deg, back 0 deg
- Purple: Front 0 deg, back 90 deg
Calculated response to structure-borne sound (4)

- With the same excitation, more sound originates from front vibration isolators
- Mutual phases of excitations only have a minor effect
Calculated response to external diffuse sound field excitation (1)
Structure displacement magnitude (logarithmic) at 100 Hz
Diffuse sound field at exterior of walls, windows and floor
Calculated response to external diffuse sound field excitation (2)

Sound pressure level in cabin at 100 Hz

Diffuse sound field at all windows, walls and floor

Diffuse sound field at upper front window
Calculated response to external diffuse sound field excitation (3)

Response in ears of HATS

External diffuse sound field excitation
Parametric study for inner roof properties (1)

Porosity
Internal loudspeaker excitation

Increasing porosity leads to better absorption in the vicinity of 100 Hz peak
Parametric study for inner roof properties (2)

Flow resistivity
Internal loudspeaker excitation

Reducing flow resistivity leads to slightly better absorption in the vicinity of 100 Hz peak.
Parametric study for inner roof properties (3)
Tuning inner roof as panel resonator to 100 Hz
Internal loudspeaker excitation

- Tuning is very sensitive to small changes
- Absorption band is very narrow
- Not very useful to be applied
We have now

- Cabinet interior and steel + glass + chassis structure model valid up to 400 Hz with and without the inner roof
  - Damping calibrated with the reverberation times
    - Some disagreement remains with respect to measurements
- Wool modeled with Biot’s model (Actran database material)
- Inner roof modeled as solid and as porous Biot material

- Calculated example results with internal loudspeaker excitation and external diffuse sound field excitation
Future work

- Enhancing material models and models for glass (layers, viscoelasticity, mounting)
- Including acoustic radiation to exterior air
- Increasing frequency range from sub – 400 Hz
- Experimental validation of airborne sound model
- Sound field analysis with different inner roofs
- Vibration damping materials
- Virtual testing of different materials
- Model auralization
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