Sound propagation through forest: literature review

Pierre Chobeau (PhD student: Ifsttar - LRPC)

Meeting J82FAUNE - LRPC de Strasbourg

3rd December 2013

Introduction

The topic:

What are the acoustic phenomena influencing sound propagation inside/around forested areas?

Why is the forest an interesting area for the study of sound propagation?

- Alternative way to protect quiet areas (European directive 2002/49/CE).
- Accurate prediction of sound levels inside and around forests (noise mapping),
- Protection of biodiversity from anthropogenic noise (traffic noise abatement).
Content

1. Ground effects specific to forest floors
2. Sound scattering inside forest
3. Micrometeorological influences on sound propagation in forest
4. Long range sound propagation models and forest
5. The forest: a natural noise barrier?
Sections’ content:

1. **Ground effects specific to forest floors**
   - Ground arrangement in forest
   - Impedance models
   - Four tested models compare to experimental results

2. **Sound scattering inside forest**
   - Tree trunks influences
   - Foliage influences
   - Sound reverberation inside forest

3. **Micrometeorological influences on sound propagation in forest**
   - Micrometeorological fluctuations caused by forest

4. **Long range sound propagation models and forest**
   - Reference long range sound propagation models and forest
   - Engineering noise prediction method:

5. **The forest: a natural noise barrier?**
   - From the external point of view
   - From the internal point of view
Ground effects

Ground arrangement in forest: the different layers

- **Upper layer** made of organic deposits:
  - surface layer: litter,
  - intermediate layer: humus.
- **Substrate** made of minerals:
  - lower layer: sand, compacted soils...

---

Ground effects

Impedance models

- Structural semi-infinite multi-layer (Talaske [2]):
  - based on the transmission-line theory:
    \[ Z(d) = Z_1 \frac{Z_2 - iZ_1 \tan(k_b d)}{Z_1 - iZ_2 \tan(k_b d)} . \quad (1) \]
  - hypothesis:
    - thin upper layer and \(|Z_1/Z_2| \ll 1|,
    - homogeneous medium,
    - high flow resistivity,
    - only at low frequency.

- Two parameters model (Attenborough [3]):
  \[ Z \approx \frac{1 + i}{\sqrt{\pi \gamma \rho}} \sqrt{\frac{\sigma_e}{f}} + \frac{ic}{2\gamma \omega \Omega d} . \quad (2) \]

**Ground effects**

### Impedance models

- Zwikker and Kosten (phenomenological):
  - adiabatic conditions inside the pore,
  - introduction of the tortuosity.

\[
Z_c = \frac{1}{\Omega} \sqrt{T + \frac{i\Omega\sigma}{\omega\rho}} \quad (3)
\]

- identical tortuosity model (2 effectives parameters):

\[
Z_{ce} = \frac{1}{\Omega_e} \sqrt{1 + \frac{i\Omega_e\sigma_e}{\omega\rho}} \quad (4)
\]

Values obtained after fitting the curves for a pine forest [4].

<table>
<thead>
<tr>
<th>Effective resistivity (kPa.s.m(^{-2}))</th>
<th>Effective porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.4 – 46.0</td>
<td>0.40 – 0.57</td>
</tr>
</tbody>
</table>

Ground effects

Four tested models compare to experimental results:

- Delaney & Bazley,
- Taraldsen,
- Biot \((slit-pore)\),
- Zwicker & Kosten (phenomenological).

Level differences \((\text{dB/100 ft})\) as a function of the frequency \((\text{Hz})\) at 50 ft for a pine forest \((a)\) and a beech forest \((b)\) [4].

Sections’ content:

1. Ground effects specific to forest floors
   - Ground arrangement in forest
   - Impedance models
   - Four tested models compare to experimental results

2. Sound scattering inside forest
   - Tree trunks influences
   - Foliage influences
   - Sound reverberation inside forest

3. Micrometeorological influences on sound propagation in forest
   - Micrometeorological fluctuations caused by forest

4. Long range sound propagation models and forest
   - Reference long range sound propagation models and forest
   - Engineering noise prediction method:

5. The forest: a natural noise barrier?
   - From the external point of view
   - From the internal point of view
Multiple scattering: analytical models


\[
K^2 = k^2 + 4igN.
\]  \hspace{1cm} (5)

- Linton et Martin [7, 8]:

\[
K^2 = k^2 - 4iNg + (g_1^2 - g^2) \left( \frac{2N}{k} \right)^2,
\]  \hspace{1cm} (6)

avec

\[
g = \sum_{n=-\infty}^{\infty} A_n, \quad g_1 = \sum_{n=-\infty}^{\infty} (-1)^n A_n.
\]  \hspace{1cm} (7)

Sound scattering inside forest

Tree trunks influences

- Example of plane wave propagation through arbitrary located cylinders:

![Image of sound attenuation](image)

Horizontal section of sound attenuation simulated from an FDTD numerical model [9].

- Regular tree trunk’s placement:

![Geometric placements](image)

Three geometric placements studied in [10, 11, 12].

Comparison of measured attenuation spectra due to regular and perturbed $(2.0r) \times 10$ square arrays of PVC pipes with source height $0.02$ m, receiver height $0.1$ m and separation $1.0$ m (a) over MDF (b) over felt; measured attenuation spectra due to periodic, perturbed and random arrays over MDF with (c) source height $0.1$ m and (d) source height $0.02$ m. [12].

Sound scattering inside forest

Foliage influences

- Study of the absorbing properties of the foliage:


Sound pressure levels measured at 6 m from source with 6 types of plants (with and without foliage) [13].
Sound scattering inside forest

Sound reverberation inside forest

- Experimental study of the reverberation time inside forest:
  - Sound pressure levels are persisting around the frequency 2 kHz.
- From a study of bird communication inside forest:
  - Adaptation of some birds to Morton's window [14].

![Graph showing sound attenuation for two forests and free field](image)

Sound attenuation for two forests (---) and (---); and for free field (.....): identification of Morton's window (zone B, gray) [15].

Sections’ content:

1. Ground effects specific to forest floors
   - Ground arrangement in forest
   - Impedance models
   - Four tested models compare to experimental results

2. Sound scattering inside forest
   - Tree trunks influences
   - Foliage influences
   - Sound reverberation inside forest

3. Micrometeorological influences on sound propagation in forest
   - Micrometeorological fluctuations caused by forest

4. Long range sound propagation models and forest
   - Reference long range sound propagation models and forest
   - Engineering noise prediction method:

5. The forest: a natural noise barrier?
   - From the external point of view
   - From the internal point of view
Micrometeorological fluctuations caused by forest

Temperature and wind profiles:

Simulation of realistic wind profiles: (a) roughness length; (b) drag coefficient [16].

Profiles of (a) wind speed and (b) temperature for three leaf array indexes (LAI) [17].

Micrometeorologiques fluctuations caused by forest

Turbulences originated from forest edges:
- wind shear on the top of the canopy,
- heat flow, evapotranspiration.

Horizontal instantaneous wind speed at 10 m above the ground during the experimental campaign of Lannemezan 2005 where the green areas correspond to forest edges. [16].

Micrometeorologiques fluctuations caused by forest

Integration into the numerical prediction models

- Effective sound speed approach:
  \[ c_{\text{eff}}(z) = c(z) + u(z) = \sqrt{\gamma RT(z)} + u(z). \] (8)

Profiles of effective sound speed through the atmosphere for downwind propagation (solid) and upwind propagation (dashed) inside and above the forest canopy. [17].

- Consequences of the turbulence⇒sound absorption (generated by the scattering of the acoustic wave).

Sections’ content:

1. **Ground effects specific to forest floors**
   - Ground arrangement in forest
   - Impedance models
   - Four tested models compare to experimental results

2. **Sound scattering inside forest**
   - Tree trunks influences
   - Foliage influences
   - Sound reverberation inside forest

3. **Micrometeorological influences on sound propagation in forest**
   - Micrometeorological fluctuations caused by forest

4. **Long range sound propagation models and forest**
   - Reference long range sound propagation models and forest
   - Engineering noise prediction method:

5. **The forest: a natural noise barrier?**
   - From the external point of view
   - From the internal point of view
Long range sound propagation models and forest

Reference models in frequency domain:

- Ray tracing [1],
- Parabolic equation (GFPE [18, 19]; CNPE [20]).

Level difference between propagation with and without a forest edge: (a) homogeneous wind conditions with temperature inversion, (b) downwind with no temperature inversion [19].

Long range sound propagation models and forest

Reference models in time domain:

- Finite difference time domain method (FDTD),
- Coming soon? Transmission line matrix method (TLM).

Vertical snapshot of the attenuation (dB) for downwind propagation taking into account sound scattering by tree trunks [9].

Long range sound propagation models and forest

Engineering noise prediction models

- ISO9613-2 [21]
  - foliage attenuation.
- Nord2000 [22] et Harmonoise [23]
  - ground effects: Delany & Bazley impedance model,
  - scattering: stochastic method.

[23] Harmonoise, Engineering method for road traffic and railway noise, 2005
Sections’ content:

1. Ground effects specific to forest floors
   - Ground arrangement in forest
   - Impedance models
   - Four tested models compare to experimental results

2. Sound scattering inside forest
   - Tree trunks influences
   - Foliage influences
   - Sound reverberation inside forest

3. Micrometeorological influences on sound propagation in forest
   - Micrometeorological fluctuations caused by forest

4. Long range sound propagation models and forest
   - Reference long range sound propagation models and forest
   - Engineering noise prediction method:

5. The forest: a natural noise barrier?
   - From the external point of view
   - From the internal point of view
The forest: a natural noise barrier?

From an external point of view:

- An interesting noise barrier in downwind and temperature inversion conditions (i.e. in positive refraction condition):
  
  FDTD simulation shows that a 15 m wide forest edge is comparable to a 1.5 m high noise barrier [10].

- Reduction of the shadow zone in negative refraction condition [19].

---

The forest: a natural noise barrier?

From an internal point of view:

- global sound pressure level reduction,

Road traffic noise abatement from four forests [24].

- persistence of sound pressure levels in specific frequency ranges ⇔ sound scattering → reverberation.

Conclusion

Observations from this literature review:

- since Eyring publication in 1946 [25] there is constant interest for sound propagation in forest,
- each acoustic phenomenon is investigated through different approach and theory,
- the results appears to be in contradiction for some measurement campaign,
- although the analytical models are becoming more and more accurate, strong hypothesis remains for most them.

Outlook:

- description of sound propagation through forest with time domain method would enables to get deeper understanding of each acoustic phenomenon,
- development of the Transmission-Line Matrix (TLM) method for the study of sound propagation through forest:

Thanks for your attention

Sound propagation through forest: literature review
Meeting J82FAUNE - LRPC de Strasbourg

Pierre Chobeau (PhD student: Ifsttar - LRPC)


3rd December 2013


**Introduction**

- **Ground effects**
- **Sound scattering**
- **Micrometeorology**
- **Propagation models**
- **Natural noise barrier?**
- **Conclusion**

---


<table>
<thead>
<tr>
<th>Introduction</th>
<th>Ground effects</th>
<th>Sound scattering</th>
<th>Micrometeorology</th>
<th>Propagation models</th>
<th>Natural noise barrier?</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>G. Guillaume, <em>Application de la méthode TLM à la modélisation de la propagation acoustique en milieu urbain</em>.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th><strong>Introduction</strong></th>
<th><strong>Ground effects</strong></th>
<th><strong>Sound scattering</strong></th>
<th><strong>Micrometeorology</strong></th>
<th><strong>Propagation models</strong></th>
<th><strong>Natural noise barrier?</strong></th>
<th><strong>Conclusion</strong></th>
</tr>
</thead>
</table>