Single Event Noise Prediction at ONERA

Application to aircraft powered by contra-rotating open rotors

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ONERA – The French Aerospace Lab
Why do single event noise prediction?

Thanks to an accurate noise prediction, one can

- Better identify noise reduction requirements (aircraft, helicopters, UAV, …)
- Better assess the impact of noise reduction concepts developed by the scientific community
  - Certification configuration
  - Basis for studies on understanding noise annoyance

Today, an important objective is to assess the impact of disruptive technologies such as

- New aircraft architectures (Wing bodies, Box wing, …)
- New engine technologies (CROR, DEP, BLI, …)
Outline

- **Ground noise prediction with CARMEN**
  - *The Acoustics module of IESTA platform*
  - *Noise source modelling*
  - *Installation effects*
  - *Sound Propagation*

- **Noise synthesis with FLAURA**
  - *Structure*
  - *Example*

- **Application to aircraft powered by CRORs**
  - *CROR noise source modelling*
  - *Ground prediction (noise levels & sound synthesis)*
Ground noise prediction with CARMEN
CARMEN
The Acoustics module of IESTA

IESTA - Infrastructure for Evaluating AirTransport Systems
Platform to design and model innovative air transport systems

Environmental impact of the air traffic surrounding airports
- Fuel consumption
- Chemical emissions
- Noise

Models implemented in the IESTA platform
- Aircraft
- Ground planning
- Engine
- Chemical dispersion
- Acoustics (CARMEN)

Objectives of CARMEN:
- To predict the acoustical impact of an aircraft
- To take into account new technologies and noise sources (shielding effects, contra-rotative propellers, etc.)
- Simulations within a « reduced » CPU time
- To generate realistic simulations, as input for auralization + perception and annoyance studies
Simulation for each time step along the flight trajectory

**Static/dynamic parameters**
- **engine data** → jet velocities, fan rotation speed etc.
- **airframe data** → slat/flap geometry/deployment, landing gear etc

**Static parameters**
- **Aircraft geometry**

**Static/dynamic parameters**
- **Meteorological conditions** (wind, $T^\circ$ profile,...)
- **Flight trajectory**

**Simulation**
- **Acoustic Sources**
- **Installation effects**
- **Propagation in the atmosphere**

**Post-processing**
- SPL
- Spectra
- Other metrics (Loudness, sharpness, tonality,...)
- Noise synthesis tool (FLAURA)
**Propulsion noise + Airframe noise**

- Semi-empirical methods from literature
- Free far field, point source
- Comparison with experimental results for model improvement

- Fan, Jet
- Turbopropeller
- CROR
- Slat, Flap
- Landing Gear
- Rotors

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**CARMEN**
Noise source modelling

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Single Event Noise Prediction at ONERA
CARMEN
Installation effects

Model based on the ray tracing technique

1- Direct + Reflected + Diffracted field from Uniform Theory of Diffraction
Scattering by the edges (leading edge) and creeping waves (fuselage)

2- Geometry described from analytical curves surfaces (NURBS) from CAD files

Comparison to Boundary Elements Method (BEMUSE code)
Objective:
Prediction of the noise on a sphere surrounding the aircraft including installation effects, to provide the input to the sound propagation in the atmosphere

How:
The directivity and spectra are calculated for every source on a sphere of 1m radius

Input to installation effects module: position of the sources

Output of installation effects module: Sphere of 100m radius including at each gridpoint the information on: ray kind (direct, reflected, ...), ray path distance and first angles for each source location

Coupling with source directivity and spectra
CARMEN
Coupling (source + installation) with sound propagation

Sources (jet, fan, landing gear) + installation effects

Propagation in the atmosphere:
- wind & temp. profiles
- atmospheric absorption

SPL footprint, 3 approach trajectories
Noise synthesis with FLAURA
**FLAURA**  
Structure – Coupling

<table>
<thead>
<tr>
<th>CARMEN</th>
<th>Noise sources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Propagation</td>
</tr>
<tr>
<td></td>
<td>Spectra at receiver</td>
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</tbody>
</table>

**FLAURA v0**

+ Ground effects:
  - with or w/o turbulence
  - sum of direct and reflected rays

<table>
<thead>
<tr>
<th>IFFT</th>
<th>Tonal noise</th>
<th>Broadband noise</th>
</tr>
</thead>
</table>

Sum of tonal and broadband noise
Mid range aircraft take-off measured at microphone below flight path

- Aircraft trajectory and engine ratio known
- Landing gear not deployed
- Only engine noise prediction
- Ground resistivity at 60 000 rayls/m
- Microphone height at 1.2 m

Analysis

- Buzz Saw Noise overprediction
- BSN frequency distribution:
  -> equal for synthesis
  -> seemingly random in measured data
- Missing temporal modulation
Application to aircraft powered by CROR
Scope of the CROR application

Given that...

... the **CROR tonal noise** is expected to be **the most annoying** noise
... and is dominating the take-off conditions

→ **As a first step in this work, we focus on the CROR tonal noise & take-off conditions**

**Objective:**

*to assess the capabilities of predicting CROR ground noise with simulations based on semi-empiric models in the perspective of sound synthesis*

**Stakes:**

- *Development of an accurate but general enough CROR noise modeling*
- *Illustration of the CROR noise particularity for noise perception*
Model built for **a quick noise prediction** based on global characteristics of the CROR such as blade number, propeller diameter, thrust, … (no blade design)

→ can also be included in an **aircraft design tool**

**Basis of the tonal noise model**

- Derived from the propeller noise theory
- Assuming for each of the two propellers
  - no spatially fixed perturbations (e.g. pylon)
  - nor flow incidence
  - Same rotation speed
- Extension to contra-rotating propellers by including the mutual interaction between the rotors
- A generic blade load model based on ONERA’s CFD experience is included
- Additional assumptions (neglecting rotor-rotor distance in far-field, …)
Finally, the CROR tonal noise model inputs are thrust, efficiency, rotating and axial speeds, blades number, radius and height for each propeller.

Comparison to CFD/CAA results (Falissard et al. AIAA 2017-3869)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Rotor Blades, B_1</td>
<td>11</td>
</tr>
<tr>
<td>Rear Rotor Blades, B_2</td>
<td>9</td>
</tr>
<tr>
<td>Front Rotor Tip Radius, R_t [m]</td>
<td>2.134</td>
</tr>
<tr>
<td>Hub-to-Tip Ratio, R_h/R_t</td>
<td>0.35</td>
</tr>
<tr>
<td>Rear Rotor Cropping</td>
<td>10%</td>
</tr>
<tr>
<td>Rotor-Rotor Axial Spacing, x/D</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Z49 is the existing 1/5th scale model

Tests in ONERA’s S1MA transonic wind tunnel
The CROR noise source

Tonal noise comparison with a CROR geometry

(a) 10 dB
(b) 10 dB
(c) 10 dB

(d) 10 dB
(e) 10 dB
(f) 10 dB

ONERA
Single Event Noise Prediction at ONERA
The CROR broadband noise characteristics

- Generally less annoying in the propeller noise perception, in particular at take-off
  
  *In the current case, we take into account*

  - Rotor-alone noise
  - Rotor-rotor noise (in absence of pylon, only wake/rotor interaction)

The CROR broadband noise model

- Based on empiric laws inferred from Blandeau’s results (Blandeau’s work is based on airfoil noise theory derived from Sear’s and Amiet’s works)
  
  - Logarithmic law as function of frequency and directivity law in function of the polar angle

- Maximum SPL adapted to the tonal noise according to an empiric ratio deduced from experimental tendencies
LI4

.. as function of ...

Legriffon Ingrid; 16/08/2018
Rudimentary test-case for the present ground noise assessment

Assumptions
- 1 engine [instead of 2]
- No installation effect
- Restricted to propeller noise

Simplifications
- Straight flight path at constant altitude
- No wind nor temperature gradient (only atmospheric absorption in the sound propagation)
Ground noise levels prediction
_Rudimentary flight case_

Simulated flight duration: $120\ s$
Microphones: 2 (certification-like)
Ground noise levels prediction
Convergence study

Convergence study to ensure the accuracy of the results
(in the same manner as CFD)

Time and space discretizations in CARMEN:

- Time step of the flight path
  - EPNdB calculation based on ground noise levels collected every 0.5 s
  - $\Delta t = 0.5$ s is adapted
    - (no significant interpolation error due to retarded time are expected on ground)

- Directivity spheres of the sources and directivity sphere attached to the aircraft for atmospheric propagation, i.e. **angular discretizations of the noise source and sound propagation**
  - These two angular discretizations are defined equal in CARMEN
  - Each discretization is defined according to $\Delta \theta = \Delta \varphi = \text{constant}$
  - A convergence study based on this angular discretization is relevant
  - One expects that the convergence depends on the directivities of the noise sources, *i.e.* the convergence depends on the simulation case.
Convergence study to ensure the accuracy of the results

<table>
<thead>
<tr>
<th></th>
<th>Coarse</th>
<th>Medium</th>
<th>Fine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angular resolution ($\delta \theta, \delta \phi$)</td>
<td>$9^\circ$</td>
<td>$3^\circ$</td>
<td>$1^\circ$</td>
</tr>
<tr>
<td>CPU time</td>
<td>$t_{\text{ref}}$</td>
<td>$\sim 7 * t_{\text{ref}}$</td>
<td>$\sim 70 * t_{\text{ref}}$</td>
</tr>
</tbody>
</table>

Simulation using the CROR model

- a. Flyover Microphone
- b. Sideline Microphone

**Ground noise levels prediction**

**Convergence study**
Comparison of the ground noise prediction according to

- either URANS/FW-H input as a noise source
- either the CROR tonal noise model

URANS/FW-H – or – CROR tonal noise model

+ Broadband noise model

Atmosphere propagation (including flight effects)

GROUND NOISE PREDICTION
Ground noise levels

First tones contribution on the flyover microphone

a. U-RANS/FW-H noise source

b. CROR noise prediction model
Ground noise levels

**Ground noise predictions from CARMEN simulations**

Ground noise levels

a. Flyover Microphone

\[ \Delta(EPNdB) = +0.6 \text{ dB} \]

b. Sideline Microphone

\[ \Delta(EPNdB) = -1.5 \text{ dB} \]

\[ \Delta \equiv \text{Prediction model – URANS/FW-H} \]
Ground noise synthesis

Sound Synthesis on the Flyover microphone

CROR tonal noise model  URANS/FW-H

→ Significant discrepancy in terms of heard sound when the aircraft is approaching
→ Tonal noise is dominating, the synthesis model should be improved for more realistic rendering
Conclusion – CROR application

- This work is a first attempt to provide a CROR noise model
  - based on global propeller characteristics, i.e. without any blade geometry as input and
  - accurate enough for community noise annoyance assessment

- This challenging task is partially reached
  - The model has been built according to the first requirement
  - But the accuracy of the tonal noise model is to be improved.
    - significant discrepancies for few tones (currently investigated), contrary to the close agreement of most of the predicted tones.

- A few tones can have a significant impact on the ground noise prediction & their accurate prediction is then crucial

- The sound synthesis requires high accuracy of the tonal noise prediction
General Conclusion

- A complete chain going from aircraft and engine data to a synthesised sound on the ground was developed.

- The noise prediction tool is operative for most existing classic aircraft.
- New configurations require on-going adaptation of the prediction noise tool:
  - New noise models adapted to new technologies.
  - New aircraft architectures can increase the installation effect role so that its calculation accuracy is crucial.
  - Far-field noise source models vs. Near-field interaction.
  - Point source assumption...
  - Acceptable CPU time cost.

**Perspectives:**
- Compare different computational methods for the installation effects module.
- Improve the noise synthesis tool for more realism (including temporal variations at the source, amplitude and phase modulation due to turbulence).
- Needs of noise synthesis highlight the required accuracy of noise prediction.
This CROR applicative work has been achieved in collaboration with several ONERA colleagues: Fabrice Falissard, Alain Chelius and Sylvette Canard-Caruana.

The author also thanks Airbus for the sharing of its AI-PX7 blade design and the mid range aircraft measurement data.

A part of this research has received funding from the European Union's H2020 Programme for the Clean Sky 2 Joint Technology Initiative under Grant Agreement CS2-LPA-GAM-2016-2017-01.
Thank you for your attention