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Single Event Noise Prediction at ONERA

Application to aircraft powered by contra-rotating open rotors

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Introduction

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 developped 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

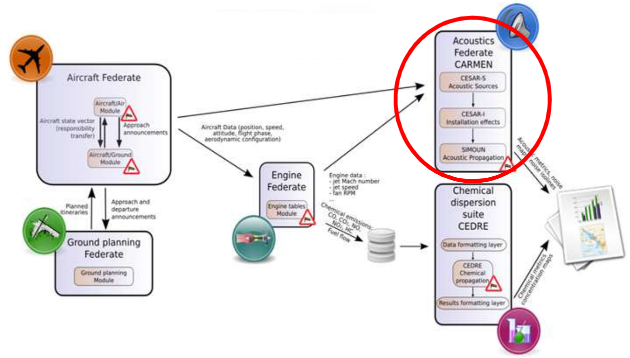
- **Ground noise prediction with CARMEN**
  - *The Acoustics module of IESTA platform*
  - *Noise source modelling*
  - *Installation effects*
  - *Sound Propagation*
- **Noise synthesis with FLAURA**
  - *Structure*
  - *Example*
- **Application to aircraft powered by CRORs**
  - *CROR noise source 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 trafic surounding 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

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CARMEN
Structure

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/deployement, landing gear etc)

Static parameters

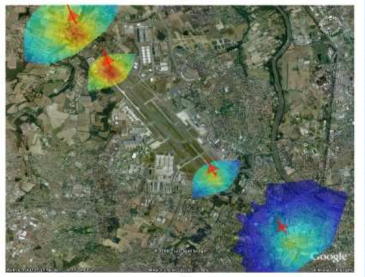
Aircraft geometry

Static/dynamic parameters

- **Meteorological conditions** (wind, T° 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)

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CARMEN
Noise source modelling

Propulsion noise + Airframe noise

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

Fan, Jet

Turbopropeller

Slat, Flap

CROR

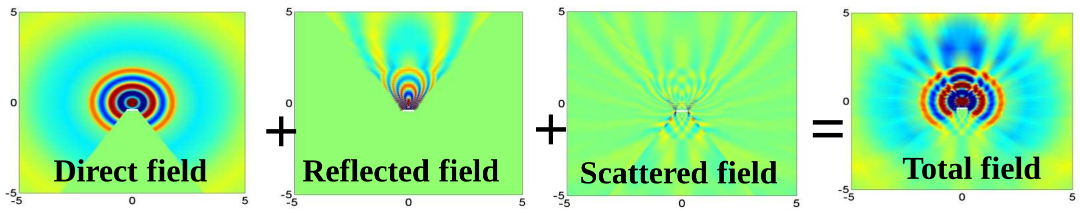
Landing Gear

Rotors

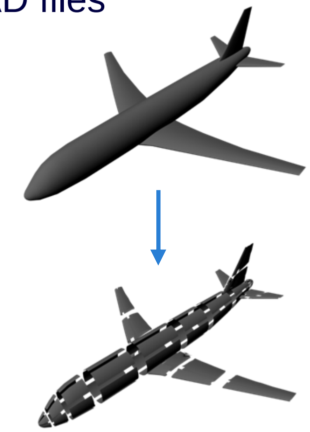
CARMEN
Installation effects

Model based on the ray tracing technique

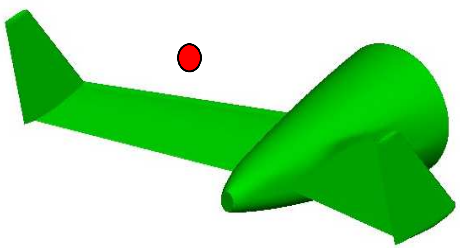
1- Direct + Reflected + Diffracted field from Uniform Theory of Diffraction
Scattering by the edges (leading edge) and creeping waves (fuselage)

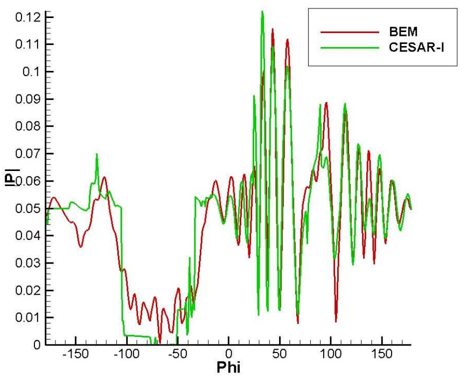


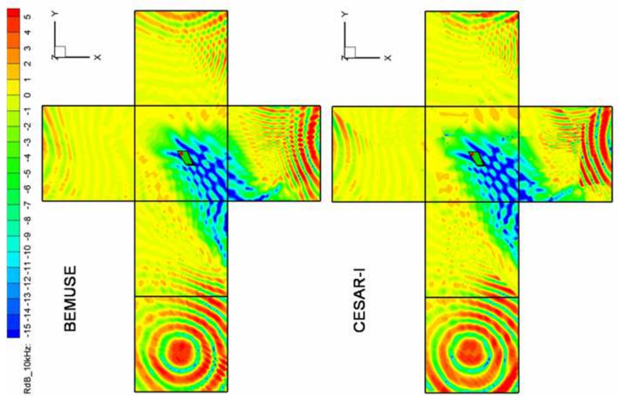
2- Geometry described from analytical curves surfaces (NURBS) from CAD files



Comparison to Boundary Elements Method (BEMUSE code)







BEMUSE CARMEN

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CARMEN
Coupling source models and installation effects

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

↓

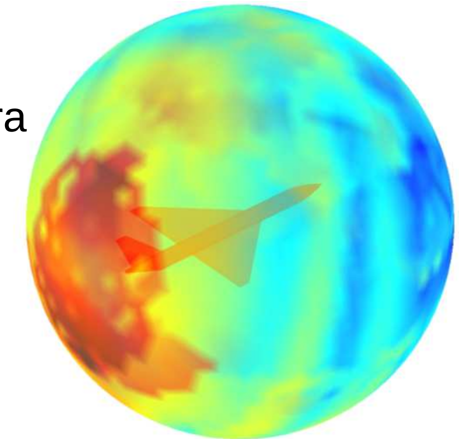
Input to installation effects module: position of the sources

↓

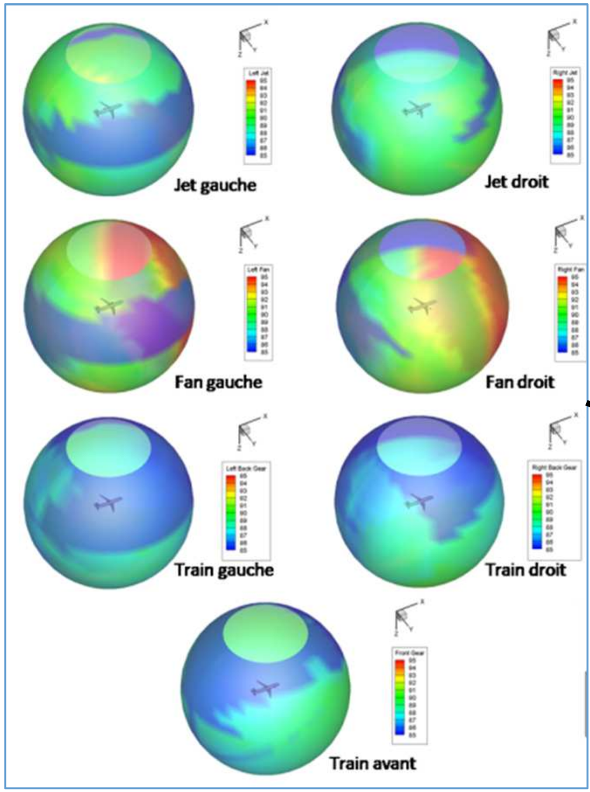
Output of installation effects module: Sphere of 100m radius including at each gridpoint the information on: ray kind (direct, reflected, …), ray path distance and first angles for each source location

↓

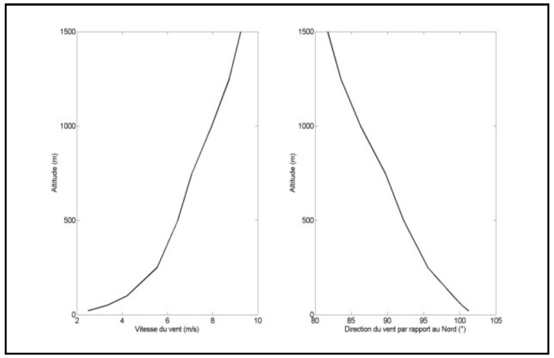
Coupling with source directivity and spectra



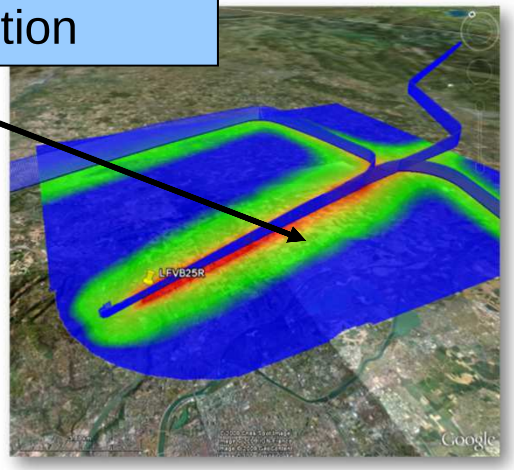
CARMEN
Coupling (source + installation) with sound propagation



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



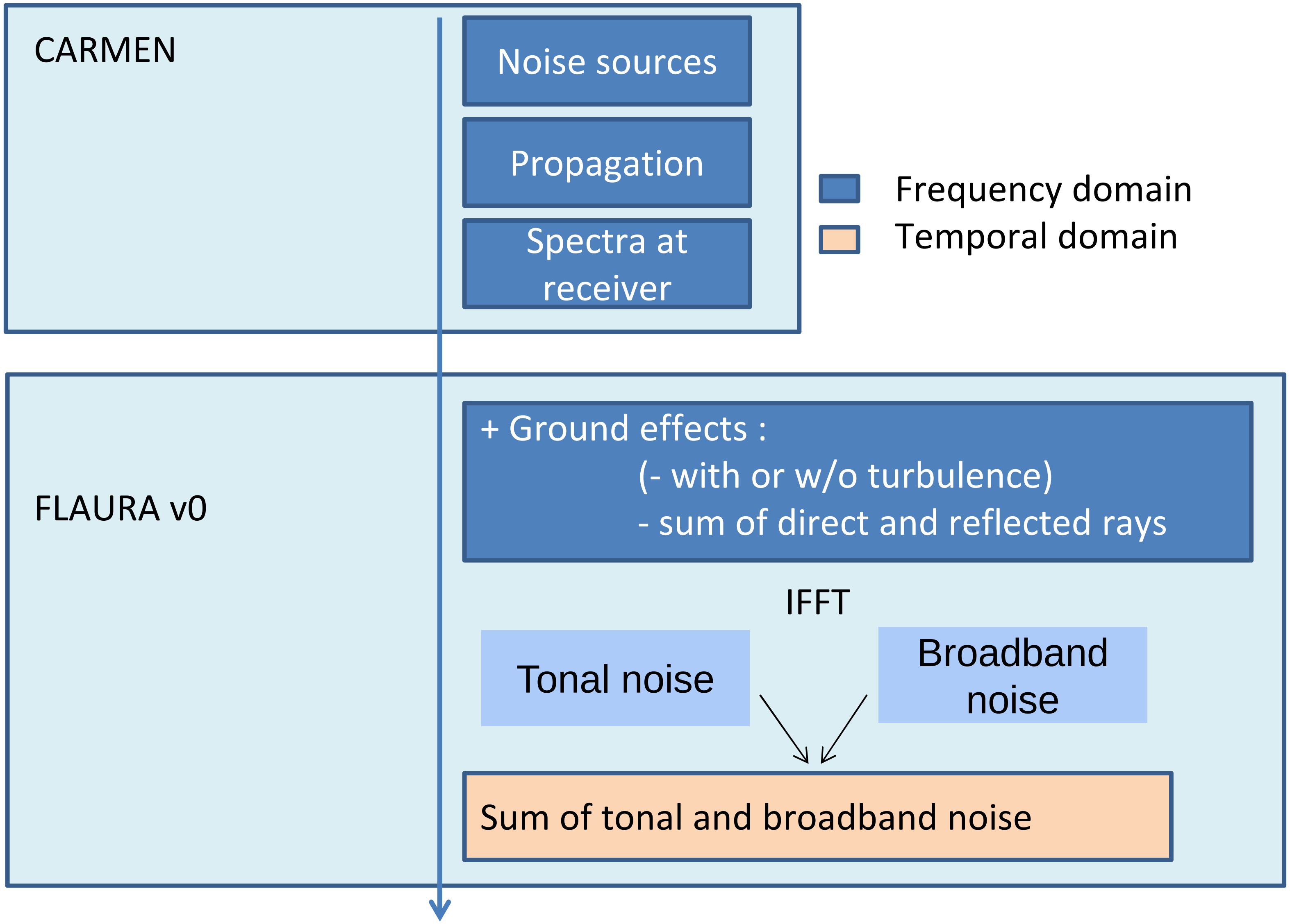
Propagation in the atmosphere:
- wind & temp. profiles
- atmospheric absorption



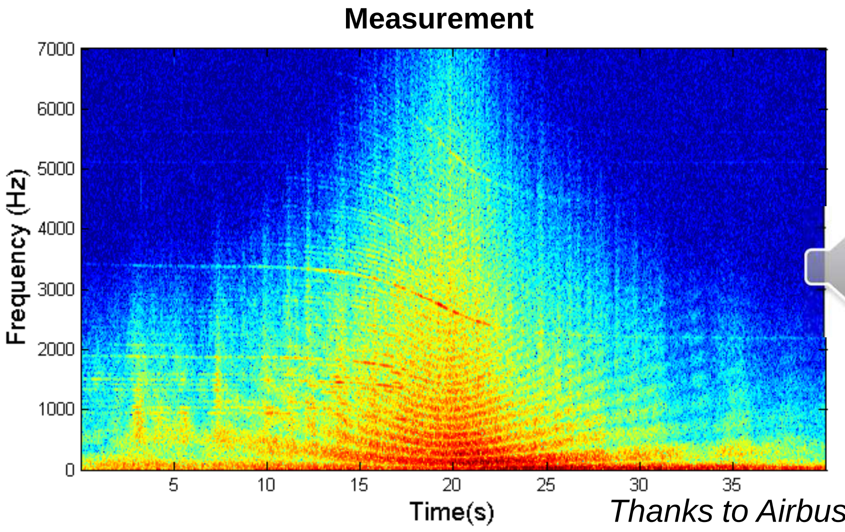
SPL footprint, 3 approach trajectories

Noise synthesis
with FLAURA

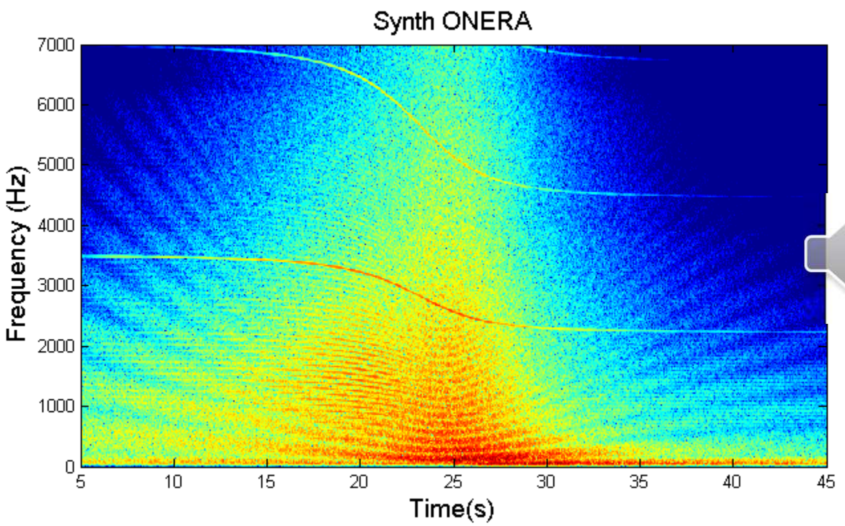
FLAURA
Structure – Coupling



Example : Mid range aircraft take-off



Thanks to Airbus



Mid range aircraft take-off measured at microphone below flight path

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

The CROR noise source
The CROR tonal noise model

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

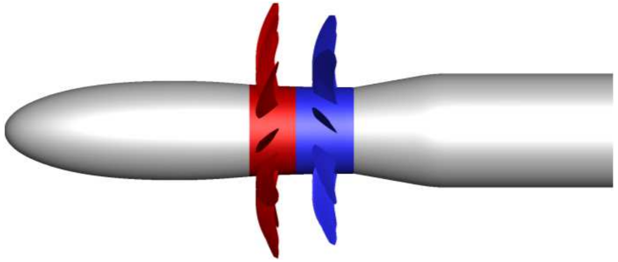
- Derived from the propeller noise theory
- Assuming for each of the two propellers
  - ✓ no spatially fixed perturbations (e.g. pylon)
  - ✓ nor flow incidence
  - ✓ Same rotation speed
- Extension to contra-rotating propellers by including the mutual interaction between the rotors
- A generic blade 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)

The Airbus Clean Sky generic Open Rotor AI-PX7

Z49 *CFD computations*



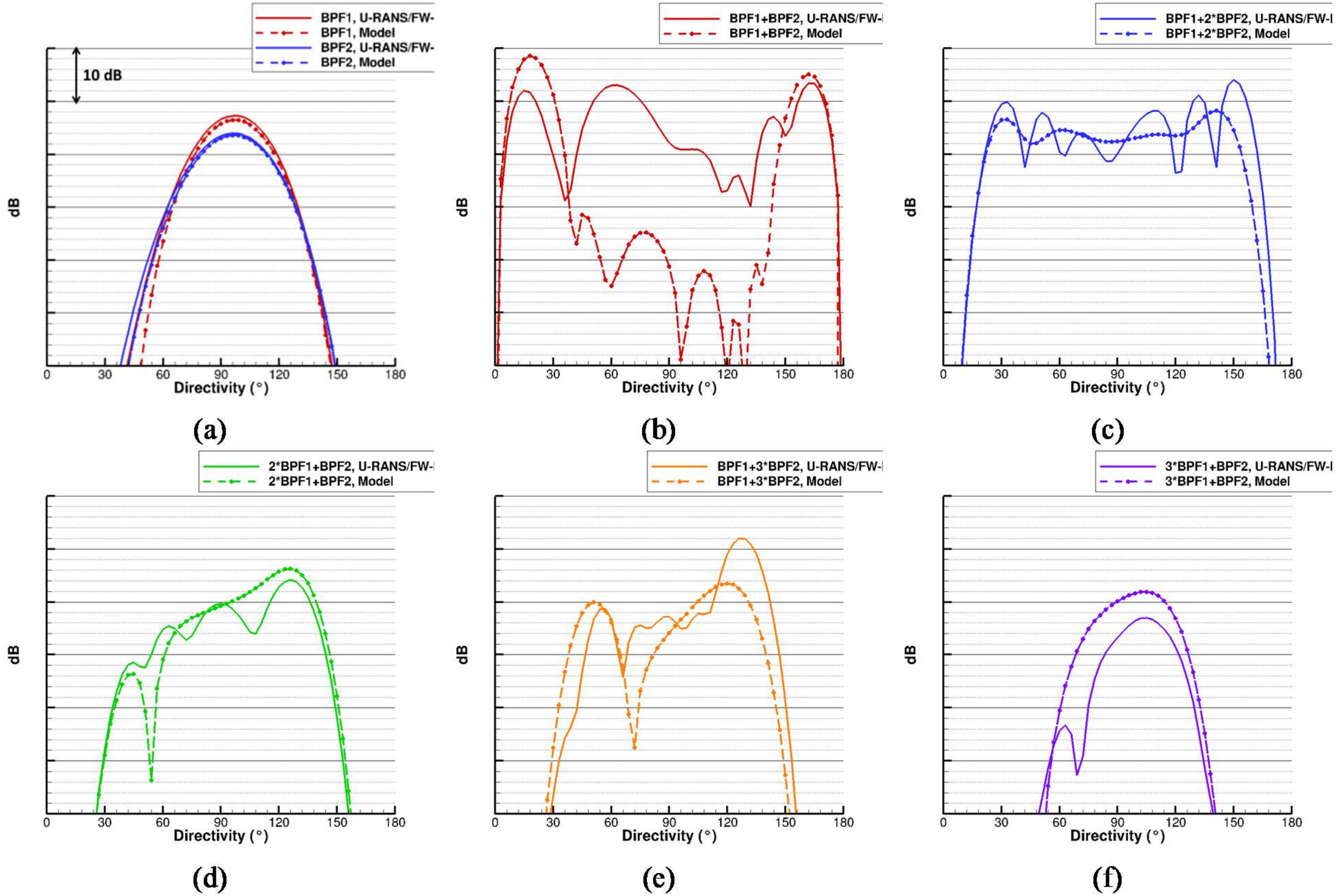
Z49 is the existing 1/5th scale model

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

AI-PX7 open-rotor characteristics

Tests in ONERA's S1MA transonic wind tunnel

The CROR noise source
Tonal noise comparison with a CROR geometry



The CROR noise source
The CROR broadband noise

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)
  - LI4 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 tendancies

Diapositive 19

LI4 .. as function of ...

Legriffon Ingrid; 16/08/2018

Ground noise levels prediction
Rudimentary flight case

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)

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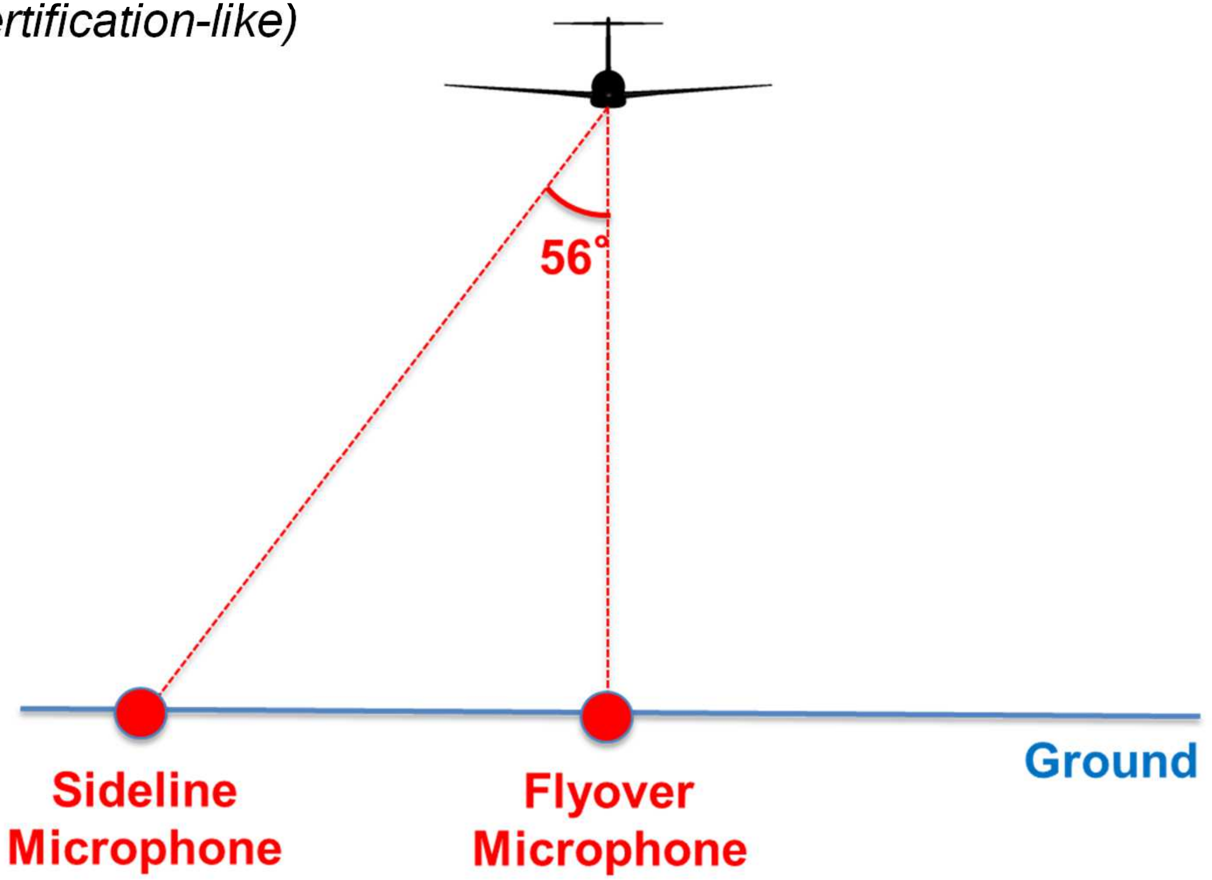
Ground noise levels prediction
Rudimentary flight case

Simulated flight duration: *120 s*

Microphones: *2 (certification-like)*



Ground noise levels prediction
Convergence study

<u>Convergence study to ensure the accuracy of the results</u>

(in the same manner asCFD)

Time and space discretizations in CARMEN:

- ❑ Time step of the flight path

  EPNdB calculation based on ground noise levels collected every 0.5 s

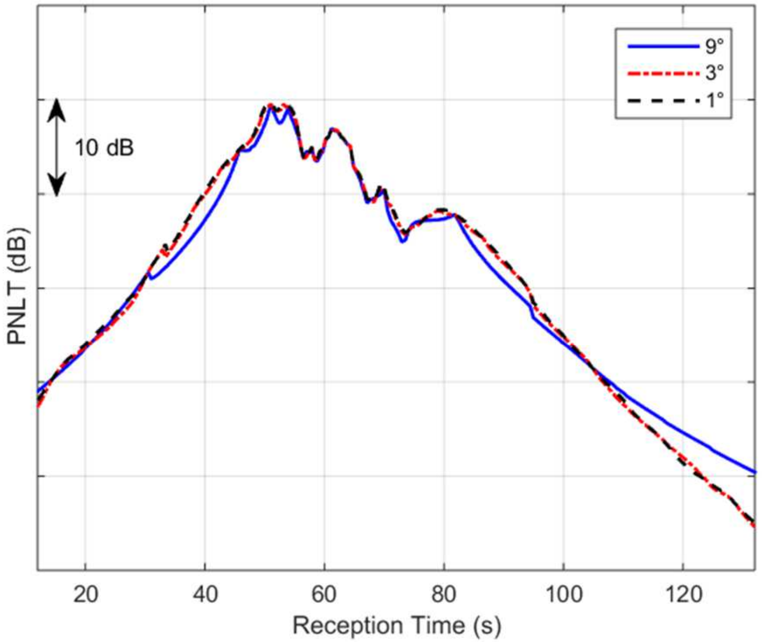
  - ➢ $\Delta t = 0.5\ s$ is adapted

    (no significant interpolation error due to retarded time are expected on ground)

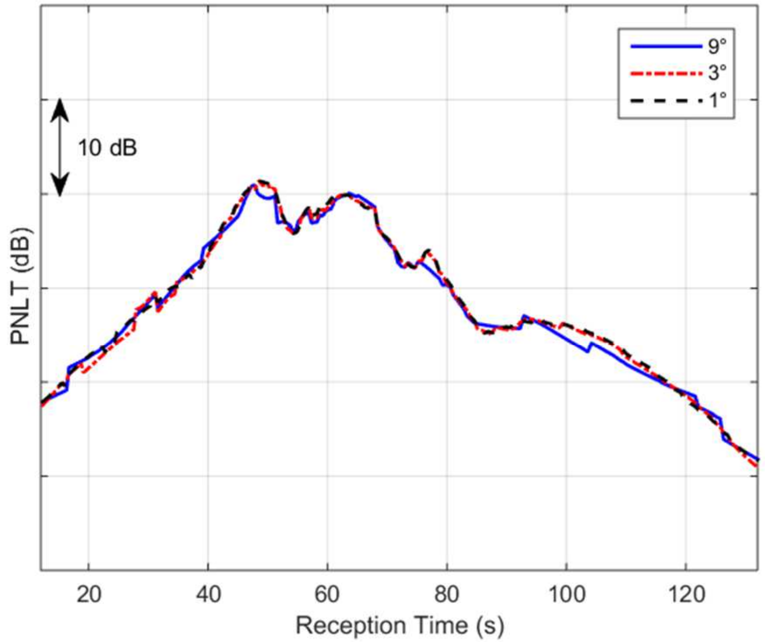
- ❑ Directivity spheres of the sources and directivity sphere attached to the aircraft for atmospheric propagation, i.e. **angular discretizations of the noise source and sound propagation**
  - ▪ These two angular discretizations are defined equal in CARMEN
  - ▪ Each discretization is defined according to $\Delta\theta = \Delta\varphi = constant$
  - ➢ **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

	Coarse	Medium	Fine
Angular resolution ($\delta\theta$, $\delta\varphi$)	9°	3°	1°
CPU time	t_{ref}	$\sim 7 * t_{ref}$	$\sim 70 * t_{ref}$



a. Flyover Microphone



b. Sideline Microphone

Simulation using the CROR model

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

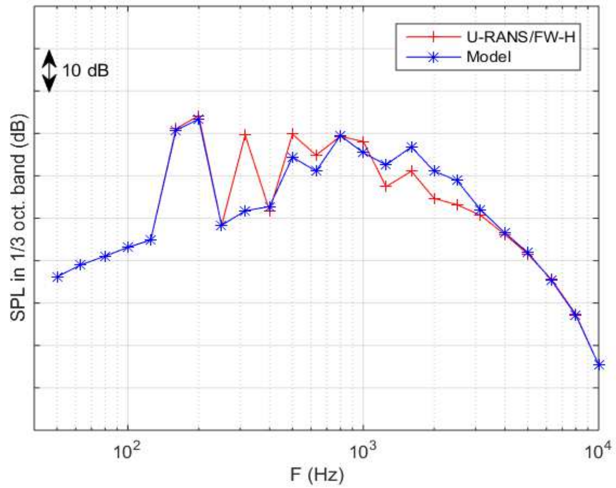
\+

Broadband noise model

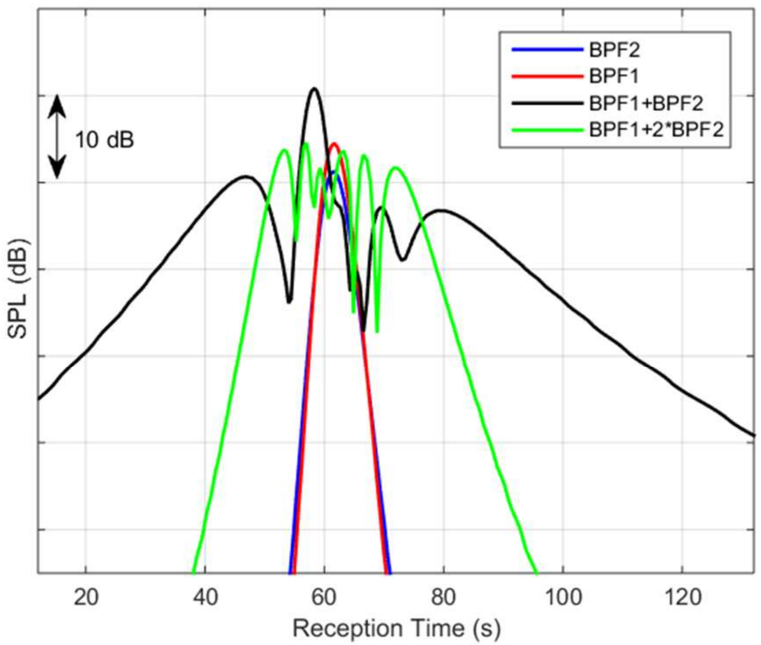
Noise source

Atmosphere propagation (including flight effects)

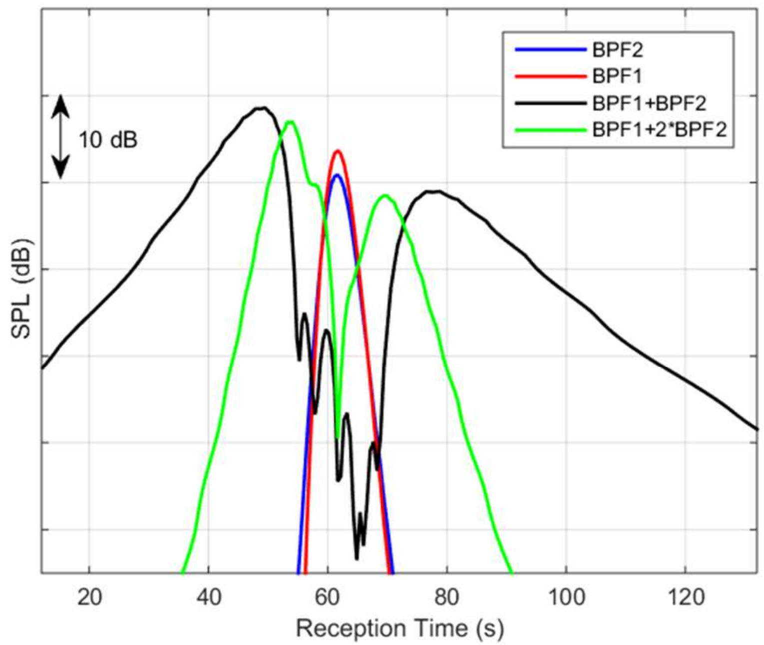
GROUND NOISE PREDICTION



<u>First tones contribution on the flyover microphone</u>

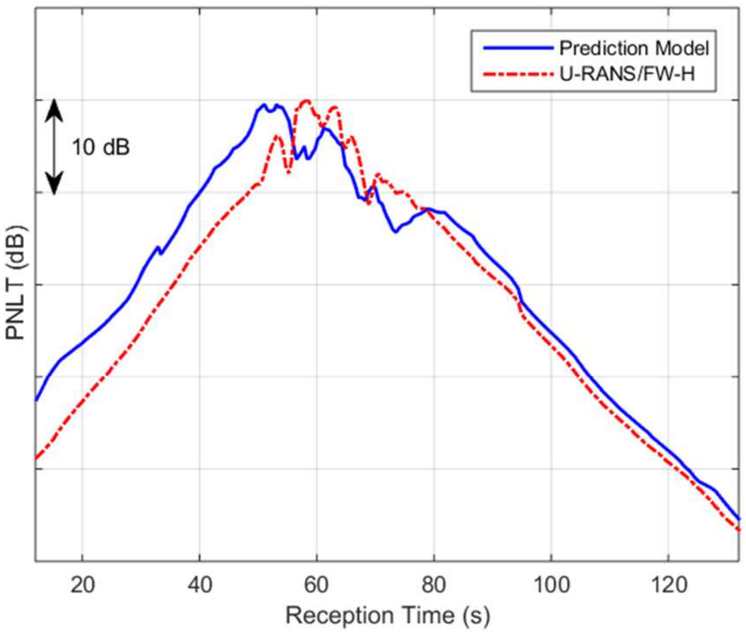


a. U-RANS/FW-H noise source



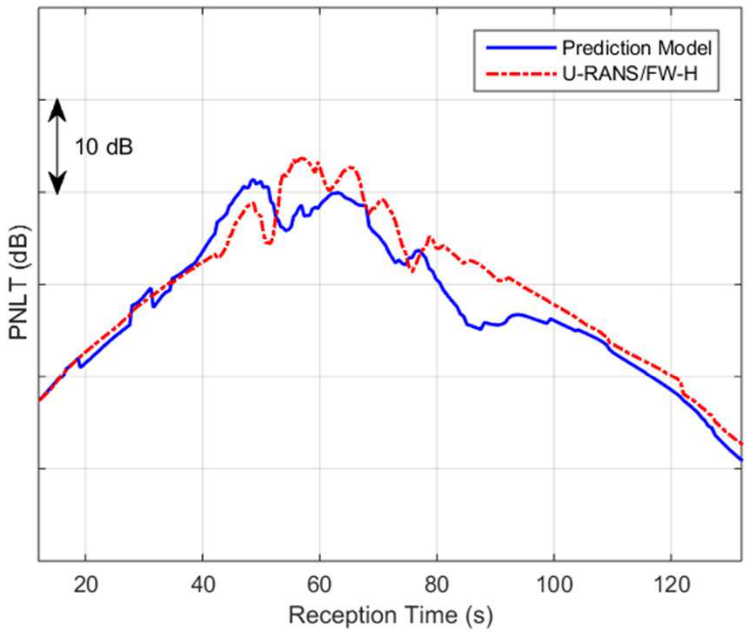
b. CROR noise prediction model

Ground noise levels



a. Flyover Microphone

Δ(EPNdB) = +0.6 dB



b. Sideline Microphone

Δ(EPNdB) = -1.5 dB

Δ ≡ Prediction model – URANS/FW-H

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

Objectives

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

Results

- 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.

Analysis

- **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 synthezised 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

Acknowledgements

- 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.

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Thank you for your attention