



A numerical tool for aircraft engine noise in flight conditions

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Most of the engine makers for aircraft applications apply to the European legislation norms concerning noise by measuring noise around an engine on a bench in an open environment. The next generation of noise law will certainly require for each aircraft operator to know precisely the noise generated by the engines in an actual environment, that is airport topography, prevailing meteorological conditions, LTO path...

In that case, the experimental monitoring is not feasible anymore and traditional simulations remain too costly. A numerical tool is presented here, which help in the prediction of the noise generated by an engine in any kind of environment. The methodology is the following: from bench data, *fluidyn-AVNOISE* retropropagate the acoustic field so that an equivalent acoustic source is obtained. The retropropagation is obtained by minimization of the quadratic norm between predicted and measured pressure. The equivalent acoustic source can be placed underneath the wings of an aircraft modeled in finite element and the acoustic field obtained from there in the vicinity of the plane. The retropropagation module AVNOISE has been tested and validated for a number of analytical problems. It has then been tested on a set of real measurements from a monitoring campaign.

1. INTRODUCTION

Most of the engine makers for aircraft applications apply to the European legislation norms concerning noise by measuring noise around an engine on a bench in an open environment. The next generation of noise law will certainly require for each aircraft operator to know precisely the noise generated by the engines in an actual environment, that is airport topography, prevailing meteorological conditions, LTO path... In that case, the experimental monitoring is not feasible anymore and traditional simulations remain too costly.

In the area of computational acoustics, procedures that accurately predict the far-field sound radiation are much sought after. The development of such a procedure is described in this paper. The inverse method presented here is an alternate approach to predicting far field sound based on a combination of simple and double layer potentials installed on a virtual surface replacing the unknown source(s). This method has many advantages. It requires only a free space Green's function, it can accommodate arbitrary shapes of surfaces, and it is readily extendable to three-dimensional problems. Results are presented here for aircraft engine noise, but it can be adapted easily to other areas of interest. Section 2 describes briefly the inverse method that is used in *fluidyn-Avnoise*. In section 3, a validation case is presented, for which a complete analytical solution is available. Eventually, the measurements made on an aircraft engine are compared to the estimated pressure field proposed by Avnoise.

We consider a region in which pressure measurements have been realized. The pressure satisfies the Helmholtz equation in the region. Consider then a set of acoustic sources (virtual or

equivalent sources) for which the radiated pressure field can be calculated, either analytically or numerically. The radiated field can be compared to the values measured and associated with the unknown sources. Using a minimization technique, it is possible to choose one of the equivalent sources as the closest representation of the unknown sources.

2. MAIN EQUATIONS

2.1. General presentation

In the following, we consider a virtual source given by a surface associated with a hybrid potential. This potential is a linear combination of simple and double layer potentials. Details can be found in the references (see for example [1-4]).

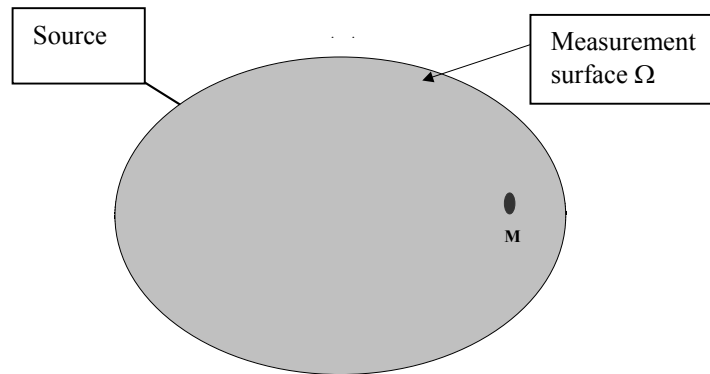


Figure 1: *General scheme of the problem*

The potentials can be expressed as follows:

- Simple layer potential:

$$p_s(M) = \int_{\Gamma} \mu_s(M) G(M, P) d\Gamma(P) \quad (1)$$

- Double layer potential:

$$p_d(M) = \int_{\Gamma} \mu_d(M) \partial_{n(P)} G(M, P) d\Gamma(P) \quad (2)$$

- Hybrid potential:

$$p(M) = a_s \cdot p_s(M) + a_d \cdot p_d(M) \quad (3)$$

with μ_s density for the simple layer potential and μ_d density for the double layer potential. G is the free space Green function. These expressions satisfy the Sommerfeld conditions for the far-field behavior. However, the problem of finding the density function from the pressure measurements involves solving a complex set of equations and is not well-posed. Calculations must be done carefully. Once the densities are found, it is possible to obtain the pressure field in the region where the derivation has been done.

2.2. Virtual source characterization

The following assumptions are done. The real source is replaced by a virtual source defined by its surface Γ (Figure 1). Simple and double layer potentials are associated with this surface. The equivalent (or virtual) source radiates an acoustic field given by the following expression:

$$p_e(M) = a_s \int_{\Gamma} \mu_s(P) G(M, P) d\Gamma(P) + a_d \int_{\Gamma} \mu_d(P) \partial_{\vec{n}(P)} G(M, P) d\Gamma(P) \quad (4)$$

The different parameters (a_s, a_d) and densities (μ_s, μ_d) are determined by minimization of the quadratic norm between the measured pressures and estimated pressures :

$$QN_{me} = \int_{\Omega} |p_m(M) - p_e(M)|^2 d\Omega(M) \quad (5)$$

where Ω represents the surface on which measurements are done (usually discrete vector).

2.3. Numerical discretization

The Γ surface associated with the virtual source is divided into elements. These elementary surfaces are noted Γ_j (Figure 2).

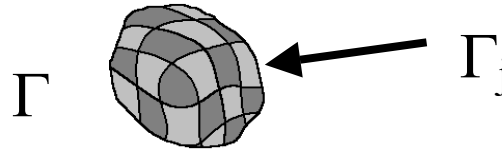


Figure 2: *Virtual source discretization*

The layer density is then considered as defined on each elementary surface:

$$\mu(P) = \sum_{j=1}^{Ne} \mu_j f_j(P) \quad (6)$$

where P is a point on the discretized surface, Ne is the total number of elements, $f_j(P)$ is a repartition function and $\mu_j = \alpha_j + \beta_j$ is a complex variable. Taking into account the discretization of the virtual source, the expression of the quadratic norm (5) is then replaced by the following expression:

$$QN_{me}^D = \sum_{k=1}^{Nm} \left| p_m(M_k) - \sum_{j=1}^{Ne} \int_{\Gamma} f_j(P) [a_{sj} \mu_{sj} G(M_k, P) + a_{dj} \mu_{dj} \partial_{n(P)} G(M_k, P)] d\Gamma \right|^2 \quad (7)$$

where N_m represents the number of pressure measurements available. The minimization of QN_{me}^D can be done using different recent numerical methods. Up to now, a 2D and an axisymmetrical 3D versions exist. Note that different surfaces can be used for the virtual source.

3. SIMULATION CASES

Many validation cases have been tested in 2D and 3D. We have chosen to describe first a simple 2D validation study, for which a complete analytical solution is available. Doing so, it is possible to use a set of points as “measurement points” for the retropropagation technique, and to check

the pressure field on another set of points, that will be called “propagation points”, for which the analytical solution also gives the exact results.

3.1. Test case of a non centered source point.

In a first step, Avnoise is used to characterize the virtual source from the measurement points. In a second step, propagation points are chosen, and the estimated pressure, given by the virtual source is compared to the real value of the pressure field, given by the analytical solution (see Figure 3).

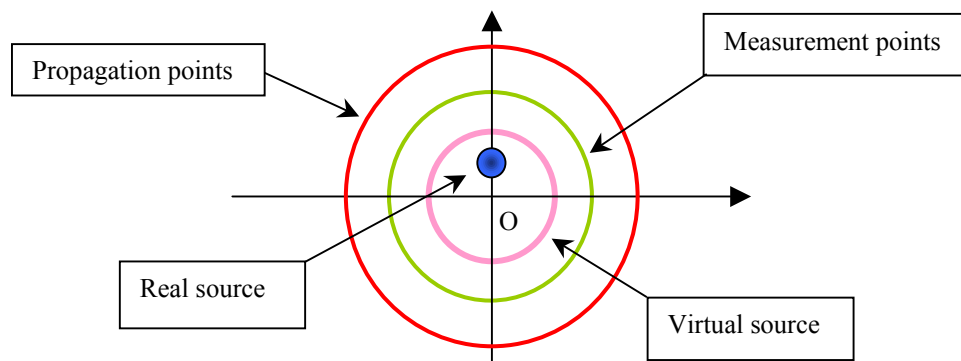


Figure 3: *Scheme of the test case*

The monopole is placed on the y-axis ($y = 0.9$ m). The measurement points are placed on a circle centered in O (radius: 4 m). The virtual source is also a circle, smaller than the measurement circle, but containing the real source (radius: 1 m). The propagation points are placed on a circle centered in O, that is larger than the measurement circle (radius: 8 m). See details on Figure 3. We first checked that the pressure values given by the virtual source $p_e(M)$ were equal to the pressure measurements made on the measurement circle $p_m(M)$. This is the case, and the values perfectly match for all the measurement points.

We then compare the predictions given by the virtual source on a propagation circle with a radius of 8 m to the real pressure field, obtained by analytical solution. This is done in Figure 4, where it can be seen that both curves match well in amplitude and phase.

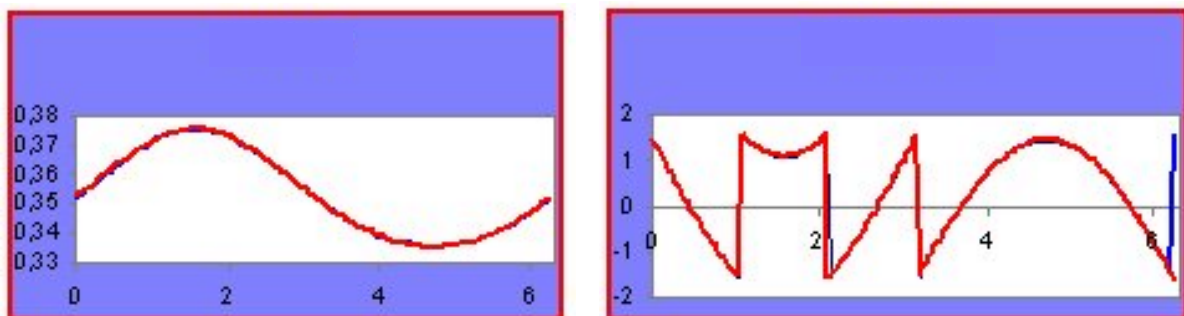


Figure 4: *Comparison between real and estimated pressure field given by the virtual source. Left: pressure amplitude, right: pressure phase.*

Results obtained here are satisfying. Other test cases have been performed, especially with the axisymmetrical 3D version of Avnoise.

3.2. Prediction of an aircraft engine noise.

The AVNOISE program has then been tested on a set of real measurements from a monitoring campaign. 25 measurements were made on a semi-circle, at a distance of about 45 m from the aircraft engine (Figure 5). These measurements have been realized for three different regimes and spectral analysis was performed on pressure amplitude. Results were given as a function of third octave frequencies.

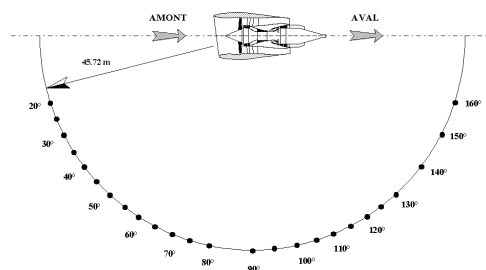


Figure 5: *Pressure measurement points in the vicinity of the engine*

The data that are used in the present paper correspond to the “full-throast” regime (4880 tr/min). Using the spectral analysis, frequencies between 1000 and 2000 Hz are chosen. Avnoise simulates an ellipsoidal virtual source associated to the engine. Results are described below. We specifically focus on the contribution associated with the frequencies $f = 1000$ Hz and 2000 Hz. Figure 6 shows the estimated pressure at a distance of 45 m as a function of the angle θ . It is compared to the curve associated with the pressure measurements.

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Figure 6: *Comparison between estimated and measured pressure for the aircraft engine, for two frequencies. Results are presented as a function of θ , the angle associated with the microphone positions (see Figure 5). Left: $f = 1000$ Hz. Right: $f = 2000$ Hz.*

The agreement is excellent for $f = 1000$ Hz (cumulated error: 0.3%) and satisfying for $f = 2000$ Hz (cumulated error: 1.1%). An optimization of the discretization parameters should help in improving these results. Results for other frequencies have also been obtained. Prediction of the noise can be made at distances other than 45 m using the virtual source.

4. CONCLUSIONS

A numerical tool is presented here, which help in the prediction of the noise generated by an engine in any kind of environment. The methodology is the following: from bench data, fluidyn-AVNOISE retropropagate the acoustic field so that an equivalent acoustic source is obtained. The retropropagation is obtained by minimization of the quadratic norm between predicted and measured pressure. The retropropagation module AVNOISE has been tested and validated for a number of analytical problems. It has then been tested on a set of real measurements from a



monitoring campaign. The equivalent acoustic source can be placed underneath the wings of an aircraft modeled in finite element and the acoustic field obtained from there in the vicinity of the plane. This should be done in association with other modeling for the noise sources that are not taken into account (jet noise,...).

ACKNOWLEDGEMENTS

Support for this research was provided by the French Agency for Environment and Energy Management (ADEME).

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