AIRCRAFT NOISE PREDICTION IN THE IESTA PROGRAM

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ABSTRACT

The aim of the IESTA program (Infrastructure for Evaluating Air Transport Systems) is to provide an efficient tool in the design and modelling of innovative air transport systems through a global evaluation platform. The first application of IESTA is focused on the environmental impact of the air traffic surrounding airports, including noise and chemical emissions. This paper presents the acoustic model dedicated to the aircraft noise prediction. Based on the different physical phenomenon, this model includes three modules: the acoustic source models, the installation effects and the atmospheric propagation. The noise source module describes the models for jet, fan, landing gears and high-lift devices which are mainly responsible for aircraft noise during take-off and landing. The module for the installation effect concerns the influence of aircraft surfaces on acoustic radiation, using a Ray Tracing method. Both direct and reflected fields are computed using Geometrical Acoustics principles, while the diffracted field is approximated using the Uniform Theory of Diffraction. The accuracy of this module is investigated thanks to comparisons with analytical solutions and BEM (Boundary Element Method) computations. The propagation in the non-uniform atmosphere is computed using the Ray Tracing Theory. It allows us taking into account wind profiles and temperature gradients, together with the atmospheric absorption.

1. INTRODUCTION

The Advisory Council for Aeronautics Research in Europe (ACARE) has strongly warned the aeronautical community that the European Air Transport System (ATS), presently close to its limit, is facing the challenge of a continuously growing demand with a wish of sustainable and economically viable development [1]. The challenge is to accommodate the forecast increase in air traffic as well as reducing the relative impact of aviation, with respect to noise and emissions. The goals emphasize the efforts air transport industry needs in order to reduce the environmental impact in the global warming, community noise nuisance and airport pollution.

This requires the ability to evaluate the benefit of innovative concepts and technologies through the whole set of complex and performance criteria. The objective of the IESTA program (Infrastructure for Evaluating Air Transport Systems) is to provide an efficient tool in the design and modelling of innovative air transport systems through a global evaluation platform [2]. Such an approach is complementary to the so-called Integrated Noise Model used by Federal Aviation Administration, based on a very large experimental database developed since few dozens of years. The PANAM tool appears to be similar to the acoustical part of IESTA, however in contrast, it includes a set of additional source modelling and it neglects the shielding effects and the propagation in the heterogeneous atmosphere [3]. The first application of IESTA, called "Clean Airport", is focused on the environmental impact of the air traffic surrounding airports, including noise and chemical emissions. This application of IESTA assumes a fleet of few dozens of aircrafts surrounding an airport. In practice, the noise contribution of each aircraft is predicted and the global impact is determined as an incoherent summation over the aircrafts.

The whole physical models (acoustics, chemistry, weather, aircraft trajectory, propulsion, etc.) are integrated in a powerful and versatile platform. According to the "Clean Airport" application, a significant part concerns the development of an acoustic model dedicated to aircraft noise prediction. The acoustic

model is made of three modules: the acoustic source models, the installation effects and the atmospheric propagation, as described in [4]. This paper illustrates these models and presents recent results based on installation and sound propagation effects.

2. ACOUSTIC SOURCE MODELING

Different acoustic sources are involved in the radiated noise by a standard aircraft. Figure 1 summarises the relative components of aircraft acoustic sources during take-off and landing. It shows that, at take-off the engine noise including the fan and the jet contributions dominates, while the airframe noise generated from the landing gears and the high-lift devices is of same order of magnitude as the engine during approach. The noise source program in IESTA, named CESAR-S, is made up of several modules, each predicting the acoustical sources. Noise generated by each component is evaluated independently, the interactions between components being not modelled. To save CPU time, appropriate analytical formulations are favoured, when available. To reach the objective of an accurate predicting tool, there is a need is to provide relevant spectral properties and free-field directivity for each source. The modular approach allows integrating noise models, as database for new concepts, such as for instance open-rotor or counter-rotating fans, when no relevant semi-empirical or analytical solutions exist. This section concerns the engine noise models from the jet and the fan, pointing out comparisons with experimental results.
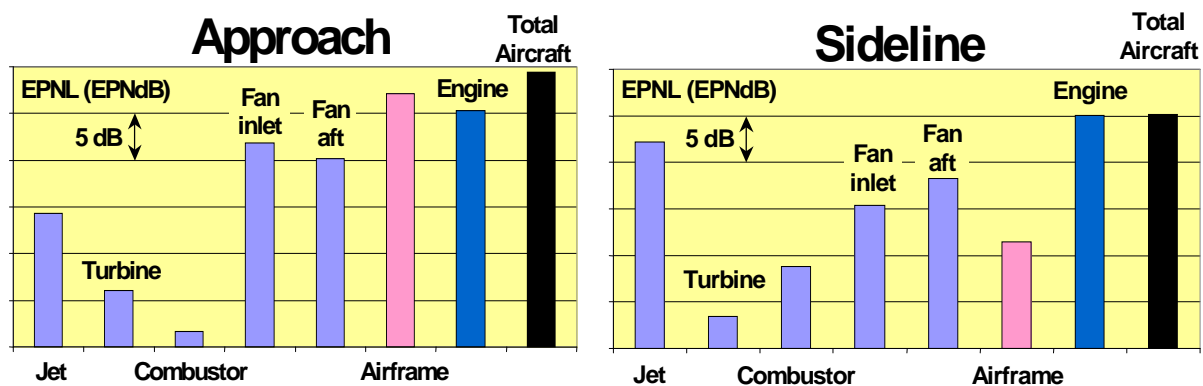

Figure 1: Aircraft acoustic sources - Relative contribution.

2.1. Jet noise

The prediction of the coaxial jet noise is based on the model proposed by Stone *et al.* [5]. It is derived from the NASA interim method and is able to predict the noise radiated by a conventional coaxial jet noise in far field, free field. Stone et *al.* already validated the model for static conditions. In the IESTA framework, the Stone's model has been validated for the prediction of the forward flight effects thanks to experimental results from the EU-project VITAL [6]. Figure 2 plots the mock-up of the exhaust of the engine installed in the CEPRA-19 Wind Tunnel. Figure 3 shows a good agreement between model and experiments of the Overall Sound Pressure Level (OSPL) both for static and flight conditions. In particular the model finds the expected flight effects: the tendency to decrease jet noise (reaching up to 8 dB in the aft region)
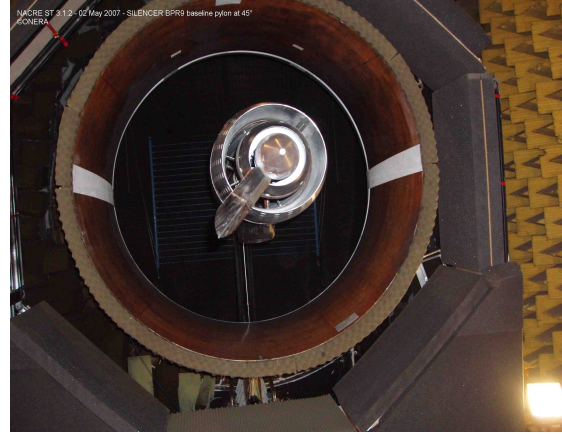
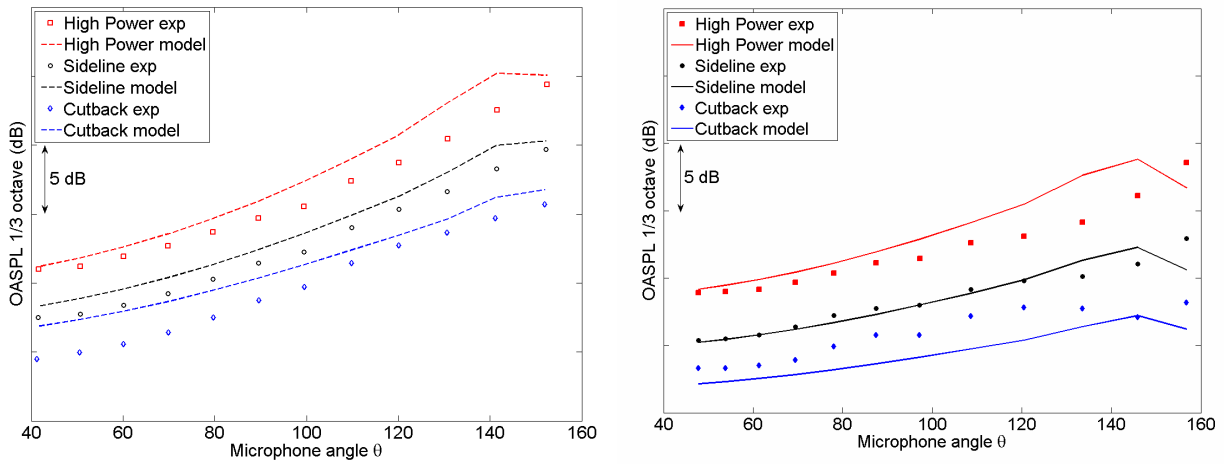Figure 2: Mock-up of the engine installed in the CEPRA-19 Wind Tunnel.

Figure 3: Coaxial jet noise - Comparison between the model proposed by Stone and the experiment-Overall Sound Pressure. Left: static conditions; right: flight conditions.

2.2 Fan noise

The fan noise module implemented in CESAR-S is based on the semi-empirical model proposed by Heidmann in 1979 [7]. Since the model was established several decades ago using experimental results from noisier fans than current fans, it over-predicts the sound pressure level at inlet and discharge, for both tonal and broadband noise of recent engines. Based on experimental results collected during the two past decades on engine fans by Onera, the model is currently being improved to match the noise radiated by fans operating on aircraft nowadays. Figure 4 presents the improvements at inlet and discharge on the tonal power level, for a conventional fan.
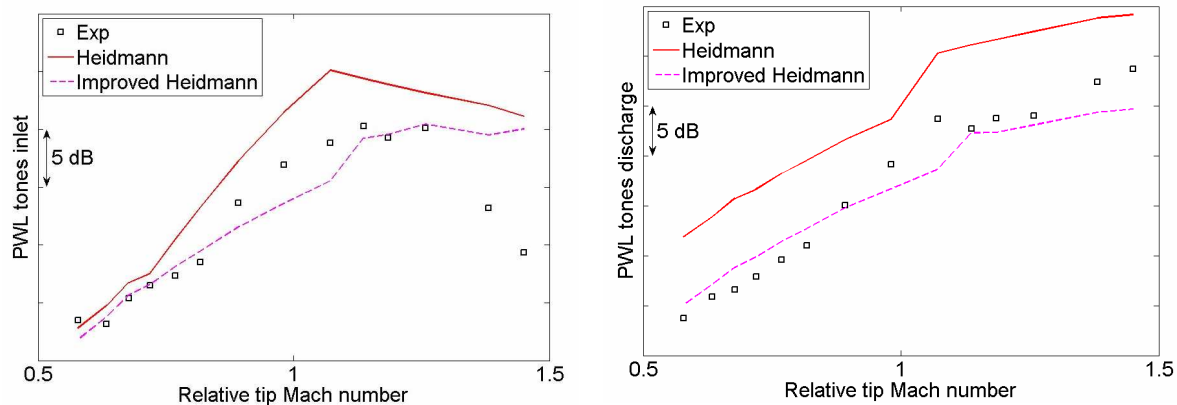
Figure 4: Fan noise - Comparison between the tonal overall sound pressure level predicted by Heidmann's model and measured for a recent engine .Left: inlet; right: discharge.

3. INSTALLATION EFFECTS

The installation effects designate here the influence of scattering objects on the pressure field compared to the free-field. It is well-known that the installation effects are strongly related to the frequency of interest: they are significant in the high frequency range, i.e., when the wavelength is smaller than the characteristics size of the scattering object and negligible in the low frequency range.

The capability of IESTA to take into account the installation effects is of importance, as a predictive tool. This is especially of interest for new concepts, for instance, when the masking effects of the engine noise by the wing are expected to introduce a significant noise reduction. Since the growing development of computer resources, numerical methods based on the Euler equation's or Boundary Element Method are candidates to deal with installation effects, but these methods remain computationally too expensive in the high frequency range (i.e., $ka >> 30$, where k is the wave number and a is a typical size of the object). As an alternative, the installation effect module (CESAR-I) is based on the ray tracing technique. The total pressure is computed as the contribution of:

- the incident field generated from the acoustical source,
- the reflected field on the surface,
- the diffracted fields from edges and surfaces of the scattering object.

The diffracted field is obtained according to the Uniform Geometrical Theory of Diffraction by edge and the Uniform GTD Analysis for the diffraction by a smooth convex surface [8, 9]. In practice, the structure is described by Non-Uniform Rational B-Spline (NURBS) curves and surfaces, allowing us the description of a realistic shape of the aircraft.

CESAR-I has been validated in number of configurations of canonical geometries (cylinder, sphere, strip, etc.). Figure 5 illustrates the comparison between the analytical solution and the ray-method for the scattering by a strip. As expected, in the high frequency range, $ka = 27.7$, CESAR-I and the analytical results are in good agreement. A study has confirmed that the approximation of the geometrical acoustic is no more valid at very low frequencies, typically when $ka << 1$, and it is satisfactory in the mid-frequency, when ka reaches 4.

Validations thanks to Boundary Element Method (BEM) are also considered to enable complex geometries. The scattering by an empennage has been examined (Fig. 6). The red point represents the location of the acoustical source at the frequency of 800 Hz, close to the Blade Passing Frequency of the fan. For this computation where only the incident and the reflected fields are considered in the ray-model, the directivity pattern around the empennage is in very good agreement with the BEM, except deep in the shadow zone (Phi in the range -100° to -50°), where the diffraction effects are more sensitive. Under certain configurations, it seems to be quite fair to neglect part of the diffraction field, leading to significant computational resources reductions. However, such assumptions should result from a specific sensitive study.
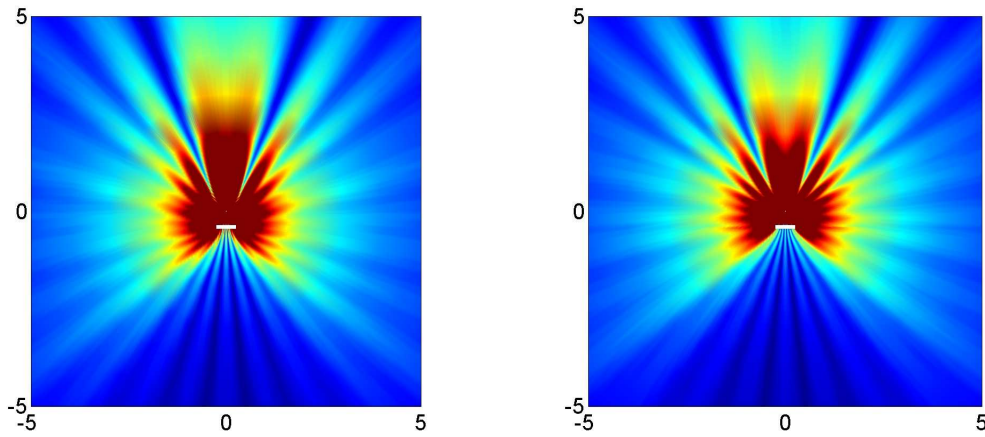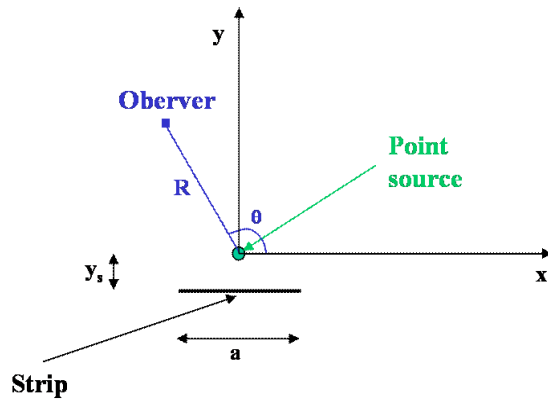
*Figure 5: Diffraction by a strip – Comparison between the analytical solution and CESRA-I, ka= 27,7.
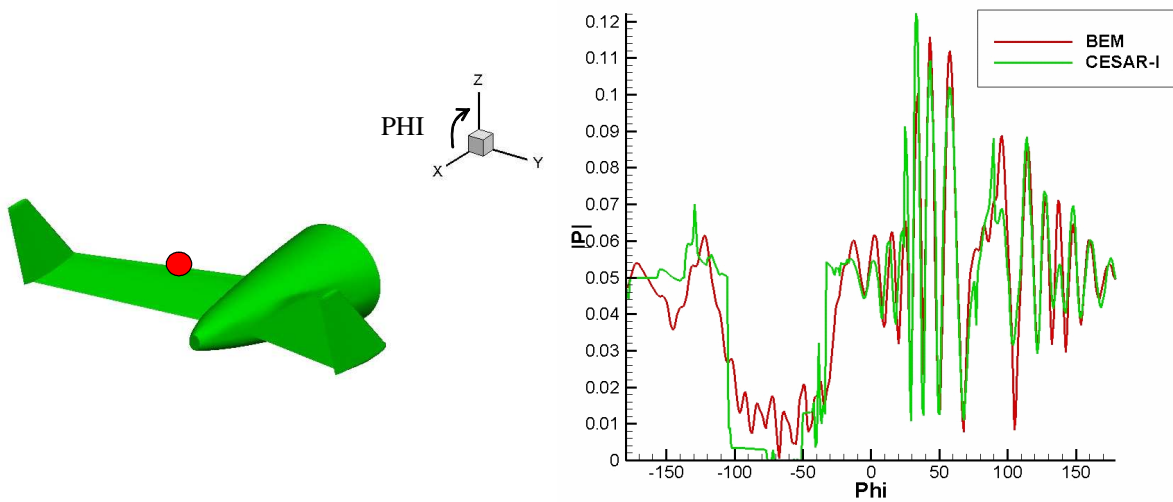Left: analytical solution, right: CESAR-I*

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Figure 6: Scattering by an empennage, f = 800 Hz. Comparison between CESAR-I and the BEM.
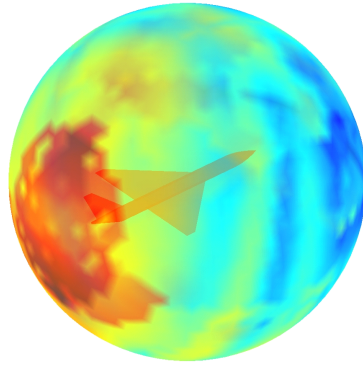
Figure 7: Sound pressure level surrounding an aircraft, including jet and fan noises and the installation effects.

4. SOUND PROPAGATION

Given an aircraft configuration, the CESAR-S and CESAR-I modules allow to compute the pressure field radiated during take-off and landing, on a sphere surrounding the aircraft, taking into account the flight conditions (engine trust, high-lift devices and landing gear position, etc.) at each discretisation step of its flight trajectory (see Fig. 7). The last step is to compute the sound propagation from the sphere to the ground. A number of methods are available to predict the sound propagation in a heterogeneous atmosphere, such as the gaussian beams, the parabolic equation, the Fast Field Program. Recent computations solving the Euler's equations are now performed to solve the sound propagation in the atmosphere at short distances. These method are accurate and allow us to take into account the diffraction effects, the topography, however, again they still require a large amount of computing resources. As an alternative, the standard Ray-method is implemented in IESTA. The ray-equations are integrated using a Range-Kutta method of 4th order. The sound propagation module, called SIMOUN, propagates the pressure field from the sphere to the airport surrounding, taking into account the wind profiles, the temperature gradients, the atmospheric absorption, as well as the Doppler effect generated by the moving aircraft. Based on a high frequency approximation, in practice this method can also handle the sound propagation at mid frequency, as remind in Section 3. Another advantage of the Ray-model is its capability to straightforwardly integrate the atmospheric absorption along the ray path, which, at long distances dominates the sound pressure level reduction, in addition to the spreading law. In the IESTA platform several stratified atmospheres are available. The ray-tracing is computed for an appropriate set of sources altitudes from few dozens meters up to 3000 meters and the results are load as a database. This post-processing speeds up the run time to predict the sound pressure level footprint during the whole aircraft trajectory. As an example, figure 8 plots the footprint of the maximum Sound Pressure Level generates by an aircraft during landing, in presence of wind in the North-Est direction.
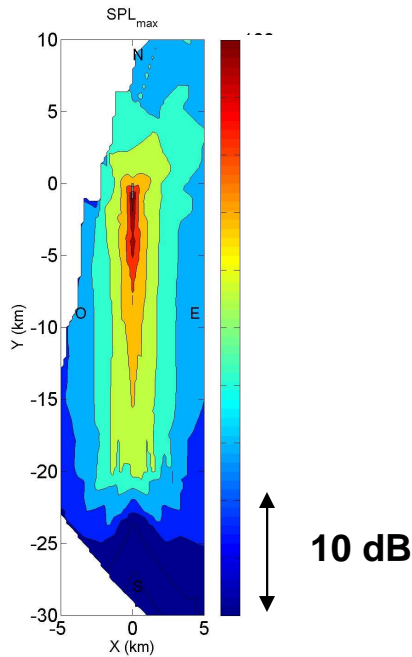
Figure 8: Footprint of the maximum sound pressure level surrounding an airport.

5. CONCLUSION

The first application of the IESTA is dedicated to environmental impact of the air traffic surrounding airports including noise and chemical emissions. The acoustical model of the IESTA platform has been presented in this paper. This model is splitted into 3 modules the source modelling, the shielding effects and the sound propagation:

- In the source modelling modules the main acoustical sources are implemented, validated and improved, when possible. For new concepts, such as open rotor or contra-rotative fans, when semi-empirical or analytical formulations are not available, the platform can integrate computed sources with CFD/CAA, as database. More generally, the platform offers to include specific source modelling if required.
- The shielding effects are computed thanks to the ray-theory, well-suited to the high frequency range. The module can take into account the incident, the reflected and the diffracted waves. The discretsiation of the aircraft using a set of Non-Uniform Rational B-Spline curves and surfaces provides a very accurate description and is implemented in the ray-module. Number of validations of the CESAR-I based on canonical geometries have been performed, as well as comparisons with BEM for empennage and fuselage. Additional comparisons with the BEM are in progress including the whole aircraft.
- Using the ray-method, the sound propagation in the atmosphere includes the wind gradients and temperature profiles, the spreading law and the atmospheric absorption, the Doppler effect. The capability of the ray-method to predict long range sound propagation for sound source at low altitude will be investigated in the near future.

These modules implemented in the IESTA platform aim at providing an efficient tool in the design and modelling of innovative air transport systems. This modular approach is versatile and under development.

REFERENCE

[1] Advisory Council for Aeronautics Research in Europe. Strategic Research Agenda 1, October 2002.

[2] M. Brunet M., P. Malbéqui, W. Ghedhaifi. A novel approach to air transport system environmental impact evaluation through physical modelling and simulation, 26th International Congress of the Aeronautical Sciences (ICAS'08), USA, September 2008.

[3] L. Bertsch, W. Dobrzynski and S. Guérin, Tool Level for low-noise aircraft level, AIAA Paper 2008-2995, May 2008, Vancouver, British Columbia Canada.

[4] Y. Rozenberg, J. Bulté, Fast Aircraft Noise Prediction Including Installation Effects for the Evaluation of Air Transport Systems, Inter-noise 2008, Shanghai, China, October 2008.

[5] J. R. Stone, D. E. Groesbeck and C. L. Zola, "Conventional Profile Coaxial Jet Noise Prediction," AIAA Journal, 21(3), 336-342 (1983).

[6] J. Hubert, M. Omais, A. Vuillemin, and R. Davy, Installation effects characterization of VHBR Engines, Part 4 : assessment of jet acoustics, AIAA Paper 2009-3371.

[7] M. F. Heidmann, "Interim prediction method for fan and compressor source noise," NASA TM-X-71763 (1979).

[8] R. G. Kouyoumjian, P. H. Pathak, A Uniform Geometrical Theory of Diffraction for an Edge in a Perfectly Conducting Surface, Proc. IEEE, vol. 62, no. 11, pp. 1448-1461, Nov. 1974.

[9] P. H. Pathak, W. D. Burnside, R. J. Marhefka, A Uniform GTD Analysis of the Diffraction of Electromagnetic Waves by a Smooth Convex Surface, IEEE Trans. Antennas Propagat., vol. AP-28, pp. 631-642, Sept. 1980.

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