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# THE ACOUSTIC CENTER OF ECOLE CENTRALE DE LYON

# FROM 1970 TO TODAY

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**ABSTRACT**

The research team in acoustics at Ecole centrale de Lyon was created 50 years ago by Prof. Geneviève Comte-Bellot. In this paper we describe the growth of this team, known now as the Acoustic center of Ecole centrale de Lyon (or Centre Acoustique in French), from the early 70s to today. The evolution of the research interests and of the experimental facilities is emphasized, and a selection of "historical" references is given at the end of the paper. The main current research topics are also listed, illustrated and completed by a partial list of recent references.

**Keywords:** *Aeroacoustics, jet noise, fan noise, sound propagation, nonlinear acoustics.*

## 1. HISTORICAL PERSPECTIVE

### 1.1 The early years (1970-1980)

The acoustic team of the Fluid Mechanics and Acoustics Laboratory (LMFA) of Ecole centrale de Lyon was created by Prof. Geneviève Comte-Bellot (born in 1929) at the very beginning of the 1970s. This creation resulted from the vision of Geneviève Comte-Bellot, a world-renowned expert in the study of turbulent flows, that the new discipline resulting from the intersection between fluid mechanics and acoustics, or *aeroacoustics*, was destined for a very strong development, both in its fundamental aspects and in its applications, particularly in the aeronautical industry.

On the practical side, the construction of a silent wind tunnel associated with an anechoic chamber [1] was rapidly finalized, a first in France in the university context. The installation was completed by two coupled reverberation chambers used to measure the absorption coefficient of acoustic materials and the transmission loss of panels placed in the large opening connecting the two rooms. Fig. 1 gives the plan of the experimental installation located in a basement to limit the transmission of parasitic noise. A first experimental paper [2] appeared very quickly, in which cross-correlations between surface pressure and acoustic far-field were used to characterize airfoil noise.

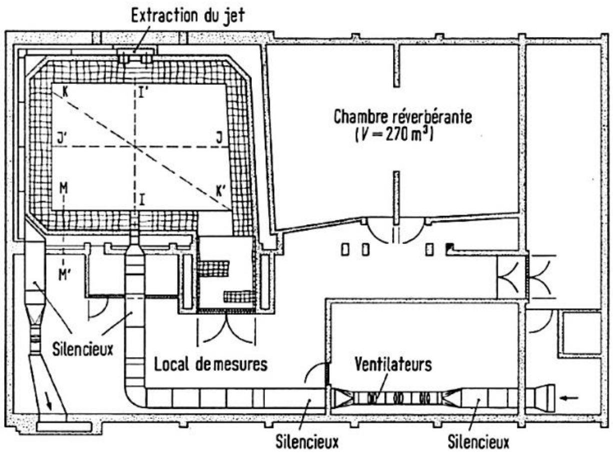


**Figure 1**. The experimental facility in the early 70s, see ref. [1].

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The initial research topics focused on the noise of fans and of their basic components, airfoil or blade profiles. The operational team then consisted of only two members, Prof. Michel Sunyach and a young Assistant Prof., Henri Arbey. In 1974, the installation was completed with the construction of a wind tunnel intended for the study of the noise generated by subsonic jets (D. Juvé, [3]).
The research themes quickly widened to the diffusion of sound by turbulence (D. Juvé-M. Sunyach, 1976), then to the propagation of high frequency sound waves through an extended zone of kinematic or thermal turbulence (Ph. Blanc-Benon-D. Juvé, 1978 [4]).
The initial research activities centred on airfoil noise were supplemented by the study of aircraft compressor noise (M. Roger-H. Arbey, 1980, [5]).

### 1.2 Creation of the Acoustic Center (1980s)

Very rapidly, the characteristics of the initial installation proved to be too limited for foreseen applications, the Mach number being restricted to 0.4 for small diameter jets (typical diameter of 2cm) and to 0.2 for the noise of airfoil profiles placed in the potential core of a rectangular jet (section of 30cmx10cm).

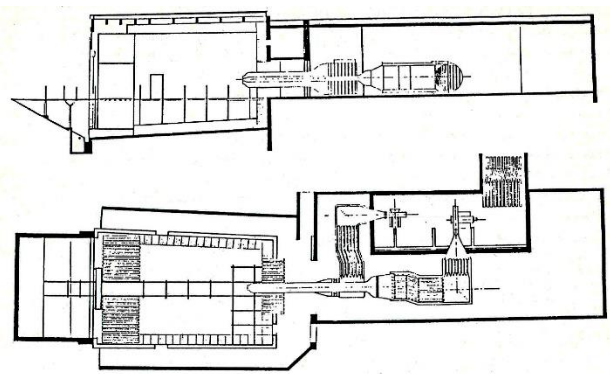

**Figure 2**. The experimental facility of the Acoustic center in the 80s, [6].

From the end of the 1970s, G. Comte-Bellot sought the necessary funding to create a world-class facility, complete with the measurement rooms and offices needed to increase the size of the team. The construction of a new building began in 1980 and the official inauguration of the Acoustic Center of Ecole centrale de Lyon was carried out in 1985 on the occasion of the holding of the IUTAM symposium "Aero and Hydro-Acoustics", organized by G. Comte-Bellot and J.E. Ffowcs-Williams.

A large anechoic chamber (10m x 8m x 8m) was coupled to a wind tunnel allowing a Mach number of 0.5 to be reached in a section of 0.4m x 0.2m. A second fan fed a half-velocity flow into jets adjacent to the main stream and intended to enhance the emergence of the noise from airfoils placed in the potential core of the primary jet (Fig. 2). The detailed characteristics of the installation are described in reference [6]. A compressor to power a supersonic jet stream was part of the original plan but could not be installed due to insufficient funding.
To the noise studies of fans, airfoils and obstacles of more complex shapes, was added that of the excitation of structures by flows: measurement of wall pressure fluctuations under turbulent boundary layers and of the resulting vibrations of flexible plates and, somewhat latter, of pipes (G. Robert, [7], [8]).
In parallel, under the impetus of M. Sunyach, the possibility of active strategies was developing to reduce noise in ducts or control combustion instabilities, (M-A. Galland, [9], [10], [11]).

### 1.3 The development of numerical simulation (1985-2005)

Researches in the Acoustic Center were initially focused on experimentation and theoretical modelling. They have gradually been extended to numerical simulation. The first works were directed toward the propagation of acoustic waves in random media, using first ray techniques and then parabolic approximations: interaction of acoustic waves with kinematic turbulence [12], sound propagation in the atmosphere [13] and nonlinear effects [14].

With the arrival of C. Bailly (1995), soon joined by C. Bogey, the team quickly turned to the simulation of acoustic propagation in high velocity flows [15]. Then the direct simulation of the generation of noise by turbulent flows was developed, based on the resolution of the compressible Navier-Stokes equations using high-precision discretization schemes in time and space developed by the team. The flows studied were high Mach number subsonic jets [16] (Fig. 3), but also cavity flows [17]. Supersonic jets, airfoils and turbulent boundary layers were then considered by the team.

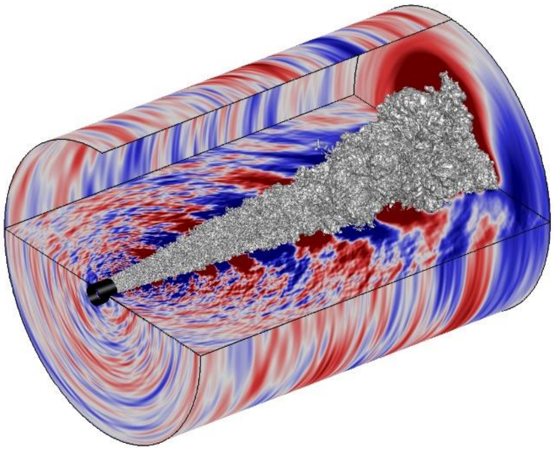

**Figure 3**. Direct numerical simulation of the vorticity and sound pressure of a jet at high Reynolds and Mach numbers.

## 2. CURRENT FACILITIES

If the structure of the buildings has remained substantially the same over the years, the experimental facilities have been constantly improved to allow the extension of research possibilities.

In 1994, the installation of a centrifugal compressor allowed the study of supersonic jets up to a Mach number of 1.5, with applications in the aeronautics and space sectors.

Very recently, the replacement of the coating of the walls of the anechoic chamber and the installation of a two-stage high-pressure blower allowed the study of the noise of airfoils and of wall-pressure fluctuations under turbulent boundary layers in the high subsonic regime (Mach number up to 0.7), where compressibility effects become very important. The joint use of the blower and of the centrifugal compressor also enables the study of the noise generated by coaxial jets, with a subsonic or a supersonic primary stream.

A schematic 3D view of the new facility in given in Fig. 4. The interior of the anechoic chamber is also shown in Fig. 5, in which the exhausts sections of both the subsonic and supersonic wind tunnels can be seen.


**Figure 4**. 3D schematic view of the main experimental facility of the Acoustic Center (blower and compressor, wind tunnels and anechoic chamber).

Other additional facilities have also recently been built. For fundamental studies, a low Mach ducted fan test rig was instrumented with both external and internal large microphone arrays (LP3 test bench, displayed on Fig. 6).

**Figure 5**. Internal view of the anechoic chamber and of the exhausts of the subsonic and supersonic wind tunnels.

Another test bench is also used to study the performance of passive and active materials in ducts with flow (Mach<0.3) under multimodal excitation.

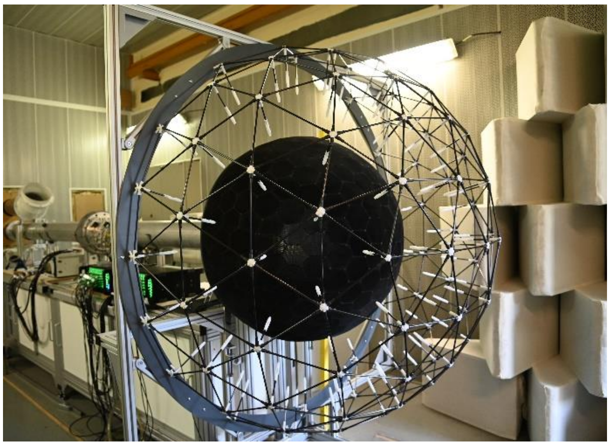

**Figure 6**. Partial view of the LP3 test bench, with emphasis on the 89 microphone external array. (The black half sphere is a (porous) Turbulent Control Screen used to reduce incident fluctuations in the sucked flow).

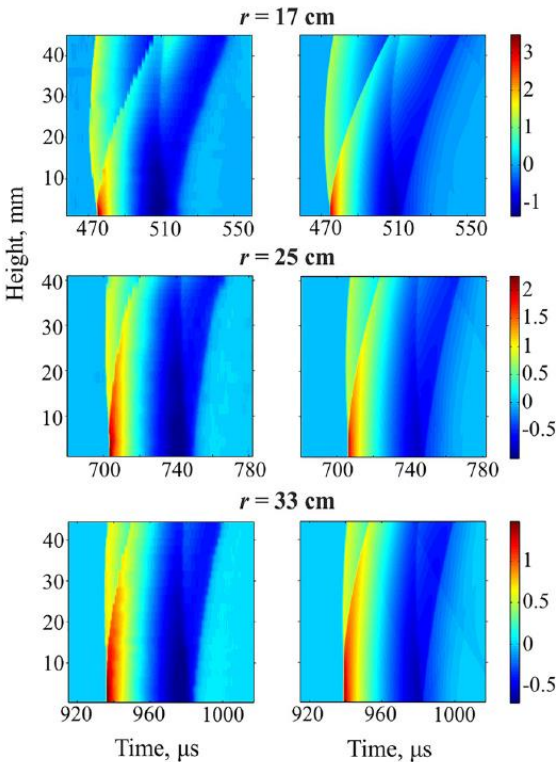


**Figure 7**. Reflection patterns of spark-generated shock pulses measured by a Mach-Zehnder interferometer (left) and numerically simulated (right), [24].

A facility for studying non-linear sound propagation was developed in which innovative optical measurement techniques (Schlieren and Mach-Zehnder interferometry) are used to characterize weak shock waves created by electric arcs. This facility is used in particular to simulate the propagation of sonic booms in the atmosphere and their interaction with buildings and a realistic ground topography.
A comparison between measurements and numerical simulations using non-linear Euler equations is given in Fig. 7.

On the more applied side, the team is strongly involved in studies carried out on the Phare-B2 test bed. This installation, engineered in partnership with Safran Aircraft Engines, reproduces the operation of an aeronautical fan on a 1/3 scale, and develops a power of 2MW (Fig. 8). Thanks to an anechoic environment, the external radiated noise can be measured and correlated with internal in-duct sensors. The innovative array techniques developed on the LP3 rig can then be transposed to this quasi-industrial installation.

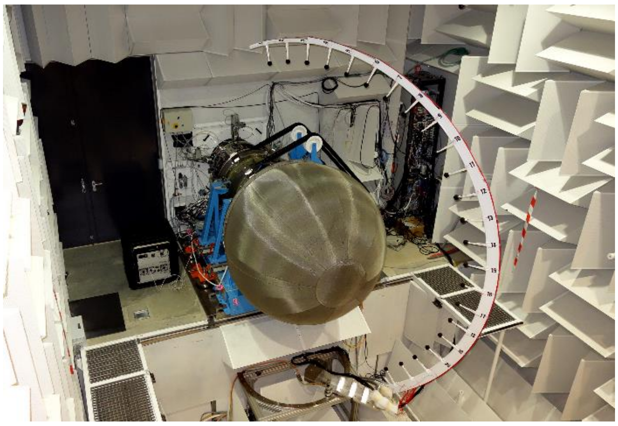

**Figure 8**. Phare-B2 facility. Partial view of the anechoic chamber and of the external microphone array (the inlet of the compressor is hidden by the TCS).

## 3. COLLABORATIONS AND RESEARCH PHILOSOPHY

Since its creation and until today, the philosophy of the Acoustic Center has been to achieve a harmonious balance between basic research and applications. The link with the industrial environment has always been very close, especially with that of transport, whether automotive (Renault, Stellantis), rail (Alstom, SNCF) and of course aeronautics (Dassault, Airbus, Safran) and space (CNES, ArianeGroup). These links facilitate access to sources of financing necessary for the development of experimental facilities, in addition to national or regional public funds. They also constitute a source of difficult and interesting problems to deal with, after the search for an adequate schematization allowing the highlighting of the physics of the main phenomena involved. The very close relationship with Safran notably enabled the construction of the Phare platform (rotating machinery platform for environmental risk control) as well as the improvement of the performance of our large anechoic wind tunnel via the creation of two industrial chairs co-funded with the French National Research Agency (ANR).

On the university level, many international collaborations have been built over the years, with for example Cambridge, Johns Hopkins, Penn State, Austin or Moscow State, as well as with many European teams through participation in European programs from the very beginning of the 90s.
These close collaborations made possible the organization of important international conferences, such as Euromech 142 “Acoustics of turbulent flows” in 1982, the IUTAM “Aero- and Hydro-Acoustics” symposium in 1985, several Long Range Sound Propagation symposia (LRSP 1996, 2008, 2018), an International Symposium on Nonlinear Acoustics (ISNA 2015) and the Aeroacoustics 2016 conference of the Council of European Aeronautical Societies and the American Institute of Aeronautics and Astronautics.

Regional and national collaborations have always been in the spotlight with the aim of federating strengths and skills. In the 1980s, G. Comte-Bellot was at the origin of a CNRS research group associating research teams in Lyon (LMFA and ICPI-now CPE), Grenoble (Cephag-now Gipsa-Lab) and Marseille (LMA).
In Lyon, this desire for cooperation led to the creation in 1980 of the DEA (i.e. Master degree) in acoustics associating ECLyon with INSA and the University of Lyon I. In 2018 this was transformed into an International 2-year Master of Science in Acoustics from the University of Lyon, taught in English.
This Master of Science relies strongly on the teams of the CeLyA (Centre Lyonnais d'Acoustique) Laboratory of Excellence. Created in 2011, this LabEx is the only one in France focused exclusively on acoustics. Headed first by Daniel Juvé, then since 2018 by Etienne Parizet, it brings together all the main research teams from Lyon and Saint-Etienne. It covers many areas ranging from physical acoustics (vibroacoustics, aeroacoustics, ultrasound), to medical applications, sound perception, neurosciences and bioacoustics. CeLyA's teams and work are described on the website https://celya.universite-lyon.fr/.

## 4. THE ACOUSTIC CENTER TODAY AND TOMORROW

Composed of only 2 researchers in 1973, the Acoustic center is currently made up of 21 permanent staff and around 25 doctoral and post-doctoral students. A group photo of team members in given on Fig. 9.
168 PhD theses have been defended to date, and more than 400 articles have appeared in the best international journals.

**Figure 9**. Team members at the occasion of a group seminar in July 2021.

The complete list is available on the website https://acoustique.ec-lyon.fr/, where the majority of the texts of the articles and presentations at conferences can be found.

We give below the list of the main research topics currently treated together with references to related papers and a selection of illustrations of experiments or numerical simulations:

- **Aeroacoustics of free flows** [18], [19], Fig. 10.

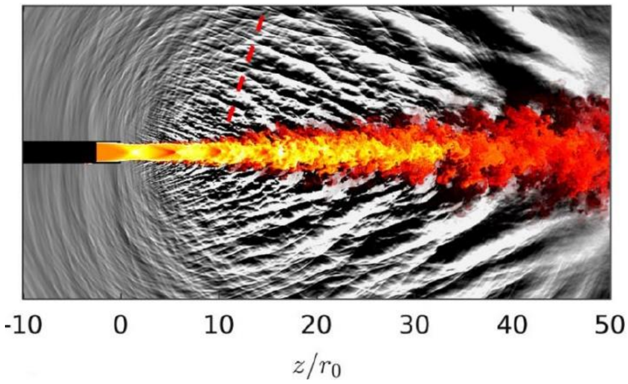


**Figure 10**. High Mach number supersonic jet: Snapshot of temperature fluctuations inside the flow and of pressure fluctuations outside, [19]. (The red dotted line indicates the direction of propagation of Mach waves).

- **Aeroacoustics of airfoils and turbomachinery** [20], [21], Fig. 11.

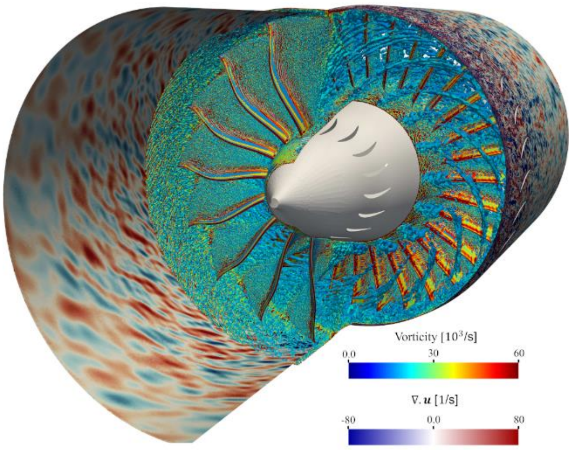


**Figure 11**. Ultrahigh bypass ratio fan. Instantaneous contours of the dilatation rate at 99% of the rotor span and iso-surface of the Q-criterion colored by the vorticity magnitude, [21].

- **Wall-pressure fields and excitation of structures by turbulent flows** [22], [23].

- **Linear and non-linear acoustic propagation** [24], [25], Fig. 12.

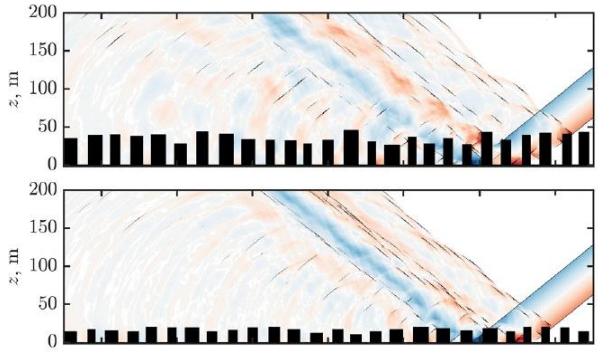


**Figure 12**. Numerical simulation of sonic boom propagation over urban areas, [25].

- **Bubble dynamics and medical applications** [26], [27], Fig. 13.

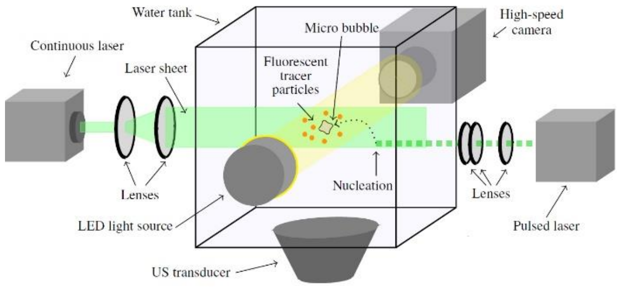


**Figure 13**. Microstreaming induced by oscillating microbubbles: Schematic of the experimental set-up, [26].

- **Active and passive acoustic materials under grazing flow** [28], [29], Fig. 14.

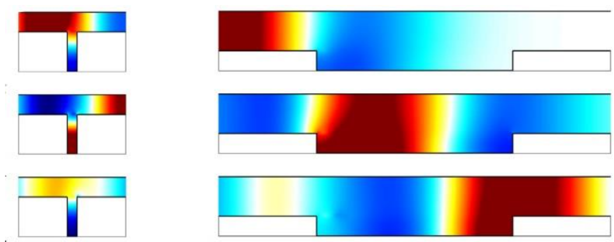

**Figure 14**. Time-domain simulation of sound propagation in a flow duct with extended-reacting liners: successive snapshots of the pressure field, [28].

- **Innovative optical measurements: Schlieren imaging, interferometry, Rayleigh scattering** [30], [31]

- **Innovative microphone arrays techniques, inverse problems, 3D sound field reconstruction** [32], [33], [34], Fig. 15.

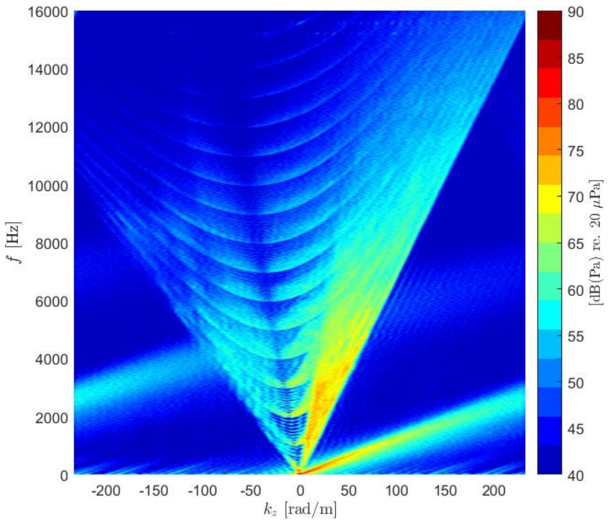


**Figure 15**. Wavenumber-frequency analysis of in-duct fan broadband noise using a Bayesian approach, [34].

## 5. ACKNOWLEDGMENTS

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