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AEROACOUSTIC RESEARCH IN EUROPE: THE CEAS-ASC REPORT ON 1998 HIGHLIGHTS

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This paper is a report on the highlights of aeroacoustics research and development in Europe in 1998, compiled from information provided to the CEAS Aeroacoustics Specialists Committee (ASC). The Confederation of European Aerospace Societies (CEAS) comprises the national Aerospace Societies of France (AAAF), Germany (DGLR), Italy (AIDAA), The Netherlands (NVvL), Spain (AIAE), Sweden (FTF), Switzerland (SVFW) and the United Kingdom (RAeS).

1. INTRODUCTION

The role of the CEAS-ASC is to serve and support the scientific and industrial aeroacoustics community in Europe. Here "Aeroacoustics" includes all the aerospace acoustics and related areas. Each year the Committee will highlight some of the research and development activities in Europe. This is the report of the 1998 highlights.

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2. AIRCRAFT INTERIOR NOISE

2.1. GENERIC ACTIVE VIBRATION CONTROL SYSTEM OF SURFACES (GASS)

This 3-year Brite-Euram basic research project is jointly developed by Greece (UNPA, AFC Advance), Germany (THD), Italy (CIRA), Finland (VTT) and France

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(CTTM, ACTIVIB). The main objective is to develop a self-contained, "black-box"-type Active Vibration Control System (AVCS) for the vibration control of flexible surfaces. This will be obtained through the use of a smart surface consisting of a number of actuator/sensor layers (piezoceramic, polyvinylene fluoride or electromechanically treated films) coupled to a power supply and a controller containing all the software required to make the AVCS a "black-box"-type product. The operational mode of the smart AVCS will be as follows: The smart surface will be fitted to the shape of the vibrating surface, attached/glued to it and connected to the power supply and controller; the vibration of the composite sheet (consisting of the smart surface and the vibrating surface) will be detected by the distributed sensors; appropriate software in the controller will allow the dominant vibration frequencies to be determined; an appropriate Artificial Neural Network (ANN) algorithm will be activated in the controller to reduce the vibration level.

The AVCS system is expected to be independent of the shape of the vibrating surface, so that no specific measurements or modelling of the structure and of the smart surface will be required: i.e., the proposed smart surface AVCS will really be a generic one. Numerical simulations were performed on a simple system consisting of a plate (instrumented with piezoceramics actuators and sensors) coupled to a cavity with highly absorbent walls, and excited at low frequency. Several tests have been conducted using a coupled FEM acoustic/structural analysis, for different materials and dimensions of the plate/box system. As a result, a selection of the appropriate actuators has been made, taking into account both the physical limits of the ceramic materials and the voltage limitation related to the available electronic instrumentation. New electronic devices for driving the piezoelectric ceramic sensors and the actuators have been designed; full integrated systems will be realized in the near future. (S. Ianiello)

2.2. IDENTIFICATION OF AN AIRCRAFT PASSENGER COMFORT INDEX (IDEA PACI)

The aim of the 3-year Brite-Euram project IDEA PACI is twofold:

- to identify a novel Passenger Comfort Index, that is able to take into account both the noise and vibrations, on the basis of the experimental tests conducted on the mock-ups and on a real aircraft in flight;
- to develop an Artificial Neural Network able to reproduce the response of a virtual "mean passenger", by training on the data acquired in these tests.

The aim of this study is to relate the physical and the modelled environment to the human response, so that psycho-acoustic studies, numerical simulations, experimental results and ANN definition are strongly interdependent. The following issues will be considered:

- the development of a "design to comfort" tool, to provide the information required to enable improvement of the aircraft characteristics will respect to the customers' needs and expectations;

- the definition of a global index for both vibration and acoustics to classify aircrafts in terms of comfort as well as of other performance characteristics;
- the improvement of the specifications for active or passive noise suppression systems through effective identification of the final target.

Thus far, a summary of definitions and measurement procedures of known psycho-acoustical parameters and a preliminary version of a questionnaire to be used in the experimental activities have been prepared. The questionnaire is aimed at identifying the transfer function between the physical environment and the customer. Experimental tests were carried out on the various mock-ups (at Agusta (A109), Alenia (ATR42), Dornier (Do328 ATC) and ITAP (SVRS)) and, for a limited set of in-flight recordings, on a real A109 helicopter. Many flight conditions were simulated and the relative internal noise and vibration fields were recorded, to construct a data base that allows the selection of the most important synthetic parameters for the description of the internal environment (to be used as input to the ANN), and to train properly and validate the ANN.

A preliminary definition on the design of the ANN, based on the first experimental results was also performed. In particular, different lay-outs of ANN architecture were considered for the development of the "virtual passenger", which is meant also as a "design to comfort" tool. (S. Ianiello)

2.3. ACTIVE NOISE REDUCTION INSIDE AIRCRAFT

In the framework of the BRITE-EURAM ASANCA II project, the Laboratoire de Mécanique et d'Acoustique (LMA) worked on the problem of active noise reduction inside aircraft. An active noise-control system using a classical x-LMS algorithm has its best performance at the location of the control microphones. However, in many applications it is not possible to put the control microphones where an important reduction of noise is required (the passenger head position for example).

For this reason a new algorithm called "Remote Microphone Technique" (RMT) has been studied and tested during flight tests on a Dornier 328. In the first step of this technique, transfer function matrices are measured between the secondary sources (loudspeakers) and "control microphones" or "virtual microphones" (see Figure 1). This identification step is necessary for the real-time controller to calculate the optimal command voltage to be sent to the loudspeakers to minimize the noise. Afterwards "virtual microphones" can be removed and the controller is ready to work. An example of results is given in Figure 2. In this configuration four seat rows of the Dornier 328 were considered. On the first three rows, nine virtual microphones were located at the passengers' head position, and nine control microphones and nine loudspeakers were mounted on the trim-panels or on the headracks. A first reference test had been done with the x-LMS algorithm using virtual microphones as error sensors. With the RMT algorithm, only microphones located on the trim-panel or headracks were used and results were measured on the virtual microphones. Figure 2 shows the noise level at the first harmonic (105 Hz) of

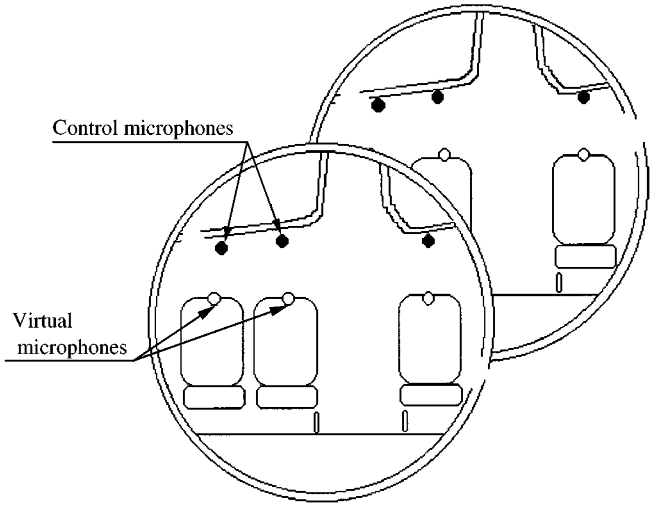


Figure 1. Transducers location for active noise control inside the aircraft.

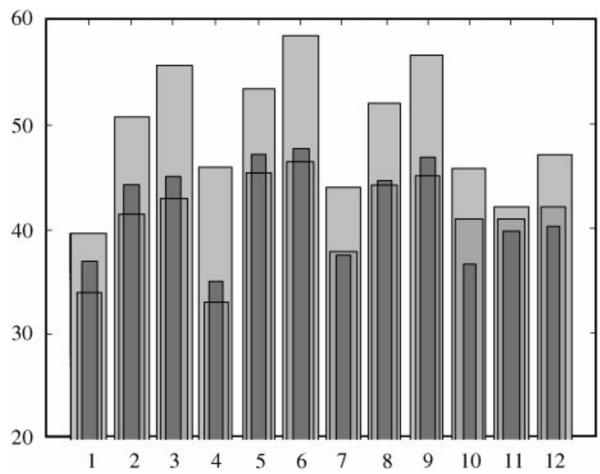


Figure 2. Comparison between x-LMS (in dark grey) and RMT (in black) algorithm for active noise reduction; the level measured without control is plotted in light grey.

the fan noise measured at the 12 passenger head positions. It appears that the RMT algorithm provides a noise reduction comparable to that of the x-LMS algorithm. (A. Albarrazin and A. Roure)

2.4. PREDICTIVE STATISTICAL ENERGY ANALYSIS

A collaborative programme of work in the field of Statistical Energy Analysis (SEA) was started in 1996 by DERA and ONERA. A box structure (see Figure 3) consisting of 26 flat isotropic aluminium plates of differing thicknesses and with five internal volumes was specifically designed, built and tested with the aim of

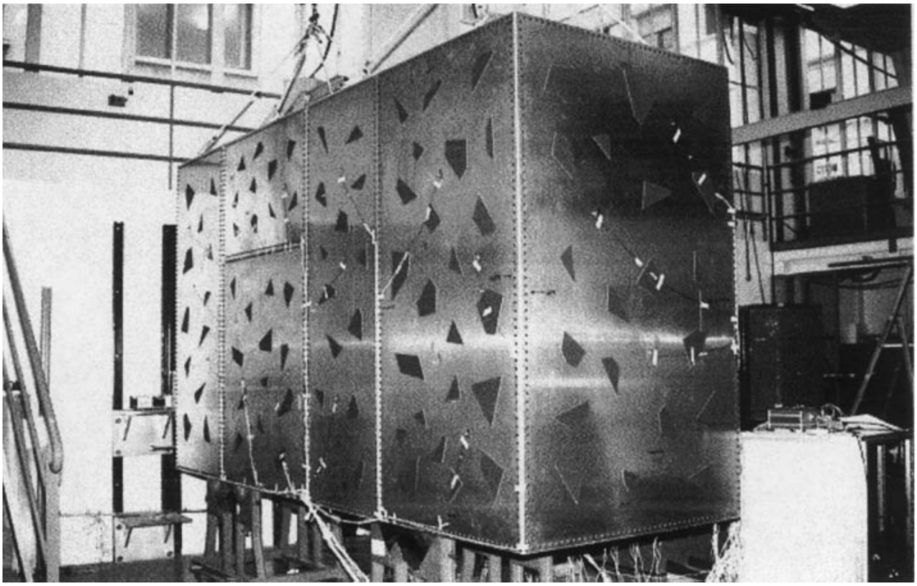


Figure 3. Box structure consisting of 26 aluminium plates and five internal volumes and designed to validate SEA theory.

validating SEA theory. The results of the experiments conducted by both the DERA and ONERA, using different measurement techniques, are generally in agreement. These experimental results were compared with DERA predictions, based on the wave approach, and ONERA predictions, based on a semi-empirical modal approach. There are differences between the two theories and the former is concluded to be the better approach for this type of structure [1]. Good agreement was obtained between the experimental results and the SEA wave approach theory [2]. (K. Heron)

3. FAN AND JET NOISE

3.1. EUROPEAN-FUNDED COLLABORATIVE PROGRAMMES ON AIRCRAFT NOISE REDUCTION

The principal aircraft and engine manufacturers in Europe are facing increasing pressure to reduce the aircraft noise levels. This arises both from the community expectations of the improved quality of life, and from the need to compensate for the expected growth in air traffic. A recent EC DGXII policy statement on aircraft noise declares: "a co-ordinated strategic approach at European level is essential and major efforts need to be developed to techniques for further reduction of exterior aircraft noise to overcome today's technology barrier. Hence the objective for R&TD is to enable a breakthrough in the noise-control technology".

Following on from the collaborative EC-funded FANPAC programme on fan noise (1992–1996), four new EC-funded collaborative research projects on aircraft noise reduction were started on 1 January 1998. One of the three Type I projects, called Reduction of Engine Source Noise through Understanding and Novel Design (RESOUND), concentrates on engine noise reduction at source, and in particular on turbomachinery noise reduction as summarized below.

The objective of RESOUND is to acquire the technology necessary to support the design of derivative and new aero-engines with noise levels that are 4 dB quieter than those of the aircraft currently entering service. This will provide the foundation for the achievement of a mid-term (8 years) objective of reducing aircraft noise levels by at least 6 dB, and allow the European industry to complete on an equal footing with the U.S.

RESOUND addresses the challenge of reducing the noise at source, in particular turbo-machinery noise, through engine component aeroacoustic design and through novel noise-controlling devices that can be integrated within the engine structure. Innovative technologies to be evaluated, with the aid of theoretical techniques and experiments at model and full scale, include: fan noise reduction through reduced tip speed and pressure ratio optimization; noise reduction with fan and stator axial sweep and circumferential lean; fan-noise reduction with variable by-pass nozzle and passive fan-tip treatments; combustion noise reduction through improved and validated generation model; assessment of potential noise hazards of low NO_x combustors; LP turbine noise reduction through exit guide vane design; turbomachinery noise reduction through active stator design; and turbomachinery noise reduction by means of auxiliary aeroacoustic control devices.

Encouraging progress has been made towards developing and evaluating these technologies during the first 12 months. The main achievements to date are as follows:

- the application of computational fluid dynamic codes to the design of lower noise turbo-machinery components in particular fan rotors and LPT exit guide vanes;
- some significant improvements in our engineering models of fan buzz-saw noise and in our understanding of fan rotor–stator interaction tone noise and the benefits of swept/leant fan outlet guide vanes;
- an initial evaluation of the most promising active control devices supported by theoretical and experimental feasibility studies;
- substantial progress towards the definition, design and manufacture of experimental hardware for verification, testing of the down-selected low-noise technologies and the resolution of test facility, rig and instrumentation problems.

Based on the technology acquired, RESOUND will deliver a full assessment of the community noise benefits of controlling engine noise at source, through design and with novel active/passive devices.

The reduction of aircraft noise through improved nacelle technology and airframe design is being addressed by complementary projects (RANNTAC and RAIN respectively), supported by a Type 2 project (DUCAT) all of which are being co-ordinated through the X-NOISE thematic network that has been formed as a result of the Environmentally Friendly Aircraft study (TEFA). Such a combined effort is necessary to meet the challenge of the U.S. industry, which is backed by a fully funded programme ($ 200M over 7 years). (B. Tester)

3.2. ONERA STUDIES ON ACOUSTICS OF GAS TURBINE ENGINES

Several new studies of fan and jet noise were launched by ONERA in 1998. In the field of computational aeroacoustics (CAA), previous work on the Kirchhoff method applied to helicopter rotors was extended to ducted fans. A transonic ducted rotor was considered in a first step because rotor alone tones dominate. Good predictions of radiated acoustic power were achieved for both the axial and centrifugal compressors of turboshaft engines, using the inputs computed by Navier–Stokes CFD codes developed either by Turbomeca or ONERA. Rotor–stator interaction tones will be considered in a second step. This is more intricate, as it implies unsteady aerodynamic computations in the rotor frame.

The study of the transmission through the rotor of the upstream-propagating acoustic waves generated on the outlet guide vanes also started in 1998. The method is based on the rotor wake–stator interactions computed by SNECMA, and on a 2-D model established by Hanson. This model will be extended to axisymmetric geometries in order to include the radial-mode splitting.

ONERA's partnership in the European project RESOUND (1998–2000) covers two areas. Firstly, the study of fan broadband noise (previously begun under contract with Snecma) is continuing in this framework. Further analyses of the upstream measurements made during the past FANPAC tests in the Rolls-Royce facility enabled us to isolate the broadband component in the acoustic spectra. Some regressions have already led to the useful semi-empirical laws as a function of the relative helical tip Mach number, and of the flow angle of attack on the rotor blades.

The second issue is related to the active noise control using flow management. A basic laboratory experiment is being prepared in the CERF facility of ONERA. The principle is as follows. An interaction acoustic mode between the rotor and the outlet guide vanes (OGV) is selected at the blade-passing frequency. A rotating ring of radial rods is fitted upstream of the rotor. The number of rods, their axial location and their diameter have been calculated such that the interaction between the rod wakes and the rotor generates the same spinning mode as the rotor–OGV interaction, with roughly the same amplitude. The two modes cancel each other if they are out of phase, which can be achieved for a given azimuthal angle of the upstream ring. (S. Lewy)

3.3. MIXER-EJECTOR NOZZLE TESTS IN CEPRA 19 WIND TUNNEL

A test campaign has been carried out in CEPRA 19 anechoic wind tunnel by ONERA for SNECMA and IHI to characterize the aeroacoustic performances of a mixer–ejector nozzle model [3, 4]. The objectives were to characterize the radiated noise and the thrust losses associated with various upstream flow distributions and internal acoustic absorber configurations. Acoustic and thrust measurements were performed simultaneously. Far-field noise measurements were made for static and flight conditions up to a Mach number of 0·4. Third-octave band directivities were obtained from 40° to 150° (relative to the downstream

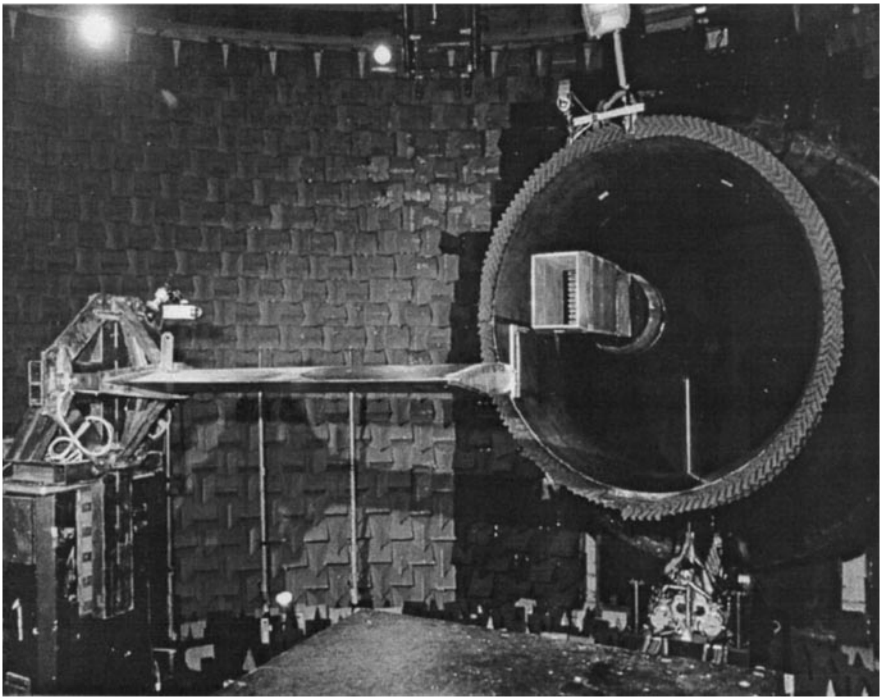


Figure 4. Aerothermic measurements in the exit plane of a mixer–injector nozzle model (CEPRA 19 wind tunnel).

direction), for frequencies ranging from 200 Hz to 80 kHz. The aerothermic field at the nozzle exit plane was also investigated for various configurations using a five-hole probe and a total temperature probe (see Figure 4). These results will be used to relate the jet-noise reduction to thrust losses, and to predict the EPNL at full scale. (D. Gély)

3.4. MARTEL FACILITY: AEROACOUSTIC REPRESENTATIVITY OF SPATIAL LAUNCHERS AT LIFT-OFF CONFIRMED

The MARTEL facility, built in CEAT Poitiers by CNES, is dedicated to the aeroacoustic studies related to the lift-off of the Ariane 5 launcher [5]. The main studies concern the reduction of noise by water injection [6], and the impingement of boosters jets on the launch pad table, represented by a simple configuration (hole in a circular plate) or by a realistic 2·1% mock-up (see Figure 5). A new water-injection device has been studied using this mock-up, and then set up on the real launch pad (ELA3) in the Kourou spatial center for the third Ariane 5 flight ("Ariane 503"/V112). A significant noise reduction has been achieved, confirming the aeroacoustic representativity of the MARTEL facility. Activities in progress concern the measurement of the aerodynamic properties of high-speed hot

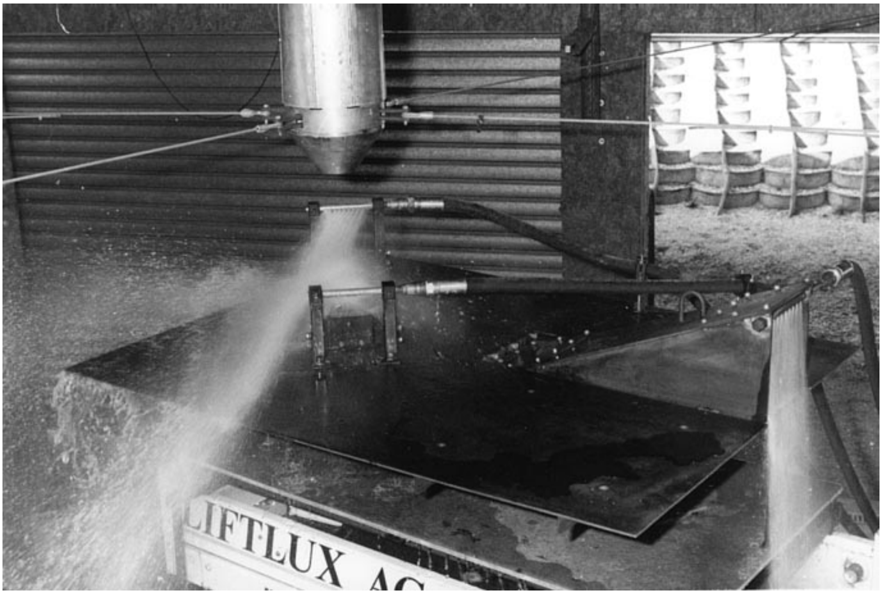


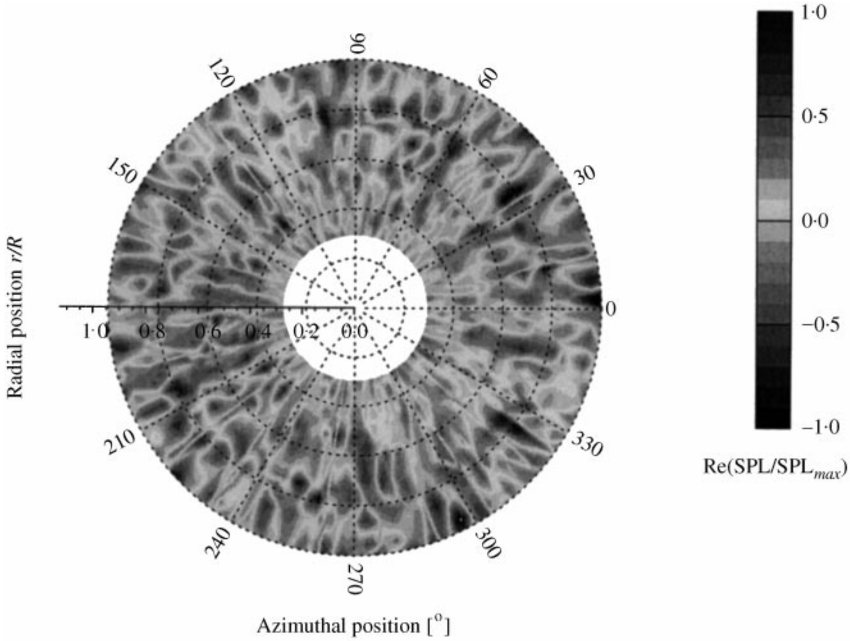
Figure 5. Mock-up of the launch pad table of Ariane 5, used to optimize water injection to reduce noise at lift-off (MARTEL facility).

jets; intrusive and non-intrusive metrology will be used (5-hole probe, LDV, CLS, etc.), in a very complex environment which is due to the extreme characteristics of the jets (stagnation pressure and temperature up to 30 bar and 2100 K, velocity up to 1800 m/s). (H. Foulon)

3.5. SOUND FIELD OF AXIAL COMPRESSORS

The sound field in the inlet duct of a transonic three-stage axial compressor was studied by the DLR-Berlin (Institute of Propulsion Technology, Turbulence Research Division) and by MTU-Münich. Fourteen 1/4″ pressure microphones mounted on a radial microphone rake were traversed azimuthally in steps of $1{\cdot}5^\circ$ to give a total of 14×240 measurement points. The measurement plane was about 3 rotor-1-diameters upstream of the first compressor stage. Two compressor inlet configurations with different sets of inlet guide vanes were tested for two operating conditions [7, 8]. An impression of the complex nature of the sound field in the duct is obtained from Figure 6. Plotted are the real part (top) and the magnitude (bottom) of the sound pressure at the blade-passage frequency of the first rotor stage.

The decomposition of the radiated sound field into azimuthal and radial modes permits direct conclusions on the dominant interaction mechanisms between the intake flow, the stators, and the rotors. (W. Neise, L. Enghardt, K. Heinig and F. Kennepohl)



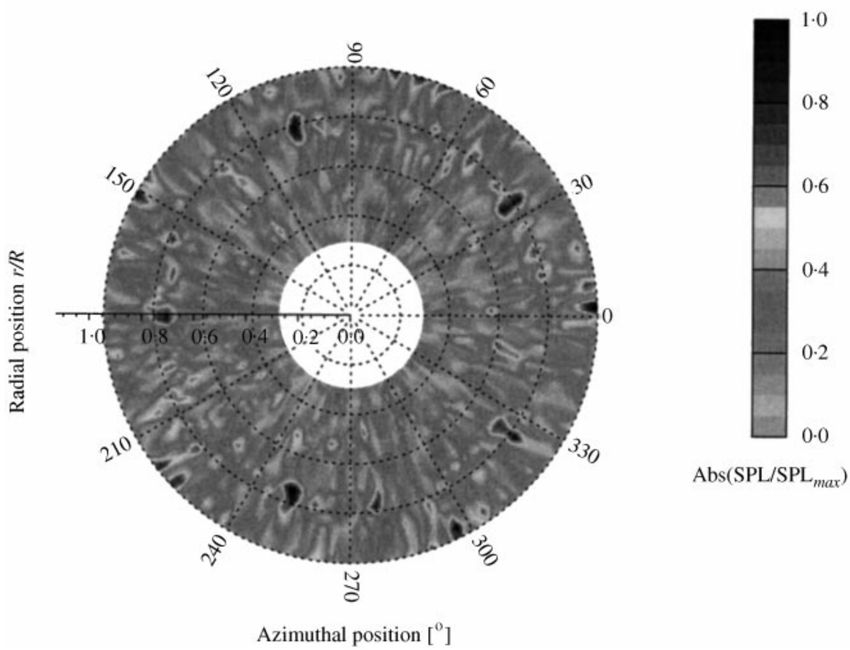


Figure 6. Measured sound field in the inlet duct of a transonic three-stage axial compressor. Real part (top) and magnitude of the sound pressure at the blade passage frequency of the first rotor stage.

3.6. BASIC RESEARCH ON DUCT ACOUSTICS AND RADIATION (DUCAT)

Since fan noise will be a major contributor to the exterior noise of Very High By-pass Ratio (VHBR) and Ultra High By-pass Ratio (UHBR) turbofans, the aerospace industry plans to introduce new nacelle noise-reduction technologies. Optimization of these reduction means requires a thorough understanding and an accurate description of the sound propagation in ducts.

In January 1998, a Brite-Euram project with acronym DUCAT (Basic Research on DUCT Acoustics and Radiation, 11 partners participating from industry, research establishments and universities) has been initiated. In this project, various models for duct acoustics propagation, including radiation, are developed, validated and assessed for industrial aerospace application. For duct acoustics models to be of interest to industry, they have to be reliable, accurate, fast and versatile. Furthermore, the models should ideally be able to handle realistic nacelle geometries, non-uniform flow and liner, realistic frequencies and SPLs, and radiation into the far-field. These aspects are not expected to be addressed by one single model in the near future. Therefore, in 1998 the development of a small number of numerical models (Finite Element (FEM), Boundary Element (BEM), coupled FEM/BEM, a non-linear propagation model and a ray-acoustics model) in

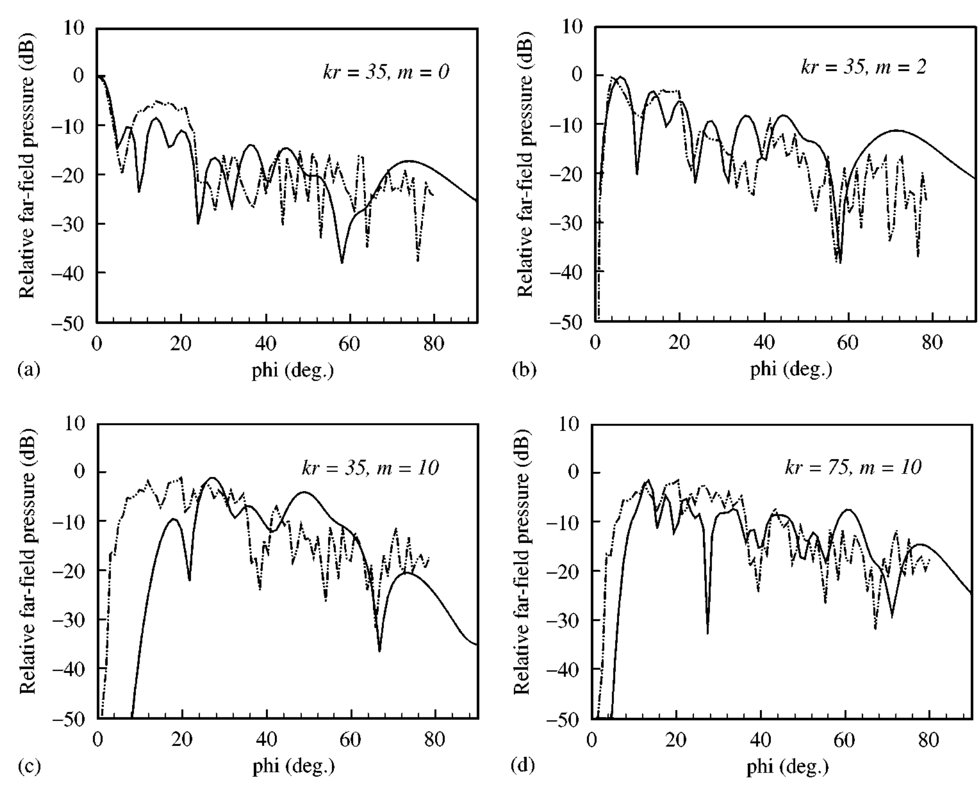


Figure 7. Sound propagation in a duct: comparison between the analytical solution (in dark) and a ray model (in grey) for various reduced frequencies.

DUCAT has been started, which cover the whole frequency range of interest for fan noise ($kR_{max} = 100$). The models focus on such items as 3-D geometry, non-uniform (potential or shear) flow, high frequencies and non-linear propagation. These models are partially complementary and partially overlapping, which offers the possibility of finding the best model for each aspect of duct acoustics. In 1998 model developers have generated various predictions, which were compared with analytical solutions. Preliminary results show a good agreement (see Figure 7 for the ray-acoustics model). Furthermore, preparations for two experiments have been started. At UTC (Université Technologique de Compiègne), the existing Spinning Mode Synthesizer has been modified to automatically carry out and control lined-duct acoustics experiments. At NLR, a test set-up with a model turbofan in the DNW Large Low-speed Facility (LLF) has been defined to experimentally study the sound radiation from the model intake and exhaust.

In 1999 model developers will further extend their models and validation experiments will be carried out. (E. Rademaker)

4. HELICOPTER NOISE

4.1. NEW CODES FOR HELICOPTER ROTOR NOISE

A drawback of all the existing rotor noise-prediction codes based on the Kirchhoff method is their gross-time consumption when the acoustic signatures at many observer locations is required, for example for directivity studies. The code KIM based on a new integration technique has been developed by ONERA in 1997 to overcome this difficulty [9]. It has been validated for forward flight in 1998. The code has a high numerical efficiency: it takes 30 min of CRAY 90 (instead of 300 or 400 h with other codes) for calculation of acoustic signatures at 4000 observer locations (see Figure 8). The same integration technique has been implemented in a more general acoustic code (FIM) [10], based on the Ffowcs Williams–Hawkings (porous surface) equation. In view of the applications to acoustic flight tests, a code named CONGA has been developed, which is able to predict Blade Vortex Interaction (BVI) noise using blade pressures measured by a small number of sensors. It will be validated first on the basis of wind-tunnel results. The code uses an original iso-event interpolation of acoustic elementary radiation from every instrumented blade section [11]. (J. Prieur)

4.2. LOW-NOISE ROTOR OPTIMIZATION

A low BVI noise rotor geometry (with performance and dynamic constraints) has been designed and a model rotor has been manufactured in 1997 within the framework of the ERATO cooperation between ONERA and DLR. The optimized and reference rotors have been successfully tested at high speed in ONERA S1 Modane wind tunnel. Significant noise reduction has been recorded with the ERATO blades. The low speed and descent flight tests are to be performed in DNW by DLR during December 1998. Thus, a comprehensive data base including

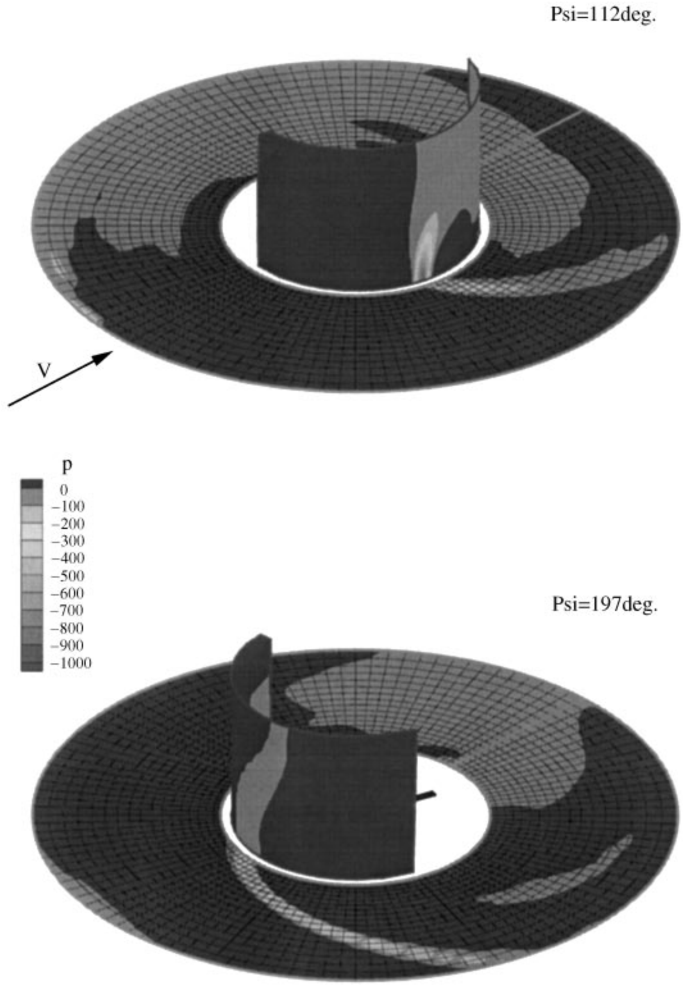


Figure 8. Acoustic radiation in the rotating plane (fixed mesh) of a non-lifting two-bladed rotor in forward flight. Kirchhoff computations from CFD data on a cylindrical rotating mesh.

extensive blade pressure, strain gauge, microphone and wake measurements, with implementation of PIV by DLR at DNW, will have been acquired at low and high speed. (J. Prieur)

4.3. ACOUSTIC FLIGHT TESTS

A flight-test campaign has been performed by ONERA on a Dauphin helicopter with the participation of Istres Flight Test Center (CEV). The objective was to study the feasibility of helicopter noise-source localization using microphone antenna methods, developed at ONERA and already implemented for aircraft noise studies [12]. The method has proved successful. (J. Prieur)

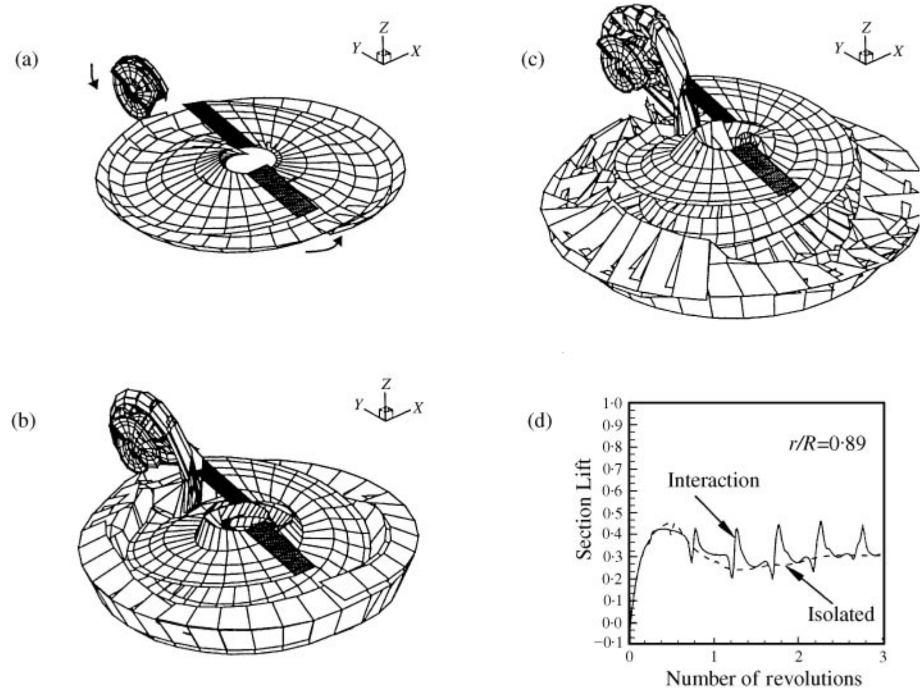


Figure 9. Helicopter main rotor/tail rotor interference and its influence on the section lift on the tail rotor blade.

4.4. HELICOPTER MAIN ROTOR/TAIL ROTOR INTERFERENCE

The close proximity of the main and tail rotors on a helicopter produces aerodynamic interference leading to the generation of unsteady loads (with ensuing flight instabilities), vibrations and noise. The ability to predict these phenomena is important for the design of helicopters. DLR-Braunschweig (Institute of Design Aerodynamics, Technical Acoustics Division) studied the evolution of the pressure distribution on rotor blades employing a generic model of a main-/tail rotor configuration. The computation scheme developed is based on a 3-D Unsteady Panel Method, simulating finite-thickness blades and a vortex lattice free wake, which is emitted from the blade-trailing edge and evolves in space as the calculation proceeds in time [13]. Results shown are for hover flight with the tail rotor turning at twice the rpm of the main rotor; the fuselage is not modelled. In Figure 9, the evolution of the combined wakes of the main and tail rotors are shown after one, two and three revolutions of the main rotor. The process of the tail rotor wake being sucked into the descending main-rotor wake is clearly visible. The variation of section-lift for a location at 89% tail rotor radius is shown in Figure 9(d). Results for both the tail rotor in isolation and under the interaction of the main rotor are plotted. The strong section-lift peaks on the tail rotor blade, due to its interaction with the combined wakes are clearly seen. The computed unsteady blade pressures serve as input to an acoustic code based on FWH-equations to predict the noise generation from the main and tail rotors. (S. Ahmed and Jianping Yin)

4.5. ROTORCRAFT SIMULATION WITH ADVANCED AERODYNAMICS (ROSAA)

The primary objective of the ROSAA project is to develop a framework for a unique integrated rotorcraft simulation system for the improved analysis of the aerodynamic, aeroacoustic and aeroelastic performance of rotors. The project is jointly developed by industry (AGUSTA and GKN-Westland Helicopters), research establishments (CIRA, ONERA, DERA and NLR) and a university (Univ. Roma 3), within the Brite-EuRam programme of the European Commission. This two-year project will end in 1999.

The numerical simulation of rotorcraft requires the mastering of numerous disciplines from structural dynamics to flight dynamics and control and from aerodynamics to aeroacoustics. It is a common practice to calculate complex rotorcraft phenomena by analysing the various disciplines in isolation, but this is an insufficient solution for advanced rotor configurations. It usually happens that such an approach leads to a very sophisticated analysis in a particular technical area (core discipline), and very simplistic analyses in other parts due to simplifying approximations. The basic idea of the ROSAA project is to meet the needs of the European rotorcraft community by developing an advanced rotorcraft simulation system that is able to integrate advanced aerodynamics and aeroacoustics codes (fully capitilizing on the efforts dedicated to the past and recent EU-funded projects: DACRO, HELINOISE, HELISHAPE, EROS, HELIFLOW) with the in-house comprehensive aeroelastic codes available to European manufacturers. The research project develops through the following tasks: Industrial Requirements; Aerodynamic Prediction Method; Aeroacoustic Prediction Methods; Coupling to Comprehensive Rotor Loads Codes; Rotorcraft Simulation System & Software Coordination; Verification of Simulation System, Management.

The ROSAA rotorcraft simulation system is conceived so as to allow in time the improvement of its various components (the aerodynamic codes and interface; the grid generation codes and interface; the comprehensive aeroelastic codes and interface; the aeroacoustic codes and interface), while maintaining the same user interface, thus giving the user all the benefits of the improved components without any additional workload. The participating organizations have numerous aeroacoustic codes based on the linear acoustic analogy (FWH), on the Kirchhoff approach, on the modified Kirchhoff approach and on a unified aerodynamic/aeroacoustic boundary integral equation method (UBIEM). A number of these methods are being enhanced within the ROSAA project, and all will have access to an aeroacoustic interface that will be able to extract the needed data from the aerodynamic codes. The unique interface allows a simple and efficient transfer of aerodynamic data to the acoustician and promises to drastically reduce the time needed to acoustically characterize a new rotor. (S. Ianiello)

5. AIRFRAME NOISE

5.1. REDUCTION OF AIRFRAME AND INSTALLATION NOISE (RAIN)

European aviation industry is working towards reducing aircraft noise in view of the expected demand on the future widebody, large passenger aeroplanes which

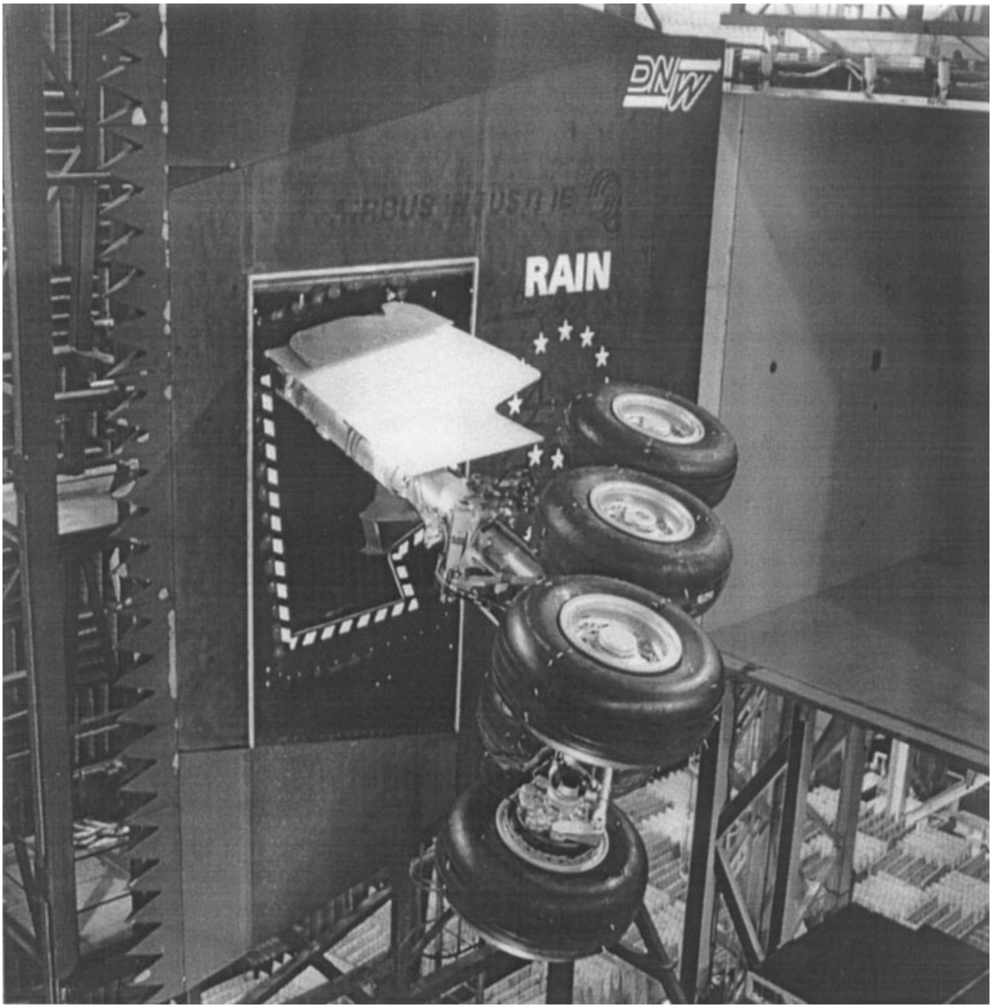


Figure 10. Aeroacoustic study of a full-scale A340 landing gear in the DNW wind tunnel.

have to withstand very stringent noise regulations. Within the European 4th framework, Reduction of Airframe and Installation Noise (RAIN) is one of the aircraft noise research projects being funded by the EC. The objectives of this project are to identify airframe noise-generation mechanisms, develop and assess low-noise schemes, improve prediction methods, identify and experimentally evaluate aircraft installation effects on the farfield noise radiated by the main engine noise sources (fan, jet and core); evaluate prediction models of various installation effects and develop noise-reduction schemes.

Towards these objectives, a major experiment took place in the German Dutch Wind Tunnel (DNW) during the summer of 1998, where full scale A340 landing gears were investigated for their aeroacoustic behaviour (see Figure 10). Advanced techniques for identifying and ranking the contributions from individual components of such highly complex landing gear configurations were employed, which included an acoustic mirror, an extended microphone array and the farfield microphones. The major sources were identified and first technically feasible noise-reduction solutions tested, which indicated a substantial noise reduction potential, without jeopardizing the primary function of the landing gears. Full airframe noise flight tests using an A340 aircraft has also been conducted and by using source localization technique, noise sources on the airframe have been identified. The information will be used to correlate with the wind tunnel full scale and scale model test data. (L.C. Chow)

6. TECHNIQUES AND METHODS IN AEROACOUSTICS

6.1. ACTIVE CONTROL OF KELVIN–HELMHOLTZ WAVES

The question of whether the normal instability of the shear layer might possibly be avoided by active control is studied. What is considered is the simplest inviscid and incompressible idealization of a shear flow, two-dimensional disturbances to an unbounded vortex sheet at the plane interface of a uniformly moving fluid and a fluid at rest. A sensor is introduced which monitors the velocity fluctuations at its position and a linear system which controls a point source in such a manner as to create an exactly opposite wave. Hence, it cancels by destructive interference the disturbance downstream of the controller. This model problem can be analyzed exactly. It is found that the linear system has a positive "pseudo-dissipation"—i.e. the transfer function has positive imaginary part for positive frequencies—if the sensor and source positions are suitably chosen. This linear system is not causal, but there are causal systems with a transfer function which differs only for small frequencies. It can be shown that this system cancels not only the incident Kelvin–Helmholtz waves but also the disturbances generated by point sources, provided that they are in a $\pm$ 45-sector upstream of the sensor–actuator position [14]. (W. Möhring and J.E. Ffowcs-Williams)

6.2. EXACT MULTIPLE SCALES SOLUTION IN LINED FLOW-DUCT ACOUSTICS

An explicit solution is found for the multiple-scales problem of modal sound propagation through slowly varying lined ducts with isentropic mean flow [15]. No *ad hoc* simplifications, but a consistent and systematic approximation at all levels (equations, boundary condition, mean flow) is just sufficient to obtain the exact result. Since a slow variation of diameter and mean flow is inherent to any aero-engine inlet duct, it is suggested that the present solution provides an attractive alternative to full numerical solutions. The present result is equally valid for hollow and annular cylindrical ducts, and hence includes the unique feature of a systematic approximation to the spinner or hollow-to-annular cylinder transition problem (see Figure 11). (S. Rienstra)

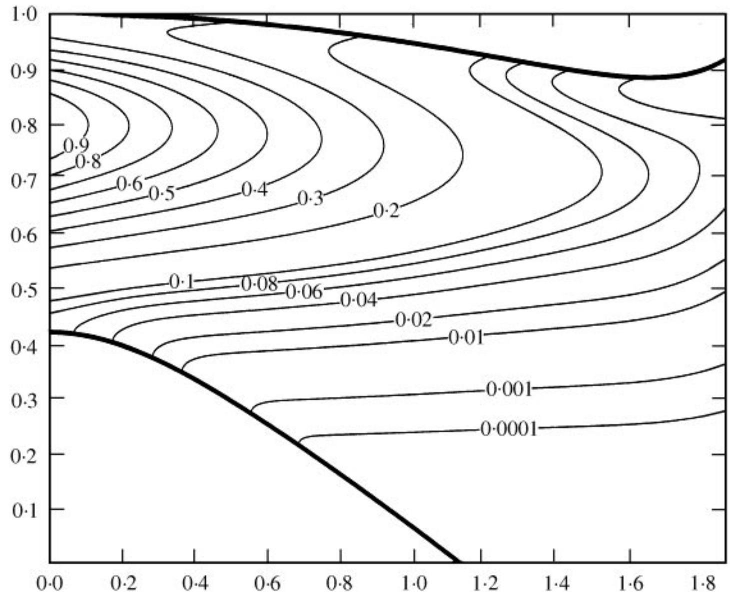


Figure 11. Iso-pressure contours of first radial mode of $m = 10$, $kR = 16$, and outer wall $Z = 2 - i$, fan-plane Mach number $= 0{\cdot}5$.

6.3. SOURCE LOCATION BY NEW MICROPHONE ARRAYS IN THE DNW-LLF

Two new microphone arrays for locating aeroacoustic sources on models have become operational in the Large Low-speed Facility of the DNW: one for wall measurements in closed test sections, the other for out-of-flow measurements in the open jet. Both arrays consist of 100 microphones. The microphones for the wall array were mounted flush in a $0{\cdot}5 \times 0{\cdot}6\,\mathrm{m}^2$ plate. This plate has the width of a closed test section floor panel, so that it can be installed and removed easily. Installation in a side-wall panel is also possible. Optionally, the array can be covered with a 0·5 cm thick layer of acoustic foam and a 5% open perforated plate, to suppress boundary-layer noise. For the positioning of the microphones, an irregular, sparse design was used, which is able to locate sources at frequencies between 2·5 and 30 kHz, with at least 12 dB sidelobe fall off [16]. Locating sources at frequencies higher than 30 kHz is also possible in principle, but then the side-lobe fall off is less.

Measurements were carried out on two transport aircraft models. Sources were found at the expected locations, and at a resolution close to the resolution predicted by simulations. The array proved to be capable of filtering out the turbulent self-noise. Typical results are shown in Figure 12. The microphones for the out-of-flow array were mounted in a $4 \times 4\,\mathrm{m}^2$ aluminium lattice. Because of the sparse-array design, this array is capable of locating sources between 500 Hz and 10 kHz, with at leat 12 dB sidelobe fall off. It was successfully applied to measurements on a full-size landing gear (see section 5.1). (P. Sijtsma and H. Holthusen)

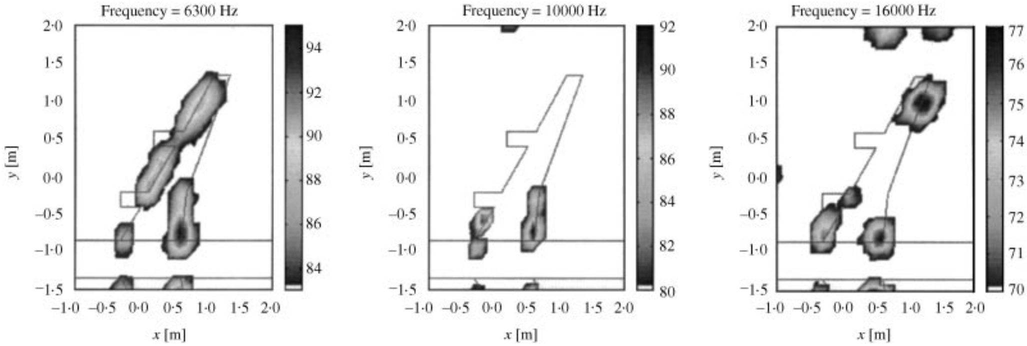


Figure 12. Sound source location on an aircraft model using planar arrays of microphones (DNW-LLF wind tunnel).

6.4. DIRECT SIMULATION OF AERODYNAMIC NOISE GENERATION

The noise generated by vortex pairing in a 2-D mixing layer at moderate Reynolds number was studied through direct simulation [17]. Due to the fact that acoustic fluctuations are several orders of magnitude smaller than the turbulent fluctuations, a special code was developed to correctly estimate the distant field. This compressible LES code uses the DRP scheme of Tam & Webb in space together with an optimized fourth order Runge–Kutta scheme for time discretization; the boundary conditions of Tam & Dong are implemented together with a Perfectly Matched Layer "sponge" zone for the outflow boundary condition. The mixing layer is excited at its fundamental frequency and at its first sub-harmonic to obtain only one pairing, and at a fixed location. Superposition of the vorticity field and of the dilatation field provides a clear illustration of the mechanism of noise generation in the form of a rotating quadrupole (see Figure 13). The noise generated by a 3-D subsonic jet is currently under study using a similar approach. (C. Bailly)

6.5. CHARACTERIZATION AND NUMERICAL SIMULATION OF HELMHOLTZ RESONATORS

A special acoustic absorber, in the form of a cylindrical Helmholtz resonator, has been designed and developed for the Ariane 5 launcher in order to reduce the low-frequency noise inside the fairing. The behaviour of this absorber was studied by ONERA both in the linear and non-linear regimes. The absorption coefficient and the impedance of the resonator were determined with a standing-wave apparatus, for several excitation pressure levels. It was shown in particular that the absorption coefficient increases with the level of excitation. In order to understand the mechanisms inducing these non-linear effects, ONERA carried out LDA measurements of the acoustic particle velocity inside a 2-D Helmholtz resonator equipped with two parallel glass sidewalls. The resonator was excited at its resonance frequency, and the two components of the acoustic particle velocity were

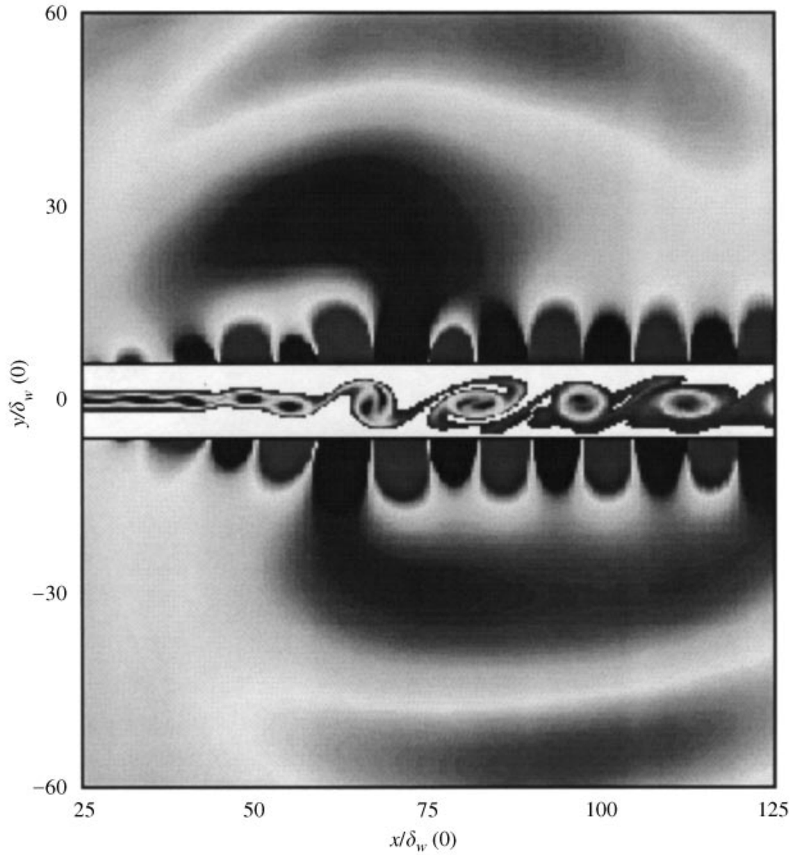


Figure 13. Direct computation of the noise of a mixing-layer; snapshot of the vorticity field in the flow region and of the dilatation field.

measured at 500 points distributed in the neck region and in the cavity. A numerical simulation of this resonator was also made, using a CFD code (SIERRA) to solve the full Navier–Stokes equations. This code has been thoroughly validated for acoustic regimes and is currently using to study the unsteady flows in solid propellant rocket motors, including vortex-shedding-driven instabilities. The numerical results are in good agreement with LDA measurements. (D. Gély)

7. SCIENTIFIC EXCHANGE AND INTERACTION

7.1. AIAA/CEAS AEROACOUSTICS CONFERENCE

The fourth joint AIAA/CEAS Aeroacoustics Conference took place in Toulouse, France, 2–4 June 1998, under the Chairmanship of Dr. Gérard Fournier (France) and Prof. Tim Colonius (USA). More than 300 people attended the conference. Out of approximately 160 papers presented, about 50% were given by scientists from the CEAS-countries, 40% from U.S.A. and most of the remaining from Asia (L. Morino)

7.2. ASC-WORKSHOPS

The considerable success of the last ASC-Workshop on "Aircraft Interior Noise Control" held on 8–9 June 1998 at the Daimler Benz Aerospace Company of Friedrichshafen (Germany) and organized by Dr. Ingo Borchers, has urged the ASC to turn the next meeting in a real "Forum". Its title will be "CEAS Forum on Aeroacoustics of Rotors and Propellers"; it will be held in Rome, 9–11 June 1999, under the Chairmanship of Prof. Luigi Morino. (L. Morino)

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