Journal of Sound and Vibration (1998) **214**(1), 139–164

AEROACOUSTICS RESEARCH IN EUROPE: THE CEAS-ASC REPORT ON 1997 HIGHLIGHTS

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(*Received* 6 *February* 1998)

This paper is a report on the highlights of aeroacoustics research and development in Europe in 1997, 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 aerospace acoustics and related areas. Each year the Committee will highlight some of the research and development activities in Europe. This is the report on the 1997 highlights.

Contributions to the report have been made by the following people: H. Foulon (CEAT); J. Prieuo, S. Lewry, D. Gely, S. Pauzin and F. Simon (ONERA); D. Berge and J. Julliard (SNECMA); U. Michel, J. Delfs, X. Li and H. Heller (DLR); O. Recker, G. Neuwerth and D. Jacob (RWTH Aachen); G. Algermissen, S. Wagner and G. Guidati (Stuttgart University); P. di Francescantonio (AGUSTA); S. Ianniello, P. Renzoni and A. Pagano (CIRA); F. Marulo and S. de Rosa (Naples University); M. Gennaretti (Rome University 3); A. de Boer, T. Dassen, F. P. Grooteman and J. B. H. M. Schulten (NLR); F. J. M. van der Eerden, H.-E. de Bree, and H. Tijdeman (Twente University); P. Luengo, J.-L. Rioboo and H. Climent (CASA); E. Campos (INTA); P. García-Fogeda and F. de la Iglesia (Madrid Polytechnic University); S. Chow (BAe Airbus); L. Ilston and D. E. Patience (BAe Defence); N. Peake (Cambridge University); R. A. Pinker (DERA Pyestock); B. J. Tester (Rolls-Royce plc); R. G. White, R. S. Langley and M. G. Smith (Southampton University); K. H. Heron (DERA Farnborough).

2. AIRCRAFT INTERIOR NOISE

2.1. FUSELAGE WALL TRANSMISSION LOSS ANALYSIS

In the framework of the European (EU) research programme BRAIN ("Basic Research on Aircraft Interior Noise") and a national research programme on "Cabin Noise Reduction" the Structures Technology Department (SC) of the National Aerospace Laboratory (NLR) developed analysis tools for the prediction of noise transmission through a double wall structure. The double wall consists of a stiffened and unstiffened

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shell structure with a cavity filled with thermal insulation material and air in between. Both shell structures are connected to each other mechanically with so-called connectors.

To model the thermal insulation, porous acoustic finite elements and boundary elements have been developed, while special coupling elements serve to describe the coupling between air and structure. The elements have been implemented in the modular analysis programme B2000. Various damping models for the structure have been implemented. With these numerical tools several studies have been carried out. The finite element model for structure and cavity have been compared with the combination of a boundary element model for the cavity and a finite element model for the structure. Also, the damping models have been studied. As a specific goal for the BRAIN project the response to a harmonic force applied to the stiffened panel of a flat double wall structure with a cavity filled with thermal insulation and air has been calculated (see Figure 1) and measured. In Figure 2 the response of the unstiffened panel due to sine sweep (force) excitation between 20 and 200 Hz, obtained with the combined BEM/FEM, is compared with a measured response. (André de Boer, Frank P. Grooteman)

2.2. ACTIVE CONTROL OF PROPELLER NOISE

CASA has been participating in the European (EU) project ASANCA II devoted to active control of interior noise in turbopropeller aircraft. The task of CASA was to develop a methodology to implement transfer functions in the finite element method to compute interior noise levels. The fuselage structure was modelled with a fine mesh, using traditional design techniques. The acoustic cavity was also modelled using traditional techniques.

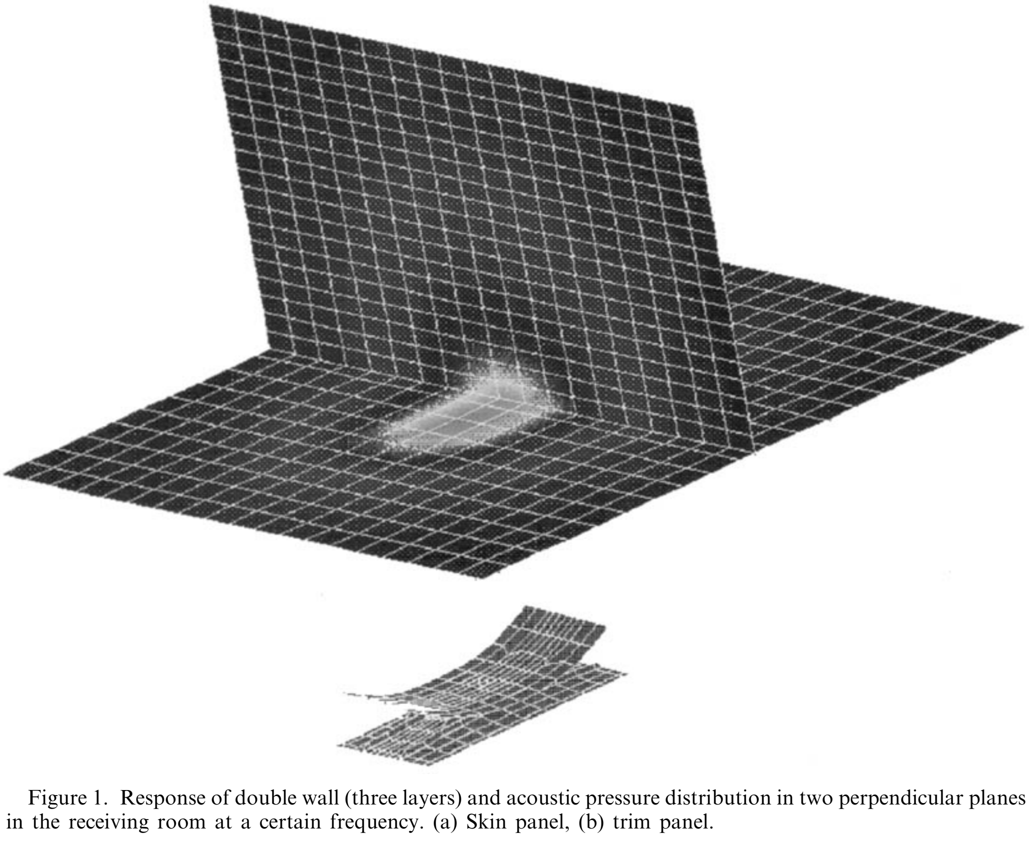

Figure 1. Response of double wall (three layers) and acoustic pressure distribution in two perpendicular planes in the receiving room at a certain frequency. (a) Skin panel, (b) trim panel.

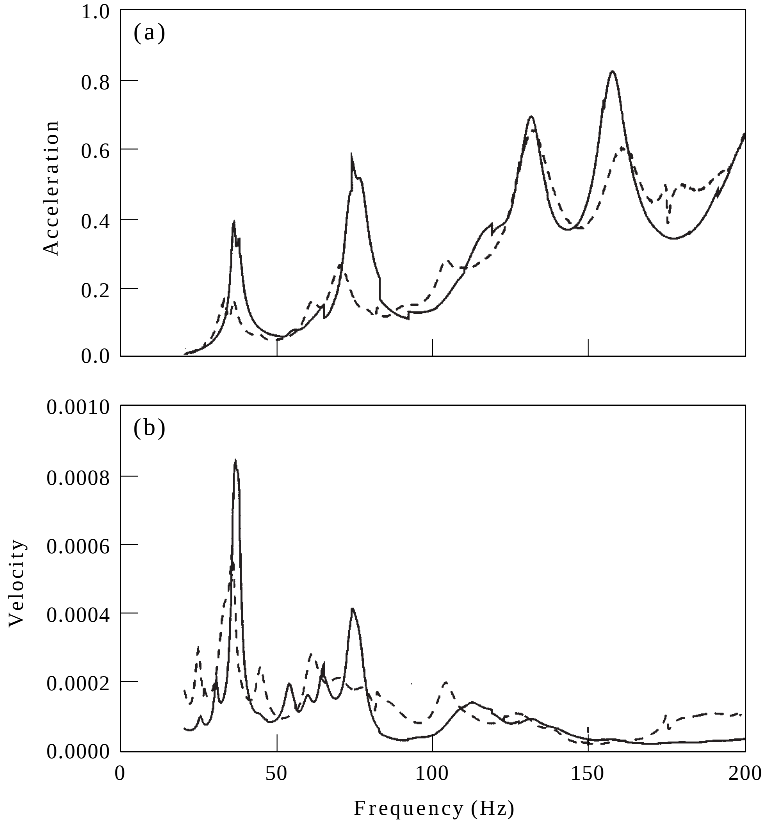

Figure 2. Measured (– – –) and calculated (——) response of stiffened (upper) and unstiffened (lower) panel for a cavity filled with thermal insulation and air. (a) Skin panel, (b) trim panel.

However, instead of modelling the trim panel, blankets, thermal insulation and so on, results from the tests (transfer functions relating outside skin pressures with inside trim panel displacements) are embodied in the problem of acoustic–structure coupling. This methodology has been successfully developed and documented within the ASANCA project. (Hector Climent)

2.3. ACTIVE CONTROL OF HELICOPTER NOISE

ONERA-CERT has tested the feasibility of structural active control to reduce the noise in a helicopter cabin, generated via the mechanical deck by the vibrating gearbox. A prediction model of the vibro-acoustic behaviour of the orthotropic composite plane panel (core in Nomex honeycomb and fibreglass layers) fitted with actuators (mini shakers and piezo patches (2 or 3)) is developed. The active control procedure is obtained with an LMS (Least Mean Square) algorithm and microphones (3 to 5) as error sensors [1]. Furthermore, it is possible to compute the structural intensity distribution supporting the active control arrangement and providing information on the energy redistribution induced by the active control [2]. Experimental and theoretical results deliver the noise level reductions achieved after active control. Noticeable reductions have been obtained in large areas for the two kinds of actuators, even for rather high modal densities, with a low number of actuators and error sensors (Table 1, [3]). (Simone Pauzin, Frank Simon)

TABLE 1

Comparison of reductions obtained for different actuators, modal densities and error sensors

	Noise reduction (dB)
282 Hz (two shakers)	
AC with three sensors 1, 3, 5	−14·9
AC with five sensors	−15·7
1158 Hz (three shakers)	
AC with three sensors 2, 3, 5	−10
AC with five sensors	−11·2
282 Hz (two piezo patches)	
AC with three sensors 1, 3, 5	−10·8
AC with five sensors	−13·3

3. FAN AND JET NOISE

3.1. ACOUSTIC RESPONSE OF FAN BLADES TO INGESTED VORTICITY

Asymptotic analysis has been used to study the acoustic response of a blade row to unsteady forcing by upstream vorticity. The aim has been to include in a systematic way the full effects of the blade camber, thickness and mean loading, and thereby extend the wide range of existing methods which rely purely on flat-plate theory. It has been seen that these effects can be very significant indeed for the high frequencies often encountered in rotor–stator systems, and an efficient, analytically based prediction method for the radiation has now been developed at Cambridge University [4, 5]. Currently, this method is being extended into the transonic regime.

In a different direction, a model for the noise generated by the interaction between ingested atmospheric turbulence and the fan has been developed [6]. The idea is that the radiation spectrum is related directly to the turbulence spectrum far upstream, with rapid distortion theory being used to account for the distortion through the intake. The elongation of eddies by the stream-tube contraction leads to the strong generation of tonal noise at low forward speed, and the levels of these tones, and of the broadband, can now be assessed in terms of the incident turbulence and flight parameters. Extension of this work to swirling intake flow is now being completed.

The use of scarfed intakes for the preferential modification of far field directivities continues to be considered, and the development of predictive models, using a blend of ray theory and uniform asymptotics, is well underway. (Nigel Peake)

3.2. ACOUSTIC RESONANCE

The phenomenon of acoustic resonance is thought to occur when some unsteady process, typically vortex shedding, locks onto an acoustic mode of the compressor. Theoretical work at Cambridge University has progressed in two directions. First, models of the vortex shedding by compressor blades have been developed by using hydrodynamic stability theory [7, 8], and predictions of critical Reynolds numbers for shedding, and of linear onset and non-linear saturated frequencies have been made. Second, the resonant frequencies of rotor–stator systems have been determined by using a blend of analytical and numerical techniques; at least two distinct physical mechanisms for resonance have been identified, and very satisfactory agreement with experiment has been achieved [9]. (Nigel Peake)

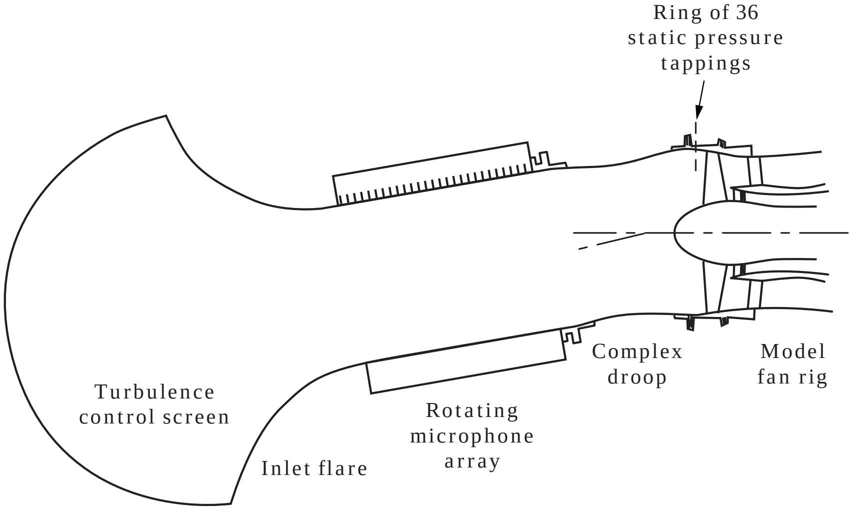

Figure 3. Test fan with complex droop.

3.3. SIGNIFICANT IMPROVEMENT IN FAN NOISE PREDICTION CAPABILITIES

Following the completion of the EU-funded FANPAC project in 1996, a considerable effort has been made by the partners to utilize the results to improve our understanding and validate our prediction methods for fan noise. For example, the effects of steady intake distortion on fan tone noise have been investigated in detail and used to validate a Rolls-Royce prediction method (see Figure 3, 4). (Brian J. Tester)

3.4. FAVOURABLE EFFECT OF VANE SWEEP ON ROTOR/STATOR INTERACTION NOISE

A new lifting surface theory [10] was successfully applied by NLR to compute the aerodynamic and acoustic response of a swept vane stator to impinging viscous rotor wakes. Sample calculations showed that vane sweep can be exceptionally effective in

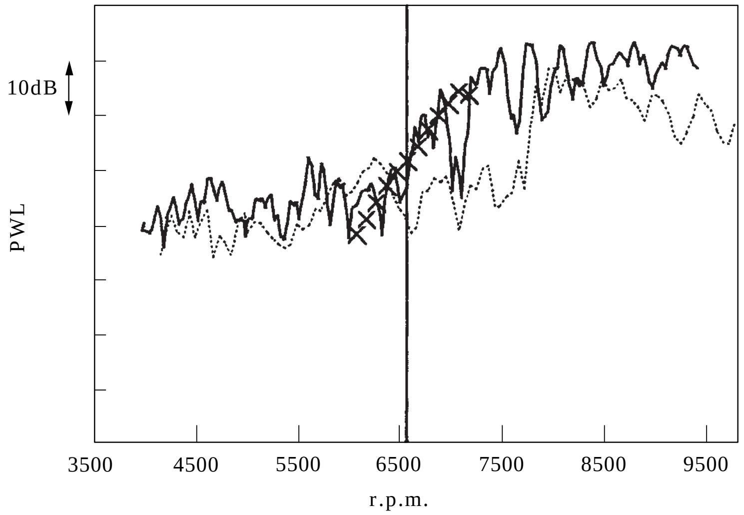

Figure 4. Measured versus predicted tone level for the fan with complex intake droop. ——, Complex droop; . . . . , clean intake; ×, complex droop (theory); ——, $m=20$ cut-on frequency.

reducing the noise resulting from this major fan noise mechanism. Although the potential benefits of vane sweep have been recognized for a long time, its significance for real fans remained unclear.

The new method avoids the familiar summation of radial modes, which becomes cumbersome for swept vanes, and can be considered as an extension of a propeller lifting surface formulation [11] to include sound reflections from hub and casing. It was found (see Figure 5) that at conditions relevant for a modern, very high bypass design, interaction noise reductions of the order of 8 dB are obtainable with 20° of vane sweep. On the other hand, sweep angles smaller than 10° are ineffective or may even cause an increase in noise level. The weak coupling of the unsteady vane pressure and the cut-on duct modes was positively identified as the reason for the sound reduction by sweep. Vane sweep seems to be a practical way to achieve a substantial fan noise reduction. In particular the down-stream propagating noise, which is not shielded by the rotor, may be reduced by swept vanes. The new method will play a key role in the 3-year European programme RESOUND (section 9.1). (Johan B. H. M. Schulten)

3.5. BROADBAND TURBOFAN NOISE PREDICTION

Noise from high by-pass ratio turbofans is mainly due to the fan. The tonal levels have been greatly reduced during the past decades, and therefore the broadband component has become the main contribution to the Effective Perceived Noise Level. Prediction and reduction of high-speed rotor broadband noise is thus a very important challenge in turbofan noise control. ONERA has developed a prediction method based on first principles (the Ffowcs Williams-Hawkings equation for a rotating random axial dipole), because more sophisticated computations require input data which are not available yet, neither from CFD nor from experiments. The basic equation has been extended to include tangential dipoles and to non-compact sources along the blade span. Results shows that the sound power varies with the rotation speed to the fifth power, which is in good agreement with test data. The shape of the acoustic spectrum is also well predicted. More

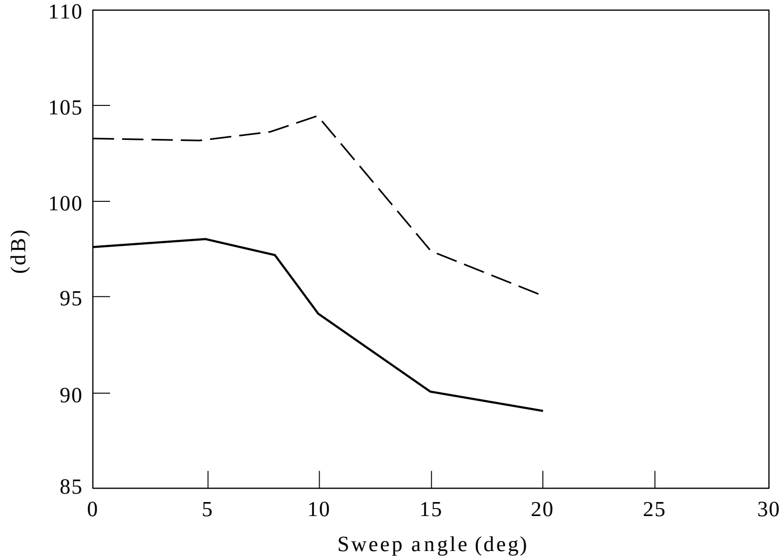

Figure 5. Acoustic intensity of second harmonic, upstream (——) and downstream (– – –) of stator, versus sweep angle.

work is required on two issues: (1) the computation of the directivity taking into account the ducted propagation; (2) the effect of quadrupole terms for transonic rotors.

This work will be pursued in the framework of a European programme. (Serge Lewy)

3.6. NOISE FAN CONTROL AND REDUCTION SYSTEMS

The need for reducing the fan noise (tones and broad-band components) radiated by turbofan engines has led SNECMA to start investigations into noise control and other reduction systems. First, a new sound propagation code has been developed, taking into account both elastic (Biot theory) and rigid porous materials within a cylindrical duct. In the mean time, the active noise control technique has been applied successfully to a model fan by using a new controller unit (multi-processor/16 channels) developed by LMA Marseille. Configurations with external and in-duct error sensors were successfully tested. (Jacques Julliard)

3.7. ACOUSTIC RESEARCH AT BAE MILITARY AIRCRAFT AND AEROSTRUCTURES

British Aerospace Military Aircraft and Aerostructures have been continuing to develop prediction methods for the near field acoustic environment on and around aircraft with high pressure ratio and high temperature jets, with particular application to STOVL aircraft. Refinement of the vertical thrust (i.e., for jet borne landing) acoustic prediction codes has taken place to provide a better estimate of the groundsheet flows and to enable more rapid modelling of specific configurations of interest. Work has been continuing to explain the near field under prediction at high frequencies for high velocity jets using the prediction method presented in reference [12].

Research is being conducted on the application of CFD codes to estimate the acoustic levels inside cavities which are excited by air flow (e.g., weapon bay cavities on aircraft). Estimates are being validated against model scale data. (Len Ilston, D. E. Patience)

3.8. IMPORTANT IMPROVEMENT IN JET EXHAUST NOISE TEST CAPABILITY

Until recently, the major thrust of the civil jet noise research at DERA Pyestock has been concerned with the noise sources associated with buried or mixed flow configurations usually with forced mixers. However, the trend towards the very large engines has meant that, on the grounds of weight and interference drag, the emphasis has shifted towards consideration of exhaust systems with separate core and fan nozzles. A model test programme, currently underway, has the overall aim of identifying potential concepts for jet noise reduction for such configurations. A set of relatively simple test models has been produced using a modular approach to enable the systematic investigation of the effect of design parameters on the basic noise characteristics of separate exhausts. In the initial phase, a number of generic exhaust builds—representing current practice—were tested to determine the detailed effect on the noise of engine core protrusion, core external angle and centre bullet. This has revealed the presence of only small changes which in most cases can be related to the anticipated change in jet structure with build configuration. The quietest design is the co-planar configuration by about 1/2 PNdB.

To improve the understanding and prediction of the processes associated with the generation of coaxial jet noise a detailed study of the jet structure in terms of turbulence and velocity profiles is currently underway using dual focus laser anemometry (see Figure 6). (Richard A. Pinker)

3.9. FIIGHT EFFECTS ON JET EXHAUST NOISE TEST

The installation of a turbofan engine under an aircraft wing can have a substantial effect on the character of the radiated jet noise and this has been the subject of studies at DERA

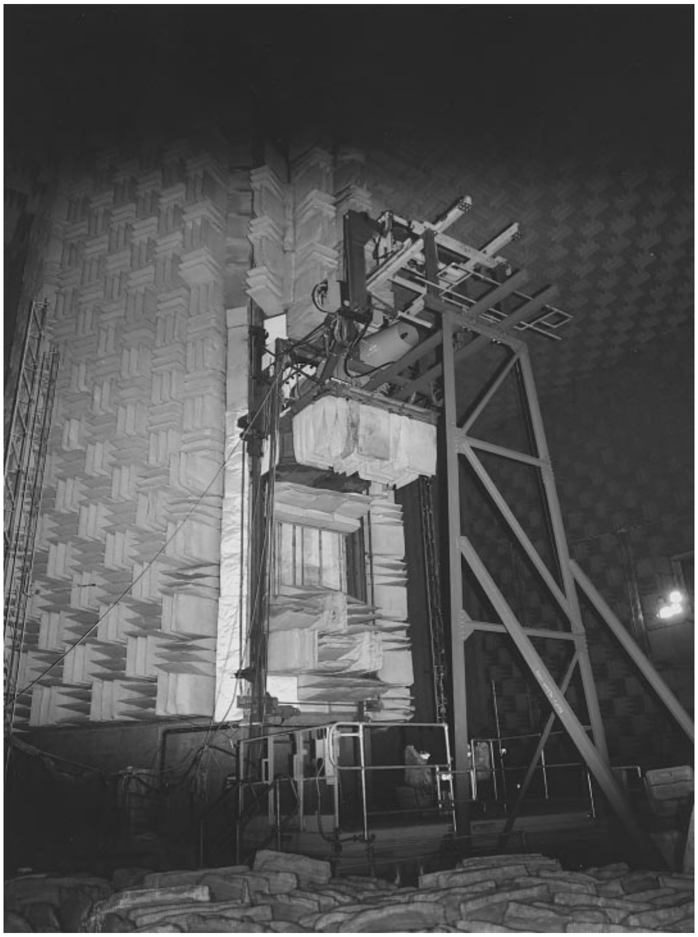

Figure 6. Jet noise—measurements of jet structure using laser anemometry in DERA Noise Test Facility.

Pyestock for several years. However, these were limited to the flyover orientation, whereas the sideline legislative limit is usually more difficult to meet. A programme of testing in the DERA Noise Test Facility has recently been carried out to investigate installation effects in the sideline orientation. The tests utilized several wing geometries, from a rectangular flat plate to a detailed, three-dimensional model of the wing. The installation effect, at least statically, is observed to consist of two major separate effects—reflection of the jet noise by the wing, and excess noise produced by the interaction of the turbulent jet with the wing or flap trailing edge. The forward motion of the aircraft introduces further complexities to the problem. Some limited simulated flight data was obtained during the tests, and it is anticipated that once the static data is analyzed, improved prediction of in-flight noise levels should be possible (see Figure 7). (Richard A. Pinker)

3.10. A NEW NOZZLE SUPPORT IN THE CEPRA19 WIND TUNNEL

A new series of nozzle models, equipped with a balance, has been installed in the CEPRA19 anechoic wind tunnel. From now on, thrust measurements and the acoustic characterization of a jet can be performed simultaneously. The thrust balance ranges up to 10 000 N. To improve the performance of this new equipment, ONERA carried out calibration tests both on the acoustics with well-known nozzles and on the thrust

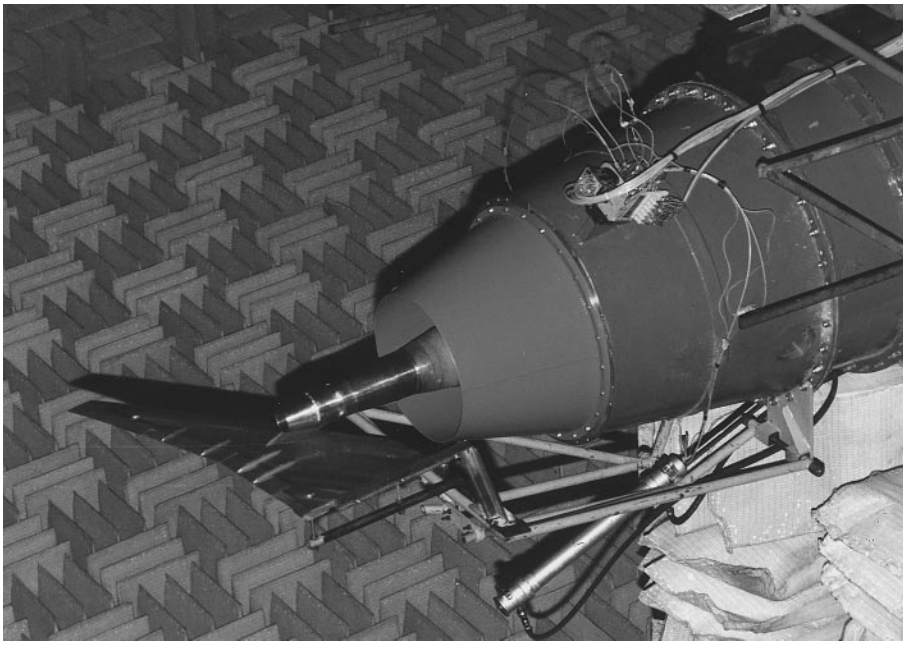

Figure 7. Installation effects on jet noise—test rig in DERA Noise Test Facility showing wing removal actuator system.

measurements with a standard dynamometer. This equipment will be in service in future tests to be conducted for SNECMA, especially on mixer–ejector and Mid Tandem Fan models. (Denis Gely)

3.11. MARTEL—AN AEROACOUSTIC TEST FACILITY FOR ROCKET NOISE

Installed in CEAT Poitiers by CNES in collaboration with French laboratories (AEROSPATIALE, ECL, EDF, LEA, ONERA), the MARTEL facility for high speed and high temperature jets can reproduce an aeroacoustic ambiance similar to that of the space launchers. This facility will be used to study and reduce jet noise emissions which may induce damage to the payload during lift-off. In operation since May 1996, several acoustic investigations have already been carried out into the acoustic field of the free jet (LEA), jet impingement on a plate simulating the launch pad table (ONERA), water injection effects (ECL, LEA) (see Figure 8), acoustic field radiated by a 2·1% model of half the Ariane 5 ELA3 launch pad table (ONERA) (see Figure 9). Acoustic experiments are now in progress with a new fully expanded convergent–divergent nozzle; aerothermic measurements (intrusive or not) and visualizations are planned.

It is also planned to make the facility available for external researchers who could benefit from this particular aeroacoustic environment. (Henry Foulon)

3.12. ROCKET NOISE PREDICTION

Instituto Nacional de Tecnica Aeroespacial (INTA) has been developing in recent years research activities on the subject of rocket noise (i.e., high speed jet noise).

From a series of missile launchings a rocket noise data base has been obtained, including data in the geometric near field and in the acoustic far field. Sound power and power spectrum were derived from the near field data, disregarding near field effects, and agreement was found with the predictions of empirical methods designed to be used with

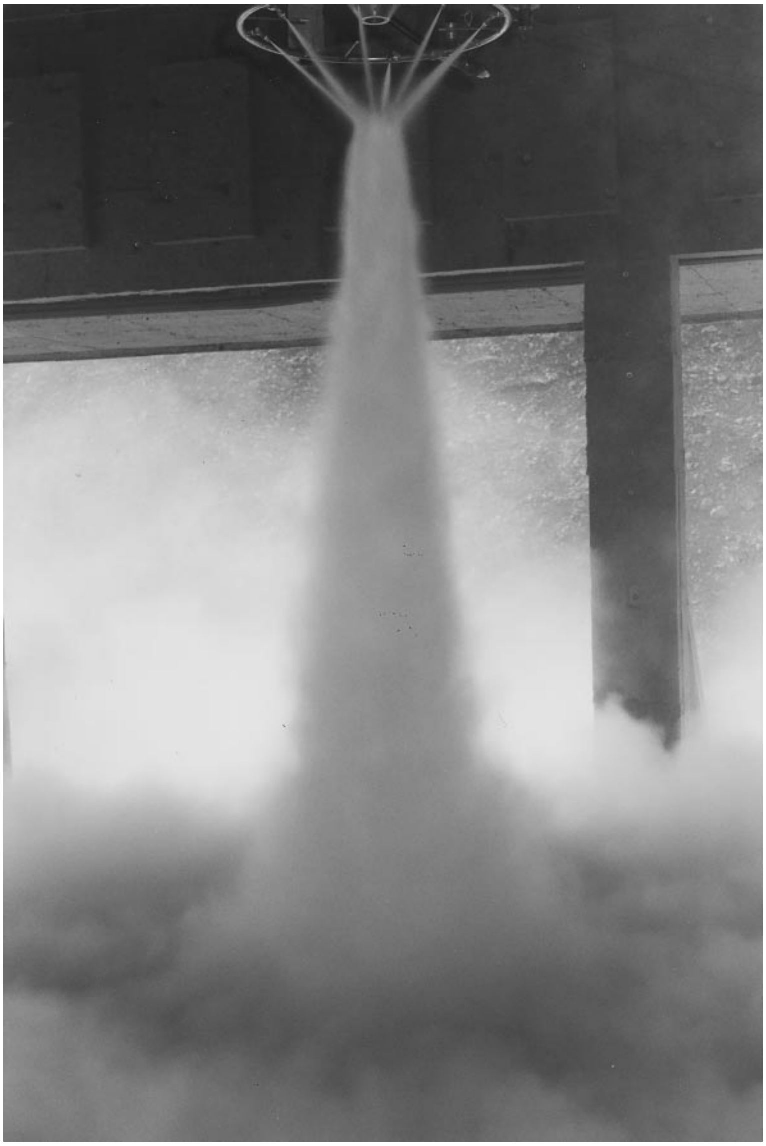

Figure 8. Water injection in a free supersonic jet.

far field data. Likewise, the dimensionless power spectrum fits with the values supplied by well-known prediction curves, although a disagreement appears at very low frequencies. Thus, apparently geometric near field data provide a good description of sound power and power spectrum, except at very low frequencies when the wavelength is so large that the distance from the source to the observer is smaller than the Rayleigh distance, and acoustic near field effects must be taken into consideration [13].

Recently, a code has been developed for the prediction of sound pressure and pressure spectra, by using a spectral decomposition of the total sound power, based on a dimensional analysis of the sound radiated from a high Mach number jet. Values provided by this code are similar, although a bit higher, to corresponding measured values [14]. (Emilio Campos)

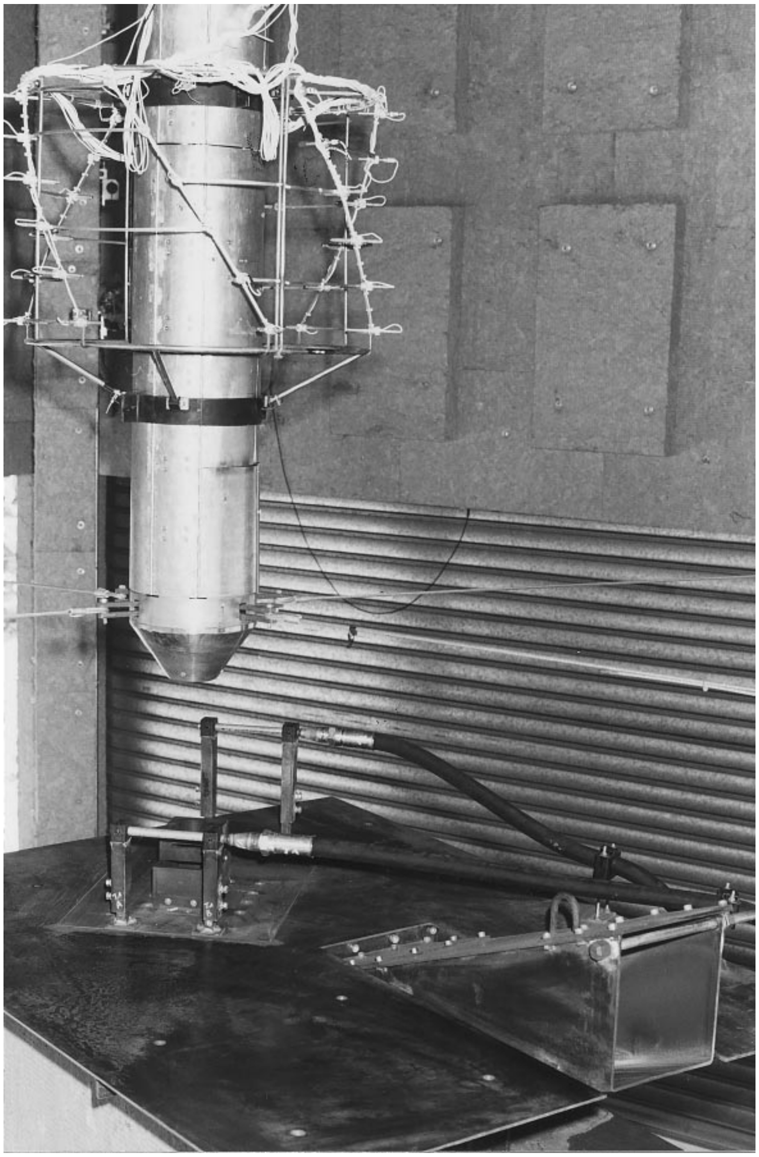

Figure 9. Acoustic characterization of a launch pad mock-up.

4. PROPELLER NOISE

4.1. ACOUSTIC EFFECT OF LEADING EDGE VORTEX OF ADVANCED PROPELLERS

The acoustic module of the NLR lifting surface method for advanced propellers [15] was successfully extended with the leading edge suction analogy. This extension has greatly improved the prediction accuracy for highly loaded take-off conditions.

As pointed out in reference [16], the leading edge suction force—a higher order effect which yields zero drag for a plate under an angle of attack in a subsonic, inviscid flow—is not captured by the lifting surface approximation. Still, this force can be recovered by applying locally the two-dimensional potential theory of a semi-infinite plate.

It is well known, however, that for the sharp leading edge of airfoils of advanced propellers a local separation occurs at the suction side which develops into a leading edge vortex. Similar to that for swept wings, the effect of this vortex is to rotate the leading edge suction force over 90° to the suction side of the blade. This effect is known as the leading edge suction analogy.

A comprehensive validation was carried out [17] with data generated in the EU Brite-EuRam project SNAAP ("Study of noise and aerodynamics of advanced propellers"), concluded in 1996. A typical result is shown in Figure 10 for the High Speed Propeller (HSP), designed for a cruise speed of Mach = 0·78. It has the characteristic very thin, highly swept blades of advanced propellers (propfans). The conditions in Figure 10 are low speed and high aerodynamic loading. The sound level was measured along a side line at a distance of 1·22 tip radius from the propeller axis. The acoustic effect of the inclusion of the suction analogy is a surprisingly large increase of about 5 dB. As a result the agreement with the measured data improves substantially. (Johan B. H. M. Schulten)

5. HELICOPTER NOISE

5.1. HELICOPTER ROTOR NOISE

A new implementation of the Kirchhoff method which uses subsonically as well as supersonically rotating CFD grids has been developed.

The specially developed time integration technique considers each grid element as acoustically non-compact. The method works well even with relatively wide surface elements and large emission time steps. The code KIM based on this integration technique has been validated by comparison with analytical calculations and with experiments for the case of a model rotor in delocalized hover conditions. The method is robust and saves much computational time.

Furthermore, an investigation on broadband Blade–Wake Interaction (BWI) noise has been performed for realistic rotor cases based on experimental wind tunnel results and on

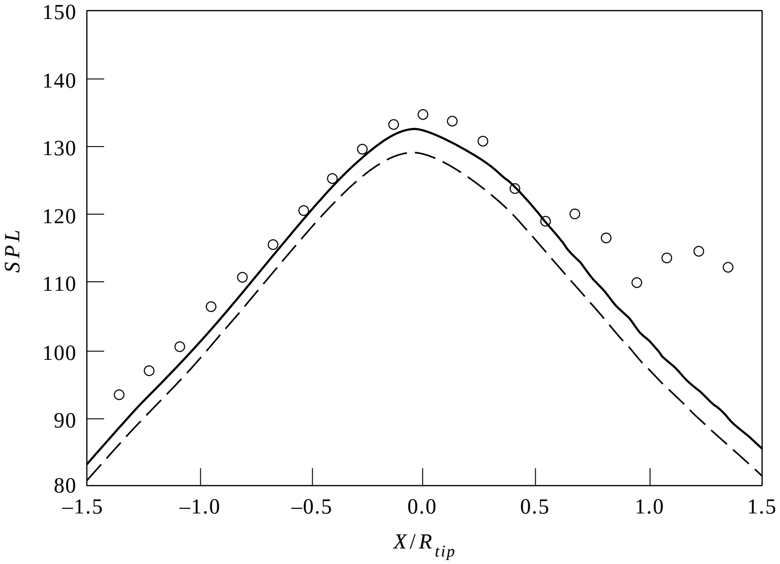

Figure 10. Sound level of first harmonic versus axial co-ordinate. ——, With rotated suction; – – –, without suction; ○, experiment.

rotor wake numerical simulations. The study confirms the part played by vortex turbulence during perpendicular blade–vortex interactions. It also shows that very close parallel interactions which generate impulsive noise in descent flight can also generate BWI noise. (Jean Prieur)

5.2. ADVANCED AEROACOUSTIC PREDICTION METHODS FOR HIGH-SPEED ROTORS

A new Kirchhoff code, INKA (Impulsive Noise Kirchhoff Algorithm) has been developed at the Institute for Aerodynamics and Gasdynamics, University of Stuttgart [18]. In order to predict high-speed impulsive noise this code has been coupled to the Euler solver INROT which is of the same parentage. For the calculation, not only are the aerodynamic grids used for the Euler computation as adapted to the noise radiation characteristics, but also for discretization of the non-rotating Kirchhoff surface. Together with the application of accurate interpolation schemes and refined timesteps for the acoustic calculation the efficiency of the Euler/Kirchhoff computation could be increased significantly. Very good agreement between computed and experimental results is achieved for the non-lifting hover case and good agreement for the lifting forward flight case. (Gerhard Algermissen, Siegfried Wagner)

5.3. REDUCING THE NOISE EMISSION OF FENESTRONS

In 1995 a new research initiative on fenestron noise reduction started at the Institut für Luft- und Raumfahrt (ILR), University of Technology, Aachen, in cooperation with Eurocopter Germany. It involves the noise reduction of fenestrons with the help of Helmholtz Resonators integrated into the rotor shroud. A model of the EC 135 fenestron (scale 0·7:1) was built for experimental investigations (see Figure 11).

One volume was used consisting of a hollow ring in the shroud surrounding the rotor. First the incident sound pressure level and the velocity distribution on the shrouding surface were measured. With these data a suitable distribution of orifices was computed

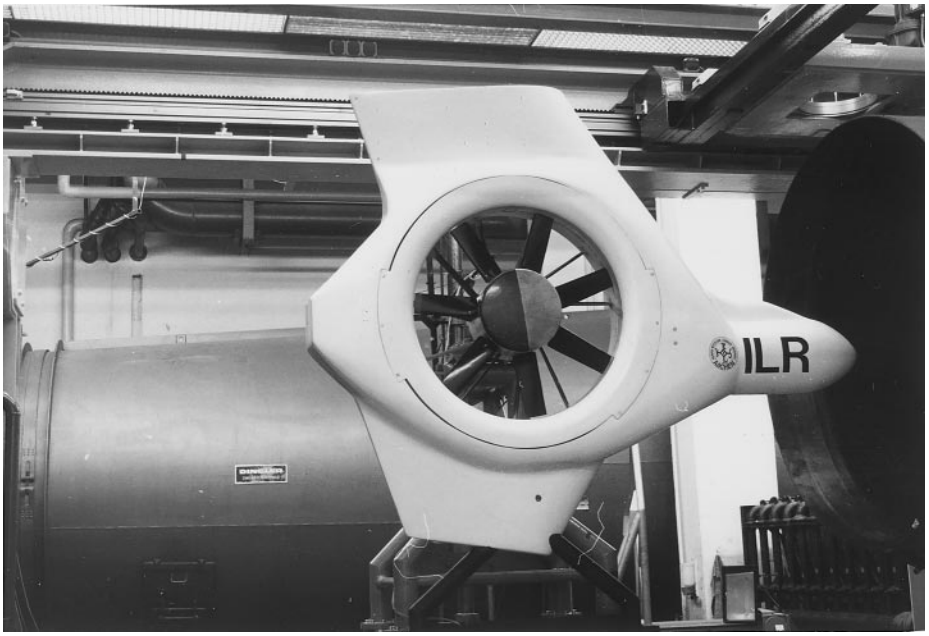

Figure 11. The fenestron—a helicopter shrouded tail rotor.

by using the theories of Ingard [19], Brown [20] and Hersh and Walker [21]. The computed resonator geometries were investigated experimentally in a Kundt tube and in a test facility where the influence of the outer flow on the absorption of a Helmholtz resonator could be measured. The observed flow-dependent mass exchange between resonators decreases their ability to reduce the incident sound pressure because of a partial loss of the volume's spring effect. The use of resonators with several orifices turned out to be a compromise between low structural requirements and the ability to reduce the emitted noise.

After designing a suitable orifice distribution, sound power measurements were made in the wind tunnel of the ILR using the EC 135 model. A maximum absorption of 3·5 dB at the blade passing frequency was measured in hover. With increasing forward flight speed the absorption decreases due to changes in the axial velocity through the fenestron and due to the highly turbulent flow behind the rotor. In the next step a reduction of the influence of the outer flow with the help of a sieve dividing the outer flow and the resonator flow will be attempted. (Olaf Recker, Günther Neuwerth, Dieter Jacob)

5.4. HELICOPTER NOISE FUSELAGE EFFECTS

Agusta and CIRA are involved in the Brite-Euram project HELIFLOW, concerning the aerodynamic and aeroacoustic analysis of the phenomena due to interaction between the different components of the helicopter (main rotor, tail rotor, fuselage), and the study of some particular and complex operating conditions (e.g., sideward and quartering flight). The attention is presently focused on the evaluation of the fuselage scattering. A particular configuration (see Figure 12) has been analyzed, in conjunction with the Third University

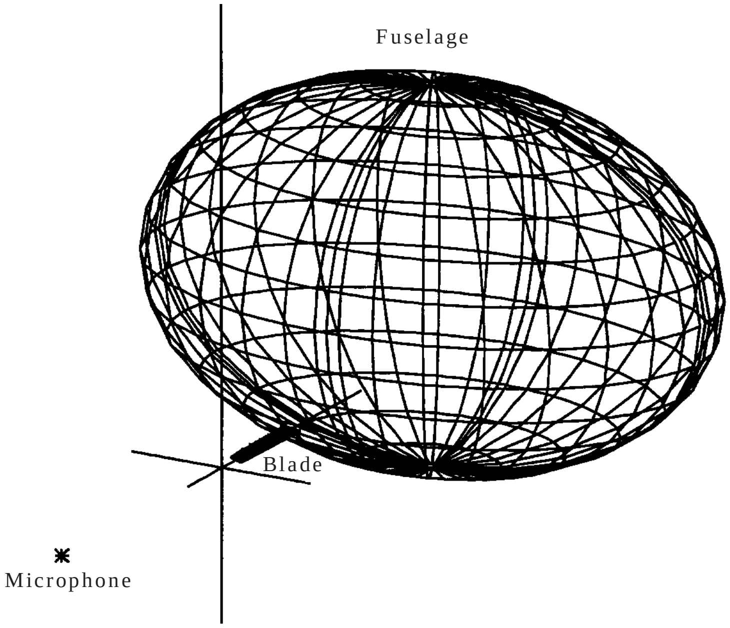

Figure 12. Fuselage influence on the noise from an isolated blade.

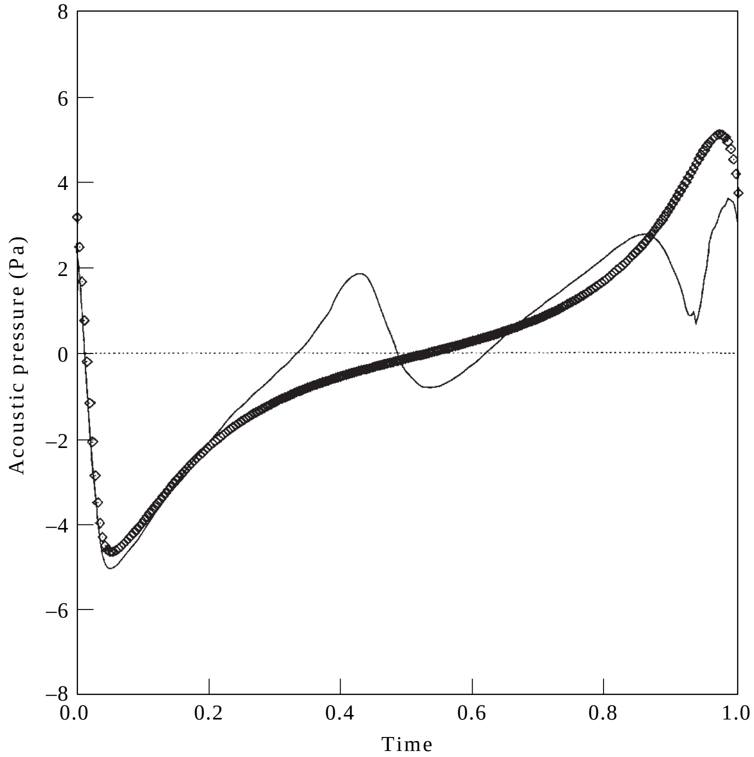

Figure 13. Fuselage effect on the waveform from an isolated blade. ◇, Isolated blade; ——, blade and fuselage.

of Rome, in order to assess the fuselage influence on the noise radiated by a rotating, isolated blade. Figure 13 shows how the presence of the fuselage affects the resulting noise waveform arising from the isolated blade for an in-plane observer location, while Figure 14 reports the comparison between the three different numerical formulations adopted to compute the acoustic pressure time history: Ffowcs Williams-Hawkings (CIRA), Kirchhoff (Agusta) and a Boundary Element Method (Third University of Rome). (Paolo di Francescantonio, Massimo Gennaretti, Sandro Ianniello)

5.5. NEW CODE FOR HELICOPTER NOISE

Over the last few years the main aim of the CIRA aeroacoustic group has been the achievement of a reliable prediction of the High Speed Impulsive (HSI) noise through the use of the FW-H equation. A new code has been developed implementing the far field approximation through an emission surface algorithm in order to avoid the Doppler singularity and extend the integration domain outside the sonic cylinder. An excellent numerical estimation of noise has been achieved for a hovering rotor blade up to a tip Mach number of 0·95, when a strong delocalization of the shock occurs in the flow field. Figure 15 shows the comparison with the available experimental data for a hovering blade at $M_{tip} = 0{\cdot}90$: the agreement is very good, both for the predicted negative peak value and the unsymmetrical shape of the resulting waveform. The new code will be adapted and used in the APIAN Project, where CIRA is involved in conjunction with Alenia and the analysis of modern propeller blades (operating at a supersonic tip speed) is required. (Sandro Ianniello)

5.6. A NEW ACOUSTIC BOUNDARY INTEGRAL FORMULATION

Concerning the prediction of the noise radiated by a transonic blade, a new boundary integral formulation has been developed at Agusta [22]. The new formulation, called Kirchhoff-FWH (KFWH) is obtained by removing the non-penetration condition in the FW-H equation. From an applicative point of view the method is very similar to the classical Kirchhoff method since the sound radiation is evaluated by executing some integrals on a closed surface surrounding the sound source. The advantages are that it is no longer necessary to evaluate the pressure normal derivative, simplifying the coupling with CFD codes, and that the formulation is much less prone to the large errors that the classical Kirchhoff formulation can produce if the integration surface is not correctly placed. A comparison of KFWH formulation with experimental data and classical Kirchhoff results is given for UH-1H hovering rotor at a tip Mach number equal to 0·95 (see Figure 16). (Paolo di Francescantonio)

6. AIRFRAME NOISE

6.1. THEORETICAL INVESTIGATION OF AIRCRAFT LANDING GEARS' AIRFRAME NOISE

Airframe noise is defined as the noise generated as a result of the airframe moving through the air. The main airframe components which lead to airframe radiation are landing gears and high lift devices. The continual development of quiet engines over the years has resulted in airframe noise levels comparable with the engine noise at approach. Airframe noise will become an equally significant noise source for the proposed future large aircraft. During the past 5 years noise research has been taken up again in the U.S.A.

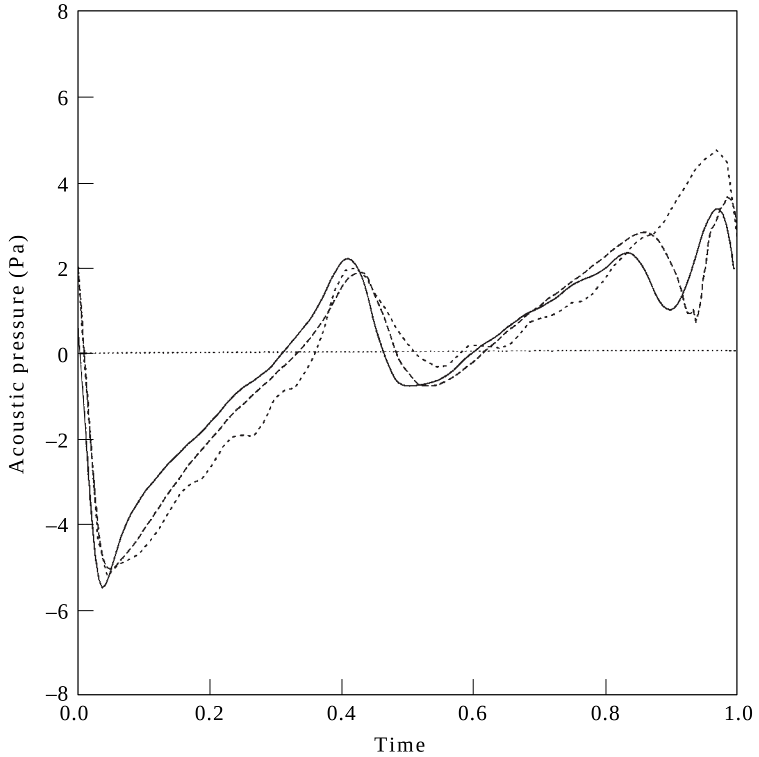

Figure 14. Acoustic pressure from BEM (——), FW-H (– – –) and Kirchhoff (····).

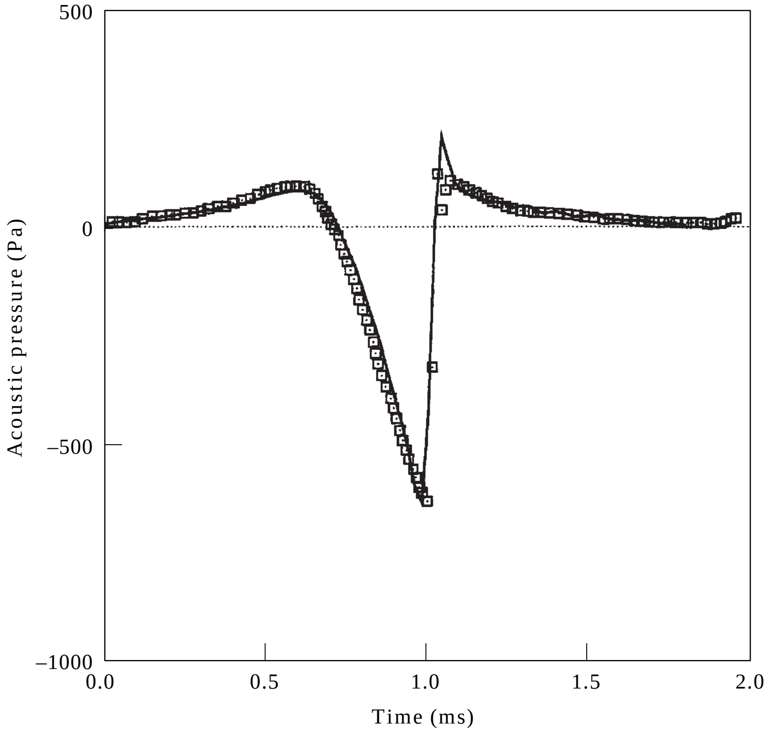

Figure 15. HSI noise for a hovering UH-1H blade; $M_{tip} = 0{\cdot}90$. □, Experimental; ——, numerical.

and this includes research into airframe noise. Airbus Industrie in 1995 has also sponsored two research projects: (1) noise source localization for a scaled A320/A321 aircraft in the CEPRA 19 wind tunnel; (2) determination of full scale A320 landing gear noise characteristics in the DNW. The experimental data of the latter form the basis for the current theoretical investigation in refining the landing gear airframe noise prediction methods. The validity of the improved model has been tested by using it to predict flyover noise from a range of Airbus aircraft, and has been found to give good agreement without any modification to the constants, which was required by the old model.

Part of this improvement has come about through the realization that the noise is a function of local flow around each component of the landing gear rather than simply a function of flight speed of the aircraft. However, the new model contains more geometrical details than the existing models, but it can be used with greater confidence to predict aircraft landing gear airframe noise. (Malcolm G. Smith, Steve Chow)

6.2. MICROPHONE ARRAY TECHNIQUE TO IDENTIFY AIRFRAME NOISE SOURCE ON REAL COMMERCIAL AEROPLANES IN LANDING APPROACH CONFIGURATION

An acoustic arrray was developed by DLR Berlin consisting of 111 microphones, sparsely and non-redundantly distributed on an 8×8 m^2 plate (see Figure 17). The array was mounted about 500 m before the threshold of one of the runways at Frankfurt Main airport. About 160 landings of commercial aircraft of all sizes were recorded. The exact location and the frequency spectra of the airframe noise sources and the sound emitted from the engine inlets and exhaust nozzles can be determined (see Figure 18). A comparison between the different aircraft types will help to identify unnecessarily loud noise sources. It was found that relatively quiet airframe noise sources can be detected even

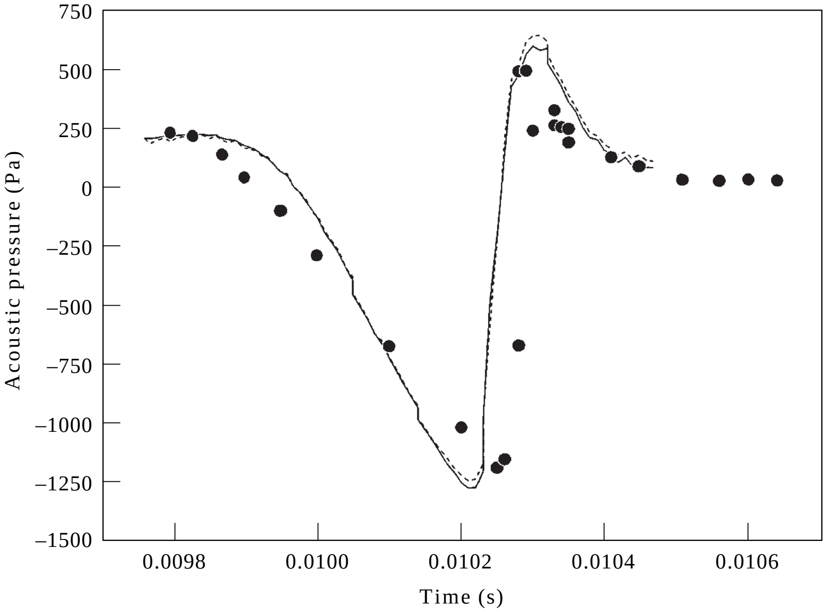

Figure 16. Kirchhoff-FWH code for noise from transonic blade.

in the presence of strong additional airframe or engine sources. The spatial resolution at 2 kHz was found to be about 0·4 m. The data analysis is carried out in cooperation with the acoustic consulting firm Akustik-Data. The investigation is supported by the German

Figure 17. Acoustic array at Frankfurt Main airport.

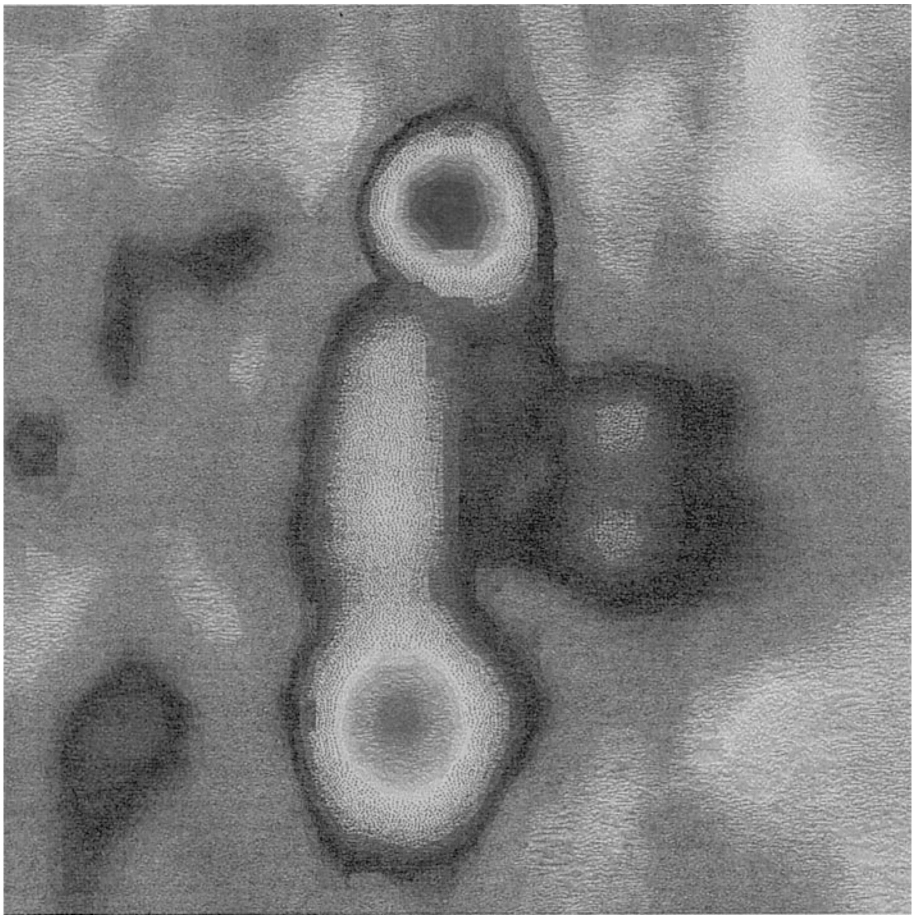

Figure 18. Acoustic pattern of aircraft (flying from right to left, rear engines right).

Ministry of Education, Science, Research, and Technology in cooperation with Daimler Benz Aerospace Airbus, DeutscheLufthansa AG, and Flughafen Frankfurt AG. (Ulf Michel)

7. TECHNIQUES AND METHODS IN AEROACOUSTICS

7.1. THE NOISE TEST FACILITY (NTF) AT DERA, PYESTOCK, U.K.

A new acoustic data acquisition and analysis system has recently been commissioned for the NTF anechoic chamber at DERA Pyestock. This system provides a considerable enhancement of the facility's acoustic data gathering/processing and analysis with synchronous sampling of 16 channels at 16 bit resolution at a sampling frequency of up to 250 kHz per channel. The raw acoustic digital data is acquired and stored in a matter of seconds thereby allowing the user a choice of on-line/post analysis of narrow-band and third-octave signal processing. The system also incorporates a comprehensive data processing/analysis software suite for specialist requirements. (Richard A. Pinker)

7.2. THE MICROFLOWN, A NEW ACOUSTIC PARTICLE VELOCITY SENSOR, TESTED IN AN IMPEDANCE TUBE

Recently, De Bree *et al*. [23] developed a new acoustic sensor at the University of Twente, The Netherlands, which measures the acoustic particle velocity. The new sensor, hereafter called the Microflown, can be used in the frequency range of zero to 20 kHz.

The Microflown consists of two cantilevers of silicon nitride with a platinum on top of them. The size of the cantilevers is $800 \times 40 \times 1\ \mu\mathrm{m}$. The measurement principle of the Microflown is based on the temperature difference between two resistive sensors, i.e., the two cantilevers, which are $40\ \mu\mathrm{m}$ apart.

Since the Microflown is a new sensor which has not fully been exploited yet, it was tested in an impedance tube (Kundt's tube). A special aluminium sample at the end of the tube has an orifice which accounts for the absorption. Excellent agreement is obtained when comparing the results both with theory [24], and with microphone measurements [25].

The Microflown can be a very attractive alternative to microphones, while it can also be used to determine sound level or acoustic intensity. Furthermore, the sensitivity to the direction of the waves can be a useful feature. The simplicity, the small dimensions, the dynamic range, the uniformity, the absence of resonant parts, and the expected low price promise to make the Microflowns a very useful tool in acoustics. (Frits J. M. van der Eerden, Hans-Elias de Bree, Henk Tijdeman)

7.3. CAA-SIMULATION OF TRAILING EDGE NOISE

In cooperation with BUAA (Beijing University of Aeronautics and Astronautics) DLR Braunschweig has started a research initiative into numerical aeroacoustics, aiming at solving the unsteady linearized Euler equations. The CAA-code was successfully used to simulate the noise generated by a single vortex with finite core C which is convected past the trailing edge of a plate with length L and zero thickness. The code, based on Tam's DRP-scheme was able to show the expected characteristics of sound generation and radiation pattern. For low Mach numbers of the mean flow, the results are in very good agreement with the classical analytical theory of trailing edge noise, including then third-power-law dependence of $\langle p^2 \rangle / \rho_\infty^2 c_\infty^4$ on the flow velocity, or its linear dependence on the flow Mach number. Figure 19 shows the simulated directivity in comparison with theory, including convective amplification following Howe. The a-symmetry of the result is due to the finite size of the vortex. An alternating passage of vortices on the upper and lower side of the plate would average out the directivity pattern to almost exactly the theoretical curve. (Jan Delfs, Xiaodong Li)

7.4. CFD METHODS OF FAN AERO-ACOUSTICS DESIGN

To predict the fan-OGV (Outlet Guide Vanes) interaction tones, and to be able to design a quiet fan, CFD methods have been applied at SNECMA. The methodology consists of performing a steady state 3-D calculation of the flow around the fan, from 3-D Navier–Stokes equations, then an unsteady compressible 3-D Euler calculation on OGV's, by using the description of the flow coming from the N.S. results. The load harmonics spectrum is computed from the unsteady static pressure field, and is used as input in an acoustic code to predict the rotor–stator interaction noise. (Daniel Berge)

7.5. BEM/FEM METHOD FOR FLUID–STRUCTURE COUPLING

In collaboration with the research project of CASA Space Division on acoustic loads on very lightweight antennas, a method has been developed at the Polytechnic University of Madrid to determine the complete coupling of fluid and structure. The method is based on a FEM for the structure and a BEM for the fluid. The advantages of the method are

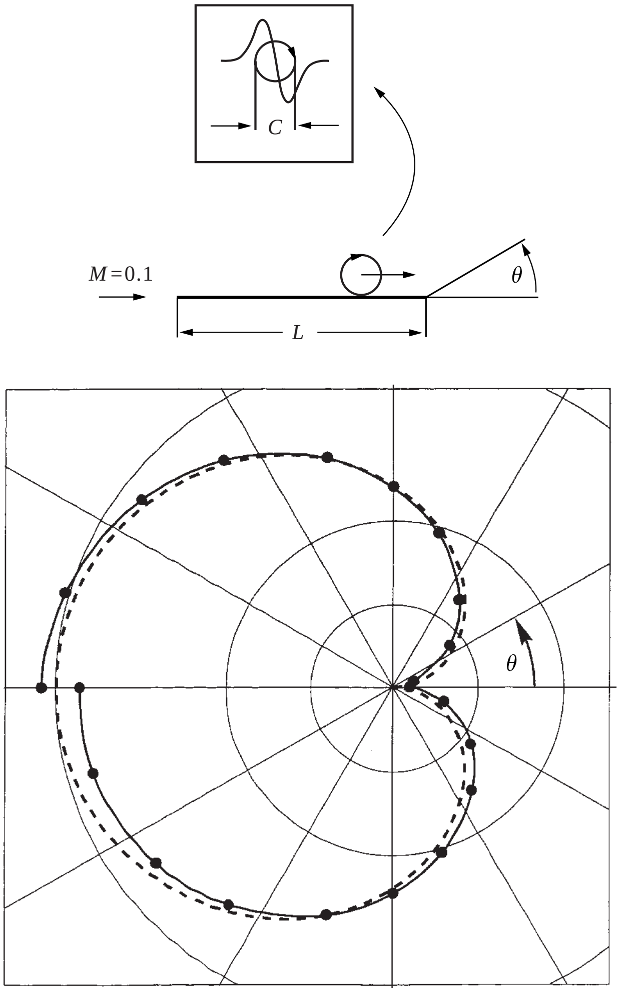

Figure 19. CAA-simulation of trailing edge noise, $L/C = 11{\cdot}25$. Lengths are proportional to rms value of pressure. ---, Theory (Howe).

the accurate solution of Kirchhoff's integral formulation of the Helmholtz equation including the exact Sommerfeld radiation condition at the far field and the computation of the natural frequencies and normal modes of the coupled fluid–antenna system. The method has been compared successfully with experimental data for different support conditions of the antenna. (Pablo García-Fogeda, Fernando de la Iglesia)

8. MISCELLANEOUS TOPICS IN AEROACOUSTICS

8.1. SUCCESSFUL CONCLUSION OF EU-FUNDED RESEARCH PROJECT DRAW

The project DRAW (Development of Design Tools for Reduced Aerodynamic Noise Wind Turbines) was aimed at improving the prediction of broadband noise from wind turbine blades. For the dominant trailing-edge noise mechanism a prediction model was developed at the TNO-Institute of Applied Physics (NL) which is based on a detailed description of the structure of the turbulent boundary layer close to the trailing edge. Input quantities can be obtained either from measurements or from CFD calculations. For the second important mechanism of inflow-turbulence noise an improved model was created at the Institute of Aerodynamics and Gasdynamics IAG (D). The model is based on Howe's acoustic analogy and on the boundary-element method. Both models are able to consider the true airfoil shape and can therefore serve as a design tool for low noise airfoils. The models were validated against wind tunnel measurements on airfoil sections which were carried out in the Small Anechoic Wind Tunnel of the National Aerospace Laboratory NLR (NL). The validation revealed that the absolute level of trailing-edge noise can be computed with reasonable accuracy. The differences in inflow-turbulence noise which are due to airfoil shape are predicted accurately. A first design of a silent airfoil was successful. (Gianfranco Guidati, Siegfried Wagner)

8.2. HIGH-SPEED TRAIN PANTOGRAPH MEASUREMENTS

In the framework of a national Dutch research programme, measurements of the aerodynamic noise of an Adtranz DSA 350 SEK high-speed train pantograph were performed by the National Aerospace Laboratory (NLR) in the German Dutch Wind Tunnel DNW-LLF [26].

Thirteen configurations—each at four or more different wind speeds—were tested, using an acoustic antenna and "single" microphones. The acoustic antenna consisted of 49 microphones, non-redundantly positioned in a plane $\approx 4 \times 4\ \mathrm{m}^2$, aimed at the localization of the pantograph noise sources and the determination of their respective contributions (see Figure 20). A number of tonal and broadband noise sources were found and spectral data of these sources were used by the Institute of Applied Physics (TNO-TPD) for the development and validation of a semi-empirical prediction code.

Analyses revealed that vortex shedding from various sharp and bluff parts of the pantograph is the most important noise producing mechanism. Inflow-turbulence noise, generated in the foot region of the pantograph, may also be important depending on the level and spectrum of the turbulence in the inflow (i.e., in the boundary layer along the

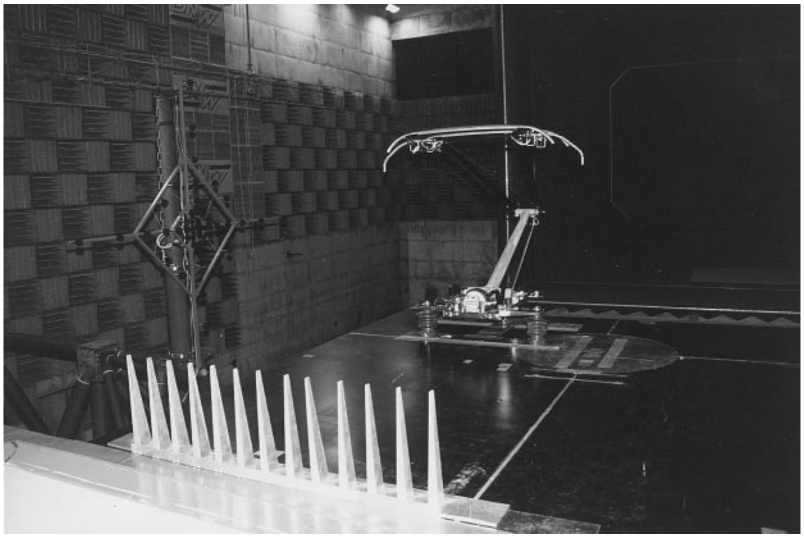

Figure 20. Overview of experimental set-up showing pantograph (middle), acoustic antenna (left) and vortex generators (front).

train roof). The results suggest that by optimizing the shape of the pantograph top region, a reduction in the order of 10 dB may be possible.

The findings of the research will be used by Technical Research of The Netherlands Railways (NS-TO) for defining measures to limit the noise nuisance caused by future operation of high-speed train operation in The Netherlands. (Ton Dassen)

8.3. ACOUSTIC FATIGUE OF AIRCRAFT STRUCTURES

Although near field jet noise levels have been reduced on civil aircraft since Concorde, specific components (e.g., flaps on aircraft) still experience high acoustic excitation levels combined with some jet efflux impingement and consequent thermal loads. The lack of a complete theoretical treatment led to the development of design guides and data sheets starting in the 1970s. However, the introduction of composites, and other new materials, presents problems in the design process. A 3-year research project is therefore being carried out using advanced analytical procedures, finite element analysis and complementary experimental studies in order to develop dynamic response prediction procedures which will result in guides for the design of box-type structures, such as flaps, made from these materials. It is particularly important that simple procedures be available for initial design, which could be supported by more complicated analysis as the final proposed configuration is chosen. (Steve Chow, Bob G. White, Robin S. Langley)

8.4. ACOUSTIC LOADS ON SPACECRAFT ANTENNAS

The presently available methods to predict the dynamic response and stresses, induced in antenna reflectors by the strong acoustic loads during launching, has been reviewed and applied by CASA to the mechanical design of the reflectors of the IOLA (Inter-Orbit Link Antenna) and LBA (L-Band Antenna) antennas of the ARTEMIS spacecraft (to be launched by ARIANE V). Simplified methods have been compared with sophisticated vibro-acoustic formulations to select the method which correlates best with experimental results. Also the way to model the environment inside the reverberant chamber, in which the tests have been carried out, has been one of the major topics under review. At present, a diffuse acoustic field is assumed although the measurements suggest that this assumption could not be true for the low frequencies.

Another point of interest has been the identification of the main parameters of the structure that controls the response, and methods to characterize the structure using both analytical and experimental techniques. The modal characterization of the specimen, including modal shapes and damping in the frequency range of interest, has been found to be most critical. The correlation between analysis and test must be done such that the surrounding air and the correct boundary conditions are taken into account. Finally, design solutions, that guarantee structural integrity, have been implemented and proved by tests after a full and successful qualification process. (Pedro Luengo, Jose-Luis Rioboo)

9. PROSPECTS

9.1. FUTURE COLLABORATION PROGRAMMES ON FAN NOISE REDUCTION

Following on from FANPAC, new proposals for collaborative research on aircraft noise reduction have been submitted to the EC and subsequently accepted, albeit with some reduction in funding. These proposals have been co-ordinated through the X-NOISE thematic network which has been formed as a result of the Environmentally Friendly Aircraft study (TEFA). One of the three Type I proposals, called RESOUND (Reduction of Engine Source noise through Understanding and Novel Design), concentrates on engine noise reduction at source, and in particular on fan noise reduction as summarized below.

The principal aircraft and engine manufacturers in Europe are facing increasing pressure to reduce aircraft noise levels. This arises both from the community expectations of 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 devoted 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 noise control technology".

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 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 European industry to compete on an equal footing with the U.S.

RESOUND addresses the challenge of reducing the noise at source, in particular turbomachinery noise, through (1) engine component aeroacoustic design and (2) 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 the following: 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 noize hazards of low NOx combustors; LP turbine noise reduction through exit guide vane design; turbomachinery noise reduction through active stator design; turbomachinery noise reduction by means of auxiliary aeroacoustic control devices. 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 proposals (RANNTAC and RAIN, respectively), supported by a Type 2 proposal (DUCAT) all of which will be 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 (US 200 million over 7 years).

RESOUND and the other related projects are due to start on 1 January 1998. (Brian J. Tester)

9.2. ROSAA PROJECT LAUNCHED

The Brite-Euram project ROSAA has been launched in 1998 (1 March), in which a unique rotor-craft simulation system will be developed integrating advanced aerodynamic codes with the comprehensive aeroelastic codes available to European manufacturers and with the latest generation European aeroacoustics codes. An important task of this project will be devoted to aeroacoustic prediction methods. The activities that will be performed are: the improvement of DERA's KIRAC code (based on a Kirchhoff formulation) for HSI noise prediction, the development of the unified aerodynamic–aeroacoustic BIEM method of the Third University of Rome, the testing of existing FW-H based codes (Agusta and Westland) and the development of a common interface to the aerodynamic full-potential code of ROSAA. (Piergiovanni Renzoni, Antonio Pagano)

9.3. MADAVIC PROGRAMME ON ACTIVE CONTROL

There is a strong demand in industry for new actuators with smaller size and improved properties; e.g., more power, less weight, higher reliability, less power consumption, and better compatibility to microelectronics. A new and expanding area of potential application for these advanced actuators is that of so-called smart (or intelligent) structures, material and systems. The target of the MADAVIC programme (Magneto Strictive Actuators for Damage Analysis and Vibration Control), co-ordinated by the Dipartimento di Progettazione Aeronautica of Naples "Federico II", is to address the particular and unique characteristics of magnetostrictive materials in this respect, aiming at two specific and very important fields of application: (1) detection and identification of damaged structures and (2) active control of vibration.

In the field of active vibration control and insulation, the conventional actuators are often reported to be strongly limited by narrow frequency bandwidths, a complicated design, the inability to support static weight, and lack of robustness. Hence, the entire project covers the following areas: reliability and quality of materials and products, safety and reliability of production systems, and technologies for vehicle and aircraft safety. The results of this multidisciplinary programme will provide the basic building blocks for the technology required to build actuator systems for the above mentioned new technologies, and a wide variety of other industrial applications. (Francesco Marulo, Sergio de Rosa)

10. SCIENTIFIC EXCHANGE AND INTERACTION

10.1. AIAA/CEAS AEROACOUSTICS CONFERENCE

The third joint AIAA/CEAS Aeroacoustics Conference took place in Atlanta, GA (U.S.A.), 12–14 May 1997. Six members of the ASC served on the Program Committee with Dr Andrew Kempton, Rolls-Royce, being the European General and Technical Chairman. Out of approximately 130 papers, about 25 papers were given by scientists from the CEAS-countries. This number corresponds to the previous 1996 conference at Penn State, reflecting again the restricted travel budget situation. However, the next, the fourth joint Conference, will be held in Toulouse, France, 2–4 June 1998, under the Chairmenship of Dr Gérard Fournier (France) and Prof. Tim Colonius (U.S.A.) where many more Europeans are expected to attend. (Hanno Heller)

10.2. ASC-WORKSHOPS

During 5–6 November 1997, at the DNW, The Netherlands, a Workshop on "Wind Tunnel Testing Techniques" was held, organized by the Aeroacoustics Specialists' Committee and the Dutch NVvL. It was the first of a planned series of dedicated ASC-Workshops. This highly successful meeting with 20 presentations was attended by almost 80 scientists and engineers (including several from the U.S.A.), with substantial participation from the aviation and automobile industry.

Directly following the Toulouse Conference, the second ASC-Workshop on "Aircraft Interior Noise Control" will be held on 8–9 June 1998, at the Daimler Benz Aerospace Dornier Company in Friedrichshafen, Germany, organized by Dr Ingo U. Borchers. (Hanno Heller)

REFERENCES

1. F. SIMON and S. PAUZIN 1997 *Proceedings of Active*'97, *Budapest*. Simulation of an active vibration control procedure: simulations–experiments comparison.

2. S. Pauzin and F. Simon 1996 *Proceedings of Inter Noise* 96, *Liverpool*, 1505. Development and application of structural intensity on composite panels.
3. F. Simon and S. Pauzin 1997 *Proceedings of Technical Specialists' Meeting for Rotorcraft*, *Williamsburg*. Active vibration control procedure to reduce internal noise of helicopter.
4. N. Peake and E. J. Kerschen 1996 *Journal of Fluid Mechanics* **347**, 315–346. Influence of mean loading on noise generated by the interaction of gusts wiht a flat-plate cascade: upstream radiation.
5. I. Evers and N. Peake 1997 *AIAA Paper* 97-1633. Forward noise generation by a cascade with camber and thickness.
6. S. J. Majumdar and N. Peake 1997 *Journal of Fluid Mechanics*, to appear. Noise generation by the interaction between ingested turbulence and a rotating fan.
7. B. M. Woodley and N. Peake 1997 *AIAA Paper* 97-1814. Vortex shedding from a cascade of aerofoils.
8. B. M. Woodley and N. Peake 1997 *Journal of Fluid Mechanics* **339**, 239–260. Global linear instability of aerofoil wakes.
9. B. M. Woodley and N. Peake 1997 *Journal of Fluid Mechanics*, submitted. Acoustics resonance in blade rows.
10. J. B. H. M. Schulten 1997 *AIAA Journal* **35**, 945–951. Vane sweep effects on rotor/stator interaction noise.
11. J. B. H. M. Schulten 1996 *AIAA Journal* **34**, 251–258. Effects of asymmetric inflow on near-field propeller noise.
12. L. W. Ilston, R. G. A. Angel, D. E. Patience and R. E. Burns 1993 *Proceedings AIAA International Powered Lift Conference*, *Santa Clara*, *CA*. Assessment methods for near field noise and ground erosion.
13. E. Campos and F. Mallén 1995 *CEAS/AIAA Aeroacoustics Conference*, *Munich*, *Germany*. Analysis and prediction of the noise generated by missile launching.
14. E. Campos and F. Mallén 1996 *Proceedings of NOISE-CON* 96, *The* 1996 *National Conference on Noise Control Engineering*, *Seattle*, *WA*, 867–872. Prediction methods for the noise generated by missiles.
15. J. B. H. M. Schulten 1996 *AIAA Journal* **34**, 251–258. Effects of asymmetric inflow on near-field propeller noise.
16. J. B. H. M. Schulten 1996 *Journal of Propulsion and Power* **12**, 477–485. Advanced propeller performance calculation by a lifting surface method.
17. J. B. H. M. Schulten 1997 *AIAA Paper* 97-1709, *Proceedings* 3*rd AIAA Aeroacoustics Conference*, *Atlanta*, *GA*. Comparison of measured and predicted noise of the Brite-EuRam SNAAP advanced propellers.
18. G. Algermissen and S. Wagner 1997 *Technical Specialists' Meeting for Rotorcraft Acoustics and Aerodynamics*, *Williamsburg*, *VA*. Computation of high-speed impulsive noise by an enhanced Kirchhoff method.
19. U. Ingard 1953 *Journal of the Acoustical Society of America* **25**. On the theory and design of acoustic resonators.
20. D. Brown 1970 *NASA CR*-1653. Investigation of the influence of duct-mounted Helmholtz resonators on the sound field of a model ducted propeller.
21. A. Hersh and B. Walker 1995 *CEAS/AIAA*-95-078/079. Acoustic behaviour of helmholtz resonators, Part I & II.
22. P. di Francescantonio 1997 *Journal of Sound and Vibration* **202**, 491–509. A new boundary integral formulation for the prediction of sound radiation.
23. H.-E. Bree, P. J. Leussink, M. T. Korthorst, H. V. Jansen, T. Lammerink and M. Elwenspoek 1996 *Sensors and Actuators A* **54**, 552–557. The microflown: a novel device measuring acoustical flows.
24. H. Tijdeman 1975 *Journal of Sound and Vibration* **39**, 1–33. On the propagation of sound waves in cylindrical tubes.
25. F. J. M. van der Eerden, H.-E. de Bree and H. Tijdeman *Sensors and Actuators A*, to be published. Experiments with a new acoustic particle velocity sensor in an impedance tube.
26. T. Dassen, P. Sijtsma, R. van Haaren, R. Parchen, K. Looijmans and H. Holthusen 1997 2*nd International Workshop on the AeroAcoustics of High-Speed Trains* (*AAT*), *Berlin*. The noise of a high-speed train pantograph as measured in the German-Dutch wind tunnel DNW.