UNCLASSIFIED

Defense Technical Information Center Compilation Part Notice

ADP011116

TITLE: Active Control of the Directivity of Fan Tones Noise

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: Active Control Technology for Enhanced Performance Operational Capabilities of Military Aircraft, Land Vehicles and Sea Vehicles [Technologies des systemes a commandes actives pour l'amelioration des performances operationnelles des aeronefs militaires, des vehicules terrestres et des vehicules maritimes]

To order the complete compilation report, use: ADA395700

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, etc. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP011101 thru ADP011178

UNCLASSIFIED

Active Control of the Directivity of Fan Tones Noise

J. JULLIARD , H. ANTOINE & CH. LOZACHMEUR
SNECMA Villaroche
Département Acoustique
Rond Point René Ravaud
77550 MOISSY-CRAMAYEL
FRANCE

A. ROURE
CNRS
Laboratoire de Mécanique et d'Acoustique
31, chemein Joseph Aiguier
13402 MARSEILLE Cedex 20
FRANCE

ABSTRACT

Experiments on a fan model (diameter 47 cm, 48 blades, nominal rotation speed 12,600 rpm) installed in an anechoic test cell have recently been carried out to assess the technique of Active Noise Control (ANC) applied to reduce the tones noise at the blade passage frequency. This paper describes in details the test model with the selected test configurations, the test facility and the ANC system.

Having already demonstrate the feasibility and the interest to reduce engine tones by application of this technique, the objective of this study was to evaluate the acoustic benefits brought by this technology, to check the robustness of the controller especially with engine rpm variations and to identify the realistic and promising configuration in view of engine applications. Loudspeakers wall-mounted and located in a duct cross-section close to the fan source were used as secondary sources. Error sensors were successively located outside the inlet and wall-mounted in the duct according to different distributions.

A multichannel controller highly efficient in term of frequency (up to 2500 Hz) and channels number (up to 16 channels) was specifically developed for this application.

For a 3D visualization of the far field a moving acoustic antenna was used to measure the upstream directivity. As for downstream radiation it was measured by a moving microphone. In order to know the space structure of the sound field with and without ANC, measurements of acoustic spinning modes were achieved and some radial acoustic pressure profiles were measured. In a first step, an acoustic driver was used as primary source and experimental results have shown different ways to reduce the noise radiated from the air intake. The first one consists in rejecting the noise to the backward duct, the second consists in redirecting the noise in an unannoyant area, the third consists in reducing and canceling (particular case) the total energy. A combination of these phenomena is as well found.

With the fan running, tests have indicated that the controller was robust and stable even if the speed variations were important. At first, error sensors were located on the Inflow Control Device and in this case an important tone noise reduction was observed. According to the frequency and actuators/sensors configuration, it was found either a global reduction of the tone level or a large decrease in the controlled angular sector with reinforcement elsewhere.

The uncontrolled downstream radiation was as well affected with either a global decrease or increase of the tone noise according to the test configuration. An increase of error sensors number has allowed to extend the quiet area. Far field SPL reductions up to 15 dB were obtained in a large angular range. Experiments for controlling the broadband noise did not provide good results on the fan source due to the weak coherence between the reference microphone signal and error sensors signal. From some error sensors configurations within the duct (realistic configuration for engine application) a significant reduction of tones noise was achieved but the sensors locations are more difficult to define.

Further studies should on the one hand include a methodology leading to a better optimization of the in-duct sensors location and on the other hand take into account the

Paper presented at the RTO AVT Symposium on "Active Control Technology for Enhanced Performance Operational Capabilities of Military Aircraft, Land Vehicles and Sea Vehicles", held in Braunschweig, Germany, 8-11 May 2000, and published in RTO MP-051.

effects of combining conventional passive liner always essential (efficient to high order modes rather associated with medium & high frequencies) and active techniques (efficient to low order modes rather associated with low frequencies).

INTRODUCTION

The continuous increase of the air traffic linked to the operations around airports leads to increase the community noise problem. Face to this situation, a significant number of airports have implemented their own rules often drastically more stringent than the international standard (ICAO-Chapter 3 of the annex 16). So a new international noise regulation, leading to the adoption of more severe noise limits, is discussed to be applied in a near future and thus avoided to have a proliferation of specific rules for each airport.

With pressure continually building towards lower community and cabin noise environment, an important research effort to improve the noise control has to be undertaken. For current Turbofan engines (bypass ratio between 5 and 8), the fan noise (tones and broadband) is a major component at approach in spite of a quiet fan design and treated (passive liner) ducts. For the future turbo-machine concepts such as ultra high bypass ratio (UHBR) engines, the fan noise will be a component major at approach and as well at take-off. In addition, UHBR engines with shorter inlet and exhaust ducts, lower tip speed and lower blade numbers have a noise signature more extended to low frequencies and a nacelle treated area significantly reduced compared to current engines. So passive technology will not be likely sufficient to reduce the fan noise and especially low frequencies tones (Multiple Pures Tones for interior noise and Blades Passage Frequencies tones for community noise).

So novels means of further reducing engine noise have to be implemented and active techniques applied to the source (action on aerodynamic or acoustic mechanisms) and to the sound propagation are promising ways to improve the noise situation.

SNECMA in close collaboration with LMA/CNRS Marseille led a large number of tests on a fan model in order to investigate the application of the Acoustic Noise Control (ANC) to control the inlet noise radiation. They have experimentally demonstrated the potential of these techniques as efficient mean to reduce the fan tones noise. Others experiments mainly US performed on ducted fan showed as well a good potential for attenuating the tones radiation[1,2,3].

In this paper are described experiments performed by Snecma knowing that for developing controller and software SNECMA was associated with LMA Marseille. Hardware and measurements system relative to this experimental study are presented. Different tests configurations were assessed in positioning the control sensors at first outside the inlet in the spatial area where the noise is to be reduced and then for a realistic configuration wall-mounted in the inlet. Acoustic results are presented and discussed from far field measurements in a 3D visualization and in-duct measurements.

EXPERIMENTAL SETUP

A fan model driven by an electrical engine (1,2 MW) is installed in an anechoic test cell at the SNECMA Villaroche Center (figure 1).

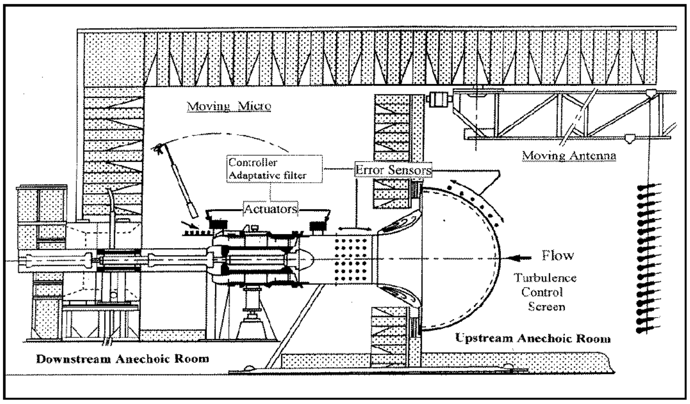

Figure 1 : Schematic diagram of the fan model in the anechoic test cell

The facility includes an upstream and downstream anechoic room separated by an acoustic barrier. A moving antenna equipped with 27 acoustic sensors enables the measurement of the radiated upstream sound field on a large angular range in two directions. In the downstream part, only a moving microphone gives information about the radiated noise.

The fan model used is a single stage axial fan with 48 blades and a stator with 98 blades. The design rotation speed is 12,600 rpm and the fan diameter is 47 cm. Nine and then twelve rods (figure 2), equally spaced circumferentialy, were located upstream of the fan stage in order to generate wakes interacting with the rotor blades. These interactions produce a relative high level of tones noise by exciting particular cut-on spinning modes function of rotor blades and rods number. The lower excited mode is a plane wave with 12 rods and a spinning mode 3 with 9 rods at the fan Blades Passage Frequency .

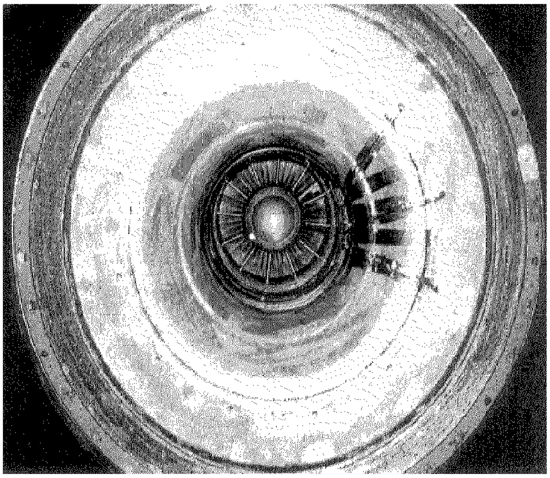

Fig. 2 : Face view of the inlet

THE ACTIVE NOISE CONTROL SYSTEM HARDWARE

As represented in figure 1, the ANC components are the followings :

- As secondary acoustic sources, an actuators ring constituted of eight loudspeakers flush mounted and equally spaced on 360° at the same axial location.
- As control transducers, eight electret sensors installed in a first stage out of the duct on the ICD to control the directivity and in the second stage inside the inlet to control the propagation.
- As controller, a multichannel designed and manufactured by LMA/CNRS Marseille has been used. It enables to manage signals coming from ten error transducers and to drive up to eight noise sources.
- Concerning the software relative to the control unit, several adaptive algorithms developed by LMA have been tested and the best selected one to control the fan noise is based on a least mean-square (LMS), a method which adapts continuously the coefficients of the adaptive filter to make the best of slightly rotation speed.
- The reference signal, required for the feedforward controller, is provided both from an optical sensor or an magnet sensor. It generates a sequence of pulses correlated with the RPM and therefore the fan BPF.

MINIMIZATION METHOD

The LMS algorithm requires a good evaluation of transfer function between all actuators and error sensors. So it is important than the degree of coherence between signals to be the closest of 1 to get an high level of attenuation.

The first step consists of identifying paths secondary sources to sensors from set of pulses injected successively on each actuators. The algorithm determines then in a real time the coefficients of filter (FIR) associated to each channel to drive actuators. It uses the filter reference coming from the convolution of the reference signal with the pulse response relative to the paths sensors/actuators. After determination of filters and in considering the reference signal, the controller is able to drive actuators through amplifiers in order to minimize (square mean method), the quadratic average of the function fast variation of phase with the frequencies. For instance at the same frequency a slight modification of the temperature leads to a fast variation of the transfer function phase. So it is important than the software to be enough robust in order to take into account these abrupt evolution.

STRATEGIES OF CONTROL

The approach selected is based on the well-known principe of destructive interference which consists of superposing at the fan noise an other sound field in order to reduce in all space or in a selected angular range the radiated tone noise. Two strategies have been investigated. The first one is the generation one or several antimodes. The second one is an approach based on the restructuration of the sound field to create a controlled quiet sector. The aim is to generate an acoustic field able to produce a modal structure which combined to the fan source modal structure rejects the acoustic energy in an annoyant area and create a quiet zone. This last strategy seems to be the way to privilege for engine application because of the BPF' tones modal structure is rich and complex and the interaction stator-rotor modes represent only a small part of tones energy. Nevertheless for buzz-saw noise the modal approach control appears more adequate with a known and specific spinning mode for each MPT's.

In order to examine the potential reduction of a perfect active noise control system implement on an relatively quiet recent engine (by-pass ratio between 5 and 7), calculation in EPNL by canceling discrete tones radiating from the engine fan inlet and fan exhaust was conducted. The conclusion is that the attenuation can reach 5 EPNL cumulated on the three monitoring points with a consequent reduction at take-off and a smaller benefit at approach and sideline.

In our experimental work, it is the way the more difficult aiming the reduction of the far field noise which has mainly been investigated.

INTERNAL AND EXTERNAL ACOUSTIC INSTRUMENTATION

Besides the instrumentation relative to operate the ANC , in-duct measurements consists of :

- Wall-mounted microphones, one fixed and one moving (360° rotating ring) for spinning modal measurements
- A profiled acoustic probe allowing the measurement of the acoustic pressure radial profile

The upstream and downstream directivity pattern on engine is usually regarded as an axisymmetric radiation because of the modal richness and a weak coherence between modes. With the ANC working the combination between modes of secondary and primary sources which leads to create an area of silence is very often represented as an asymmetric field and thus a 3D visualization is recommended.

So in order to get a better characterization of the radiated noise in the upstream arc (controlled radiation) a vertical antenna (fig 3) equipped with 27 microphones has been developed to sweep an angular range from +60° up to -60°. In the downstream part a moving microphone allows to check if the system rejects or not additional tones noise to the aft duct .

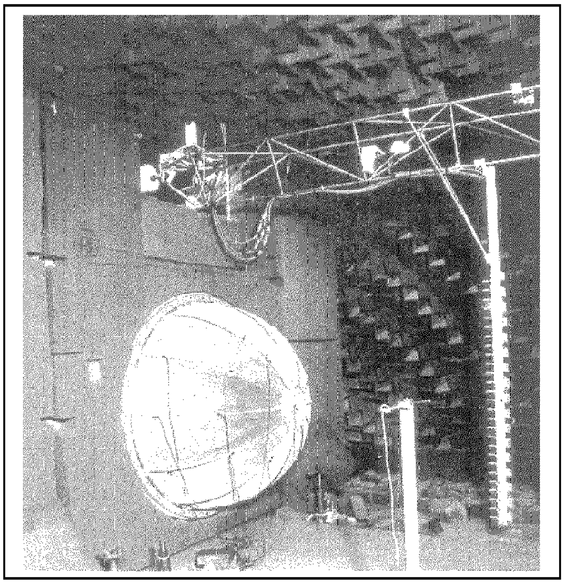

Fig. 3 : Upstream acoustic instrumentation

FIRST COMPAIGN OF TEST : RESULTS ANALYSIS

In a first step and especially for error sensors located in-duct, some configurations using a loudspeaker as primary source have been evaluated to study the influence of actuators and errors sensors number and location. Experimental results from fig 4 up to fig 11 are shown at 600 Hz and 1000 Hz for configurations using four error sensors and four actuators

At 600 Hz, a complete cancellation of the tone is observed as well in the aft arc as in the forward arc by using 4 errors sensors equi-distributed on the bell-mouth. Modal analysis confirms an attenuation of modes (1,0,-1) by 40 dB.

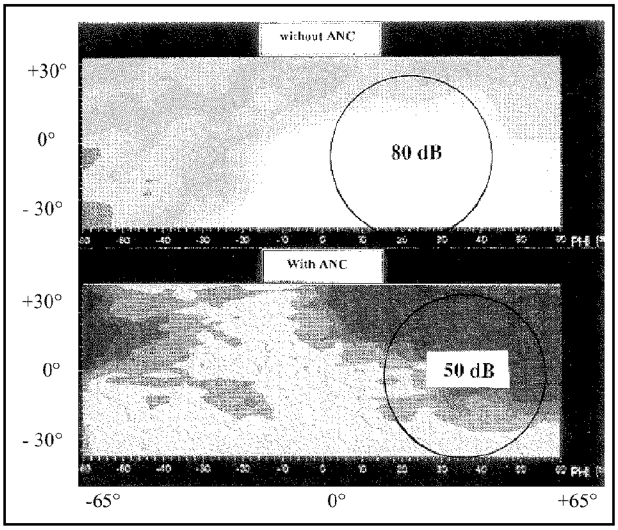

Fig. 4 : Upstream far field at 600 Hz

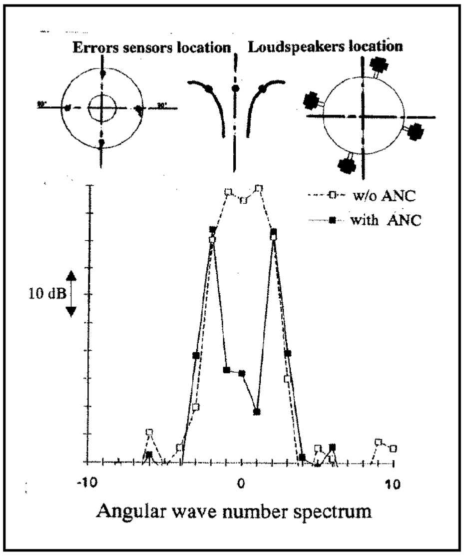

Fig. 5 : Angular wave number spectra at 600 Hz

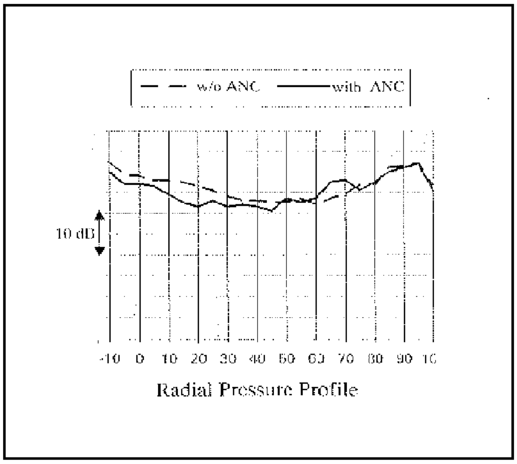

Fig 6 : Inlet Radial Pressure Profile at 600Hz

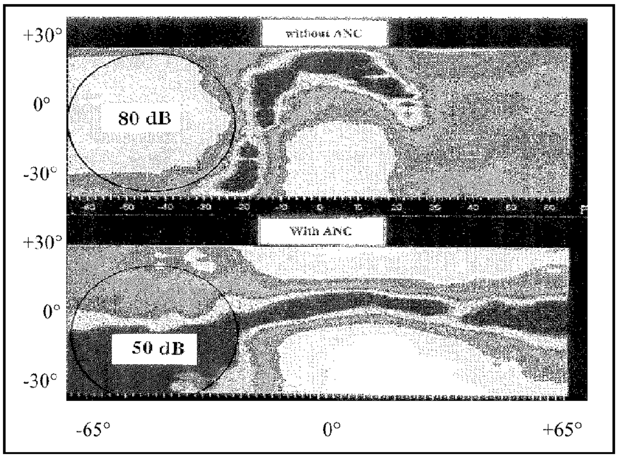

Fig. 8 : Upstream far field map at 1000 Hz

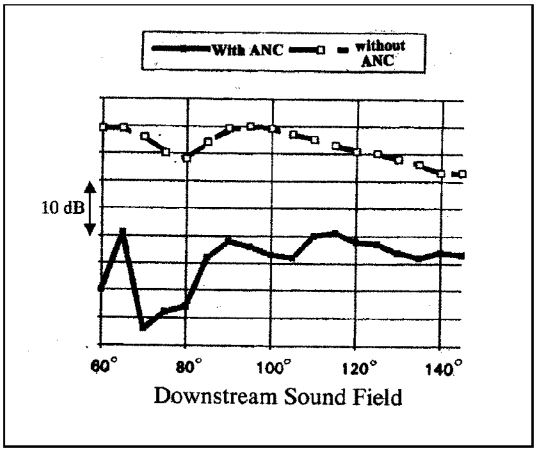

Fig 7 : Downstream far field at 600Hz

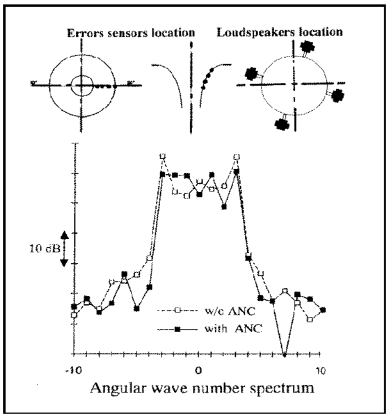

fig. 9 : Angular wave number at 1000 Hz

At 1000 Hz, with a more complex modal structure, acoustic results (fig 8 to 11) in the form of map of sound level, with active control on and off, are more difficult to analyze with in the forward arc a reduction in the opposite direction where the sensors are located (location on a axial line). However in the aft arc the tone level increases. With the ANC working the modal analysis shows that the inlet angular wave number spectra is enough similar whereas the radial pressure profile is different. In fact, the reduced number of error sensors does not allow an adequate modal control and it is rather aimed to have a control of the directivity.

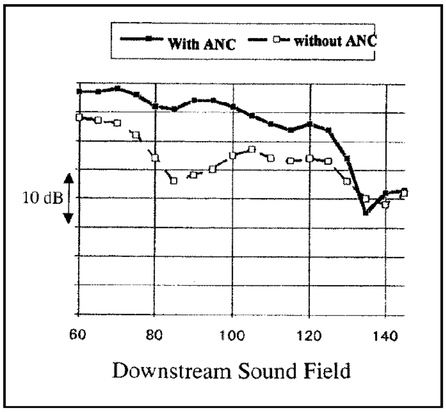

Fig. 10 : downstream far field at 1000 Hz

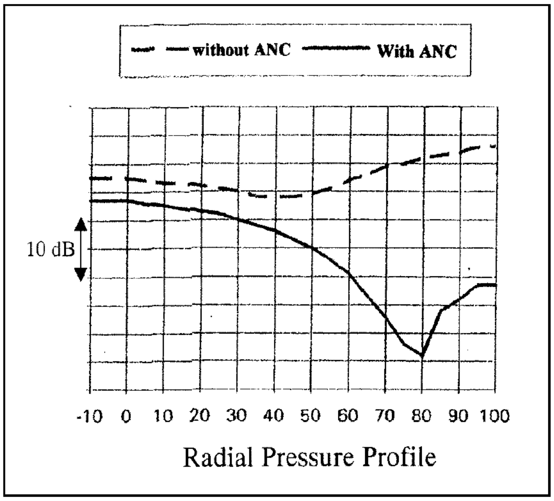

Fig. 11: Inlet radial pressure profile at 1000 Hz

Using a loudspeaker supplied from white noise and flush-mounted in the aft duct as primary source, it has been performed an active control by using 2 error sensors (out of the duct) and two actuators. Results in the far field show a significant reduction of noise on the frequency range 400-800 Hz in a large angular sector (fig 12).The good correlation between primary and secondary signal explains this good result, however no significant result was obtained from a fan broadband noise. The poor coherence between error sensors and reference signals explains this result.

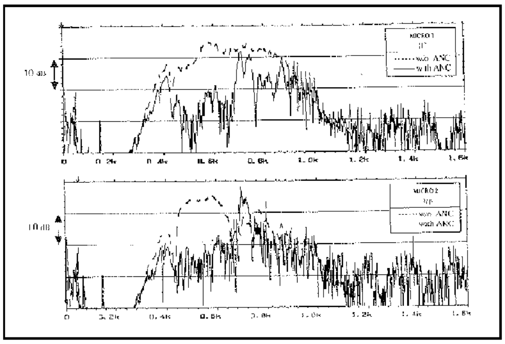

Fig 12 : Broadband far field spectra with and without control

In a second step, ANC was implemented on the fan fundamental tone (1 BPF). The fan model was running at low rpm because of the large number blades of the rotor and the low frequency range aimed for the ANC application. So the tones emergence was not always important compared to the broadband noise in spite of rods located in front of the fan for excited specific spinning modes.

In fact in term of frequency, it is representative of the aimed frequencies range on engine but not quite in term of ka (k : wave number & a : duct radius) and therefore of the modal richness.

Error sensors were at first located on the ICD. The first test[4] was achieved by using a microphone system to explore the forward radiation in a horizontal plane and the aft radiation in a vertical plane. Results presented in fig 13 and 14 show a good efficiency at 750 Hz (7 cut-on modes) with a global reduction anywhere of the BPF by 10 up to 20 dB and at 840 Hz a reduction by 10 dB on the controlled area with a reinforcement of level in the aft arc. The broadband noise is a floor noise which is a limitation to measure the true acoustic benefit at some angles.

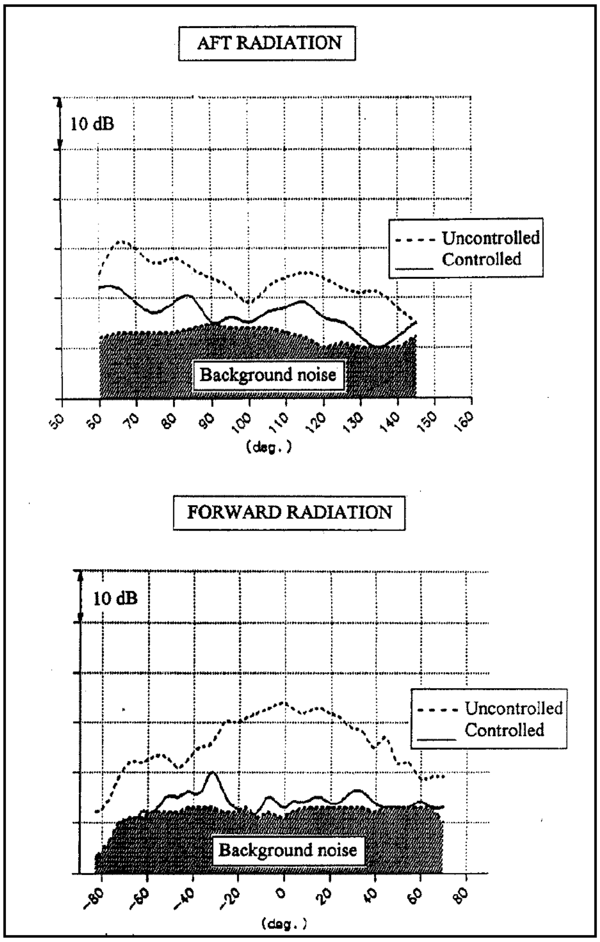

Fig. 13 : Upstream and downstream directivity (1 BPF / 750Hz) before and after control

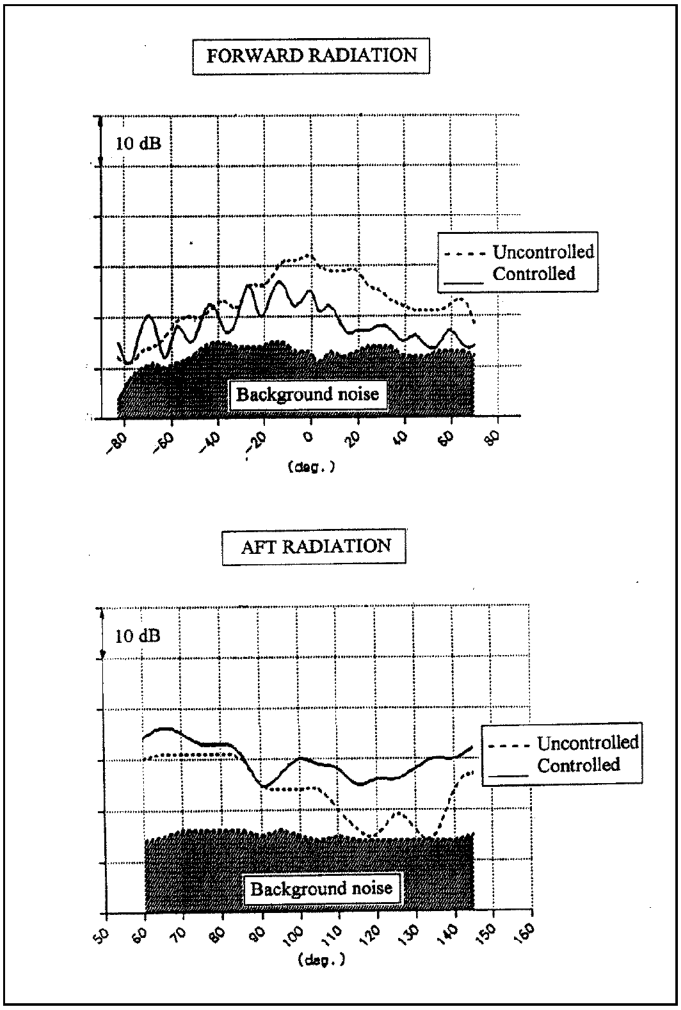

Fig 14 : Upstream and downstream directivity
(1 BPF / 840 Hz) before and after control

SECOND TEST CAMPAIGN : RESULTS ANALYSIS

An additional test was conducted by using several relevant error sensors & actuators configurations with the fan model running at different stabilized rpm. A new moving antenna measuring the radiated noise in a large area was installed.

All acoustic analysis was performed at the BPF by using a tracking system drove by the rpm.

Our strategy was to minimize the radiated energy over a sector rather to reduce the total radiated power.

The control, with error sensors located on the ICD (out-duct) shows a good efficiency and the quiet area is well in the extension of the controlled zone. In addition with an increase of the number of error sensors the quiet area is larger. In figure 15, it is shown a sound map representing the forward radiation of the BPF with and without control for a configuration of 3 sensors and 4 actuators at 2100 Hz. A reduction by at least 10 dB is noticed on a 60° angular range. Elsewhere, the trend is to increase the sound level and especially in the aft radiation. The acoustic pressure radial profile measured in the duct confirms this result.

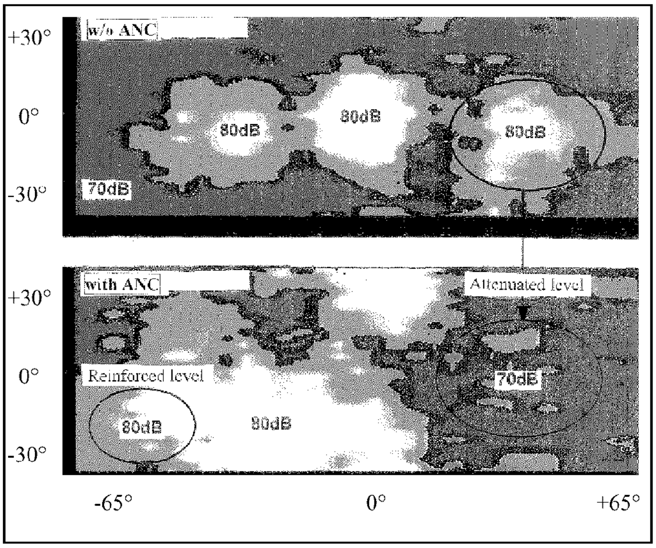

Fig. 15 : Upstream far field map (1 BPF / 2100 Hz)

The plots of the angular wave number spectrum in figure 16 are more complicated to analyze.

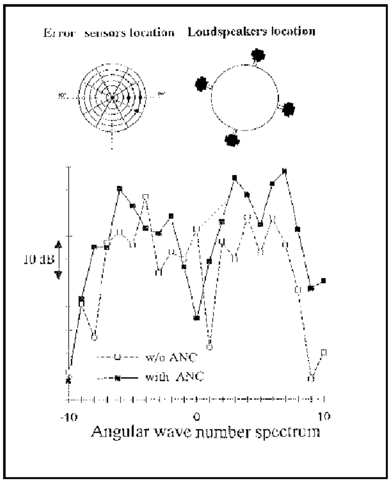

Fig 16. : Angular wave number spectrum
(1 BPF / 2100 Hz)

More interesting and realistic is the control from in-duct microphones. In figure 17 is shown, for a configuration of 7 in-duct error sensors distributed on 2 close axial arrays (figure 18) and 4 actuators, results obtained with the control working on the BPF at 1700 Hz. Relative to the forward radiation, it is found an increase of the tone level in the angular range towards sensors whereas a significant reduction is measured in the opposite direction of the location sensors. In the aft, sound levels are reinforced on the overall measured angular range.

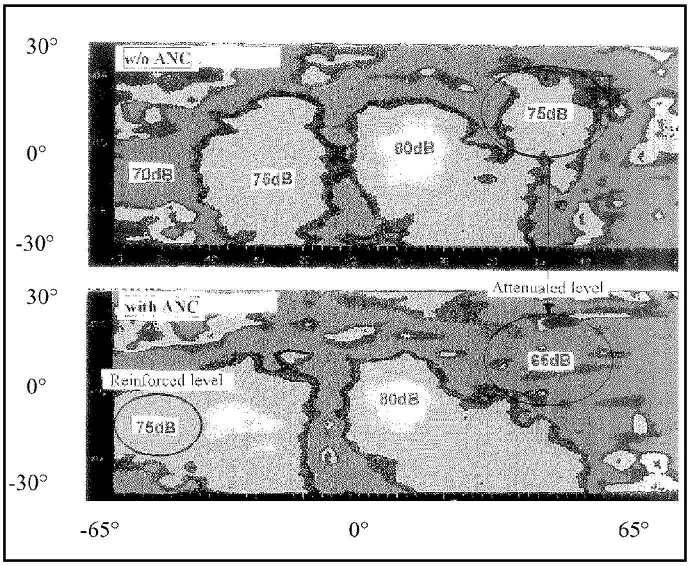

Fig 17 : Upstream far field map (1BPF/1700Hz)

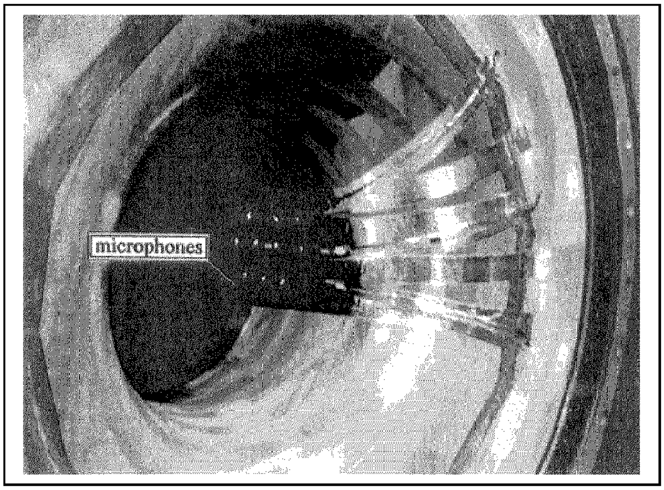

Fig. 18 : In-duct error sensors location

Others configurations were tested with results more or less good and it was observed that the number of channels was insufficient to investigate more. It was found that the reduction obtained in any particular case depended upon the frequency of tones and their shift with rpm and the amount of ANC suppression depended on as well the tone protrusion from the broadband noise.

DISCUSSION

The modal control strategy requires to use a large number of error sensors and actuators and its application gives relative good results for an acoustic source with some angular dominant mode. Nevertheless with a complex modal structure as met on engine results are probably less good. An other interest is a weak reinforcement in the uncontrolled area .

An other strategy consists in working on the duct axial wave-numbers which is connected to the radiation far field angle. Recent works [5,6] showed interesting results by minimizing a specific wave-number relative to the sideline radiation

With a limited number of transducers and a complex modal structure, a strategy aiming at redirection the radiation to obtain a low noise area in the far field by a mechanism of modal restructuring in combining for instance 2 different modal structure has been investigated. The difficulty consist of having the right information from the in-duct measurements to generate with actuators the required sound field .

FUTURE WORKS

Further experimental studies are going on in the European framework in order to assess and optimize different strategies based on the ANC technique applied to the control of the tones radiation. For instance, several rings of actuators should be used to have a better control of the secondary sources modal characteristic (especially the radial modal structure).

A combination passive and active technologies is to be investigated knowing that these techniques are complementary. Indeed the passive liner more dedicated for the broadband noise reduction has already shown it can contribute to improve the performance of the ANC to reduce tones. In fact the attenuation of the passive liner increases with the mode order and the frequency showing a good efficiency on higher modes which radiate on the side. Whereas the ANC is easier to work out on low modes and low frequencies. The benefit of combined effects are still to assess more accurately

An other way of work, in cooperation with European partners, is investigated to develop specific secondary compact acoustic sources to lead to flight-worthy actuators.

CONCLUSION

An active noise control system with out-duct & in-duct error sensors (inlet-mounted) and a ring of actuators has demonstrated a good performance to suppress the inlet tones noise from a fan model. Using a multichannel controller and an adaptive algorithm based on a Least-Mean-Square (LMS) method, the control system was robust enough to accommodate of rotation speed variations.

Control configurations of far field error sensors yields attenuation of up to 15 dB on the inlet fan tones noise on a large angular range in the radial extension of the sensors location. Elsewhere it is often obtained an increase of noise level. The aft duct radiation uncontrolled is slightly higher. In this case the mechanism of control involves a complex restructuring of the spinning modes leading to destructive interference in the control area. At low frequency with low order modes a sound power attenuation is observed everywhere and in this case the mechanism is rather a modal suppression.

The use of in-duct wall-mounted sensors evenly distributed according to either the azimuthal or axial direction allows to obtain in the far field a quiet angular range area with suppression up to 10 dB. Nevertheless, the quiet area is smaller and the benefit depends on test configuration and source characteristic. Criteria based on modal distribution and radial wave-number have been used as a guide.

The strategy of redirectioning in the space the tones radiation to provide a quiet area seems to be well adapted to the complex modal structure of the engine source. Nevertheless in function of specific source characteristic an other strategy can be required. So further works have to be undertaken in terms of criteria for designing optimal configurations, of development of hardware (controller, actuators,..), of combination passive and active technologies to provide a flight-worthy system.

REFERENCES

1 Smith, J.P., Burdisso R.A., and, Fuller C.R., " Experiments on the active control of inlet noise from a turbofan jet engine using multiple circumferential control arrays", AIAA/CEAS paper 96-1792.

2 Sutliff, D.L., Ziquiang, H., Pla, F.G., Heidelberg, L.J., " Active noise control of low speed fan rotor-stator modes" AIAA paper 97-1641.

3 Ikelheimer, B.J. and Nagel,R.T., " Active noise control of multiple acoustic modes in a circular duct ", AIAA paper 96-1781.

4 Julliard, J., Riou, G. and Lozachmeur, C.," Recent developments in turbomachinery noise control and reduction systems ", AIAA paper 93-4375.

5 Smith, J.P. & Burdisso R. A., "Active Control of Inlet noise from a Turbofan Using Inlet Wave-number Sensors", AIAA paper 99 - 1808

6 Joseph, P., Nelson, P.A., & Fisher, M.J.," Active Control of Turbofan radiation using an In-duct error Sensor Array " Proceedings of active 97, Budapest, Hungary, August 1997.

Paper#18

Q by G.E.A. Meier: A real engine generates sound of high power. Can one provide corresponding sound energy by a loud speaker?

A. (J. Julliard, H. Antoine): Some studies are on-going to design loud speakers which can generate high sound pressure levels. First results are very promising.