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AERO-ACOUSTIC OPTIMIZATION OF THE FANS AND COOLING CIRCUIT ON SNCF'S X 72500 RAILCAR

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This paper presents the results of studies concerning the fans on SNCF's X 72500 railcar with a view to reducing the level of ambient noise. The paper first describes the operation of an axial fan and then the main sources of noise generated by this type of fan. The interactions between acoustic emissions and mass output are then described to illustrate the advantages of an acoustic and pneumatic predictive device. Finally, a new design of axial wheel on the SNCF railcar is described which has reduced the acoustic emission by 10 db whilst still improving the initial ventilation performance.

1. INTRODUCTION

For many years railway cars have suffered from acoustic problems linked to the sub-assemblies that dissipate the heat energy. Palliative solutions are generally used. For example, by controlling the rotational speed of the fans' airscrews or by acoustical treatment of the ventilation circuits using special materials.

These solutions can be expensive (controlling speed) and may not be durable. In certain cases they can reduce the service life of the sub-assemblies that have to be ventilated because of the reduction of output. This approximate and corrective approach is based on the following:

- noise pollution levels noted recently following the imposition of European legislation relating to ambient noise;
- the acoustic function is not integrated into railway vehicle design at the conceptual study stage;
- the main function of a fan is to dissipate the heat energy;
- the predictive acoustic tools are not considered to be very reliable;
- the technology used to make fans is very basic for economic reasons;
- the ventilation circuits have been optimized.

2. DESCRIPTION OF THE OPERATION OF AN AXIAL FAN

A fan is composed of several components (see Figure 1):

- an airscrew;
- an electric motor to drive the airscrew;

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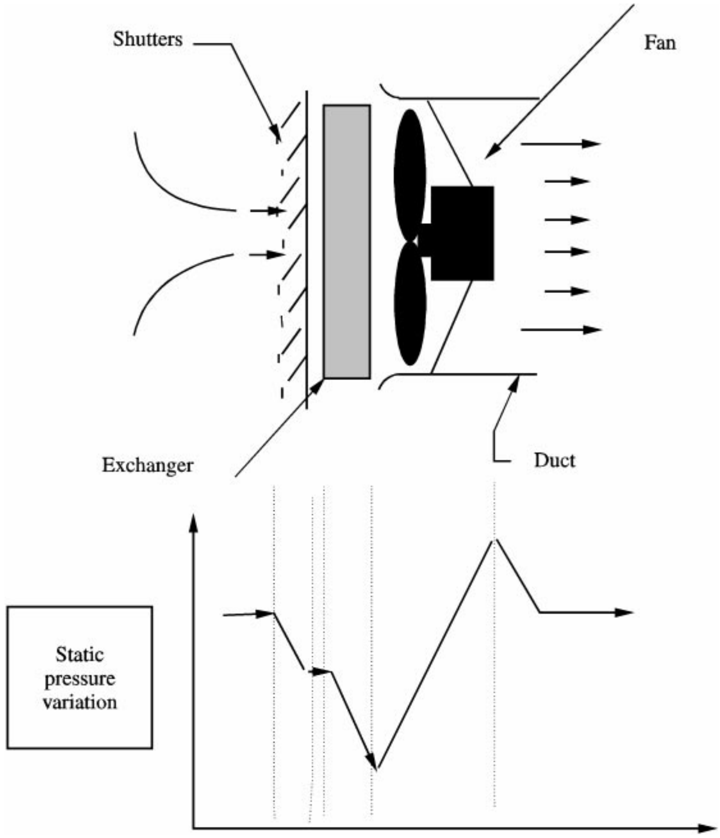

Figure 1. Axial fan and cooling system.

- a duct, with or without a straightener, to direct the air flow;
- supports to hold the motor in place;
- an electronic module to control the speed of the electric motor.

The main function of a fan is to provide a sufficient flow of air through heat exchangers and to compensate for the loss of flow from the cooling circuit.

The mass of air, which is not initially in motion, is moved by the rotation of the airscrew. The airscrew creates a difference in static pressure at its edges.

When the airscrew turns, the blades cause aerodynamic drag (varying according to the rotational speed), which is reflected in the electric power consumed by the motor driving the airscrew.

Downstream of the airscrew, the rotating air is driven at a speed approximately equal to 50% of the rotational speed of the motor and the axial air speed corresponds to the output of the airscrew divided by the area of the annulus formed by the rotating blades.

The vector sum of these rotation and translation speeds corresponds to a "helicoidal" speed that creates a dynamic pressure P_{dyn}. This dynamic pressure can reach high levels compared to the static pressure provided by the airscrew.

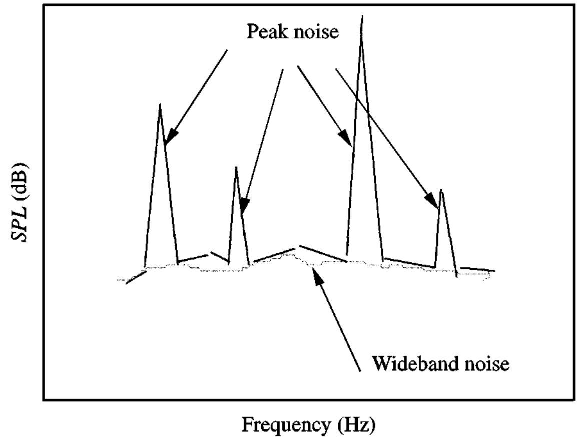

Figure 2. Spectrum analysis of a fan.

In certain applications, manufacturers fit straighteners to recover the rotational energy. This significantly increases the level of noise emitted by the fan.

When the air flow leaves the duct the dynamic pressure decays in the atmosphere. *A conventional fan therefore creates a static pressure that corresponds to the performance of the airscrew alone.*

3. MAIN SOURCES OF ACOUSTIC EMISSIONS FROM A FAN

The noise generated by a fan includes:

- aerodynamic noise (airscrew, supporting feet, duct);
- vibration (interaction between the component parts);
- electromagnetic noise (electric motor and speed control).

There are two types of aerodynamic noise (see Figure 2):

- peak noise (often called siren noise);
- turbulence or wide band noise.

The following elements contribute to aerodynamic noise:

PEAK NOISE	WIDE BAND NOISE
• **Airscrew-stator interaction** • **Fluctuations upstream** • **Blades** • **Supports** • **Rotational speed**	• **Whirls released** • **Airscrew stalling** • **Blade ends**

The aerodynamic sources created by an airscrew in rotation are described in Figure 3.

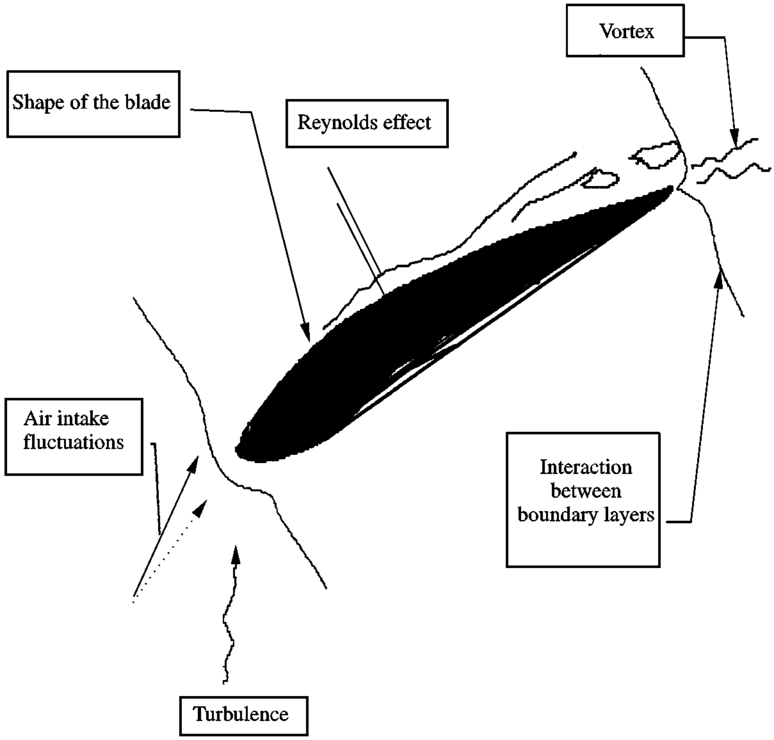

Figure 3. Sources of aerodynamic noise produced by the airscrew in rotation.

The air flow straighteners and the feet supporting the motor in the path of the airflow cause additional peak noise.

The manufacturing tolerances linking the airscrew and the motor are originally static and dynamic unbalances cause additional mechanical vibration.

4. CHARACTERISTIC CURVES OF A FAN

A fan can be described by its acoustic and ventilation performance. The curves in Figure 4 show the development of pressure against output and acoustic power against output for an airscrew.

When the blades of the fan stall, it causes a rapid increase in the acoustic power emitted, which occurs at the same time as a drop in ventilation performance (see Figure 4).

When the fan is functioning correctly, the development of the acoustic power against output is linear. It depends in particular on the following parameters:

- diameter of the airscrew;
- rotational speed;
- number of blades;
- form and surface area of the blades.

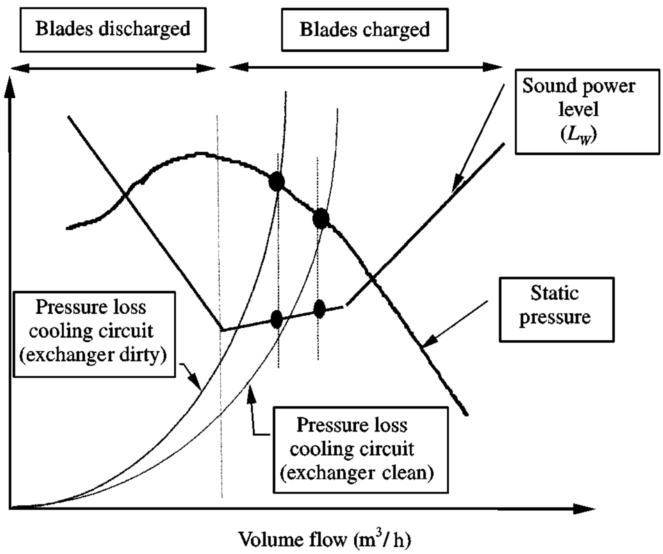

Figure 4. Characteristic curves of a fan.

The difficulty when designing a silent fan is to remain in the lower part of the acoustic power curve whilst guaranteeing the required ventilation performance.

5. STUDY CARRIED OUT FOR THE X 72500 RAILCAR

The method used to reduce the level of noise from an axial output wheel for cooling a heat exchanger is now described.

The specific remit of the optimization process is as follows:

- reduce the acoustic emission from the cooling unit by 10 dB;
- provide at least the same mass output as the reference airscrew in order to guarantee cooling;
- provide at least the same overpressure as the non-optimized reference airscrew in order to overcome the problem of the loss of flow caused by the surrounding circuit;
- make mass-production of the product as inexpensive as possible.

This process was carried out in a partnership between the following companies: ALSTOM, SNCF, FMVQIP and SARDOU S.A.

The new airscrew was designed in the first instance using a computer program developed by SARDOU which links together the ventilation and acoustic performance.

Without changing the pneumatic performance and given a certain topological environment, this software program rapidly optimizes acoustic emissions by varying the following parameters:

- rotational speed;
- number of blades;

- angle of the blades;
- laws of twist of the blades;
- properties Cx, Cz of the wing profile used to design the blades;
- diameter of the airscrew;
- chord length of the blade;
- diameter of the boss;
- upstream and downstream geometry of the duct.

The output parameters from the computer simulation program provide the following information:

- static and total pressure;
- overall geometry of an optimized blade;
- the ventilation power provided and the electric power consumed;
- the acoustic power level emitted by the fan in dB lin and dB(A);
- the basic frequencies and acoustic lobes;
- indication of possible inter-blade interference (detection, percentage of pressure lost).

A correlation between the "Rateau" laws and the "Ponsonnet" laws is obtained.

The new form of airscrew resulting from the predictive calculations has made it possible to achieve the following gains relative to the non-optimized reference airscrew:

- required static pressure at the operating points improved by 20%;
- reduction in the acoustic emissions by 15dB linear;
- reduction of 10% in the consumption of electricity at nominal rotation speed.

The new fan design includes a diffuser which recovers part of the dynamic pressure provided by the airscrew. The new MS 30 fan therefore creates a static pressure that corresponds to the performances of the airscrew and the recovery performances of the diffuser.

After the numerical definition of an optimum airscrew, development tests were carried out on a prototype aluminium airscrew that had been produced using numerical control.

The development testing was done on an *AMCA rig* in two stages.

In the *first stage* only the basic airscrew was tested in order to validate the computer predictions (ventilation and acoustic). There was an excellent correlation between measurements and predictions. The acoustic deviations were of the order of 1 dB.

The *second stage* consisted of testing the performance of the fan with the ventilation circuit upstream of the turbulence generator (see Figure 5).

In this second stage, the following modifications were made to the ventilation circuit to reduce the loss of flow from that circuit:

- the shape of the shutters was changed;
- the obstacles in front of the airscrew were removed.

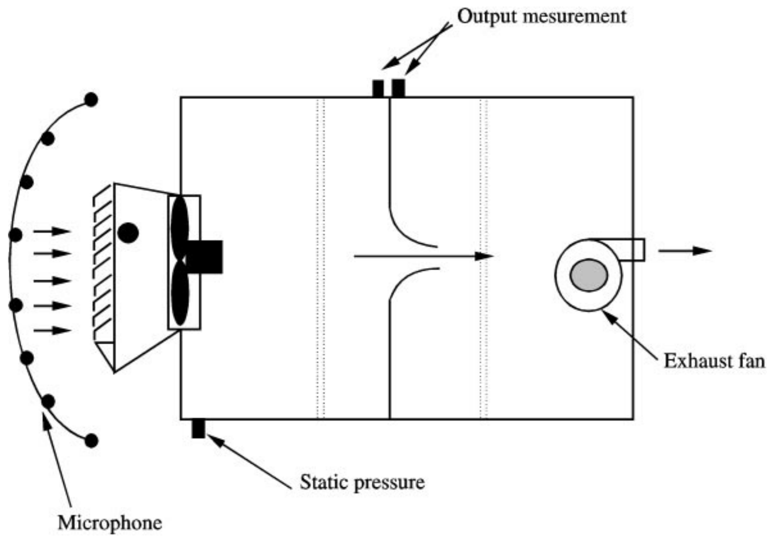

Figure 5. AMCA rig.

TABLE 1

Results obtained on AMCA rig

		Old fan	New fan
	Speed (r.p.m)	2930	2960
	Diameter (mm)	360	320
	Blades	7	13
Exchanger	Static pressure (Pa)	460	460
clean	Output (m^3/h)	3350	3350
	L_W (dBA)	99	89
Exchanger	Static pressure (Pa)	410	540
dirty	Output (m^3/h)	2900	3100
25%	L_W (dBA)	102	89

By the end of the development process, gains of 10 $dB(A)$ *had been obtained relative to the original fan whilst retaining the initial gain in ventilation performance.*

The results obtained on the AMCA rig are summarized in Table 1.

Following this development work on the rig, the prototype fan was tested on a stationary and on a moving railcar is order to verify the acoustic and vibration performance.

The results were similar to the AMCA's rig results.

The spectrum analysis of the two fans, tested on the AMCA rig, is shown in Figure 6.

The wide band noise level and the peak noise level (number of peaks and peak level) are reduced.

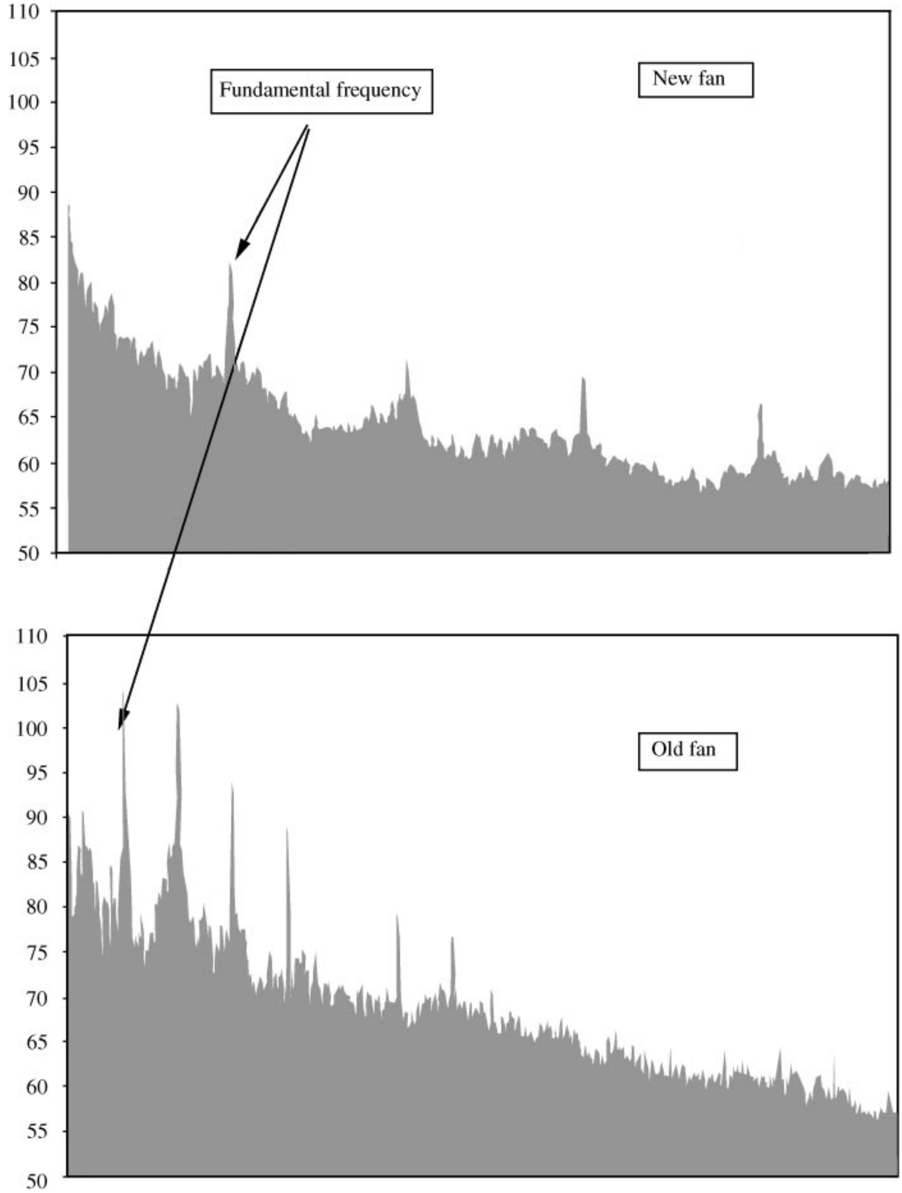

Figure 6. Spectrum analysis of the two fans.

The optimization of the shape of the blades, their number, and their twist law contribute to the performance.

Given these positive results, ALSTOM fitted the X 72500 railcars with this type of fan.

The specifications for the mass-produced fans were drawn up by SARDOU and they are produced by FMV-QIP.

The mass-produced airscrews are made of a composite material (smoke/fire classification: M1F1) and are moulded. Their acoustic performance is similar to that of the prototype aluminium airscrew.

6. CONCLUSION

It is possible to predict accurately by calculation the ventilation and acoustic performance of an airscrew.

The methodology used in this development programme has made it possible to reduce acoustic emissions by 10 dB whilst improving the ventilation performance and reducing the amount of electricity consumed.

This approach means that the acoustic criteria set down by SNCF have been met.

The costs of mass-producing this new design of airscrew are close to those of current airscrews. SNCF wish to maintain an acceptable noise environment close to the railway. It is hoped that industry will use this approach more widely in the future.