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RESEARCH: AIRCRAFT NOISE REDUCTION IN FRANCE

Marc Pianko

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16. Abstract

Since 1967 the French aeronautics industry has undertaken extensive research in the field of noise abatement. Substantial progress has been achieved for both supersonic and subsonic transports as well as for helicopters.

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RESEARCH: AIRCRAFT NOISE REDUCTION IN FRANCE

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HISTORY

Motivation

In order to put a stop to the increasing nuisance, the major airplane manufacturing nations began to jointly prepare the first proposals to limit airplane noise in 1966. The threat presented by these proposed norms caused the French government and French aircraft construction companies to finance research in this area so as to permit the industry to be able to meet whatever standards were established. These efforts were initiated around 1967. /31*

Noise abatement standards were published by the ICAO in 1971. They were revised several times and made even stricter.

The Situation in France in 1967

In 1967 several small groups (at SNECMA, ONERA, and Bertin) were working on various aspects of aircraft noise. The research at that time was not coordinated and the apparatus necessary to carry out the experiments needed for a comprehensive approach was not available. One of the actions undertaken by DGAC was to develop an overall attack on the problem and to coordinate the research of the different groups. This coordination is the responsibility of the Aeronautical Technical Service, which oversees the research carried out as well as providing the appropriate material support.

*Numbers in the margin indicate pagination in the foreign text.

Efforts Made since 1967

The amount of money invested in noise abatement in France can be approximately evaluated by looking at the funds distributed annually by DGAC since 1968. This is shown in the following table:

Year	68	69	70	71	72	73	74	75	76	77	78
Expenditure (millions in Francs)	5	13	15	14	9	9	13,5	15,5	14,4	12,9	11,9
Running Total		18	33	47	56	65	78,5	94	108,4	121,3	133,2

In addition to the state money, private companies and laboratories contribute an amount often equalling fifty per cent of the cost. Those providing financial backing are SNECMA, ONERA, AMD-BA, SNIAS, and Bertin. A few universities and institutes are also involved in certain studies. All together, researchers in this field number between 115 and 130 persons.

DIRECTION AND GOAL OF THE RESEARCH

Direction

The research into aeronautical acoustics carried out in France has two main aspects:

(a) The gradual inclusion of all types of aircraft. At first only jet transports, both subsonic and supersonic, were the object of active research. Since 1967 other aircraft (short takeoff and landing airplanes, helicopters, and light propeller-driven aircraft) have also been included.

(b) Emphasis has been placed on reducing the noise of aircraft that have not yet been built.

This stems from the fact that it was not considered necessary to know all the effects of the noise before acting. The nuisance was such that action to reduce the amount of noise as quickly as possible around airports was called for.

A detailed study showed that modifying existing aircraft to make them less noisy was relatively ineffective and very costly. As a result research was directed toward reducing the noisiness of aircraft fabricated after a certain cut-off date, to be set as near to the present as possible. /32

Reducing noise involves the following steps:

-- Understanding the mechanism of noise-generation in each source and its relative importance.
-- Creating quiet, reliable, and competitive materials to block these mechanisms.
-- Being capable of predicting the acoustic qualities of these materials and their behavior in use.

The Goal

The table below indicates the sources of noise in the different sorts of aircraft under consideration. Each of the principal sources generates noise in several different ways. Following the table these will be described for two types of engines.

Aircraft	Principal Source of Noise	Secondary Source of Noise
Subsonic Jet Transport	Engine	Aerodynamic airframe noise
Supersonic Transport	Engine	
Turbo prop	Propeller	Engine (exhaust)
Light propeller-driven airplane	Propeller or motor	Motor or propeller
Helicopter	Main rotor	Tail Rotor Engine
STOL airplane with jet engine	Interaction of the jet flow with the lift increasing devices	Engine

The Engines of Subsonic Jet Transports

The engines of modern airplanes are turbo fan jets with a high bypass ratio. They generate noise in several different ways, whose relative importance varies according to the phase of flight considered (e.g., take-off or landing), the method of operation (reduction of jet exhaust where possible), or the position of the listener in relation to the airplane (distance and angle).

The main sources of noise are:

The fan. Fan noise is caused by fluctuations in the air current as it passes around the vanes of the fan. The noise is propagated both toward the front of the aircraft by way of the air intake and toward the rear through the exhaust channel.

The jet. Noise from the jet is a function of the velocity of the ejected gasses. Predominating in early jet engines, the sound of the jet is weaker than the noise of the fan in a turbofan because the gas ejection velocity is lower.

The compressor. The compressor is located behind the fan and noise that it makes is related to that of the fan.

Other sources. These are turbine noise (like a reverse compressor), combustion noise, interaction noise, etc.

The Engines of Supersonic Transports

The engines installed on this type of aircraft are usually of regular turbojet design. There is sometimes a low ratio engine bypass. In a jet engine of this type, gas is expelled at a very high velocity, and the noise of the jet represents the major part of the radiated acoustic energy.

Since all types of aircraft have to be dealt with, a large number of sources of noise, all operating in fundamentally different ways, must be identified and studied. To reduce aircraft noise is therefore a very complex problem. It entails a series of difficulties each of which require a different experimental approach and a different solution.

ACTIONS UNDERTAKEN AND RESULTS OBTAINED

The programs undertaken since 1968 have served to develop the required experimental apparatus, carry out theoretical studies, perform the actual experiments, and check the results in the field.

Technical Equipment

A certain amount of machinery has been constructed since 1968. These tools are indispensable to the research carried out, and we are obliged to describe some of it.

CEPR's A17 Echo-free Chamber

This is a fairly large facility (630 cubic meters) designed so as to suppress all echo and keep all exterior sound from interfering with the measurements being taken. It was originally built to study jet exhaust noise, but it is equally useful in studying noise originating in rotors, propellers, the lift increasing devices of STOL aircraft, etc. as well as for general acoustical studies relating to reflexion, refraction, and absorption. This chamber ranks among the best installations of its type in the world. However, jet noise can only be studied within it in a stationary position. In order to investigate the influence of flight speed, a new device has recently been constructed: the echo-proof wind tunnel CEPR A19 (see below).

Test Beds to Study Noise in Model Jets

There exist several test beds auxiliary to the CEPR chamber which are used to study the noise created by model jet engines (built at approximately 1/10 scale).

The table below summerizes the uses to which this equipment is put.

TEST BEDS FOR MEASURING THE NOISE OF MODEL ENGINES IN FREE AIR

	SNECMA Bed 32 ER	Bertin Quai de la Gare	CEPR Bed A04	ONERA Palaiseau cell
Acoustic Measurements	x	x		
Aerothermodynamic Measurement	x	x	x	x
Measurment of Thrust		x	x	
Study of the fine structure of the jet				x
Visualization		x	x	

The Hovertrain

The effects of flight are very important. A means to study them exists which reproduces the air flow around an engine at a cost much lower than an actual test flight, which in any case is not always possible. The devices to be studied (mostly jet exhaust silencers) are mounted on the experimental Hovertrain 02 located at Gometz. This 2.5 metric ton vehicle reaches speeds of the same order as a subsonic airplane at takeoff (300 km/h).

Bed for Testing Compressor Noise at SNECMA (5CC)

This is an echo-free room of approximately 145 cubic meters. It contains a power source large enough to run engine compressor models ($\frac{1}{2}$ scale). A special feature of this apparatus is that it permits the measurement of noise radiated toward the front as well as toward the rear of the compressor. The noise resulting from a wide range of design parameters (number of vanes, their separation, etc.) can thus be fully investigated.

Ventilator at ONERA

Certain basic studies concerning the sound made by moving parts are carried out in a large fan whose characteristics permit the duplication of elementary phenomena.

Apparatus for Testing the Effectiveness of Soundproofing Material (Bertin) /33

One way of making a jet engine quieter is to muffle the interior noise by covering the walls of the engine with special sound absorbent material. This facility measures the attenuation of a reference frequency which is propagated along a channel (30 cm long, with a cross-section of between 16 and 40 cm^2) coated with the substance being tried out.

Installation for Acoustic Experiments with Turbo-Jets (RM3)

At CEV in Istres a large area has been covered with concrete so that its reflection factor can be precisely determined. This allows the noise of the jet engine to be distinguishable from the noise reflected off the floor.

AMD (Villaroche) Laboratory

These facilities are used to certify sound deadening products used around the intakes of jet engines. The noise created by small scale mock-up engines is also studied here.

SNECMA 5CC Test Bed for Studying Turbine Noise

The echo-free chamber of approximately 380 cubic meters is used to examine jet turbines. The power source available, 2000 kilowatts, and the size of the room allow turbines of 500 millimeters to be tried out. These turbines can be run with air that has been both compressed (up to 50 kg/s with a pressure of 4 atmospheres) and heated (650 ^{o}C).

The CEPR A19 Wind Tunnel

The flow produced by the wind tunnel around experimental models can be used to reproduce the acoustic effects produced by an airplane in flight. Flight speeds of up to 100 m/s (that of a supersonic aircraft at take-off) can be simulated. Besides jet exhausts, other sources of noise, such as rotors, propellers, the obstruction of gas flow by solid walls, and even a small complete engine can be studied.

Miscellaneous Technical Capacity

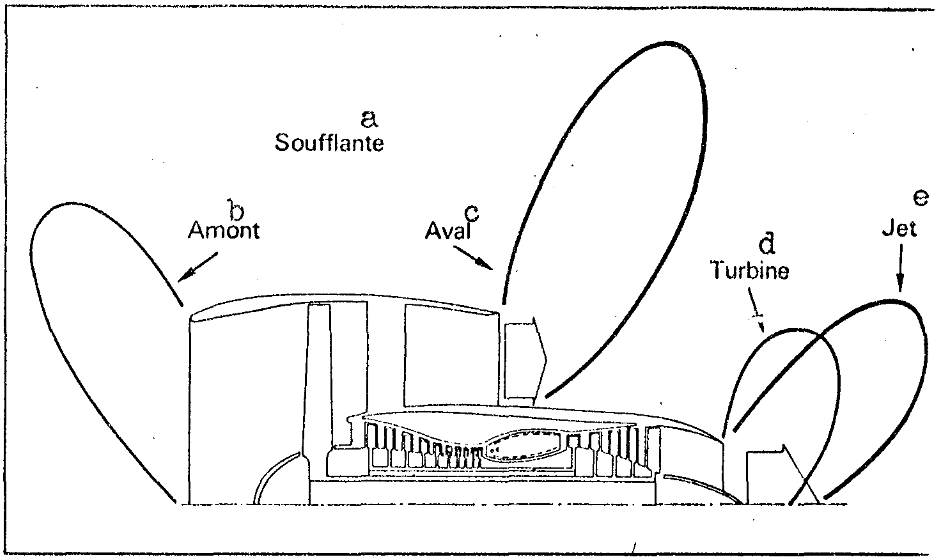
Besides the facilities already mentioned, various other laboratory devices also exist.

Experimental Methods: Instrumentation and Signal Processing

Each of the experimental facilities described above requires its own set of instruments for measuring sound and its own system for analyzing the data collected.

Since the necessary equipment was not available on the market, a variety of specific devices had to be invented as various problems arose. Examples of this equipment are a dielectric microphone using the electret effect, a sensor for measuring turbulence in a jet exhaust, microphonic probes, and special film.

Even the analysis of the data collected from the simplest sensor used in acoustic research (the ordinary microphone) calls for a highly involved set of calculations. An experiment of a few seconds' duration would require days if not weeks of manual manipulation of the data afterwards. Today, every organization uses electronic computers working in real time to accomplish this.



Sources of Noise

Key: (a) fan, (b) upstream, (c) downstream, (d) turbine, (e) jet exhaust

Studying the Sources of Noise

Now that we have finished summarizing the apparatus that is indispensable to research on aircraft noise, we shall examine the programs undertaken and the results obtained since 1968. The principal effort has been directed toward discovering the different sources of noise in a jet engine and on how to alleviate the worst problems.

FAN AND COMPRESSOR

Identifying the Source

The original studies (1968-1969) were carried out on aeronautic fans of classic design, but reduced to one-half scale. They demonstrated the influence on upstream noise of such variables as speed, number of vanes, and vane separation. Comparison with the experiments carried out in other countries (GE in collaboration with NASA) have led to a new level of experimental and theoretical sophistication. It is possible today to predict how noisy a compressor will be.

In 1967 French researchers had no method of predicting compressor noise. Adapting methods found in foreign publications yielded very inaccurate results (approximately ± 8 decibels), and a very sketchy description of the acoustic field. Our research has enabled us to predict the sound of a compressor fan to within three decibels and to give a much more detailed description of the acoustic phenomena involved, specifying the direction of the sound, for example. We can therefore limit their effects.

Reducing the Noise of the Fan

At first, methods for evaluating the effectiveness of the various sound-proofing products were nonexistent. Even though there is some correlation between the theory and practical experience, at present only the experimental method yields sufficiently accurate estimates of actual performance. The results obtained have been applied to the Mercury and the Olympus (the engine on the Concorde).

The materials developed in France are comparable to those used on such American airplanes as the Boeing 727 and 737. For example, a reduction of 6 decibels during landing and 2.5 decibels during takeoff have been obtained on the Mercury at a cost of 65 kg added to the weight of the engine. The experiments not only verified the ability of the material but also yielded a rating of the different solutions for different situations. The variables considered included engine size, engine compartment space available, the frequencies to be reduced, and the direction of the emitted sound (frontwards or rearwards).

We still lack the experience needed to state the characteristics of many types of experimental material. A major effort also remains to be carried out to reduce material weight, and to perfect ground-based experimental techniques (cheaper than experiments in flight). Finally, more precise methods of calculations must be developed which would yield not just a relative ranking, but the actual reductions obtained.

JET EXHAUST NOISE

Identifying the Source

A means of predicting jet exhaust noise now exists thanks to experiments on model engines carried out in the CEPR echo-free chamber. This very complete empirical method is applicable despite large changes in the aerothermodynamic parameters of the jet (either pressure or temperature) or variations of design (fairing shape, engine bypass, etc.). Very high accuracy, within one decibel, is obtained so long as experimental conditions are duplicated, i.e., fixed position, consideration of only the jet exhaust itself, small size, and a simple circular after-burner. Estimates outside of these conditions can be done, but with less and less accuracy the further one gets from the ideal case. In the case of large engines with a complicated design, such as the Olympus, the margin of error is never less than 5 decibels.

The quality and the sophistication of the studies carried out in France on jet exhaust noise are recognized throughout the world.

Reduction of Jet Exhaust Noise

The only procedure in France for developing a jet engine silencer is entirely empirical at this point. In order to diminish the loss of performance and of fuel economy at cruising speed, detailed studies of silencers have been limited to silencers which are retractable in flight.

In any case, experiments have shown that the effectiveness of silencers is greatly reduced at cruising speed. For this reason, one of the most important problems in aeronautics today is the simulation of the effects of flight.

The mass of experiments already conducted seems to indicate that there is no acoustically effective silencer that doesn't cause unacceptable losses in performance in a supersonic transport. Nevertheless all possibilities continue to be investigated. A large number of trials have been conducted using the hovertrain, and new facilities such as the echo-free wind tunnel CEPR A19 will soon be put to use in this area.

Turbine Noise

Studies done mostly with SNECMA's 5CC apparatus have furnished the first data for elaborating a procedure to predict turbine noise. Such predictions must take into account aerodynamic and design differences as well as the specifications for any sound-deadening material used.

The Noise Caused by Small Propeller Driven Airplanes

There have been many studies concerning propeller noise during the past few years. The sources of noise in propeller driven airplanes can now be sorted out. The ground has thus been prepared for experiments to find a solution to the problems posed by these aircraft.

The Noise Caused by Helicopters

An analysis has been made of the contributions of the different parts (main rotor, engine, rear rotor) of the helicopter to the noise problem. Attempts to reduce the sound of machines produced in France have been crowned with success. However, these techniques have not been widely applied. Insulating the engine ducts results in a noise reduction of up to 4 db in the SA 341, up to 6 db in the SA 360, and can even attain 9 db in the SA 315, 316, and 319.

Noise Created by STOL Aircraft

The particularity of this type of aircraft is that the means of propulsion is closely connected to the methods used to increase lift (the aerodynamics of the aircraft). Enough has been learned about the various types of STOL designs to have an idea of the amount of noise that they would produce. However, research into actually reducing this noise has not been pursued since the chances of this type of aircraft being fabricated in France in the near future are very slim.

CONCLUSIONS AND PERSPECTIVES

Average government expenditures exceed 10 million francs per year. To this figure must be added the expenses incurred by industrial concerns and laboratories.

What Are the Results of this Effort?

There have been two principal areas of success. First, it has been demonstrated that airplanes already in service can be modified to obtain a total noise reduction of about 6 decibels (2 decibels each for the front, the side, and underneath the airplane). However, this gain of 2 decibels at each position does not justify the allocation of the large amount of resources needed to modify certain types of airplanes. Secondly, newly developed engines which are just being unveiled by research departments or just being introduced represent a significant gain in noise reduction. These engines are 10 decibels quieter than 1967 models and more than 25 decibels quieter than 1959 vintage engines which are still in operation today.

To give concrete examples, the "Mercury" airplane has been given a soundproofing of mostly French origin and has thus been able to pass its acoustic certification. The CFM 56 engine, produced by SNECMA (which had the responsibility for reducing the main source of noise both in terms of design and of acoustic insulation) in collaboration with GE, represents the quietest engine possible. The research accomplished constitutes a solid base for designing the engines for the next generation or airplanes, whether subsonic or supersonic.

This base must be consolidated. Research will be pursued to validate the results already obtained, maintain the level of our knowledge close to that of foreign countries and to construct engines and civilian aircraft that are equal to the competition.

What Are the Perspectives for Future Research?

It seems that the acoustic levels attained by the quietest subsonic jets (the A 300 or future airplanes equipped with the CFM 56) is close to the best that can be achieved in practice. Two or three more decibels can probably be eliminated, but the price will be rather high and airplane performance will suffer.

On the other hand, significant progress can be made in terms of the costs of and the delays in applying the techniques that have been discovered. Recent research has made the industrial application of acoustic insulation easier, quicker, and therefore cheaper. Thanks to this progress, the development and perfection phases of future engine programs will be shorter and less expensive. It is entirely likely that a successor to the Concorde will hardly be any noisier than subsonic airplanes. A reduction of noise on the order of 10 decibels can reasonably be expected. The area exposed to noise would be reduced from 6 to 8 times.

Helicopters of the future will also be more silent. Gains superior to 5 decibels are a reasonable objective. New light airplanes will also benefit from present research. It is realistic to expect the propellers to be 5 decibels quieter and engine noise to be 10 decibels less.