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THE REDUCTION OF AIRCRAFT ENGINE FAN-COMPRESSOR NOISE USING ACOUSTIC LININGS

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1. INTRODUCTION

Community noise in the vicinity of airports resulting from jet aircraft operations falls broadly into the two categories of take-off noise and approach - landing noise. The former contains predominantly low frequency energy radiated from the jet efflux, whereas the latter contains predominantly high frequency energy radiated from the engine nacelle inlet and exhaust and originates from the fan-compressor. The development of a method is discussed which is directed in particular at the reduction of approach - landing noise by means of treating the engine nacelle inlet and fan exhaust duct with acoustic linings. The treatment also reduces take-off noise to some extent as a result of attenuating the high level components of fan-compressor noise.

2. METHOD OF STUDY

The study was commenced by investigating the maximum potential reduction of engine noise that could be achieved with a given aircraft configuration by determining the relative amplitudes of the spectral components of the various sources of engine noise from fly-over tests and hence their respective contributions to the preceived noise level (PNL). For an aircraft in the design stage, these are estimated from predicted spectra of the various sources of engine noise. Potential methods for attenuating the various noise sources (e.g. sonic inlet, duct linings, etc) were then evaluated to determine the most effective method of consistent with a minimum loss of engine performance. The devices were evaluated theoretically and by limited laboratory model tests. The use of acoustical linings on the walls of the engine nacelle inlet and exhaust was judged to be the most practical concept for an existing engine and theoretical lining concepts were evaluated by laboratory tests, in a full scale engine nacelle and finally by means of flight tests.

3. AIRCRAFT SUBJECTIVE NOISE SPECTRA

When an aircraft in flight approaches an observer on the ground, flies by and recedes, the observer perceives a succession of noises which are emitted by predominantly different sources on the aircraft although at any instant of time during the flight the observer is exposed to noise components from most of the sources but with one or two of these being the principal contributors. Prior to the aircraft reaching the observer the major component of the noise is the highly directional high frequency fan whine emanating from the engine nacelle intake, as the aircraft approaches closer to the observer a similar noise is heard from the fan duct exit and finally as the aircraft reaches the overhead position and recedes the predominant noise which is lower in frequency originates from the primary and the secondary jet effluxes. The perceived noise levels for each position along the flight path are calculated however from the whole noise spectrum received at a particular instant. The component PNL curves from each source indicate the potential amount by which the component noise sources can be attenuated, and from this the maximum attenuation of peak PNL can be established. Noise reduction is achieved by attenuating physical sound consequently frequency spectra are required for determining the frequency components and the broad band frequency noise that must be attenuated to achieve a target. These spectra are obtained from existing untreated aircraft data, or from predicted spectra for projected aircraft.

4. NOISE REDUCTION METHODS

The reduction of fan-compressor noise can be achieved to some extent by basic modifications to an engine either during the design stage or in some instances by modification of existing engines. This can be done for example by increasing the rotor-stator separation between fan stages, dispensing with inlet or exit guide vanes, restoring the wake velocity profile behind rotors and stators by air blowing techniques, varying the number of rotor blade-stator vane combinations, and variations or combinations of such devices. The most effective although usually complicated method developed for reducing inlet noise is the sonic throat references 2 and 3, which consists of an inflatable or movable centrebody or a flexible walled intake by means of which the velocity of air flow into the inlet is increased so that the transmission of acoustic energy out of the inlet is substantially reduced. The use of acoustic absorbing linings has been found in practice to require the least amount of modification to an existing engine installation and can provide substantial noise attenuation in parts of an engine where other devices are difficult or impractical to install. The nacelle intake and fan exhaust duct of existing engines are most amenable to this type of treatment on the inner and outer walls, concentric rings and splitters and other duct surfaces, hence the lining method was selected for this study.

5. ACOUSTIC LINING TECHNOLOGY

The basic types of lining that are suitable for acoustically treating engine ducts references 4 and 5 can be classified broadly as the absorber type, the resonator type and a combination of both these characteristics. Absorber linings consist of a thick layer of porous material, most suitable to attenuate a broad band of noise. Resonant (or reactive) linings consist of a thin sheet of perforated facing material separated from an impervious surface by a cavity divided into compartments by a honeycomb spacer structure, which forms an array of resonators. These effectively attenuate a predominantly narrow frequency band of noise centred on a discrete frequency. Lastly a lining combining the features of both of these types consisting of a thin porous absorptive facing material backed by resonant cavities has good attenuation characteristics over a wide range of discrete frequency components together with a substantial attenuation of broad band noise. The most important acoustic and geometric characteristics of duct linings were determined by combining the results of a theoretical study with an experimental result from which a duct lining design technology was developed. The two most important factors were found to be the separation between lined surfaces and a sufficient length of treatment to obtain the desired noise attenuation. Where these two requirements can be satisfied together with efficient engine operation linings provide the most practical approach available to the attenuation of engine noise. To determine the principal lining and duct characteristics influencing the attenuation of sound a theoretical model was developed as summarised below and described in detail in reference 4.

a. Development of an equation to describe all acoustic modes that are generated in a duct of given geometric cross-section, assuming that all components of propagating waves have equal amplitude and occur at all angles of incidence to the duct walls.

b. Solution of the equations to determine the attenuation of these modes by assuming a range of values of acoustic admittance at the lined wall boundaries.

c. Computation of the attenuation at a given frequency which is a component of the input noise spectrum of the wave by determining the influence of a lining on the associated modes excited by the wave components.

d. Parametric evaluation of the maximum attenuation over the frequency range of interest made for a range of acoustic and geometric details of typical linings.

Significant theoretical parameters were verified experimentally using a flow duct facility, which simulates the flow conditions in an engine duct environment. The flow duct facility consisted of two acoustically reverberant chambers separated by a test duct whose walls are treated with the acoustic linings to be evaluated. A noise source and an air supply is provided in one of the chambers so that the linings in the duct are exposed to a noise and air flow environment simulating an engine duct. The facility is used to determine (a) verification of theoretically predicted noise attenuation spectrum, the influence of the duct and lining geometry, and the theoretical assumptions made in the study (b) search for acoustic, aerodynamic and air flow phenomena not included in the theoretical analysis (c) compiling of parametric design data such as influence of lining length, depth, surface area, etc. (d) evaluation and development of potential lining materials in conjunction with use of an acoustic impedance tube and porous material flow resistance tube apparatus. The combined results from the theoretical analysis and experimental work lead to the most important design parameters, which were then further evaluated in a full scale engine.

6. ENGINE NACELLE TECHNOLOGY

The final stage in developing the lining technology was to evaluate their acoustic efficiency in a full scale engine. The lining technology was thus developed from theoretical models, laboratory experiments and the full scale engine tests. Reference 4 the influence of acoustic linings on the engine performance was investigated simultaneously by means of duct wall drag loss tests in the flow duct facility and in the engine ducts. The actual noise reduction resulting from acoustically treating a nacelle is determined from the full scale far field noise surveys around the engine in the presence of other noise sources such as aerodynamic flow noise generated in the engine intake and exhaust duct and the primary and secondary jet noise. The results of these tests and their correlation with the laboratory flow duct work lead to an engine nacelle technology.

7. FLIGHT TESTING

The final evaluation was accomplished by flight testing an aircraft with treated nacelles to verify the noise reduction achieved in an operational environment. Flight tests were conducted for the principal conditions of operation, but in particular for the cases of take-off, flyover and approach-landing.

8. CONCLUDING REMARKS

The application of acoustic linings for reducing aircraft fan-compressor noise has been successfully demonstrated with a P & WA JT3D engine, resulting in a reduction of in excess of 15 EPNdB approach-landing noise with no measurable loss in engine performance. The principal characteristics of the lining technology developed are applicable to other engine noise problems such as reduction of turbine noise. There are however several limitations in the use of linings for reducing turbo-fan engine noise, which are (a) the limitation by other unattenuated noise sources such as jet noise and aerodynamic background noise, (b) aerodynamic noise generated at high Mach numbers inside the ducts can be a limiting noise floor, (c) if the portion of the noise spectrum attenuated by linings is not the predominant contributor to the perceived noise level the effectiveness of the lining will be correspondingly decreased. The theoretical and experimental work on acoustic linings covered in this study was sufficient to develop a lining technology that was successfully used, nevertheless, several areas in this field require further work. In particular a better understanding is needed of the mechanisms of lining absorption and the interaction of these mechanisms with the air flow over the surface of the lined walls particularly in the high Mach number range > 0.5, so that the maximum attenuation may be attained with a minimum amount of treatment. The behaviour of linings subjected to high level fluctuating pressures also needs further investigation aimed at providing optimum absorption by linings close to rotating machinery sound sources, e.g. near the blade tips of fan and compressor rotors.

9. REFERENCES

1.	Anon	Proceedings of a Symposium on Acoustical Duct Treatments for Aircraft - Journal of the Acoustical Society of America Volume 48 Number 3 (Part 3) 1970.
2.	Anon	Progress of NASA Research Related to Noise Alleviation of Large Subsonic Jet Aircraft NASA SP-189, 1968.
3.	Anon	Proceedings of NASA Conference on the NASA Acoustically Treated Nacelle Program. NASA SP-220, October 15 1968.
4.	R A Mangiarotty	Paper S2 Acoustic-Lining Concepts and Materials for Engine Ducts, contained in Ref 1 above.
5.	J Atvars and R A Mangiarotty	Paper S4 Parametric Studies of the Acoustic Behaviour of Duct Lining Materials - contained in Ref 1 above.

6. F W Fischer and A O Andersson — The optimisation of Duct-Linings for Sound Attenuation - Boeing Document D6-29356TN (1968).

The views expressed in this paper are those of the author and do not reflect in anyway those of the Department of Trade and Industry.

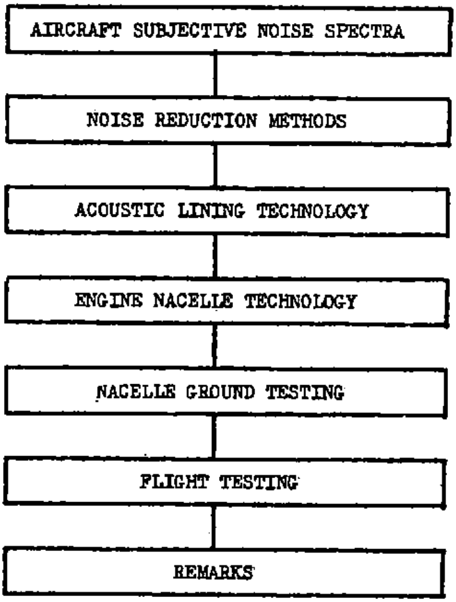

FIGURE 1 OUTLINE OF STUDY