Proceedings of the Institute of Acoustics

AN INVESTIGATION INTO THE SOUND TRANSMISSION PERFORMANCE OF AIRCRAFT SIDE-WALL TREATMENTS USING A RECIPROCITY TECHNIQUE

K R Holland (1), F J Fahy (1) & L C Chow (2)

(1) ISVR, University of Southampton, UK.
(2) British Aerospace Regional Aircraft Ltd, Hatfield, UK.

1. INTRODUCTION

The testing of the sound insulation properties of aircraft side-wall treatments poses many problems. The fitting of prototype treatments to full-scale aircraft and subsequent in-flight testing is very time consuming and expensive, and if testing on the ground is attempted, the generation of representative external sound fields may be very costly. The theoretical prediction of the external sound field generated by propellers under in-flight conditions is currently well developed, so if the detailed sound transmission properties of a fully-fitted aircraft are measured on the ground, these can be combined with the theoretical data to yield internal cabin noise levels. This paper describes the results of using a vibro-acoustic reciprocity technique to measure the sound insulation properties of various side-wall treatments fitted to a one-quarter-scale model aircraft fuselage in response to theoretically derived external sound fields. The sponsorship of this research by British Aerospace is gratefully acknowledged.

2. THE MEASUREMENT TECHNIQUE

The development and validation of the technique is the subject of a PhD Dissertation [1] and two papers [2, 3]. A one-quarter-scale model fuselage is excited by an internal volume velocity source and the resultant vibration of the fuselage wall is measured using a capacitance probe. The probe has a surface area such that the vibration of the complete fuselage can be measured on an area-grid of 30 axial × 30 circumferential positions. Positioning of the probe, measurement of each transfer function and subsequent data storage is automated and controlled by a computer. According to the principle of vibro-acoustic reciprocity shown in figure 1, these measurements serve to calibrate the model fuselage as a transducer of pressure from the outside wall to that at the internal source position; these calibration data are then combined with theoretically derived external sound fields to predict the sound pressure at the source position in response to such a field. The result of applying the reciprocal relationship illustrated in figure 1 can be written:

$$\tilde{p}_s = \sum_i \tilde{p}_i \left[\frac{\langle \tilde{v} \rangle_i S_i}{\tilde{Q}_s} \right]$$

where p_s is the pressure at the internal source position, p_i is the external sound pressure acting on elemental area S_i, $\langle v \rangle_i$ is the surface normal velocity averaged over S_i and Q_s is the volume velocity of the internal source. The quantity $\langle v \rangle_i S_i / Q_s$ is determined from the reciprocal experiment.

AIRCRAFT SIDE-WALL INVESTIGATION

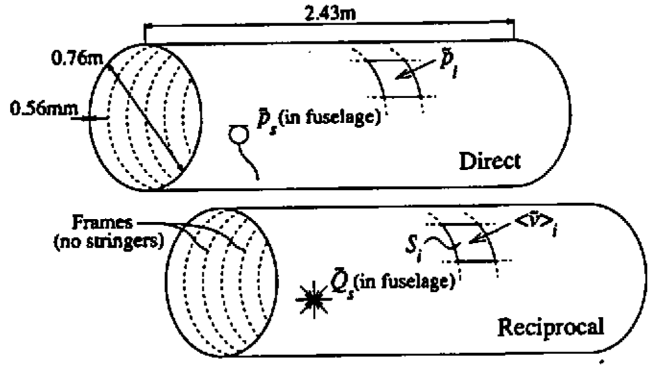

Fig. 1 Vibro-Acoustic Reciprocity Applied to Model Fuselage.

3. DETAILS OF SIDE-WALL TREATMENTS TESTED

3.1 Lightweight Treatment.

Tests were initially carried out to determine whether the whole of the inside of a fuselage needs be treated or whether treatments need be applied only in the vicinity of the maximum external sound pressures such as those generated by wing-mounted propellers. It was decided that a treatment that exhibited a reasonably high insertion loss would be necessary and a combination of mineral wool (25mm thick Rockwool 319 equivalent) and a limp-mass layer (polythene sheeting of mass $0.3kgm^{-2}$) was considered optimum in terms of effectiveness and ease of fitment. The plane-wave insertion loss of a 'blanket' of this treatment was expected to be 6.5dB at 400Hz, rising to 15dB at 1200Hz.

A series of measurements were carried out on the 'green' (untreated) fuselage model prior to the fitting of any side-wall treatment. These measurements were taken with the volume velocity source at five different axial positions within the fuselage. The fuselage was then completely fitted with the side-wall treatment and the measurements repeated. Finally, the side-wall treatment was removed except for a strip of six frames width in the region of maximum external sound pressure from a simulated propeller field, and the measurements repeated. All of the results were measured over a frequency range of 400Hz to 1200Hz to permit direct comparison with previously published results [1, 2, 3].

3.2 Foam / Heavy Limp-Mass Treatment.

Initial tests indicated that side-wall treatments are most effective when applied to the region of maximum external sound pressure (see section 5.1). A plastic foam / heavy limp mass treatment was applied to the six frame-widths area; the rest of the fuselage being treated with the lightweight treatment as before. It consisted of a layer of mineral-loaded 'dead-sheet' with a mass of $5kgm^{-2}$ attached to 70mm thick open-cell polyether foam having a density of $15kgm^{-3}$. The mass-air-mass resonance frequency of this combination is about 85Hz so the theoretical plane-wave insertion loss of a blanket of this treatment at the quarter-scale blade-passage frequency of 400Hz is then approximately 26dB. As this treatment was designed principally to be effective at and around this blade-passage frequency, these tests were carried out over a frequency range of 200Hz to 600Hz.

3.3 Helmholtz Resonator Treatment.
One hundred and twenty Helmholtz resonators were carefully constructed from aluminium tubing and tuned to 408 Hz to coincide with the quarter-scale blade-passage frequency. The resonators were attached to the fuselage frames using double-sided sticky pads with twenty resonators to each of the six frames, and the rest of the fuselage was treated with the lightweight treatment. Polythene sheeting identical to that fitted to the rest of the fuselage was attached to the fuselage frames over the resonators, but no absorbent treatment was fitted into the cavity. Tests were carried out over a frequency range of 200Hz to 600Hz.

4. MEASURED RESULTS

4.1 Lightweight Treatment.
Figures 2 and 3 show the insertion loss (relative to the 'green' case), averaged over the five internal source (receiver) positions, of the *fully fitted* lightweight treatment, for a simulated plane-wave excitation field (90° incidence) and a simulated propeller field (flight Mach N° M = 0.8) respectively. Figures 4 and 5 are as figures 2 and 3 but for the *locally treated* fuselage as described in section 3.1.

4.2 Foam / Heavy Limp-Mass Treatment.
In order to determine the effectiveness of this heavy treatment relative to the more conventional lightweight mineral wool / limp-mass treatment, the measurements for the *fully treated* case were repeated for the 200Hz to 600Hz frequency range. Figures 6 and 7 shows the insertion loss of the foam / heavy limp-mass treatment *relative to the fully treated mineral wool / limp-mass* case, for a propeller field and a uniform excitation field (unit pressure over whole surface) respectively. The results shown are for a single internal source position within the treated region.

4.3 Helmholtz Resonator Treatment.
Measurements were carried out first with all of the resonator holes 'blocked' with heavy-duty adhesive tape, and then with the tape removed; a comparison between the results thus eliminates any effect that the attachment of the resonators may have on the structure of the fuselage. The results are presented as insertion losses; a positive number thereby indicates an improvement in transmission loss due to the acoustic action of the resonators. Figures 8, 9 and 10 show this insertion loss for a propeller field, a uniform field and a localised uniform field (over the six treated frame-widths only) respectively. The results shown are for a single internal source position within the treated region. The design resonance frequency is indicated as f_r.

AIRCRAFT SIDE-WALL INVESTIGATION

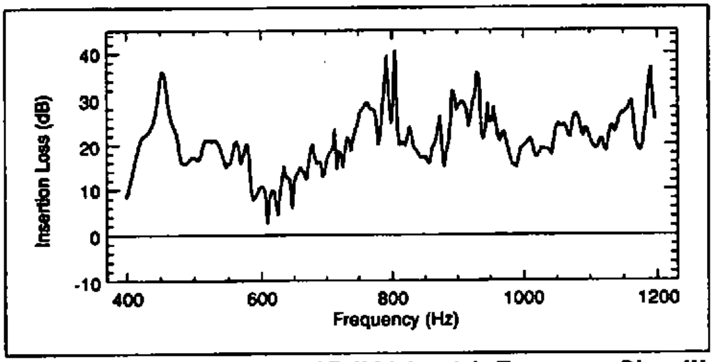

Fig. 2 Space-Averaged Insertion Loss of Full Lightweight Treatment - Plane Wave (90°).

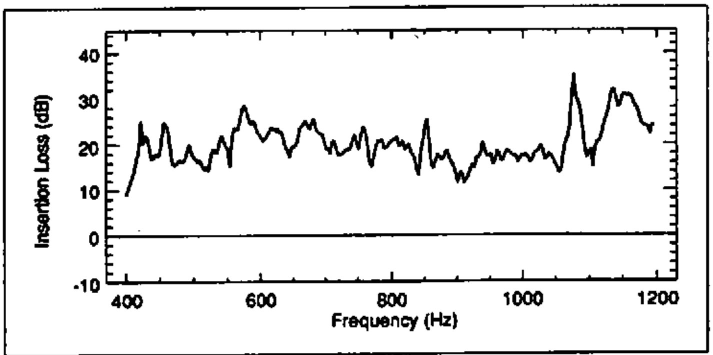

Fig. 3 Space-Averaged Insertion Loss of Full Lightweight Treatment - Prop. Field (M = 0.8).

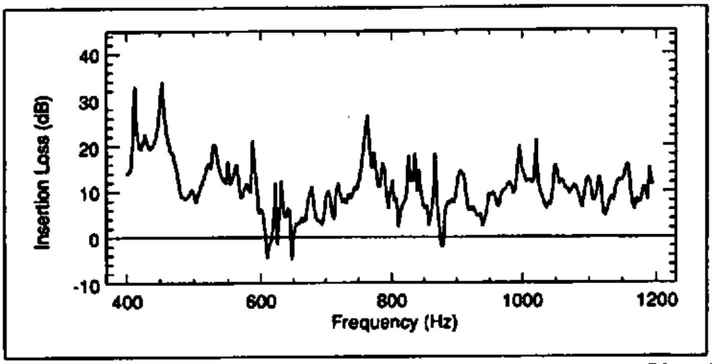

Fig. 4 Space-Averaged Insertion Loss of Localised Lightweight Treatment - Plane Wave (90°).

AIRCRAFT SIDE-WALL INVESTIGATION

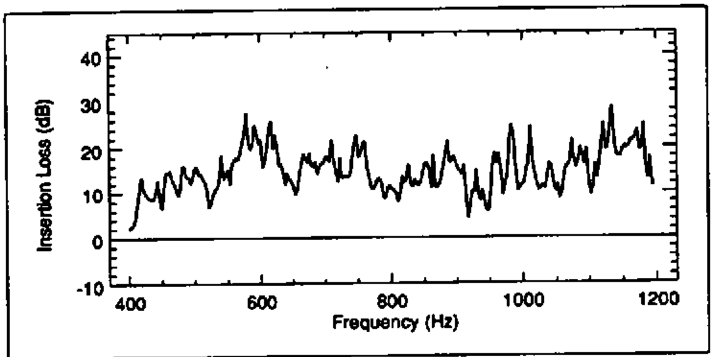

Fig. 5 Space-Averaged Insertion Loss of Localised Lightweight Treatment - Prop. Field (M = 0.8).

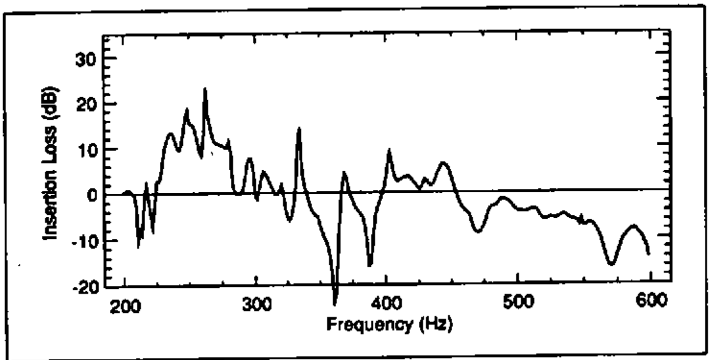

Fig. 6 Relative Insertion Loss of Foam / Limp-mass - Prop. Field (M = 0.8).

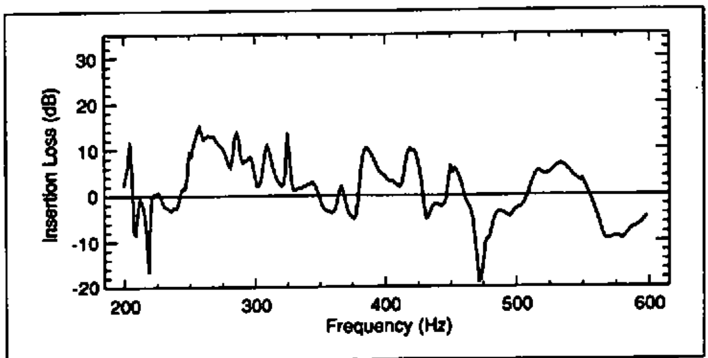

Fig 7 Relative Insertion Loss of Foam / Limp-mass - Uniform Field.

AIRCRAFT SIDE-WALL INVESTIGATION

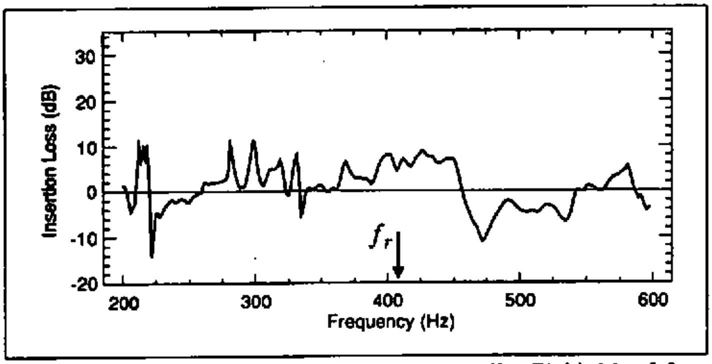

Figure 8 Insertion Loss of Resonators - Propeller Field (M = 0.8).

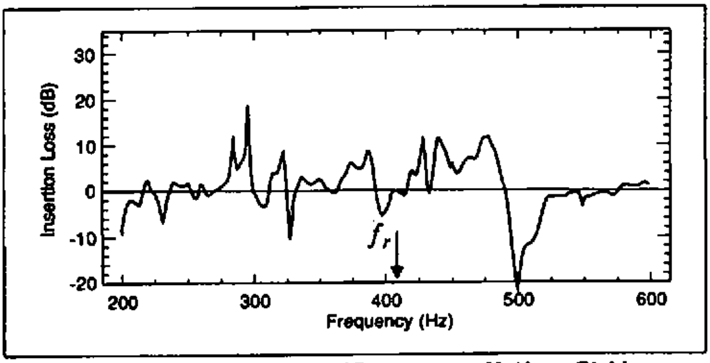

Figure 9 Insertion Loss of Resonators - Uniform Field.

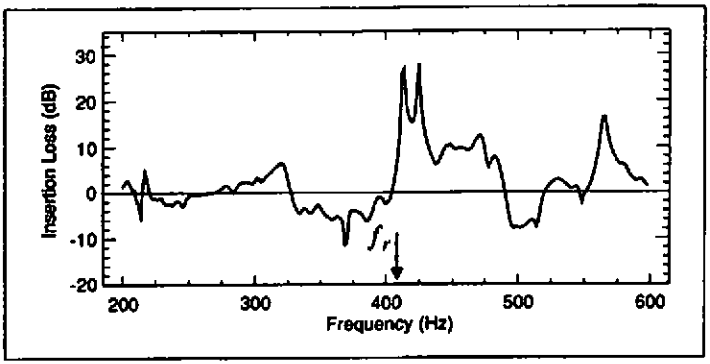

Figure 10 Insertion Loss of Resonators - Localised Uniform Field.

AIRCRAFT SIDE-WALL INVESTIGATION

5. DISCUSSION

5.1 Lightweight Treatment.
It is clear from a comparison of figures 2, 3, 4 and 5 that the improvement in insertion loss of the full treatment over the localised treatment is generally less for propeller excitation than for plane waves (except at frequencies less than 600Hz). This shows that the application of side-wall insulation to the fuselage in the region of maximum external sound pressure provides a greater insertion loss than installation in other regions. (Comparisons between the results for the individual internal positions shows that the greatest improvement in insertion loss of the full insulation relative to the partial insulation occurs at internal positions remote from the region of maximum external sound pressure).

5.2 Foam / Heavy Limp-Mass Treatment.
Generally, the limp-mass treatment does not produce the extra attenuation that was expected, especially in the frequency range around the quarter-scale blade-passage frequency of 400Hz. Some reasons why this is the case may be as follows. The lightweight treatment with which this treatment is compared significantly increased the structural damping of the fuselage wall; the added damping was considerably less in the case of the very soft plastic foam used with the limp-mass treatment. The combination of thin plastic covering and 'rockwool' filling would also considerably damp the internal acoustic modes of the fuselage, whereas the heavy limp-mass treatment is considerably more reflective; thus internal acoustic damping is also reduced. Considering the vast difference in weight (approx. 5:1) between the two treatments, the wisdom of fitting the foam / heavy limp-mass treatment to real aircraft is in doubt. The results demonstrate the influence of added structural damping due to trim on the transmission of sound.

5.2 Resonator Treatment.
Figures 8 and 9 show that the resonators exhibit only very limited insertion loss when the fuselage is excited by a propeller field or a uniform field, with little or no evidence of the desired effect at the tuned frequency of 408Hz. Figure 10 however, shows an insertion loss of approximately 20dB near the resonance frequency of 408Hz for *localised* uniform excitation. To investigate this phenomenon, miniature electret microphones were inserted into five resonators randomly chosen from the one hundred and twenty fitted. The fuselage was then excited by the internal source (not on-axis) and the spectra of the pressure responses inside each of the resonators were measured under the test conditions (figure 11). The five resonators were then removed from the fuselage and measured individually under free-field conditions (figure 12). A comparison between these sets of spectra shows clearly that, under free-field conditions, each resonator responds at, or very near to, the designed resonance frequency, but when they are mounted in the fuselage and excited by a non-axisymmetric sound field, each resonator is seen to respond at a different frequency and, in general, all have acoustic resonance frequencies that are lower in frequency than under free-field conditions. Clearly, because of coupling between the resonators, such a system will only work effectively in an axisymmetric array if the excitation field is itself axisymmetric. Although the non-localised uniform field is axisymmetric, the effect of the resonators is probably largely 'short-circuited' by the transmission through the rest of the fuselage.

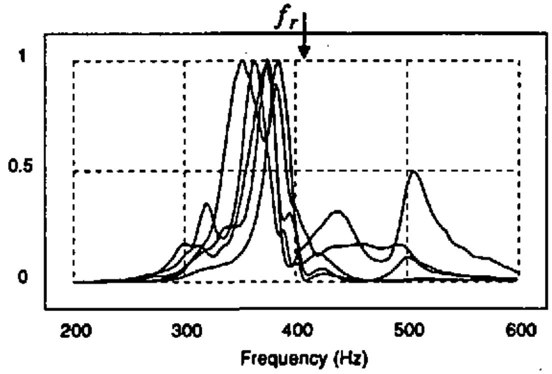

Figure 11 Response of Five Resonators Fitted in Fuselage (internal source excitation).

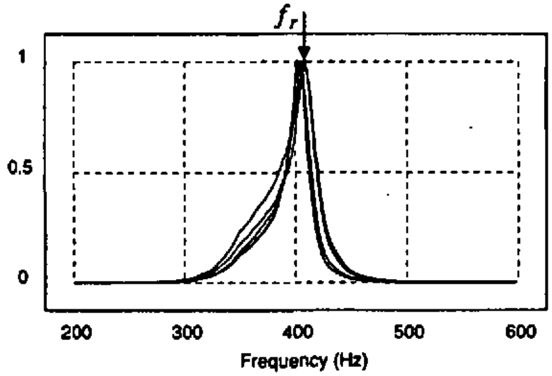

Figure 12 Response of Same Five Resonators under Free-field Conditions.

6. REFERENCES

[1] J. M. Mason, "A Reciprocity Technique for the Characterisation of Sound Transmission into Aircraft Fuselages", University of Southampton PhD Thesis, (1990).

[2] J. M. Mason & F. J. Fahy, "Development of a Reciprocity Technique for the Prediction of Propeller Noise Transmission through Aircraft Fuselages", Noise Control Engineering Journal, 34 (2), p43, (1990).

[3] F. J. Fahy & J. M. Mason, "Measurements of the Sound Transmission Characteristics of Model Aircraft Fuselages using a Reciprocity Technique", Noise Control Engineering Journal, 37 (1), p19, (1991).