BRITISH ACOUSTICAL SOCIETY: Meeting on "ABSORPTION OF SOUND": 17th September 1971 at the University of Salford.

Measurement of Normal Incidence Impedance of Laminar Absorbers at High Intensities

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Rolls-Royce (1971) Limited

1. Introduction

A knowledge of the behaviour of sound absorbers at high intensities has become desirable in the aero-engine industry in order that turbo machinery noise emanating from present and future engines can be reduced to a minimum. Absorbers in aero-engines are subjected to noise levels which, in general, are in the range 150-160 dB and which can reach over 170 dB in certain parts.

The very rugged conditions that such absorbers are subjected to imposes a severe mechanical limitation on the type of absorber that can be used. A laminar absorber consisting of an acoustically resistive face sheet supported at some distance from a rigid wall by a honeycomb structure most readily satisfies the mechanical requirements. The impedance of such an absorber is given by $Z=R+j(kM-\cot kl)$ where M is the inertance, l the cell depth and k the wave number.

A standing wave tube has been designed to investigate the variation of the acoustic impedance of laminar absorbers at sound pressure levels up to 155 dB in the frequency range 1-6 KHz. This range is typical of turbomachinery noise and encompasses the frequencies that are subjectively most objectionable, i.e. 3-4 KHz. Higher sound pressure levels are obtainable over the frequency range 1-3KHz.

2. Description of Tube

Basically the standing wave tube is of convensional design but contains many details not normally encountered. Acoustic power is supplied by four electrodynamic drivers each electrically rated at 100 watt. The sound field is examined by a 0.125 inch diameter condenser microphone mounted on a special adaptor. The microphone is traversed axially along the tube by a lead screw driven by a small electric motor. The position of the microphone is determined to ±0.05 mm by the number of turns of the lead screw from a datum position. A small probe microphone is used to monitor the sound pressure level at the sample face. Both microphone signals are monitored by microphone amplifier/narrow band filter combinations.

3. Operation

It was necessary to determine whether or not the same measurement technique could be used at high intensities as at low intensities. It was postulated that the same type of standing wave pattern would be observed if the signal from the traversing microphone was filtered so that only the amplitude of the fundamental was measured at any driving frequency, and that any degredation of the high intensity wave as it travels down the tube would give the same effect as extra wall attenuation. Experiments with the tube terminated by a massive metal plug satisfactorily justified this postulation.

4. Results

The majority of the materials tested fall into two categories; namely, fibrous metal types and perforated sheets. These two groups differ in the relative amounts of viscous (R_0) and non-linear (R_1) losses that contribute to their resistance which can be written approximately as $R=R_0+R_1u$ (2) where u is the velocity through the sample. In the case of fibrous metal layers R_0 is large and R_1 small, i.e. R varies little with the velocity. For perforated plates R_0 is almost zero and R_1 is dominant, i.e. R depends almost entirely on velocity.

4.1 Fibrous Metal Layers

The first objective was to show that the resistance was solely due to the fibrous sheet and not to any property of the cell. To this aim the impedance of one material was measured using cell depths of 0.5, 1.0 and 2.0 inch. In general the resistance is not exactly constant with frequency there being a slight curvature to the impedance locus. This is most pronounced with the largest cell depth as the first anti-resonance is reached. However, the general agreement between the three sets of measurements is extremely good. The deviation from a straight line is explainable in that equation 1 is only approximate.

Several materials have been measured using a cell depth of 1.0 inch. In each case the impedance locii for a particular intensity approximate to straight lines. Also, for each material, as the intensity is increased a small increase in resistance is observed although no change occurs in the reactance.

The straightness of the impedance locii was considered surprising as for a given value of intensity the surface particle velocity varied quite markedly with frequency. However when graphs were plotted of resistance versus particle velocity at constant frequency lines were obtained that were parallel to the flow resistance line. The line for the frequency closest to resonance almost coincides with the flow resistance line but at frequencies above and below resonance the acoustic resistance progressively increases.

The conclusion is reached that the linear resistance R_0 is dependent on frequency but the non-linear resistance term R_1 is independent of frequency. Also the flow resistance curves have successfully predicted the non-linear part of the acoustic resistance and the value of the acoustic resistance at resonance.

4.2 Perforated Sheet

A series of measurements have been carried out on perforated sheets to determine the effects of the various geometric parameters, namely porosity (the ratio of open area to total area), hole diameter and sheet thickness. Hole shape and array have also been considered.

The change in resistance with intensity was observed to be far greater than that for fibrous materials as expected. Also the variation in resistance with frequency at a constant intensity was greater. Unlike fibrous sheets some slight variation in reactance of the absorber with intensity was noted.

It was found that by far the most important parameter in determining the resistance was the porosity of the sheet. This is in agreement with Ingard and Ising (1) who obtained a unique curve that related resistance of a single orifice to particle velocity, which was independent of hole geometry. The transition from a single orifice to a perforated sheet would be expected therefore to depend only on the proportion of hole area to the total area i.e. on the porosity.

The mean, calculated particle velocity in the holes was plotted against the resistance of the holes for five porosities ranging from 0.05-0.225, all other parameters being the same. These graphs showed that as for the fibrous sheets the resistance varied with frequency at a constant velocity. But unlike fibrous sheets the variation of resistance with velocity at a constant frequency was not completely linear. However, in all cases the flow resistance curve gave a good indication of the acoustic resistance.

1. Ingard U. and Ising H.
Acoustic nonlinearity of an orifice
HASA Vol. 42 No.1 (1967) 6-17