A NOVEL NON-DESTRUCTIVE METHOD FOR THE MEASUREMENT OF AIRFLOW RESISTANCE OF JET ENGINE NACELLE COMPONENTS

T.R.T. Nightingale Institute for Research in Construction, National Research Council, Ottawa, Ontario, Canada K1A OR6
Brandon Tinianow Johns Manville Technical Center, 10100 West Ute Ave., Littleton, Colorado USA 80127

Introduction

As a noise control measure to reduce inlet fan noise of jet engines, the nacelles are often equipped with a thin resistive wire mesh placed over a honeycomb structure. Historically there has been a problem to measure, in non-destructive fashion, the airflow resistance of repaired or refurbished nacelle parts for the purpose of demonstrating OEM compliance. ASTM C522 is the traditional airflow resistance test method and is destructive requiring a sample be cut from the specimen and fit into an apparatus where the flow velocity due to a constant pressure drop can be measured. This paper presents a non-destructive test method for measuring the airflow resistance using an E1050 impedance tube.

Theory

Assume that plane wave is incident on the face of a nacelle as shown in Figure 1. In general, the impedance will have both a resistive and reactive component and can be obtained using a transfer matrix approach. The pressure and particle velocity on either side of a layered system are given by a two by two matrix[i],

$$\begin{bmatrix} p_1 \\ v_1 \end{bmatrix}_{x=o} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} p_2 \\ v_2 \end{bmatrix}_{x=d} \quad (1)$$

In the event that there are *n* layers in the system then the transfer matrix for the complete system is given by the product of the matrices for the individual layers i.e., $[T] = [T_1][T_2]\ldots[T_n]$.

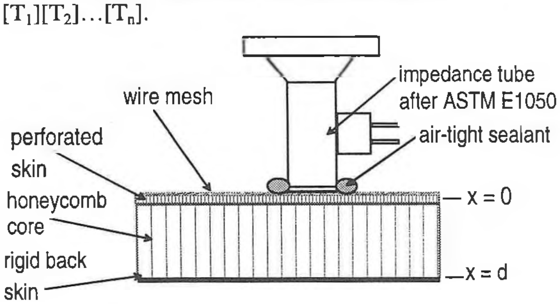

Figure 1: Sketch showing the nacelle and the impedance tube.

Assuming normal incidence, the transfer matrix for the airspace between the wire mesh and the rigid backing is,

$$[T_2] = \begin{bmatrix} \cos(kd) & i \cdot \rho_o c \cdot \sin(kd) \\ i \cdot \dfrac{\sin(kd)}{\rho_o c} & \cos(kd) \end{bmatrix} \quad (2)$$

The transfer matrix for a thin layer having both mass and resistance is given by

$$[T_1] = \begin{bmatrix} 1 & Z_m \\ 0 & 1 \end{bmatrix} \quad (3)$$

where Z_m is the impedance of the wire mesh and is given by,

$$\frac{1}{Z_m} = \frac{1}{R_m} + \frac{1}{i \cdot \omega \cdot m} \quad (4)$$

and R_m is the resistance of the wire mesh, ω is the angular frequency, and m is the effective surface density.

For the system shown in Figure 1 the velocity at the rigid termination at x=d is zero and equations 1, 2 and 3 give the impedance of the total system as

$$Z_t = \frac{T_{11}}{T_{21}} = \frac{-i\cos(kd)}{\sin(kd)}\rho_o c + Z_m \quad (5)$$

The first term is the air volume impedance and will become zero at the resonant condition,

$$kd = n\pi / 2 \quad (6)$$

where n is an odd integer. For frequencies where this condition is satisfied, the measured impedance is just that of the wire mesh,

$$Z_m\Big|_{kd=n\frac{\pi}{2}} = \frac{-R_m\omega \cdot m}{-\omega \cdot m + iR_m} \quad (7)$$

If the wire mesh is well bonded to the perforated skin it will not vibrate and the mesh will behave as if it had infinite mass. Equation 7 reduces to

$$Z_m\Big|_{kd=n\frac{\pi}{2}} = R_m \quad (8)$$

and the measured impedance will be purely resistive; the mesh resistance. In the event that measured reactance is not zero (i.e., R_m>>ωm) it might be an indication that the adhesive has completely filled the wire mesh or that the material is not adequately bonded to the substrate.

Measured Results

The impedance of the nacelle at the resonance condition was measured at nine points using an impedance tube as shown in Figure 1. Using the same nacelle nine specimens were cut and the airflow resistance measured using the ASTM C522. The results shown in Table 1 indicate that the proposed method provides an alternate non-destructive method for measuring the air flow resistance of materials.

	C522 Method (mks Rayls)	Proposed Method (mks Rayls)
Mean ± 95% conf. (mks Rayls)	362.5 ± 9.1	356.2 ± 3.3

Table 1: Mean measured airflow resistance of the nine samples using the two methods. A 9.5 cm/s flow velocity was used in both.

[i] K.U. Ingard, *Notes on Absorption Technology*, Noise Control Foundation, Poughkeepsie, NY, 1994, p. A1—A8.