Technical Comments

Brief discussions of previous investigations in the aerospace sciences and technical comments on papers published in the AIAA Journal *are presented in this special department. Entries must be restricted to a maximum of 1000 words, or the equivalent of one* Journal *page including formulas and figures. A Discussion will be published as quickly as possible after receipt of the manuscript. Neither the AIAA nor its editors are responsible for the opinions expressed by the correspondents. Authors will be invited to reply promptly.*

Comment on "Material Damping of Simple Structures in a Simulated Space Environment"

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IN the subject article,[1] Edberg describes a damping test technique, several material damping theories, and the results of a series of tests. It is heartening to see careful experimental research like this progressing in the important area of damping in advanced space structures.

Several observations are in order. First, Edberg states that two particular damping theories [Eqs. (9) and (13) in Ref. 1] give consistent and comparable estimates of the damping in unidirectional graphite/epoxy composites. It is shown in the following sections that Eq. (13) is a special case of Eq. (9) and that both are specific applications of what this author refers to as the "modal strain energy rule of mixtures" damping theory.

Second, in the discussion leading to Eq. (6) of Ref. 1, Edberg states that the treatment of thermoelastic damping in isotropic plates involves thermal gradients in two directions. In Zener's treatment of thermoelastic damping in thin metal beams,[2] thermal gradients along the length of the beam are neglected in favor of the transverse thermal gradients. A similar one-directional assumption seems justified in the case of plate vibration, so long as the thickness is many times smaller than the characteristic lengths of the vibration mode of interest.

It may also be of interest that this author estimates the average microstructural damping ratio of P100 graphite reinforcement (at room temperature and frequencies from 300–2000 rad/s) to lie between 4×10^{-4} and 9×10^{-4},[3] consistent with Edberg's results for T300 fibers. Data used to estimate this range were obtained for metal matrix composites in cooperation with van Schoor and Crawley of MIT.[4]

Damping in Unidirectional Graphite/Epoxy Composite Materials

Equations (9) and (13) of the subject article are reproduced below. Equation (9) is termed the "bending stiffness rule of mixtures" (attributed to Ref. 5), while Eq. (13) is based on a complex modulus concept (following Ref. 6). Both are said to be appropriate for flexural vibrations of unidirectional composite materials.

$$\zeta=\zeta_f\left(\frac{E_f}{E}\right)\left(\frac{I_f}{I}\right)+\zeta_m\left(\frac{E_m}{E}\right)\left(\frac{I_m}{I}\right)=\frac{\zeta_f E_f I_f+\zeta_m E_m I_m}{EI} \tag{9}$$

$$\zeta=\frac{\zeta_m+\zeta_f(E_f v_f/E_m v_m)}{1+(E_f v_f/E_m v_m)}=\frac{\zeta_f E_f v_f+\zeta_m E_m v_m}{E_f v_f+E_m v_m} \tag{13}$$

For a unidirectional composite composed of uniformly distributed fibers whose transverse dimensions are small compared to the thickness of the composite, we have the following relations:

$$I_f/I=v_f,\quad I_m/I=v_m,\quad v_f+v_m=1$$

In addition, the following approximate relation for the composite longitudinal modulus is employed:

$$E=E_f v_f+E_m v_m$$

Substituting the preceding relations into Eq. (9), we find

$$\zeta=\frac{\zeta_f E_f v_f+\zeta_m E_m v_m}{E_f v_f+E_m v_m}=\frac{\zeta_f E_f v_f+\zeta_m E_m v_m}{E}$$

This is seen to be identical to Eq. (13). For unidirectional composites possessing significantly nonuniform cross sections, such as a thick matrix-rich surface layer, Eq. (9) is more appropriate than Eq. (13). In applying Eq. (9), care must be taken to refer the area moments of inertia to the modulus-weighted centroid of the cross section. Equation (13) is appropriate for use when the cross section is nearly uniform or when extensional (as opposed to flexural) vibrations are under consideration.

Modal Strain Energy Rule of Mixtures Damping Theory

In the design of viscoelastic damping treatments, the following formula, based on complex modulus concepts, is often used to estimate the effectiveness of a particular design.[7] See Refs. 8 and 9 for representative applications and design procedures. This formula was originally used to estimate the damping in *structures* from the damping of substructures made from a single material; the extension to composite

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materials is clear if they are considered to be assemblages of constituent substructures

$$\zeta = \sum_i \zeta_i U_i^*$$

where ζ is the effective composite viscous damping ratio for a particular mode of vibration; ζ_i the damping ratio for constituent material i, generally a function of frequency and temperature; and U_i^* the fraction of the strain energy of deformation (in the particular mode shape) found in material i.

For illustrative purposes, consider an undamped composite rod with isotropic constituents executing extensional vibration in its fundamental mode (in vacuum and free fall, if desired). At the instant of maximum amplitude, the energy of vibration is found entirely as strain energy. If shear and end effects are neglected, we find uniform extensional strain and nonuniform stress at any cross section. The strain energy density can then be approximated as follows:

$$U = \tfrac{1}{2} E\epsilon^2 = \tfrac{1}{2}(E_f v_f + E_m v_m)\epsilon^2$$

Now, applying the "modal strain energy rule of mixtures" damping theory, we find that

$$U_f^* = \frac{E_f v_f}{E}, \qquad U_m^* = \frac{E_m v_m}{E}$$

$$\zeta = \frac{\zeta_f E_f v_f + \zeta_m E_m v_m}{E}$$

Notice that this result is identical to Eq. (13). A similar derivation for a composite beam in flexure yields Eq. (9). A more general form of this theory would account for the fact that the total strain energy is the sum of that associated with different types of deformation, as follows:

$$\zeta = \sum_i \sum_j \zeta_{ij} U_{ij}^*$$

where the subscript j indicates different types of deformation (e.g., dilation or distortion of an isotropic material).

The description given in Ref. 1 indicates some similarity of this approach to that of Ni and Adams,[10] but is applicable to composites of arbitrary composition and geometry.

Note that the preceding theories are only appropriate for use when applied to damping mechanisms with characteristic geometric scales much smaller than the constituent or specimen dimensions. (Thermoelastic damping due to transverse thermal currents, for example, does not meet this restriction.) In addition, material damping values should generally be treated as functions of temperature and frequency.

This author trusts that research activity in the general area of damping in advanced space structures will flourish and that the line of research related in Refs. 1 and 11 will continue to lead to new insights.

References

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Errata

Shuttle Entry Data System Preflight Test and Analysis

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TABLES 1 and 2 were inadvertently omitted and are printed below.

Table 1 SEADS columbium port test summary

Test temperature (°C)			
Target	Actual	Cycles	Remarks
1260	1259	6	No observable port/coating damage
1430	1410	6	No observable port/coating damage
1540	1543	3	Mid-coated surface polishing; coating not breached