

DAMPING IN ACOUSTICALLY EXCITED STRUCTURES

1. NOTES

Damping is the energy dissipation from a vibrating system. It is an important parameter in defining the response of a structure to high intensity acoustic loading. Increasing this parameter provides a means of reducing the amplitudes of vibration and associated stresses in a structure. At present no reliable method for predicting damping values has been devised. In this Data Item the sources of damping in typical structures are described and some guidance on the range of values likely to be found on different types of structure, without special damping treatment, is provided. Also some guidance is given on methods of increasing structural damping.

Two theoretical models, viscous and hysteretic, are used to represent damping. In the viscous model the energy dissipated per cycle is proportional to the product of the frequency and the square of the displacement amplitude. In the hysteretic model the energy dissipated during a harmonic* vibration is independent of frequency and proportional to the square of the displacement. For structures subjected to harmonic excitation hysteretic damping may be treated as viscous damping using an equivalent damping coefficient inversely proportional to the driving frequency. In this Data Item the viscous damping model is used.

Many terms are used to define the magnitude of damping. In this Data Item the measure used is the damping ratio, *i.e.* the ratio of the actual damping coefficient to the critical damping coefficient for the mode of vibration considered, which represents the total damping within the structure from all sources. The relationships between some common measures of damping are given in Appendix A.

2. DAMPING SOURCES

2.1 General

The main sources of damping of structural response, before any attempt is made to increase it by artificial means, are structural, where energy is dissipated within the structure in the form of heat, and acoustic, where energy is radiated from the structure as sound. Although it is not possible to give exact relationships between the magnitudes of structural and acoustic damping ratios, it is generally expected that, for typical aircraft structures, structural damping is dominant. Other sources are present but generally these make relatively small contributions to the overall damping.

2.2 Structural Damping

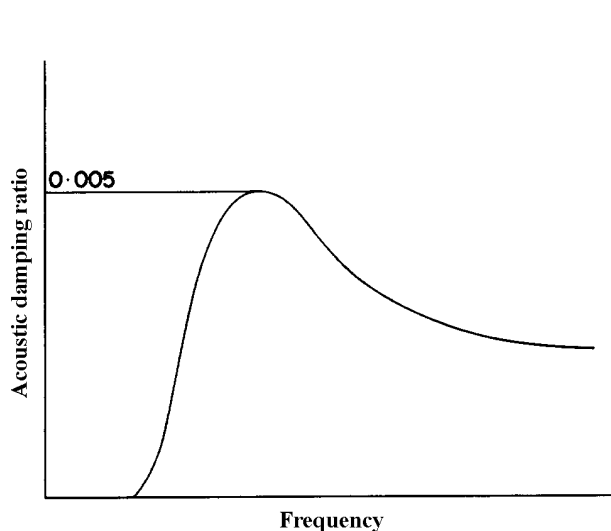
Slip of mechanical joints and internal hysteresis of materials contribute to structural damping. The internal hysteretic damping of structural materials normally used in aircraft is small compared with that attributable to slipping of joints. At small amplitudes of vibration slip does not occur and any damping can only arise from material hysteresis. As the amplitude of vibration increases slip begins to occur near rivets and bolts and damping increases more rapidly. Because the two causes of damping act independently of one another the total structural damping is not proportional to the amplitude of vibration. The onset of slip depends on the relationship between the joint load and the pressure between mating surfaces. When the amplitude of vibration is large there is some evidence to show that the friction between mating surfaces is reduced during the early stages of excitation and the damping is reduced accordingly. In a complex structure individual joint loadings will be different in each mode; hence the contribution to the overall damping from the joint will be different in each mode.

* In a harmonic vibration the amplitude is represented by the circular functions sine or cosine, e.g. $A \sin(Bt + C)$, where A , B and C are constants and t is time.

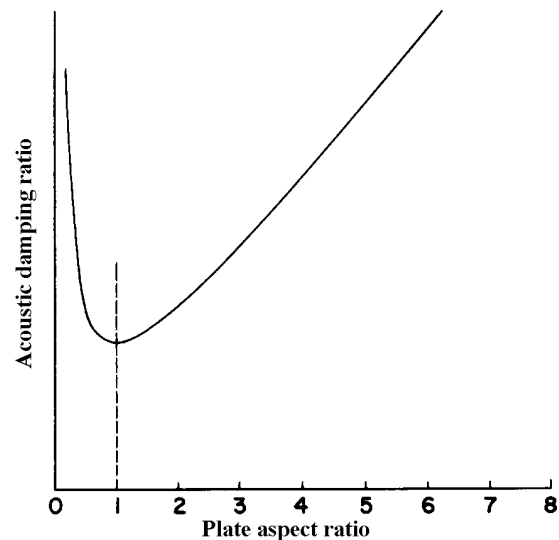
2.3 Acoustic Damping

Both overall structural vibration modes and local single panel modes contribute to acoustic radiation damping. However, it is not possible to give quantitative data for these damping values.

Damping from modes involving distortion of the whole structure is dependent on the mode of vibration and the wavelength of the radiated sound. The acoustic damping ratio for a typical mode varies with frequency as shown in Sketch 2.1. When the wavelength of the radiated sound is greater than the longitudinal wavelength of the vibrating mode there is no acoustic damping.



Sketch 2.1



Sketch 2.2

Acoustic damping in local panel modes results from radiation from each element of the panel acting as a piston having the local velocity and amplitude of the vibrating panel. When adjacent plates, separated by a stiff edge member, vibrate in phase the damping pressure on one plate also acts on adjacent plates increasing the overall acoustic damping ratio. If, however, adjacent plates vibrate in anti-phase their damping pressures tend to cancel each other giving a small overall acoustic damping ratio. The variation of acoustic damping ratio with plate aspect ratio for a typical rectangular plate vibrating in its fundamental mode is shown in Sketch 2.2.

3. DAMPING VALUES FOR TYPICAL STRUCTURES

3.1 Data Presented

In Figures 1 – 4 the results of damping measurements made on different types of aircraft structure under discrete frequency excitation are presented. In each figure the measured damping ratio is plotted against the response frequency without differentiating between the modes of vibration and this may account for some of the scatter. As an aid to data comparison, a line is drawn through data points, the line having been positioned by a least squares method on the arbitrary assumption that the damping ratio is inversely proportional to frequency (*i.e.* viscous damping).

3.2 Skin and Stringer Panels

In Figures 1 and 2 measured values of damping ratio are presented for flat and curved panels respectively. These figures demonstrate the scatter which is typical of damping measurements. The horizontal shift of the mean line of Figure 2, compared with Figure 1, may be explained by the increase in frequency due to the curvature of the panels.

The damping ratio for typical aircraft skin and stringer panels vibrating in their fundamental mode usually lies in the range 0.005 to 0.030.

3.3 Integrally-machined Panels

In Figure 3 damping ratio is plotted against frequency for built-up structures having integrally-machined panels. The reduction in damping ratio, compared with built-up skin and stringer panels, is attributed to there being fewer joints in machined panel structures. Again the viscous damping line is drawn but is likely to be less representative as there is less joint slip due to fewer joints.

The damping ratio for a typical integrally-machined panel vibrating in its fundamental mode usually lies in the range 0.003 to 0.012.

3.4 Honeycomb Structures

In Figure 4 damping ratio is plotted against frequency for flat honeycomb panels and honeycomb wedges.

The damping ratio for a typical honeycomb panel vibrating in its fundamental mode usually lies in the range 0.010 to 0.030.

4. FACTORS AFFECTING DAMPING

4.1 Structural Joints

The area of contact between jointed surfaces and the normal pressure between them affect the joint load at which slip first occurs, and hence the damping.

The use of a viscoelastic jointing compound can modify the stress distribution near the joint and reduce fretting but might not necessarily increase the overall damping ratio and could even reduce it (see Figure 1). The separation of the metal surfaces by the jointing compound tends to prevent any reduction in damping with time, which may result from oxidation of rubbing metal surfaces.

4.2 Frequency

Viscous damping ratios are inversely proportional to the frequency of vibration and hysteretic damping ratios are inversely proportional to the square of the frequency of vibration. As each individual damping source is most closely represented by one of the two damping models, an assemblage of all damping sources usually involves a combination of both models so that a general relationship between damping and frequency is not possible.

4.3 Skin Thickness

The effect of skin thickness on the damping ratio is dependent on the mode of vibration. For a stiffened panel vibrating in its stringer bending mode damping increases with plate thickness; as plate thickness is increased, damping in the stringer torsion mode passes through a maximum. Further information on the effect of skin thickness on damping is given in Derivation 4.

4.4 Curvature

Limited experimental data, on similar structures, suggest that curvature has little effect on the damping ratio. Curvature is likely to have the greatest effect in panel modes where stringers bend. An approximate method for estimating the effect of curvature on the damping ratio for a particular mode is given in Derivation 4.

4.5 Flow Velocity

Air flowing past panels can reduce the damping ratio. This is important in aircraft structures where the reduction in damping may lead to panel flutter particularly in supersonic and transonic flow conditions.

4.6 Amplitude of Vibration

The variation of damping with amplitude of vibration for some typical flat, riveted skin-stringer panels under discrete frequency excitation is shown in Figure 5. All data presented on this figure are from one series of tests in a travelling wave tube. Damping ratios calculated using the single mode (all edges fixed) response theory are plotted against the root mean square panel stress. There is some indication that damping ratios are reduced with increase in response amplitude for these specimens, which is against the expected trend for structural damping (see Section 2.2). In Reference 13 data for sandwich panels show an increase in damping ratio with increase in stress amplitude.

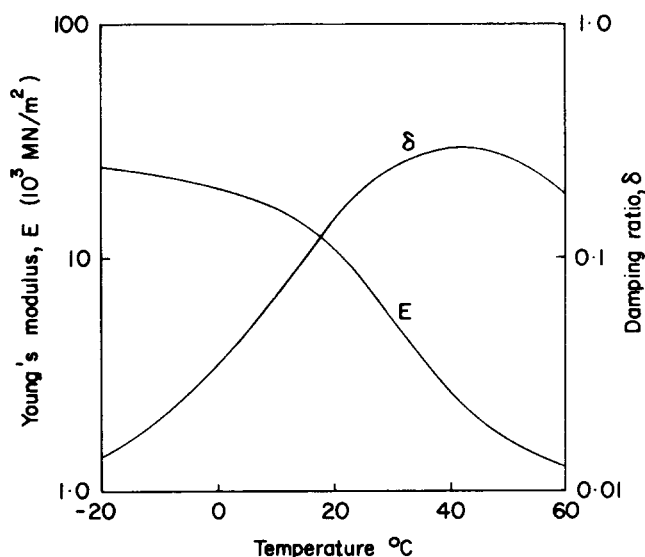
5. METHODS OF INCREASING DAMPING

In general, damping treatments have so far only been used on aircraft structures to alleviate a service problem not foreseen at the design stage. A better understanding of the advantages of good damping should eventually lead to its consideration as a design criterion. Consideration of damping at the design stage may allow panels with sandwiched viscoelastic material to be used which are continuous across stringer joints. However, where primary structure is concerned, there are difficulties to be overcome including loss of stiffness in joint fabrication and creep under steady load.

To increase damping in a structure efficiently, a knowledge of the frequency and shape of the mode requiring additional damping is necessary. Changing the stiffness of a structure does not improve damping unless the critical resonant frequency can be made to approach the frequency for peak acoustic damping. However increasing structural stiffness increases the natural frequencies and may thereby provide an acceptable remedy for excessive vibration if the higher frequencies are not excited during normal operating conditions.

The use of viscoelastic damping materials provide the most practical method for improving damping. To be effective these materials must be applied so that they will undergo high strain. It is also necessary to select a material with suitable physical properties over the range of operating temperatures. Material properties vary greatly with temperature and are also frequency dependent.

Sketch 5.1 shows the variation of damping ratio with temperature and the reduction of material stiffness (indicated by the curve for E) with increase in temperature for a typical viscoelastic material intended for use at normal ambient temperatures.



Sketch 5.1

Viscoelastic material may be applied to a structure as an unconstrained layer. For optimum damping effect the material should be placed in a region of high bending strain (usually at the anti-node positions) and it is an advantage to have the damping material as far removed as possible from the neutral axis.

Unconstrained viscoelastic material need only be used in areas of high bending strain in the modes requiring additional damping. However, if several modes need increased damping, it may be necessary to cover the whole skin surface. For stiffened panels having stiffeners of low flexural stiffness, such as integrally-machined panels, it is an advantage to use viscoelastic material on the stiffener face remote from the skin.

Constrained viscoelastic layers, formed by sandwiching damping material between skins, give increases in damping when the viscoelastic material is subjected to high shear strain. A similar constrained layer damping system is formed by attaching foil-backed damping tape to the skin surface. Expressions and calculated values for damping ratios of panels with viscoelastic damping layers are given in Derivation 7 and Reference 14.

Damping in structures may be increased by using viscoelastic inserts at joints. This method is not likely to give as high increases in damping ratio as plate-surface layer treatments but it reduces joint fretting.

Addition of viscoelastic material leads to an increase in mass and changes in stiffness of the structure. These changes should be considered in optimising the overall effect of the damping materials.