ment In the case of a uniform beam where damping is a function of displacement, Eq (4) becomes

$$\tan(\alpha_2 - \alpha_1) = \frac{\omega k(c_1 - c_2)}{2k^2 + \omega^2 c_2(c_1 + c_2)} \tag{5}$$

Hence, a massless beam may have a phase shift

Effect of Aerodynamic Damping on Flutter of Thin Panels

H M Voss* and E H Dowell†
The Boeing Company, Seattle, Wash

THIS note discusses the role of aerodynamic damping in determining the flutter boundary for thin panels, primarily within the framework of piston theory aeiodynamics

In the early work on the flutter of unstressed, flat, rectangular panels, it was shown that the neglect of aerodynamic damping was a very good approximation for panels of moderate to large aspect ratios (see, e g , Refs 1 and 7) Thus, the flutter boundary could be described in terms of the now well-known parameter,

$$\lambda = 2qL^3/(M^2 - 1)^{1/2}D$$

The omission of aerodynamic damping was equivalent to setting the mass ratio

$$\mu = \rho L/\rho mh$$

equal to zero

Subsequent to this work, the approximation $\mu = 0$ has been used in determining the stability boundaries for numerous configurations Here we would like to note that there are situations where this approximation may lead to inaccurate results This is usually associated with flutter involving modes of nearly identical frequency but weak aerodynamic coupling

1 Cylindiical Shell

As discussed in Ref 2, for the cylindrical shell there are two types of flutter modes of interest One of these is a coupling of the first two axial modes at a large circumferential mode number For this type of flutter mode the approximation is still a good one (under the assumption of piston theory aerodynamics) The other flutter mode of interest is an axisymmetric coupling of two higher axial modes For this type of flutter mode aerodynamic damping has a very pronounced effect on the flutter boundary In addition, flutter involving other modes of nearly identical frequency, but weakly coupled aerodynamically, can be shown to be unimportant due to aerodynamic damping

2 Rectangulai Panels under Shearing Loads

Recently, Eisley and Luessen[3] considered the problem of a rectangular, flat panel under shearing loads These shearing loads lead to the merging or crossing of the natural frequencies associated with an otherwise unstressed panel, and flutter boundaries would be obtained with sharp minimums in the fluttei dynamic pressure for certain values of the shearing loads for $\mu = 0$ The inclusion of aerodynamic damping removes these unrealistic "dips "

3 Rectangular Panel Aligned at an Arbitrary Angle to the Flow

As a final example, the case of a flat, rectangular panel aligned at an arbitrary angle to the airflow is considered This problem has been studied previously in Refs 3–5 Recent calculations by the present authors *including* aerodynamic damping have led to the results shown in Fig 1 This figure gives the flutter parameter λ as a function of flow angle φ for two values of μ/M; $\mu/M = 0\,1$ was chosen as being representative of practical values of the mass ratio As may be seen, the addition of aerodynamic damping changes the character of the curve markedly In particular, the rapid vaiiation of λ in the neighborhood of $\phi = 0$ is no longer present for $\mu/M = 0\,1$

Fortunately, the inclusion of the aerodynamic damping term in the piston theory (or quasi-steady theory) is relatively simple for panels of uniform mass distribution For these panels a nondimensional generalized eigenvalue may be identified as

$$\theta = K^2 - i[\lambda\mu/M]^{1/2}K \tag{1}$$

where

$$K^2 = \rho mhL^4\omega^2/D$$

is a nondimensional, complex panel frequency Equating real and imaginary parts of Eq 1 and specifying the flutter condition, $K_{\mathrm{im}} = 0$, gives

$$K_R = \pm(\theta_R)^{1/2} \tag{2}$$

$$\mu/M = (1/\lambda)\,(\theta_I{}^2/\theta_R) \tag{3}$$

Strictly speaking, for the quasi-steady theory, μ/M should be replaced by

$$[\mu/(M^2 - 1)^{1/2}]\,[(M^2 - 2)/(M^2 - 1)]^2$$

It is to be noted that θ is only a function of λ (for a given panel geometry) Thus the mathematical problem is reduced to finding $\theta = \theta(\lambda)$ After θ has been deteimined, Eqs (2) and (3) may be used to determine flutter fiequency and mass ratio, respectively This is essentially the sta bility parabola concept of Movchan[6] and Houbolt[7] Viscous structural damping also may be included by an analogous procedure

Finally, it should be mentioned that there are other aerodynamic damping effects which piston theory is incapable of predicting Foremost among these is the possibility of single degree of freedom flutter when the aerodynamic damping becomes negative at low supersonic Mach numbers For this type of instability, λ is no longer an appropriate parameter

Lock and Fung[8] have investigated this phenomenon experimentally and theoretically for a nominal two-dimensional panel Moie recent work on the subject has shown that it exists over a limited range in Mach number which decreases

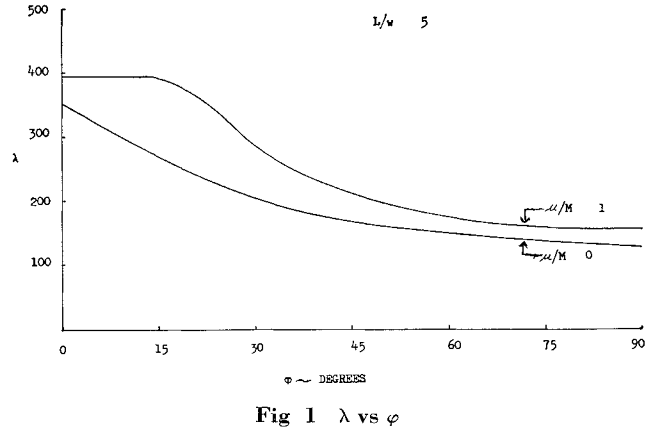

Fig 1 λ vs φ

Received September 23, 1963

* Chief, Dynamics and Loads, Structural Research and Development, Structures and Materials Technology, Aerospace Division Associate Fellow Member AIAA

† Formerly Research Engineer, Aero Space Division; now Research Associate, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology Cambridge, Mass Member AIAA

with increasing panel length to width ratio The occurrence of single degree of freedom flutter, its experimental definition and theoretical prediction, remains one of the important problems in panel flutter A detailed discussion is not possible here, but the reader is referred to Refs 8–11 for the literature on the subject

References

1 Hedgepeth, J M , "Flutter of rectangular simply supported panels at high supersonic speeds," J Aeronaut Sci **24,** 563–573 (1957)

2 Voss, H M , "The effect of an external supersonic flow on the vibration characteristics of thin cylindrical shells," J Aerospace Sci **28,** 945–956, 961 (1961)

3 Eisley, J G and Luessen, G , "The flutter of thin plates under combined shear and normal edge forces including the effects of varying sweepback," AIAA J **1,** 620-627 (1963)

4 Kordes, E E and Noll, R B , "Theoretical flutter analysis of flat rectangular panels in uniform coplanar flow with arbitrary direction," NASA TN-1156 (January 1962)

5 Voss, H M , "The effect of some practical complications on the flutter of rectangular panels," AIA Symposium on Structural Dynamics of High Speed Flight (April 1961)

6 Movchan, A A , "On vibrations of a plate moving in a gas," Prikl Mat Mek **20,** 2 (1961)

7 Houbolt, J C , "A study of several aerothermoelastic problems of aircraft structures," Doctoral Thesis, Eidgenössischen Technischen Hochschule, Zurich (1958)

8 Lock, M H and Fung, Y C , "Comparative experimental and theoretical studies on the flutter of flat panels in a low supersonic flow," Air Force Office Sci Res TN 670 (May 1961)

9 Cunningham, H J , "Analysis of the flutter of flat rectangular panels on the basis of exact three-dimensional linearized supersonic potential flow," IAS Paper 63-22 (January 21–23, 1963)

10 McClure, J D , "On perturbed boundary layer flows," Mass Inst Tech Fluid Dynamics Res Lab Rept 62 2 (June 1962)

11 Dowell, E H and Voss, H M , "Experimental and theoretical panel flutter studies in the Mach number range 1 0 to 5 0" (rept confidential, title unclassified), Aeronaut Systems Div ASD-TDR 63 449 (June 1963)

Optical-Acoustic Effects in Solid Films

Arthur V Houghton*
University of New Mexico, Albuquerque, N Mex

AND

Russell U Acton†
Sandia Corporation, Albuquerque, N Mex

Acoustics effects of light radiation on solid film are noted, and a measurement method is described Acetylene soot, camphor soot, flat black paper, glass, white papeı, aluminum, and blackbody cavities were investigated Proposed uses are noted

OPTICAL-ACOUSTIC effects were noted in gases in 1881 Recently, several Soviet investigators were concerned with different spectral regions and measurement methods in gases [2–6] In some of our studies on diffusivity, similar optical-acoustic effects have been found in solid films In the system used in this investigation (Fig 1) the specimens were irradiated with a xenon gas phototube which puts out 1 megalumen for 1 msec The acoustic pickup was a microphone with a flat response from 60 to 13,000 cps

Received September 24, 1963

* Associate Professor of Mechanical Engineering

† Staff Member

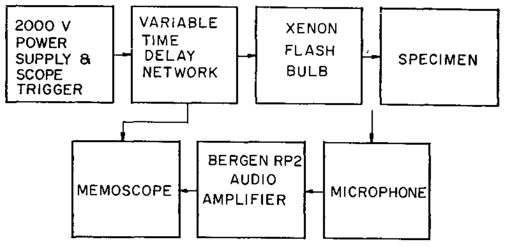

Fig 1 Flash and audio system

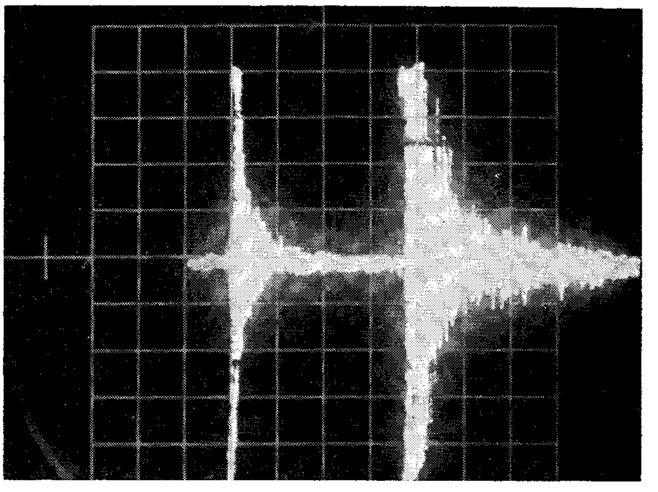

Fig 2 Photograph of scope trace

Very sharp audible pulses were noted from acetylene soot covering on both electrical conductors and nonconductors Less sharp reports were obtained from camphor soot and a very small noise from the flat black paper White paper and various transparent plastics gave no report at all The report given off by the black materials apparently is due to air motion following energy absorption

In the use of uncoated aluminum sheet, no effect was noted for plates over 1 cm in thickness Very thin aluminum sheets gave out a high pitched tone when irradiated This effect appears to be due to light radiation pressure Figure 2 shows the scope trace for acetylene soot The left-hand pulse is relay noise obtained by closing the relay when the speciemen is not irradiated, and the right-hand grouping is due to the combination of this same relay and the audible report due to energy absorption This is a second sweep obtained when the horizontal sweep is moved and the specimen is irradiated The sweep speed was 20 msec per division, and the vertical scale was 1 v per division Reversing the acetylene coated glass so that the uncoated side is to the light stops the noise, thus indicating that the effect is beyond 2 7 μ because the glass is not transparent beyond that point

In this case, the light pressure or the formation of gas between the glass and the coating was sufficient to blow the coating off of the glass Measurements from force transducers behind the specimen were inconclusive since several types of transducers appeared to be sensitive to the electrical transients in the circuit Measurements of blackbody cavities gave results similar to the acetylene soot

It is proposed that the order of magnitude of thermal absorptivity of nearly black specimens may be evaluated by a comparison of the magnitude of the acoustic energy released upon irradiation with the flash bulb Extensive study would appear to be required if high accuracy were to be obtained

References

1 Tyndall, J , "Action of an intermittent beam of radiant heat upon gaseous matter," Nature **23,** 374–377 (1881)

2 Gerlovin, Ya I , "Optico-acoustic effects in the ultra violet region of the spectrum," Optics Spectroscopy **8,** 352 (1959)