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Study on the Random Vibration of an Elastic Body Caused by a Turbulent Flow

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In engineering problems, there are very often systems which are irregularly excited by random inputs. In this study aiming at the design of a structure under random loading, e. g. the wing of aircraft in flight through a turbulence, the responses of structure are investigated by a stochastic method on the basis of simplified representations of structure.

This study consists of two parts, i. e. linear and nonlinear problems. The linear problem constitutes main part of this study and it is composed of two-dimensional and three-dimentional problems. When the scale of turbulence is larger than the size of structure such as the chord length and the span of wing, we can apply a two-dimensional analysis, and when the scale of turbulence is much smaller than the span of wing, we must apply a three dimensional analysis.

In the analysis of two-dimensional problem, the structure under consideration is replaced by a mass-spring-damper system having a single-degree of-freedom. The statistical properties of the response, i. e. the mean square values and power spectral densities of the lift acting on the structure, the displacement of the structure, etc., are investigated, assuming that the structure is situated in a stationary homogeneous isotropic turbulence with two dimensional construction.

In the analysis of three-dimensional problem, the structure under consideration is replaced by an elastic beam with homogeneous cross section. The response, i.e. the lift acting on the beam, the deflection and bending stress of the beam, etc., is investigated, assuming that the structure is situated in a turbulence with three-dimensional construction. The three-dimensional problem has a distinctive feature thnt the loading on the structure and the responses of the structure vary irregularly not only on the time scale, but also along the span of beam. Here the boundary conditions of the beam are assumed to be both ends supported by pin joints and to be both ends free.

From the theoretical results of linear problems, it was shown what influences the mean flow velocity, the intensity of turbulence, the scale of turbulence, etc., have upon the mean square values and power spectral densities of the response and also what influences the characteristics of the structure such as aspect ratio, damping coefficient, natural frequency, etc. have upon the response. Furthermore for practical purposes it was shown how we can use these results, especially the mean

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square values of stress, in estimating the strength and fatigue life of the structure under random loading.

The experimental study using a simple model was made for the two-dimensional problem, and its results were compared with the theoretical results. Another purpose of the experimental study is to show an example of experimental methods used for investigations of stochastic phenomena in aeroelastic problems. From the experimental results, it was shown that the root mean square value of the response approaches to a difinite value, when the mean flow velocity has sufficiently large value, because the aerodynamical damping force acting on the wing increases in company with the lift according to the mean flow velocity. These experimental results were found to be in reasonably good agreement with the theoretical results.

In the analysis of nonlinear problem, the structure is replaced by a vibratory system having a single-degree of freedom, whose restoring force exhibits nonlinearity of Duffing type. These nonlinear problem consists of two parts, i. e. symmetrical nonlinear system and unsymmetrical nonlinear system. The former has a nonlinear spring, whose characteristic curve is symmetric about an equilibrium point and given as a cubic expression of deflection, while the latter has a nonlinear spring, whose characteristic curve is unsymmetric and given as a quadratic expression. In this analysis, the random loading is given as a function having a discrete power spectrum, and an iteration method is applied to solve the problem, assuming that the nonlinearity and loading have small values. In order to linearize the problem, the concept of equivalent loading is introduced and then the first order approximate solution is derived. By this analysis it was estimated what influences the nonlinearity of restoring force and the level of loading have upon the mean square values and power spectra of the response such as the displacement in the system.

These theoretical results of nonlinear problem were compared with the solutions obtained through an analog computer and the influences of nonlinearity upon the mean square value of displacement were evaluated. From the results obtained through an analog computer, the range of the nonlinearity and the level of loading, in which the first order approximation is valid, was estimated, and it was shown by practical examples of nonlinear spring that the first order approximation is usually available to practical problem.

The most part of this study was already published by the author in the following papers :

(1) "On the Beam under Random Loading." Bulletin of JSME, Vol. 3, No. 9, (1960), 60—65.

(2) "Nonlinear Vibrations of Systems under Random Loading." Bulletin of JSME, Vol. 6, No. 21 (1963), 44—52

(3) "Unsymmentrical Nonlinear Vibration Systems under Random Loading." Bulletin of JSME, Vol. 6, No. 21 (1963), 53—59.

(4) "On the Vibration of Beam under Time-space Random Loading." Proc. 8 th Japan National Congr. for Appl. Mech., 1958, 389—392.
(5) "Experimental Investigation of the Response of Wing to Turbulence." Proc. 12 th Japan National Congr. for Appl. Mech., 1962, 249—252.
(6) "Experimental Investigation on the Response of a Wing to Turbulence." Proc. Faculty of Engg., Keio Univ., Serial No. 57, 1962, 37—47.