Engineering Notes

A Forced-Oscillation Method for Dynamic-Stability Testing

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Introduction

In order to predict the motion of a body in flight, it is necessary to know the dynamic-stability parameters. Among the most important are those associated with the damping and oscillatory stability in roll, pitch, and yaw. Although these parameters may at times be obtained by theoretical methods, it is usually necessary to determine them experimentally because of the unpredictable flow characteristics of present-day aerodynamic bodies. This note briefly describes a small-amplitude rigidly-forced-oscillation technique that has been developed at the NASA Langley Research Center and that has provided much useful dynamic-stability data. Details of this technique are presented in Ref. 1.

Oscillation-Balance Mechanism

Exploded and assembled views of the forward portion of the oscillation-balance mechanism, showing the mechanical components used to obtain the rigid drive, are presented in Fig. 1. As can be seen, the strain-gage bridge that is used to measure the forcing moment is located forward of the pivot axis so that the forcing moment is sensed between the model and the pivot axis. This location completely eliminates the measurement of damping due to pivot friction and thereby results in a lower and more nearly constant value of tare damping.

Accuracy

Probable error

The probable error of the dimensional damping coefficient has been determined to provide an indication of the ability of the small-amplitude forced-oscillation technique, as used at Langley, to determine accurately the aerodynamic damping characteristics of a model. This was done by oscillating a large copper plate between the poles of a permanent magnet and measuring the resulting eddy-current damping. The damping coefficients measured for two positions of the magnet with respect to the pivot axis were found to be

$$C_2 = 0.6993 \pm 0.0014 \text{ ft-lb/radical/sec}$$

$$C_1 = 0.1507 \pm 0.0009$$

The mechanical or tare damping coefficient with no eddy current damping was

$$C_0 = 0.0132 \pm 0.0010$$

It is important to note that the tare value C_0 is small, and the values of the probable error are small and independent of the magnitude of the damping coefficient. Thus, except for very low-damped systems, the uncertainty in the tare value would have little effect on the measured coefficients.

Effects of random noise

A problem that can be very important, especially at transonic speeds, is noise introduced into the system by airstream turbulence. Basic to the system that is in use at Langley is the resolution of the forcing moment into components in phase and out of phase with model displacement. These components are, of course, proportional to the stability and damping parameters. This resolution of the forcing moment is accomplished by passing the signal proportional to the forcing moment through an induction resolver that rotates at the frequency of oscillation of the model. After passing through the resolver, the component signals are demodulated and read on damped voltmeters. This system, composed of the resolver and damped voltmeter, acts as an extremely narrow band-pass filter and eliminates the effects of random moment due to airstream turbulence or other causes. The unique feature of this type of filter is that the center frequency of the band is always the frequency of oscillation of the model system. Since the noise encountered in wind tunnels is usually spread over a wide range of frequencies, the effect of random noise is, for all practical purposes, completely eliminated by the filtering action of the resolver—damped-voltmeter system.

Present Capabilities

At present, small-amplitude forced-oscillation tests can be made at Langley in pitch or yaw at Mach numbers from about 0.2 to 1.2 in the Langley 8-ft transonic pressure tunnel and from about 1.5 to 4.6 in the Langley unitary plan wind tunnel. Models are oscillated in pitch to determine the damping-in-pitch parameter and the oscillatory-longitudinal-stability parameter and in yaw to determine the corresponding damping and stability parameters in yaw as well as the parameters associated with rolling moment due to yawing motion. Using presently available equipment, models can be forced to oscillate at amplitudes of $\frac{1}{2}°$, 1°, and 2° at frequencies from about 2 to 30 cps. Extension of this technique to include the testing of models in pitch at Mach 10 and in roll in both the 8-ft and unitary tunnels will soon be realized.

Typical Results and Applications

Figures 2 and 3 show two examples of small-amplitude dynamic-stability data that have been used in the development of re-entry vehicles. Figure 2 shows the effect of a minor change in the nose shape of a model on both the damp

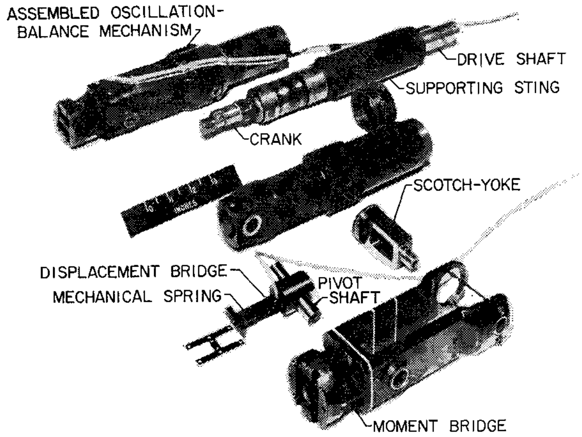

Fig. 1 Photograph of the forward portion of the oscillation-balance mechanism.

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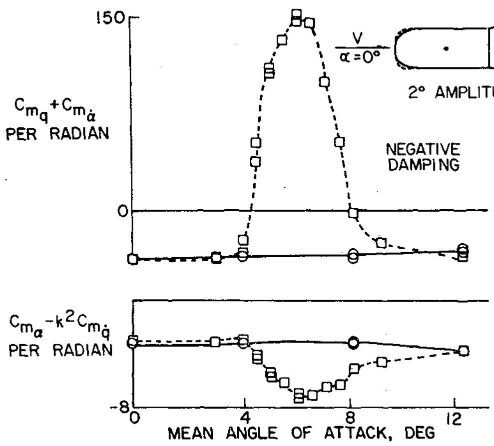

Fig. 2 Effect of nose shape on dynamic-stability parameters of a proposed re-entry vehicle.

ing and stability parameters. For the rounded-nose model, indicated by the solid lines both in the sketch and fairing of the data, both damping and stability are positive and almost constant with angle of attack. The model with a slightly more blunt nose has a region of negative damping and increased stability near 6° angle of attack due to flow separation from the upper surface of the model. Although acceptable stability parameters exist near 0° for both configurations, the negative damping near 6° for the more blunt-nose configuration indicates a possible stability problem if the body approaches 6°. Flight tests did show dynamic instability for the more blunt-nose configuration and indicated, as do these small-amplitude forced-oscillation data, that the less blunt configuration is to be preferred from the dynamic-stability point of view.

The data of Fig. 3 show some rather unexpected results of changing the shape of a body of revolution in a region of completely separated flow. For the model with a flat base, there was observed both positive damping and stability through the angle-of-attack range. With the addition of a truncated-cone fairing cap to the base of the model, in a region where the flow would certainly be completely separated, the model exhibits negative damping over a wide range of angle of attack. Free-flight tests of a similar configuration show that the addition of the base did indeed lead to dynamic instability.

An example of some small-amplitude data that have been applied to the prediction of large-amplitude motion is given in Fig. 4. These data were obtained at an oscillation amplitude of 2° over a range of angle of attack for a simple body of revolution that, when given freedom in pitch, had been observed to perform a large-amplitude limit-cycle oscillation. When these small-amplitude forced-oscillation data were used in a single-degree-of-freedom analog-computer program,

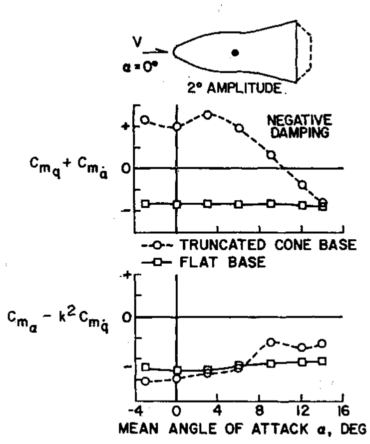

Fig. 3 Effect of base shape on dynamic-stability parameters of a proposed re-entry vehicle.

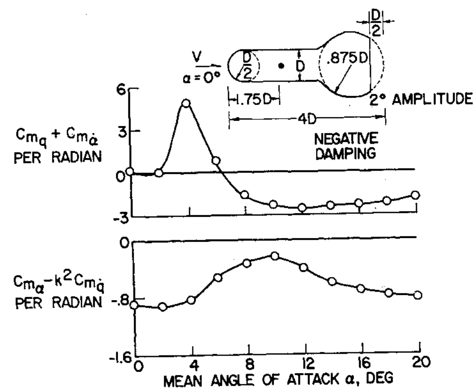

Fig. 4 Dynamic-stability parameters of a research model.

a quantitative prediction of an amplitude of 15° was obtained, compared with an observed amplitude of 13.5°. A predicted frequency of 6.8 cps was obtained, compared with an observed frequency of 7 cps.

In summary, the small-amplitude forced-oscillation technique now being used at the NASA Langley Research Center provides an accurate and convenient method of measuring some of the important dynamic-stability parameters. The small-amplitude data may be used both in the development of an acceptable configuration and in the accurate prediction of large-amplitude motion.

Reference

[1] Braslow, A. L., Wiley, H. G., and Lee, C. Q., "A rigidly forced oscillation system for measuring dynamic-stability parameters in transonic and supersonic wind tunnels," NASA TN D-1231 (1962).

Supplementary Note on Effect of Wing Geometry on Volume and Weight

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Nomenclature

W_{BB} = weight of box beam, lb
ρ = material density, lb/in.^{3}
p = pressure, lb/in.^{2}
C_R = root chord, in.
h_R = maximum root thickness, in.
f = effective stress, lb/in.^{2}
λ = taper ratio
k_{ib} = bending integration factor (see Ref. 1)
AR = aspect ratio
b = wing span, in.
S = wing area, in.^{2}
n = load factor
ϕ = box chord/wing chord
r = average box height/max box height
W = gross weight, lb
V = box beam volume, in.^{3}
θ = angle of twist, rad
T = torque, in.-lb
G = modulus of rigidity, lb/in.^{2}
J = torsion constant, in.^{4}
s = box beam perimeter, in.
t = box beam skin thickness, in.

IN the optimization procedure discussed in Ref 1 a more useful expression for wing weight may be obtained in terms of the parameters of wing area and aspect ratio. Since

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