Dynamic Stability Testing of Unconventional Configurations

K. J. ORLIK–RÜCKEMANN,* P. A. ADAMS†, and J. G. LABERGE†
National Aeronautical Establishment‡ Ottawa, Ontario, Canada

Theme

SITUATIONS frequently occur when standard wind-tunnel test equipment, based on the concept of an all-containing rear-sting support is impractical or even impossible to use. In this paper, two alternative test arrangements are indicated and descriptions are given of the actual experimental equipment and procedures. Full and half-model techniques are discussed and the experimental procedures include free and forced-oscillation methods. Examples contain cases such as flat elliptic cones, cones at incidence and combinations of two models in close proximity (space shuttle), at supersonic and hypersonic speeds.

Contents

Oscillatory experiments on three-dimensional models often are performed with stings which contain the model-release mechanism as well as the main elastic constraint and the displacement transducer. Two-dimensional models are investigated using a side-support and that technique sometimes is extended to three-dimensional configurations using half-models. None of these techniques is applicable for testing flat, slender, three-dimensional configurations, such as those resembling some of the typical delta-wing hypersonic lifting vehicles. A new experimental arrangement has therefore been developed which, by transferring all the aforementioned functions of the sting out of the tunnel and by retaining the sting only for positioning the axis of oscillation, made it possible to make the sting much smaller than before and thus compatible with the space restrictions of this particular class of models.

In the new apparatus, the main system stiffness is provided by gimbal springs mounted externally on the tunnel structure and attached to the rear of the model by means of a fine wire. Thus, the excitation and recording of the model motion as well as the changing of the system stiffness (frequency) can be performed outside the wind tunnel. The model motion is restricted to one degree of freedom in pitch, yaw, or roll as desired, with amplitude of oscillation of up to $\pm 2°$ and design frequencies up to 100 Hz. Different stings are required for oscillation in pitch (or yaw) and in roll. The experimental arrangement is shown in Fig. 1. The model is sting-mounted from the rear and is attached to the sting by means of a pair of commercially available flexural pivots. These are frictionless and torsionally weak but resist substantial lateral loads; their main function is to fix the axis of oscillation of the model. Since these pivots are available in very small sizes, they can be placed well forward inside conventional models or can accommodate relatively slender or flat models. The oscillatory motion is imparted to the system by means of an electromagnetic driver which acts on one of the gimbal springs. The motion is detected by a linear variable displacement transducer, the core of which is firmly connected to the other gimbal spring.

In oscillatory experiments, the required restoring forces or moments are usually provided by mechanical springs. If the natural frequency of a participating spring is much higher (say at least by a factor of five) than the natural frequency of the entire oscillatory system, the dynamics of the spring itself may be neglected and the analysis of the oscillatory motion may be performed without taking into account the surging effects which are caused by a finite rate of propagation of stress waves through the mass of the spring. For most practical situations, the aforementioned condition is satisfied and the use of the standard light spring theory is justified. In cases, however, when the natural frequencies of the system and of at least one of the participating springs are sufficiently close to each other to render the standard approach invalid, a more complete analysis, taking into account the inertial effects in the springs, must be employed. It can be shown, that the stability derivatives evaluated on the basis of the standard light spring theory (denoted by subscript "L") can be corrected for spring surging effects by means of the following relations

$$C_{m\theta} = [C_{m\theta}]_L \cdot X_1$$
$$C_{m\dot{\theta}} = [C_{m\dot{\theta}}]_L \cdot X_2 - (\delta/2\pi^2\nu)[C_{m\theta}]_L \cdot (X_2 - X_1)$$

where δ and ν are the logarithmic decrement and frequency of the oscillatory motion, respectively, and X_1 and X_2 are correction factors which are given in the paper as functions of the ratio of the spring natural frequency ω_s to the system natural frequency ω. The corrections given are based on the use of the one-dimensional wave equation to describe the

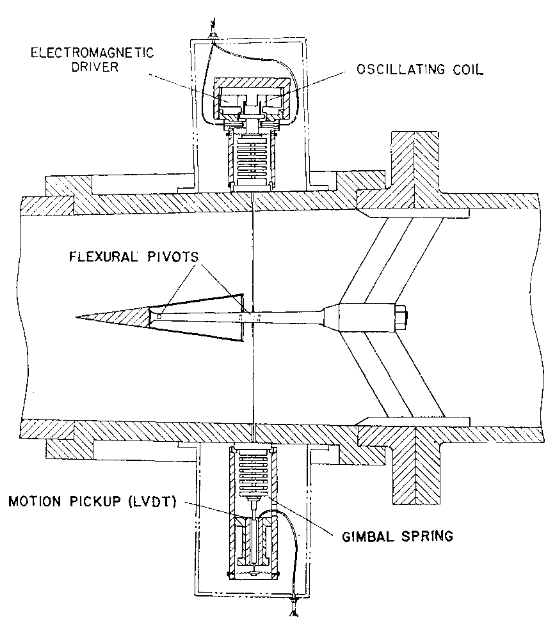

Fig. 1 Apparatus for testing slender or flat configurations.

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* Head, Unsteady Aerodynamics Laboratory, Associate Fellow AIAA.

† Research Officers.

‡ A division of the National Research Council of Canada. Member AIAA.

motion of the spring; it has been experimentally confirmed that this assumption is acceptable for the gimbal springs used in the present apparatus.

A very convenient way to perform oscillatory experiments on two models in proximity of each other is to use the technique of half-models, also known as the reflection-plane technique. This technique consists of conducting the measurements on only one half of the actual configuration and of using the tunnel wall or a suitably designed reflection plate as the model longitudinal plane of symmetry. Any problems of sting interaction or sting oscillation are automatically eliminated and in addition most of the experimental equipment can be located outside of the wind tunnel, where there are no space limitations. Also, the variation of the inclination and of the relative position of the two models is extremely simple. To be sure, the half-model technique has some unique interference problems of its own, such as the effect of the gap between model and reflection plate and the interaction between model shock-wave and reflection-plate boundary-layer. However, these interference effects can be reduced to acceptable levels by a suitable design of the equipment. Comparison of half-model and full-model data gives encouraging results for damping-in-pitch measurements on wing-body configurations and on slender bodies at zero or small angles of attack.

An excellent example of the use of the half-model technique for oscillatory experiments on two models in proximity of each other is its application to dynamic stability tests on the two components of the shuttle spacecraft during an abort separation. Such an arrangement is shown in Fig. 2. One of the models is attached to a half-model dynamic apparatus mounted on the wind-tunnel plate whereas the other, which may be either stationary or also performing an oscillatory motion, can be mounted in a number of alternative positions on the reflection plate; the incidence of the entire two-model combination can be varied by simply rotating the wind-tunnel plate. The dynamic apparatus consists of an elastic model suspension and an electromagnetic oscillator; the suspension

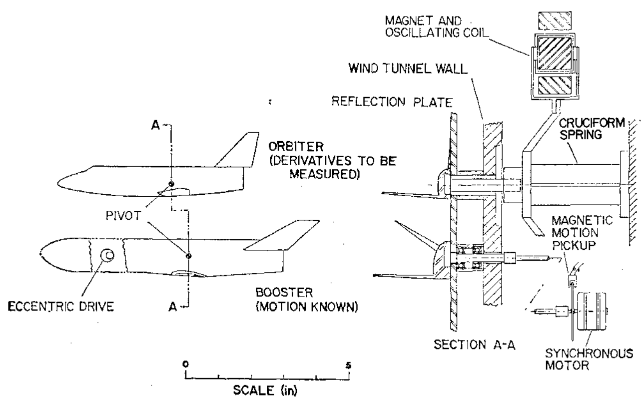

Fig. 2 Arrangement for Oscillating both components of the shuttle system using half-model technique.

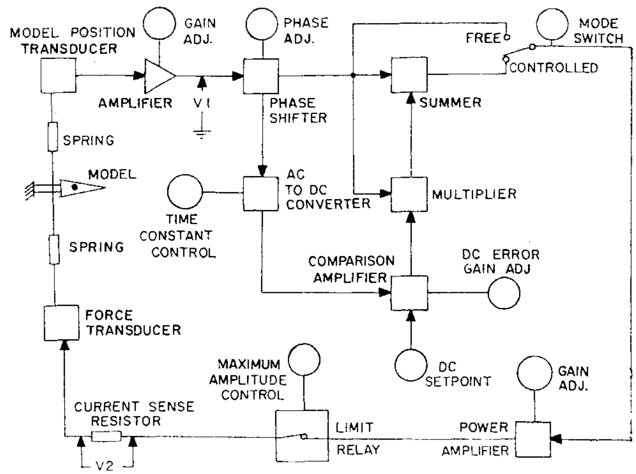

Fig. 3 Feedback circuit and amplitude stabilizer for forced-oscillation testing.

is in the form of a cruciform spring for angular oscillation and a double-cantilever spring for translational oscillation, whereas the oscillator consists of light-weight coils moving in a magnetic field and imparting the desired motion to the model end of the spring. The oscillating model is firmly attached to the spring by means of an adapter which passes right through both the wind-tunnel plate and the reflection plate. A strain-gauge bridge on the spring generates a signal analogue of the model displacement.

All the equipment described in this paper can be used for experiments employing either the free-oscillation or the forced-oscillation method of derivative measurement. The free-oscillation method has been in use at NAE for several years and can best be described as "free oscillation with automatically recycled feedback excitation." The procedure is based on the standard free-oscillation method, but employs an electronic data reduction device and a feedback controlled excitation oscillator, as well as automatic recycling and automatic data read-out. The forced-oscillation method, which is illustrated by the block diagram in Fig. 3, employs an amplitude stabilizer (with a fast AC to DC converter and comparison, analogue and summation amplifiers) and a loop phase shifter as well as suitable output devices for the oscillation amplitude (VI) and the drive current amplitude (V2). Details of the two instrumentation systems as well as examples of the results obtained with the various combinations of the two experimental arrangements and the two methods of measurement are given in the paper.

The half-model technique is also very convenient for oscillatory experiments on models at non-zero mean angle-of-attack (of interest to shuttle spacecraft), models which lack a rear centerbody suitable for sting-mounting (such as F-14, F-15, and launch configuration of the shuttle) and models with simulated jet exhaust plume.