4. SOME RECENT DEVELOPMENTS OF DYNAMIC TECHNIQUES FOR WIND TUNNELS

By Harleth G. Wiley, Robert A. Kilgore,
and Jean Gilman, Jr.
NASA Langley Research Center

SUMMARY

Some recent developments in improved dynamic techniques for wind-tunnel research are discussed. A new method for experimental gust research permits measurement of the response of a dynamically scaled model to a gust field generated in a wind tunnel by an oscillating airstream. Preliminary investigations indicate that the technique should be useful for determination of aerodynamic-structural transfer functions and dynamic-stability derivatives. Two types of magnetic model suspension and balance systems for wind tunnels that have been developed in the United States and in Europe are described. The National Aeronautics and Space Administration is sponsoring in-house and contract studies to define the engineering problems of developing these magnetic suspension systems into operational wind-tunnel research facilities. Equipment has been developed for determining the significant and unpredictable damping derivatives of current aircraft configurations at high angles of attack and in regions of gross aerodynamic instabilities. Experimental research with these techniques provides the basis for developing methods for more accurately predicting damping levels and trends, especially at flight angles of attack.

INTRODUCTION

Many of the dynamic problems of current and proposed aircraft configurations arise from the inability of researchers to predict, by reliable theory, the mechanics of the aerodynamic phenomena involved. The dynamic aerodynamic characteristics of configurations with swept wings, complex engine packages, and slender bodies are difficult to predict theoretically at realistic angles of attack. In addition, the aeroelastic study is becoming increasingly complex because of more flexible structures and more stringent mission requirements. Aerodynamic and structural responses, of course, can be obtained by full-scale flight tests, and some dynamic characteristics can be measured with pilotless free-flight model tests. However, one of the best approaches to the fundamental understanding and ultimate solution of these dynamic problems continues to be from experiments in the controlled environment of the wind tunnel. Therefore, efforts have continued within NASA to develop and improve wind-tunnel techniques for studying these dynamic problems.

The purpose of this paper is to review recent developments for three separate dynamic techniques for wind tunnels. The three areas to be discussed are: (1) An oscillating airstream technique for determining gust response, (2) recent developments in magnetic model suspension and balance systems, and (3) techniques for measuring dynamic-stability derivatives at angles of attack.

SYMBOLS

C_{l_p}	damping-in-roll parameter
$C_{m_q} + C_{m_{\dot{\alpha}}}$	oscillatory damping-in-pitch parameter
$C_{n_r} - C_{n_{\dot{\beta}}} \cos \alpha$	oscillatory damping-in-yaw parameter
$C_{l_p} + C_{l_{\dot{\beta}}} \sin \alpha$	oscillatory damping-in-roll parameter
k	reduced-frequency parameter
M	Mach number
V	stream velocity
α	angle of attack
θ_v	vane amplitude

DISCUSSION

Oscillating Airstream Technique

A system for measuring the response of an aeroelastically scaled model to an oscillating vertical gust field, generated by oscillating vanes, has been developed. A plan view of the major components of the system is presented in figure 1. A set of biplane vanes is located on each wall in the entrance nozzle of the Langley transonic dynamics tunnel. The three-dimensional vanes have a span of 3.5 feet and a panel aspect ratio of 1.2. The biplane vanes on each tunnel wall are hydraulically driven and are synchronized to oscillate sinusoidally in pitch. The vertical velocity component of the flow field generated by the oscillating vanes causes an oscillation of the airstream, which simulates a time-varying vertical gust field of controlled frequency in the test section. A complete description of the principle and details of the technique is contained in references 1 and 2.

The vanes are located well upstream in the subsonic portion of the entrance nozzle so that local shock waves cannot be generated on the vanes. Thus, tests can be made at transonic speeds in the test section without shock interference from the vanes. In addition, the test area lies between the vane wakes so that the spanwise gust distribution in the test area is essentially uniform (within about 10 percent) and allows tests of models with spans up to about 6 feet.

The oscillator system was designed for operation at vane amplitudes θ_v from 3° to 12° at frequencies up to 20 cycles per second. Currently, however, operation is power limited by the power absorbed by the aerodynamic damping of the vanes, which is a function of vane amplitude and dynamic pressure. Figure 2 presents the typical variation of gust amplitudes obtained at the center line of the test area for various gust frequencies. These particular calibrations were made for Freon as the test medium and for Mach numbers of 0.8, 1.0, and 1.1. The vane amplitude θ_v was 9°. Although the characteristic decrease in gust amplitude with increasing frequency is appreciable, as shown in figure 2, the gust amplitude at the higher frequencies appears to be adequate for test purposes.

For the initial development tests, a simple dynamically scaled model was mounted in the test area on a two-cable support system with sufficient freedom to allow the model to be flown by remote control. Thus, both the rigid-body response and the structural response of the model to the oscillating airstream simulates free-flight response to vertical gusts. A trailing umbilical cable carries control signals to the model and data measurements of the model flight characteristics. (Snubber cables, which are slack in flight, are used as safety restraints as explained in reference 2.)

As an illustration of the usefulness of the technique, some preliminary measurements, at a Mach number of 1.0, of the acceleration response at the center of gravity of the dynamically scaled airplane model are presented in figure 3. (The reduced-frequency parameter k covers only the short-period, rigid-body frequency range for the purposes of this discussion. Actually, the attainable reduced frequency for these test conditions is about three times that shown.) The experimental normal-acceleration functions are shown as symbols and the calculated normal acceleration is shown as the solid line. At a reduced frequency of about 0.006 a model plunging mode is apparent. This secondary plunging mode is introduced by the characteristics of the cable-support system which modify the otherwise free-flight response of the model. Modifications to the cable support system probably can reduce the model response in the plunging mode obtained in these preliminary tests. The second peak is the longitudinal response of the model in the short-period, rigid-body mode. The calculated and experimental values of the normal-acceleration function are in reasonably good agreement. The discrepancies may well be due to the rigid-body stability derivatives that were used for these preliminary calculations or to possible undefined effects of the cable support system. Further details of these preliminary tests and calibrations are presented in reference 2.

The initial development tests show that a satisfactory experimental technique for subjecting a dynamically scaled model to a controlled gust field has been developed. A method for mounting the model to simulate the free-flight modes is available. Although several improvements are needed, the technique, when fully developed, should be especially valuable for experimental research in two dynamic problem areas. First, it should permit better determination and evaluation of transfer functions at transonic speeds. These functions can be derived from experimental measurement of the amplitude and phase of model response to gust inputs through ranges of gust frequencies. The functions relate the instantaneous loads and structural response of aerodynamic configurations to gusts and turbulence caused by atmospheric phenomena or by man-made explosions. These frequency-response functions are especially critical for the design of aircraft for low-altitude high-speed missions and for large flexible aircraft and boosters with low natural frequencies and low load factors. In addition, the technique should be adaptable to the determination of dynamic-stability derivatives for both rigid and flexible aerodynamic configurations.

Magnetic Suspension and Balance Systems

Magnetic suspension and balance systems for wind tunnels have been developed both in the United States and in Europe. This discussion is a résumé of recent progress in the area and of the contribution of NASA in sponsoring research contracts and grants to study the problems of developing two types of magnetic suspension systems into operational wind-tunnel research facilities. The two systems differ fundamentally in the type and degree of restraint imposed on the model by the magnetic fields.

The first system provides firm magnetic control in all major model degrees of freedom. This type of magnetic suspension system was first developed in France. (See ref. 3.) A similar system has been developed at the Massachusetts Institute of Technology (MIT) under sponsorship of the U.S. Air Force (ref. 4). The fundamentals of these systems are shown in figure 4. The magnetic fields of direct-current lift coils act on a cylindrical iron core embedded within a nonmagnetic model. Light and photocell systems sense vertical movement of the model and control the current to the two lift coils to maintain the desired model vertical position. The angle of attack can be changed by raising or lowering the two horizontal light and photocell systems relative to each other. Similar lateral coils and position-sensing systems are mounted in a horizontal plane to control the side forces. A large air-core drag coil surrounds the tunnel upstream of the model to hold the model against the drag forces.

The elimination of the aerodynamic interference of mechanical support structures is the obvious primary advantage of this system. Thus, measurements of heat-transfer rates, aerodynamic pressures, and forces and moments are unaffected by flow distortions; and studies of true wakes and base effects can be made. In addition, the systems should be adaptable to forced-response dynamic-stability testing. However, these devices as they now exist are subject to several operational problems. The asymmetrically arranged support coils cause complicated magnetic-field and model-position interactions. The optical position-sensing schemes work well only for symmetrical models or for models with straight-line elements. Finally, for use in large wind tunnels, the physical size and power requirements of the coils are large, especially if the coils are operated at normal temperature.

The Langley Research Center is now sponsoring a research contract with MIT to study some of these problems as they apply to a magnetic suspension and balance system for a 15-inch-diameter, Mach 10, hypersonic wind tunnel. These studies have resulted in an advanced concept of symmetrical coil arrangements to minimize magnetic-field interactions. More versatile position-sensing devices are being investigated. In addition, the studies show that for the 15-inch-diameter hypersonic wind tunnel, coil sizes and power requirements are large but appear feasible, even with normal-temperature coil construction.

The second magnetic suspension concept is a system that is uniquely adapted to simulated free flight in that it allows model response in certain degrees of freedom. A pilot facility was built at the Langley Research Center to verify the concept and to permit component development (ref. 5). The device, in its simplest form, utilizes a single, large, direct-current coil encircling the wind-tunnel test section, as illustrated in figure 5. The magnetic field generated by the single coil is axially symmetrical and diverges from the center line. A sphere of magnetic material is suspended in the field. When the sphere is fixed in the axial position by the typical position-sensing and current-control system, the divergent field stabilizes the sphere toward the center line. This 4.75-inch-inside-diameter pilot facility suspended an iron sphere successfully in 1964. Results from subsequent tests showed that a combined 12-pound load applied to a 3-inch-diameter sphere could be supported with a total power expenditure of less than 5000 watts.

It is conceived that a special magnetic material with negligible eddy-current losses will allow the sphere to rotate freely about any of its axes. The magnetic sphere could then be mounted at the center of gravity of an aerodynamic model of nonmagnetic material. This concept could be used in a wind tunnel to allow dynamic simulation of an aerodynamic body in free flight, with virtually complete rotational response about all major axes.

An advanced concept of the magnetic suspension system just described, but with three-dimensional magnetic model control, was developed by the University of Virginia for the study of wakes and sphere drag (ref. 6). More recent developments were presented in a paper by Dr. H. M. Parker of the University of Virginia at a symposium at Wright Patterson Air Force Base, April 1966. The Langley Research Center has recently sponsored a grant to the University of Virginia for a study of the engineering aspects of scaling up this three-dimensional magnetic system to a more useful size. In this study the feasibility of using supercooled or superconducting coils for magnet construction is being explored. These techniques offer the possibility of large reductions in coil size and power requirements.

Thus, two basic types of magnetic model suspension systems for wind tunnels have been developed and are being successfully operated. The advantages of these new systems are obvious. Both in-house and contract efforts are presently under way at the Langley Research Center to define the problems of developing both magnetic suspension systems into operational wind-tunnel research facilities.

Techniques for Measuring Dynamic-Stability Derivatives

The third experimental technique to be discussed involves the measurement of rigid-body dynamic-stability derivatives. Much dynamic research is accomplished at the Langley Research Center with the well-known free-flight-model techniques in the full-scale tunnel at low speeds. Equipment and techniques also are available at the Ames and Langley Research Centers of NASA for the measurement of damping derivatives at moderate to high Mach numbers. The present discussion is confined, however, to the rigidly forced dynamic-stability mechanisms developed at Langley especially for investigating configurations at appreciable angles of attack. These devices permit experimental determination of the theoretically unpredictable damping derivatives at angles of attack where separated flow may be present and in regions of gross aerodynamic instabilities. A résumé of the capabilities of the existing Langley dynamic-stability equipment, and the characteristics of several new devices which should be in operation within the year, is presented in table I.

TABLE I.- EXPERIMENTAL DYNAMIC-STABILITY CAPABILITIES

Mode	Damping derivatives	Mach number	Angle of attack, deg	Amplitude, deg	Frequency, cps
Steady roll	C_{l_p}	0.2 to 1.0	±35	-------	3 to 10 (rps)
Oscillatory pitch	$C_{m_q} + C_{m_{\dot{\alpha}}}$	0.13	±180	0 to 30	0 to 2
or		0.2 to 1.2	-5 to 64	$\frac{1}{2}$, 1, 2	3 to 30
Oscillatory yaw	$C_{n_r} - C_{n_{\dot{\beta}}} \cos \alpha$	1.5 to 4.6	-3 to 25	$\frac{1}{2}$, 1, 2	3 to 30
		10.0	-18 to 24	1.2	*5 to 60
Oscillatory roll	$C_{l_p} + C_{l_{\dot{\beta}}} \sin \alpha$	0.13	±180	0 to 30	0 to 2
		0.2 to 1.2	-2 to 22	2.5	*3 to 30

*Equipment under construction.

As shown, the steady-state rolling derivatives can be obtained at Mach numbers from 0.2 to 1.0 for angles of attack from -35° to 35°. The oscillatory pitching, yawing, and rolling derivatives can be determined over a wide range of Mach numbers and angles of attack. The dynamic-stability equipment described in table I can be operated through the full Reynolds number ranges of the wind tunnels in which they are used. Although not shown in the table, these dynamic-stability devices also can obtain the aerodynamic stiffness derivatives and the pertinent lateral cross derivatives, where applicable.

These experimental techniques are used extensively for investigations of the rigid-body dynamic-stability characteristics of current aircraft and spacecraft configurations. A chart of some of the research accomplished, and that presently underway, is presented in figure 6. The horizontal bars indicate the Mach number ranges for which research has been accomplished for a broad range of configuration types. (The results of some of these investigations are presented in references 7 to 27.) The programs have involved studies of the effects on the pitching, yawing, and rolling derivatives of configuration-component breakdowns, angle of attack, Mach number, Reynolds number, and oscillation frequency and amplitude. The research has provided a better understanding of some of the aerodynamic phenomena involved and should provide the basis for development of better methods of prediction, especially at angles of attack where flow separation occurs.

These wind-tunnel investigations have uncovered some interesting and significant damping trends for several current aircraft configurations. The variation of pitch damping with angle of attack at a Mach number of 0.40 for two airplane models with moderately swept subsonic-wing configurations is presented in figure 7. (Positive aerodynamic damping is indicated by the arrow.) The characteristics of a typical, swept-wing, subsonic transport with four wing-mounted jet engines are shown by the solid curve (from ref. 8). The dashed line indicates the pitch-damping characteristics of a variable-sweep fighter model with the wings swept 20°. (For the latter tests the highly-swept inboard leading edge, or glove, was removed. This change resulted in a relatively thick, subsonic type of wing, with the leading edge straight in to the fuselage.) The pitch damping for both configurations is about constant at the lower angles of attack, but becomes negative near the stall region. The negative pitch damping near the stall for these subsonic, swept-wing configurations may well expedite entry into the stall and/or intensify a pitch-up tendency. Incorporation of the highly swept inboard glove on the variable-sweep fighter model considerably increased the level of pitch damping near the stall as shown in figure 7.

From the data of figure 7 it is also apparent that the levels of pitch damping determined at an angle of attack of 0° cannot reasonably be extrapolated to the higher angles of attack. In addition, it is obvious that rigidly forced dynamic-stability mechanisms are required for investigations of unstable flight regions such as those shown here.

The Langley rigidly forced dynamic-stability equipment is especially useful for investigations of high-angle-of-attack phenomena such as the deep stall of T-tail airplane configurations. The pitch-damping characteristics of a T-tail transport model with aft-fuselage-mounted jet engines are presented in figure 8. (The typical decrease in damping near the stall previously discussed is also a characteristic of this T-tail configuration.) In the deep-stall region, near an angle of attack of 40°, sharply decreased damping is also evident.

Although this unexpected, and theoretically unpredicted, decrease in pitch damping is not understood at present, research on T-tail configurations is continuing. The characteristic itself may be quite significant. Simulator studies at Langley, of the characteristics of T-tail airplanes, show that decreased or negative pitch damping is beneficial in preventing "lock-in" at a deep-stall attitude (ref. 28). Thus, the seemingly adverse decreased damping characteristic may well prove to be helpful. The ability to define, experimentally, unpredictable damping phenomena such as those just discussed again illustrates the value of these techniques for investigations of dynamic-stability derivatives at pertinent angles of attack.

CONCLUDING REMARKS

Several experimental dynamic techniques for wind-tunnel research have been reviewed. One such technique is a new method for experimental gust research. This method permits measurement of the response of a dynamically scaled model to a gust field generated in a wind tunnel by an oscillating airstream. In addition, studies are being undertaken both at the Langley Research Center and under NASA contract to define the engineering problems associated with the development of two types of magnetic-suspension systems into operational wind-tunnel research facilities. Techniques have also been developed for determining the significant and unpredictable damping derivatives of current aircraft configurations at high angles of attack and in regions of gross aerodynamic instabilities. Experimental research with these techniques provides the bases for developing methods for more accurately predicting damping levels, expecially at flight angles of attack.

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PLAN VIEW OF OSCILLATING AIRSTREAM SYSTEM

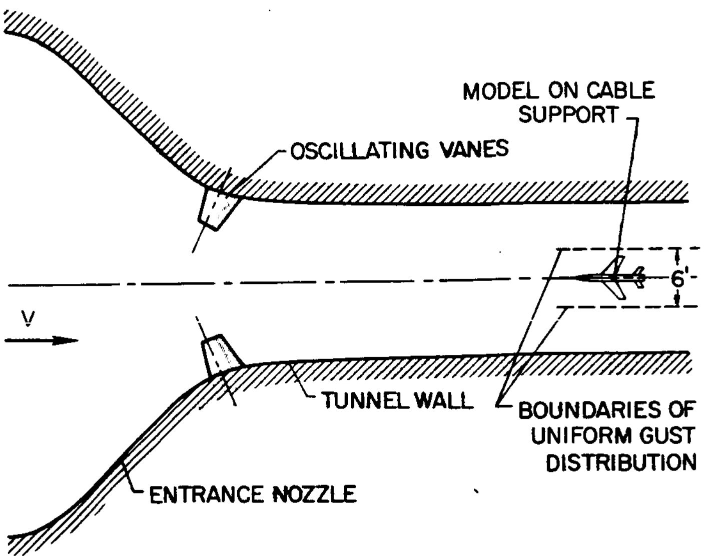

Figure 1

VARIATION OF GUST AMPLITUDE WITH FREQUENCY

FREON; M = 0.8 TO 1.1; $\theta_V = 9°$

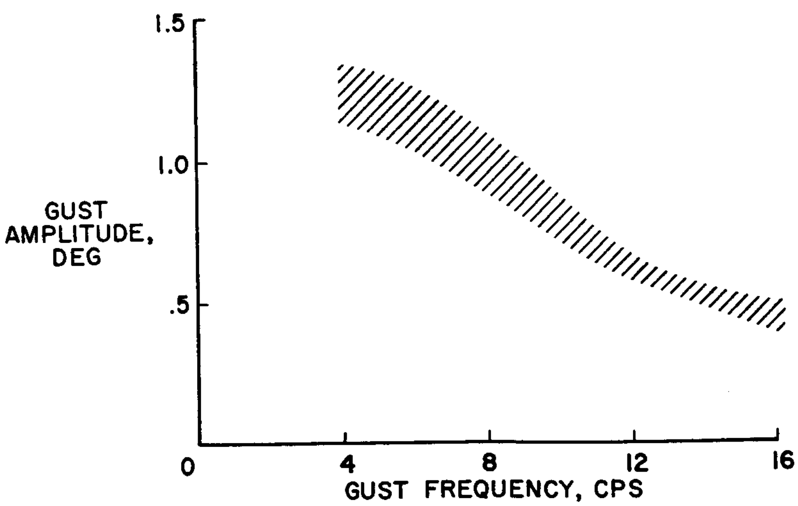

Figure 2

ACCELERATION RESPONSE AT CENTER OF GRAVITY
M = 1.0

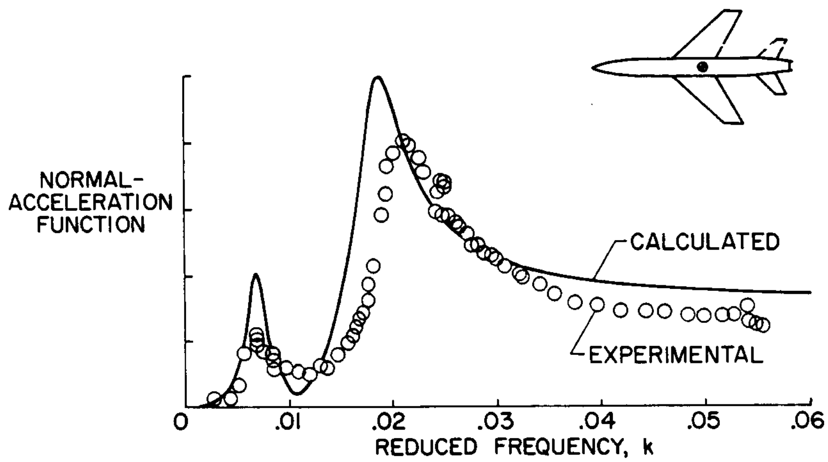

Figure 3

MULTIPLE-CONTROL MAGNETIC SUSPENSION SYSTEM

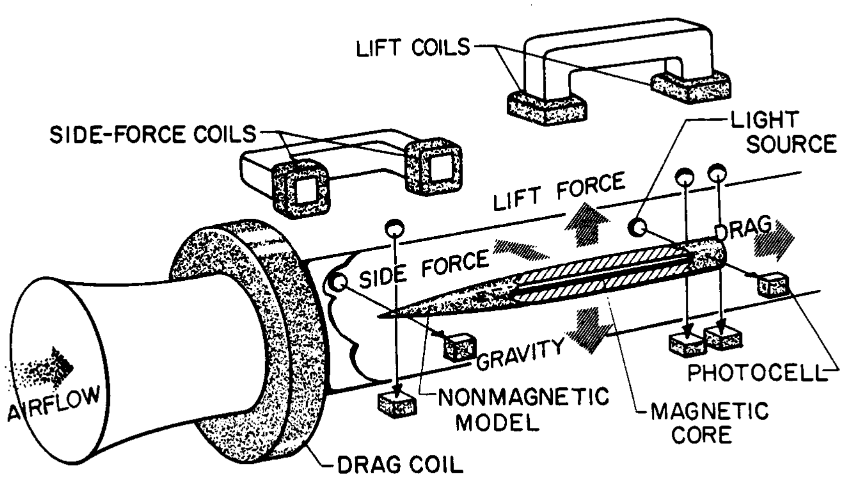

Figure 4

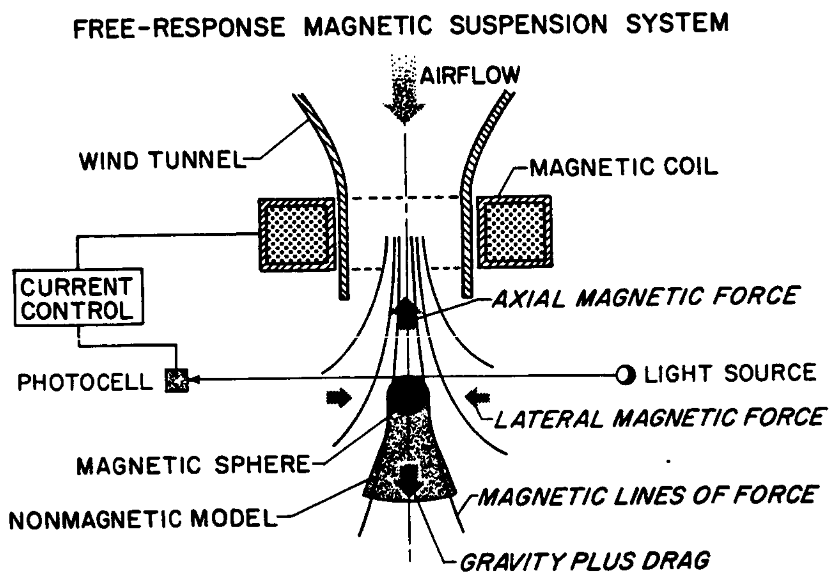

Figure 5

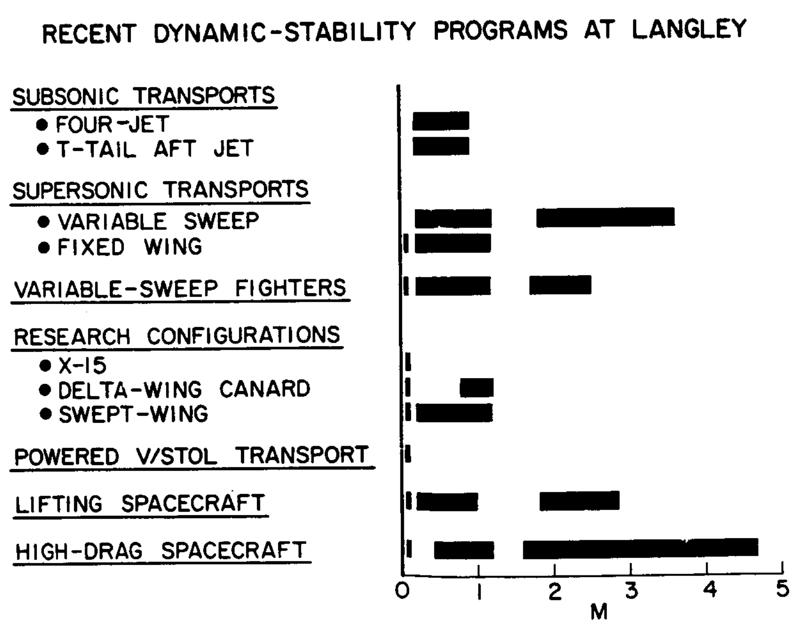

Figure 6

PITCH DAMPING FOR SUBSONIC-WING CONFIGURATIONS

M=0.40

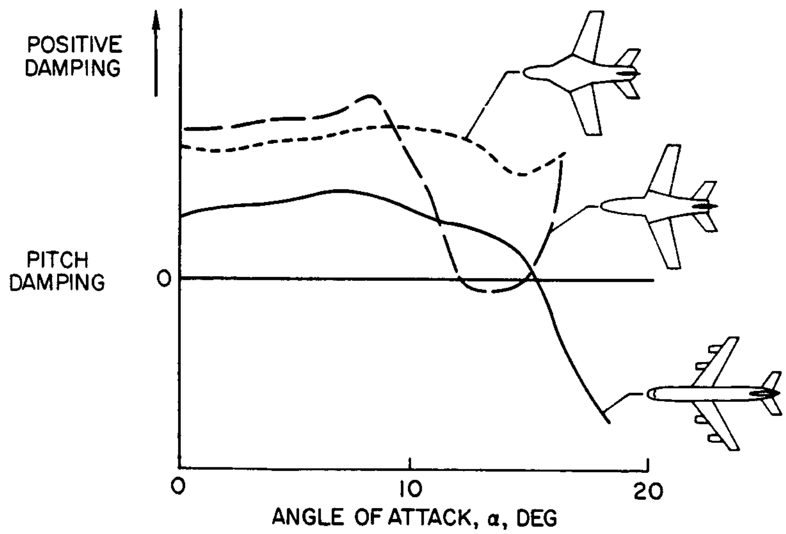

Figure 7

PITCH DAMPING OF T-TAIL CONFIGURATION

M=0.40

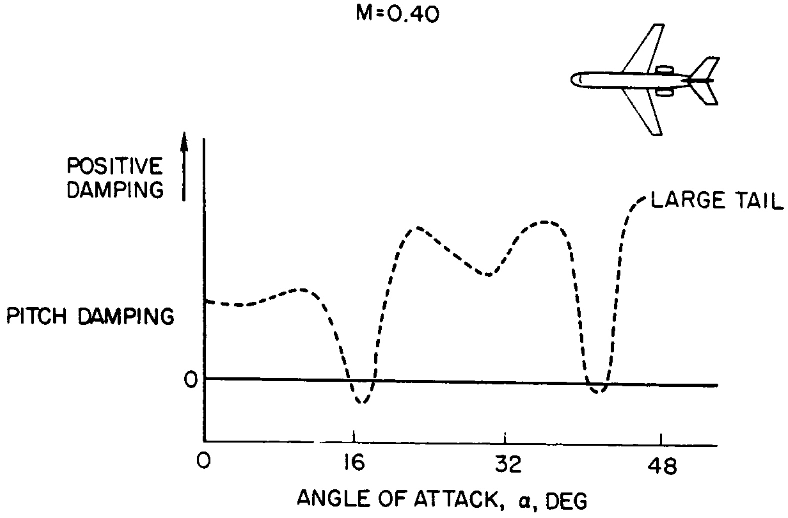

Figure 8