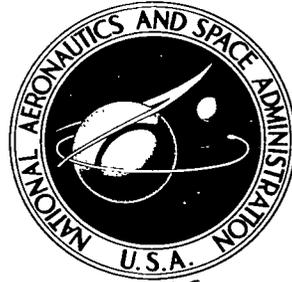


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AERODYNAMIC DAMPING AND OSCILLATORY STABILITY IN PITCH FOR A MODEL OF A TYPICAL SUBSONIC JET-TRANSPORT AIRPLANE

by Bruce R. Wright and Margaret L. Brower

Langley Research Center

Langley Station, Hampton, Va.



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SUMMARY

Wind-tunnel measurements were made in the Langley 8-foot transonic pressure tunnel at Mach numbers from 0.20 to 0.94 to determine the aerodynamic damping and oscillatory stability in pitch for a model of a typical swept-wing subsonic jet-transport airplane. Tests were made at angles of attack from about -6° to 18° at Reynolds numbers, based on the mean aerodynamic chord of the wing, from about 0.6×10^6 to about 1.8×10^6 . Tests were made at an oscillation amplitude of 1° by using a forced-oscillation technique. The reduced-frequency parameter varied from 0.0026 to 0.0301.

Aerodynamic damping was positive throughout the Mach number and angle-of-attack ranges except for negative damping at angles of attack greater than 15° at Mach numbers from 0.20 to 0.60. The sting, which entered the bottom of the model at an angle of 10° with respect to the model reference line, may have influenced the flow on the tail surfaces at the higher angles of attack. Negative values of the oscillatory-longitudinal-stability parameter were present except at a Mach number of 0.60 at an angle of attack of 6° and at Mach numbers of 0.90 and 0.94 near an angle of attack of 9° . The sting entering the bottom of the model may also have influenced the oscillatory-longitudinal-stability parameter at the higher angles of attack.

INTRODUCTION

Studies are being made by the National Aeronautics and Space Administration to determine the flight characteristics and handling qualities of large swept-wing subsonic jet-transport airplanes during flight in rough-air conditions. These studies are intended to provide a better understanding of the airplane handling and recovery procedures necessary during the high angle-of-attack excursions and Mach number overspeed sometimes encountered in rough-air flight.

As a part of these studies, the aerodynamic characteristics of the airplane must be determined for the large angle-of-attack and Mach number ranges of interest. Although

the aerodynamic characteristics of these airplane configurations may at times be predicted by theoretical methods, accurate predictions are usually confined to low angles of attack. Wind-tunnel tests are usually necessary to determine the aerodynamic characteristics at high angles of attack and in regions of unsteady flow which do not lend themselves to theoretical treatment. Therefore, wind-tunnel measurements of the dynamic-stability characteristics were made for a model of a typical swept-wing subsonic transport airplane with four wing-mounted jet engines. These tests are intended to provide a consistent set of experimental aerodynamic stability parameters for the airplane through large angle-of-attack and Mach number ranges which might be attained in rough-air flight.

This paper presents the damping and oscillatory-stability parameters in pitch for a typical subsonic transport model as determined in the Langley 8-foot transonic pressure tunnel at Mach numbers from 0.20 to 0.94 for angles of attack from -6° to 18° . The Reynolds numbers, based on the mean aerodynamic chord of the wing, varied from about 0.6×10^6 to about 1.8×10^6 . Tests were made at an oscillation amplitude of 1° by using a forced-oscillation technique. The reduced-frequency parameter varied from about 0.0026 to 0.0301.

SYMBOLS

The aerodynamic parameters are referred to the body system of axes originating at the oscillation center of the model (quarter chord of the mean aerodynamic chord of the wing) as shown in figure 1. The equations used to reduce the dimensional aerodynamic parameters of the model to nondimensional aerodynamic parameters are presented in the section entitled "Measurements and Reduction of Data." SI units are used herein with U.S. Customary Units given parenthetically.

C	damping coefficient, $\frac{\text{meter-newton-sec}}{\text{radian}}$ $\left(\frac{\text{ft-lb-sec}}{\text{radian}}\right)$
\bar{c}	mean aerodynamic chord of the wing, 0.1536 meter (0.504 ft)
f	frequency of oscillation, cps
I_Y	moment-of-inertia coefficient about body Y-axis, $\frac{\text{meter-newton-sec}^2}{\text{radian}}$ $\left(\frac{\text{ft-lb-sec}^2}{\text{radian}}\right)$
K_Y	torsional-spring coefficient about body Y-axis, $\frac{\text{meter-newton}}{\text{radian}}$ $\left(\frac{\text{ft-lb}}{\text{radian}}\right)$
k	reduced-frequency parameter, $\omega\bar{c}/2V$, radians
M	free-stream Mach number

- q pitching velocity, radians/sec
 q_∞ free-stream dynamic pressure, newtons/meter² (lb/ft²)
 R Reynolds number based on \bar{c}
 S reference area, 0.1413 meter² (1.521 ft²)
 T maximum torque required to oscillate the model, newton-meter (lb-ft)
 V free-stream velocity, meters/sec (ft/sec)
 α angle of attack, degrees or radians; mean angle of attack, degrees
 η phase angle between T and Θ , degrees
 Θ maximum angular displacement in pitch of model with respect to sting, radians
 ω angular velocity, $2\pi f$, radians/sec
 C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{q_\infty S \bar{c}}$
 $C_{m_q} = \frac{\partial C_m}{\partial \left(\frac{q\bar{c}}{2V} \right)}$ per radian
 $C_{m_{\dot{q}}} = \frac{\partial C_m}{\partial \left(\frac{\dot{q}\bar{c}^2}{4V^2} \right)}$ per radian
 $C_{m_\alpha} = \frac{\partial C_m}{\partial \alpha}$ per radian
 $C_{m_{\dot{\alpha}}} = \frac{\partial C_m}{\partial \left(\frac{\dot{\alpha}\bar{c}}{2V} \right)}$ per radian
 $C_{m_q} + C_{m_{\dot{\alpha}}}$ damping-in-pitch parameter, per radian
 $C_{m_\alpha} - k^2 C_{m_{\dot{q}}}$ oscillatory-longitudinal-stability parameter, per radian

A dot over a quantity denotes the first derivative with respect to time.

APPARATUS

Model

Design dimensions are presented in figure 1 for the test model, which is considered representative of current subsonic jet-transport airplanes. The model has a low swept wing with a chord extension inboard of the engine pylons. The chord extension has a leading-edge sweep of 41.5° . The wing, outboard of the extension, has a leading-edge sweep of 37.5° . The four jet-engine nacelles are mounted on slab pylons beneath the wing and full-scale airflow is simulated through the nacelles. Photographs of various views of the model are presented in figure 2.

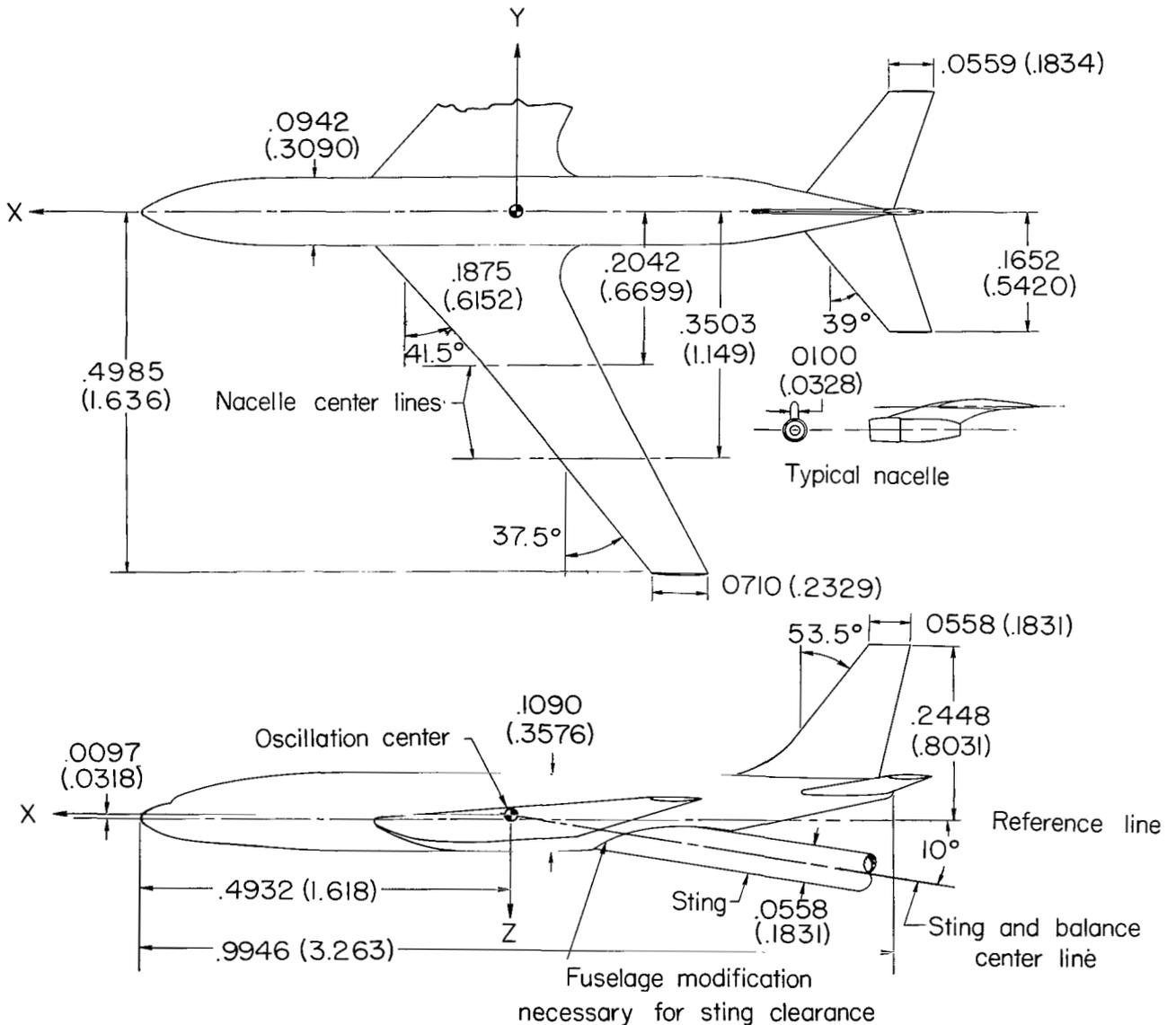
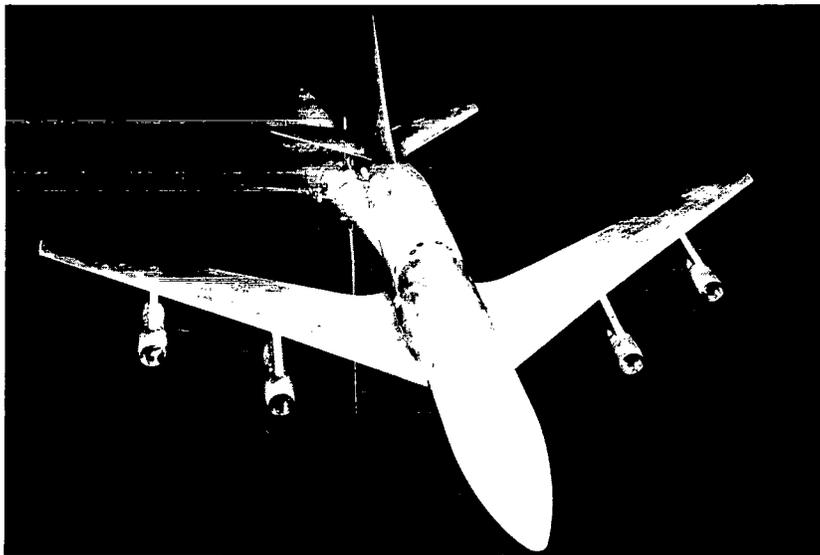


Figure 1.- Dimensions of test model. (Linear dimensions given first in meters and parenthetically in feet.)



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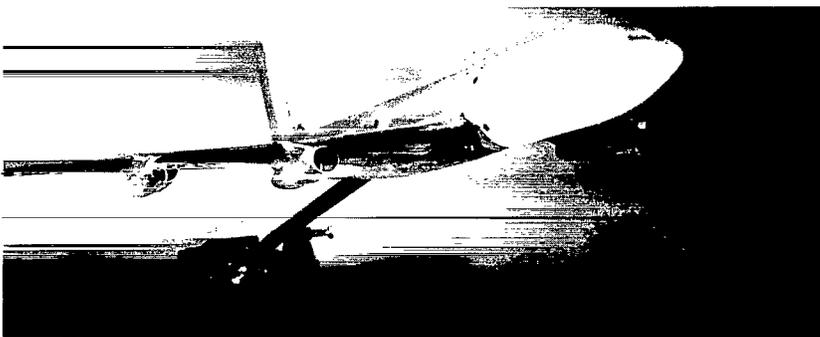


Figure 2.- Photographs of test model.

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Some of the geometric properties of the wing, horizontal tail, and vertical tail are as follows:

Wing:

Area,		
meters ²	0.1413	
ft ²	1.5209	
Span,		
meters	0.9970	
ft	3.2710	
Mean aerodynamic chord,		
meters	0.1536	
ft	0.5039	
Aspect ratio	7.035	
Taper ratio	0.33	
Geometric dihedral, deg	7	

Horizontal tail:

Area,		
meters ²	0.0321	
ft ²	0.3455	
Span,		
meters	0.3304	
ft	1.0840	
Mean aerodynamic chord,		
meters	0.1015	
ft	0.3330	
Root chord,		
meters	0.1359	
ft	0.4459	
Aspect ratio	3.43	
Taper ratio	0.41	
Geometric dihedral, deg	7	

Vertical tail:

Area,		
meters ²	0.0196	
ft ²	0.2110	
Mean aerodynamic chord,		
meters	0.1125	
ft	0.3691	
Aspect ratio	1.80	
Taper ratio	0.31	

The airfoil coordinates for the wing and horizontal tail are given in table I. The model has no movable control surfaces.



The model is made principally of magnesium except for a fiber glass forward portion of the fuselage and an aluminum wing. The sting extends into the model through the bottom of the fuselage at an angle of 10° with respect to the horizontal reference line of the model in order to retain the geometry of the vertical and horizontal tail configurations.

The model was tested in an aerodynamically smooth condition except for three-dimensional roughness which was applied to the model to assure that a turbulent boundary layer existed. The roughness consisted of 0.25-centimeter-wide (1/10-in.-wide) strips of No. 150 carborundum grains near the leading edge of the wing, horizontal and vertical tail surfaces, and engine nacelles; and a strip of No. 220 carborundum grains was located 0.86 centimeter (0.34 in.) rearward from the nose. The size and location of the roughness were computed prior to testing with the use of the method of reference 1 to insure a turbulent boundary layer aft of the applied roughness.

Oscillation-Balance Mechanism

A view of the forward portion of the oscillation-balance mechanism which was used for these tests is presented in figure 3. Since the oscillation amplitude is small, the rotary motion of a variable-speed electric motor is used to provide essentially

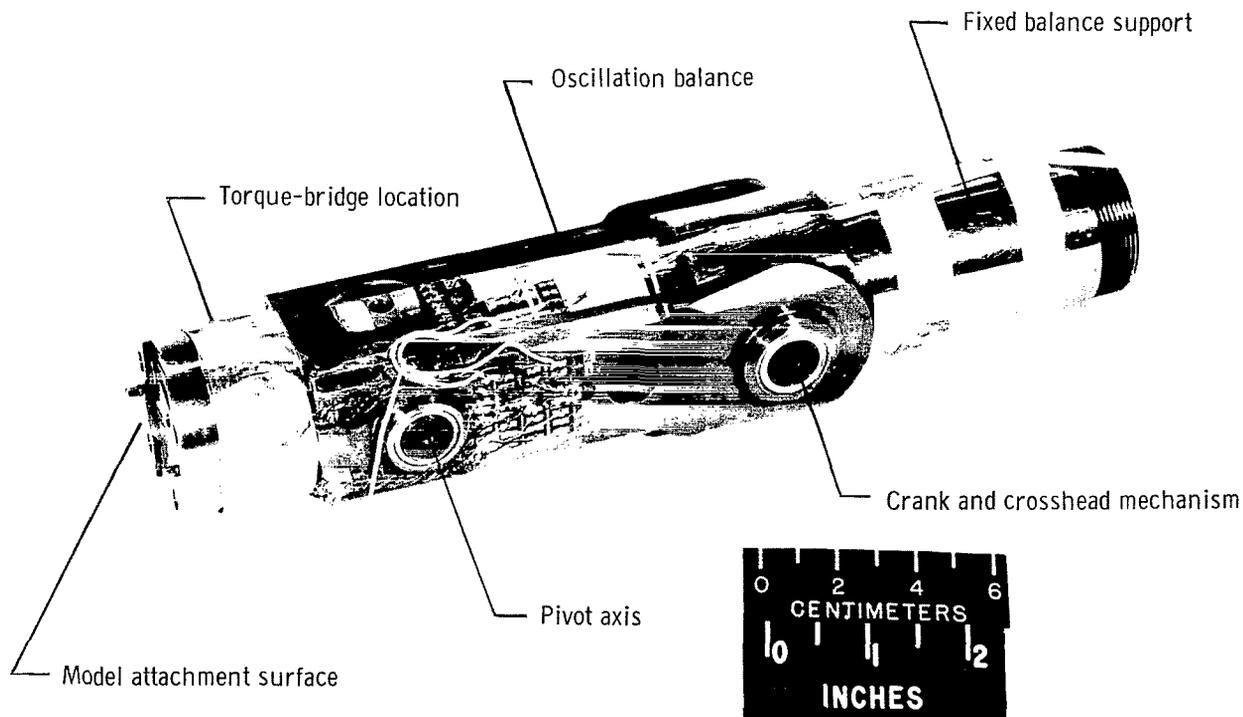


Figure 3.- Forward portion of the oscillation-balance mechanism.

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sinusoidal motion of constant amplitude to the balance through the crank and crosshead mechanism. Although constant amplitudes of $1/2^\circ$, 1° , and 2° can be obtained by changing the crank, an amplitude of 1° was used for this investigation. The oscillatory motion is about the pivot axis which was located at the model station corresponding to the proposed center of mass of the configuration tested ($\bar{c}/4$).

The strain-gage bridge which measures the torque required to oscillate the model is located between the model attachment surface and the pivot axis. This torque-bridge location eliminates the effects of pivot friction and the necessity to correct the data for the changing pivot friction associated with changing aerodynamic loads. Although the torque bridge is physically forward of the pivot axis, the electrical center of the bridge is located at the pivot axis so that all torques are measured with respect to the pivot axis.

A mechanical spring, which is an integral part of the fixed balance support, is connected to the oscillation balance at the point of model attachment by means of a flexure plate. The mechanical spring and flexure plate were electron-beam welded in place after assembly of the oscillation-balance and fixed-balance support in order to minimize mechanical friction. A strain-gage bridge, fastened to the mechanical spring, provides a signal proportional to the model angular displacement with respect to the sting. Although the forced-oscillation balance may be oscillated through a frequency range from about 1 to 30 cycles per second, as noted in reference 2 the most accurate measurement of the damping coefficient is obtained at the frequency of velocity resonance. For these tests, the frequency of oscillation varied from 1.64 to 9.02 cycles per second.

Wind Tunnel

The tests reported herein were made in the Langley 8-foot transonic pressure tunnel. The test section of this single-return closed-circuit wind tunnel is about 2.2 meters square (7.1 feet square) with upper and lower walls slotted to permit continuous operation throughout the transonic-speed range. Although test-section Mach numbers from near 0 to 1.30 can be obtained and kept constant by controlling the speed of the tunnel-fan drive motor, for these tests the aerodynamic damping and oscillatory stability in pitch were obtained at Mach numbers from 0.20 to 0.94. The Mach number distribution is reasonably uniform throughout the test section with a maximum deviation from the average free-stream Mach number of about 0.010 at the higher Mach numbers.

The sting-support system, when used in conjunction with the oscillation-balance mechanism used for these tests, is designed so as to keep the model near the center of the tunnel throughout a 25° angle-of-attack range. The angle-of-attack range for these tests was from about -6° to 18° .

MEASUREMENTS AND REDUCTION OF DATA

Strain-gage bridges are used to measure the torque required to oscillate the model and the angular displacement of the model with respect to the sting. The bridge outputs are passed through coupled electrical sine-cosine resolvers which rotate with constant angular velocity at the frequency of the model oscillation. The resolvers resolve each signal into two components which are read on damped digital voltmeters. Details of the apparatus and procedure used in reducing the data are given in references 2 and 3.

From the computed values of the maximum torque required to oscillate the model T , the maximum angular displacement in pitch of the model with respect to the sting Θ , the phase angle η between T and Θ , and the angular velocity of the forced oscillation ω as explained in detail in reference 2, the viscous-damping coefficient for this single-degree-of-freedom system is computed as

$$C = \frac{T \sin \eta}{\omega \Theta} \quad (1)$$

Also, the spring-inertia parameter is computed as

$$K_Y - I_Y \omega^2 = \frac{T \cos \eta}{\Theta} \quad (2)$$

where K_Y is the torsional-spring coefficient of the system and I_Y is the moment-of-inertia coefficient of the system about the Y-axis of the body.

The damping-in-pitch parameter was computed as

$$C_{m\dot{\alpha}} + C_{m\dot{\alpha}} = -\frac{2V}{q_\infty S c^2} \left[\left(\frac{T \sin \eta}{\omega \Theta} \right)_{\text{wind on}} - \left(\frac{T \sin \eta}{\omega \Theta} \right)_{\text{wind off}} \right] \quad (3)$$

and the oscillatory-longitudinal-stability parameter was computed as

$$C_{m\alpha} - k^2 C_{m\dot{\alpha}} = -\frac{1}{q_\infty S c} \left[\left(\frac{T \cos \eta}{\Theta} \right)_{\text{wind on}} - \left(\frac{T \cos \eta}{\Theta} \right)_{\text{wind off}} \right] \quad (4)$$

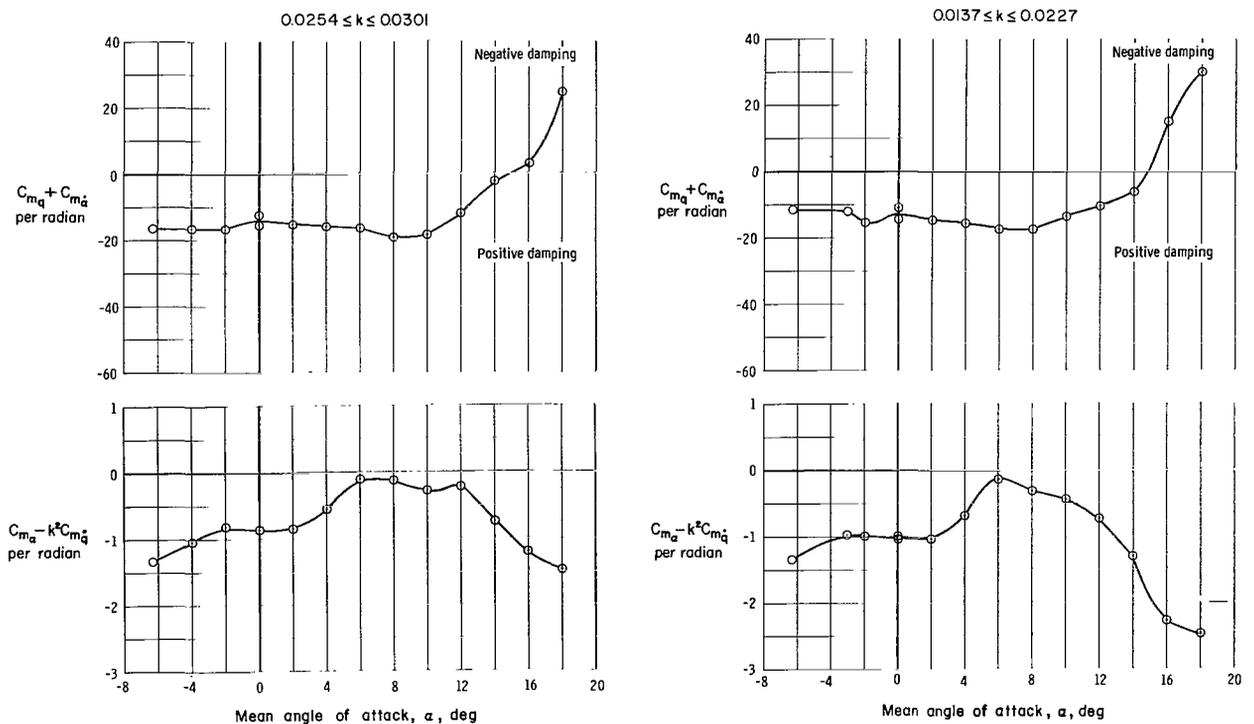
Inasmuch as the wind-off value of $\frac{T \sin \eta}{\omega \Theta}$ is not a function of the oscillation frequency, it is determined at the frequency of wind-off velocity resonance, because, as explained in reference 2, the wind-off value can be determined most accurately at the frequency of velocity resonance. The wind-on and wind-off values of $\frac{T \cos \eta}{\Theta}$ are determined at the same frequency since these quantities are functions of frequency.

TESTS

The aerodynamic damping and oscillatory stability in pitch were obtained at Mach numbers from 0.20 to 0.94 at angles of attack from about -6° to 18° at 0° angle of sideslip. The Reynolds numbers, based on the mean aerodynamic chord of the wing, varied from about 0.6×10^6 to about 1.8×10^6 . Tests were made at an oscillation amplitude of 1° by using a forced-oscillation technique. The reduced-frequency parameter varied from 0.0026 to 0.0301.

RESULTS AND DISCUSSION

The variation of the damping-in-pitch parameter and oscillatory-longitudinal-stability parameter with mean angle of attack is shown plotted in figure 4. The subsonic-transport configuration has positive aerodynamic damping in pitch (a negative value of $C_{m_q} + C_{m_{\dot{\alpha}}}$) throughout the subsonic Mach number range except for angles of attack



(a) $M = 0.20$; $R = 0.6 \times 10^6$.

(b) $M = 0.40$; $R = 1.2 \times 10^6$.

Figure 4.- Variation of damping-in-pitch parameter and oscillatory-longitudinal-stability parameter with mean angle of attack.

greater than about 15° at Mach numbers of 0.20 to 0.60. At these low Mach numbers, the damping decreases rapidly with angle of attack for values of α greater than 8° and becomes negative for values of α greater than 15° . Because the sting entered the bottom of the model at an angle of 10° with respect to the model reference line (see fig. 1), the sting may possibly alter the flow on the tail surfaces at the higher angles of attack. The negative damping at the higher angles of attack and lower Mach numbers, therefore, may be caused by interference of the sting on the flow over the horizontal tail rather than by some sting-interference-free flow phenomenon such as wing stall. Additional tests are required to evaluate this possibility.

The negative values of the oscillatory-longitudinal-stability parameter $C_{m\alpha} - k^2 C_{m\dot{q}}$ are indicative of generally stable trim conditions except at a Mach number of 0.60 at an angle of attack of 6° (fig. 4(c)) and at Mach numbers of 0.90 and 0.94 near an angle of attack of 9° (figs. 4(e) and 4(f)). The sting entering the bottom of the model may have also influenced the oscillatory-longitudinal-stability parameter at the higher angles of attack.

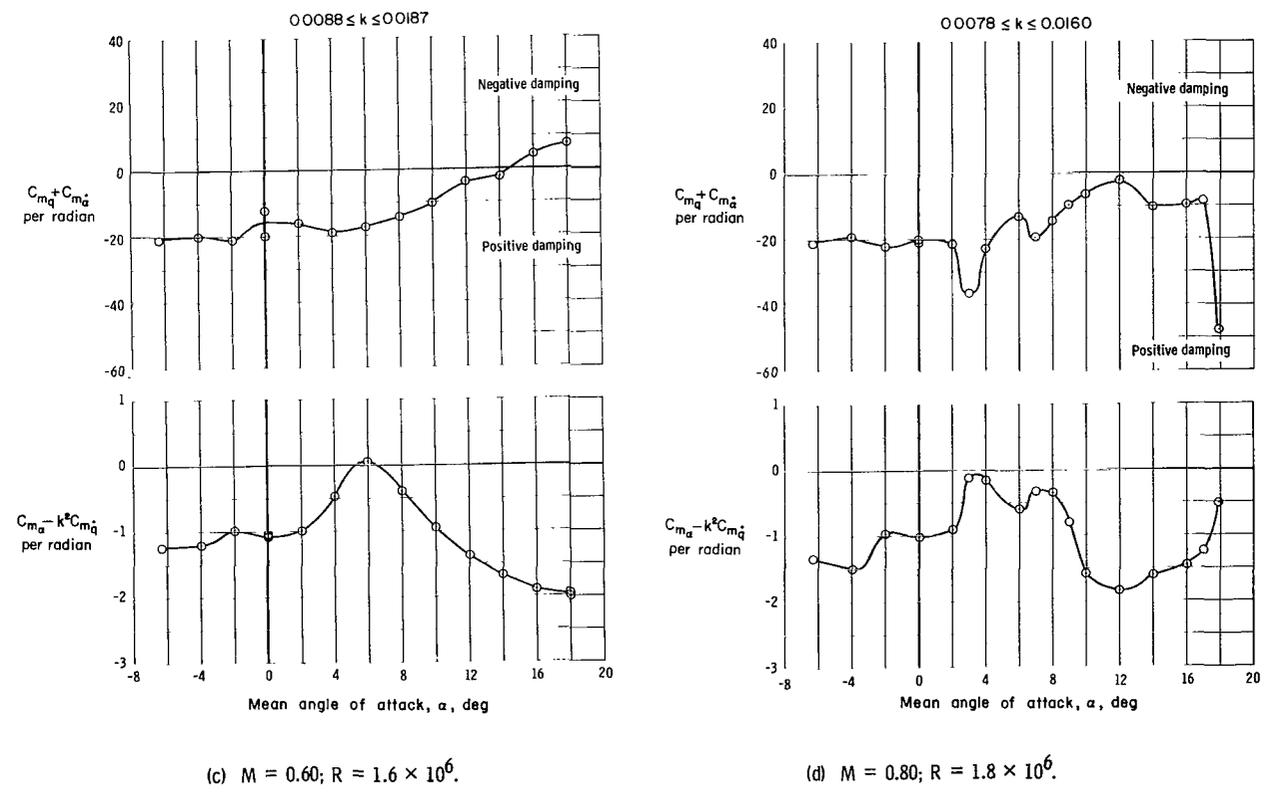


Figure 4.- Continued.

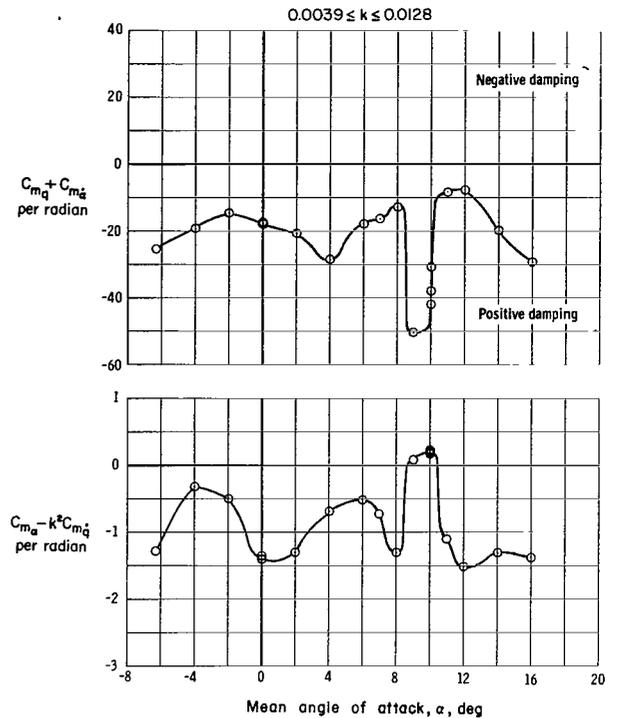
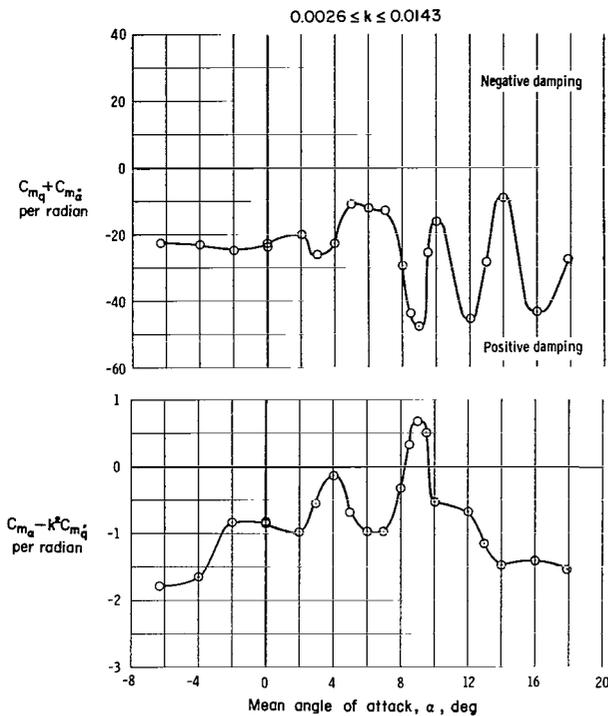


Figure 4.- Concluded.

CONCLUDING REMARKS

Measurements made to determine the aerodynamic damping and oscillatory stability in pitch for a model of a typical subsonic jet-transport airplane indicate that aerodynamic damping was positive throughout the Mach number and angle-of-attack ranges except for negative damping at angles of attack greater than 15° at Mach numbers from 0.20 to 0.60. The sting, which entered the bottom of the model at an angle of 10° with respect to the model reference line, may have influenced the flow on the tail surfaces at the higher angles of attack. Negative values of the oscillatory-longitudinal-stability parameter were present except at a Mach number of 0.60 at an angle of attack of 6° and at Mach numbers of 0.90 and 0.94 near an angle of attack of 9° . The sting entering the bottom of the model may also have influenced the oscillatory-longitudinal-stability parameter at the higher angles of attack.

Langley Research Center,

National Aeronautics and Space Administration,

Langley Station, Hampton, Va., September 29, 1965.

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3. Bielat, Ralph P.; and Wiley, Harleth G.: Dynamic Longitudinal and Directional Stability Derivatives for a 45° Sweptback-Wing Airplane Model at Transonic Speeds. NASA TM X-39, 1959.

TABLE I.- AIRFOIL COORDINATES

[Stations and ordinates have been nondimensionalized with respect to airfoil chord]

(a) Wing

Upper surface		Lower surface		Upper surface		Lower surface		Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate	Station	Ordinate	Station	Ordinate	Station	Ordinate	Station	Ordinate
0	0.0236	0	0.0236	0	0	0	0	0	0.0030	0	0
.0050	.0357	.0050	.0146	.0050	.0149	.0050	-.0066	.0050	.0099	.0050	-.0046
.0074	.0382	.0074	.0115	.0083	.0165	.0083	-.0074	.0074	.0120	.0074	-.0055
.0126	.0421	.0126	.0089	.0125	.0206	.0125	-.0083	.0126	.0147	.0126	-.0065
.0250	.0523	.0250	.0032	.0249	.0256	.0249	-.0091	.0250	.0215	.0250	-.0074
.0500	.0631	.0500	-.0051	.0500	.0330	.0500	-.0099	.0500	.0303	.0500	-.0090
.0750	.0676	.0750	-.0102	.0748	.0396	.0748	-.0124	.0753	.0385	.0753	-.0105
.1000	.0727	.1000	-.0159	.1000	.0446	.1000	-.0132	.1000	.0442	.1000	-.0118
.1500	.0778	.1500	-.0242	.1500	.0545	.1500	-.0165	.1500	.0520	.1500	-.0149
.2000	.0803	.2000	-.0319	.2000	.0578	.2000	-.0215	.2000	.0570	.2000	-.0177
.2500	.0790	.2500	-.0382	.2500	.0628	.2500	-.0248	.2500	.0604	.2500	-.0206
.3000	.0784	.3000	-.0433	.3000	.0661	.3000	-.0297	.3000	.0627	.3000	-.0227
.4000	.0752	.4000	-.0459	.4000	.0661	.4000	-.0297	.4000	.0644	.4000	-.0253
.5000	.0726	.5000	-.0459	.5000	.0611	.5000	-.0289	.5000	.0618	.5000	-.0250
.6000	.0561	.6000	-.0408	.6000	.0512	.6000	-.0264	.6000	.0541	.6000	-.0208
1.0000	0	1.0000	0	.7000	.0413	.7000	-.0198	.7000	.0427	.7000	-.0156
				1.0000	0	1.0000	0	.8000	.0290	.8000	-.0105
								.9000	.0145	.9000	-.0051
								1.0000	0	1.0000	0
Span station: 0.0952 meter (0.3125 ft) Chord length: 0.1993 meter (0.6538 ft)				Span station: 0.2000 meter (0.6562 ft) Chord length: 0.1537 meter (0.5042 ft)				Span station: 0.2688 meter (0.8819 ft) Chord length: 0.1333 meter (0.4372 ft)			

(b) Horizontal tail

Upper surface		Lower surface		Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate	Station	Ordinate	Station	Ordinate
0	0.0142	0	0.0142	0	0.0127	0	0.0127
.0050	.0250	.0050	.0026	.0050	.0223	.0050	.0018
.0075	.0267	.0075	.0004	.0075	.0236	.0075	0
.0125	.0288	.0125	-.0026	.0125	.0254	.0125	-.0023
.0250	.0317	.0250	-.0078	.0250	.0282	.0250	-.0050
.0500	.0347	.0500	-.0151	.0500	.0304	.0500	-.0136
.0750	.0364	.0750	-.0207	.0750	.0323	.0750	-.0186
.1000	.0377	.1000	-.0258	.1000	.0332	.1000	-.0227
.1500	.0403	.1500	-.0338	.1500	.0355	.1500	-.0295
.2000	.0428	.2000	-.0398	.2000	.0377	.2000	-.0350
.2500	.0452	.2500	-.0444	.2500	.0395	.2500	-.0386
.3000	.0476	.3000	-.0476	.3000	.0418	.3000	-.0418
.3500	.0498	.3500	-.0498	.3500	.0436	.3500	-.0436
.4000	.0512	.4000	-.0511	.4000	.0445	.4000	-.0445
.5000	.0504	.5000	-.0504	.5000	.0445	.5000	-.0445
.6000	.0442	.6000	-.0442	.6000	.0414	.6000	-.0414
.7000	.0338	.7000	-.0338	.7000	.0336	.7000	-.0336
.8000	.0226	.8000	-.0226	.8000	.0227	.8000	-.0227
.9000	.0114	.9000	-.0114	.9000	.0114	.9000	-.0114
1.0000	0	1.0000	0	1.0000	0	1.0000	0
Span station: 0 meter (0 ft) Chord length: 0.1359 meter (0.4459 ft)				Span station: 0.1652 meter (0.5420 ft) Chord length: 0.0559 meter (0.1834 ft)			

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