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RESEARCH MEMORANDUM

SOME MEASUREMENTS AT SUBSONIC SPEEDS OF THE AERODYNAMIC

FORCES AND MOMENTS ON TWO DELTA WINGS OF

ASPECT RATIOS 2 AND 4 OSCILLATING

ABOUT THE MIDCHORD

By Sumner A. Leadbetter and Sherman A. Clevenson

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
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SUMMARY

Air forces and moments acting on delta wings of aspect ratios 2 and 4 oscillating about the root midchord position have been measured and are reported herein. The Mach number and Reynolds number ranges covered were from 0.19 to 0.81 and 0.90×10^6 to 4.40×10^6, respectively, and the reduced-frequency range was from 0.08 to 0.81. Comparisons of the measured values were made with the results of the analysis of Lawrence and Gerber and, in general, reasonably good agreement was obtained. The measured values for the delta wing with aspect ratio of 2 were also compared with the results of "vanishing-aspect-ratio" theory and good agreement was shown for the lift coefficients.

INTRODUCTION

The experimental measurement of oscillating air forces is receiving increased attention because of the importance of these forces in flutter and related problems and because the experimental values are urgently needed to assess existing theoretical work. Despite the importance of this problem there exists only a limited amount of data for restricted ranges of aspect ratio, Mach number, and Reynolds number (see, for example, ref. 1).

There exists only a rather meager amount of theoretical work on oscillating air forces on delta wings. For incompressible flow, for instance, coefficients have been tabulated by Lawrence and Gerber for delta wings of low aspect ratio (ref. 2) and the "vanishing-aspect-ratio" theory of reference 3 has been developed for delta wings of very low

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aspect ratio. No experimental work on oscillating air forces on delta wings has been reported that can be used to appraise the theoretical results.

This paper presents some experimental measurements of oscillating air force and moment coefficients as well as their respective phase angles as determined from tests of two delta wings of aspect ratios 2 and 4 which were oscillated about the root midchord position. The coefficients were determined for a Mach number and Reynolds number range of 0.19 to 0.81 and 0.90×10^6 to 4.40×10^6, respectively. The reduced frequency ranged from 0.08 to 0.81. The measurements were made in the Langley 2- by 4-foot flutter research tunnel using a resonant oscillation technique used previously in the tests of rectangular wings of low aspect ratio reported in reference 4. The results of the experimental investigation discussed in this paper are compared with the theoretical results of reference 2 and with those of the vanishing-aspect-ratio theory (ref. 3).

SYMBOLS

A   aspect ratio

c   root chord of wing, ft

k   reduced-frequency parameter, $\omega c/2v$

$|l_\alpha|$ absolute value of lift coefficient per unit amplitude

    of oscillation, $\dfrac{|L_\alpha|}{\pi q S |\alpha|}$

l_1 lift coefficient in phase with angular displacement, $|l_\alpha|\cos\Phi$

l_2 lift coefficient in phase with angular velocity, $|l_\alpha|\sin\Phi$

L_α oscillating lift vector, positive when acting

    upward, $|L_\alpha| e^{i\left(\omega t + \frac{\pi\Phi}{180}\right)}$

$|L_\alpha|$ absolute value of lift vector

M   Mach number

$|m_\alpha|$ absolute value of moment coefficient per unit amplitude of oscillation, $\dfrac{|M_\alpha|}{\pi q S\left(\frac{c}{2}\right)|\alpha|}$

m_1 moment coefficient in phase with angular displacement, $|m_\alpha|\cos\Theta$

m_2 moment coefficient out of phase with angular displacement, $|m_\alpha|\sin\Theta$

M_α oscillating moment vector referred to axis of rotation, root midchord, positive in direction of leading edge up, $|M_\alpha|e^{i\left(\omega t+\frac{\pi\Theta}{180}\right)}$

$|M_\alpha|$ absolute magnitude of moment vector

q dynamic pressure, lb/sq ft

R Reynolds number based on root chord of wing

S area of wing, sq ft

t time, sec

v velocity of test medium, fps

α angle of incidence vector, positive when leading edge up, radians

$|\alpha|$ absolute magnitude of angle of incidence, radians

Θ phase angle that the moment vector leads the incidence vector, $180^\circ - \tan^{-1}\dfrac{m_2}{m_1}$

Φ phase angle that the lift vector leads the incidence vector, $\tan^{-1}\dfrac{l_2}{l_1}$

ρ density, slugs/cu ft

ω circular frequency of pitching oscillation of wing, radians/sec

ω_h circular frequency of first natural wing bending
              oscillations, radians/sec

ω_{vac} circular frequency of pitching oscillations in a near
              vacuum, radians/sec

APPARATUS AND METHOD

Tunnel.- The Langley 2- by 4-foot flutter research tunnel which
permits testing at various pressures was used for the tests reported
herein. All tests were made in air. Further description of this tunnel
can be found in reference 4.

Wing models.- The semispan wing models were of thick-skin balsa
construction covered with glass cloth and had an NACA 65A010 airfoil
section. Both models had a 12-inch semispan. The model with aspect
ratio of 4 had a root chord of 12 inches and the $A = 2$ model had a
root chord of 24 inches. These wings were designed to have high nat-
ural frequencies in order to minimize elastic deformation and result-
ant correction to the measured forces. The first natural cantilever
bending frequency was 198 cycles per second for the $A = 4$ wing and
171 cycles per second for the $A = 2$ wing.

Oscillating mechanism.- The oscillating mechanism is the one
described in considerable detail in reference 4. Stated briefly, the
oscillating mechanism may be considered as a simple torsional vibratory
system consisting of a torsion spring which is fixed at one end, a hol-
low steel shaft which is supported by bearings, and the semispan wing.
(See fig. 1.) The mechanism was oscillated at its natural frequency by
applying a harmonically varying torque with an electromagnetic shaker.
The amplitude of oscillation was ±2°. Four different torsion springs
were used to cover a range of frequency of oscillation. The pitching
natural frequencies in a near vacuum ω_{vac} for the two wings were as
follows:

Torsion spring	ω_{vac} (radians/sec) for -	
	$A = 2$ wing	$A = 4$ wing
1	$20 \times 2\pi$	$21 \times 2\pi$
2	29	32
3	38	42
4	48	Not tested

Instrumentation and calibration.- The instrumentation is the same as that described in reference 4. The lift was obtained from strain-gage beams and its phase angle was determined with the aid of an electronic counter chronograph. The damping moment (out of phase) was obtained from a decrement trace of the wing position on a recording oscillograph. The in-phase moment was determined from the difference in resonant frequency between the model oscillating in a vacuum and in air at the test Mach number as measured with the electronic counter chronograph. The phase angle Φ between lift vector and the angle of incidence was also measured with an electronic counter chronograph. The calibrations of the balances and angular displacement were essentially the same as those in reference 4 with the exception of the wing-position determination. For these delta wings, the fine chordwise line used in the photographic technique was placed on the root plate instead of on the wing tip.

Data reduction.- The lift forces as determined from the strain-gage balances were corrected for an inertia component resulting from wing-bending deformation. These corrections were small; therefore, a simple approximate method developed in appendix A of reference 4 was used. The inclusion of this correction leads to the following factor which when multiplied by the measured lift gives the actual applied lift: for spring 1, 0.996 and 0.997; for spring 2, 0.992 and 0.992; for spring 3, 0.984 and 0.986; and for spring 4, 0.975 for the $A = 2$ and $A = 4$ delta wings, respectively.

Methods for determining the in-phase and the out-of-phase components of the moment coefficients from the measured data are discussed in detail in references 4 and 5, as are some of the accuracies involved in this type of measurement. The phase angle Θ between the moment vector and the angle of incidence was obtained from the ratio of the measured components.

RESULTS

The experimental data obtained from the lifts, moments, and their respective phase angles are given in tables I to IV for the $A = 2$ and $A = 4$ wings. Also given in these tables are the corresponding Mach number, Reynolds number, and reduced frequencies. The in-phase moments were omitted in tables III and IV for the $A = 2$ wing since the frequency shift was too small to obtain satisfactory values. The theoretical values are given in table V. To show trends and comparisons, the experimental and theoretical values are shown in figures 2 to 12. A small part of the $A = 2$ wing data has been previously shown in reference 6.

DISCUSSION

Tunnel-Wall Effects

Oscillatory coefficients obtained from wind-tunnel measurements may be influenced by tunnel-wall interference which may take the form of a resonance phenomenon (see ref. 7). Thus, before presenting and discussing the measured lift, moments, and phase angles, the range of these experimental studies in relation to critical tunnel-wall interference is stated. In order to show the proximity of the data to the region of critical tunnel-wall interference based on two-dimensional flow, a plot of k against M for the various torsion springs is shown with curves of critical tunnel-wall effects in figure 2. The curves representing the experimental data are well away from their corresponding curve of critical wall interference and, thus, the tunnel-wall effects are expected to be small.

Effects of Mach Number and Reynolds Number

Since the testing technique used did not readily permit either M or R to be held constant while varying the other parameters, considerable cross-plotting would have been necessary to obtain an indication of any effect. It was found in reference 4 that, for the ranges of speed and frequencies covered, the overall effects of M and R did not appear to be of first order and perhaps were within the accuracy of the experimentation. For this investigation a sufficient quantity of data was not obtained to attempt to isolate the effects of M and R; however, a few data points which could be compared did not show significant effects.

Comparisons of the Measured Values for A = 2 Wing With Theory

The oscillating lift coefficient $|l_\alpha|$ for the A = 2 wing are shown as a function of reduced frequency in figure 3. Also shown are the coefficients calculated by the method of Lawrence and Gerber (ref. 2) and the results of vanishing-aspect-ratio theory (ref. 3). Over most of the range of k investigated, the results of the vanishing-aspect-ratio theory generally showed good agreement with the experimental results. The coefficients of Lawrence and Gerber are found to be considerably lower than the experimentally determined coefficients. The phase angle by which the oscillating lift force leads the angular displacement of the wing is shown in figure 4. As indicated in this figure, the results of Lawrence and Gerber give phase angles slightly above the experimentally determined values, and the results of the vanishing-aspect-ratio theory give results slightly above those of Lawrence and

Gerber. The analytical lift phase angles as determined from both methods are considered to be in fair agreement with the experimental phase angles.

Inasmuch as the aerodynamic moment data were obtained experimentally in component form, it is appropriate to compare these values with the analytical values of the components of the aerodynamic moment. The damping moment coefficients (out-of-phase component) for the A = 2 wing are shown as a function of reduced frequency in figure 5. It may be seen that the measured coefficients are in good agreement with the theoretical coefficients of Lawrence and Gerber, but they are lower than those predicted by the vanishing-aspect-ratio theory by approximately a factor of 3.

In figure 6, a comparison of the measured in-phase moment coefficient with those given by theory may be made. The coefficients of Lawrence and Gerber and the coefficients of the vanishing-aspect-ratio theory are shown. The results of the theory of Lawrence and Gerber underestimate the coefficients in the range of k covered whereas the results of the vanishing-aspect-ratio theory are higher than the experimental coefficients.

As in reference 4, the phase angle between the moment vector and the angular position vector was obtained from the ratio of the out-of-phase (damping) and in-phase moment coefficients and is shown in figure 7. The measured phase angles are in fair agreement with those of vanishing-aspect-ratio theory while the theory of Lawrence and Gerber has phase angles whose magnitudes are slightly smaller than the experimental values.

Comparison of the Measured Values for A = 4 Wing With Theory

The A = 4 delta-wing coefficients and phase angles are presented in figures 8 to 12. Since the root chord of this wing is one-half the root chord of the A = 2 wing, and since the frequency of oscillation and air velocity are essentially the same, the reduced-frequency range is less by a factor of 2. The oscillating lift coefficients for the A = 4 delta wing are shown as a function of reduced frequency in figure 8. Also shown for comparison are the coefficients of Lawrence and Gerber for an A = 4 delta wing. The results of the vanishing-aspect-ratio theory are not shown as it is felt that A = 4 is too large to be considered a vanishing aspect ratio. Over most of the reduced-frequency range covered, good agreement is shown between the experimental and theoretical coefficients.

The phase angles by which the oscillating lift force leads the angular displacement of the wing are shown in figure 9 as a function of k. Good agreement with the theoretical phase angles of Lawrence and Gerber is shown for the larger part of the range covered in these tests. At the lower values of k, the experimental phase angles tend to become negative indicating that the lift is lagging the angular displacement.

Figure 10 shows the damping moment coefficient as a function of reduced frequency. It may be seen that the experimental coefficients are lower than the theoretical coefficients.

Referring to figure 11, a comparison of the measured moment coefficients in phase with angular displacement with those given by Lawrence and Gerber may be made. The large scatter in the experimental data may be attributed to the technique of obtaining the coefficients. The moment is determined basically from a shift in resonant frequencies from the frequency in a vacuum to the frequency at a particular test point. This frequency shift is usually small compared with the resonant frequency of the system. The process of taking small differences of relatively large numbers tends to introduce considerable scatter in the data.

The phase angle by which the resultant moment leads the angular position is shown in figure 12. As may be seen, the phase angles predicted by the theory of Lawrence and Gerber are considerably smaller than the experimentally determined magnitudes of the moment phase angles.

Comparison of A = 2 With A = 4 Data

A comparison of the A = 2 data may be made with the A = 4 data by comparing figures 3 to 7 with figures 8 to 12. Figures 3 and 8 show the lift coefficients as functions of reduced frequency. Although the results of Lawrence and Gerber indicate the lift coefficients for the A = 4 delta to be roughly 35 percent greater than the lift coefficients for the A = 2 delta wing, the experimentally determined coefficients show the A = 4 wing to have only slightly higher lift coefficients than the A = 2 wing at the lower values of reduced frequencies. For values of reduced frequencies greater than 0.46, forces and phase angles were not obtained for the A = 4 wing, and thus are not compared with the A = 2 wing in this range.

A comparison of the lift phase angles (figs. 4 and 9) as determined by Lawrence and Gerber show the A = 4 phase angles to be slightly less than the A = 2 phase angles. Correspondingly, the experimental phase angles for A = 4 were somewhat smaller than the A = 2 phase angles.

A comparison of the damping moment coefficients for these two delta wings (figs. 5 and 10) indicated that both the analytical and experimental coefficients decrease as the aspect ratio decreases from 4 to 2. A comparison of the in-phase moment coefficients indicate that, analytically, the in-phase moment coefficient increases from A = 4 to A = 2, whereas the experimental moment coefficients, based on average data shown in figures 6 and 11, tend to decrease from A = 4 to A = 2. The phase angles of the moment coefficients are seen to be of about the same magnitude for

the two delta wings, whereas the results of Lawrence and Gerber indicate an increase in magnitude for the $A = 4$ to the $A = 2$ wing (figs. 7 and 12).

CONCLUDING REMARKS

The oscillating air forces and moments acting on delta wings of aspect ratios 2 and 4 oscillating about the root midchord position have been measured and are reported herein. The Mach number and Reynolds number ranges covered were from 0.19 to 0.81 and 0.90×10^6 to 4.40×10^6, respectively, and the reduced-frequency range was from 0.08 to 0.81. Comparisons of the measured values were made with the results of the analysis of Lawrence and Gerber and, in general, reasonably good agreement was obtained. The measured values for the delta wing with aspect ratio of 2 were also compared with the results of "vanishing-aspect-ratio" theory and good agreement was shown for the lift coefficients.

Langley Aeronautical Laboratory,
    National Advisory Committee for Aeronautics,
        Langley Field, Va., October 13, 1953.

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TABLE I.- EXPERIMENTAL DATA FOR TORSION SPRING 1

k	ρ	M	R	Φ	$\left|l_\alpha\right|$	Θ	$-m_1$	$-m_2$
For A = 2 wing								
0.16	100×10^{-5}	0.78	4.4×10^6	6	0.89	158	0.163	0.064
.17	104	.70	4.1	6	.90	154	.113	.055
.18	108	.65	3.9	6	.97	154	.128	.062
.19	110	.60	3.7	8	.94	161	.143	.050
.20	112	.57	3.5	9	.99	164	.159	.046
.20	114	.54	3.4	9	.97	152	.097	.051
.21	115	.50	3.2	10	1.00	152	.109	.058
.24	117	.46	3.0	9	.97	150	.124	.071
.26	118	.43	2.8	12	1.03	151	.142	.079
.28	120	.39	2.6	12	1.01	149	.120	.071
.31	120	.35	2.3	15	1.02	154	.155	.076
.31	120	.36	2.4	14	1.02	131	.086	.100
.35	122	.31	2.1	15	1.04	127	.083	.111
.35	124	.30	2.0	20	1.00	144	.121	.087
.41	124	.25	1.7	30	1.00	107	.036	.115
For A = 4 wing								
0.08	96×10^{-5}	0.76	2.15×10^6	-1	1.36	171	0.29	0.047
.09	98	.72	2.05	0	1.25	175	.24	.019
.09	100	.68	2.00	-1	1.30	173	.20	.025
.09	102	.65	1.95	0	1.25	171	.23	.037
.10	105	.60	1.85	1	1.13	174	.19	.022
.10	106	.56	1.75	1	1.28	172	.21	.031
.11	107	.54	1.70	1	1.17	173	.17	.021
.11	109	.51	1.65	1	1.22	159	.09	.034
.12	110	.48	1.55	2	1.03	167	.17	.039
.13	112	.45	1.48	2	1.06	170	.19	.034
.14	113	.42	1.40	1	1.18	165	.20	.055
.15	114	.39	1.30	3	1.11	169	.20	.038
.17	115	.35	1.15	2	1.11	152	.12	.067
.17	116	.34	1.15	4	1.26	166	.25	.061
.19	116	.31	1.05	3	1.14	165	.25	.069
.23	117	.26	.90	3	1.63	---	----	.077

TABLE II.- EXPERIMENTAL DATA FOR TORSION SPRING 2

k	ρ	M	R	Φ	$|l_\alpha|$	Θ	$-m_1$	$-m_2$
			For A = 2 wing					
0.22	94×10^{-5}	0.74	4.2×10^6	7	0.97	152	0.133	0.072
.24	97	.70	4.1	9	.99	157	.153	.067
.25	99	.67	4.0	8	.90	160	.158	.057
.26	100	.64	3.8	10	1.00	157	.167	.072
.27	101	.61	3.7	10	1.10	158	.179	.073
.28	102	.58	3.6	11	1.10	155	.169	.079
.29	104	.55	3.5	11	1.08	160	.186	.073
.30	104	.52	3.3	12	1.07	150	.134	.078
.32	106	.49	3.2	14	1.12	153	.147	.074
.34	107	.46	3.0	15	1.20	141	.094	.077
.37	108	.43	2.8	16	1.19	149	.145	.088
.39	109	.40	2.6	18	1.22	148	.167	.105
.43	110	.37	2.4	21	1.30	143	.146	.109
.48	112	.33	2.2	21	1.36	146	.177	.119
.54	113	.29	1.9	24	1.57	150	.226	.132
.54	113	.29	2.0	24	1.43	120	.093	.147
.65	114	.24	1.6	29	1.85	142	.203	.157
.81	116	.19	1.3	32	2.06	135	.214	.218
			For A = 4 wing					
0.13	102×10^{-5}	0.71	2.05×10^6	3	1.09	169	0.19	0.037
.14	104	.67	1.98	3	1.08	169	.20	.041
.15	107	.61	1.85	3	1.05	165	.17	.045
.16	108	.57	1.78	3	1.01	168	.19	.041
.17	110	.53	1.70	4	.97	166	.17	.044
.18	112	.50	1.60	5	1.00	165	.18	.049
.19	114	.46	1.50	7	.92	156	.10	.046
.21	115	.42	1.38	9	.83	150	.11	.062
.22	116	.41	1.35	8	1.19	152	.13	.071
.23	117	.37	1.25	10	.84	145	.12	.084
.26	119	.33	1.08	12	1.01	154	.19	.090

TABLE III.- EXPERIMENTAL DATA FOR TORSION SPRING 3

k	ρ	M	R	Φ	$\|l_\alpha\|$	Θ	$-m_1$	$-m_2$
For A = 2 wing								
0.28	80×10^{-5}	0.81	4.4×10^6	7	1.12	---	----	0.094
.29	81	.77	4.3	9	1.04	---	----	.081
.32	91	.69	4.1	11	1.05	---	----	.073
.33	93	.66	4.0	13	1.06	---	----	.096
.35	94	.62	3.8	13	1.06	---	----	.090
.36	96	.59	3.6	14	1.07	---	----	.094
.39	97	.55	3.5	15	1.10	---	----	.095
.41	98	.52	3.3	18	1.11	---	----	.111
.43	99	.50	3.2	18	1.13	---	----	.109
.46	100	.46	3.0	20	1.27	---	----	.125
.49	102	.43	2.8	22	1.27	---	----	.125
.54	103	.39	2.6	24	1.31	---	----	.147
.57	104	.37	2.5	27	1.34	---	----	.163
.61	105	.34	2.3	26	1.42	---	----	.174
.55	106	.39	2.6	23	1.48	---	----	.193
.71	108	.30	2.0	29	1.58	---	----	.249
For A = 4 wing								
0.16	97×10^{-5}	0.76	2.15×10^6	1	1.15	144	0.12	0.09
.17	99	.72	2.05	3	1.11	156	.19	.08
.18	102	.69	2.01	4	1.12	161	.18	.06
.18	104	.66	2.00	5	1.08	162	.21	.07
.20	107	.58	1.80	7	1.12	163	.26	.08
.22	110	.55	1.73	7	1.07	147	.17	.11
.23	112	.52	1.65	7	1.10	151	.16	.09
.24	113	.49	1.55	9	1.08	159	.26	.10
.26	115	.46	1.50	9	1.09	164	.34	.10
.27	116	.43	1.43	10	1.11	160	.30	.11
.29	117	.40	1.34	13	1.15	149	.22	.13
.39	117	.31	1.05	23	.99	159	.45	.17
.32	119	.37	1.22	13	1.16	151	.26	.14
.46	119	.26	.90	28	.94	142	.33	.26
.35	120	.33	1.10	16	1.10	155	.28	.13

TABLE IV.- EXPERIMENTAL DATA FOR TORSION SPRING 4 FOR A = 2 WING

k	ρ	M	R	Φ	$|l_\alpha|$	$-m_2$
0.36	85×10^{-5}	0.74	4.2×10^6	12	1.24	0.103
.36	86	.76	4.3	9	1.19	.094
.39	87	.68	4.0	14	1.27	.119
.41	88	.65	3.9	36	1.27	.106
.45	91	.58	3.6	·18	1.30	.122
.49	93	.54	3.4	19	1.36	.130
.52	94	.50	3.2	23	1.34	.146
.56	95	.47	3.1	25	1.32	.155
.61	97	.43	2.8	27	1.44	.172
.66	99	.39	2.6	31	1.42	.184
.66	100	.40	2.6	27	1.45	.186

TABLE V.- THEORETICAL VALUES

k	$|l_\alpha|$	Φ	$-m_1$	$-m_2$	Θ
Vanishing aspect ratio					
0	1.00	0	0.33	0	0
.25	1.06	23	.32	.25	142
.50	1.24	42	.27	.50	118
.75	1.49	57	.18	.75	104
1.00	1.80	68	.07	1.00	94
A = 2 delta wing (see ref. 2)					
0.125	0.69	8.3	0.09	0.05	151
.250	.71	16.7	.09	.10	131
.500	.77	31.8	.07	.19	111
1.000	1.00	55.0	.01	.38	106
A = 4 delta wing (see ref. 2)					
0.125	1.07	5.7	0.037	0.08	116
.250	1.07	12.1	.04	.14	106
.500	1.11	25.6	.04	.26	99
1.000	1.34	48.6	.02	.48	87
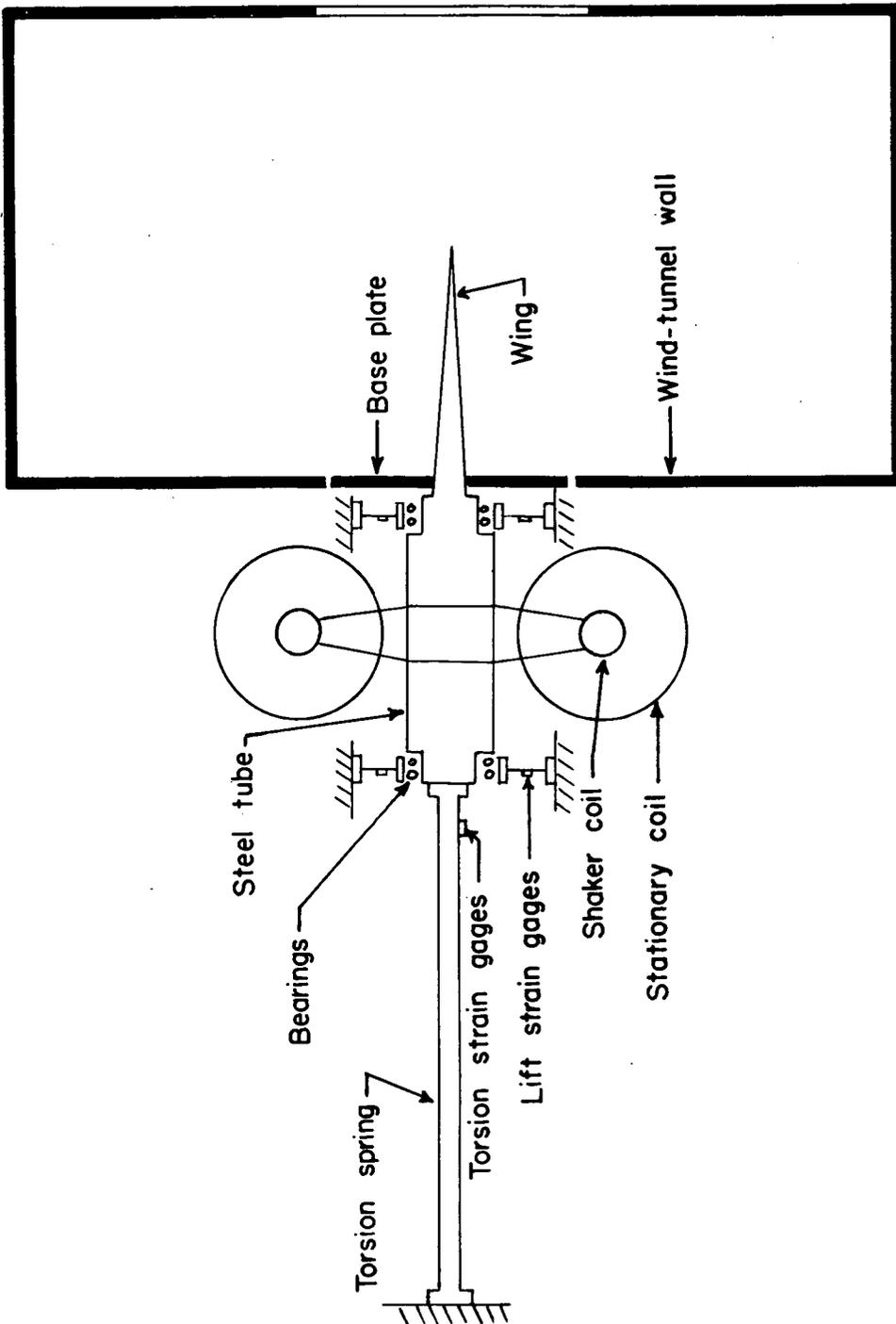
Figure 1.- Diagram of oscillating mechanism and wing mounted in the Langley 2- by 4-foot flutter research tunnel.
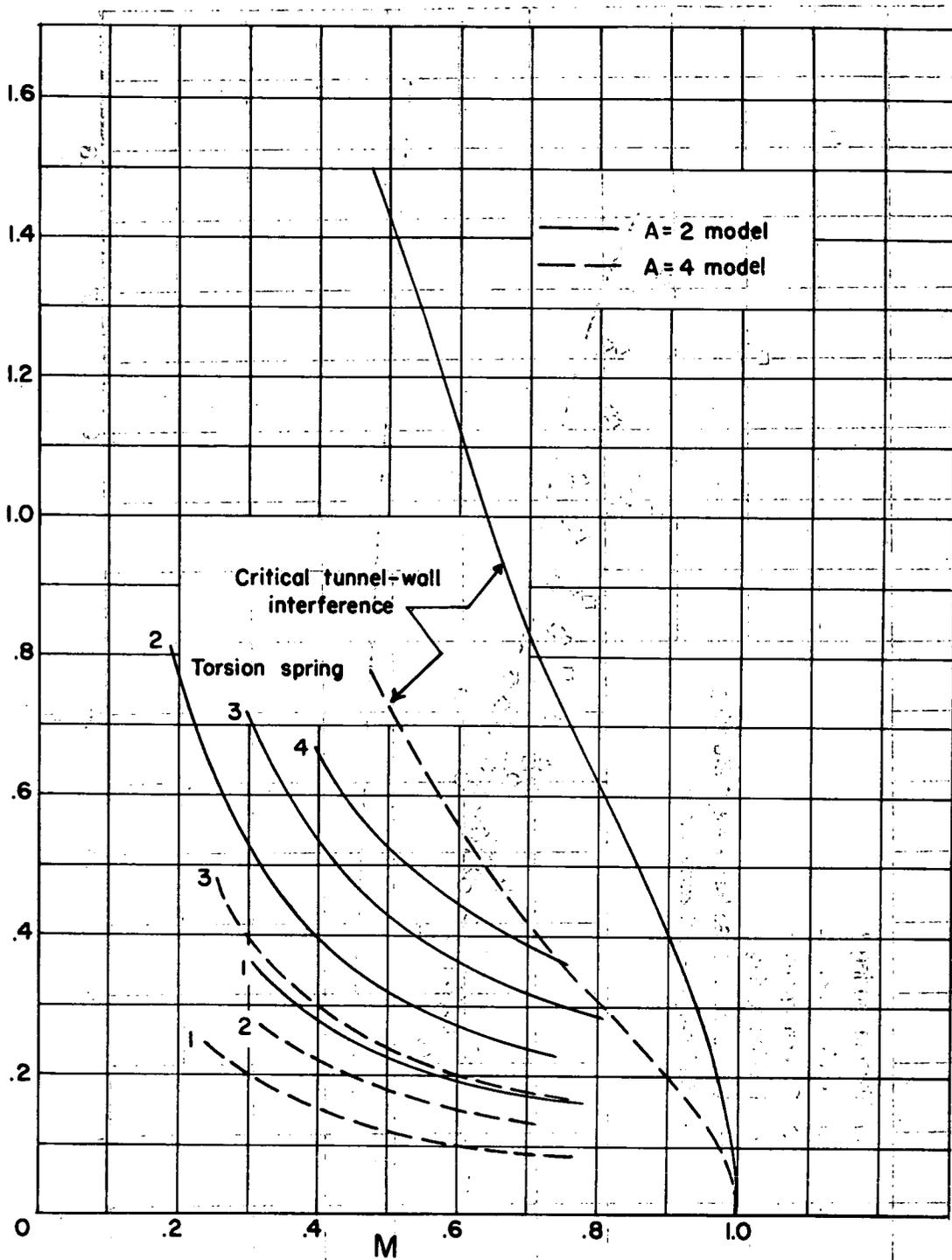
Figure 2.- Reduced frequency against Mach number showing range of experimental studies in relation to critical tunnel-wall interference.
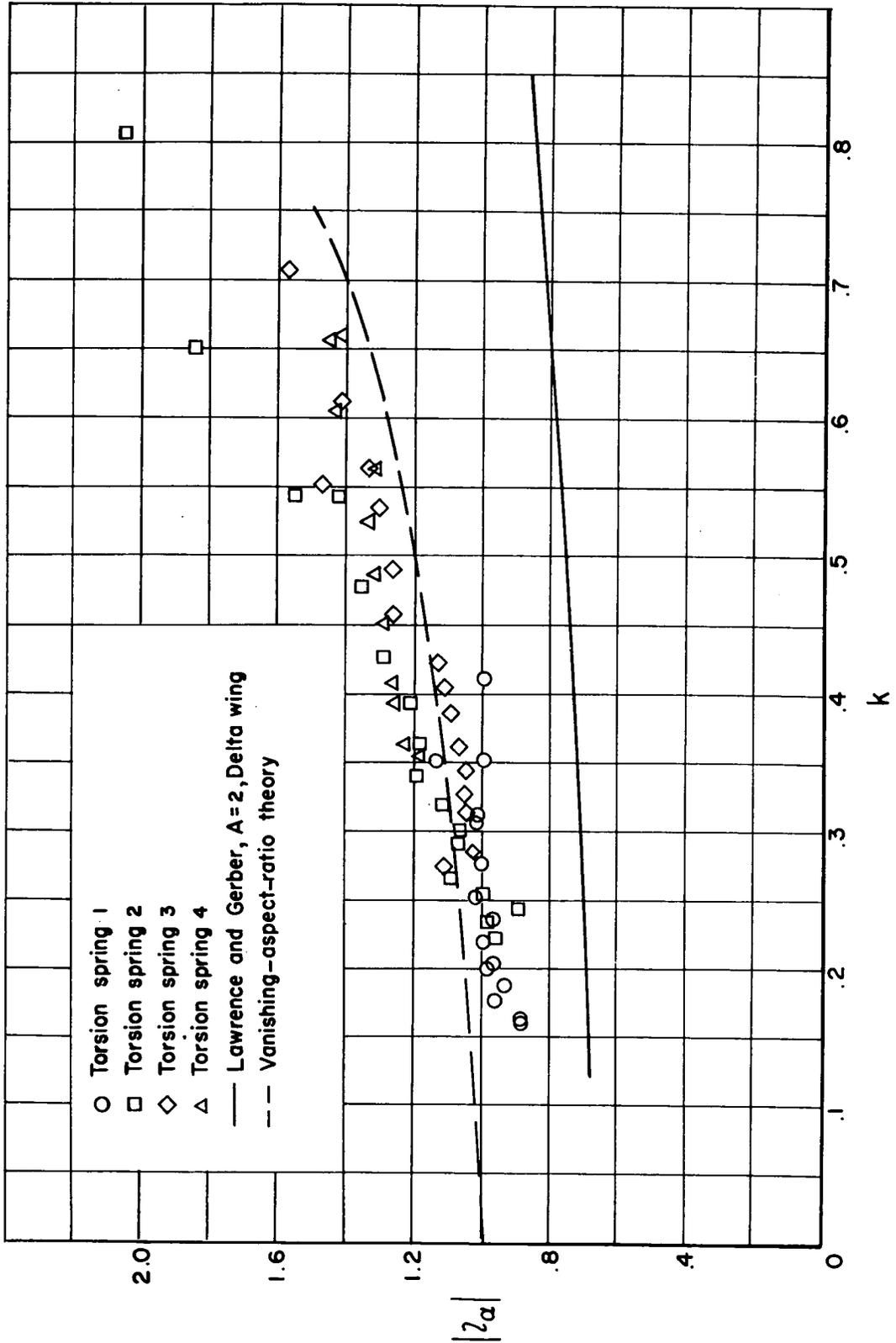
Figure 3.- Oscillating lift coefficients as a function of reduced frequency for 63.4° delta wing. A = 2.
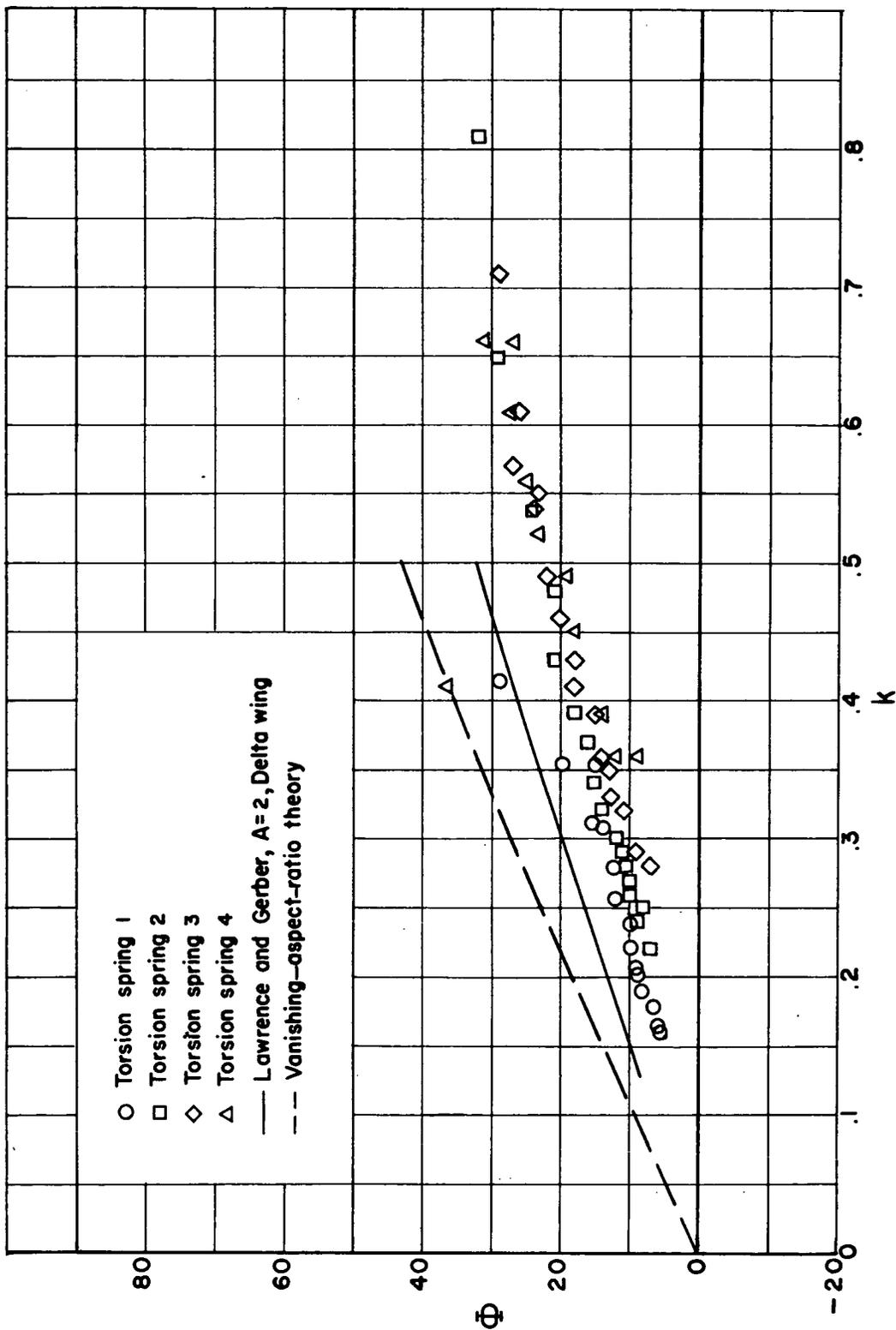
Figure 4.- Lift phase angle as a function of reduced frequency for 63.4° delta wing. A = 2.
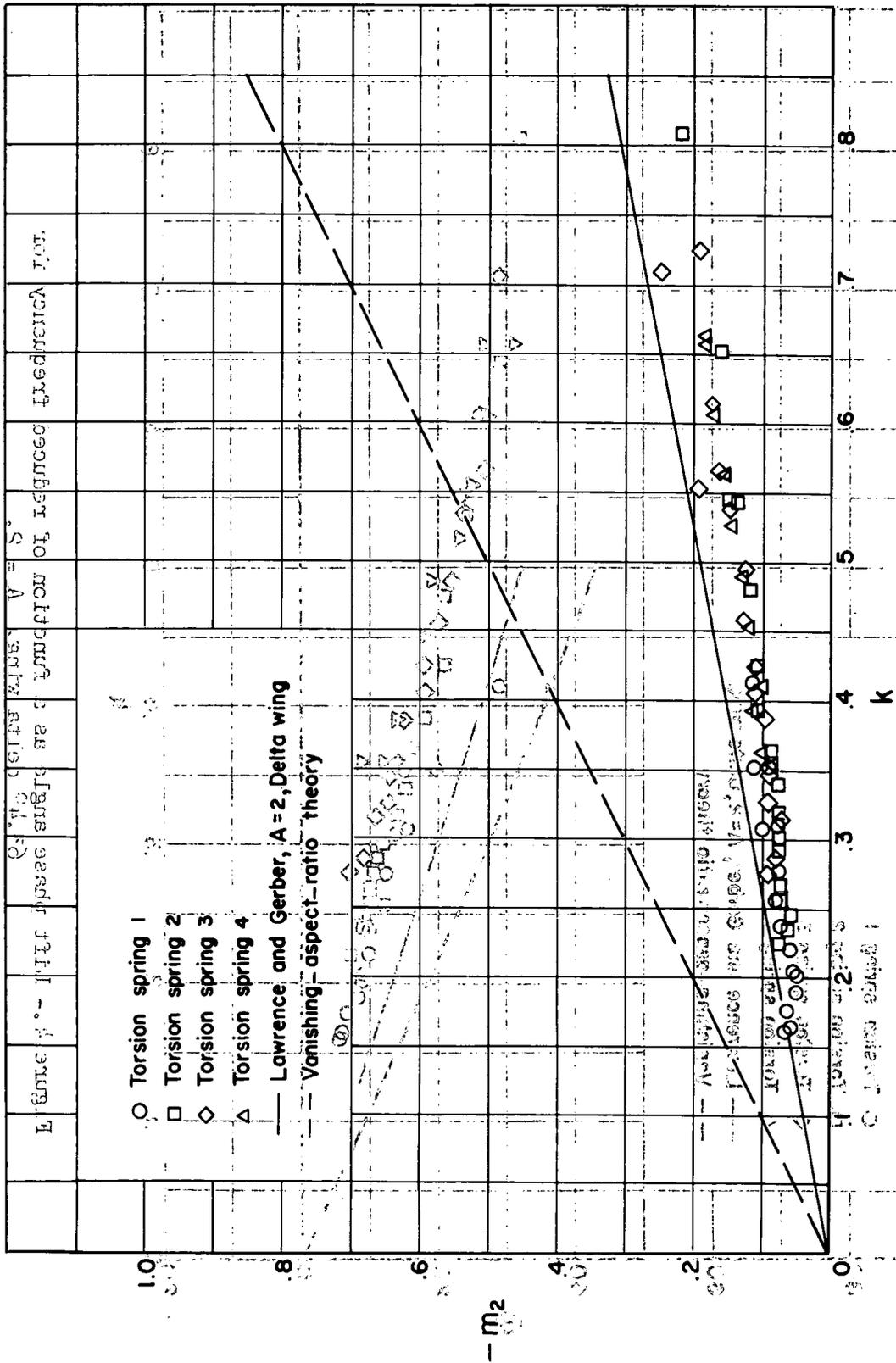
Figure 5.- Damping moment coefficient as a function of reduced frequency for 63.4° delta wing. A = 2.
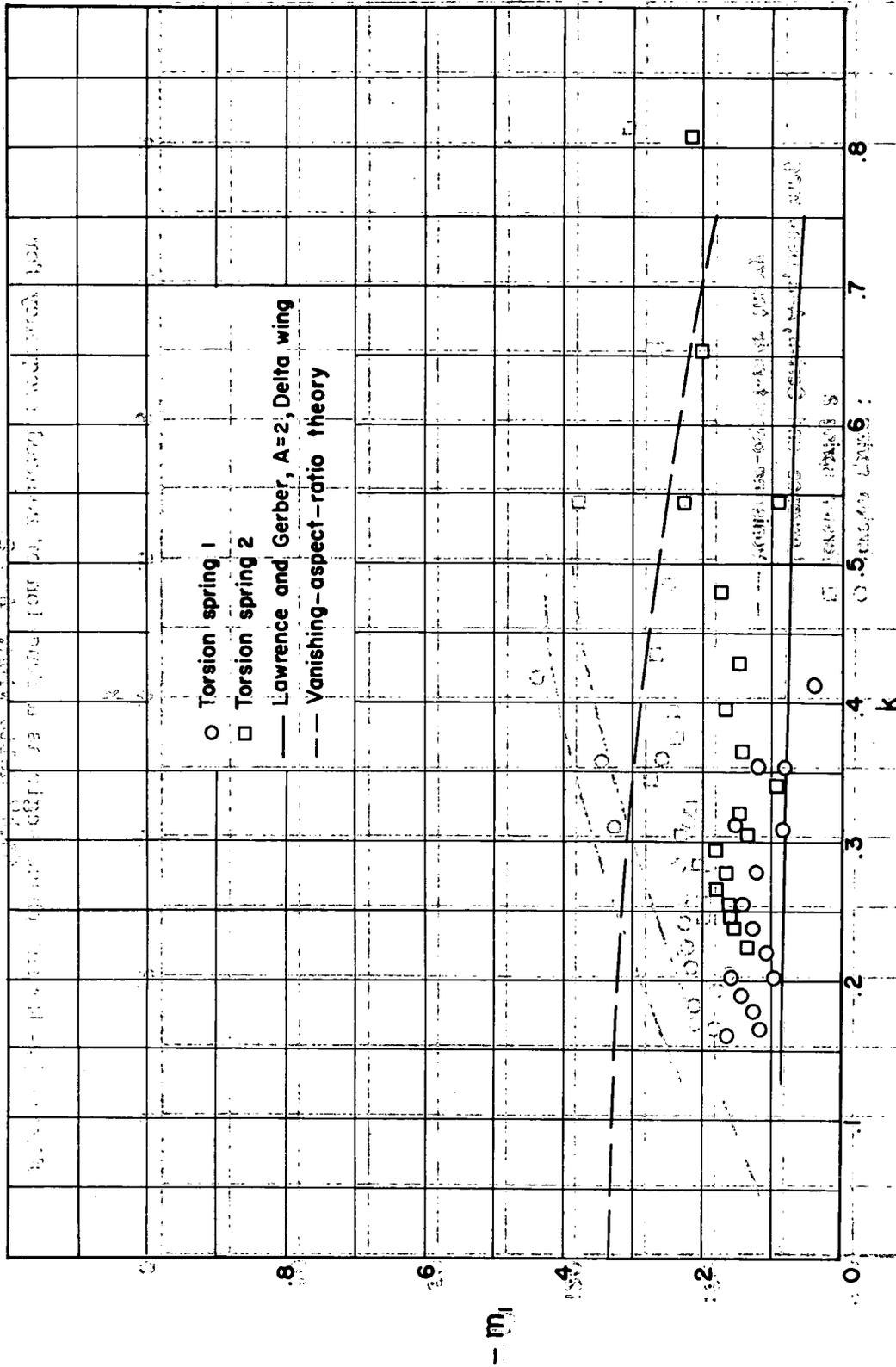
Figure 6.- In-phase moment coefficient as a function of reduced frequency for 63.4° delta wing. A = 2.
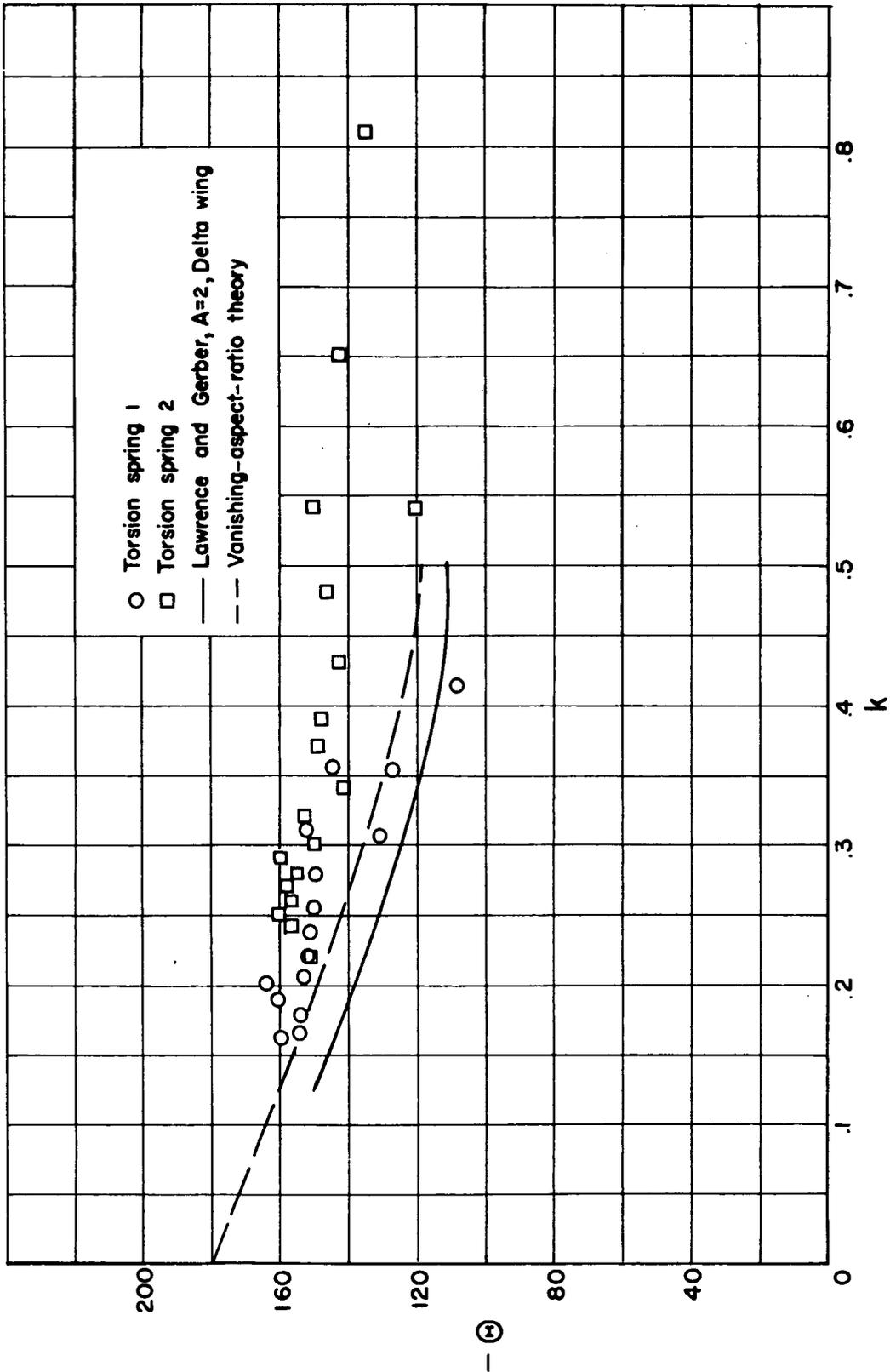
Figure 7.- Moment phase angle as a function of reduced frequency for 63.4° delta wing. A = 2.
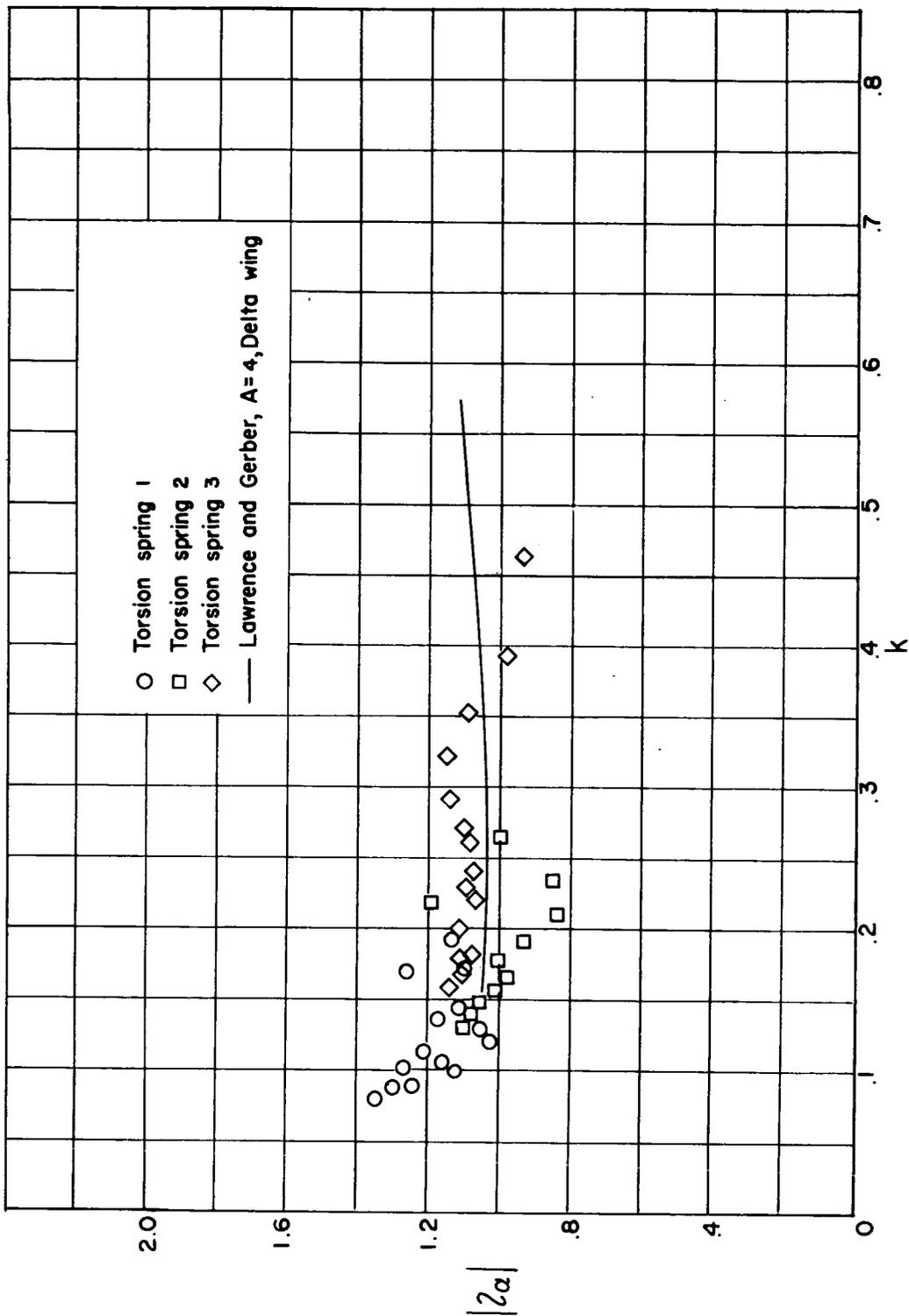
Figure 8.- Oscillating lift coefficient as a function of reduced frequency for 45° delta wing. A = 4.
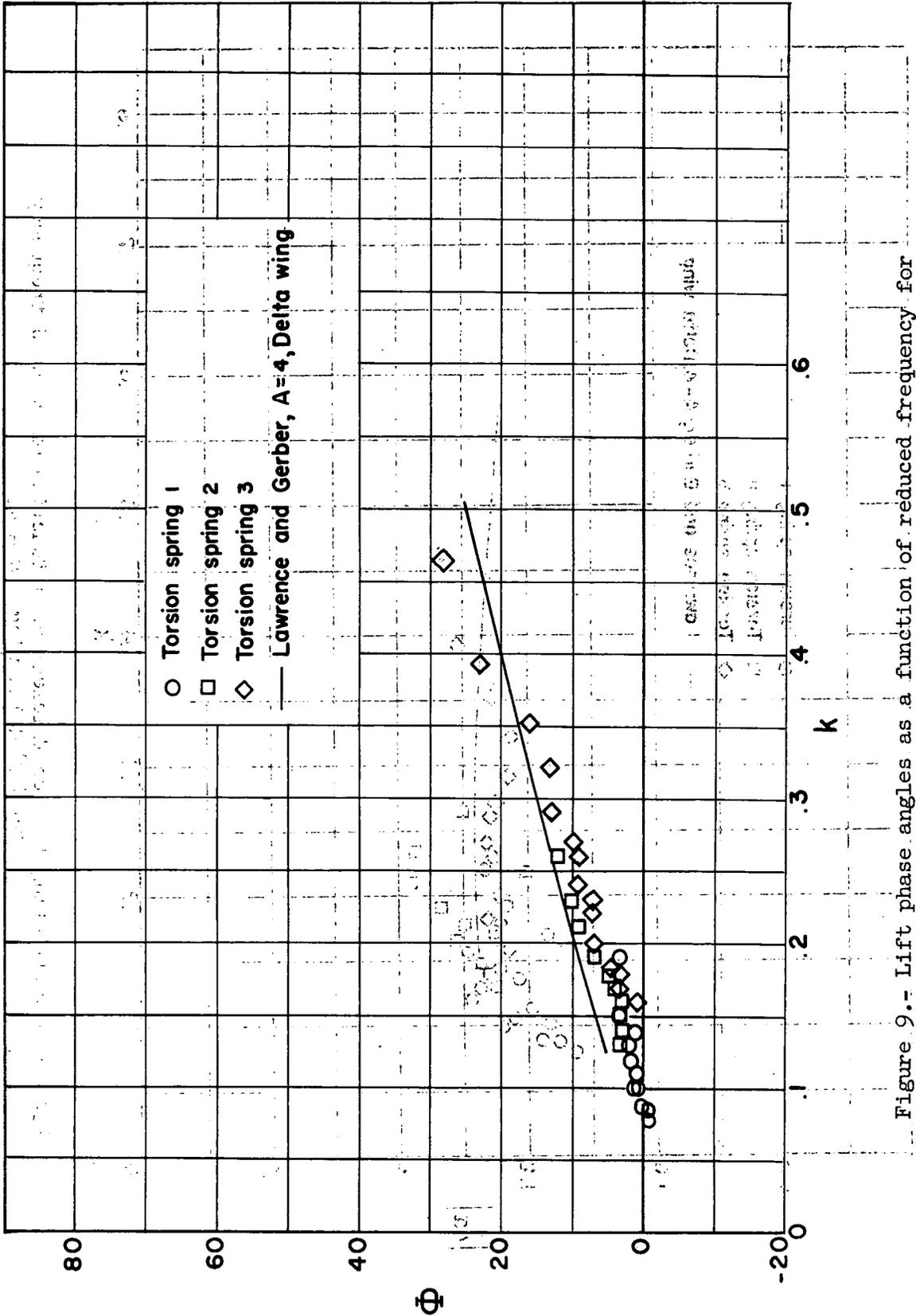
Figure 9.- Lift phase angles as a function of reduced frequency for 45° delta wing. A = 4.
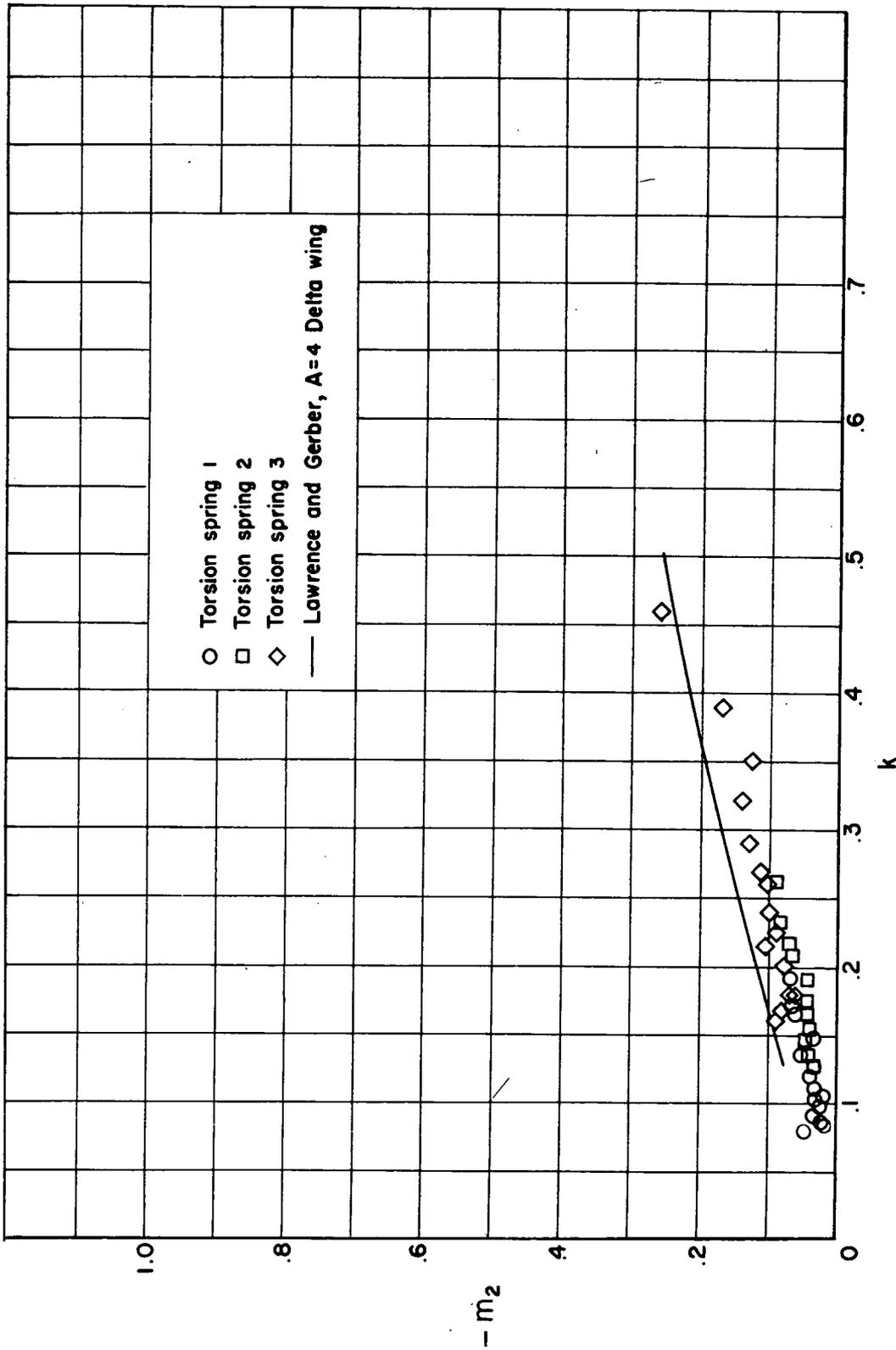
Figure 10.- Damping moment coefficients as a function of reduced frequency for 45° delta wing. A = 4.
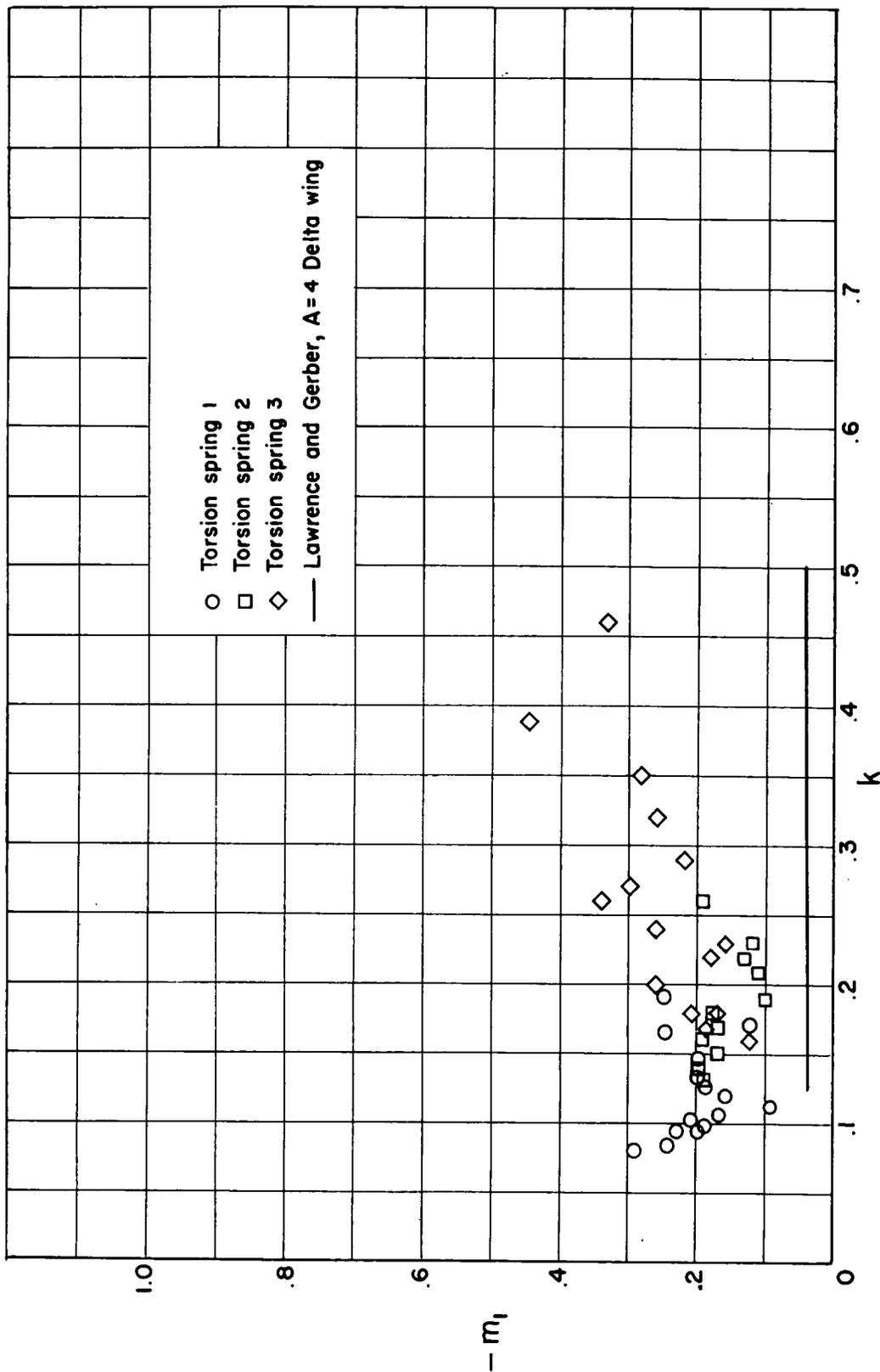
Figure 11.- In-phase moment coefficient as a function of reduced frequency
for 45° delta wing. A = 4.
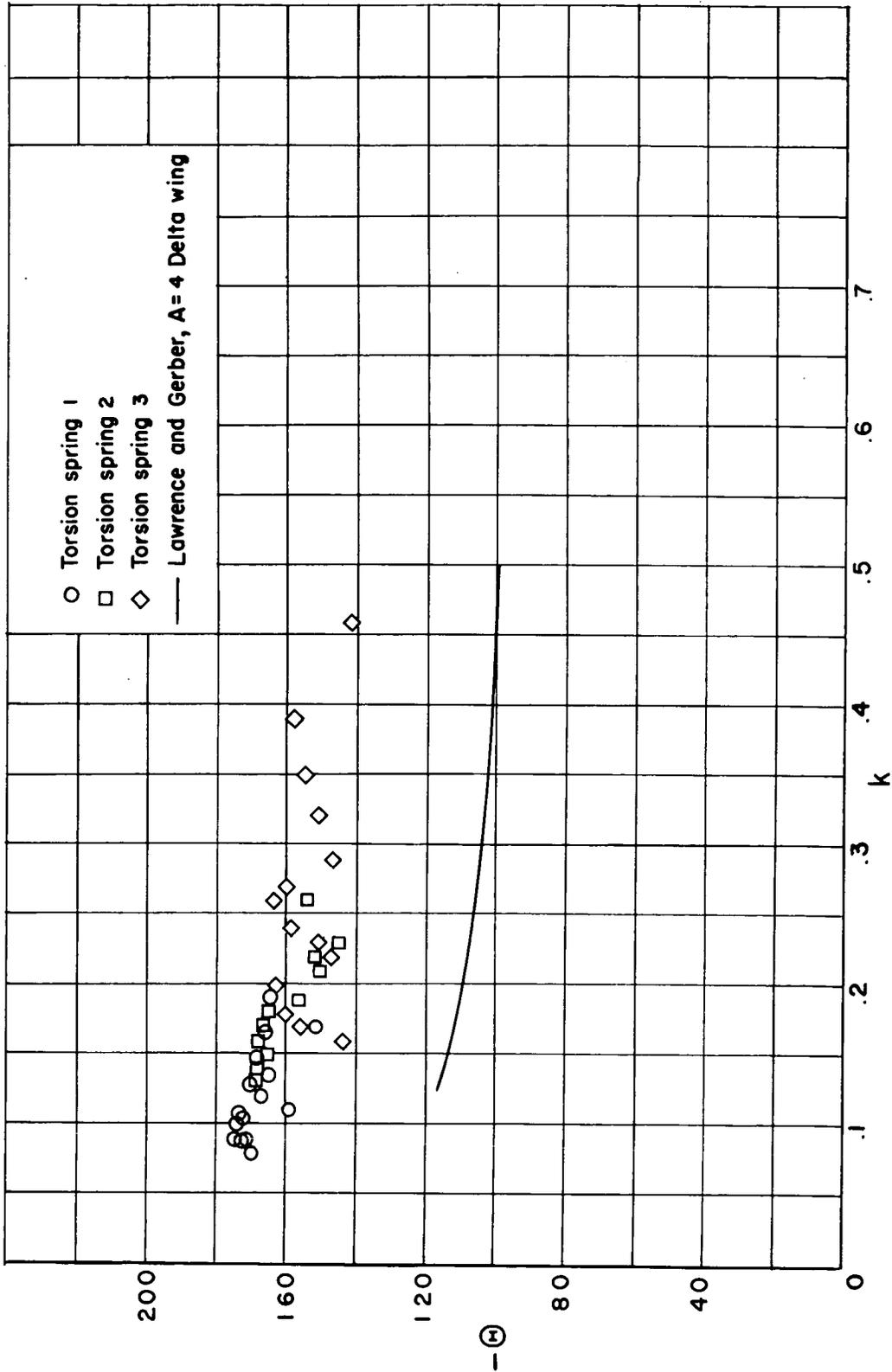
Figure 12.- Moment phase angles as a function of reduced frequency for
45° delta wing. A = 4.