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RESEARCH MEMORANDUM

EFFECTS OF RIGID SPOILERS ON THE TWO-DIMENSIONAL FLUTTER
 DERIVATIVES OF AIRFOILS OSCILLATING IN PITCH
 AT HIGH SUBSONIC SPEEDS

By James C. Monfort and John A. Wyss

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RESEARCH MEMORANDUM

EFFECTS OF RIGID SPOILERS ON THE TWO-DIMENSIONAL FLUTTER

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SUMMARY

A study was made of the effects of spoilers having fixed heights equal to 2-1/2 and 4 percent of the airfoil chord, on the aerodynamic lift and moment flutter derivatives of two-dimensional airfoils oscillated in pitch about the quarter-chord axis with a mean angle of attack of 2° and an amplitude of $\pm 1^\circ$. The reduced frequency varied from 0.045 to 0.45 at 0.5 Mach number and from 0.025 to 0.25 at 0.9 Mach number. The spoilers were affixed at the 70-percent-chord station on the upper surface of airfoils with NACA 65A012, 65A008, 2-008, and 877A008 profiles. The spoilers increased the magnitude of the lift and for some cases the moment derivatives at the higher Mach numbers, particularly at the lower reduced frequencies. The effects on the phase angle of the lift derivative were small, but large changes in the phase angle of the moment derivative occurred. The airfoils with spoilers had negative aerodynamic damping at supercritical speeds, except for the NACA 877A008 airfoil, and the addition of spoilers decreased the Mach number at which a single-degree-of-freedom type of flutter in the torsional mode became a possibility. A comparison of the data for the three models of equal thickness shows, for a given spoiler height, a decrease in the Mach number for torsional instability as the location of the maximum ordinate of the airfoil was moved toward the leading edge. Changing the thickness of the NACA 65A-series airfoil from 8 to 12 percent of the chord significantly reduced the Mach number at which instability occurred for each spoiler height.

INTRODUCTION

The importance of continuing research to determine the dynamic effects of spoilers has been emphasized by the instances of spoiler-induced destructive flutter at sonic speeds reported in reference 1.

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The effectiveness of spoilers as lateral-control devices has been the subject of numerous research investigations. A number of these have been reported in the papers listed in a bibliography in reference 2. The authors, however, have knowledge of only two investigations other than that reported in reference 1 which were concerned with the dynamic aspects of spoiler-type controls. The first of these investigations was reported in references 3 and 4, and was concerned with the determination of flutter speeds and frequencies of a combination of a cusp-type spoiler, mounted on a three-dimensional wing. The spoiler was free to oscillate into and out of the air stream. The wing was mounted to provide for either pitching or rolling motion or flutter. The second investigation, reported in reference 5, was concerned with the determination of the oscillatory forces and moments due to the effects of an oscillating spoiler, acting on a two-dimensional wing fixed at zero angle of attack. In contrast and complementary to these investigations, the assumption was made for the purpose of this report that a mechanical solution to spoiler oscillation was possible in order to simplify and limit the aerodynamic problem to the effects of fixed spoilers on the flutter derivatives of oscillating airfoils. This report is therefore concerned with a study of the effects of spoilers of fixed deflection on the aerodynamic lift and moment flutter derivatives of two-dimensional airfoils oscillated in pitch.

SYMBOLS

| | |
|------------|--|
| a | velocity of sound in undisturbed air, ft/sec |
| b | wing semichord, ft |
| c_l | dynamic section lift coefficient |
| c_m | dynamic section moment coefficient about quarter point of chord |
| f | frequency of oscillation, cps |
| i | $\sqrt{-1}$ |
| k | reduced frequency, $\frac{\omega b}{V}$ |
| M | Mach number, $\frac{V}{g}$ |
| M_α | oscillatory aerodynamic section moment on wing about axis of rotation, positive with leading edge up |
| P_α | oscillatory aerodynamic section lift on wing, positive upwards |

| | |
|---------------------------------------|---|
| q | free-stream dynamic pressure, lb/sq ft |
| V | free-stream velocity, ft/sec |
| α | oscillatory angular displacement (pitch) about axis of rotation, positive with leading edge up, radians |
| α_m | mean angle of attack about which oscillation takes place, deg |
| θ | phase angle between oscillatory moment and position α , positive for moment leading α , deg |
| ϕ | phase angle between oscillatory lift and position α , positive for lift leading α , deg |
| ω | circular frequency, $2\pi f$, radians/sec |
| $\left \frac{dc_l}{d\alpha} \right $ | magnitude of dynamic lift-curve slope, $\left \frac{P_{\alpha} e^{-i\phi}}{2bq\alpha} \right $, per radian |
| $\left \frac{dc_m}{d\alpha} \right $ | magnitude of dynamic moment-curve slope, $\left \frac{M_{\alpha} e^{-i\theta}}{4b^2 q\alpha} \right $, per radian |

APPARATUS AND METHOD

Tunnel and Model Drive System

A downstream view of the two-dimensional channel in the Ames 16-foot high-speed wind tunnel in which the models were oscillated and a diagrammatic sketch of the model drive system are shown in figure 1. The channel was 20 feet long and 16 feet high. The drive rods, cables, and sector arm attached to the model were contained within one of the walls.

Models and Instrumentation

Profiles of the NACA 65A012, 2-008, 65A008, and ¹877A008 airfoils are illustrated in figure 2. A tabulation is also included which indicates the 15 chord stations at which electrical pressure cells

¹An NACA 847A110 airfoil was modified to a symmetrical section by using the lower surface coordinates for both upper and lower surfaces and then reducing the thickness ratio to 8 percent.

were mounted flush with the upper and lower surfaces along the midspan of each model. A pressure orifice adjacent to each pressure cell was used to provide an internal reference pressure for each cell through about 50 feet of 1/16-inch tubing. The pressure orifices were also used in conjunction with a multiple-tube mercury manometer to determine steady-state chordwise distributions of pressure. Each model had a chord of 24 inches and a span of 18-1/4 inches, with the gaps at the tunnel walls sealed with felt pads or brass strips which moved with the model.

The same models and associated mechanical and electronic equipment were used in investigations reported in references 6 and 7, where more detailed descriptions may be found. Reference 7 contains the results for the same group of models without spoilers, which will be referred to herein as results for spoilers of zero height. The two spoilers used were mounted with the spoiler leading edge at the 70-percent-chord station. They were made from right-angle aluminum extrusions with one side machined down to either 2-1/2 or 4 percent of the wing chord. A 4-percent spoiler mounted on the NACA 65A012 model is illustrated in figure 3.

Method

Data were obtained at from 4 to 40 cps for an amplitude of oscillation of $\pm 1^\circ$. The airfoils were oscillated in pitch about the quarter-chord axis with a mean angle of attack of 2° and at Mach numbers from 0.5 to 0.9. The reduced frequency varied from 0.045 to 0.45 at 0.5 Mach number, and from 0.025 to 0.25 at 0.9 Mach number. The Reynolds number varied from 5 million to 8 million. The principal data consisted of oscillograms recorded on 14-channel oscillographs. Sample oscillograms for one of the airfoils are shown in figure 4. Traces were recorded representing the differences in pressure between the upper and lower surface at each chord station, the lift on the airfoil from a summation of the electrical output of all cells, and the model angle of attack by means of an NACA slide-wire transducer. The lift derivatives and phase angles were evaluated from the fundamental components of 12-point harmonic analyses of each of three consecutive cycles of the sum traces. The pitching moments were evaluated by 12-point harmonic analyses of the individual traces for one cycle.

Because of the effects of wind-tunnel resonance, data taken within 10 percent of the tunnel resonant frequencies have been omitted. (See refs. 8, 9, and 10.) Although the use of such a procedure does not mean tunnel-wall effects have been completely eliminated over the entire frequency range, it is felt that any remaining tunnel-wall effects are but a small factor in the trends of the data (see ref. 7).

RESULTS

Before presenting the results, it is desired to emphasize the fact that the flutter derivatives contained herein are representative of the slope of the lift and moment curves, rather than of the absolute values of lift and moment. This is illustrated in figure 5, which shows the lift characteristics at zero and low frequencies for the NACA 65A008 airfoil with and without spoilers at 0.59 Mach number. In this figure, the symbolized points represent data derived from steady-state pressure distributions measured by means of the pressure orifices and multiple-tube mercury manometer. The dashed lines represent the variation in lift for a frequency of oscillation of about 2 cps. It is obvious from this figure that even though the slopes of all the curves are nearly the same, spoiler deflection resulted in large reductions in the absolute magnitude of the lift forces acting on the wing. Such a reduction occurred on all models over the entire speed range of the investigation.

The measured lift and moment flutter derivatives and their phase angles for fixed spoiler heights of 2-1/2 and 4 percent of the wing chord are presented in tables I, II, III, and IV, for the NACA 2-008, 65A008, 877A008, and 65A012 airfoils, respectively. As previously indicated, corresponding values are tabulated in reference 7 for the airfoils without spoilers.

In figures 6 and 7 are presented the magnitudes and phase angles of the lift and moment derivatives, respectively, for the NACA 65A008 airfoil for two Mach numbers. The derivatives are plotted as functions of reduced frequency to show typical effects of this parameter.

Figures 8, 9, 10, and 11 contain cross plots of the lift derivative and phase angle for fixed spoiler deflections as a function of Mach number for three representative reduced frequencies for the NACA 2-008, 65A008, 877A008, and 65A012 airfoils, respectively.

Figures 12, 13, 14, and 15 contain cross plots of the moment derivative and phase angle presented in the same order as the lift derivatives. This order of presentation was chosen to correspond to the rearward change in the location of maximum thickness for the NACA 2-008, 65A008, and 877A008 airfoils which have maximum ordinates at about 16, 42, and 63 percent of the chord, respectively. Since the NACA 65A008 airfoil is intermediate, it is considered the reference airfoil. The investigation included only two models of different thickness-to-chord ratios, the NACA 65A012 and 65A008 airfoils. The derivatives for the NACA 65A012 airfoil provide some indication of the effects of increasing the thickness of the reference airfoil.

Figures 16 and 17 contain aerodynamic torsional instability boundaries for various spoiler deflections for the three models which

differed in thickness distribution and for the two models which differed in thickness, respectively.

DISCUSSION

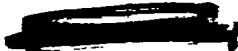
Typical Effects of Spoiler Deflection

In figures 6 and 7, the lift and moment flutter derivatives and phase angles are presented as functions of reduced frequency for the reference airfoil, the NACA 65A008. Included in each figure are results for supercritical Mach numbers of 0.68 and 0.84. The critical Mach number for the plain airfoil at an angle of attack of 2° was 0.59, which was calculated from the pressure distributions measured by means of the pressure orifices and multiple-tube mercury manometer.

Included in figures 6 and 7 and in subsequent figures are curves derived from thin-airfoil theory. Theoretical values at Mach numbers of 0.5, 0.6, and 0.7 were obtained from the work of Dietze (refs. 11 and 12), at Mach number of 0.8 from Minhinnick (ref. 13), and at Mach number of 1.0 from Nelson and Berman (ref. 14).

In figure 6 it is perhaps not surprising, in view of the data already presented in figure 5, to see the relatively small effects at 0.68 Mach number of spoilers of fixed heights on the lift derivative and phase angle. At 0.84 Mach number, the largest effects appear to occur at the lower and higher extremes of reduced frequency, although the trends with reduced frequency are similar.

In figure 7 the large variation from theory of the moment derivative phase angle at 0.68 Mach number can be attributed to a center-of-pressure location nearer the leading edge than theory predicts. (See ref. 15.) An increase in Mach number to 0.84 resulted in a greater effect of spoiler deflection on the moment derivative and phase angle than was the case for the lift derivative and phase angle in figure 6. The large shift in the phase angle of the moment derivative is of particular importance in that at reduced frequencies of 0.016 and 0.053, the phase angle shifted from a lagging to a leading phase angle; that is, the phase angle shifted so that $0^\circ < \theta < 180^\circ$. For these instances, the sign of the moment damping component became positive, which means that the aerodynamic damping forces acting on the wing were negative with the possibility of a single-degree-of-freedom type of flutter. It thus appears that the spoiler resulted in a shift from a stable to an unstable condition.


Effects of Mach Number

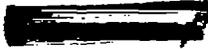
Figures 6 and 7 indicate that reduced frequency and Mach number each have important effects on the flutter derivatives. Figures 7 through 14 have been prepared to show the salient effects of these parameters. The lift and moment flutter derivatives are presented as functions of Mach number for three reduced frequencies.

Lift derivative and phase angle.- Examination of figures 8 through 11 indicates that the spoilers had a greater effect on the magnitude of the lift derivative than on the phase angle. Although there were exceptions, the effect at the higher Mach numbers was to increase the magnitude of the lift derivative, particularly at the lower values of reduced frequency. A comparison of figure 9 for the NACA 65A008 airfoil with figure 11 for the NACA 65A012 airfoil indicates that the increase in the magnitude of the lift derivative with spoiler deflection was larger for the thicker airfoil. It is interesting to note that at 0.6 Mach number, reasonable agreement was obtained for all spoiler heights with the theory for a wing without spoiler.

In reference 7 it was proposed that the Mach number for lift divergence could be used as an approximate criterion for the Mach number at which large variations in the magnitude of the lift flutter derivative occurred as Mach number was increased. The approximate Mach numbers for lift divergence for the plain airfoils were 0.72, 0.77, 0.76, and 0.68 for the NACA 2-008, 65A008, 877A008, and 65A012 profiles, respectively. Although the Mach number for lift divergence for an airfoil with a spoiler would not be the same, it would appear from figures 8 to 11 that this criterion is still useful, even with a deflected spoiler.

The effect of spoiler height on the phase angle of the lift derivative was small and a definite trend is difficult to detect. It would appear that with or without the spoilers, at the higher Mach numbers an increasing lag of the phase angle of the lift derivative occurred relative to the theoretical values. The change in phase angle was sufficiently small that the theory for a wing without a spoiler is considered to provide a reasonable prediction for the lift-derivative phase angles for the spoiler heights and location investigated.

Moment derivative and phase angle.- It is obvious from examination of figures 12 through 15 that the spoilers had significant effects on the phase angle as well as on the magnitude of the moment derivative. With regard to the magnitude of the moment derivative, it would appear that, again, even though there were exceptions, the spoilers increased the magnitude, particularly at the lower values of reduced frequency, at the higher Mach numbers.



It may be of interest to note that the phase shift in figure 12 could be presented in such a manner as to show an increasing lead of the moment derivative in going from the stable to the unstable condition, rather than an increasing lag. However, it is felt that the Mach number increments at which data were taken were not sufficiently small to clearly define for all cases whether the moment derivative approached the unstable condition by either an increasing lag or increasing lead.

The general effect of the spoilers on the phase angle, with an exception for the NACA 877A008 airfoil, was to decrease the Mach number at which occurred the large shift of approximately 180° from a lagging to a leading phase angle, with a resultant change from a stable to an unstable condition. In figure 12 another exception appears in that a reversal occurred such that instability occurred for the 2-1/2-percent spoiler at Mach numbers less than those for the 4-percent spoiler. No explanation for this exception can be given.

Aerodynamic Torsional Instability Boundaries for Fixed Spoiler Heights as Affected by Airfoil Profile

In order to show the effects of airfoil profile on the Mach numbers at which instability occurred, the Mach numbers at which the moment-derivative phase angle became less than 180° in figures 12 through 15 are presented in figures 16 and 17 in terms of the flutter-speed parameter, V/wb , the reciprocal of reduced frequency, k . In this manner, what is termed an aerodynamic torsional instability boundary was established. This boundary defines the Mach number for which any further increase in free-stream velocity results in the possibility of torsional single-degree-of-freedom flutter.

Figure 16 contains the boundaries for the three 8-percent-thick models. It may be noted that without a spoiler only the NACA 2-008 airfoil, with the maximum thickness at an extreme forward position, had a boundary within the limits of the investigation. Spoiler deflection for this model resulted in a reduction in Mach number at which instability occurred. The effect of spoilers on the NACA 65A008 airfoil was to cause torsional instability, which otherwise did not occur. In contrast, the NACA 877A008 airfoil was stable throughout the speed range of the investigation. In order to emphasize the effects of thickness distribution, and for this reason only, boundaries based on extrapolation are also included.

The usefulness of figure 16 is twofold: It indicates the effect of spoilers in reducing the Mach number at which instability occurred, and also indicates that this Mach number decreased as the location of the maximum ordinate of the airfoil was moved toward the leading edge.

The boundaries for the NACA 65A012 and NACA 65A008 airfoils are compared in figure 17. As in figure 16, this figure illustrates the reduction in Mach number of the boundary due to spoiler deflection. It also indicates the reduction in Mach number of the boundaries when the thickness of the reference airfoil was increased.

This figure should not be construed to indicate that a reduction of the reference airfoil thickness would necessarily be beneficial in increasing the Mach number of the boundaries. Results presented in reference 7 for an NACA 65A004 airfoil without a spoiler indicate that this airfoil became abruptly unstable at 0.88 Mach number.

CONCLUSIONS

Within the limitations of speed range, reduced frequency, and spoiler height of the investigation, the following conclusions can be drawn:

1. The spoilers increased the magnitude of the lift and for some cases the moment derivatives at the higher Mach numbers, particularly at the lower reduced frequencies. The effects on the phase angle of the lift derivative were small, but large changes in the phase angle of the moment derivative occurred.
2. The airfoils with spoilers had negative aerodynamic damping at supercritical speeds, except for the NACA 877A008 airfoil, and the addition of spoilers decreased the Mach number at which a single-degree-of-freedom type of flutter became a possibility.
3. A comparison of the data for the three models of equal thickness showed, for a given spoiler height, a decrease in the Mach number for torsional instability as the maximum ordinate of the airfoil was moved toward the leading edge.
4. When thickness of the airfoil was increased from 8 percent to 12 percent of the wing chord, the Mach number for instability for each spoiler height was significantly reduced.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., Sept. 22, 1954

REFERENCES

1. Strass, H. Kurt, and Marley, Edward T.: Recent Experiences with Flutter Failure of Sweptback, Tapered Wings Having Outboard, Partial-Span Spoiler Controls. NACA RM L53H26, 1953.
2. Lowry, John G.: Data on Spoiler-Type Ailerons. NACA RM L53I24a, 1953.
3. Johnson, Carl G.: Spoiler Flutter Tests in the Wind Tunnel. Wright Air Dev. Center. (Serial) WCNSY-4595-7-4, Mar. 1952.
4. Schwab, R. H., and Fotieo, G.: An Experimental Investigation of the Flutter Characteristics of a Cusp-Type Spoiler. Wright Air Dev. Center. TR 5785, Jan. 1953.
5. Clevenson, Sherman A., and Tomassoni, John E.: Experimental Investigation of the Oscillating Forces and Moments on a Two-Dimensional Wing Equipped with an Oscillating Circular-Arc Spoiler. NACA RM L53K18, 1954.
6. Coe, Charles F., and Mellenthin, Jack A.: Buffeting Forces on Two-Dimensional Airfoils as Affected by Thickness and Thickness Distribution. NACA RM A53K24, 1954.
7. Wyss, John A., and Monfort, James C.: Effects of Airfoil Profile on the Two-Dimensional Flutter Derivatives for Wings Oscillating in Pitch at High Subsonic Speeds. NACA RM A54C24, 1954.
8. Runyan, Harry L., and Watkins, Charles E.: Considerations on the Effect of Wind-Tunnel Walls on Oscillating Air Forces for Two-Dimensional Subsonic Compressible Flow. NACA TN 2552, 1951.
9. Runyan, Harry L., Woolston, Donald S., and Rainey, A. Gerald: A Theoretical and Experimental Study of Wind-Tunnel-Wall Effects on Oscillating Air Forces for Two-Dimensional Subsonic Compressible Flow. NACA RM L52I17a, 1953.
10. Woolston, Donald S., and Runyan, Harry L.: Some Considerations on the Air Forces on a Wing Oscillating Between Two Walls for Subsonic Compressible Flow. IAS Preprint No. 446, 1954.
11. Dietze, F.: The Air Forces of the Harmonically Vibrating Wing in Compressible Medium at Subsonic Velocity (Plane Problem). AAF, Air Mat. Com., Wright Field, Tech. Intelligence. Trans. F-TS-506-RE, Nov. 1946.

12. Dietze, F.: The Air Forces of the Harmonically Vibrating Wing in a Compressible Medium at Subsonic Velocity (Plane Problem). Part II: Numerical Tables and Curves. AAF Air Mat. Com., Wright Field, Tech. Intelligence. Trans. F-TS-948-RE, Mar. 1947.
13. Minhinnick, I. T.: Subsonic Aerodynamic Flutter Derivatives for Wings and Control Surfaces (Compressible and Incompressible Flow). British R.A.E. Structures 87, July 1950.
14. Nelson, Herbert C., and Berman, Julian H.: Calculations on the Forces and Moments for an Oscillating Wing-Aileron Combination in Two-Dimensional Potential Flow at Sonic Speed. NACA Rep. 1128, 1953. (Supersedes NACA TN 2590.)
15. Wyss, John A., and Herrera, Raymond: Effects of Angle of Attack and Airfoil Profile on the Two-Dimensional Flutter Derivatives for Airfoils Oscillating in Pitch at High Subsonic Speeds. NACA RM A54E12, 1954.

TABLE I.- MEASURED FLUTTER DERIVATIVES FOR THE NACA 2-008 AIRFOIL WITH SPOILERS AT THE 70-PERCENT-CHORD STATION ON THE UPPER SURFACE; $\alpha_{fl} = 2^\circ$

| Spoiler height 2-1/2 percent | | | | | | | Spoiler height 1/2 percent | | | | | | |
|------------------------------|-------|----------|-------------------|--------|-------------------|----------|----------------------------|-------|----------|-------------------|--------|-------------------|----------|
| M | k | ω | $\frac{dc_1}{dc}$ | ϕ | $\frac{dc_2}{dc}$ | θ | M | k | ω | $\frac{dc_1}{dc}$ | ϕ | $\frac{dc_2}{dc}$ | θ |
| 0.590 | 0.041 | 28.3 | 6.438 | 350.5 | --- | --- | 0.590 | 0.038 | 26.0 | 6.669 | 351.2 | --- | --- |
| | .079 | 54.2 | 5.801 | 348.0 | --- | --- | | .077 | 52.3 | 5.966 | 351.8 | --- | --- |
| | .111 | 75.9 | 5.929 | 344.5 | --- | --- | | .111 | 75.5 | 5.959 | 352.8 | --- | --- |
| | .154 | 105.4 | 5.408 | 349.1 | --- | --- | | .151 | 102.7 | 5.616 | 351.3 | --- | --- |
| | .186 | 127.7 | 5.339 | 347.9 | --- | --- | | .187 | 126.9 | 5.297 | 355.1 | --- | --- |
| | .226 | 154.8 | 5.195 | 347.4 | --- | --- | | .229 | 155.1 | 5.033 | 349.9 | --- | --- |
| | .340 | 232.7 | 5.032 | 2.8 | --- | --- | | .343 | 232.7 | 5.205 | 2.6 | --- | --- |
| .376 | 257.5 | 6.413 | 6.7 | --- | --- | .370 | 251.3 | 6.169 | 356.9 | --- | --- | | |
| .680 | .068 | 54.3 | 7.338 | 347.0 | 0.612 | 319.2 | .680 | .033 | 26.5 | 6.936 | 356.0 | 0.534 | 347.0 |
| | .096 | 75.9 | 6.787 | 348.0 | --- | --- | | .066 | 52.0 | 6.865 | 352.5 | .608 | 329.1 |
| | .130 | 103.5 | 6.315 | 338.0 | .592 | 315.9 | | .096 | 76.2 | 6.358 | 345.9 | --- | --- |
| | .161 | 128.0 | 5.706 | 344.3 | --- | --- | | .130 | 102.7 | 6.012 | 347.3 | .534 | 312.6 |
| | .193 | 152.9 | 5.512 | 337.0 | .691 | 296.2 | | .161 | 127.4 | 5.347 | 346.3 | --- | --- |
| | .291 | 231.0 | 5.903 | 357.4 | --- | --- | | .196 | 154.8 | 5.253 | 340.8 | .668 | 276.4 |
| | .327 | 259.6 | 7.448 | 348.8 | .950 | 272.5 | | .295 | 232.7 | 5.730 | 359.0 | --- | --- |
| .728 | .034 | 29.1 | 7.999 | 349.2 | .561 | 345.1 | .728 | .029 | 24.5 | 8.094 | 351.9 | .623 | 340.3 |
| | .062 | 53.7 | 7.228 | 344.1 | .819 | 322.9 | | .062 | 52.8 | 7.386 | 345.6 | .706 | 317.4 |
| | .089 | 76.7 | 6.638 | 343.8 | --- | --- | | .088 | 74.9 | 7.067 | 344.9 | --- | --- |
| | .125 | 107.6 | 6.326 | 340.3 | .661 | 311.1 | | .147 | 125.2 | 6.127 | 339.5 | --- | --- |
| | .149 | 128.5 | 5.722 | 338.9 | --- | --- | | .240 | 204.6 | 5.525 | 359.3 | .773 | 287.8 |
| | .246 | 211.6 | 5.321 | 353.8 | .601 | 287.4 | | .270 | 230.2 | 6.224 | 352.2 | --- | --- |
| | .274 | 235.3 | 6.311 | 353.1 | --- | --- | | .303 | 258.6 | 6.519 | 349.4 | 1.087 | 255.4 |
| .787 | .034 | 31.5 | 12.711 | 339.3 | .077 | 134.5 | .787 | .030 | 27.5 | 10.108 | 357.6 | .204 | 347.0 |
| | .056 | 52.5 | 10.645 | 334.9 | .196 | 65.8 | | .056 | 51.5 | 8.755 | 344.9 | .397 | 322.3 |
| | .079 | 73.9 | 8.946 | 329.4 | --- | --- | | .083 | 77.1 | 7.887 | 339.0 | --- | --- |
| | .114 | 106.7 | 7.993 | 323.3 | .446 | 12.2 | | .112 | 103.7 | 7.206 | 331.7 | .903 | 285.9 |
| | .136 | 127.4 | 6.774 | 325.1 | --- | --- | | .138 | 128.5 | 6.423 | 325.1 | --- | --- |
| | .222 | 208.0 | 5.947 | 342.7 | .666 | 319.0 | | .228 | 211.6 | 6.005 | 343.2 | .813 | 273.0 |
| | .253 | 237.1 | 7.021 | 340.2 | --- | --- | | .252 | 233.5 | 6.593 | 347.5 | --- | --- |
| .273 | 255.4 | 7.546 | 341.3 | 1.041 | 290.5 | .282 | 261.8 | 8.648 | 357.8 | 1.310 | 256.0 | | |
| .801 | .026 | 25.3 | 13.428 | 340.2 | --- | --- | .801 | .027 | 26.0 | 13.626 | 343.2 | 1.211 | 149.6 |
| | .052 | 49.8 | 11.347 | 329.0 | --- | --- | | .060 | 56.9 | 11.870 | 324.7 | .787 | 103.0 |
| | .079 | 75.6 | 9.962 | 319.9 | --- | --- | | .082 | 77.7 | 9.945 | 329.7 | --- | --- |
| | .107 | 102.5 | 8.592 | 319.9 | --- | --- | | .109 | 103.7 | 7.838 | 326.2 | .372 | 32.5 |
| | .132 | 126.4 | 6.985 | 312.1 | --- | --- | | .136 | 129.0 | 6.305 | 324.7 | --- | --- |
| | .185 | 177.0 | 5.998 | 330.2 | --- | --- | | .194 | 183.7 | 6.203 | 342.0 | --- | --- |
| | .217 | 207.3 | 5.909 | 328.7 | --- | --- | | .217 | 206.0 | 5.816 | 335.9 | .412 | 301.0 |
| .249 | 238.0 | 6.824 | 333.5 | --- | --- | .249 | 236.2 | 7.557 | 345.6 | --- | --- | | |
| .275 | 262.9 | 8.212 | 327.2 | --- | --- | .270 | 256.5 | 8.706 | 336.4 | 1.150 | 280.0 | | |
| .835 | .030 | 30.2 | 13.928 | 338.5 | 1.014 | 158.6 | .835 | .025 | 25.1 | 16.196 | 333.2 | 2.380 | 156.1 |
| | .054 | 53.9 | 12.350 | 323.5 | .948 | 142.8 | | .053 | 52.4 | 12.022 | 331.3 | 1.846 | 127.5 |
| | .076 | 76.5 | 10.372 | 317.6 | --- | --- | | .076 | 75.5 | 10.286 | 324.2 | --- | --- |
| | .107 | 106.9 | 7.645 | 311.4 | .520 | 117.8 | | .107 | 105.8 | 7.701 | 318.4 | 1.032 | 124.3 |
| | .186 | 185.9 | 5.964 | 331.6 | --- | --- | | .181 | 179.0 | 4.872 | 326.3 | --- | --- |
| | .209 | 209.4 | 6.877 | 330.8 | .086 | 123.1 | | .210 | 208.0 | 5.414 | 339.0 | .126 | 91.8 |
| | .234 | 234.4 | 7.476 | 331.1 | --- | --- | | .232 | 230.2 | 6.728 | 334.6 | --- | --- |
| .258 | 258.6 | 7.855 | 325.0 | .696 | 228.1 | .262 | 259.6 | 7.912 | 329.5 | .358 | 171.0 | | |
| .857 | .027 | 27.5 | 15.798 | 342.8 | --- | --- | .857 | .027 | 27.7 | 14.008 | 340.7 | 2.626 | 142.8 |
| | .051 | 52.7 | 12.563 | 323.8 | --- | --- | | .050 | 50.6 | 11.568 | 325.7 | 2.127 | 143.5 |
| | .073 | 75.3 | 10.644 | 317.7 | --- | --- | | .074 | 76.0 | 9.739 | 318.5 | --- | --- |
| | .102 | 105.4 | 8.696 | 296.8 | --- | --- | | .100 | 102.4 | 6.948 | 310.1 | 1.417 | 115.5 |
| | .150 | 154.4 | 5.680 | 331.0 | --- | --- | | .152 | 155.1 | 4.915 | 324.2 | .952 | 116.7 |
| | .177 | 183.2 | 5.918 | 327.7 | --- | --- | | .177 | 181.1 | 5.989 | 330.2 | --- | --- |
| | .202 | 208.0 | 7.502 | 333.5 | --- | --- | | .197 | 201.4 | 6.113 | 337.9 | .753 | 129.3 |
| .231 | 238.9 | 8.015 | 329.2 | --- | --- | .230 | 235.3 | 6.979 | 331.4 | --- | --- | | |
| .249 | 256.5 | 7.822 | 316.5 | --- | --- | .251 | 256.5 | 7.692 | 325.7 | .963 | 127.6 | | |
| .884 | .026 | 27.5 | 11.499 | 342.8 | 2.062 | 150.6 | .884 | .028 | 29.4 | 9.025 | 357.7 | 2.669 | 165.5 |
| | .049 | 52.5 | 9.413 | 332.9 | 1.706 | 145.6 | | .050 | 52.7 | 8.663 | 338.9 | 2.468 | 141.9 |
| | .071 | 75.4 | 8.178 | 324.2 | --- | --- | | .071 | 74.5 | 7.801 | 336.0 | --- | --- |
| | .095 | 101.3 | 5.676 | 316.4 | .819 | 121.9 | | .100 | 105.1 | 5.401 | 326.7 | 1.191 | 110.4 |
| | .142 | 151.4 | 5.192 | 333.1 | .692 | 114.0 | | .149 | 157.5 | 5.245 | 346.4 | .676 | 139.0 |
| | .170 | 181.1 | 5.327 | 344.5 | --- | --- | | .167 | 176.5 | 5.996 | 341.6 | --- | --- |
| | .196 | 209.4 | 6.948 | 336.9 | .772 | 167.5 | | .197 | 207.3 | 6.653 | 337.3 | .978 | 130.2 |
| .218 | 232.7 | 6.687 | 330.8 | --- | --- | .222 | 234.4 | 6.394 | 334.7 | --- | --- | | |
| .244 | 260.7 | 6.996 | 333.1 | .607 | 162.2 | .247 | 260.7 | 7.008 | 324.0 | .987 | 155.7 | | |

TABLE II.- MEASURED FLUTTER DERIVATIVES FOR THE NACA 65A008 AIRFOIL WITH SPOILERS AT THE 70-PERCENT-CHORD STATION ON THE UPPER SURFACE; $\alpha_m = 2^\circ$

| Spoiler height 2-1/2 percent | | | | | | | Spoiler height 4 percent | | | | | | | | |
|------------------------------|--------|--------|------------------------|--------|------------------------|----------|--------------------------|--------|--------|------------------------|--------|------------------------|----------|-------|-------|
| M | k | w | $\frac{dc_1}{d\alpha}$ | ϕ | $\frac{dc_2}{d\alpha}$ | θ | M | k | w | $\frac{dc_1}{d\alpha}$ | ϕ | $\frac{dc_2}{d\alpha}$ | θ | | |
| 0.590 | 0.029 | 19.4 | 7.217 | 352.0 | --- | --- | 0.590 | 0.090 | 33.2 | 5.816 | 349.9 | --- | --- | | |
| | -0.078 | 53.2 | 6.711 | 352.4 | --- | --- | | -0.081 | 54.3 | 5.900 | 349.7 | --- | --- | | |
| | -1.81 | 82.4 | 5.878 | 351.2 | --- | --- | | -1.118 | 78.7 | 5.607 | 351.0 | --- | --- | | |
| | -1.96 | 105.6 | 5.760 | 349.2 | --- | --- | | -1.199 | 106.1 | 5.337 | 356.4 | --- | --- | | |
| | -1.96 | 133.1 | 5.698 | 351.4 | --- | --- | | -1.195 | 130.6 | 5.228 | 356.7 | --- | --- | | |
| | -2.13 | 157.9 | 5.730 | 351.5 | --- | --- | | -2.239 | 159.5 | 4.932 | 353.1 | --- | --- | | |
| | -2.71 | 183.7 | 5.297 | 347.4 | --- | --- | | -2.273 | 182.7 | 4.834 | 345.0 | --- | --- | | |
| | -3.45 | 234.4 | 5.435 | 343.3 | --- | --- | | -3.351 | 234.4 | 4.822 | 359.0 | --- | --- | | |
| | -3.86 | 261.8 | 7.115 | 354.3 | --- | --- | | -3.387 | 258.6 | 6.286 | 354.0 | --- | --- | | |
| | .680 | 0.030 | 23.2 | 7.789 | 375.1 | 0.4675 | | 349.1 | .680 | 0.041 | 32.2 | 7.398 | 350.9 | --- | --- |
| 0.066 | | 52.1 | 6.907 | 351.2 | -.5796 | 328.5 | 0.070 | 54.7 | | 6.661 | 349.8 | 0.334 | 318.7 | | |
| 0.103 | | 80.7 | 6.758 | 344.0 | --- | --- | -0.105 | 81.5 | | 6.087 | 348.5 | --- | --- | | |
| -0.135 | | 105.8 | 6.905 | 344.3 | -.513 | 315.0 | -0.138 | 107.1 | | 5.925 | 342.4 | -.392 | 307.4 | | |
| -0.170 | | 133.1 | 6.274 | 341.9 | --- | --- | -0.172 | 133.7 | | 5.857 | 338.9 | --- | --- | | |
| -0.202 | | 158.3 | 5.861 | 337.1 | -.602 | 287.9 | -0.205 | 159.1 | | 5.137 | 335.1 | -.940 | 265.2 | | |
| -0.300 | | 235.3 | 6.321 | 358.3 | --- | --- | -0.304 | 236.2 | | 5.653 | 344.0 | --- | --- | | |
| -0.325 | | 255.4 | 6.517 | 349.9 | -.934 | 281.2 | -0.335 | 260.7 | | 6.121 | 353.7 | -.899 | 289.3 | | |
| .728 | | 0.026 | 21.9 | 8.237 | 357.2 | -.900 | 342.2 | .728 | | 0.038 | 32.2 | 7.795 | 349.8 | -.350 | 322.8 |
| | | -0.054 | 53.2 | 7.657 | 348.1 | -.477 | 325.7 | | | -0.066 | 55.5 | 7.123 | 345.3 | -.350 | 318.4 |
| | -0.098 | 81.2 | 6.947 | 343.1 | --- | --- | -0.099 | | 83.1 | 6.806 | 345.3 | --- | --- | | |
| | -0.128 | 106.5 | 6.723 | 343.6 | -.543 | 311.6 | -0.127 | | 106.9 | 6.388 | 345.6 | -.419 | 295.5 | | |
| | -0.158 | 131.4 | 6.254 | 337.3 | --- | --- | -0.157 | | 131.4 | 5.955 | 341.0 | --- | --- | | |
| | -0.250 | 208.7 | 5.502 | 325.0 | -.712 | 291.5 | -0.252 | | 211.6 | 5.652 | 326.0 | -.589 | 280.4 | | |
| | -0.279 | 232.7 | 6.729 | 350.5 | --- | --- | -0.279 | | 234.4 | 6.175 | 355.1 | --- | --- | | |
| | -0.311 | 259.6 | 7.296 | 352.3 | 1.093 | 281.4 | -0.312 | | 261.8 | 7.094 | 353.1 | -.994 | 244.3 | | |
| | .787 | 0.021 | 19.7 | 9.162 | 373.8 | -.643 | 348.8 | | .787 | 0.038 | 34.5 | 8.076 | 356.2 | -.307 | 333.3 |
| | | 0.056 | 51.8 | 8.748 | 346.0 | -.692 | 318.5 | | | -0.058 | 52.8 | 8.128 | 350.6 | -.330 | 302.5 |
| 0.085 | | 78.9 | 7.988 | 340.8 | --- | --- | -0.087 | 79.0 | | 7.749 | 343.8 | --- | --- | | |
| -0.113 | | 104.4 | 7.153 | 339.0 | -.714 | 287.6 | -0.113 | 103.0 | | 6.796 | 333.7 | -.413 | 272.5 | | |
| -0.141 | | 130.4 | 6.853 | 329.4 | --- | --- | -0.147 | 133.6 | | 5.926 | 335.4 | --- | --- | | |
| -0.196 | | 182.6 | 5.834 | 320.9 | --- | --- | -0.206 | 187.6 | | 5.463 | 322.6 | --- | --- | | |
| -0.224 | | 206.6 | 6.156 | 331.8 | -.866 | 294.3 | -0.230 | 209.4 | | 5.454 | 321.5 | -.999 | 264.3 | | |
| -0.251 | | 231.8 | 6.994 | 351.3 | --- | --- | -0.259 | 235.3 | | 6.908 | 353.6 | --- | --- | | |
| -0.278 | | 256.5 | 8.392 | 351.1 | 1.473 | 274.7 | -0.284 | 258.6 | | 8.488 | 353.8 | 1.476 | 250.3 | | |
| .801 | | 0.022 | 21.0 | 10.152 | 372.3 | --- | --- | .801 | | 0.034 | 31.2 | 8.902 | 352.6 | -.195 | 333.8 |
| | 0.056 | 52.7 | 9.560 | 342.0 | --- | --- | -0.056 | | 52.2 | 8.725 | 353.7 | --- | --- | | |
| | 0.085 | 79.9 | 8.677 | 338.6 | --- | --- | -0.086 | | 80.0 | 8.288 | 342.7 | --- | --- | | |
| | -0.111 | 104.7 | 8.124 | 335.0 | --- | --- | -0.113 | | 105.4 | 7.826 | 330.6 | -.406 | 276.4 | | |
| | -0.158 | 136.3 | 6.833 | 331.1 | --- | --- | -0.159 | | 129.5 | 6.094 | 333.0 | --- | --- | | |
| | -0.191 | 180.0 | 6.179 | 342.7 | --- | --- | -0.199 | | 184.8 | 5.717 | 343.6 | --- | --- | | |
| | -0.218 | 205.0 | 6.669 | 350.8 | --- | --- | -0.228 | | 212.2 | 6.005 | 349.0 | -.629 | 260.7 | | |
| | -0.247 | 232.7 | 7.502 | 351.6 | --- | --- | -0.258 | | 239.8 | 8.500 | 351.3 | --- | --- | | |
| | -0.273 | 257.5 | 9.190 | 348.8 | --- | --- | -0.281 | | 261.8 | 9.258 | 344.5 | -.872 | 227.8 | | |
| | .835 | 0.022 | 21.8 | 12.331 | 353.1 | -.341 | 350.7 | | .835 | 0.016 | 15.8 | 10.194 | 354.8 | -.931 | 181.9 |
| 0.051 | | 50.3 | 10.938 | 334.7 | -.167 | 299.3 | -0.053 | 51.1 | | 9.133 | 347.0 | -.424 | 141.0 | | |
| 0.079 | | 77.8 | 9.250 | 328.7 | --- | --- | -0.080 | 77.0 | | 8.464 | 334.9 | --- | --- | | |
| -0.106 | | 104.4 | 7.723 | 324.6 | -.471 | 280.9 | -0.104 | 100.8 | | 7.398 | 327.3 | -.256 | 215.1 | | |
| -0.160 | | 156.7 | 5.092 | 347.4 | -.428 | 300.0 | -0.160 | 155.1 | | 5.432 | 351.4 | --- | --- | | |
| -0.185 | | 181.6 | 5.918 | 341.9 | --- | --- | -0.181 | 175.5 | | 5.335 | 348.8 | --- | --- | | |
| -0.207 | | 202.7 | 6.541 | 353.6 | 1.037 | 289.5 | -0.207 | 200.1 | | 6.790 | 355.1 | -.755 | 267.8 | | |
| -0.234 | | 229.3 | 7.458 | 351.1 | --- | --- | -0.236 | 228.5 | | 7.896 | 345.1 | --- | --- | | |
| -0.259 | | 254.4 | 8.934 | 335.1 | 1.776 | 296.7 | -0.261 | 252.3 | | 8.606 | 345.6 | -.899 | 216.5 | | |
| .897 | | 0.022 | 21.8 | 15.661 | 342.9 | --- | --- | .897 | | 0.033 | 32.5 | 11.298 | 336.2 | 1.656 | 126.4 |
| | 0.053 | 53.5 | 11.770 | 318.7 | --- | --- | -0.077 | | 76.8 | 9.138 | 317.8 | --- | --- | | |
| | 0.079 | 79.9 | 8.267 | 301.7 | --- | --- | -0.104 | | 103.0 | 7.285 | 315.8 | -.624 | 93.6 | | |
| | -0.104 | 104.5 | 6.969 | 310.7 | --- | --- | -0.106 | | 104.8 | 7.041 | 342.7 | -.339 | 139.1 | | |
| | -0.132 | 133.2 | 4.954 | 335.6 | --- | --- | -0.120 | | 128.5 | 6.001 | 347.1 | --- | --- | | |
| | -0.180 | 182.1 | 4.912 | 340.5 | --- | --- | -0.204 | | 202.7 | 7.254 | 346.3 | -.458 | 197.8 | | |
| | -0.201 | 203.3 | 6.645 | 341.1 | --- | --- | -0.232 | | 231.0 | 8.318 | 332.6 | --- | --- | | |
| | -0.229 | 231.0 | 6.868 | 333.1 | --- | --- | -0.253 | | 251.3 | 7.483 | 324.1 | -.821 | 142.5 | | |
| | -0.257 | 259.6 | 7.596 | 333.9 | --- | --- | .884 | | 0.050 | 51.3 | 11.663 | 329.7 | 1.907 | 139.8 | |
| | 0.048 | 49.7 | 12.099 | 320.5 | 2.863 | 124.9 | | | -0.076 | 79.0 | 8.929 | 321.4 | --- | --- | |
| -0.076 | 78.9 | 8.345 | 308.7 | --- | --- | -0.098 | | 101.7 | 6.077 | 304.1 | 1.176 | 94.7 | | | |
| -0.101 | 104.4 | 6.110 | 297.4 | 1.461 | 22.7 | -0.153 | | 158.3 | 5.613 | 335.2 | -.767 | 92.3 | | | |
| -0.152 | 160.7 | 4.273 | 325.7 | -.703 | 41.1 | -0.172 | | 177.5 | 6.269 | 335.7 | --- | --- | | | |
| -0.175 | 181.1 | 5.128 | 330.5 | --- | --- | -0.197 | | 204.0 | 6.695 | 329.3 | -.896 | 128.6 | | | |
| -0.194 | 200.7 | 6.151 | 331.5 | -.249 | 273.9 | -0.228 | | 235.3 | 6.580 | 326.0 | --- | --- | | | |
| -0.224 | 231.8 | 6.331 | 330.7 | --- | --- | -0.245 | | 253.4 | 6.205 | 331.6 | -.241 | 74.9 | | | |
| -0.250 | 258.5 | 5.998 | 324.5 | -.439 | 130.7 | | | | | | | | | | |
| .902 | 0.018 | 18.5 | 11.238 | 346.2 | 2.708 | 178.4 | | | | | | | | | |
| | 0.047 | 49.3 | 9.290 | 320.5 | 2.456 | 118.4 | | | | | | | | | |
| | 0.073 | 76.8 | 7.537 | 321.3 | --- | --- | | | | | | | | | |
| | -0.121 | 127.2 | 4.361 | 334.5 | --- | --- | | | | | | | | | |
| | -0.144 | 150.7 | 4.862 | 346.2 | -.532 | 99.1 | | | | | | | | | |
| | -0.170 | 178.0 | 6.076 | 349.9 | --- | --- | | | | | | | | | |
| | -0.199 | 208.8 | 6.637 | 332.6 | -.450 | 150.7 | | | | | | | | | |
| | -0.216 | 226.8 | 6.019 | 331.9 | --- | --- | | | | | | | | | |
| | -0.242 | 253.3 | 6.282 | 335.5 | -.406 | 150.3 | | | | | | | | | |

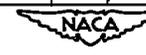


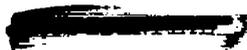
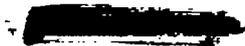
TABLE III.- MEASURED FLUTTER DERIVATIVES FOR THE NACA 877A008 AIRFOIL WITH SPOILERS AT THE 70-PERCENT-CHORD STATION ON THE UPPER SURFACE; $\alpha_m = 2^\circ$

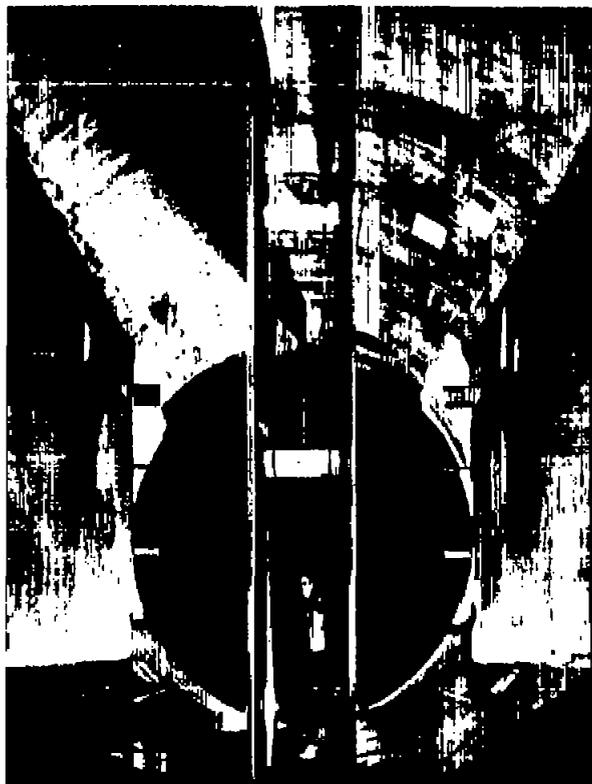
| Spoiler height 2-1/2 percent | | | | | | | Spoiler height 4 percent | | | | | | | |
|------------------------------|-------|----------|------------------------|--------|------------------------|----------|--------------------------|-------|----------|------------------------|--------|------------------------|----------|-------|
| M | k | ω | $\frac{dc_l}{d\alpha}$ | ϕ | $\frac{dc_m}{d\alpha}$ | θ | M | k | ω | $\frac{dc_l}{d\alpha}$ | ϕ | $\frac{dc_m}{d\alpha}$ | θ | |
| 0.596 | 0.043 | 29.5 | 7.035 | 6.2 | --- | --- | 0.596 | 0.046 | 30.8 | 6.240 | 3.1 | --- | --- | |
| | .081 | 55.4 | 6.649 | 0 | --- | --- | | .083 | 56.0 | 6.187 | 354.6 | --- | --- | |
| | .120 | 82.2 | 5.682 | 357.0 | --- | --- | | .122 | 81.6 | 5.897 | 352.2 | --- | --- | |
| | .158 | 108.3 | 5.872 | 352.2 | --- | --- | | .164 | 110.0 | 5.105 | 343.2 | --- | --- | |
| | .194 | 132.8 | 5.401 | 342.6 | --- | --- | | .204 | 136.9 | 4.557 | 345.7 | --- | --- | |
| | .219 | 149.6 | 4.787 | 340.7 | --- | --- | | .226 | 151.7 | 4.422 | 344.5 | --- | --- | |
| | .262 | 179.0 | 4.750 | 340.9 | --- | --- | | .266 | 179.0 | 3.199 | 331.0 | --- | --- | |
| | .366 | 250.3 | 3.988 | 355.5 | --- | --- | | | | | | | | |
| | .386 | 264.0 | 4.086 | 2.9 | --- | --- | | | | | | | | |
| | .693 | .034 | 27.4 | 8.129 | 348.1 | 0.434 | | 324.4 | .693 | .040 | 30.5 | 6.367 | 1.4 | 0.707 |
| .069 | | 55.5 | 8.295 | 347.0 | .463 | 339.8 | .072 | 56.6 | | 6.555 | 353.3 | .651 | 333.2 | |
| .100 | | 79.9 | 6.948 | 337.2 | --- | --- | .106 | 83.9 | | 6.698 | 351.4 | --- | --- | |
| .132 | | 105.8 | 6.506 | 337.0 | .496 | 314.1 | .142 | 111.6 | | 5.864 | 343.7 | .787 | 313.9 | |
| .163 | | 130.4 | 6.174 | 335.5 | --- | --- | .169 | 133.4 | | 5.199 | 332.7 | --- | --- | |
| .189 | | 151.0 | 4.355 | 332.3 | .708 | 293.2 | .195 | 154.0 | | 4.384 | 348.4 | .517 | 324.2 | |
| .261 | | 208.7 | 3.790 | 350.3 | .357 | 293.6 | | | | | | | | |
| .300 | | 239.8 | 4.626 | 333.3 | --- | --- | .745 | .032 | | 27.6 | 7.364 | 352.0 | .308 | 308.8 |
| .324 | | 259.6 | 5.481 | 347.6 | .677 | 285.9 | .066 | 56.4 | | 7.244 | 349.9 | .188 | 268.8 | |
| .745 | | .027 | 23.3 | 8.253 | 352.1 | .396 | 326.1 | .745 | | .097 | 82.6 | 6.296 | 334.2 | --- |
| | .060 | 52.3 | 8.499 | 343.1 | .347 | 314.3 | .127 | | 108.1 | 6.124 | 331.9 | .373 | 259.6 | |
| | .093 | 80.7 | 7.188 | 337.4 | --- | --- | .160 | | 136.6 | 5.324 | 331.7 | --- | --- | |
| | .122 | 105.6 | 6.756 | 337.6 | .505 | 275.7 | | | | | | | | |
| | .152 | 132.0 | 6.761 | 331.8 | --- | --- | .798 | | .031 | 28.5 | 6.851 | 351.5 | .607 | 334.0 |
| | .241 | 209.4 | 4.729 | 342.5 | .406 | 306.3 | .057 | | 52.6 | 6.697 | 345.2 | .693 | 316.9 | |
| | .279 | 242.6 | 5.224 | 341.7 | --- | --- | .089 | | 82.1 | 6.358 | 343.1 | --- | --- | |
| | .298 | 258.6 | 4.918 | 353.0 | .907 | 356.6 | .116 | | 107.2 | 6.126 | 333.7 | .682 | 298.3 | |
| | | | | | | | .151 | | 138.7 | 4.273 | 326.4 | --- | --- | |
| | | | | | | | .200 | | 183.7 | 4.068 | 345.1 | --- | --- | |
| .798 | .028 | 26.1 | 8.672 | 349.8 | .340 | 322.0 | .798 | .055 | 55.2 | 6.227 | 342.3 | .670 | 321.6 | |
| | .059 | 55.5 | 8.353 | 342.0 | .434 | 320.1 | | .081 | 81.2 | 6.138 | 336.1 | --- | --- | |
| | .089 | 83.3 | 7.176 | 336.2 | --- | --- | | .106 | 106.5 | 5.204 | 333.3 | .767 | 264.7 | |
| | .113 | 106.1 | 6.684 | 331.8 | .661 | 317.1 | | .152 | 152.5 | 4.821 | 336.4 | .251 | 276.7 | |
| | .142 | 133.1 | 5.574 | 323.4 | --- | --- | | .186 | 186.4 | 5.327 | 339.4 | --- | --- | |
| | .195 | 182.1 | 3.963 | 339.6 | --- | --- | | | | | | | | |
| | .227 | 212.2 | 3.926 | 336.0 | .360 | 349.6 | | | | | | | | |
| | .258 | 241.6 | 5.099 | 345.1 | --- | --- | | | | | | | | |
| | .283 | 265.1 | 4.983 | 340.1 | .638 | 280.9 | | | | | | | | |
| | .860 | .021 | 21.1 | 7.797 | 7.0 | .624 | | 358.4 | .860 | .083 | 84.2 | 7.140 | 337.4 | --- |
| .055 | | 55.4 | 7.649 | 355.8 | .635 | 318.8 | .105 | 106.9 | | 6.884 | 327.0 | .592 | 295.1 | |
| .105 | | 106.9 | 6.884 | 327.0 | .592 | 295.1 | .152 | 153.6 | | 4.152 | 331.9 | .356 | 216.9 | |
| .152 | | 153.6 | 4.152 | 331.9 | --- | --- | .180 | 182.1 | | 4.022 | 347.3 | --- | --- | |
| .180 | | 182.1 | 4.022 | 347.3 | --- | --- | .203 | 206.0 | | 5.646 | 338.6 | .741 | 275.9 | |
| .203 | | 206.0 | 5.646 | 338.6 | .741 | 275.9 | .237 | 239.8 | | 5.277 | 333.4 | --- | --- | |
| .237 | | 239.8 | 5.277 | 333.4 | --- | --- | .261 | 265.1 | | 4.698 | 325.0 | .307 | 192.4 | |
| .261 | | 265.1 | 4.698 | 325.0 | .307 | 192.4 | | | | | | | | |

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TABLE IV.- MEASURED FLUTTER DERIVATIVES FOR THE NACA 65A012 AIRFOIL WITH SPOILERS AT THE 70-PERCENT-CHORD STATION ON THE UPPER SURFACE; $\alpha_m = 2^\circ$

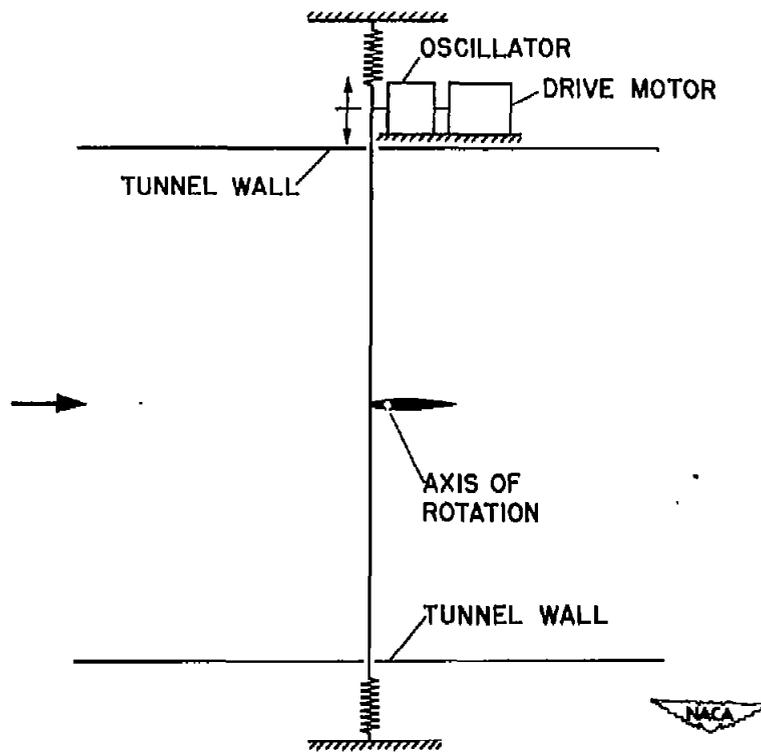
| Spoiler height 2-1/2 percent | | | | | | | Spoiler height 4 percent | | | | | | |
|------------------------------|-------|-------|-----------------------------|-----------|-----------------------------|----------|--------------------------|-------|-------|-----------------------------|-----------|-----------------------------|----------|
| H | k | w | $\frac{d\alpha_1}{d\alpha}$ | φ | $\frac{d\alpha_m}{d\alpha}$ | θ | H | k | w | $\frac{d\alpha_1}{d\alpha}$ | φ | $\frac{d\alpha_m}{d\alpha}$ | θ |
| 0.590 | 0.043 | 29.0 | 6.824 | 1.3 | --- | --- | 0.590 | 0.042 | 28.2 | 6.528 | 3.0 | --- | --- |
| | .073 | 48.9 | 6.806 | 350.0 | --- | --- | | .078 | 52.5 | 6.931 | 357.9 | --- | --- |
| | .113 | 75.5 | 6.322 | 352.1 | --- | --- | | .117 | 78.2 | 6.184 | 351.0 | --- | --- |
| | .153 | 102.5 | 5.765 | 352.1 | --- | --- | | .154 | 103.3 | 5.560 | 359.9 | --- | --- |
| | .189 | 126.7 | 5.603 | 354.2 | --- | --- | | .196 | 131.4 | 5.549 | 356.1 | --- | --- |
| | .231 | 154.4 | 5.265 | 347.5 | --- | --- | | .234 | 157.1 | 5.676 | 347.6 | --- | --- |
| | .340 | 227.6 | 4.572 | 8.4 | --- | --- | | .343 | 230.2 | 5.199 | 8.7 | --- | --- |
| | .380 | 254.4 | 5.181 | 9.3 | --- | --- | | .382 | 256.4 | 5.565 | 12.3 | --- | --- |
| | .682 | .036 | 28.3 | 7.374 | 350.6 | 0.323 | | 326.6 | .682 | .038 | 29.4 | 7.858 | 357.6 |
| .068 | | 52.9 | 7.043 | 354.5 | .391 | 328.7 | .062 | 48.3 | | 7.427 | 351.7 | .262 | 310.2 |
| .100 | | 78.4 | 6.519 | 350.1 | --- | --- | .099 | 77.2 | | 6.665 | 348.5 | --- | --- |
| .132 | | 102.9 | 6.500 | 337.3 | -.502 | 291.4 | .133 | 104.0 | | 6.179 | 345.1 | .445 | 287.0 |
| .166 | | 129.6 | 5.992 | 351.0 | --- | --- | .165 | 129.2 | | 6.040 | 350.0 | --- | --- |
| .197 | | 153.6 | 5.358 | 343.3 | -.561 | 279.5 | .203 | 159.0 | | 5.335 | 337.4 | .469 | 272.9 |
| .294 | | 229.3 | 5.172 | 1.7 | --- | --- | .297 | 231.8 | | 5.575 | 357.7 | --- | --- |
| .330 | | 257.5 | 5.650 | 359.1 | -.694 | 276.4 | .329 | 257.5 | | 5.832 | 359.3 | .858 | 283.5 |
| .731 | | .034 | 28.3 | 8.223 | 2.9 | .329 | 326.0 | .731 | | .034 | 28.3 | 8.640 | 357.4 |
| | .060 | 50.2 | 7.567 | 354.5 | .391 | 311.7 | .061 | | 51.0 | 7.638 | 348.9 | .146 | 11.9 |
| | .092 | 77.2 | 6.189 | 345.5 | --- | --- | .094 | | 78.9 | 6.967 | 341.0 | --- | --- |
| | .124 | 104.4 | 6.380 | 345.9 | .431 | 289.8 | .126 | | 105.9 | 6.470 | 337.9 | .220 | 284.2 |
| | .158 | 133.4 | 5.688 | 344.8 | --- | --- | .155 | | 130.9 | 6.405 | 341.6 | --- | --- |
| | .248 | 208.7 | 5.111 | 333.9 | -.608 | 275.9 | .243 | | 204.6 | 5.278 | 344.7 | .610 | 276.1 |
| | .281 | 237.1 | 5.482 | 356.6 | --- | --- | .274 | | 231.0 | 5.655 | 350.5 | --- | --- |
| | .303 | 255.4 | 5.791 | 355.7 | .873 | 286.8 | .301 | | 253.3 | 5.758 | 355.5 | .831 | 279.8 |
| | .765 | .032 | 28.3 | 8.310 | 359.6 | --- | --- | | .765 | .031 | 27.7 | 9.773 | 353.3 |
| .058 | | 51.1 | 7.731 | 350.0 | --- | --- | .057 | 50.0 | | 8.709 | 344.5 | .216 | 198.1 |
| .088 | | 77.9 | 7.682 | 344.2 | --- | --- | .089 | 78.4 | | 7.736 | 338.8 | --- | --- |
| .117 | | 103.7 | 6.812 | 339.0 | --- | --- | .117 | 103.8 | | 7.071 | 339.3 | .244 | 192.1 |
| .146 | | 129.3 | 5.749 | 328.7 | --- | --- | .145 | 128.7 | | 6.479 | 332.2 | --- | --- |
| .231 | | 204.6 | 5.700 | 350.1 | --- | --- | .230 | 204.0 | | 5.961 | 341.4 | .226 | 238.8 |
| .258 | | 228.5 | 5.888 | 353.4 | --- | --- | .263 | 232.7 | | 6.542 | 348.6 | --- | --- |
| .285 | | 252.3 | 6.164 | 0.3 | --- | --- | .284 | 251.3 | | 6.950 | 354.8 | .931 | 262.8 |
| .790 | | .032 | 29.0 | 9.328 | 347.1 | .292 | 246.0 | .790 | | .027 | 25.1 | 9.530 | 0 |
| | .056 | 51.0 | 8.701 | 346.6 | .359 | 229.3 | .054 | | 49.9 | 8.414 | 345.7 | .668 | 164.1 |
| | .087 | 79.4 | 7.445 | 334.3 | --- | --- | .083 | | 76.6 | 7.356 | 336.2 | --- | --- |
| | .114 | 104.2 | 6.874 | 330.8 | -.362 | 210.1 | .112 | | 102.8 | 6.882 | 330.3 | .514 | 140.3 |
| | .143 | 130.6 | 5.492 | 328.4 | --- | --- | .141 | | 129.5 | 5.455 | 332.3 | --- | --- |
| | .195 | 178.5 | 5.419 | 353.6 | --- | --- | .197 | | 181.0 | 5.485 | 353.9 | --- | --- |
| | .219 | 200.7 | 4.795 | 340.1 | -.399 | 260.5 | .221 | | 202.6 | 5.102 | 344.1 | .144 | 11.6 |
| | .254 | 232.7 | 5.700 | 346.0 | --- | --- | .253 | | 232.7 | 7.066 | 348.0 | --- | --- |
| | .279 | 255.4 | 6.697 | 346.4 | -.779 | 233.2 | .279 | | 252.3 | 8.708 | 348.7 | .421 | 189.4 |
| .802 | .030 | 28.0 | 9.836 | 349.3 | .730 | 196.0 | .802 | .027 | 24.9 | 9.965 | 345.7 | 1.375 | 141.3 |
| | .054 | 50.3 | 9.221 | 337.8 | .871 | 171.8 | | .056 | 52.5 | 9.077 | 337.1 | 1.103 | 128.7 |
| | .083 | 77.7 | 8.483 | 325.9 | --- | --- | | .086 | 80.3 | 8.279 | 330.7 | --- | --- |
| | .109 | 101.7 | 7.641 | 322.6 | -.623 | 157.3 | | .113 | 105.6 | 7.894 | 333.4 | .591 | 112.1 |
| | .140 | 130.6 | 5.625 | 315.6 | --- | --- | | .140 | 130.9 | 6.545 | 332.4 | --- | --- |
| | .194 | 181.1 | 5.676 | 338.8 | --- | --- | | .195 | 182.1 | 6.009 | 345.1 | --- | --- |
| | .218 | 203.3 | 4.761 | 349.6 | -.956 | 332.2 | | .214 | 199.4 | 6.152 | 338.9 | .228 | 305.0 |
| | .247 | 230.2 | 6.917 | 340.3 | --- | --- | | | | | | | |
| | .267 | 249.3 | 7.967 | 352.5 | 1.318 | 290.5 | | | | | | | |
| .837 | .026 | 25.5 | 12.336 | 335.3 | 2.448 | 156.0 | .837 | | | | | | |
| | .053 | 51.4 | 9.849 | 318.2 | 2.234 | 118.8 | | | | | | | |
| | .078 | 76.3 | 7.197 | 310.6 | --- | --- | | | | | | | |
| | .105 | 102.7 | 7.320 | 311.0 | 2.026 | 95.4 | | | | | | | |
| | .189 | 184.8 | 4.022 | 336.6 | --- | --- | | | | | | | |
| | .206 | 201.4 | 4.995 | 339.3 | -.163 | 286.4 | | | | | | | |
| | .237 | 231.8 | 6.141 | 336.1 | --- | --- | | | | | | | |
| | .269 | 262.7 | 5.767 | 335.9 | .456 | 199.5 | | | | | | | |
| | .857 | .027 | 27.5 | 10.125 | 343.5 | 1.645 | | 160.9 | .857 | | | | |
| .051 | | 51.1 | 7.283 | 333.3 | .407 | 153.2 | | | | | | | |
| .077 | | 77.8 | 6.147 | 324.5 | --- | --- | | | | | | | |
| .101 | | 101.7 | 4.833 | 328.8 | -.390 | 80.6 | | | | | | | |
| .154 | | 155.1 | 4.187 | 344.8 | .463 | 6.7 | | | | | | | |
| .179 | | 179.5 | 3.906 | 357.4 | --- | --- | | | | | | | |
| .206 | | 207.3 | 5.410 | 355.4 | -.633 | 299.1 | | | | | | | |
| .232 | | 233.5 | 5.521 | 350.7 | --- | --- | | | | | | | |
| .259 | | 260.7 | 5.400 | 347.5 | 1.082 | 307.5 | | | | | | | |





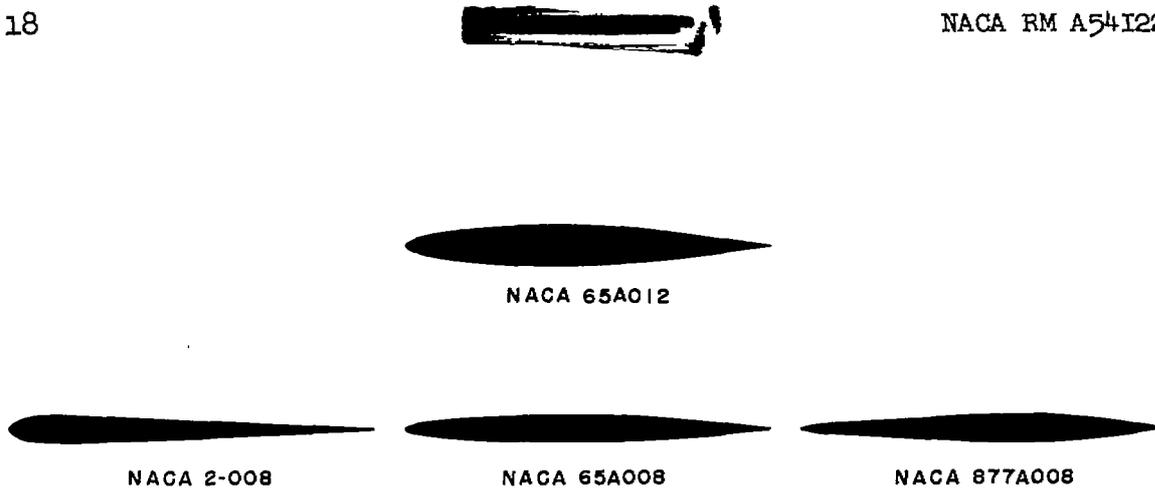
A-14566

(a) Downstream view.



(b) Drive system.

Figure 1.- View of test section with model in place, and diagrammatic sketch of drive system.

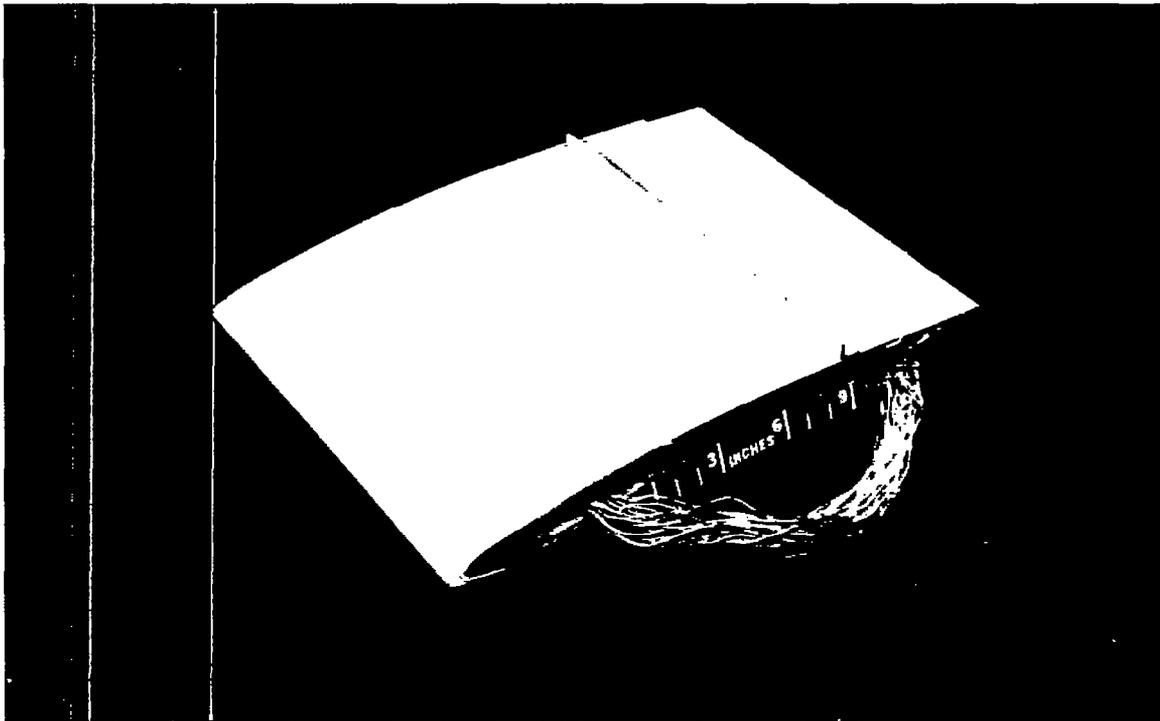


MODEL PRESSURE-CELL LOCATIONS
[In percent of model chord]

| Cell no. upper and lower surface | 65A012 and 65A008 | 2-008 and 877A008 |
|---|-------------------------|-------------------------|
| 1 | 1.25 | 1.25 |
| 2 | 3.75 | 3.75 |
| 3 | 7.5 | 7.5 |
| 4 | 15 | 15 |
| 5 | 22.5 | 22.5 |
| 6 | 27.5 | 27.5 |
| 7 | 35 | 35 |
| 8 | 45 | 45 |
| 9 | 52.5 | 52.5 |
| 10 | 57.5 | 57.5 |
| 11 | 62.5 | 62.5 |
| 12 | 67.5 | 67.5 |
| 13 | 75 | 75 |
| 14 | 85 | 85 |
| 15 | 95 | 90 |



Figure 2.- Section profiles and pressure-cell locations of models.



A-19114.1

Figure 3.- NACA 65A012 airfoil with spoiler mounted at the 70-percent-chord station.

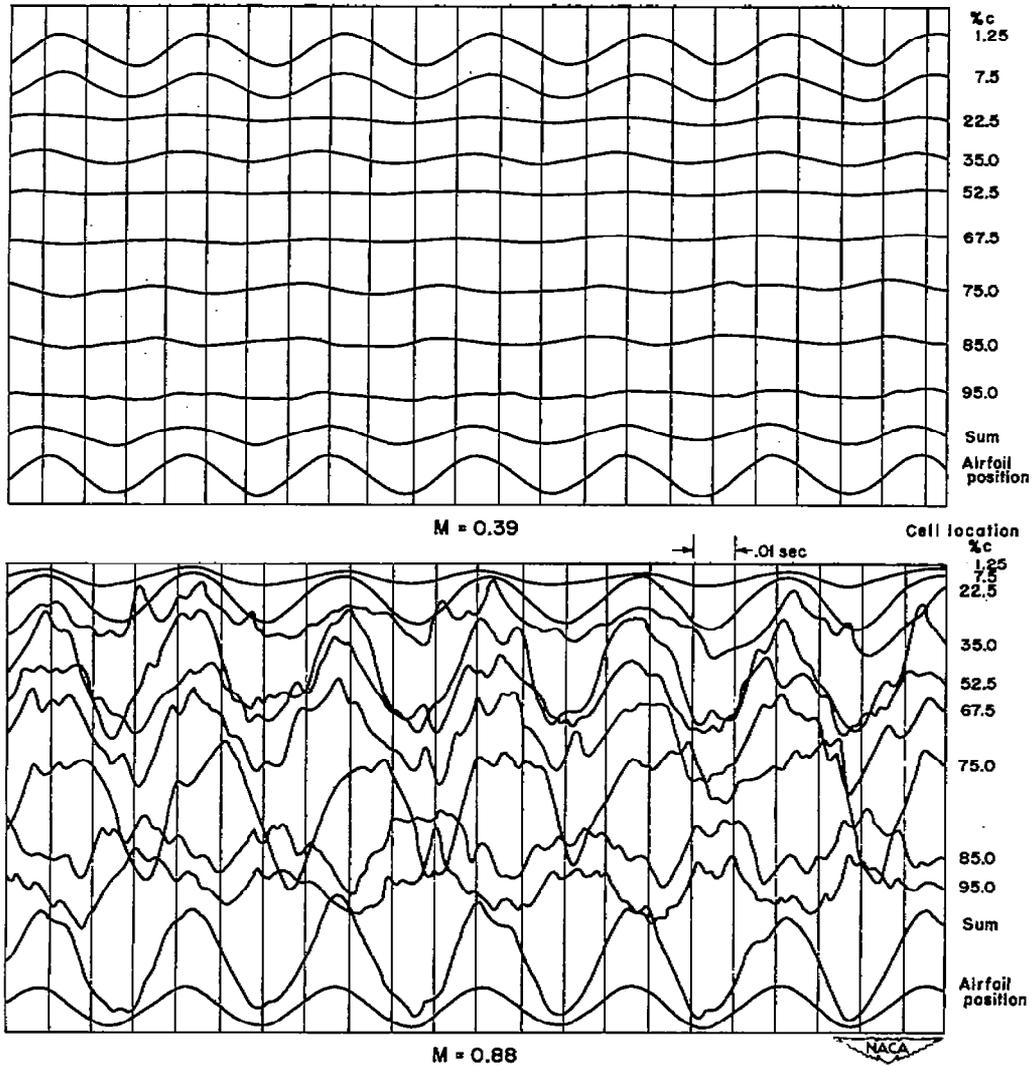


Figure 4.- Sample Oscillograms for the NACA 2-008 airfoil.

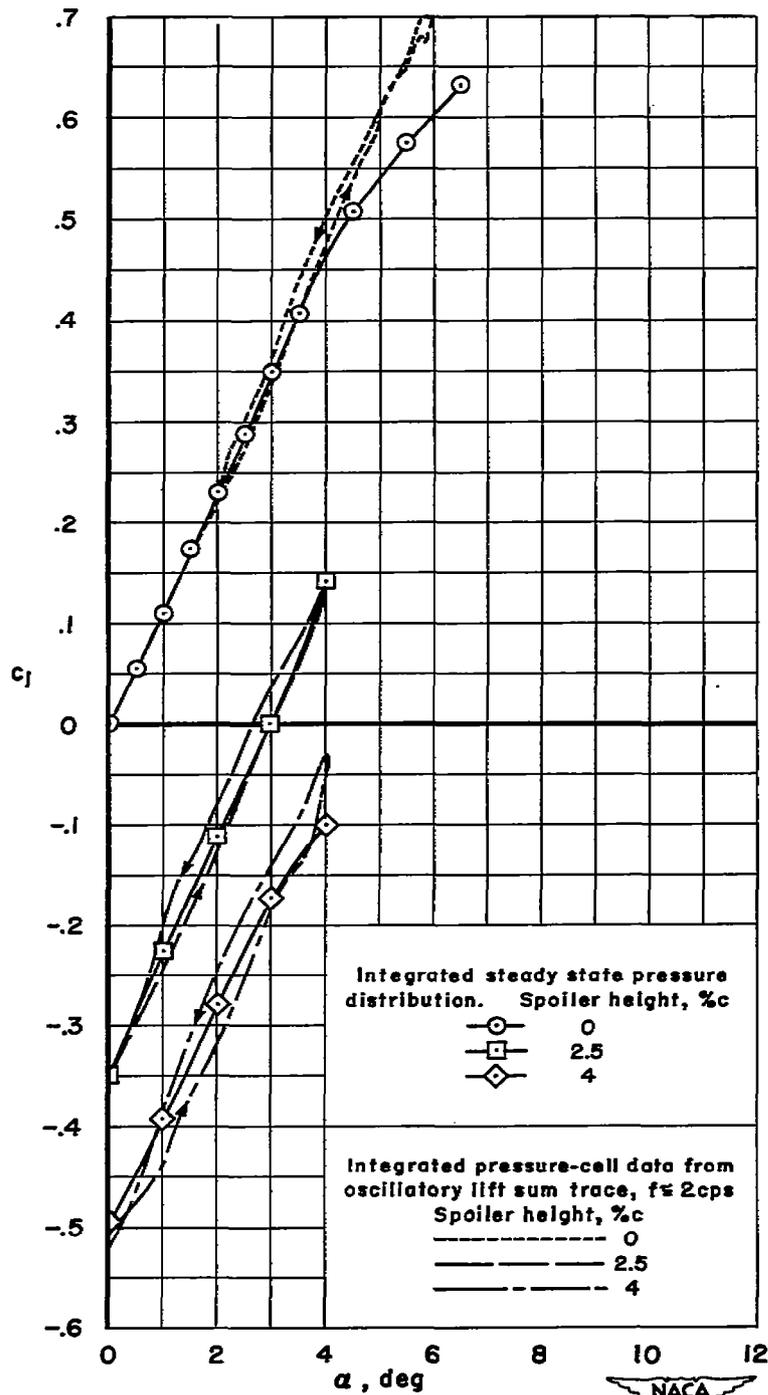


Figure 5.- Effect of spoiler deflection on the aerodynamic lift characteristics of the NACA 65A008 airfoil; $M = 0.59$.

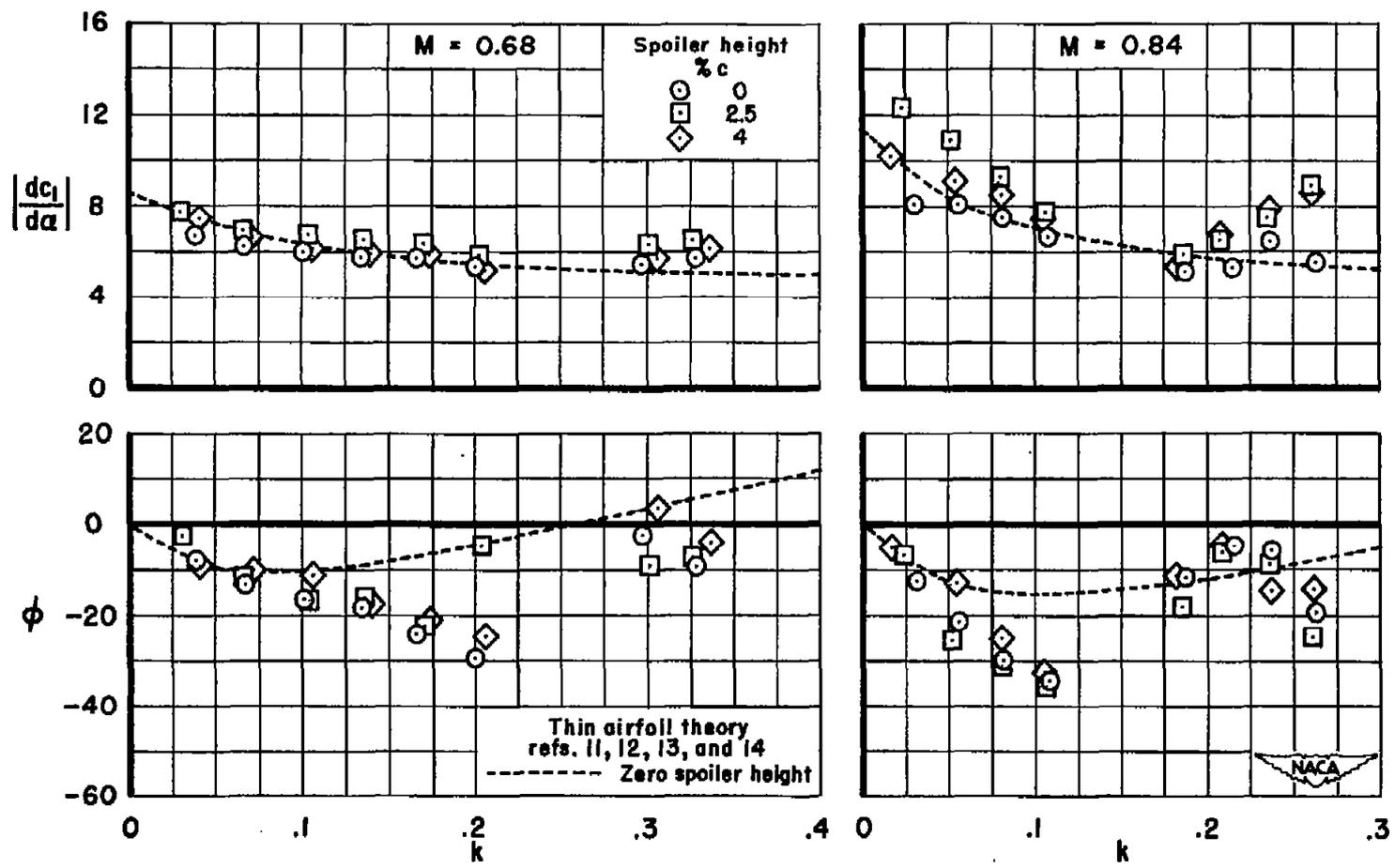


Figure 6.- Lift flutter derivative and phase angle as a function of reduced frequency for two Mach numbers for the NACA 65A008 airfoil; $\alpha_m = 2^\circ$.

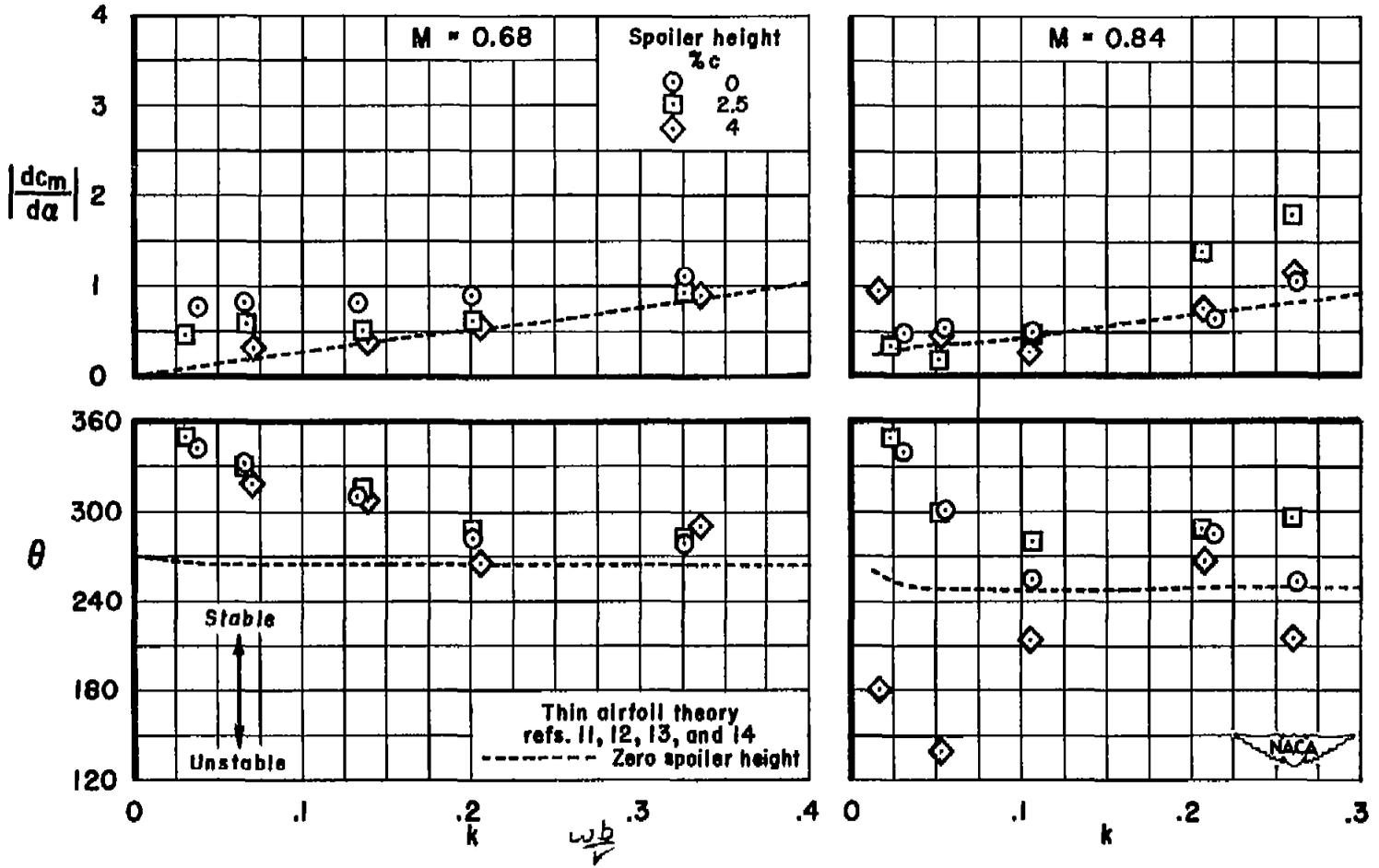


Figure 7.- Moment flutter derivative and phase angle as a function of reduced frequency for two Mach numbers for the NACA 65A008 airfoil; $\alpha_m = 2^\circ$.

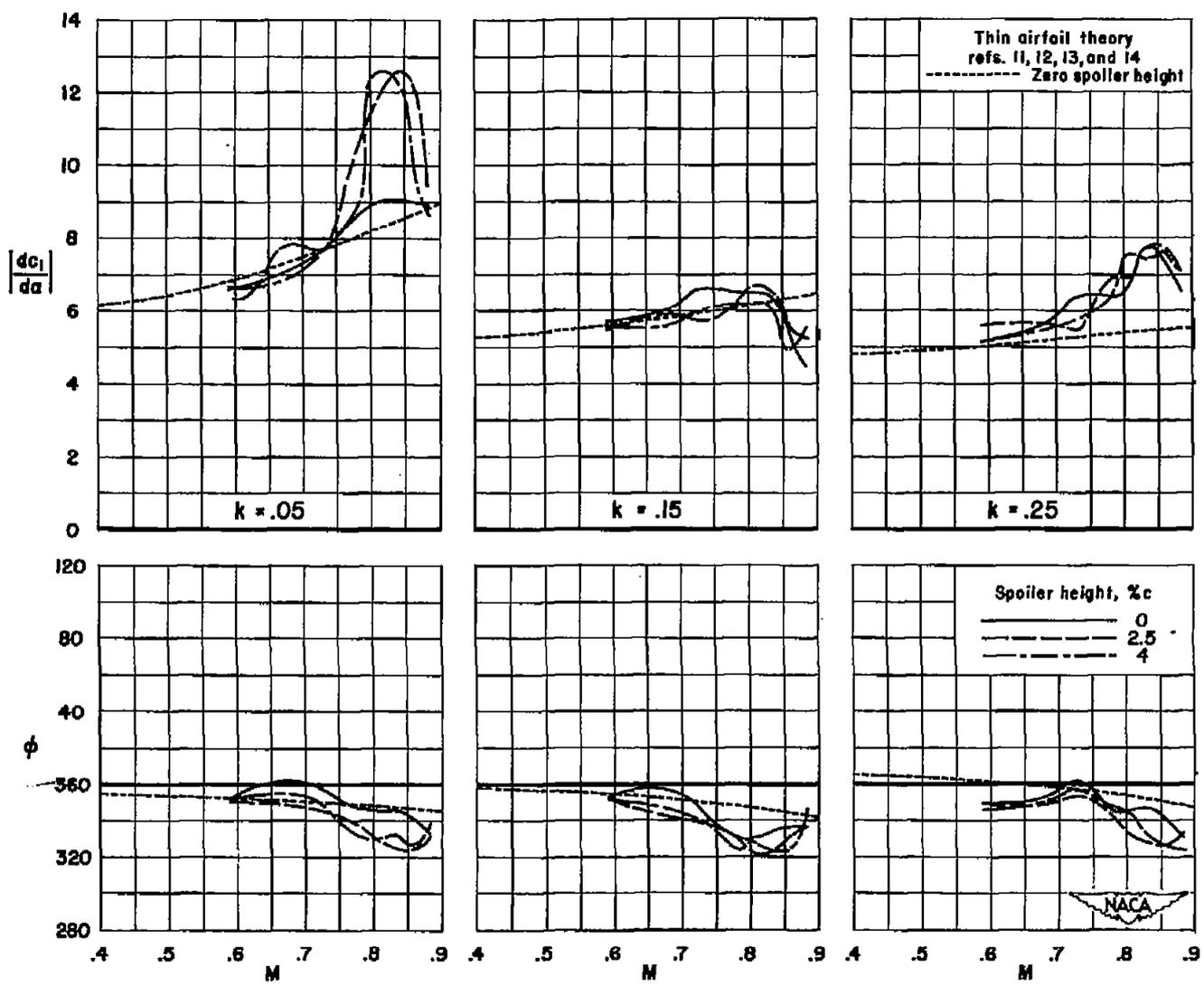


Figure 8.- Effect of fixed spoiler deflections on the lift flutter derivative and phase angle for the NACA 2-008 airfoil; $\alpha_m = 2^\circ$.

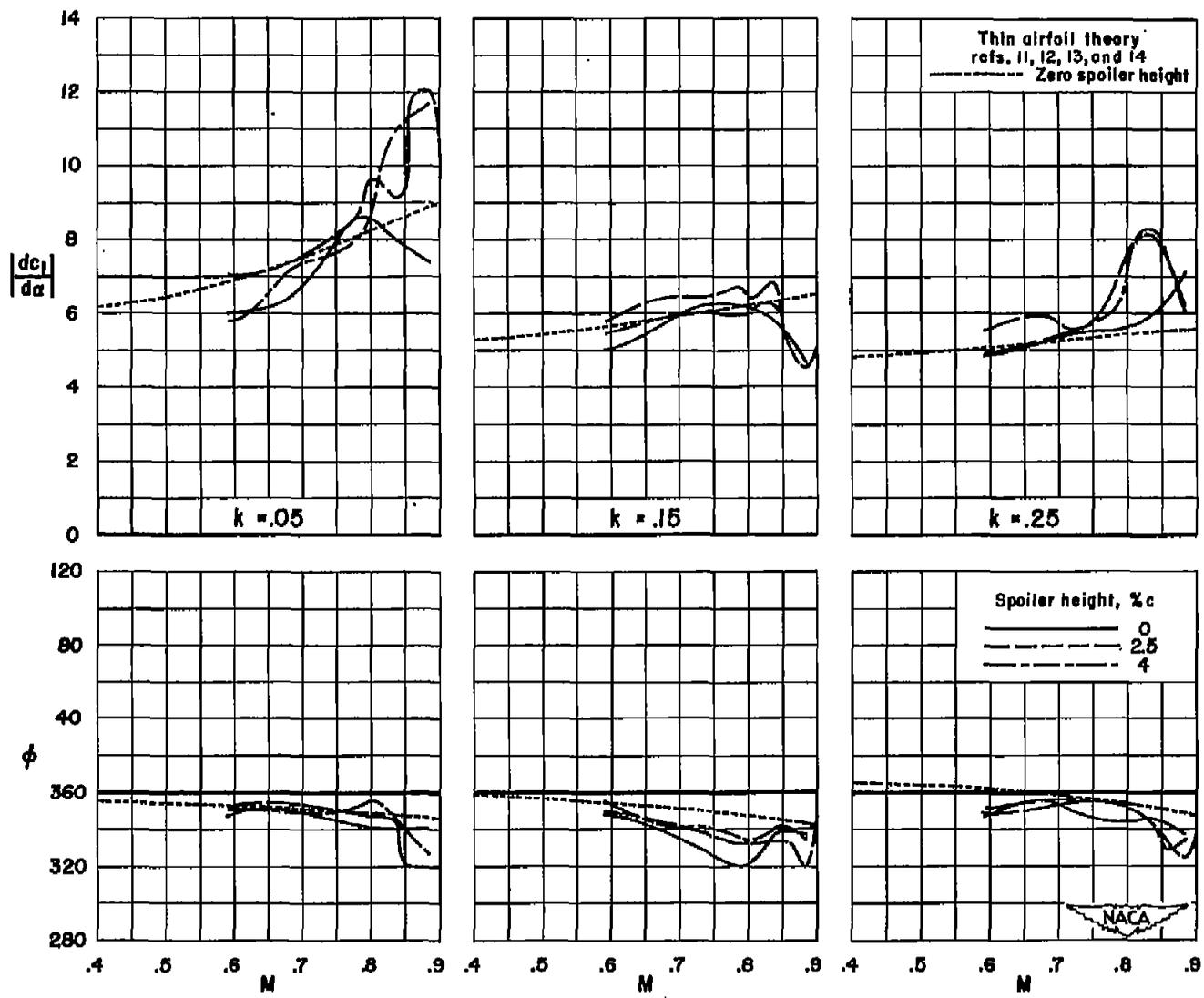


Figure 9.- Effect of fixed spoiler deflections on the lift flutter derivative and phase angle for the NACA 65A008 airfoil; $\alpha_m = 2^\circ$.

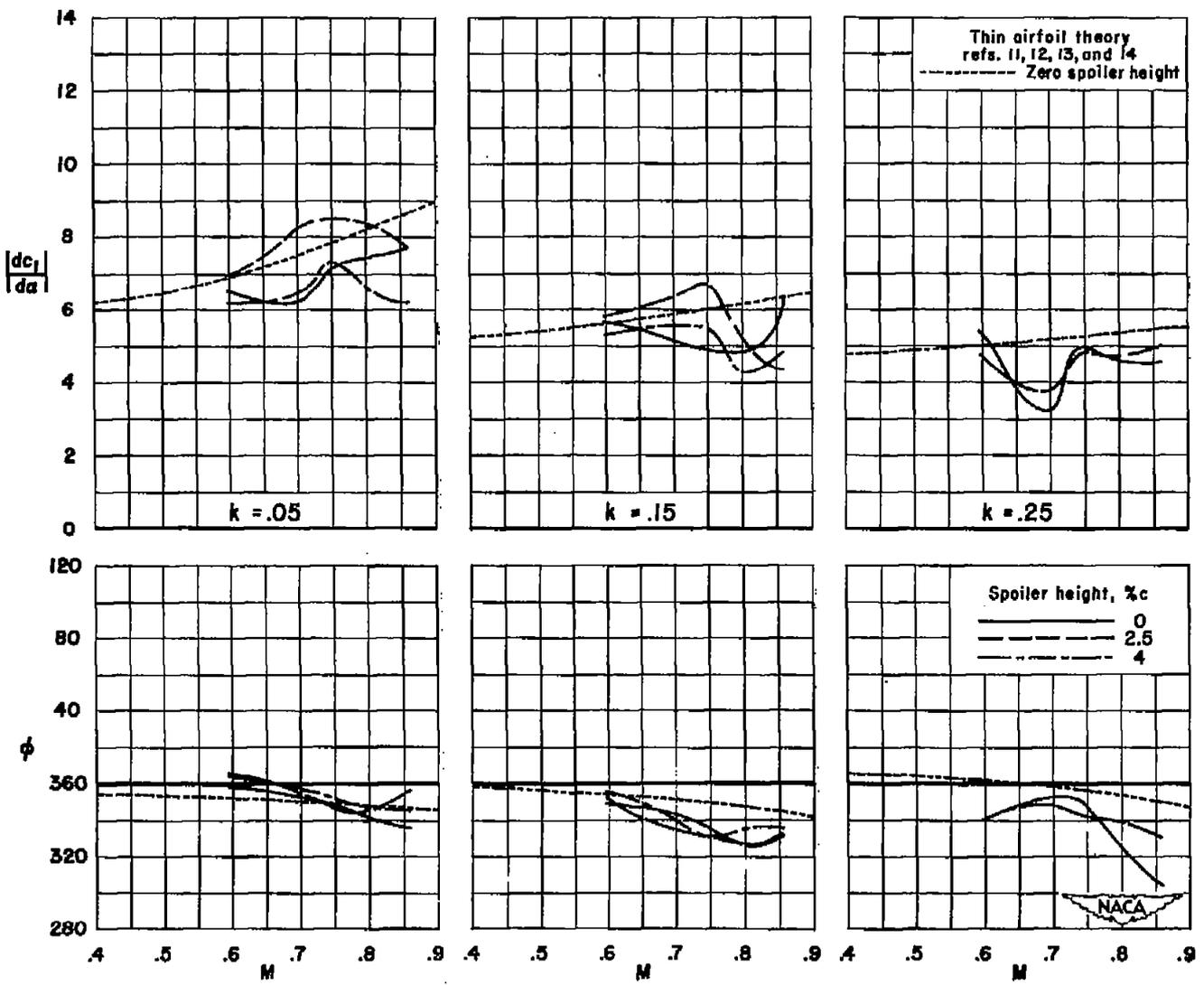


Figure 10.- Effect of fixed spoiler deflections on the lift flutter derivative and phase angle for the NACA 877A008 airfoil, $\alpha_m = 2^\circ$.

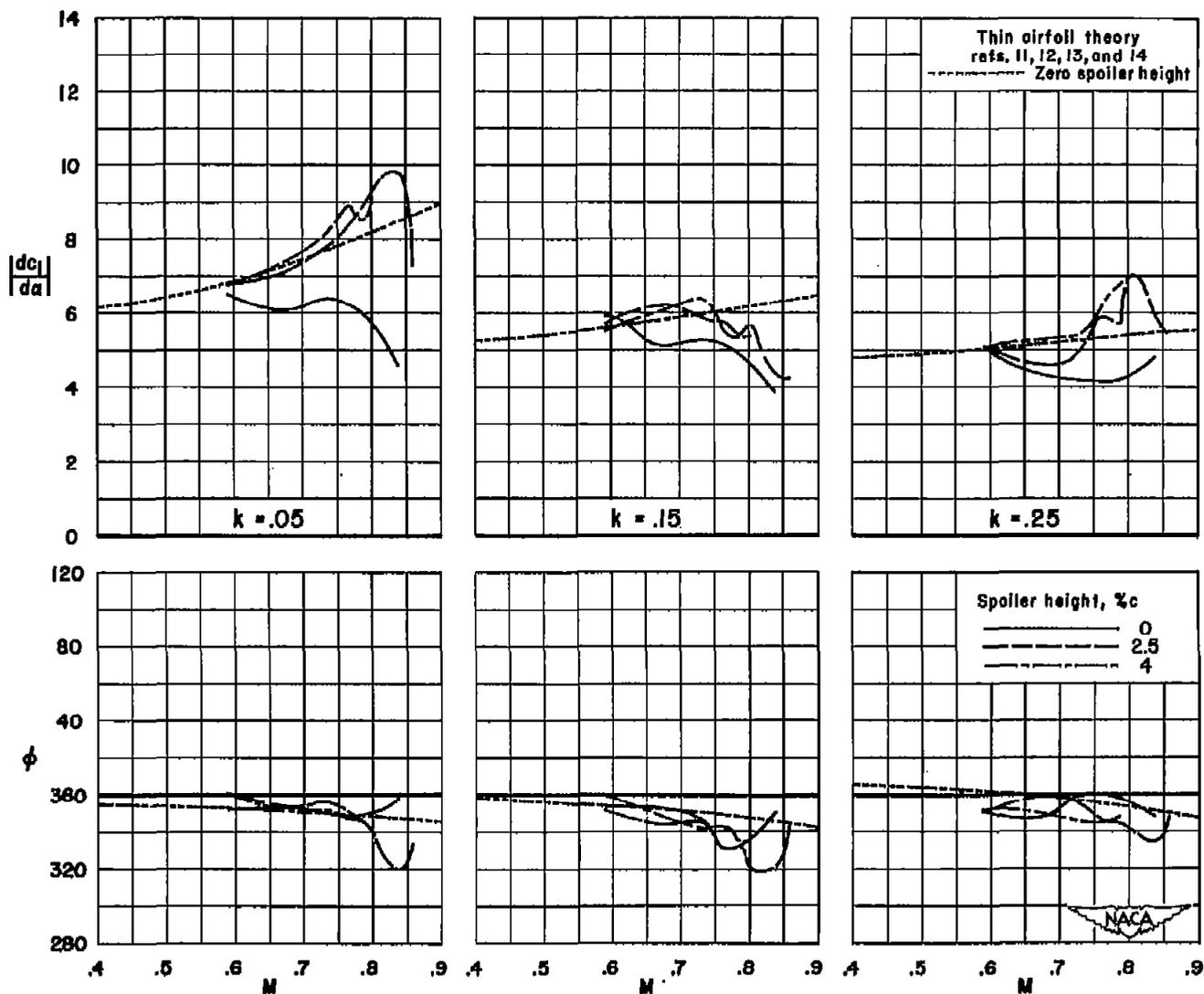


Figure 11:- Effect of fixed spoiler deflections on the lift flutter derivative and phase angle for the NACA 65A012 airfoil; $\alpha_m = 2^\circ$.

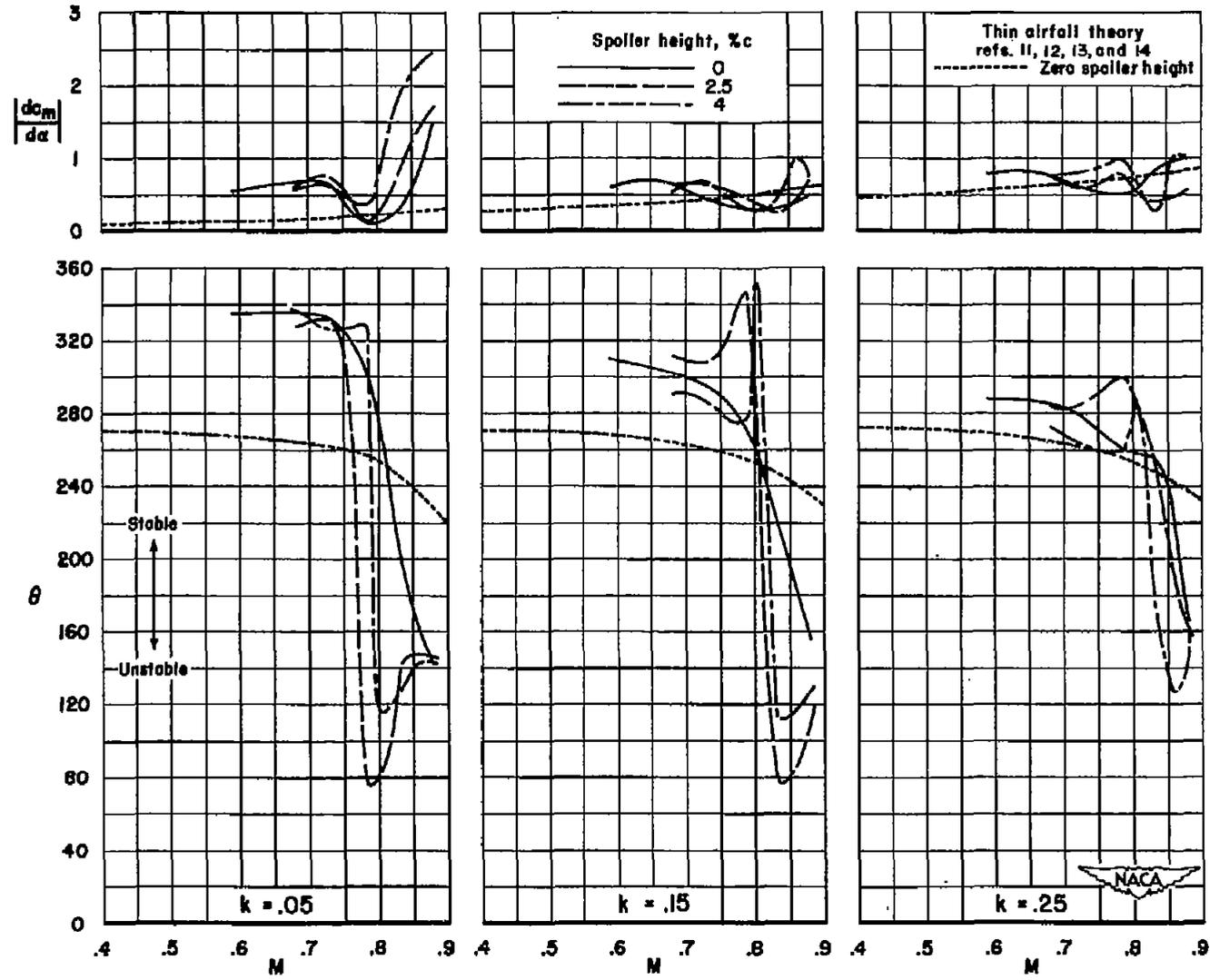


Figure 12.- Effect of fixed spoiler deflections on the moment flutter derivative and phase angle for the NACA 2-008 airfoil; $\alpha_m = 2^\circ$.

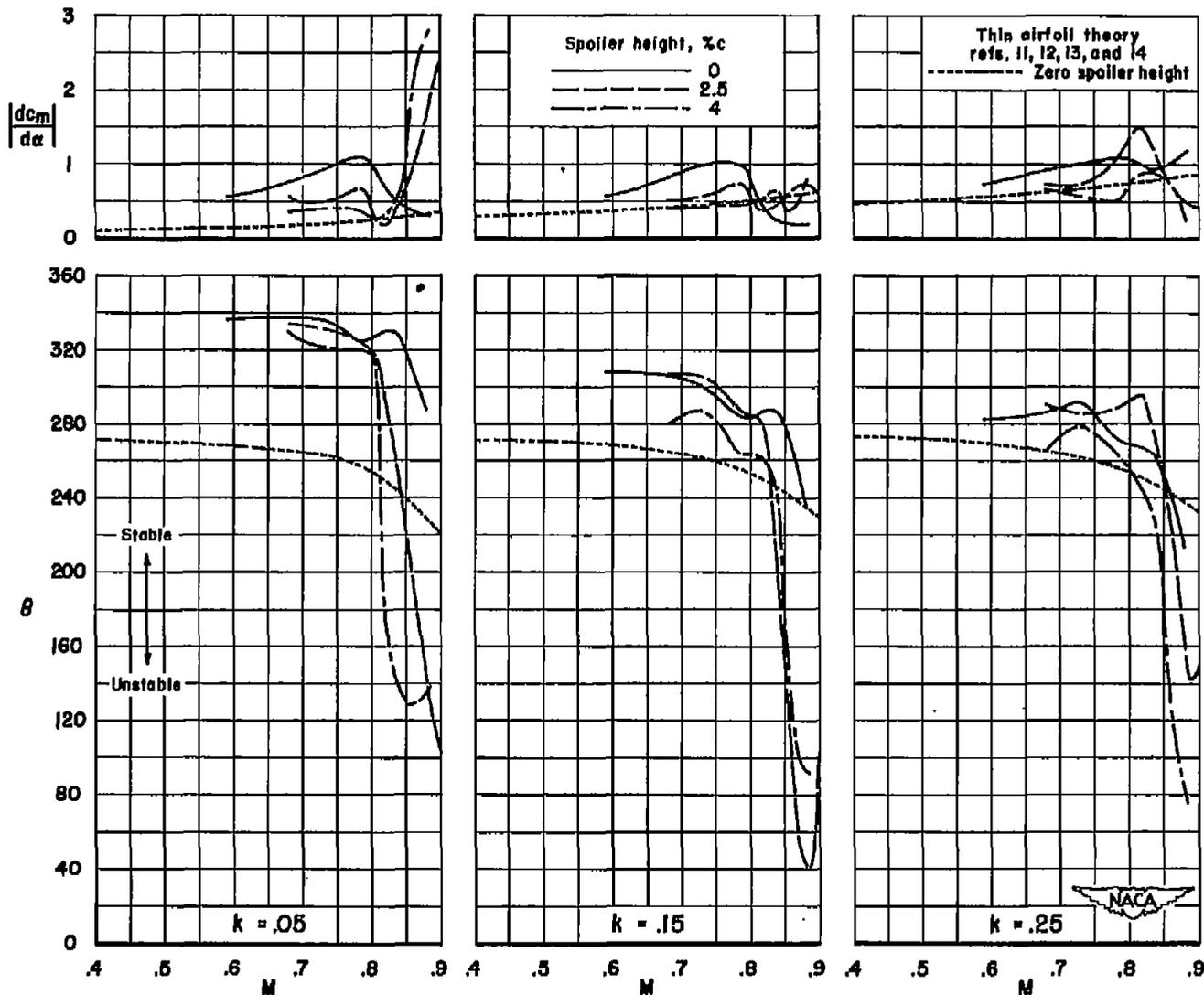


Figure 13.- Effect of fixed spoiler deflections on the moment flutter derivative and phase angle for the NACA 65A008 airfoil, $\alpha_m = 2^\circ$.

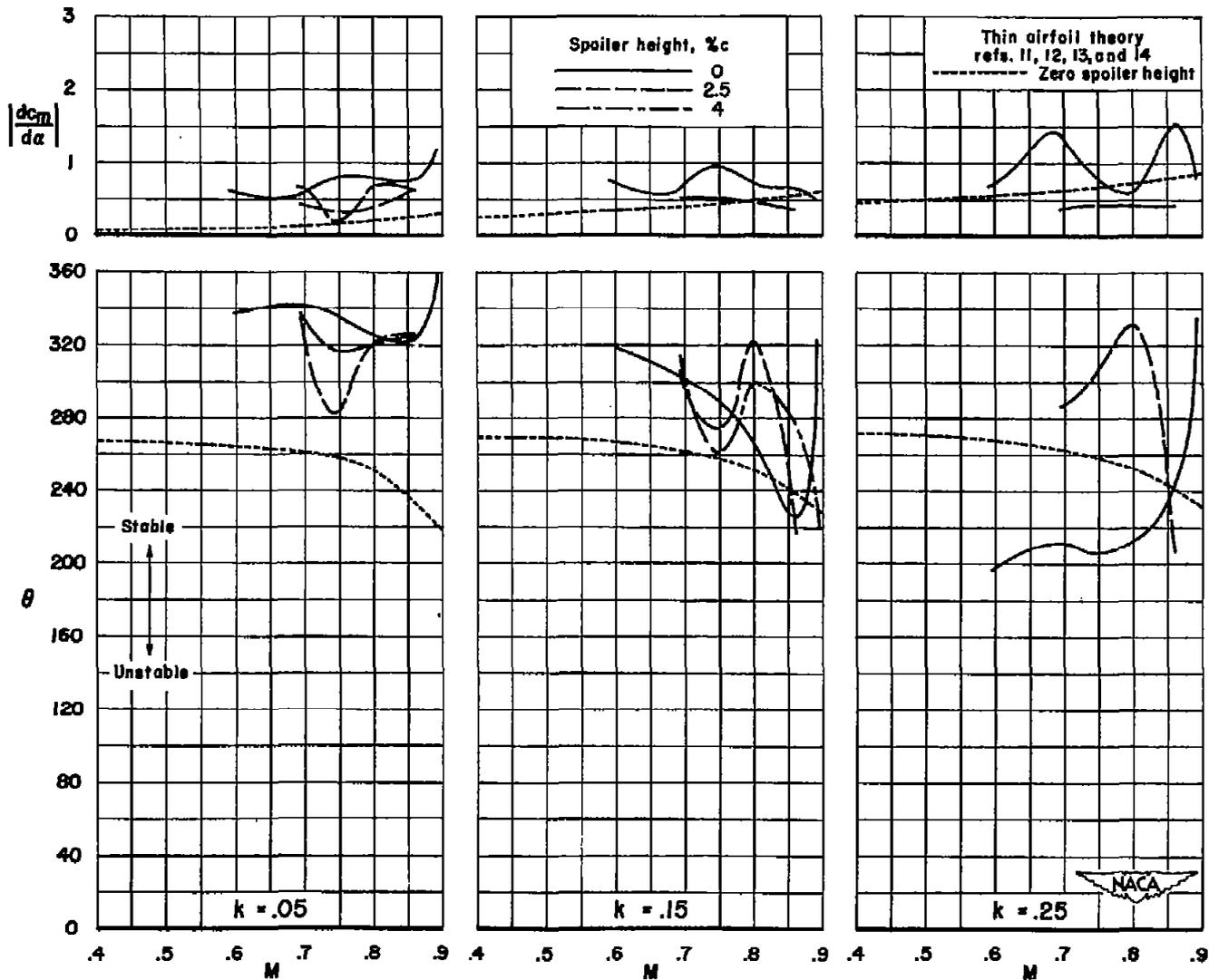


Figure 14.- Effect of fixed spoiler deflections on the moment flutter derivative and phase angle for the NACA 877A008 airfoil, $\alpha_m = 2^\circ$.

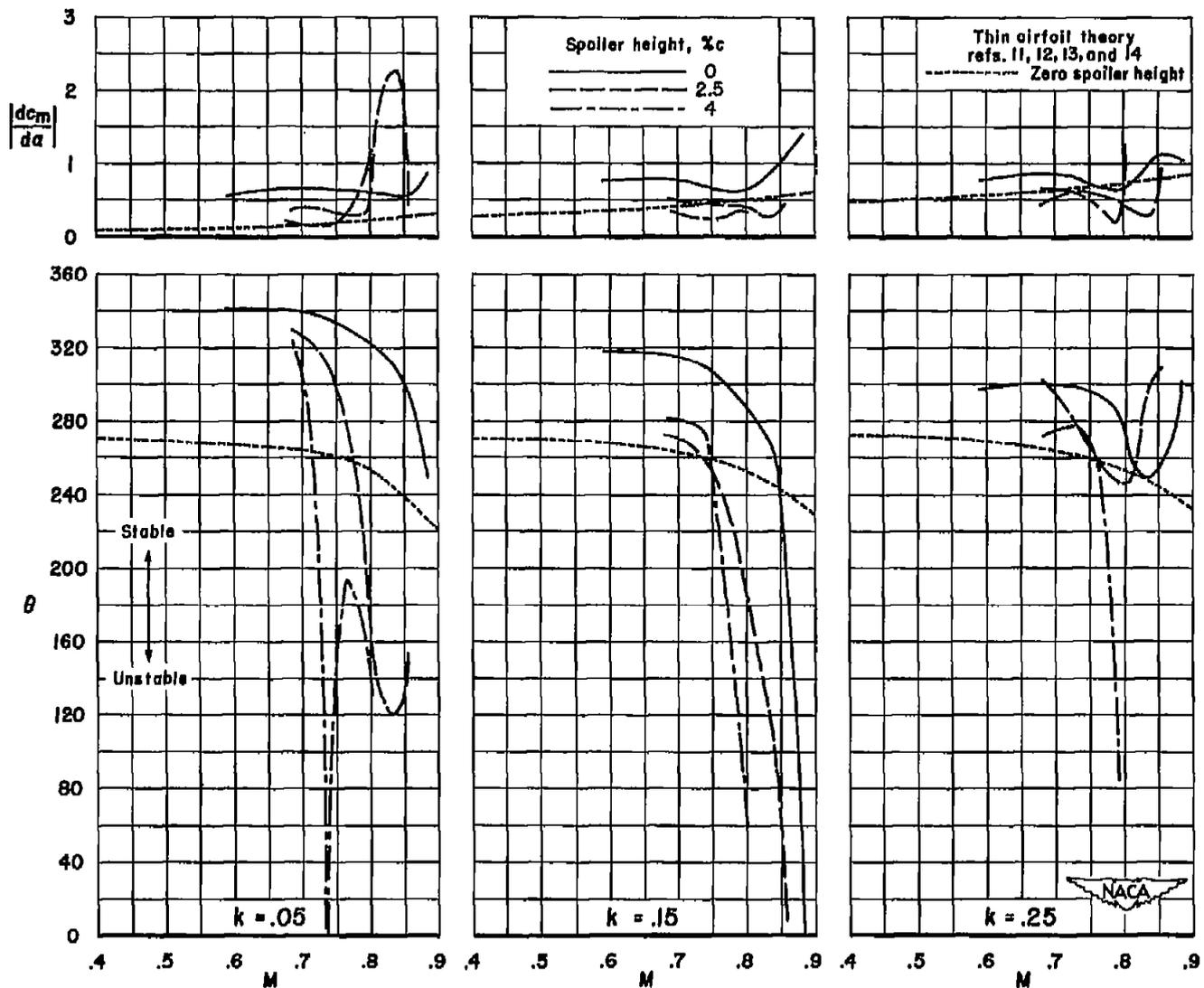


Figure 15.- Effect of fixed spoiler deflections on the moment flutter derivative and phase angle for the NACA 65A012 airfoil; $\alpha_m = 2^\circ$.

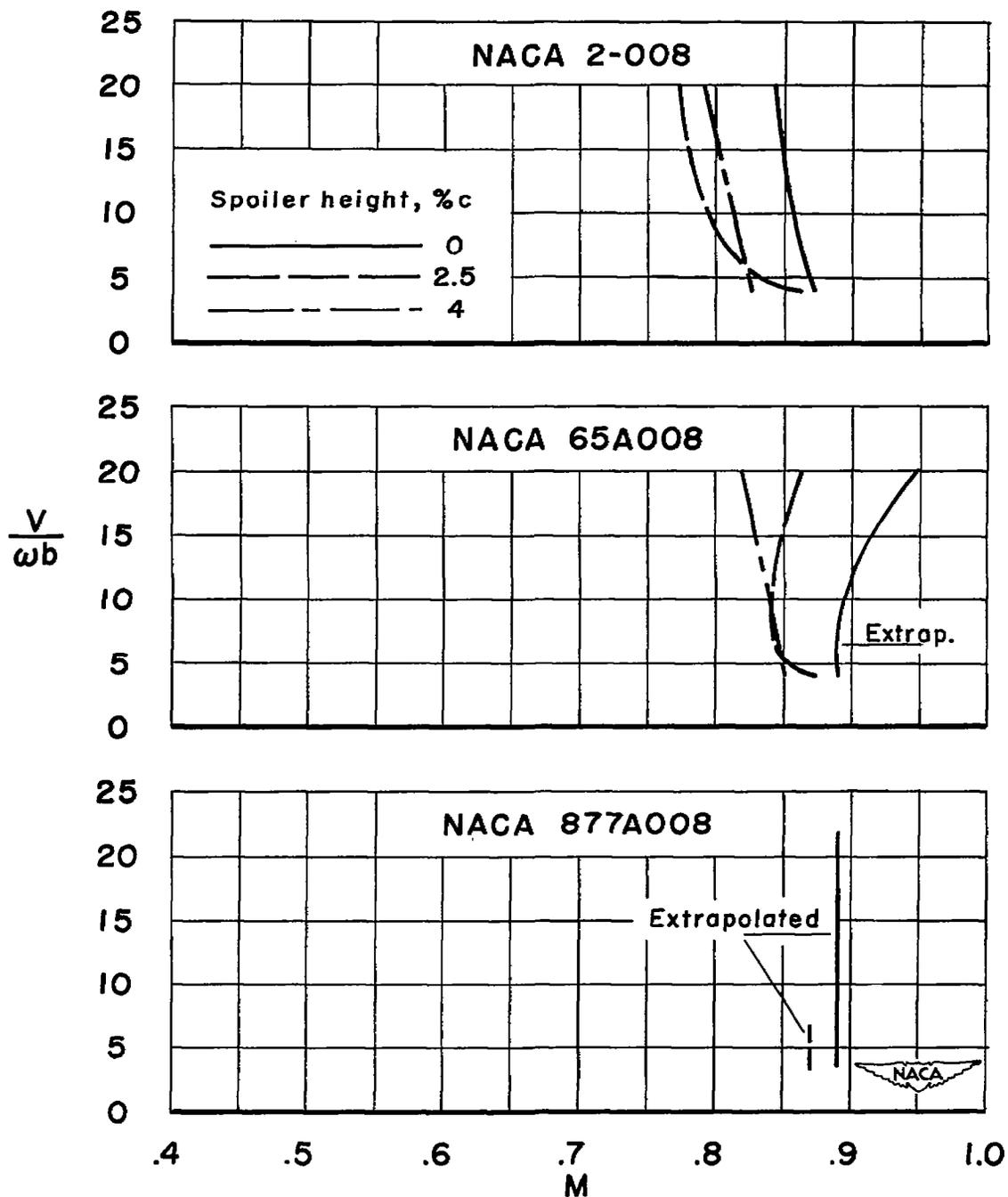


Figure 16.- Aerodynamic torsional instability boundaries as affected by airfoil thickness distribution; $\alpha_m = 2^\circ$.

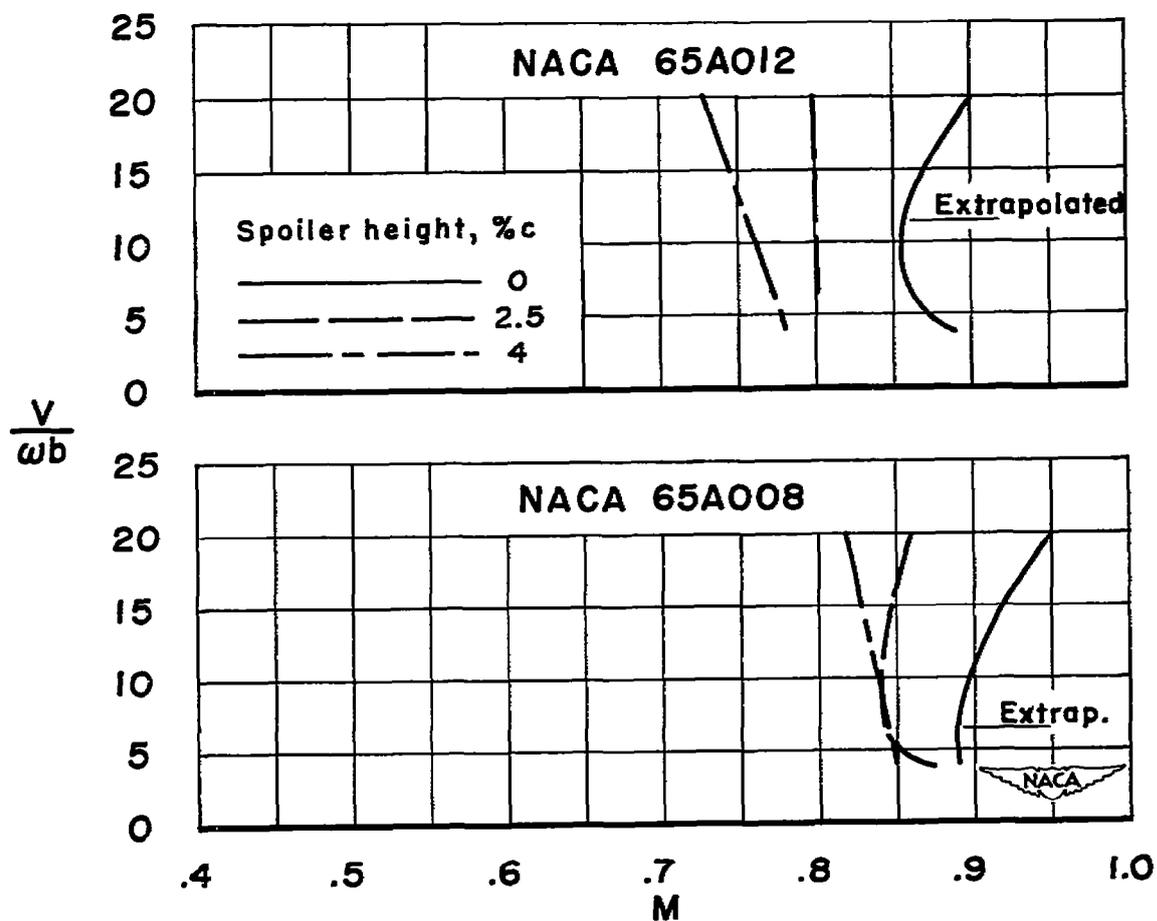


Figure 17.- Aerodynamic torsional instability boundaries as affected by airfoil thickness; $\alpha_m = 2^\circ$.



3 1176 01434 7703

