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RESEARCH MEMORANDUM

QUALITATIVE MEASUREMENTS OF RELATIVE FLAP EFFECTIVENESS

AT TRANSONIC SPEEDS ON A SERIES OF FIVE THIN AIRFOILS

WITH 25-PERCENT-CHORD FLAPS AND VARIOUS

AMOUNTS OF SWEEPBACK

By

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NATIONAL ADVISORY COMMITTEE
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QUALITATIVE MEASUREMENTS OF RELATIVE FLAP EFFECTIVENESS AT TRANSONIC SPEEDS ON A SERIES OF FIVE THIN AIRFOILS WITH 25-PERCENT-CHORD FLAPS AND VARIOUS AMOUNTS OF SWEEPBACK

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SUMMARY

A series of five flat plate models of aspect ratio 2.0 with 25-percent-mean-aerodynamic-chord flaps have been tested at Mach numbers from 0.5 to 1.1 to gain information on the effect of sweepback on flap effectiveness. The fixed portion of each model had flat parallel sides with a thickness of 3 percent based on the average chord and an elliptical nose. The flaps, which tapered to a fine edge, were also flat-sided.

Relative flap effectiveness was determined qualitatively from the change in floating angle of freely pivoted airfoil models caused by fixed changes in flap deflection. An unswept model had the highest flap effectiveness at subsonic speeds. The most highly swept model (45° at leading and trailing edges) had the smallest variation of flap effectiveness and the lowest effectiveness throughout the speed range. Other models with 45° sweptback leading edges and various amounts of trailing-edge sweep less than 45° had flap-effectiveness characteristics between the extremes already mentioned. In no case did the flap effectiveness fall off to zero or reverse and there was less difference between the effectiveness characteristics of the models tested than had been measured in previous tests of swept and unswept models of greater thickness and higher aspect ratio. Also, there was no large dip (decrease followed by recovery) in the effectiveness curves near a Mach number of 1. Supplementary tests on the model having 45° sweep at the leading and trailing edges with only the outer half of the flap deflected showed that the half-span flap had slightly over 40 percent the effectiveness of the full-span flap.

Some variation in Reynolds number was obtained in the tests, for example, at $M = 0.8$ the Reynolds number ranged from 700,000 to 1,500,000. Over this range flap effectiveness decreased noticeably with increasing Reynolds number for all the models tested.

INTRODUCTION

Investigations conducted on various airfoil models in the transonic speed range have shown that there is in many cases a large variation of control effectiveness with Mach number. Tests reported in reference 1 indicate that an airfoil of rectangular plan form with a plain flap was subject to a large loss in control effectiveness at speeds near sonic; whereas tests discussed in reference 2 indicate that an airfoil of extreme sweepback and low aspect ratio with a sweptback trailing-edge flap maintained substantially constant control effectiveness through the transonic speed range. In order to obtain more information on the effects of Mach number on control effectiveness, tests have been conducted on five airfoil models having an aspect ratio of 2.0. Of these models, one was unswept and the others had 45° sweepback at the leading edge and -30°, 0°, 30°, and 45° sweepback of the flap hinge line and the trailing edge. All the models had the same span and area and had a full-span flap with a chord equal to 25 percent of the mean aerodynamic chord. The fixed portion of each model had flat parallel sides with a thickness of 3 percent based on the average chord and had an elliptical nose. The flaps which tapered to a fine edge were also flat-sided.

The tests were run by the wing-flow method, which is described in reference 1. As a measure of control effectiveness, the variation with Mach number of the floating angle of each model about a pivot approximately 5 inches ahead of the center of the model for several flap settings was determined. The flap deflections tested were in the range from -2° to 7.5° and the test Mach number range was approximately 0.5 to 1.1. It was possible to obtain some variation in Reynolds number independent of Mach number by making runs at several altitudes. The test range of Reynolds numbers was from 500,000 to 1,600,000.

Supplementary tests were made on the model which had 45° sweepback of the leading-edge, trailing-edge, and hinge line in which only the outer half of the flap was deflected. The purpose of these tests was to obtain an indication of how much the flap effectiveness on a sweptback airfoil surface varied with spanwise flap position.

APPARATUS AND TESTS

The investigation was made using the method of testing small models in the high-speed flow over an airplane wing (reference 1). A modified ammunition door on the wing of a P-51D airplane was used to mount the test apparatus.

Drawings and photographs of the airfoil models and the test apparatus are presented in figures 1 to 4. The models were made of $\frac{1}{8}$-inch flat steel plate. The airfoil sections were of uniform thickness back to the flap hinge line with elliptical noses. The quarter-chord flaps tapered in thickness from $\frac{1}{8}$ inch at the leading edge to a thin trailing edge. The junctures between the flaps and the fixed portions of the models were formed by semicircular grooves approximately $\frac{1}{32}$-inch deep and $\frac{1}{16}$-inch wide cut in both sides of the plates. Setting of the flaps at a desired angle was effected by bending the plates at these grooves. It has been calculated that changes in flap deflection in flight due to aerodynamic loads were negligible. An end plate, curved to follow the contour of the airplane wing, was attached to each model along the root chord. The end plates were 4 inches across and either round or elliptical depending on the chord of the model. There was approximately $\frac{1}{8}$-inch clearance between the end plate and the test panel. The models were supported on shanks, which passed through a slot in the ammunition-compartment door and were attached to a position recorder. The models were free to float at the angle of attack for zero pitching moment about the pivot axis on an arm approximately 5 inches in length.

In these tests, the change in floating angle of a model due to a change in flap setting was measured as an indication of relative flap effectiveness. Because of the finite length of the pivot arm and the moment about the aerodynamic center caused by flap deflection, the values of relative flap effectiveness obtained are higher than the true values. However, the drag acting on the model produces a restoring tendency which tends to offset this effect. In addition, the floating angles obtained are affected by any movement of aerodynamic center position. The change in floating angles with flap deflection as measured in these tests, however, represents the effectiveness of the flap in changing the angle of attack of a similar airfoil in free flight with the center of gravity at the same relative location as the pivot in the model tests.

The direction of local air flow was determined by means of a wedge-shaped free-floating vane which was located on the airplane wing approximately 20 inches outboard of the model. The spacing of the vane and model was such that the mutual interference was believed to have been negligible. The method of mounting the vane and of recording its angular position was the same as for the model. The difference between the direction of flow at the vane location and at the model location had been determined prior to the model tests through the use of a second vane mounted at the model location.

The local Mach number was determined from pressure-distribution data which had been taken at the test section before model or vane was installed. Pressure gradients chordwise and spanwise and perpendicular to the airplane wing were measured at the model station. Typical plots of chordwise and vertical Mach number gradients are presented in figure 5. The spanwise gradient was negligible. The effective local Mach number for a given flight Mach number and lift coefficient was taken as the mean for the area of the model. Both chordwise and vertical flow gradients were considered.

Tests were run first with the flaps set at 0° in order to eliminate errors due to incidence or twist of models or vanes. The flap deflections usually tested were approximately 0°, 3°, and 6°. Because of the method of setting flap deflections, no effort was made to obtain exactly these angles. However, the actual deflections were measured to within $\pm 0.1^{\circ}$. For each flap deflection three runs were made: a dive from 28,000 feet to an airplane Mach number of 0.73, a dive from 18,000 feet to $M = 0.68$ and a run at 5000 feet where the Mach number was decreased from $M = 0.64$. The Reynolds numbers based on average chord in the stream direction ranged from a minimum of 500,000 to a maximum of 1,600,000. A plot showing test Reynolds numbers is presented in figure 6. The three curves correspond to the three runs discussed above and are labeled circles, squares, and diamonds to identify the corresponding data in figures 7 to 11.

PRESENTATION OF DATA

Presented in figures 7 to 11 are plots of floating angle against Mach number for each model tested. The values of flap deflection given in figures 7 to 11 were measured in a plane perpendicular to the hinge line. Figure 12 contains comparative plots of the values obtained for the change in floating angle produced by a 6° increment of flap deflection. The measured data are compared on the basis of equal amounts of deflection with the angle measured in a plane perpendicular to the hinge axis and with the angle measured in a plane parallel to the air flow. Also with these two conventions for measurement of deflection, the data are compared after being corrected in proportion to the differences in the ratio of flap area to total area. This correction is based on the assumption that flap effectiveness varies linearly with the ratio of flap area to total area. The errors introduced by this assumption are small but of unknown magnitude. The data of figure 12 were obtained from the low Reynolds number runs which extended to the highest value of Mach number.

Figure 13 contains plots of floating angle against Mach number for the model which was swept back 45° at leading edge and trailing edge with only the outboard half of the flap deflected. Figure 14 presents a comparison of the change in floating angle due to a 6° change in flap deflection for the half-span and full-span flaps.

DISCUSSION OF RESULTS

Because of the low Reynolds number range covered and other limitations of the test procedure, it is believed that the data presented herein are of value only for establishing trends. A discussion of the data presented in figures 7 to 14 follows.

The unswept model had the highest flap effectiveness at low speeds but was subject to the greatest loss in effectiveness due to compressibility effects. The model which was swept back 45° at leading and trailing edges had the smallest change in flap effectiveness with Mach number, but had the lowest flap effectiveness throughout the speed range. The other models tested fell between these extremes.

In no case did the flap effectiveness reverse or fall off to zero. In the present tests no extreme difference between the flap effectiveness of the swept and unswept models was noted. Previous tests of airfoil models having thicker sections and higher aspect ratios have shown somewhat greater difference in the flap effectiveness of swept and unswept models at high Mach numbers.

Comparison of the data for the 3-percent-thick unswept floating model with that obtained in reference 3 for an airfoil having a similar plan form and a NACA 65-009 section showed considerably different flap-effectiveness characteristics near a Mach number of 1.0. The 9-percent-thick airfoil was subject to an abrupt loss of 30 or 40 percent in flap effectiveness at a Mach number of 0.9. Most of this loss was regained by a Mach number of 0.98. There was no such dip in the effectiveness curve for the flap on the 3-percent-thick unswept model which was used in the present tests.

The effectiveness of the outboard half-span flap on the model having 45° sweep at leading and trailing edges was slightly over 40 percent as great as the effectiveness of the full-span flap.

Over the range of Reynolds number covered, for example, from 700,000 to 1,500,000 at $M = 0.8$, flap effectiveness decreased noticeably with increasing Reynolds number.

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REFERENCES

1. Gilruth, R. R., and Wetmore, J. W.: Preliminary Tests of Several Airfoil Models in the Transonic Speed Range. NACA ACR No. L5E08, 1945.

2. Daum, Fred L., and Sawyer, Richard H.: Tests at Transonic Speeds of the Effectiveness of a Swept-Back Trailing-Edge Flap on an Airfoil Having Parallel Flat Surfaces, Extreme Sweepback, and Low Aspect Ratio. NACA CB No. L5H01, 1945.

3. Sandahl, Carl A.: Free-Flight Investigation of Control Effectiveness of Full Span, 0.2-Chord Plain Ailerons at High Subsonic, Transonic, and Supersonic Speeds to Determine Some Effects of Wing Sweepback, Taper, Aspect Ratio, and Section Thickness Ratio. NACA RM No. L7F30, 1947.

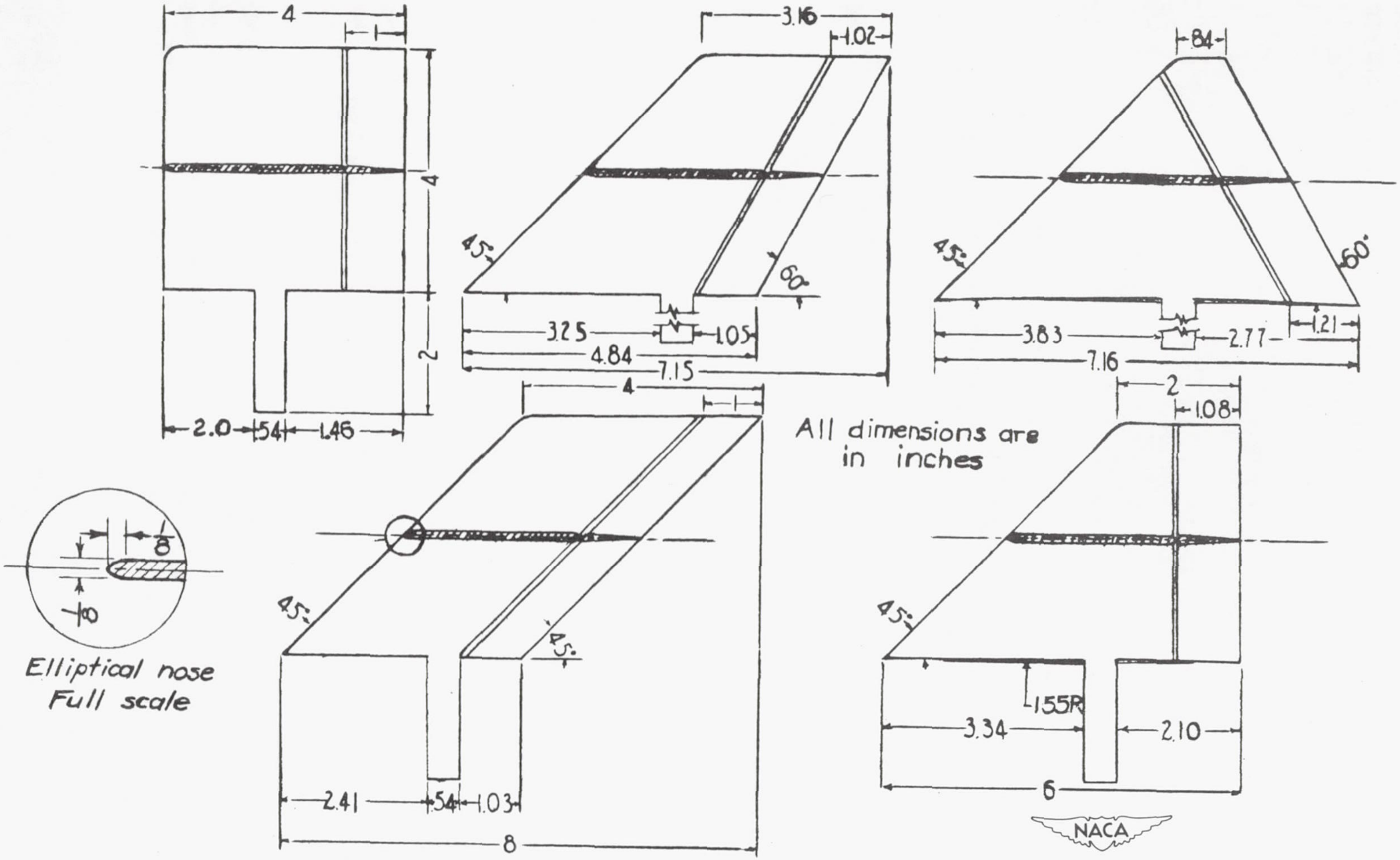

Figure 1.- Drawing of the series of five airfoils used for flap effectiveness investigation.

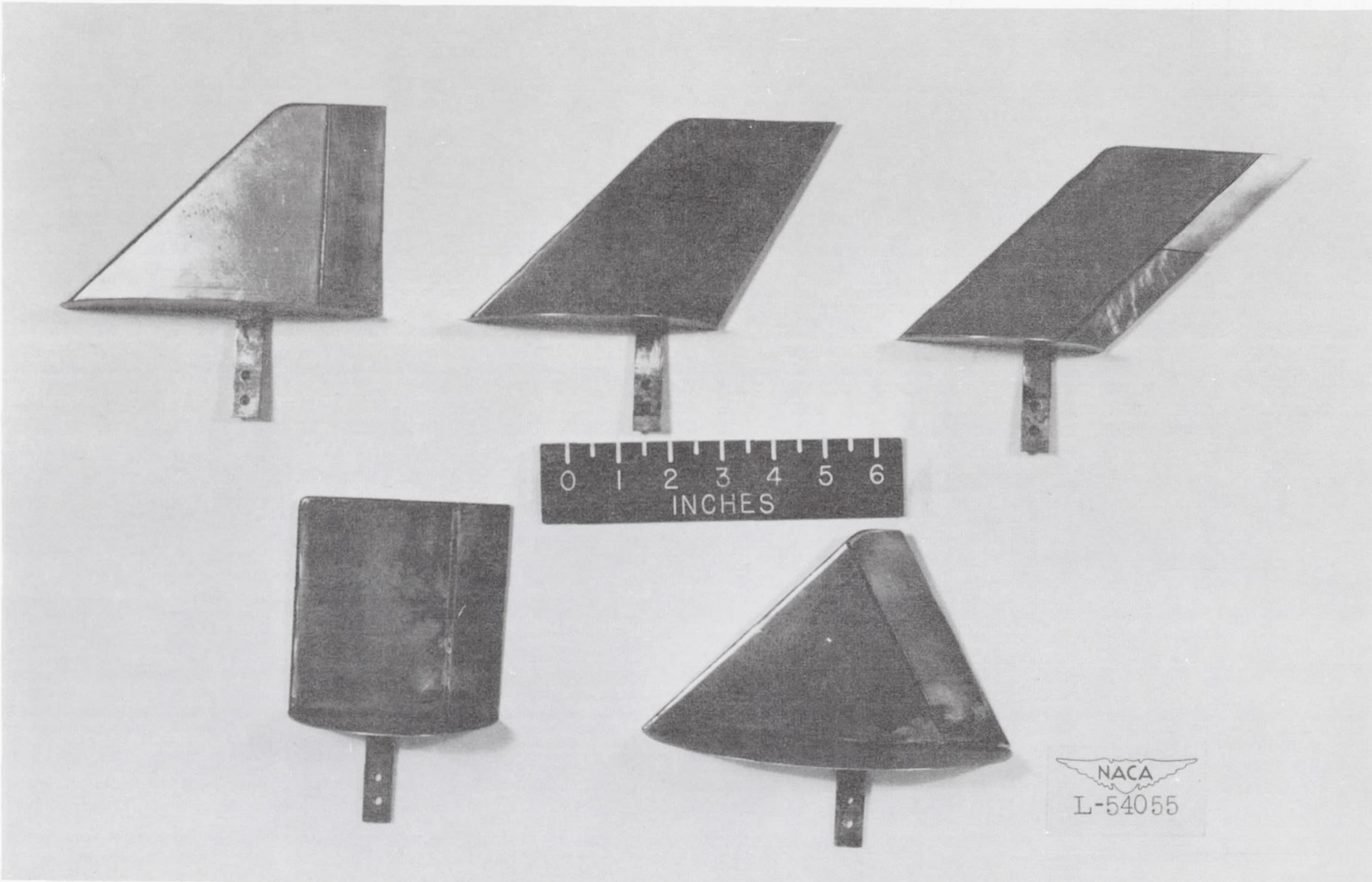

Figure 2.- Photograph of the series of five airfoils used for the flap-effectiveness investigation.

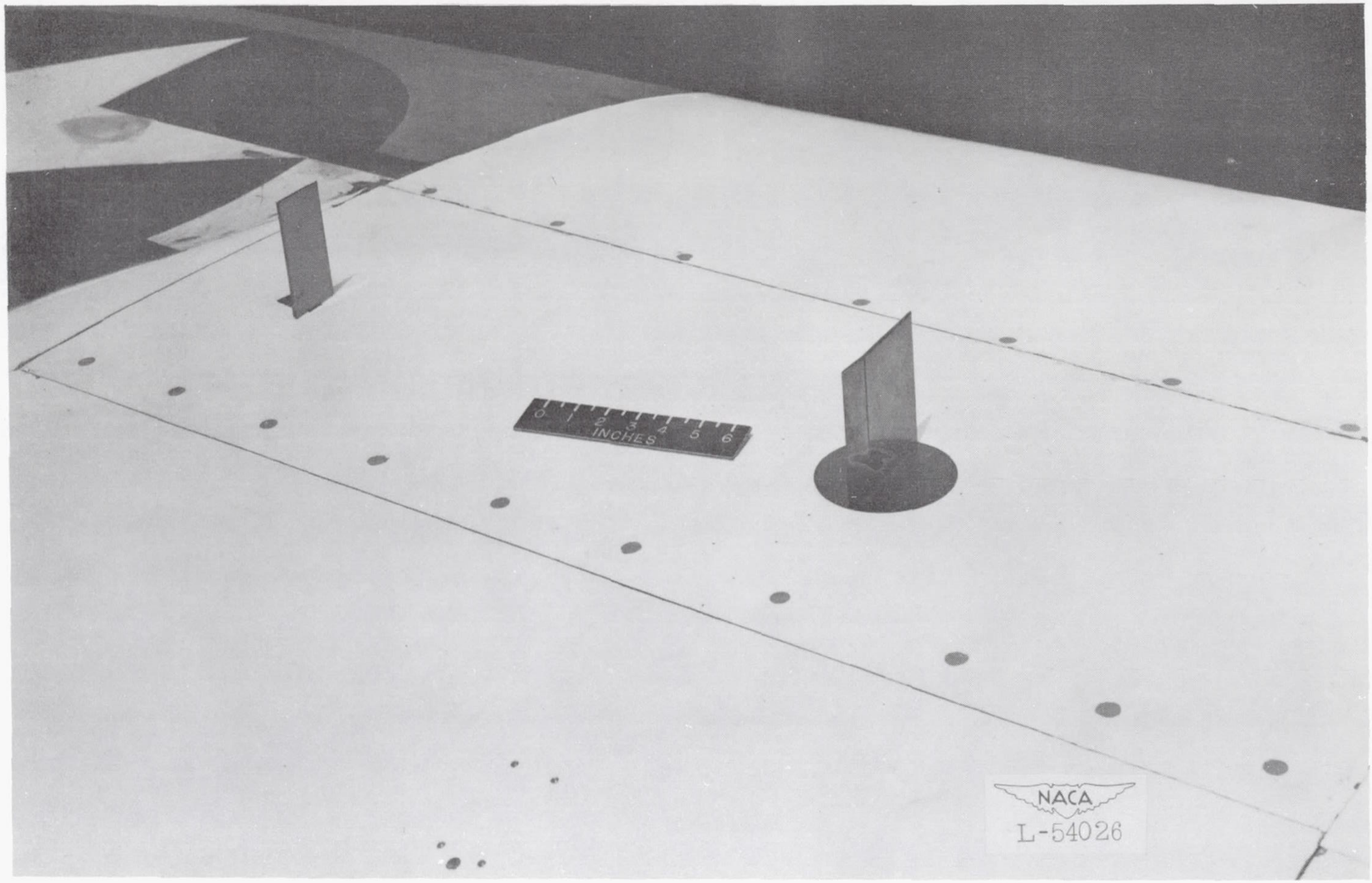

Figure 3.- Photograph of unswept floating model and angle-of-attack vane mounted on test panel.

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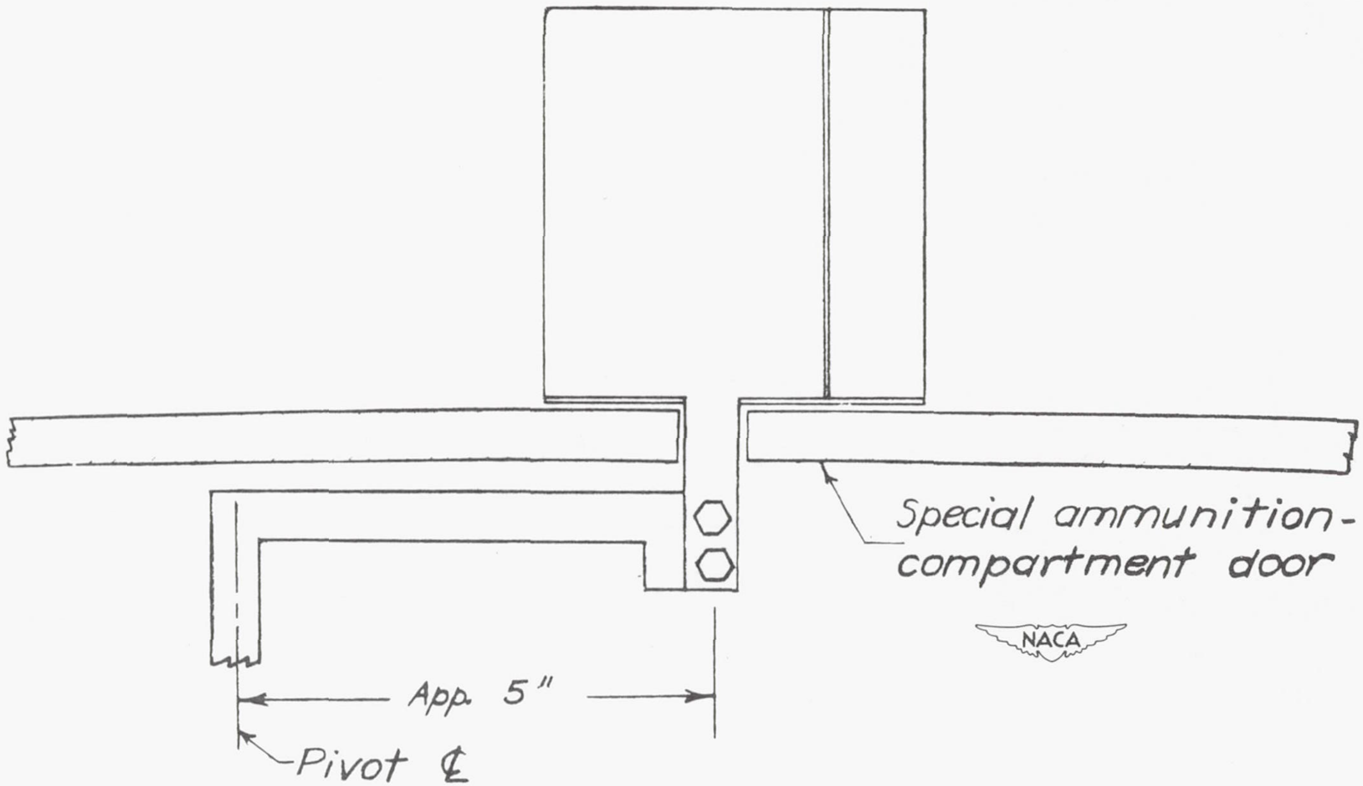
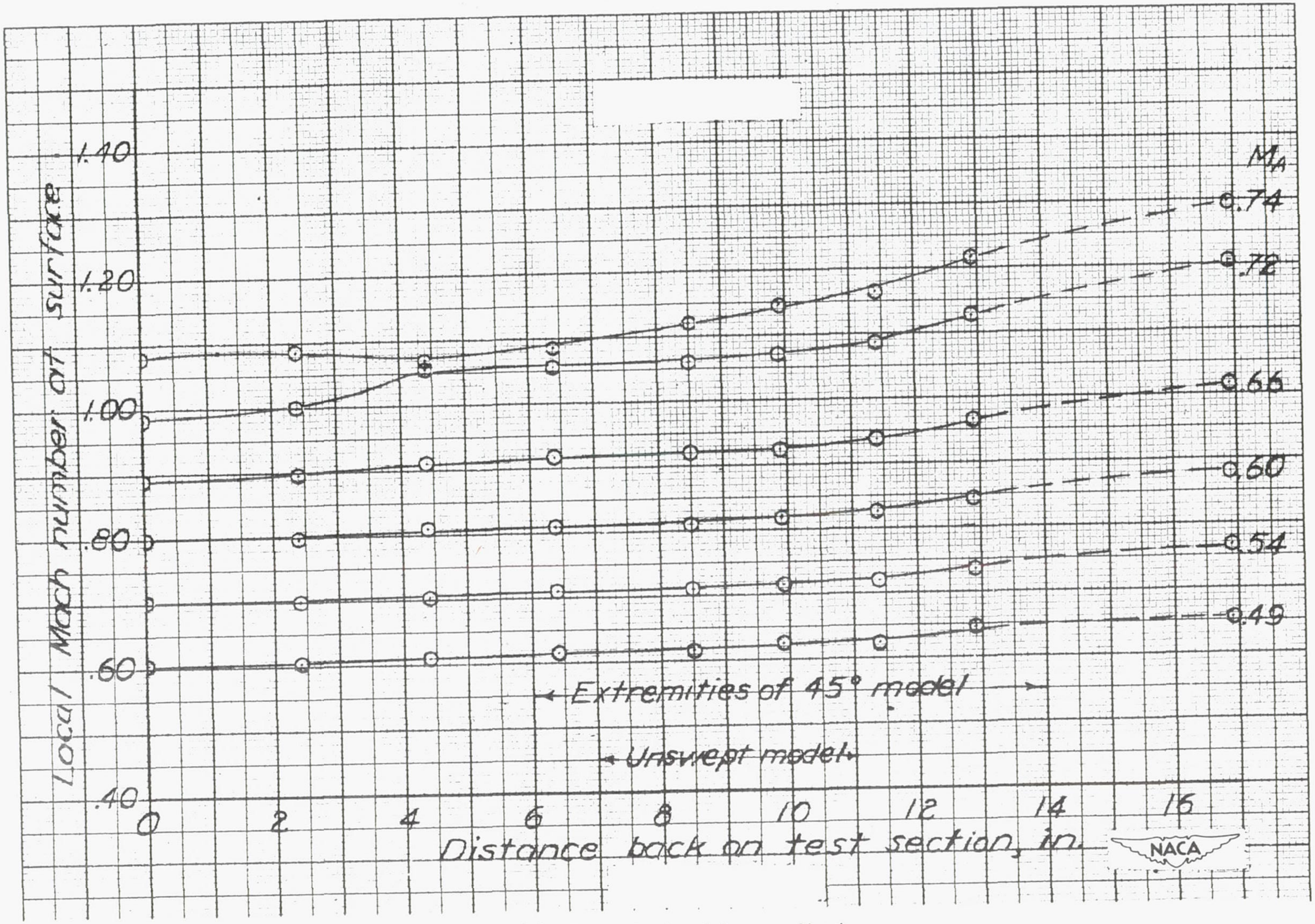
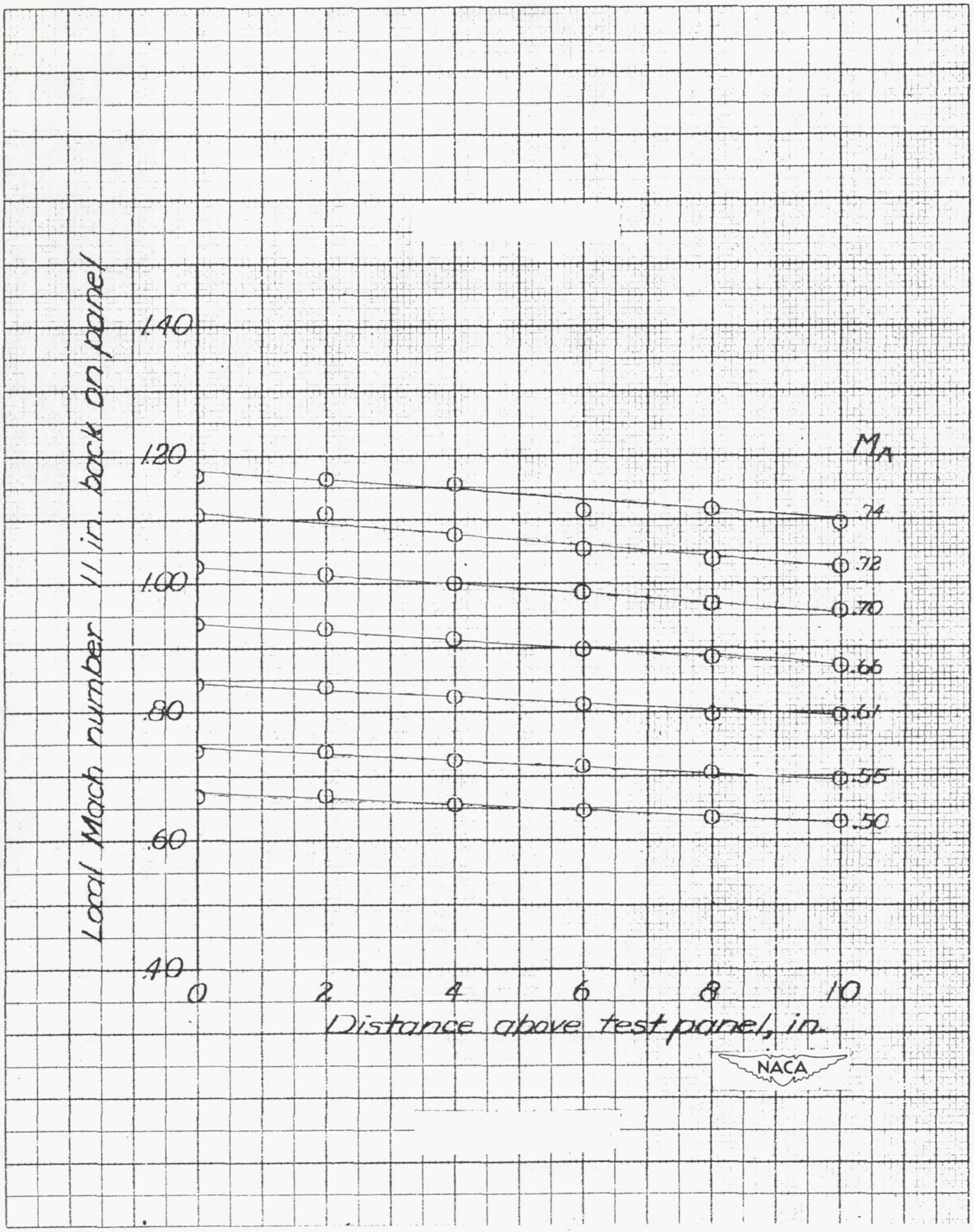


Figure 4.- Section view with unswept model in place on pivot arm.



(a) Typical chordwise gradient.

Figure 5.- Local Mach number gradients at test section for various values of airplane Mach number M_A.



(b) Typical vertical gradient.

Figure 5.- Concluded.

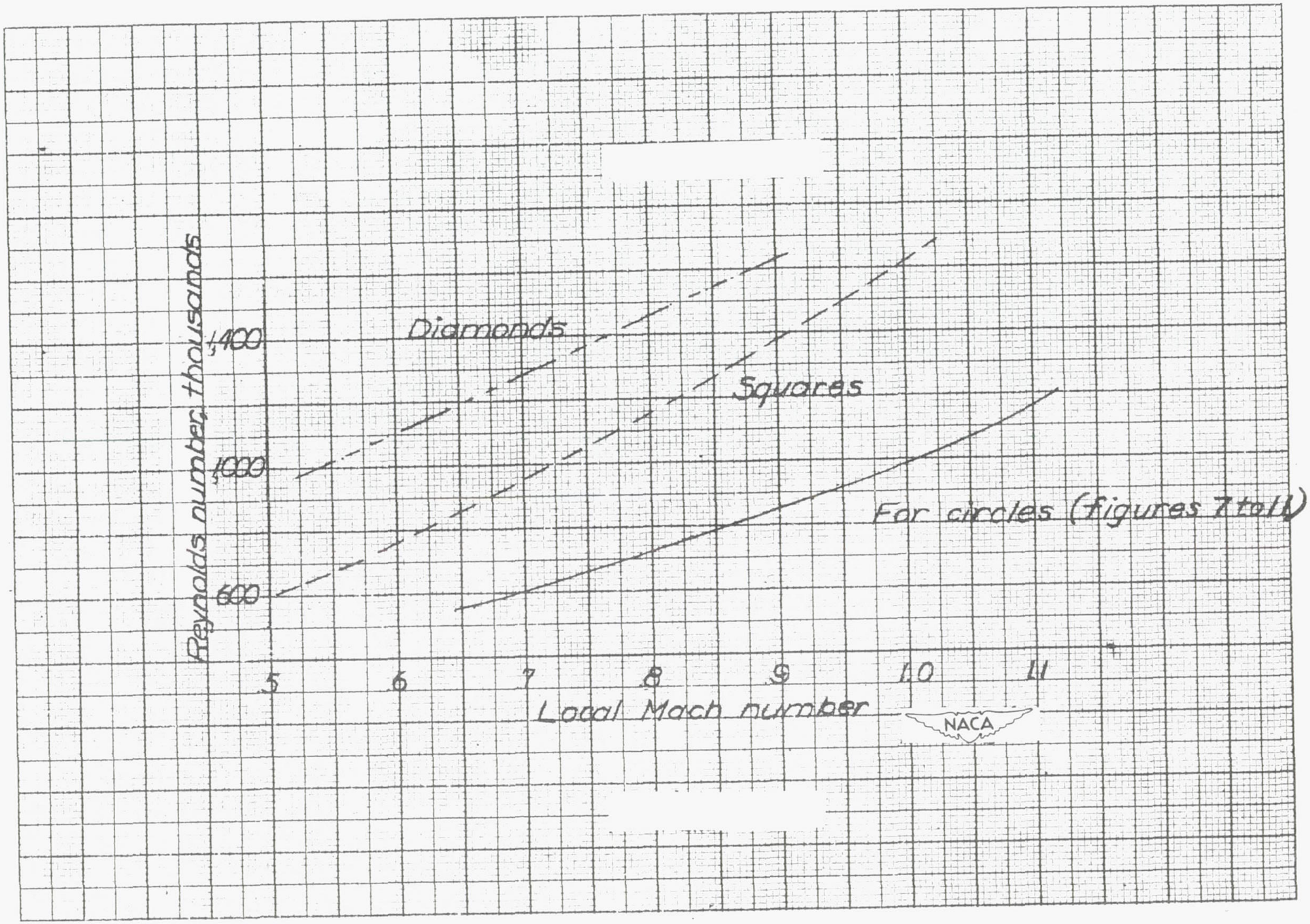


Figure 6.- Plot showing typical variation of Reynolds number for the data presented in figures 7 to 11.

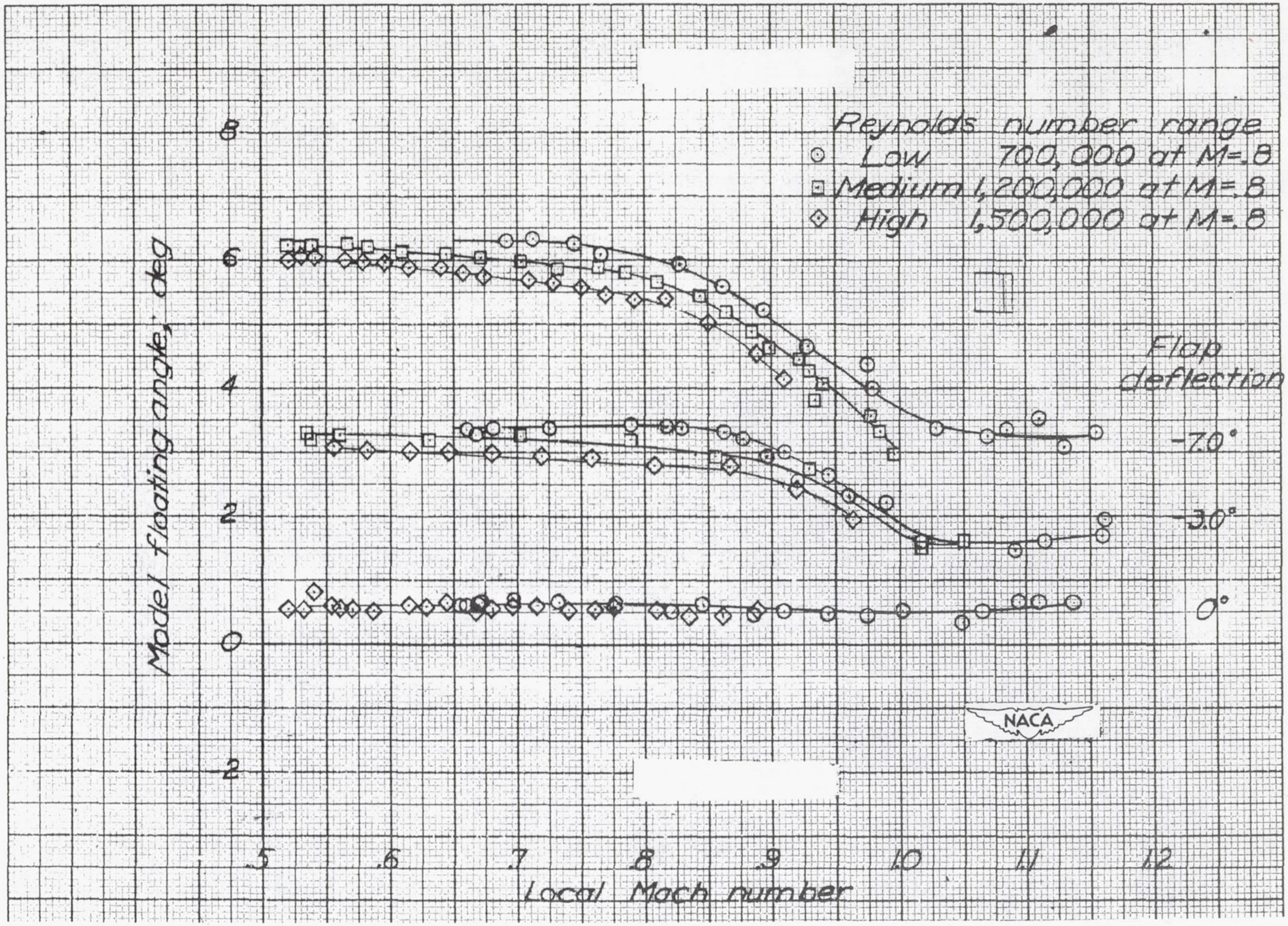


Figure 7.- Variation of floating angle with local Mach number for the unswept airfoil.

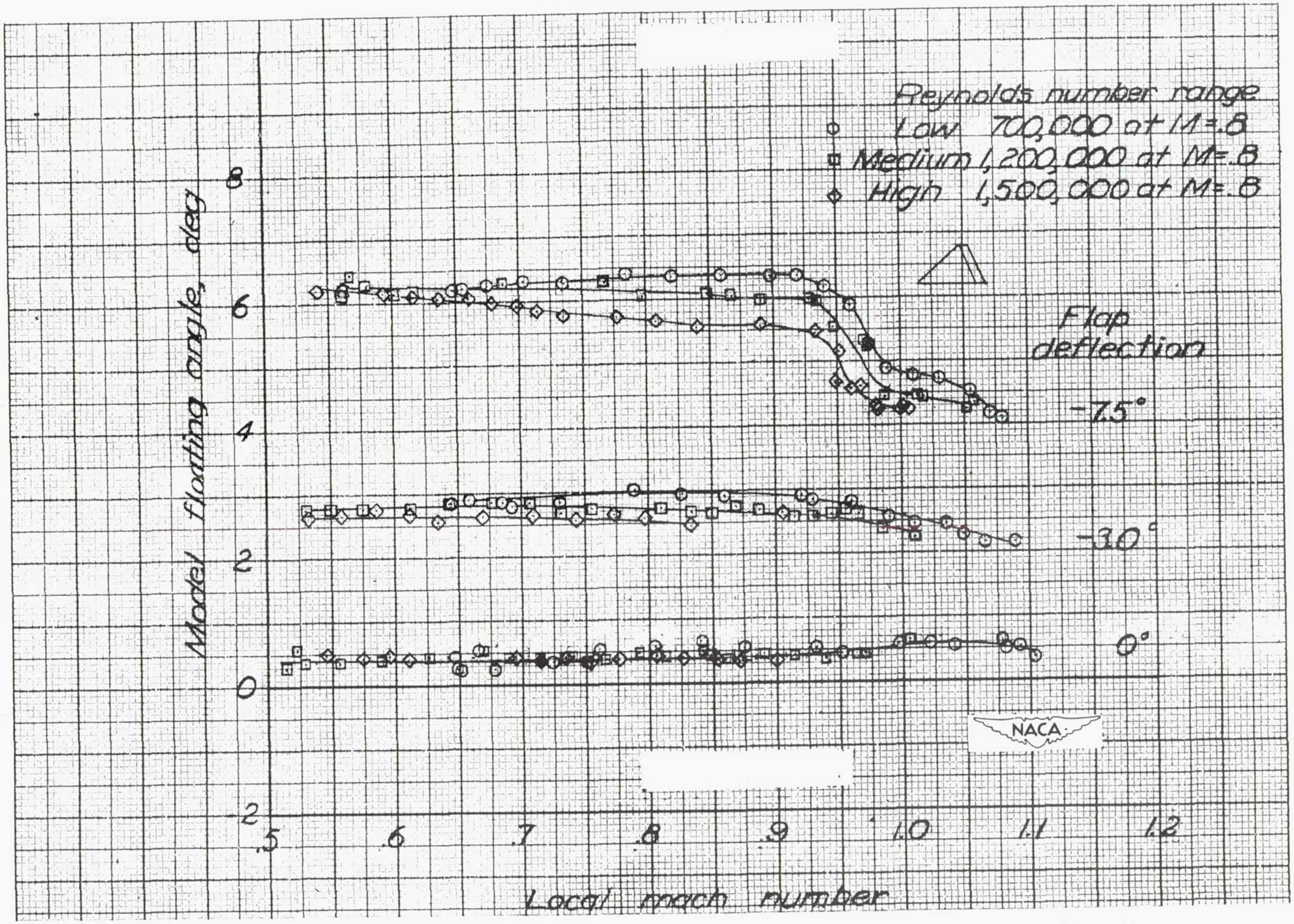


Figure 8.- Variation of floating angle with local Mach number for the airfoil with the leading edge swept back 45° and the hinge line and trailing edge swept forward 30°.

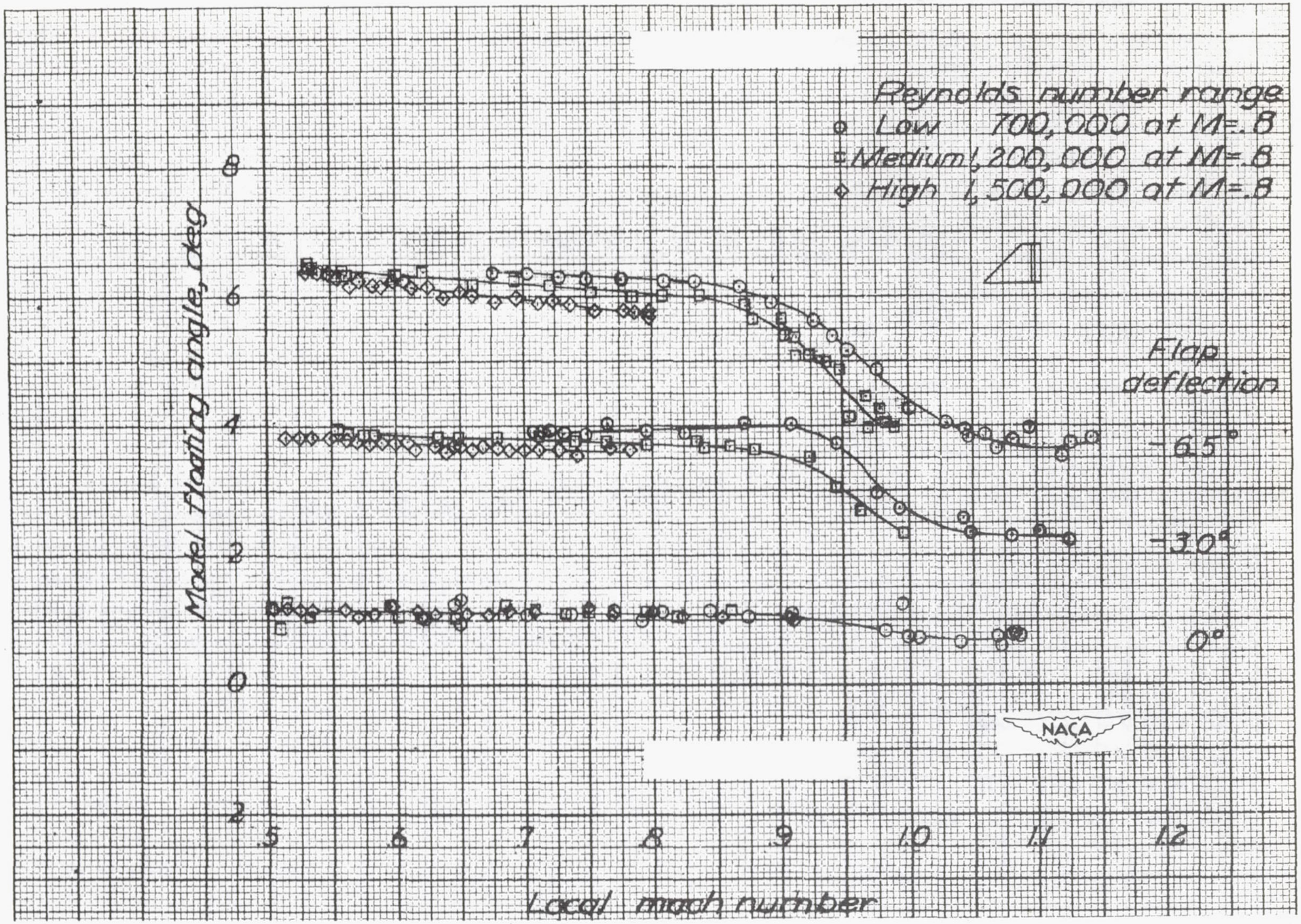


Figure 9.- Variation of floating angle with local Mach number for the airfoil swept 45° at the leading edge and unswept at the hinge line or trailing edge.

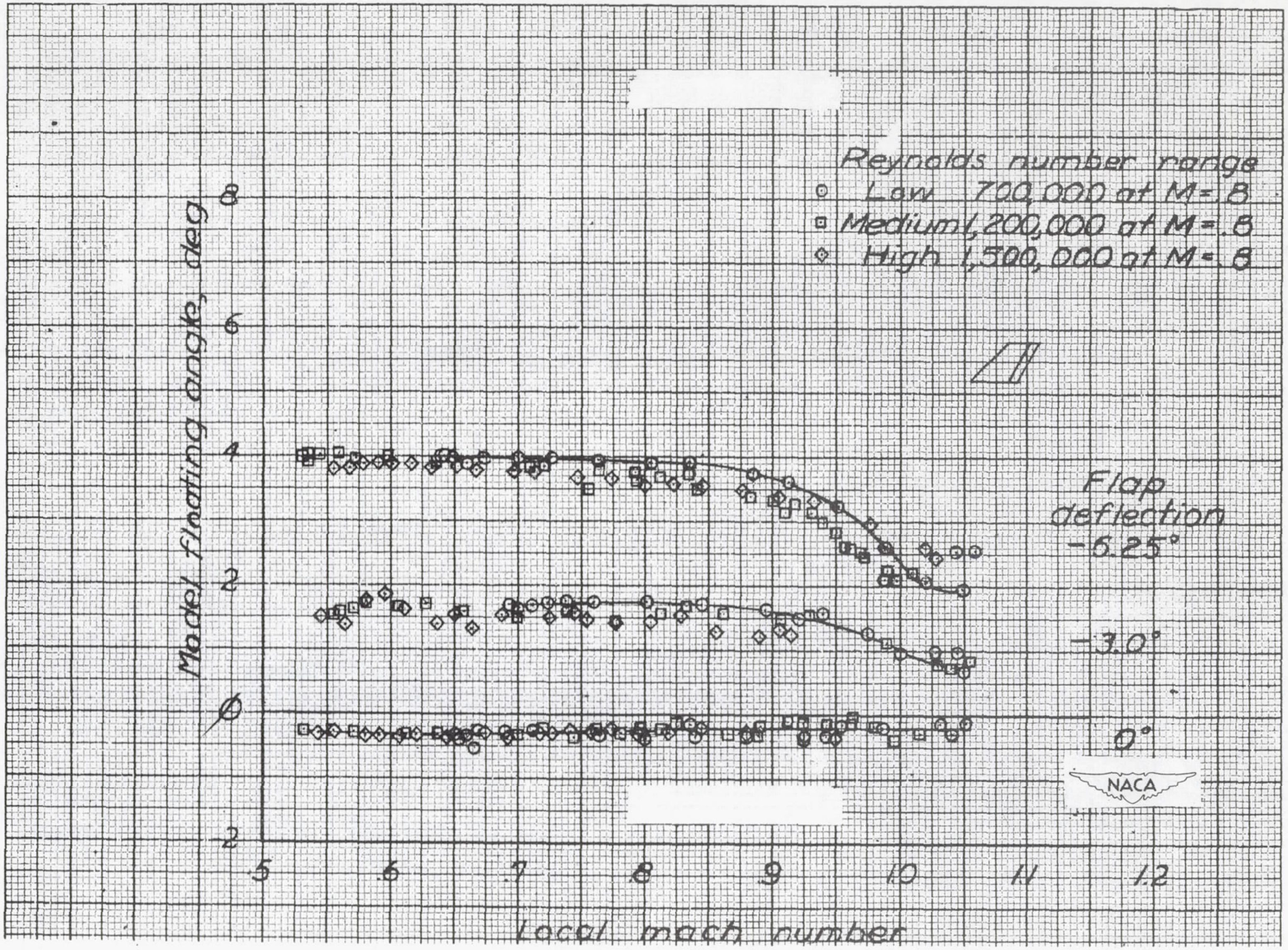


Figure 10.- Variation of floating angle with local Mach number for the airfoil with the leading edge swept back 45° and the trailing edge and hinge line swept back 30°.

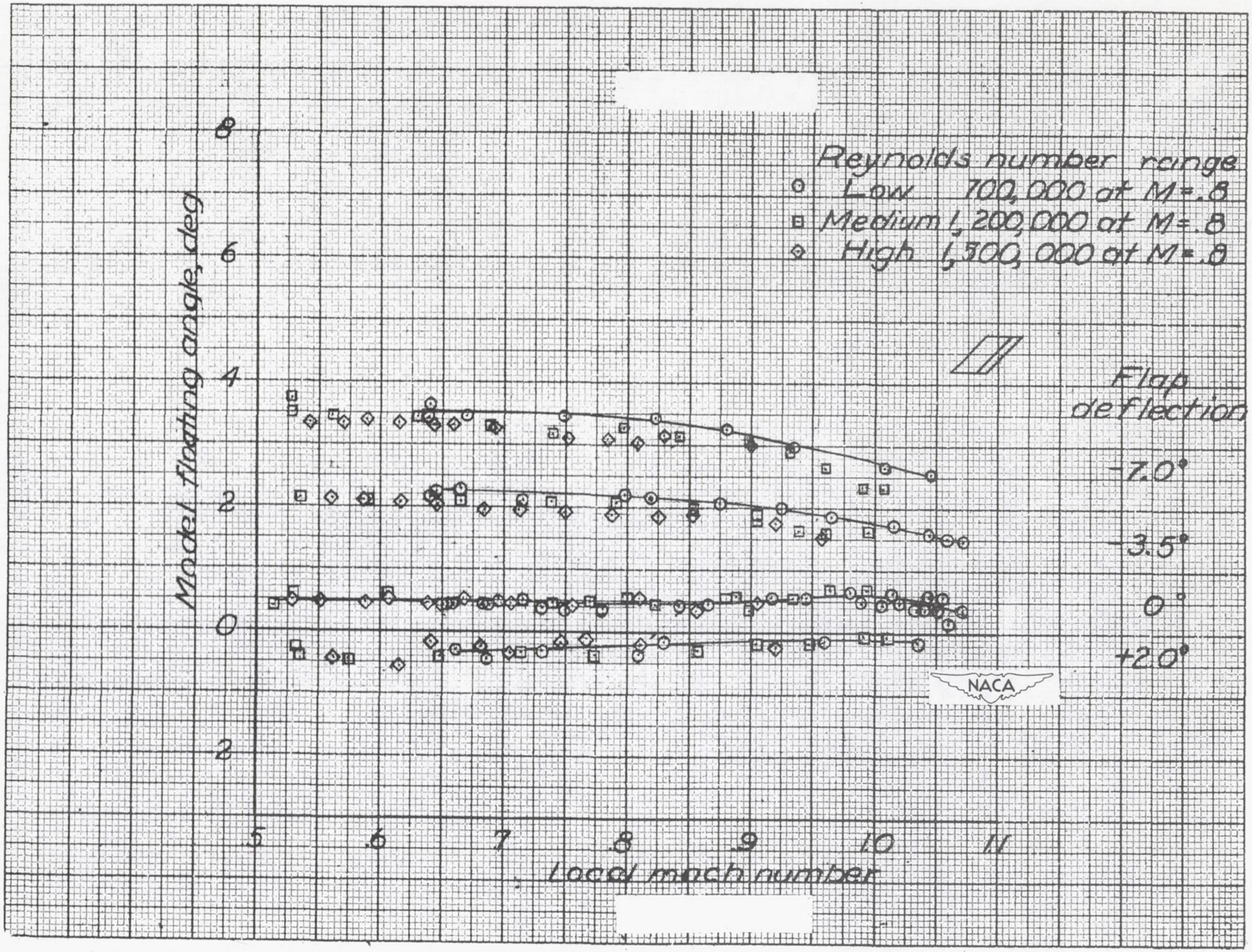


Figure 11.- Variation of floating angle with local Mach number for the airfoil with the leading edge, hinge line, and trailing edge swept back 45°.

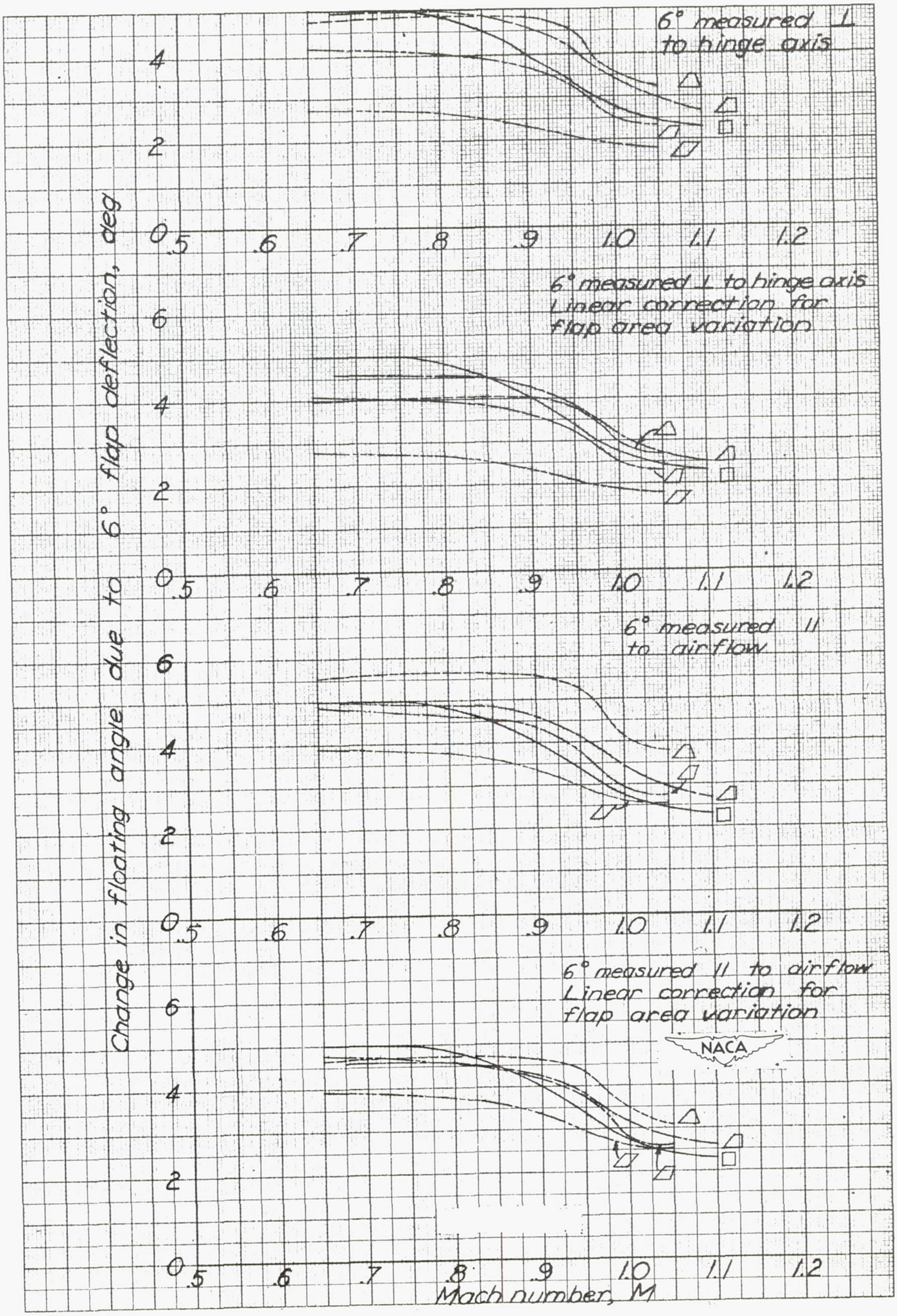


Figure 12.- Comparison of flap effectiveness for the five floating models based on measurement of flap angles perpendicular and parallel to the air stream with and without linear correction for difference in flap areas.

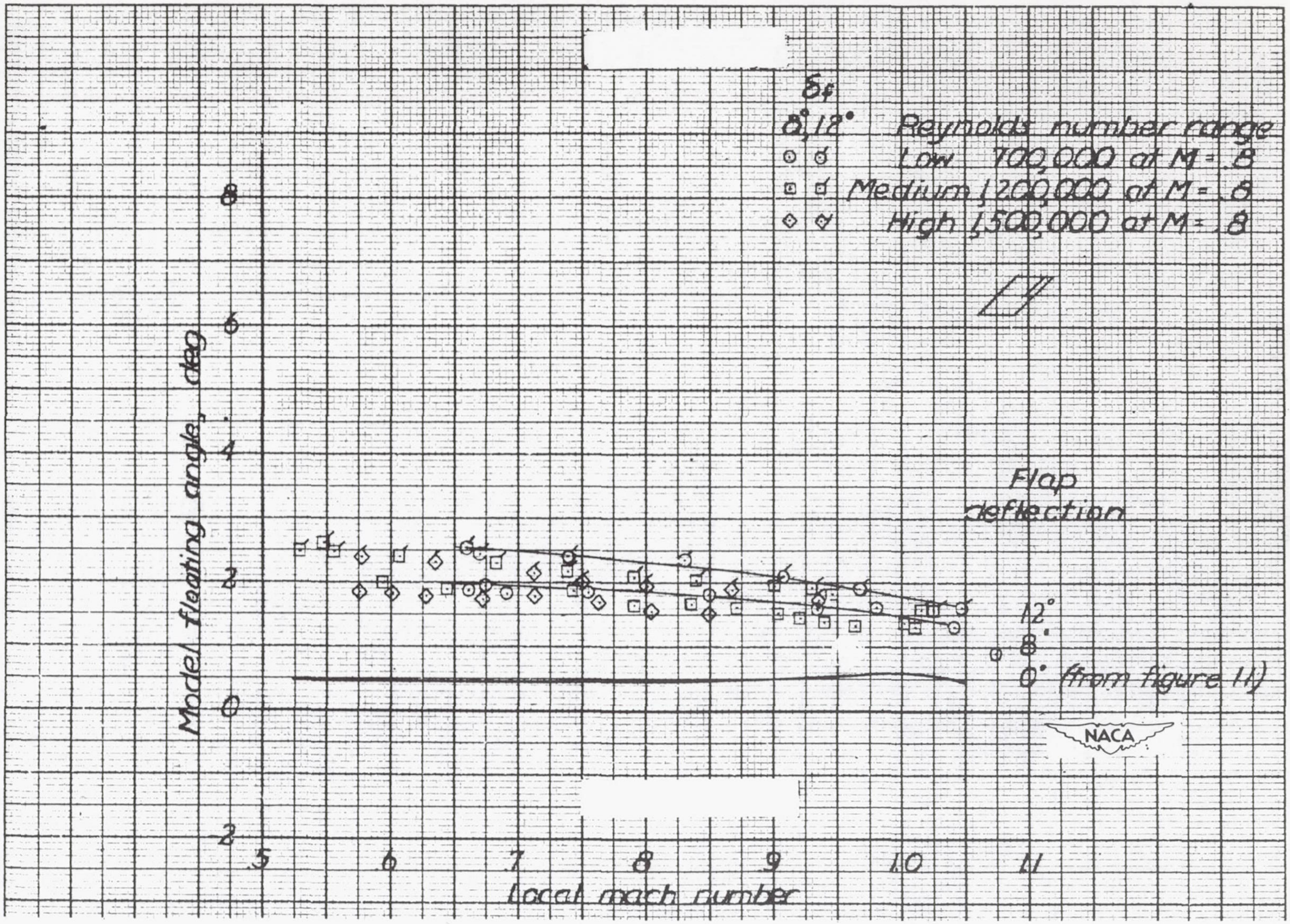


Figure 13.- Variation of floating angle with local Mach number for the model with 45° sweep of leading edge, hinge line, and trailing edge with only the outer half of the flap deflected.

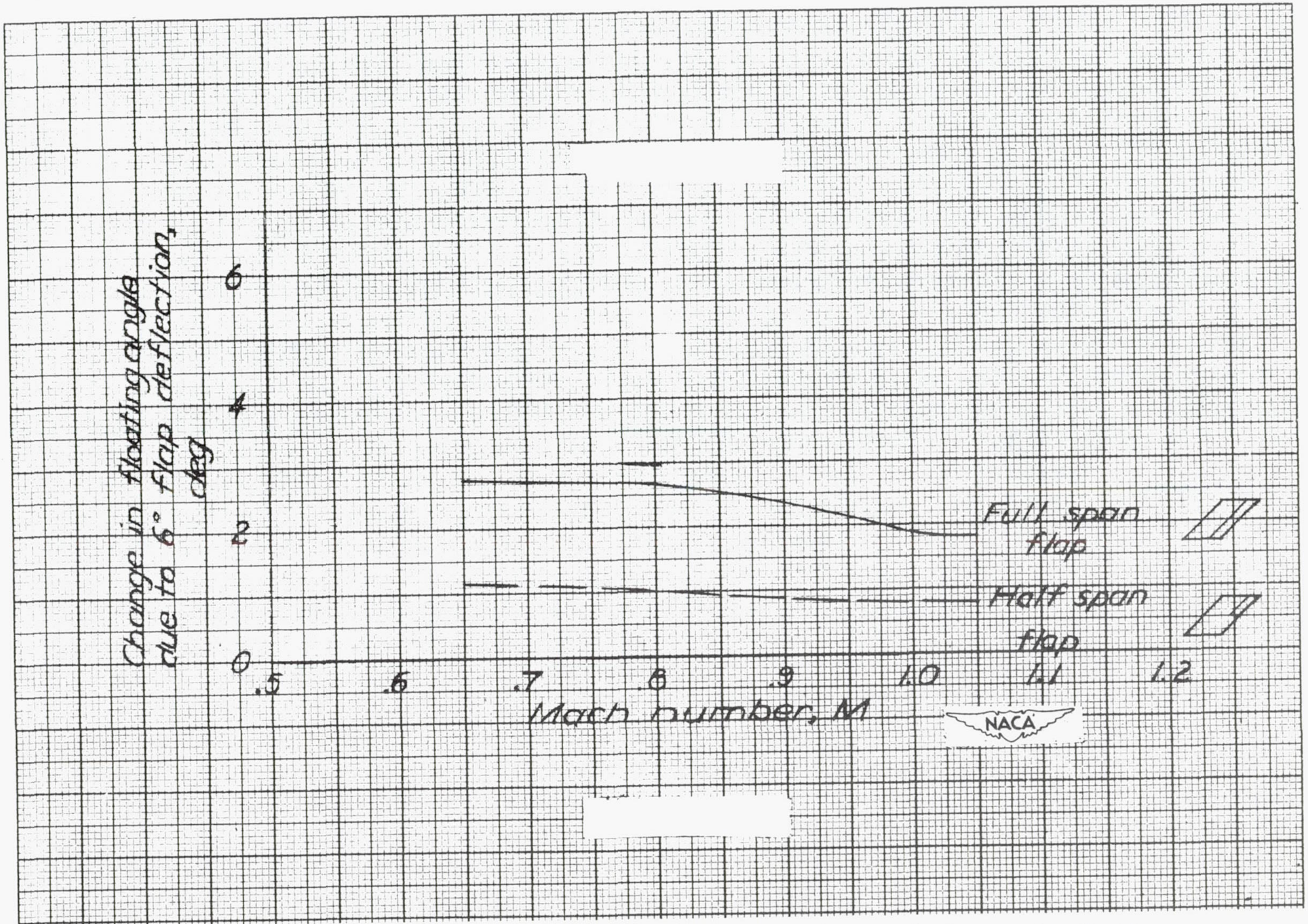


Figure 14.- Comparison of effectiveness of full-span and half-span (outboard) flaps on the floating model with 45° sweepback at leading and trailing edges.