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## WIND-TUNNEL INVESTIGATION OF DEVICES FOR IMPROVING THE DIVING CHARACTERISTICS OF AIRPLANES

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NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Materiel Command, Army Air Forces

# WIND-TUNNEL INVESTIGATION OF DEVICES FOR IMPROVING THE DIVING CHARACTERISTICS OF AIRPLANES

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## SUMMARY

A 1/6-scale model of a pursuit type airplane was tested in the 16-foot wind tunnel at the Ames Aeronautical Laboratory for the purpose of determining the effect of several devices that might be applied to the airplane to improve the high-speed pitching-moment characteristics. This investigation was initiated because some difficulties have been experienced with this airplane in recovering from high-speed dives.

The results indicate that up to a Mach number of 0.74, auxiliary flaps at the 33-percent-chord station on the lower surface of the wing, or a controllable stabilizer, will provide adequate control to overcome the large pitching moments encountered during high-speed dives of the airplane. The results also indicate that a change in wing contour at the center section will relieve the diving tendency up to a lift coefficient of 0.1 and a Mach number of 0.74. This change will improve the diving characteristics and could be applied to airplanes already constructed and in service.

## INTRODUCTION

Pilots of the airplane tested have had difficulty in recovering from high-speed dives. Investigation of the problem by the National Advisory Committee for Aeronautics was begun at the Langley Memorial Aeronautical Laboratory, Langley Field, Virginia. A full-scale airplane was tested in the full-scale wind tunnel, and a 1/6-scale model of the airplane was tested in the 8-foot high-speed wind tunnel. Further investigation of the 1/6-scale model was carried on in the 16-foot wind tunnel at the Ames Aeronautical Laboratory. Results of these investigations are reported in references 1, 2, 3, and 4.

A change in the shape of the fuselage was recommended in reference 4, but the results did not indicate that it would overcome the objectionable pitching moments at all lift coefficients. Therefore, the model was returned to the Ames Aeronautical Laboratory, at the request of the National Advisory Committee for Aeronautics, to investigate the effect of auxiliary flaps, controllable stabilizer, and change of wing contour upon the diving characteristics in an endeavor to provide adequate control.

## APPARATUS AND METHOD

### Wind Tunnel and Equipment

The tests were conducted in the 16-foot wind tunnel at the Ames Aeronautical Laboratory. This wind tunnel has a closed test section, a single closed-return passage, and is of circular cross section throughout. The model was supported on two struts with links for controlling the angle of attack in the same manner as for the tests reported in reference 4. The forces on the model were measured by self-balancing, recording beam scales.

The results of the tests have been corrected for tunnel-wall effects by adding the following corrections:

$$\Delta\alpha = 0.331 \; C_L \quad \text{in degrees}$$

$$\Delta C_{D_T} = 0.00573 \; C_L^2$$

Approximate corrections for tare forces and moments have been applied. The pitching moments were computed with respect to the 25-percent point on the mean aerodynamic chord, 3.23 inches above the trunnion.

## Model

The model of the airplane (fig. 1) was furnished by the manufacturer. Except for the modifications investigated, it was the same as used for the tests reported in reference 4. The Prestone, oil, spark-plug cooling and carburetor scoops, and the turbosupercharger installations were not on the model, because previous tests (reference 4) had shown that these accessories had no significant effect on the pitching-moment characteristics. A complete description will be found in reference 5. The principal model dimensions were as follows:

| | |
|---|---|
| Wing area | 9.10 square feet |
| Wing span | 8.66 feet |
| Mean aerodynamic chord | 1.17 feet |
| Stabilizer area | 1.5 square feet |
| Elevator area | 0.68 square feet |
| Horizontal tail area | 2.18 square feet |

The auxiliary flaps were tested at two chord positions on the model, one with a hinge line at approximately 33 percent, and the other with a hinge line at approximately 66 percent of the wing chord from the leading edge. The locations thus chosen were structurally suited for application of these flaps to the full-scale airplane. These auxiliary flaps are illustrated in figure 2.

The changes to the contour of the wing center section, consisting of several alterations to the upper and lower surfaces, are shown in figures 3 and 4.

In the tests of auxiliary flaps and wing contour changes, the stabilizer and elevator were set at 0°. Additional tests of the standard model were made with several elevator angles and the stabilizer set at 0° and -2°.

## RESULTS AND DISCUSSION

### Auxiliary Flaps

The auxiliary flaps may be considered controllable devices to provide longitudinal control at the higher Mach numbers at which the stability of the airplane increases to such an extent that the elevator is incapable of providing control. The more important results, which are given in figures 5, 6, and 7, show that all of the flaps tested produced positive increments of pitching moment which, in general, increased as the Mach number increased.

Of the flaps tested, those at the 33-percent-chord station were the most effective. The flaps inboard of the booms produced larger increments of pitching moment than did the flaps outboard of the booms. In fact, with flaps at the 33-percent-chord station, the 1-inch inboard flaps had a larger effect than the 2-inch flaps outboard of the booms.

As indicated in figure 6, the 1-inch inboard flaps had little effect on the pitching moments when they were set at 7.5°, but as the angle was increased to 15°, their effectiveness increased rapidly, especially at the higher Mach numbers. Because of this rather rapid increase in effectiveness, the flaps should be operated carefully to prevent the development of too large accelerations.

Figure 8 shows the effect of the inboard flaps on the lift coefficient at which the model balanced. At a Mach number of 0.725, a 45° deflection of the 1-1/2-inch flaps increased the lift coefficient for balance by 0.55. At this Mach number, at an altitude of 25,000 feet and with a wing loading of 45 pounds per square foot, a lift coefficient of 0.55 will produce a 3.5g pull-out from a vertical dive.

The variation of pitching-moment coefficient with lift coefficient for the 1-inch inboard flaps at the 33-percent-chord station, at a Mach number of 0.725, is shown in figure 9. Figure 10 shows the drag coefficient, angle of attack, and pitching-moment coefficient versus lift coefficient for the 1-1/2-inch inboard flaps, set 30°, at the same station. Corresponding data for the standard model without flaps are shown in figure 11. These data are presented for use in making additional comparisons if desired.

The inboard and outboard flaps had nearly the same effect on lift coefficient, as may be seen by comparing the results given in figure 12 with those of figure 13. The large differences in moment increment previously noted in figure 5 are probably accounted for by the larger effect of the inboard flaps on the downwash at the tail.

The drag increments due to the flaps are indicated in figures 14 and 15. The flaps were not intended for use as dive brakes, but it is natural that they should increase the drag at certain lift coefficients. However, at high lift coefficients, the model actually had a lower drag with the 1-inch inboard flaps at the 33-percent-chord station than without the flaps, as is indicated in figure 16.

With reference to the question of what loads will occur on the flaps and attachments, figure 17 shows the pressure that occurred on the 1-1/2-inch flaps at the 33-percent-chord station. At a Mach number of 0.74 and a flap angle of 45°, the maximum difference between the pressures on the front and back faces of the flaps was 1.3 times the dynamic pressure.

Altogether, the results indicate that the auxiliary flaps should provide a practical and effective longitudinal control to pull out of high-speed dives. With the elevator free, the lift coefficients for trim will differ from the balance lift coefficients shown in figure 8, but the effectiveness of the flaps should not be impaired.

## Wing-Contour Changes

The wing-contour changes may be considered fixed devices that alter the variation of pitching moments with Mach number so as to improve the high-speed diving characteristics. The upper-surface contour changes were tested because, in some previous tests of the standard model (reference 4), the diving moments started to decrease at a Mach number of 0.75, and when the critical speed of the center section of the wing was increased by a change of contour, this tendency disappeared. It was therefore reasoned that decreasing the critical speed at the wing center section would cause the diving moments to start decreasing in the same manner at a lower Mach number. The lower-surface contour changes were tested because it was believed that the shock which they cause to form on the lower surface of the wing at high Mach numbers might have an effect similar to the auxiliary flaps and thereby improve the diving characteristics.

Figure 18 shows the variation of pitching-moment coefficient with Mach number at lift coefficients of 0.1, 0.2, and 0.4, due to changes to the contour of the upper surface of the wing. The large inboard upper-surface contour change (fig. 18, curve C) is the only one of these changes that had any appreciable effect on the pitching-moment characteristics. This change causes the diving moments to decrease at Mach numbers above 0.725 for a lift coefficient of 0.1, but the effect is too small to be of value.

Figure 19 shows the effect of lower-surface contour changes. At a lift coefficient of 0.1, the contour change at the 52-percent-chord station shows a relatively small variation of pitching-moment coefficient with Mach number. The other changes had less favorable effects.

The curves of pitching-moment coefficient versus lift coefficient (fig. 20) show that for lift coefficients less than about 0.1, the pitching-moment coefficient increases as the Mach number increases, and for greater lift coefficients, it decreases with increasing Mach number. These characteristics tend to make the airplane balance at a lift coefficient of about 0.1 as the speed increases above that corresponding to the critical Mach number.

The lift increments due to the contour changes are shown in figure 21. At an angle of attack of $-1^\circ$, all the contour changes decreased the lift coefficient at low speeds and increased it at high speeds, except for the contour change at the trailing edge, which acted oppositely. The contour change at the 52-percent-chord station gave the maximum reduction in lift at low speeds and did not increase the lift until a Mach number of 0.675 was exceeded. Above this value, the lift increment increased rapidly. This increase in lift increment tends to maintain the downwash at the tail, which is probably responsible for the favorable effects on the pitching moments. The results for the standard model (fig. 11) show that for all lift coefficients greater than -0.18, the pitching-moment coefficient decreased as the Mach number increased above the critical. The results with the wing contour change at the 52-percent-chord station (fig. 20) show that the lift coefficient, above which the pitching coefficients decrease with increasing Mach number, is increased from -0.18 to 0.1. Therefore, there should be less difficulty in recovery from dives at Mach numbers up to at least 0.74, the limit of the tests.

All the contour changes on the lower surface increased the drag at a Mach number of 0.725 or less (fig. 21). Above this Mach number, the drag was reduced by the contour changes at the 48-percent- and 52-percent-chord stations. The contour change which gave the best pitching-moment characteristics (that at the 52-percent-chord station) caused the least increase in drag.

## Controllable Stabilizer

A $2^{\circ}$ decrease in stabilizer incidence increased the pitching-moment coefficient by approximately 0.1 throughout the speed range (fig. 22). For the standard airplane, this change in pitching-moment coefficient corresponds to an increase in lift coefficient for balance of about 0.2 at a Mach number of 0.725. Figure 22 also shows that the effectiveness of the elevator, in producing changes in pitching moment, remained essentially constant for all Mach numbers of the test for both $0^{\circ}$ and $-2^{\circ}$ stabilizer incidence. Although the elevator is effective in producing changes in moment, these are too small to overcome the greatly increased stability produced by a fixed stabilizer when the angle of downwash decreases at the higher Mach numbers. However, the moment required can be produced by changing the stabilizer angle. These results indicate that a controllable stabilizer should provide longitudinal control of the airplane in dives up to at least a Mach number of 0.74.

## CONCLUSIONS

For Mach numbers up to at least 0.74, the limit of the tests, the results indicate that:

1. Auxiliary flaps at the 33-percent-chord station on the lower surface of the wing between the booms and fuselage will provide longitudinal control in dives.

2. A change to the contour of the lower surface of the wing between the booms will relieve the diving tendency for values of the lift coefficients up to 0.1. This change amounts to thickening the wing at the 52-percent-chord station and fairing to the original wing surface.

3. A controllable stabilizer will provide longitudinal control in high-speed dives.

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

## REFERENCES

1. Guryansky, Eugene R., and Preston, G. Merritt; Full-Scale Wind-Tunnel Investigation of Buffeting and Diving Tendencies of the YP-38 Airplane. NACA RMR, March 1941.

2. Preston, G. Merritt, and Guryansky, Eugene R.: Drag Analysis of the Lockheed YP-38 Airplane. NACA RMR March 1942.

3. Draley, Eugene C.: Tests of 1/6-Scale P-38 Model in the 8-Foot High-Speed Tunnel. NACA RMR May 1942.

4. Erickson, Albert L.: Investigation of Diving Moments of a Pursuit Airplane in the Ames 16-Foot High-Speed Wind-Tunnel. NACA CMR Oct. 1942.

5. Model Design Group: P-38 1/6-Scale High-Speed Wind-Tunnel Model. Lockheed Aircraft Corporation Report No. L.A.L. 17, Parts I, II, III, IV, and Appendix, December 16, 1941, and April 10, 1942.

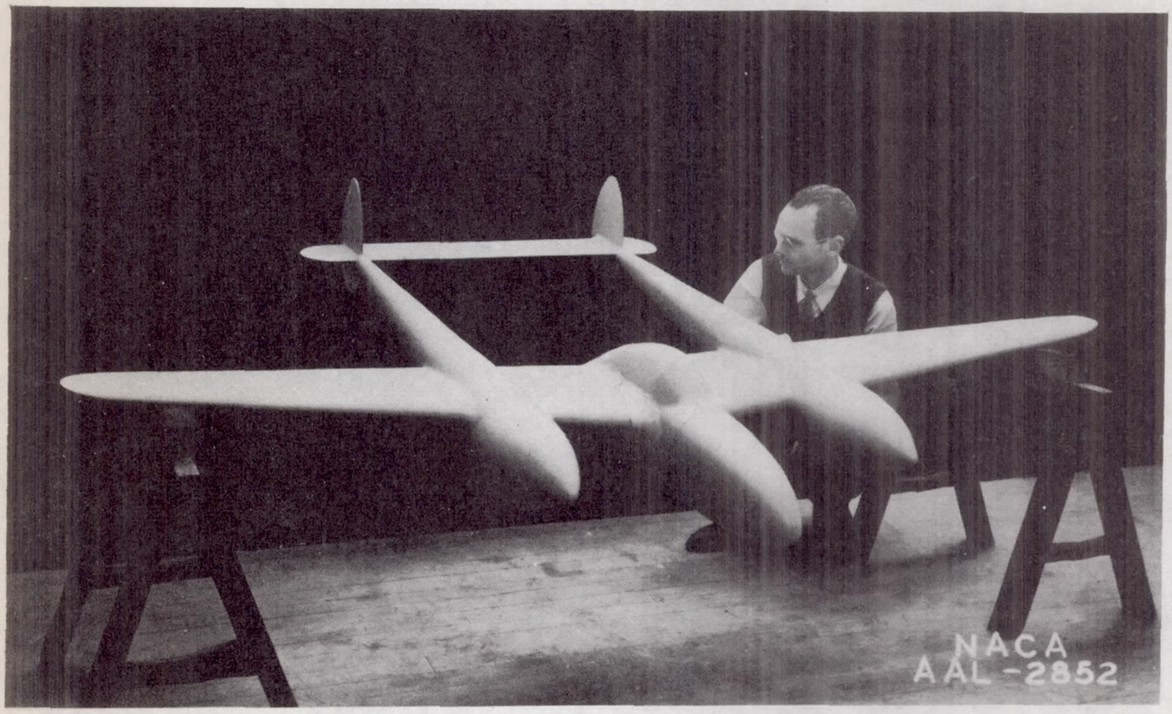



Figure 1.- Model used in tests with standard fuselage.

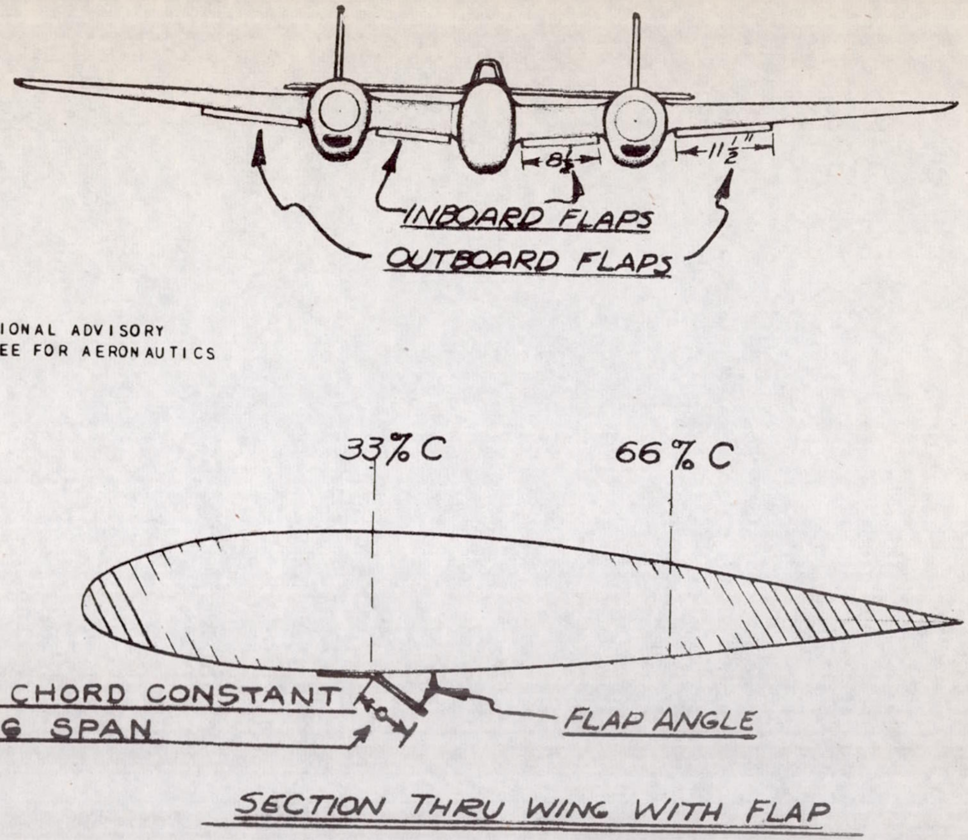
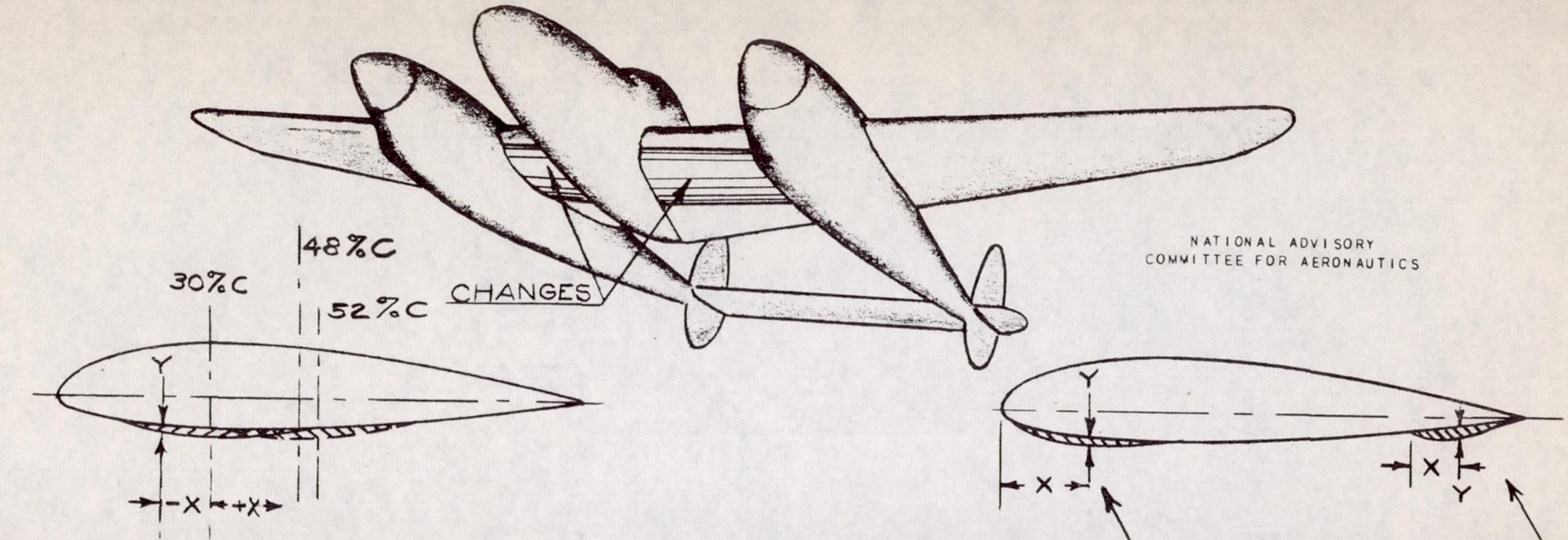





FIGURE 2.- AUXILIARY FLAPS




CHANGES AT 0.30, 0.48, 0.52 C.

| X | Y |
|---|---|
| 0 | 0.35 |
| +0.5 | 0.36 |
| +1.0 | 0.34 |
| +1.5 | 0.29 |
| +2.0 | 0.23 |
| +2.5 | 0.19 |
| +3.0 | 0.12 |
| -0.5 | 0.32 |
| -1.0 | 0.29 |
| -1.5 | 0.24 |
| -2.0 | 0.20 |
| -2.5 | 0.14 |
| -3.0 | 0.06 |

ALL COORDINATES GIVEN IN INCHES FOR MODEL

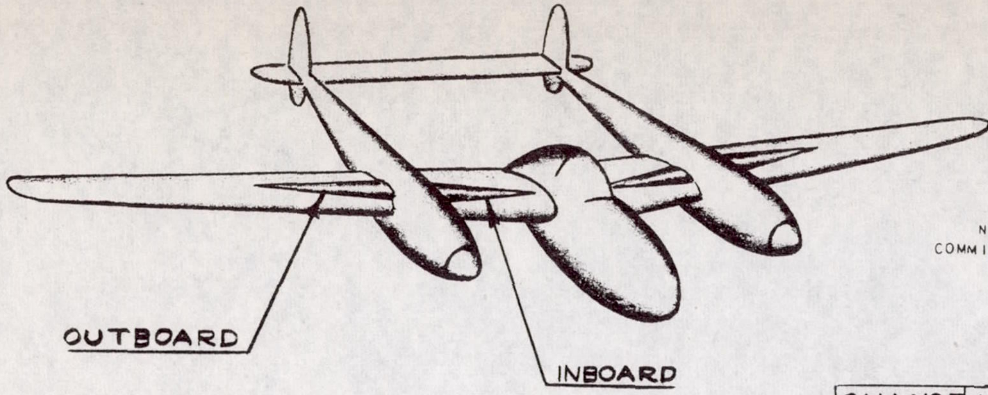
LEADING EDGE CHANGES

| X | Y |
|---|---|
| 0 | 0 |
| 0.5 | 0.12 |
| 1.0 | 0.26 |
| 1.5 | 0.36 |
| 2.0 | 0.40 |
| 2.5 | 0.42 |
| 3.0 | 0.41 |
| 3.5 | 0.36 |
| 4.0 | 0.29 |
| 4.5 | 0.20 |
| 5.0 | 0.13 |
| 6.0 | 0.03 |

TRAILING EDGE CHANGES

| X | Y |
|---|---|
| 0 | 0 |
| 0.5 | 0.29 |
| 1.0 | 0.38 |
| 1.5 | 0.39 |
| 2.0 | 0.31 |
| 2.5 | 0.19 |
| 3.0 | 0.10 |
| 3.5 | 0.04 |
| 4.0 | 0 |

FIGURE 3. - COORDINATES OF CHANGES TO LOWER WING SURFACE CONTOURS.

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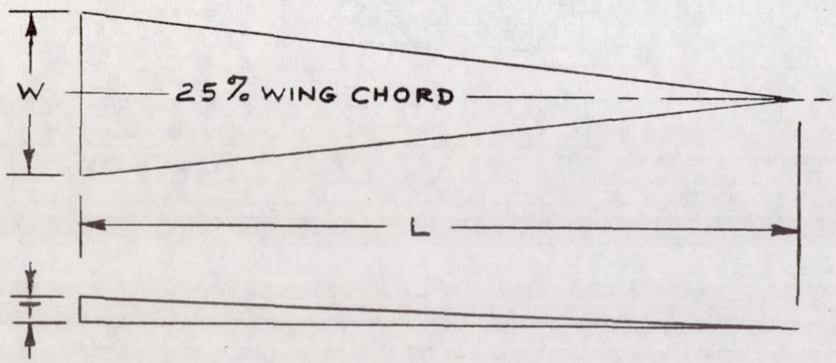
| CHANGE | W | T | L | LOCATION |
|---|---|---|---|---|
| A | 2 | 1/4 | 9 | OUTBOARD |
| B | 2 | 1/4 | 8 | INBOARD |
| C | 2 | 3/8 | 8 | INBOARD |

ALL DIMENSIONS IN INCHES




CIRCULAR
ARC SECTION

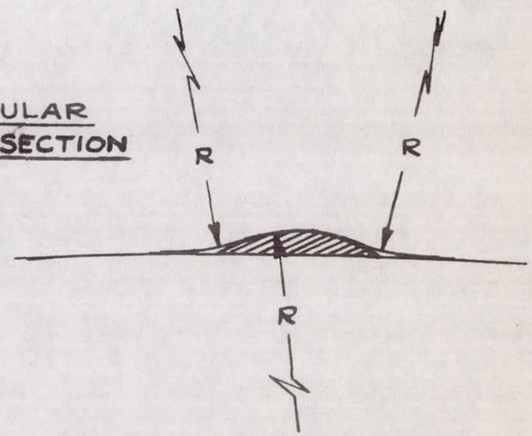



FIGURE 4 .– COORDINATES OF CHANGES TO UPPER WING SURFACE CONTOURS.

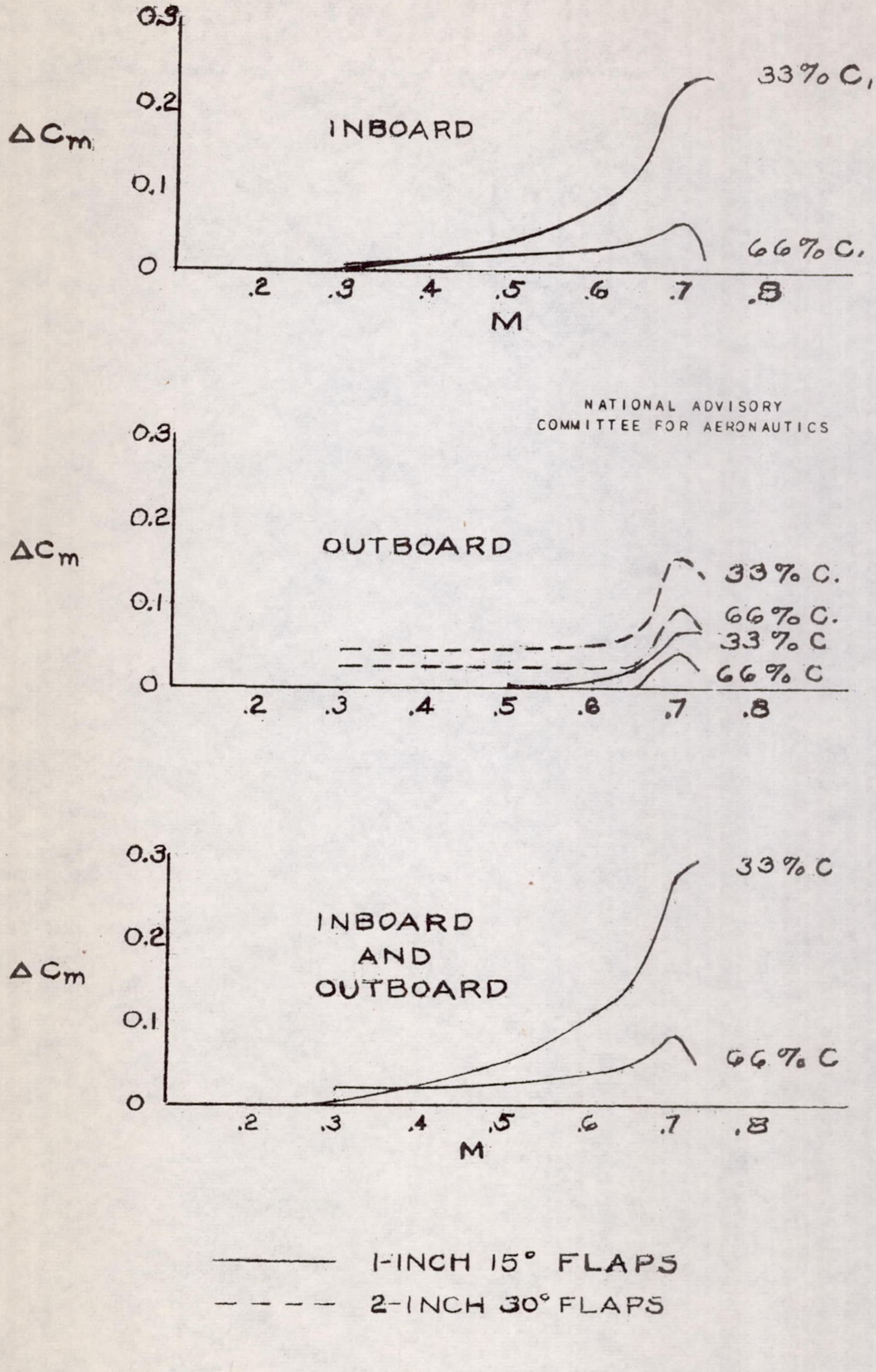
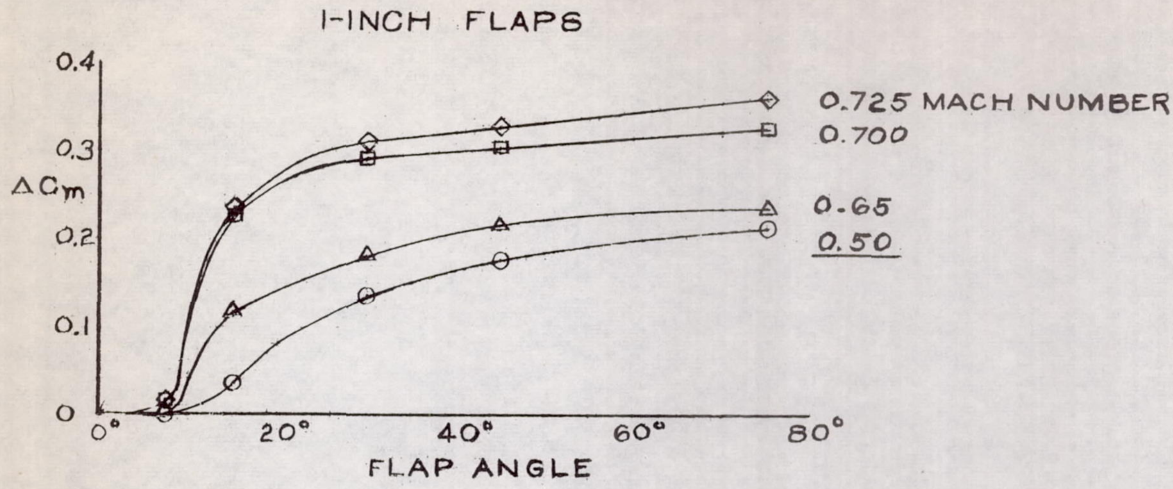



FIGURE 5.- EFFECT OF CHORD POSITION OF FLAPS ON MOMENT COEFFICIENT.

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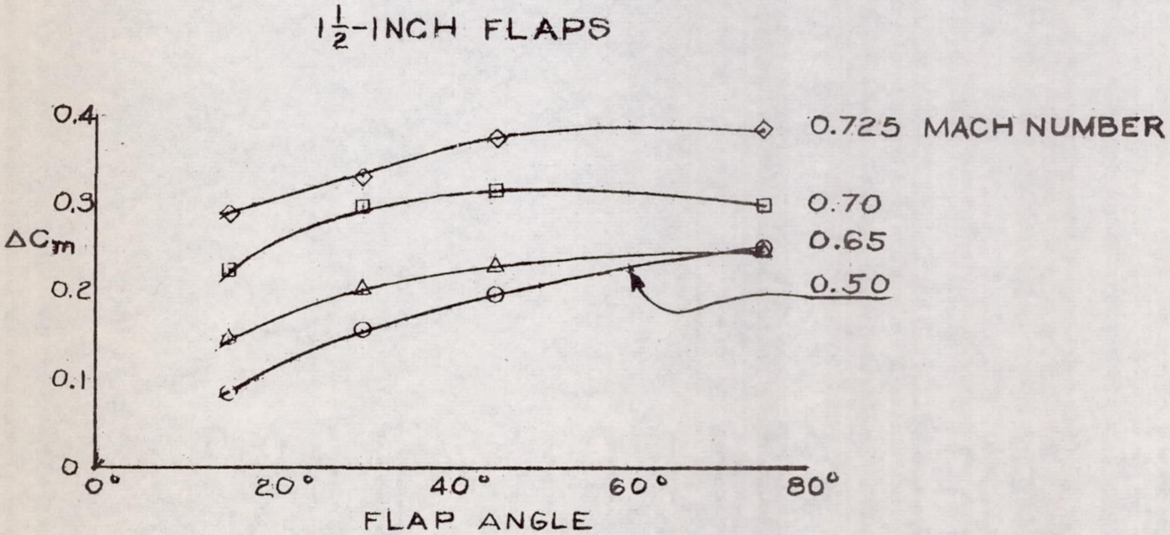
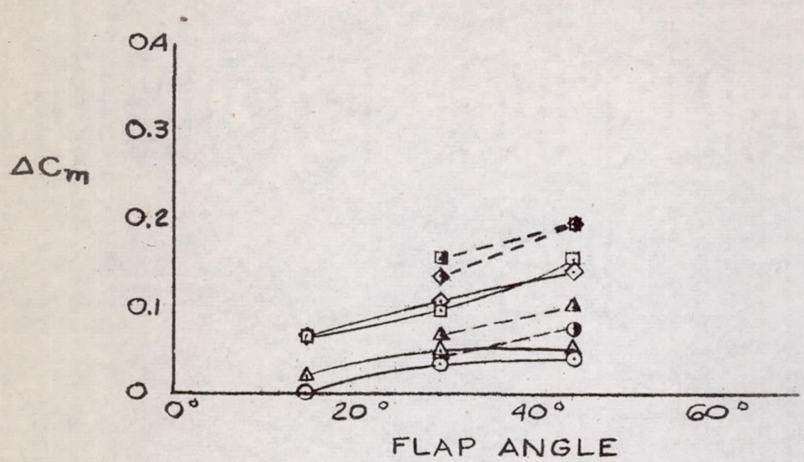



FIGURE 6 .-EFFECT OF INBOARD FLAPS AT 35% CHORD ON MOMENT COEFFICIENT FOR $C_L = 0.15$.

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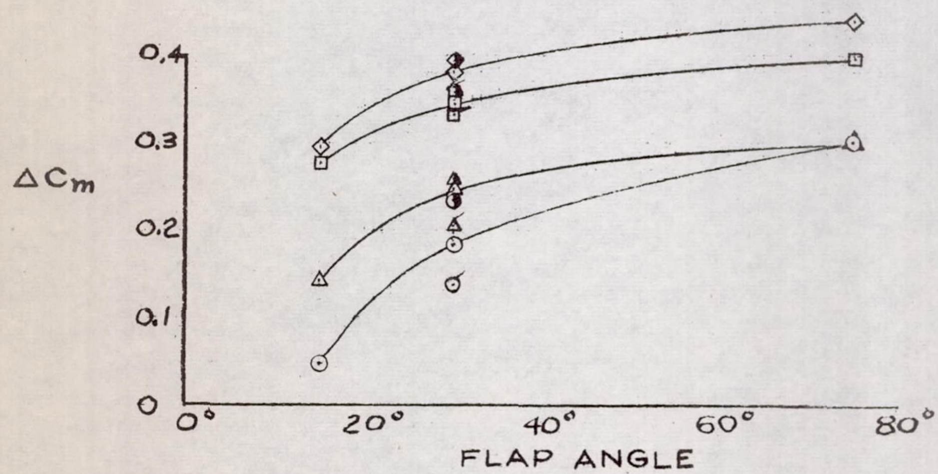



| MACH NUMBER | 0.50 | 0.65 | 0.70 | 0.725 |
|---|---|---|---|---|
| 0.66 INCH CHORD | | | | |
| 1.00 INCH CHORD | ⊙ | △ | ⊡ | ◇ |
| 2.00 INCH CHORD | ◑ | ▲ | ◧ | ◆ |

FIGURE 7 .- EFFECT OF OUTBOARD AND INBOARD-OUTBOARD FLAPS AT 33% CHORD ON MOMENT COEFFICIENT FOR $C_L = 0.15$.

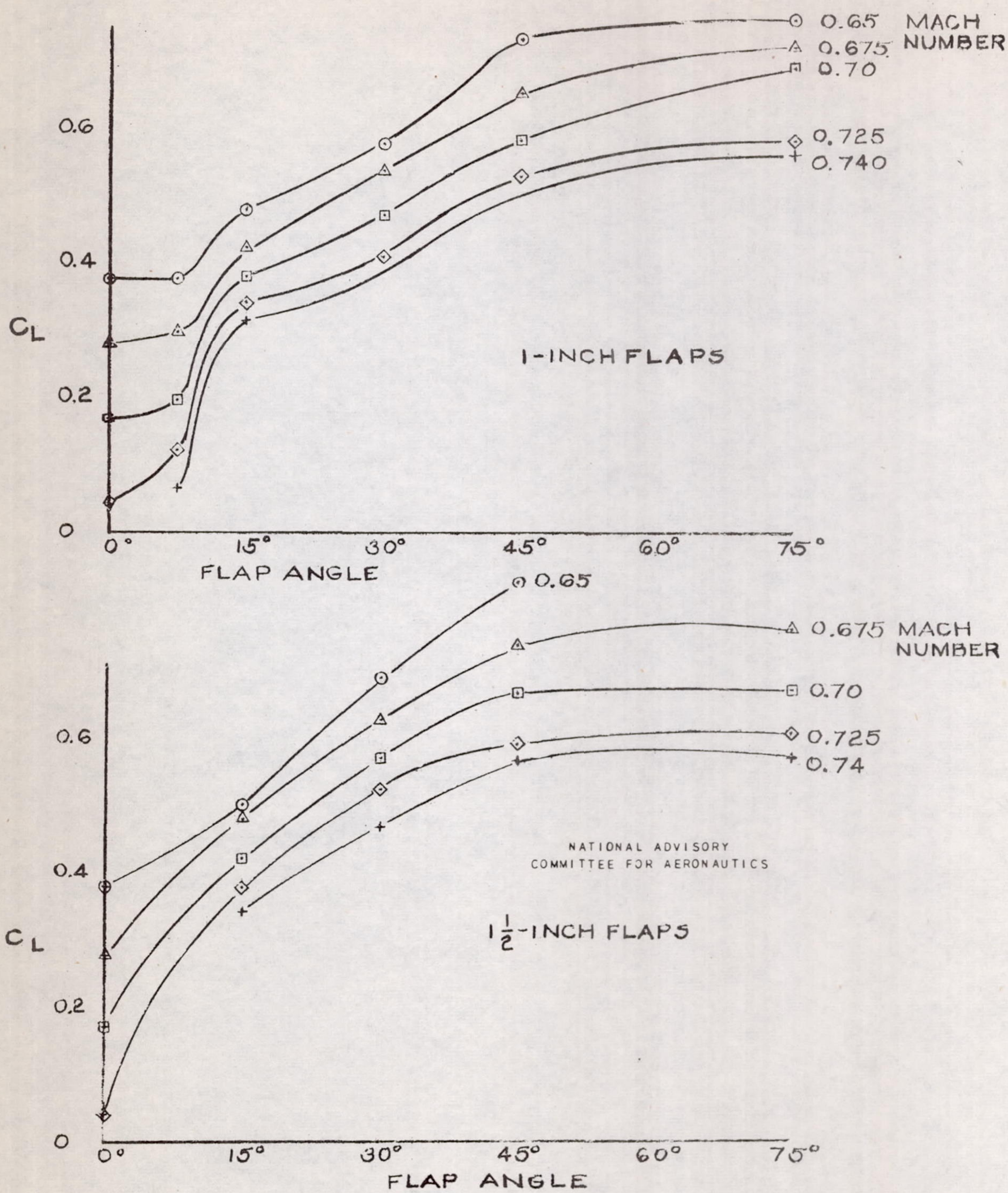



FIGURE 8.- EFFECT OF FLAP ANGLE ON THE $C_L$ AT BALANCE, ELEVATOR AND STABILIZER AT 0°, FLAPS INBOARD AT 33% CHORD.

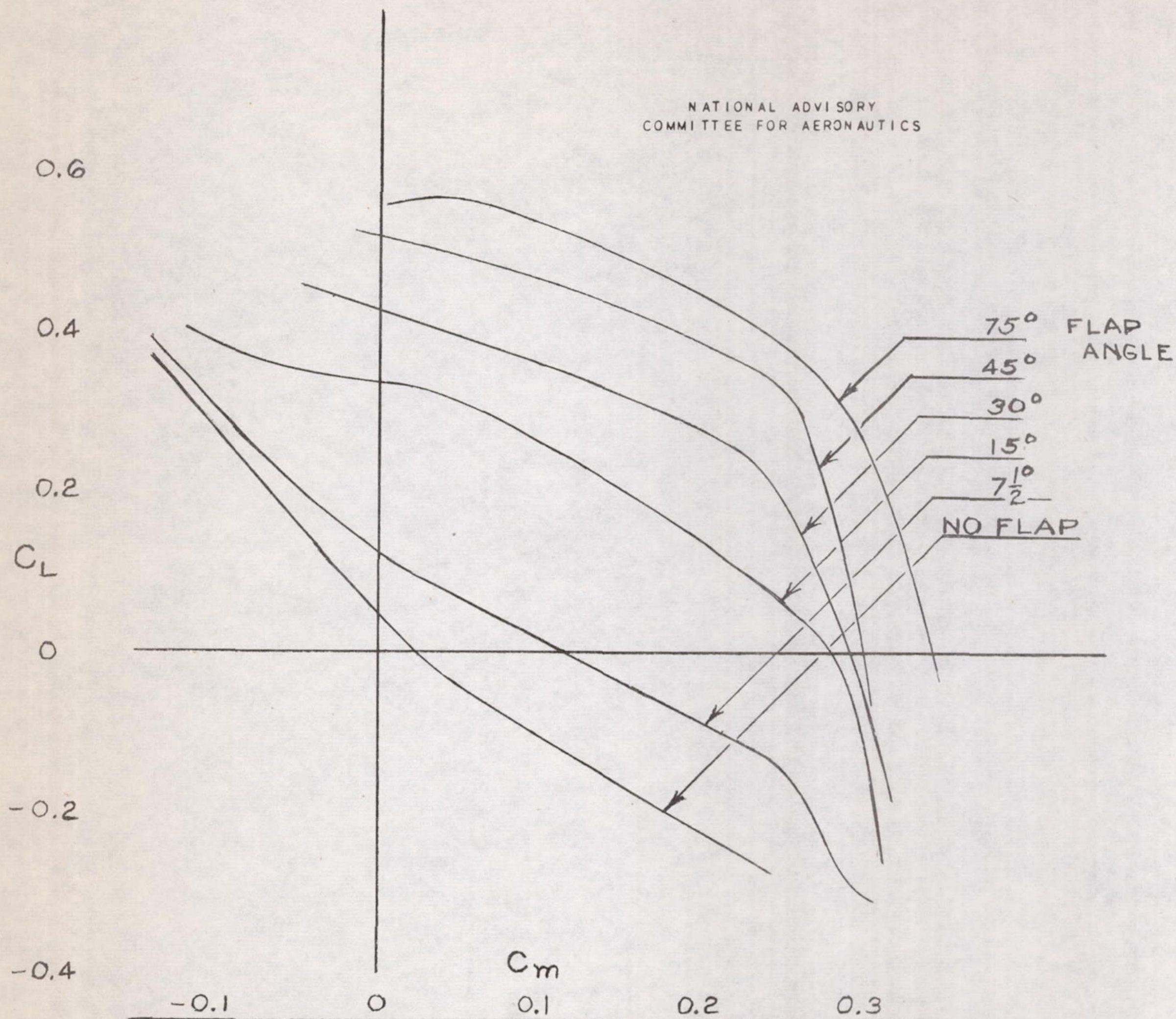



FIGURE 9.–EFFECT OF FLAP ANGLE ON MOMENT AT M = 0.725. ONE-INCH PLAPS INBOARD AT 33% CHORD.

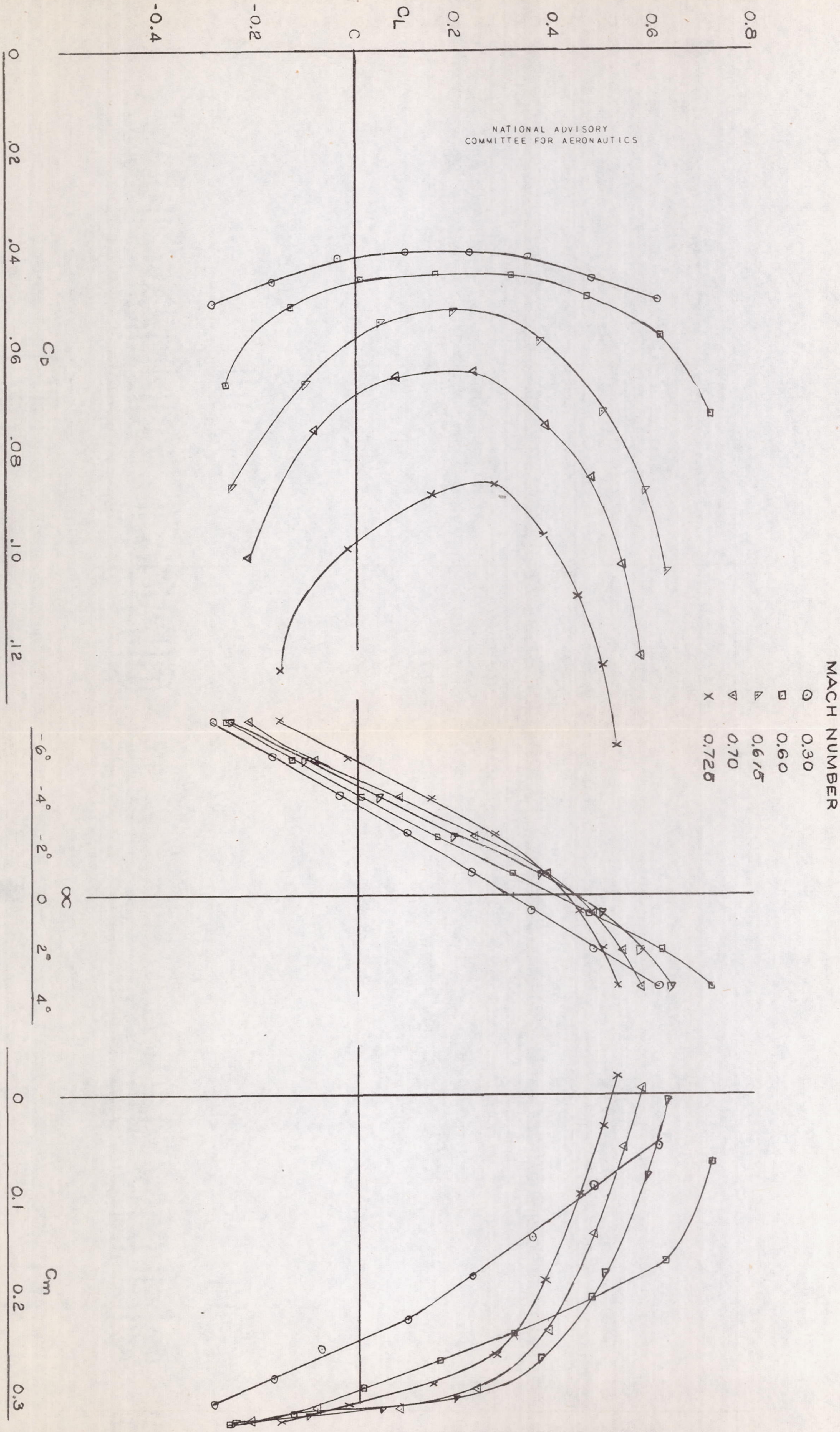



FIGURE 10.-AERODYNAMIC CHARACTERISTICS FOR STANDARD MODEL WITH $1\frac{1}{2}$-INCH 30° FLAPS INBOARD OF BOOMS AT 33% CHORD ON LOWER SURFACE.

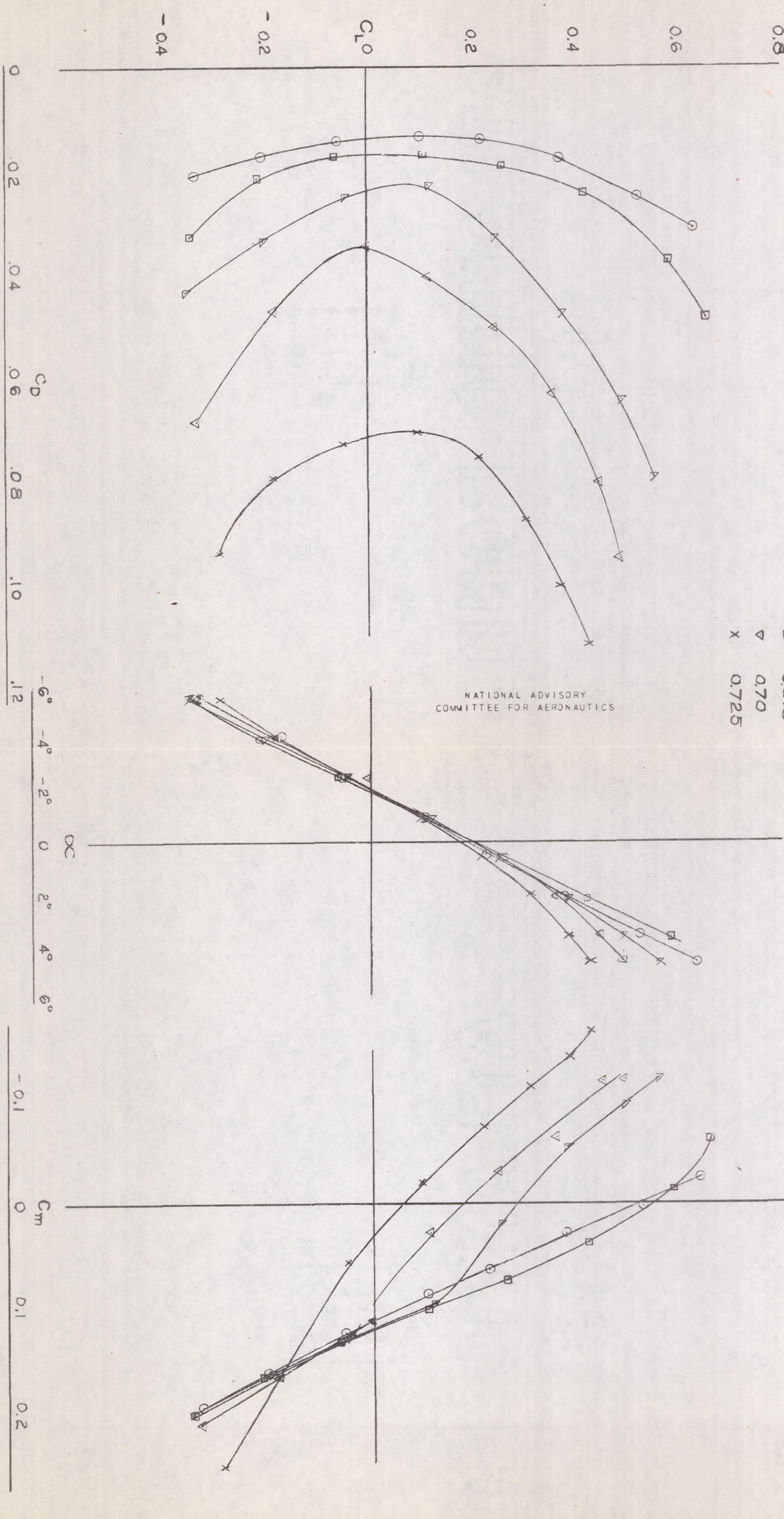
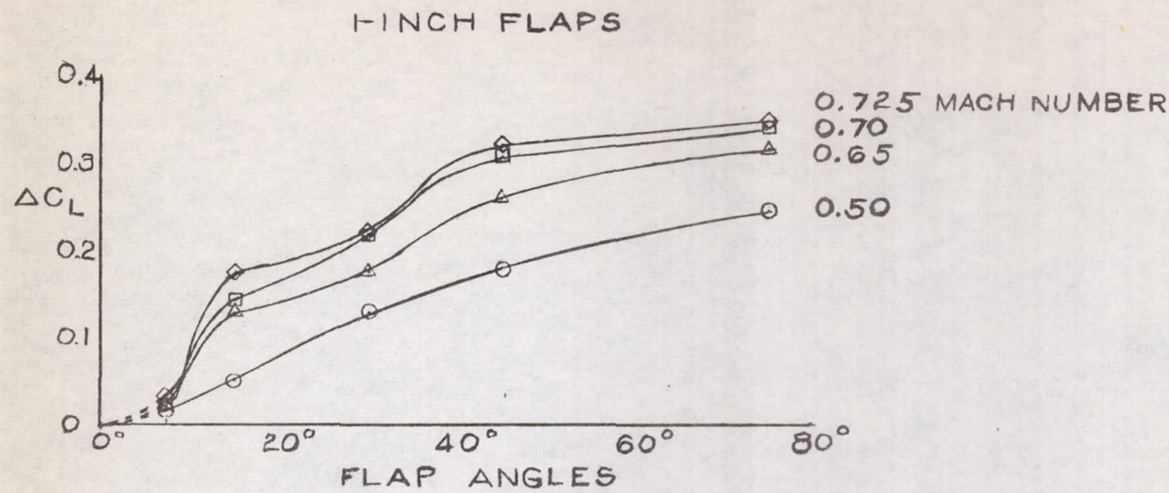



FIGURE 11.-AERODYNAMIC CHARACTERISTICS FOR STANDARD MODEL

A-66

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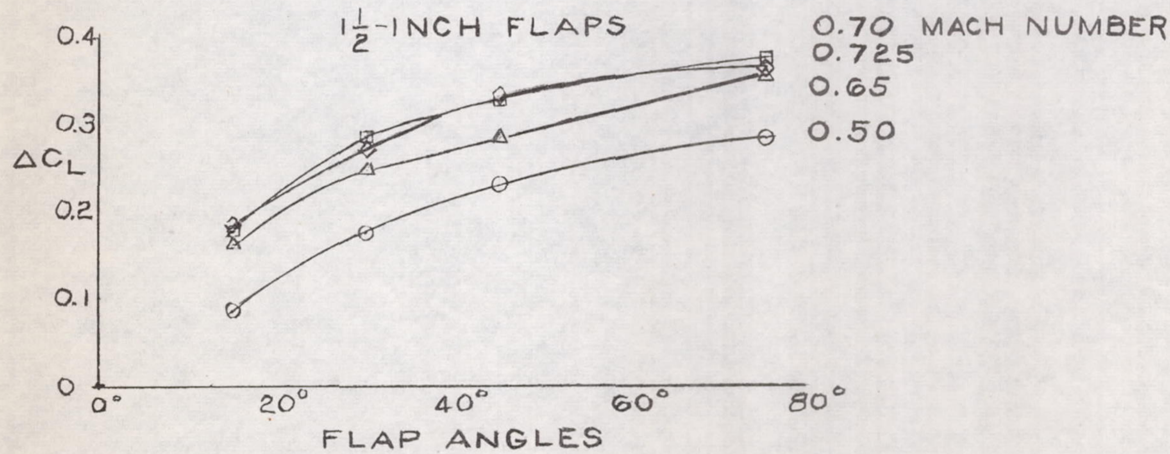



FIGURE 12.- EFFECT OF INBOARD FLAPS AT 33% CHORD ON LIFT COEFFICIENT FOR $\alpha = -1°$

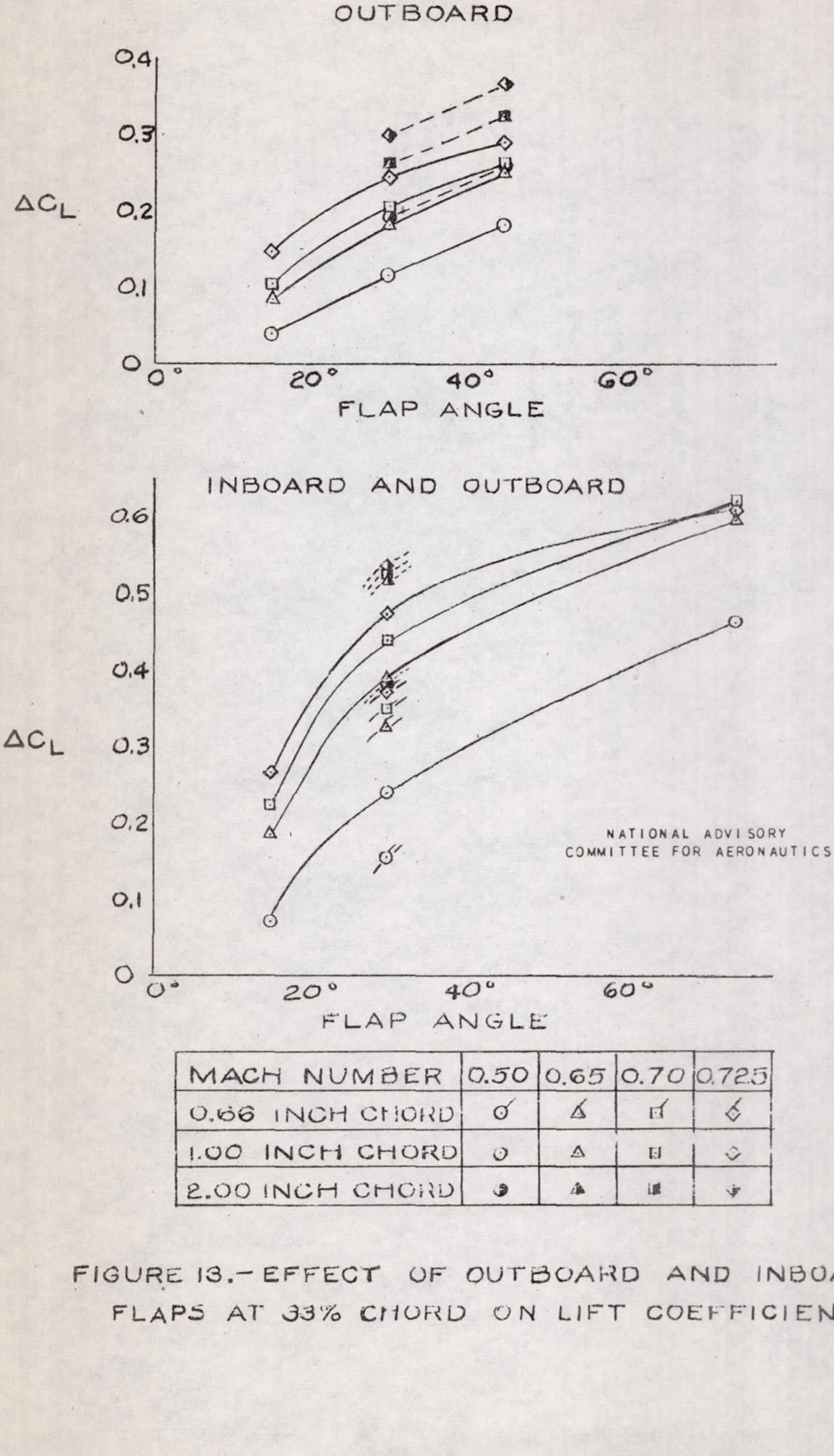
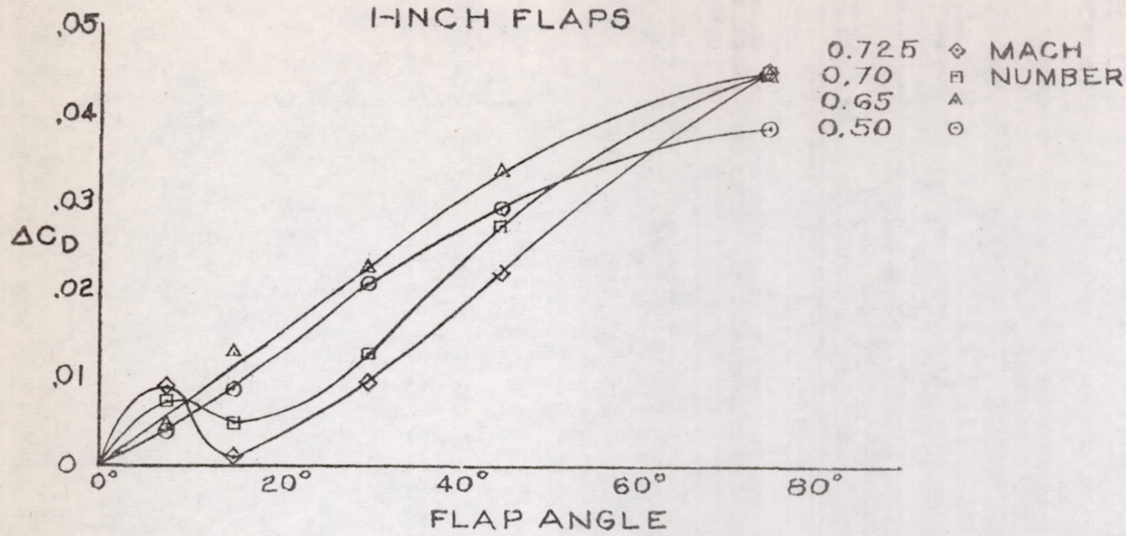



FIGURE 13.– EFFECT OF OUTBOARD AND INBOARD-OUTBOARD FLAPS AT 33% CHORD ON LIFT COEFFICIENT FOR $\alpha = -1°$.



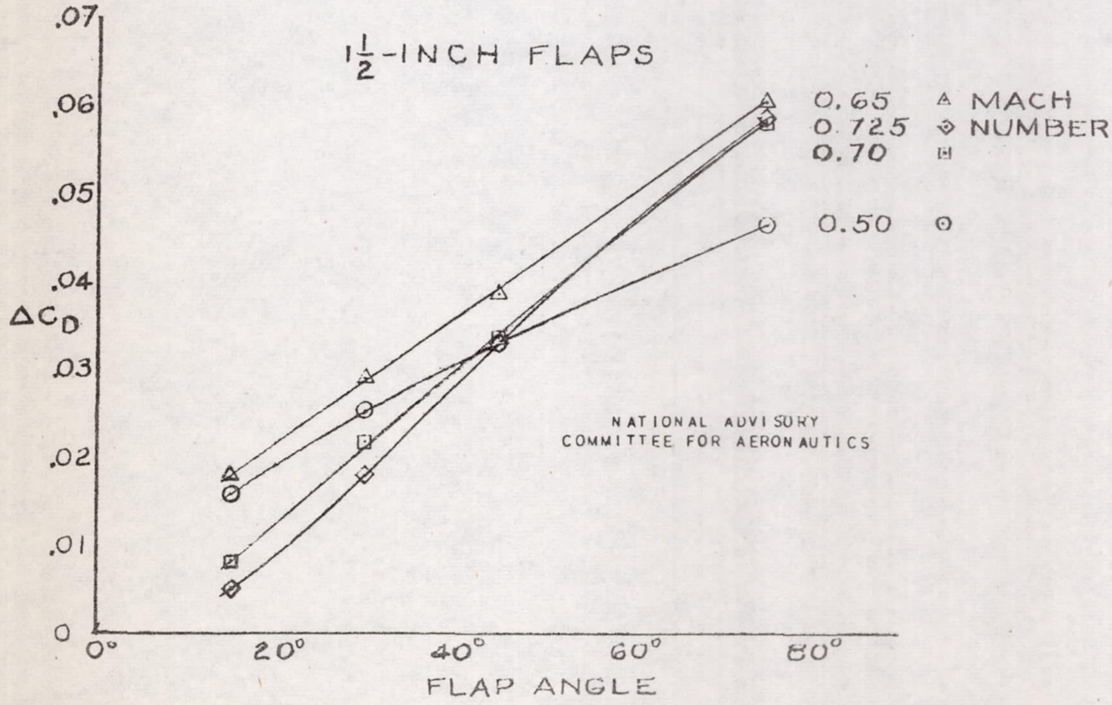




FIGURE 14.- EFFECT OF INBOARD FLAPS AT 33% CHORD ON DRAG COEFFICIENT FOR $C_L = 0.15$

A-66

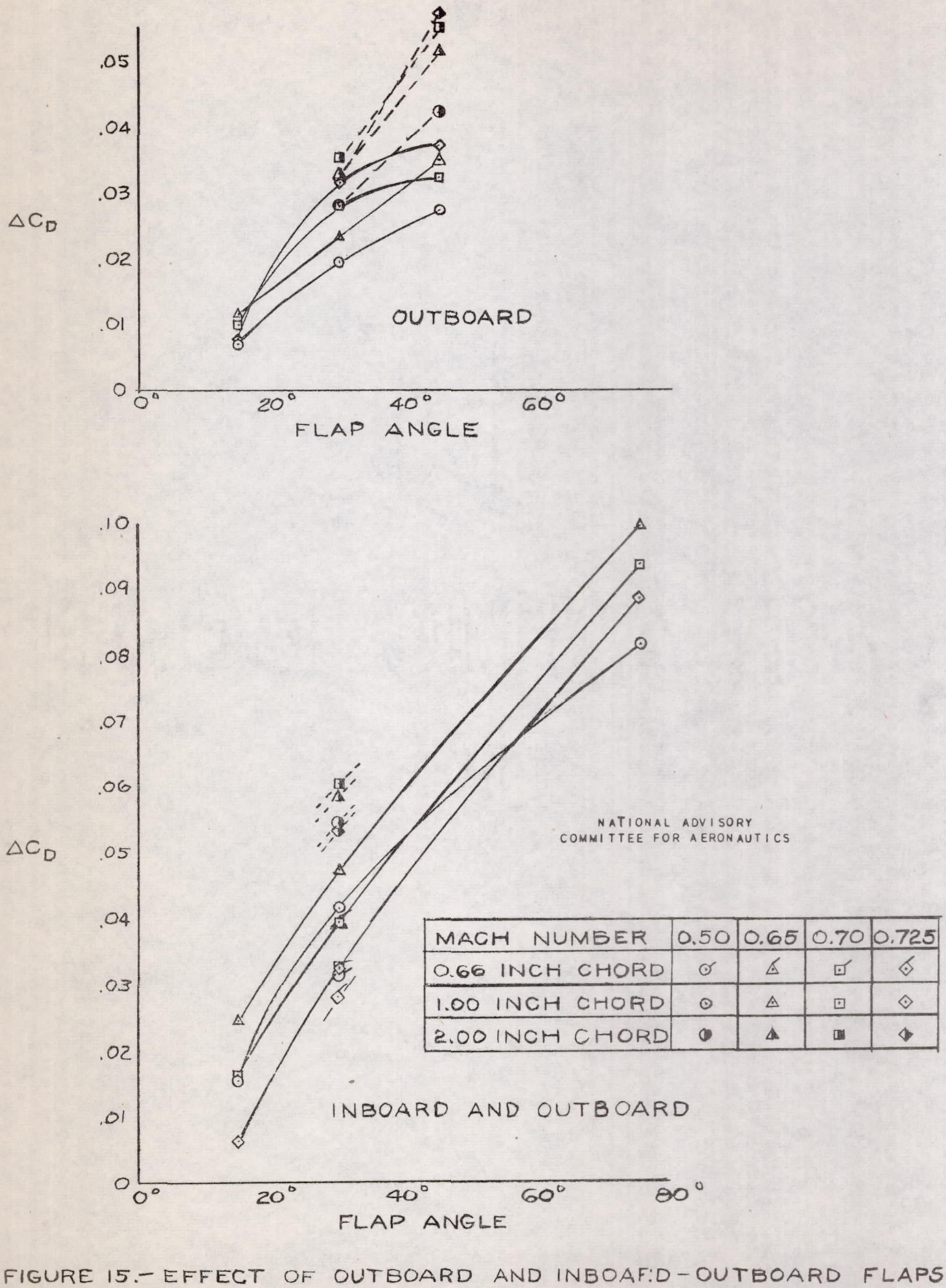



FIGURE 15.– EFFECT OF OUTBOARD AND INBOARD–OUTBOARD FLAPS AT 33% CHORD ON DRAG COEFFICIENT FOR $C_L = 0.15$.

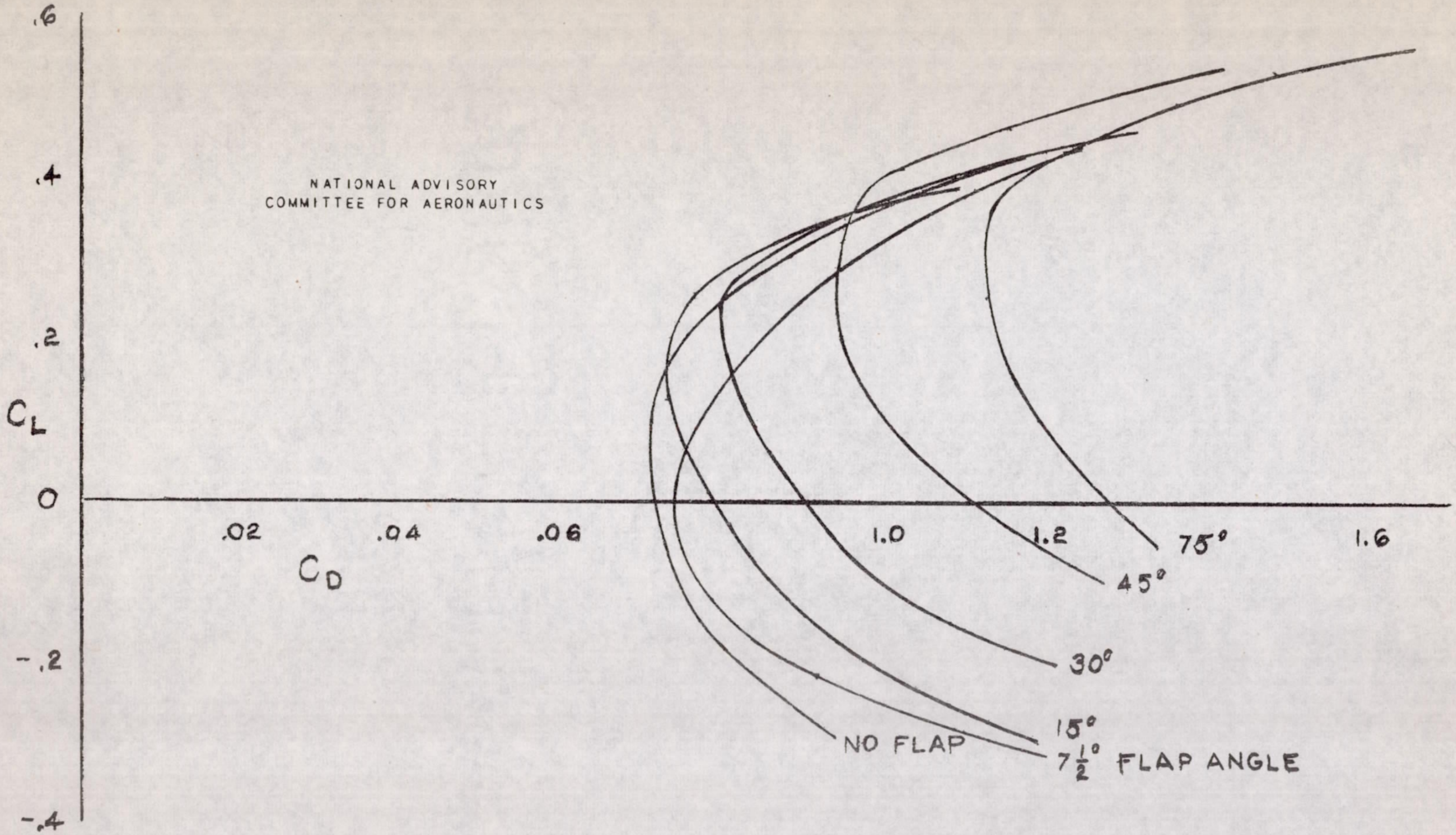



FIGURE 16.- EFFECT OF FLAP ANGLE ON DRAG AT M=0.725
ONE-INCH FLAPS INBOARD AT 33% CHORD.

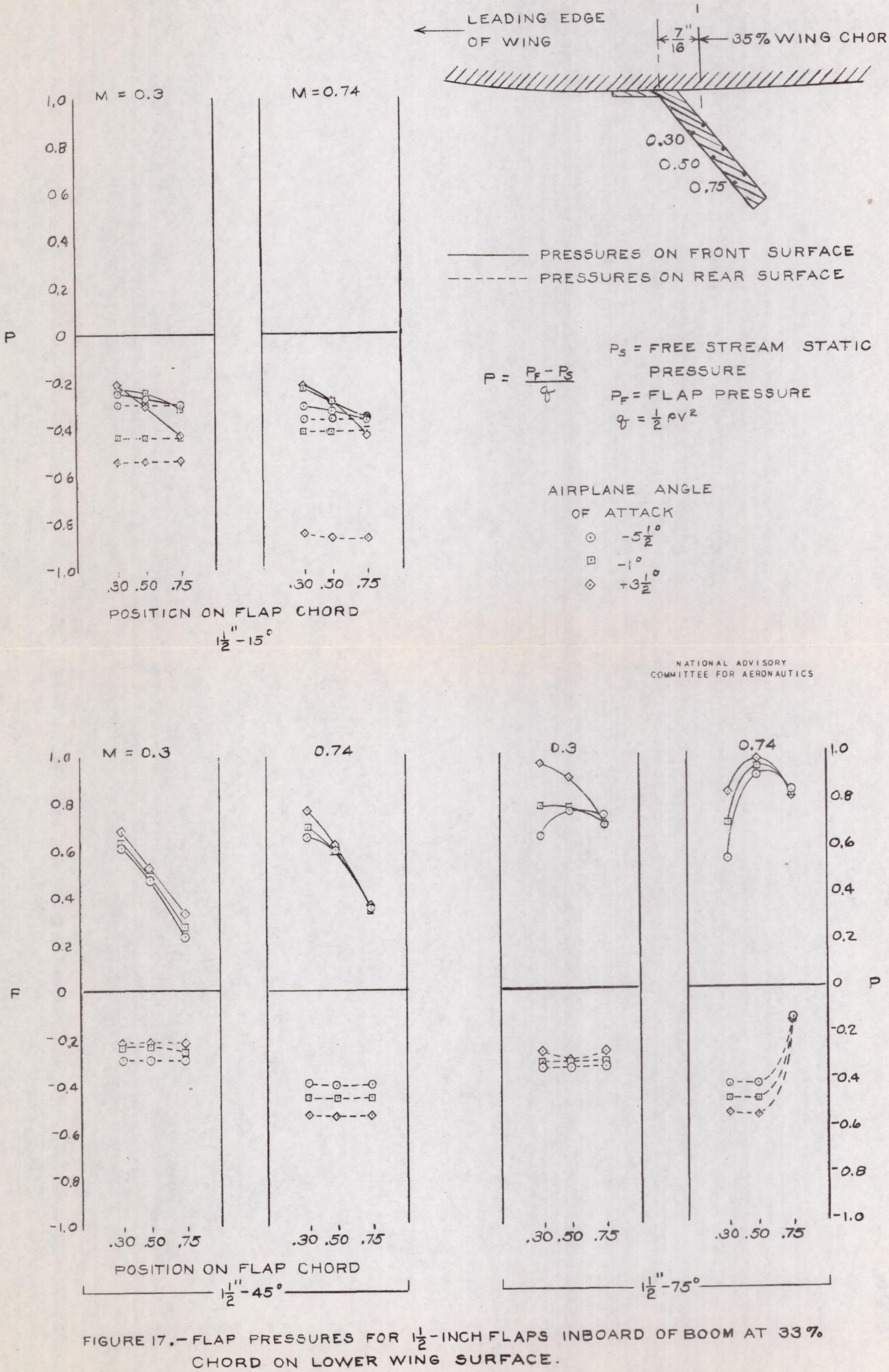



FIGURE 17.- FLAP PRESSURES FOR $1\frac{1}{2}$-INCH FLAPS INBOARD OF BOOM AT 33% CHORD ON LOWER WING SURFACE.

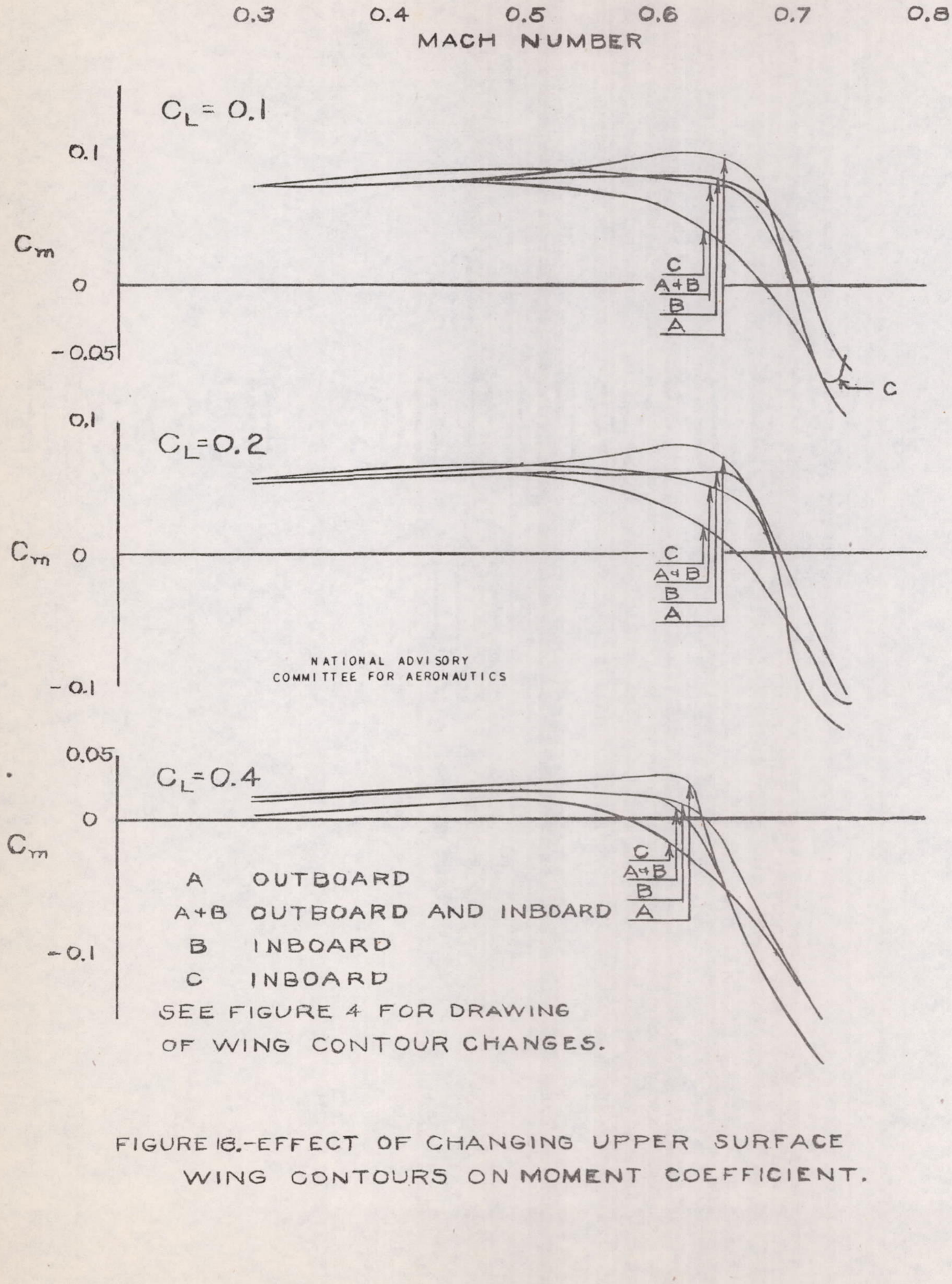



FIGURE 18.-EFFECT OF CHANGING UPPER SURFACE WING CONTOURS ON MOMENT COEFFICIENT.

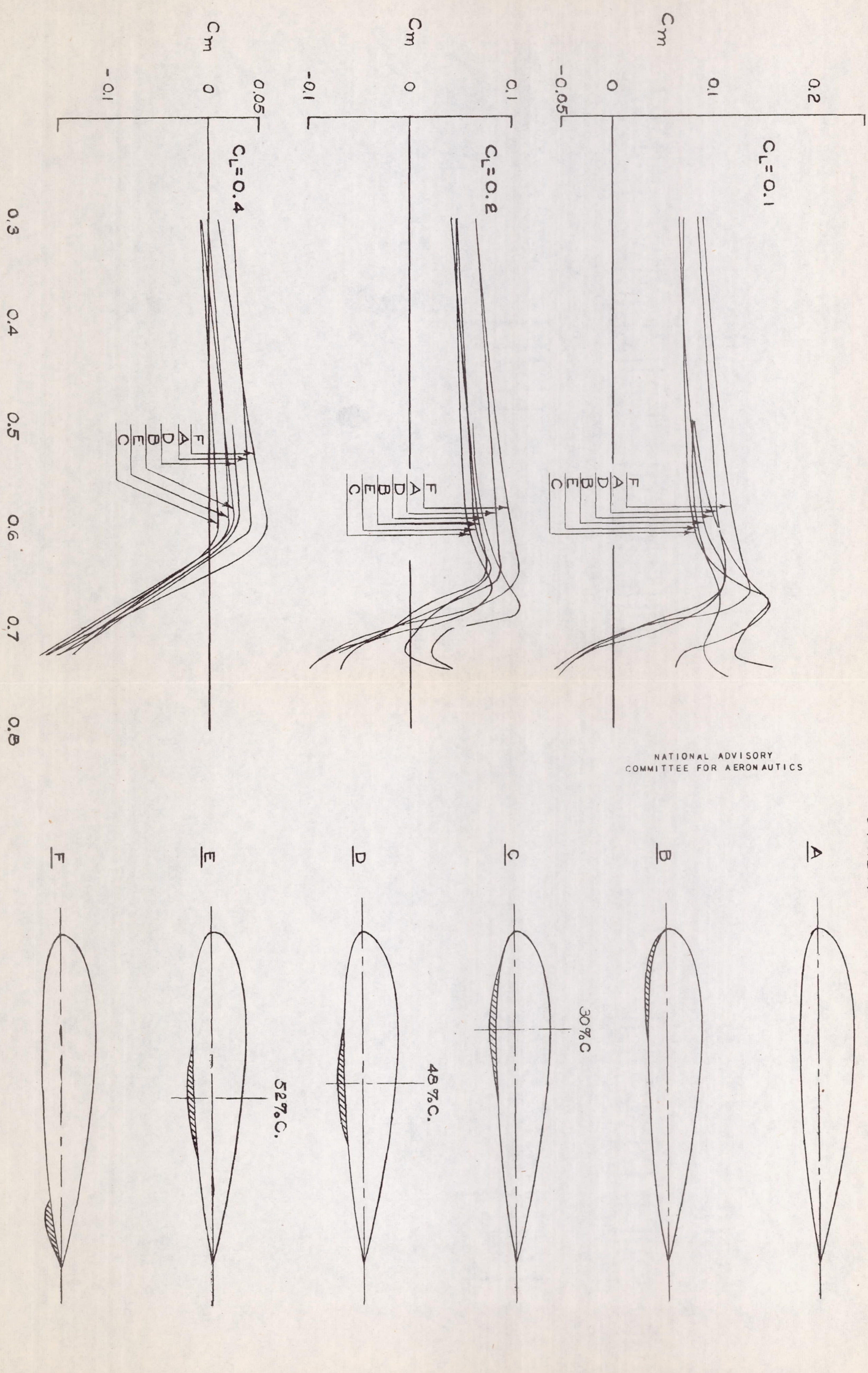



FIGURE 19.- EFFECT ON MOMENT COEFFICIENT OF CHANGING LOWER SURFACE WING CONTOUR.

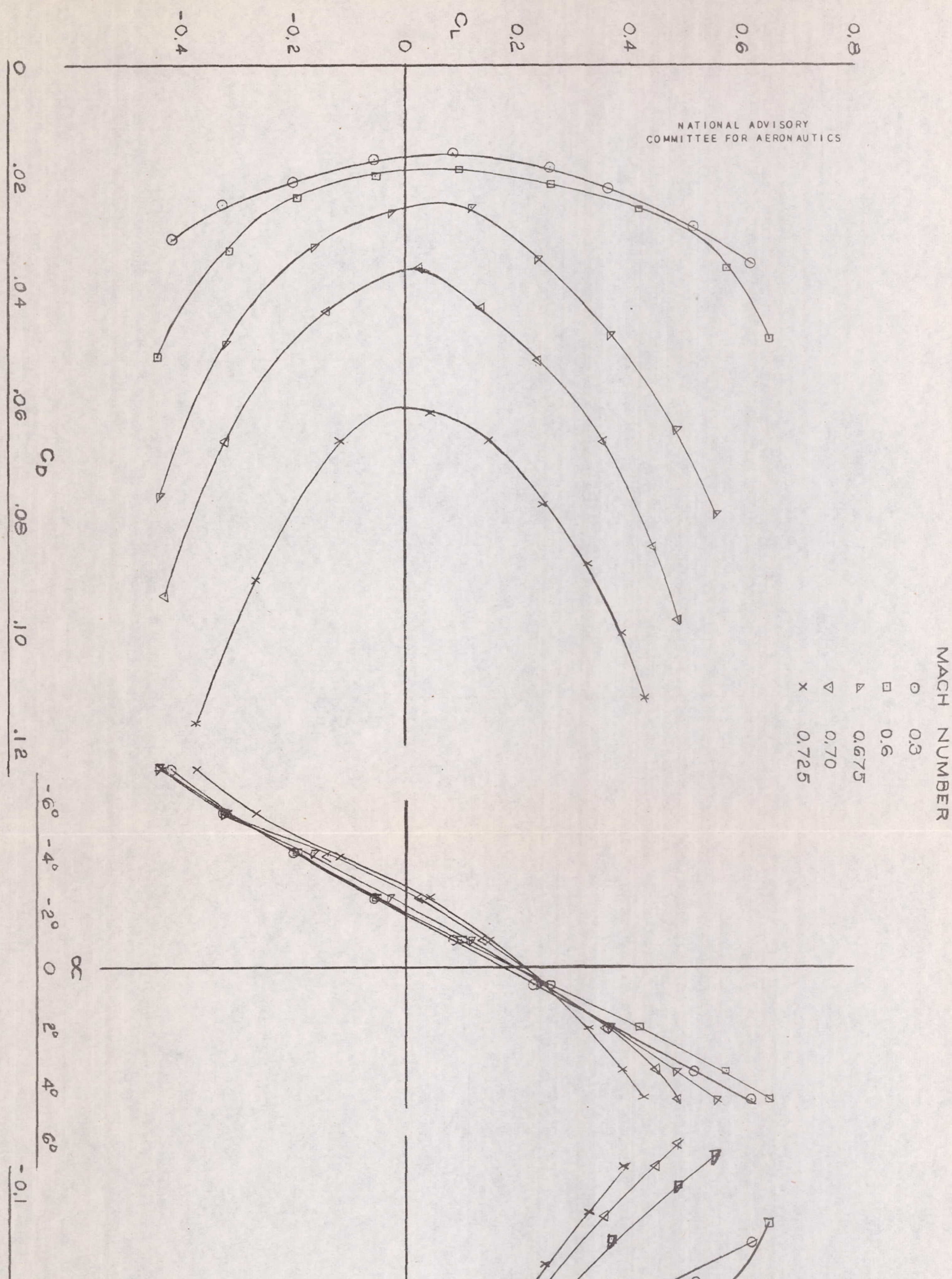



FIGURE 20.-AERODYNAMIC CHARACTERISTICS FOR STANDARD MODEL WITH WING CONTOUR CHANGE AT 52% CHORD ON LOWER SURFACE.

A-66

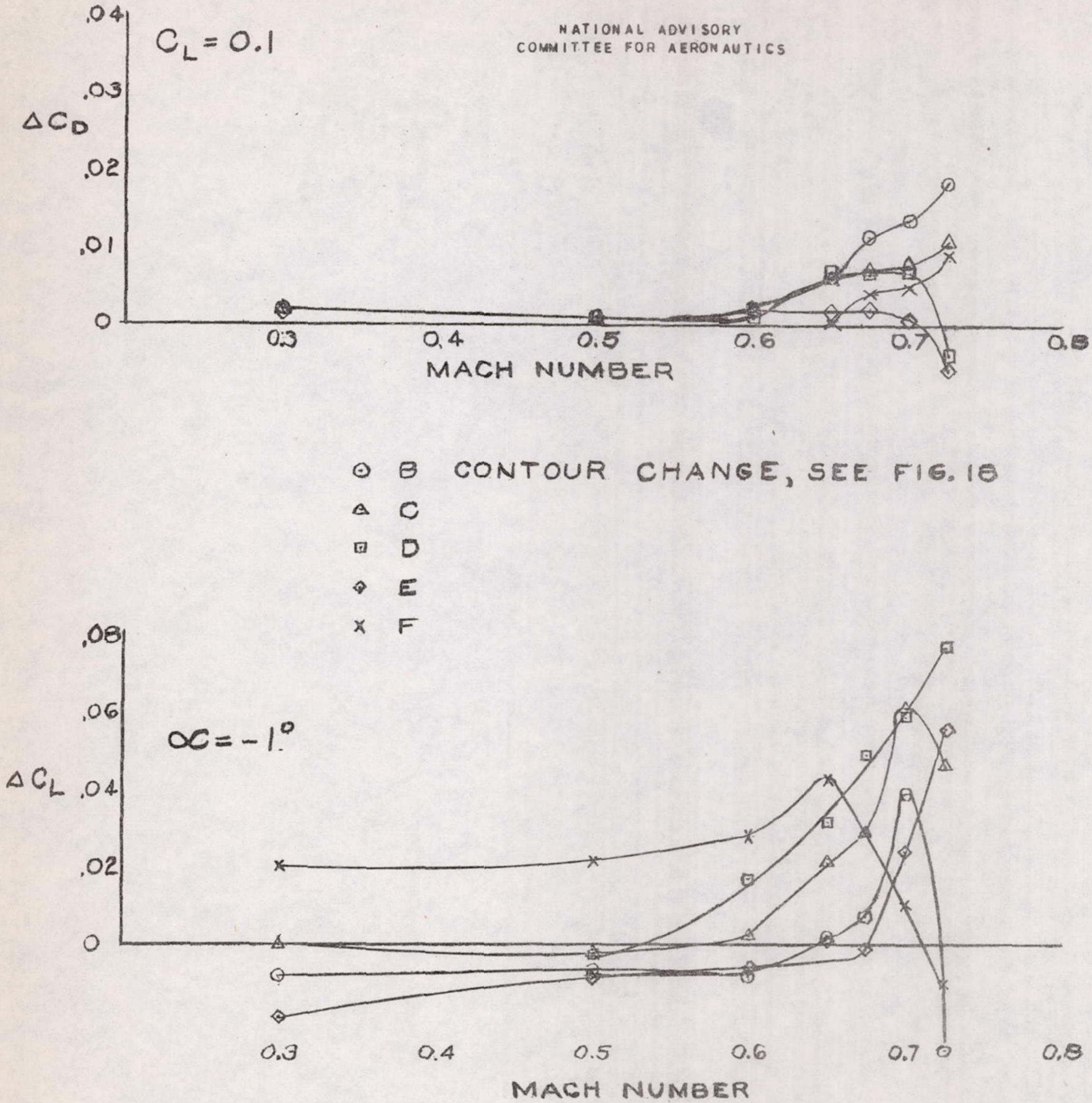
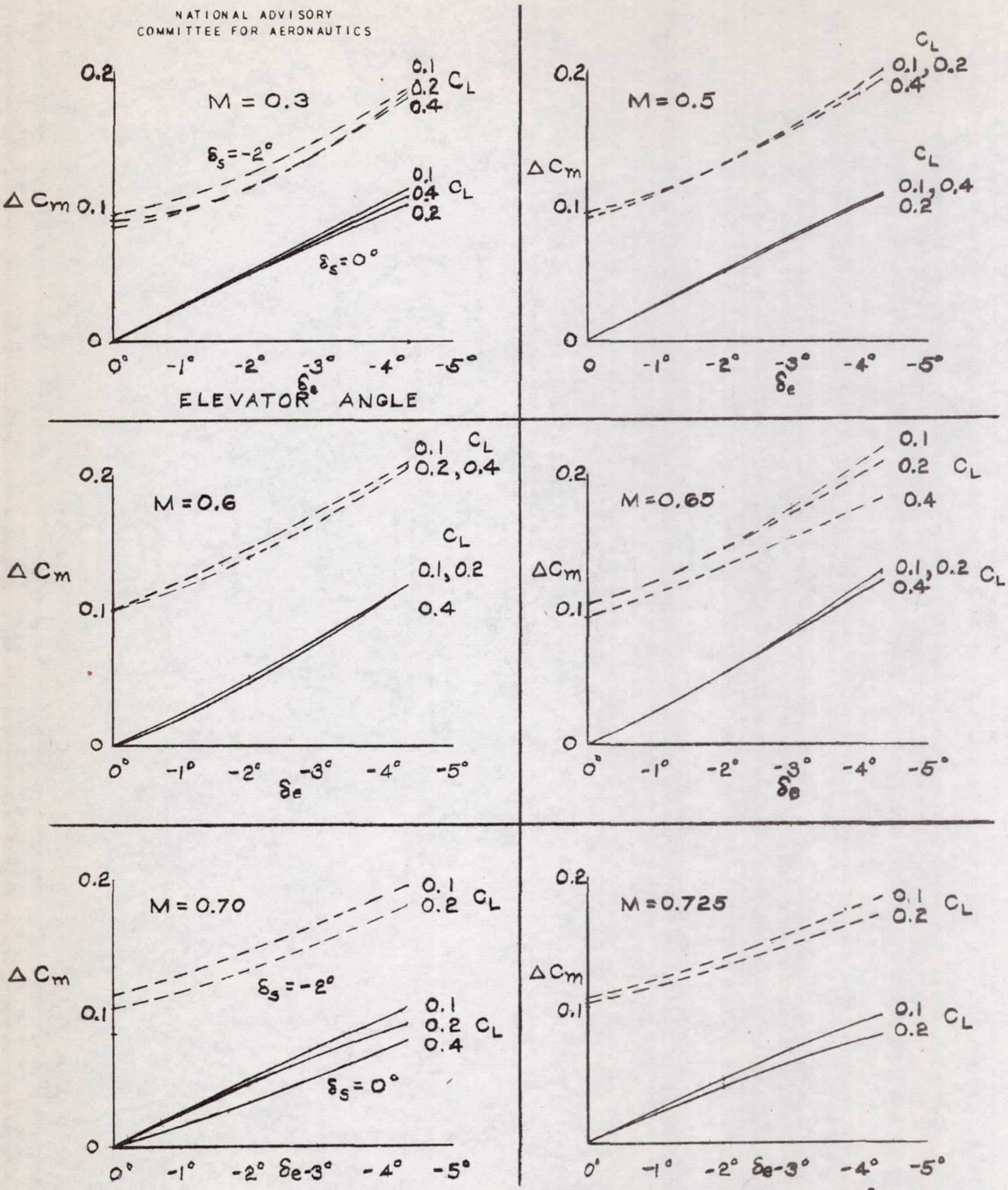



FIGURE 21.—EFFECT OF CHANGING LOWER SURFACE WING CONTOURS ON LIFT AND DRAG.




DASHED LINES FOR STABILIZER AT -2°
SOLID " " " " 0°

FIGURE 22.- EFFECT OF ELEVATOR AND STABILIZER ANGLE ON MOMENT COEFFICIENT.