TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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WIND-TUNNEL INVESTIGATION OF FUSELAGE STABILITY IN YAW WITH VARIOUS ARRANGEMENTS OF FINS

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SUMMARY

An investigation was made in the 7- by 10-foot wind tunnel to determine the effects of dorsal-type fins and of various arrangements of fins on the aerodynamic characteristics of a streamline circular fuselage. Comparative plots of the aerodynamic characteristics of the fuselage alone and the fuselage with various fin arrangements are given to show their effects on coefficients of yawing moment, drag, and lateral force. Results are also given for one case in which a rear fin on a circular fuselage was faired with modeling clay to obtain a fuselage shape with the same side elevation as the fuselage with the unfaired fin but with an elliptical cross section over the rearward portion of the fuselage.

The results indicated that fin area to the rear of the center of gravity of the fuselage was beneficial in reducing the magnitude of the unstable yawing moments at large angles of yaw; whereas, fin area forward of the center of gravity was harmful. The dorsal-type fin was more effective for increasing the yawing stability of the fuselage than was a smoothly faired rearward portion with the same side elevation as the fuselage with the unfaired dorsal-type fin. The minimum drag coefficient and the slope of the curve of yawing-moment coefficient of the fuselage at zero yaw were unaffected by the addition of the fins, within the experimental accuracy of the tests.

INTRODUCTION

The greater portion of the fixed vertical tail surfaces of aircraft is required to counteract the directional instability of conventional fuselage shapes. Methods have therefore been suggested of reducing the maximum value of the unstable fuselage moment to permit a reduction of the vertical tail. One method, which has been employed on commercial aircraft, is the addition of a narrow strip of fin area, referred to as a "dorsal" fin, along the top center line of the fuselage ahead of the usual vertical tail surface. Another method is the shaping of the rear of the fuselage into a wedge, effectively adding fin area at the top and the bottom. A third method recently suggested is the addition of a sharp-edge protuberance along the vertical center line of the forward portion of the fuselage. It was thought that such a protuberance, by disturbing the flow over the down-wind side of the yawed fuselage, might decrease the magnitude of the negative pressure in that region forward of the center of gravity and thereby reduce the unstable moment.

These methods are primarily intended to reduce the maximum value of the fuselage yawing moment, which occurs at moderately large angles of yaw where vertical tail surfaces of conventional aspect ratios are normally stalled. Any reduction of slope of the yawing-moment curve in the vicinity of zero yaw is incidental. None of the methods is expected appreciably to increase the drag of the fuselage for the unyawed condition of the airplane.

In the reported investigation two fuselage shapes were tested in combination with fin area at various locations on the fuselage to prove the effectiveness of each of the three methods.

MODELS

The two fuselage shapes used in this investigation are shown in figures 1 and 2. One of these fuselages is a body of revolution that was previously used for the wing-fuselage investigation reported in reference 1. The other shape was obtained by fairing the rearward portion of the fuselage with modeling clay as shown in figures 2, 3, and 4. The fuselages will hereinafter be referred to as "fuselage A" and "fuselage B."

The fin arrangements used are also shown in figures 1 and 2. All fins except one of 1/32-inch-diameter wire were made of 1/32-inch sheet brass cut to conform to the fuselage shape. In this report the constant-width fins (fig. 1) will be called type 1, the tail-type fin (fig. 2) will be called type 2. The fins were soldered to the heads of flat-head wood screws, imbodded in the fuselage, which held the fins snugly against the fuselage to prevent air leakage under them.

The type 1 fins were made in four widths, 0.0312, 0.172, 0.344, and 0.688 inch, which are equal to 0.45, 2.5, 5.0, and 10.0 percent, respectively, of the maximum fuselage diameter. The fins were cut in sections so that they could be attached to the fuselage in various combinations. The fins attached to the forward portion of the fuselage are designated forward fins and those attached to the rearward portion of the body are designated rearward fins. The action of these rearward fins, although they are disposed symmetrically above and below the fuselage, should be similar to that of the dorsal-type fin used on several present-day transports.

The type 2 fin was made to be attached to the rearward portion of fuselage A. This fin has a width at the trailing edge 50 percent of the fuselage diameter and is faired into the top and the bottom contours of fuselage A at a station 70 percent from the fuselage nose.

TESTS

The tests were made in the NACA 7- by 10-foot wind tunnel, which is described in references 2 and 3. The tests were made at a dynamic pressure of 16.37 pounds per square foot, which corresponds to a velocity of about 80 miles per hour under standard sea-level conditions and to a test Reynolds number of about 618,000 based on the cube root of the fuselage volume (0.846 ft).

No preliminary tests were made to determine the tare forces and the moments caused by the model-support fittings because it was believed that the relative merit of the various arrangements would be unaffected by the values of tare.

The tests were made at zero angle of attack and at angles of yaw, ψ, ranging from $-10°$ to $60°$.

RESULTS AND DISCUSSION

The results of the tests are given in the form of NACA standard coefficients of forces and moments with respect to the wind axes that intersect at the center-of-gravity location previously used in reference 1 and shown in figure 1.

The coefficients used are based on the volume of fuselage A in accordance with the procedure of reference 4, and are defined as follows:

C_D drag coefficient $\left[\frac{\text{drag}}{q(V)^{2/3}}\right]$

$C_Y{}'$ lateral-force coefficient $\left[\frac{\text{lateral force}}{q(V)^{2/3}}\right]$

$C_n{}'$ yawing-moment coefficient $\left(\frac{\text{yawing moment about c.g.}}{qV}\right)$

where

q dynamic pressure (16.37 lb/sq ft)

V volume of fuselage A (0.606 cu ft)

The effect of the rearward fins on the aerodynamic characteristics of fuselage A is shown in figure 5. The curves of yawing-moment coefficient show that, with the 0.172-inch fin added to the rearward portion of the fuselage, the maximum value of the unstable yawing moment is reduced by more than half. Increasing the fin height progressively decreased the maximum unstable yawing moment and the trim angle. The effectiveness of increasing the fin height, however, became progressively smaller with height. The type 2 fin was only slightly more effective than the 0.172-inch type 1 fin although its area-moment is nearly equal to that of the 0.344-inch type 1 fin. This result, coupled with the fact that the effectiveness of the type 1 fins was not proportional to the fin height, appears to indicate that the effectiveness of these fins primarily depends on the length of the sharp edges and their spoiling effect depends on the type of flow over the rear portion of the fuselage. This conclusion appears to be substantiated by the drag curves, which show that the increase in drag at large angles of yaw is also less for the type 2 fin than the 0.344-inch type 1 fin.

The slope of the curve of the yawing-moment coefficient at small angles of yaw is appreciably reduced by the rearward fins. As expected, however, the reduction is small. The effect of the fins on the drag at zero yaw (normal-flight condition) was not measurable.

In order to check further on the relative effects of the sharp edges and the increased area back of the center of gravity, the unfaired type 2 fin on fuselage A has been compared with fuselage B in figure 6. Fuselage B, as previously mentioned, has the same side area as fuselage A plus the type 2 fin and was derived by fairing the type 2 fin into the fuselage tail with modeling clay to eliminate the sharp edges. Figure 6 shows that, although both the type 2 fin and fuselage B were less unstable than fuselage A, the improvement obtained from fuselage B was less than half that obtained from the type 2 fin. It is therefore apparent that the sharp edges of the unfaired fin were advantageous in reducing the unstable yawing-moment coefficients of the fuselage shapes.

Fuselage A with the type 2 fin had the largest values of lateral-force coefficient at large angles of yaw, fuselage B had smaller values, and fuselage A alone had the smallest values. Inasmuch as a large lateral force is desirable for stability when sideslipping, fuselage A with the type 2 fin would also be better than fuselage B for this maneuver. The values of drag coefficient at large angles of yaw decreased in the same order as the values of lateral-force coefficient. The minimum drag coefficient at zero yaw was unaffected by fuselage shape or type 2 fin, within the experimental accuracy of the tests, in spite of the fact that the drag coefficients in every case were based on the volume of fuselage A.

The fins mounted forward (fig. 7) proved to be harmful to stability in yaw. The anticipated spoiler action did not occur and these forward fins are therefore undesirable. The lateral-force and drag coefficients increase with the angle of yaw and the fin width.

The comparative plots (fig. 8) for fins mounted in both forward and rearward locations show that these arrangements are in every case less desirable than the comparable arrangements with the rearward fin alone (fig. 5) from consideration of stability in yaw. The lateral-force and the drag coefficients for the combination forward-and-rearward location increase with increases in the angle of yaw and the fin area and are greater than for comparable arrangements of forward or rearward fins alone.

A comparison of the several locations of the fins with a width of 0.344 inch (fig. 9) shows that only combinations with the rearward fin decrease the unstable yawing-moment coefficient of the fuselage at large angles of yaw. The drag and the lateral-force coefficients at large angles of yaw, however, increase in proportion to an increase in the fin area. The drag and the stability in yaw at small angles of yaw are only slightly affected by the various locations of the 0.344-inch fin on fuselage A.

CONCLUSIONS

1. The rearward fins were very effective in decreasing the unstable yawing moment of the fuselage at the large angles of yaw.

2. The beneficial effects of the forward-and-rearward combination of fins and of the fin completely around the fuselage were due to the presence of the fin area behind the center of gravity of the model.

3. The sharp fin edges were found definitely beneficial at large angles of yaw.

4. The minimum drag coefficient and the slope of the curve of the yawing-moment coefficient of the fuselage at zero yaw were unaffected by the addition of the fins, within the experimental accuracy of the tests.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., October 22, 1940.

REFERENCES

1. Bamber, M. J., and House, R. O.: Wind-Tunnel Investigation of Effect of Yaw on Lateral-Stability Characteristics. II - Rectangular N.A.C.A. 23012 Wing with a Circular Fuselage and a Fin. T.N. No. 730, NACA, 1939.

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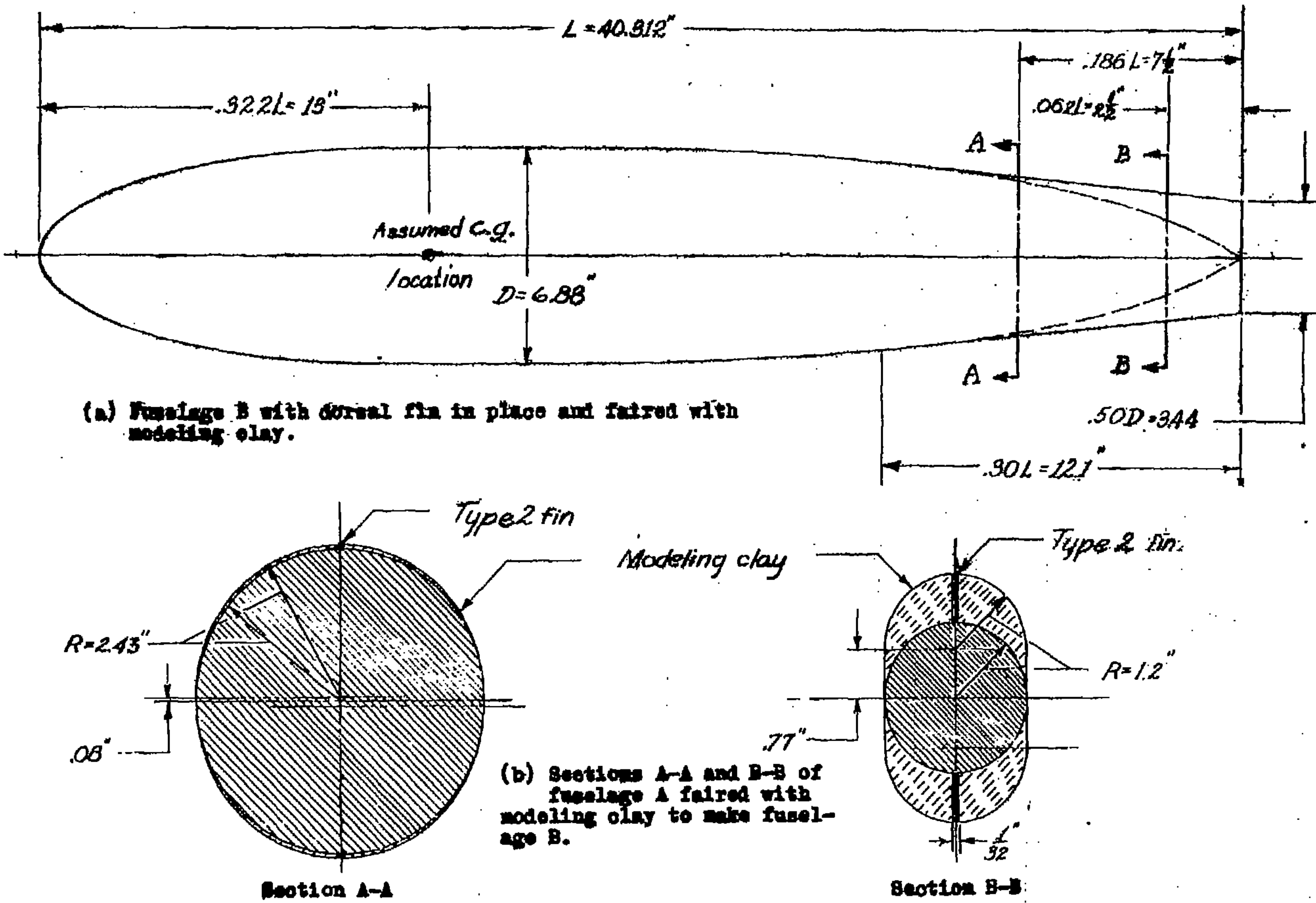
4. Freeman, Hugh B.: Force Measurements on a 1/40-Scale Model of the U. S. Airship "Akron." Rep. No. 432, NACA, 1932.



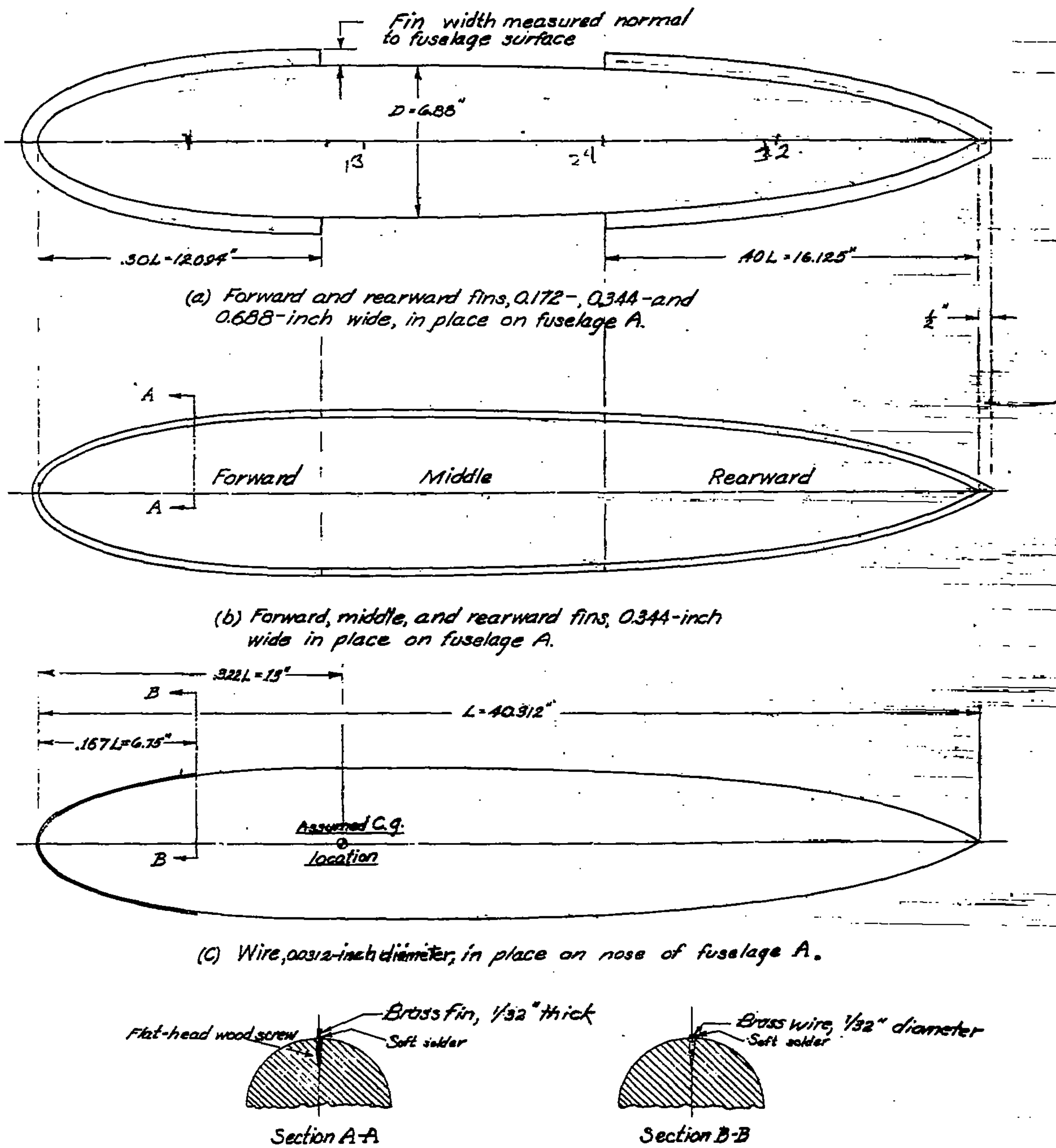
(a) Fuselage B with dorsal fin in place and faired with modeling clay.

(b) Sections A-A and B-B of fuselage A faired with modeling clay to make fuselage B.

Figure 2.- Circular fuselage A showing type 2 fin and fairing used to convert it into fuselage B.

Dimensions of circular fuselage A

Station from L.E. (in.)	Radius (in.)	Station from L.E. (in.)	Radius (in.)	Station from L.E. (in.)	Radius (in.)
0	0	8.312	3.288	32.312	2.516
.312	.772	12.312	3.410	34.312	2.170
.812	1.242	16.312	3.440	36.312	1.698
1.312	1.572	20.312	3.406	38.312	1.000
2.312	2.044	24.312	3.268	39.312	.548
4.312	2.650	28.312	2.990	40.312	0



(a) Forward and rearward fins, 0.172-, 0.344-and 0.688-inch wide, in place on fuselage A.

(b) Forward, middle, and rearward fins, 0.344-inch wide in place on fuselage A.

(C) Wire, 0.0312-inch diameter, in place on nose of fuselage A.

Figure 1.— Circular fuselage showing fin arrangements tested on fuselage A.

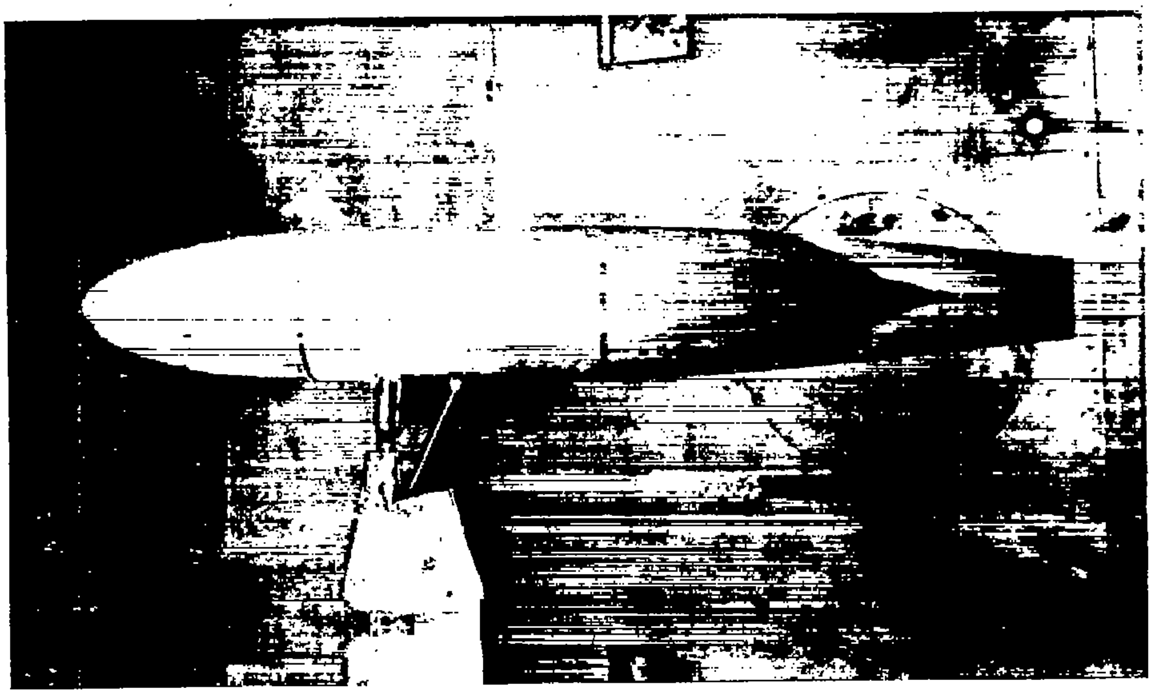


Figure 3.- Side view of streamline circular fuselage B with faired type 2 fin in place.mounted in the 7-by 10-foot wind tunnel.

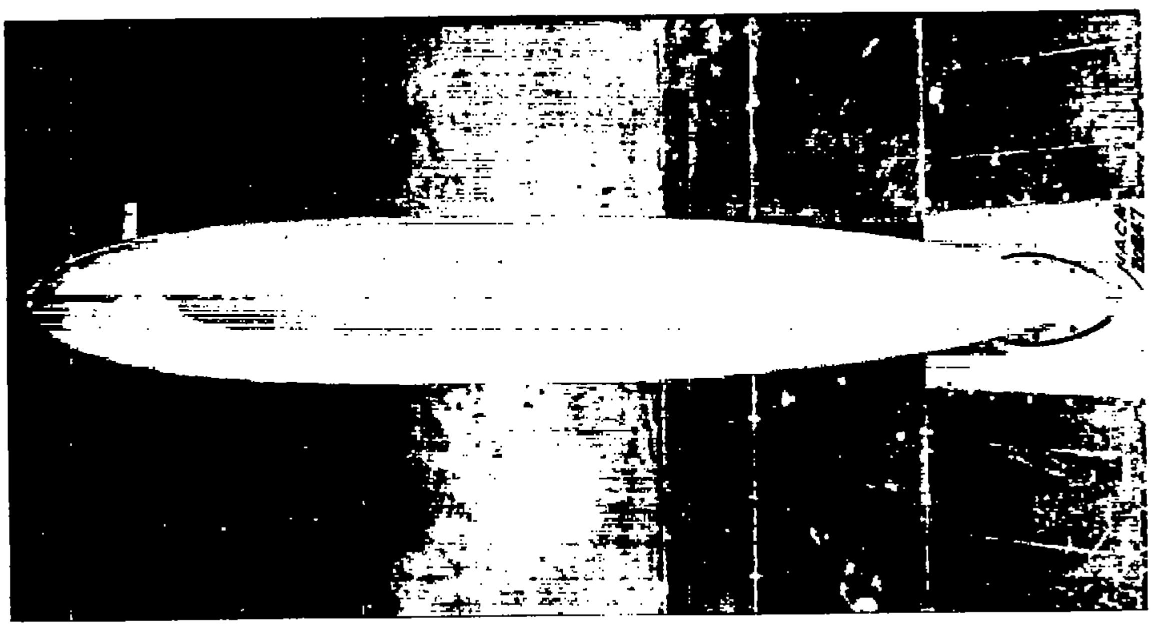


Figure 4.- Top view of fuselage B showing contour of clay fairing.

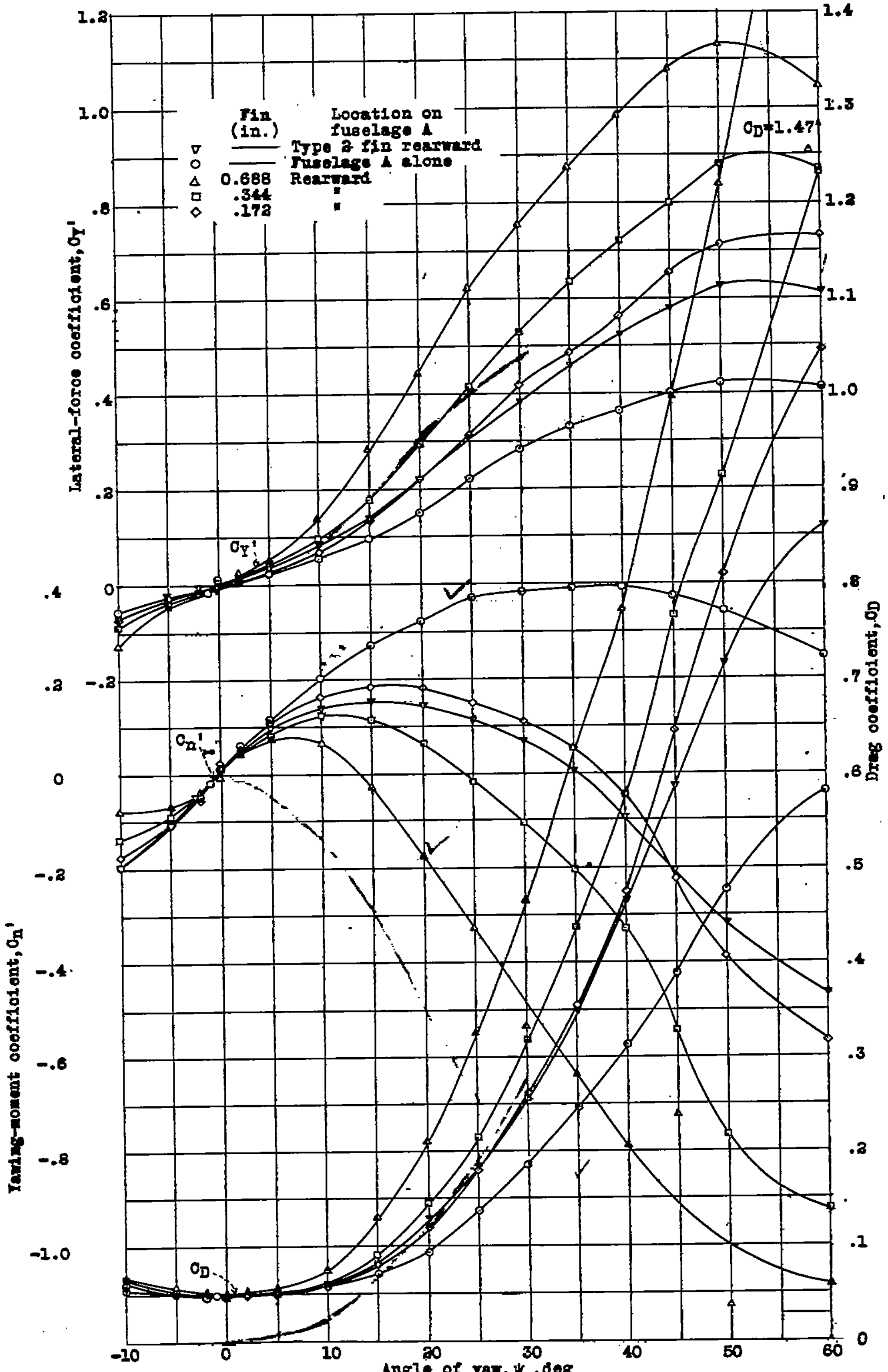


Figure 5.- Effect on fuselage characteristics of various fin arrangements rearward.

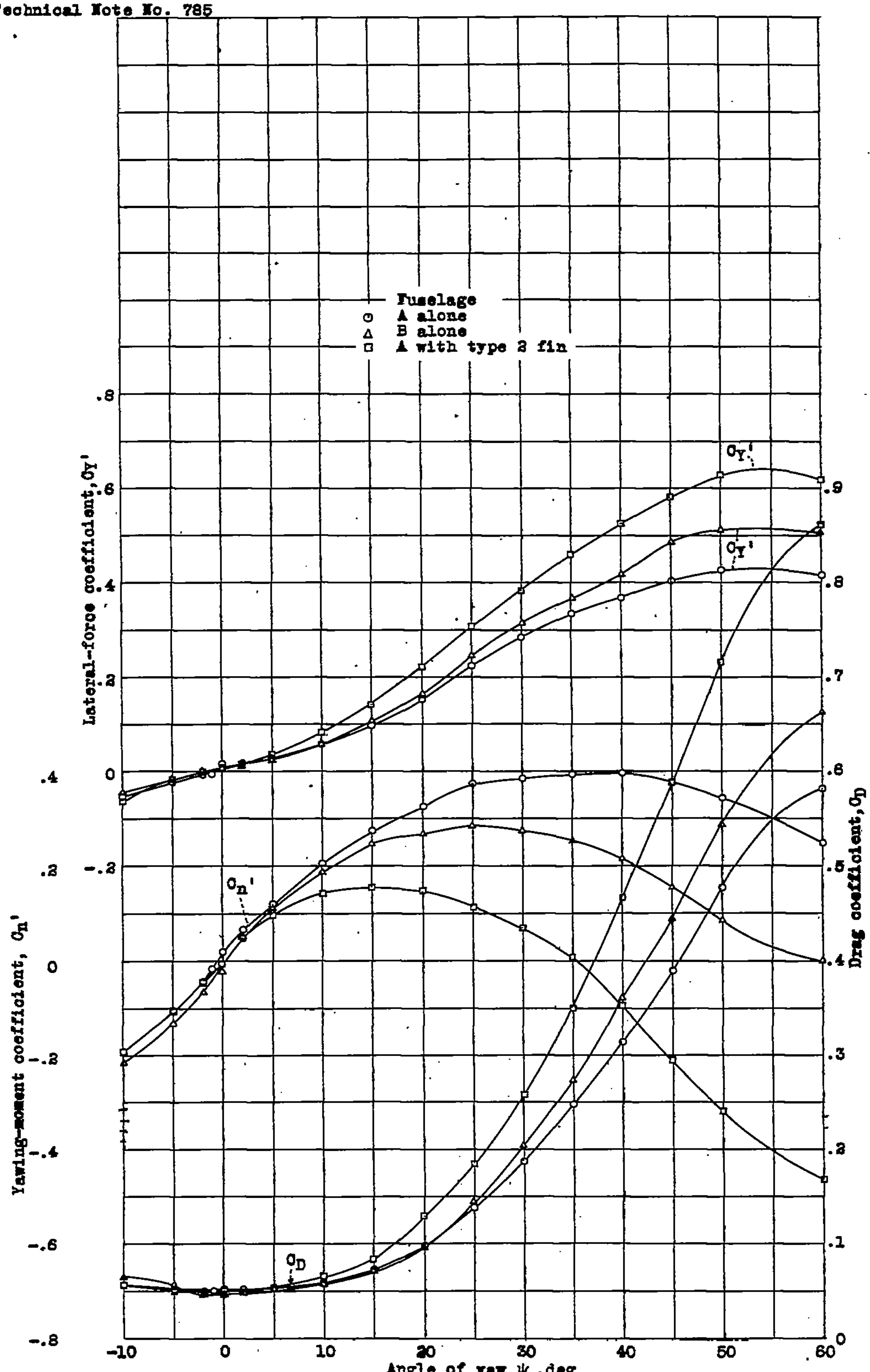


Figure 6.- Comparison of aerodynamic characteristics of fuselage A alone, fuselage A with type 2 fin, and fuselage B.

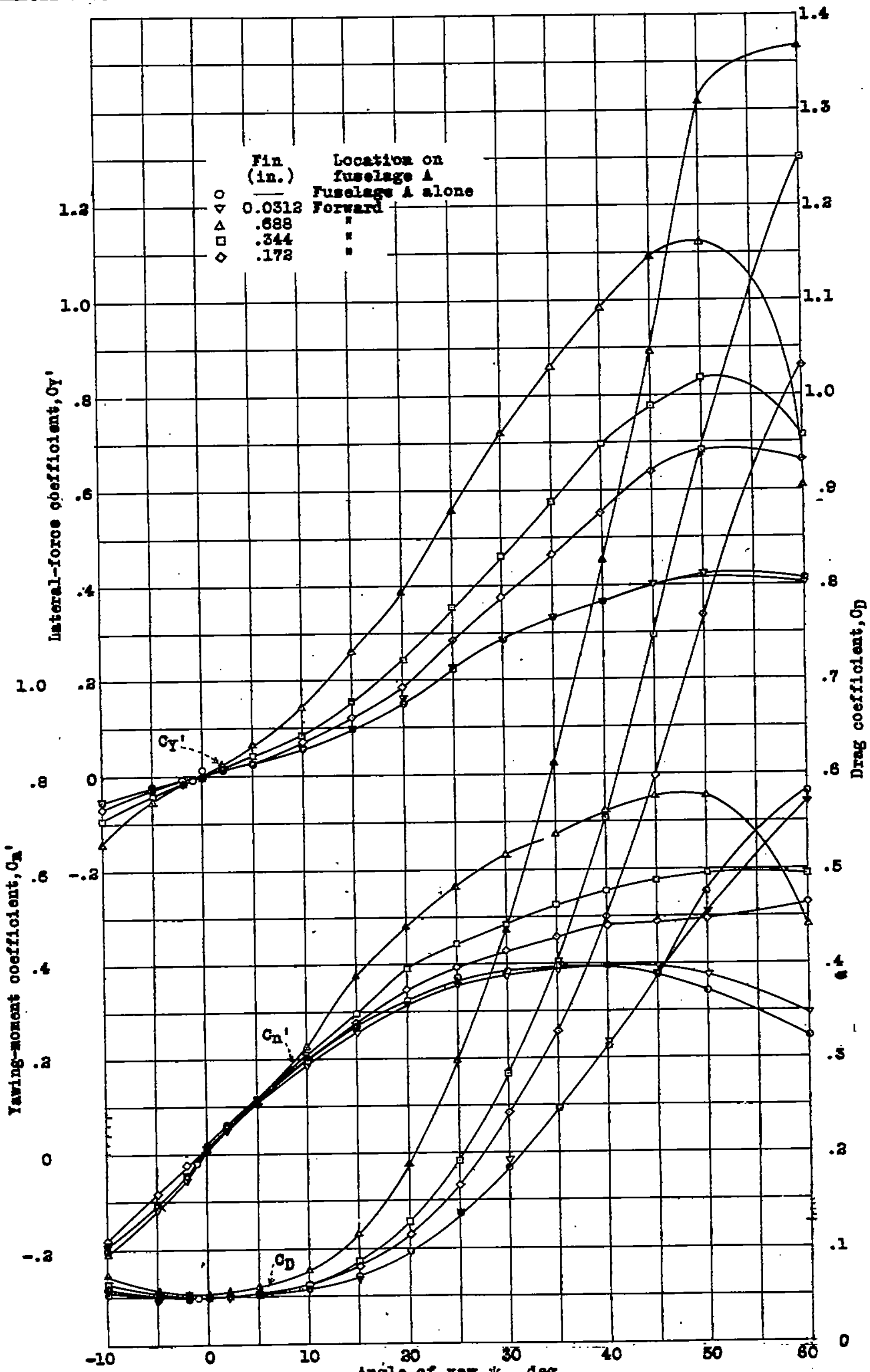


Figure 7.- Effect on fuselage characteristics of various fin arrangements forward.

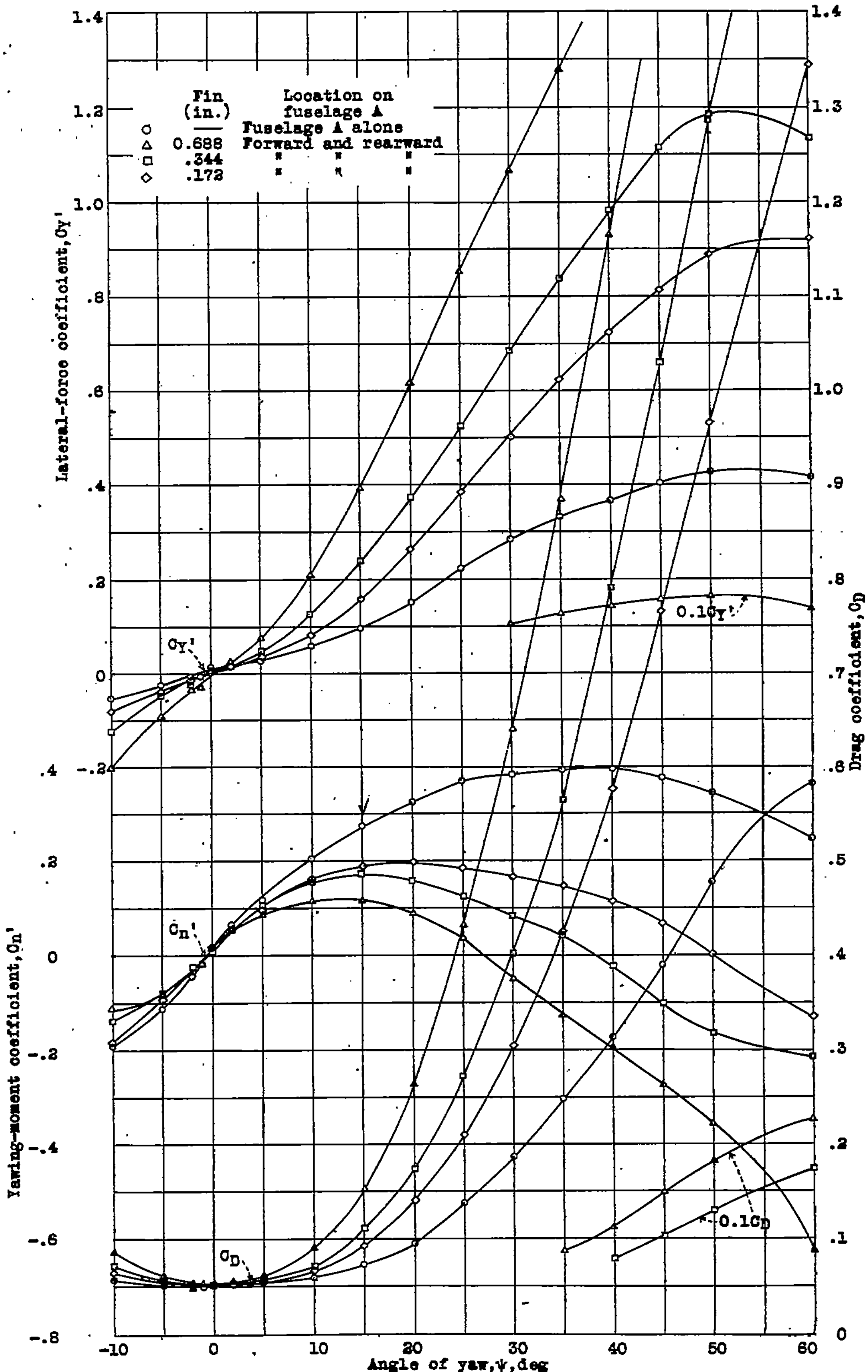


Figure 8.- Effect on fuselage characteristics of various fin arrangements forward and rearward.

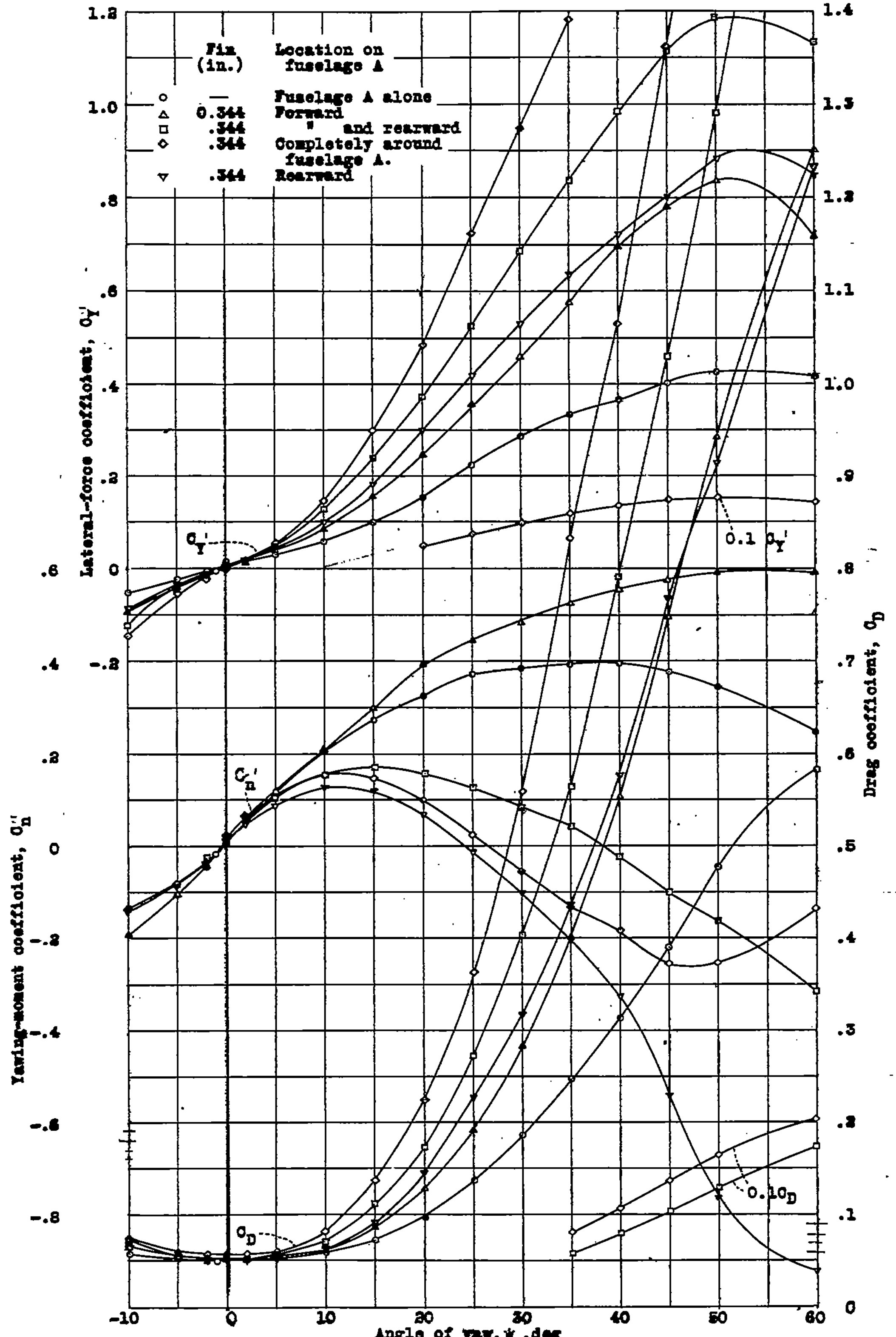


Figure 9.- Comparison of aerodynamic characteristics of fuselage A alone with combinations of location of fins of 0.344 inch width on fuselage A.