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# WIND TUNNEL TESTS OF FIVE STRUT SECTIONS IN YAW.

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The tests described in this report were made for the Engineering Division of the Army Air Service in the spring of 1918. The models were made at McCook Field and tested in the old wind tunnel (N.P.L. type 4' in diameter) of the Massachusetts Institute of Technology, the experiments being conducted by the writer under the general direction of Lieut. Alexander Klemin.

All of the models were made of mahogany, varnished but not highly polished. All were 18 inches long except No. 83-2, which was 24 inches and they ranged from .675 to .859 inches in breadth. The sections, all of which are shown in Fig. 1, had originally been designed to serve as fairings for single or double wires or cables, and two of them, Nos. 73-1 and 73-2, were nearly symmetrical about a minor axis, the radii of curvature at the nose and tail being the same and the point of maximum breadth being displaced only very slightly forward of the middle of the section. The other three sections approximated more closely to conventional forms, 76-1 and 76-2 being of similar general form but of different fineness ratios, while 83-2 had a somewhat sharper nose than the 76 series.

## Drag and Cross-wind Force in Yaw.

In the first series of tests, the drag and cross-wind force of all the struts were measured at a wind speed of 30 miles an hour and at angles of yaw from $0^\circ$ to $20^\circ$. All runs were made with the ends of the struts perfectly free, no attempt being made to simulate infinite length. The models were mounted on a 5/16 inch round spindle screwed into one end. The results have been plotted in Figs. 2 and 3, the absolute coefficients being given in terms of the area projected on a plane perpendicular to the wind direction at $0^\circ$ yaw. In accordance with the usual standard, a positive angle of yaw corresponds to a turn to the right, while a positive cross-wind force acts to the left.

The drag at zero yaw is, as would be expected, much less for the streamline forms of series 76 than for the nearly elliptical shapes of series 73. The best of the four struts, No. 76-1, has a coefficient of .13, which is fairly good for so low a Reynolds Number, although by no means unprecedented. It corresponds to a resistance of 27 lb per 100 ft of strut per inch of breadth at 100 M.P.H. The best of the U. S. Navy strut sections appears* to give a coefficient of .10 under conditions similar to those under which these tests were made.

At large angles of yaw (in excess of $10^\circ$) the drag of the streamline sections rises very rapidly, and becomes greater than that of the more symmetrical forms at the same angle. At $14^\circ$ yaw,

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* By extrapolation from the curves in Report No. 137, N.A.C.A.: "Drag of Navy No. 1 Struts Modified," by A. F. Zahm, R. H. Smith, and G. C. Hill.

for example, the best of the five struts is 83-2, and the next best is 73-2, which is the worst of all at small angles. The strut which gave lowest resistance at zero yaw has here become the worst of the five, its resistance having increased over 400% from the minimum while that of No. 83-2 has gone up less than 70%.

The curves of the cross-wind force show the struts divided into three separated groups even more clearly than do those of drag. The two models of series 73, the elliptical ones, give a negative coefficient of cross-wind force, steadily increasing up to an angle of yaw of about 15° and dropping off sharply immediately thereafter. Those in series 76, on the other hand, give somewhat less force at every angle and reach a maximum at approximately 10°, after which point there is a discontinuous drop. No. 83-2, finally, behaves quite differently from any of the others. The force is positive at small angles of yaw, reaching a positive maximum at 4°, but becomes negative at 8° and reaches a negative maximum, four times as large in absolute value as the positive one, at 15°. The existence of a positive cross-wind force at positive angles of yaw is, of course, indicative of great instability of flow. It is a common phenomenon around struts of this general form, having a moderate or low fineness ratio and a rather finely pointed nose.*

The forces on two of the struts, Nos. 73-1 and 76-1, were measured at 20 and 38 M.P.H. as well as at 30. There was no

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* Determination of the Forces Acting on Struts of Different Forms Inclined to the Relative Wind: R&M 74, British Advisory Committee for Aeronautics.

marked change in the form of the curves except for a slight decrease of drag and increase of the angle of maximum cross-wind force as the speed was raised, the latter effect being especially noticeable on the streamline form, for which the break of the curve after passing the maximum was particularly marked. Both of these results are, of course, in accordance with past experience.

The cross-wind force on struts is a factor of considerable importance in directional stability, especially in pusher biplanes where the struts supporting the tail booms are well to the rear of the center of gravity and act as fin surface. The total transverse force on the struts of a 4000-lb airplane, side-slipping at 70 M.P.H. and an angle of yaw of $8^{\circ}$, may reach 350 lb, and the struts supporting the tail-booms of a pusher may have a total fin effect a third as great as that of the whole vertical tail surface, an effect which may be practically annihilated, as has been seen, by slightly changing the form of the nose of the strut.

## Variation of Drag with VL.

To determine the magnitude of the VL effect, so far as the rather restricted range of the tunnel would allow, each strut was tested at zero yaw and at a series of speeds ranging from 15 to 38 M.P.H., and the resultant curves are plotted in Fig. 4, a heavy cross on each curve showing the location of the 30 M.P.H. point, used as the basis of the first part of this discussion.

The most striking feature of the curves is the relative unimportance of the VL effect on a strut of high fineness ratio, fine tail lines, and blunt nose, such as 76-1, and its very great importance on 76-2, a strut of similar form but somewhat smaller fineness ratio, or 83-2, which has both a smaller fineness ratio and a more pointed nose. If the curves be extended even a little to the right, as indicated by the dotted lines, the order of excellence is much changed from that at the lowest Reynolds Numbers covered by the curve.

The general conclusion that the best fineness ratio for a strut is a function of the Reynolds Number, decreasing steadily as that quantity increases, has of course been reached many times, both by theory and experiment.* It is here confirmed once more, and the effect of form on sensitiveness to VL is also strikingly shown. It seems probable that this effect of form is largely due to interaction between the nose and the tail, and to the influence which the form of the nose exerts over the whole flow around the strut, as experiments at the Washington Navy Yard** have shown that the actual local intensities of pressure on the part of the strut forward of the maximum breadth are substantially independent of VL, the whole VL effect making itself felt through variation of the suctions on the part of the section behind that point. This, however, may no longer be true when the strut is very blunt.

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* See, for example, Zahm, Smith and Hill, loc. cit., p.12.
** Zahm, Smith and Hill, loc. cit., p.8.

## Strut Sections as Airfoils.

Although designed as fairing for cables, part of these sections gave such high cross-wind forces that they seemed to have possibilities as airfoils. The lift (identical with the cross-wind force) and drag coefficients have therefore been recalculated for four sections on the basis of "broadside" area, to make them comparable with wing coefficients, and plotted in Fig. 5, with the L/D ratios in Fig. 6. Two of the four models had an aspect ratio of exactly 6, and were therefore directly comparable with the standard airfoil models made for the same tunnel. The other two had a slightly higher aspect ratio, and the drag coefficients were therefore modified to correct for the reduction of induced drag and make all the results directly comparable.

The struts of series 76 are useless as airfoils, despite their low minimum drag, because of the low maximum lift, which is even less than that of the thin doubly convex sections sometimes used on racing airplanes. The two models of series 73, however, give a fairly good maximum lift, about equal to that of an R.A.F.15, and an exceptionally high maximum L/D for sections so thick and tested at so low a Reynolds Number. To an even greater degree than is usually the case for thick sections, the L/D remains very near the maximum over a large range of angles. For 73-1, for example, the maximum L/D is 10.3, at $9^\circ$, and the ratio stays above 9.5 from $6^\circ$ to $14^\circ$.

The possible merits of these sections can best be shown by tabulating some of their properties in comparison with those of a few other thick sections.

| Section | 73-1 | 73-2 | N.A.C.A.71 | N.A.C.A.77 | U.S.A.T.S.1 |
|---|---|---|---|---|---|
| VL($ft^2$/sec) | 11 | 10 | 24.6 | 24.6 | 11 |
| Max. thickness | .241 | .269 | .267 | .231 | .243 |
| Thickness at 10% from leading edge | .163 | .171 | .186 | .146 | .165 |
| Thickness at 70% | .193 | .235 | .184 | .157 | .162 |
| Maximum $C_L$ | 1.15 | 1.18 | 1.56(?) | 1.17 | 1.16 |
| Minimum $C_D$ | .041 | .078 | .059 | .018 | .037 |
| Maximum L/D | 10.3 | 9.6 | 12.3 | 15.6 | 10.6 |
| Max.$C_L$/Min.$C_D$ | 28.0 | 15.1 | 26.4 | 65.0 | 31.3 |

Although the tabulation shows the other sections to be somewhat superior to the strut forms, at least part of that superiority in the case of the N.A.C.A. airfoils arises from the much higher Reynolds Number used in those tests. The sections of series 73, or others resembling them, may be found very useful for some purposes, especially at the inner end of a cantilever wing. The torsion of such wings, which has been a source of much trouble in fast monoplanes, arises chiefly from insufficient stiffness of the rear spar, and sections such as those in series 73 have the merit of being exceptionally deep in the neighborhood of the rear spar, about 20% deeper than a conventional airfoil section of the same maximum thickness. They at least merit further investigation at higher Reynolds Numbers.

Fig. 1

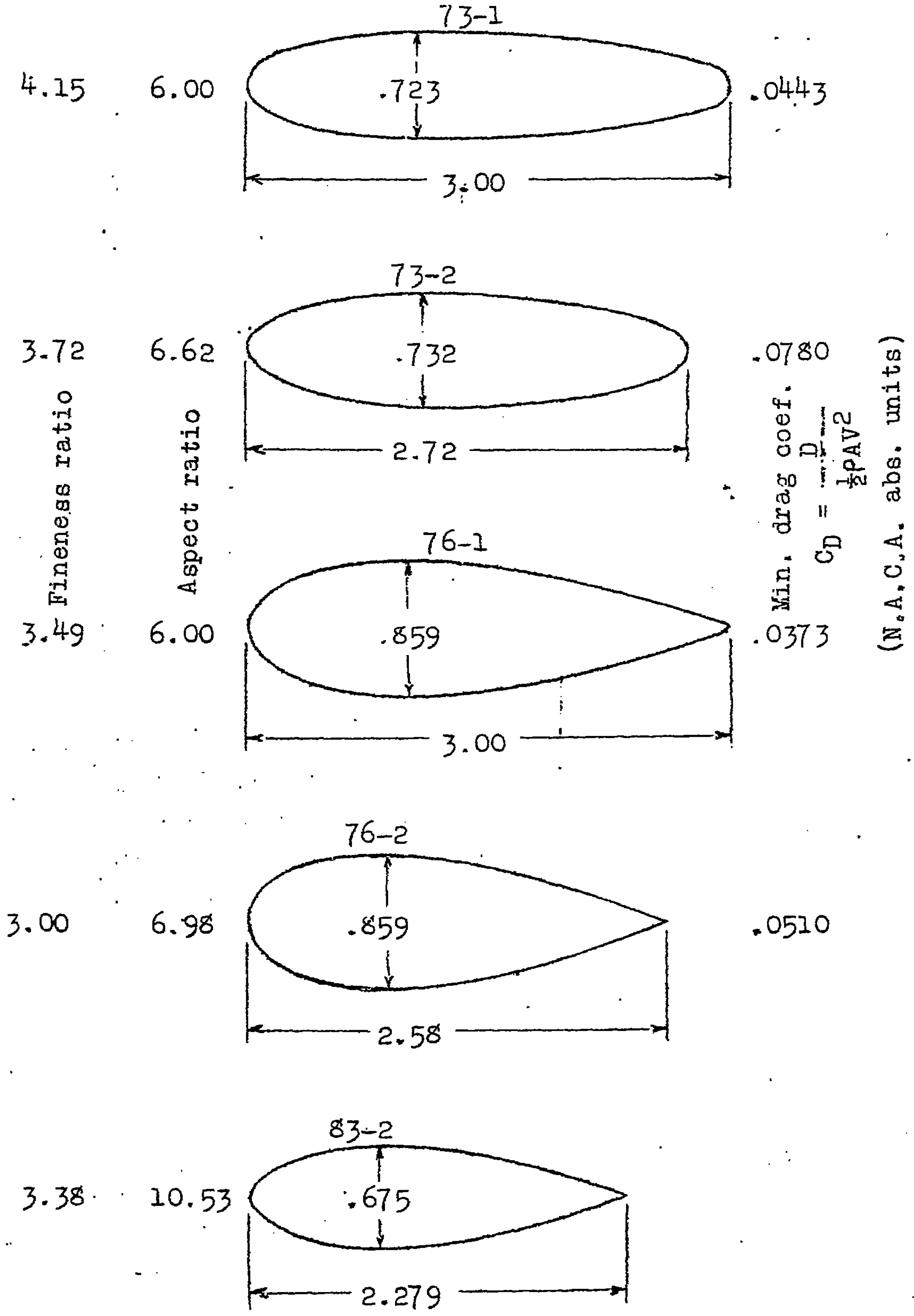

Fig. 1 Strut sections tested as airfoils. Aero. Lab. M I T Wind velocity 30 M.P.H. (44 ft/sec.)

Fig. 2

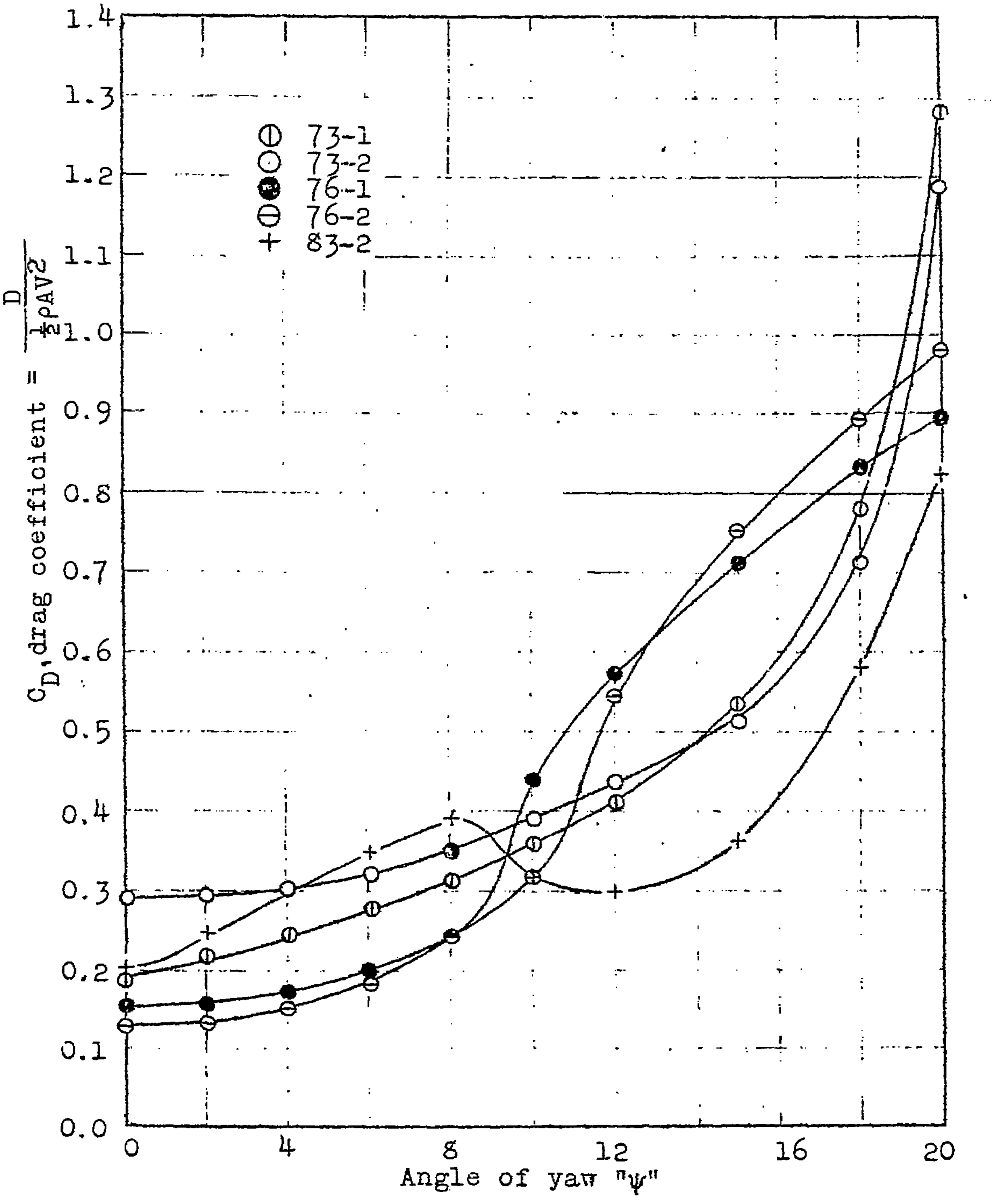

Fig. 2 Drag coefficient curves. Wind velocity 40 M.P.H. (58.67 ft/sec.)

Fig. 3

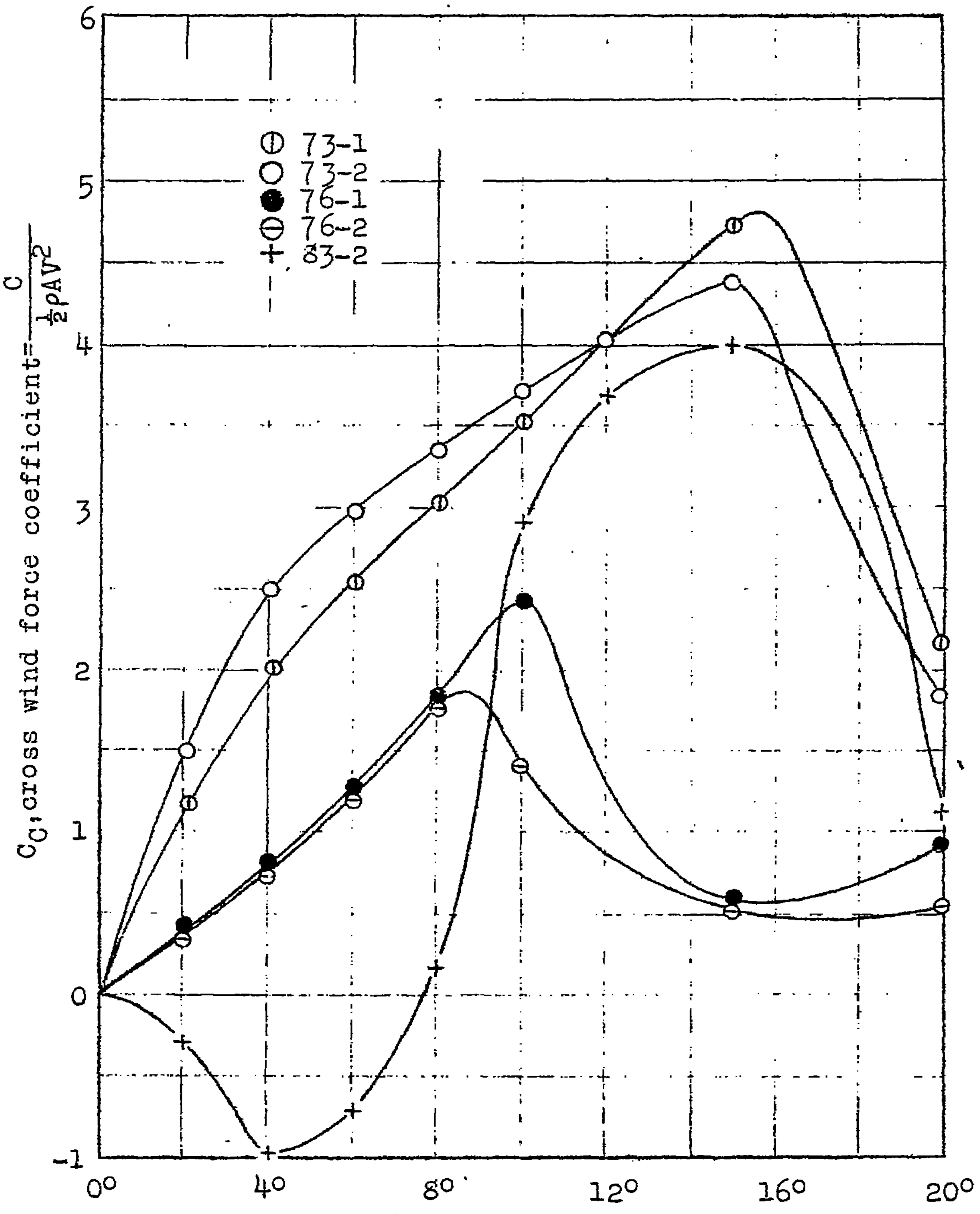

Fig. 3 Cross wind force coefficient curves. Wind velocity 30 M.P.H. (44 ft/sec.)

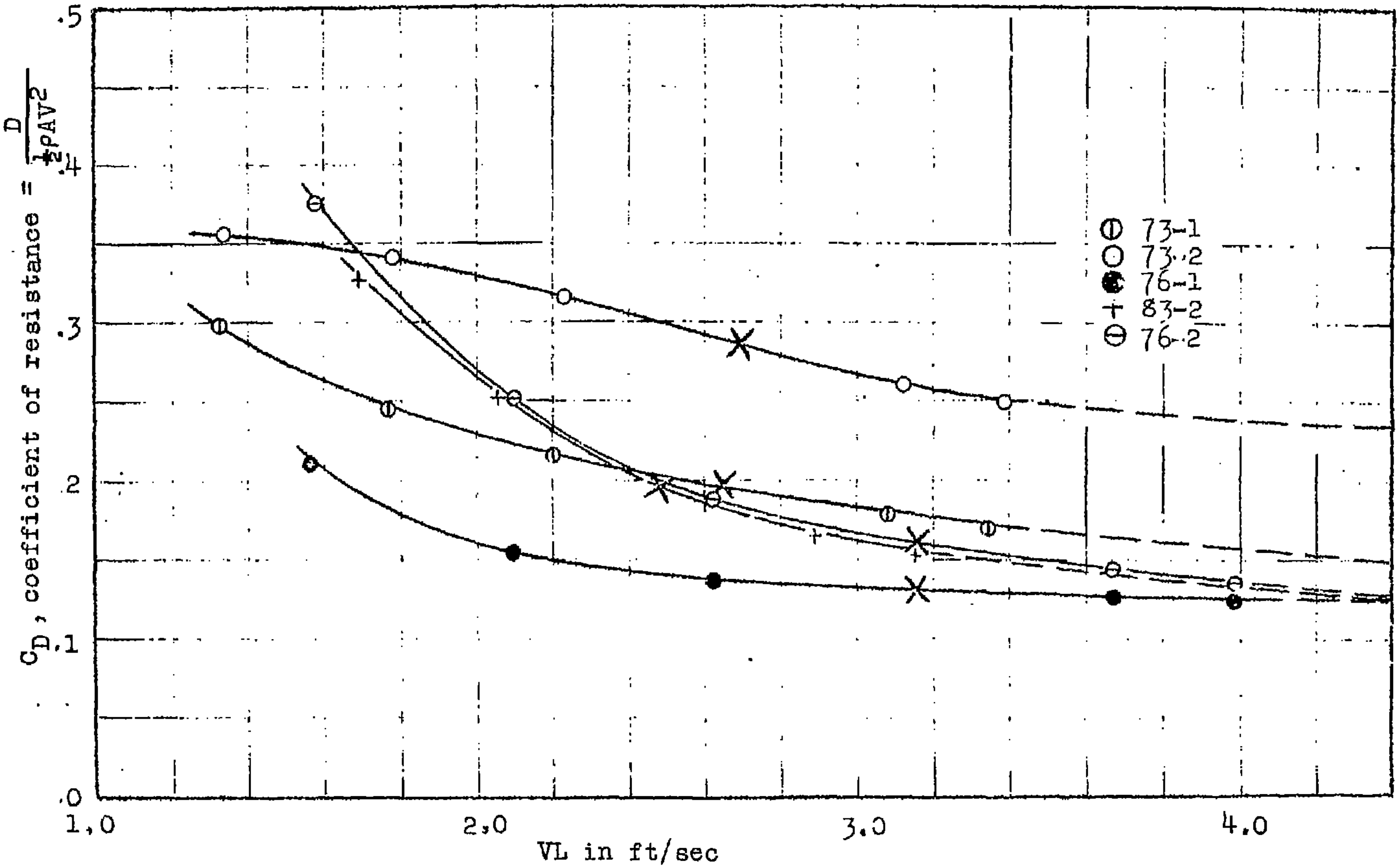

Fig. 4 Resistance coefficient against VL

Fig. 5

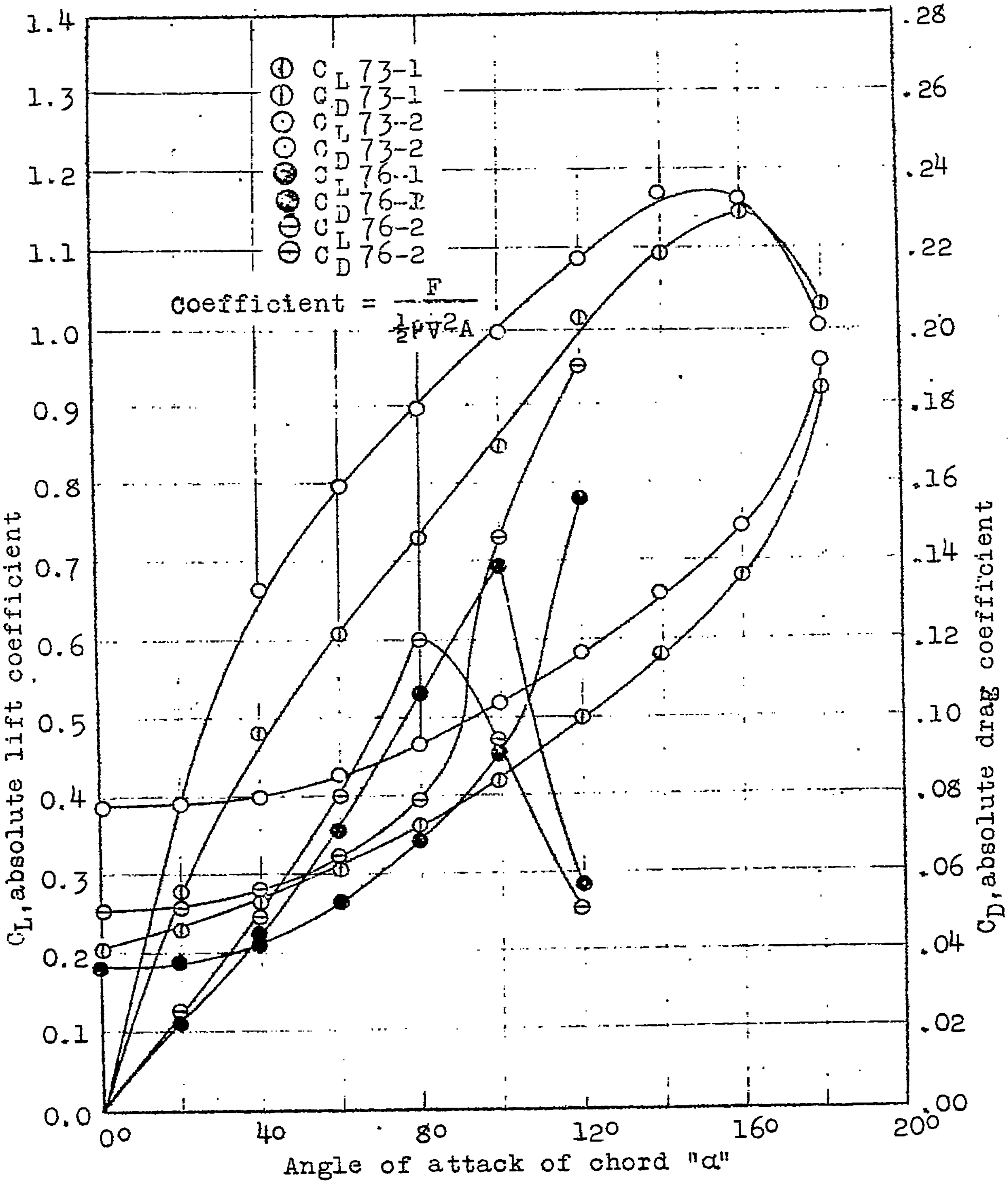

Fig. 5 Lift & Drag coefficient. N.A.C.A. absolute units
Wind velocity 30 M.P.H. (44 ft/sec.)

Fig. 6

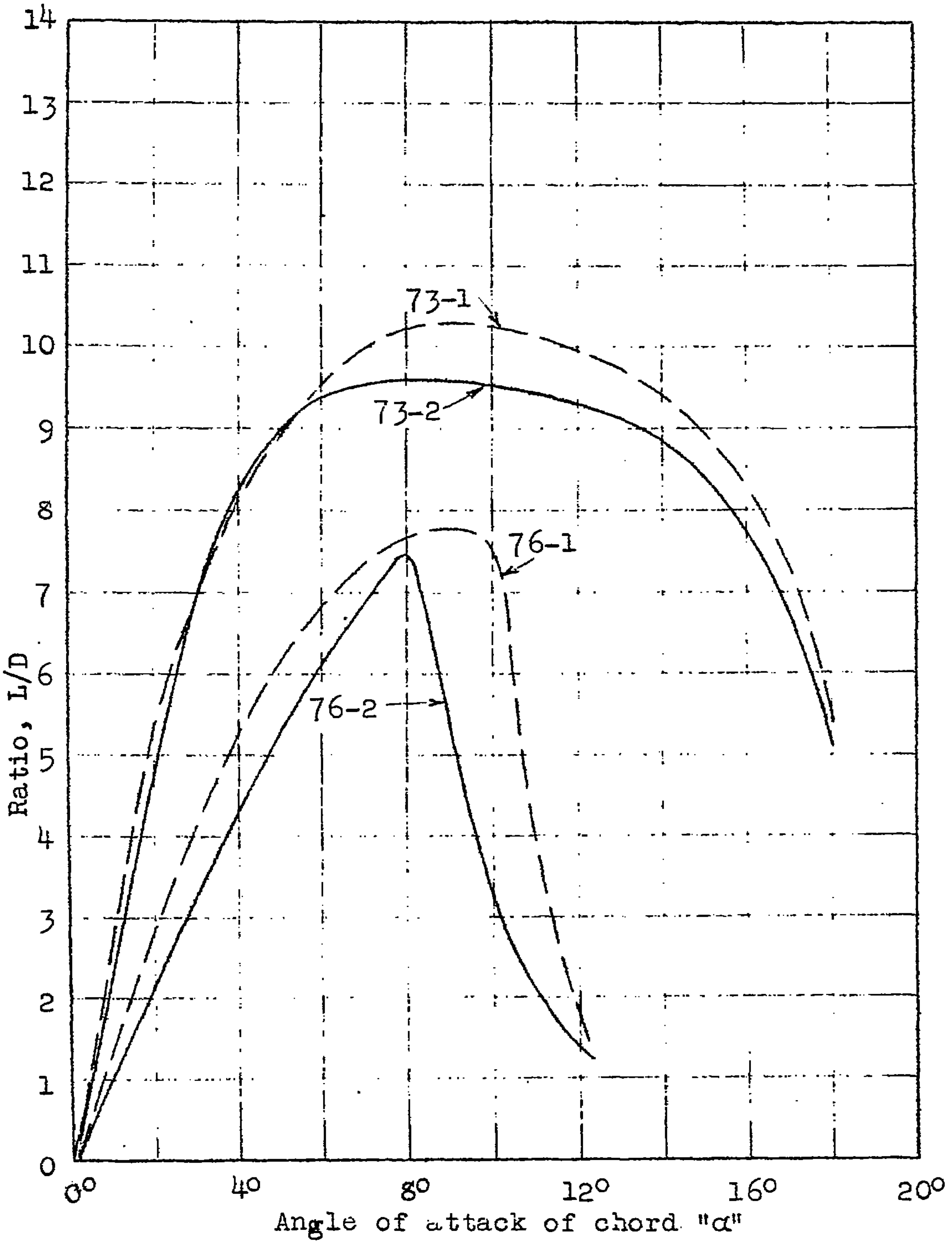

Fig. 6 L/D curves. Wind velocity 30 M.P.H. (44 ft/sec.)