NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

SPECIAL REPORT #83.

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# CORRECTION OF PROFILE-DRAG RESULTS FROM THE VARIABLE-DENSITY TUNNEL AND THE EFFECT ON THE CHOICE OF WING-SECTION THICKNESS

By Eastman N. Jacobs
Langley Memorial Aeronautical Laboratory

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March 1938

# CORRECTION OF PROFILE-DRAG RESULTS FROM THE VARIABLE-DENSITY TUNNEL AND THE EFFECT ON THE CHOICE OF WING-SECTION THICKNESS

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## INTRODUCTION

Profile-drag coefficients published from tests in the N.A.C.A. variable-density tunnel (Technical Reports Nos. 460, 537, 586, and 610, references 1 to 4) have tended to appear high as compared with results from the N.A.C.A. full-scale tunnel (Technical Report No. 530, reference 5) and from foreign sources (references 6 to 8). Such discrepancies were considered in Technical Report No. 586, and corrections for turbulence and tip effects were derived that tended to reduce the profile-drag coefficients, particularly for the thicker airfoils. The corrected profile-drag coefficients, designated by the lower-case symbol $c_{d_0}$ as contrasted with the older $C_{D_0}$, have been employed in the airfoil reports published since Technical Report No. 460, but even these corrected results continued to appear high, particularly for the thicker sections. The important practical result is that a smaller increase of drag with airfoil thickness is indicated, which may be of primary importance to the airplane designer in choosing the optimum airfoil sections for actual wings.

Further investigations of this subject were, of course, undertaken, one of the most important being an investigation of three symmetrical sections N.A.C.A. 0009, 0012, and 0018 under conditions of low turbulence in the full-scale tunnel. Preliminary results from this investigation also indicate a smaller increase in drag with airfoil thickness than the results from the variable-density tunnel. Furthermore, comparative tests made in the two tunnels by applying strings to the surface of the N.A.C.A. 0012 airfoil to move the transition point to a predetermined position indicated that the effective Reynolds Number concept would account approximately for the drag as affected by the position of transition from laminar to turbulent flow in the boundary layer.

Another correction, however, was suggested by the investigation in the full-scale tunnel. Differences between force and momentum methods of measurement suggested the presence of support-interference drag increments increasing with section thickness. A subsequent investigation in the full-scale tunnel by means of additional dummy supports verified the presence of this type of support-interference increment. Tests were therefore started in the variable-density tunnel to investigate any variation of support interference with airfoil thickness in spite of the fact that previous investigations reported in the appendix of Technical Report No. 586 had shown no definite corrections for two airfoils, N.A.C.A. 0012 and 4412.

Some results from this investigation, which is still in progress, are now available. These results indicate that marked support-interference increments, easily measurable, are present in the drag results for thick symmetrical airfoils, the increments increasing with airfoil thickness. After these support-interference drag increments are removed and the results are corrected to the effective Reynolds Number by the method suggested in footnote 1 on page 21 of Technical Report No. 586, all the available large Reymolds Number data give substantial agreement on the variation of minimum drag with thickness.

This preliminary memorandum is intended to supply aircraft manufacturers with tentative corrections for application to the published results from the variable-density tunnel to give more reliable values of $c_{d_0}$ for airfoils of various thicknesses pending the results of further investigation. The practical result of the correction on the choice of the optimum section is also briefly considered.

## DISCUSSION

The minimum-drag results for the symmetrical series of airfoils, the only ones for which the support-interference results are yet available, are presented in table I. The interference values are in the fourth column. Only three measured values are given; the ones enclosed in parentheses are taken from a faired curve against section thickness. These measured results were obtained in exactly the same way as those described and presented in the appendix of Technical Report No. 586. Consequently, the value of 0.0010 for the N.A.C.A. 0012 is at variance with the earlier result which indicated a value less than 0.0004.

The present result for the 12-percent airfoil is used, however, because it fairs better with the results from the thicker airfoils and because the tunnel balance and testing technique have been improved since the earlier tests were made.

The second column of table I gives the $C_{D_o}$ values originally published in Technical Report No. 460. The third column gives the $c_{d_o}$ values taken from Technical Report No. 610 except for the N.A.C.A. 0025. Some of these $c_{d_o}$ values were obtained by correcting the $C_{D_o}$ values for the drag increment (0.0011) to correct to the effective Reynolds Number and for the tip-drag increment $\left[0.0002\left(\frac{t - 6 \text{ percent}}{3}\right)\right]$. (See Technical Report No. 586.) The remaining $c_{d_o}$ values are from the results of more recent measurements similarly corrected.

The finally corrected $c_{d_o}$ values in column 5 were obtained from column 3 after correcting the results for support interference and changing the correction to the effective Reynolds Number to conform with the procedure suggested in the footnote on page 21 of Technical Report No. 586. Corresponding values obtained directly from the recent support-interference tests are presented in column 6.

The principal result of this preliminary memorandum is presented in the last column. These increments may be tentatively considered as applying approximately to airfoils of the same thickness but having small amounts of camber. Hence these increments may be subtracted from the previously published $c_{d_o}$ values from the variable-density tunnel to obtain the basic drag coefficients to be used for the time being in design problems.

The resulting variation of minimum profile drag with thickness is presented in figure 1 for the N.A.C.A. airfoils most commonly employed. This figure may be considered a correction of figure 53 of Technical Report No. 610. It is evident that the smaller increase in drag with section thickness will affect the choice of wing sections.

Considering that the best simple criterion for the selection of wing sections is the speed-range index

$c_{l_{max}}/c_{d_{o_{min}}}$, figure 2 has been prepared from the corrected data of figure 1 to be used in connection with figure 61 of Technical Report No. 610 to study the effect of the correction on the thickness of the optimum section. The comparison indicates the following result:

| | Thickness of section for highest $c_{l_{max}}/c_{d_{o_{min}}}$ (percent chord) | |
|---|---|---|
| | from T.R. 610 | corrected results (fig. 1) |
| 00 series | 11.5 | 11.5 |
| 230 series | 9.5 | 10 |
| 430 series | 10 | 10.5 |
| 230 series with 0.2c split flap | 11 | 13 |

The change in optimum thickness is evidently small for airfoils without flaps. The losses associated with exceeding the optimum thickness, however, become less marked so that a compromise airfoil will tend to be thicker by a greater amount than the table would indicate. This conclusion is particularly significant when full advantage can be taken of the fact that the maximum-lift increment produced by a high-lift device may increase with section thickness. The upper curve of figure 2 indicates that the optimum thickness for the 230 series may then increase to 13 percent and that the aerodynamic loss associated with thicker sections is considerably smaller than that previously indicated.

In conclusion, the corrections here presented are recommended for immediate use, but much recent data have suggested that these or other corrections will not produce ultimately satisfactory results. It is planned, therefore, to obtain further airfoil-section data under test conditions more favorable than those in the variable-density tunnel.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 18, 1938.

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# TABLE I

## DATA ON CORRECTION OF MINIMUM DRAG OF SYMMETRICAL AIRFOILS

Effective Reynolds Number approximately 8,000,000

| (1) Airfoil | (2) $C_{D_o}$ (T.R.460) ✓ | (3) $c_{d_o}$ (T.R.610) TIP & E.R.N. CORRECTION | (4) Support interference | (5) $c_{d_o}$ (corrected) | (6) $c_{d_o}$ (from support interference tests) | (7) Correction increment |
|---|---|---|---|---|---|---|
| 0006 | 0.0065 | 0.0054 | (0.0004) | 0.0052 | -- | 0.0002 |
| 0009 | .0074 | .0064 | ( .0007) | .0058 | -- | .0006 |
| 0012 | .0083 | .0069 | .0010 | .0060 | 0.0060 | .0009 |
| 0015 | .0093 | .0077 | ( .0012) | .0065 | -- | .0012 |
| 0018 | .0108 | .0088 | .0015 | .0071 | .0073 | .0017 |
| 0021 | .0120 | .0100 | ( .0019) | .0078 | -- | .0022 |
| 0025 | .0143 | .0119 | .0026 | .0088 | .0092 | .0031 |

Values of Column (5) = [values of (3) + .0011 − support interference] x.85

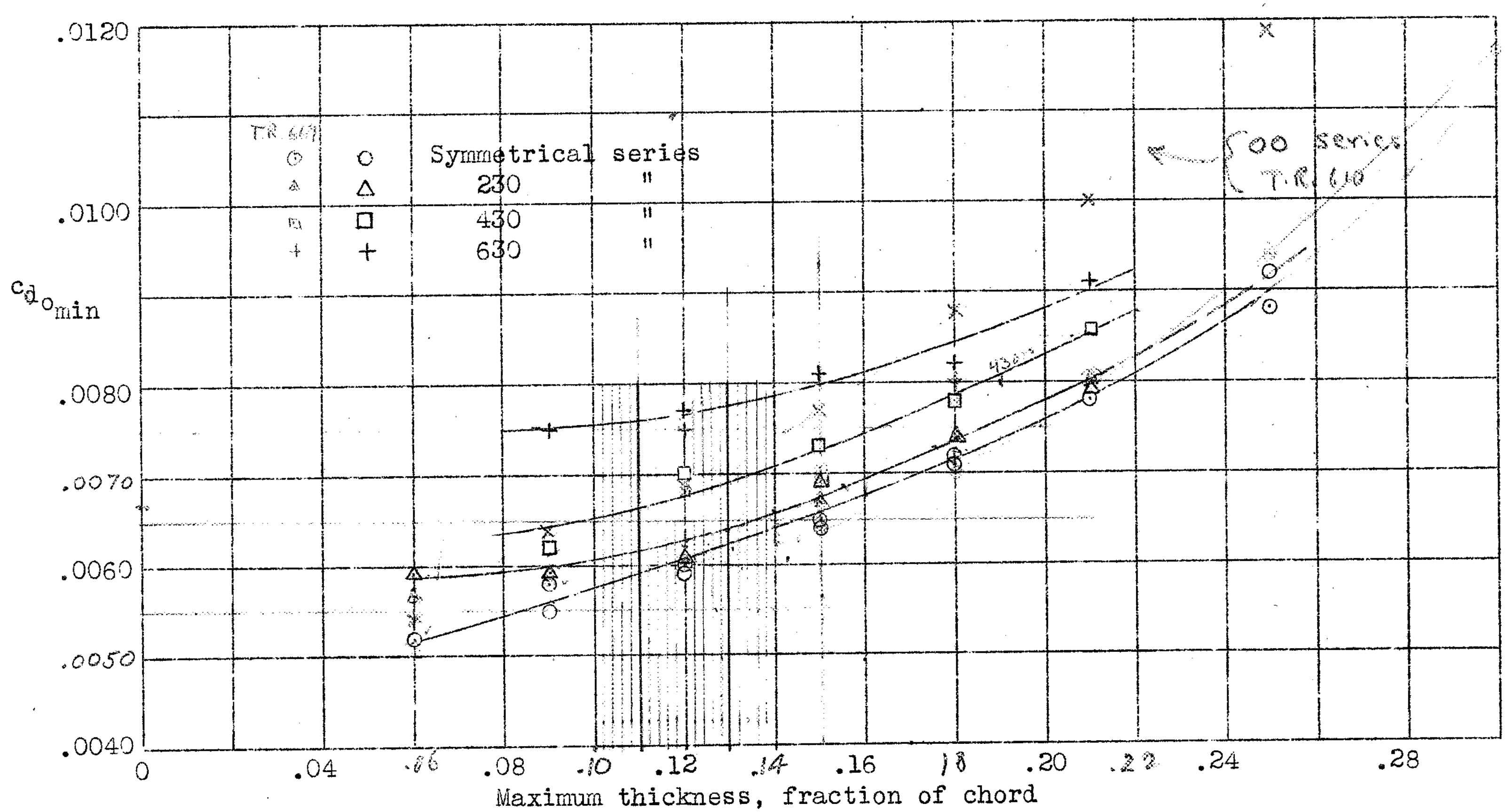


Figure 1.- Variation of minimum drag with thickness.

EFFECTIVE R.N. 8,000,000, APPROX.

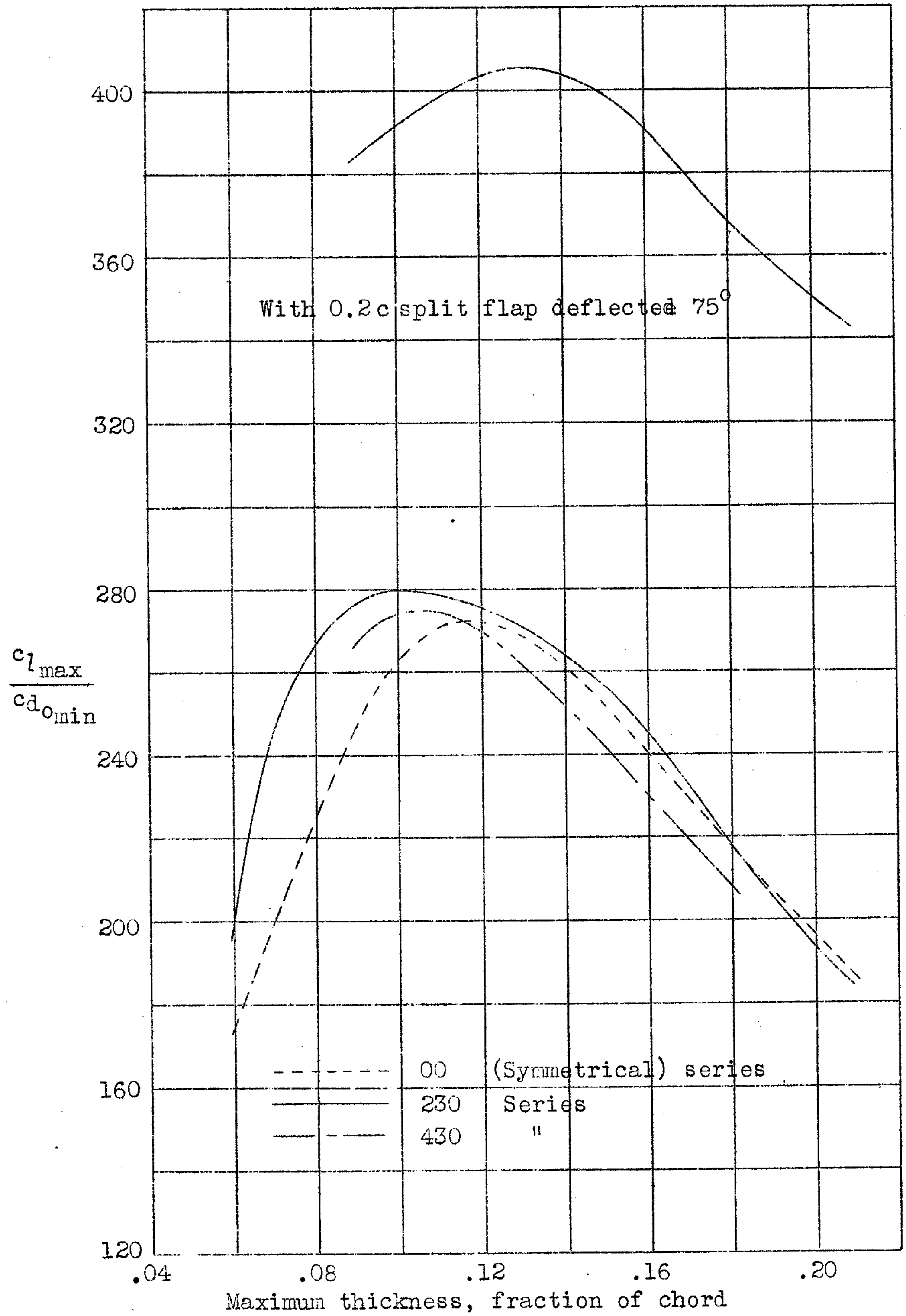


Figure 2.- Variation of $c_{l_{max}}/c_{d_{o_{min}}}$ with thickness.