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No. 365

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## Summary

Tests were conducted in the Variable Density Wind Tunnel of the National Advisory Committee for Aeronautics to determine the importance of the interference effects and drag of struts on a monoplane wing. Inclined struts were placed upon a Göttingen 387 airfoil in two lower surface positions and in two upper surface positions. Tests were made at values of Reynolds Number comparable with those obtained in flight. It was found that the interference drag of struts may be as great as the drag of the struts alone. The struts in the lower surface positions had less effect upon the airfoil characteristics than those in the upper surface positions. The results justify further investigation of this subject.

## Introduction

With the increasing popularity of the monoplane greater attention is being given to the relative merits of the strut-braced wing and the internally-braced wing. It is well known that the strut-braced wing is more rigid and lighter than the internally-braced wing, and that the strut-braced wing can be constructed at less cost than the usual internally-braced form, the tapered wing. The two types, however, are difficult to compare aerodynamically, as little full-scale information is available on either type of wing.

The present brief investigation was made to determine the importance of the interference effects of struts upon the aerodynamic characteristics of an airfoil at large Reynolds Numbers. Tests were conducted in the Variable Density Tunnel at the Langley Memorial Aeronautical Laboratory upon a Göttingen 387 airfoil with inclined struts attached to its upper and lower surfaces in several positions.

Tests have also been made on three tapered airfoils suitable for internal bracing and the results will be published in a later report. The two reports will form a basis for comparing the strut-braced wing and the internally-braced wing.

## Apparatus and Tests

A description of the Variable Density Wind Tunnel and a statement of the principles upon which its operation is based are given in Reference 1. This reference, however, describes the tunnel as originally designed. Figure 1 shows the tunnel in its present form.

The airfoil used in these tests was a standard rectangular duralumin model, 5 by 30 inches, with a Göttingen 387 section

(Reference 2). The struts were 8.1 inches long, 0.6 inch wide, and were of the Navy No. 1 section (Reference 3) with a fineness ratio of 5. The axes of the struts were in a plane perpendicular to the chord plane of the airfoil and parallel to the leading edge, and were inclined toward the mid-section of the airfoil so that the angle between the strut axes and the chord plane of the airfoil was 20 degrees. The chords of the strut sections were parallel to the chords of the airfoil sections. Two struts joined at the top made up one strut set (Figure 2) which was attached to the wing by base plates recessed into the surface to a depth that gave approximately equal exposed strut areas for each position. The specified and measured ordinates of the struts and airfoil are given in Table I. Figure 3 shows the struts as mounted in tandem upon the airfoil.

The model was tested in the usual manner as described in Reference 1, first without struts and then with the struts arranged successively in four different ways as follows: (1) tandem struts on the lower surface located at 15 per cent and 65 per cent of the chord back from the leading edge; (2) single struts on the lower surface at 15 per cent; (3) tandem struts on the upper surface at 15 and 65 per cent, and (4) single struts on the upper surface at 15 per cent. The tests were made at an average Reynolds Number of 3,400,000 for the airfoil which was obtained by using a working pressure of 20 atmospheres in the tunnel. The comparative results are accurate to within ±0.5

per cent. This figure was obtained by comparing the results of two tests of the wing alone, one made before and one after the tests with struts.

## Discussion of Results

The aerodynamic effects of struts attached to the wing are shown by comparative polar curves (Figures 4 and 5) of the drag and moment coefficients plotted against the lift coefficient. Actual values of the coefficients are given in Tables II to VI, inclusive.

In Figure 4 curves are plotted for the wing alone, and for single and tandem struts on the lower surface. Referring to this figure, it may be seen that the addition of struts decreased the lift slightly and increased the drag; tandem struts had the greatest effect. The moment was influenced slightly by the presence of struts.

The effects of single and tandem struts on the upper surface, indicated in Figure 5, are much larger than for the lower surface positions. Single struts increased the drag and (unlike the effect caused by the struts in a similar position on the lower surface) increased the maximum lift. This increased lift was probably a result of a "slot effect," as the struts were close to the leading edge of the airfoil. Tandem struts caused a large increase in drag and gave the lowest maximum lift of the five conditions. The pitching moment was decreased by the addition of struts.

The absolute coefficients were obtained from the usual relations:

$$C_D = \frac{D}{q\,S} \qquad C_L = \frac{L}{q\,S} \qquad C_{M_{c/4}} = \frac{M_{c/4}}{c\,q\,S}$$

where:

$D$ = drag.

$L$ = lift.

$M_{c/4}$ = moment (about quarter chord).

$q$ = dynamic pressure = $1/2\,\rho\,V^2$.

$S$ = area.

$c$ = chord.

The interference drag produced by the presence of struts was determined from the following relations:

$$\Delta C_D = (C_{D_{WS}} - C_{D_W})\,\frac{S_W}{S_S} - C_{D_S}$$

where:

$\Delta C_D$ = interference drag coefficient.

$C_{D_{WS}} - C_{D_W}$ = difference in drag coefficients between the wing with struts attached and the wing alone.

$\frac{S_W}{S_S}$ = ratio of wing area to strut area (plan form).

$C_{D_S}$ = strut drag coefficient.

The minimum drag coefficient ($C_{D_S}$), based on the plan form area, of 0.0152 used for the struts alone is an average value obtained from a number of tests on strut forms (References 3 to 6, inclusive) similar in shape to the struts used in the present tests. The values obtained from the references were corrected for fineness ratio and scale where necessary.

The calculated interference drag coefficient of the struts for the minimum drag attitude for each test is given in Table VII. This table also includes the interference drag as a percentage of the strut drag, the minimum drag coefficients, and the percentage increase in minimum drag over the drag of the wing alone. It may be noted by referring to the table that the interference drag produced by single struts on the lower surface is greatly reduced when rear struts are added in tandem. The total increase in minimum drag for tandem struts is very little more than the increase for single struts; the small increase may be attributed to the favorable interference or "screening" produced by the forward struts (Reference 7). For the upper surface positions the interference drag for tandem struts is six times the interference drag for single struts. The rear struts in the upper surface tandem combination probably do not lie directly in the wake of the forward struts because of the type of air flow over the upper surface of the airfoil and because the struts are not geometrically in tandem.

It is probable that a reduction in unfavorable interference drag might be obtained by placing fillets between the struts and the wing. The drag might be further reduced, for a particular attitude of flight, by twisting the struts so that the angle between any strut section and the relative air flow would be the angle of minimum drag for the section. An extensive investigation of the effects of fillets, twist, shape, and position of struts should give valuable information.

## Conclusions

1. The interference drag of struts attached to a wing may be as great as the drag of the struts alone.

2. Struts attached to the lower surface have less effect upon the airfoil characteristics than struts placed upon the upper surface.

3. The interference effects are sufficiently large to justify further investigation.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 31, 1931.

References


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TABLE I

Ordinates of Göttingen 387 and Strut Section

All dimensions are in per cent of chord

| Distance from L.E. | Göttingen 387 | | | | Strut Section | | | |
|---|---|---|---|---|---|---|---|---|
| | Specified | | Measured | | Specified | | Measured | |
| | Upper | Lower | Upper | Lower | Upper | Lower | Upper | Lower |
| 0 | 3.61 | 3.61 | --- | --- | 0 | 0 | --- | --- |
| 1-1/4 | 6.74 | 1.35 | 6.74 | 1.42 | --- | --- | --- | --- |
| 2-1/2 | 7.98 | .81 | 7.98 | .84 | 3.70 | 3.70 | 4.78 | 4.41 |
| 5 | 9.87 | .36 | 9.88 | .38 | 5.28 | 5.28 | 6.20 | 5.93 |
| 7-1/2 | 11.32 | .18 | 11.30 | .18 | 6.35 | 6.35 | 7.11 | 6.91 |
| 10 | 12.40 | .13 | 12.38 | .10 | 7.20 | 7.20 | 7.80 | 7.63 |
| 15 | 13.83 | .00 | 13.82 | .00 | 8.40 | 8.40 | 8.77 | 8.60 |
| 20 | 14.77 | .08 | 14.78 | .06 | 9.17 | 9.17 | 9.37 | 9.27 |
| 30 | 15.36 | .22 | 15.38 | .20 | 9.87 | 9.87 | 9.94 | 9.93 |
| 40 | 14.88 | .38 | 14.88 | .34 | 10.00 | 10.00 | 9.95 | 9.89 |
| 50 | 13.48 | .54 | 13.52 | .49 | 9.60 | 9.60 | 9.50 | 9.33 |
| 60 | 11.59 | .54 | 11.62 | .49 | 8.60 | 8.60 | 8.50 | 8.25 |
| 70 | 9.16 | .54 | 9.22 | .48 | 7.38 | 7.38 | 7.16 | 6.78 |
| 80 | 6.58 | .50 | 6.60 | .44 | 5.68 | 5.68 | 5.36 | 4.88 |
| 90 | 3.61 | .27 | 3.62 | .24 | 3.40 | 3.40 | 3.02 | 2.58 |
| 95 | 1.99 | .16 | 2.04 | .14 | 1.95 | 1.95 | 1.61 | 1.30 |
| 100 | .37 | .00 | .48 | .00 | .00 | .00 | --- | --- |

TABLE II

Göttingen 387 Airfoil Without Struts

Aspect ratio 6, corrected for tunnel wall effect

| $\alpha$ | $C_L$ | $C_D$ | L/D | $C_{M_{c/4}}$ |
|---|---|---|---|---|
| -6.0 | .046 | .0109 | 4.22 | -.098 |
| -3.9 | .193 | .0136 | 15.32 | -.097 |
| 0.2 | .496 | .0249 | 19.92 | -.090 |
| 4.3 | .812 | .0500 | 16.25 | -.094 |
| 8.4 | 1.102 | .0853 | 12.92 | -.097 |
| 12.5 | 1.364 | .1296 | 10.52 | -.097 |
| 16.6 | 1.548 | .1891 | 8.19 | -.113 |
| 18.6 | 1.555 | .2366 | 6.58 | -.122 |
| 24.6 | 1.479 | .3811 | 3.88 | -.162 |

TABLE III

Göttingen 387 Airfoil Single Struts on Lower Surface

Aspect ratio 6, corrected for tunnel wall effect

| $\alpha$ | $C_L$ | $C_D$ | L/D | $C_{M_{c/4}}$ |
|---|---|---|---|---|
| -6.0 | .027 | .0130 | 2.08 | -.100 |
| -3.9 | .184 | .0139 | 13.24 | -.099 |
| -1.9 | .334 | .0180 | 18.56 | -.100 |
| 0.2 | .478 | .0250 | 19.12 | -.096 |
| 4.3 | .784 | .0490 | 16.00 | -.098 |
| 8.4 | 1.085 | .0848 | 12.80 | -.098 |
| 12.5 | 1.356 | .1287 | 10.53 | -.098 |
| 16.6 | 1.550 | .1881 | 8.24 | -.110 |
| 18.6 | 1.552 | .2367 | 6.56 | -.122 |
| 20.6 | 1.529 | .2838 | 5.39 | -.140 |
| 24.5 | 1.441 | .3787 | 3.81 | -.159 |

TABLE IV

Göttingen 387 Airfoil

Tandem Struts on Lower Surface

Aspect ratio 6, corrected for tunnel wall effect

| $\alpha$ | $C_L$ | $C_D$ | L/D | $C_{M_{c/4}}$ |
|---|---|---|---|---|
| -6.0 | .025 | .0133 | 1.88 | -.093 |
| -3.9 | .184 | .0145 | 12.69 | -.095 |
| -1.9 | .330 | .0189 | 17.46 | -.097 |
| 0.2 | .483 | .0261 | 18.50 | -.097 |
| 4.3 | .787 | .0490 | 16.06 | -.093 |
| 8.4 | 1.092 | .0849 | 12.86 | -.097 |
| 12.5 | 1.367 | .1305 | 10.47 | -.104 |
| 16.6 | 1.534 | .1966 | 7.80 | -.103 |
| 18.6 | 1.520 | .2395 | 6.35 | -.125 |
| 20.6 | 1.520 | .2883 | 5.27 | -.134 |
| 24.5 | 1.416 | .3845 | 3.68 | -.158 |

TABLE V

Göttingen 387 Airfoil

Single Struts on Upper Surface

Aspect ratio 6, corrected for tunnel wall effect

| $\alpha$ | $C_L$ | $C_D$ | L/D | $C_{M_{c/4}}$ |
|---|---|---|---|---|
| -6.0 | .043 | .0121 | 3.55 | -.096 |
| -3.9 | .198 | .0138 | 14.35 | -.092 |
| -1.9 | .353 | .0189 | 18.69 | -.088 |
| 0.2 | .502 | .0269 | 18.66 | -.086 |
| 4.3 | .804 | .0516 | 15.59 | -.090 |
| 8.4 | 1.103 | .0890 | 12.40 | -.090 |
| 12.5 | 1.374 | .1360 | 10.10 | -.095 |
| 16.6 | 1.590 | .1940 | 8.20 | -.099 |
| 18.6 | 1.595 | .2423 | 6.58 | -.120 |
| 20.6 | 1.578 | .3067 | 5.14 | -.137 |
| 24.6 | 1.459 | .4109 | 3.55 | -.167 |

TABLE VI

Göttingen 387 Airfoil

Tandem Struts on Upper Surface

Aspect ratio 6, corrected for tunnel wall effect

| $\alpha$ | $C_L$ | $C_D$ | L/D | $C_{M_{c/4}}$ |
|---|---|---|---|---|
| -6.0 | .018 | .0155 | 1.16 | -.093 |
| -3.9 | .175 | .0170 | 10.30 | -.089 |
| -1.9 | .325 | .0219 | 14.84 | -.085 |
| 0.2 | .480 | .0301 | 15.95 | -.083 |
| 4.3 | .780 | .0541 | 14.42 | -.084 |
| 8.4 | 1.065 | .0908 | 11.73 | -.085 |
| 12.5 | 1.326 | .1407 | 9.42 | -.089 |
| 16.6 | 1.487 | .2117 | 7.02 | -.114 |
| 18.6 | 1.525 | .2573 | 5.92 | -.130 |
| 20.6 | 1.507 | .3101 | 4.86 | -.146 |
| 24.5 | 1.436 | .4170 | 3.44 | -.182 |

TABLE VII

The Interference Drag of Struts

For Minimum Drag Attitude

| | Minimum Drag | | Interference Drag | |
|---|---|---|---|---|
| | $C_D$ | Per cent increase | $\Delta C_D$ | Per cent of strut drag |
| Wing alone | .0109 | -- | -- | -- |
| Single struts on lower surface | .0130 | 19 | .0172 | 113 |
| Tandem struts on lower surface | .0133 | 22 | .0033 | 22 |
| Single struts on upper surface | .0121 | 11 | .0033 | 22 |
| Tandem struts on upper surface | .0155 | 42 | .0202 | 133 |

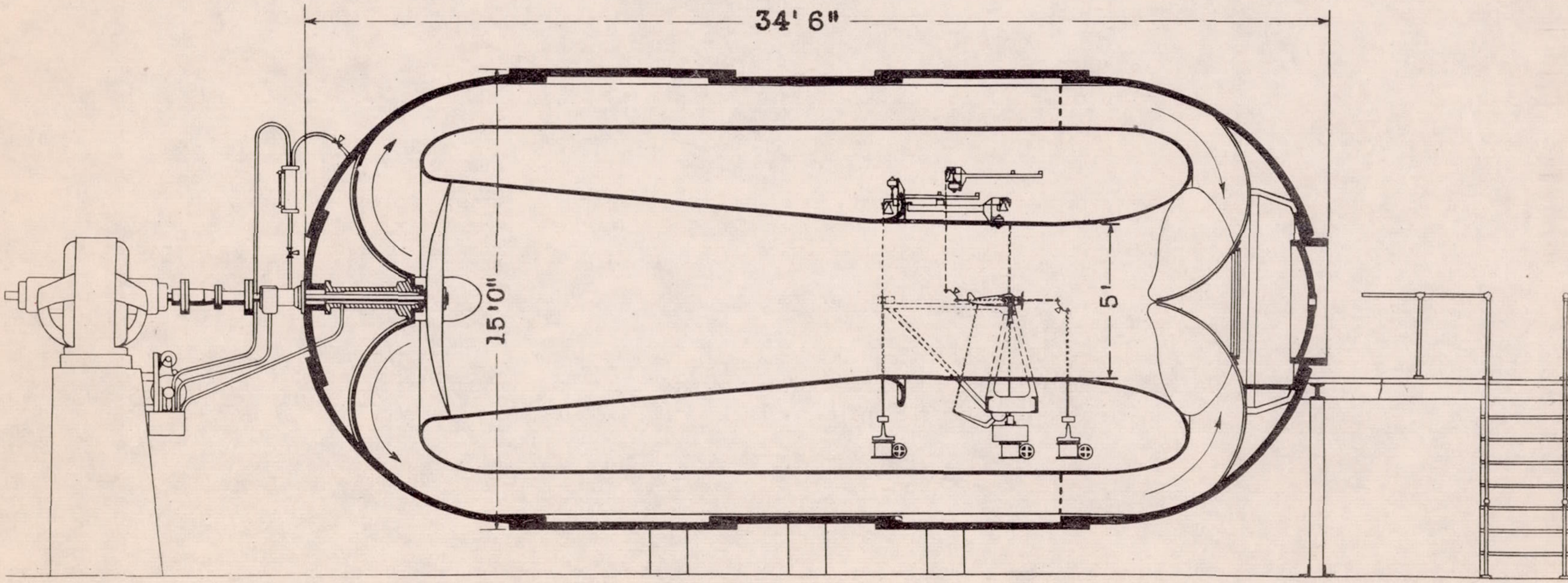


Fig. 1 The modified closed throat variable density wind tunnel.

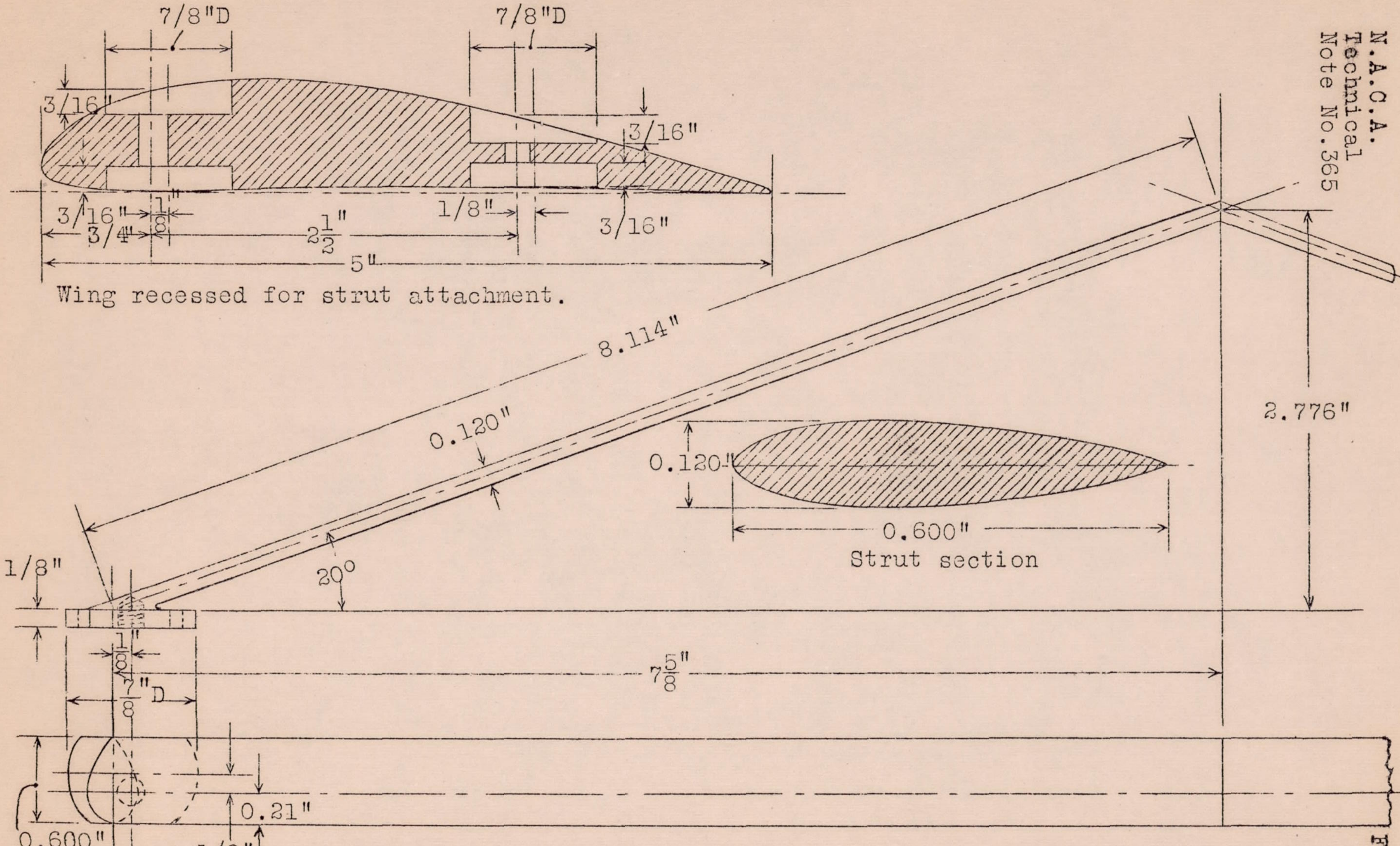


Fig.2 Inclined strut

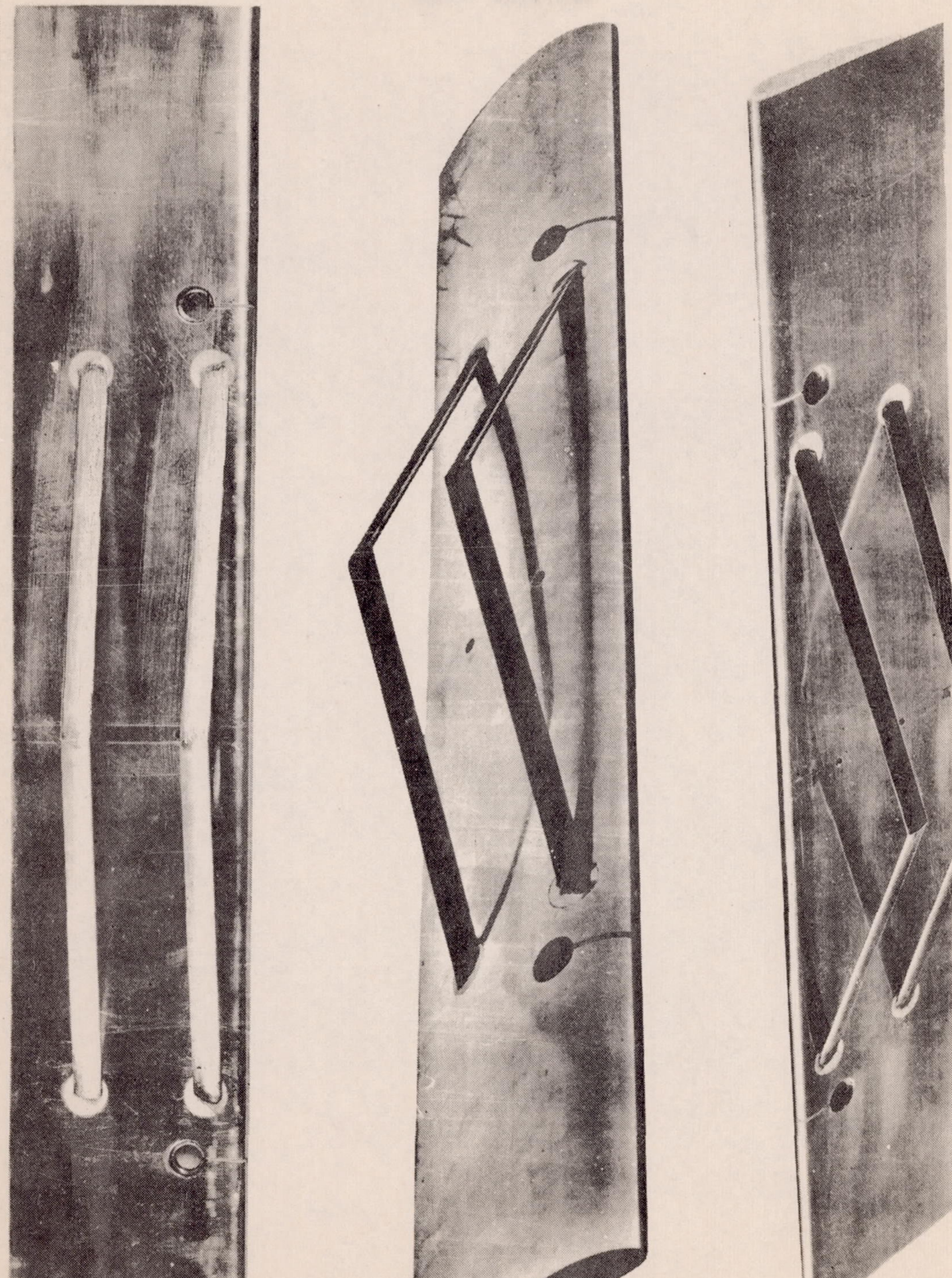

Fig.3 Tandem struts mounted on wing.

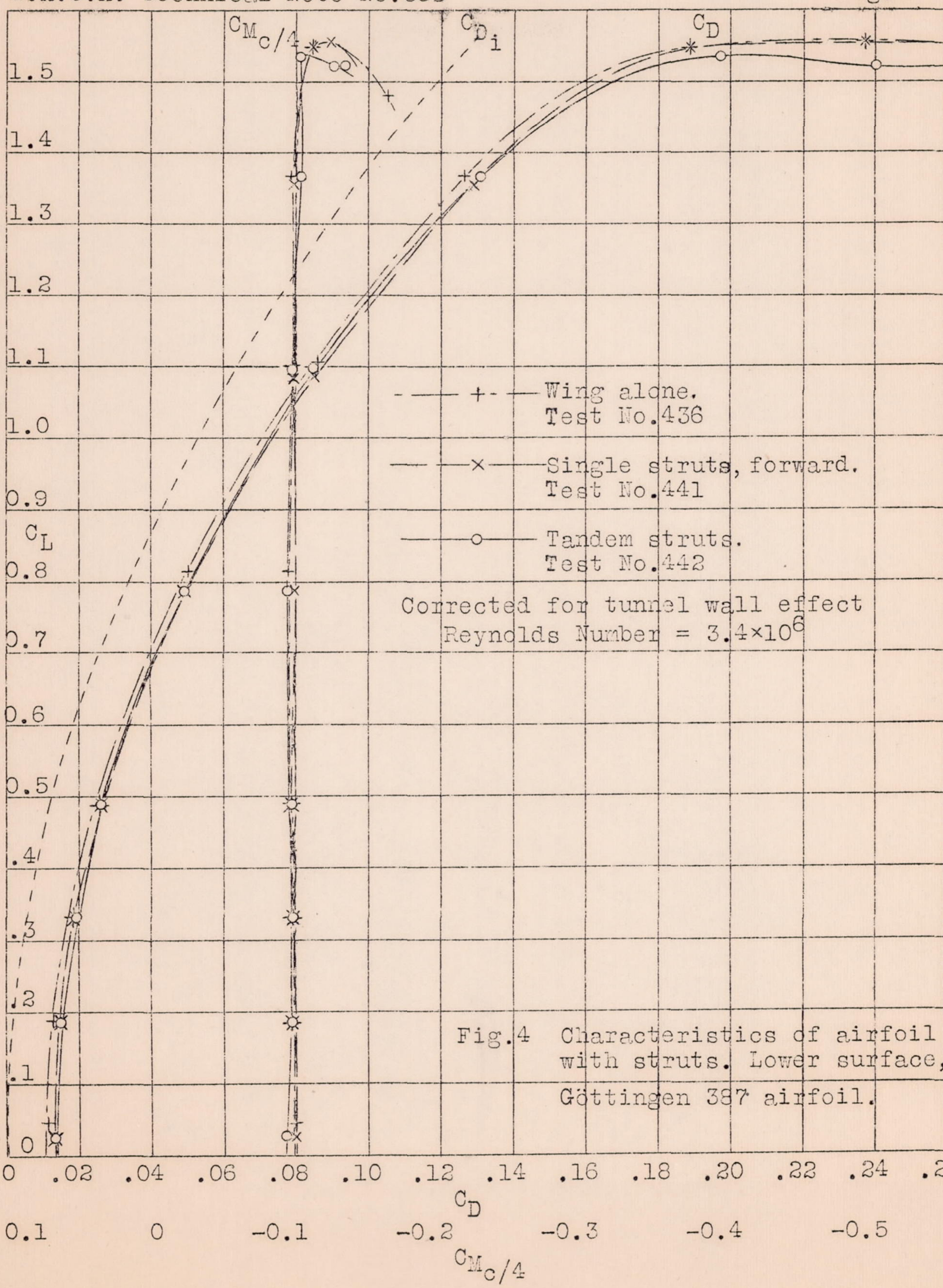


Fig.4 Characteristics of airfoil with struts. Lower surface, Göttingen 387 airfoil.

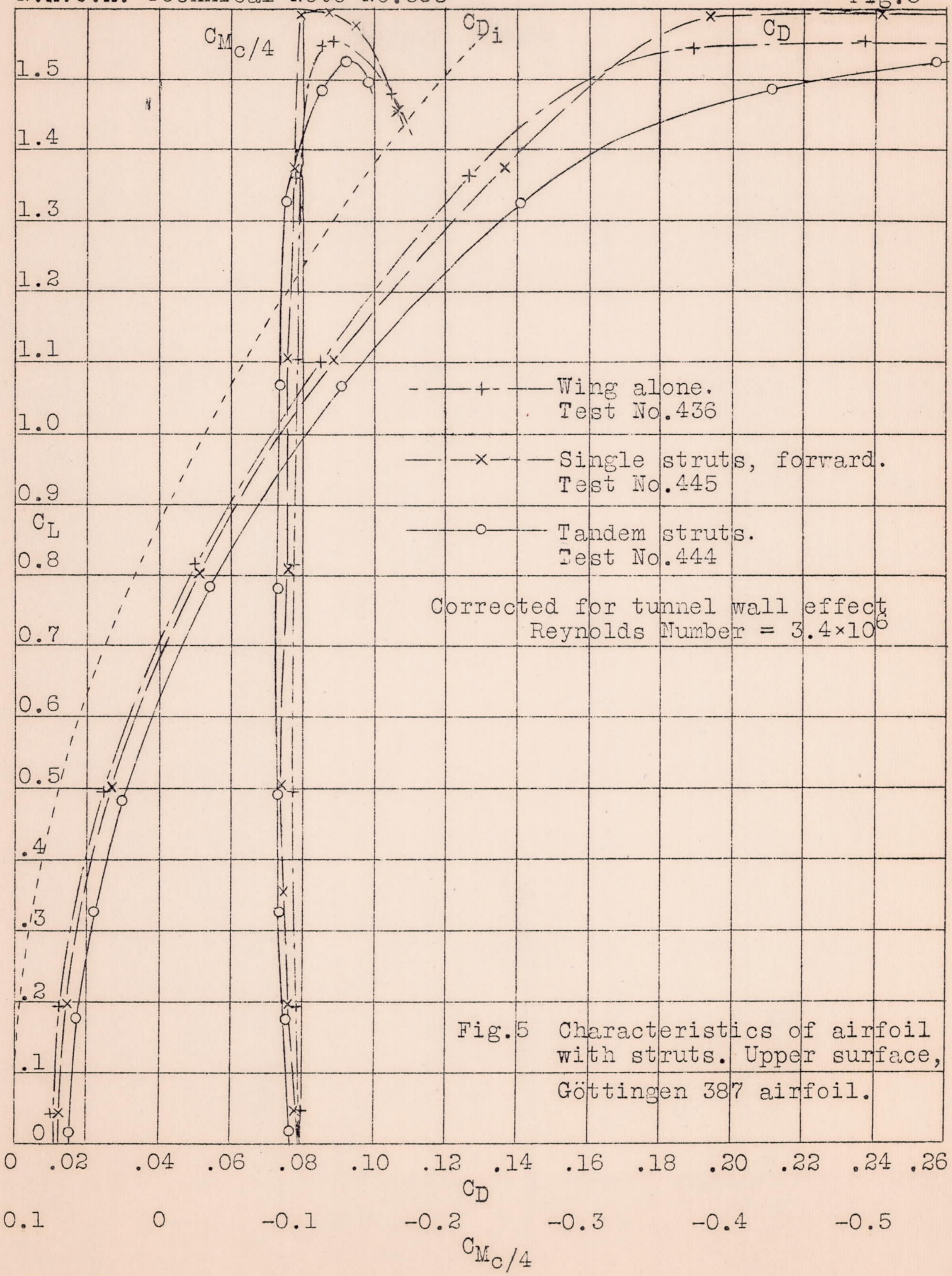


Fig.5 Characteristics of airfoil with struts. Upper surface, Göttingen 387 airfoil.