TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 323

WIND TUNNEL TESTS ON AIRFOIL BOUNDARY LAYER CONTROL USING A BACKWARD OPENING SLOT

By Montgomery Knight and Millard J. Bamber
Langley Memorial Aeronautical Laboratory

Washington
October, 1929

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL NOTE NO. 323.

WIND TUNNEL TESTS ON AIRFOIL BOUNDARY LAYER CONTROL USING A BACKWARD OPENING SLOT.

By Montgomery Knight and Millard J. Bamber.

Summary

This report presents the results of an investigation to determine the effect of boundary layer control on the lift and drag of an airfoil equipped with a backward opening slot. Various slot locations, widths of opening, and pressures, were used. The tests were conducted in the Five-Foot Atmospheric Wind Tunnel of the Langley Memorial Aeronautical Laboratory.

The greatest increase in maximum lift was 96 per cent, the greatest decrease in minimum drag was 27 per cent, and the greatest increase in the ratio, $\frac{\text{maximum lift coefficient}}{\text{minimum drag coefficient}}$, was 151 per cent.

Introduction

This preliminary report gives in brief the results of an airfoil boundary layer control investigation made to determine the effect of slot location, size, pressure maintained on the inside of the wing, and the quantity of air flowing through the slot. These tests were made in the Five-Foot Atmospheric Wind Tunnel of the Langley Memorial Aeronautical Laboratory, and were a continuation of those described in Reference 1. The backward opening type of slot was used because, in the former tests, this type of slot, when not in operation, gave the least detrimental effect upon the aerodynamic characteristics of the airfoil. The complete results of this investigation will be published in a later report.

Apparatus and Tests

The tests were made on an airfoil equipped with a rearward opening slot which was adjustable both as to width and location along the chord. A sketch of the slot and its proportions is shown in Figure 1.

The N.A.C.A. 84-M profile was used. A sketch of this profile is shown in Figure 2, together with the locations of the slot along the chord.

The hollow airfoil of 15-inch chord and 25-1/4-inch span was mounted vertically between two large horizontal planes at its ends. This arrangement gave practically two-dimensional air-flow conditions, and made it possible to conduct the air for the slot to or from the interior of the wing (by means of a mercury seal) without affecting the measurement of the forces. The quantity of air flowing through the slot was measured by means of an orifice meter.

The tests were divided into five main groups:

1. No slot.
2. Slot position 13.1 per cent of chord from L.E. (1.97 in.).

3. Slot position 32.5 per cent of chord from L.E. (4.88 in.)

4. Slot position 53.9 per cent of chord from L.E. (8.09 in.)

5. Slot position 72.6 per cent of chord from L.E. (10.9 in.)

For each slot position four widths of the slot were tested:

1. Slot width 0.167 per cent of chord (.025 in.).
2. Slot width 0.333 per cent of chord (.050 in.).
3. Slot width 0.500 per cent of chord (.075 in.).
4. Slot width 0.667 per cent of chord (.100 in.).

For each slot position and width, tests were made at "wing pressures" of -6, -2, 0, +1, 2, 6, and 12 times dynamic pressure (q). "Wing pressure" signifies the difference between the mean pressure inside the hollow wing and the static pressure of the test section.

For each slot position, width, and pressure, measurements of lift, drag, and slot air quantity were made at angles of attack α = -6, 0, 6, 9, 12, 15, 18, 21, 24, 27, and 30°.

The dynamic pressure was held constant at 4.06 lb. per sq. ft. during the tests. This corresponded to an average air speed of 40 m.p.h., and an average Reynolds Number of 455,000.

Results

These brief results show the general effect of pressure, slot position and width on the

1. Increase in maximum lift coefficient (Figs. 3 and 4)
2. Decrease in minimum drag coefficient (Figs. 5 and 6).
3. Increase in speed range ratio (Figs. 7 and 8).

In Figure 9, typical lift and drag coefficients C_L and C_D, respectively, are plotted against angle of attack α, for the plain airfoil and also for the slot combination giving the greatest increase in maximum lift. Two drag curves are given for the slotted airfoil, one being the drag coefficient C_D, as determined from drag balance measurements; the other being the effective drag coefficient $C_D + C_{DS}$. C_{DS}, a hypothetical drag coefficient, when used in the equation $p = \frac{1}{2} \rho S V^3 C_{DS}$, gives the power required to maintain the air flow through the slot to or from the inside of the airfoil. This power does not include the losses in the blower or connecting air ducts, since these losses will vary with different duct-blower installations. For a particular installation the duct-blower losses must, of course, be included in C_{DS} or accounted for in some other suitable way in calculating the over-all wing efficiency. The derivation of the coefficient C_{DS} is given in Reference 1.

It should be noted that the drag coefficient on the airfoil C_D, is actually negative under certain conditions, but that this negative coefficient is obtained by the expenditure of power represented by C_{DS} so that the airfoil has an effective drag coefficient equal to $(C_D + C_{DS})$.

The ratio $\frac{C_L \text{ maximum}}{(C_D + C_{DS}) \text{ minimum}}$, may be considered as a figure of merit for the various slot combinations. Since C_L maximum represents the low-speed condition and $(C_D + C_{DS})$ minimum represents the high-speed condition, the larger the value of the above ratio the larger the speed range, and the better the wing for general purposes. This criterion is practically independent of aspect ratio.

In the above ratio, in every case, the value of $(C_D + C_{DS})$ minimum is that obtained at a wing pressure approximately equal to q, since this pressure gives, in general, the greatest reduction in minimum drag as shown in Figure 6.

In comparison with the plain airfoil:

1. The greatest increase in maximum lift coefficient C_L maximum, was 96 per cent, with the widest slot (0.667 per cent chord) located at 53.9 per cent of the chord from the leading edge and at the greatest wing pressure (12 q).

2. The greatest decrease in minimum drag coefficient $(C_D + C_{DS})$ minimum, was 27 per cent, with the widest slot (0.667 per cent chord) at 72.6 per cent of the chord from the leading edge and at a wing pressure approximately equal to 1 q.

3. The greatest increase in the ratio $\frac{C_L \text{ maximum}}{(C_D + C_{DS}) \text{ minimum}}$, was 151 per cent with the widest slot (0.667 per cent chord) located at 53.9 per cent of the chord from the leading edge. The wing pressure in the above ratio for C_L maximum was the greatest (12 q) and for C_D minimum was about equal to 1 q, and at the test speed of 40 m.p.h., the quantity of air in cu.ft. per sec. per sq.ft. of wing area was 1.095 for C_L maximum and .407 for C_D minimum.

The above statements indicate the advantages that might be gained by the use of a slot under the ideal condition of 100 per cent duct-blower efficiency.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 15, 1929.

R e f e r e n c e

1. Reid, E. G. and Bamber, M. J. : Preliminary Investigation on Boundary Layer Control by Means of Suction and Pressure with the U.S.A. 27 Airfoil. N.A.C.A. Technical Note No. 286, 1928.

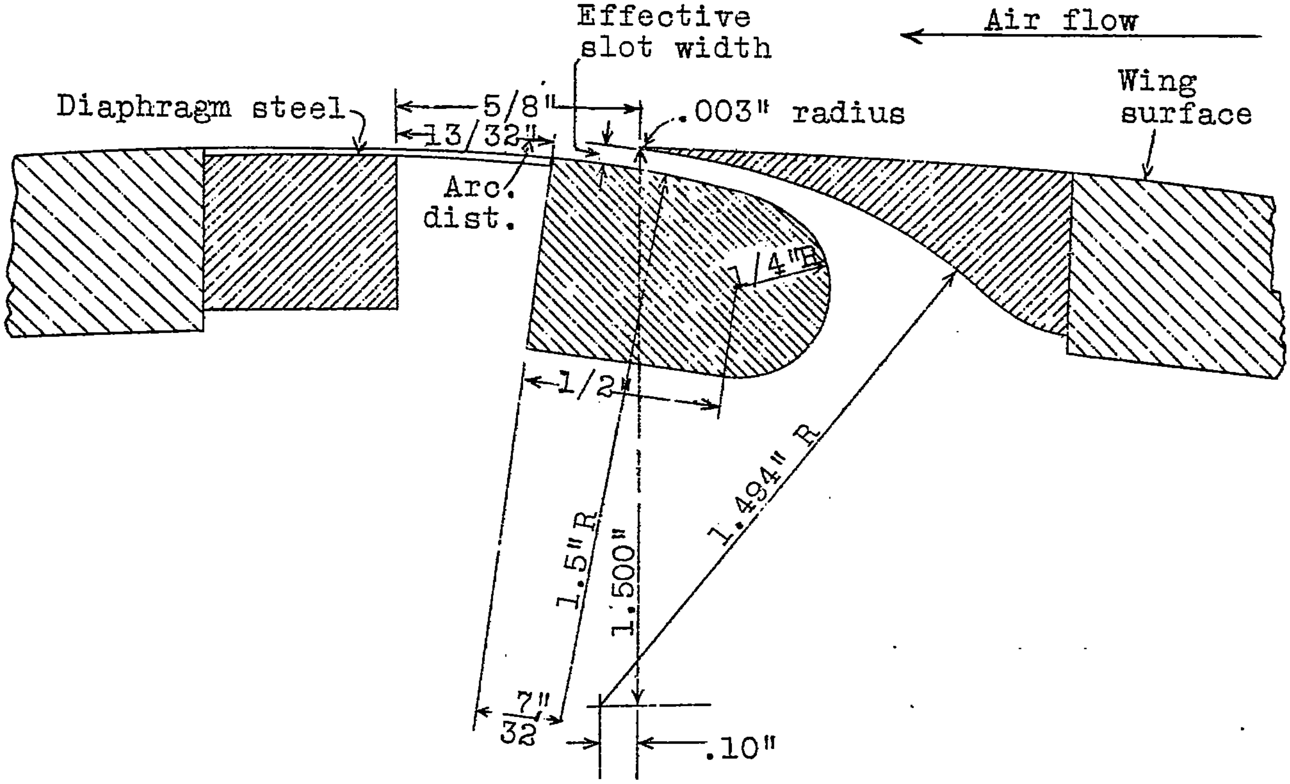

Fig.1 Diagram of adjustable slot.

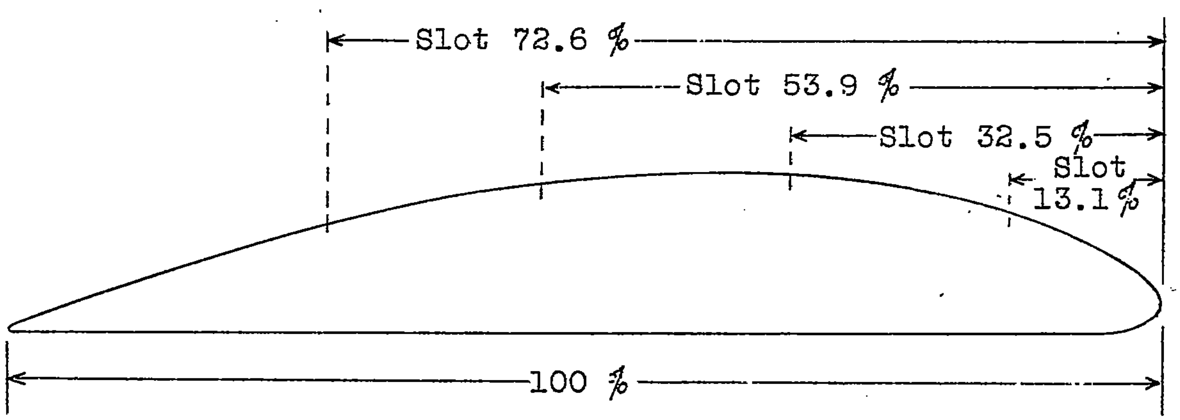

Fig.2 N.A.C.A. 84-M profile with slot locations.

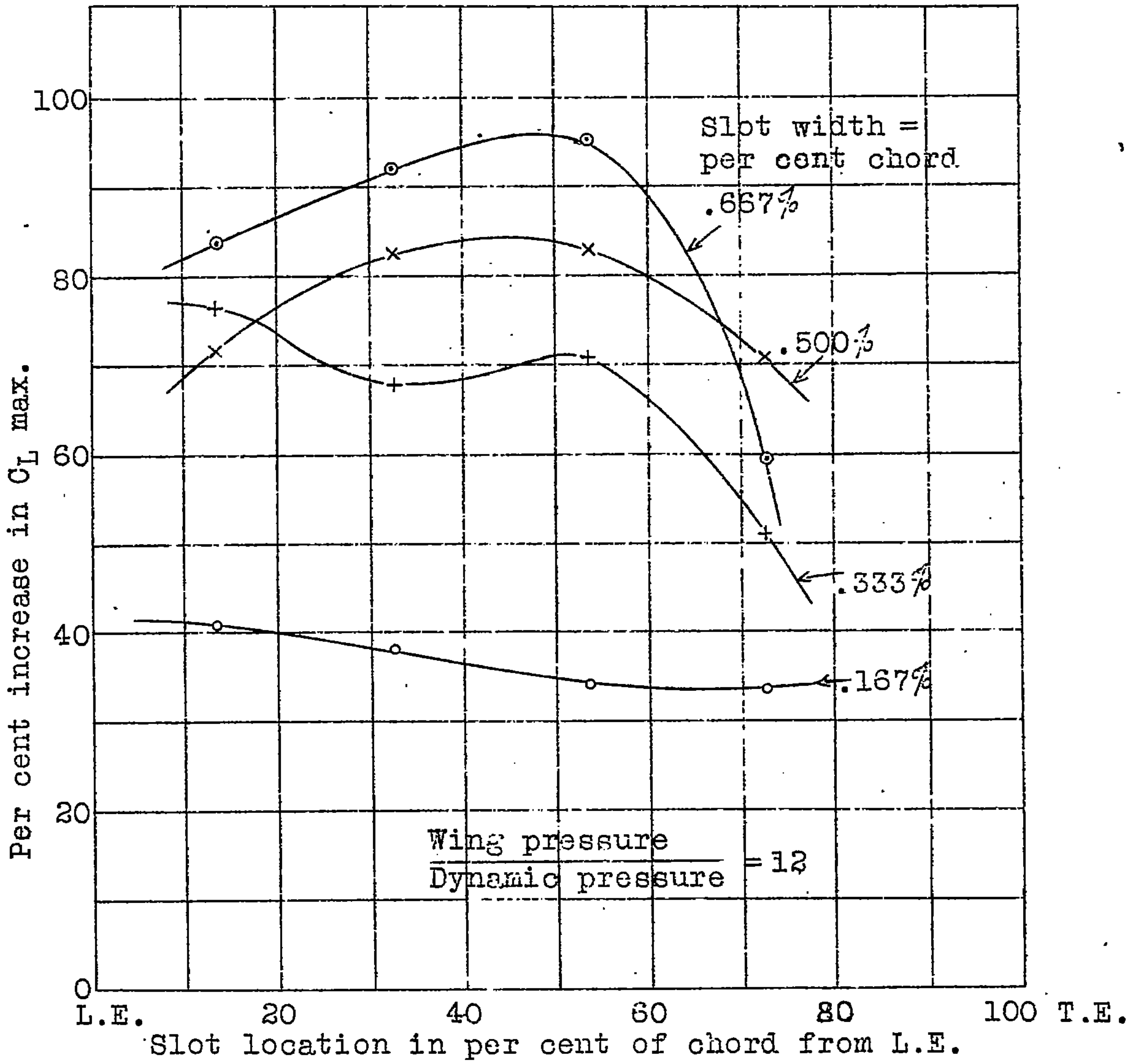

Fig.3 Increase in maximum lift due to the slot at various locations and widths.

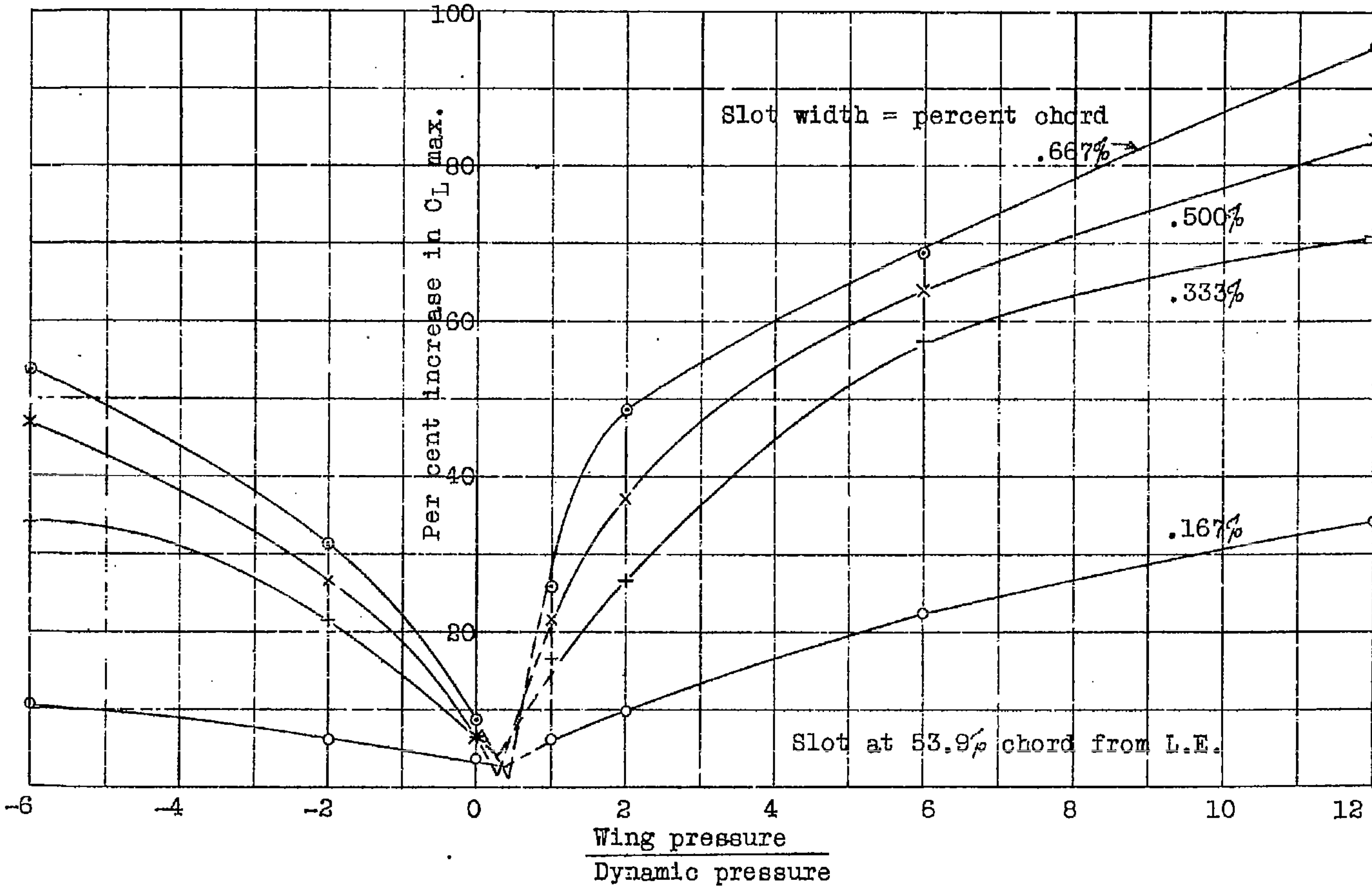

Fig.4 Increase in maximum lift due to slot at various widths and wing pressure.

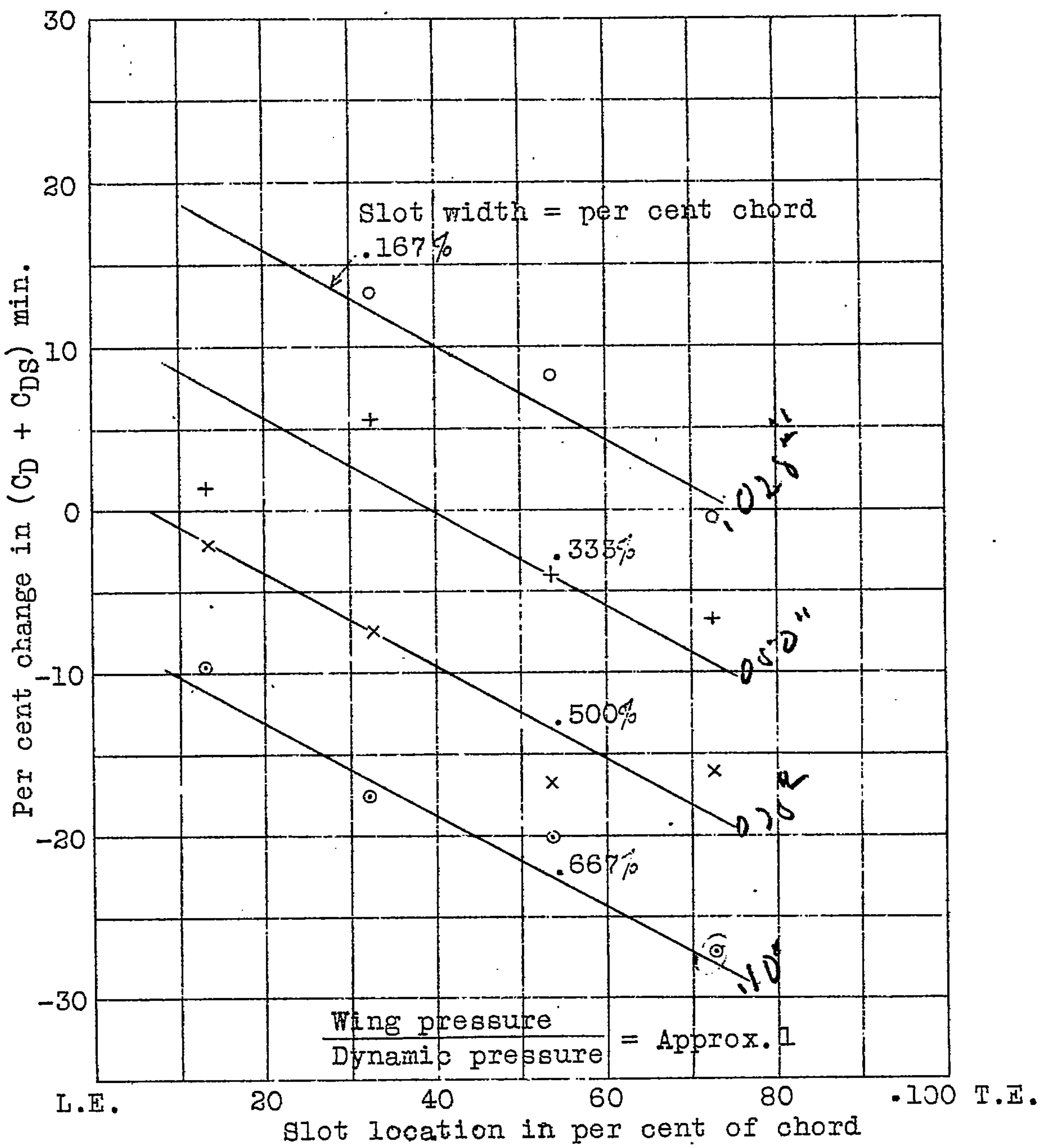

Fig.5 Change in minimum drag due to the slot at various locations and widths.

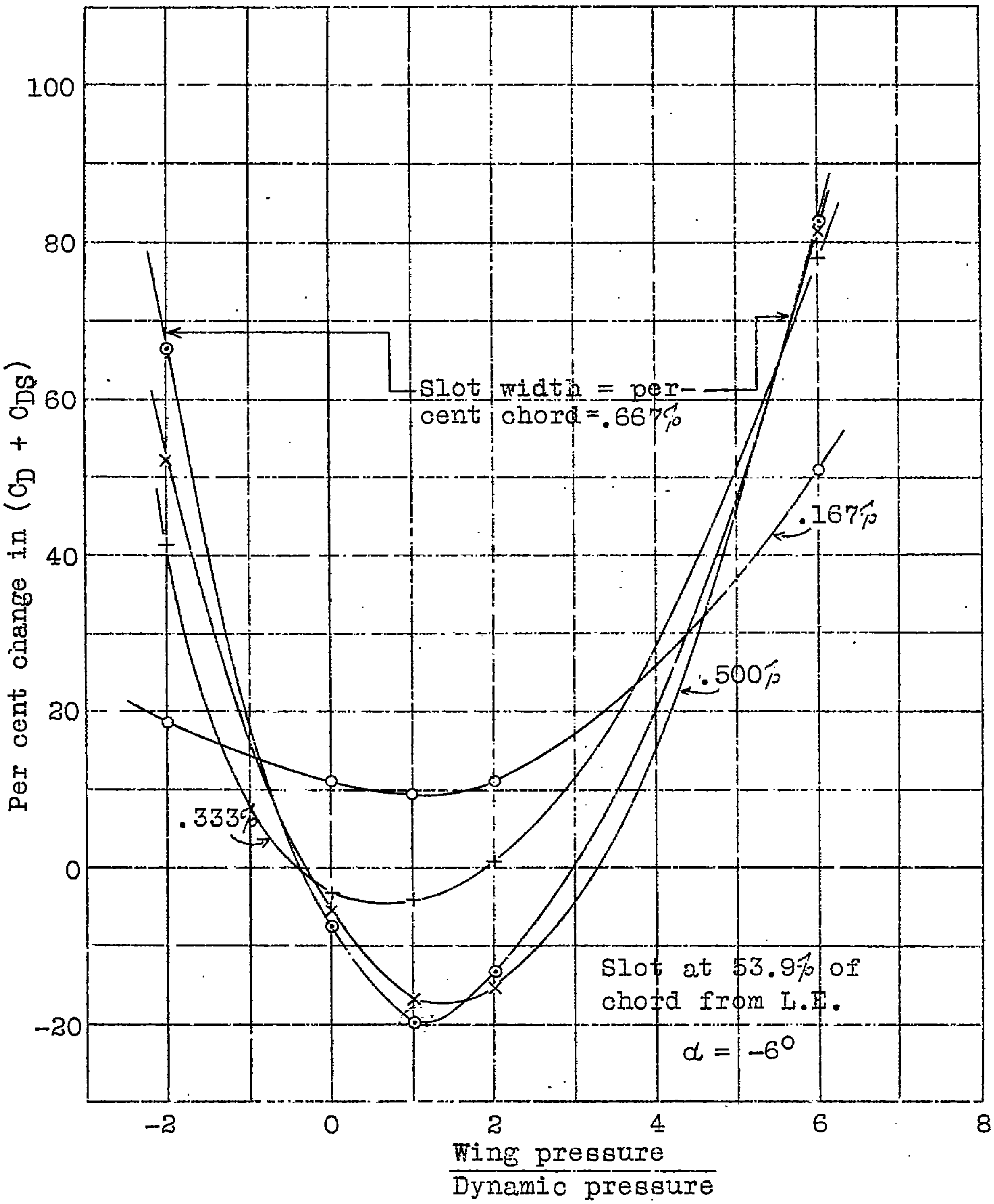

Fig.6 Change in minimum drag due to slot at various widths and pressures.

$$\frac{\text{Wing pressure}}{\text{Dynamic pressure}} = 12 \text{ for } C_L \text{ max.}$$

$$\frac{\text{Wing pressure}}{\text{Dynamic pressure}} = \text{Approx. 1 for } (C_D + C_{DS}) \text{ min.}$$

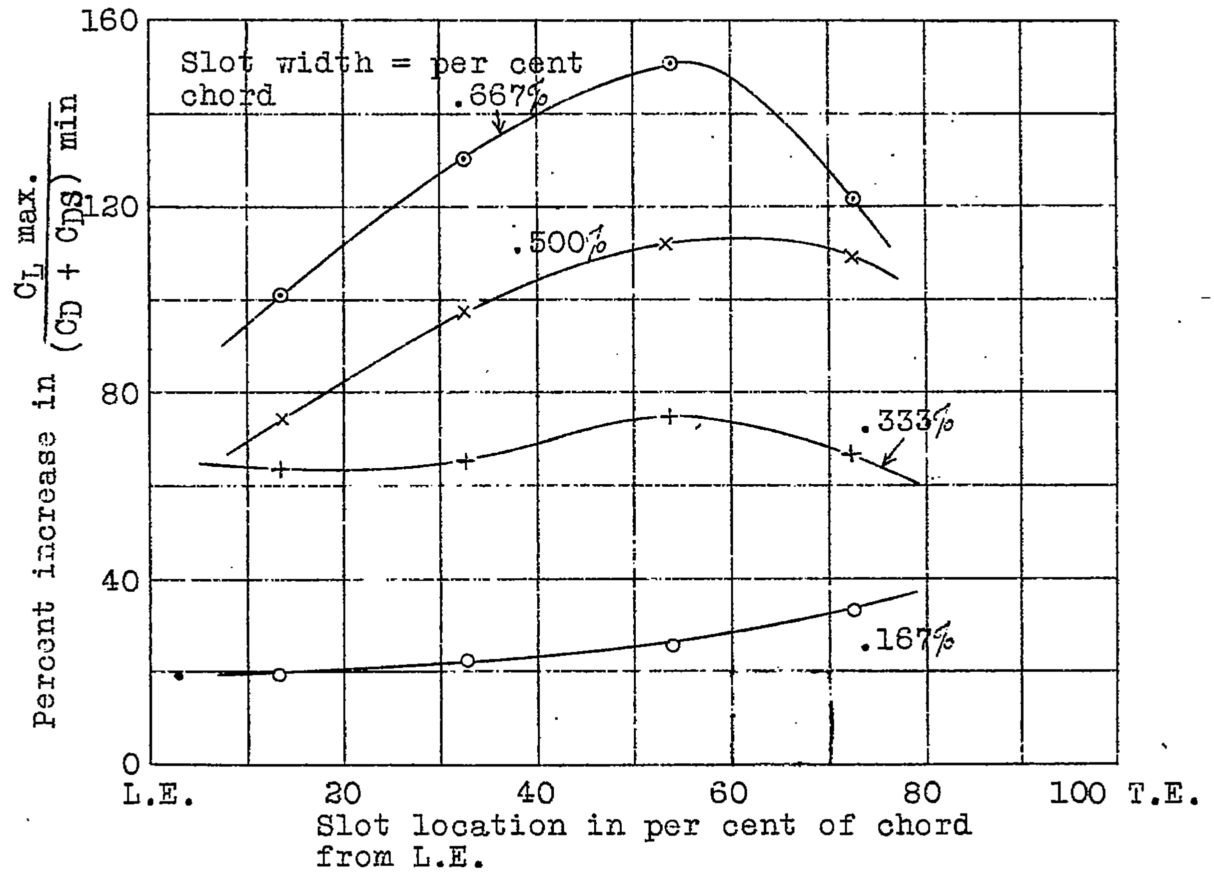

Fig.7 Increase in the ratio $\frac{C_L \text{ max.}}{(C_D + C_{DS}) \text{ min.}}$ due to slot at various locations and widths.

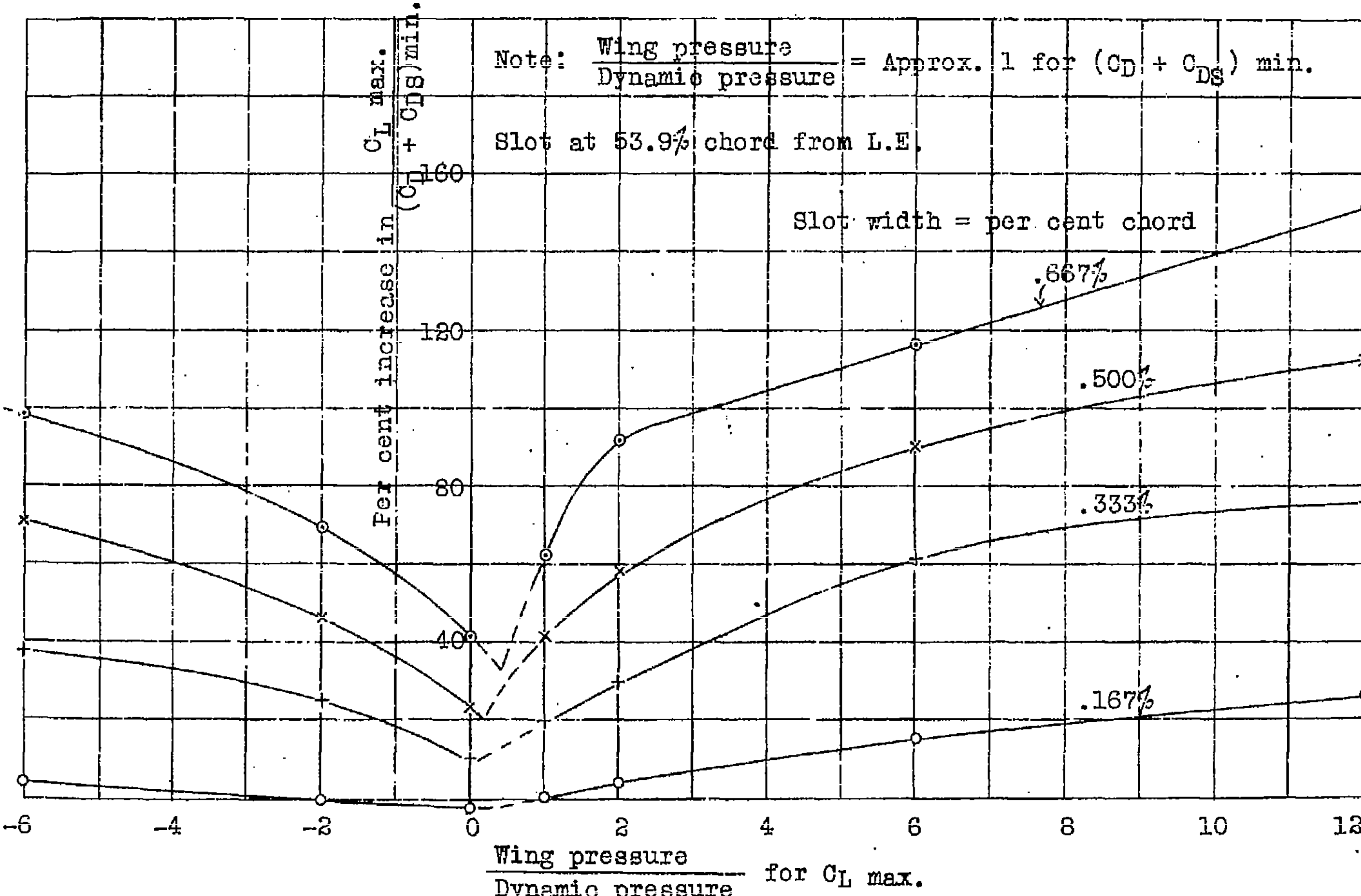

Fig.8 Increase in the ratio $\frac{C_L \text{ max.}}{(C_D + C_{DS}) \text{ min.}}$ due to slot at various widths and pressures.

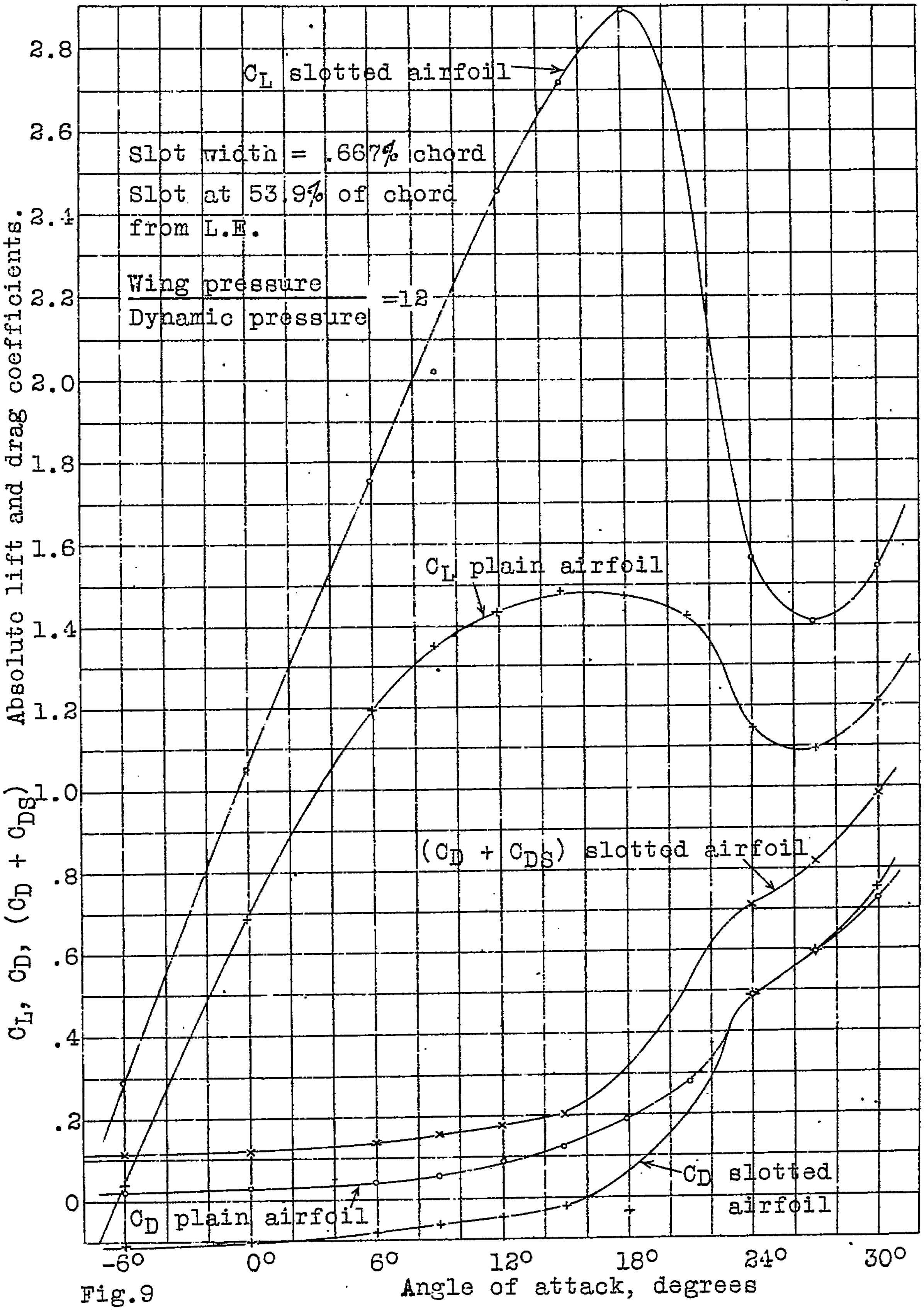
CL slotted airfoil
Slot width = .667% chord
Slot at 53.9% of chord from L.E.
Wing pressure / Dynamic pressure = 12
CL plain airfoil
(CD + CDS) slotted airfoil
CD slotted airfoil
CD plain airfoil
CL, CD, (CD + CDS) Absolute lift and drag coefficients.
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
-6°
0°
6°
12°
18°
24°
30°
Angle of attack, degrees

Fig.9