REPORT No. 742

WIND-TUNNEL INVESTIGATION OF AN NACA 23012 AIRFOIL WITH 30-PERCENT-CHORD VENETIAN-BLIND FLAPS

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SUMMARY

An investigation has been made in the NACA 7- by 10-foot wind tunnel of an NACA 23012 airfoil with 30-percent-chord venetian-blind flaps having one, two, three, and four slats of Clark Y section. The three-slat arrangement was aerodynamically the best of those tested but showed practically no improvement over the comparable arrangement used in the preliminary tests published in NACA Report No. 689. The multiple-slat flaps gave slightly higher lift coefficients than the one-slat (Fowler) flap but gave considerably greater pitching-moment coefficients. An analysis of test data indicates that substitution of a thicker and more cambered section for the Clark Y slats should improve the aerodynamic and the structural characteristics of the venetian-blind flap.

INTRODUCTION

The NACA is undertaking an extensive investigation of various wing-flap combinations for improving safety and performance in flight. One promising combination developed to date by the NACA is the venetian-blind flap (reference 1), which gave higher maximum lift coefficients and lower drag coefficients at moderately high lift coefficients than any flap previously tested by the NACA (references 1 and 2).

A further development of the 30-percent-chord venetian-blind flap hinged at the trailing edge of the wing appeared promising. In the present investigation various arrangements were tested to determine the effect of number of the slats and chords of the slats used to form the flap, of the slot gap between the slats, and of the position of the slats with respect to each other and to the wing.

The characteristics of an NACA slotted flap and of a plain wing are included for comparison.

MODELS

MAIN AIRFOIL

The basic wing, or plain airfoil, was built to the NACA 23012 profile and has a chord of 3 feet and a span of 7 feet. The wing was constructed of laminated mahogany and tempered wallboard with a steel trailing-edge plate. It was specially made for these tests. The cut-out required for the retraction of the one-slat (Fowler) 30-percent-chord venetian-blind flap was retained in all the models.

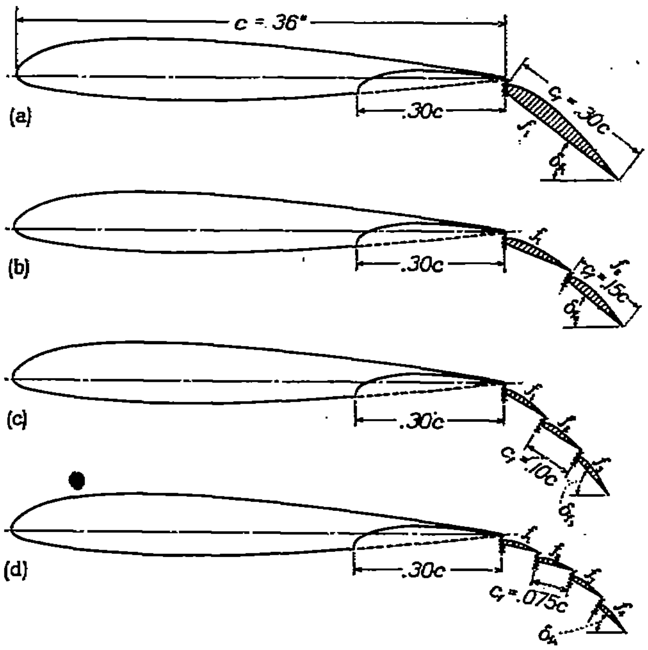
VENETIAN-BLIND FLAPS

All the venetian-blind flap arrangements had an over-all chord of 30 percent of the wing chord and a flap-hinge axis at the trailing edge of the wing with the flap fully extended. This arrangement was considered optimum from the tests of reference 1.

The first slat of each combination was hinged below the trailing edge of the wing and the successive slats were hinged on the preceding ones. A slat chord spacing (distance between slat-hinge axes) of one slat chord length, concluded as optimum in reference 1, and a slat-hinge axis at the slat nose (3.5 percent of the slat chord above the slat chord line) were used for all the tests. The slat deflections were measured between the wing chord line and the chord lines of the slats.

All the slats were made of wood and conformed to the Clark Y profile. They were secured to the wing with four sets of slat-hinge fittings located spanwise to give minimum slat bending deflection. Each slat required a separate set of hinge fittings.

The combinations tested (fig. 1) were: The one-slat (Fowler) flap composed of one 30-percent-chord slat,



(a) One 0.30c slat (Fowler). (b) Two 0.15c slats. (c) Three 0.10c slats. (d) Four 0.075c slats.

FIGURE 1.—Sections of NACA 23012 airfoil with several arrangements of 0.30c venetian-blind flaps. Test hinge axes of slats (x) at 0.005c, 0.015c, and 0.025c below trailing edge and perpendicular to chord line of preceding slat or airfoil.

the two-slat combination composed of two 15-percent-chord slats, the three-slat combination composed of three 10-percent-chord slats, and the four-slat combination composed of four 7½-percent-chord slats. In the tests the one-slat (Fowler) flap is considered to be the limiting case of the venetian-blind flap.

Equal slot gaps of ½, 1½, and 2½ percent of the wing chord were used. These slot gaps were measured from the slat nose-hinge point to the chord line of the immediately preceding slat or main airfoil. The slot gap defined is not the minimum air gap between two adjacent slats or between the first slat and the main airfoil but is the distance between the slat-hinge axis (at the slat nose) and the chord line of the preceding slat or main airfoil.

TESTS

The models were mounted in the closed test section of the NACA 7- by 10-foot wind tunnel so as to span the jet completely except for small clearances at each end. (See reference 3.) The main airfoil was rigidly attached to the balance frame by torque tubes, which extended through the upper and the lower boundaries of the tunnel. The angle of attack of the model was set from outside the tunnel by rotating the torque tubes with a calibrated drive. Approximately two-dimensional flow is obtained with this type of installation and the section characteristics of the model under test may be determined.

A dynamic pressure of 16.37 pounds per square foot was maintained for all the tests, which corresponds to a velocity of 80 miles per hour under standard atmospheric conditions and to an average test Reynolds number of about 2,190,000. Because of the turbulence in the wind tunnel, the effective Reynolds number R_e was approximately 3,500,000. For all tests, R_e is based on the chord of the airfoil with the flap fully retracted and on a turbulence factor of 1.6 for the tunnel.

Each venetian-blind flap combination was tested through a complete range of slat deflections with 1.5-percent-chord slot gaps. The optimum slat deflections were then tested again with equal slot gaps of 0.5- and 2.5-percent chord. An angle-of-attack range from $-6°$ to the angle of attack for maximum lift was covered in 2° increments for each test. Lift, drag, and pitching moment were measured at each angle of attack.

No tests were made of a plain wing; the plain-wing data used herein are taken from reference 3.

RESULTS AND DISCUSSION

SYMBOLS

Test results are presented in standard section non-dimensional coefficient form, corrected as in reference 3. The following symbols are used:

c_l	section lift coefficient (l/qc)
$c_{l_{e_{max}}}$	effective section maximum lift coefficient for complete airplane
c_{d_0}	section profile-drag coefficient (d_0/qc)
$c_{m_{(a.c.)_0}}$	section pitching-moment coefficient about aerodynamic center of plain airfoil $(m_{(a.c.)_0}/qc^2)$

where

l	section lift
d_0	section profile drag
$m_{(a.c.)_0}$	section pitching moment
q	dynamic pressure $\left(\frac{1}{2}\rho V^2\right)$
c	chord of basic airfoil with flap retracted

and

α_0	angle of attack for infinite aspect ratio
δ_f	deflection of individual slats

The subscript carried by f refers to the number of the slat, counting as 1 the slat hinged to the wing trailing edge.

PRECISION

The accuracy of the various measurements in the tests is believed to be within the following limits:

α_0	$\pm 0.1°$	$c_{d_{0_{(c_l=1.0)}}}$	± 0.0006
$c_{l_{max}}$	± 0.03	$c_{d_{0_{(c_l=2.5)}}}$	± 0.002
$c_{m_{(a.c.)0}}$	± 0.003	δ_f	$\pm 0.2°$
$c_{d_{0_{min}}}$	± 0.0003	Slat position	$\pm 0.001c$

The accuracy of δ_f refers to the deflection of the slat relative to the preceding slat and may be an additive error for successive slats, giving a maximum possible error of $\pm 0.8°$ for δ_{f_4} in the four-slat combination.

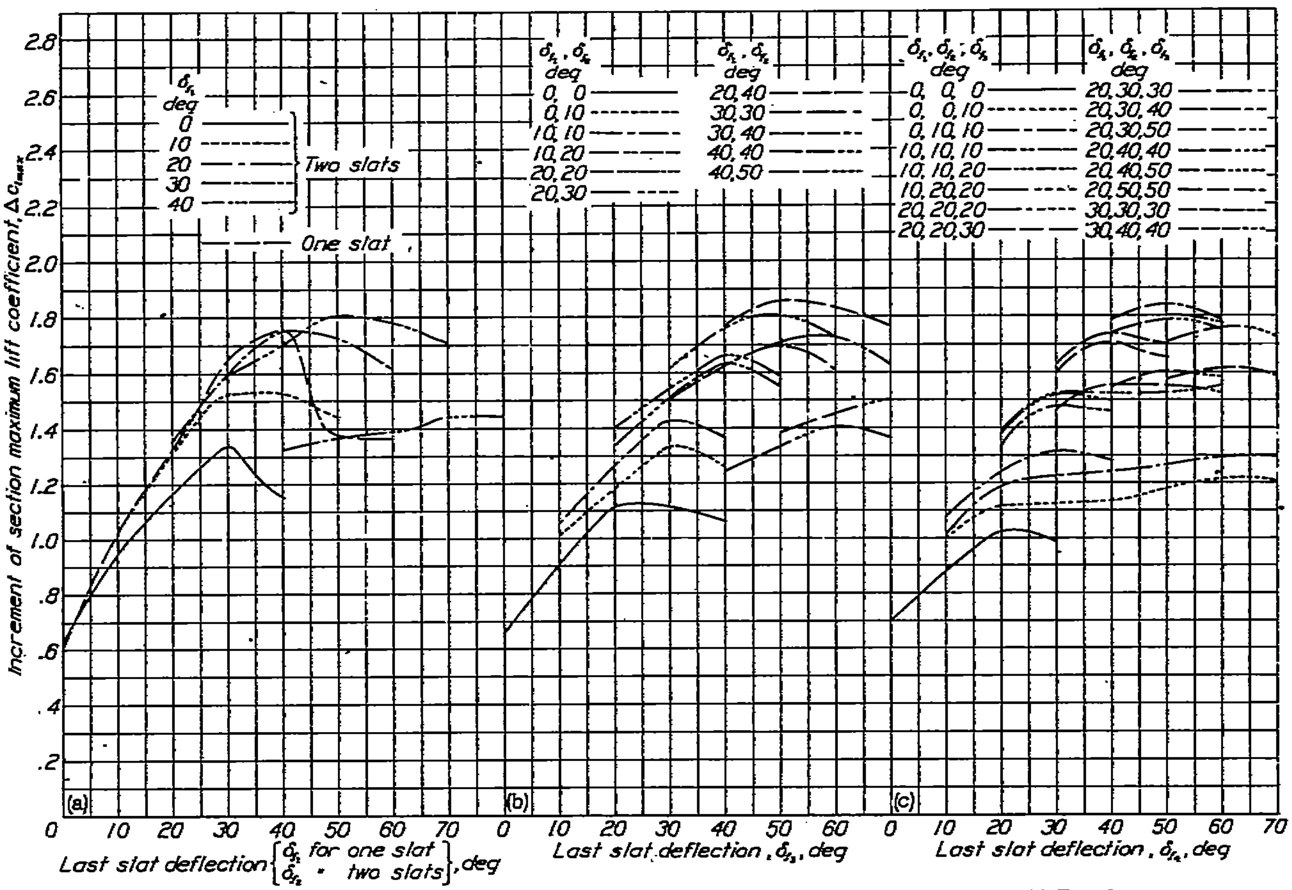
No tare tests were run to determine the effect of slat-hinge fittings on profile drag and the data are not corrected for this effect. Each slat required a separate set of fittings and the tare drag probably increased with the number of slats.

VENETIAN-BLIND FLAP ARRANGEMENT

Maximum-lift characteristics.—In order to determine the optimum venetian-blind flap arrangements from consideration of maximum lift, the various arrangements have been compared in figure 2 on the basis of increase of section maximum lift coefficients $\Delta c_{l_{max}}$ due to slat deflections. The value of $\Delta c_{l_{max}}$ is the difference between the section maximum lift coefficient of the wing with the flap extended and the section maximum lift coefficient of the plain wing.

The values of $\Delta c_{l_{max}}$ for the two- and the three-slat arrangements increase almost linearly over the one-slat arrangement giving $\Delta c_{l_{max}}$ of 1.75, 1.80, and 1.85 for the one-, the two-, and the three-slat arrangements, respectively. The three-slat arrangement was the optimum of those tested and its value of $\Delta c_{l_{max}}$ was slightly above that of the comparable three-slat arrangement of reference 1, which gave a value of $\Delta c_{l_{max}}$ of 1.80 for slightly different slat locations and profile-drag coefficient and lowest maximum lift coefficient.

The three-slat arrangement with optimum slat deflections and with a set of differential slot gaps consisting of a 0.015c slot gap between the main wing and the first slat and 0.005c slot gaps between the other



(a) One and two slats. (b) Three slats. (c) Four slats.

FIGURE 2.—Increments of maximum lift coefficients for various arrangements of 0.30c venetian-blind flaps with 0.015c gaps.

deflections. The $\Delta c_{l_{max}}$ of the four-slat optimum arrangement was 1.84, indicating that a further increase in the number of slats would probably give no improvement in high-lift characteristics.

Differential deflection of slats with the last slat set at 50° proved optimum for the two-, the three-, and the four-slat arrangements and, as the number of slats composing the flap increased, the differential deflection between slats decreased for optimum arrangements.

The effect of slot gap on the increment of maximum lift coefficient is shown in figure 3. The effect of slot gap on other aerodynamic section characteristics is shown in figure 4. For all arrangements the 0.015c slot gap was optimum for maximum lift and low profile drag; the 0.005c slot gap was next best; and the 0.025c slot gap was least desirable with large increases in

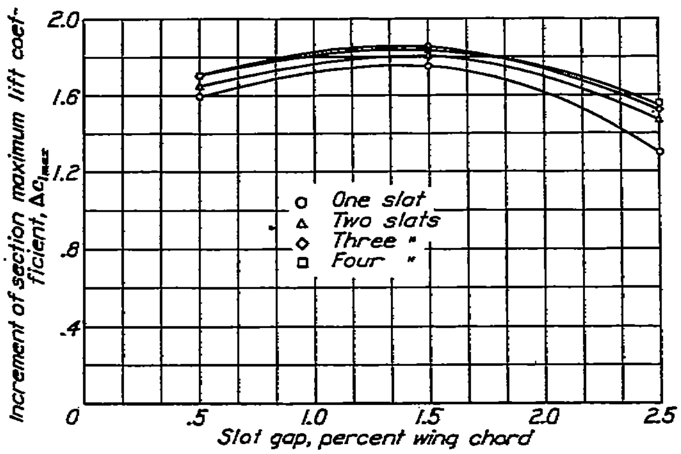
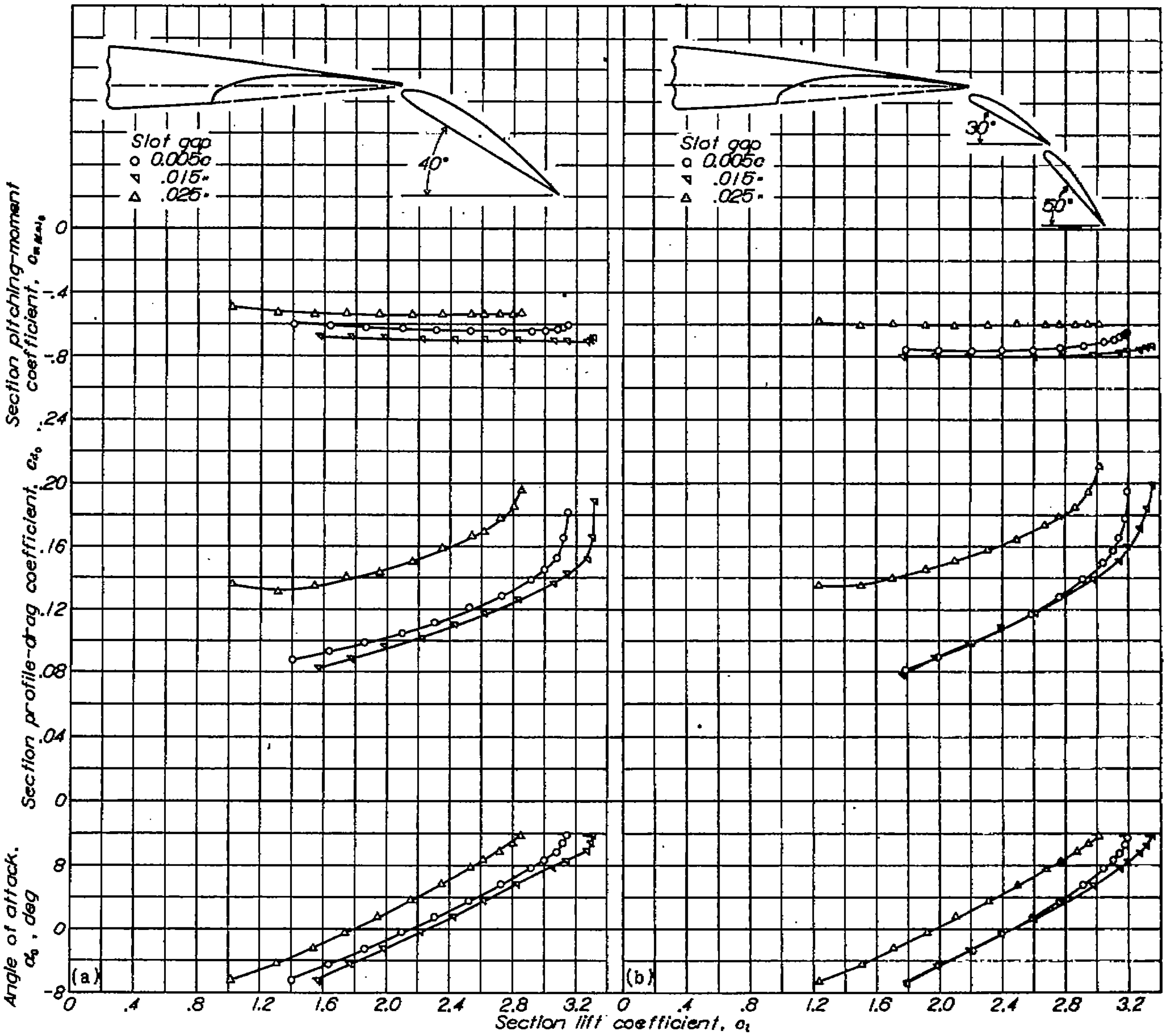


FIGURE 3.—Effect of slot gap on maximum lift of 0.30c venetian-blind flaps at optimum deflections

slats (see fig. 4) gave a higher maximum lift coefficient than it gave with the equally spaced slot gaps of 0.005c and 0.025c but gave a lower maximum lift coefficient than with the equally spaced 0.015c slot gaps. The optimum slot gaps of 0.015c for the venetian-blind flap are in agreement with the optimum slot gaps for the slotted flap in reference 3.

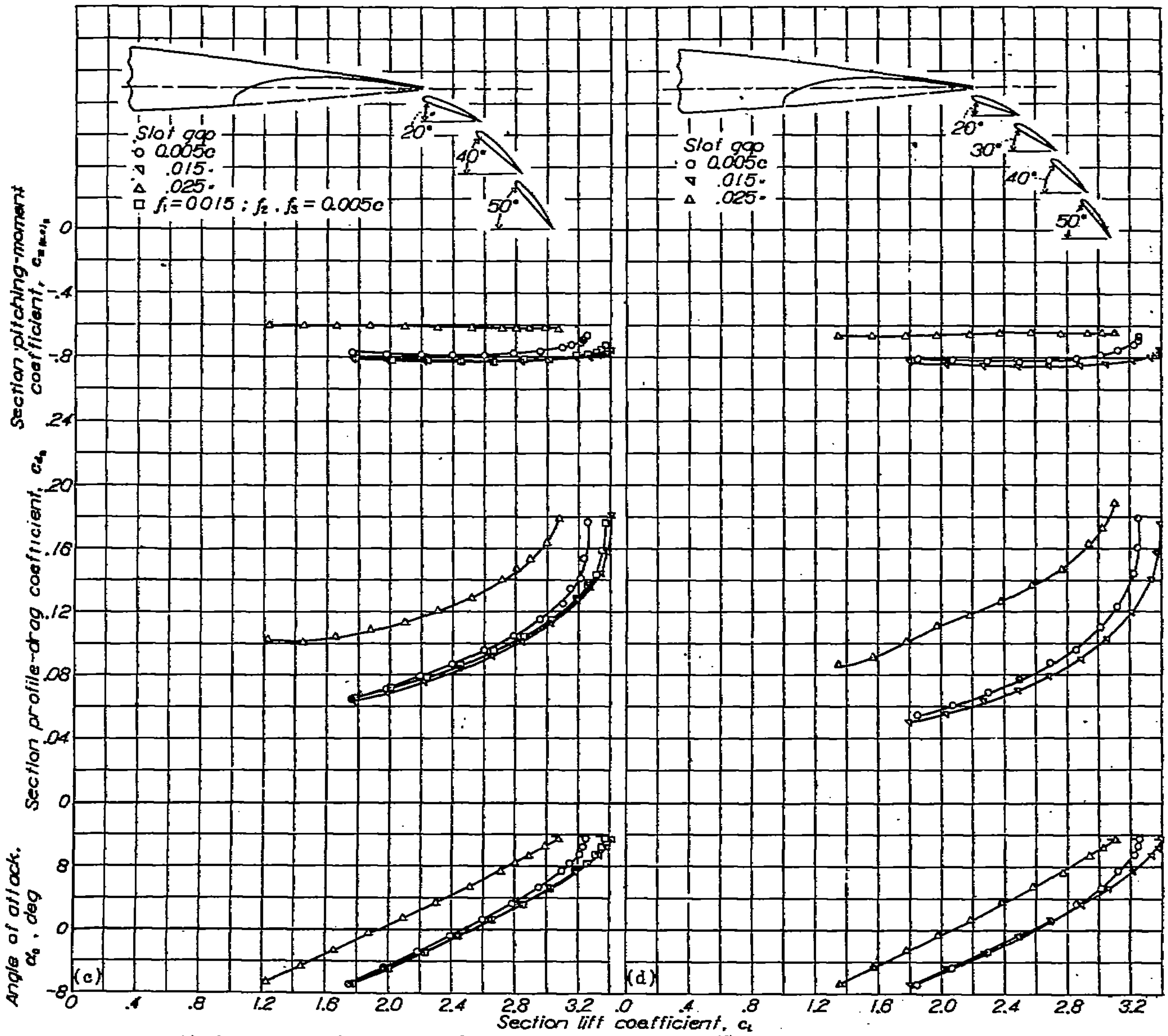
for the slats in the present investigation. Although the results of reference 4 were obtained for plain airfoils, it appears that similar effects would probably be obtained for the individual airfoils of the venetian-blind flap arrangement with a resultant improvement in the maximum lift of the wing-flap combination. This belief is supported by results of tests of Fowler flap combinations in which the replacement of a flap airfoil of NACA 23012 section (reference 3) by a flap airfoil of Clark Y section (unreported) gave considerable improvement in the maximum lift of the wing-flap combination. An additional advantage of very thick highly cambered airfoil sections, such as the NACA 8318, for the venetian-blind flap arrangement is their relatively high resistance to bending. These thick sections may retract into a fairly thin wing and will provide a smooth



(a) One slat; $\delta_{f_1}=40°$.
(b) Two slats; $\delta_{f_1}=30°$; $\delta_{f_2}=50°$.

FIGURE 4.—Effect of slot gap on aerodynamic section characteristics of 0.30c venetian-blind flaps at optimum deflections.

In consideration of possible increases in the maximum lift of the venetian-blind flap, it is interesting to note that the slats are of such small chord that the range of Reynolds number in which they operate is low, being about 600,000 to 1,000,000 for landing and take-off conditions. The results of reference 4 show that, for Reynolds numbers within this range, highly cambered thick airfoils give higher maximum lift coefficients than do airfoils with sections of the type used



(c) Three slats; $\delta_{f_1}=20°$; $\delta_{f_2}=40°$; $\delta_{f_3}=50°$. (d) Four slats; $\delta_{f_1}=20°$; $\delta_{f_2}=30°$; $\delta_{f_3}=40°$; $\delta_{f_4}=50°$.

FIGURE 4.—Continued.

lower surface when retracted. Further consideration of the use of such airfoils for the venetian-blind flap combinations appears desirable.

Effect on profile-drag of various types of flap.—Envelope polars of profile-drag coefficient for the four combinations of venetian-blind flaps, the plain wing, and slotted flap 2-h of reference 3 are compared in figure 5. As previously mentioned, no tare tests were made of the venetian-blind flap arrangements or of the slotted flap 2-h of reference 3; the profile-drag coefficients shown include the drag of the hinge fittings. For lift coefficients less than 1.2, only plain-wing data are shown, because, from low-drag considerations, a plain wing is superior to a wing with a flap partly or fully extended.

For lift coefficients greater than 2.0, the venetian-blind flap arrangements gave less profile-drag coefficient than the best slotted flap of reference 3. For a lift

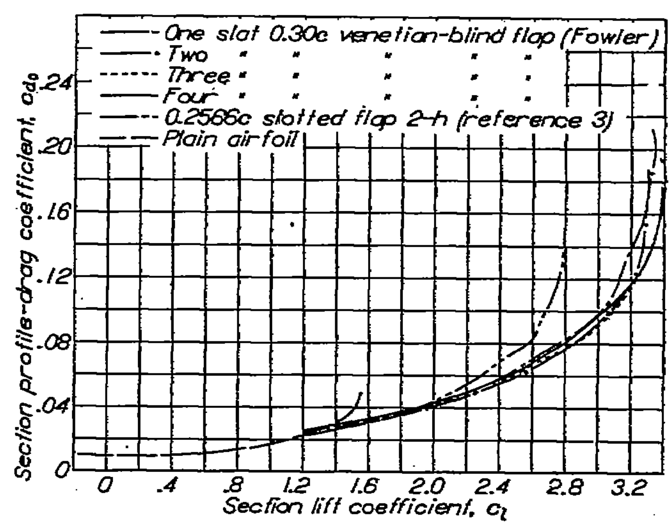


FIGURE 5.—Profile-drag envelope polars for NACA 23012 airfoil with various flaps. Venetian-blind flap arrangements shown are with all slats fully extended.

coefficient of 2.5, the two-slat arrangement had the least drag, giving 27 percent less drag coefficient than the best slotted flap of reference 3 at the same c_l; and, at a c_l of 3.0, the three-slat arrangement had the lowest drag coefficient, the two-, the four-, and the one-slat combinations, respectively, giving successively higher drag coefficients. As an example of the high variable profile-drag coefficient at high lift coefficient, the profile-drag coefficient of the three-slat combination increased 31 percent for an increase in lift coefficient of only 0.1 in going from c_l of 3.3 to 3.4.

Comparison of pitching moments.—The venetian-blind flap arrangements gave large pitching-moment coefficients, which increased with the number of slats. The four-slat arrangements, however, gave only slightly higher pitching-moment coefficients than the three-slat arrangement. The optimum three-slat arrangement gave a pitching-moment coefficient of −0.76 at $c_{l_{max}}$, which was 10 percent greater than the pitching-moment coefficient of the one-slat (Fowler) flap at its maximum lift coefficient.

In order to give a more comprehensive comparison of maximum lift coefficients of flaps with different values of pitching-moment coefficient, the effect of tail loads required to balance the pitching-moment coefficients should be considered in determining the net or the effective maximum lift coefficient. Figure 6 gives a comparison of the effective maximum lift coefficients of several flaps for varying tail lengths. For simplicity in the computation of $c_{l_{e_{max}}}$, the center of gravity was assumed to be at the aerodynamic center of the wing with the flap fully retracted. The following formula was used:

$$c_{l_{e_{max}}}=\left[c_{l_{max}}+\frac{\left(c_{m_{(a.c.)_0}}\right)_{c_{l_{max}}}}{\text{tail length}}\right]$$

The large pitching-moment coefficients of the venetian-blind flaps made no difference in relative values of $c_{l_{e_{max}}}$ of the various flaps and, for tail lengths of 1 to 5 airfoil chord lengths (conventional length is about 2½ to 3 chord lengths), the three-slat arrangement was still optimum and the two- and the four-slat arrangements gave slightly higher values of $c_{l_{e_{max}}}$ than the one-slat, or Fowler flap, arrangement.

Slotted flap 2-h of reference 3 gave considerably lower effective $c_{l_{max}}$ than the venetian-blind flap arrangements shown. Although the slotted flap had a chord of only 0.2566c as compared with 0.30c for the venetian-blind flap, the comparison is valid in view of the fact that tests have shown a chord of about 0.25c to produce very nearly the same $c_{l_{max}}$ as a chord of 0.40c for the slotted flap. (See reference 5.)

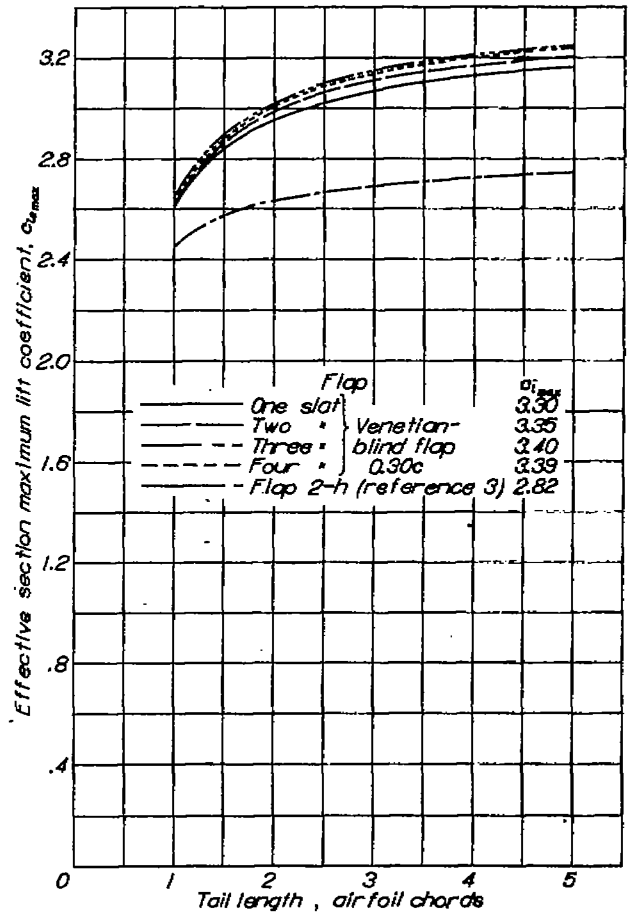
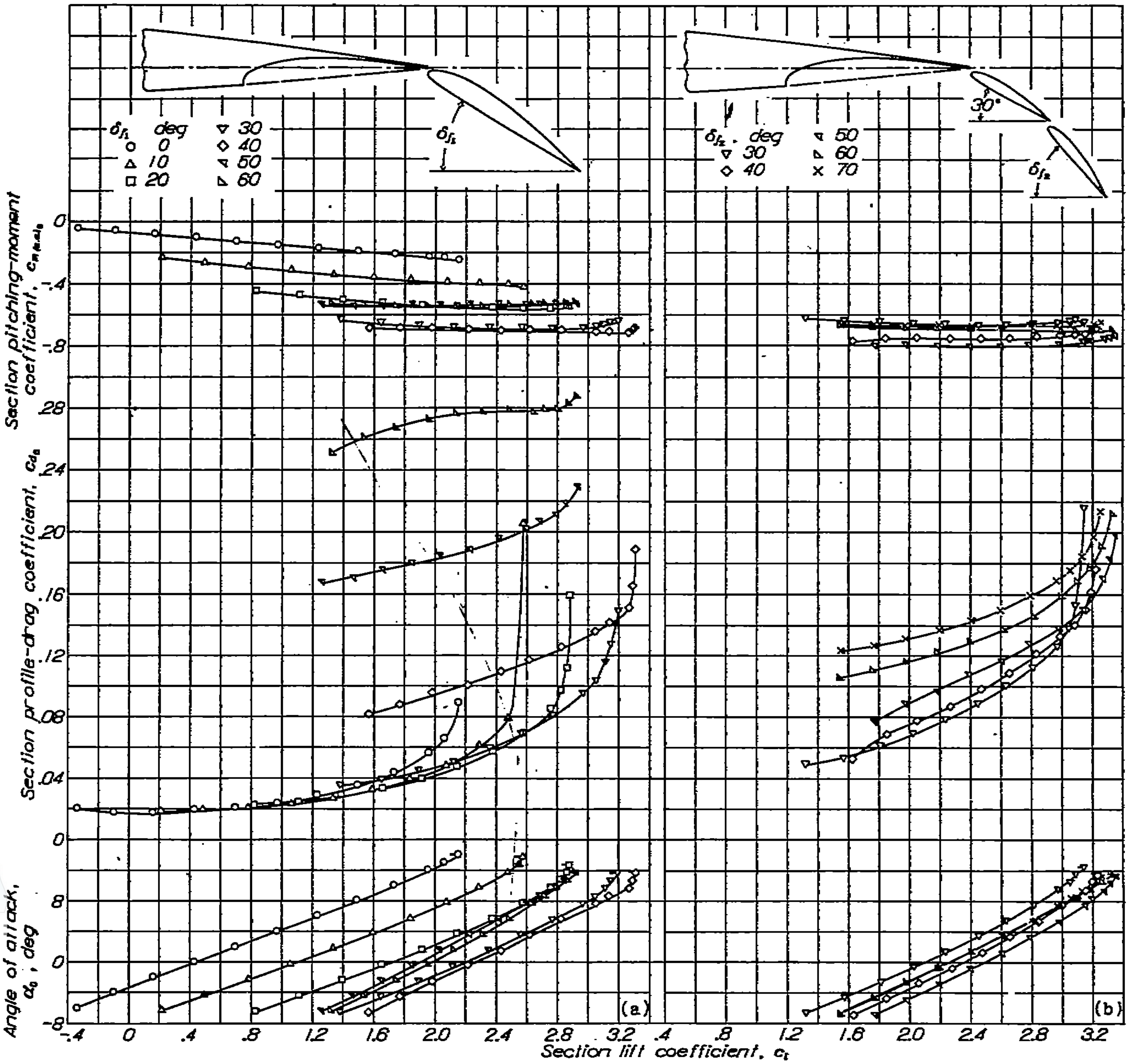


FIGURE 6.—Effective section maximum lift coefficients of NACA 23012 airfoil with several flaps.

Aerodynamic section characteristics of optimum arrangements.—The aerodynamic section characteristics of the highest lift arrangements of the one-, the two-, the three-, and the four-slat combinations with the last slats of the two-, the three-, and the four-slat combinations deflected through a short range are presented in figure 7.



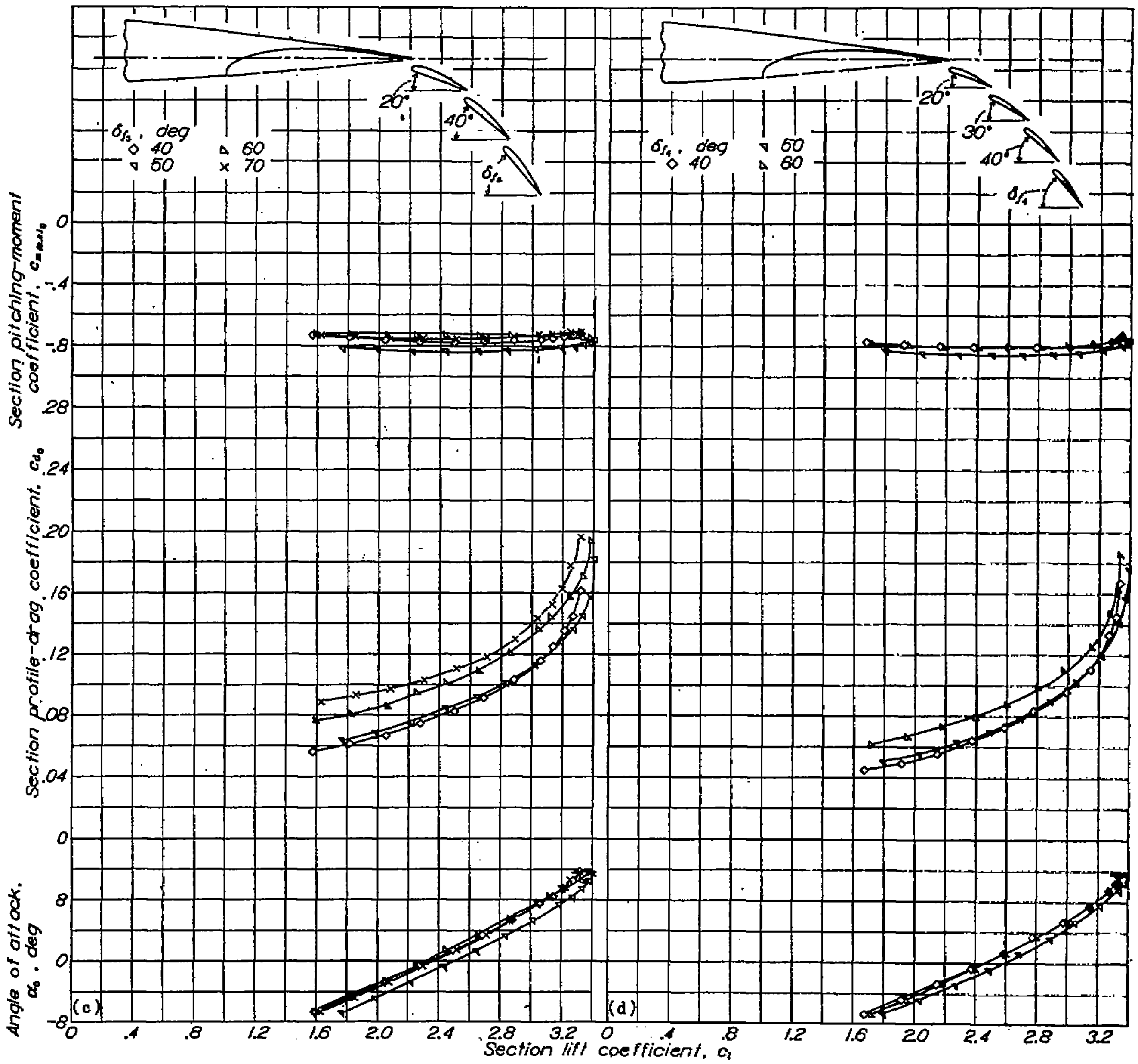
(a) One slat, various deflections. (b) Two slats; $\delta_{f_1}=30°$.

FIGURE 7.—Aerodynamic section characteristics of an NACA 23012 airfoil with optimum arrangements of 0.30c venetian-blind flaps, 0.015c slot gaps.

CONCLUSIONS

1. The best arrangements of the venetian-blind flaps tested used differentially deflected slats and 1.5-percent-chord slot gaps.

2. The results indicate that the best venetian-blind flap arrangement tested was only slightly better aerodynamically than the best comparable arrangement of the preliminary investigation reported in reference 1. The multiple-slat flaps did not give significantly higher lift coefficients than the single-slat (Fowler) flap and gave considerably greater pitching-moment coefficients. It appears, however, that improvement in high-lift characteristics could be obtained with the use of more highly cambered thick slats than with those of the present investigation.



(c) Three slats; $\delta_{f_1}=20°$; $\delta_{f_2}=40°$.

(d) Four slats; $\delta_{f_1}=20°$; $\delta_{f_2}=30°$; $\delta_{f_3}=40°$.

FIGURE 7.—Continued.

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