NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
MAILED
SEP 27 1929
TO: L M A L

TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 319

SOME EXPERIMENTS ON AUTOROTATION OF AN AIRFOIL

By Shatswell Ober
Massachusetts Institute of Technology

Washington
September, 1929

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL NOTE NO. 319.

SOME EXPERIMENTS ON AUTOROTATION OF AN AIRFOIL.

By Shatswell Ober.

Summary

These experiments show that the rate of autorotation of a monoplane airfoil is reduced by sweepback, ceasing entirely when the sweepback is 30°. They confirm previous results on the increase in rate of rotation with decrease in aspect ratio. In addition a very serious increase in rate and range of autorotation with yaw is shown.

Object.- These experiments were made as portions of two theses on autorotation, the first (Reference 1) undertaken with the definite object of studying the effect of sweepback on the autorotation of an airfoil; the second, (Reference 2) to complete the first and incidentally the effect of yaw was studied. It is the purpose of this note to give the results of the experimental work, omitting other than a brief description of apparatus and method, with little discussion in regard to causes, reasons, and theory of the phenomena observed. It is felt that the work itself is of sufficient general interest.

Apparatus.- Three airfoils were used, a rectangular 18-inch by 3-inch Clark Y made of wood, a duralumin 18-inch by

3-inch Clark Y made in halves with sweepback adjustable (Fig. 1), and a wooden airfoil of various spans, 3.46-inch chord of the section through a Clark Y with 30° sweepback. The arrangement of the sweepback model is such that the section along the wing varies with the angle of sweepback while that perpendicular to leading edges is constant.

The rotation apparatus (Fig. 2) is so familiar that only a brief description is needed. The axis is a steel tube carried at either end in ball bearings. The airfoil is held on a rod passing through the tube. During the tests the airfoil was always above the tube. The angle of attack and of yaw may be varied. Both are fixed by friction.

Tests.- All experimental work was done in the 4-foot wind tunnel at the Massachusetts Institute of Technology, unless otherwise indicated, at a speed of 40 m.p.h. The tests fall into three series. A preliminary set was made with the 18-inch × 3-inch Clark Y airfoil at zero yaw to determine range and rate of turning. The range of angles of attack was from 10° to beyond 90°. This series is of interest merely at very large angles when, on account of excessive rotational velocity, the wind speed was reduced to 15-20 m.p.h.

The second series, made with the sweepback airfoil, covered a range of angles of attack from about 10° to 35° with various angles of sweepback from 20° forward to 30° back. The third series, really a combination of two, made with the modified Clark Y airfoil, consisted of tests over a range of angles of attack with model span reduced in steps from 27.75 inches to 17.2 inches with square tips giving successively, aspect ratios of 8, 7, 6, and 4.95. At each aspect ratio the model was yawed up to 20°.

In all cases the procedure for a given test was to start at some low angle, try to secure autorotation by spinning the wing artificially, increase the angle until it would autorotate, measure the r.p.m. by a stroboscope fitted with a tachometer for a series of angles of attack until autorotation ceased and could not be secured artificially. Usually revolutions in both directions were determined and the mean used near the angles at which autorotation ceased or commenced. Sometimes rotation in one direction only could be secured (either with or opposed to the rotation of the wind tunnel propeller). Whenever the rotation tended to pass to a much higher rate, tests were stopped to avoid possible damage to the apparatus.

Test results are expressed as an "index value"

$$R = \frac{ps}{V}$$

p = angular velocity (radians per second)

V = wind speed (feet per second)

s = semispan (feet)

Index values are plotted for constant conditions vs. α (the angle of attack at the center) or for constant α against aspect ratio, sweepback, or yaw.

Results and Discussion

It is well known that in the case of biplane cellules there may be above the normal range of steady autorotation another range in which the rate of rotation is much greater. These two regions may and often do overlap so that as the angle of attack is increased, the rate of rotation progressively increases to a very high angle. Monoplane tests usually do not show these second regions. In the first series of tests the model rotated through the expected range of angles. As the angle increased up to 50° or 60° it was impossible to secure autorotation, in fact, the opposite was true; there was a large damping moment. At 90°, however, if rotation at a fair rate was started, a very high rate was reached, some twelve times the normal (Fig. 3). There is a question whether this should be called autorotation, as it might be considered a windmill effect, except one blade is travelling trailing edge first. This regime extended down to about 80°, then ceased suddenly. It has no connection with the ordinary regime when there is no yaw - a question which will be discussed later.

The results of the second series of tests - those of the effect of sweepback - are given by Figures 4 or 5, in which R is plotted against angle of attack α and Figure 6, in which R is plotted against sweepback. Passing from the straight wing to one with sweepback, the range and rate of autorotation progressively decrease until with 30° sweepback rotation ceased, though the damping was very slow. The rate of rotation was not greatly affected by sweep-forward, the total range remained about the same, but the region tended to move to higher angles of attack as sweep-forward increased.

To make certain that the decrease and finally, the stopping of the autorotation was not merely due to the change in airfoil section that occurred as the sweepback was increased, an airfoil with section through a Clark Y with 30° sweepback, rounded wing tips, and same span was tested. This airfoil had almost the same range of autorotation as the original Clark Y, but the maximum rate was lower, $R = .23$, compared with $R = .39$. This result agrees with the customary variation of R with airfoil camber but the reduction is somewhat large. Differences in bearing friction, etc., may affect the result, but it is quite evident that the change in airfoil section does not of itself account for the prevention of autorotation by sweepback.

The model with 30° sweepback was then tested as an airfoil; C_L and C_D compared with those of a normal Clark Y are given in Figure 7. The drag may be somewhat inaccurate because of the center portion of the model. From the curves, Glauert's criterion for the occurrence of autorotation $\frac{dC_L}{d\alpha} + C_D < 0$ indicates that autorotation should occur through a somewhat limited range of angles starting at 17°. The negative value is much less than in the case of the normal airfoil with no sweepback. As already mentioned, the damping is very slight, not very different from that due the bearings alone, so the reserve against autorotation is practically zero. The criterion was developed by the strip method and has been found to give unreliable results at, and just beyond the angle of maximum lift. This has been attributed to the inaccuracy of the primary assumption of uniform force distribution (Reference 3). This assumption, perhaps poor enough near maximum lift on a straight airfoil, is even more questionable on one with 30° sweepback.

The sweepback tests with confirming experiments, give the interesting information that at zero yaw autorotation may be prevented by excessive sweepback. Tests with model yawed will be discussed briefly later. It is true that during all these tests the center of the airfoil was above the axis of rotation, but the wing tips, as sweepback increased, were far below it.

The results of the third series which concerned the effect of yaw and aspect ratio on autorotation, are given by the following figures:

Figure 8, R vs. aspect ratio 8
" 9, R " " " 6
" 10, R " " " 4.95
" 11, R " " " peak values

At zero yaw the index value R increases with increase in aspect ratio, but rather slowly. Actual r.p.m., however, increase slightly as the aspect ratio decreases except with the lowest, 4.95, the revolutions decrease again. With no bearing friction, it seems that the index value should be constant, except that the higher aspect ratio has a more sudden drop in

C_L. The results show that as the aspect ratio is decreased, larger and larger departures from a constant tip speed are needed to give sufficient moment to overcome the bearing friction.

When with no rotation the airfoil is set at an angle of yaw, a rolling moment $L\psi$, is introduced tending to cause rotation. Even with a straight airfoil (no dihedral or sweepback) this is positive, i.e., tending to make the forward wing tip rise, small at low angles, increasing with angle of attack. The effect is to completely upset the usual autorotation phenomena. First, at stalling angles, rotation against the yaw is not possible. At low and sometimes at high angles, there is a slow rotation, caused by the rolling moment due to yaw and opposed by the damping in roll L_p (where the damping is small the rate of rotation is no longer small). Second, the additional rolling moment at stalling angles greatly increases the rate of rotation and extends the range through which autorotation occurs, not far below the usual regime, but considerably above it. The curves show clearly the importance of these changes.

Quantitatively, the effect of yaw on different aspect ratio models is different; it causes greater changes at the smaller aspect ratios. The effects beyond the normal autorotation regime are particularly interesting. With large aspect ratio models beyond 40°, the rate of rotation at small angles of yaw drops off suddenly, but does not become zero until 90°. At larger angles of yaw the decrease is gradual and as the angle of attack approaches 90°, the rate of rotation tends to pass over to the very high value found in first series of experiments. When the aspect ratio of the model is low, the rotation even at small angles of yaw persists to 90°, decreasing as the angle increases, but finally merging with the high rotational region near 90°. Large angles of yaw merely increase the certainty that rotation will persist until the windmill effect automatically starts. With tips rounded, the effect of yaw on the smallest aspect ratio model was still further increased. No measurements of the rates in the high region were made as there was some danger of damaging the apparatus.

The effect of varying the distance of the airfoil from the axis was not covered by this investigation. This variation might be expected to modify the flow near the center of the airfoil considerably, near the tips very little, from which it appears that the variation in rotation rate would be only slightly affected.

A few tests were made with the airfoil with 30° sweepback at angles of yaw. At small angles of yaw the rotation was either quickly damped, or occasionally the model would rotate slowly in a direction opposed to the yaw. At yaws above 15°, the model rotated rapidly with the yaw. Thus the prevention of autorotation by sweepback secured at 0° yaw is completely upset by static yaw or side slips.

Most theories of spinning neglect side slip altogether or dismiss it as being slight. Good experimental evidence of its amount is fragmentary, but apparently in some cases - by no means, all - the side slip may reach a size equivalent to 10° or 20° yaw. The direction of the side slip is "outward," i.e., to the left when spinning to the right. The rolling moment due to yaw then acts to increase the tendency of the wings to autorotate.

Contrary to most previous evidence and opinions, this series of experiments indicate that in the case of a monoplane, if the equilibrium conditions in a spin involve considerable side slip, and if the weight distribution is such that the rotation produces a large stalling moment, the spin may become very flat. "Flat spins" are usually characterized by a very great increase in rate of rotation; the monoplane with yaw would probably lack that, but if of low aspect ratio and other conditions were bad enough, even the high rate might possibly be reached.

Massachusetts Institute of Technology,
July 19, 1929.

References

1.	Wang, S. C.	The Effect of Sweepback on the Autorotation of an Airfoil. (1927)
2.	Niedelman, Samuel	An Explanation of Cessation of Autorotation of a Clark Y with 30° Sweepback and the Effects of Static Yaw and Aspect Ratio on Autorotation. (1929)
3.	Knight, Montgomery	Wind Tunnel Tests on Autorotation and the "Flat Spin." N.A.C.A. Technical Report No. 273, 1927.

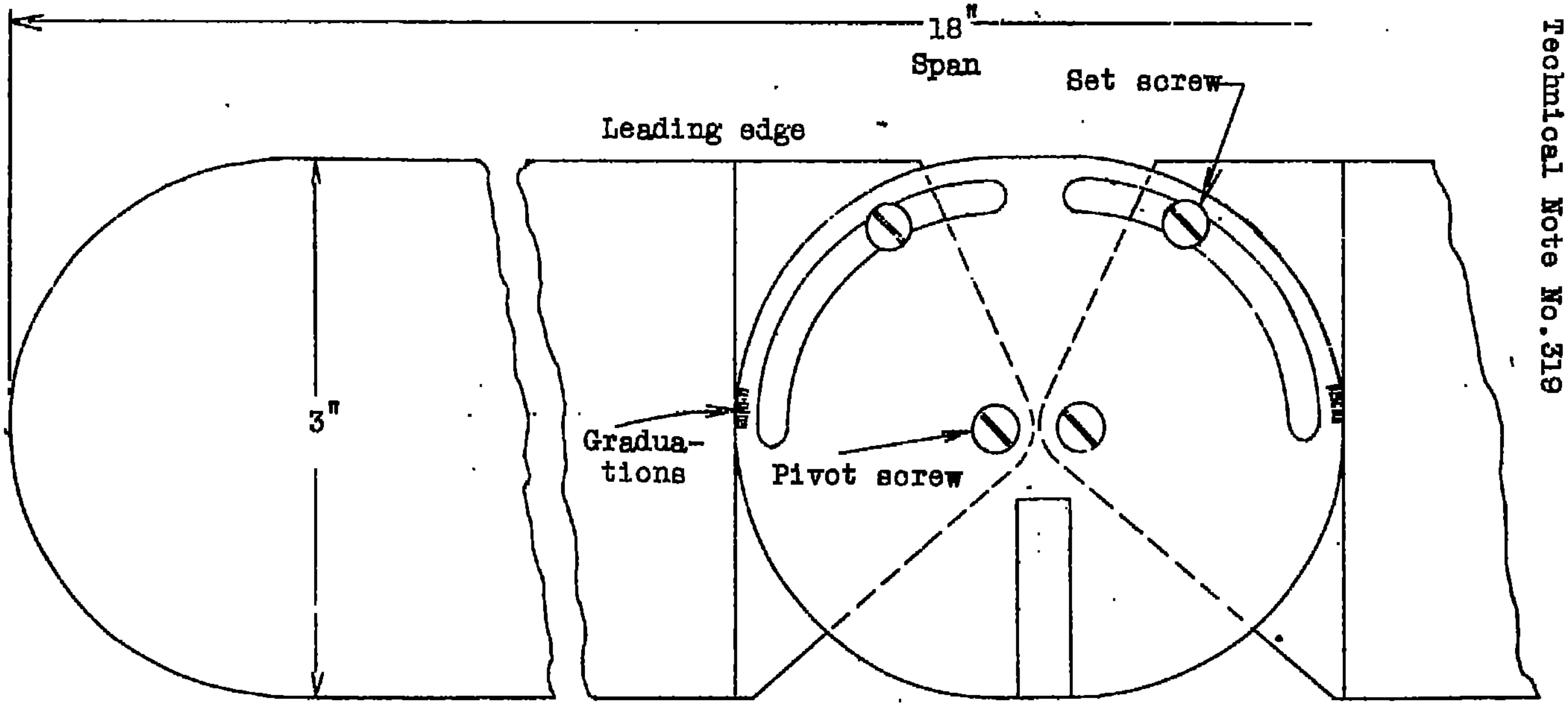


Fig.1 Airfoil with variable sweepback.
Clark Y section.

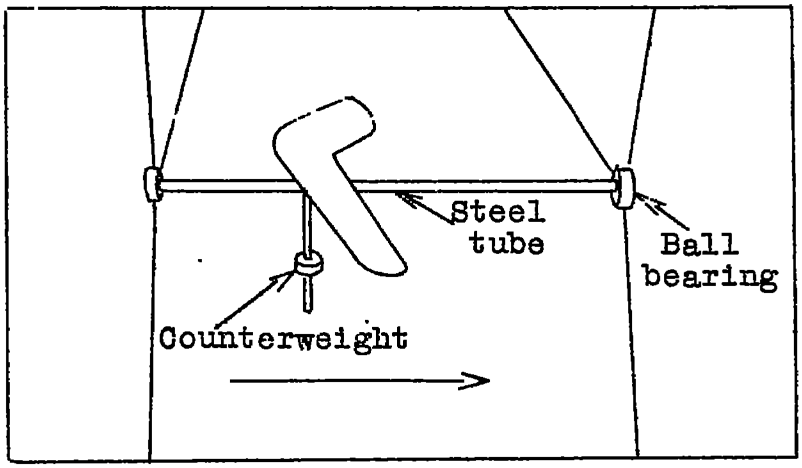
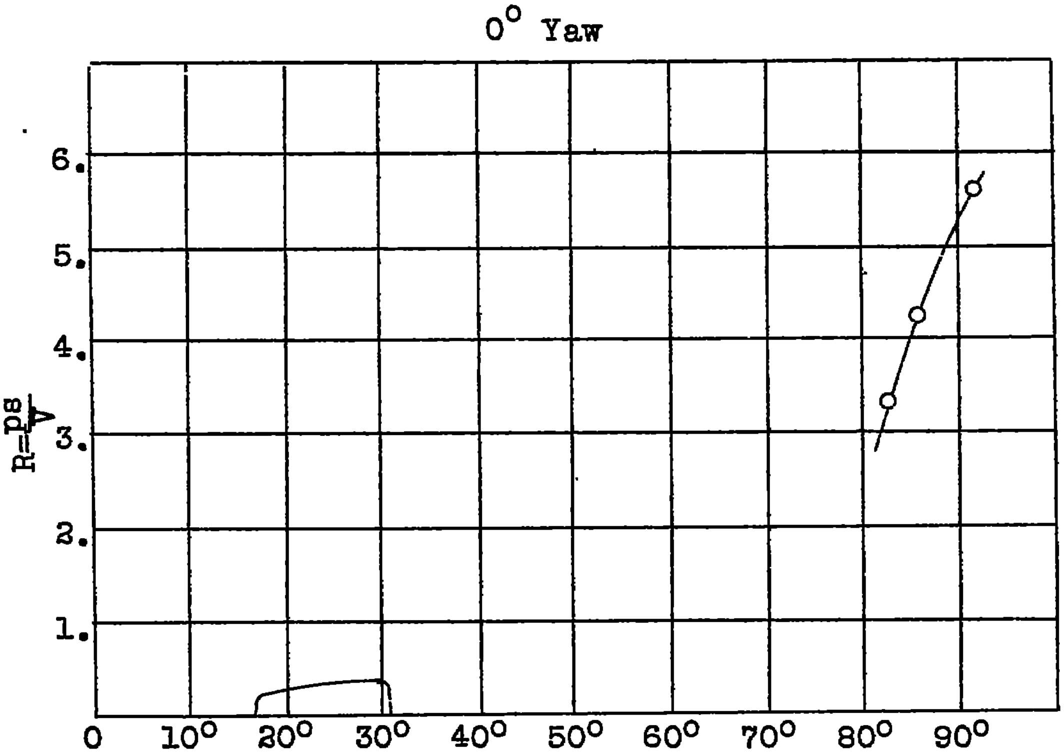


Fig.2 Rotation apparatus,
(with sweepback model)



Angle of attack, α
Fig.3 High rotation regime.
Straight wing.

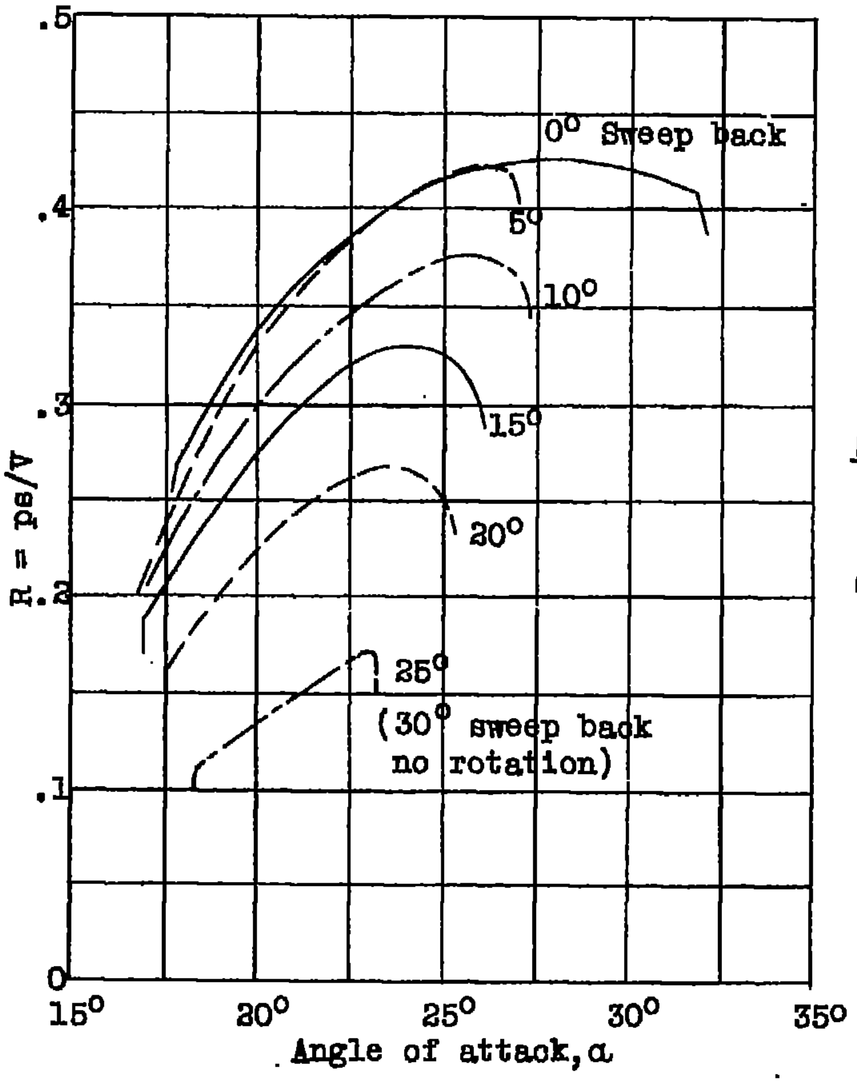


Fig.4 Effect of sweep back on R.

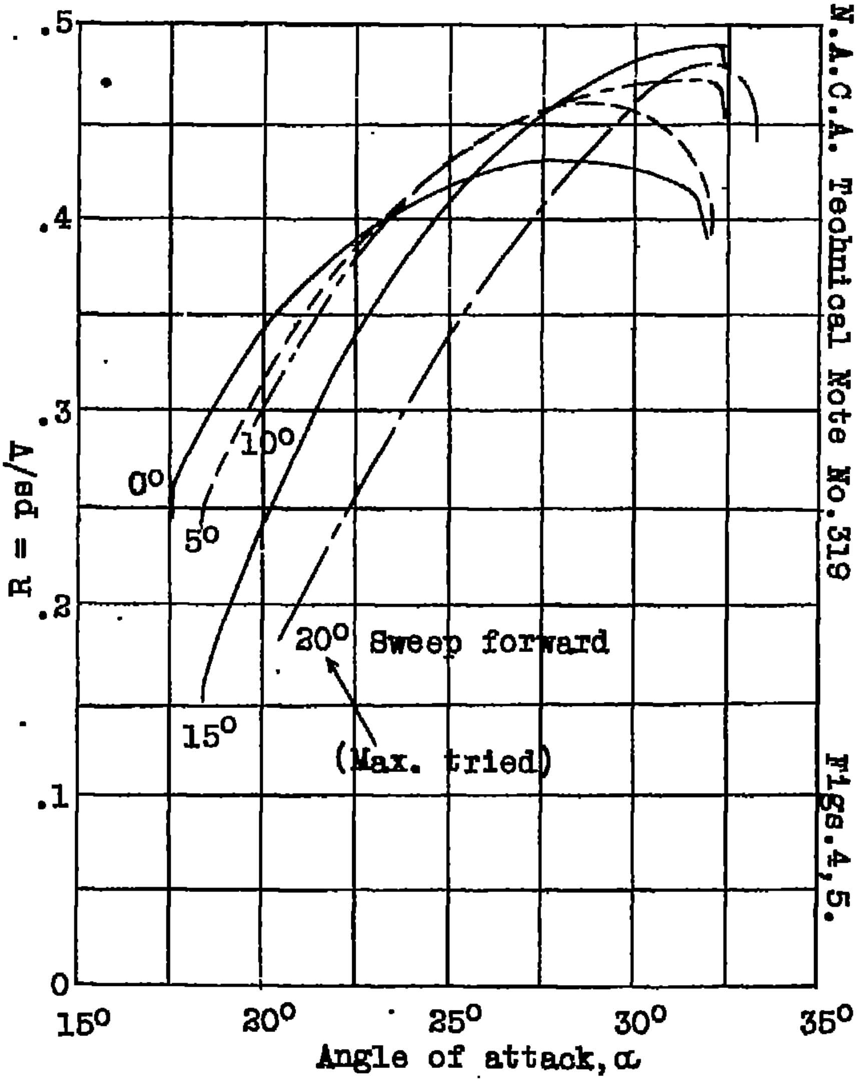


Fig.5 Effect of sweep forward on R.

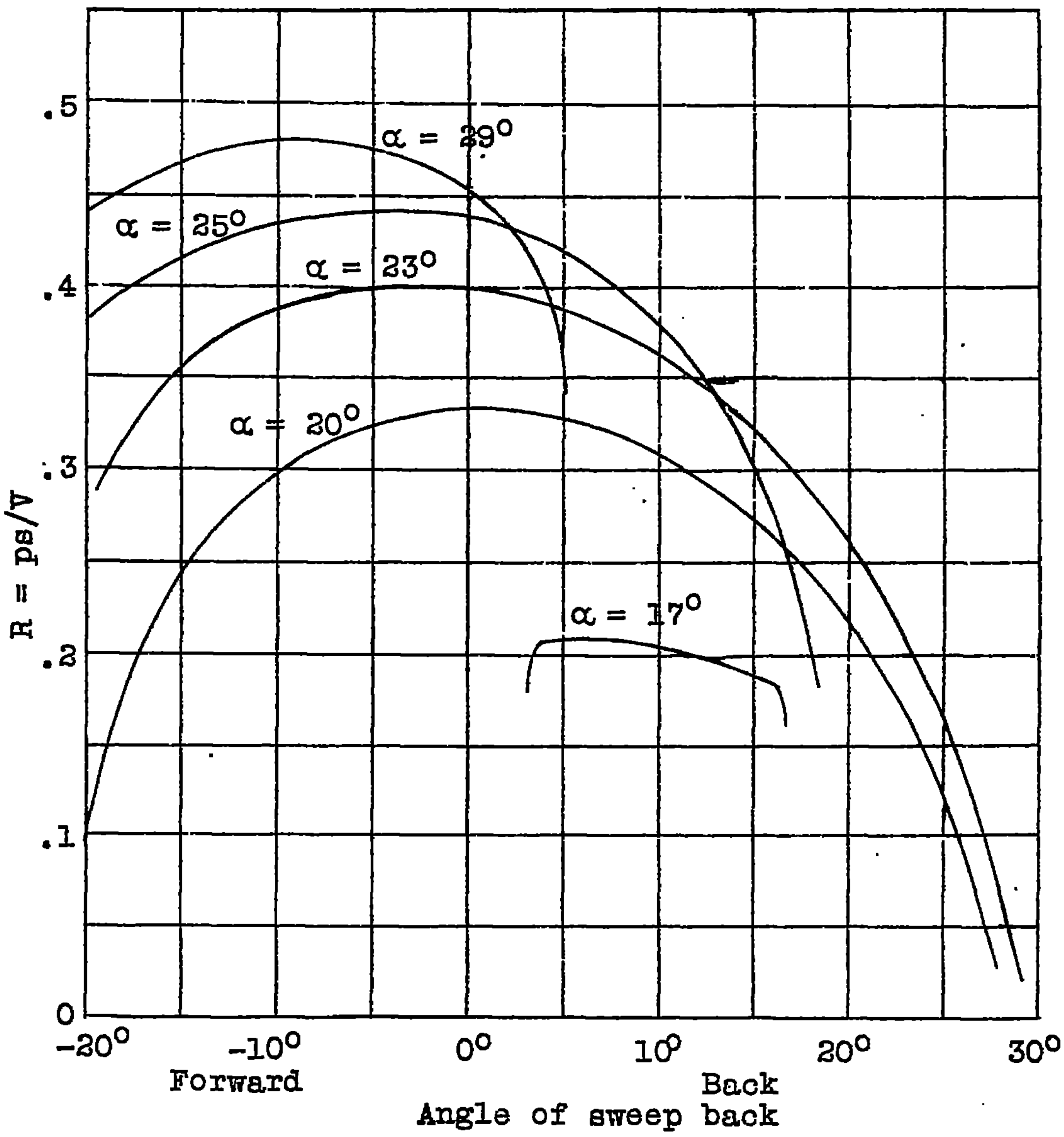


Fig.6 Effect of sweep back on autorotation.

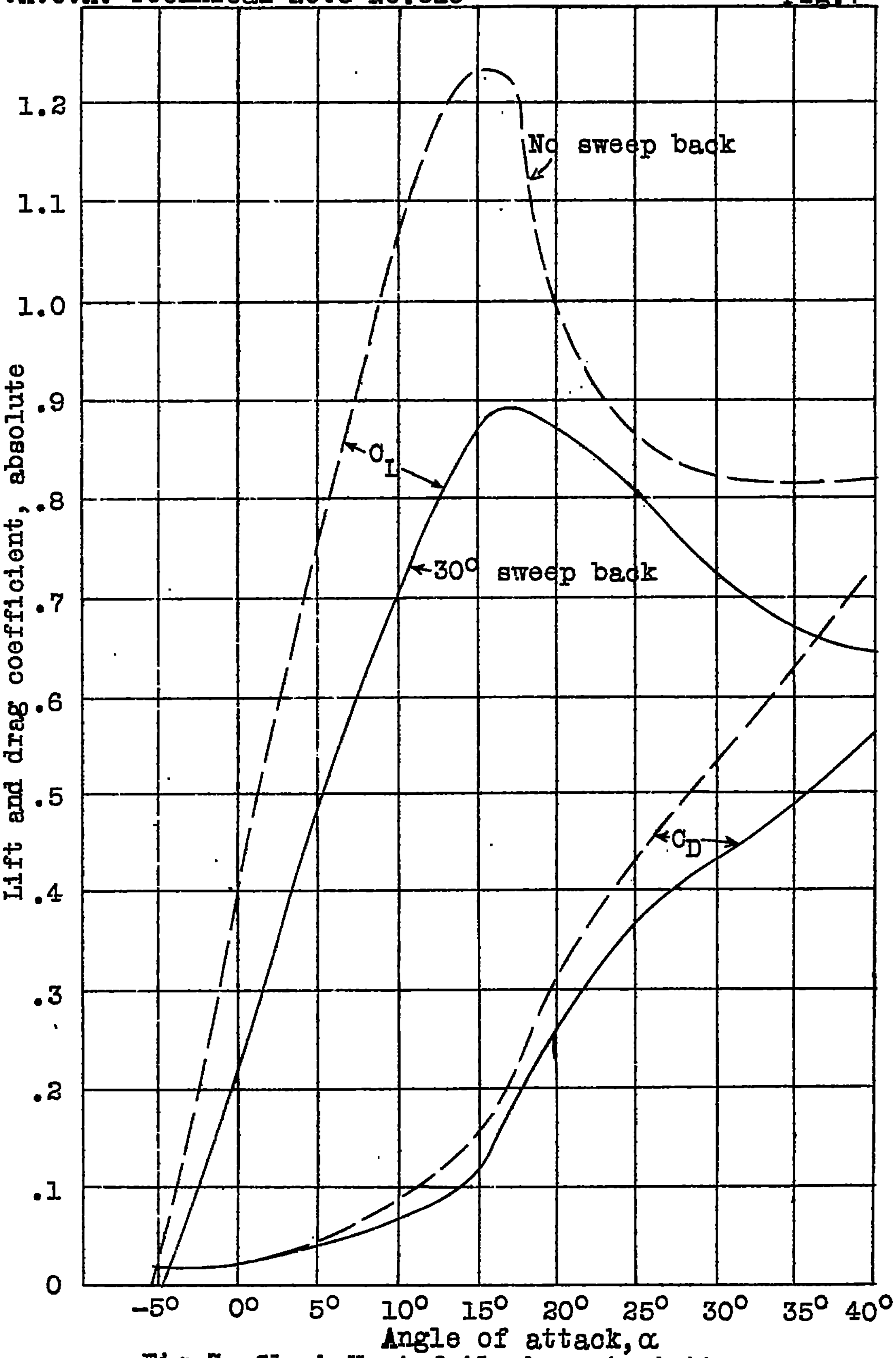


Fig.7 Clark Y airfoil characteristics.

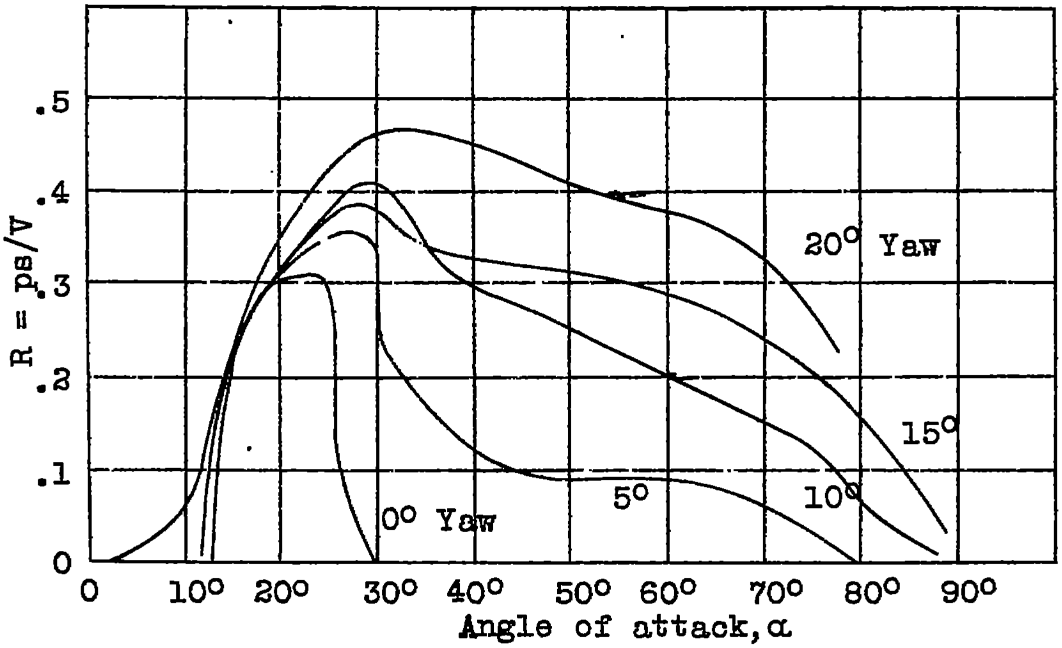


Fig.8 "R" vs α, aspect ratio 8

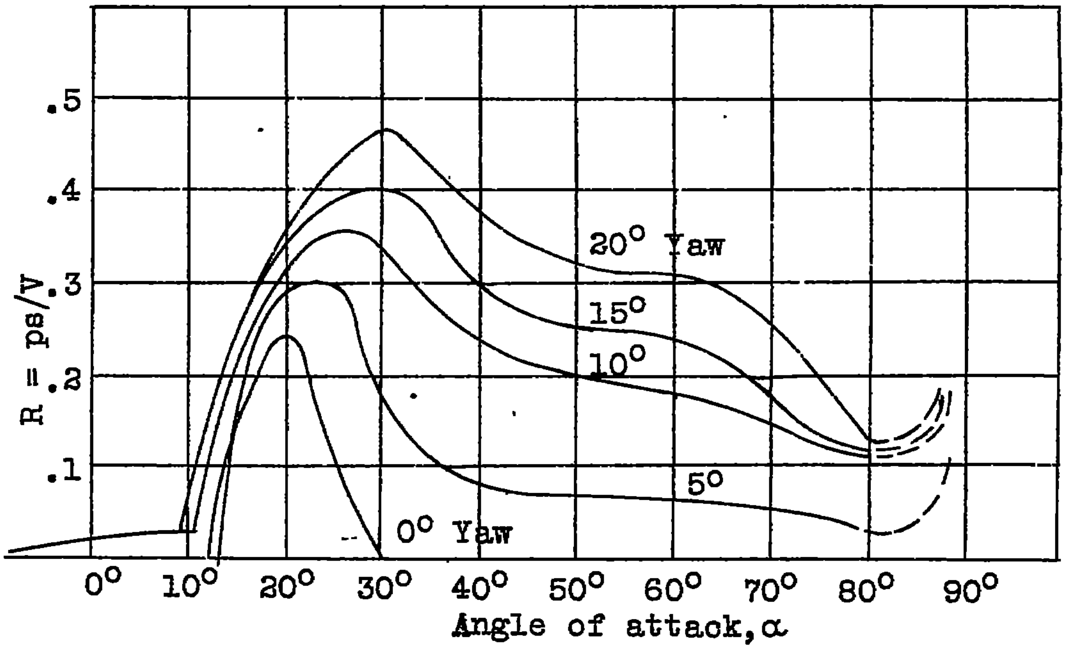


Fig.9 "R" vs α, aspect ratio 6

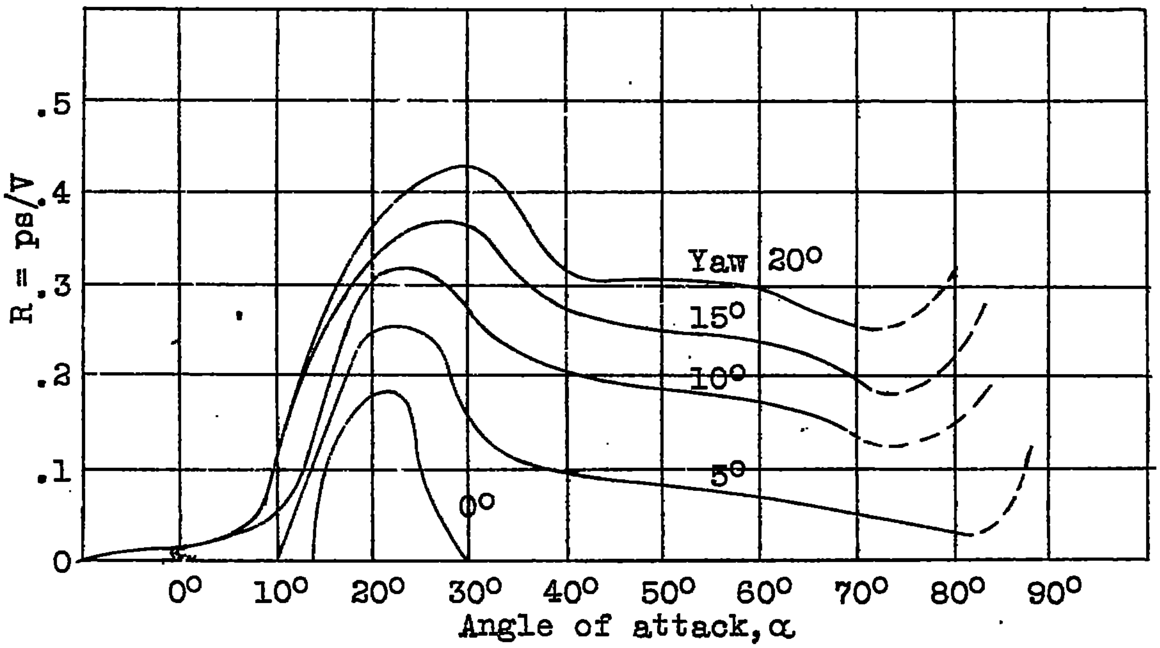


Fig.10 "R" vs α, aspect ratio 4.95

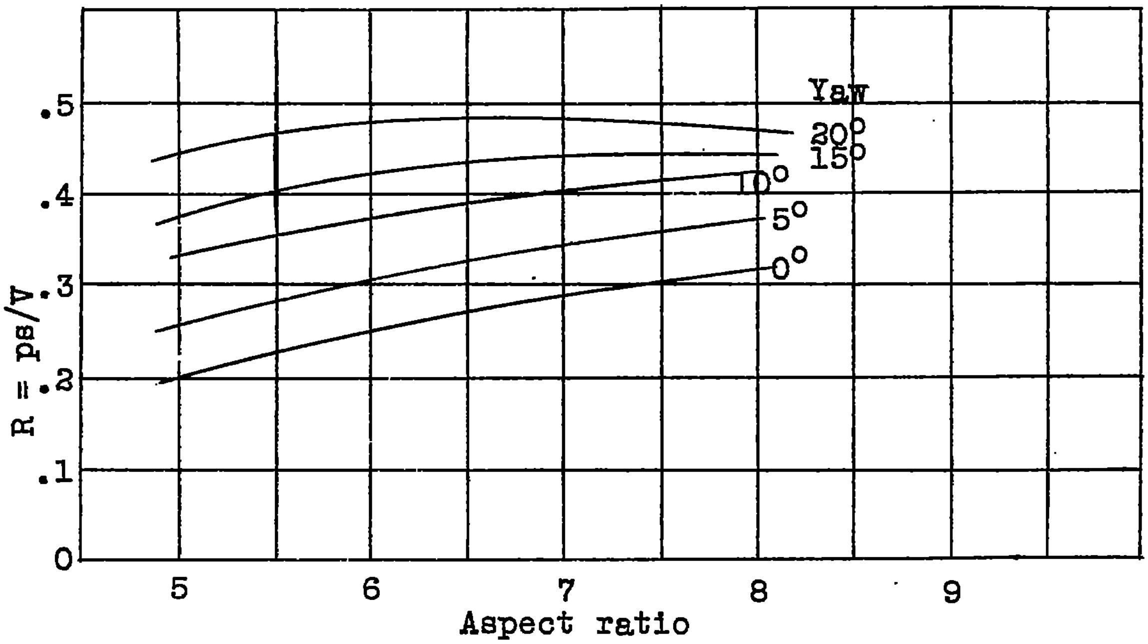


Fig.11 Effect of aspect ratio and yaw on "R".
Curves give peak values (α 20° to 30°)