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L - 784

L-784

EFFECTS OF PROPELLERS AND OF VIBRATION ON THE EXTENT OF LAMINAR FLOW ON THE N.A.C.A. 27-212 AIRFOIL

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SUMMARY

The effects of propellers and of vibration on the extent of laminar flow on the N.A.C.A. 27-212 airfoil were investigated in the N.A.C.A. 8-foot high-speed tunnel by testing the airfoil in conjunction with a tractor and a pusher propeller and with a mechanical vibrator. The Reynolds numbers of the investigation ranged from 3,500,000 to 7,600,000 for the propeller tests and to 10,300,000 for the vibration tests.

The results show that neither the pusher propeller nor vibration with amplitudes up to 0.094 inch and with a frequency of 1,650 cycles per minute had any consequential effect on the extent of laminar flow but that the tractor propeller had a very pronounced effect. The tractor propeller caused transition to move from approximately midchord to a position near the leading edge; the accompanying increase in drag probably exceeded 100 percent for the N.A.C.A. 27-212 airfoil. The corresponding drag increase for the N.A.C.A. 0012 airfoil would be approximately 25 percent because this airfoil normally has a less extensive laminar boundary layer.

INTRODUCTION

For some time it has been suspected, but never definitely ascertained that tractor propellers increase wing drag by reducing the extent of laminar flow over the wing back of the propeller, nor has it been ascertained whether pusher propellers behind the wing or vibration of the wing produce similar effects. The investigation described in this paper was therefore made to evaluate the effects of propellers, both tractor and pusher, and of vibration on the extent of laminar flow as an indication of the effect on wing drag. The N.A.C.A. 27-212 airfoil, one of the laminar-flow airfoils recently developed by the N.A.C.A. (reference 1), was used for the tests because airfoils of this type are especially sensitive to flow disturbances.

APPARATUS AND METHODS

The investigation was conducted in the N.A.C.A. 8-foot high-speed wind tunnel, a closed-throat tunnel of circular cross section. Sphere-drag tests in this tunnel (reference 2) have shown an average critical Reynolds number of 380,000, indicating a relatively low degree of turbulence.

The airfoil used was made to the N.A.C.A. 27-212 section and has a 5-foot chord. The maximum thickness is 12 percent of the chord and the camber line shape and the thickness distribution entail falling pressures in the downstream direction over the forward 70 percent of the chord, on both surfaces, when the airfoil is operating at the design lift coefficient of 0.2. Drag and transition measurements for this airfoil without propellers or vibration are described in reference 1. The model was accurately constructed of wood; both surfaces were lacquered and sanded to a smooth finish. In position for tests, it completely spanned and was rigidly supported by the test section of the tunnel, as shown in figure 1.

L-784

The propeller used for the tests was a left-hand, two-blade propeller of 4-foot diameter, the complete description and characteristics of which are given in references 3 and 4. The propeller was driven by a windmill mounted 7 feet downstream from the propeller on the opposite end of the propeller shaft. In the tractor position (fig. 1), the propeller was 20 percent of the chord (0.2c) ahead of the leading edge, the windmill then being 0.2c behind the trailing edge; in the pusher position, the propeller and the windmill were 0.2c and 1.6c, respectively, behind the trailing edge. In all cases, the axis of the propeller was parallel to and 7.5 inches (0.125c) below the chord of the airfoil at the center of the span. The investigation was conducted at values of the thrust coefficient C_T of 0 and 0.068; the propeller blade angle was set at 40° throughout the tests. In order to obtain the desired thrust coefficient, the corresponding advance-diameter ratio V/nD was estimated from the propeller characteristics (fig. 8 of reference 4) and the windmill was adjusted to drive the propeller at that value of V/nD.

The model was vibrated by two eccentric weights driven by a variable-speed electric motor and spur-geared to rotate oppositely to produce vibrations only in a vertical direction. Weights, gearing, and motor were mounted on the under surface of the airfoil. The amplitude of the vibration was measured by means of a shielded vertical rod firmly anchored at one end to the under surface of the airfoil; the total amplitude was read directly on a scale at the lower end of the rod with the aid of a magnifying glass.

The transition point was located by measuring the velocities in the boundary layer close to the airfoil surface. (See reference 1.) Velocities 0.0035 inch from the surface were measured with small total- and static-pressure tubes mounted on the upper surface of the airfoil at the center line and 16 inches on either side (fig. 1). Because of the large damping of the tubes, the indicated velocities were the temporal mean values.

The propeller-removed data were obtained with the propeller shaft and the supports in place but with the propeller and the windmill removed.

The propeller shaft and the supports mounted beneath the model affected the general flow over the airfoil; in order to obtain a pressure gradient favorable to extensive laminar flow, the model was tested at 0° angle of attack. The resulting gradient and boundary-layer flow (figs. 2 and 3) were about the same as were obtained at an angle of attack of 0.5°, the angle of minimum drag, with no obstructions in the air stream. The static-pressure coefficient S, used in figures 2 and 3, is equal to $\frac{H - p}{q}$

where

H free-stream total pressure

p local static pressure

q dynamic pressure of the air stream

RESULTS AND DISCUSSION

The results of this investigation, uncorrected for tunnel effects, are presented as curves of a transition parameter plotted against chord position at the following Reynolds numbers and corresponding air speeds:

Reynolds number	Air speed (m.p.h.)
5,000,000	116
7,500,000	177
10,000,000	243

The transition parameter is $\frac{u/U_o}{\sqrt{R\ y/c}}$, where u is the velocity indicated by the surface tubes; U_o, the free-stream velocity; R, the Reynolds number based on the chord; y, the effective height of the total-pressure tubes from the surface; and c, the chord of the airfoil. The transition from the low-drag laminar boundary layer to the higher-drag turbulent boundary layer produces a definitely higher velocity near the surface, resulting in a marked increase in the value of the parameter. A marked increase in the value of the parameter at any point, therefore, indicates that the boundary layer at that point has changed from the laminar to the turbulent type with a consequent increase in drag.

Figure 4 shows the effect of a tractor propeller on the boundary layer as indicated by the transition parameter. Although it is difficult to judge the location of the transition from a single curve of the type shown in figure 4, a comparison of the curves for the different test conditions at common chord positions indicates that, with the propeller operating, transition has in every case moved forward to between the leading edge and the 0.10c position. Unpublished plots of the transition parameter as a function of Reynolds number showed that transition without the propeller occurred at about 0.40c and 0.50c at Reynolds numbers of 7,500,000 and 5,000,000, respectively. On the basis of unpublished test results, the corresponding increase in drag is estimated to be of the order of 100 percent or more. With a conventional airfoil, the drag increase would be less. If it is assumed, for example, that a tractor propeller would move the transition point on a smooth N.A.C.A. 0012 airfoil from its normal position (about 0.30c for a Reynolds number of 6,000,000) to the 0.05c position, the drag would be increased about 25 percent.

L - 784

The change in the boundary-layer flow with increase in the thrust coefficient C_T from 0 to 0.068 was small. This result indicates that the turbulence created by the propeller even at zero thrust was sufficient to prevent any extensive laminar flow on the wing in the propeller wake and that the thrust condition at which the propeller operates is, therefore, unimportant. The greatest increase in the value of the transition parameter occurred at the center line directly behind the propeller hub, which may be attributed to the poor aerodynamic shape of the hub and the adjacent blade sections and also to the fact that the solidity of the propeller is greatest at the hub and hence the flow is disturbed a greater percentage of the time than behind portions of lower solidity.

Additional tests showed that, at 0.60c, the effects of the propeller extended approximately 28 inches from the center of the span. The corresponding angle of spread of the disturbed region was 7.5° on either side measured from the points on the leading edge directly behind the propeller tips.

Because the N.A.C.A. 27-212 airfoil is designed to have the peak pressure located at 0.70c, the transition position is more sensitive to disturbances than is the transition position on more conservative types of airfoils. The effects shown may, therefore, be larger than would occur on other more conservative types.

Figure 5 shows that the pusher propeller, even at a value of C_T of 0.068, had very little effect on the flow in the boundary layer and that the change in the boundary layer, as indicated by the value of the transition parameter, was small. With regard to its effect on transition, the pusher propeller had no consequential effect on the drag.

Figure 6 shows that the vibration of the airfoil had no appreciable effect on the boundary-layer flow; consequently, the vibration had no appreciable effect on the drag. The intensity of vibration can be expressed nondimensionally as the root-mean-square of the vibration velocity divided by the free-stream velocity, $\sqrt{\overline{w^2}}/U_o$. This expression is analogous in form to that generally used to express the intensity of turbulence. The scale of vibration can be considered as a wave length based on the free-stream velocity and expressed in terms of the airfoil chord. The following table shows the corresponding Reynolds numbers, frequencies, amplitudes, vibration intensities, and vibration wave lengths:

Reynolds number	Frequency (cycles per min.)	Total amplitude (in.)	$\sqrt{\overline{w^2}}/U_o$ (percent)	Wave length (chords)
5,000,000	1,600	0.032	0.090	1.27
5,000,000	1,650	.094	.262	1.24
10,000,000	1,600	.032	.043	2.68
10,000,000	1,650	.094	.130	2.60

Air-stream turbulence of an intensity equal to the maximum vibration intensity investigated (0.262 percent) would be expected to have an appreciable effect on the extent of laminar flow on the N.A.C.A. 27-212 airfoil. The vibrations investigated, however, were of much larger scale (i.e., lower frequency) than the type of air-stream turbulence to which laminar flow is sensitive. Laminar flow might possibly be disturbed by vibrations of frequencies much higher than the frequencies used in the present investigation. It is also possible that local vibration of part of the wing surface, as opposed to vibration of the wing as a whole, would increase the drag because local vibration would constitute transitory deformation of the profile. It has been shown in reference 5 that a small deformation of the profile will cause premature transition and a consequent increase in drag.

CONCLUSIONS

1. The tractor propeller caused transition on the N.A.C.A. 27-212 airfoil to move from approximately midchord to a position near the leading edge; the accompanying increase in drag probably exceeded

L - 784

100 percent for this airfoil. The corresponding drag increase for the N.A.C.A. 0012 airfoil would be approximately 25 percent because this airfoil normally has a less extensive laminar boundary layer.

2. The effect on the location of the transition point of a pusher propeller 20 percent of the chord behind the airfoil was inconsequential.

3. The largest vibration amplitude of the airfoil as a whole, 0.094 inch at a frequency of 1,650 cycles per minute, had no measurable effect on the laminar flow over the airfoil.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 9, 1939.

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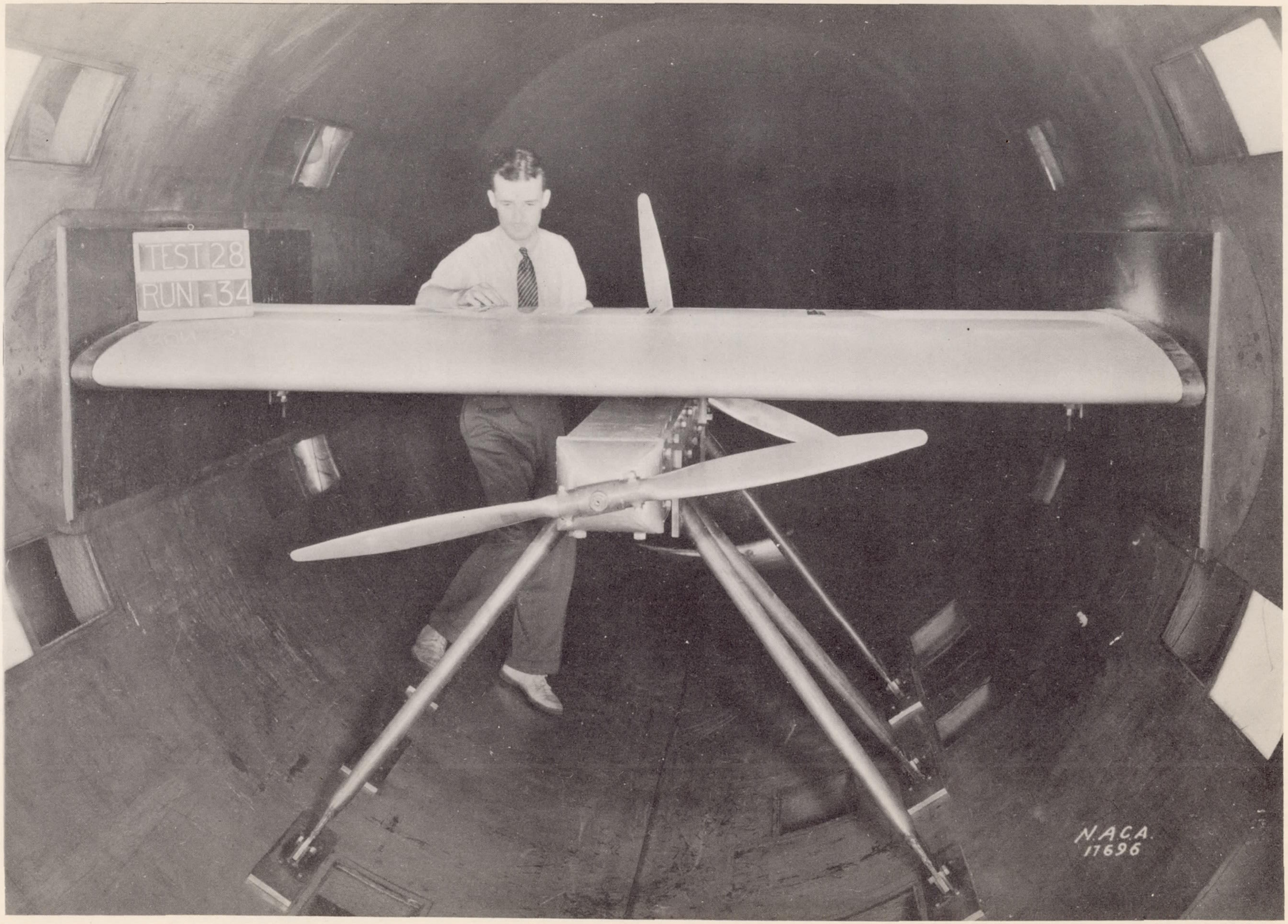

Figure 1.- Wing and propeller unit mounted in tunnel, tractor position.

L-784

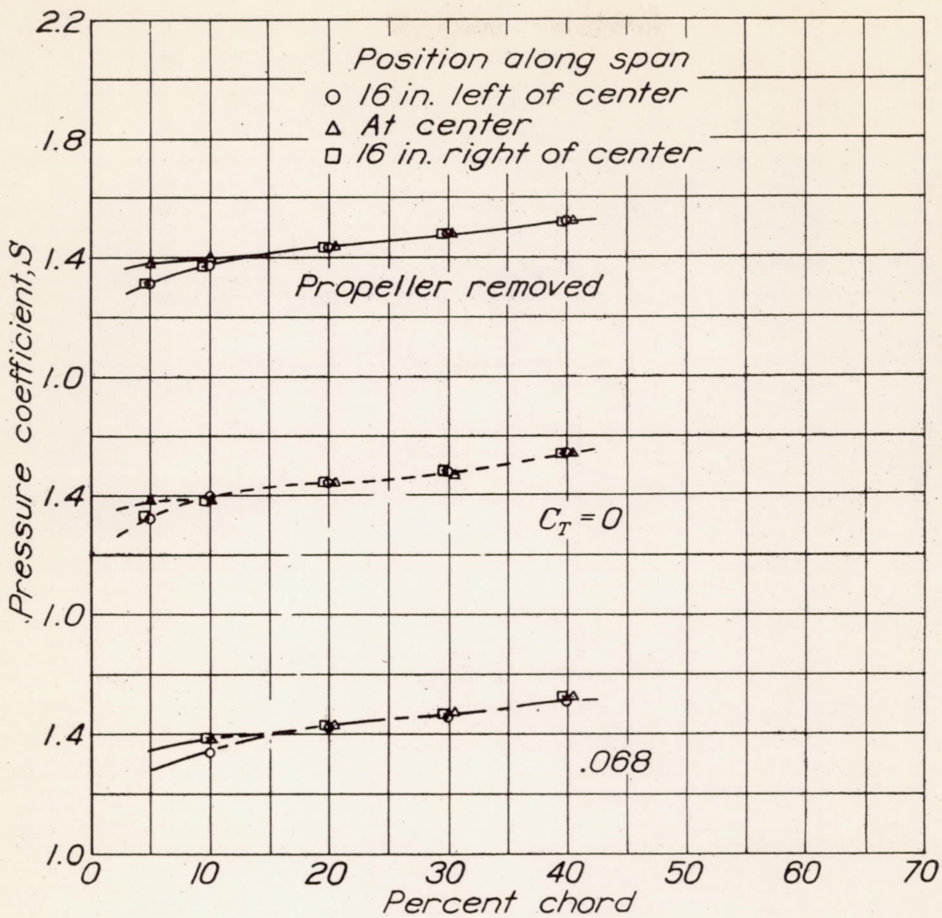

Figure 2.- Effect of tractor propeller on pressure distribution. N.A.C.A. 27-212 airfoil; C_L, approximately 0.2; R, 5,000,000

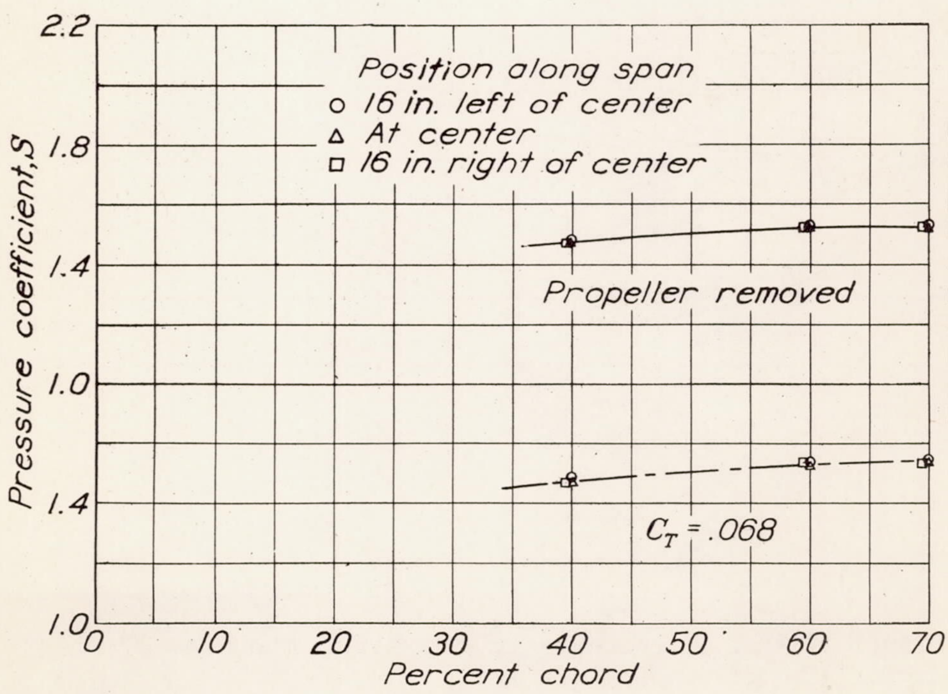

Figure 3.- Effect of pusher propeller on pressure distribution. N.A.C.A. 27-212 airfoil; C_L, approximately 0.2; R, 5,000,000

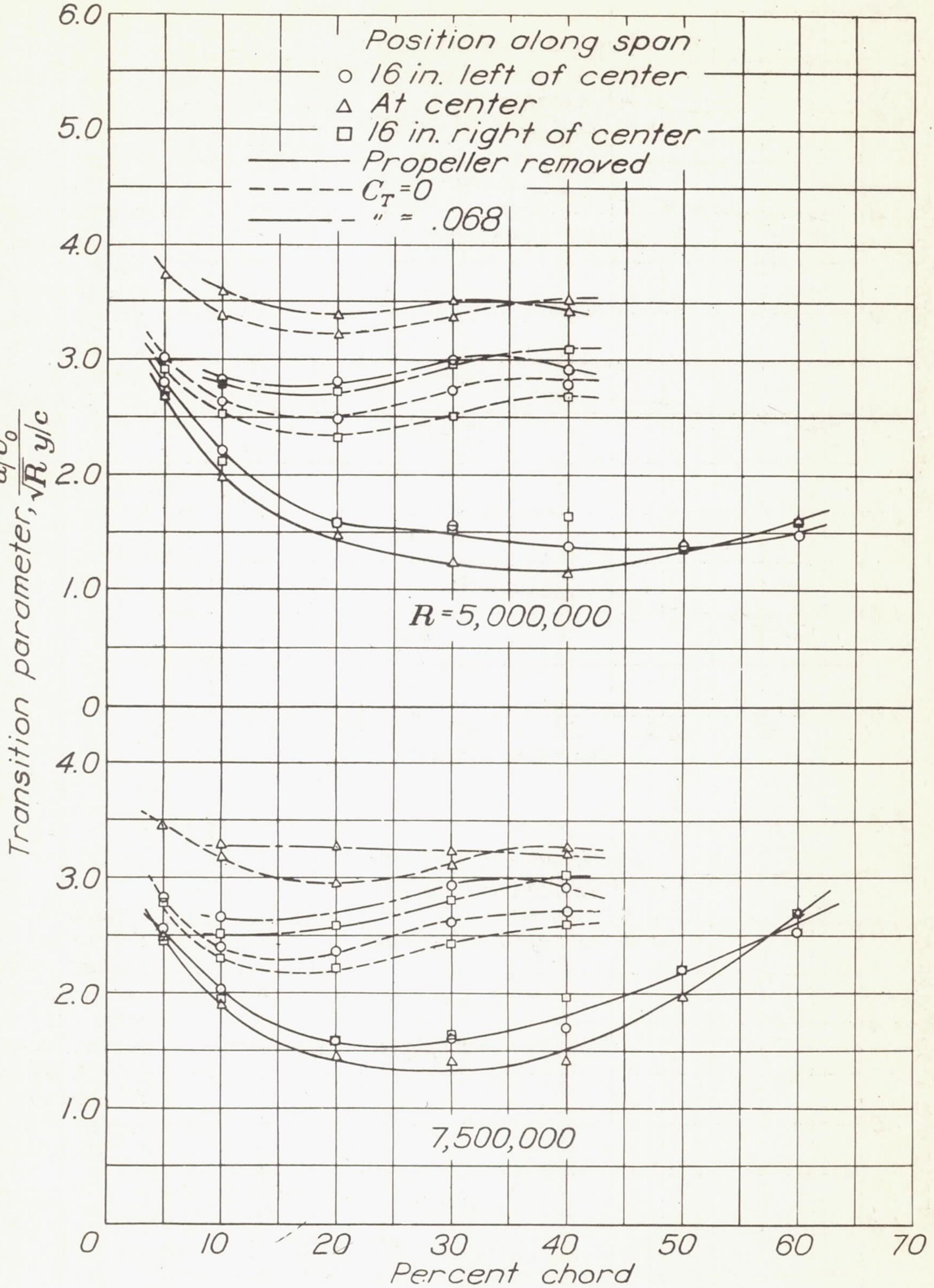

Figure 4.- Effect of tractor propeller on transition. N.A.C.A. 27-212 airfoil; C_L, approximately 0.2

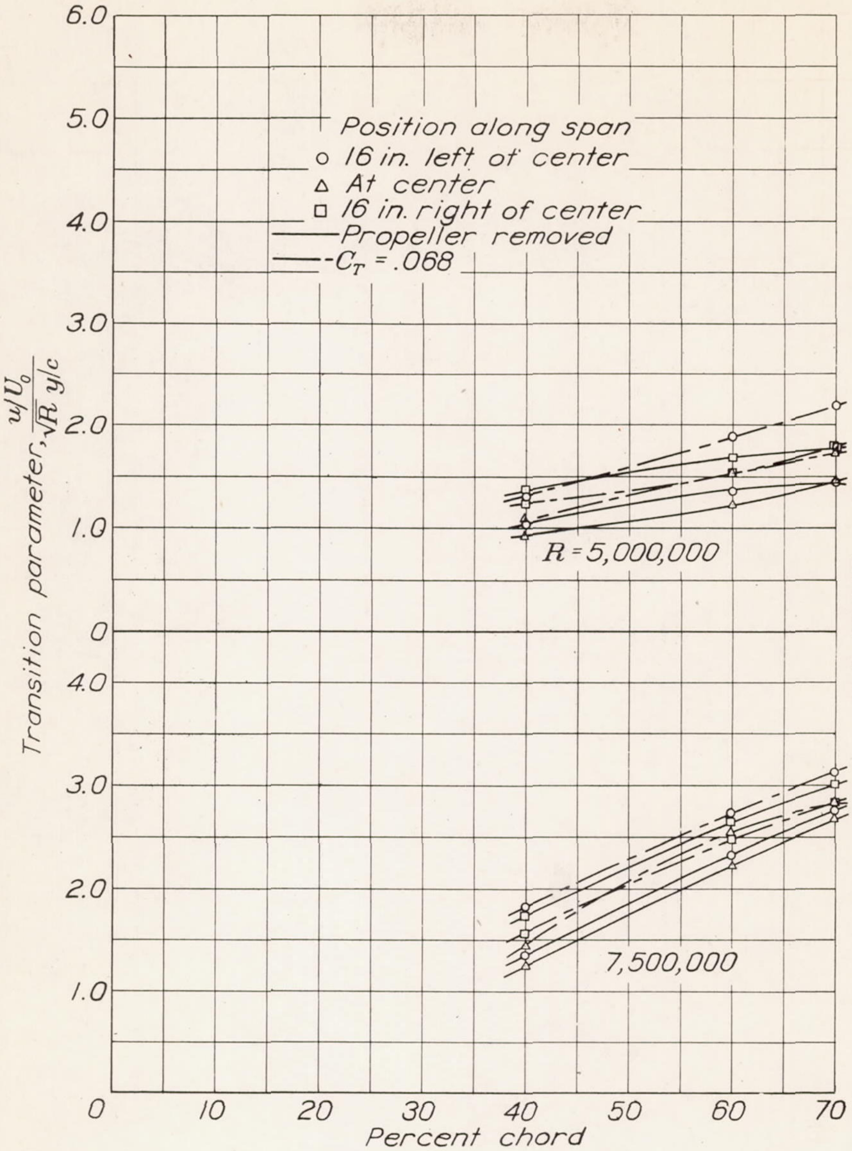

Figure 5.- Effect of pusher propeller on transition. N.A.C.A. 27-212 airfoil; C_L, approximately 0.2

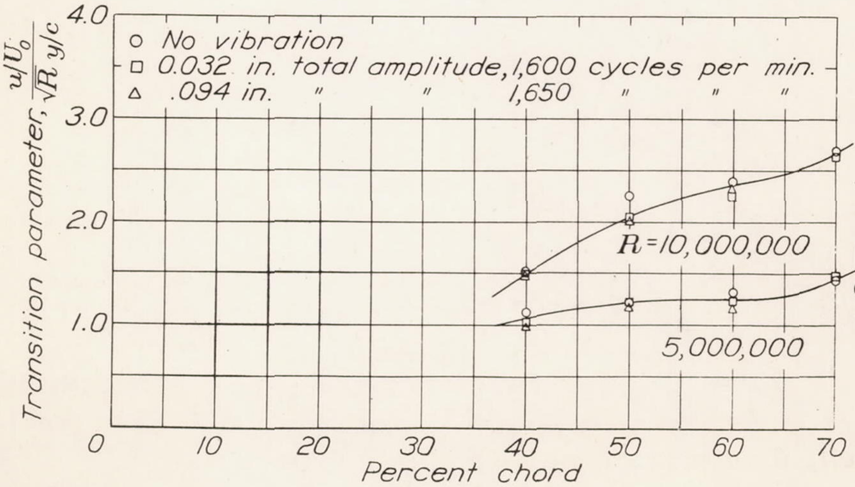

Figure 6.- Effect of vibration on transition. N.A.C.A. 27-212 airfoil; C_L, approximately 0.2