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RESEARCH MEMORANDUM

INVESTIGATION OF A SIMPLE DEVICE FOR PREVENTING SEPARATION DUE TO SHOCK AND BOUNDARY-LAYER INTERACTION

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON
November 29, 1950

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INVESTIGATION OF A SIMPLE DEVICE FOR PREVENTING SEPARATION DUE TO SHOCK AND BOUNDARY-LAYER INTERACTION

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SUMMARY

Results are presented of a preliminary investigation of vortex generators introduced into the region of boundary layer to increase the turbulent mixing, in an attempt to prevent separation due to boundary-layer and shock interaction. Prevention of such separation and some of its adverse effects up to Mach numbers ahead of the shock of the order of 1.4 appears possible by means of this simple device. Preliminary flight tests show that this method is effective in controlling shock-induced separation on the wing of an airplane at high speed.

INTRODUCTION

One of the most important aerodynamic problems is the elimination of the adverse effects of the separation resulting from boundary-layer and shock interaction. In particular, if possible, the shock-induced separation that occurs on wings at transonic speeds should be eliminated.

One measure proposed as a remedy for this separation - that is, removal of the boundary layer by suction through porous walls, though it should be effective - poses certain very considerable difficulties in practical application. Another method of preventing separation, the use of vortex generators, has been employed to control separation in subsonic flows. (See reference 1.)

The present work is a preliminary investigation of the effectiveness of vortex generators as a means of preventing shock-induced separation in a channel. The results of an additional test in flight are cited in reference 2.

SEPARATION

Separation of the boundary layer upon a surface occurs whenever the rate at which the pressure gradient removes momentum from the bottom of the boundary layer exceeds for a long enough time the rate at which the boundary layer can transmit momentum from the free stream toward the surface.

A turbulent boundary layer will negotiate a larger pressure rise than a laminar boundary layer because the mechanism of turbulent exchange permits a momentum transfer to the layers near the surface far larger than that possible through the action of laminar shear alone. However, the rate at which the pressure gradient due to a shock wave upon an airfoil at transonic speeds seeks to remove momentum from the boundary layer is so large that no ordinary boundary layer can negotiate the shock wave without separation. It might be possible, however, to put enough mixing into the boundary layer by some external means to make the rate of momentum transfer in the boundary layer sufficient to enable it to negotiate moderate shock waves without separating.

Increased mixing can be accomplished if lifting elements are introduced into the boundary layer, as shown in figure 1, and the tip vortices generated by these elements allowed to trail downstream in the boundary layer. Such devices to increase the turbulent mixing have been used at low speeds by both the British and the Americans for some time to improve boundary-layer flow in the presence of adverse pressure gradients both on airfoil sections and in the diffusers of wind tunnels. In these tests this method has been applied to the control of shock-induced separation.

TESTS

Tests of this system were made with an apparatus similar to that shown schematically in figure 1. A block (the top view of which is shown in fig. 2) was constructed to simulate half an airfoil of 8-inch chord and a thickness ratio of 15 percent. This block was placed in the floor of a small wind tunnel of 3- by 3-inch cross section. The vortex generators used in these tests were crude wings of square plan form 3/32 by 3/32 of an inch spaced every 1/4 inch along the span of the profile at the 19-percent chordwise station. All the generators were set at the same angle of attack of 17° so that all the vortices produced were of the same sign. The boundary layer in the tunnel ahead of the model was turbulent; therefore the vortex generators were working in a turbulent layer.

As the tunnel power was increased, a shock formed and then moved rearward on the profile. Since the tunnel choked soon after the shock formed, the tests do not represent an airfoil traveling through free air. Hence, comparisons of the wake surveys behind the profile with and without vortex generators were made for equal maximum local Mach numbers ahead of the shock wave.

Wake surveys were made behind the profile with the shock wave at four positions corresponding to Mach numbers ahead of the shock of 1.0, 1.2, 1.3, and 1.4. Schlieren photographs of the flow were taken at the same time as the wake measurements. All wake surveys are presented in terms of a total-pressure-loss factor $\frac{H - H'}{H}$ where H is the total pressure ahead of the profile and H' is the total pressure in the wake.

RESULTS

Figures 3 and 4 are schlieren photographs of the flow past the clean profile and past the profile with vortex generators added when the maximum local Mach number is very close to 1. Since there should be no serious adverse effect of the small shock type of disturbances seen in the photograph upon the boundary layers, the wakes may be compared at this condition to estimate the drag increment due to the vortex generators before shock effects occur. A comparison of the wakes in the two cases in figure 5 shows that very little increase in losses is caused by the addition of vortex generators.

Figures 6 and 7 are schlieren photographs of the two flows when the Mach number ahead of the shock is increased to 1.2. The wakes in the two cases are compared in figure 8. Although it is difficult to see any separation in the schlieren photograph of the flow over the clean airfoil, the large increase in losses and the telltale kink (indicated by the arrow in fig. 8) in the wake survey for this condition is indicative of some separation. The absence of the kink and the large decrease in losses with the addition of vortex generators indicates that the action of vortex generators is to suppress separation.

When the Mach number ahead of the shock is increased to 1.3, the schlieren photograph of the flow over the clean profile (fig. 9) shows that the boundary layer behind the shock diverges from the surface indicating separation, while there is no indication that the boundary layer diverges from the surface of the profile with vortex generators (fig. 10). Figure 11 compares the wakes in these two cases. The wake behind the clean profile shows the bad separation, while the wake behind the profile with vortex generators is still relatively unaffected by the shock wave.

Figures 12 and 13 show the flow over the two profiles with the shock moved almost to the trailing edge of the profile, so that the Mach number ahead of the shock is 1.4. At this condition there could be little static pressure recovery between the shock and wake-measuring rake under any circumstances. As a result, the difference between a separated and a nonseparated flow will be less pronounced. However, there is still less loss in the case of the profile equipped with vortex generators (fig. 14).

In order to show the beneficial effect upon boundary-layer losses (as distinct from shock losses) of the vortex generators, the areas under the wake loss curves to the right of a line drawn from the point of minimum loss perpendicular to the abscissa are compared in figure 15.

An examination of the original photograph reproduced in figure 13 reveals that the turbulence introduced into the boundary layer by the vortex generators dissipates in the long run of falling pressure between the vortex generators and the shock wave. This, as well as the increased shock strength, may contribute to the fact that the losses become larger as the shock wave moves toward the rear of the profile. For this reason it is thought that the vortex generators might have been more effective if the angle of attack of every other vortex generator had been reversed so that the vortices produced would have been of opposite sign and, thus would have decayed less rapidly.

PRELIMINARY TESTS IN FLIGHT

Preliminary tests in flight on a 72-inch-chord wing section (contour B, reference 3), with $\frac{1}{2}$- by $\frac{1}{2}$-inch alternate 15° vortex generators placed at 30 percent of the chord have indicated that no separation occurred up to airplane Mach numbers of 0.745 at a lift coefficient of 0.50 (reference 2). The maximum local Mach numbers on the wing section encountered in these tests exceeded 1.4, and this section, when clean, had suffered from severe separation at this flight condition. Thus, it appears possible to develop for existing high-speed aircraft, vortex generators which will reduce separation due to boundary-layer and shock interaction and the unfavorable effects which result from such separation. However, the range of flight conditions for which the use of vortex generators is advantageous has not been determined.

CONCLUSIONS

Results of tests at small scale of elements introduced into the region of the boundary layer to increase the turbulent mixing, in an attempt to prevent separation due to boundary-layer and shock interaction, are presented. Prevention of separation due to boundary-layer and shock interaction up to Mach numbers ahead of the shock wave of the order of 1.3 was possible by means of this simple device.

Preliminary tests in flight have indicated that by the addition of vortex generators in the boundary-layer region, separation may be prevented up to maximum local Mach numbers on the airfoil section of the order of 1.4.

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1. Taylor, H. D.: Application of Vortex Generator Mixing Principle to Diffusers. Concluding Report. Air Force Contract W33-038 ac-21825. U.A.C. Rep. R-15064-5, United Aircraft Corp. Res. Dept., Dec. 31, 1948.

2. Lina, Lindsay J., and Reed, Wilmer, H., III. A Preliminary Flight Investigation of the Effects of Vortex Generators on Separation Due to Shock. NACA RM L50J02, 1950.

3. Zalovcik, John A., and Luke, Ernest P.: Some Flight Measurements of Pressure-Distribution and Boundary-Layer Characteristics in the Presence of Shock. NACA RM L8C22, 1948.

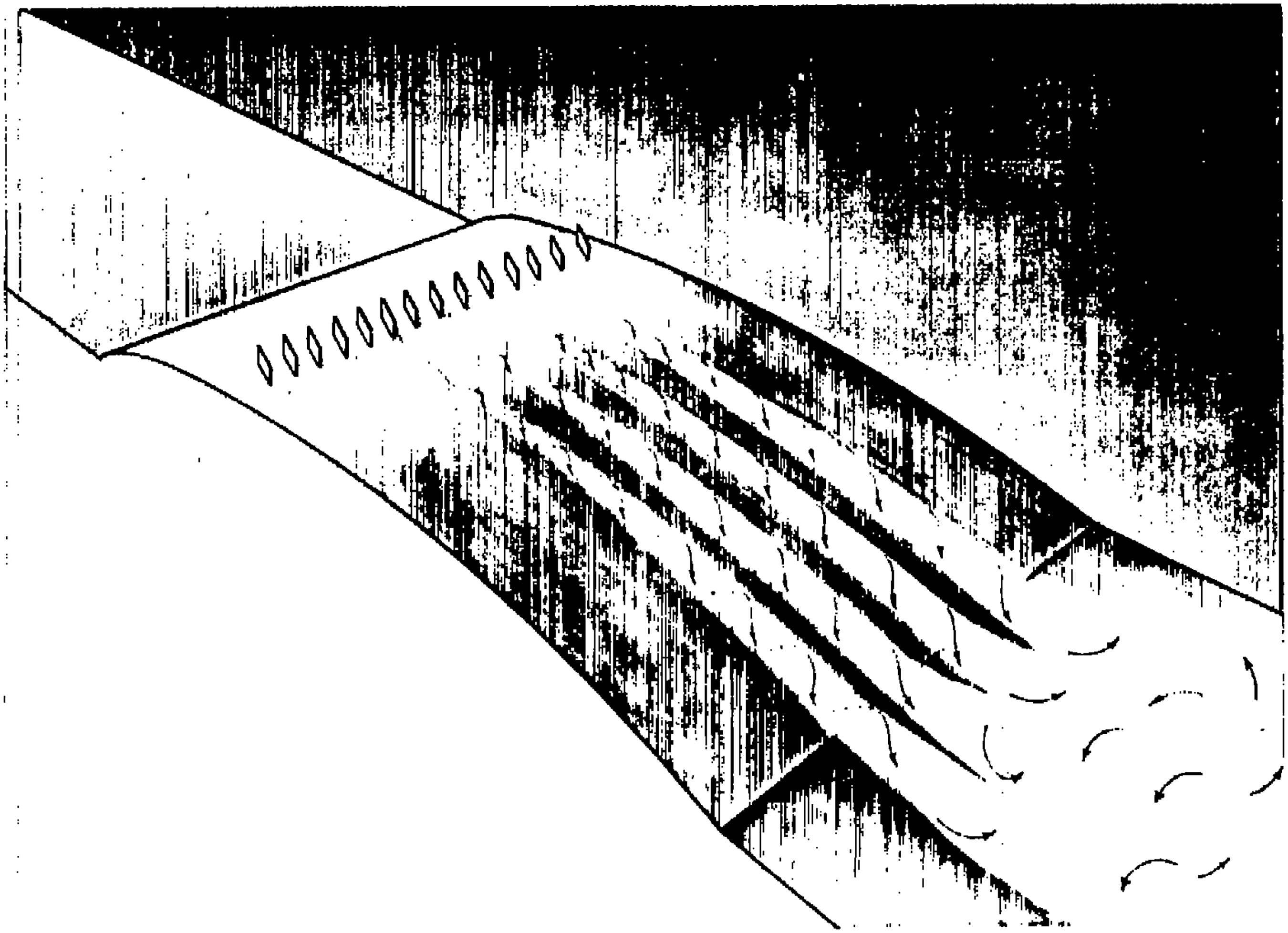

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Figure 1.- Sketch of lifting elements used to increase turbulent mixing.

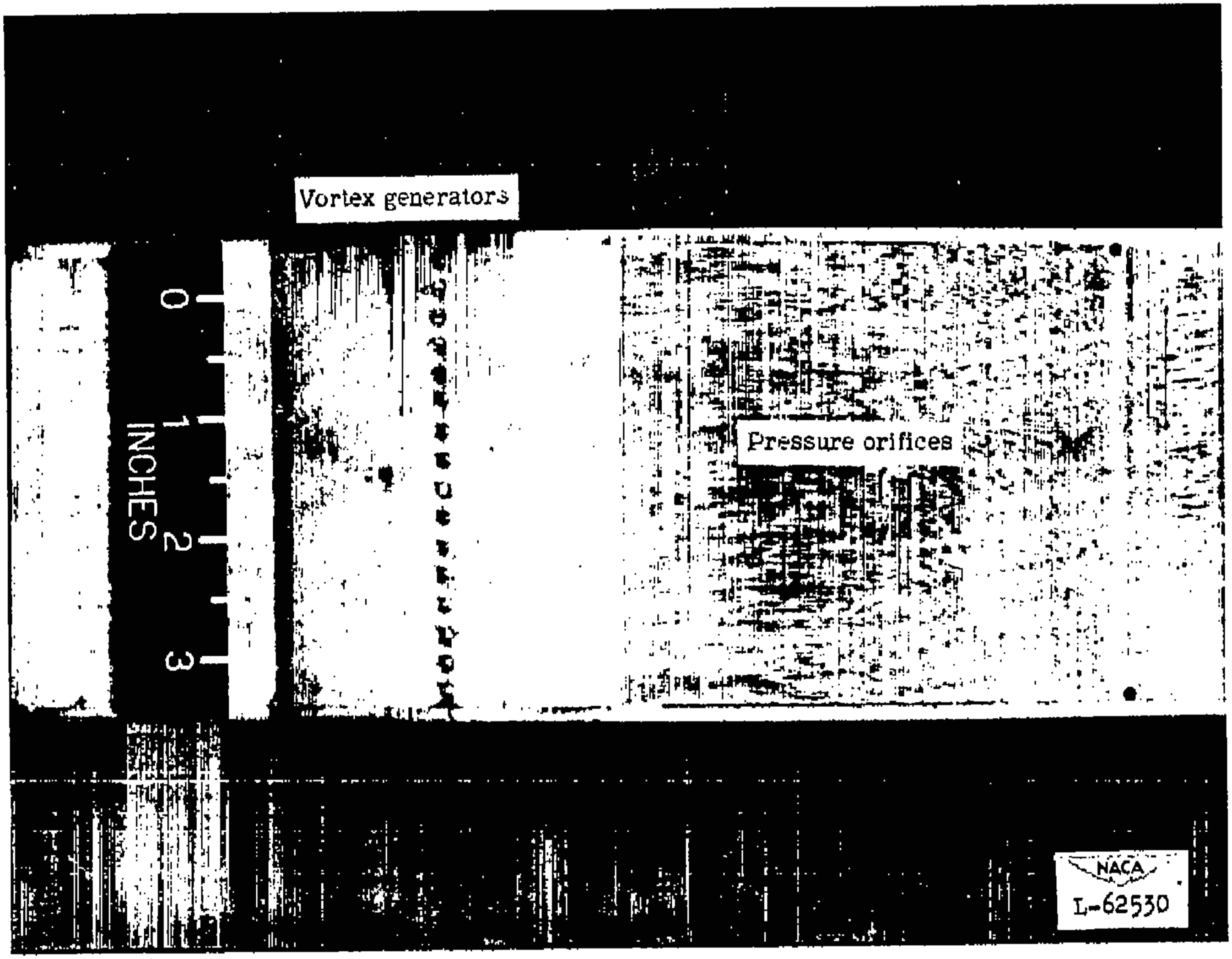

Figure 2.- Top view of model.

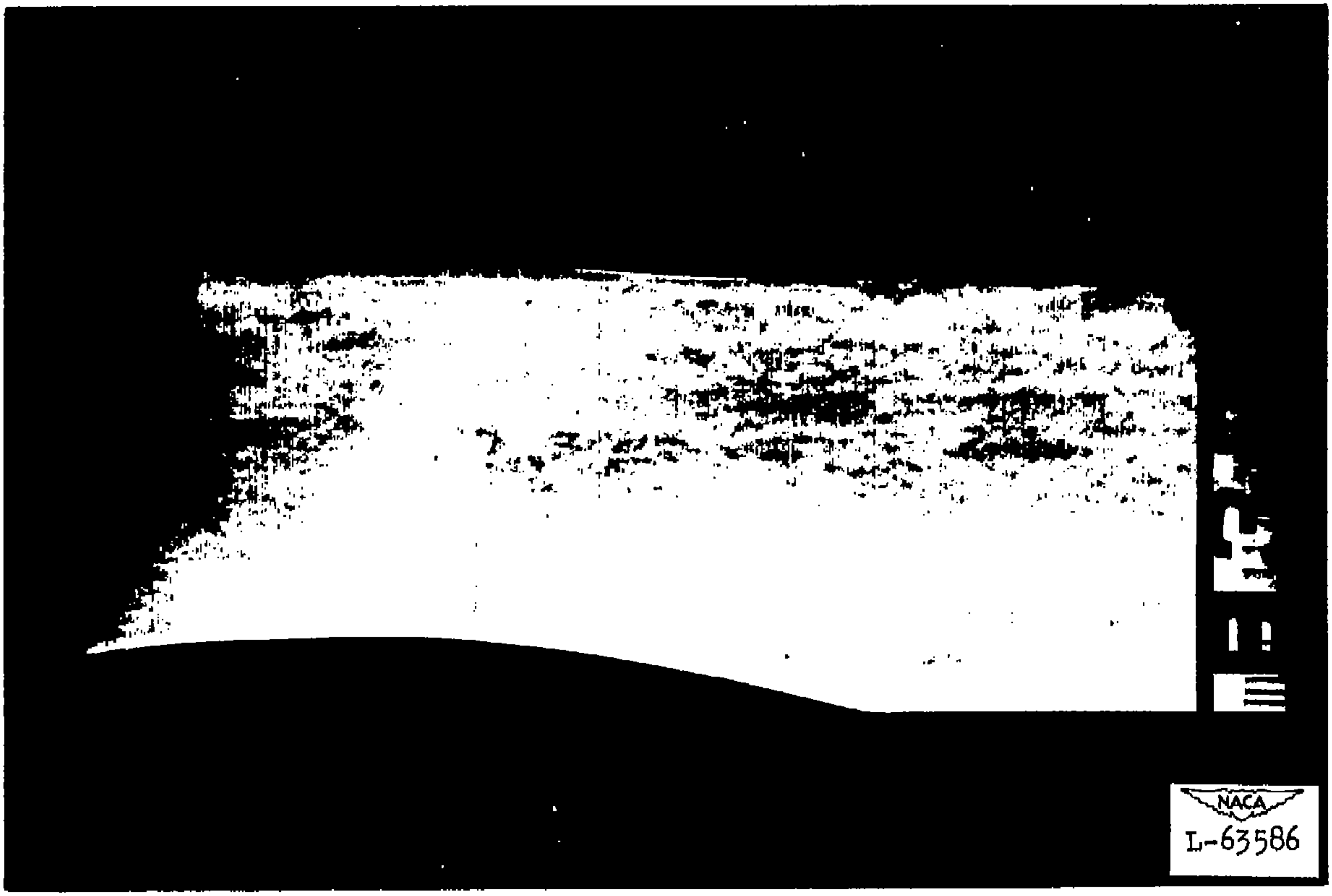

Figure 3.- Schlieren photograph of clean profile with shock at first position.

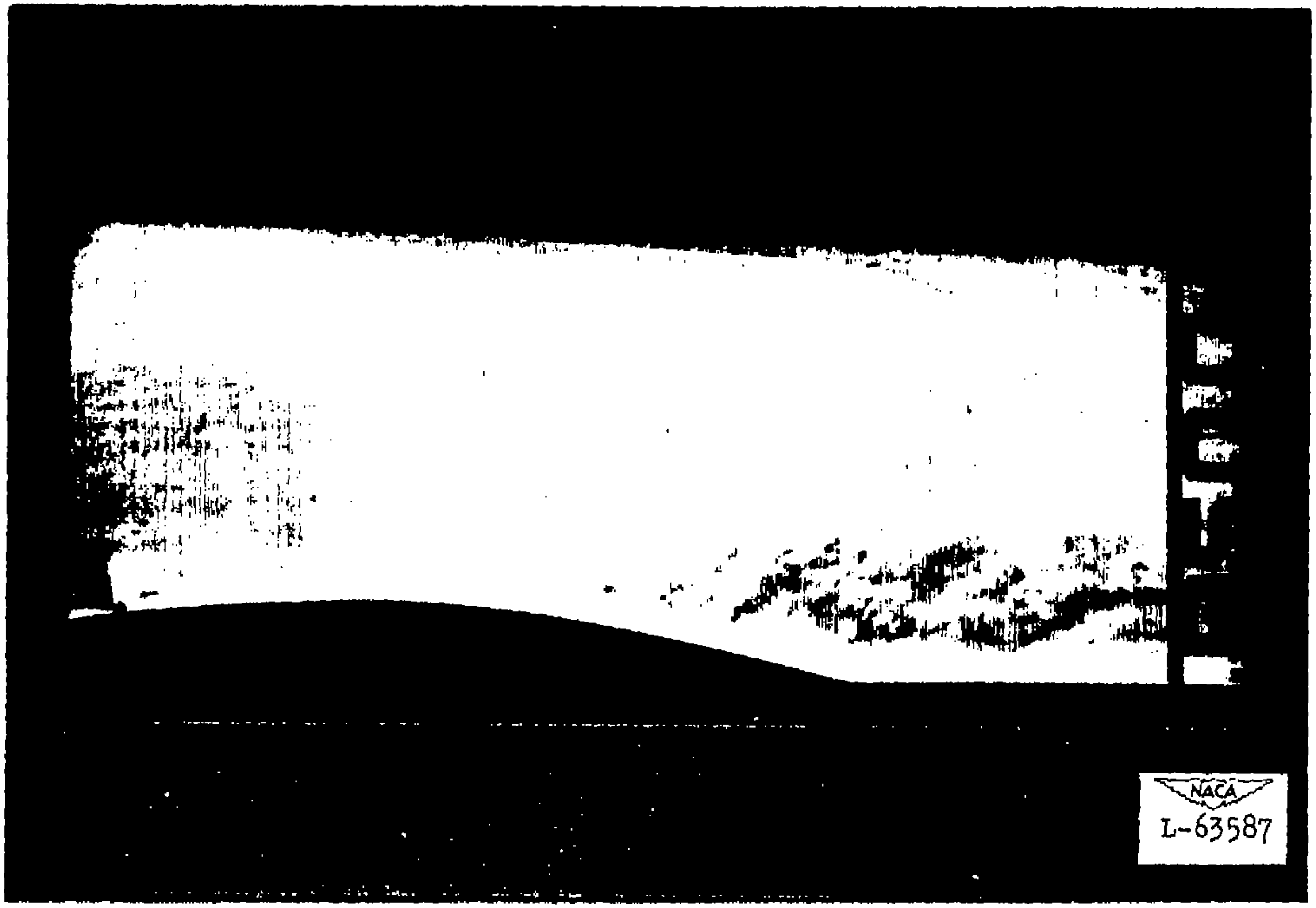

Figure 4.- Schlieren photograph of profile having vortex generators with shock at first position.

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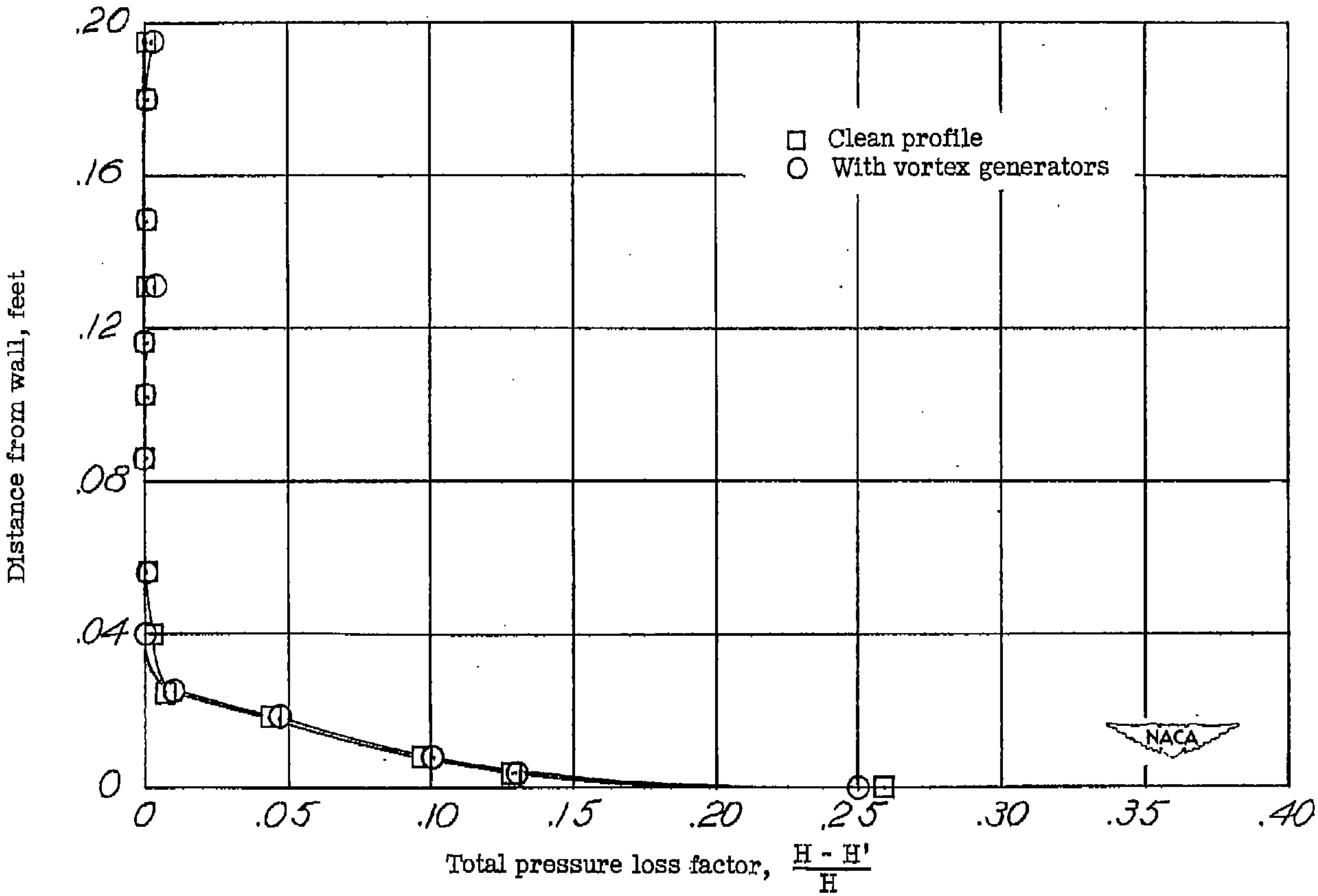

Figure 5.- Comparison of profile wake surveys with and without vortex generators with shock at first position.

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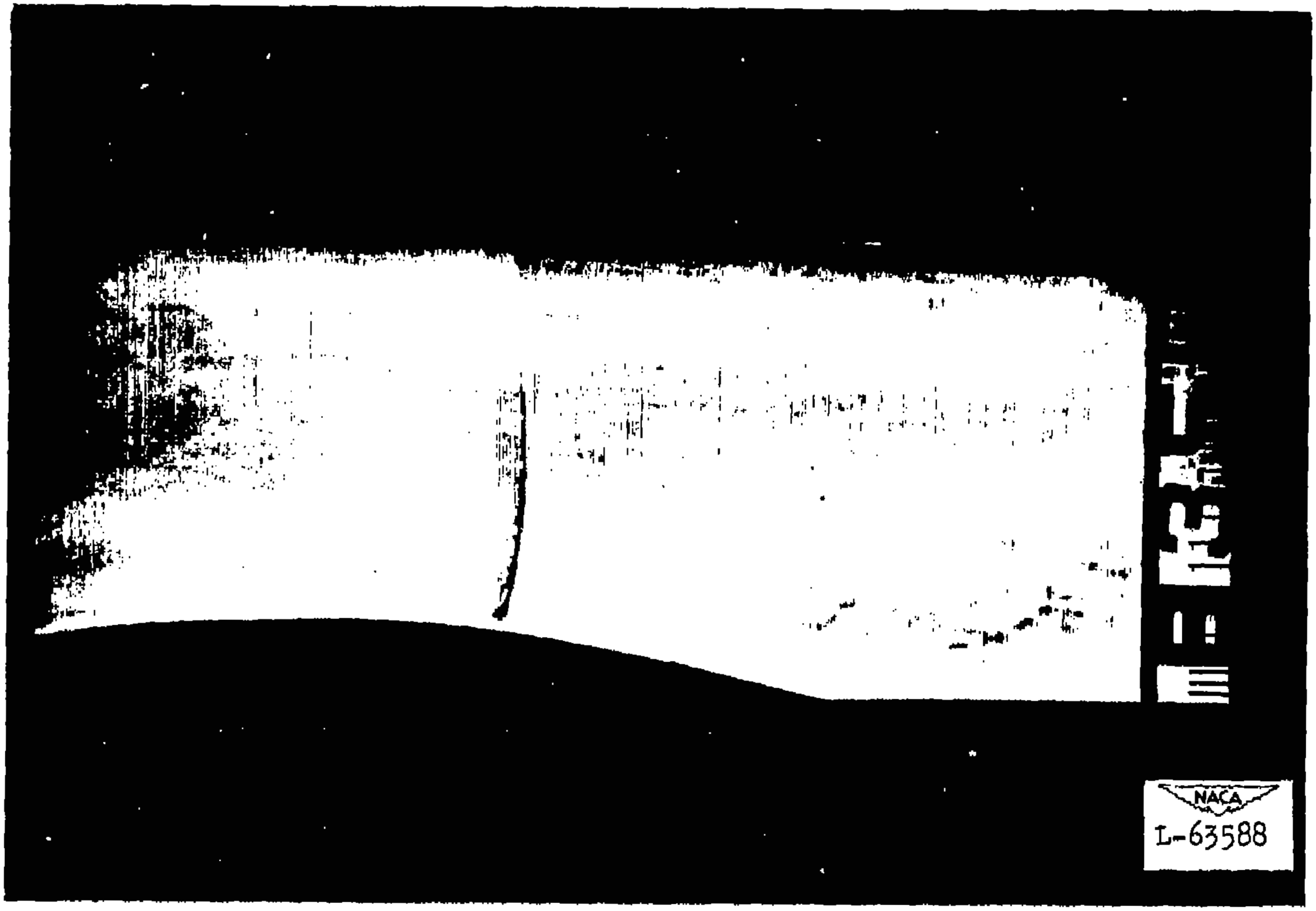

Figure 6.- Schlieren photograph of clean profile with shock at second position.

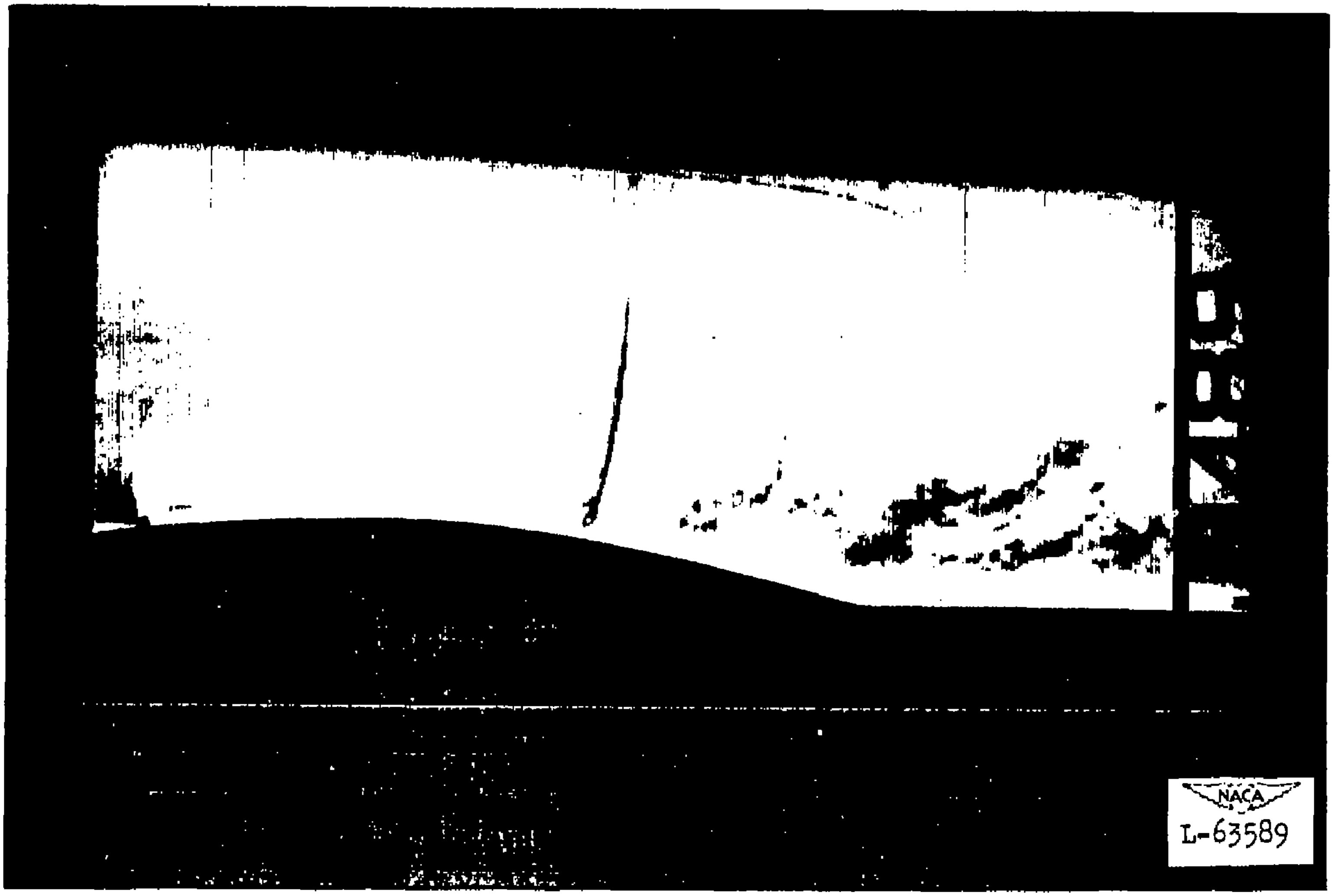

Figure 7.- Schlieren photograph of profile having vortex generators with shock at second position.

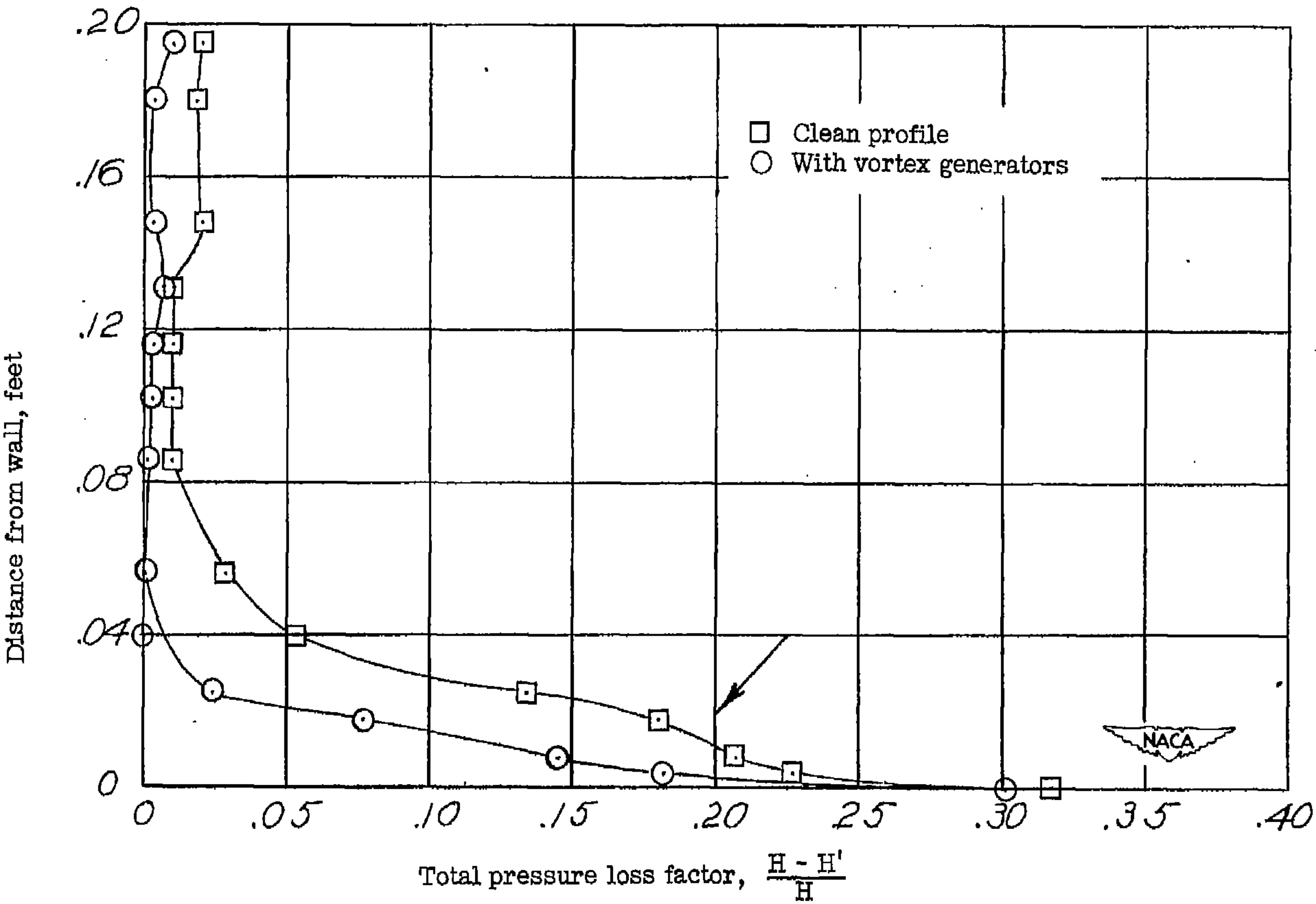

Figure 8.- Comparison of profile wake surveys with and without vortex generators with shock at second position.

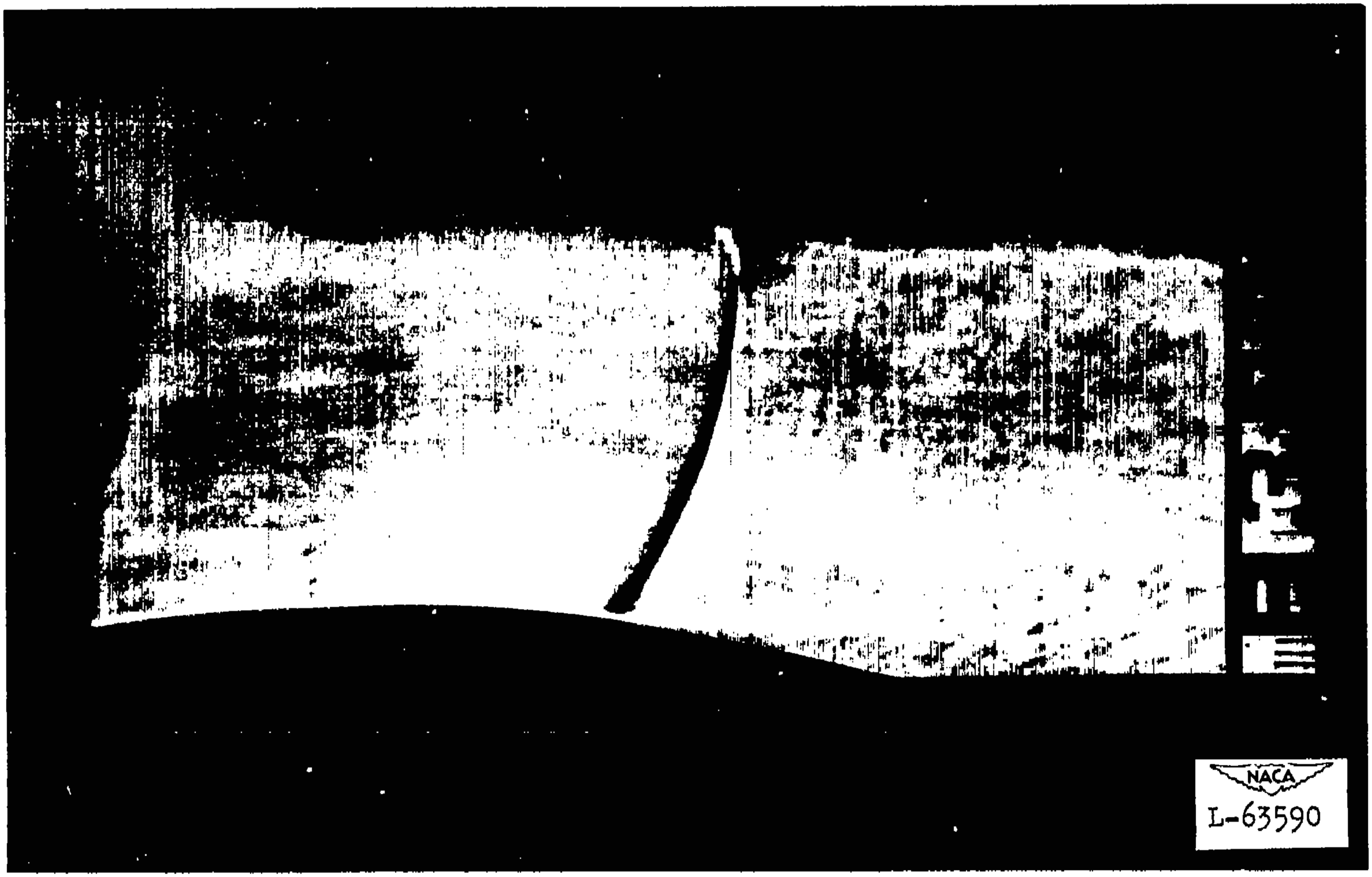

Figure 9.- Schlieren photograph of clean profile with shock at third position.

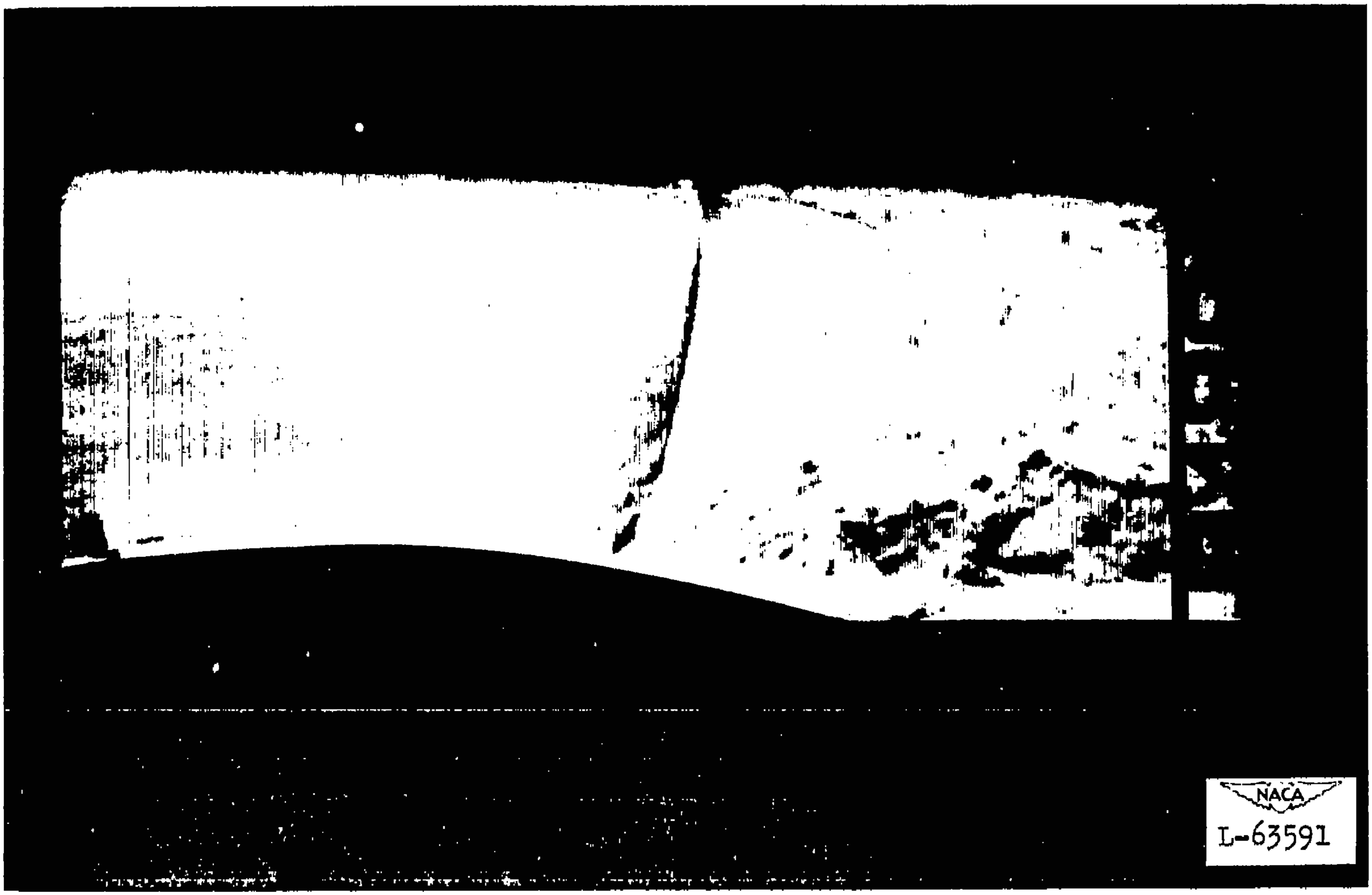

Figure 10.- Schlieren photograph of profile having vortex generators with shock at third position.

[redacted]

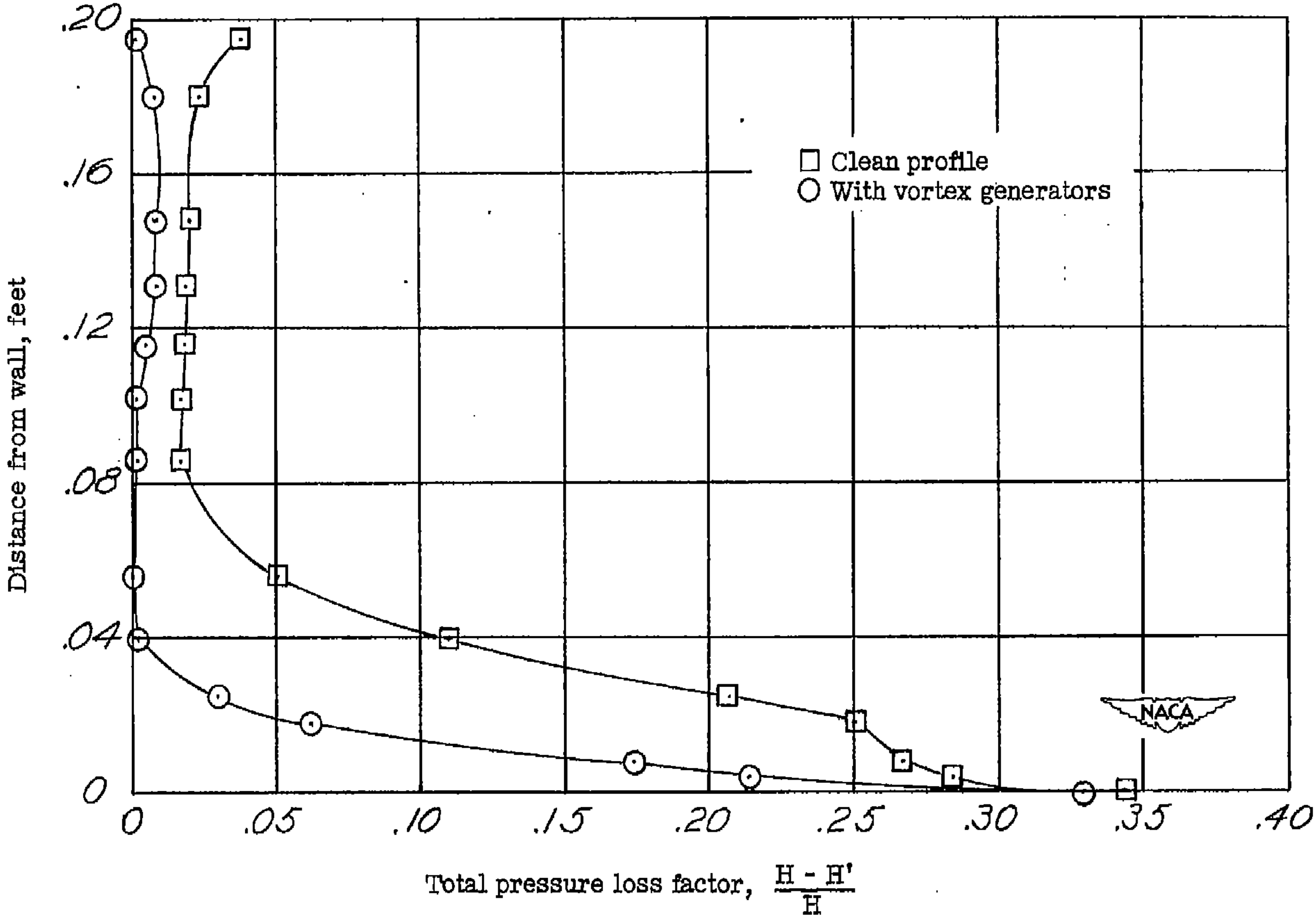

Figure 11.- Comparison of profile wake surveys with and without vortex generators with shock at third position.

Figure 12.- Schlieren photograph of clean profile with shock at fourth position.

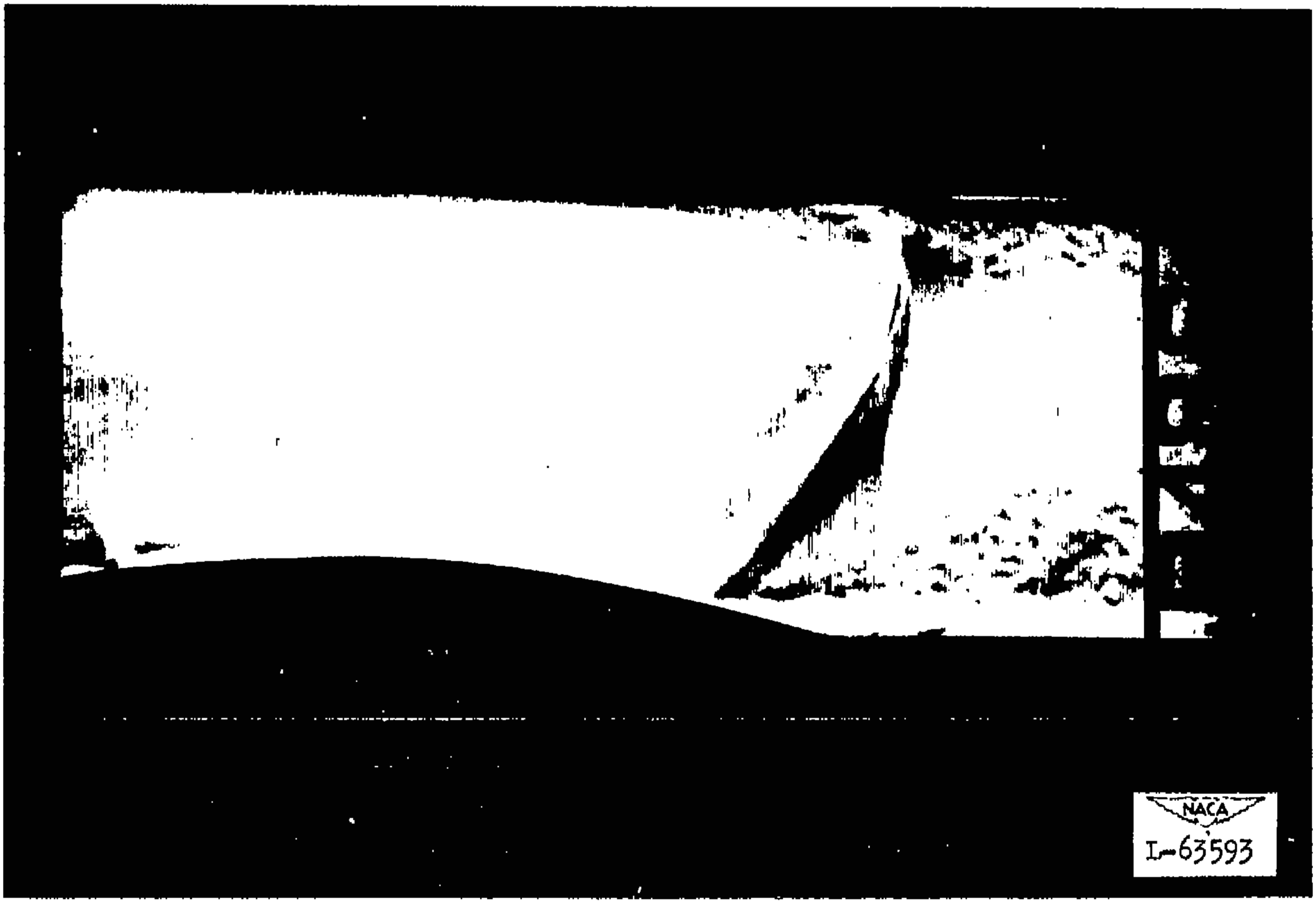

Figure 13.- Schlieren photograph of profile having vortex generators with shock at fourth position.

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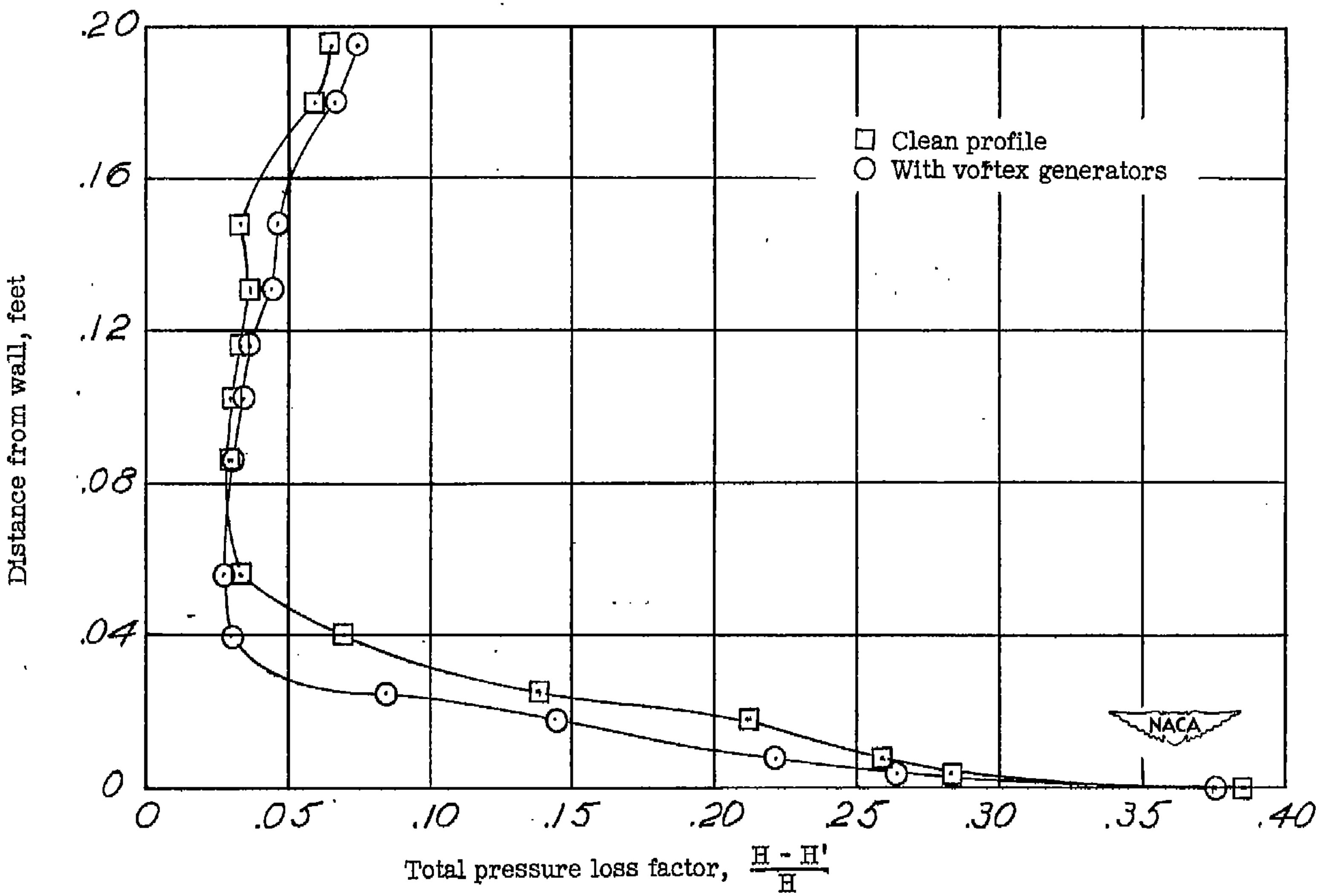

Figure 14.- Comparison of profile wake surveys with and without vortex generators with shock at fourth position.

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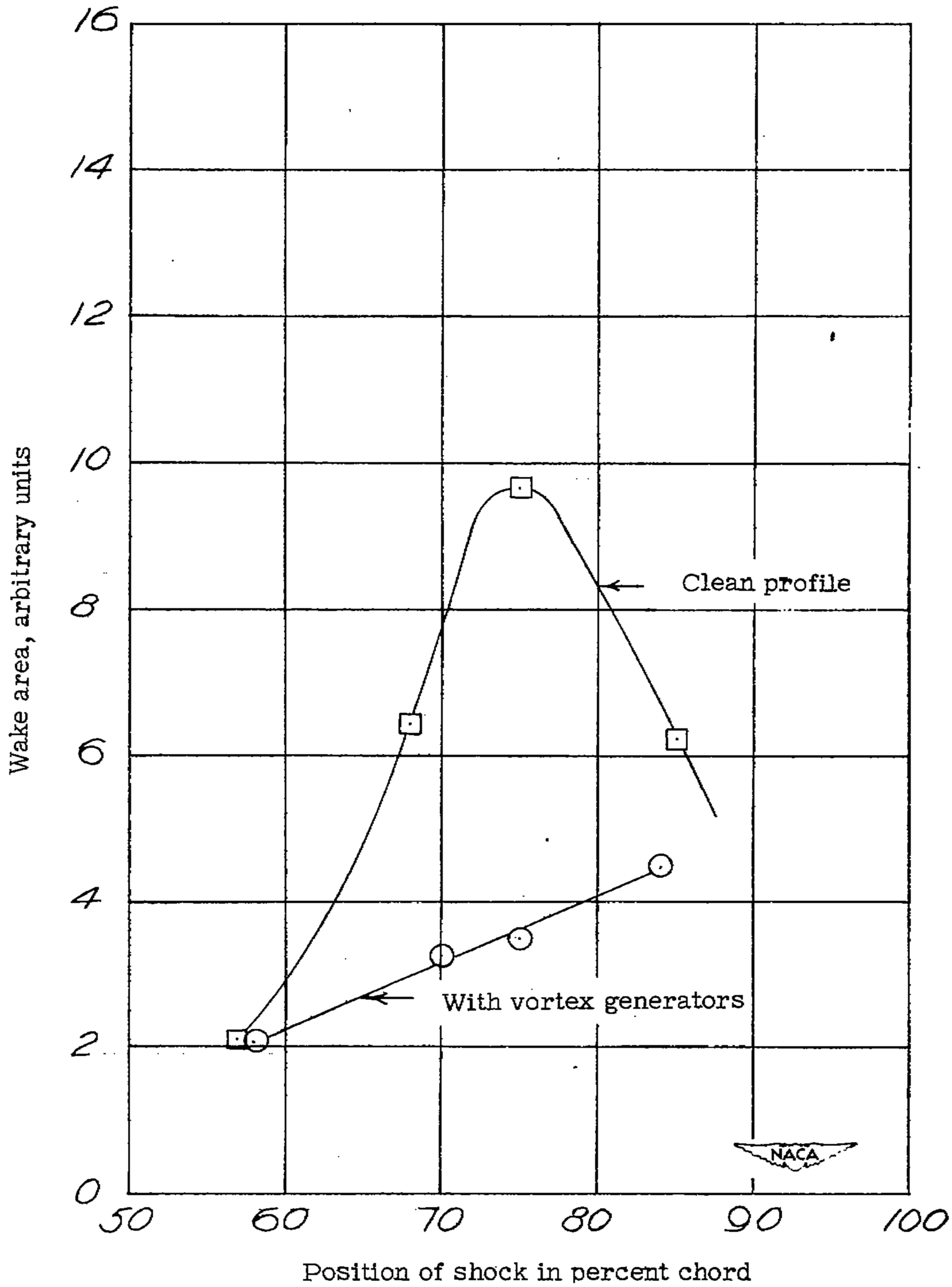

Figure 15.- Comparison of the relative sizes of the viscous wakes with and without vortex generators.