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No. 749

A NEW METHOD OF STUDYING THE FLOW OF THE WATER ALONG THE BOTTOM OF A MODEL OF A FLYING-BOAT HULL

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A NEW METHOD OF STUDYING THE FLOW OF THE WATER ALONG THE BOTTOM OF A MODEL OF A FLYING-BOAT HULL

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SUMMARY

A new method of studying the flow of the water along the bottom of a model of a flying-boat hull is described. In this method, the model is fitted with a transparent bottom and is divided down the center line by a bulkhead. The flow is observed and photographed through one-half of the model by means of the diffused illumination from a battery of lamps contained in the other half of the model. Photographs of the flow, particularly of the changes that occur when the step ventilates, are shown.

The results of the present investigation indicate that the method has considerable promise, chiefly in connection with motion-picture studies.

INTRODUCTION

Observations in regard to the flow of the water along the bottom of seaplane floats and flying-boat hulls, particularly in regard to the action of the step, are found in many reports of tests of both models and full-size craft. Most of the data have been based on observation of the type and the changes of the waves emerging from under the hull. Other observations have been made from the flow pattern obtained on the bottom of a hull, such as produced by the action of chemicals on the bottom paint. In some recent studies in the N.A.C.A. tank, the flow pattern on the bottom of a hull has been obtained by applying spots of a semiplastic fluid and recording the streaks that proceeded from them. This method is laborious and, although it does give a general picture of the flow at specific speeds, it permits no detailed study of the changes that occur. Simple transparent forms, such as the glass planing surfaces tested by Sambraus (reference 1),

have permitted direct observations of the flow over the bottom surface but, as far as is known, the method of illumination and the study of the flow over the bottom of a hull form, as herein described, has not been used prior to the present investigation.

The purpose of the present preliminary investigation was to explore the possibilities of directly observing the flow over the bottom of a model of a flying-boat hull through a transparent bottom by means of suitable illumination arranged to make the flow visible. It was desired to observe the general behavior of the water flowing along the under surface of the hull and, in particular, to observe the nature of the action of the step in the transition from the predominantly displacement condition to the predominantly planing condition.

MODEL

The form of the model of the flying-boat hull chosen for this investigation is generally similar to that of N.A.C.A. model 11-C (reference 2) with the exception that the forebody has developable surfaces, resulting in a somewhat fuller bow. The model is constructed in two sections, a forebody section and an afterbody section joined at the step; the depth of the step may be varied by raising or lowering the afterbody section with respect to the forebody section. This arrangement is similar to that used for the model of reference 3. The tail extension is omitted, the model ending at the sternpost. The bottom of the model is formed of sheets of transparent plastic, 1/8 inch thick, attached to a heavy wooden shell of the desired form. It is possible to look directly through the bottom from a position above the model.

Figure 1 shows the model as viewed from the bottom and from the top. (Fig. 1 shows the model with a V-step. The normal step is of the usual transverse form and is located on the division line of the forebody and the afterbody sections.)

A heavy bulkhead down the center line divides the model into two halves. On one side of this bulkhead is arranged a battery of lamps (five No. 2 Photoflood lamps and five 150-W projector flood lamps). The light from these lamps on the one side is diffused in the water to such an

extent that it is possible to observe and photograph the flow along the other side of the model. The side containing the bank of lamps is covered and scoop ventilators are fitted to provide air for cooling the lamps. The interior of this section is painted with white reflector paint. The observation side of the model is uncovered and the interior is painted with a flat black paint.

Strings were found to be helpful in illustrating the direction of the flow along the bottom. These strings are attached to the vertical face of the step and to the bottom surface forward and aft of the step. (See fig. 1.)

In the course of the investigation, several changes were made in the depth and the form of the step in order to note whether the resulting changes in the flow could be observed and recorded. Letters are added to the model number to identify each main change. The designations are:

Model 80-A:	Normal step,	0.033b	(9/16-inch)
Model 80-B:	Shallow step,	0.007b	(1/8-inch)
Model 80-C:	Deep step,	0.059b	(1-inch)
Model 80-D:	Ventilated step,	normal depth	
Model 80-F:	30° pointed step,	normal depth	

where b is the beam of the model, 17 inches.

PROCEDURE

Photographs of the flow were made by means of a camera mounted directly above the observation section of the model. The field included most of the afterbody and a small area forward of the step. Satisfactory photographs could be taken with the lighting arrangement described in the preceding section.

Most of the tests were made by towing the model at constant trim and constant load and at a low rate of acceleration. Photographs of the flow at representative speeds were simultaneously taken with visual readings of the tachometer indicating the speed of the carriage.

Some tests were made with the model free to trim about an axis passing through an assumed center of gravity. The model was balanced and lift was applied in the manner generally used for making specific tests in the N.A.C.A. tank. The photographs taken during these tests represented the changes of the flow over the bottom during the take-off of a flying boat. At representative speeds, a photograph was taken and, in addition to the tachometer reading, the trim and the load were read.

A number of motion-picture studies of the flow were made with the model taking off and landing. These studies included take-offs in which porpoising occurred. Some of these motion pictures were first shown at the N.A.C.A. Fourteenth Annual Inspection in May 1939.

RESULTS

The results of this study are presented in the form of photographs of the flow near the step in the transition range between the displacement condition and the planing condition. Figure 2 shows a typical sequence of the changes in flow with the model free to trim. On the typical resistance curve shown in figure 3, the changes in resistance are correlated with changes in the flow, particularly with respect to the discontinuity in the resistance curve that occurs before the hump. Tachometer readings that represent the actual speeds within ±1/2 foot per second are given in all the figures. Trims are correct to within ±1/4° and loads to within about ±1/2 pound.

The photographs taken during the tests at fixed trims and constant loads are given in figures 4 to 8. For comparisons of the data in regard to load and speed with those given in coefficient form in references 2 and 3, the following conversion factors may be used:

Load, Δ, pounds - - - - - - - - - 180 C_Δ

Speed, V, feet per second - - - 6.76 C_V

The models are all the same size so that the dimensional quantities may be directly compared within the limits of accuracy of the present tests.

DISCUSSION

General nature of changes in flow.- The nature of the changes in flow observed in this investigation is best discussed with reference to figures 2 and 3. The photographs may be identified with the corresponding points on the resistance curve by means of the values of trim, τ, indicated on the figures. The camera was mounted directly above the model so that the photograph, taken vertically down through the port side of the transparent bottom, shows the flow in the vicinity of the step. (The light area in the afterbody near the keel is caused by water inside the model.)

In the low-speed range, the hull is running almost entirely as a displacement craft, the flow is parallel with the keel, and there is no visible disturbance of the flow. (The strings attached to the bottom of the hull are not straightened out because of the low velocity of the flow.) As the speed increases and the bow rises, a small turbulent area appears at the outer edge of the step and the resistance begins to increase less rapidly. This turbulence is a result of a violent agitation of the water behind the step and is not to be confused with the lesser degree of turbulence generally associated with fluid flow. True ventilation of the step, however, has not yet taken place because the step is effectively sealed by the solid water along the side of the hull. With further increase in speed, the turbulence disappears between speeds of 7.7 and 9.5 feet per second and then reappears with greater intensity. At this stage a wave from the forebody, which is indicated by the light line close to the edge of the hull, has moved aft to such a position that air can enter from the side and ventilate the step. At a speed of about 11 feet per second, the ventilation of the step is complete, the turbulent wake goes rapidly aft, and planing becomes predominant. In this transition stage, the discontinuity in the resistance curve appears. As the turbulent wake from the step goes aft, the wetted area decreases with a corresponding decrease in the resistance. This discontinuity in the resistance curve has been discussed by Truscott (reference 4) and mentioned by Sottorf (reference 5).

As the speed continues to increase, the resistance again increases, although the planing condition has become well established. The space just aft of the step is en-

tirely clear and the hull is planing on the forebody and a small portion of the afterbody. The maximum, or hump, resistance for this model occurs about the same time that the afterbody comes clear of the water. Apparently the hump is not associated with any decided change in the flow.

The last three photographs of figure 2, at speeds from 20.0 to 25.5 feet per second, show the flow with the model planing at a speed well beyond the hump speed. The afterbody at this stage is entirely clear of the water. Of particular interest in these photographs is the light line crossing the bottom of the hull at an angle. This line is a result of the lens effect of the forward curvature of the water ahead of the stagnation points in the flow and very closely represents the line of maximum pressures on the surface of the model. Ahead of this peak-pressure line, the water is thrown to the side as a high-velocity jet. Aft of the peak-pressure line, the water flows parallel with the keel. The photograph at 25.5 feet per second shows how sharp this pressure peak is, as indicated by the close approach of the line to the string before any influence on the direction of the string is observed. The peak pressure and the divided flow may also be observed on the afterbody at lower speeds just after planing has become established. It is interesting to observe that the crest of the bow wave is a direct continuation of the peak pressure as it emerges from under the hull.

Effect of depth of step.- The data of reference 3 indicate changes in the resistance of a relatively small order with changes in the depth of the step. The increase in resistance at low speeds may be associated with an increased turbulence caused by an increase in the depth of the step and the decrease in resistance at planing speeds, with greater clearance of the afterbody resulting from an increase in the depth of step. These conclusions are substantiated by the photographs of figures 4 to 6. The nature of the flow in the transition stage is not appreciably affected but the degree of turbulence in the wake of the step is considerably increased with an increase in the depth of step. As might be expected, the transition occurs earlier and the afterbody interference at high speeds is considerably less as the depth of the step is increased. An increase in load and a decrease in trim are effective in delaying the transition.

Effect of ventilation.- The effect of additional ventilation of the step is shown by a comparison of figures 4(b) and 7. The additional ventilation was accomplished by slightly separating the forebody and the afterbody sections of model 80-A and sealing the resulting side gaps. This procedure permitted the free flow of air into the step from the top of the model. Ventilation of this form apparently has little effect other than aiding, to a small extent, the beginning of the separation of flow from the step.

In order to study further the effect of ventilation, several brief tests were made with thin, rectangular plates covering the outer edges of the step to prevent ventilation from the side. These plates extended 1-1/2 inches ahead of and 2-1/2 inches aft of the step and about twice the step depth below the forebody chine. They effectively sealed the step from entrance of air throughout the short speed range of the transition stage.

The results of these tests show that ventilation of the step can be completely prevented with the shallow step but that a deep step ventilates in spite of the plates and at about the same speed as without the plates. Some delay is experienced in the transition for the normal depth of step but, with additional ventilation from the top (model 80-D), plates on the side have no effect whatever.

Effect of plan form.- The effect of changing the plan form of the step from the normal transverse form to a V-form is shown by comparing figures 4(a) and 8. The resistance curve for model 80-F (V-step) has the same general characteristics as that for model 80-A (normal step) including the discontinuity well before the hump. These discontinuities were omitted in the curves of references 2 and 3, because of the secondary interest in the phenomenon.

The photographs of figure 8, supplemented with the motion-picture study, show a considerable difference in the type of flow in the transition range. Instead of a rough turbulence developing behind the step, the flow now develops into a definite vortex parallel with the step. This vortex becomes very strong and breaks away in an almost regular form, with an accompanying reduction in resistance, and the flow becomes similar to that for the models having transverse steps. The data of reference 2

show that the general resistance characteristics of the models with V-steps are but little different from those for the models having the conventional transverse step. This result is to be expected from the present study because of the similarity of the flows in all but the transition stage.

CONCLUSIONS

1. The method of studying the characteristics of the flow along the bottom of a model of a hull by observation and photography through a transparent bottom, particularly by the use of motion pictures, promises to be of assistance in obtaining definite explanations for many phenomena connected with take-off and landing.

2. The method should prove to be of use in conjunction with studies of bottom pressures by showing the movement of the peak pressure in landings, in rough water, and in porpoising.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 12, 1940.

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2. Dawson, John R.: A General Tank Test of N.A.C.A. Model 11-C Flying-Boat Hull, Including the Effect of Changing the Plan Form of the Step. T.N. No. 538, N.A.C.A. 1935.

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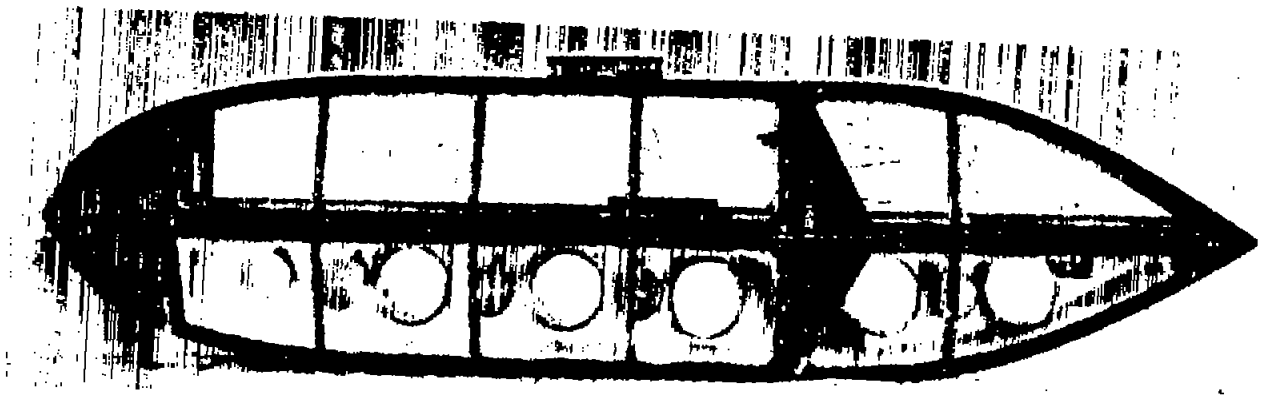
4. Truscott, Starr: The N.A.C.A. Tank - A High-Speed Towing Basin for Testing Models of Seaplane Floats. T.R. No. 470, N.A.C.A., 1933.

5. Sottorf, W.: Experiments with Planing Surfaces. T.M. No. 661, N.A.C.A., 1932.



Bottom view

Top view

Figure 1.- N.A.C.A. model 80.

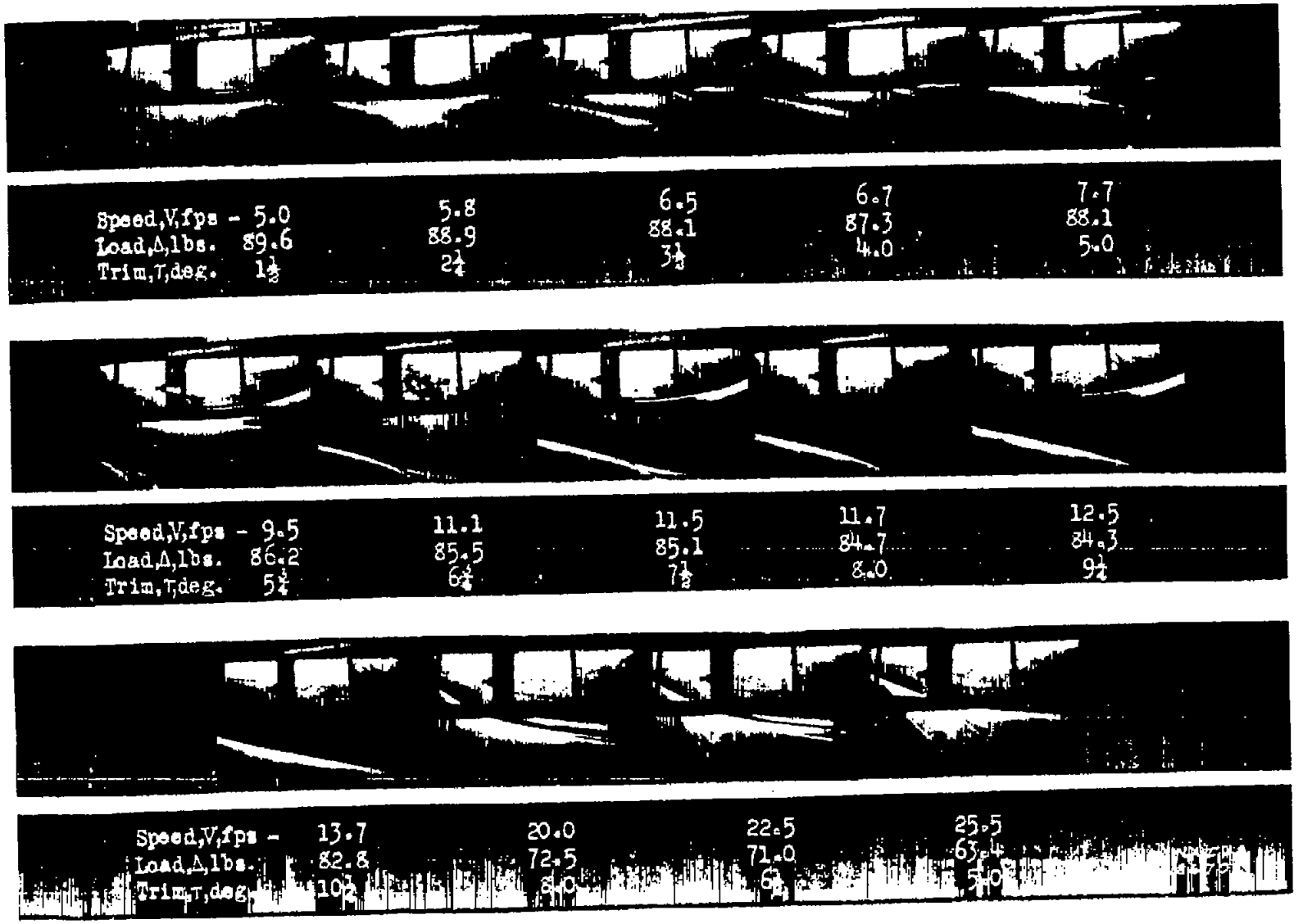


Figure 2.- Model 80-A 0.033b Step (9/16 in.) Free-to-trim.

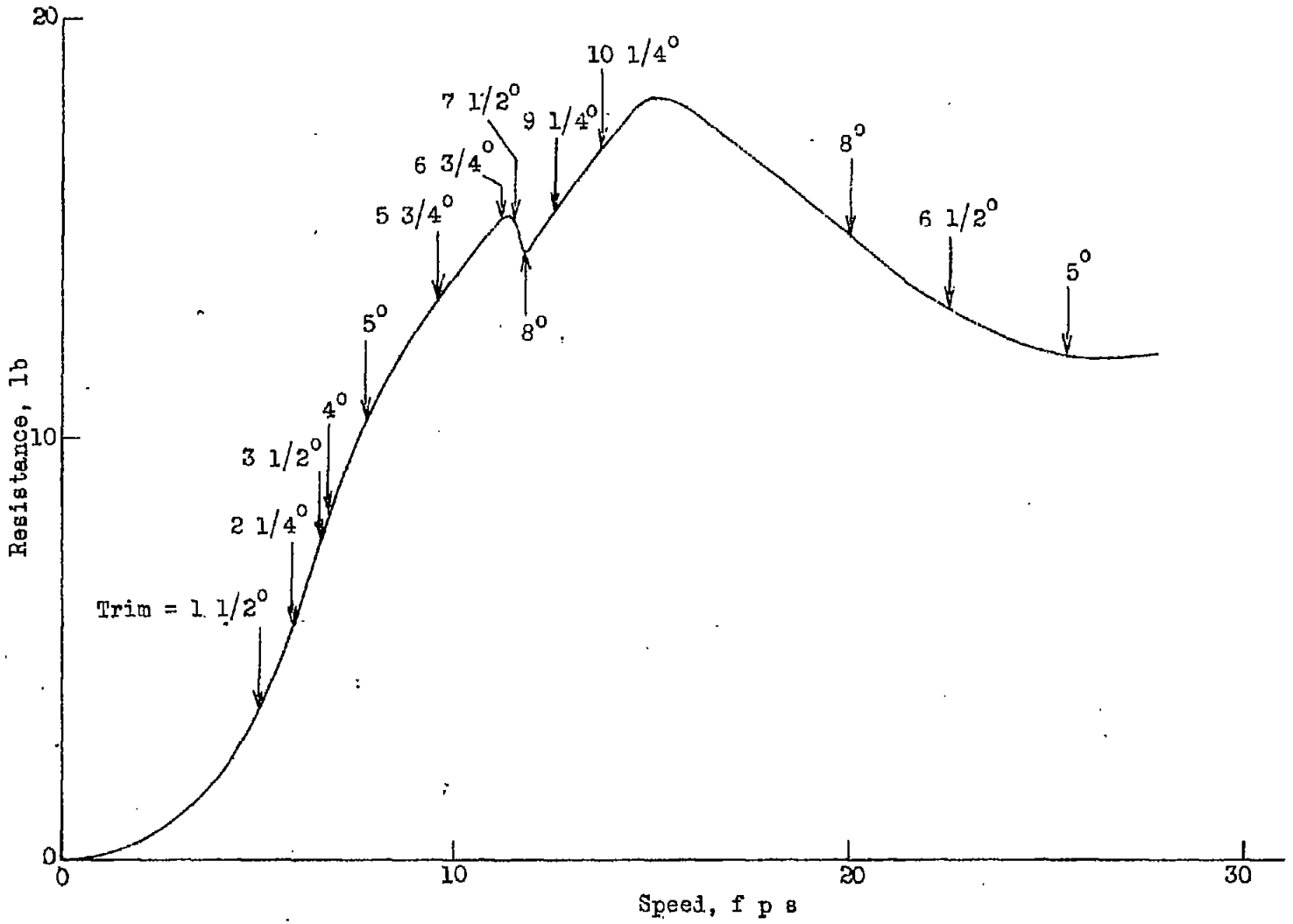


Figure 3.- Model 80-A. Resistance, free to trim, correlation with flow.

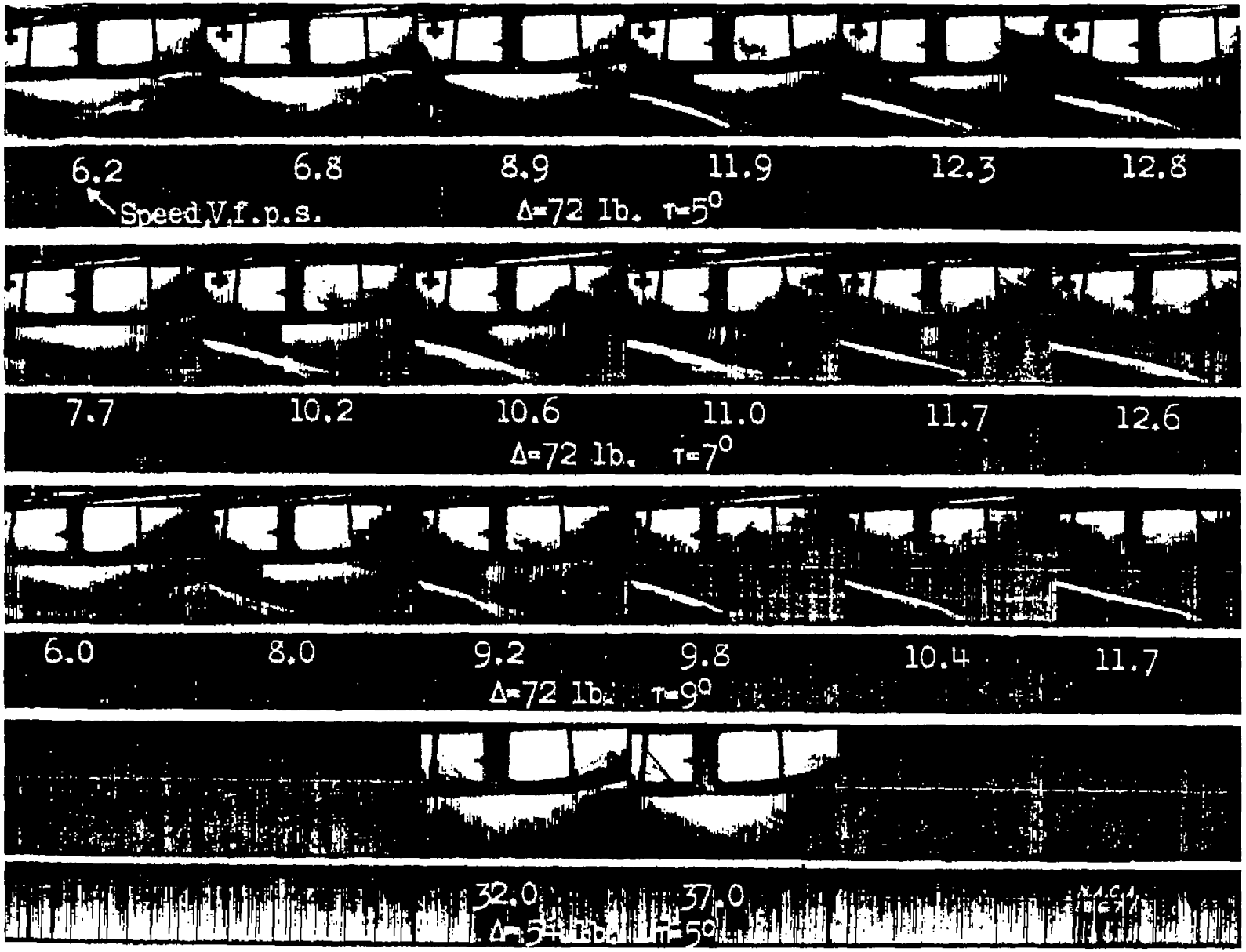


Figure 4, a to c.- Model 80-A The 0.033b step (9/16 in.).

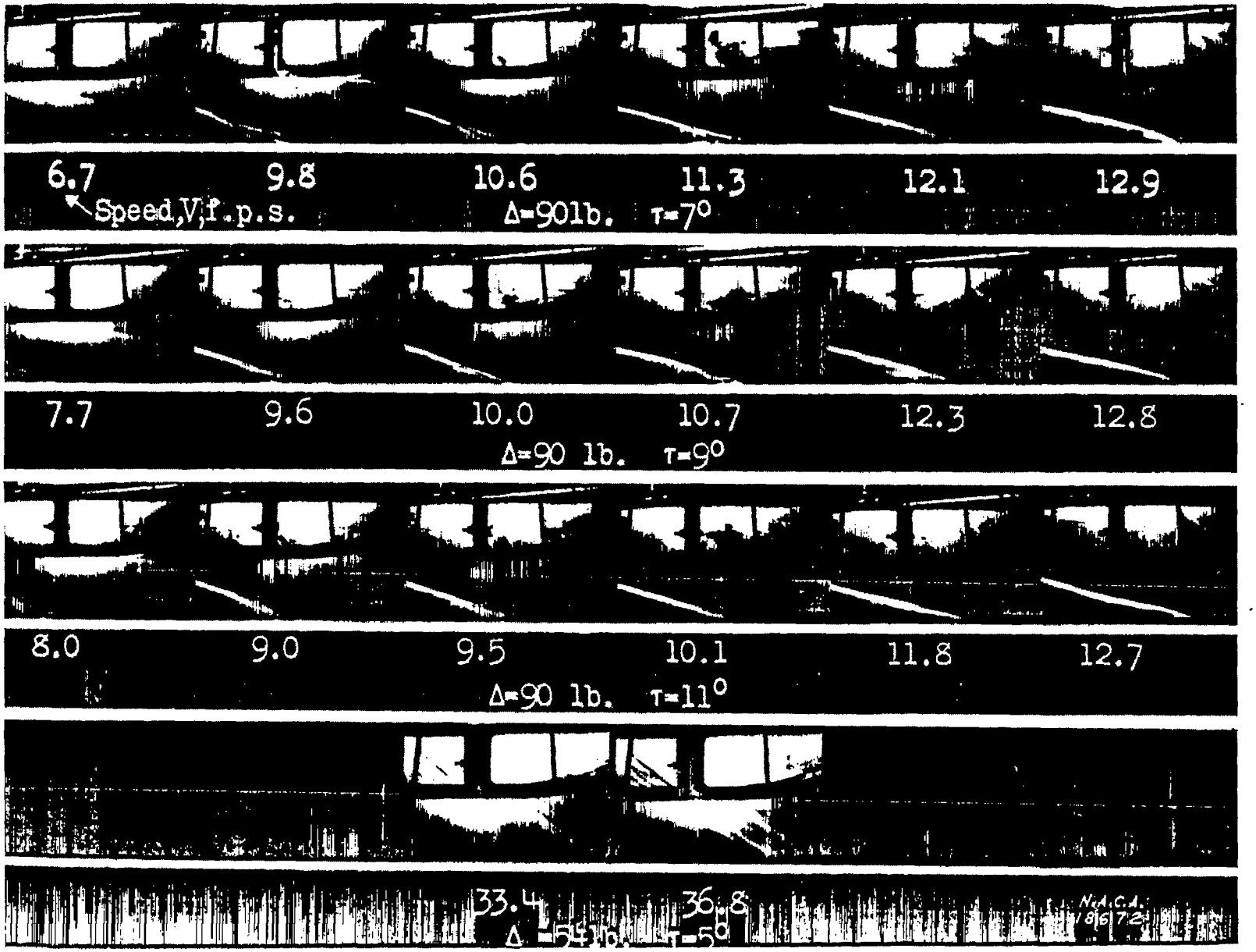


Figure 4 continued. Model 80-A The 0.033b step (9/16 in.).

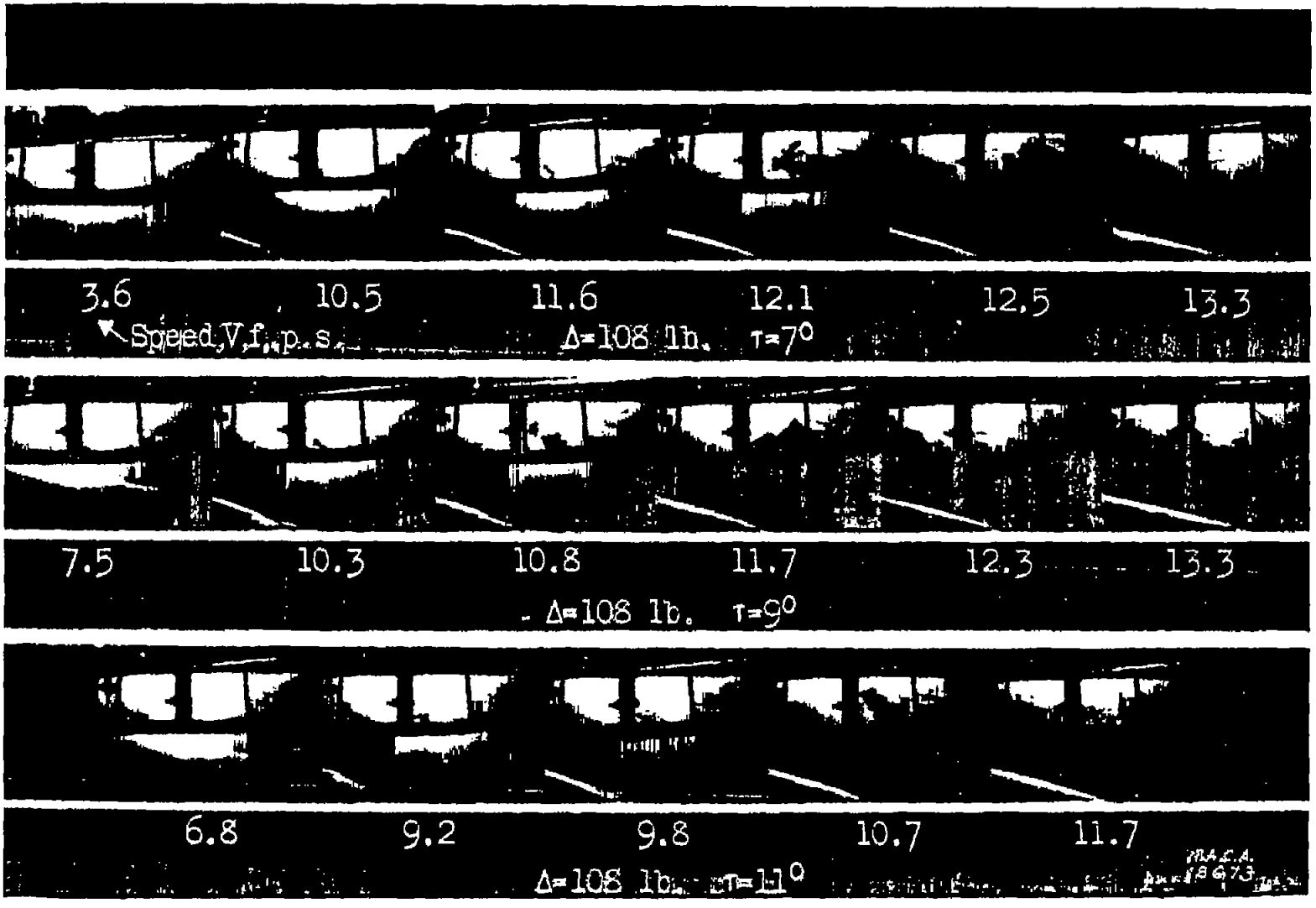


Figure 4 continued. Model 80-A The 0.033b step (9/16 in.).

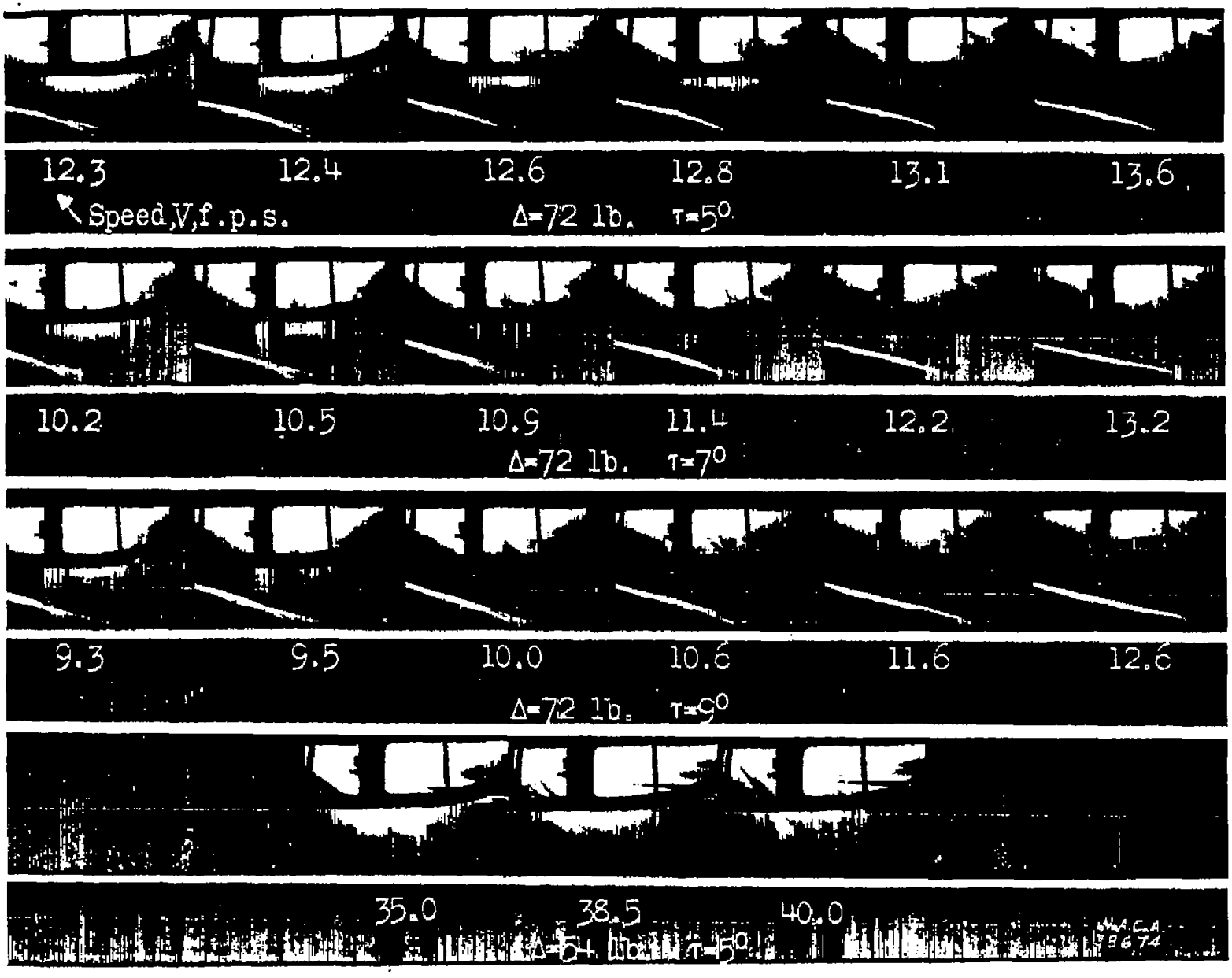


Figure 5, a to c.- Model 80-B The 0.007b step (1/8 in.).

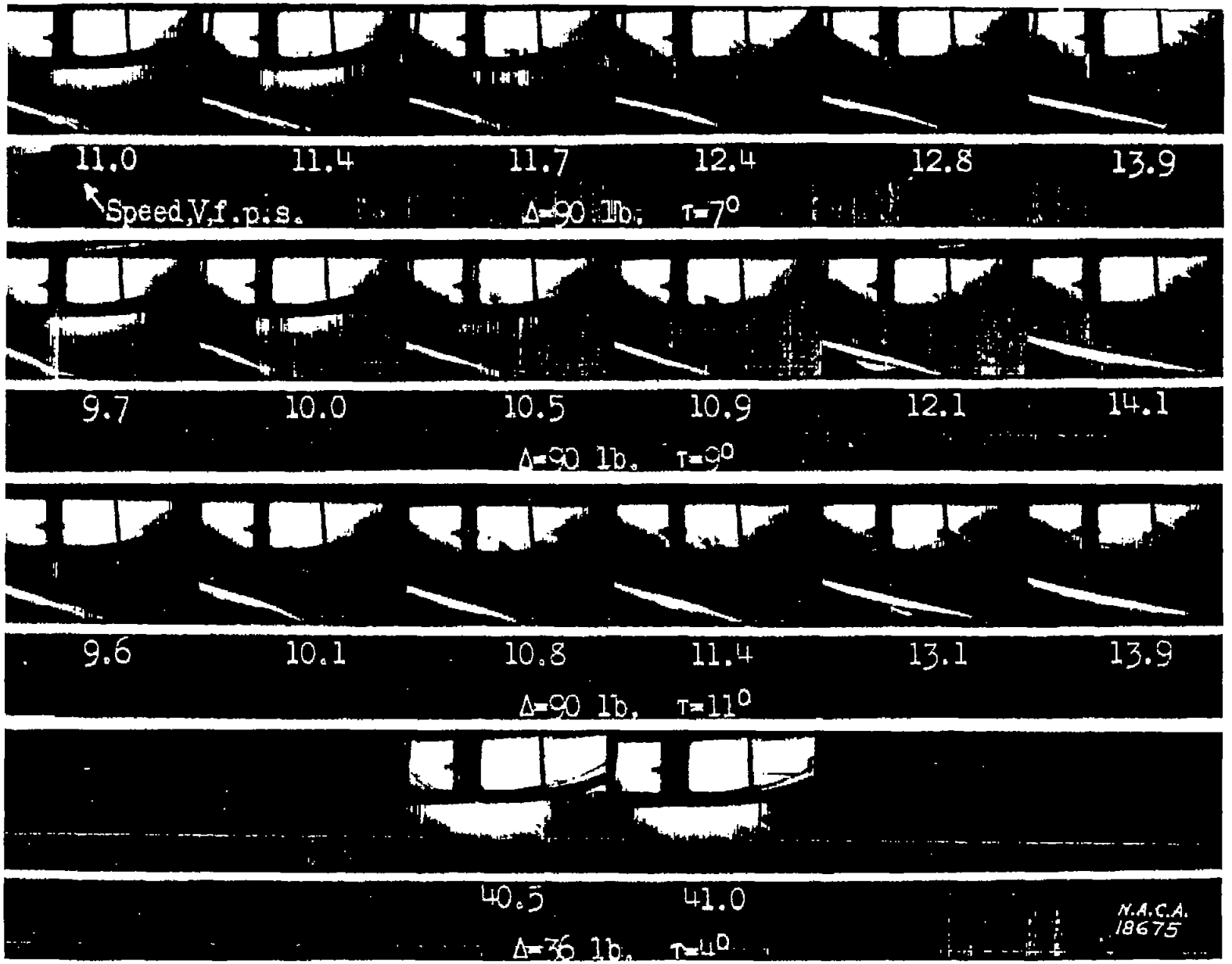


Figure 5 continued. Model 80-B The 0.007b step (1/8 in.).

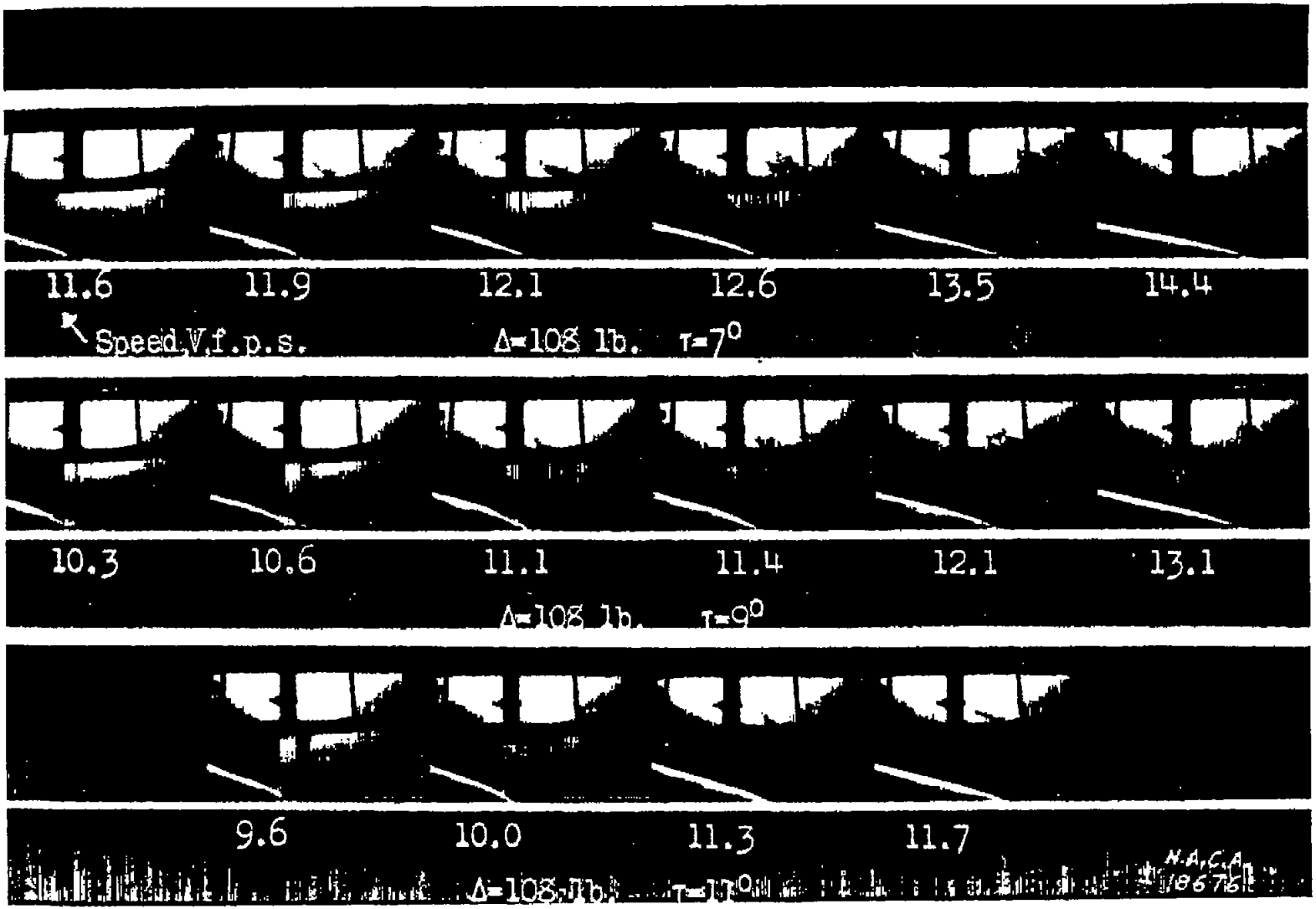


Figure 5 continued. Model 80-B. The 0.007b step (1/8 in.).

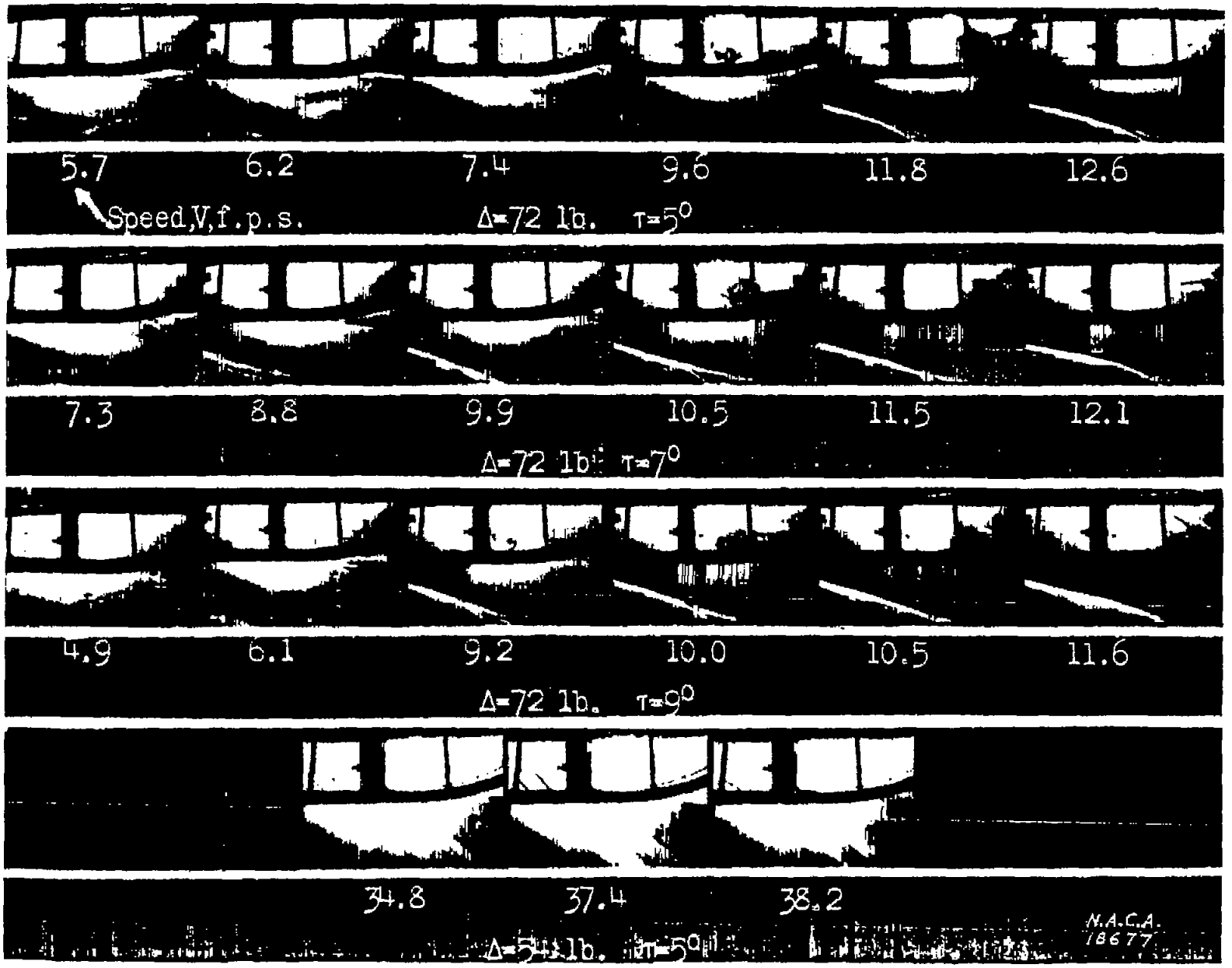


Figure 6, a to c.- Model 80-C. The 0.059b step (1 in.).

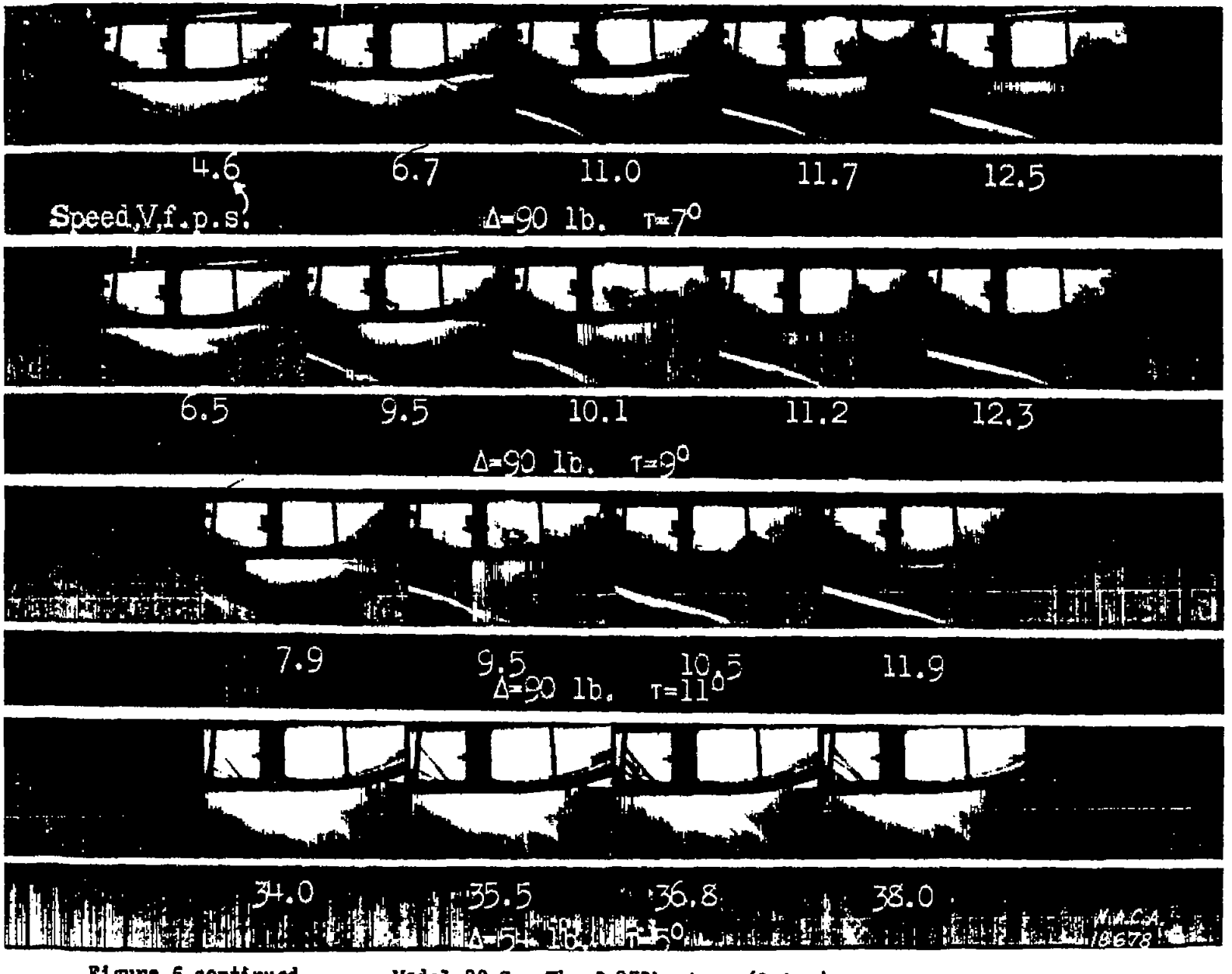


Figure 6 continued. Model 80-C The 0.059b step (1 in.).

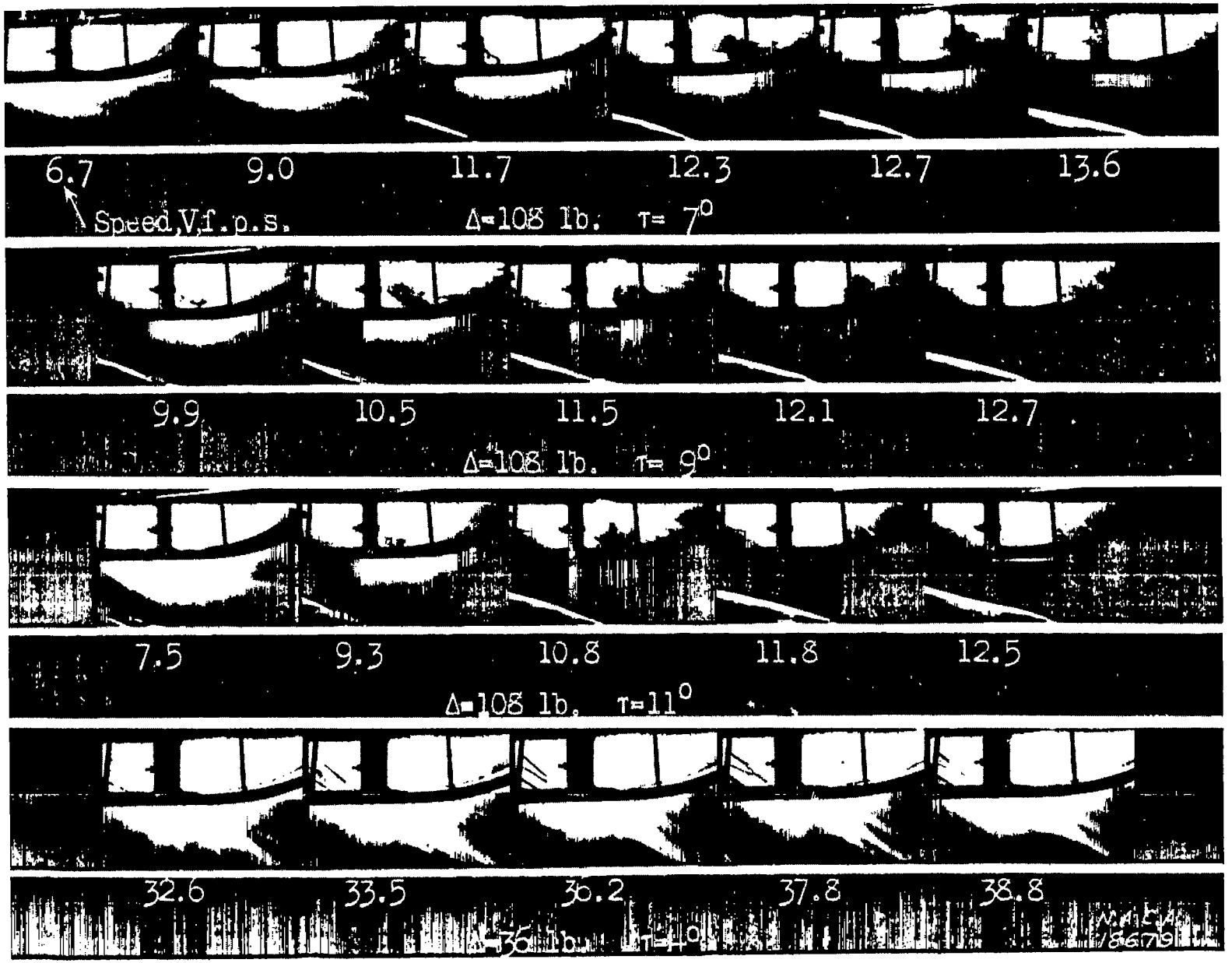


Figure 6 continued. Model 80-C The 0.059b step (1 in.).

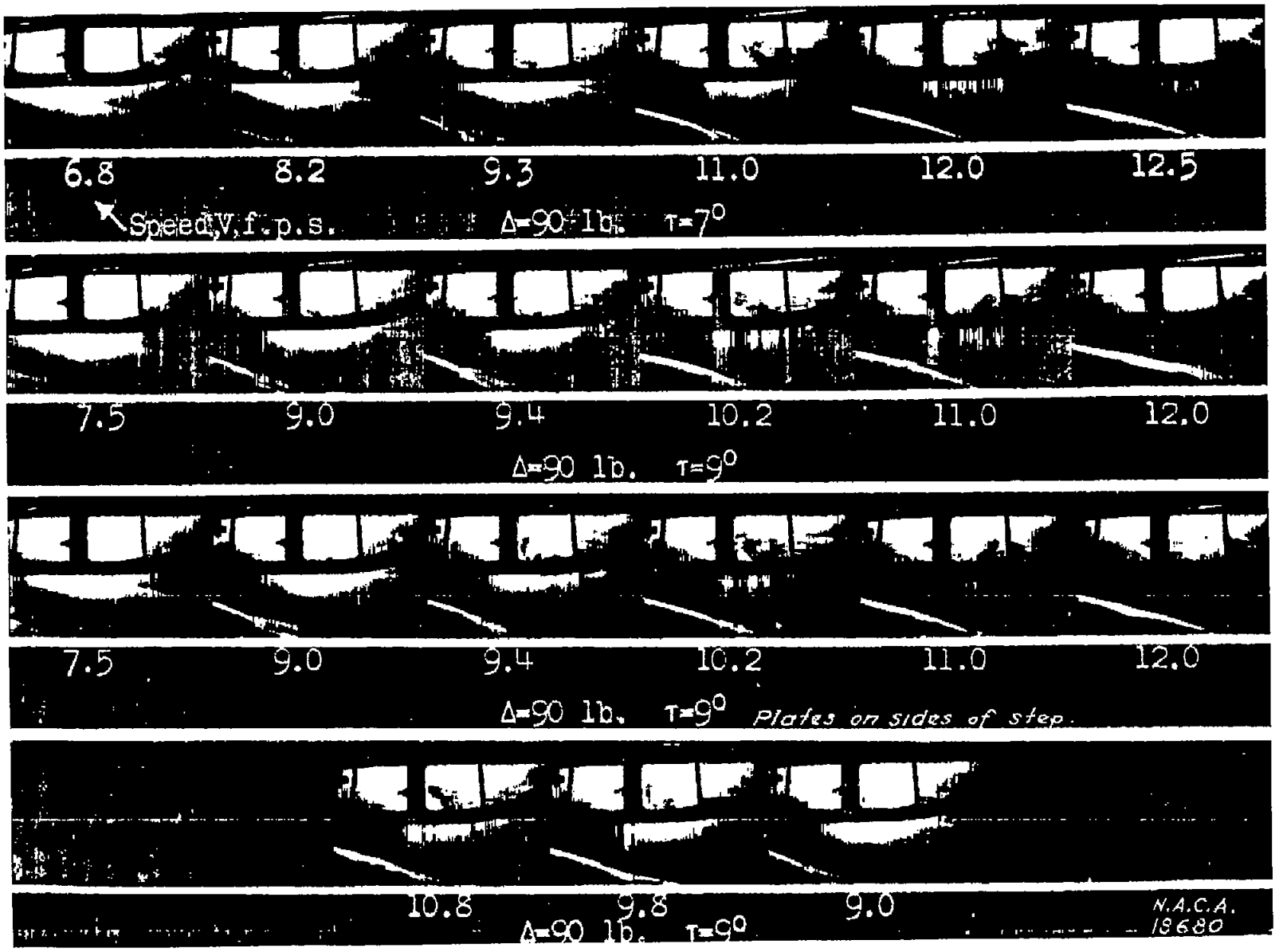


Figure 7.- Model 80-D. The 0.033b step (9/16 in.) with 1/8 inch clearance between forebody and afterbody for step ventilation.

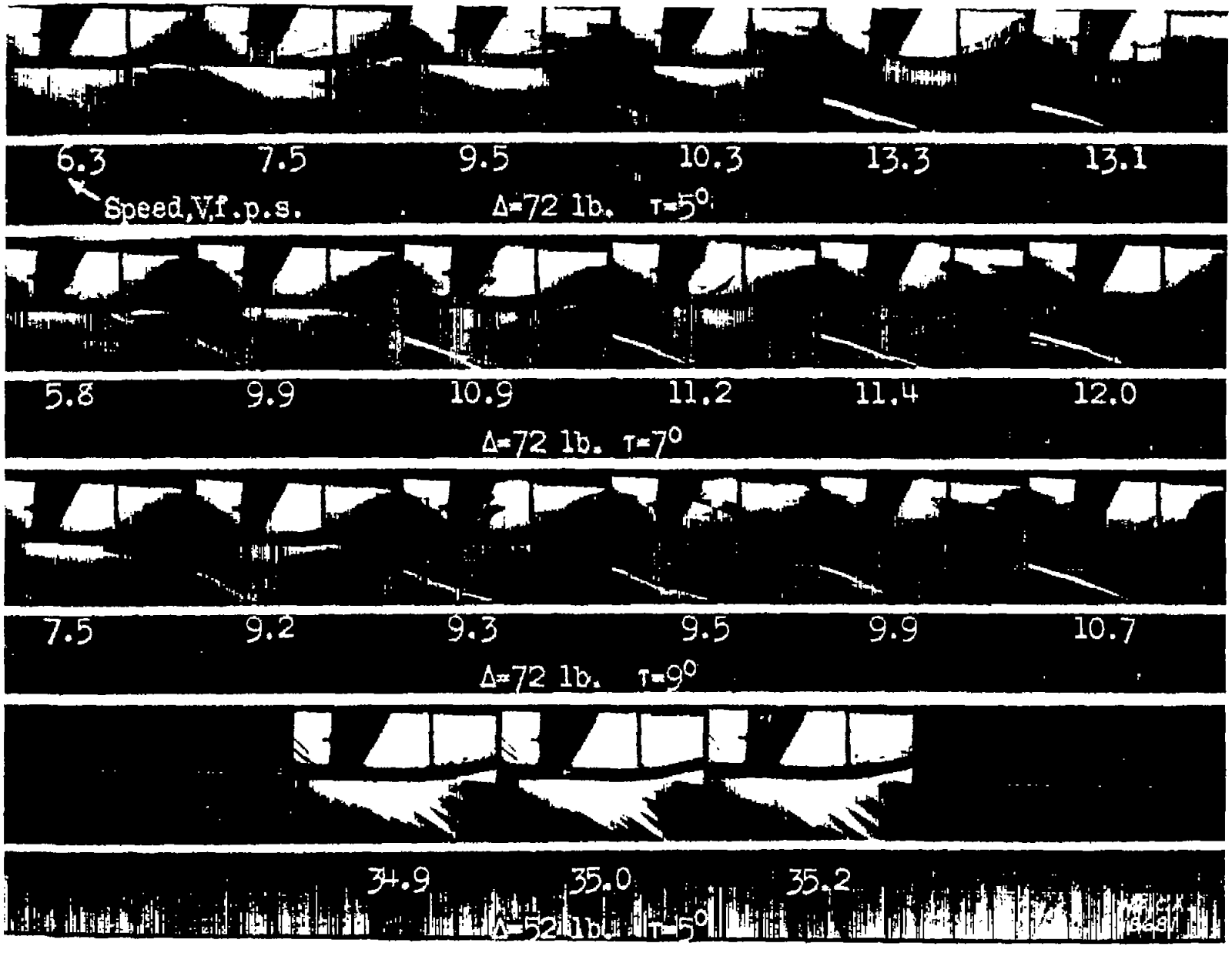


Figure 8.- Model 80-F. The 30° pointed step.