TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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THE INCREASE IN FRICTIONAL RESISTANCE CAUSED BY VARIOUS TYPES OF RIVET HEADS AS DETERMINED BY TESTS OF PLANING SURFACES

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SUMMARY

The increase in the frictional resistance of a surface caused by the presence of rivet heads was determined by towing four planing surfaces of the same dimensions in the N.A.C.A. tank. One surface was smooth and represented a surface without rivet heads or one with perfectly flush countersunk rivets. The other three surfaces were each fitted with the same number of full-size rivet heads but of a different type arranged in the same pattern on each surface. The surfaces were towed at speeds representative of the high water speeds encountered by seaplanes during take-off and the range of Reynolds Number covered by the tests was from 4×10^6 to 18×10^6.

The rivet heads investigated were oval countersunk, brazier, and round for rivets having shanks 5/32 inch in diameter. The oval countersunk heads were sunk below the surface by dimpling the plating around them.

The results of the tests showed that, for the rivet heads investigated, the increase in the friction coefficient of the surface is directly proportional to the height of the rivet head. The order of merit in regard to low resistance is flush countersunk, oval countersunk (whether sunk below the surface or not), brazier, and round.

INTRODUCTION

The use of projecting rivet heads on metal seaplane floats and hulls increases the roughness, and hence the frictional resistance, of the surface. On the other hand, the use of countersunk heads to maintain a smooth surface increases the cost of construction, particularly with thin plating. It is therefore desirable, where the take-off performance is an important consideration, to know the relative hydrodynamic resistance caused by various standard rivet heads at the water speeds to be encountered.

An investigation to obtain this information was made in the N.A.C.A. tank for the Bureau of Aeronautics of the Navy Department. Full-size standard rivet heads for rivets with a shank 5/32 inch in diameter were fitted to planing surfaces and the surfaces were towed at speeds up to 40 miles per hour. The results therefore apply directly to a typical portion of the fully immersed bottom of a hull traveling at these speeds.

THE PLANING SURFACES

Details of the surfaces tested are shown in figures 1, 2, 3, and 4. They were made in the form of duralumin boxes that fitted over a common core of oak so that no attachment screws were necessary on the bottom surface. The core provided the necessary longitudinal stiffness as well as a means of attachment to the towing gear.

In preliminary runs, it was found that the radius formed in breaking over the duralumin sheet was large enough to allow the water to flow around the sides, making the wetted area indeterminate. The fitting of square-edge steel strips for the tests, as shown in figure 4, provided a satisfactory edge for clean planing. The original trailing edge, however, proved satisfactory.

The rivet pattern (fig. 4) consisted of a single longitudinal row on the center line at 2-inch pitch and transverse rows every 10 inches at 1-inch pitch. As seen in the photographs, the duralumin plate was not perfectly flat but the departures from an ideal plane surface were no greater than those found in commercial flat sheet or in actual hulls.

The nominal size of the duralumin rivets in each case was 5/32-inch diameter. The dimensions of each type of head and the model designation of the surface upon which it was tested are shown in figure 4. Model 56-A had a smooth surface equivalent to that given by perfectly flush countersunk heads. Model 56-B represented a type of riveting developed by the Bureau of Aeronautics in which oval countersunk heads are sunk below the surface by using smooth dimples in the plating. The extent of the dimple is about twice the diameter of the head. Model 56-C had the commonly used brazier heads and model 56-D had round heads. The dimensions and form of the heads conform approximately to the standards of the Aluminum Company of America; the commercial tolerances on the dimensions of the heads are as follows:

	Height, in.	Diameter, in.
Oval countersunk	not given	±0.009
Brazier	±0.005	±.020
Round	±.005	±.016

The actual riveting was carefully done so that the heads fitted snugly against the sheet.

METHOD OF TESTING

Each model was towed in the tank as a planing surface in the manner described in reference 1. The resistance of a planing surface includes both wave-making and frictional resistance but, as brought out in reference 2, the frictional resistance becomes an increasingly large part of the total as the angle that the planing surface makes with the water surface decreases. Accordingly, the test runs were made at the lowest practicable trim, which was found from the preliminary runs to be 1-1/2°. The constant speeds for the force measurements ranged from 30 to 60 feet per second and, at these speeds, the surfaces were loaded to give wetted lengths up to 60 inches, so that the Reynolds Numbers ranged from 4×10^6 to 18×10^6.

The windage tare to be deducted from the gross resistance as measured by the dynamometer was obtained by running the smooth model at the trim used in the tests but with the trailing edge 1 inch above the water. Thus, the net resistance includes the interference effects at the intersections of the surface and the water but does not include the remaining air drag of the model and towing gear.

The wetted lengths were read visually at the side of the model on a scale graduated in inches from the trailing edge. The tests of planing surfaces made by Sottorf (reference 3) showed this length to be substantially constant across a flat surface.

RESULTS

Faired curves of the values of net resistance and wetted length obtained from the tests of the surfaces are given in figures 5 to 12. The order of merit of the various arrangements may be found by a comparison of the resistance values given. Since the wetted length is extremely sensitive to change in trim, the difference in wetted lengths may have been partly caused by very small errors in locking the gear controlling the trim for the different set-ups.

The properties of the water during the tests were as follows:

Model	Test date	Water temp., (°F.*)	Specific weight, (lb./cu. ft.)	Kinematic viscosity (ft.^{2} per sec.)
56-A	1-23-35	45.5	63.630	0.0000155
	1-29-35	43.0	63.645	.0000161
56-B	2- 4-35	41.0	63.651	.0000167
56-C	2- 6-35	41.0	63.651	.0000167
56-D	2- 8-35	41.0	63.651	.0000167

*Measured 1 foot from surface.

ANALYSIS

Figure 13, paralleling figure 11(b) of reference 2, shows the forces acting on a flat planing surface when the top and the side edges are free of water and hence under only atmospheric pressure. From the diagram, the friction component parallel to the plate may be found from the measured resistance and load.

Cross plots of resistance and wetted length against load for speeds of 30, 40, 50, and 60 feet per second were made for each model, enabling a further reduction of error in fairing the original data. The resistance and load for wetted lengths of 25, 35, 45, and 55 inches were obtained from these cross plots and the friction component was calculated for each condition. These forces were then converted to the nondimensional friction coefficient

$$C_f = \frac{F}{\frac{\rho}{2} V^2 A}$$

where

F is friction force, lb.

ρ, water density, slugs per cu. ft.

V, speed, f.p.s.

A, wetted area, sq. ft.

Figure 14 shows the calculated values of C_f for the planing surfaces plotted against speed. Values of Zahm's coefficient for a submerged plate in a turbulent flow (reference 4) are plotted for comparison. Zahm's values are calculated from the relation

$$C_f = 0.0745 \, R^{-0.218} + 0.00072$$

where R is the Reynolds Number.

This formula is the equation of a mean curve obtained from extensive friction data judiciously chosen by Schoenherr (reference 5). The coefficients calculated from tests of the smooth planing surface are generally lower than those obtained from the formula. The difference becomes greater at the shorter wetted lengths, indicating that the method used in analyzing the present data does not properly take into account the effect of aspect ratio. The fairly close agreement at the longer wetted lengths, however, establishes the value of the results from tests of planing surfaces for obtaining relative frictional resistance.

Logarithmic plots of the friction force against speed for wetted lengths of 45 and 55 inches (fig. 15) indicate that for all the surfaces the frictional resistance varies approximately as $V^{1.72}$ and that the relative merit shown will extend to the usual get-away speeds for seaplanes. The exponent is slightly lower than that generally found from tests of submerged planes, possibly because the tare resistance obtained by towing the planing surface just clear of the water is too high.

In figure 16, the friction coefficient is plotted against height of rivet head for various speeds and for the two longer wetted lengths. In this figure, the height of the oval countersunk heads is taken as what it would be if the rivets had simply been countersunk and not sunk below the surface by dimpling the plating. The most satisfactory mean lines through all the points are straight and parallel for each wetted length, which indicates that the increase in friction coefficient varies directly as the height of the heads and is independent of the shape of the heads. Moreover, the general agreement with this conclusion shown by the results for the sunken-type heads indicates that the oval countersunk heads will have the same resistance whether or not the plating is dimpled around them as in figure 4. The slope of the lines is slightly greater for the shorter wetted length but appears to be independent of speed in either case.

CONCLUSIONS

1. The increase in the friction coefficient of a surface caused by small rivet heads is directly proportional to the height of the heads above the surface.

2. The order of merit of commonly used heads in regard to low hydrodynamic resistance is: perfectly flush countersunk, oval countersunk, brazier, and round.

3. There is no hydrodynamic advantage in sinking oval countersunk heads below the surface by dimpling the plating in the manner used in the arrangement that was tested.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 7, 1938.

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2. Sottorf, W.: Experiments with Planing Surfaces. T.M. No. 739, N.A.C.A., 1934.

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

4. Zahm, A. F.: Fluid Friction on Smooth Planes. Jour. Aero. Sci., vol. 4, no. 12, Oct. 1937, pp. 504-506.

5. Schoenherr, Karl E.: Resistance of Flat Surfaces Moving through a Fluid. Trans. Soc. Nav. Arch. and Mar. Eng., vol. 40, 1932, pp. 279- .

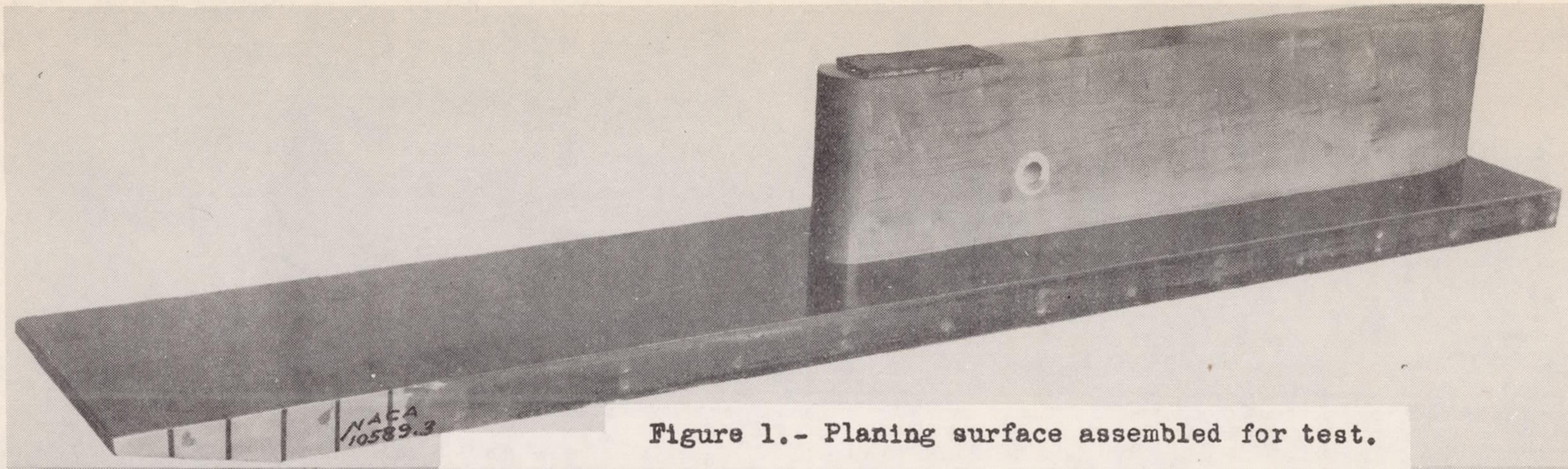


Figure 1.- Planing surface assembled for test.

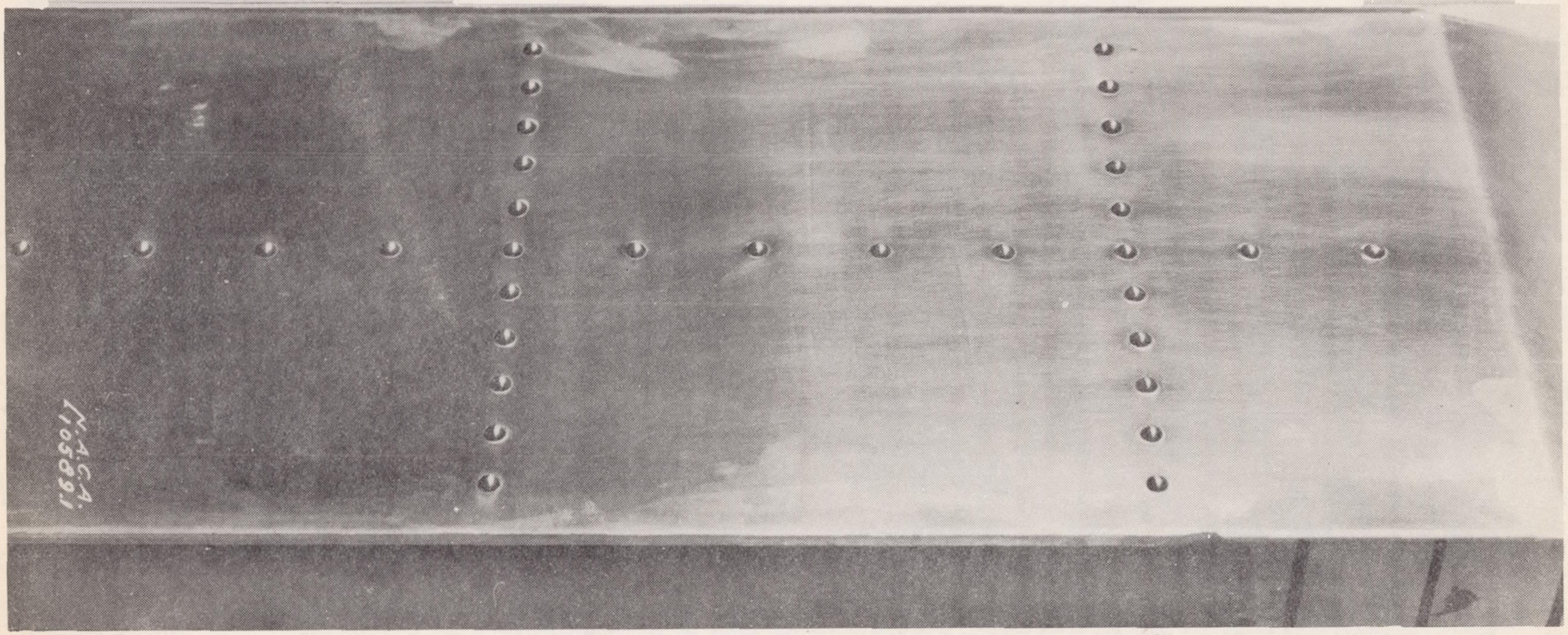


Figure 2.- Detail of planing surface 56-D.

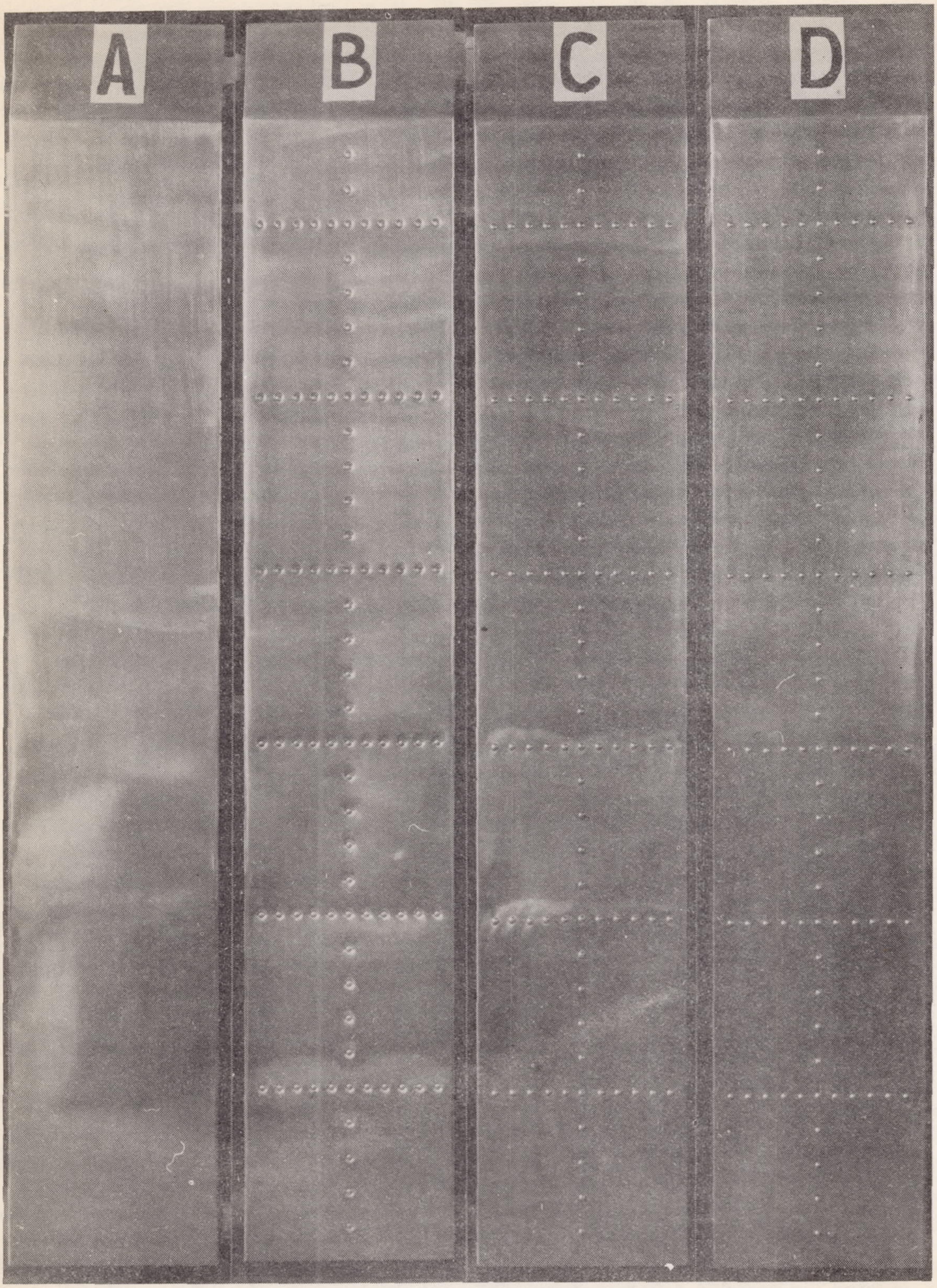
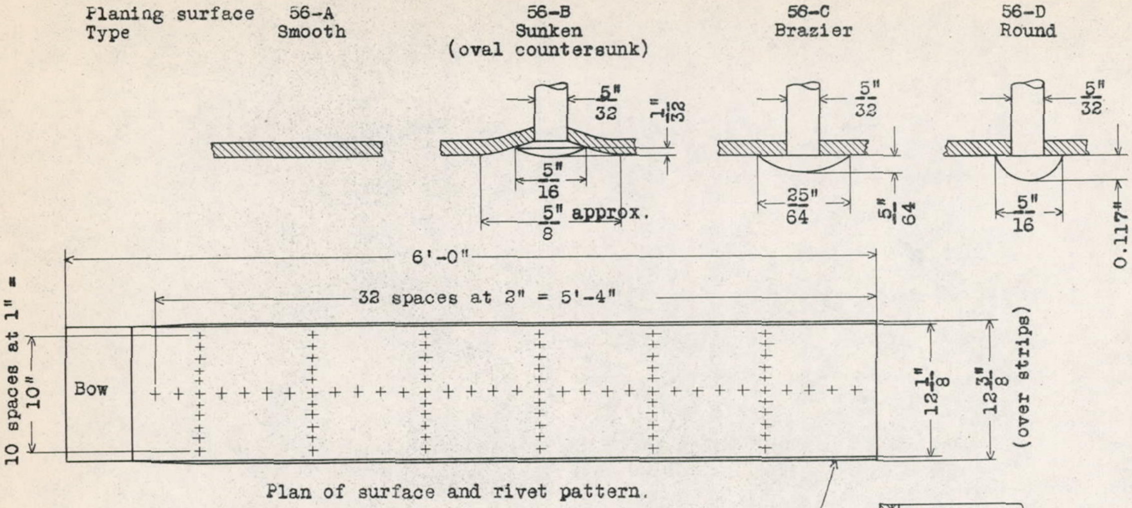


Figure 3.- Planing surfaces tested. Surface 56-D assembled with strips and core.



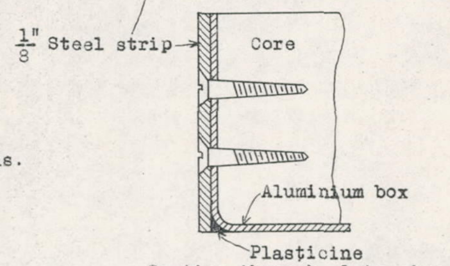


Figure 4.- Details of planing surfaces and rivet heads.

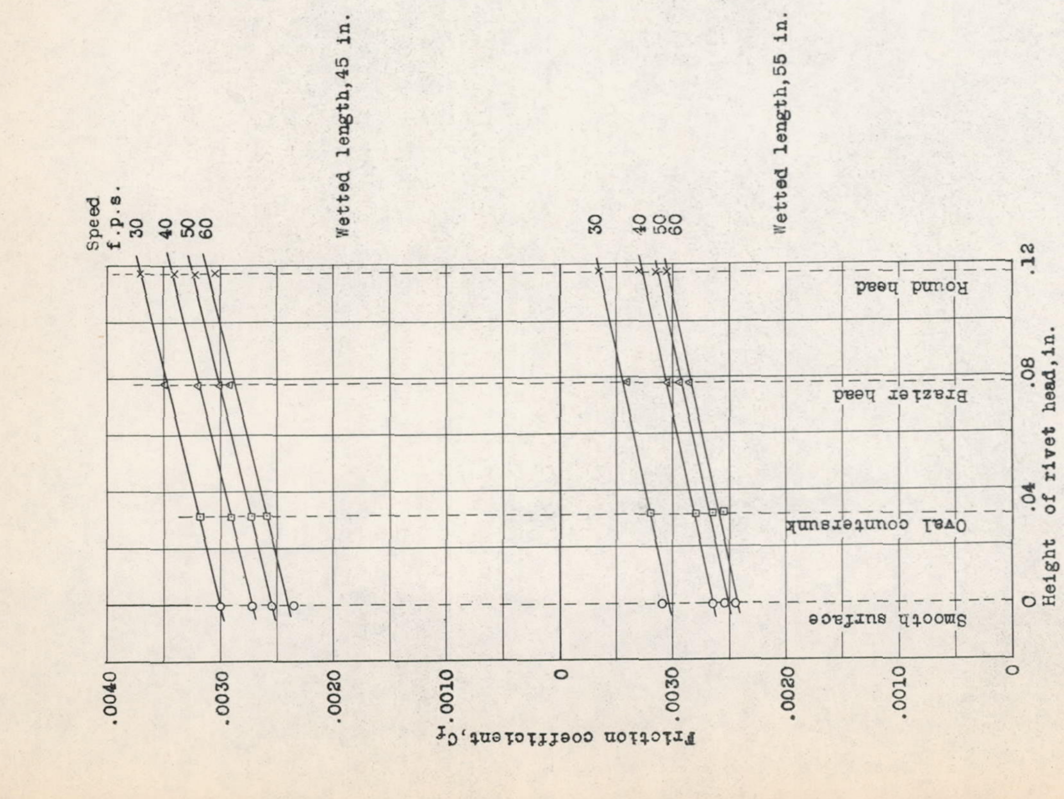


Figure 16.- Variation of friction coefficient with height of rivet head.

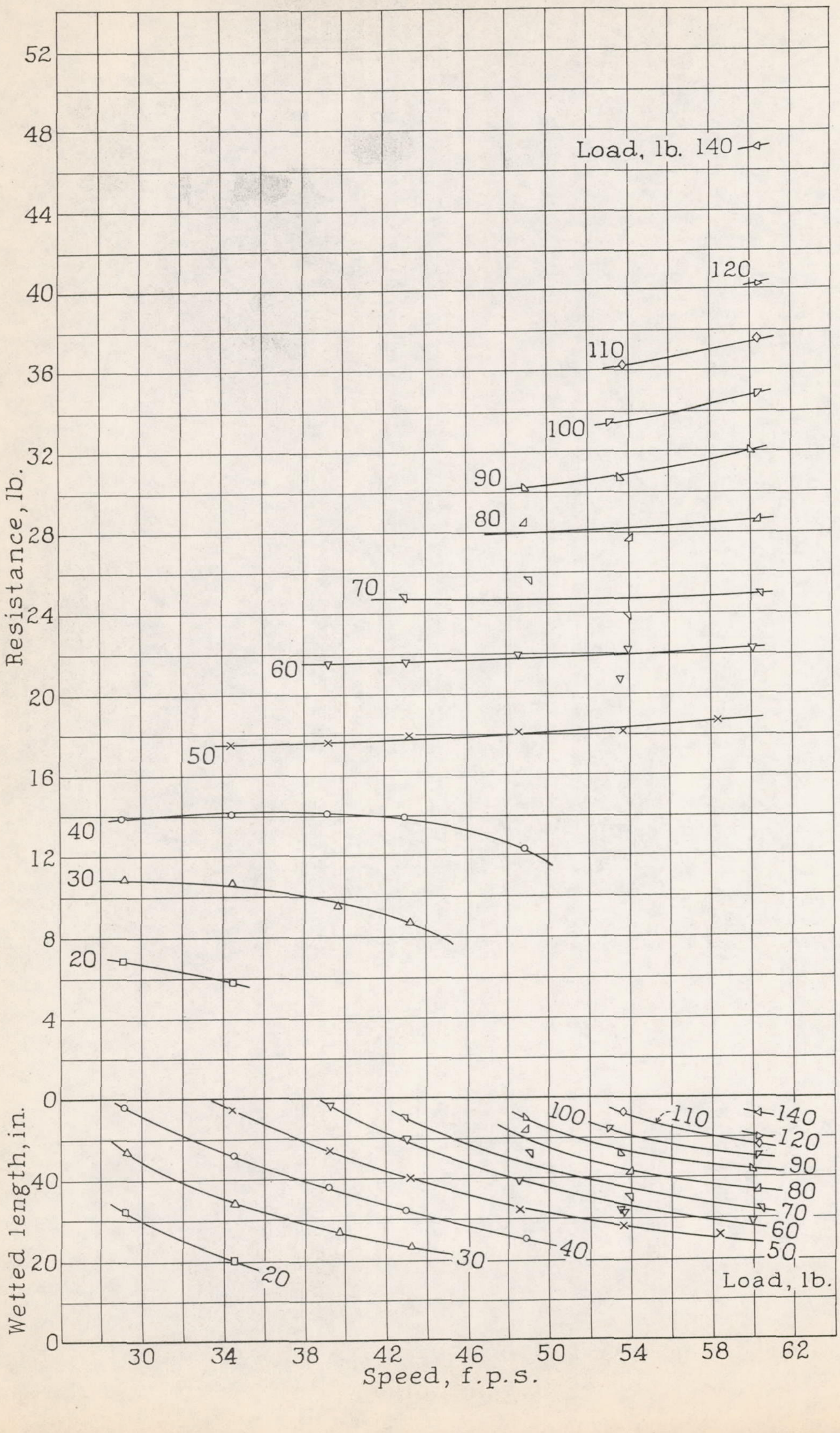


Fig. 5.- Model 56-A. Variation of resistance with speed.

Fig. 6.- Model 56-A. Variation of wetted length with speed.

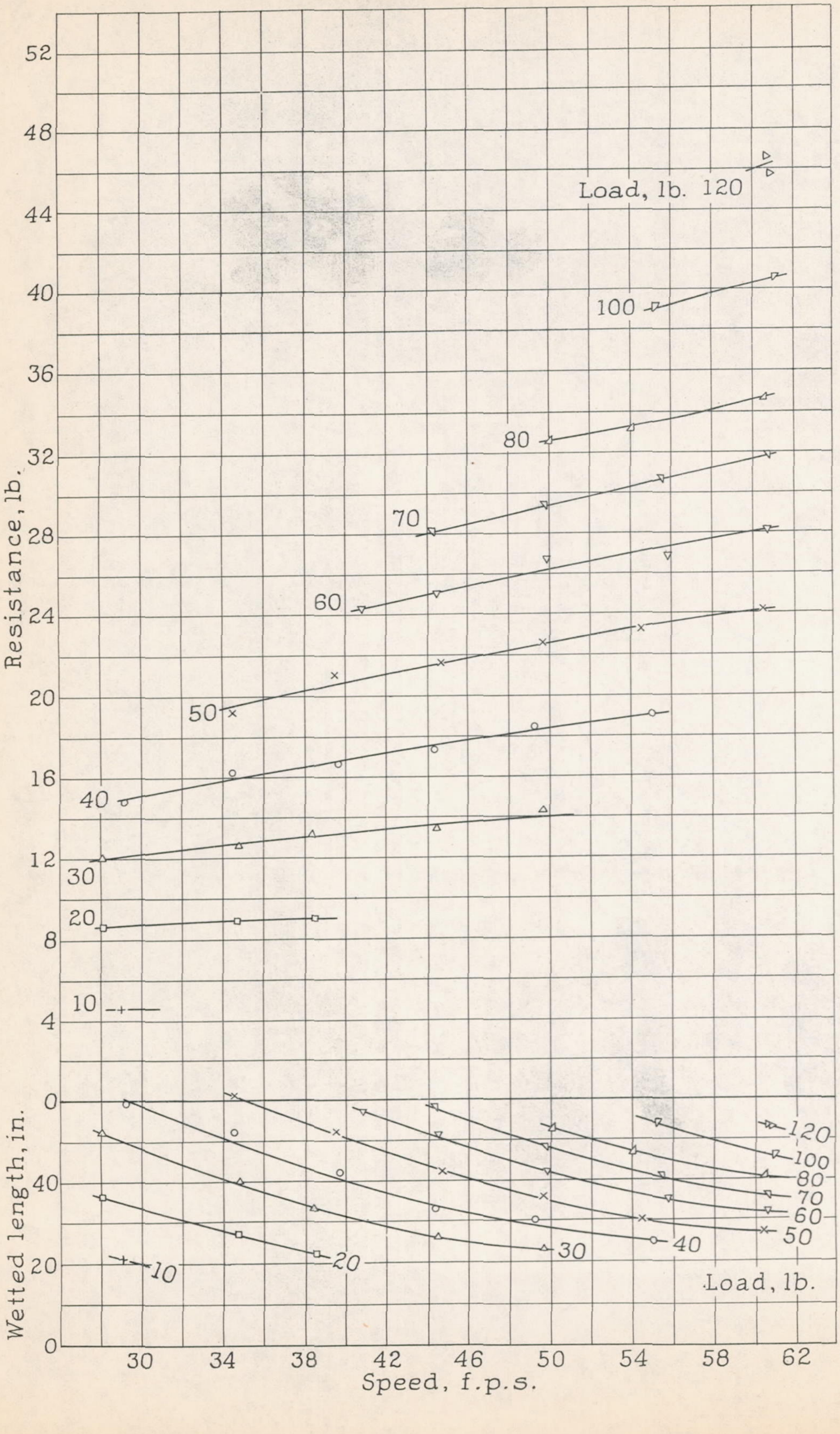


Fig. 7.- Model 56-B. Variation of resistance with speed.

Fig. 8.- Model 56-B. Variation of wetted length with speed.

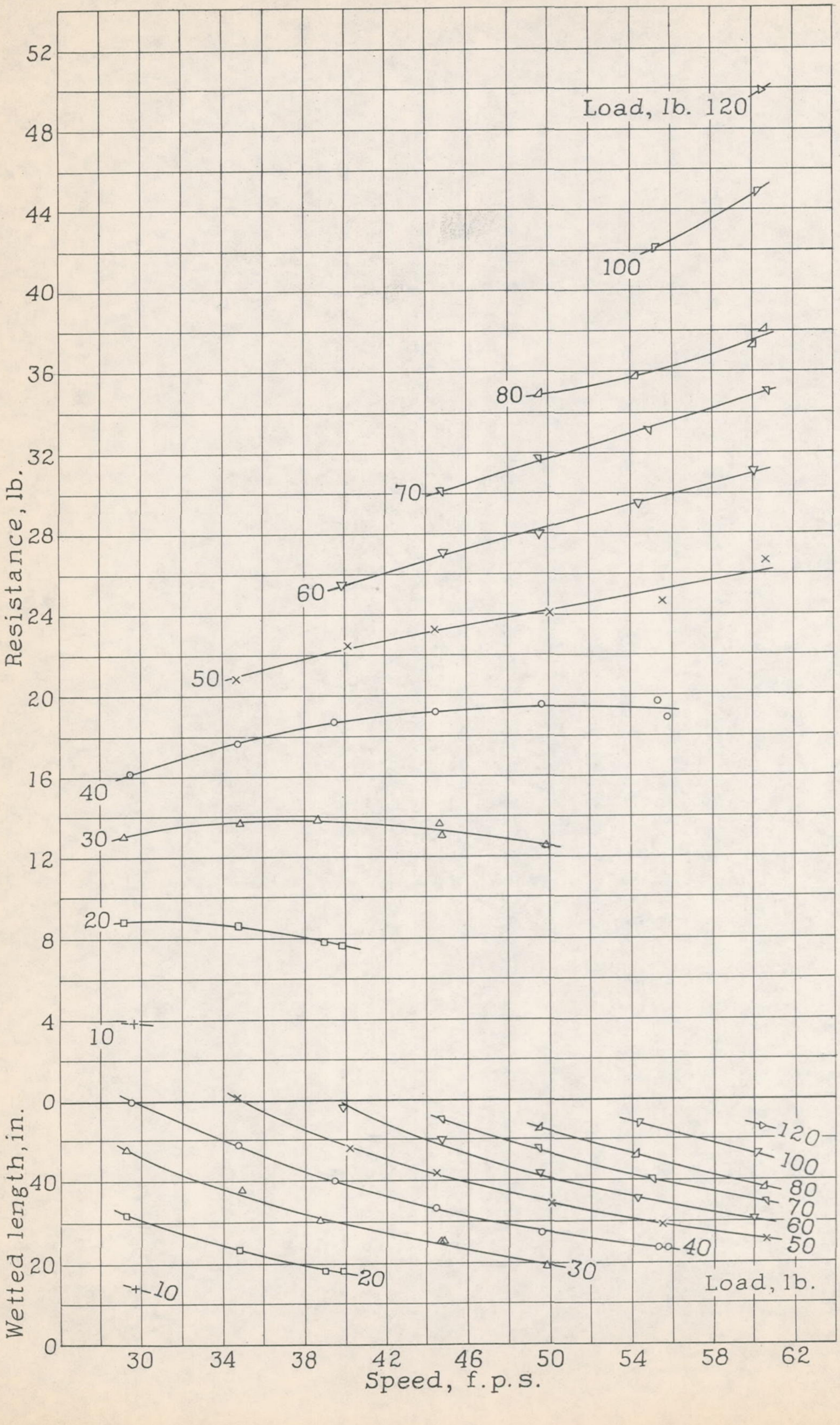


Fig. 9.- Model 56-C. Variation of resistance with speed.

Fig. 10.- Model 56-C. Variation of wetted length with speed.

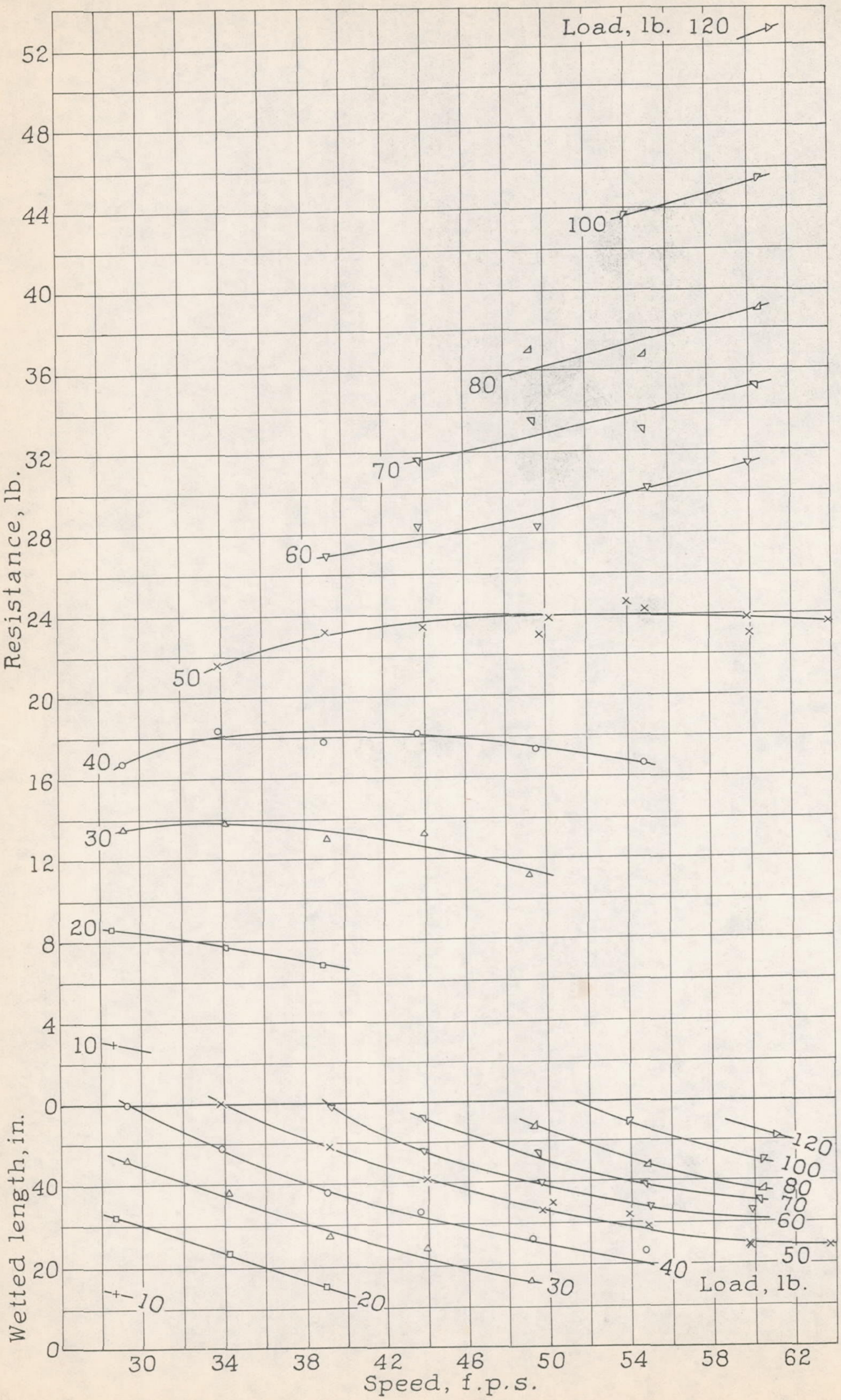


Fig. 11.- Model 56-D. Variation of resistance with speed.

Fig. 12.- Model 56-D. Variation of wetted length with speed.

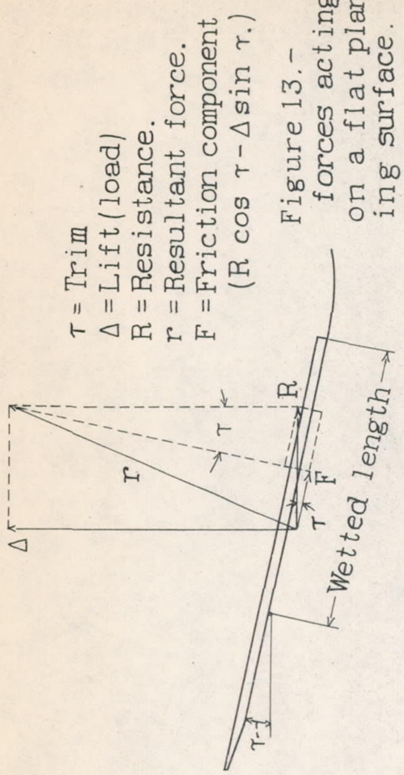


Figure 13.- forces acting on a flat planing surface.

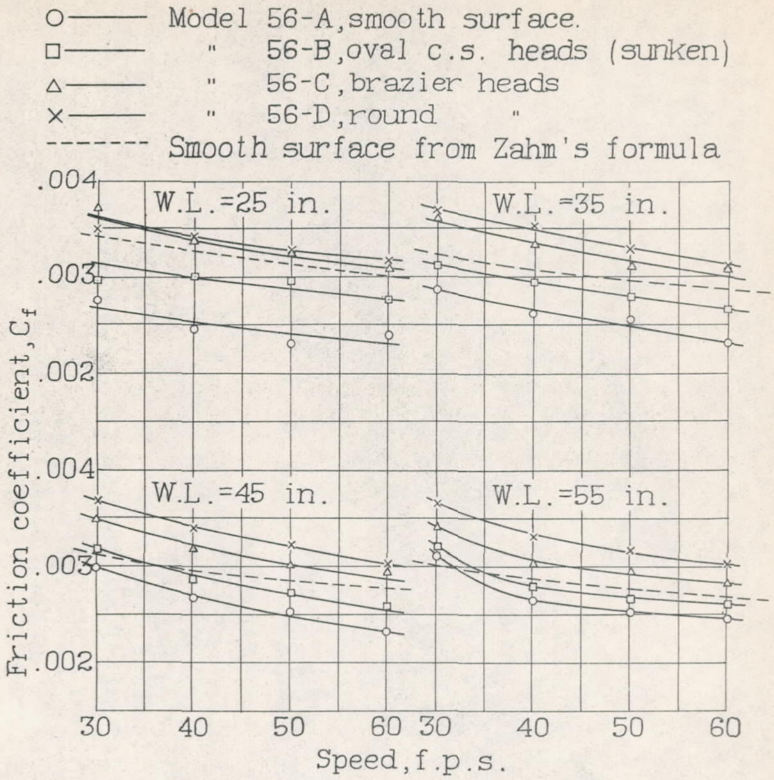


Figure 14.- Variation of friction coefficient with speed.

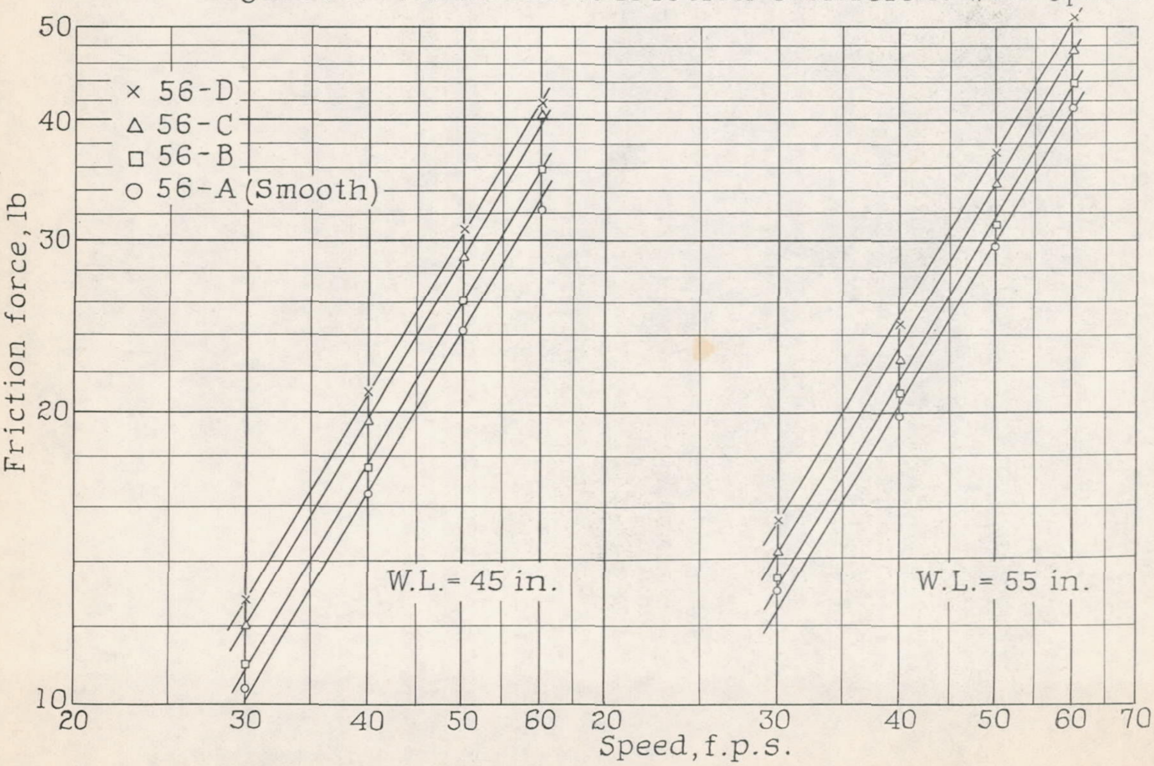


Figure 15.- Variation of friction force with speed