TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 535

THE EFFECT OF DEPTH OF STEP ON THE WATER PERFORMANCE

OF A FLYING-BOAT HULL MODEL

N.A.C.A. MODEL 11-C

By Joe W. Bell
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SUMMARY

N.A.C.A. model 11-C was tested in the N.A.C.A. tank
with four different depths of step to obtain information
as to the effect of the depth of step on the water per-
formance. The depths of step were selected to cover the
practicable range of depths and in each case the included
angle between the forebody and afterbody keels was kept
the same, 6-1/2°.

Small depths of step were found to give lower resist-
ance at speeds below and at the hump speed of the model
and greater depths of step lower resistance at high speeds.
For low resistance throughout the speed range of the model
investigated the most desirable depth of step is from 2.5
to 4.0 percent of the beam. The change of the best trim
angle τ_0 caused by variation of the depth of step was
not appreciable. Increased depths of step caused in-
creases in the maximum positive trimming moments at all
trim angles investigated.

INTRODUCTION

A seaplane hull must serve as both a displacement and
a planing boat. As a displacement boat it must have the
center of buoyancy near the longitudinal position of the
center of gravity of the seaplane; as a planing boat it
must have the center of pressure of the planing surface
near the center of gravity. Satisfactory performance can-
not be obtained from a hull composed of one planing sur-
face because the center of pressure of the surface ap-
proaches the stern as the wetted length decreases at high

speeds and light loads. A seaplane hull should therefore
consist of two or more planing surfaces separated by a
step or steps.

The single-step type of hull was selected for the
present investigation because it is a type widely used in
American practice. In this type of hull the step is lo-
cated a short distance abaft the center of gravity of the
seaplane and the afterbody keel rises several degrees
above the forebody keel projected.

For the purpose of discussing the action of the step,
the take-off run of a seaplane can be divided into three
stages: first, acting as a displacement boat at low
speeds; second, acting as two planing surfaces in the ear-
lier stages of planing; and third, acting as a single plan-
ing surface at speeds near get-away. During the displace-
ment stage a deep step increases turbulence, which adds to
the resistance. In the second, or "two-planing-surface"
stage, the afterbody acts as an additional planing surface
in the disturbed wake of the forebody. The problem of
depth of step becomes complex at this speed since it is de-
sirable to have the afterbody planing at a favorable atti-
tude. In the third stage of the take-off run, when the
lift of the afterbody has become negligible and the fore-
body or main planing surface of the hull is carrying the
load, it is desirable to have either the afterbody clear
of the water or a minimum area of the afterbody surface
touching the water. This condition can be accomplished by
a deep step or a large angle of afterbody keel.

The present investigation consists of tank tests of a
model of a flying-boat hull with the depth of step varied
to cover the practicable range of depths of the step. All
other dimensions of the model were kept at constant values
during the series of tests. A further test program in-
cluding a number of combinations of depth of step and an-
gle of afterbody keel will be started in the near future.

Although the effect of the depth of step is dependent
upon the angle of afterbody keel, the length of the after-
body, and a number of other variables, the present inves-
tigation should be helpful in showing the effect of depth
of step on this particular type of hull.

APPARATUS AND METHODS

The N.A.C.A. tank and associated equipment are discussed in detail in reference 1. The apparatus used in making the present tests was as described except for the change in the method of suspending the towing gear discussed in reference 2.

The present tests were made by the general method discussed in reference 1. The procedure in this case is to tow the model at a series of loads, speeds, and trim angles selected to include the more important combinations of these variables. The resistance, trimming moment, and draft at the step are measured for each test point.

DESCRIPTION OF MODELS

Model 11-C, which has been described in reference 3, was used as the parent model of the series investigated. Model 11-C is a model of a flying-boat hull whose depth of step and other proportions, in general, conform closely to current American practice.

The model was made in two pieces bolted together at the step. It was altered to form the three additional models for this series by moving the afterbody vertically with respect to the forebody. The small discontinuity formed in the deck when making this change was faired in with plasticine to reduce any possible windage effect. The principal lines of the model and the method of changing the depth of the step are shown in figure 1.

The designations of the models of the series were as follows:

Model	Depth of step, inch	Depth of step, percent beam
11-C-11	1/8	0.74
11-C-12	5/16	1.84
11-C	9/16	3.31
11-C-13	1	5.88

RESULTS

Test data.- The resistance, speed, trim angle, and trimming moment for each test point were determined directly from the test data by deducting the usual tares. Curves of resistance and trimming moment for each load condition plotted against speed at each trim angle investigated are shown for the four models tested in figures 2 to 25.

Nondimensional results.- The number of variables involved in the test data make the comparison of models or the application of test data to design difficult. The method used for reducing the number of variables is discussed in reference 4. The procedure consists of determining the minimum resistance and best trim angle for each speed and load by plotting resistance against trim angle at each of a series of representative speeds with load on the water as the parameter. Curves of minimum resistance for each speed are then plotted against load. The results are plotted as curves of resistance coefficient at best trim angle against speed coefficient, with load coefficient as the parameter.

The nondimensional coefficients are defined as follows:

Load coefficient $\qquad C_\Delta = \dfrac{\Delta}{wb^3}$

Resistance coefficient $\qquad C_R = \dfrac{R}{wb^3}$

Speed coefficient $\qquad C_V = \dfrac{V}{\sqrt{gb}}$

Trimming-moment coefficient $\quad C_M = \dfrac{M}{wb^4}$

where Δ is the load on the water, lb.

  R,   resistance, lb.

  M,   trimming moment, lb./ft.

  w,   specific weight of water, lb./cu.ft.

  b,   beam of the hull, ft.

V,   speed, ft./sec.

g,   acceleration of gravity, ft./sec.

Note: w = 63.5 lb./cu.ft. for water in the N.A.C.A. tank
at the time of making the tests.

The nondimensional resistance data are given in fig-
ures 26, 27, 28, and 29 for models 11-C-11, 11-C-12, 11-C,
and 11-C-13, respectively.

Precision.- The test results shown in the faired
curves are believed to be accurate within the following
limits:

Load on the water . . . . ±0.3 lb.

Resistance . . . . ±0.2 lb.

Speed . . . . ±0.1 ft./sec.

Trim angle . . . . ±0.1°

Trimming moment . . . . ±1 lb. ft.

DISCUSSION

The effect of the depth of step on the load-resistance
ratio of the model at four representative speeds is shown
in figure 30. In the family of curves corresponding to
speed coefficient of 2.0 it may be seen that the shallow
step gives the highest Δ/R and that each increase of
depth of step causes a reduction in the Δ/R. The curves
corresponding to hump speed show the same trend but do not
show as great a change in Δ/R as the curves for a speed
coefficient of 2.0. This variance may be explained in
part by the fact that the action of the model at hump
speed is a combination of displacement and planing and
that the step is not causing as much turbulence as at the
lower speed.

At a speed coefficient of 4.5, the model is planing
and the effect of the step has changed from increasing the
resistance to decreasing the resistance. It will be noted
that the deeper steps give higher values of Δ/R at this
speed. The complete reversal of the order of the curves

has been brought about by the change in the action of the
step. At the speed coefficient of 6.0, corresponding to a
speed near get-away for possible applications of this hull,
the curves for various depths of step have retained the
same order as at the 4.5 speed coefficient but show a
greater change in Δ/R than at the lower speed. At this
high speed the advantage of the deeper step lies in the
fact that it keeps more of the afterbody clear of the wa-
ter.

In figure 31 the load-resistance ratio at representa-
tive speeds is plotted against the depth of step with the
load on the water as the parameter. It will be noted that
a minimum depth of step is desirable at and below hump
speed; whereas the most desirable depth of step is about 6
percent of the beam at higher speeds. A depth of step of
about 6 percent of the beam is sufficient to keep the af-
terbody clear of the water at high speeds, therefore a
deeper step would only increase the clearance of the after-
body and cause no change in the high-speed resistance.
When all speeds are considered, the depth of step that
gives the highest average Δ/R seems to lie between 2.5
and 4.0 percent of the beam.

A comparison of the Δ/R of the four depths of step
considered for approximate take-off conditions of a pos-
sible application is given graphically in figure 32. The
load on the water for this comparison was approximated by
assuming the wing lift to vary as the square of the speed
without making allowance for changes of the angle of at-
tack. This figure indicates that the model having a depth
of step of 3.31 percent of the beam will take off in less
time and distance than any of the three other models inves-
tigated.

Figure 33 shows the effect of the depth of step on
the best trim angle at hump speed and at a speed near the
get-away speed of possible applications. The best trim
angle increases slightly with the depth of step but this
difference in best trim angle is not great at any speed.

The effect of the depth of step on the trimming mo-
ments of the model is shown in figure 34 by curves of max-
imum positive trimming-moment coefficient plotted against
load coefficient for each depth of step at four trim an-
gles. It is noted that moments increase in the positive
direction as the depth of step is increased.

CONCLUSIONS

Quantitative predictions cannot be made from this investigation because of the number of variables influencing the effect of the depth of step. The following conclusions, however, are thought to be true for models of the type investigated.

1. The depth of step of a seaplane hull does not have a critical value but can be varied through a limited range without a great effect on performance. This range was from 2.5 to 4.0 percent of the beam for the model tested.

2. At speeds below and at the hump speed a small depth of step is desirable for low resistance.

3. At high speeds, the water resistance decreases as the depth of step is increased up to a certain depth beyond which no further reduction is obtained. This depth is about 6 percent of the beam for the model investigated in the present program.

4. The depth of step may be fixed arbitrarily to reduce the resistance of a hull at the speed where the most difficulty is encountered.

5. Reduction of depth of step can be considered as a possible method for reducing air drag in flight at the expense of water performance.

Langley Memorial Aeronautical Laboratory,
    National Advisory Committee for Aeronautics,
        Langley Field, Va., June 7, 1935.

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1. 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.

2. Shoemaker, James M.: Tank Tests of Flat and V-Bottom Planing Surfaces. T.N. No. 509, N.A.C.A., 1934.

3. 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.

4. Shoemaker, James M., and Parkinson, John B.: A Complete Tank Test of a Model of a Flying-Boat Hull - N.A.C.A. Model No. 11. T.N. No. 464, N.A.C.A., 1933.

Fig. 1
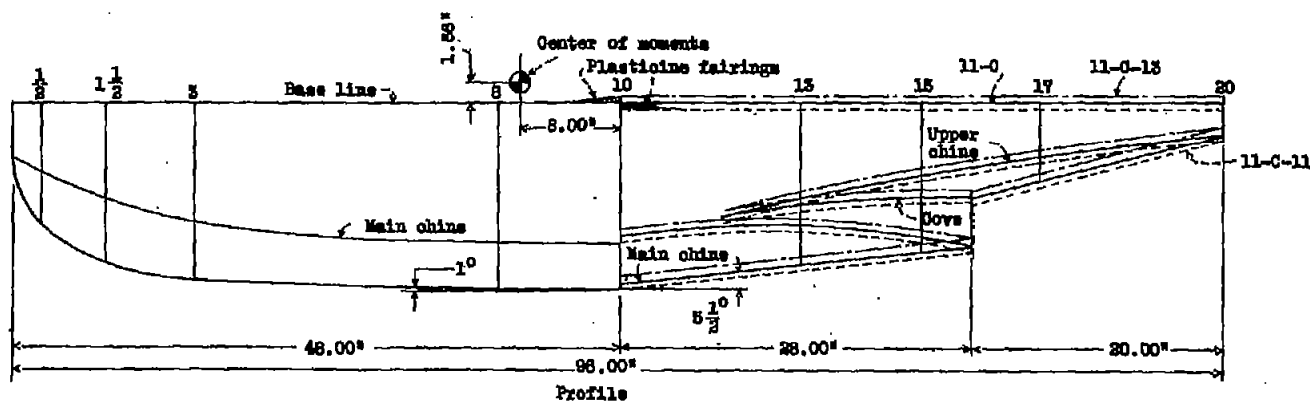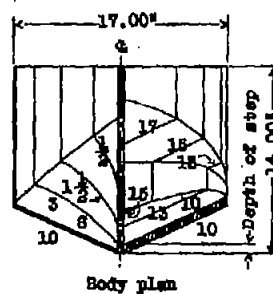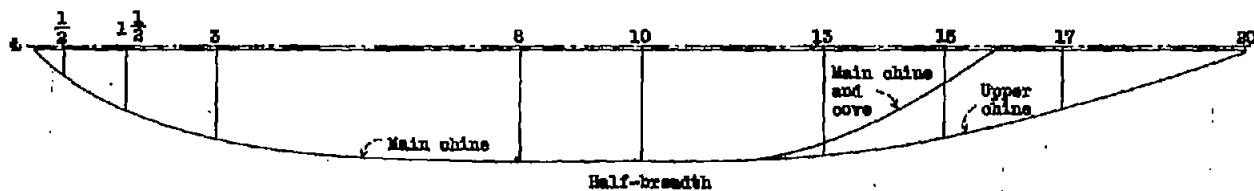
Figure 1.—Model 11-C showing method of changing depth of step.
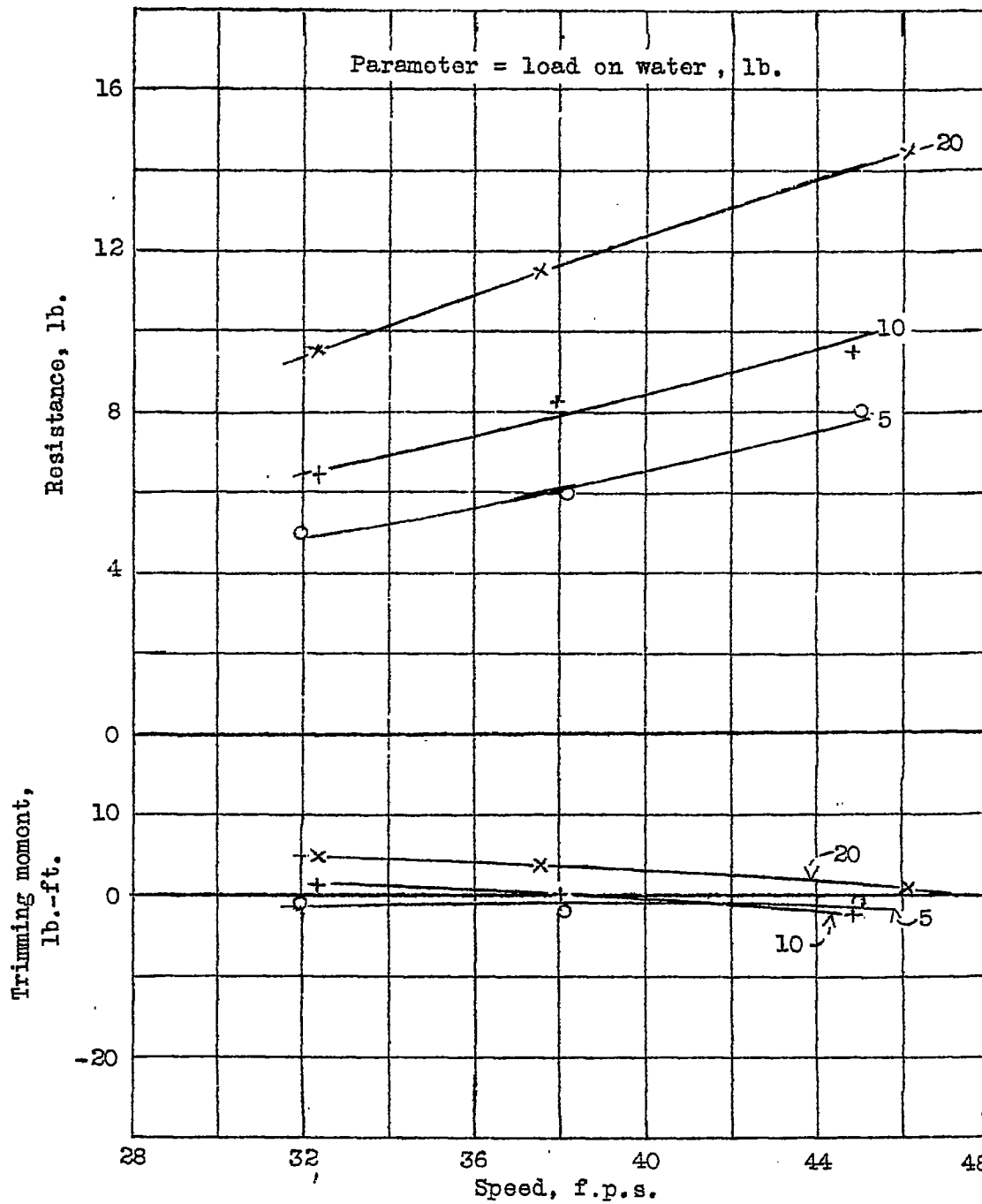
Figure 2.-Resistance and trimming momont, $\tau = 2^0$.Model 11-C-11.

FIG. 3
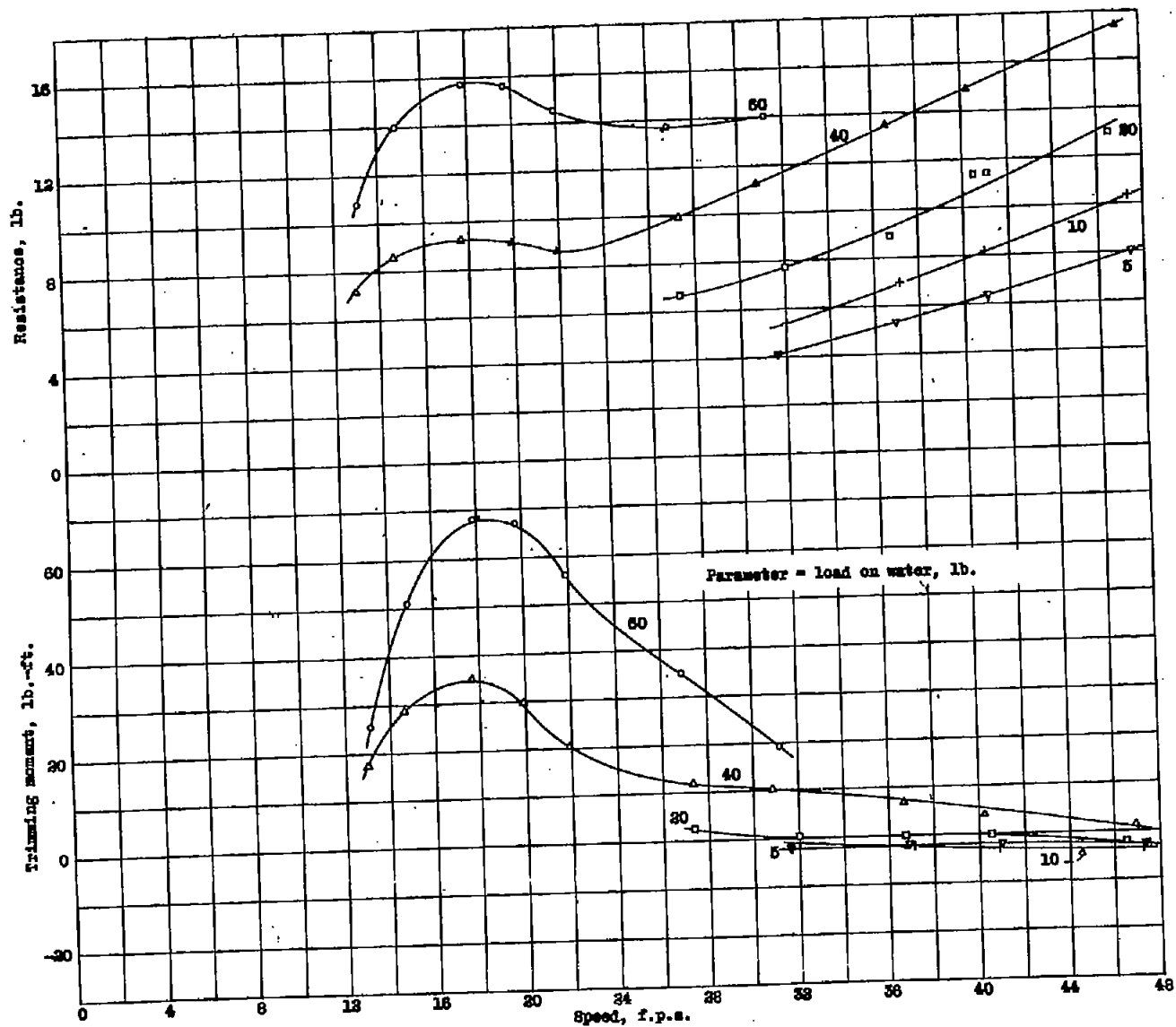
Figure 3.-Resistance and trimming moment, τ = 3°. Model 11-0-11.

Fig. 4
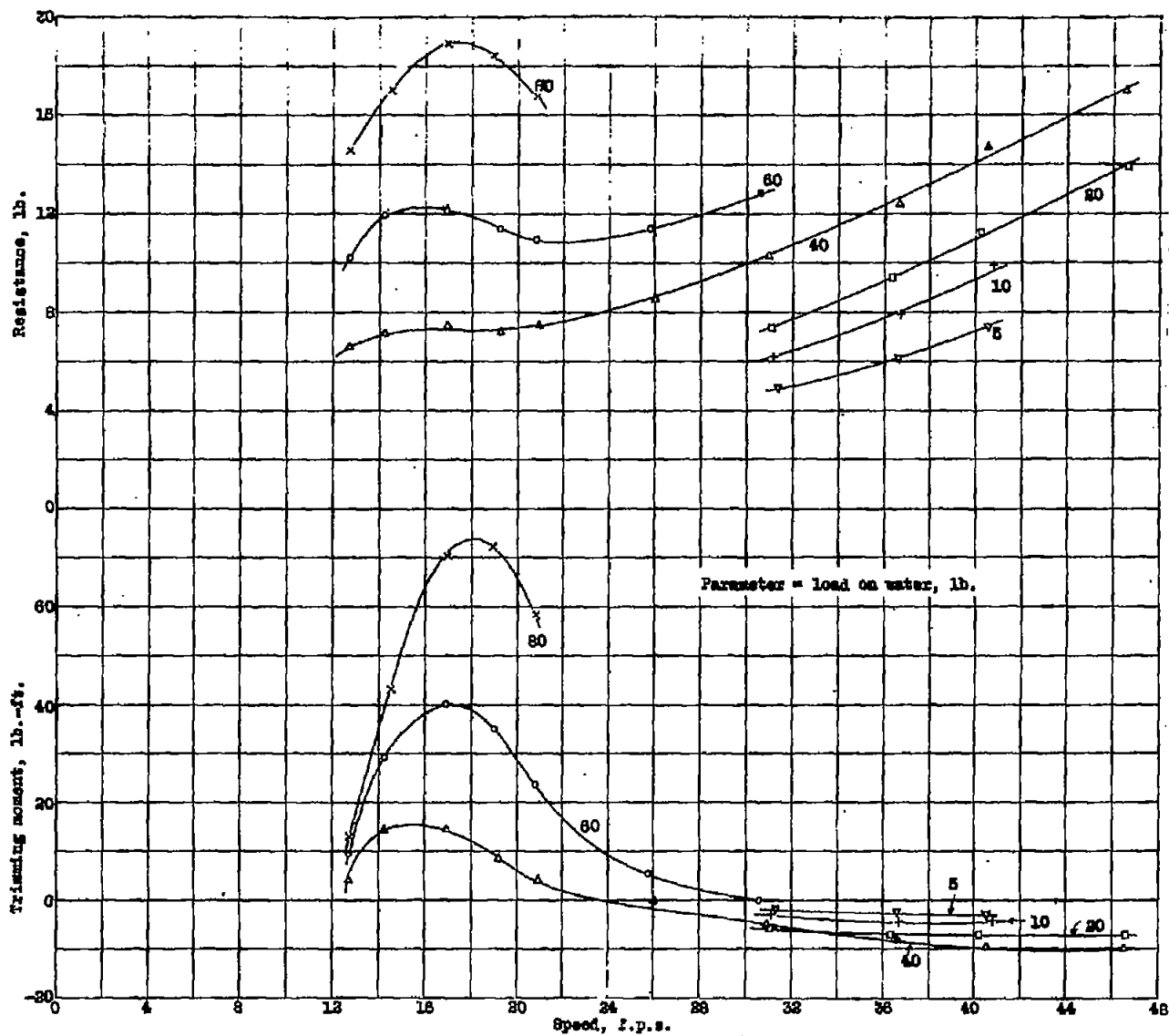
Figure 4.-Resistance and trimming moment, $\tau = 5°$. Model 11-C-11.

Fig. 5
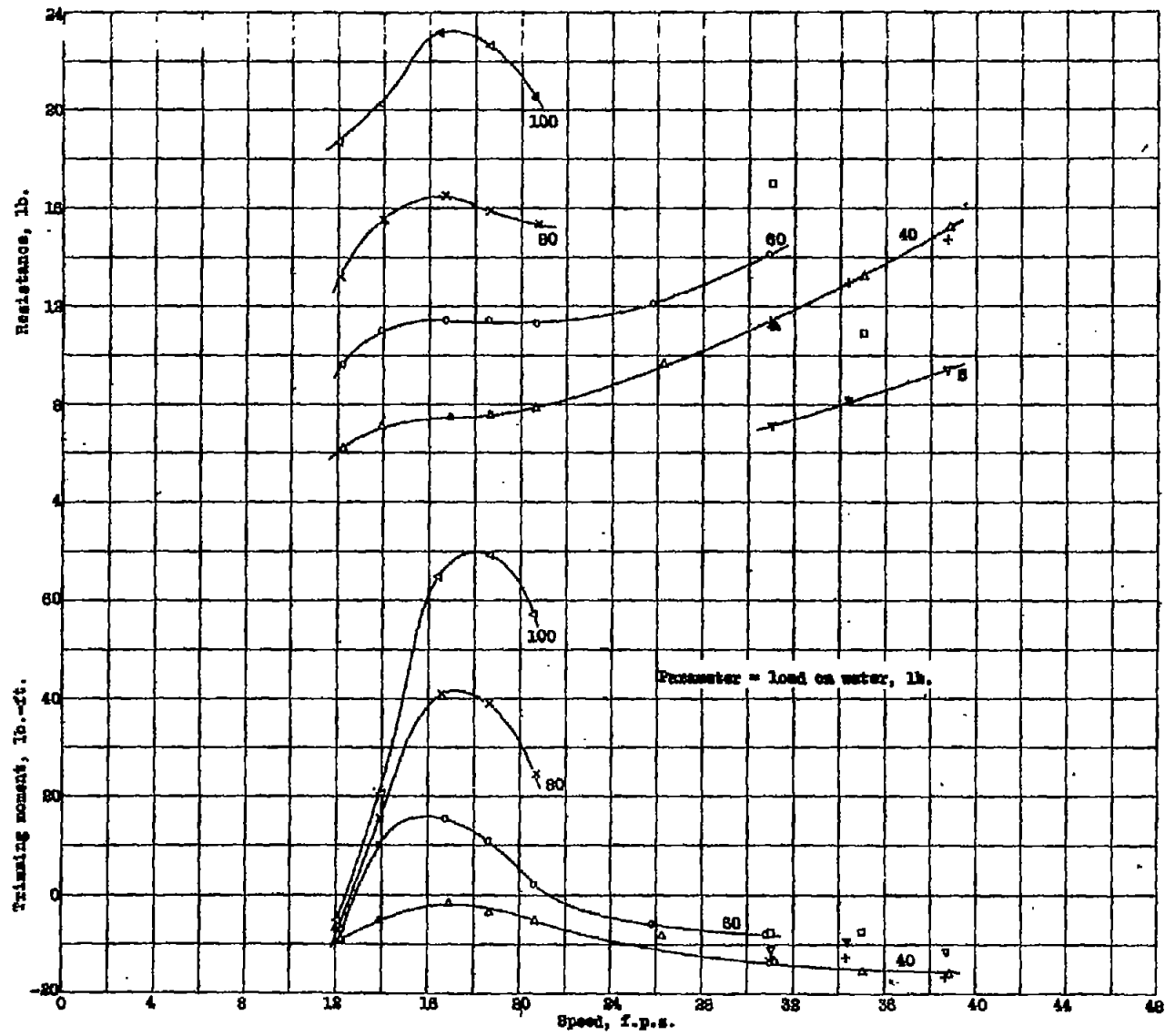
Figure 5.–Resistance and trimming moment, $\tau = 7^0$. Model 11-C-11.

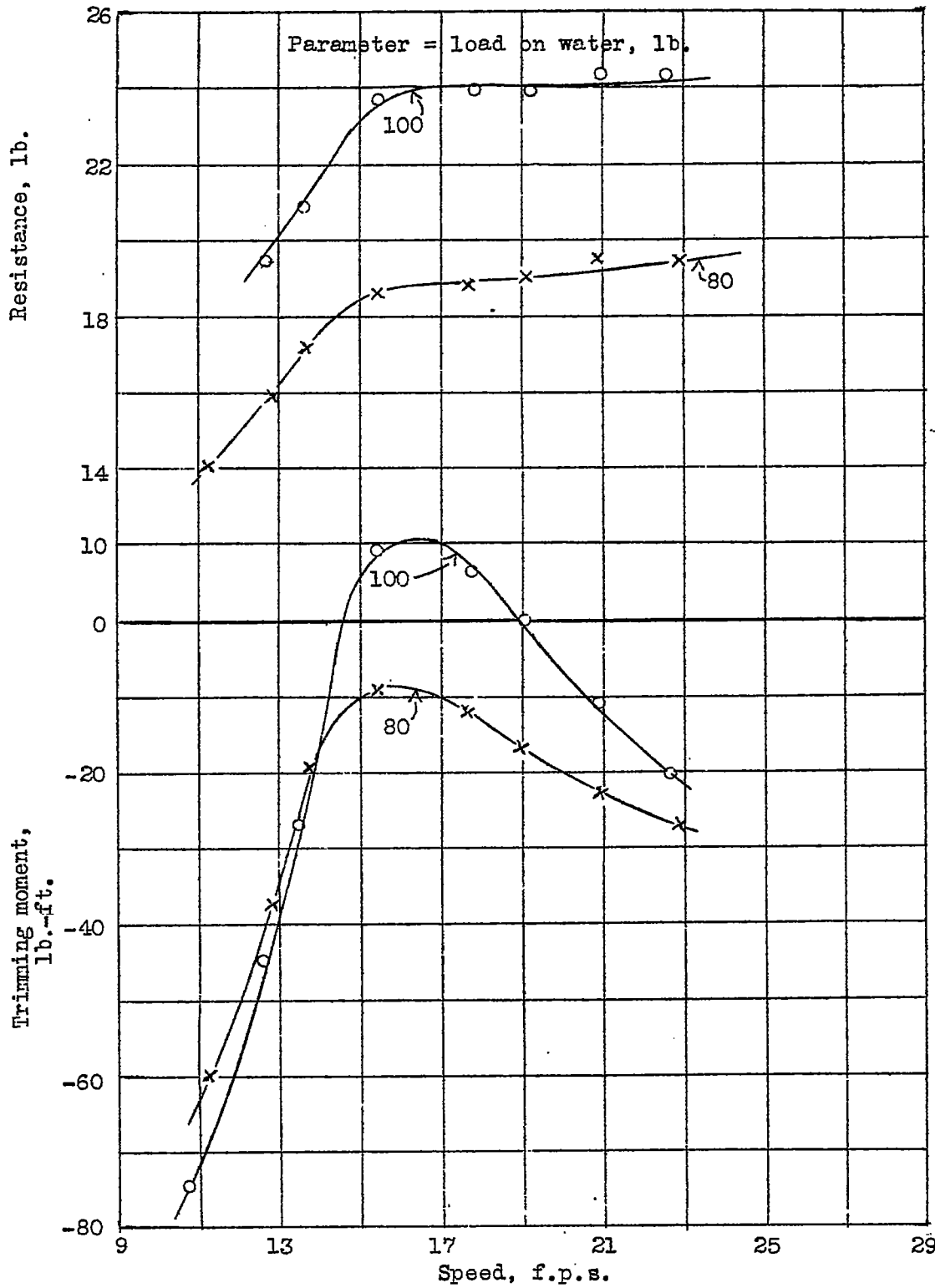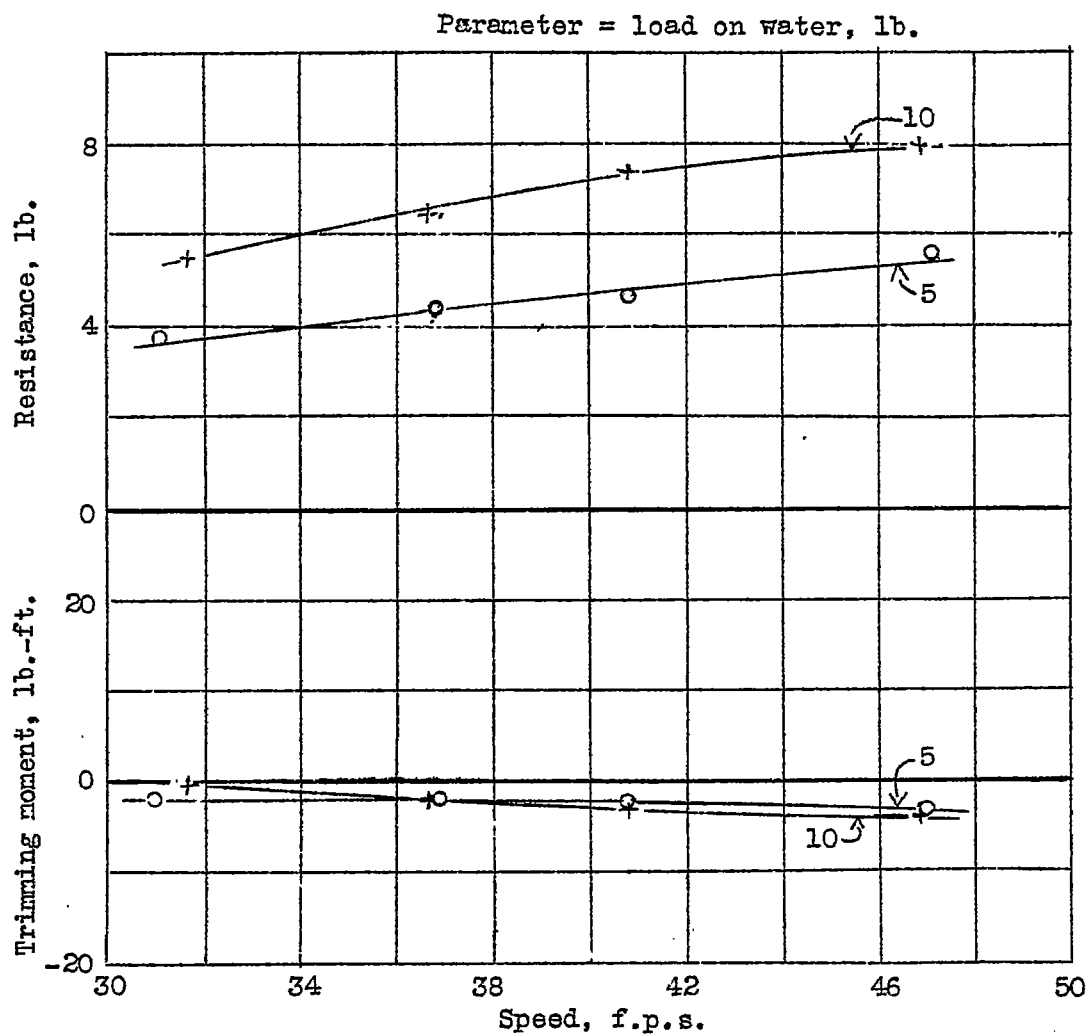Figure 6.- Resistance and trimming moment, $\tau = 9°$. Model 11-C-11.
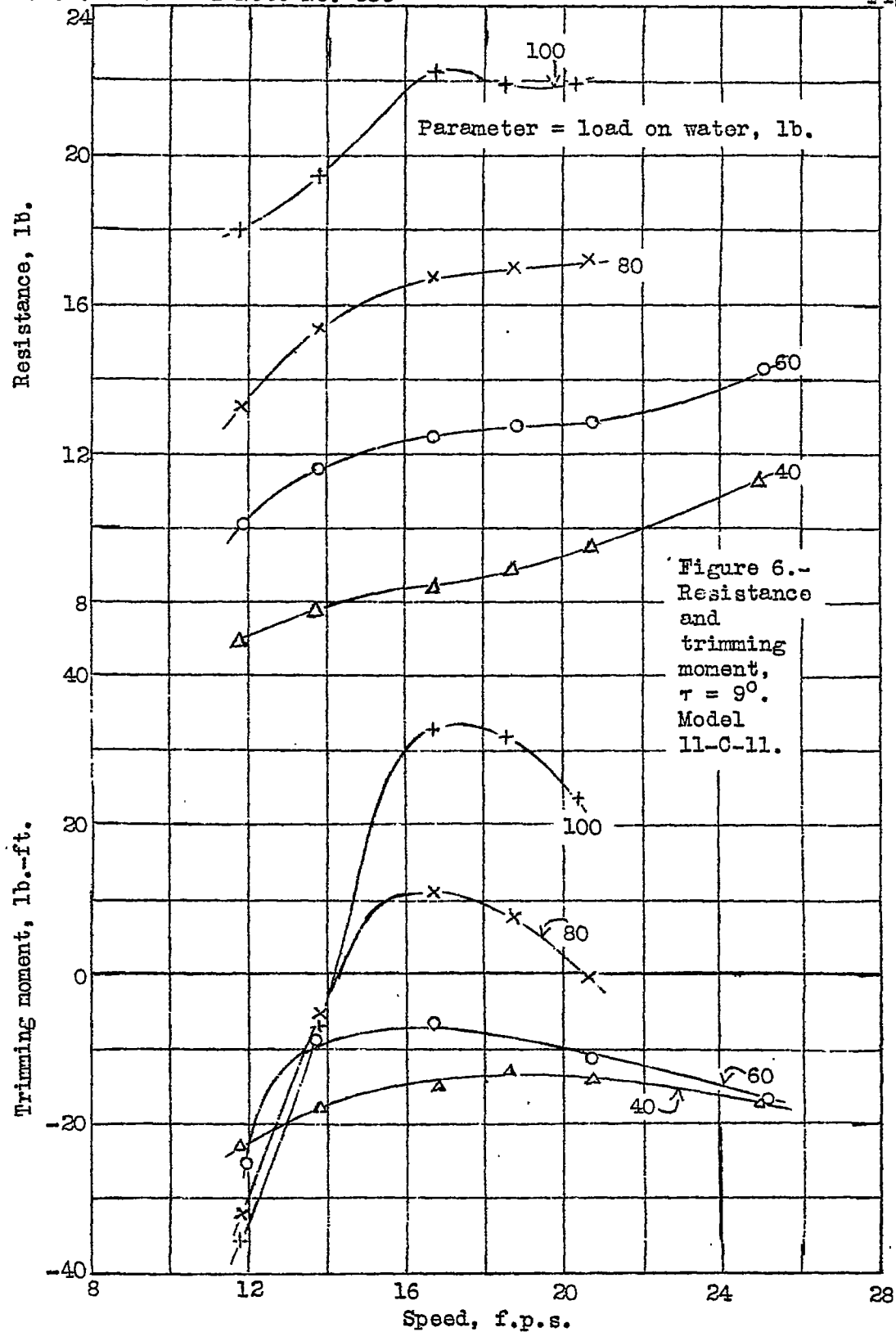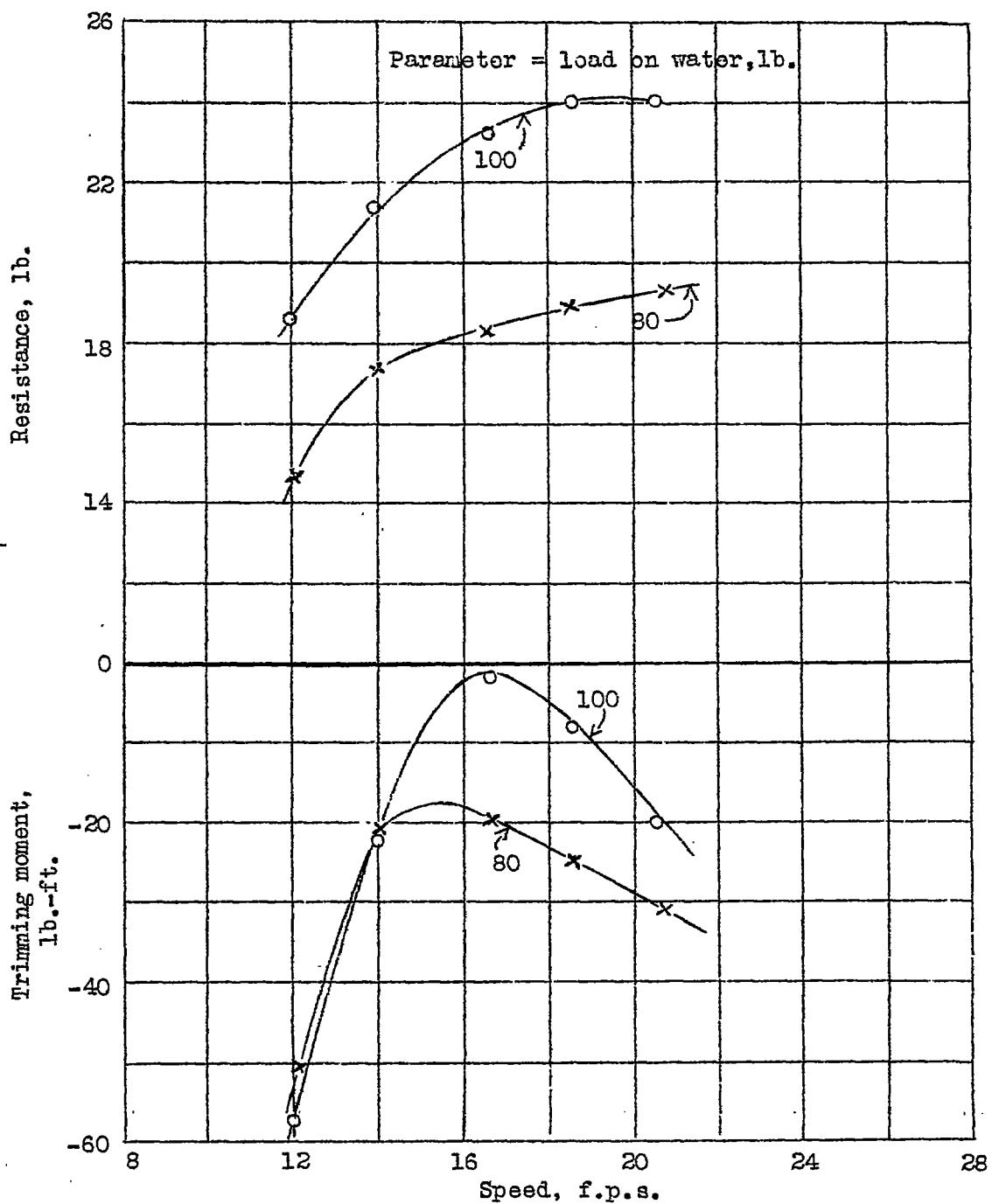
Figure 7.-Resistance and trimming moment, $\tau = 11°$. Model 11-C-11.
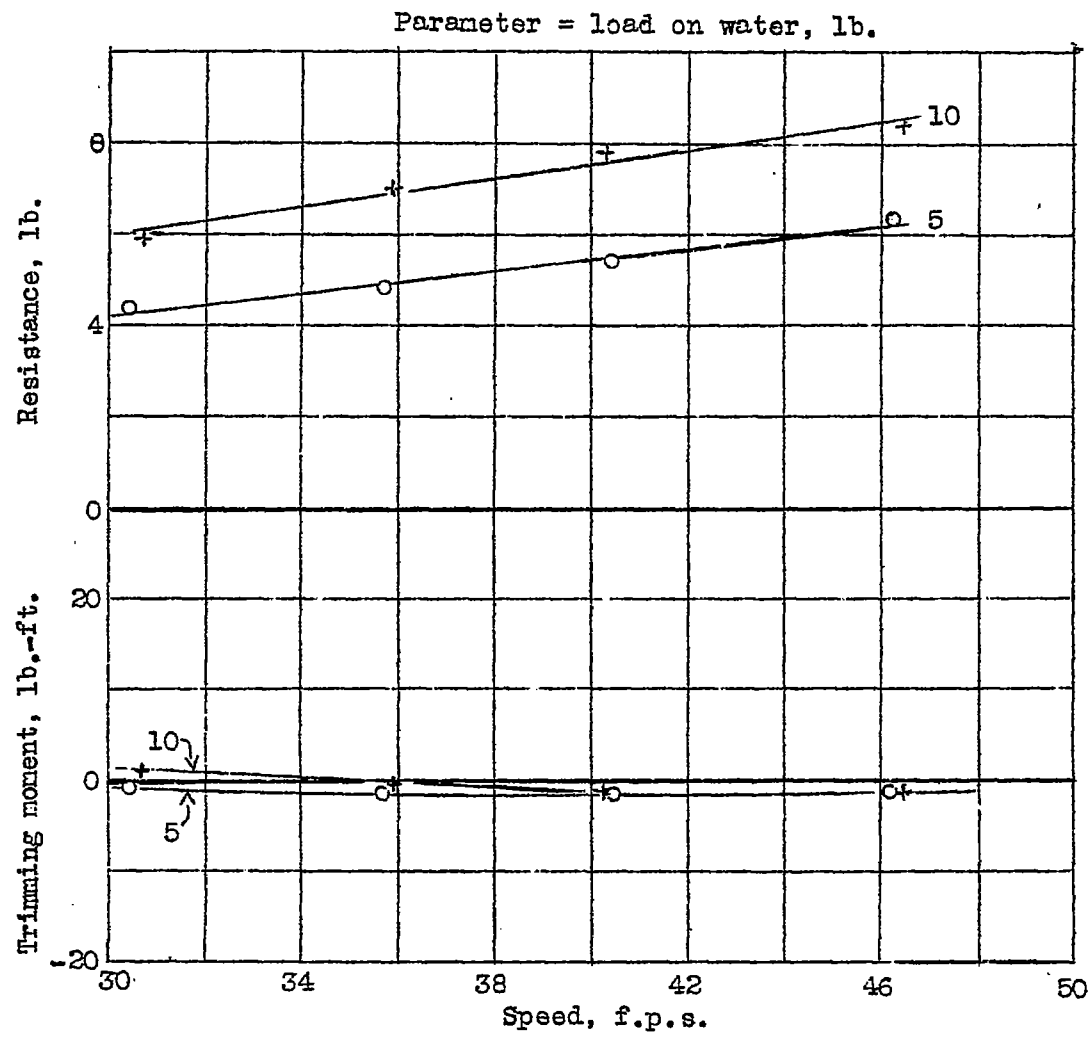
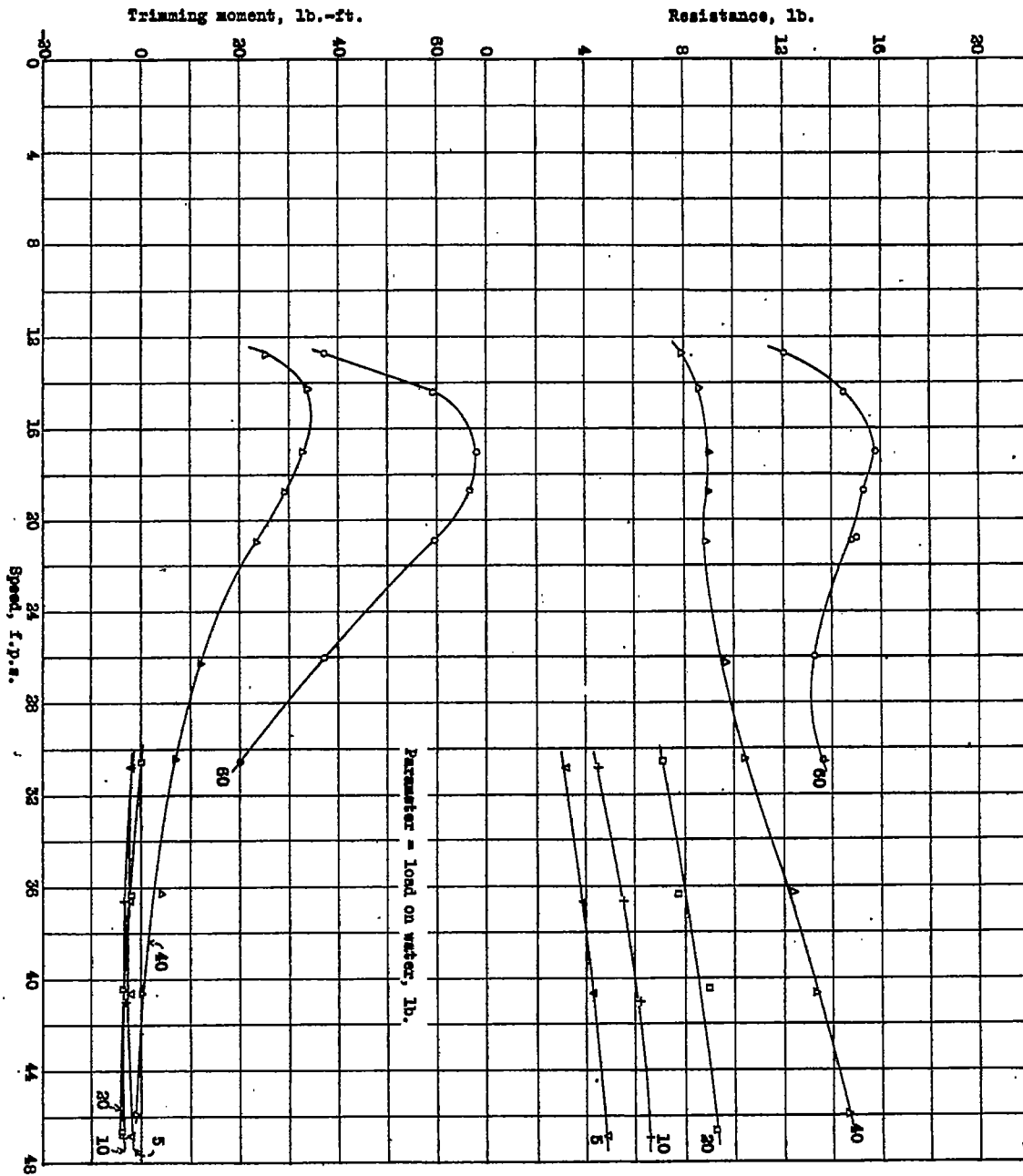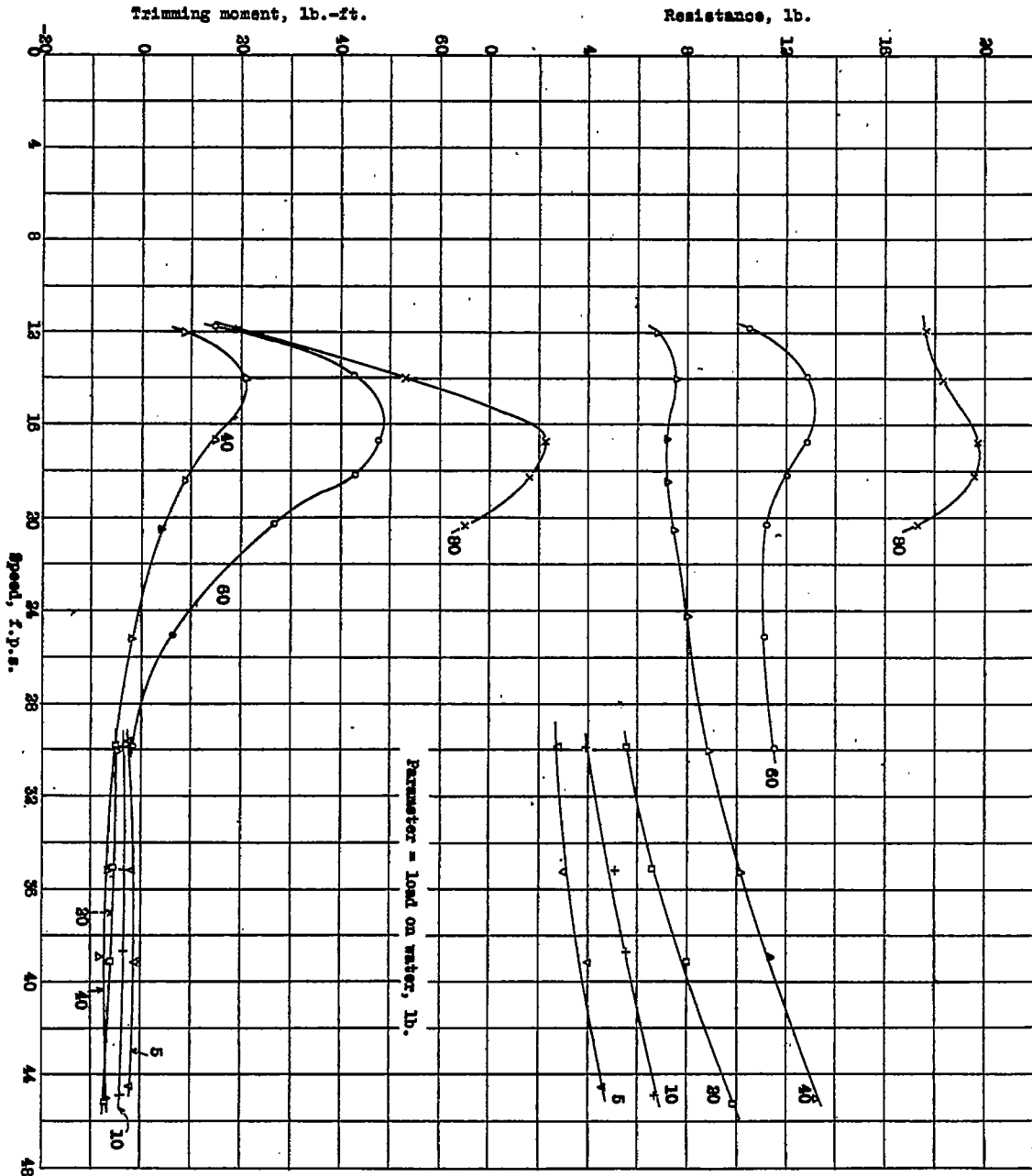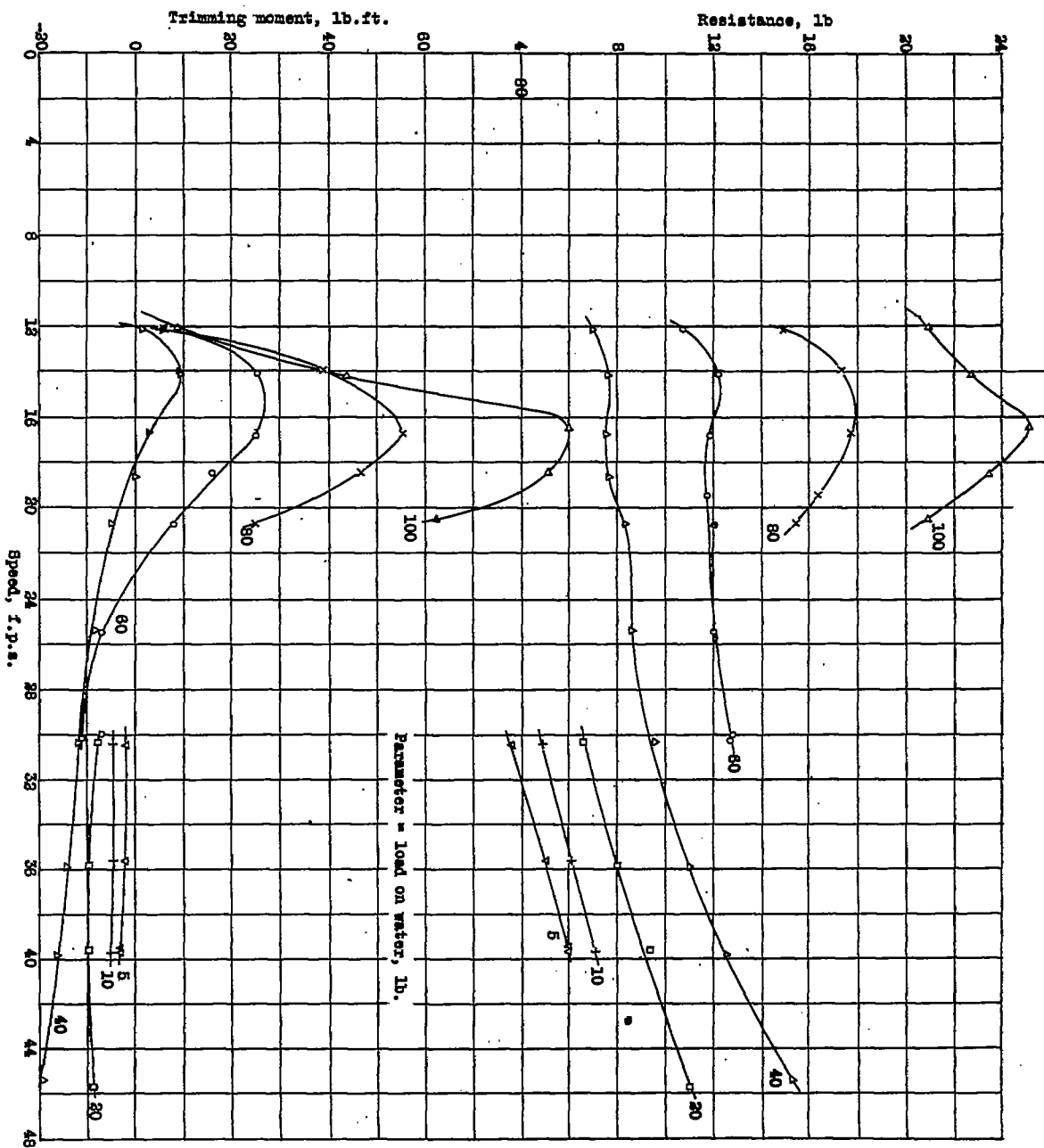Figure 8.-Resistance and trimming moment, $\tau = 2°$. Model 11-C-12.

Fig. 9
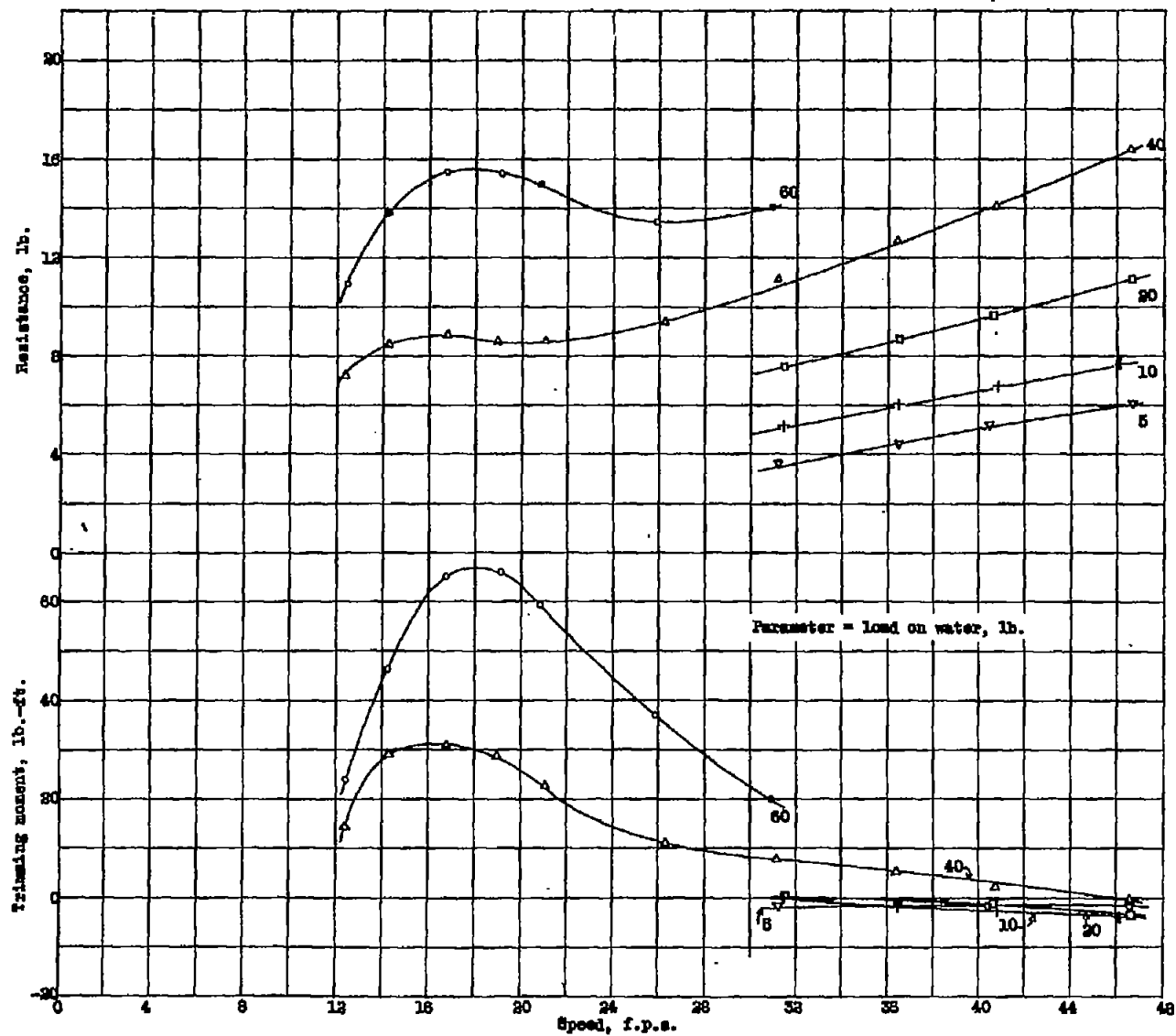
Figure 9.—Resistance and trimming moment, $\tau = 3°$. Model 11-C-12.

Fig. 10

Figure 10.-Resistance and trimming moment, $\tau = 5^0$. Model 11-C-12.
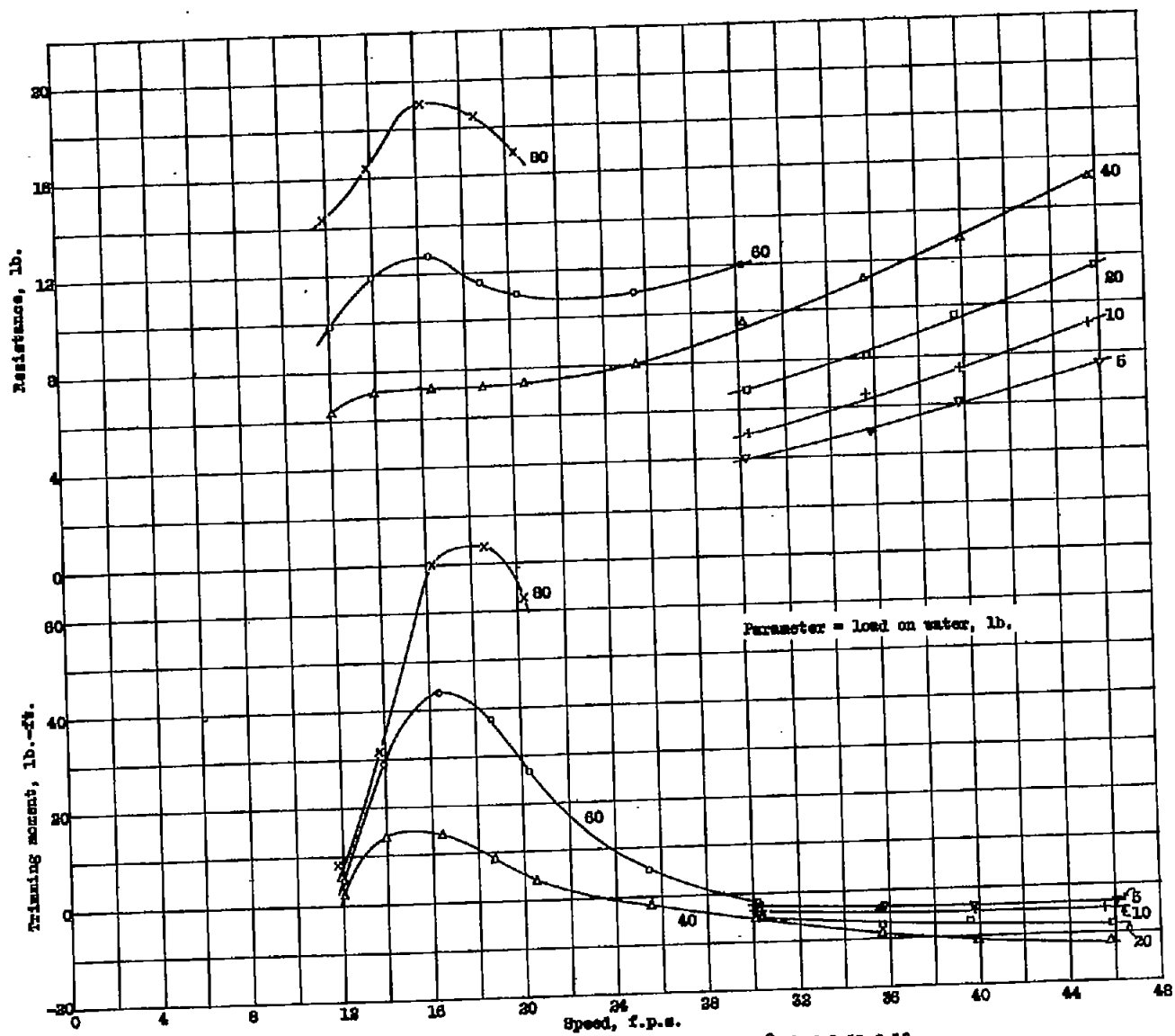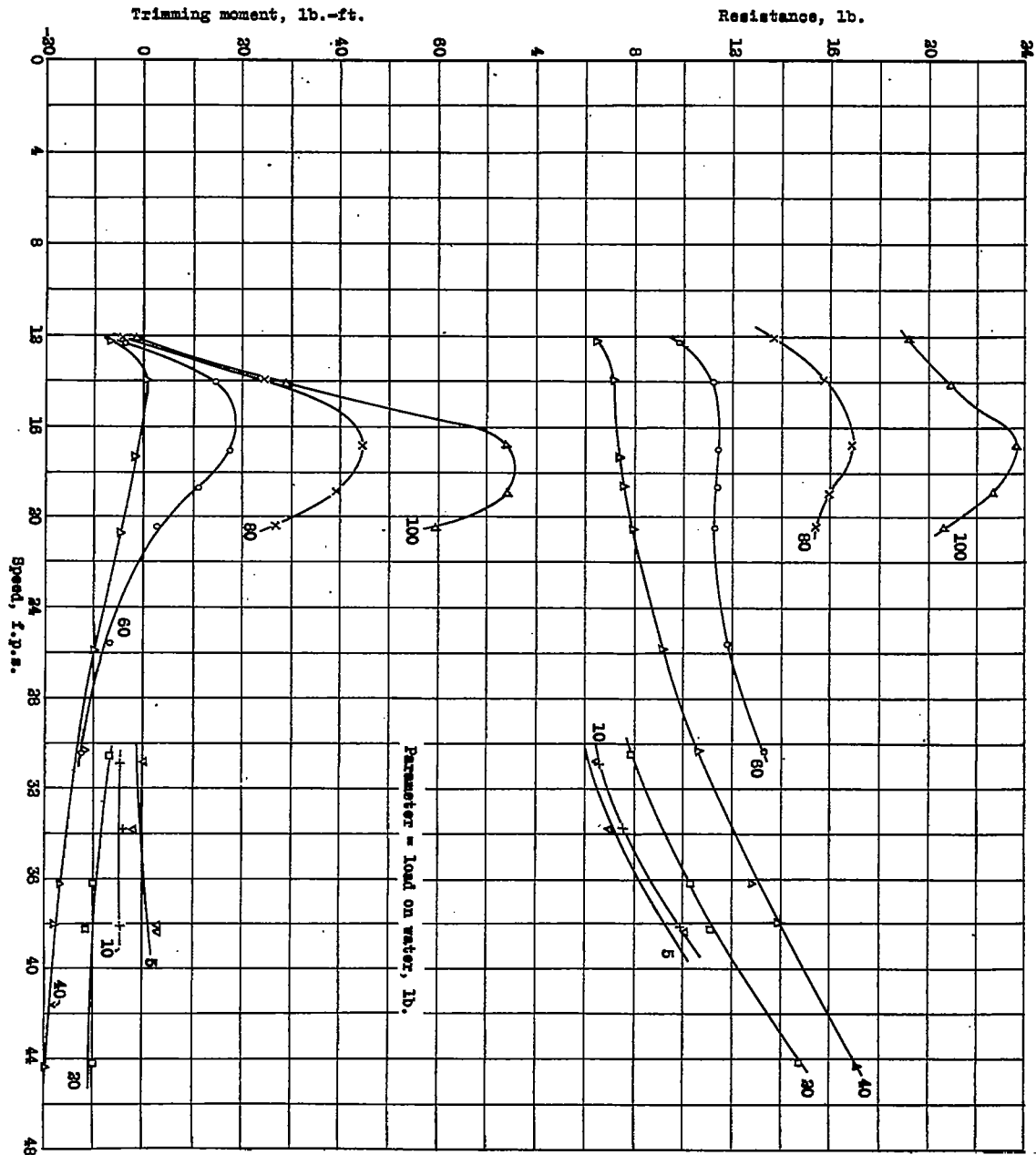
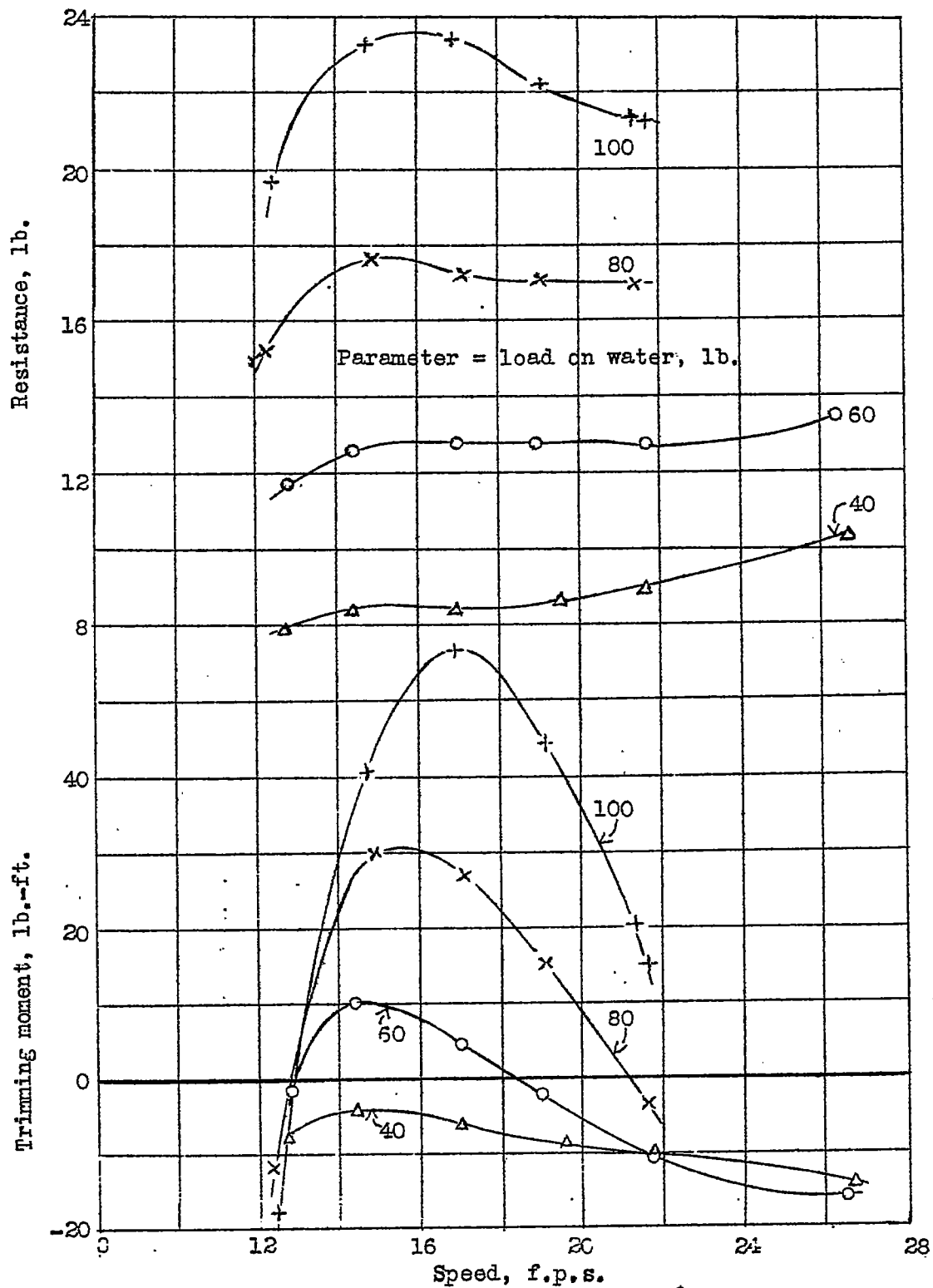Figure 11.—Resistance and trimming moment, τ=7°. Model 11-C-12.

Fig. 12

Figure 12.-Resistance and trimming moment, $\tau = 9°$. Model 11-C-12.
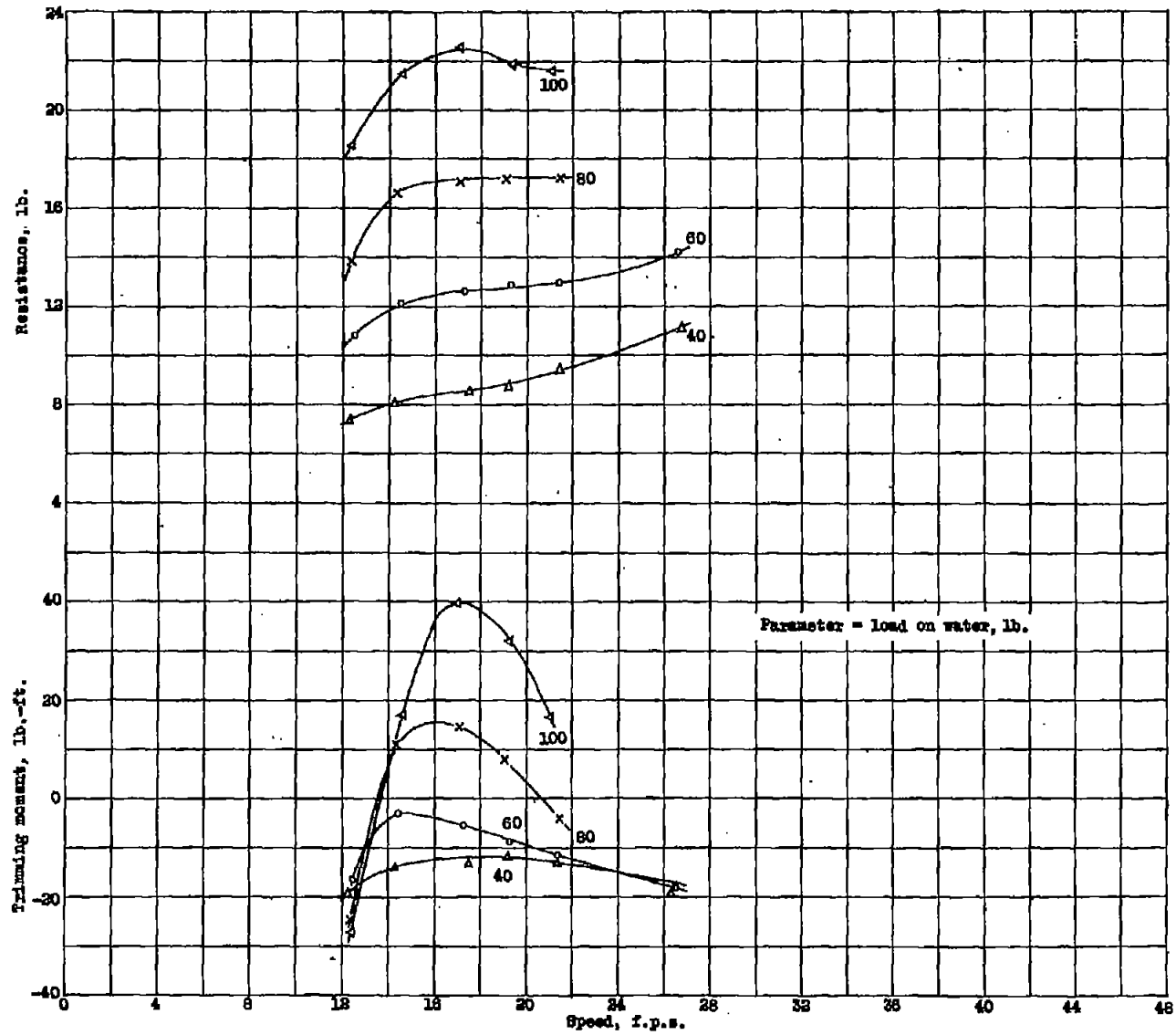
Figure 13.-Resistance and trimming moment, $\tau = 11°$. Model 11-C-12.
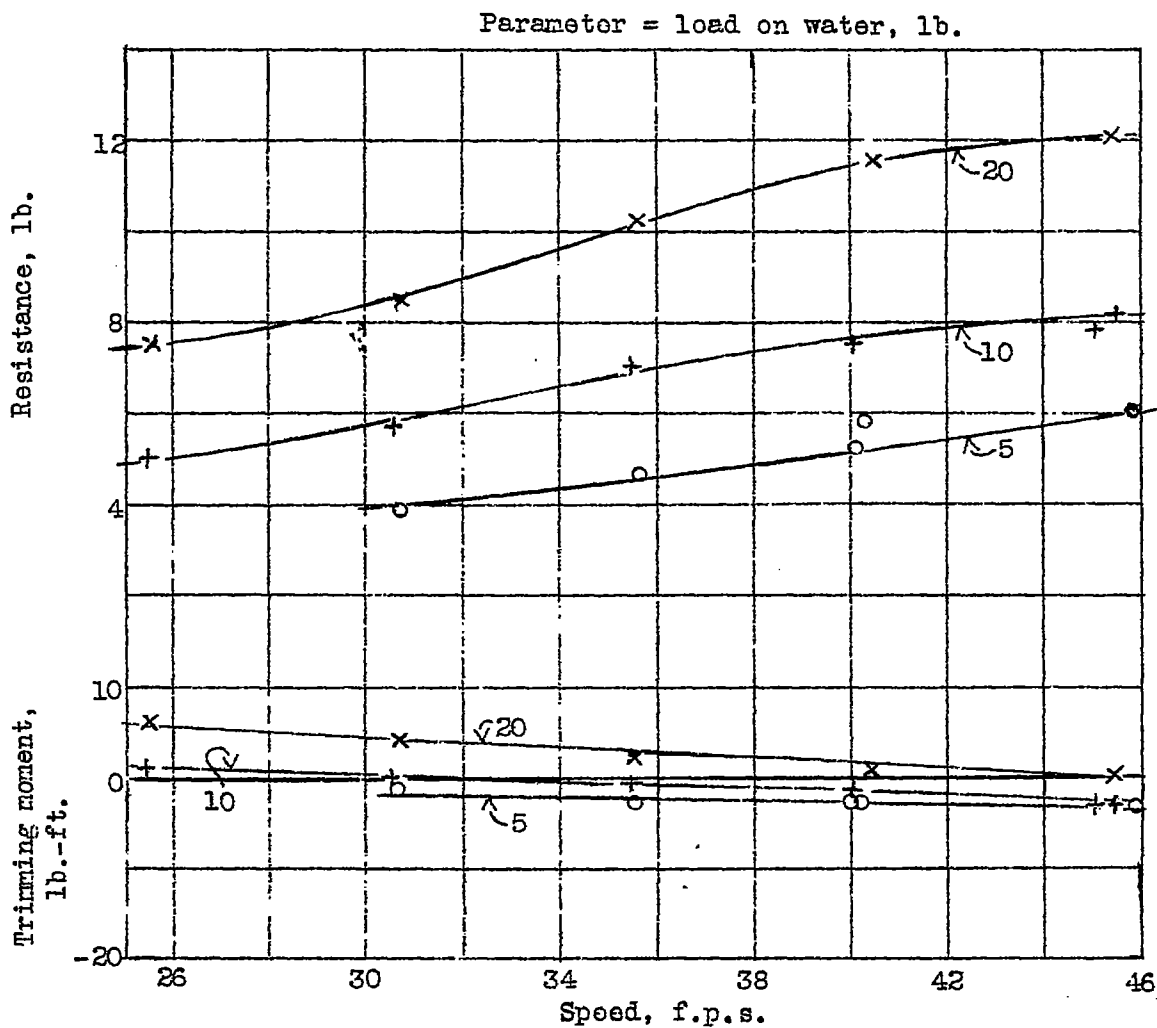
Figure 14.-Resistance and trimming moment, $\tau = 2°$. Model 11-C.

Fig. 15
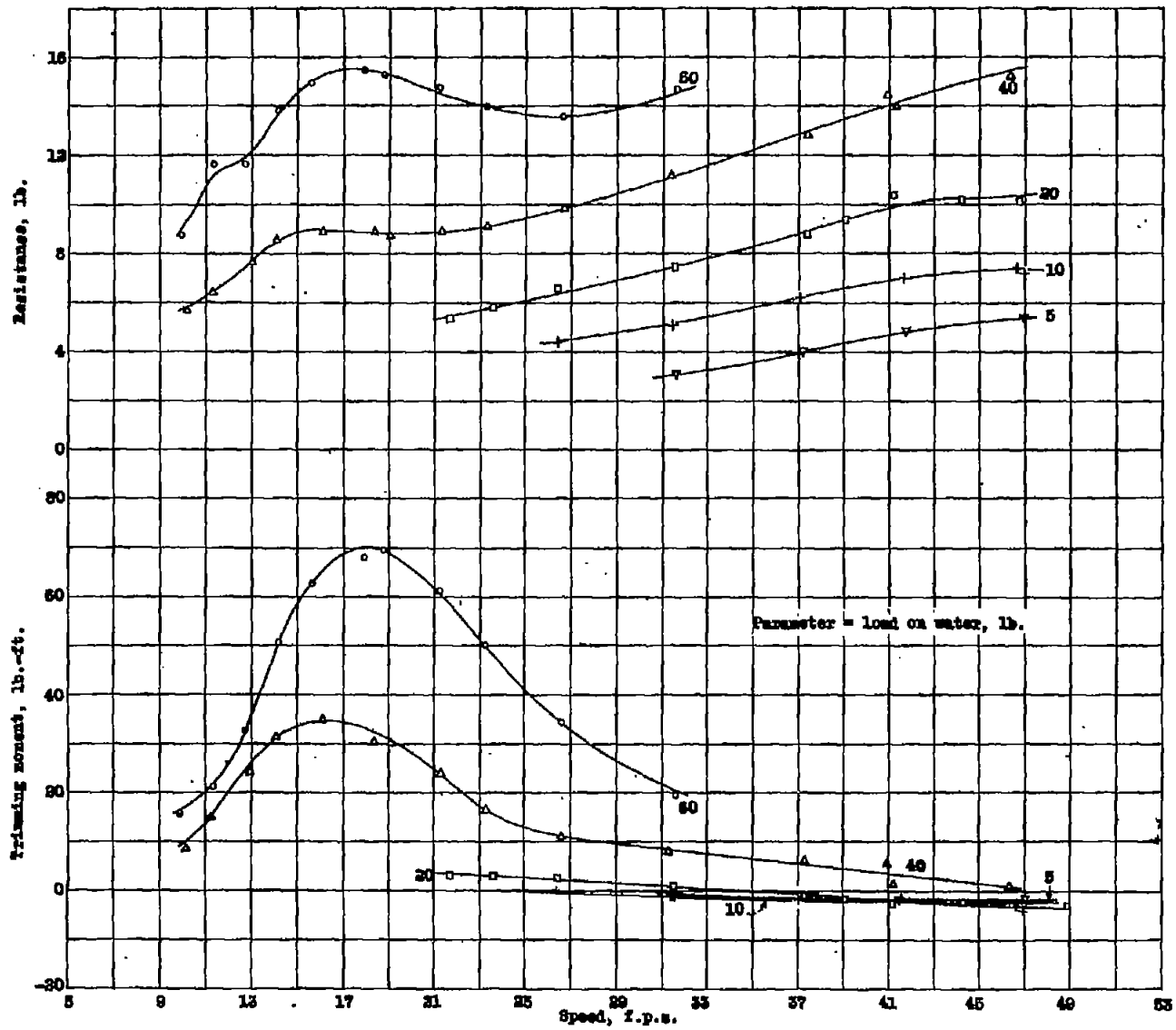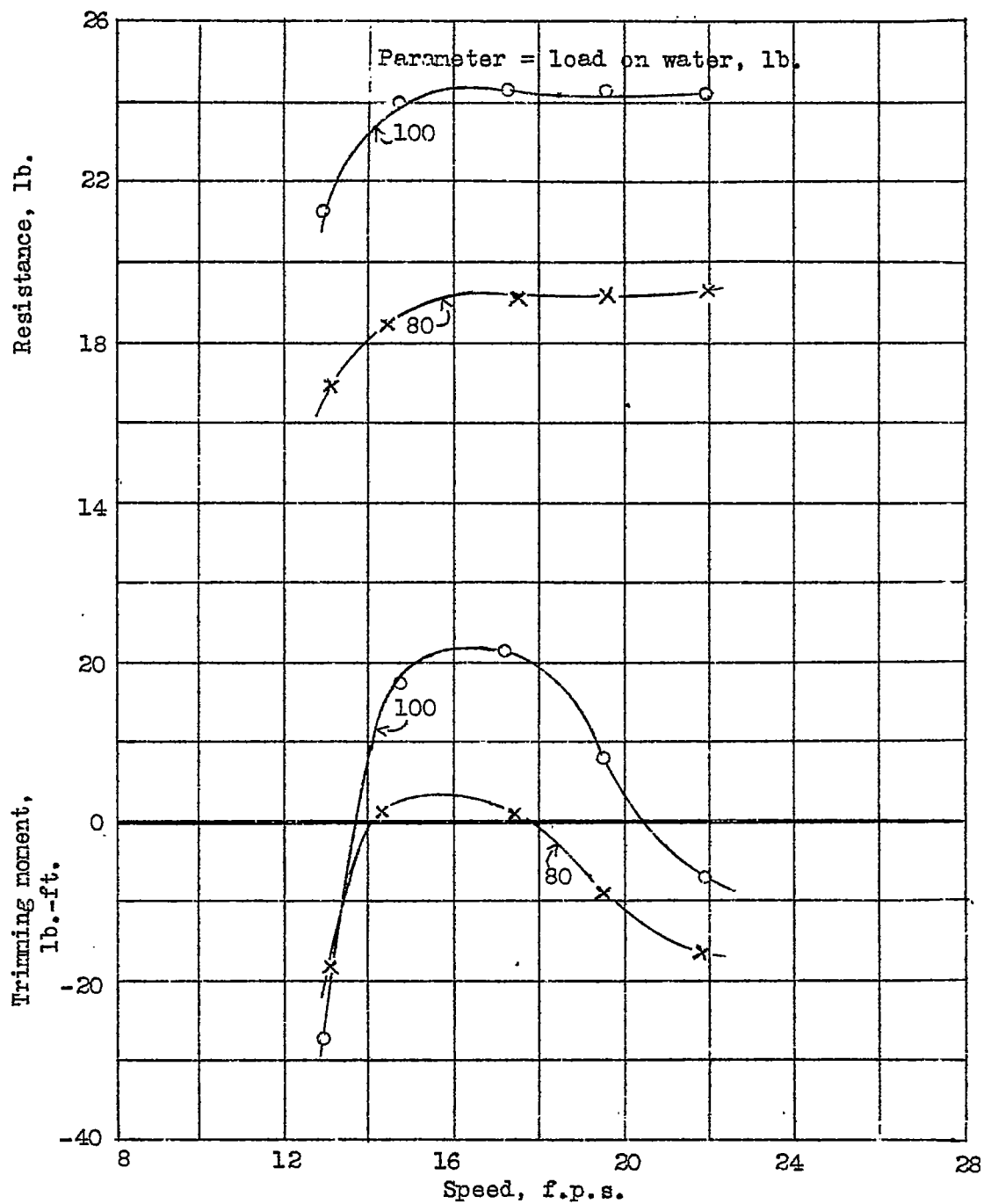

Figure 15.-Resistance and trimming moment, $\tau = 3^{\circ}$. Model 11-C.

Fig. 16
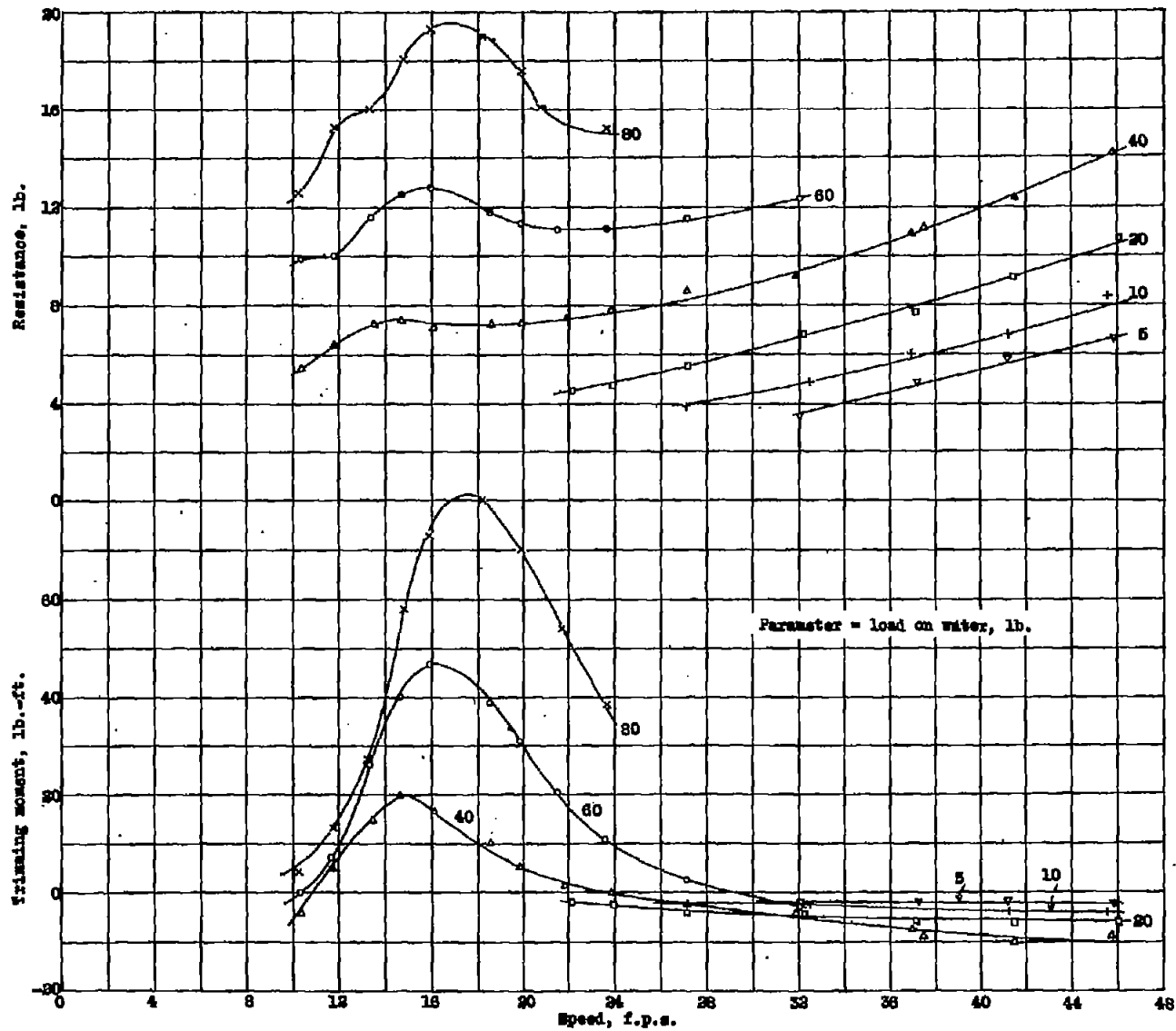
Figure 16.-Resistance and trimming moment, $\tau = 5^{o}$. Model 11-0.
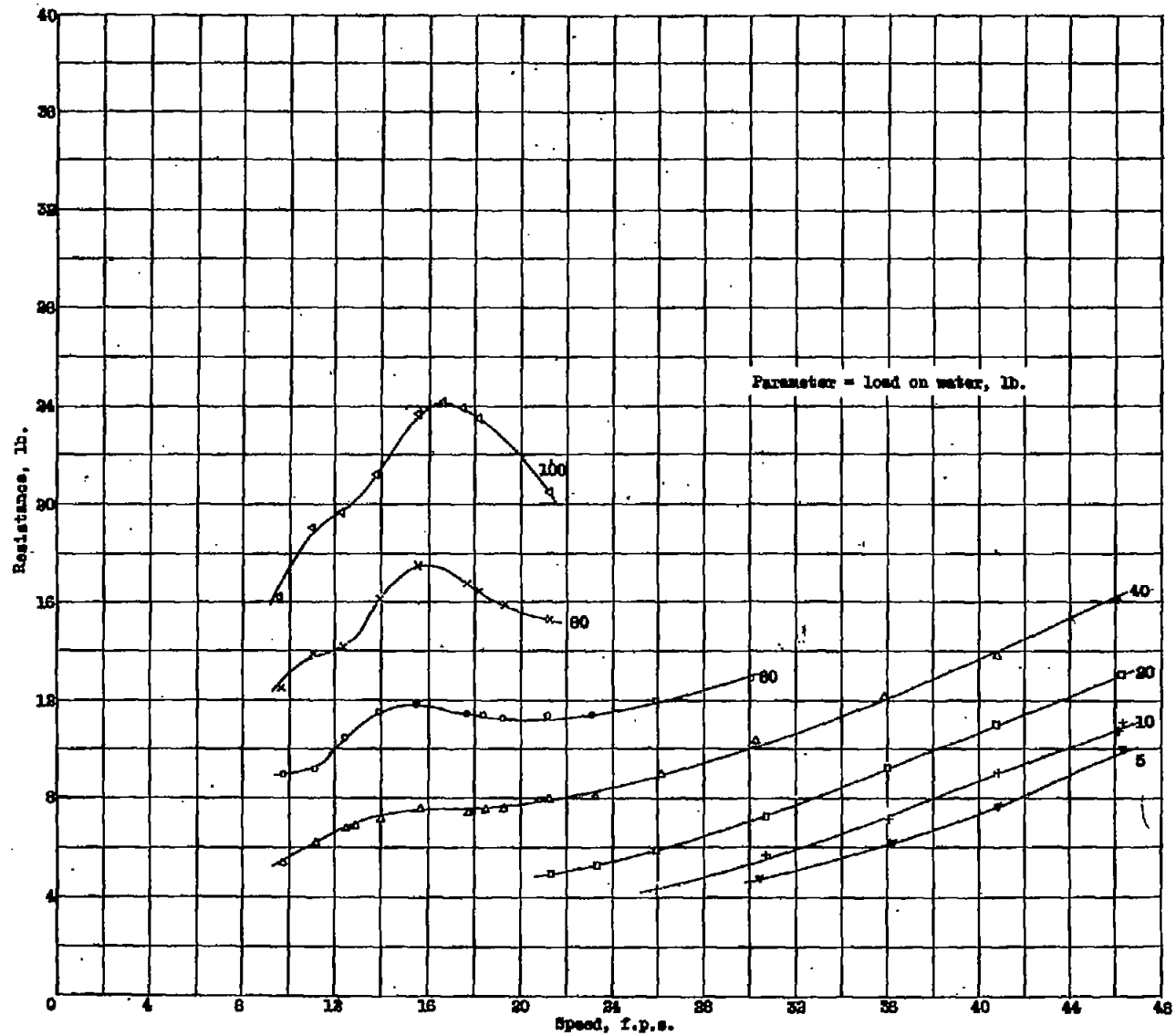
Figure 17a.-Resistance.   τ = 7°. Model 11-C.
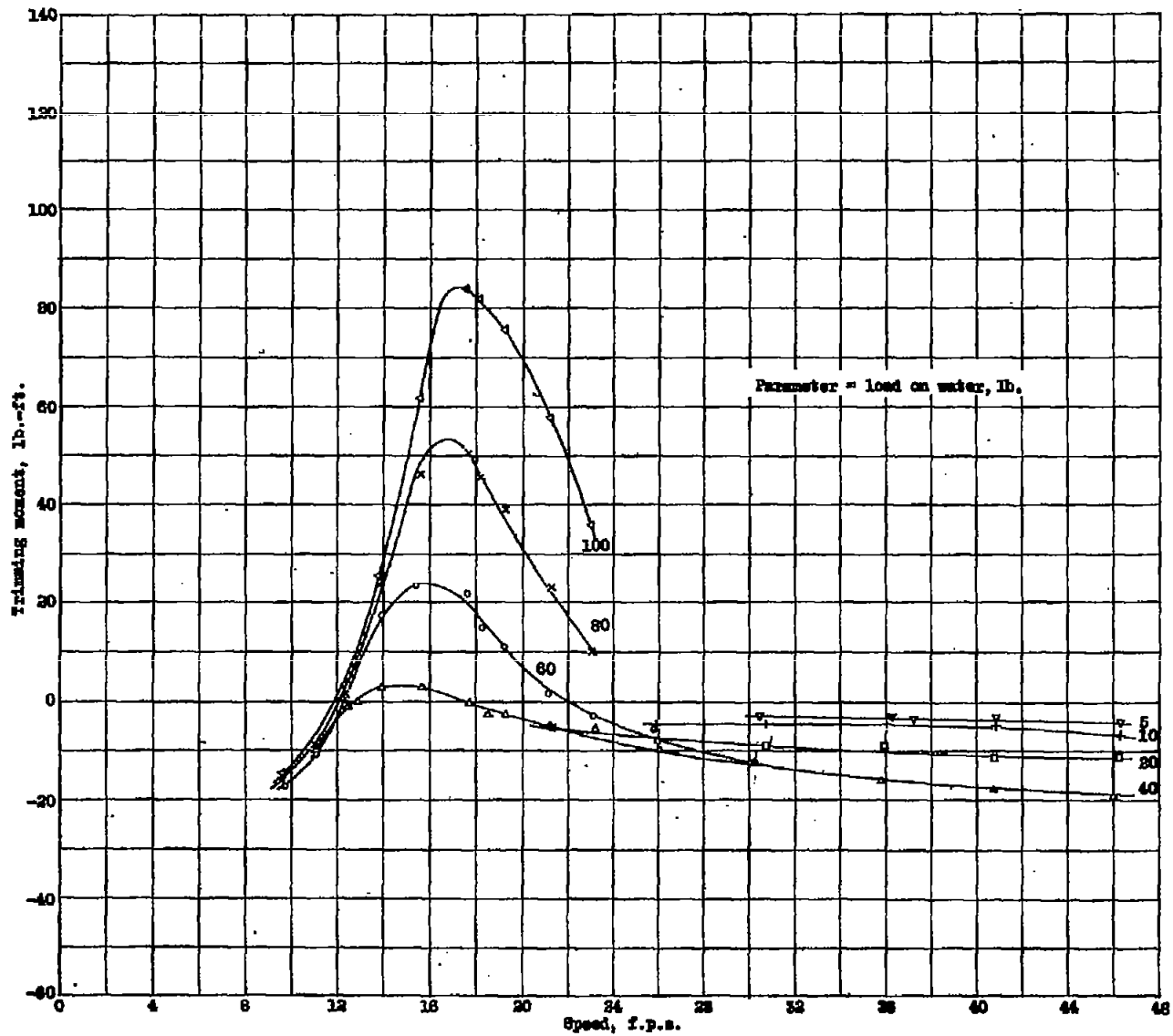
Figure 17b.—Trimming moment. $\tau = 7°$. Model 11-G.
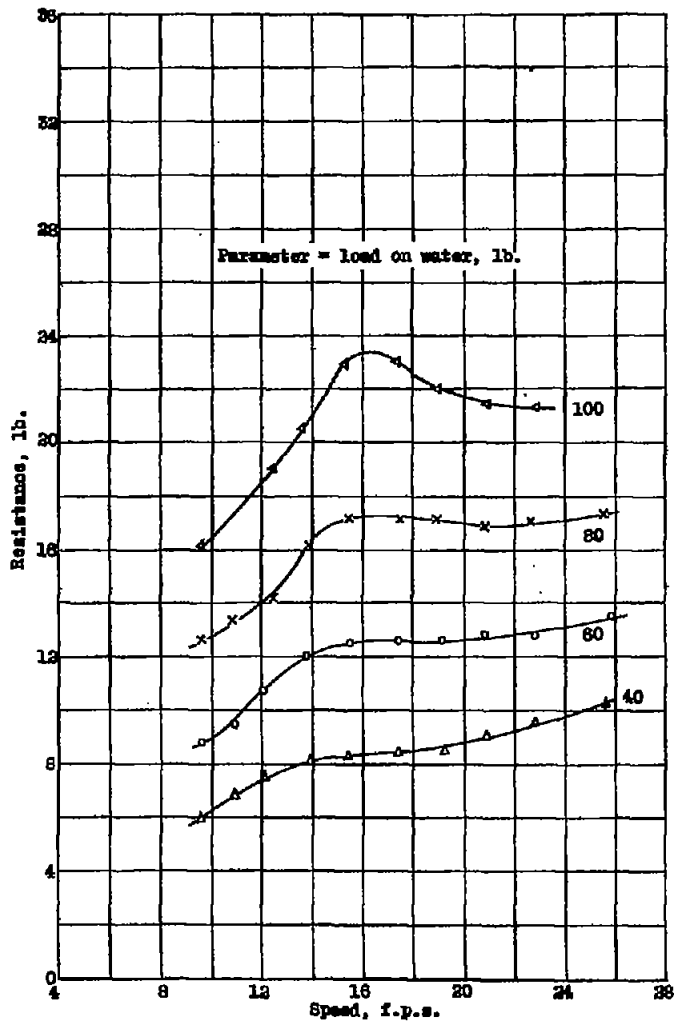
Figure 18a.-Resistance.   τ = 9°. Model 11-C.
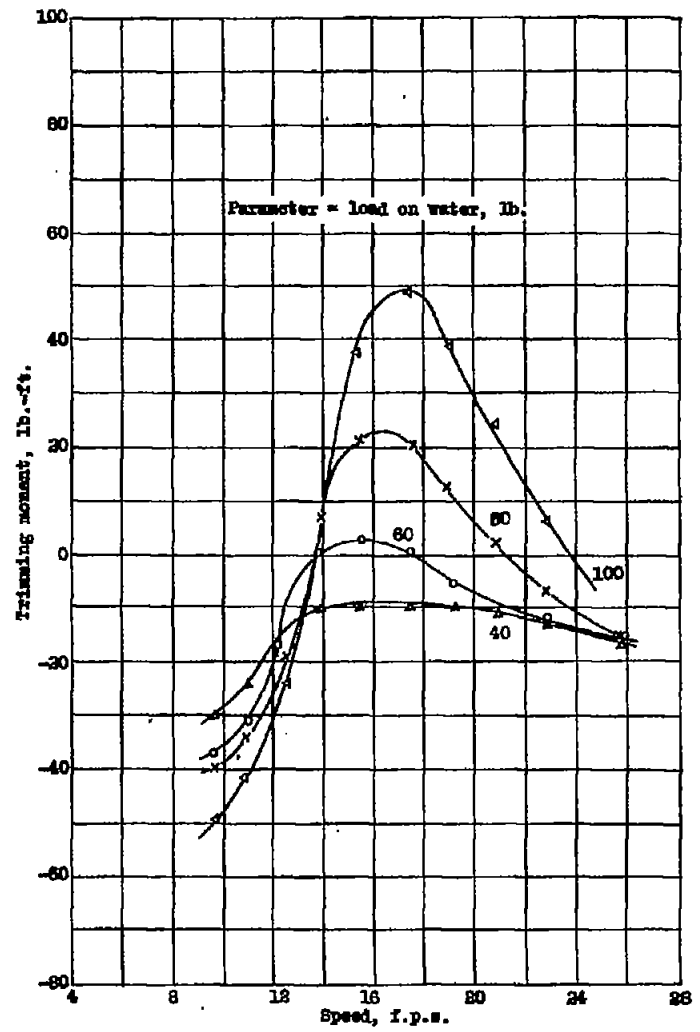
Figure 18b.-Trimming moment.   τ = 9°. Model 11-C.

Figure 19.-Resistance and trimming moment, $\tau = 11^{\circ}$. Model 11-C.

Parameter = load on water, lb.

Figure 20.-Resistance and trimming moment, $\tau = 2^{\circ}$. Model 11-C-13.

Fig. 21

Figure 21.-Resistance and trimming moment, $\tau = 3°$. Model 11-C-13

Fig. 22

Figure 22.—Resistance and trimming moment, $\tau = 5°$. Model 11-C-13.

Figure 23.—Resistance and trimming moment, $\tau = 7°$. Model 11-C-13.

Figure 24.-Resistance and trimming moment, $\tau=9°$. Model 11-C-13.

Figure 25.-Resistance and trimming moment, $\tau = 11°$. Model 11-C-13.
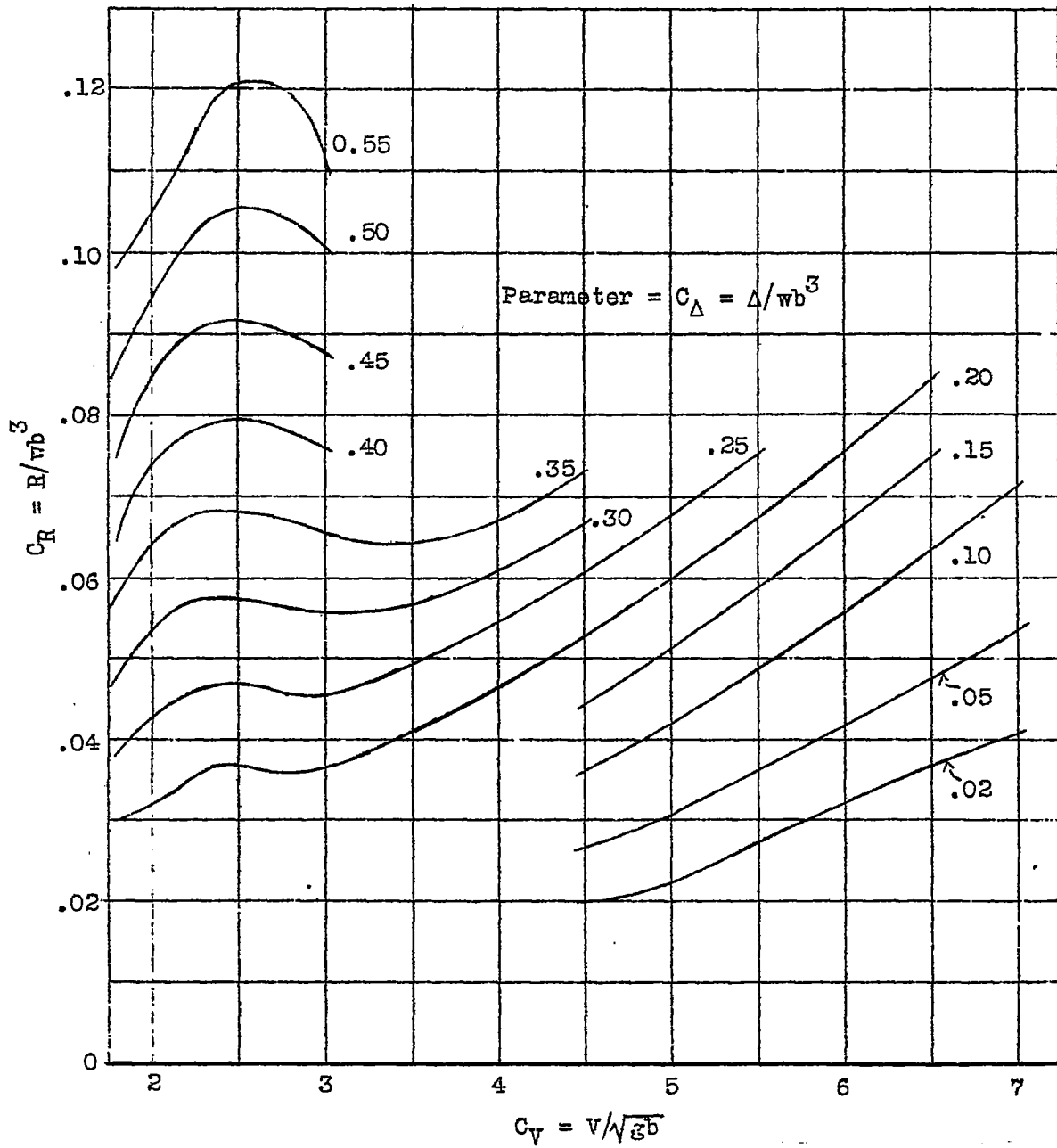
Figure 26.-Variation of C_R with C_V at best trim angles. Model 11-C-11.
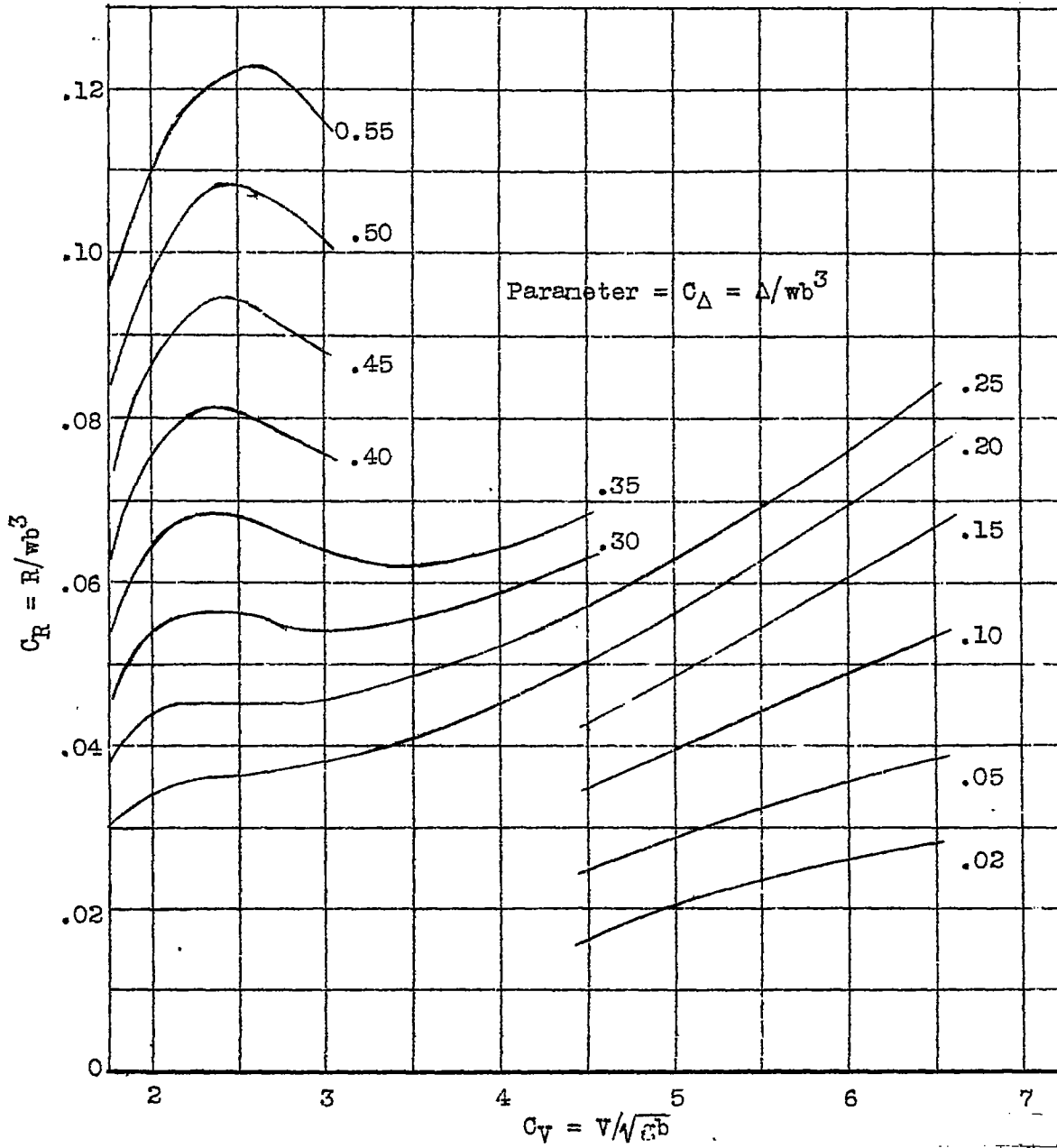
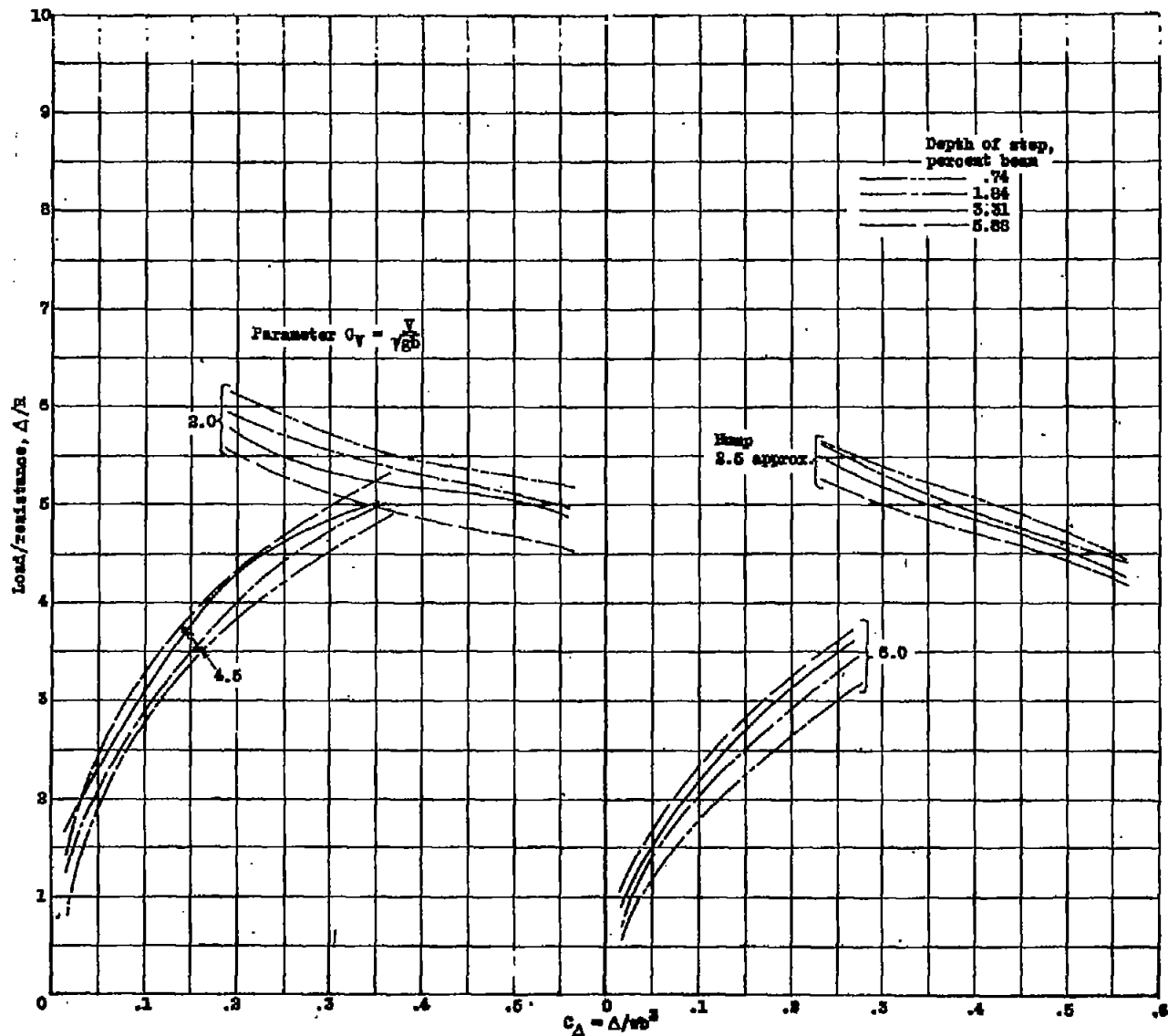Figure 27.-Variation of C_R with C_V at best trim angles. Model 11-C-12.
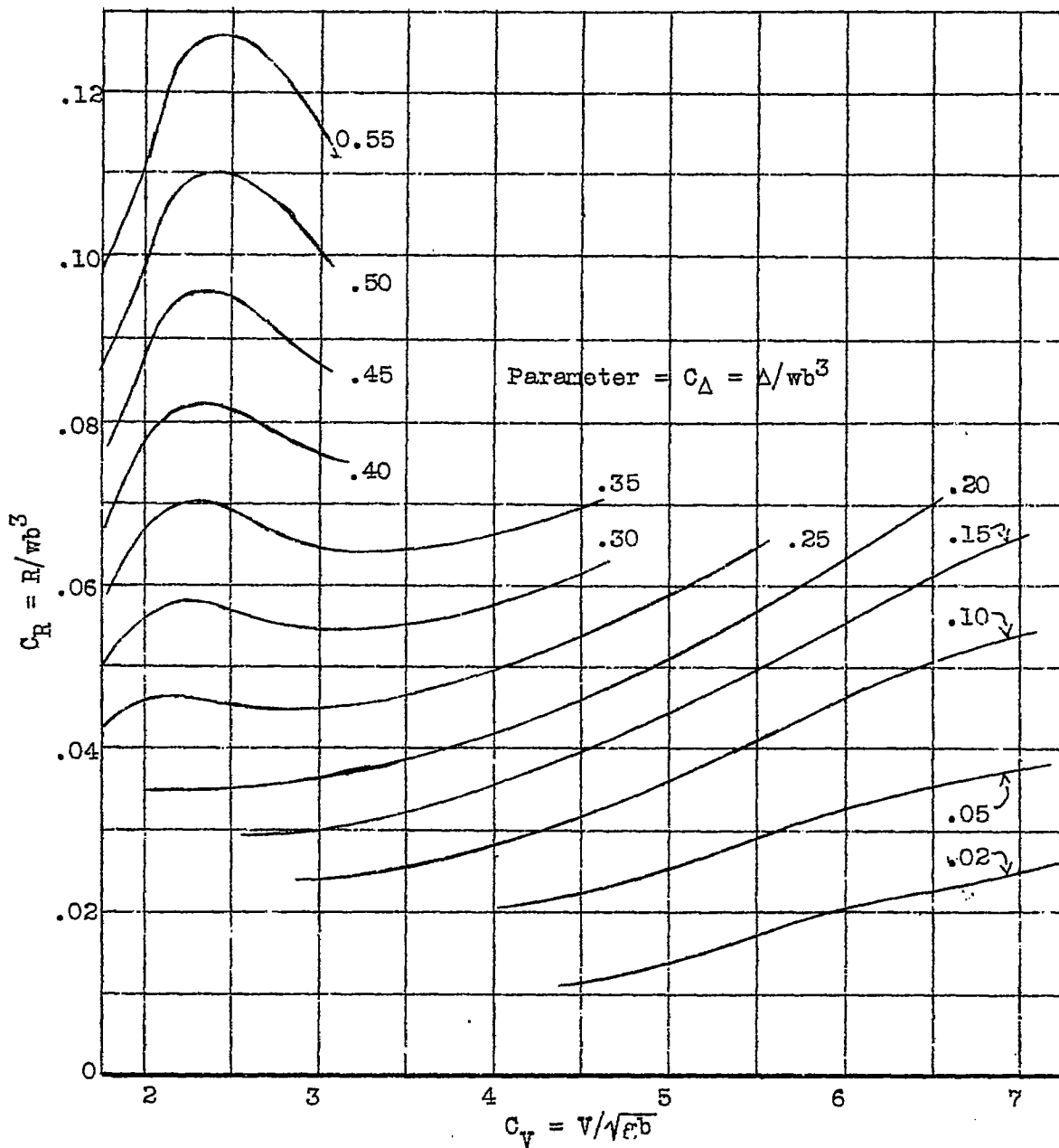
Figure 28.-Variation of C_R with C_V at best trim angles. Model 11-C.
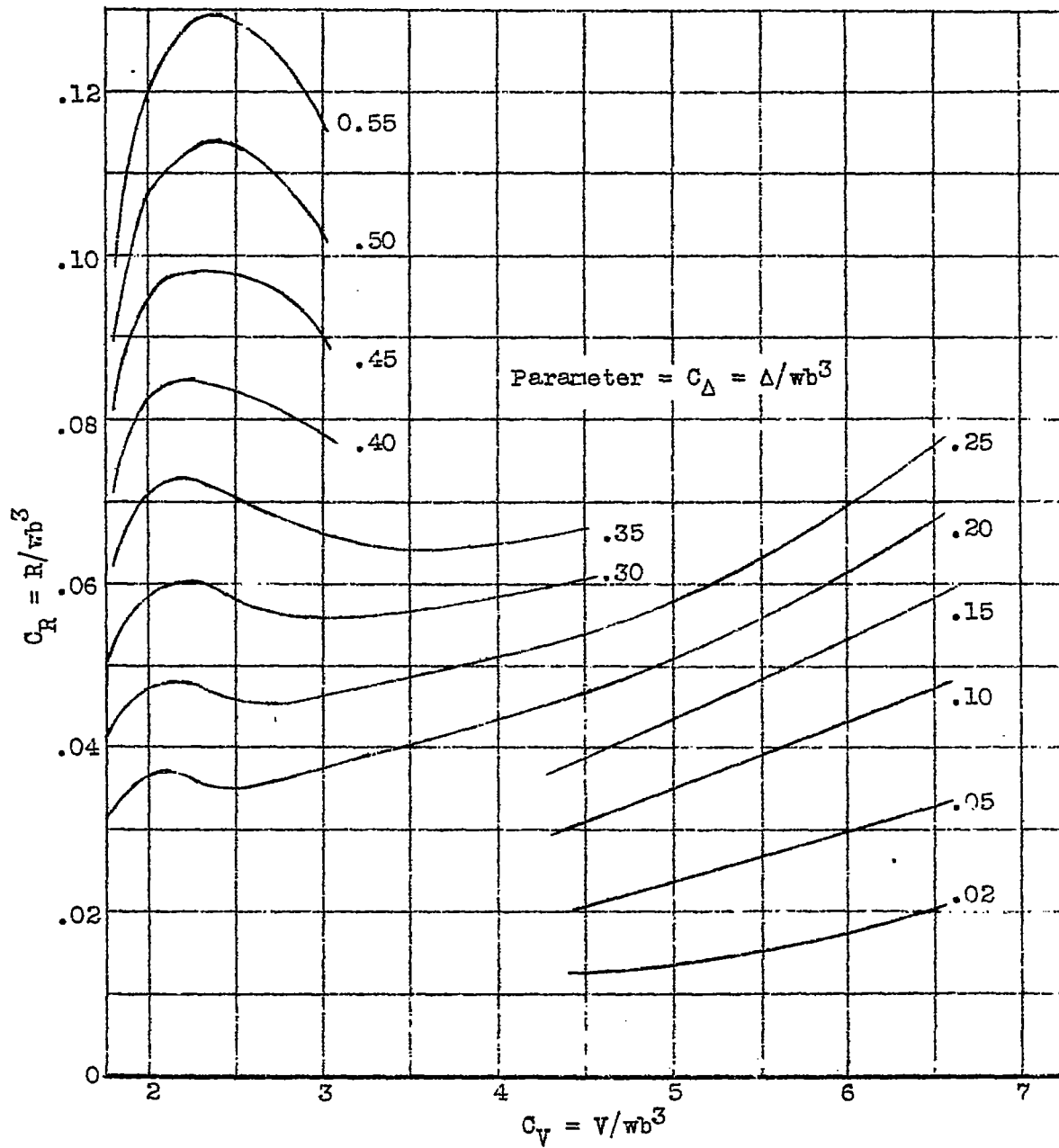
Figure 29.-Variation of C_R with C_V at best trim angles. Model 11-C-13.

Fig. 30

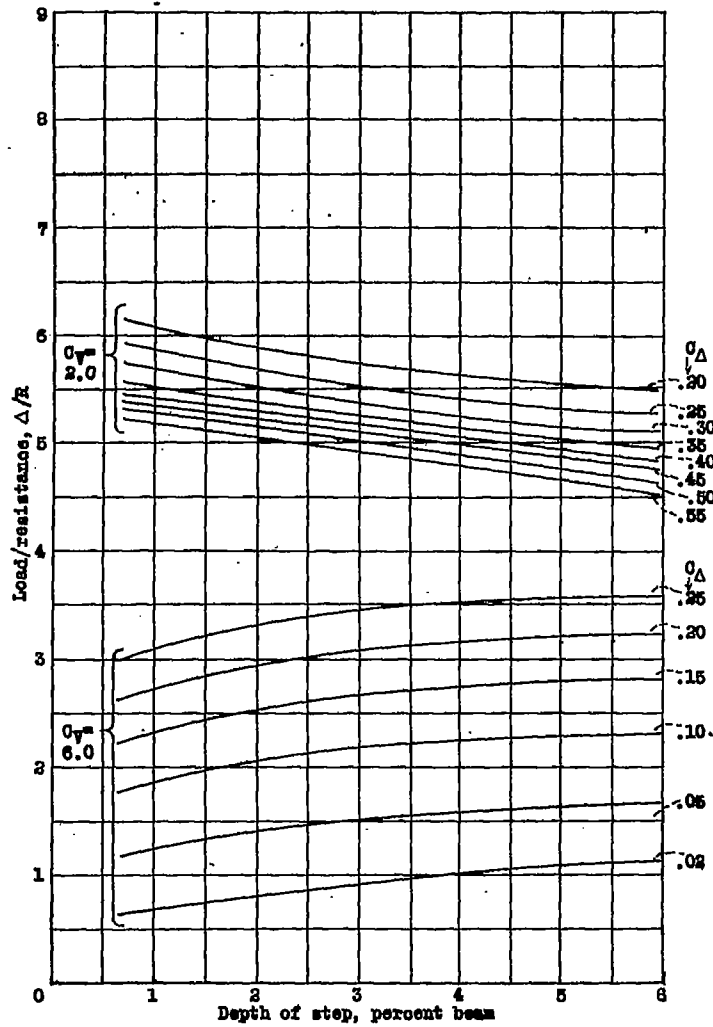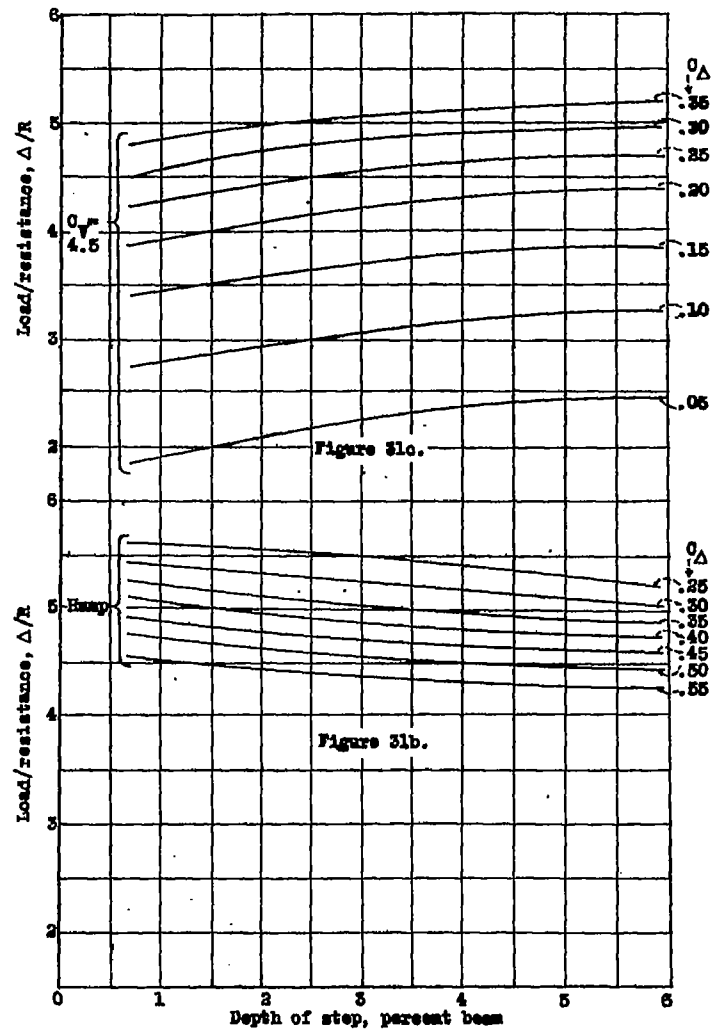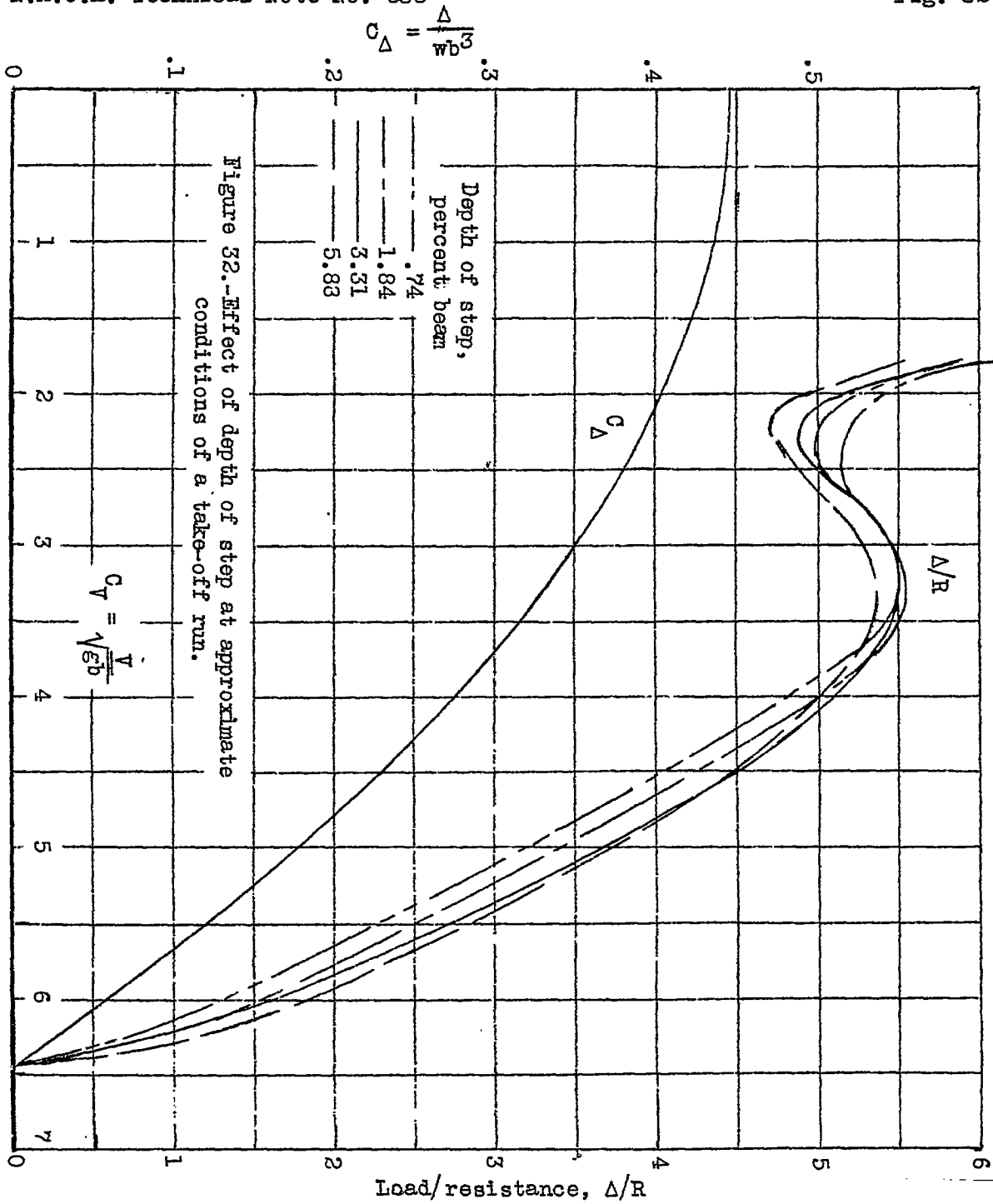Figure 30.—The effect of depth of step on load/resistance at four representative speeds.

Figure 31a.-Variation of Δ/R with depth of step.

Figures 31b,31c.-Variation of Δ/R with depth of step.

Figure 32.—Effect of depth of step at approximate conditions of a take-off run.
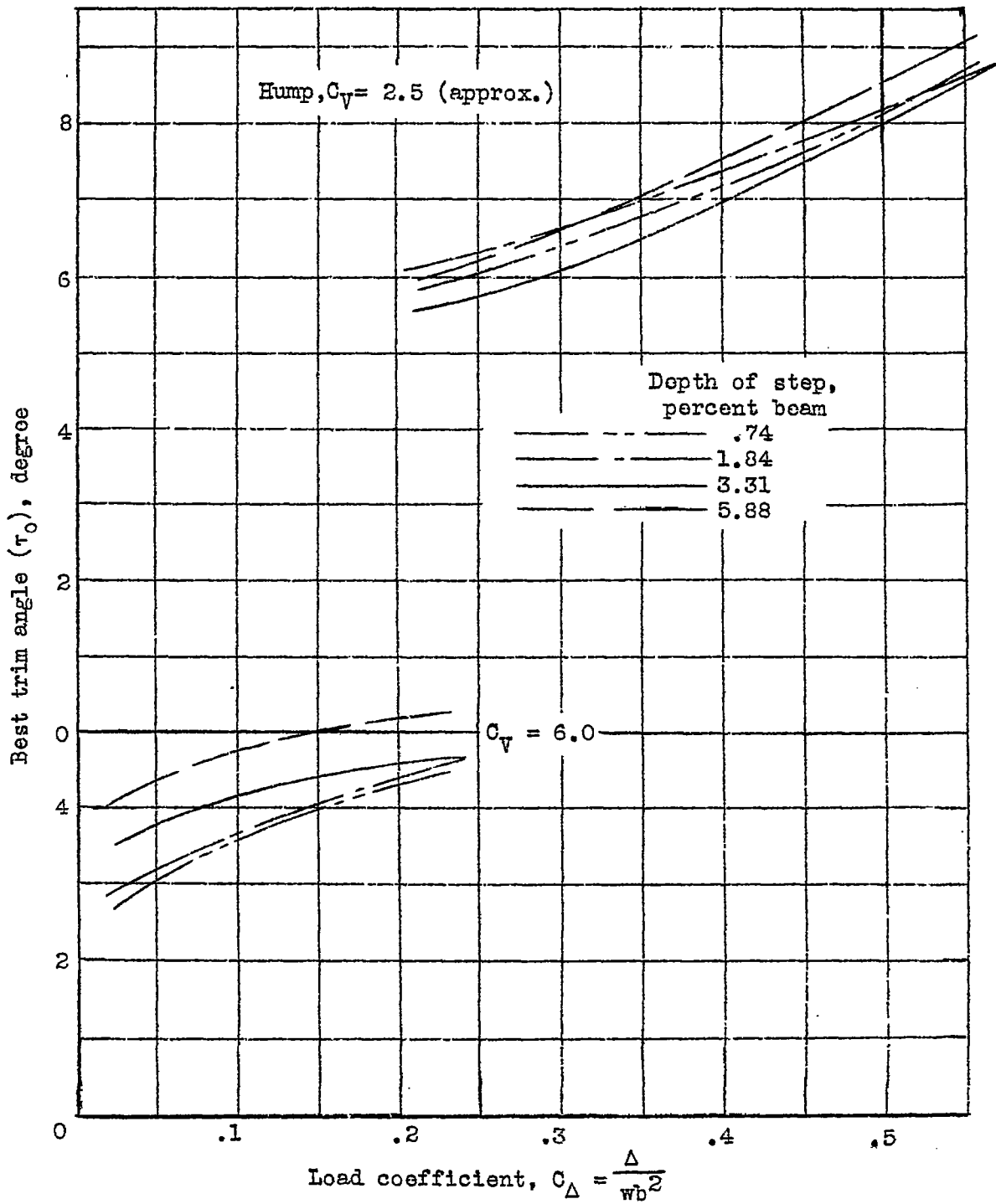
Figure 33.-Effect of step depth on best trim angle, τ.
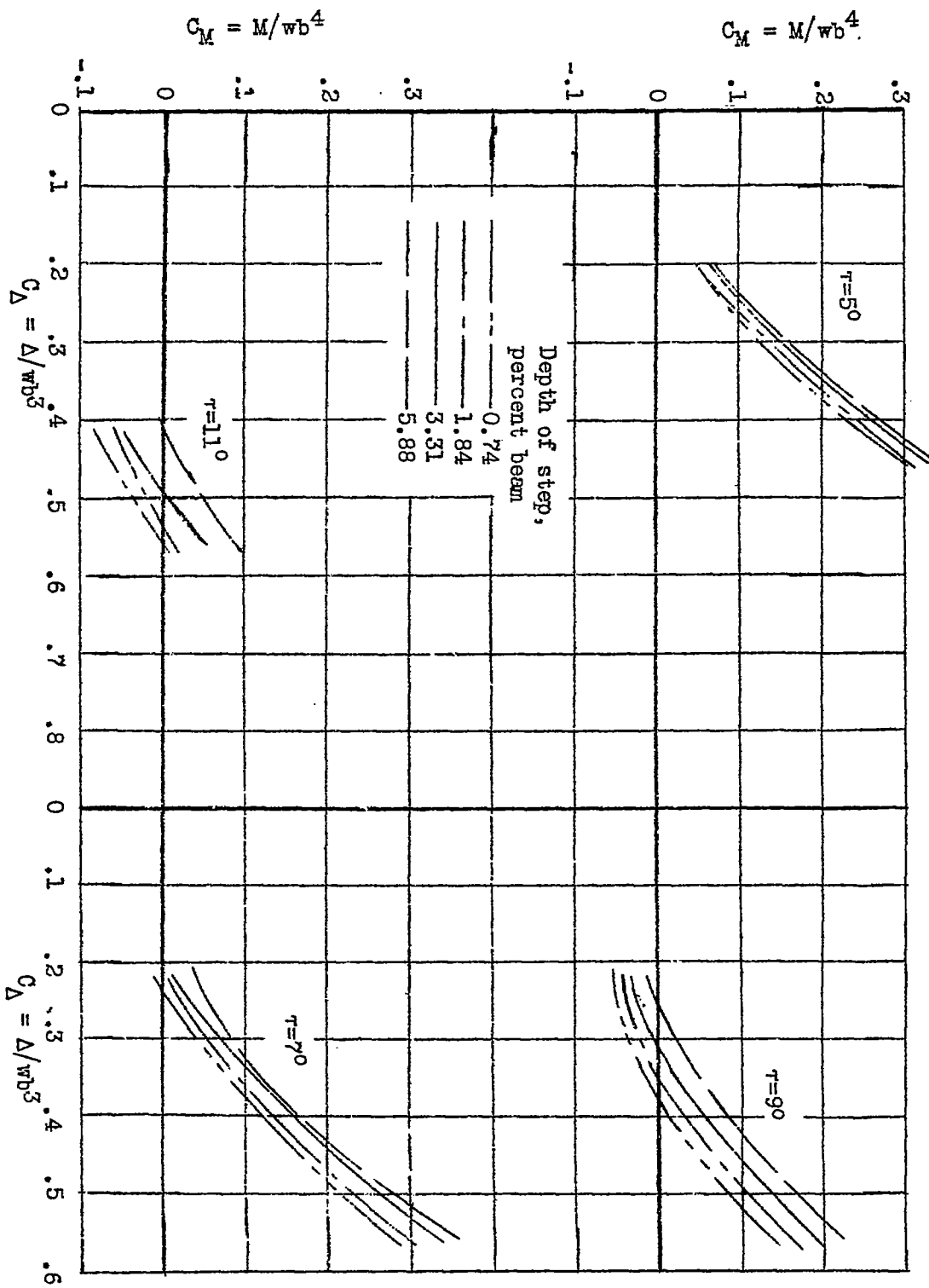
Fig. 34

Figure 34.—Effect of depth of step on maximum trimming moment in the positive direction.