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DAVID TAYLOR MODEL BASIN
WASHINGTON, D. C.

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WIND-TUNNEL TESTS TO DETERMINE AERODYNAMIC FORCES AND MOMENTS ON SHIPS HEELED IN BEAM WINDS

PART I - DD692 CLASS DESTROYERS

by

M. E. Long and C. L. Benedum

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BuShips proj SRD 1040/47

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UNITED STATES NAVY
WASHINGTON, D. C.

WIND-TUNNEL TESTS TO DETERMINE AERODYNAMIC FORCES AND MOMENTS ON SHIPS HEELED IN BEAM WINDS

by

M. E. Long and C. L. Benedum

INTRODUCTION

At the request of the Bureau of Ships (Reference 1), wind-tunnel tests were conducted on models of DD692 Class destroyers heeled in beam winds. The purpose of the tests was to determine the aerodynamic effects so that a more satisfactory criterion for stability could be set up for this class of vessel. The Bureau of Ships symbol for this project is SRD 1040/47. These tests were conducted during the period from 24 January to 18 February 1947.

MODELS AND APPARATUS

The scale of the models was 1:73.8. Since only the wind loads on the abovewater parts were to be measured in the wind tunnel, the hulls were cut off at the waterline of the models when they were heeled. Figure 1 shows these planes for the different angles of heel tested. The displacement was kept constant, corresponding to 2900 tons for the full-scale ship.

Figure 2 shows five models, with angles of heel of 0, 30, 45, 60, and 80 degrees.

Most of the deck fittings, such as rigging and radio antennas, the 20 mm guns, all radar antennas except the large fire control radar antenna, and all the lights except the 24- and 36-inch searchlights were omitted on the models as being of minor importance.

A false floor or ground board was built up above the floor of the wind-tunnel test section to provide space for installing the special six-component balance used to measure the forces and moments on the models. At the upstream end, a rounded sheet-metal leading edge extended down to the floor of the tunnel, whereas the trailing edge tapered down at a slope of 1:8. The central level section between the leading and trailing edges was used to represent the water surface, and this construction gave a uniform, steady air flow over this section. Figure 3 shows a model set up on the ground board.

In order to determine wind loads for different angles of yaw, a circular section or turntable was provided in the level surface of the ground board. A rectangular section slightly larger than the models was cut out of the turntable and a special six-component balance was installed below the level of the ground board. The rectangular cut-out in the turntable was fitted with separate plywood filler pieces for each particular model, and sections corresponding to the outline of the test waterlines of the various models were sawed out of these pieces and inserted between the balance and the

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models. The outer plywood sections were fastened to the turntable, becoming part of the ground board surface. The saw slot provided a clearance of approximately 1/16 inch between the section of plywood directly beneath the model and the surrounding outer plywood sections.

To provide a convenient electrical fouling indicator, thin sheet-metal plates were cut out and fastened on top of the plywood filler pieces. The gap between these metal pieces was 1/32 inch. The plywood and metal pieces fixed the waterline of the models at the level of the adjacent surface of the ground board.

Figure 4 shows a model set up on the special electrical strain-gage balance outside of the wind tunnel.

TEST CONDITIONS

The tests were made in the David Taylor Model Basin 8- by 10-foot closed-throat atmospheric Wind Tunnel 1. The models were tested at dynamic pressures of 51.0, 32.6, 18.4, and 8.20 pounds per square foot, corresponding to average wind-speeds of about 124, 98.6, 73.8, and 49.5 knots, and average test Reynolds numbers of 6,630,000; 5,380,000; 4,050,000; and 2,700,000 respectively, based on the overall model length of 5.10 feet.

Tests were conducted with angles of heel of 0, 10, 20, 30, 45, 60, and 80 degrees with the wind, and 10 and 30 degrees into the wind, with the wind directly abeam. Additional tests were made at 10, 30, and 60 degrees angle of heel with the wind and at 10 and 30 degrees angle of heel into the wind, with the wind 30 degrees ahead and 30 degrees abaft the beam.

The reference test windspeed was measured 8 inches above the ground board, approximately at the level of the tops of the stacks of the upright model. The windspeed profile be- tween the unobstructed ground board and this reference point was determined by a total-head survey, the static pressure being assumed constant from the reference point down to the ground board.

Figure 5 shows the average windspeed profiles measured at the center of the turntable (which point is on the center line of the tunnel) and at 2 feet on either side. This survey covered a distance equal to 80 percent of the model length. Figure 6 shows these windspeed profiles scaled up in the ratio of 73.8 to 1, together with actual measured wind gradients (References 2 and 3).

Preliminary tests were made to determine the effect of the air flow through the clearance gap between the filler pieces and the surrounding ground board. Tests were made with the gap sealed with a thin grease. The variations noted with this gap sealed and with it unsealed were negligible and therefore most of the tests were made with the gap unsealed.

RESULTS

The forces and moments measured are given directly in pounds and pound-feet for the models. The sign conventions employed correspond to the axes shown in Figure 7. The symbols used are defined as follows:

X	longitudinal force in pounds
Y	lateral force in pounds
Z	normal force in pounds
$\mathcal{L}$	heeling (rolling) moment in pound-feet
M	pitching moment in pound-feet
N	yawing moment in pound-feet
ϕ	angle of heel (roll) in degrees, positive to starboard
ψ	angle of yaw in degrees, positive to starboard
V	windspeed in feet per second
V_k	windspeed in knots
A_u	area of abovewater profile, model upright, in square feet (approximately 1.80 for models tested)
h	distance from center of area of abovewater profile to center of area of underwater profile, model upright, in feet
h'	distance from center of area of abovewater profile to waterline plane, model upright, in feet (approximately 0.25 for model tested)
q	dynamic pressure ($\rho V^2/2$) in pounds per square foot
ρ	density of air in slugs per cubic foot
R	test Reynolds number $\rho V l/\mu$
l	overall length in feet (5.10 for models tested)
μ	absolute viscosity of air in pound-seconds per square foot

The X-axis of the models was always chosen as the intersection of the plane of symmetry of the complete ship with the waterline plane. The origin for moments was taken at the midpoint between perpendiculars, which is 189.7 feet aft of the bow on the prototype ship.

The normal force was corrected for the effect of the ground board static pressure by making tare tests with the model removed, and subtracting the tare forces from those measured during the force tests.

The principal results of this investigation are given in Figure 8, which shows the variation of the aerodynamic forces and moments with angle of heel at a windspeed of approximately 124 knots, with the wind directly from the beam, and 30 degrees ahead and abaft the beam. Although only the lateral and normal forces and the heeling moment are necessary for this investigation, the other components are included as being of possible general interest. Figures 9 through 12 give the lateral and normal forces and the heeling and yawing moments as functions of the dynamic pressure, for 10, 30, 60, and 80 degrees angle of heel.

The results are believed to be accurate within 1.0 pound for the lateral and normal forces, 0.5 pound for the longitudinal force, 1.0 foot-pound for the pitching and yawing moments and 0.5 foot-pound for the heeling moment. It is believed that this uncertainty is due primarily to the unsteady character of the aerodynamic forces.

DISCUSSION

A relation that has been used by the Bureau of Ships (Reference 1) for computing the heeling moment due to the aerodynamic effects of beam winds is

$$\mathcal{L} = 0.004\, V_k^2 A_u h \cos^2 \phi$$

If h' is substituted for h in this expression, the heeling moment computed can be compared with the heeling moment measured. Conversely, using the experimental results, the constant in the expression can be re-evaluated. Thus from Figure 8 for a zero angle of heel,

$$\mathcal{L} = 10.2 = K \times (124)^2 \times 1.80 \times 0.25, \text{ from which}$$

K = 0.00147, or for convenience and to a sufficient degree of accuracy, K = 0.0015.

In Figure 13, the experimental results for the different angles of heel, with the wind from the beam, are plotted with the results from this equation, using K = 0.0015 rather than 0.004. The two curves are seen to be in reasonable agreement over the angles of heel inclined with the wind. For the opposite angle, the experimental curve maintains the maximum value, rather than decreasing. However, the effect of the moment for these angles is to restore the model to the upright position, so that the only important part of the curve is that which does follow the $\cos^2\phi$ relation.

In Figures 9 through 12, the lateral and normal forces and the heeling and yawing moments are shown as functions of the dynamic pressure for several angles of heel. In general, these plots are straight lines passing through the origin, indicating that the different forces and moments are proportional to the square of the windspeed, irrespective of angle of heel.

The heeling moments on full-scale vessels of this class about an axis in the waterline plane due to beam winds may accordingly be estimated by using the expression

$$\mathcal{L} = KV_k{}^2 A_u h' \cos^2\phi ,$$

where the value of K is taken as .0015 and the values A_u and h' are taken from the full-scale ship. It may be emphasized again that h' is the distance from the center of area of the abovewater profile to the waterline plane, with the vessel upright.

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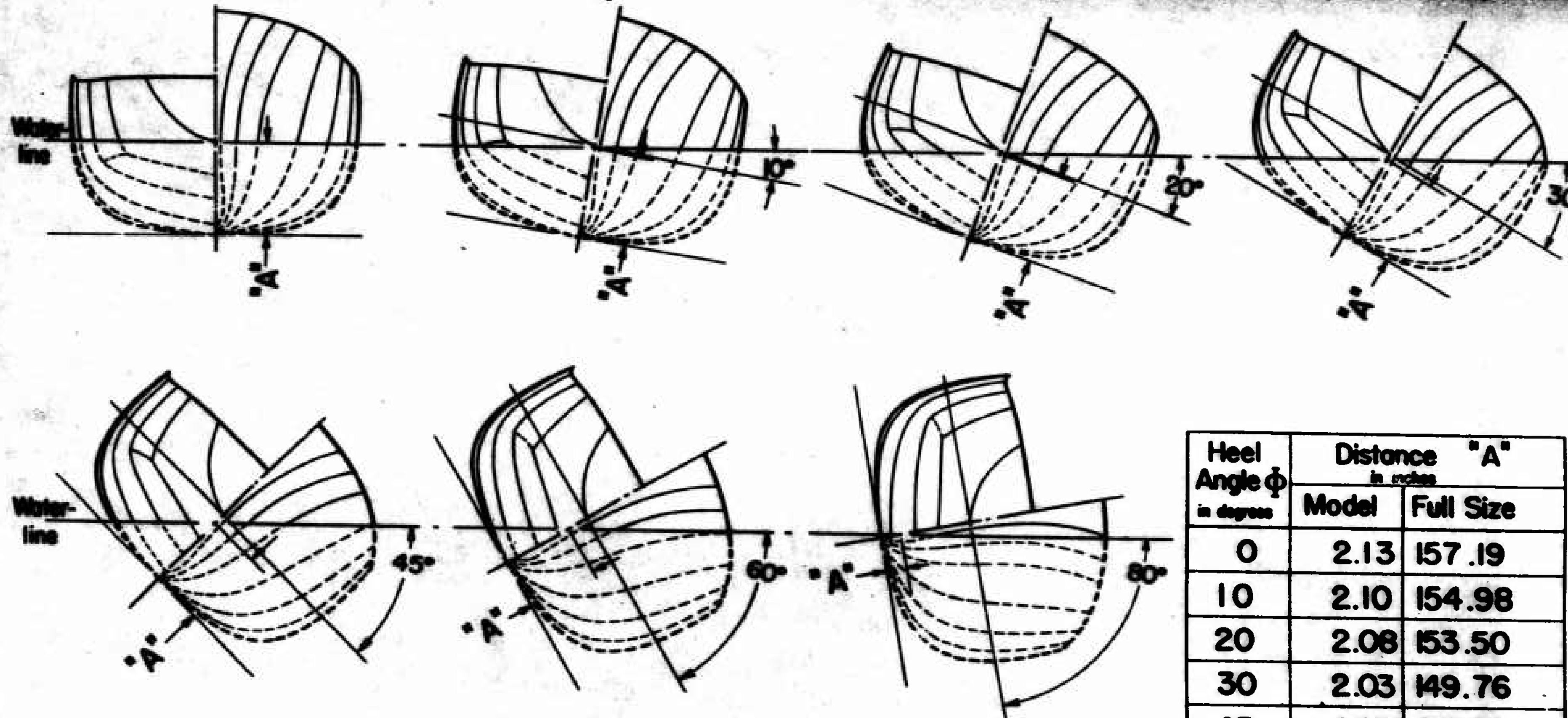
(1) BuShips ltr S29-1(456b) of 6 February 1946 to TMB.

(2) "Air Conditions Close to the Ground and the Effect on Airplane Landings," by F. L. Thompson, W. C. Peck, and A. P. Beard, NACA Technical Report No. 489, 1934.

(3) "The Air Resistance of Ship Hulls with Various Types and Distributions of Superstructure," by G. Hughes, Transactions of the Institute of Engineers and Shipbuilders in Scotland, Vol. LXXV, 1931-1932, discussion by C. Frodsham Holt, Figure 23, p. 356.

Aerodynamics Division
David Taylor Model Basin
Washington, D. C.
December 1947



Heel Angle Φ in degrees	Distance "A" in inches	
	Model	Full Size
0	2.13	157.19
10	2.10	154.98
20	2.08	153.50
30	2.03	149.76
45	1.88	138.74
60	1.67	123.25
80	0.50	36.90

Figure 1 - Waterlines for 1 : 73.8 - Scale Models of DD 692 Class Destroyers at Constant Displacement of Full-Size Vessels of 2900 Tons, for Heeling Angles from 0 to 80 Degrees.

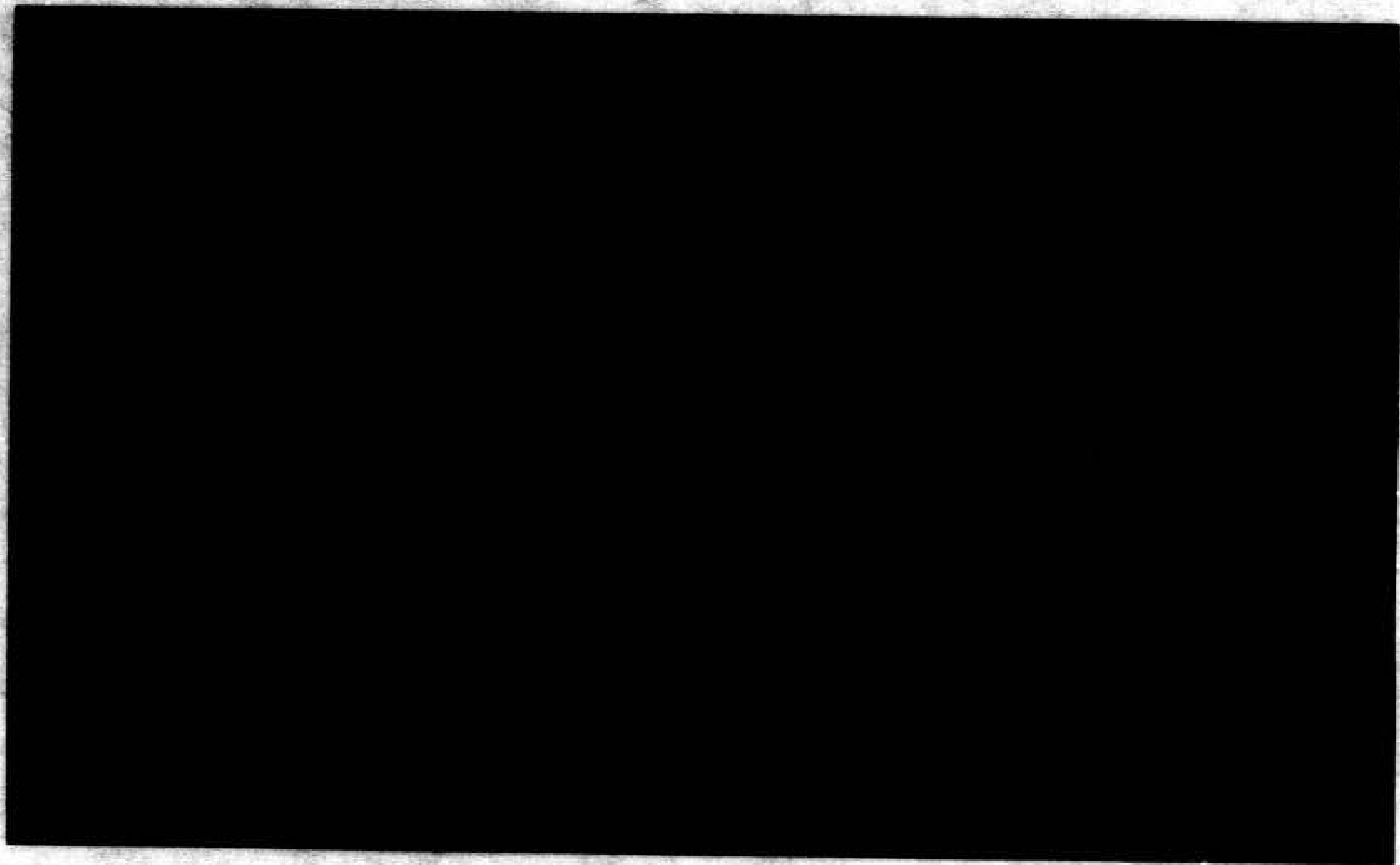


Figure 2 - Front View of 1:73.8-Scale Models of DD692 Class Destroyers with Heel Angles of 0, 30, 45, 60, and 80 Degrees

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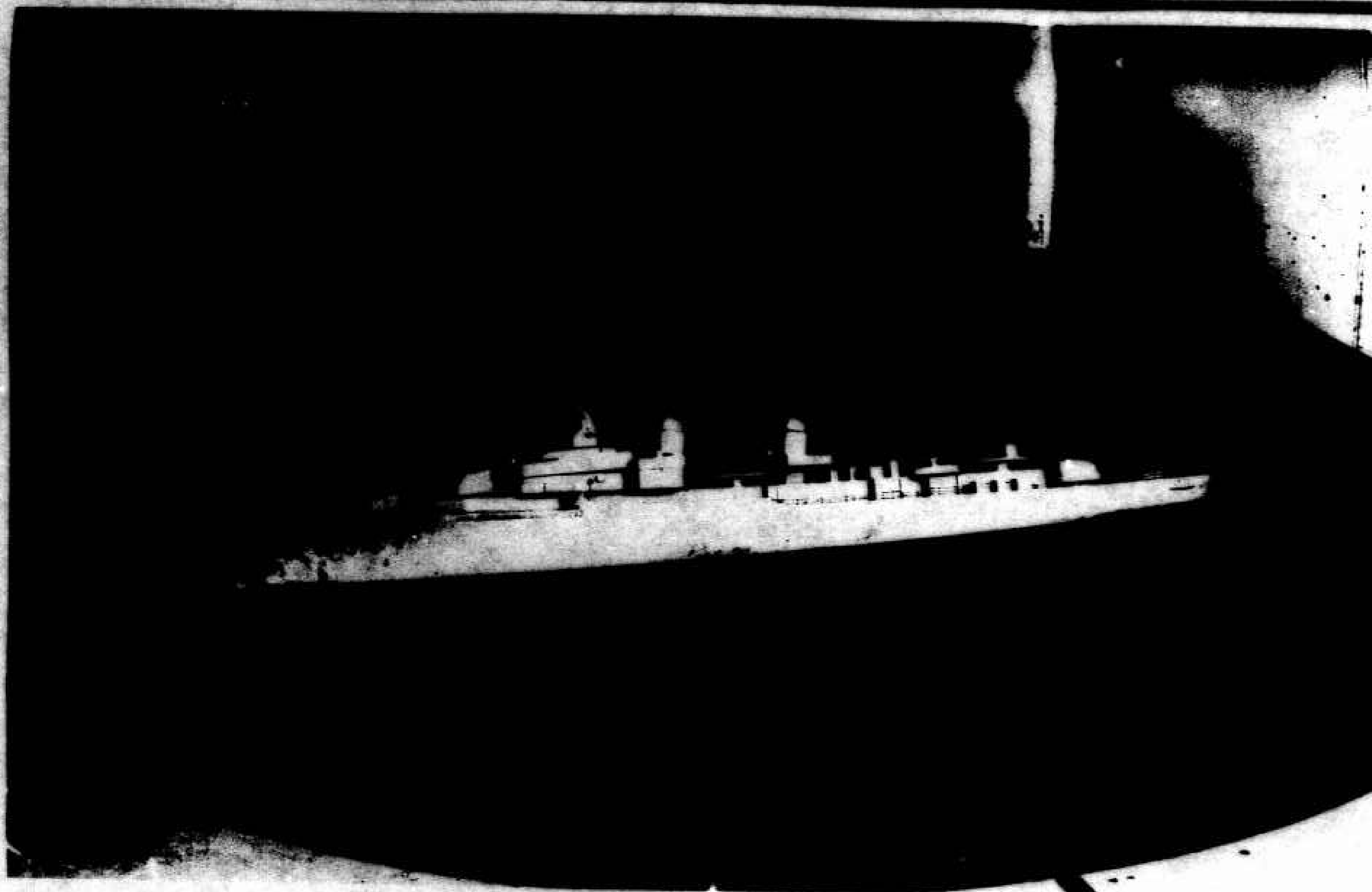

Figure 3 - Photograph of Model Installed in Wind Tunnel

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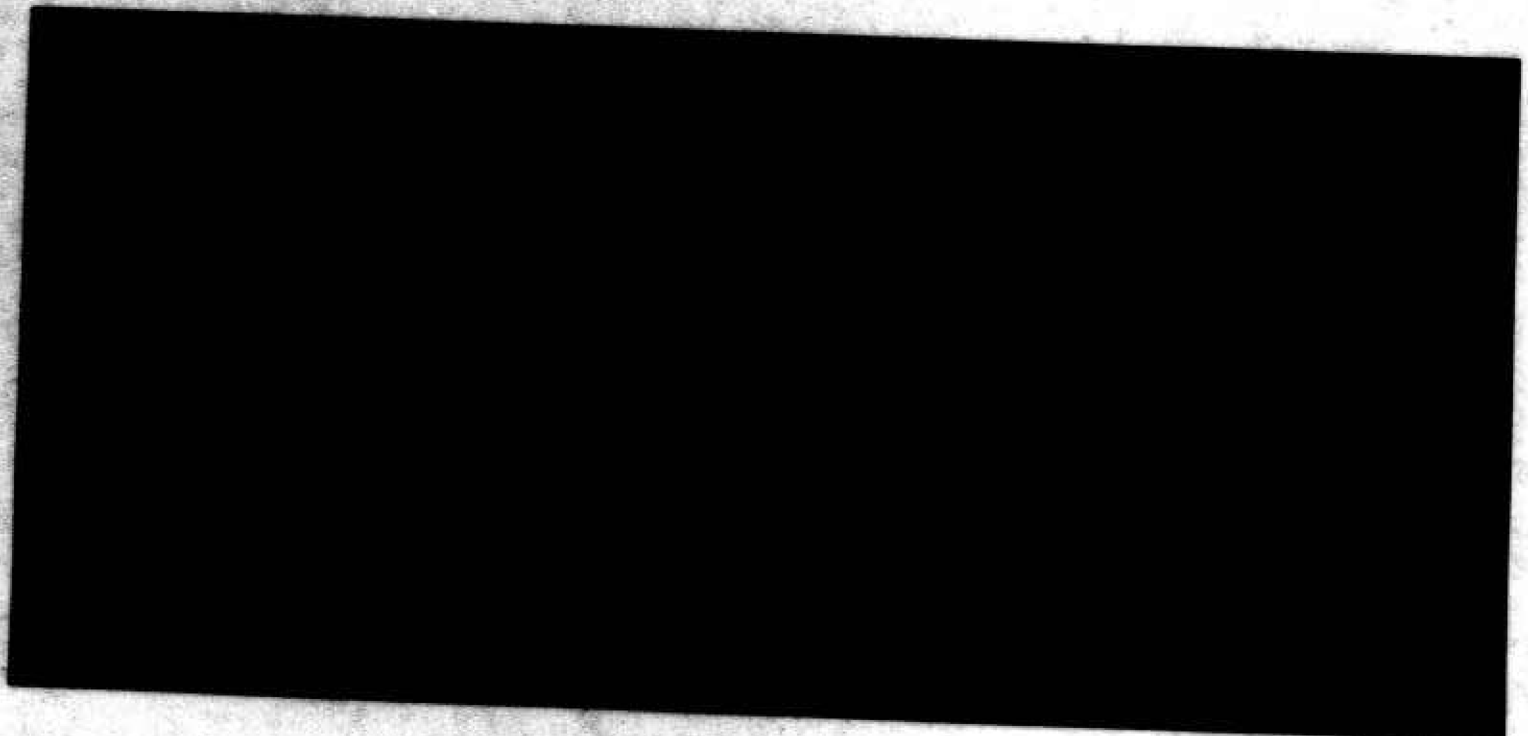

Figure 4 - Model Mounted on Six-Component Electric Strain Gage Balance

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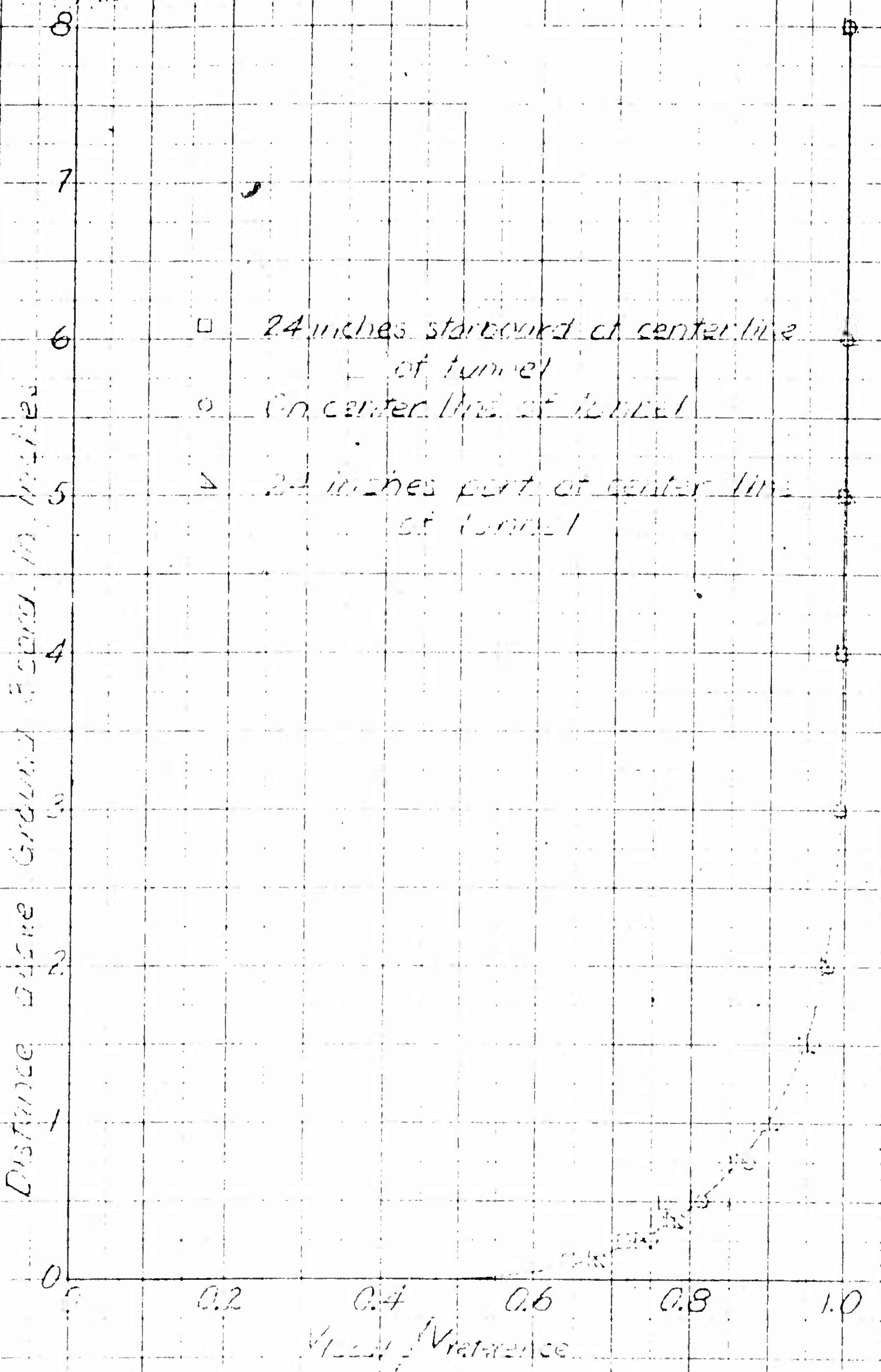

Figure 5 Wind Velocity Profile Measured Above Unobstructed Ground Board

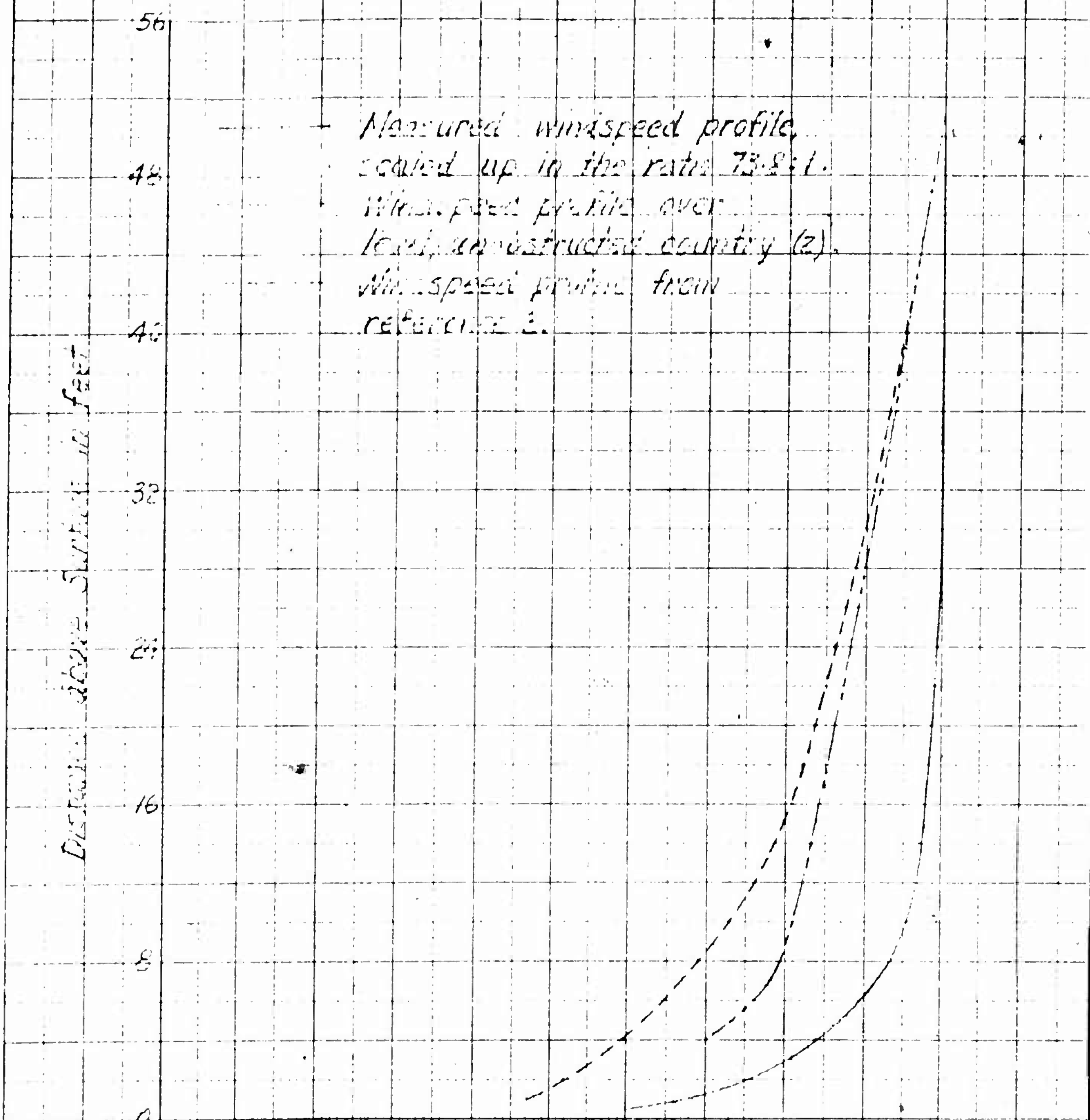

Figure 6 - Windspeed Profiles

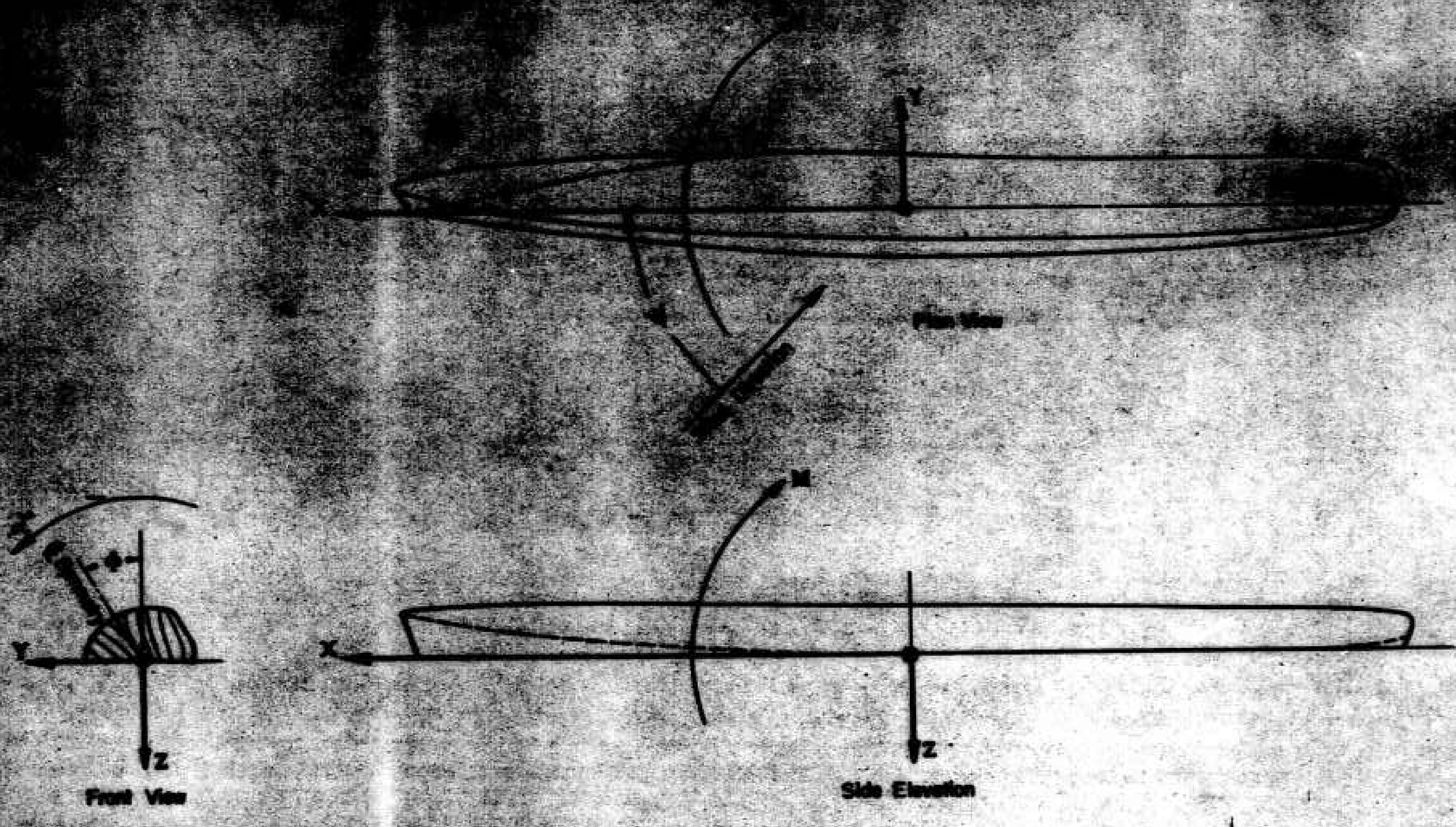

Figure 7 - [illegible] Reference Axes and Positive Directions of Forces and Moments

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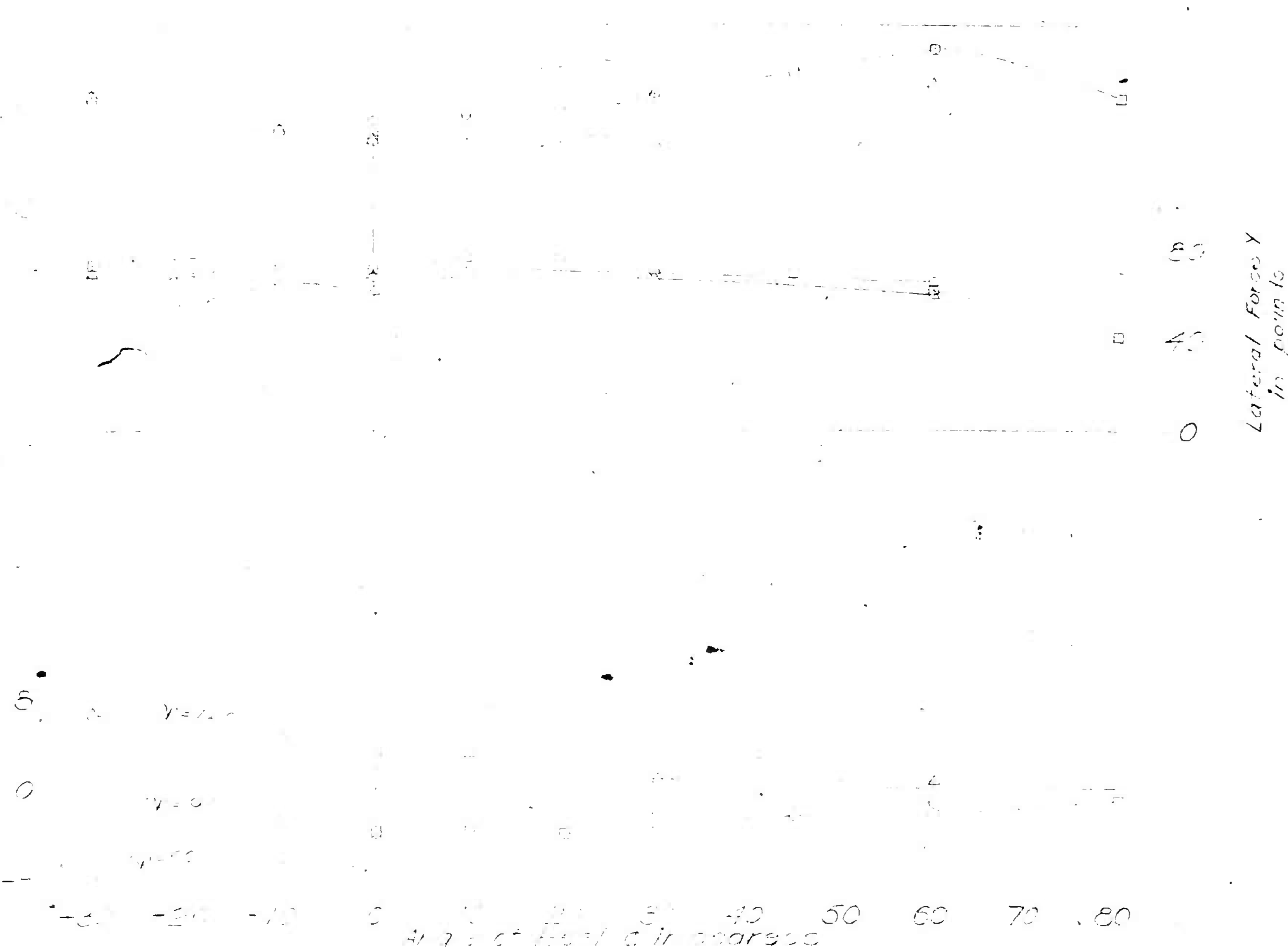
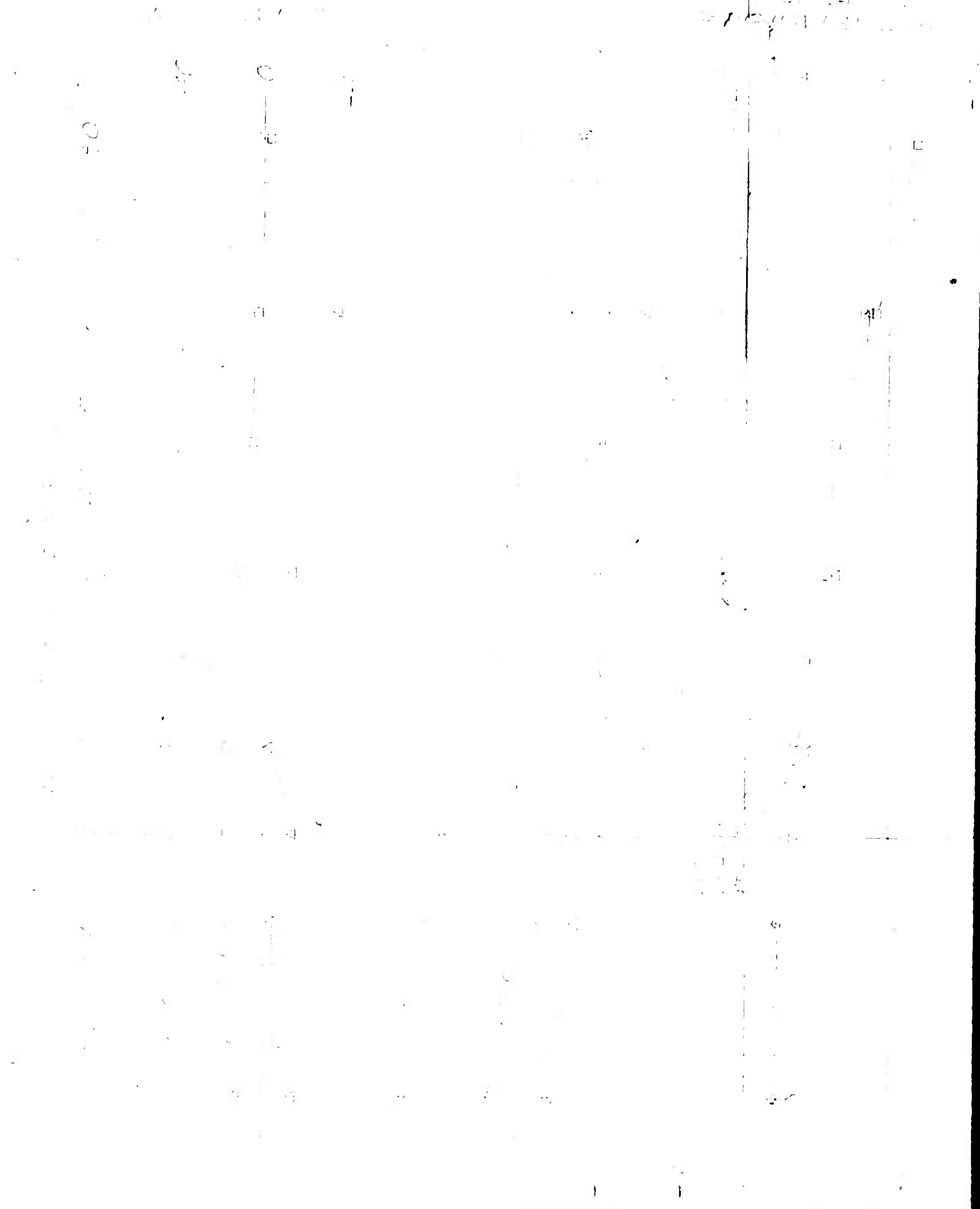


Figure 5 – Variation of Aerodynamic Forces and Moments with Angle of



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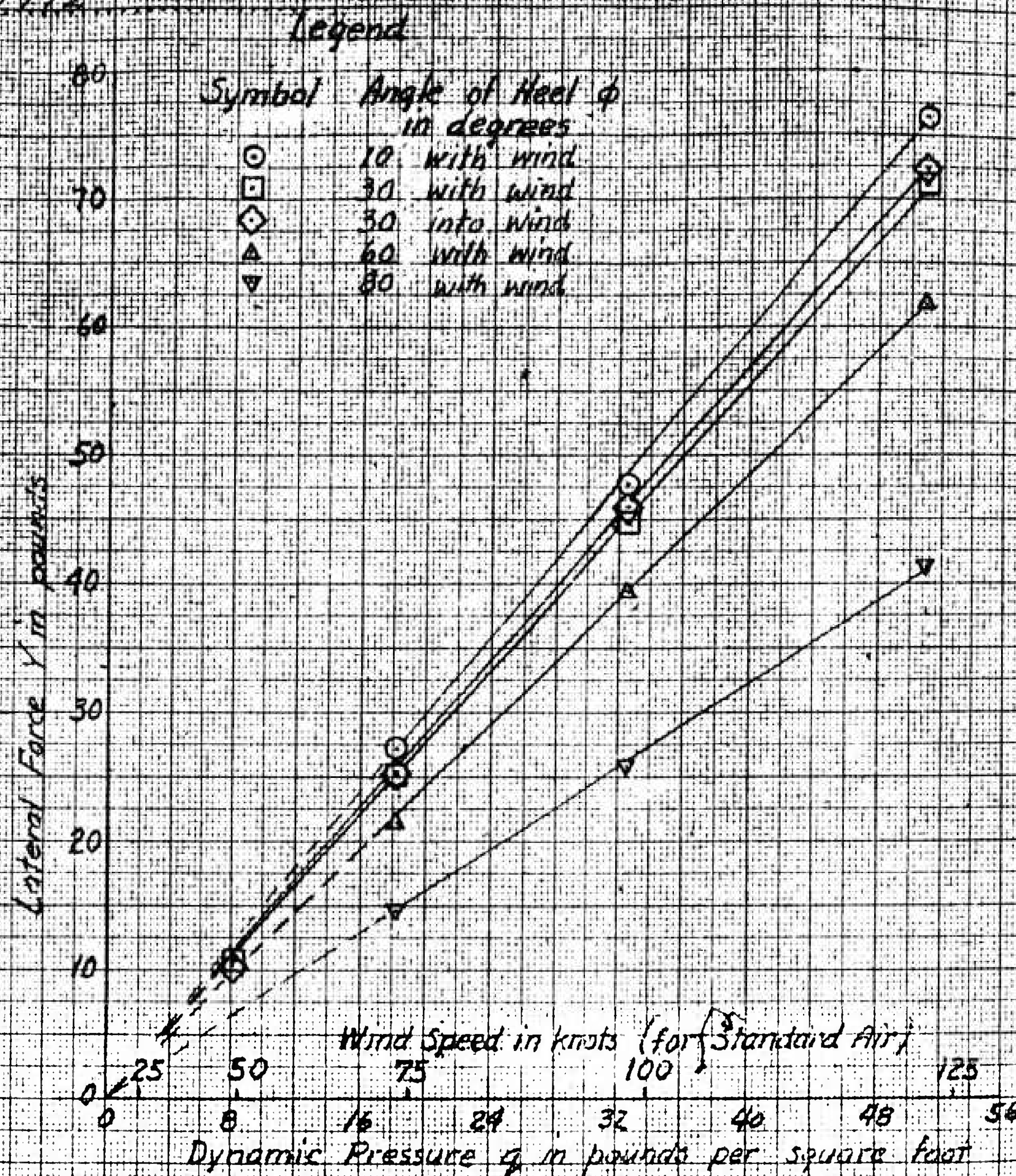

Figure 9 - Variation of Lateral Force with Dynamic Pressure for Various Angles of Heel for the 1:73.8-Scale Models DD692 Class Destroyers with Wind from the Beam

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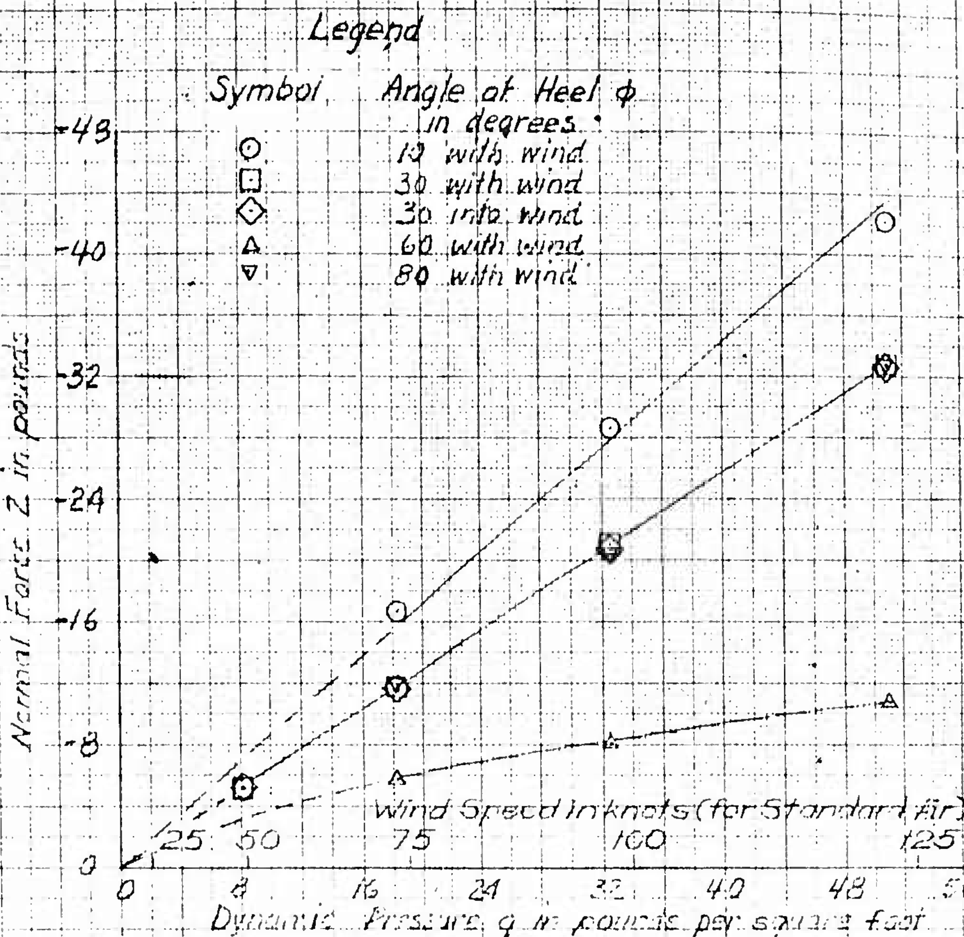

Figure 10 - Variation of Normal Force with Dynamic Pressure for Various Angles of Heel for the 1:73.8-Scale Models DD692 Class Destroyers with Wind from the Beam

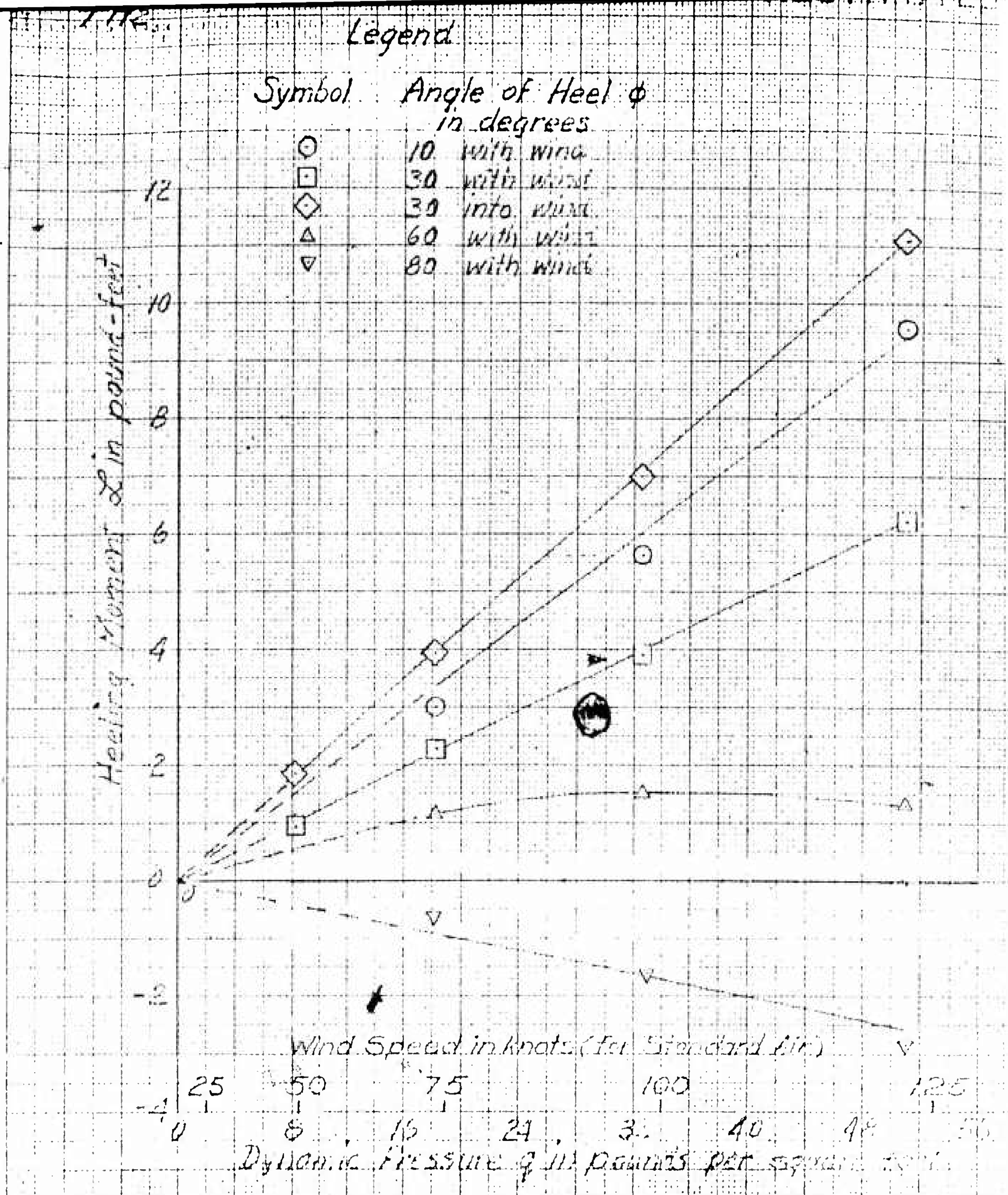

Figure 11 - Variation of Heeling (Rolling) Moment with Dynamic Pressure for Various Angles of Heel for the 1:73.6-Scale Models DD692 Class Destroyers with Wind from the Beam

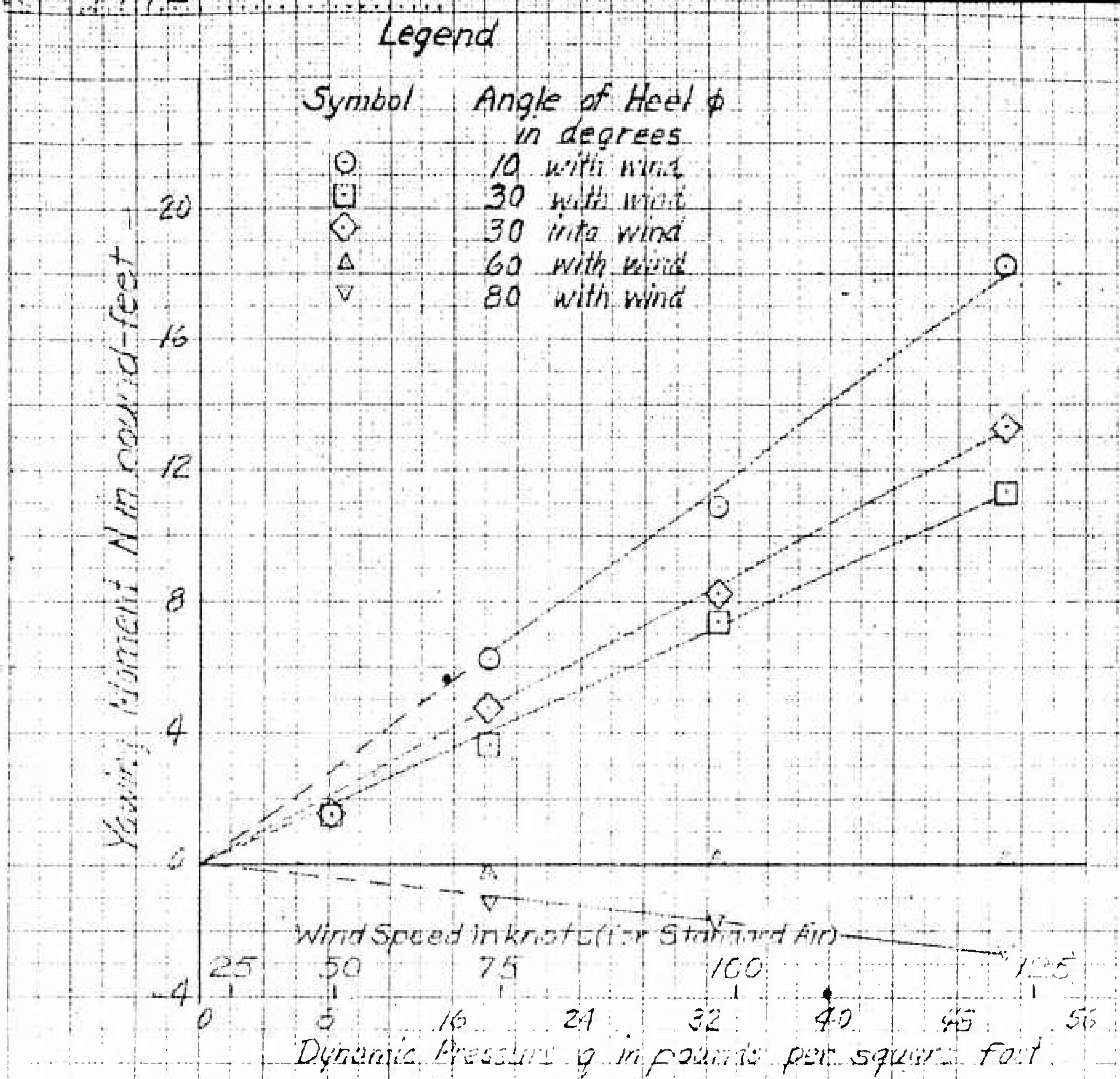

Figure 12 - Variation of Yawing Moment with Dynamic Pressure for Various Angles of Heel for the 1:73.8-Scale Models DD692 Class Destroyers with Wind from the Beam

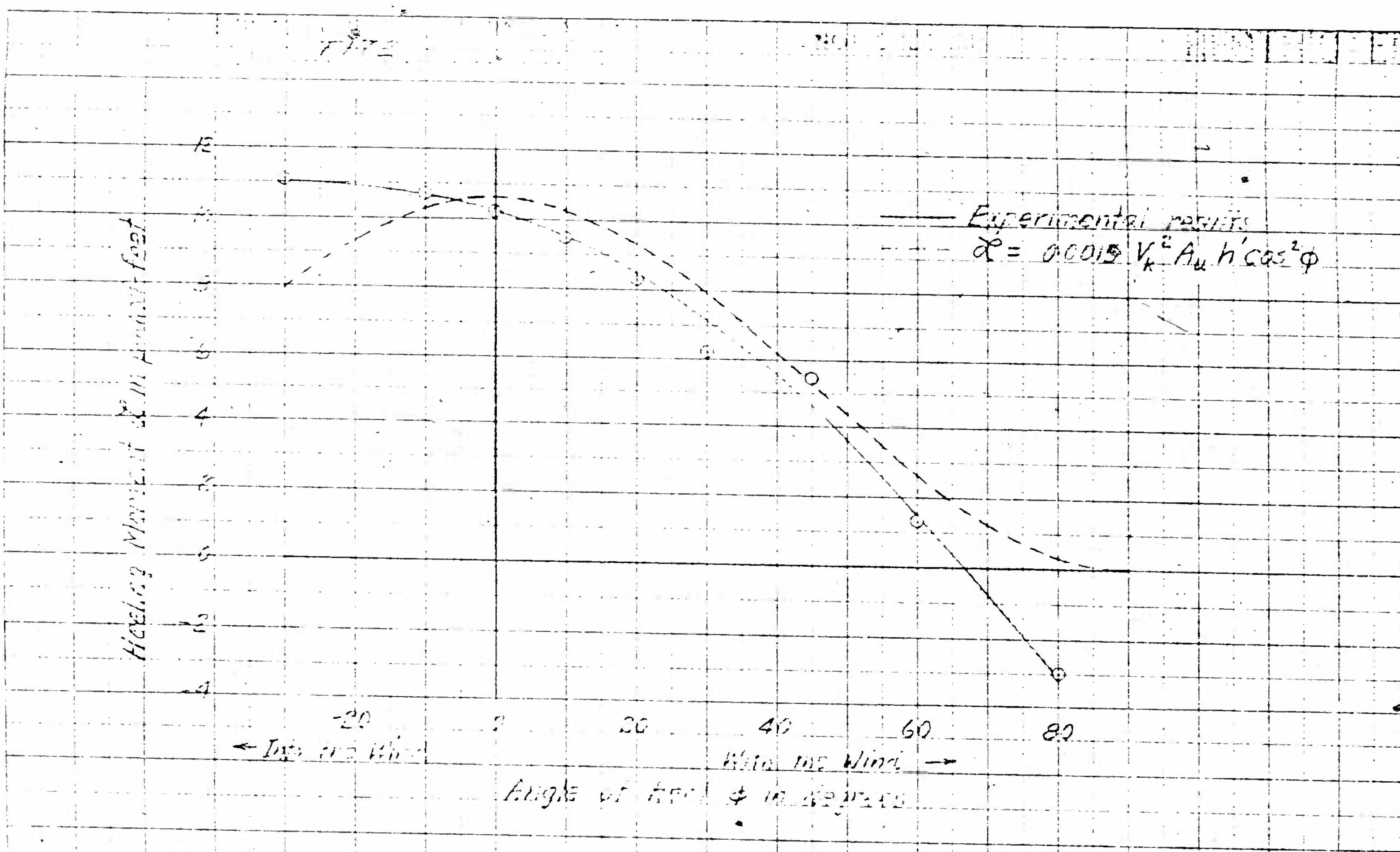

Figure 13 – Variation of Heeling Moment with Angle of Heel for ... -Scale Model of DD 692 Class Destroyer with Wind from ... Average Wind Speed 12.4 knots.