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REPORT 840

EFFECT OF AERODYNAMIC PITCH CONTROL ON THE LOADS AND MOTIONS OF A SEAPLANE IN REGULAR WAVES

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Approved

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Applied Mechanics Group

SUMMARY

An experimental investigation into the effect of aerodynamic pitch control on the behavior of a seaplane model moving at high speed in regular waves is described. Pitch control is applied to reduce the seaplane impact loads and is attained primarily by increasing the stiffness of the seaplane in pitch. A seaplane hull model is used for the tests with the aerodynamic characteristics simulated by mechanical means. The constant-speed impact test technique is employed, which consists essentially of making a number of high-speed taxi runs at 75% of the landing speed and recording the peak vertical and angular accelerations experienced by the model at each contact with the waves. Five different wave sizes are used.

The data obtained are analyzed statistically to find, for each level of pitch control and each wave size, the vertical acceleration exceeded only once in 100 contacts. The effectiveness of pitch control is judged by its ability to attenuate this acceleration. The effect of wave size on the loads and motions is also found.

It is concluded that, except in very steep waves exceeding a height length ratio of 25:1, aerodynamic pitch control has practically no effect on the loads and motions in waves longer than twice the hull length. In short steep waves, doubling the pitch stiffness results in a 20% reduction in the vertical acceleration exceeded only once in 100 impacts.

CONTENTS

Report printed at the Davidson Laboratory
containing 17 pages and 9 figures

NOMENCLATURE

A	pitch damping constant dependent on aircraft geometry
C_L	aerodynamic lift coefficient, $\text{Lift}/\frac{1}{2}\rho V^2 S$
$dC_L/d\tau$	rate of change of lift with trim, per radian
g	acceleration due to gravity, fps^2
H	wave height, ft
K	a constant, $A\ L_T/V$, per sec
L	wave length, ft
L_T	tail arm, distance from wing quarter chord point to horizontal tail quarter chord point, ft
M	aerodynamic pitch moment, lb-ft
$dM/d\tau$	pitch stiffness, lb-ft per radian
dM/dq	pitch damping, lb-ft per radian per sec
n	number of observations in a sample
P	probability that a variate does not exceed a specified amount
q	angular velocity, radian per sec
S	projected lift area, sq ft
V	horizontal velocity, fps
V_v	peak vertical velocity in any one impact, fps
α	peak angular acceleration in any one impact, radian per sec^2
η	peak CG acceleration in any one impact, normal to the forebody keel, g units
$\eta_{.99}$	peak CG acceleration that will only be exceeded once in 100 impacts, on the average, g units

θ slope of wave surface, deg

ρ density of air, slug per cu ft

τ trim angle, angle between horizontal and forebody keel, deg

Subscripts

m maximum value observed in a sample

T referring to horizontal tail of aircraft

INTRODUCTION

In recent years various hydrodynamic laboratories and the aircraft industry have made considerable efforts to improve the rough water performance of seaplanes. If the tactical advantages of seaplanes are to be fully realized they must be capable of operation in all weather, and the particular need for continuing improvement in rough water capability is stressed by a Bureau of Aeronautics publication.[1]

Many studies have been made of the effects on seaplane rough water loads and motions of varying the hull configuration and the aerodynamic characteristics. The present report is one of a series, prepared by the Davidson Laboratory for the Bureau of Naval Weapons, dealing with the landing behavior of seaplanes in rough water. Other reports in this series include Van Dyck,[2] concerning the development of a constant-speed impact testing technique, and Van Dyck,[3] dealing with effects of wing loading, wing lift rate and sternpost angle on landing impact. Further relevant investigations have dealt with the effects of hull length-beam ratio,[4] afterbody length,[5] deadrise,[5] forebody warp[5] and special devices such as hydroskis,[6] on impact characteristics.

Two further aerodynamic parameters, whose effect on landing behavior had not been investigated prior to this investigation, are aerodynamic pitch stiffness and damping. Variation of the stiffness and damping, with the intention of diminishing the landing loads and motions of seaplanes, is called aerodynamic pitch control. It has been found by Schnitzer[6] that when a seaplane with infinite applied aerodynamic pitch stiffness is landed, the maximum impact loads are reduced to 60% of those with zero applied stiffness. Infinite stiffness is achieved by landing the model with the trim fixed, and may be thought of as the ultimate in pitch control. Since a 40% reduction in impact load would be extremely useful in extending the open sea operation of seaplanes, a systematic experimental investigation was undertaken to determine the effect of aerodynamic pitch control at more attainable levels than the fixed trim case.

The results of the experimental investigation of pitch control are reported herein. The purpose of aerodynamic pitch control is set out and a quantitative definition of pitch control is given. The experimental procedures, using the constant-speed impact technique, in various regular waves, are described and the results analyzed statistically.

Object and Definition of Aerodynamic Pitch Control

Pitch control is applied during a seaplane landing runout in order to minimize the oscillations in pitch, specifically to reduce the tendency to pitch-up, and thereby reduce the impact loads.

The definitive discussion by Captain D. B. MacDiarmid[7] of open sea landings makes repeated reference to the need to depress the nose of the landing seaplane while travelling up the back of a swell, so as to reduce the tendency to plane-off--and subsequently crash down--which invariably leads to large impact loads.

Pitch-up seems to be conducive to planing-off. During the later stages of an impact the seaplane tends to develop a nose-up angular velocity, due to the impact load acting forward of the center of gravity, and hence a constantly increasing trim leading to large hydrodynamic lift. This large lift force urges the seaplane out of the water at high speed. If this situation develops on the flank of a wave, so that the effective vertical velocity of the wave is added to the high exit speed, the next contact will be made at a high glide-path angle and will lead to extreme impact loads.

The object of pitch control must then be to attenuate large trim angles, and, if possible, the angular velocities leading to these large trim angles.

Aerodynamic pitch control can be applied both by increasing the pitch stiffness, $dM/d\tau$, and by increasing the pitch damping dM/dq . These two quantities are functionally related; from the expressions given by Van Dyck:[3]

Stiffness, $$dM/d\tau = 1/2\ \rho V^2\ S_T (dC_L/d\tau)_T\ L_T$$

Damping, $$dM/dq = A\ 1/2\ \rho V\ S_T (dC_L/d\tau)_T\ L_T^2$$

hence

$$(dM/dq)(d\tau/dM) = K$$

or

(Damping) x (Compliance) = Constant

where

$$K = A\ L_T/V\ ,\quad \text{Constant for given hull at given speed.}$$

The "compliance" is defined as the reciprocal of the stiffness.

The object of pitch control is to reduce the impact loads by reducing the pitch response of the seaplane. Considering the pitch degree of freedom alone, under the action of a sinusoidal applied torque:

Dynamic pitch response = (Compliance) x (Dynamic Magnification)

At any given exciting frequency the dynamic magnification is a function of the compliance and damping of the system. However, for the seaplane, in which the product of damping and compliance is constant, the dynamic magnification is a function of the compliance only. For most seaplanes the constants in the dynamic magnification formula are such that it is relatively insensitive to variations in compliance. Although a seaplane taxiing in waves is excited in two degrees of freedom, heave as well as pitch, and is excited impulsively rather than sinusoidally, it is assumed that:

Dynamic response $\sim$ Compliance

For the purpose of this report, pitch control is identified with compliance and is measured by the percentage of the design compliance, (i.e., the design value of $d\tau/dM$).

MODEL AND APPARATUS

The model used in the experimental determination of the effect of pitch control was a typical high length-beam ratio (12.5), low sternpost angle (6°) seaplane hull model. The model and setup is shown on Fig 1 and the model lines are shown on Fig 2. This model is the same as that used in previous tests in this series and as an aid to interpret the results is taken to be a 1/20-scale model of a hypothetical prototype.[3] A complete list of the model and prototype characteristics, together with the aerodynamic parameters, is given in Table I.

The tests were run in Tank III at Davidson Laboratory using an apparatus generally similar to that used in previous investigations in this series[2,3] and illustrated in Fig 1. In these tests, however, the wing lift was simulated by a constant force "Negator" spring because it gave a greater freedom in heave than the wing previously used, and it had been established that it was unnecessary to represent the variation of wing lift with trim since this parameter had no effect on landing behavior.[3]

The aerodynamic pitch stiffness, $dM/d\tau$, was simulated by stretched fixed-length coil springs, attached to the model through a pin-connected, adjustable-radius drive link, as shown in the schematic on Fig 1. Variations in the compliance were achieved by adjusting the radius of action of the springs. The aerodynamic pitch damping was simulated by an adjustable area piston moving in a silicone-oil-filled dashpot, and also connected to the model by a pin-connected link. Variations in the damping were made by changing the area of the piston.

The model was attached at its center of gravity to the heave pole with zero roll and yaw angle, free-to-heave, and free-to-trim under the action of the simulated aerodynamic pitching restraints.

The heave and trim of the model were sensed by special transducers incorporating linear differential transformers, attached respectively to the heave pole, and at the center of gravity of the model. The vertical velocity of the center of gravity of the model was picked up by a tachometer driven by the heave pole. The accelerations of the model normal to the forebody keel were sensed by an accelerometer mounted in-line with the center of gravity, and the angular accelerations were sensed by a pair of matched accelerometers mounted 12 in. fore and aft of the center of gravity. A wave-wire was mounted ahead of and to one side of the model.

The signals from the various transducers were relayed by an overhead telemeter cable to an instrument console, and recorded in the form of time histories on an ultra-violet, direct writing optical oscillograph.

TEST PROCEDURE

The constant-speed impact test technique[2] was used for these tests. This technique consists of making constant high-speed taxi runs with the model, in various regular wave trains, at 75% of the landing speed. The following description is given in terms of prototype quantities, Froude scaling being used to reduce these quantities to the 1/20 model scale to preserve dynamic similarity.

For the prototype, with a wing loading of 120 psf, the landing speed is 201 fps, consequently all the tests were run at 151 fps (i.e., a model speed of 33.7 fps). The unloader spring was adjusted to give a corresponding amount of wing lift--56% of the gross weight.

Four levels of pitch control were investigated. The prototype design values were taken to be:

Design pitch compliance	$d\tau/dM = 0.0146/V^2$	radian/lb-ft
Design pitch damping	$dM/dq = 4000\ V$	lb-ft/radian/sec

with a product

$$K = (d\tau/dM)(dM/dq) = 58.4/V \text{ sec}$$

which at a speed of 151 fps becomes:

$$K = 0.386 \text{ sec}$$

As the compliance was varied the damping was adjusted to preserve this constant product.

The four levels of pitch control used were 100%, 50%, 25% and 0% of the design compliance. The last case of zero compliance is the fixed trim case, for which the landing trim was fixed at 6°. In the other cases the zero moment trim in the air was adjusted to 6° by varying the point of attachment to the coil springs. Since the sternpost angle was also 6°, a zero moment trim of 6° simulated a reasonable landing attitude while enhancing the chance for forebody contact with the waves without afterbody interference. In this investigation interest was concentrated on the effect of pitch control, rather than on practical means for implementing pitch control, which accounts for the inclusion of the fixed trim case as an end point.

The effect of pitch control in five regular wave sizes was investigated, covering three heights and three lengths, as follows:

	6 x 120 ft	
4 x 240 ft	6 x 240 ft	8 x 240 ft
	6 x 360 ft	

The effect of the four levels of pitch control in each of these five waves was investigated, with the exception that the 50% compliance case in the 4 x 240 ft waves was omitted, because in this wave the effect of pitch control was found to be clearly negligible. The constant-speed runs made in each of the wave trains was sufficiently prolonged so that a minimum of 46 major contacts with the waves were recorded, in order to obtain a fair size sample.

RESULTS

The results of the tests are tabulated in Tables II and III. Included in Table II are the test conditions, the number of hull-wave contacts observed (i.e., the sample size), and the maximum impact acceleration, maximum angular acceleration, and a maximum vertical sink speed in the sample. The approach conditions just prior to the maximum impact acceleration are also given. A number of derived quantities are also listed in Table II, such as the mean maximum impact acceleration in the sample and the acceleration exceeded once in 100 impacts. Frequency tables of the observed distribution of the normal impact acceleration are given in Table III for each of the test conditions.

ANALYSIS

Analysis of the effect of aerodynamic pitch control presents certain difficulties, since the primary quantity used to measure the effect in these tests, namely the peak impact accelerations, are themselves highly variable. During a high-speed taxi run in regular waves, with any fixed amount of pitch control, the model will encounter the waves in a variety of attitudes and with various vertical velocities, and as a result of these encounters will exhibit widely different peak accelerations. Thus from any one high-speed taxi run, simulating a take-off or landing runout, a whole group of peak accelerations is available. If a valid analysis is to be made, the essential problem is: What aspect of the distribution of impact accelerations should be reported as the best measure of the effectiveness of pitch control? Three possibilities were considered and are discussed below.

<u>The largest acceleration in the sample</u> While the largest observed acceleration has been used in previous reports in this series, experience indicates that it is not altogether satisfactory. The observed largest is the most unstable measure of a sample, because in repeated samples--of the same size--the size of largest acceleration will vary widely from sample to sample.[3] This situation is aggravated when, as in the present case, the samples are not of the same size. A further objection is that reporting only the largest in the sample is most uneconomical of the data, since all the information in the rest of the sample is neglected.

<u>The mean impact acceleration</u> The mean acceleration, calculated as the average of all the peak accelerations in the sample, is the most stable statistic of the distribution. However it suffers from the disadvantage that it does not reflect the spread of the data about the mean. If, for instance, the pitch control only attenuated the larger accelerations, the mean would be a relatively insensitive measure of this fact. In the present tests the mean seemed to be altogether too stable. A study of the mean accelerations given in Table II shows little variation with either pitch control or wave size, with the exception of the 8 x 240 ft wave.

<u>The acceleration exceeded once in 100 impacts</u> The acceleration that will only be exceeded in one impact out of 100, on the average, can be calculated from the sample if its distribution is known. This calculation conserves all the information in the sample and yields a measure which might well be indicative of the largest acceleration that might be experienced in a seaplane landing. The particular probability level is chosen because it represents a fairly low probability which does not involve much extrapolation of the data available. The drawback of this method of measuring pitch control effectiveness is that, strictly speaking, it depends upon a knowledge of the statistical distribution of the accelerations. Nonetheless it was decided to use the acceleration exceeded once in 100 impacts in this analysis.

An attempt to discover, on theoretical grounds, the statistical distribution of the peak accelerations in a high-speed taxi run proved fruitless. It is known that the largest acceleration in a seaplane landing has a distribution known as the "distribution of extremes".[8] This is the distribution studied exhaustively by Gumbel.[9] Since the peak accelerations in a high-speed taxi run, generated by the constant-speed impact test technique, are related to the largest landing accelerations, it was thought that they might both have the same distribution. Judging from the data, however, such did not appear to be the case.

In order to proceed with the analysis, it is assumed that the peak accelerations in any one run are normally distributed. No significance should be attached to this assumption which is made for purely heuristic reasons. The data in each sample is grouped in the manner shown in the frequency tables, Table III, at intervals of 0.5g, and plotted on normal probability paper on Fig 3 to 7.

Normal probability paper is ruled in such a manner that when a normal distribution of a variate is plotted on it, a straight line results. Consequently when a sample from a normal distribution is plotted on normal probability paper a straight line may be fitted to the data and readily extrapolated. The methods used for plotting the data and finding the best straight line fit to the data are given by Gumbel.[9]

In Fig 3 to 7 the impact accelerations are plotted against their probability of not being exceeded, and each figure shows the data collected in one size of wave and the effect of pitch control. On Fig 3, for instance, with 100% compliance, the probability of not exceeding 4g accelerations may be read off the fitted line as 0.81, and conversely the probability of exceeding 4g as 0.19, in a high-speed taxi run. In each case the lines are extrapolated to a probability of $P = 0.99$ and the corresponding acceleration read off. Hence the acceleration only exceeded once in 100 impacts, on the average, is found and is denoted by $\eta_{.99}$. The acceleration exceeded only once in 100 impacts is shown plotted as a function of the pitch control on Fig 8 for each wave size.

The acceleration exceeded once in 100 impacts is plotted as a function of wave slope for all the waves tested at the top of Fig 9. Also shown on this plot is the effect of wave slope on the observed maximum vertical velocity and observed maximum angular acceleration, with pitch control as a parameter. Because pitch control has little effect on the vertical impact acceleration (cf. Fig 8), a statistical analysis of the vertical velocities and angular accelerations is not warranted and the observed maxima are plotted on Fig 9 to obviate finding the values exceeded only once in 100 impacts.

DISCUSSION

The effect of pitch control on the prime criterion, the vertical acceleration, may be judged from both Fig 8 and 9. Apparently pitch control has no effect except in the steepest wave, 6 x 120 ft. In this wave the acceleration $\eta_{.99}$ increases with increasing compliance at a rate of 2.44g per 100%, so that halving the pitch compliance in this steep wave reduces the acceleration exceeded once in 100 impacts by 1.22g or about 20%. This trend may be fortuitous. The total increase in acceleration as the compliance varies from 0 to 100% is no greater than the variability of the data in the other waves, which is clearly random.

Pitch control has no effect on the maximum vertical velocity in any of the waves until the end point of fixed trim is reached. Since fixing the trim does not have a similar effect on the acceleration, there is apparently little correlation between the maximum vertical velocity and the vertical acceleration. Judging from the results shown on Fig 9, the vertical velocity is a function of the wave height and slope, whereas the vertical and angular accelerations are functions of the wave slope only.

The maximum angular accelerations are unaffected by pitch control except at the end point of fixed trim, when they are naturally reduced to zero.

The explanation for the observed inability of pitch control to modify the impact loads and motions in waves is thought to be of the following nature. When the seaplane hits the water surface it experiences an impulsive load of short duration compared to the natural period of the seaplane in pitch. Therefore the trim does not alter significantly during the impact; this conclusion is borne out by a study of the experimental records. Thus increasing the pitch stiffness can only reduce the already small trim increment. Since the trim is relatively unaffected by pitch control during the impact, the water exit speed will also be unaffected and consequently the vertical velocity prior to the next impact will be unaltered by pitch control. The tests confirm that pitch control does not affect the maximum vertical velocity. Since pitch control cannot affect either the behavior in the water or the approach conditions for subsequent impacts it seems reasonable that the impact loads should be relatively unaffected by pitch control.

MacDiarmid's[7] advice to hold the nose down while planing on waves probably applies explicitly to planing. During the impact process, however, it seems that there would be insufficient time for the pilot to influence the behavior of the seaplane.

As for the effect of wave size, the acceleration exceeded once in 100 impacts is a linear function of wave slope, H/L, and independent of wave height, as noticed by Parkinson[5] in the case of seaplane landings, at least for waves longer than about twice the hull length. In this investigation the effect of pitch control was studied in a number of representative waves, without attempting a systematic investigation of the effect of wave size. It is unfortunate that a systematic study of the effect of wave size on seaplane landing impact does not exist and that therefore a more explicit statement of the effect of wave size cannot be made. The series of NACA investigations of this subject summarized by Parkinson[5] are too narrow in scope and are in any event marred by certain anomolies some of which are noted by Parkinson[5] and Locke.[10]

The assumption that the peak accelerations, generated by the constant-speed impact testing technique, are normally distributed does not seem to be contradicted by the sample distributions shown on Fig 3 to 7. When the same data are plotted on paper designed to linearize the "distribution of extremes," which is the known distribution of the largest acceleration in a number of seaplane landings,[8] a nonlinear curve is obtained indicating that the accelerations in a high-speed taxi run and the accelerations in a series of landings have different distributions. This does not mean that the two accelerations are not correlated, but it does raise some question as to how the forecast of landing accelerations should be made from high-speed taxi acceleration, and in fact how the two are correlated. It also raises a question as to the sample size to be used in the constant speed technique: Van Dyck[2] has shown that by using a sample size of 45 impacts there is a probability of 0.9 that 95% of the distribution of taxi impacts, from which the sample came, will be smaller than the observed maximum; however, there is no guarantee that this covers 95% of the distribution of landing impacts since the two distributions are different.

The value of the constant-speed impact testing technique is that it facilitates the evaluation of parametric alterations in seaplane characteristics, and serves to discover those characteristics that can have a beneficial effect on seaplane impact and are worthy of development.

CONCLUSIONS

As a result of the experiments reported herein it is concluded that aerodynamic pitch control has no effect on seaplane impact accelerations in waves whose height-length ratio does not exceed 1:25. In steeper waves of 1:20 height-length ratio, doubling the aerodynamic stiffness results in a 20% reduction in the vertical acceleration exceeded only once in 100 impacts. There is no discernible effect of pitch control on either the maximum vertical velocity or the maximum angular acceleration for practical amounts of pitch control.

It is found that the distribution of impact accelerations in a high-speed taxi run, as generated by the constant-speed impact test technique, differs from the distribution of maximum accelerations in a series of seaplane landings, and that therefore caution must be exercised in forecasting the latter from the former. The usefulness of the constant-speed technique as an exploratory device is confirmed.

The general trend for impact accelerations to increase with wave slope, found by earlier investigators, is evident in these tests provided the waves are longer than twice the hull length. A systematic study of the effect of wave size on seaplane impact is still needed.

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TABLE I

MODEL AND PROTOTYPE CHARACTERISTICS

	Model	Prototype
Scale	1/20	1/1
Gross weight, lb	17.76	145,800
Position of CG		
Forward of step apex, ft	0.222	4.44
Above forebody keel, ft	0.675	13.50
Pitching radius of gyration, ft	1.01	20.20
Landing speed, fps	44.90	201.0
Test speed, 75% landing speed, fps	33.70	151.0
Pitch stiffness at test speed, $dM/d\tau$, lb-ft/radian	9.75	156.0×10^4
Pitch damping at test speed, $dM/d\dot{q}$, lb-ft/radian/sec	0.845	60.4×10^4
Maximum beam, ft	0.45	9.00
Forebody length, ft	2.696	53.93
Afterbody length, ft	2.928	58.57
Length-beam ratio	12.5	12.5
Step height, percent beam	8.33	8.33
Sternpost angle, deg	6.0	6.0
Forebody deadrise at step, deg	22.5	22.5
Included angle of step, deg	120.0	120.0

TABLE II

RESULTS OF IMPACT TESTS AT 151 FPS
(Full Size Values)

Wave	Compliance	Sample Size	Observed Maxima			Approach for η_m			Acceleration	
			η_m	V_{v_m}	α_m	θ	τ	V_v	Avg	P = .99
ft	%		g	fps	rad/sec^2	deg	deg	fps	g	g
6x120	100	77	5.2	7.3	18.2	9.0	8.4	1.0	2.62	6.26
	50	83	4.5	6.8	12.3	8.8	7.5	4.2	2.63	4.99
	25	82	4.1	6.3	12.3	8.8	7.1	5.7	2.74	4.11
	0	78	3.8	3.7	0	7.7	6.0	3.4	2.54	3.82
6x240	100	97	8.4	18.9	27.4	4.4	10.7	17.1	3.39	7.96
	50	69	7.8	18.1	23.5	4.4	5.9	17.0	3.18	6.64
	25	103	6.6	18.7	16.3	4.5	7.5	18.7	2.82	6.03
	0	87	7.4	15.6	0	4.3	6.0	15.4	3.34	7.45
6x360	100	53	5.6	21.0	14.9	1.8	4.6	20.3	2.89	5.66
	50	46	6.3	20.2	18.3	2.6	5.1	19.0	3.33	6.60
	25	71	6.4	19.0	11.0	2.3	7.8	17.7	2.44	5.42
	0	71	3.9	14.8	0	3.0	6.0	7.6	2.53	4.11
4x240	100	63	4.6	13.1	14.9	2.7	3.7	10.2	2.62	4.96
	50	-	Not Tested -							
	25	71	4.7	13.2	11.5	2.6	5.1	12.0	2.78	5.07
	0	93	4.4	11.7	0	2.7	6.0	10.3	2.22	4.32
8x240	100	63	7.5	19.0	30.8	4.9	4.8	17.5	4.72	8.03
	50	65	9.8	20.3	35.3	6.0	5.2	18.3	5.09	9.90
	25	72	9.5	19.3	28.9	6.0	5.9	18.8	5.11	10.34
	0	75	7.9	13.2	0	6.0	6.0	12.0	5.26	10.37

TABLE III

FREQUENCY OF OCCURRENCE OF PEAK
CG ACCELERATION AT 0.5g INTERVAL
(η_u = upper bound of interval)

	6x120 ft Wave Compliance-percent				6x240 ft Wave Compliance-percent			
η_u	100	50	25	0	100	50	25	0
0.5	10	1			6		4	6
1.0	6	2			8		5	7
1.5	6	7	2	3	5	6	3	0
2.0	5	13	7	7	3	8	10	6
2.5	6	11	9	21	7	9	22	4
3.0	3	19	39	34	8	13	17	10
3.5	13	14	21	11	12	9	18	13
4.0	10	8	2	2	16	8	6	7
4.5	14	7	2		7	5	7	11
5.0	3	1			5	3	3	8
5.5	1				7	2	3	7
6.0					5	2	3	4
6.5					4	3	1	3
7.0					0	0	1	0
7.5					1	0		1
8.0					1	1		
8.5					2			
n	77	83	82	78	97	69	103	87
Average	2.62	2.63	2.74	2.54	3.39	3.18	2.82	3.34
Standard Deviation	1.49	0.96	0.56	0.52	1.89	1.41	1.32	1.68

TABLE III (Contd.)

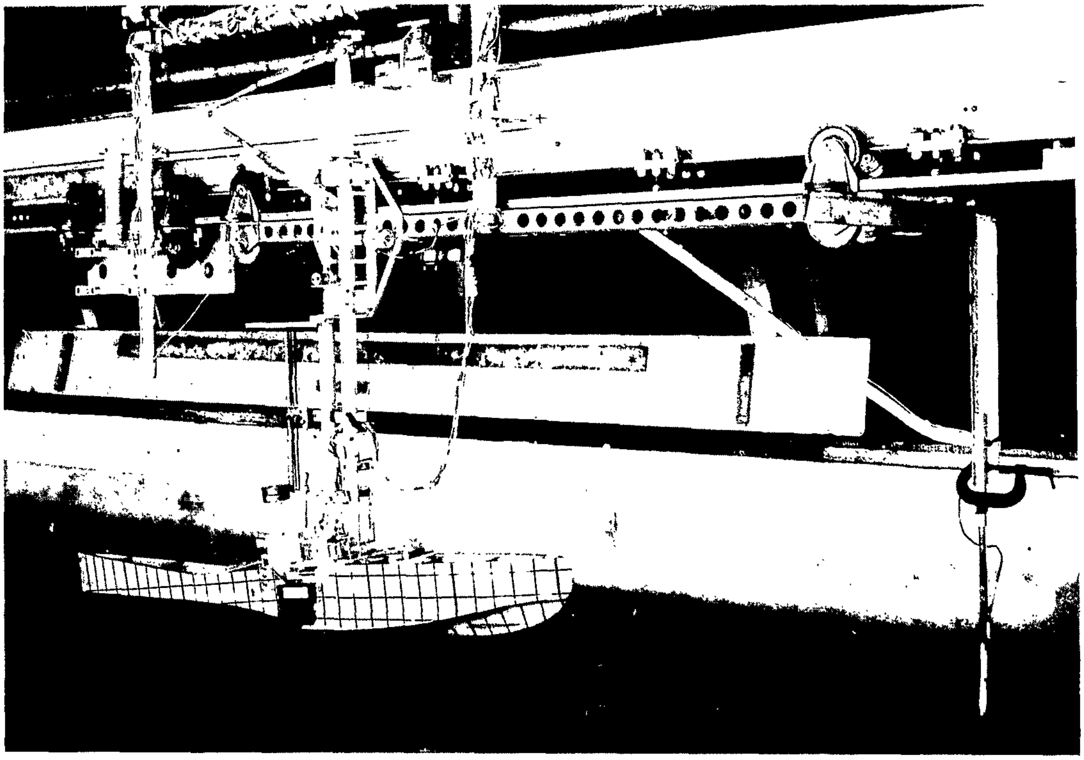
	6x360 ft Wave Compliance-percent				4x240 ft Wave Compliance-percent			
η_u	100	50	25	0	100	50	25	0
0.5								3
1.0		1		1	3		1	3
1.5	1	1	18	3	3		5	10
2.0	6	3	14	9	10		5	20
2.5	22	9	9	19	13		19	22
3.0	5	7	13	21	13		15	19
3.5	6	7	5	14	8		10	9
4.0	4	4	3	4	7		7	4
4.5	2	4	3		5		5	3
5.0	3	3	1		1		4	
5.5	2	4	4					
6.0	2	2	0					
6.5		1	1					
n	53	46	71	71	63		71	93
Average	2.89	3.33	2.44	2.53	2.62		2.78	2.22
Standard Deviation	1.12	1.30	1.21	0.65	0.95		0.94	0.86

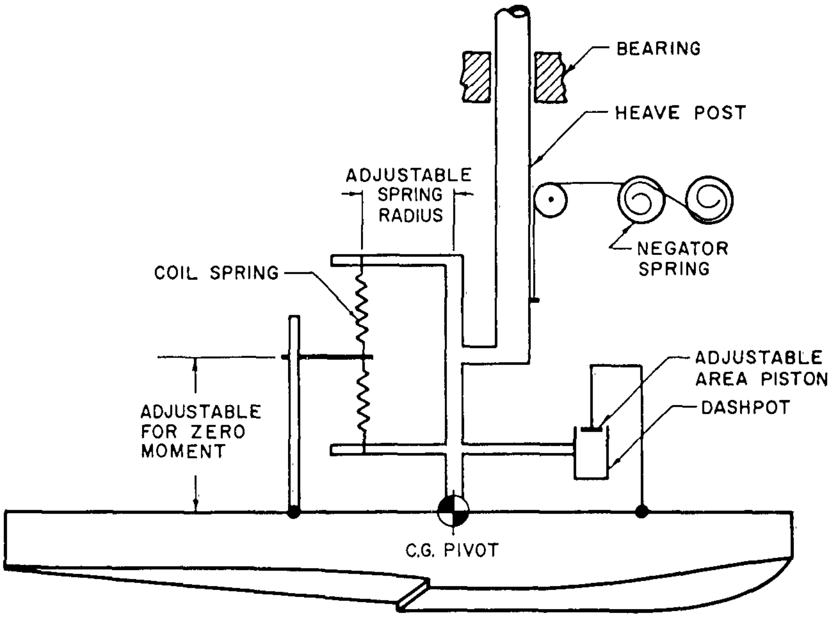
TABLE III (Concld.)

8x240 ft Wave
Compliance-percent

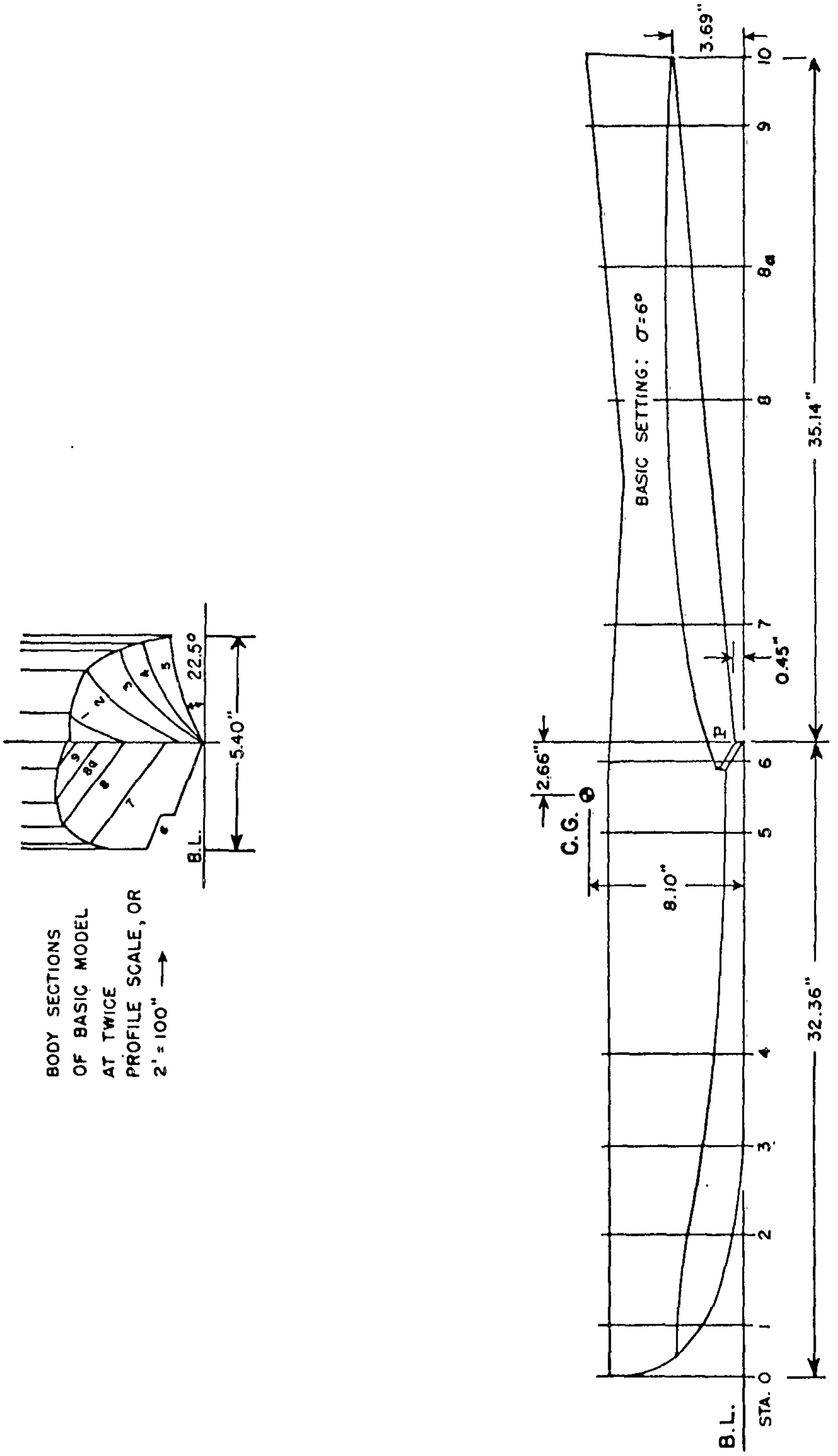
η_u	100	50	25	0
0.5			1	1
1.0	1	2	3	2
1.5	0	3	0	5
2.0	1	0	3	1
2.5	1	2	1	1
3.0	2	3	4	0
3.5	8	0	4	6
4.0	3	3	4	4
4.5	6	5	6	3
5.0	17	5	5	5
5.5	6	18	7	3
6.0	7	11	11	7
6.5	5	4	4	8
7.0	3	2	6	10
7.5	3	0	3	14
8.0		1	4	5
8.5		1	3	
9.0		1	0	
9.5		3	2	
10.0		1	1	
n	63	65	72	75
Average	4.72	5.09	5.11	5.26
Standard Deviation	1.35	1.96	2.14	2.09

MODEL SETUP AND APPARATUS

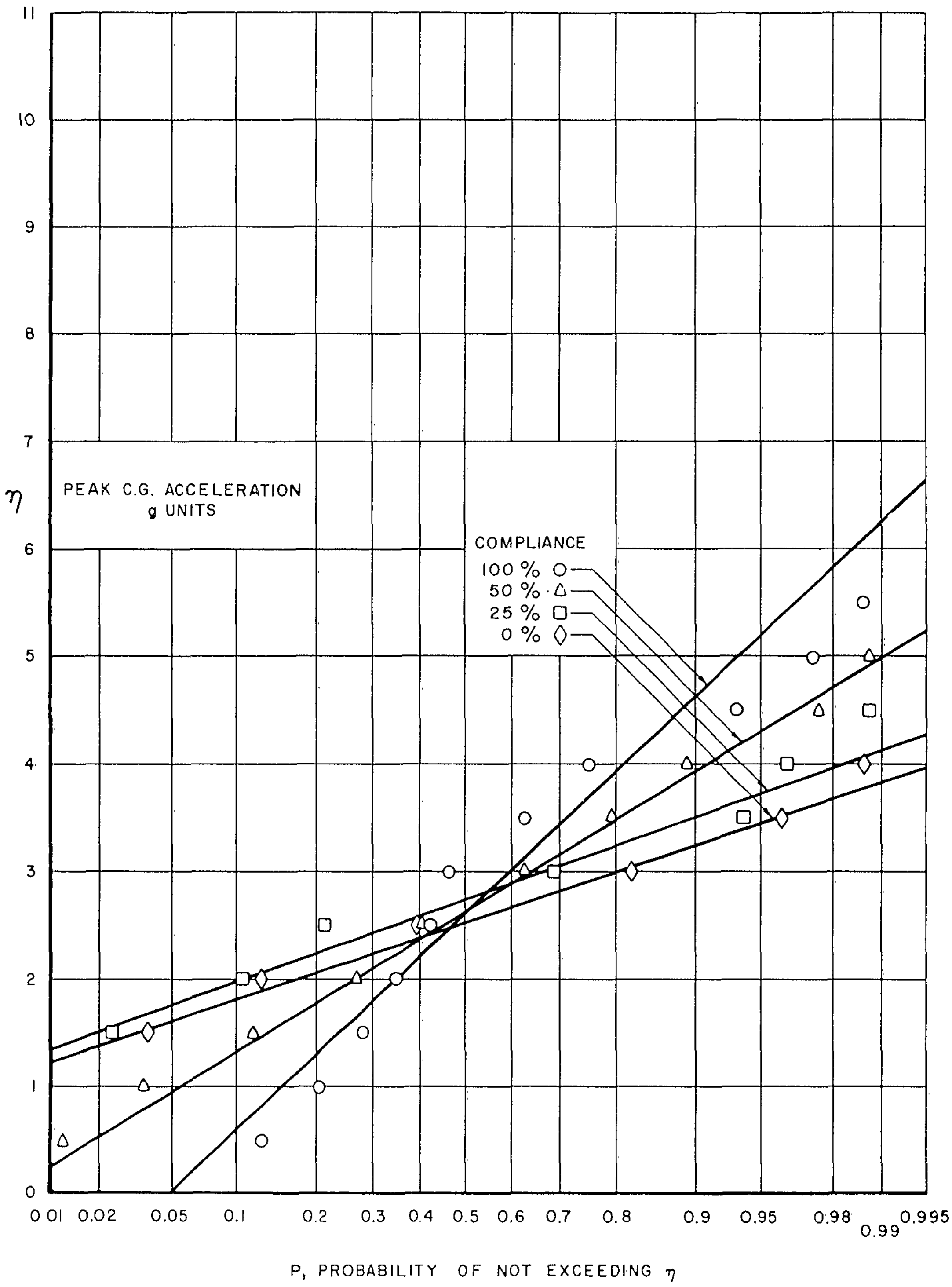




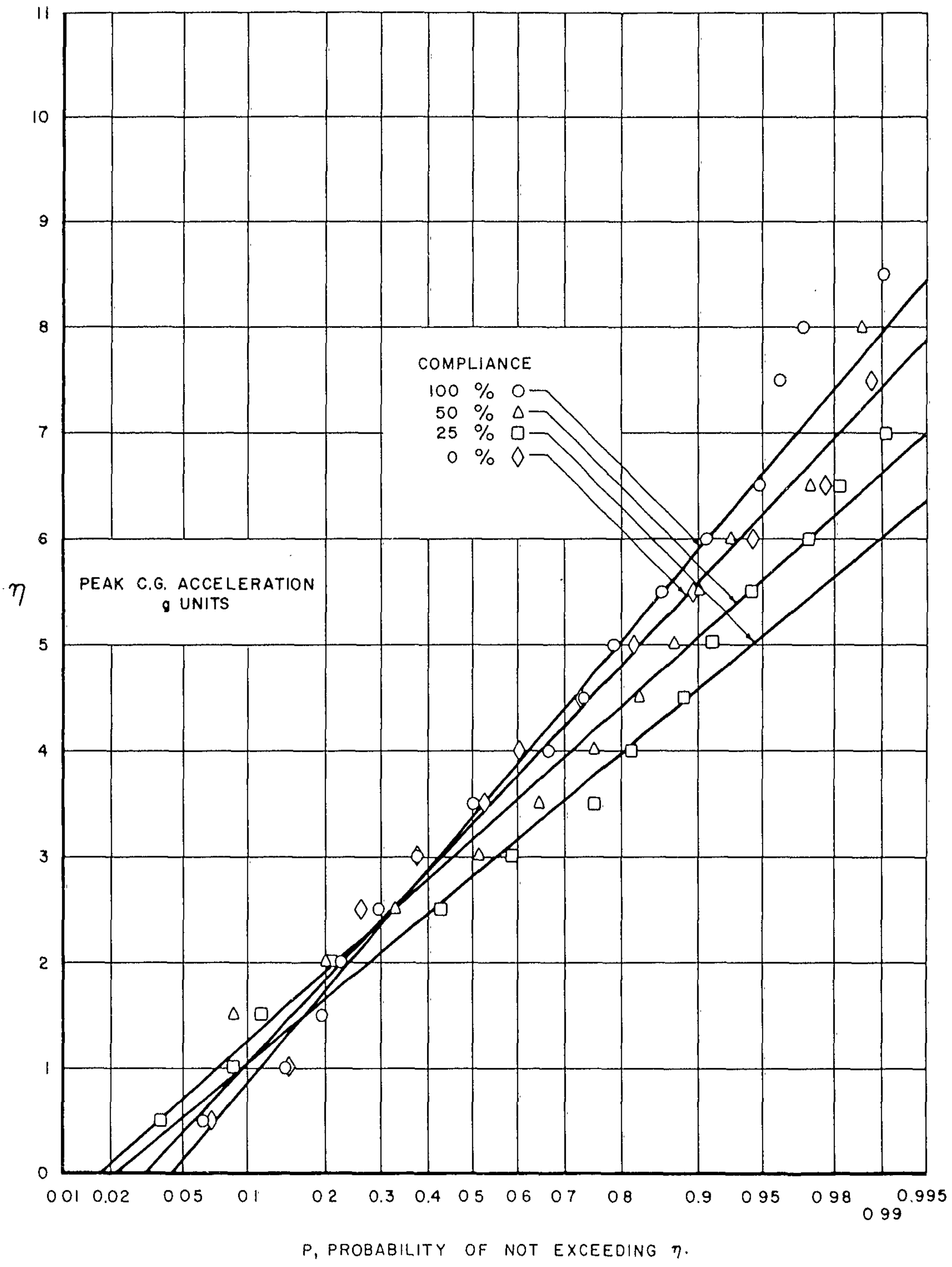
MODEL HULL LINES AND DIMENSIONS



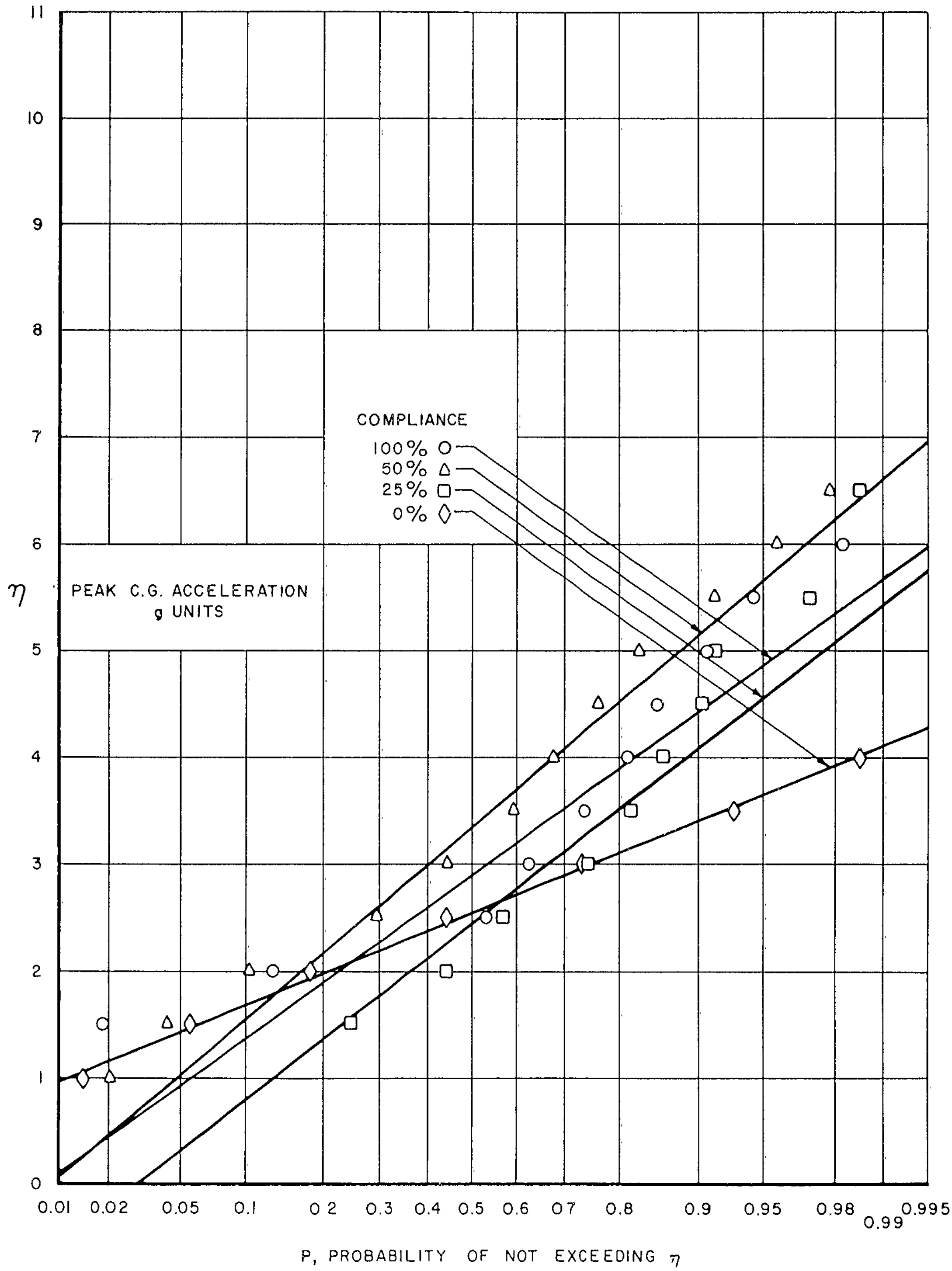
DISTRIBUTION OF C.G. ACCELERATION IN 6 x 120 FT WAVES



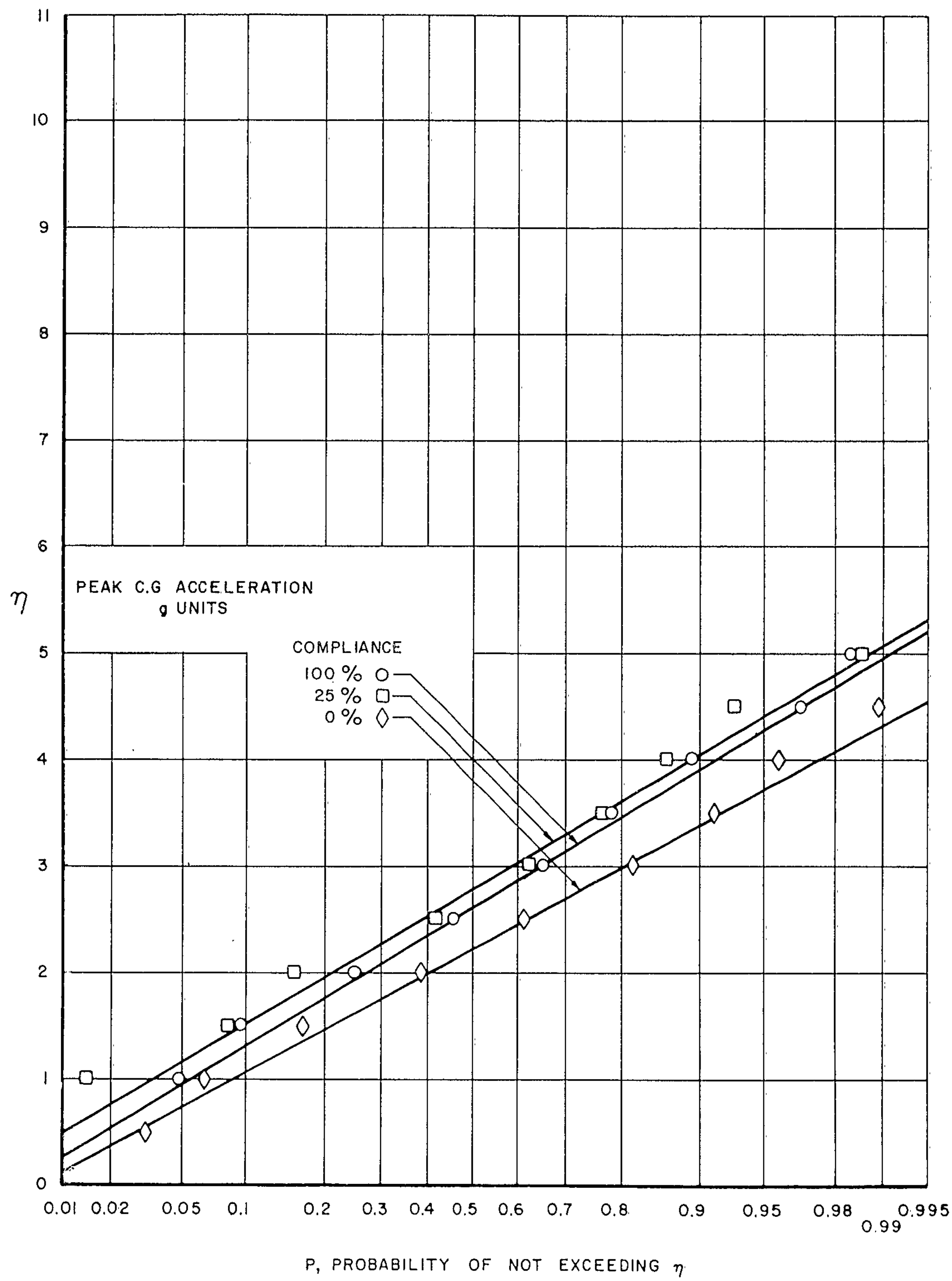
DISTRIBUTION OF C.G. ACCELERATION IN 6 x 240 FT. WAVES



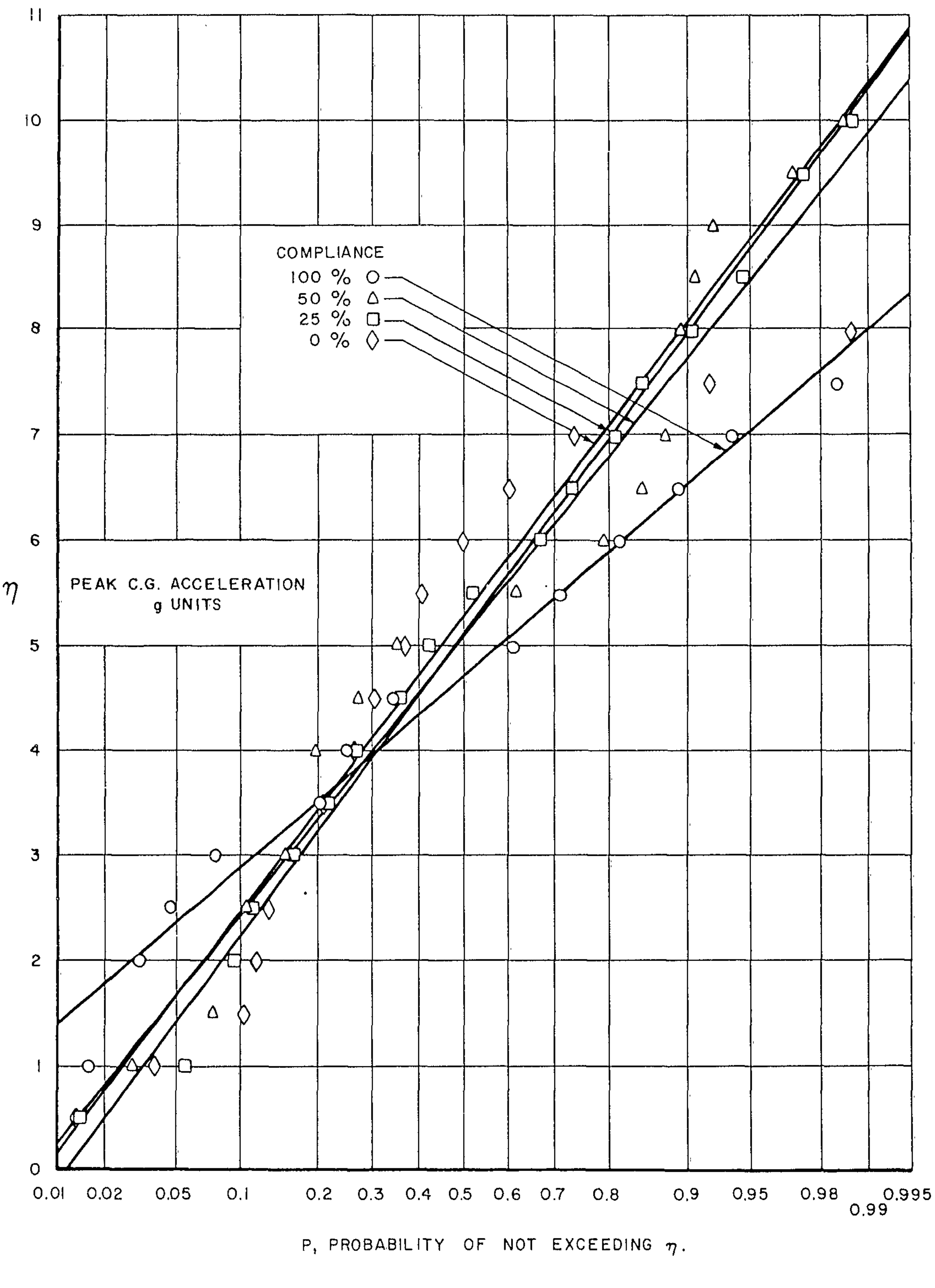
DISTRIBUTION OF C.G. ACCELERATION IN 6 x 360 FT WAVES



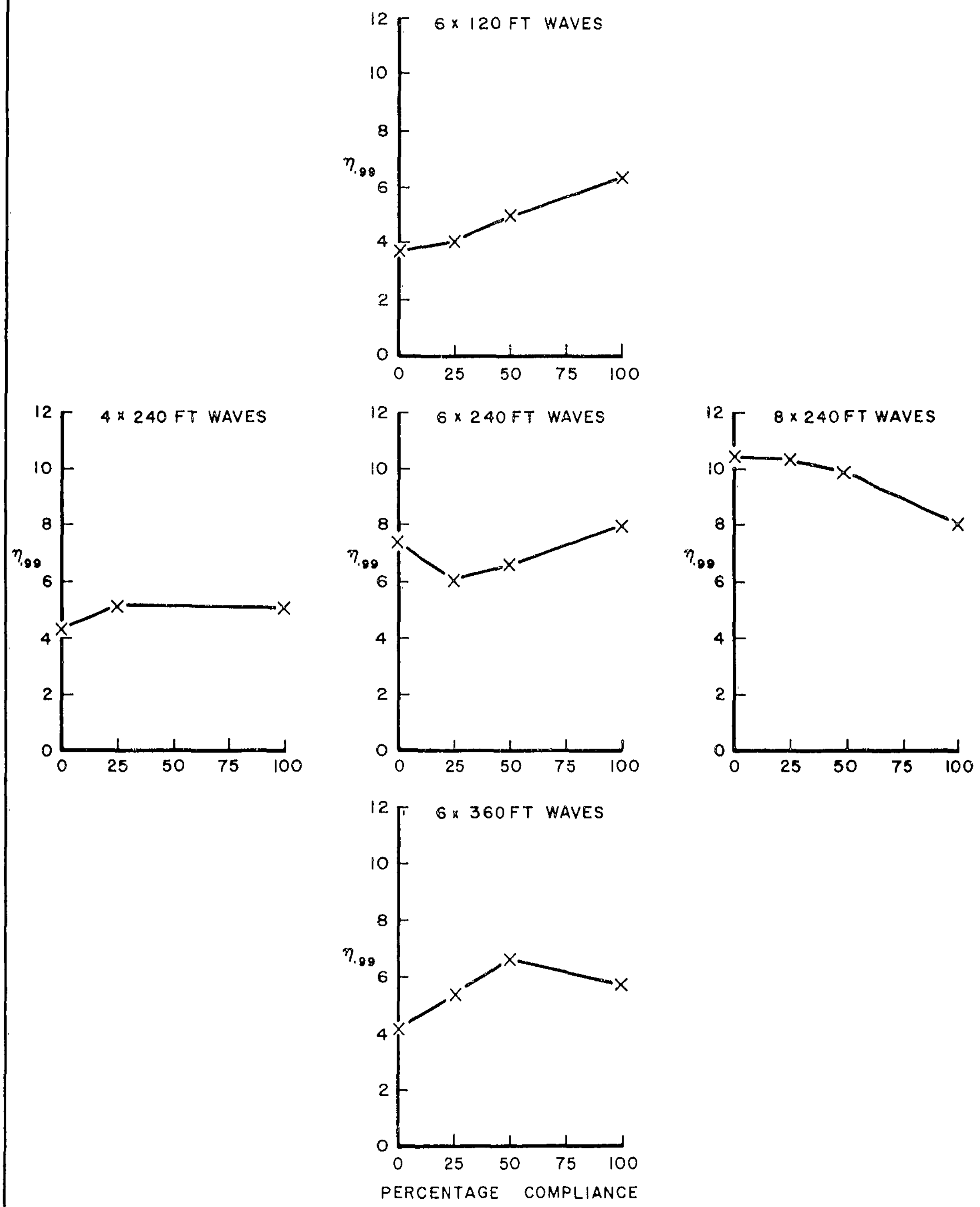
DISTRIBUTION OF C.G. ACCELERATION IN 4×240 FT. WAVES.



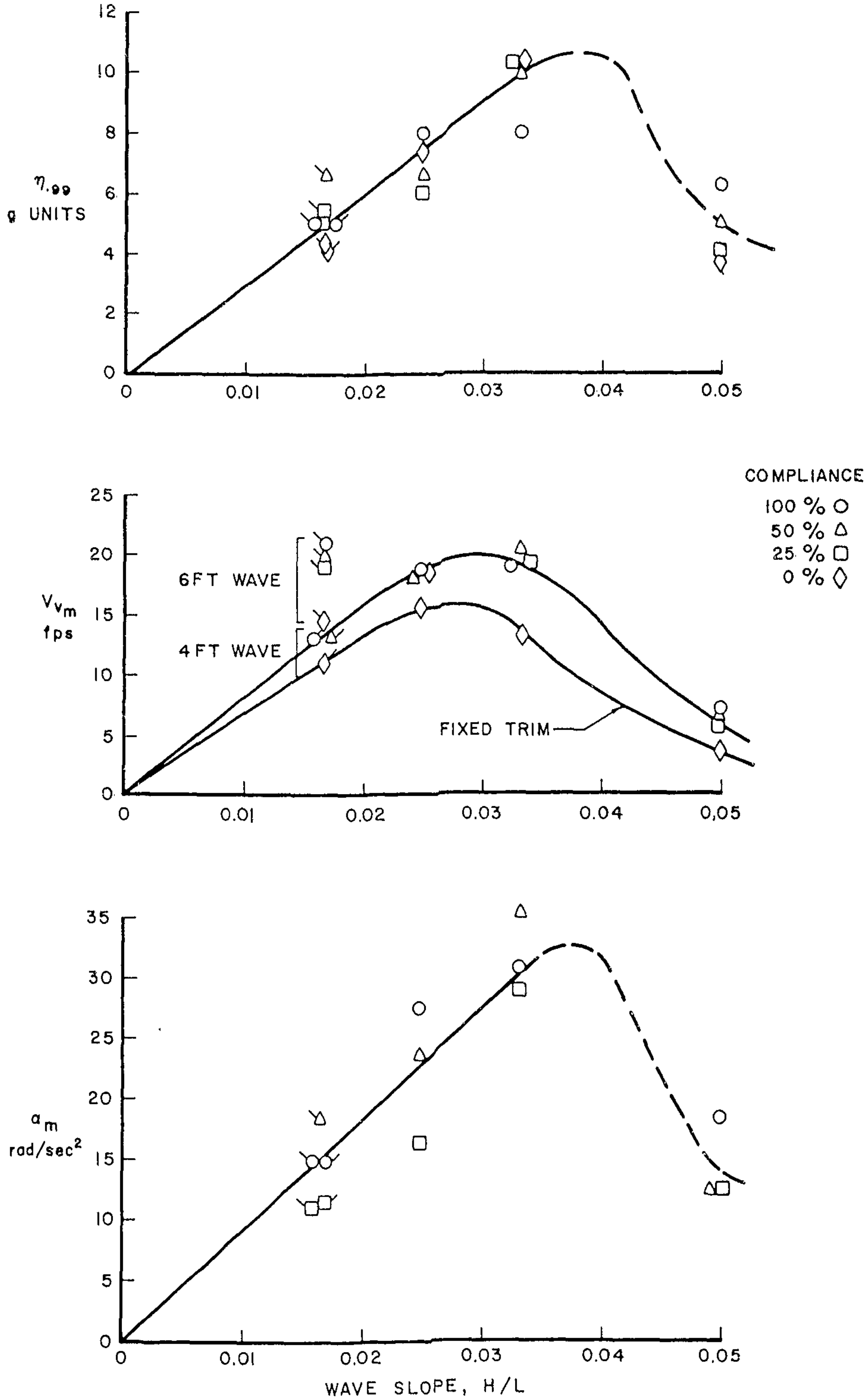
DISTRIBUTION OF C.G. ACCELERATION IN 8 x 240 FT. WAVES.



EFFECT OF PITCH CONTROL ON C.G. ACCELERATION



THE EFFECT OF WAVE SLOPE



DAVIDSON LABORATORY Report 840

EFFECT OF AERODYNAMIC PITCH CONTROL ON THE LOADS AND MOTIONS OF A SEAPLANE IN REGULAR WAVES by R.L. Van Dyck and P. Ward Brown, January 1963. Prepared for Bureau of Naval Weapons, Contract NOa(s) 60-6032-c, D.L. Project 2238
v + 17 pages and 9 figures UNCLASSIFIED

The effect of increasing the aerodynamic stiffness on the loads and motions experienced by a model seaplane making high-speed taxi runs in regular waves is determined experimentally. The results are analyzed statistically and it is found that, except in short steep waves, pitch control has practically no effect.

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