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YAW STABILIZATION OF LANDING CRAFT

R. J. Hinkle

Supervisor: Prof. M. A. Abkowitz
May 20, 1966

Thesis
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YAW STABILIZATION OF LANDING CRAFT

by
RICHARD JON HINKLE
S.B., UNITED STATES COAST GUARD ACADEMY
(1961)

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE
DEGREE OF MASTER OF
SCIENCE
at the
MASSACHUSETTS INSTITUTE OF
TECHNOLOGY
JUNE, 1966

Signature of Author.....
Department of Naval Architecture and
Marine Engineering, May 20, 1966

Certified by.....
Thesis Supervisor

Accepted by.....
Chairman, Departmental Committee
on Graduate Students

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1966

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YAW STABILIZATION OF LANDING CRAFT

RICHARD JON HINKLE

Submitted to the Department of Naval Architecture and Marine Engineering on May 20, 1966 in partial fulfillment of the requirements for the Master of Science degree in Naval Architecture and Marine Engineering.

The purpose of this work was to investigate the application of pump jet propulsion and yaw angle stabilization for a landing craft going through the surf. Linear theory was used throughout the analysis of the control problem. The stability indices and derivatives were determined in part by experiment and the remainder by analytic techniques.

It was found that LCVP landing craft are dynamically unstable without a skeg. Stability could possibly be restored by a feedback control system, but the far more practical solution is to start with a dynamically stable craft. This will provide the craft with a greater margin of stability in all cases.

Although it is felt that the craft can not be satisfactorily used without a skeg, much of the analytic data in Appendix A may be used to cover the case with a skeg. Reference (3) contains the appropriate modifications needed for the changes.

Thesis Supervisor: MARTIN A. ABKOWITZ

Title: Professor of Naval Architecture

PHILOSOPHY

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TABLE OF CONTENTS

	Page
ABSTRACT	1
SYMBOLS	1
INTRODUCTION	3
PROCEDURE	5
RESULTS	12
DISCUSSION OF RESULTS	21
CONCLUSION	27
RECOMMENDATIONS	28
BIBLIOGRAPHY	29
APPENDIX	30
APPENDIX A	31

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
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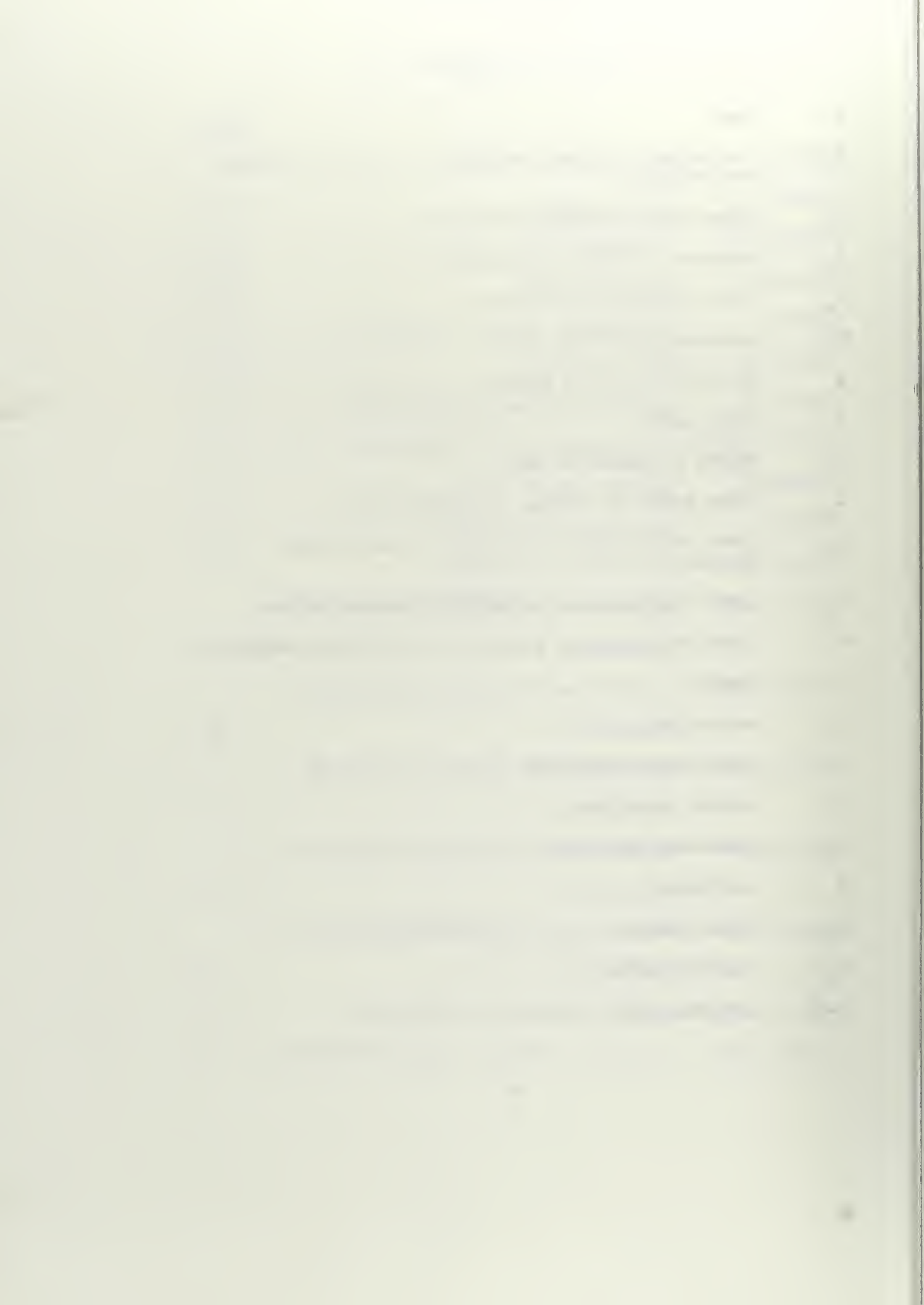
INDEX OF FIGURES

		Page
FIGURE I	Block Diagram of Ship	7
FIGURE II	Control System	10
FIGURE III	Resistance Data	15
FIGURE IV	Resistance Plot	16
FIGURE V	Experimental Values of Y_v and N_v	17
FIGURE VI	Plot of Y_v and N_v	18
FIGURE VII	Stability Indices and Derivatives	19
FIGURE VIII	Block Diagram of Ship and Control System	20
FIGURE IX	Nyquist Criteria Plot	22
FIGURE X	Root Locus at 4.5 knots	23
FIGURE XI	Root Locus at 7.5 knots	24
FIGURE XII	Calculations of Stability Indices and Derivatives	33
FIGURE XIII	Calculations of Stability Indices and Derivatives	35
FIGURE XIV	Calculations of Stability Indices and Derivatives	37
FIGURE XV	Calculations of Stability Indices and Derivatives	38
FIGURE XVI	Calculations of Stability Indices and Derivatives	39
FIGURE XVII	Lamb's Coefficients of Accession	40
FIGURE XVIII	Prohaska's Sectional Inertia Coefficients	41

Table 1

Year	Country	Value
1970	United States	1.000
1971	United States	1.000
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1974	United States	1.000
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2016	United States	1.000
2017	United States	1.000
2018	United States	1.000
2019	United States	1.000
2020	United States	1.000

B	beam
C_B	2-D lateral added mass coefficient (lateral inertia coefficient)
C_f	frictional resistance coefficient
C_r	residuary resistance coefficient
C_t	total resistance coefficient
ΔC_t	roughness correction to C_t
g	acceleration due to gravity
D	local draft
I_0	moment of inertia of hull
I_a	added moment of inertia of immersed water
k_1	lambda coefficient of accession to longitudinal inertia
k_2	lambda coefficient of accession to lateral inertia
k_3	lambda coefficient of accession to rotational inertia
l	length
m_0	mass of hull
m_1	longitudinal added mass
m_2	lateral added mass
m_3	rotational added mass
N	yaw moment
N_F	Froude Number
N_{Re}	Reynolds number
$r = \dot{\psi}$	yaw angle rate



- u_0 velocity of hull center of gravity in the forward direction
 s differential operator
 v velocity of hull C.G. in starboard direction
 x longitudinal distance from L.C.G. to the C.G. of the lateral added mass
 x_G distance to L.C.G. from the reference point for forces, moments, velocities etc.
 x_P Longitudinal distance from L.C.G. to the center of pressure at which the lateral force Y acts (taken as center of area of hull profile)
 $x_{o/l}$ approximated by half the prismatic coefficient
 Y force in the starboard direction
 ρ mass density of water
 ψ yaw angle
 $r \& v$ subscripts meaning partial derivative with respect to r & v respectively
 m subscript meaning maximum value

General Introduction	1
I. The Problem	1
II. The Method	1
III. The Results	1
IV. The Conclusions	1
V. The Summary	1
VI. The Acknowledgments	1
VII. The References	1
VIII. The Appendix	1
IX. The Bibliography	1
X. The Index	1
XI. The Glossary	1
XII. The Plates	1
XIII. The Figures	1
XIV. The Tables	1
XV. The Maps	1
XVI. The Photographs	1
XVII. The Illustrations	1
XVIII. The Diagrams	1
XIX. The Schemata	1
XX. The Models	1
XXI. The Simulations	1
XXII. The Experiments	1
XXIII. The Observations	1
XXIV. The Measurements	1
XXV. The Calculations	1
XXVI. The Computations	1
XXVII. The Analyses	1
XXVIII. The Syntheses	1
XXIX. The Formulations	1
XXX. The Derivations	1
XXXI. The Proofs	1
XXXII. The Lemmas	1
XXXIII. The Theorems	1
XXXIV. The Propositions	1
XXXV. The Corollaries	1
XXXVI. The Conjectures	1
XXXVII. The Hypotheses	1
XXXVIII. The Assumptions	1
XXXIX. The Postulates	1
XL. The Axioms	1
XLI. The Principles	1
XLII. The Laws	1
XLIII. The Rules	1
XLIV. The Procedures	1
XLV. The Algorithms	1
XLVI. The Algorithms	1
XLVII. The Algorithms	1
XLVIII. The Algorithms	1
XLIX. The Algorithms	1
L. The Algorithms	1

INTRODUCTION

Landing craft used in amphibious warfare are susceptible to broaching while transiting the surf. The craft, in the surf, is particularly vulnerable because it is in a following sea and also the relative velocity of the water in the vicinity of the rudder is small, making the rudder less effective.

A possible method of reducing this broaching problem is to use a yaw angle control system. By replacing the screw propeller and rudder with a pump jet with a controlled discharge angle, the problem of decreased rudder effectiveness would be eliminated. A pump jet propulsion system of the size required for the craft needs some means of power assist to vector the jet stream for steering. This vectoring system might easily be converted to an automatic steering control system to minimize the yaw angle and eliminate broaching. The economics of war require that in order to be effective the craft must be cheap so the control system must be of relatively simple design and accurate for small periods of time such as transiting a surf line.

The equations of motion for the craft are a pair of linearized second order differential equations relating yaw and sway to the yawing moments and the transverse force. The coefficients for the various terms in these equations were determined by either experiment on a model LCVF or the

THE HISTORY OF THE UNITED STATES OF AMERICA
 FROM THE DISCOVERY OF THE CONTINENT TO THE
 PRESENT TIME
 BY
 CHARLES C. SMITH
 EDITOR
 VOL. I
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 END OF THE SEVENTEENTH CENTURY
 NEW YORK
 G. P. PUTNAM'S SONS
 1918

analytical approach of Jacobs (2). The current LCVPs are equipped with a skeg for improved dynamic stability and protection of the propeller. The tests run on the model at the towing tank were all conducted without this skeg.

The analysis of the control problem was done using linear control theory. The criteria of stability for the system was either that of Nyquist or by root locus. A model of the system for the analog computer was made, but due to the instability the results are not shown.

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PROCEDURE

From the general linearized equations of ship motion of Abkowitz (1) the equations for yaw and sway were obtained by decoupling the equations for the other modes of freedom. The resulting equations are:

$$(Y_r - mx_G) \frac{d^2\psi}{dt^2} + (Y_r - mu_o) \frac{d\psi}{dt} + (Y_r - m) \frac{dv}{dt} + Y_v v = -Y_{rud} - Y_d \quad (1)$$

$$\begin{matrix} (N_r - I_z) \frac{d^2\psi}{dt^2} + (N_r - mx_G u_o) \frac{d\psi}{dt} + (N_v - mx_G) \frac{dv}{dt} + N_v v = -N_{rud} - N_d \\ b_{21} \qquad \qquad \qquad b_{22} \qquad \qquad \qquad b_{23} \qquad \qquad \qquad b_{24} \end{matrix} \quad (2)$$

where Y_{rud} and N_{rud} stand for the forces or moments caused by the steering device and the subscript d for the disturbance.

Noting that any force can be resolved into a force and a moment at some other location, the force, due to deflecting the pump jet, will become the Y_{rud} and N_{rud} at the reference position for the equations. N_{rud} is simply Y_{rud} multiplied by the distance k between its place of application and the reference point. A similar treatment applies to disturbance forces and moments.

Reducing the pair of simultaneous equations to one equation in ψ and Y force we have:

$$\psi [(b_{21} b_{13} - b_{11} b_{23}) s^3 + (b_{14} b_{21} + b_{13} b_{22} - b_{24} b_{14} - b_{23} b_{12}) s^2 + (b_{14} b_{22} - b_{24} b_{12}) s] = Y_{rud} [(b_{23} - kb_{13}) s + (b_{24} - kb_{14})] + Y_d [(b_{23} - k' b_{13}) s + (b_{24} - k' b_{14})]$$

1. The first part of the document is a list of names and titles, including the names of the authors and the titles of their works. This list is organized in a structured manner, likely serving as a table of contents or a reference list.

2. The second part of the document contains a list of numbers, possibly representing page numbers or sequence numbers, arranged in a columnar format.

3. The third part of the document is a list of names, which may be the names of the authors or the subjects of the works listed in the first part.

4. The fourth part of the document is a list of names, similar to the third part, but possibly representing a different set of authors or subjects.

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The block diagram representation of the ship is shown in figure 1.

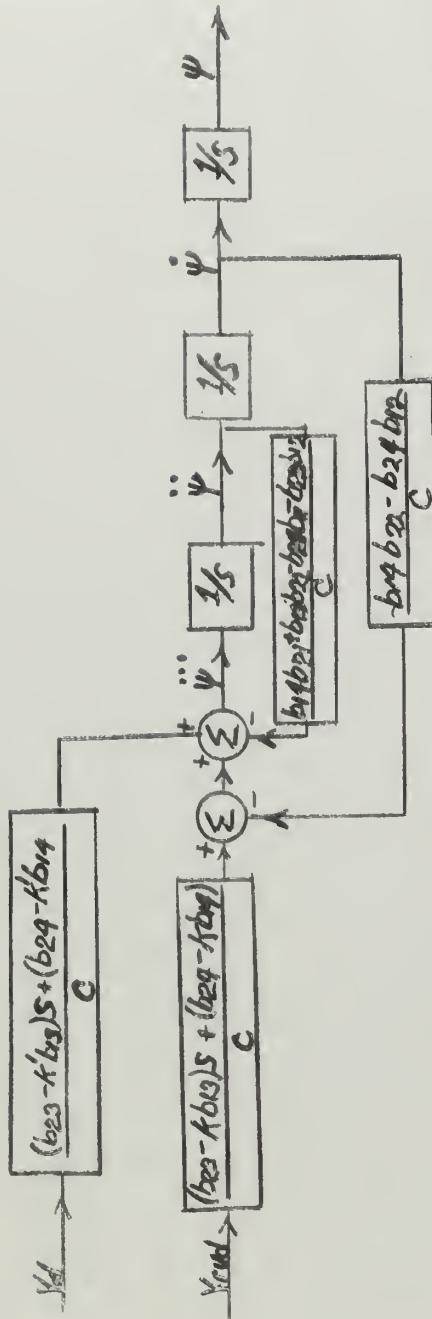
The determination of the stability derivatives was done by experiment where the necessary equipment was available and the remaining derivatives evaluated analytically. The evaluation of N_v was done by towing the model in the tank at a small yaw angle and measuring the moment. The moment was measured by constructing a heave rod with the lower eight inches machined round and instrumenting the round portion with a full bridge of strain gauges. The full bridge array allowed the measurement of torque without any effect due to the bending moment in the bar. The output of this dynamometer was averaged by an integrator to obtain the result. Measurement of Y_v was accomplished at the same time by mounting the thrust block athwartships in the model to measure the force in the Y direction. Runs were made at three separate yaw angles at each of four different speeds. These measurements were made at the longitudinal center of gravity in order to have several terms drop out of the equations. The remaining stability derivatives were calculated using the method set forth in Estimation of Stability Derivatives for Various Ship Forms, and Comparison With Experimental Results by Jacobs. This method employs a strip theory technique with lateral added mass coefficient along with Lamb's coefficients of accession to inertia and hydrofoil theory.

The use of pump jet propulsion introduces an additional

I have the honor to acknowledge the receipt of your letter of the 15th inst. in relation to the proposed extension of the term of office of the members of the Board of Education. It is a pleasure to know that you are so interested in the welfare of our schools and the future of our children. The Board of Education has given the matter its careful consideration and has decided to recommend that the term of office of the members of the Board be extended from two to four years. This recommendation is based upon the fact that it will enable the Board to carry out its duties more effectively and will also give it the opportunity to plan for the future of our schools more wisely. I am sure that you will understand the reasons for this recommendation and will be glad to support it. Very respectfully,
 Your obedient servant,
 J. W. [Name]
 Superintendent of Schools

FIGURE I

Block Diagram of Ship



$$C = b_{21}b_{12} - b_{11}b_{22}$$

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Capacitor



factor in both the Y_r and N_r derivatives. Due to the relatively high velocity of the water jet, a rotational momentum change force become significant. The force derivative is equal to twice the mass of the water in the duct times the velocity of the water jet. The moment derivative is derived by applying this force half way down the longitudinal length of the discharge duct. For purposes of calculations a ten foot duct with a six inch diameter was assumed. The thrust of the pump jet was determined by scaling up model resistance data obtained in the towing tank. An attempt was made to gather resistance data for the model in a surf but the waves would not break for a long enough distance to gather any data.

Because pump jet propulsion was employed, the skeg was not needed for protection of the propeller and was not on the model during the tests. The elimination of the skeg made the model dynamically unstable in straight line motion.

The automatic control system was chosen to be one of few parts. The quantities ψ and $\dot{\psi}$ are measured by a free gyro and a rate gyro. It may be acceptable to have accurate measurements over periods of time such as when going through the surf. In this case the measurement of $\dot{\psi}$ can be accomplished by using the gyro as a free gyroscope rather than as a null device. If the gyroscope is free, some means of sensing its position without applying much torque, such as a differential transformer, will have to be used to avoid unwanted precession. The values of ψ and $\dot{\psi}$ times their appropriate gains are summed and compared with the rudder angle and

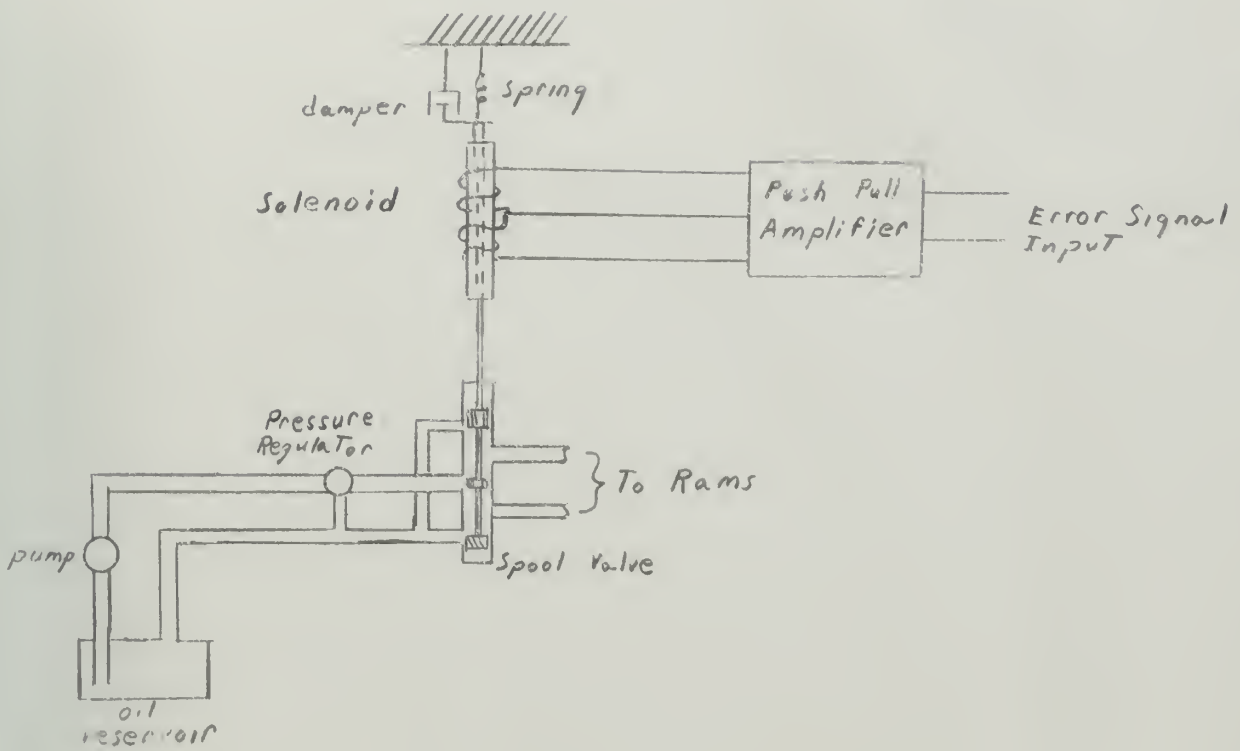
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the difference applied to a push pull amplifier. The output of the amplifier is a solenoid shown in figure II. By keeping the magnetic field in the solenoid large enough the plunger will become magnetically saturated. The force exerted by the coils on the plunger will then become directly proportional to the current. The position of the plunger is used to control an underlapped spool valve of the constant pressure hydraulic system. The reaction of the spool valve as a spring and damper were considered so that this portion of the system could be critically damped. This was done to help reduce the high frequency oscillations of the vectoring duct. The output from this four way valve drives the rams that position the jet vectoring duct.

The removal of the skeg made the craft dynamically unstable. The next step was to investigate what could be done by the control system to restore the dynamical stability. First, the effects of control, proportional only to yaw angle, was investigated. It was shown by the Nyquist Stability Criteria that, at the speed chosen for investigation, no amount of gain would suffice for stabilization. Proceeding to a control proportional to yaw angle and yaw rate again, it could be shown that the system would be ineffective. Using a root locus plot, it can be seen that the right most two poles would continue to stay on the right half plane for all values of gain. By studying the root locus further, it can be seen that a system proportional to yaw plus the first and second derivatives would be the minimum requirement to produce

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FIGURE II
Control system





a dynamically stable craft by adding two complex conjugate zeros to the root locus through the use of appropriate feed back gains, the unstable roots could be brought over to the left half plane. The design of such a system was dismissed however. Rydill (3) claims that such systems are not satisfactory due to excessive high frequency oscillations of the steering device. Also, the expense of the extra equipment needed for the control could be eliminated by reinstalling the skeg and making the craft dynamically stable to begin with.

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RESULTS

The results of this investigation were based on the following assumptions regarding the design of the system:

- a. longitudinal length of jet duct is 10 feet
- b. jet duct diameter is 6 inches
- c. Y force from deflected jet acts 15.94 feet from L.C.G.
- d. density of the hydraulic fluid 57 lbs/ft³
- e. mass of spool valve and plunger is $6.88 \times 10^3 \frac{\text{lbs-sec}^2}{\text{in}}$
- f. discharge coefficients for spool valve
- g. width of spool valve ports are 0.75 inches
- h. the rams that drive the jet vectoring conduit are 1 square inch in area and are located 6 inches from the swivel, therefore the discharge angle is equal to the ram travel in inches over 6
- i. supply pressure is constant at 1000 psi
- j. the radius of gyration equals one fourth the length

The thrust to be developed must equal the resistance of the craft for constant velocity operation. The model was tested in the towing tank and the model resistance data and scaled up results are tabulated in figure III. A plot of the full scale resistance is shown in figure IV.

The quantities Y_v and N_v were found experimentally in the towing tank. The three yaw angles used during the testing were 3.12°, 5.92°, and 9.30° and the model speeds varied from 1.3 knots

CONTENTS

PART I. THE HISTORY OF THE UNITED STATES

CHAPTER I. THE DISCOVERY OF AMERICA

CHAPTER II. THE EARLY SETTLEMENTS

CHAPTER III. THE REVOLUTIONARY WAR

CHAPTER IV. THE CONFEDERATE STATES

CHAPTER V. THE FEDERAL GOVERNMENT

CHAPTER VI. THE TERRITORIAL ACQUISITIONS

CHAPTER VII. THE WESTERN EXPLORATIONS

CHAPTER VIII. THE NATIONAL POLICY

CHAPTER IX. THE ECONOMIC DEVELOPMENT

CHAPTER X. THE SOCIAL REFORMS

CHAPTER XI. THE CIVIL WAR

CHAPTER XII. THE RECONSTRUCTION

CHAPTER XIII. THE MODERN PERIOD

CHAPTER XIV. THE PRESENT POSITION

APPENDIX

INDEX

to 2.9 knots. This corresponded to speeds between 4.75 and 10.5 knots for the full scale craft. A table of the experimental data is presented in figure V. The data was non-dimensionalized by dividing forces by $\rho/a u^2 l^2$ and moments by $\rho/a u^2 l^3$. Both N_v and Y_v were found to be dependent on Froude Number as is shown by the plot in figure VI. The variation of yaw angle due to the twisting of the rod was computed for the largest torque experienced and the effect was found to be insignificant.

The data for the remainder of the stability derivatives and indices was computed by the method outlined in reference 2. The method of non-dimensionalizing used here was to divide forces by u^2/l . The length used in all calculations here was that of the waterline 32,367 feet. The actual computations of these derivatives and indices are contained in appendix A.

The value of stability indices, derivatives, and resistance for speeds of 4 and 7.5 knots are listed in figure VII.

The spool valve is an underlapped four way valves with ports 0.75 inches wide and discharge coefficients of 0.7 at each port. The equations for flow rate for such a valve is that $j = \frac{2k}{A} \sqrt{P_s} X$ where j is ram rate, X is spool valve displacement, P_s is supply pressure, k is the product of discharge coefficient, port width and the square root of two times the acceleration of gravity divided by the mass of the density of the hydraulic fluid. ($k = CW\sqrt{\frac{2g}{\rho}}$) This equation gives $j = 3600X$ for this system. The spring reaction force of the valve is given by the equation:

The first part of the paper is devoted to the study of the
 properties of the function $f(x)$ defined by the integral

$$f(x) = \int_0^x \frac{t^2}{1+t^2} dt$$
 for $x \geq 0$. It is shown that $f(x)$ is an increasing
 function and that $f(x) < x/2$ for all $x > 0$.
 Furthermore, it is proved that $f(x)$ is concave down.
 The second part of the paper deals with the problem of
 finding the maximum value of the function $f(x)$ on the
 interval $[0, 1]$. It is shown that the maximum value is
 attained at $x = 1$ and is equal to $f(1) = \int_0^1 \frac{t^2}{1+t^2} dt$.
 The third part of the paper is devoted to the study of the
 function $g(x) = \int_0^x \frac{t^3}{1+t^2} dt$ for $x \geq 0$.
 It is shown that $g(x)$ is an increasing function and
 that $g(x) < x^2/4$ for all $x > 0$. Furthermore,
 it is proved that $g(x)$ is concave down.

$$k = 2 \times \text{discharge coefficient} \times \text{port width} \times P_s \times \cos 69^\circ$$

$$\text{or } k = 2 \times 0.7 \times 0.75 \times 10^3 \times 0.358 = 376 \frac{\text{lb}}{\text{in.}}$$

The damping reaction of the spool valve is expressed by the equation:

$$C = \text{discharge coefficient} \times \text{port width} \times \sqrt{\frac{\rho P}{g}} \times L$$

where L is the difference between distance from supply port to load port and load port to drain port. With L equal to 2, the

$$\text{value of C is } 0.7 \times 0.75 \times 0.293 \times 2 = 0.308 \frac{\text{lbs-sec}}{\text{in}}$$

By using a spring with a constant of $24 \frac{\text{lbs}}{\text{in}}$ to center the

plunger, the total spring constant becomes $400 \frac{\text{lbs}}{\text{in}}$. The plunger-

spool valve combination is assumed to have a mass of $6.88 \times 10^{-3} \frac{\text{lbs-sec}^2}{\text{in}}$

To critically damp this system, a damping constant of $3.32 \frac{\text{lbs-sec}}{\text{in}}$

is needed. An additional damper with a constant of $3.01 \frac{\text{lbs-sec}}{\text{in}}$

would be needed to critically damp the system.

The combined control system and ship block diagram for speeds of 4 and 7.5 knots is illustrated in figures VIII.

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MAY 15 1964

TO THE EDITOR
I have the honor to acknowledge the receipt of your letter of May 10, 1964, regarding the manuscript of my paper, "On the structure of the group of automorphisms of a free group", which was published in the Journal of the American Mathematical Society, Volume 1, Number 1, January 1964, pages 1-10.

I am sorry that I cannot give you a more definite answer at this time, but I am currently on a sabbatical leave and am unable to devote the necessary time to a thorough review of your manuscript. I will, however, try to get back to you as soon as possible.

Very truly yours,
J. H. Conway

FIGURE III

RESISTANCE DATA

v_{model} Kts	v/\sqrt{l}	N_R	Resistance lbs	C_t	C_f	C_r
0.608	0.288	4.33×10^5	0.05	0.00974	5.209×10^3	4.53×10^{-3}
1.116	0.528	7.91×10^5	0.1575	0.00914	4.615×10^3	4.52×10^{-3}
1.489	0.705	1.061×10^4	0.283	0.00924	4.363×10^3	4.88×10^{-3}
2.016	0.954	1.428×10^4	0.668	0.01012	4.119×10^3	6.00×10^{-3}
2.467	1.168	1.750×10^4	1.293	0.01533	3.969×10^3	1.116×10^{-2}
2.978	1.408	2.115×10^4	2.413	0.01960	3.831×10^3	1.577×10^{-2}
3.219	1.522	2.282×10^4	3.593	0.02515	3.779×10^3	2.137×10^{-2}

v_{ship} Kts	v/\sqrt{l}	N_R	$C_f + \Delta C_f$	C_t	Resistance lbs
1.718	0.288	8.07×10^6	3.439×10^{-3}	7.97×10^{-3}	21.25
3.15	0.528	1.43×10^7	3.170×10^{-3}	7.69×10^{-3}	69.1
4.2	0.705	1.97×10^7	3.035×10^{-3}	7.92×10^{-3}	126.4
5.68	0.954	2.67×10^7	2.913×10^{-3}	8.91×10^{-3}	260.5
6.98	1.168	3.275×10^7	2.837×10^{-3}	1.400×10^{-2}	616
8.40	1.408	3.94×10^7	2.771×10^{-3}	1.854×10^{-2}	1182
9.09	1.522	4.26×10^7	2.743×10^{-3}	2.411×10^{-2}	1807

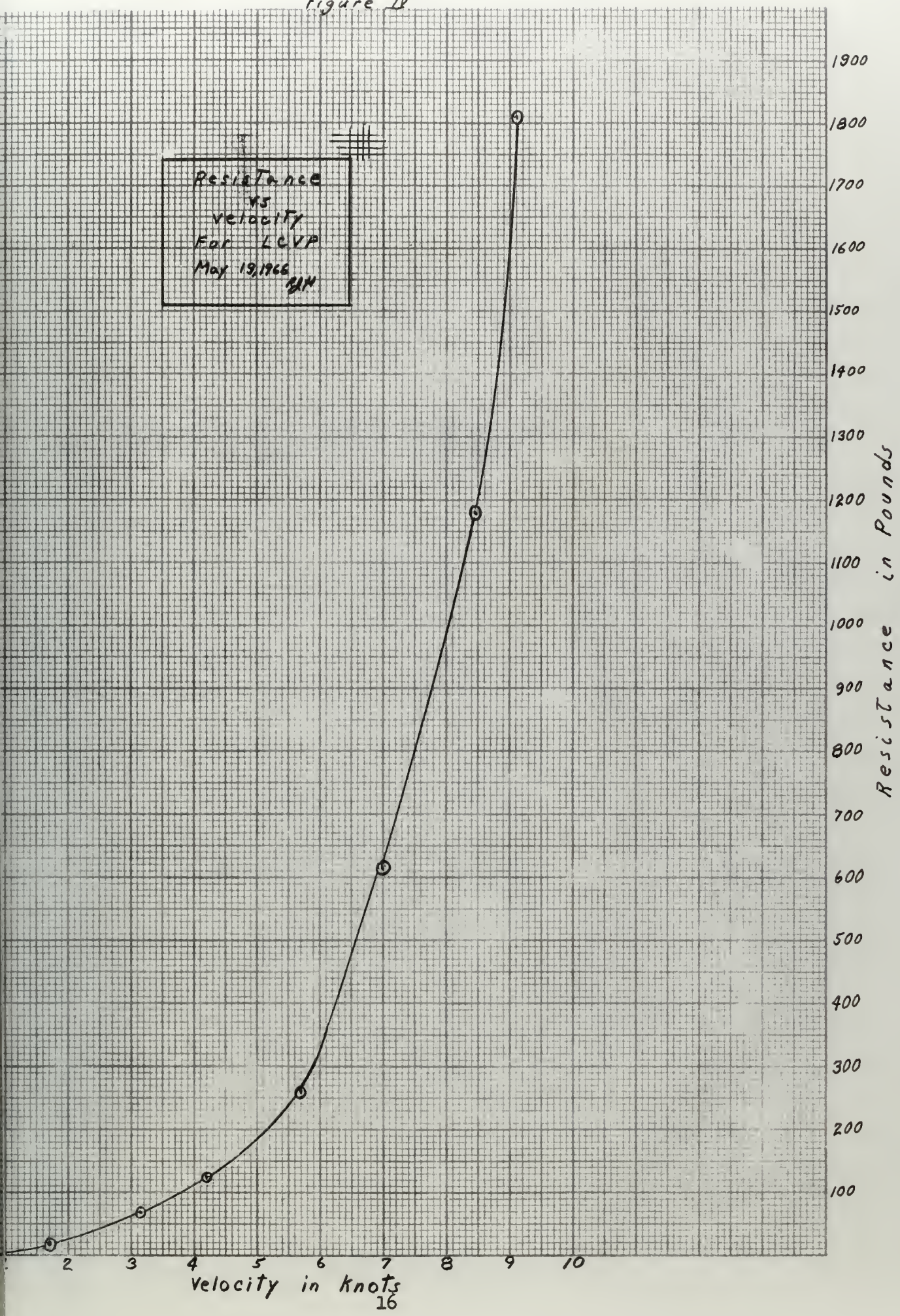
TABLE I
continued

Run	Time	Temp	Pressure	Flow	Rate	Yield
100	10:00	100°C	100 mm	100 ml	100 g	100%
101	10:15	100°C	100 mm	100 ml	100 g	100%
102	10:30	100°C	100 mm	100 ml	100 g	100%
103	10:45	100°C	100 mm	100 ml	100 g	100%
104	11:00	100°C	100 mm	100 ml	100 g	100%
105	11:15	100°C	100 mm	100 ml	100 g	100%
106	11:30	100°C	100 mm	100 ml	100 g	100%

Run	Time	Temp	Pressure	Flow	Rate	Yield
107	11:45	100°C	100 mm	100 ml	100 g	100%
108	12:00	100°C	100 mm	100 ml	100 g	100%
109	12:15	100°C	100 mm	100 ml	100 g	100%
110	12:30	100°C	100 mm	100 ml	100 g	100%
111	12:45	100°C	100 mm	100 ml	100 g	100%
112	13:00	100°C	100 mm	100 ml	100 g	100%
113	13:15	100°C	100 mm	100 ml	100 g	100%

Figure IV

RESISTANCE
VS
VELOCITY
FOR LCVP
MAY 19, 1966
SAM



velocity in knots
16

Temperature in degrees Celsius

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100



Temperature in degrees Celsius

Time in minutes

FIGURE V

Experimental Values of Y_v and N_v

$\Psi = 3.12^\circ$

U fps	Y lbs	N in lbs	Y'	N'
2.27	0.0613	2.3	6.37×10^{-4}	4.32×10^{-4}
2.27	0.0580	2.03	5.88×10^{-4}	3.81×10^{-4}
3.03	0.0833	3.48	4.72×10^{-4}	3.67×10^{-4}
4.17	0.1868	5.15	5.43×10^{-4}	2.875×10^{-4}

$\Psi = 5.92^\circ$

2.27	0.1162	3.70	1.173×10^{-3}	6.95×10^{-4}
3.01	0.1186	5.18	6.80×10^{-4}	5.53×10^{-4}
3.03	0.1035	4.75	5.86×10^{-4}	5.00×10^{-4}
4.17	0.4166	8.40	1.25×10^{-3}	4.68×10^{-4}
4.54	0.5307	10.40	1.341×10^{-3}	4.89×10^{-4}

$\Psi = 9.30^\circ$

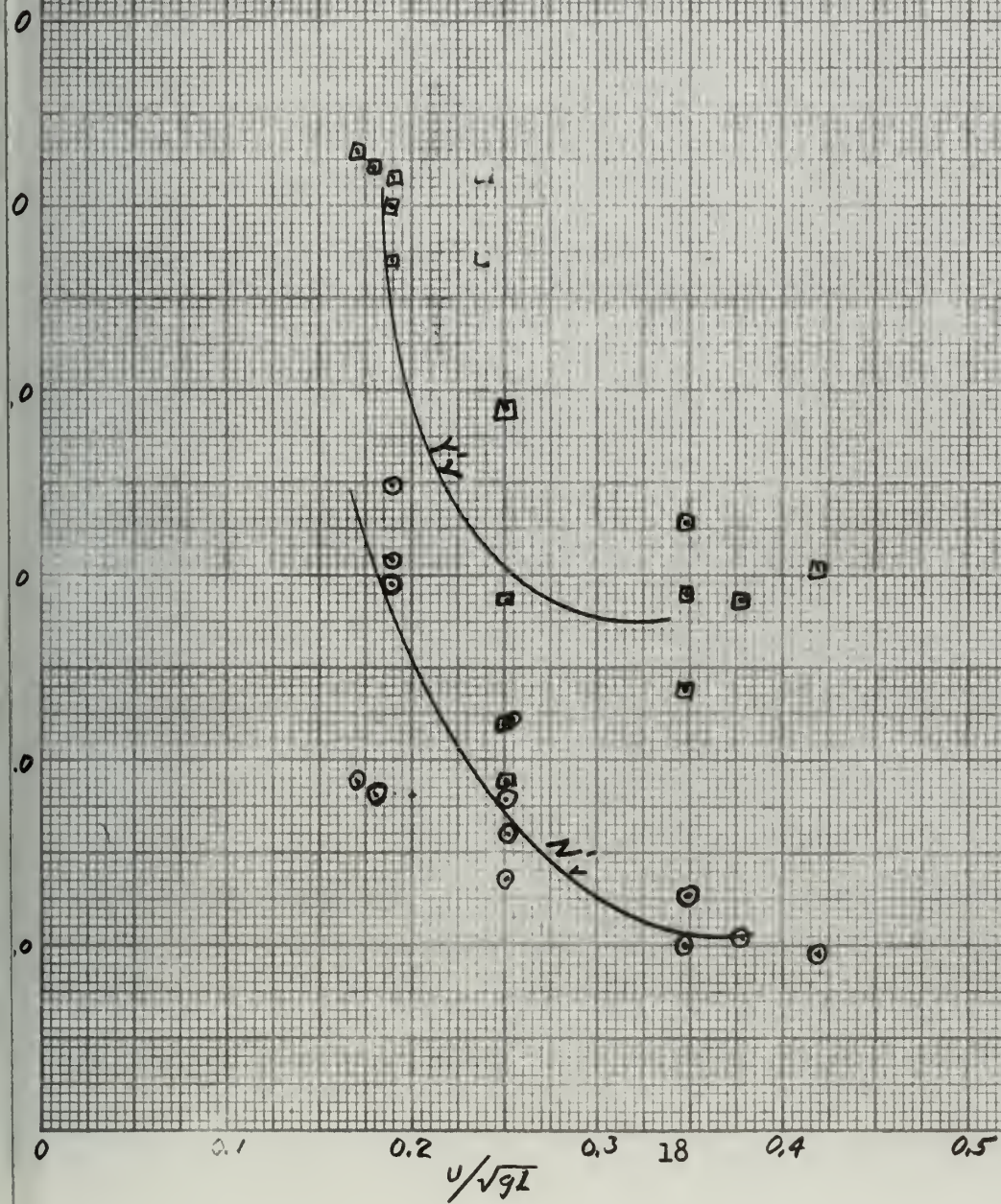
2.055	0.1414	2.73	1.749×10^{-3}	6.26×10^{-4}
2.17	0.1818	3.75	1.83×10^{-3}	7.04×10^{-4}
3.03	0.3404	6.30	1.93×10^{-3}	6.64×10^{-4}
4.17	0.7405	12.10	2.22×10^{-3}	6.74×10^{-4}
5.03	1.2020	20.40	2.47×10^{-3}	7.80×10^{-4}

TABLE I
 SUMMARY OF DATA OBTAINED

Run	Time	Temp.	Concentration	
			g/l	%
1	0.5	25.0	0.1	0.4
2	1.0	25.0	0.2	0.8
3	1.5	25.0	0.3	1.2
4	2.0	25.0	0.4	1.6
5	2.5	25.0	0.5	2.0
6	3.0	25.0	0.6	2.4
7	3.5	25.0	0.7	2.8
8	4.0	25.0	0.8	3.2
9	4.5	25.0	0.9	3.6
10	5.0	25.0	1.0	4.0
11	5.5	25.0	1.1	4.4
12	6.0	25.0	1.2	4.8
13	6.5	25.0	1.3	5.2
14	7.0	25.0	1.4	5.6
15	7.5	25.0	1.5	6.0
16	8.0	25.0	1.6	6.4
17	8.5	25.0	1.7	6.8
18	9.0	25.0	1.8	7.2
19	9.5	25.0	1.9	7.6
20	10.0	25.0	2.0	8.0

Figure VI

$\square Y_v$ and $\circ N_v$
vs
Froude No.
May, 1966
RPH



1900



FIGURE VII
 STABILITIES INDICES AND DERIVATIVES

Speed	4.0	7.5
Y_r	-111.5	-111.5
Y_v	-393.5	-393.5
Y_r	-5,230.0	-9,800.0
Y_v	-94.0	-210.5
N_r	-18,890.0	-18,890.0
N_v	-111.5	-111.5
N_r	-670.0	-1,258.0
N_v	-2855.0	-2,765.0
I	46,700.0	46,700.0
m	2,765.0	2,765.0
Coriolus Force	275.5 r	1,602.0 r
Coriolus Moment	-2,880.0 r	-16,750.0 r
Resistance	115.0	800.0

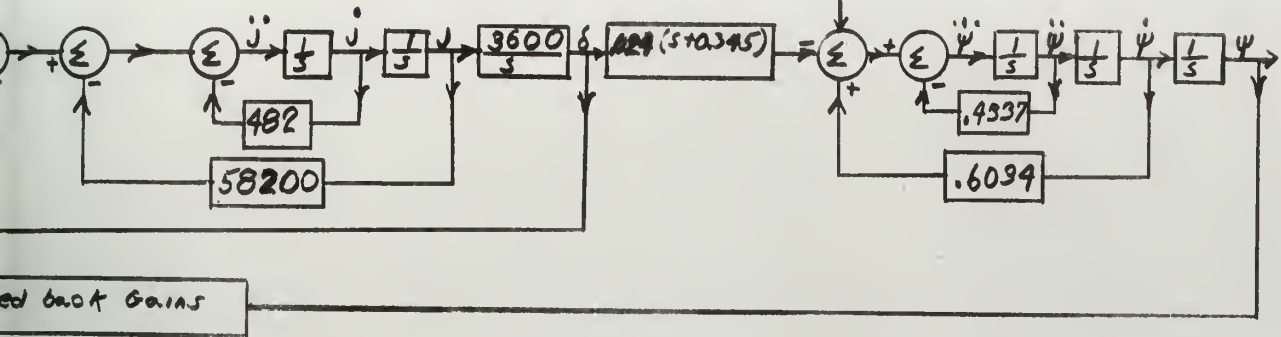
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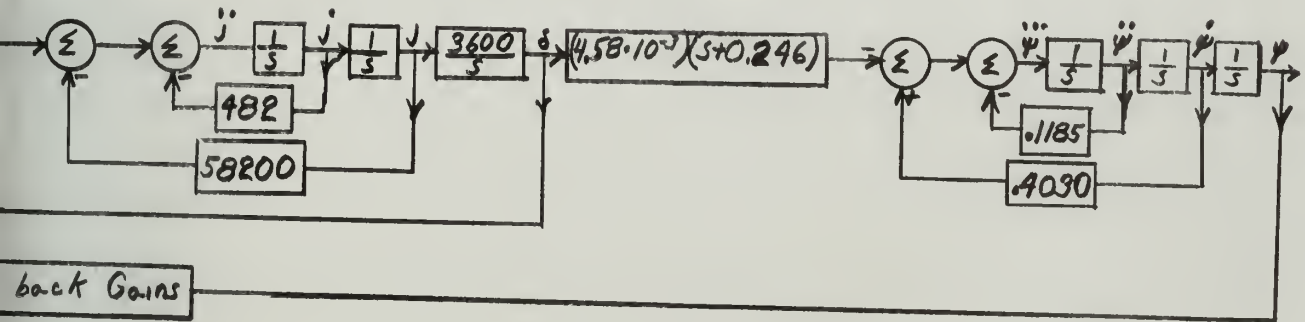
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200	200	200

FIGURE VIII

Block Diagram of Ship and Control System
disturbance



7.5 knots



4.0 knots

Q. 18

Draw a circuit diagram for the following circuit



Q. 19



Q. 20

DISCUSSION OF RESULTS

The instability of the system with control proportional only to yaw angle is shown in figure IX, a Nyquist Stability Criteria plot at 7.5 knots. There is one pole of the open loop transfer function in the right half plane. For unity gain in the control system, there are no encirclements of the minus one point, therefore there will be one root in the right half plane of the closed loop transfer function. By increasing the gain, the small loop near the origin (shown in the inset of figure IX) will expand and eventually encircle the minus one point once. This indicates that increasing the gain will only add to the instability by putting another pole in the right half plane. The Nyquist plot at a speed of 4 knots is not significantly different to change the results regarding stability.

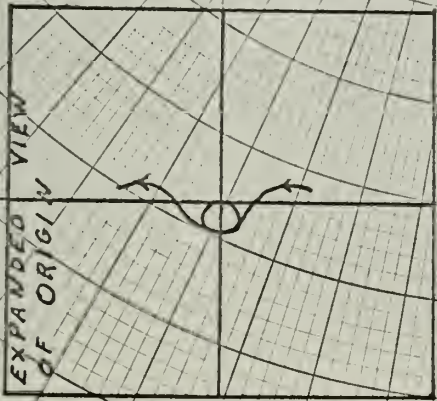
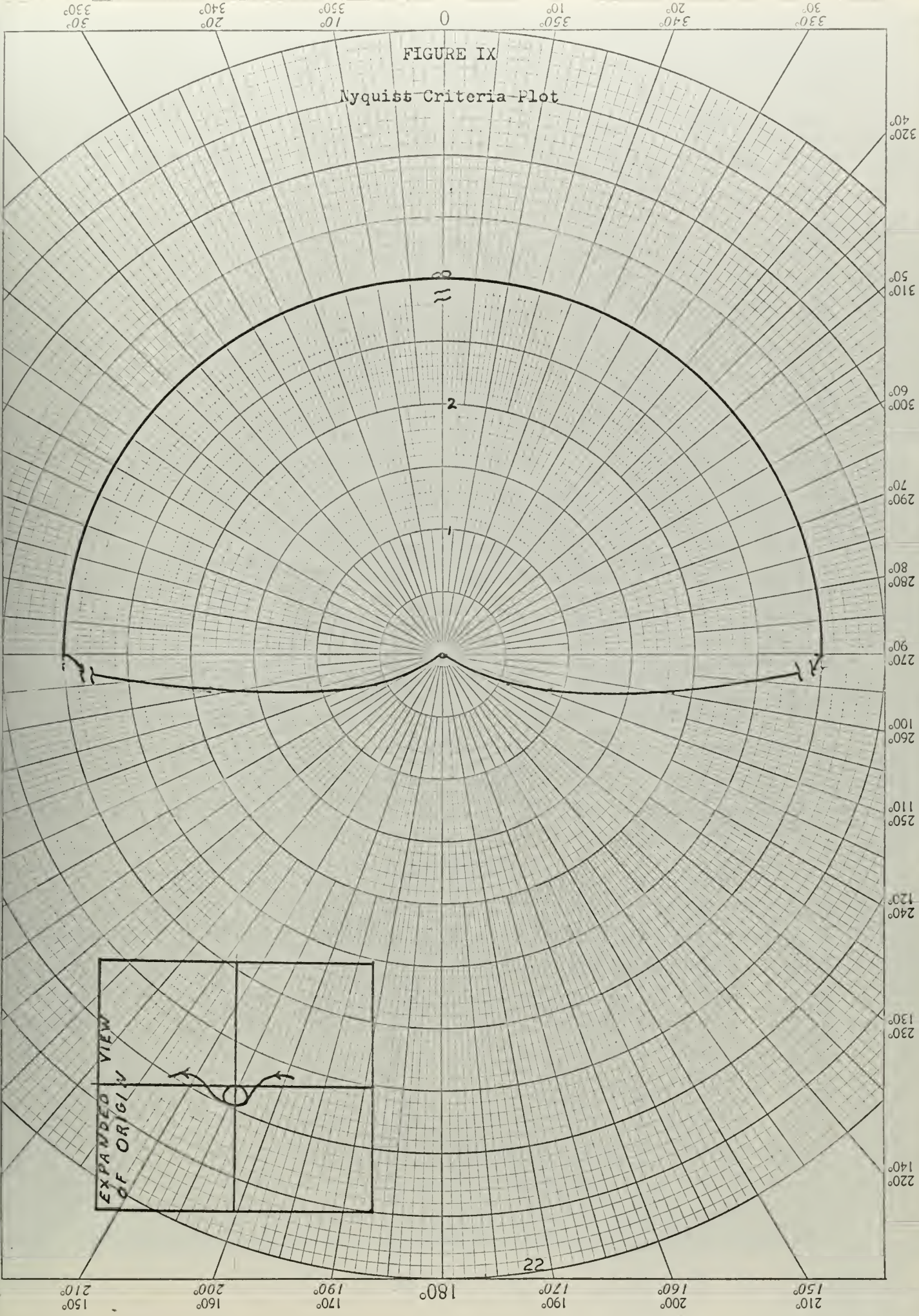
To add to the sophistication of the control system by including yaw rate feedback in the system, we can most easily visualize the stability problem by a root locus plot. The determination of the exact breakaway point requires the solution of a sixth degree equation, but the trend of the system can be seen without the exact solution. The poles and zeros of the open loop transfer function and the asymptotes for speed of 4 and 7.5 knots are plotted in figures X and XI. The effect of proportional plus first derivative control is to add another zero to the plot and its position would be governed by the ratio of the gains of the proportional to the first derivative terms. With the total

THE DEPARTMENT OF REVENUE has the honor to acknowledge the receipt of your letter of the 14th inst. in relation to the matter mentioned therein. The same has been referred to the proper authorities for their consideration and they will be glad to advise you of the result thereof as soon as it is possible to do so.

Very respectfully,
 JOHN W. WATSON, Secretary.

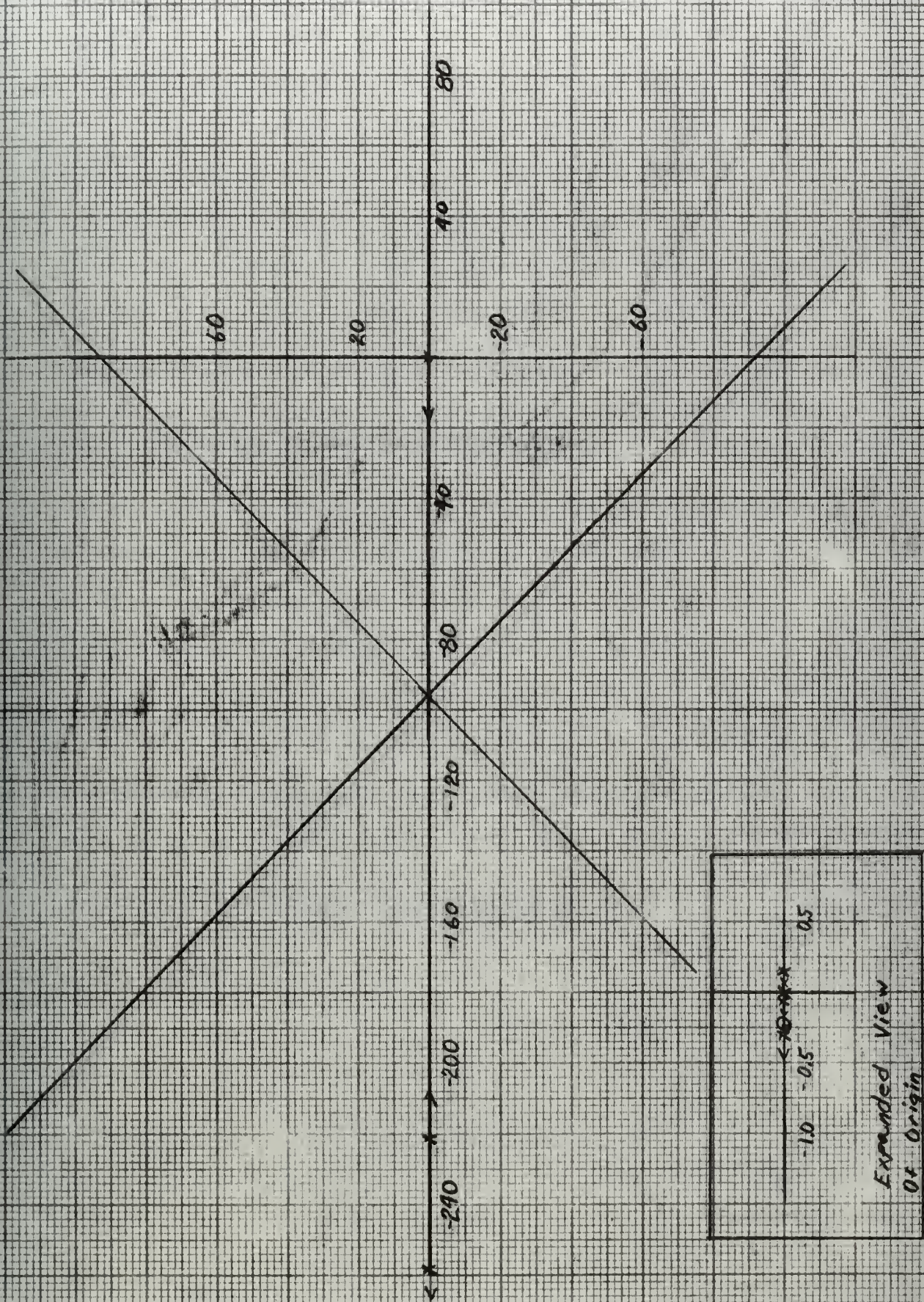
FIGURE IX

Nyquist Criteria Plot





Root locus with 4.5 Knots



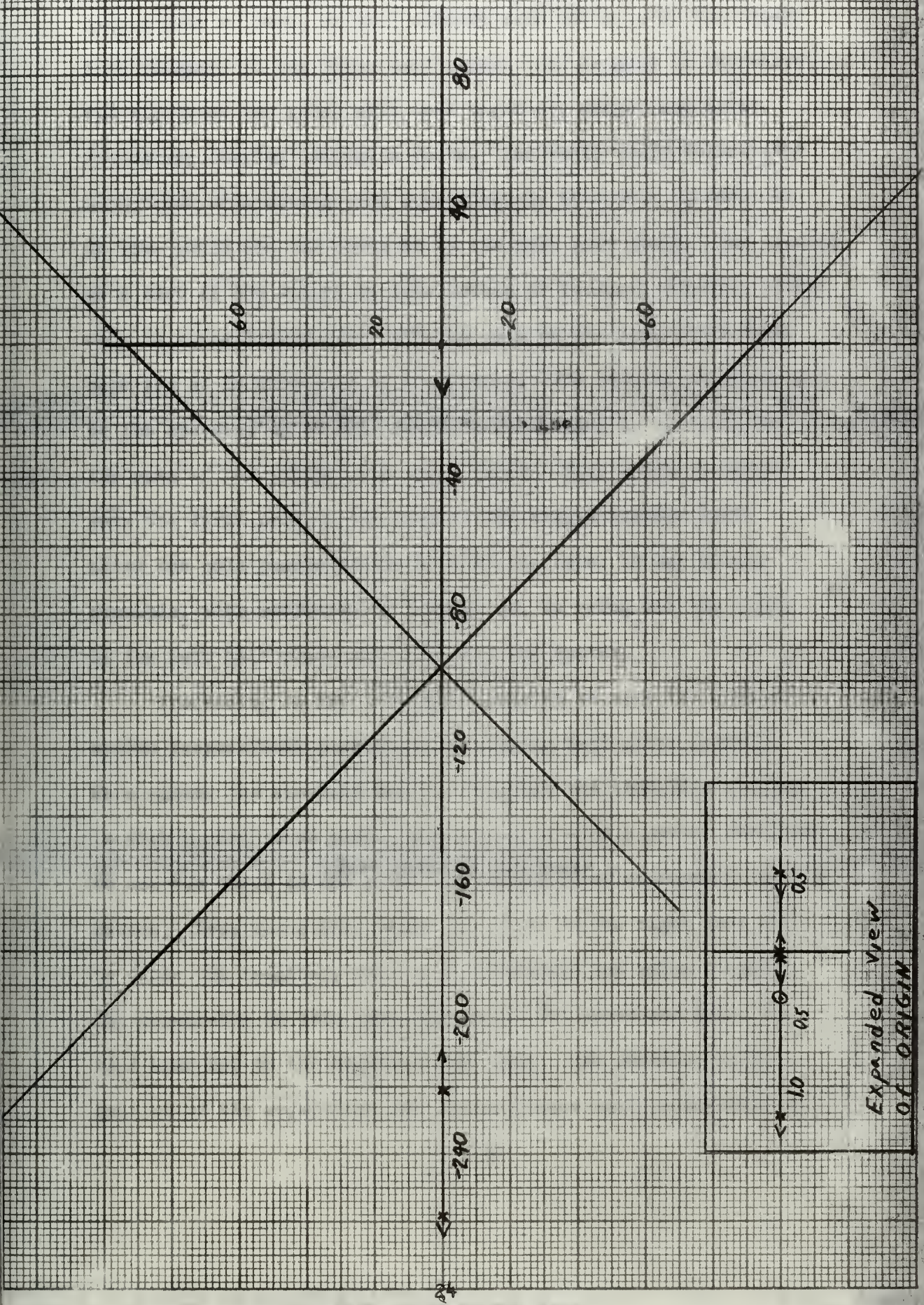
2. In the second part we shall consider the case of a homogeneous medium.

3. The third part is devoted to the study of the asymptotic behavior of the solutions.

4. Finally, in the fourth part we shall discuss the numerical results obtained.



Root Locus at 7.5 Knots



Sheet 10000 of 10000

Sheet 10000 of 10000

Sheet 10000 of 10000

Sheet 10000 of 10000

system gain at zero, we will already have one pole of the closed loop transfer in the right half plane. As the gain is increased, the rightmost two poles will come together, merge, and split, indicating complex conjugate roots. The roots would follow $\pm 45^\circ$ asymptotes originating from approximately the -95.9 point. At no time would all the roots be in the left half plane. The placing of a zero at the origin by this method of feedback control, could only be accomplished with infinite gain on the derivative feedback and so is dismissed as a solution. The only alternative will be the speeding up of the control system, such as by reducing the mass of the plunger and spool valve. This would in effect move the first pole on the left of the origin further left. After the pole passes to the left of the zero, it may become possible, with sufficiently high gains, to bring all the roots to the left half plane and stabilize the system.

Proceeding to the next step would be to make the control system proportional plus first and second derivative control. Here again, the simplest way to visualize the stability problem is with a root locus plot. The effect of such a system would be to add two zeros to the plot. By selection of appropriate gain ratios, these zeros will cause the poles on the right half plane to cross the imaginary axis at a relatively low value of gain. The asymptotes in this case will be at 60° above and below the real axis and on the negative real axis. The point of intersection of the asymptotes and the real axis will be governed by the

The first part of the report deals with the general situation of the country and the progress of the work done during the year. It then goes on to discuss the various departments and the work done in each of them. The report concludes with a summary of the work done and a statement of the progress made.

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The third part of the report deals with the various departments and the work done in each of them. It then goes on to discuss the various departments and the work done in each of them. The report concludes with a summary of the work done and a statement of the progress made.

The fourth part of the report deals with the various departments and the work done in each of them. It then goes on to discuss the various departments and the work done in each of them. The report concludes with a summary of the work done and a statement of the progress made.

The fifth part of the report deals with the various departments and the work done in each of them. It then goes on to discuss the various departments and the work done in each of them. The report concludes with a summary of the work done and a statement of the progress made.

real part of the position of the two new zeros. The 60° slopes obviously indicates that excessive gain will again place the roots in the right half plane and unstabilize the system. As was mentioned before, systems with second derivative feedback have not proved satisfactory for automatic steering control aboard ship. The control system tends to produce relatively high frequency oscillations of the steering device. A continual movement of the steering control would be necessary to stabilize a dynamically unstable ship, but these systems tend to cause much more motion than is needed for effective control. The introduction of a second degree lag network into the control system is recommended by Kydill (3) to help reduce these oscillations.

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CONCLUSION

It is evident that any attempt at automatic control for yaw stabilization of an LCVF without a skeg, will be difficult and uneconomical. By using the skeg to restore dynamic stability to the craft before the control system is added, a great deal of complexity will be eliminated. The dynamically stable craft will naturally be easier to handle when steering manually. The use of prop jet provision appears to be a practical method of propelling and controlling landing craft and is adaptable to automatic control.

The first part of the document discusses the importance of maintaining accurate records of all transactions. It emphasizes that every entry should be supported by a valid receipt or invoice. The second part outlines the procedures for handling discrepancies and errors, including the steps to be taken when a mistake is identified. The final section provides a summary of the key points and offers advice on how to prevent future errors.

100

RECOMMENDATIONS

The most important recommendation can only be to use a skeg to make the LCVF dynamically stable to begin with. If this scheme of testing is to be used again for this model, Jacob's method may be used to include the use of the skeg too.

The testing in the towing tank should include some means of obtaining resistance data while in a surf. This will govern the thrust available for control. I suggest that some ramp be installed in the tank near the wave maker to generate breakers. This ramp would have the same effect as a reef in causing the waves to become breakers. I feel any attempts to gather data using waves breaking on the tank's beach will prove futile, due to the short length of surf.

CHAPTER

The first section of the report discusses the current state of the industry and the challenges it faces. It highlights the need for innovation and investment in research and development. The second section outlines the proposed strategy for addressing these challenges, including the implementation of new technologies and the recruitment of top talent. The third section provides a detailed analysis of the market and the competitive landscape, identifying key players and their strengths and weaknesses. The fourth section discusses the financial aspects of the plan, including the projected revenue and expenses, and the required funding. The fifth section concludes the report with a summary of the key findings and recommendations, and a call to action for the board of directors and the management team.

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APPENDIX



APPENDIX A

The following is a brief description of the Jacobs' (2) method of determining stability indices. The first step was to determine the sectional inertia coefficients C_s by entering figure XVII with the values of sectional area divided by local beam times local draft ($\frac{A}{bh}$) and local beam divided by local draft ($\frac{b}{h}$). Next, Lamb's coefficients of accession to inertia (k_1, k_2, k') are found from figure XVIII by entering with $\frac{2h}{m_1}$. The prime in the following equations will denote non-dementionalized quantities. (note all quantities here are non-dementionalized by the quantities noted in the chapter on results) The limits on the integrals a, b represent bow to stern.

$$m_2 = k_2 \frac{\rho}{2} \int_{x_a}^{x_b} C_s h^2 dx \quad (4)$$

$$m_2' = \frac{m_2}{\sqrt{21} h_{IV}} \quad (5)$$

$$I_y = \frac{I_y' m}{1} \quad (6)$$

$$I_z = \frac{k' m'}{k_2 m_2} \quad (7)$$

$$\bar{x} = \frac{\int_{x_a}^{x_b} C_s x dx}{\int_{x_a}^{x_b} C_s h^2 dx} \quad (8)$$

$$\frac{\bar{x}}{1} \text{ half the prismatic coefficient} \quad (9)$$

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$$N_r^0 = k^0 \frac{\pi \rho}{2} \int_{x_s}^{x_b} C h^2 x^2 dx \quad (10)$$

$$Y_r^0 = m_1 = k_1 m_0 \quad (11)$$

$$Y_r^0 = -m_2 \bar{x} \quad (12)$$

$$N_r^0 = -m_2 \bar{x} \quad (13)$$

$$Y_r^1 = (m_0' + m_1') \frac{x_p}{1} L^0 \psi \quad (14)$$

$$Y_r^1 = Y_r^0 \frac{\rho}{2} u h l \quad (15)$$

$$N_r^0 = -m_2' \frac{\bar{x}}{1} \left(\frac{x_0}{1} \right)^2 L^0 \psi \quad (16)$$

$$N_r^1 = N_r^0 \frac{\rho}{2} u h l^2 \quad (17)$$

Figures XII through XVI are the calculations required to derive these stability derivatives and indices for the LCVP tested. The integrations were carried out by Simpson's rule and all areas found by use of a planimeter.

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 confidential and should be kept as such.

FIGURE XII

Station	h^2	C_s	$C_s h^2$	Lever	S.M.	$\int C_s h^2 dx$	$\int C_s h^2 x dx$
0	0	0	0	0	1	0	0
2	0	0	0	0	4	0	0
4	1.32	0.85	1.122	14.91	2	2.244	33.5
6	3.33	0.87	2.9	12.41	4	11.6	144.0
8	4.68	0.88	4.12	9.91	2	8.23	81.6
10	5.10	0.90	4.59	7.41	4	18.38	136.2
12	5.13	0.97	4.98	4.91	2	9.96	49.0
14	4.60	1.03	4.74	2.41	4	18.97	45.7
16	4.00	1.02	4.08	-0.09	2	8.16	-0.73
18	3.27	1.09	3.56	-2.59	4	14.25	-36.9
20	3.15	1.06	3.34	-5.09	2	6.68	-34.0
22	3.20	1.06	3.39	-7.59	4	13.58	-103.0
24	3.20	1.03	3.29	-10.09	2	6.58	-66.4
26	3.50	0.96	3.17	-12.59	4	12.7	-159.5
28	3.50	0.97	3.40	-15.09	1	3.40	-51.3
						134.73	38.17

$$\bar{x} = \frac{\int_0^b C_s h^2 x dx}{\int_0^b C_s h^2 dx} = \frac{38.17}{134.73} = 0.2835$$

$$I_{x_2} = I_{x_1} + A \bar{x}^2 = 0.955 \times \frac{1.99}{2} \times 134.73 = 393.5$$

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FIGURE XII (continued)

$$Y_r = k \frac{L}{2} \int_{x_s}^{x_s} C_s h^2 dx = 0.935 \times 0.995 \times 3.14159 \times 38.17 = 111.5$$

$$N_y = m \bar{x} = 111.5$$

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DEPARTMENT OF CHEMISTRY

RESEARCH REPORT
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BY
J. D. SMITH
AND
A. B. JONES
1955

FIGURE XIII

Station	h	E.M.	F(Area)	Lever	F(Moment)
0	0	1	0	7	0
2	0	4	0	6	0
4	1.15	2	2.30	5	11.50
6	1.83	4	7.33	4	29.32
8	2.27	2	4.54	3	13.62
10	2.15	4	8.6	2	18.2
12	2.27	2	4.54	1	4.54
14	2.15	4	8.6	0	0
16	3.00	2	4.00	-1	-4.00
18	1.15	4	2.30	-2	-4.60
20	1.78	2	3.56	-3	-10.68
22	1.79	4	7.16	-4	-28.64
24	1.79	2	3.58	-5	-17.9
26	1.82	4	7.28	-6	-43.68
28	1.88	1	1.88	-7	-13.16
			70.86		-56.06

$$x_c = \frac{714}{70.86} \times 2.5 = 2.5 \frac{56.06}{70.86} \times 2.5 = 1.98$$

$$m_c = \frac{25,000}{32.2} = 7.14 \times 10^2 \text{ slug}$$

$$m_c \frac{214}{7.90 \times 32.267} = \frac{214}{(7.995)(2.279)(.043 \times 10^3)} = 3.03 \times 10^{-1}$$

Year	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910
Population	1,000,000	1,050,000	1,100,000	1,150,000	1,200,000	1,250,000	1,300,000	1,350,000	1,400,000	1,450,000	1,500,000
Area (sq. miles)	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Population Density	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15

Source: U.S. Census Bureau

Estimated from 1910 Census

Notes: Population figures are in thousands. Area figures are in square miles.

$$L\psi = \frac{\uparrow h}{I m} = \frac{\uparrow 2.27}{32.367} = 2.205 \times 10^{-1}$$

$$m_1^! = k_1 m_0^! = (0.035)(3.03 \times 10^{-1}) = 1.06 \times 10^{-2}$$

$$m_2^! = \frac{k_1}{k_2} m_1^! = \frac{0.813}{0.935} \times 1.67 \times 10^{-1} = 1.452 \times 10^{-1}$$

$$\bar{x} = 0.2835$$

$$\frac{x_0}{I} = \frac{1}{2} \frac{23,000}{32.367 \times 15.6} = \frac{1}{2} \frac{359}{504} = 0.356$$

1870

1871

1872

1873

1874

1875

1876

1877

1878

1879

1880

1881

FIGURE XIV

Station	Area	S.M.	F(vol.)	Lever	F(moment)
0	0	1	0	7	0
2	0	4	0	6	0
4	3.84	2	7.78	5	88.90
6	8.06	4	32.24	4	128.96
8	10.85	2	21.70	3	65.10
10	12.83	4	51.32	2	102.64
12	14.75	2	29.50	1	29.50
14	15.60	4	62.40	0	0
16	13.88	2	27.76	-1	-27.76
18	13.50	4	54.00	-2	-108.00
20	12.32	2	24.64	-3	-73.92
22	12.12	4	48.48	-4	-193.92
24	11.32	2	22.64	-5	-133.20
26	10.12	4	40.48	-6	-242.88
28	10.28	1	10.28	-7	-71.96
			433.22		-416.54

$$1GB = \frac{F(M)}{F(V)} \times 30 = \frac{-416.54}{433.22} \times 30 = -28.9 \text{ inches aft } X$$

$$\Delta = F(V) \frac{30}{12 \times 3} = 433.22 \times \frac{2.5}{3} = 360 \text{ feet}^3$$

Table 1

Year	1980	1981	1982	1983	1984
1980	100	100	100	100	100
1981	100	100	100	100	100
1982	100	100	100	100	100
1983	100	100	100	100	100
1984	100	100	100	100	100
1985	100	100	100	100	100
1986	100	100	100	100	100
1987	100	100	100	100	100
1988	100	100	100	100	100
1989	100	100	100	100	100
1990	100	100	100	100	100
1991	100	100	100	100	100
1992	100	100	100	100	100
1993	100	100	100	100	100
1994	100	100	100	100	100
1995	100	100	100	100	100
1996	100	100	100	100	100
1997	100	100	100	100	100
1998	100	100	100	100	100
1999	100	100	100	100	100
2000	100	100	100	100	100
2001	100	100	100	100	100
2002	100	100	100	100	100
2003	100	100	100	100	100
2004	100	100	100	100	100
2005	100	100	100	100	100
2006	100	100	100	100	100
2007	100	100	100	100	100
2008	100	100	100	100	100
2009	100	100	100	100	100
2010	100	100	100	100	100
2011	100	100	100	100	100
2012	100	100	100	100	100
2013	100	100	100	100	100
2014	100	100	100	100	100
2015	100	100	100	100	100
2016	100	100	100	100	100
2017	100	100	100	100	100
2018	100	100	100	100	100
2019	100	100	100	100	100
2020	100	100	100	100	100
2021	100	100	100	100	100
2022	100	100	100	100	100
2023	100	100	100	100	100
2024	100	100	100	100	100
2025	100	100	100	100	100
2026	100	100	100	100	100
2027	100	100	100	100	100
2028	100	100	100	100	100
2029	100	100	100	100	100
2030	100	100	100	100	100

Source: [illegible]

[illegible]

FIGURE XV

Station	Draft	h^2	Beam	Area	$\frac{b}{h}$	bh	Area _{bh}	C_s
0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
4	1.15	1.32	7.17	3.89	6.24	8.25	.472	.85
6	1.825	3.33	7.82	8.06	4.29	14.28	.565	.87
8	2.167	4.68	8.15	10.85	3.76	17.72	.612	.88
10	2.260	5.10	8.48	12.83	3.76	19.20	.668	.90
12	2.27	5.13	8.67	14.75	3.82	19.68	.75	.97
14	2.15	4.6	8.75	15.6	4.07	18.8	.83	1.03
16	2.00	4.00	8.54	13.88	4.27	17.08	.813	1.02
18	1.81	3.27	8.38	13.5	4.63	15.18	.89	1.09
20	1.775	3.15	8.27	12.32	4.68	14.7	.84	1.06
22	1.70	3.20	8.10	12.12	4.52	14.5	.84	1.06
24	1.79	3.20	7.82	11.32	4.37	14.0	.81	1.03
26	1.82	3.30	7.53	10.12	4.14	13.7	.74	.96
28	1.875	3.50	7.23	10.28	3.86	13.58	.758	.97

minor axis major axis = $\frac{2^h m}{1} = \frac{4.54}{32.367} = 0.1402$

$k^0 = 0.813$ (rotational)

$k^1 = 0.035$ (longitudinal)

$k_2 = 0.935$ (lateral)

TABLE

Year	Month	Day	Time	Location	Latitude	Longitude	Altitude	Remarks
1912	Jan	1	0800	...	...	...	...	...
1912	Jan	2	0800	...	...	...	...	...
1912	Jan	3	0800	...	...	...	...	...
1912	Jan	4	0800	...	...	...	...	...
1912	Jan	5	0800	...	...	...	...	...
1912	Jan	6	0800	...	...	...	...	...
1912	Jan	7	0800	...	...	...	...	...
1912	Jan	8	0800	...	...	...	...	...
1912	Jan	9	0800	...	...	...	...	...
1912	Jan	10	0800	...	...	...	...	...
1912	Jan	11	0800	...	...	...	...	...
1912	Jan	12	0800	...	...	...	...	...
1912	Jan	13	0800	...	...	...	...	...
1912	Jan	14	0800	...	...	...	...	...
1912	Jan	15	0800	...	...	...	...	...
1912	Jan	16	0800	...	...	...	...	...
1912	Jan	17	0800	...	...	...	...	...
1912	Jan	18	0800	...	...	...	...	...
1912	Jan	19	0800	...	...	...	...	...
1912	Jan	20	0800	...	...	...	...	...
1912	Jan	21	0800	...	...	...	...	...
1912	Jan	22	0800	...	...	...	...	...
1912	Jan	23	0800	...	...	...	...	...
1912	Jan	24	0800	...	...	...	...	...
1912	Jan	25	0800	...	...	...	...	...
1912	Jan	26	0800	...	...	...	...	...
1912	Jan	27	0800	...	...	...	...	...
1912	Jan	28	0800	...	...	...	...	...
1912	Jan	29	0800	...	...	...	...	...
1912	Jan	30	0800	...	...	...	...	...

Prepared by _____
 Checked by _____
 Date _____

FIGURE XVI

Station	x	x ²	C _s h ²	x ² C _s h ²	S.M.	C _s h ² x ² dx
0	0	0	0	0	1	0
2	0	0	0	0	4	0
4	14.91	222	1.122	249	2	498
6	12.41	154	2.9	447	4	1788
8	9.91	98	4.12	404	2	808
10	7.41	55	4.59	252	4	1008
12	4.91	24	4.98	119.5	2	239
14	2.41	5.8	4.74	27.5	4	110
16	-0.07	.0081	4.08	.03	2	.06
18	-2.59	6.7	3.56	23.8	4	95.2
20	-5.09	25.8	3.34	86.2	2	172.4
22	-7.59	57.3	3.39	194	4	776
24	-10.09	101.5	3.29	334	2	668
26	-12.59	158	3.17	500	4	2000
28	-15.09	227	3.40	771	1	771
						8933

$$8933 \times \frac{2.5}{3} = 7443 = \int_{x_s}^{x_b} C_s h^2 x^2 dx$$

$$N_i = 0.813 \times \frac{1.9905}{2} \times 7443 = 18,890$$

$$I = 7.14 \times 65.4 \times 10^2 = 46,700$$

Account

No.	Date	Particulars	Dr.	Cr.	Balance
1	1880	To Balance			1000
2	1881	By Cash	500		500
3	1882	To Cash		200	700
4	1883	By Cash	300		400
5	1884	To Cash		100	500
6	1885	By Cash	200		300
7	1886	To Cash		100	400
8	1887	By Cash	100		300
9	1888	To Cash		200	500
10	1889	By Cash	300		200
11	1890	To Cash		100	300
12	1891	By Cash	200		100
13	1892	To Cash		100	200
14	1893	By Cash	100		100
15	1894	To Cash		100	200
16	1895	By Cash	100		100
17	1896	To Cash		100	200
18	1897	By Cash	100		100
19	1898	To Cash		100	200
20	1899	By Cash	100		100
21	1900	To Cash		100	200
22	1901	By Cash	100		100
23	1902	To Cash		100	200
24	1903	By Cash	100		100
25	1904	To Cash		100	200
26	1905	By Cash	100		100
27	1906	To Cash		100	200
28	1907	By Cash	100		100
29	1908	To Cash		100	200
30	1909	By Cash	100		100
31	1910	To Cash		100	200
32	1911	By Cash	100		100
33	1912	To Cash		100	200
34	1913	By Cash	100		100
35	1914	To Cash		100	200
36	1915	By Cash	100		100
37	1916	To Cash		100	200
38	1917	By Cash	100		100
39	1918	To Cash		100	200
40	1919	By Cash	100		100
41	1920	To Cash		100	200
42	1921	By Cash	100		100
43	1922	To Cash		100	200
44	1923	By Cash	100		100
45	1924	To Cash		100	200
46	1925	By Cash	100		100
47	1926	To Cash		100	200
48	1927	By Cash	100		100
49	1928	To Cash		100	200
50	1929	By Cash	100		100
51	1930	To Cash		100	200
52	1931	By Cash	100		100
53	1932	To Cash		100	200
54	1933	By Cash	100		100
55	1934	To Cash		100	200
56	1935	By Cash	100		100
57	1936	To Cash		100	200
58	1937	By Cash	100		100
59	1938	To Cash		100	200
60	1939	By Cash	100		100
61	1940	To Cash		100	200
62	1941	By Cash	100		100
63	1942	To Cash		100	200
64	1943	By Cash	100		100
65	1944	To Cash		100	200
66	1945	By Cash	100		100
67	1946	To Cash		100	200
68	1947	By Cash	100		100
69	1948	To Cash		100	200
70	1949	By Cash	100		100
71	1950	To Cash		100	200
72	1951	By Cash	100		100
73	1952	To Cash		100	200
74	1953	By Cash	100		100
75	1954	To Cash		100	200
76	1955	By Cash	100		100
77	1956	To Cash		100	200
78	1957	By Cash	100		100
79	1958	To Cash		100	200
80	1959	By Cash	100		100
81	1960	To Cash		100	200
82	1961	By Cash	100		100
83	1962	To Cash		100	200
84	1963	By Cash	100		100
85	1964	To Cash		100	200
86	1965	By Cash	100		100
87	1966	To Cash		100	200
88	1967	By Cash	100		100
89	1968	To Cash		100	200
90	1969	By Cash	100		100
91	1970	To Cash		100	200
92	1971	By Cash	100		100
93	1972	To Cash		100	200
94	1973	By Cash	100		100
95	1974	To Cash		100	200
96	1975	By Cash	100		100
97	1976	To Cash		100	200
98	1977	By Cash	100		100
99	1978	To Cash		100	200
100	1979	By Cash	100		100

John J. ...

...

...

FIGURE VII

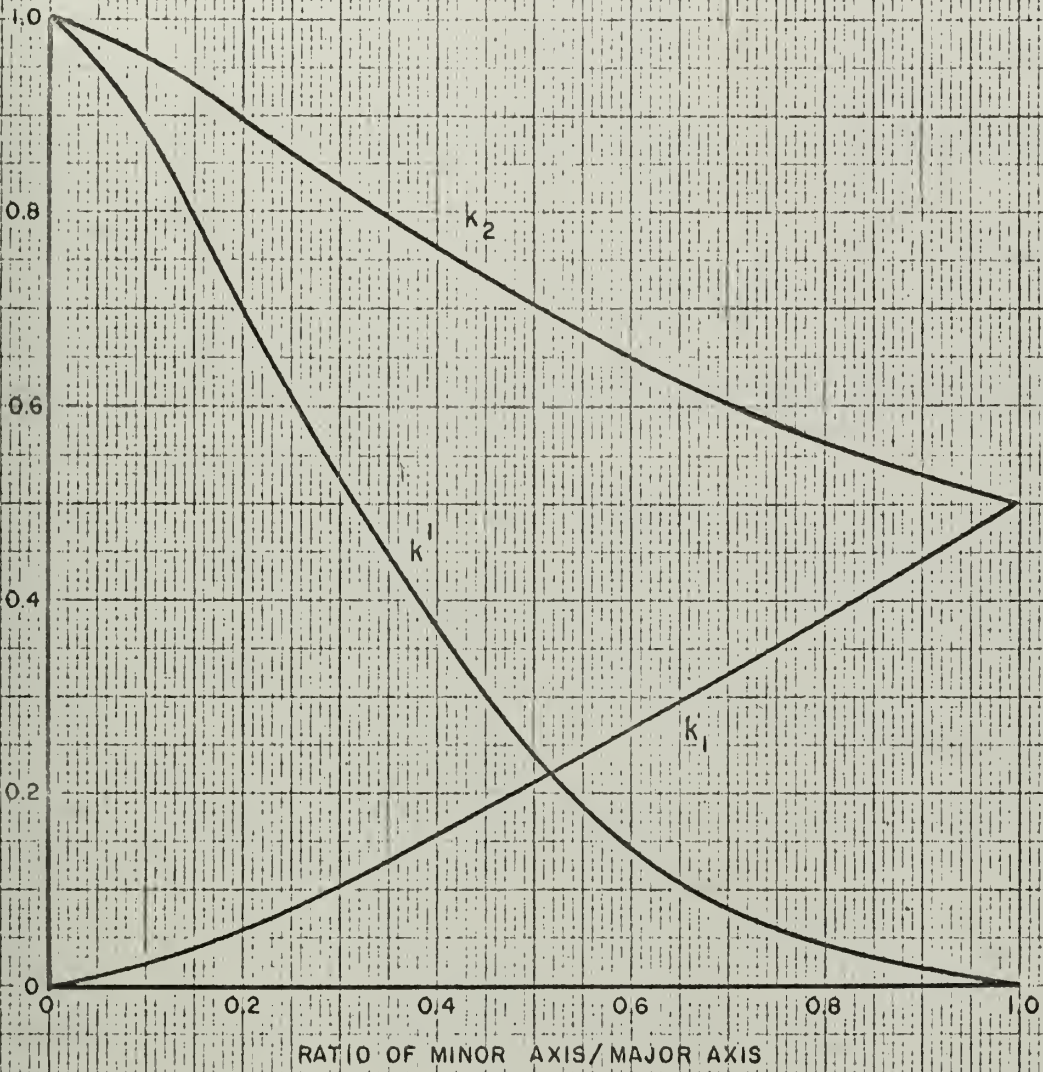
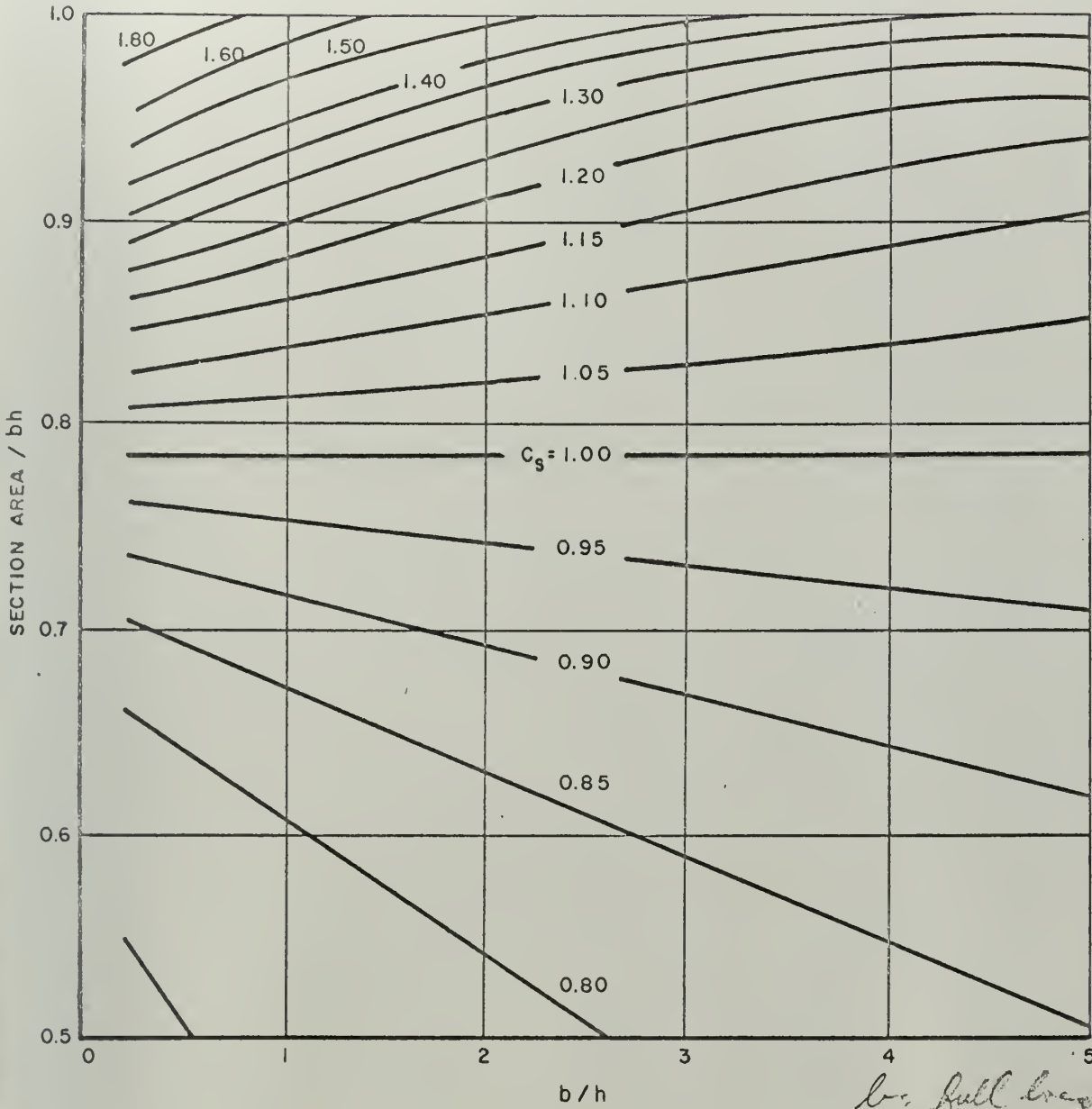


FIGURE 2. COEFFICIENTS OF ACCESSION TO INERTIA FOR PROLATE SPHEROIDS (FROM H. LAMB'S HYDRODYNAMICS)



FIGURE VIII



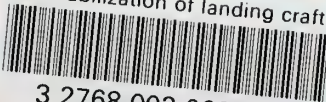
*loc. full beam beam
draft*

SECTIONAL INERTIA COEFFICIENTS C_s AS FUNCTIONS OF THE LOCAL BEAM-DRAFT RATIO b/h AND SECTION AREA COEFFICIENT, FROM PROHASKA



thesH568

Yaw stabilization of landing craft.



3 2768 002 06072 5

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