END
DATE
FILMED

6 -78

DDC

1·0 2·8 2·5

3·15 2·2

3·5 2·0

1·1 4·0

4·5 1·8

1·25 1·4 1·6

NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md.   20084

DETERMINATION OF SIZE AND LOCATION OF FOILS FOR
2000 TON HYDROFOIL SMALL WATERPLANE AREA SHIP
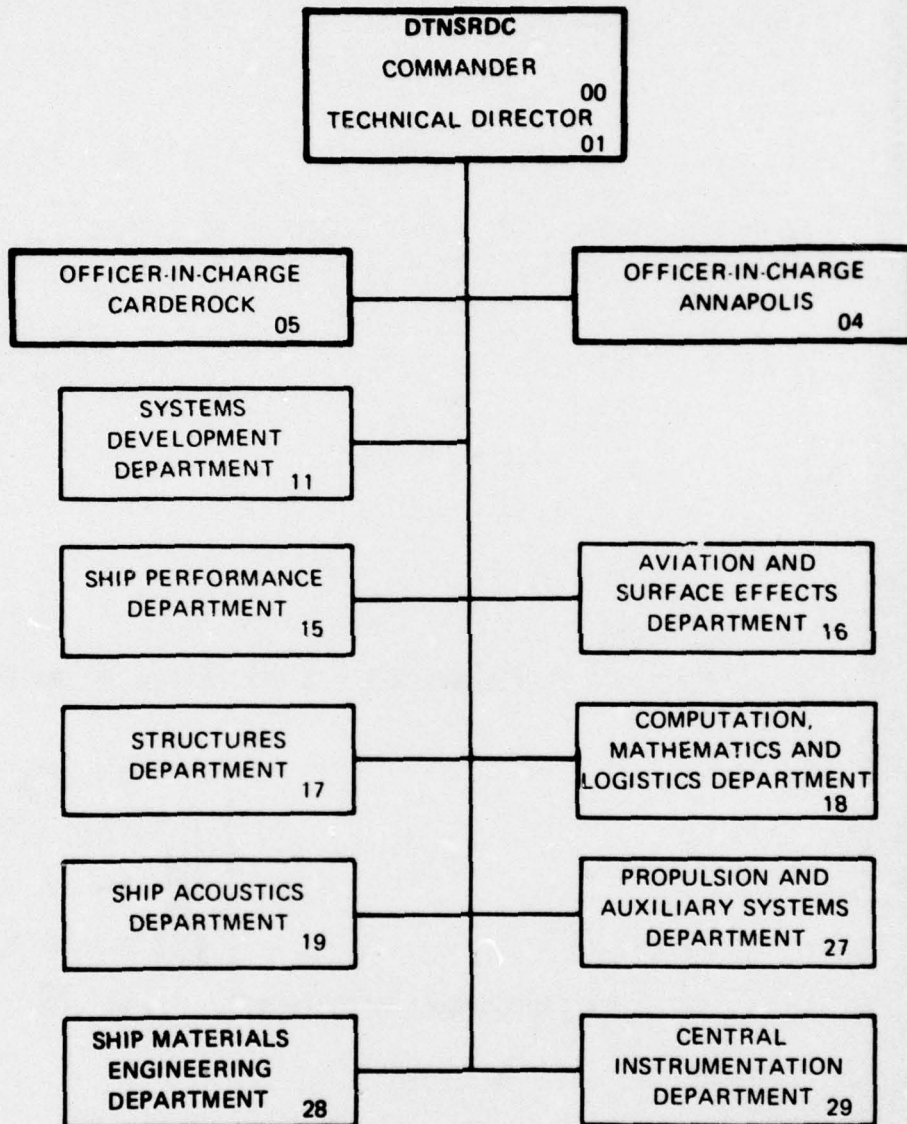(HYSWAS) FOR VERTICAL-PLANE STABILITY

by

Choung M. Lee

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

SHIP PERFORMANCE DEPARTMENT

November 1975   SPD-648-01

MAJOR DTNSRDC ORGANIZATIONAL COMPONENTS

```
                        ┌─────────────────────┐
                        │      DTNSRDC        │
                        │    COMMANDER        │
                        │                 00  │
                        │ TECHNICAL DIRECTOR  │
                        │                 01  │
                        └─────────────────────┘
```

DTNSRDC COMMANDER 00 TECHNICAL DIRECTOR 01

OFFICER-IN-CHARGE CARDEROCK 05

OFFICER-IN-CHARGE ANNAPOLIS 04

SYSTEMS DEVELOPMENT DEPARTMENT 11

SHIP PERFORMANCE DEPARTMENT 15

AVIATION AND SURFACE EFFECTS DEPARTMENT 16

STRUCTURES DEPARTMENT 17

COMPUTATION, MATHEMATICS AND LOGISTICS DEPARTMENT 18

SHIP ACOUSTICS DEPARTMENT 19

PROPULSION AND AUXILIARY SYSTEMS DEPARTMENT 27

SHIP MATERIALS ENGINEERING DEPARTMENT 28

CENTRAL INSTRUMENTATION DEPARTMENT 29

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (14) SPD-648-01	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* (6) Determination of Size and Location of Foils for 2000 Ton Hydrofoil Small Waterplane Area Ship (HYSWAS) for Vertical-Plane Stability		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Choung M./Lee		8. CONTRACT OR GRANT NUMBER(s) (16) F43411
9. PERFORMING ORGANIZATION NAME AND ADDRESS David W. Taylor Naval Ship R&D Center Bethesda, MD 20084		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS (17) SF 43 41 1201 1170-092
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE (11) November 1975 13. NUMBER OF PAGES 31
14. MONITORING AGENCY NAME & ADDRESS*(if different from Controlling Office)*		15. SECURITY CLASS. *(of this report)* Unclassified (12) 36p. 15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for Public Release: Distribution Unlimited

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*
Dynamic Stability
Control
Hydrofoil
Waves
Small Waterplane Area Ship

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

An investigation is made to determine desirable sizes and longitudinal locations of foils to provide vertical plane stability for a 2000-ton Hydrofoil Small Waterplane Area Ship (HYSWAS). After determination of the foil size and locations, the motion of the ship in regular head waves is computed and the probable range of the rate of foil deflections for the control of heave and pitch motion is examined.

Within the scope of this analysis, it is found that a proper selection of ——

DD _{1 JAN 73} FORM 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601 |

UNCLASSIFIED

389 694

20. (Continued)

size and location of foils will provide the vertical-plane stability up to 50 knots and that the required foil deflection rates are considered to be practical.

ACCESSION for

NTIS	White Section	☒
DDC	Buff Section	☐
UNANNOUNCED		☐
JUSTIFICATION		

BY
DISTRIBUTION/AVAILABILITY CODES

Dist.	AVAIL. and/or SPECIAL	
A		

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF TABLES

ABSTRACT

An investigation is made to determine desirable sizes and longitudinal
locations of foils to provide vertical plane stability for a 2000-ton
Hydrofoil Small Waterplane Area Ship (HYSWAS). After determination of
the foil size and locations, the motion of the ship in regular head
waves is computed and the probable range of the rate of foil deflections
for the control of heave and pitch motion is examined.

Within the scope of this analysis, it is found that a proper selection
of size and location of foils will provide the vertical-plane stability
up to 50 knots and that the required foil deflection rates are considered
to be practical.

ADMINISTRATIVE INFORMATION

INTRODUCTION

The Hydrofoil Small Waterplane Area Ship (HYSWAS) consists of slender submerged main hull which is a body of revolution, a plane like vertical strut, and an upper hull above the water which is a wide platform. There are wing-like hydrofoils attached to the submerged hull at two different longitudinal locations. These hydrofoils provide the necessary lift and control of the motion in both calm and rough water. A sketch of a typical HYSWAS configuration is given in Figure 1. The concept of the HYSWAS configuration was developed at the Center.*

The objective of the present study was to examine a variety of foil systems and to determine the desirable longitudinal locations of the foils to provide:

1. sufficient vertical plane stability up to a maximum speed of 50 knots,

2. sufficient controllability of the heave and pitch motion in waves, and

3. minimum excitation in pitch when the foils are activated for roll control.

The size of the foils is dictated by the lift required to be provided by the foils to meet the design draft of the ship. Thus, there is not much leeway within which to change the total plane area of the foil system, but the problem of distributing the loads between the main and secondary foils and of determining the foil longitudinal locations still remains to be resolved.

_____
*J.R. Meyer described the concept in two Systems Development Department Technical Notes.

2

The investigation of vertical-plane stability of the ship was carried out for numerous sets of main and secondary foils for various longitudinal locations either in airplane like arrangements or in canard arrangements.

The analytical method used in this investigation is similar to the one used for Small Waterplane-Area Twin Hull (SWATH) ships by Lee and Martin.[1] This method is based on a stability equation of fourth-degree polynomials which is derived from the coupled equations of motion for heave and pitch. In the analysis the foils are assumed to be stationary.

After the selection of a set of foils and their locations, the dynamic response of the ship with the foils stationary in regular head waves was examined and an estimate of the range of the control rates of the foils to reduce the wave-excited motion of the ship was made.

Within the scope of the present analysis, a main foil having an average chord of 11.9 ft and a semi-span of 35.6 ft located at 105 ft to 115 ft from the nose of the submerged hull, and a secondary foil having an average 8.3 ft chord and a semi-span of 16.6 ft located 235 ft from the nose of the hull appear to provide adequate vertical plane stability, and the required foil control rates are considered to be practical.

---

[1] Lee, C.M. and Martin, M., "Determination of Size of Stabilizing Fins for Small Waterplane-Area, Twin-Hull Ships," NSRDC Report 4495, 1974

3

A study on the roll stability was also carried out earlier at the Center. That work revealed that for dynamic roll stability an active foil control system is required. When the foils are activated for the control of roll motion, it can be excpected that a certain amount of undesired heave and pitch excitation could be induced by the foils. Thus, further study on optimum automatic control of the foils should be made to insure the stability of the ship in heave, pitch and roll as well as to provide the desired control of motion in waves.

ANALYSIS AND DISCUSSIONS

1. Vertical-Plane Stability

The hull geometric characteristics of a 2000 ton HYSWAS are given in Table 1. The first series of investigations was made for a matrix of foil sets chosen on the basis of:

1. Providing the required dynamic lift for given speeds,

2. Dividing the required lift load between the main and secondary foils by the ratios of 70% to 30%, 75% to 25%, 85% to 15%, 90% to 10% and 100% to 0%, and in airplane form or in canard form under the condition that the total pitch moment contributed by the foils about the longitudinal center of gravity (LCG) of the ship is small.

For three assumed locations of LCG of 123 ft, 125 ft, and 127 ft from the nose of the lower hull, nine sets of foils for each LCG were considered. The dimensions and locations of these foils were provided by the sponsor and are shown in Table 2*. None of the foils for the 123 ft LCG showed sufficient stability for speeds up to 50 knots, and most of them were unstable even at 30 knots. Stability improved with movement of

* J.R. Meyer provided the data.

4

LCG aft to 125 ft and 127 ft; however, the stability was still considered
to be insufficient. The prime reason for the instability came from the fact
that the longitudinal locations of the foils were chosen to counterbalance
the pitch moment about the LCG, and thus, the foils did not provide
sufficient supplemental restoring capability to counteract a destabilizing
hydrodynamic pitch moment due to forward motion which is often referred
to as Munk's moment.

From this investigation, it was found that the stability of the ship
is very sensitive to the relative distance of the foils with respect to
the LCG. Thus, a second trial was made for Foil B and Foil E (see Table 2)
which were found to be preferred foil systems based on stability. This
time, the locations of Foils B and E were also slightly modified as shown
in Table 3. The position of the LCG was changed from 125 ft from the nose
of the hull to 127 ft and 129 ft respectively. The results are shown in
Figure 2 in which the lowest absolute values of the real parts of the
stability roots, $(-\lambda_R)_{Min}$, versus ship speed are shown for different LCG
locations. The greater the value of $(-\lambda_R)_{Min}$ the greater the stability.

As can be seen from Figure 2, Foil E shows better stability than Foil
B, and for both foils the position of LCG at 125 ft aft of the hull nose
shows slightly greater stability. The measure of stability can be better
understood in terms of half-decay time $T^{(1/2)}$, which is obtained by

$$T^{(1/2)} = \ln2/(-\lambda_R)_{Min}$$

5

Thus, for instance we find that

$(-\lambda_R)$ Min	$T^{(1/2)}$ (sec)
0.09	7.7
0.05	13.9
0.01	69.3

Suppose that a wave train disturbs the ship at some instant so that the ship begins to be displaced from its equilibrium position. If the ship encounters another wave train in a period less than the half-decay time of the ship, the ship will be displaced further from its equilibrium position. This means that the smaller $T^{(1/2)}$, the better the chance for the ship to maintain its equilibrium position. Although Foil E may provide slightly better stability than Foil B, the main foil is located a great distance aft of the LCG (about 45 ft from the LCG) which may cause undesirable pitch excitation when the foils are activated for roll control.

A third trial was made for Foils B and E by fixing the LCG 125 ft from the nose of the hull, and by also fixing the locations of the secondary foils while the locations of the main foils were varied. The results are shown in Figure 3 for Foil B and in Figure 4 for Foil E. The ordinates of Figures 3 and 4 are the absolute values of the real part of the root which, of the four roots, has the least negative real part. From Figure 3, it can be seen that the main foil placed 17 ft forward of the LCG appears to be the best location from the stability viewpoint for Foil B. The best location for the main foil

6

for Foil E appears to be at a distance of 49 ft aft of the LCG. It is apparent from Figures 3 and 4 that Foil B has slightly greater stability than Foil E. Furthermore, for Foil B the location of the main foil is closer to the LCG which could result in less pitch moment in case the differential deflection of the foils at each side of the hull for roll control produces a net lift.

The foregoing investigation leads to the conclusion that Foil B, which has its main foil 17 ft forward of and the secondary foil 110 ft aft of the LCG, is the best selection of those investigated. However, it is important to note that the analytical method employed in the present study is based on estimated lift characteristics of the foils as well as estimated hydrodynamic coefficients of the non-appended hull i.e. the hull without the foils. It is almost impossible at the present stage to estimate the lift characteristics of the foils, which are attached to a large body and are influenced by the free surface, to the degree of accuracy desired in the present study. To accommodate the possible errors in the estimation of the lift-curve slopes (C_{L_α}) of the foils, the stability analysis for Foil B was repeated by reducing alternately the value of C_{L_α} for the main and secondary foils by 15%. An initial estimate of C_{L_α} for the foils was made basically following the method given by Pitts, et al[2], and the computed values were modified to account for the free surface and other unknown effects.

_____
[2] Pitts, W.C., Nielsen, J.N., and Kaattari, G., "Lift and Center of Pressures of Wing-Body-Tail Combinations at Subsonic, Transonic, and Supersonic Speeds," NACA Report 1307, 1957

7

The values of $C_{L\alpha}$ of Foil B before the 15% reduction for the accommodation for possible errors were 4.9 for the main foil and 4.4 for the secondary foil. These values are per radian of angle of attack of the foils.

The stability results for Foil B with the reduced $C_{L\alpha}$ are shown in Figures 5 and 6. It can be observed from these figures that a reduction of $C_{L\alpha}$ by 15% for the main and the secondary foils resulted in approximately a 15% increase and 15% decrease respectively, in the optimum distance of the main foil forward of the LCG. From these results, it can be deduced that if the values of $C_{L\alpha}$ were to be increased by 15%, a reverse trend to that obtained by decreasing $C_{L\alpha}$ by 15%, would occur. At any rate, the range of the optimum location of the main foil appears to lie between 10 ft and 20 ft forward of the LCG for the speed range of 30 to 40 knots, and even possibly beyond 40 knots since the results reveal little effect of speed on the optimum location of the main foil when the ship speed exceeds 30 knots. Hereafter, we shall designate Foil B with its main foil at 17 ft forward of the LCG as Foil B*.

As pointed out earlier, the relative location of the foils with respect to LCG has a significant effect on the stability of the ship. In real operation of a ship, it can be expected that the LCG position would change to a certain extent depending on loading conditions. To examine the effect of a shift of the LCG position on stability, the position of LCG of the ship with Foil B* was changed from 125 ft to 123 ft, 127 ft and 129 ft, respectively, and the results are shown

8

in Figure 7. From this figure it can be observed that as the magnitude of shift of LCG from the 125 ft position increases, the deterioration of stability also increases in the speed range of 30 to 50 knots.

In the speed range of 20 knots to 25 knots, the draft of the ship becomes 34 ft. Due to the change of draft in this speed range the hydrodynamic coefficients of the hull were reevaluated, and with these inputs the stability analysis was carried out. Following a similiar procedure the stability analysis at a speed of 15 knots, at which the draft of the ship changes to 35 ft, was also conducted. In these analyses, the foil system assumed was Foil B^*. Table 4 shows the minimum absolute values of the stability index for speeds of 15 knots to 50 knots for the 2000 ton HYSWAS with Foil B^*. The transient characteristics such as half-decay time, natural period and damping ratio of the ship with Foil B^* are given in Table 5.

2. Dynamic Response in Waves

The heave and pitch motion excited by regular head waves for the 2000 ton HYSWAS with Foil B^* was evaluated by a computer program developed at the Center. This program computes the heave and pitch motion in regular head waves at any heading for monohull ships, monohull ships with asymmetric cross sections (e.g. inclined sailing boats), and twin hull ships such as catamaran and small waterplane area configurations.

The motion was computed for 30 and 40 knots. The computation inclueds the effects of foils which are treated as stationary. The results are shown in Figures 8 and 9. Figure 8 shows the heave amplitude divided by the wave amplitude and the pitch amplitude divided by wave slope (2π times the ratio of the wave amplitude to wave length)

9

for various wave lengths. The ship length in these figures means
the lower hull length which is 257 ft. Figure 9 shows the amplitude
of the vertical motion of the forward end of the strut with respect
to the free surface elevation beneath it. The numbers shown are
nondimenstional values normalized by the wave amplitude.

To gain some physical measure of these results, let us consider
a wave length of 1800 feet which is typical for large swells in the
Pacific Ocean near Hawaii. Assume that the wave amplitude is about
20 ft. Then, from Figure 9, we find that the relative motion amplitude
of the forward end of the strut at wave length/ship length $(\lambda/L) = 7.0$
is 0.35×20 ft $= 7$ ft. This means that when encountering the above
swell at 30 to 40 knots the main hull of the 2000 ton HYSWAS will not
broach the free surface nor will the bottom of the upper hull (platform)
be subject to wave contact since both the top of the submerged hull
and the bottom of the upper hull exceed 7 feet from the mean free surface
level.

On the other hand, if we assume a wave length of 500 ft and a wave
amplitude of 15 ft, which could be roughly categorized as Sea State 7, we
find from Figure 9 that the relative vertical motion amplitude at the
forward end of the strut is about 14 ft. In this case, we expect wave
contacts on the bottom of the upper hull and broaching of the lower hull.

Figure 10 shows the vertical acceleration divided by the product of
gravitational acceleration and wave amplitude at the forward end of the

10

strut, as the LCG and at the aft end of the strut.

If we take again the wave lengths of 1800 ft and 500 ft with the respective wave amplitudes as used in the foregoing examples, we find an acceleration of 0.16g for the 1800 ft wave and 0.33g for the 500 ft wave at the forward end of the strut at a ship speed of 30 knots.

Figure 11 shows the heave force and pitch moment exerted on the ship by the waves for a speed of 30 knots. If we assume the 500 ft wave with an amplitude of 15 ft, the maximum heave force is about 800 tons and the maximum pitch moment is about 31,500 tons-ft, since the displacement of the ship at 30 knots is approximately 1,400 tons. A wave-exciting pitch moment of 31,500 tons-ft is equivalent to the moment resulting from shifting the LCG of the 2000 ton ship by about 15.8 ft from its original location. If we assume that both foils have incident-angle control, the required deflection of the foils in the same direction to counteract the wave-exciting heave force of 800 tons at the ship speed of 30 knots is obtained as follows:

The necessary deflection angle of the foils in degrees, α, is given by

$$\alpha = \frac{800 \times 2240}{\frac{\rho}{2} U^2 (2C_1 S_1 C_{L\alpha 1} + 2C_2 S_2 C_{L\alpha 2})} \times \frac{180}{\pi}$$

where ρ is the mass density of water, U is the ship speed, C is the average chord, S is the semispan, $C_{L\alpha}$ the lift-curve slope and the subscripts 1 and 2 indicate the main foil and the secondary foil, respectively. For $\rho = 1.99$ slug/ft^3, $U = 30 \times 1.69 = 50.7$ ft/sec, $C_1 = 11.9$ ft, $S_1 = 35.6$, $C_{L\alpha 1} = 4.9$, $C_2 = 8.3$ ft, $S_2 = 16.6$ ft and

11

$C_{L\alpha2} = 4.4$, we find that $\alpha = 7.5$ deg. The rate of deflection, $\dot{\alpha}$, is obtained by $\dot{\alpha} = \frac{\alpha}{Te/4}$ where Te is the wave encounter period. For 500 ft wave length at a ship speed of 30 knots in head waves the encounter period is 4.93 sec. Thus, we have $\dot{\alpha} = 6.1$ deg/sec. To counteract a wave-exciting pitch moment of 31,500 tons-ft at this speed the required deflection of the foils in opposing directions is obtained as follows:

$$\alpha = \frac{31500 \times 2240}{\frac{\rho}{2} U^2 (2C_1 S_1 C_{L\alpha1} \ell_1 + 2C_2 S_2 C_{L\alpha2} \ell_2)} \times \frac{180}{\pi}$$

where ℓ_1 and ℓ_2 are the longitudinal distance from the LCG to the 1/4-chord position of the main foil and the secondary foil, respectively. For Foil B* we have $\ell_1 = 17$ ft and $\ell_2 = 110$ ft, hence at a speed of 30 knots, we obtain $\alpha = 7.8$ deg. The rate of deflection is 6.3 deg/sec. Following a similar procedure to the above for $\lambda = 1800$ ft shows that the respective foil deflections to counteract the heave force and pitch moment are about 9 deg and 2.4 deg respectively; and the deflection rates are 7.3 deg/sec and 2.0 deg/sec, respectively.

In practice, the sensor for the foil deflections would be motion of the ship rather than the wave-exciting forces or moments. Thus, the above estimate of the necessary foil deflections is intended only to provide some idea as to the feasibility of foil control. It appears that with the Foil B* the design of a control system for foils for vertical-plane motion in waves would be well within practical design limits.

12

CONCLUDING REMARKS

The following findings are made from the present analysis:

1. Relative location of the foils with respect to the longitudinal center of gravity of the ship is a dominant factor for the vertical-plane stability.

2. The optimum locations of the foils for the vertical-plane stability do not appear to change significantly with ship speed..

3. Vertical-plane stability can be maintained, if there is no cavitation or ventilation, up to 50 knots for the 2000-ton HYSWAS by proper selection of the size and location of the foils. A foil system which can provide the necessary lift and vertical-plane stability has the following dimensions and locations:

Foil	Average Chord (ft)	Semi-Span (ft)	Location* (ft)
Main	11.9	35.6	108
Secondary	8.3	16.6	235

*Distance from the nose of the lower hull

4. Although a preliminary analysis of the vertical-plane motion of the ship in head waves at the fully foil-borne condition is presented in this report, it is recommended that further investigations be conducted to assess the relative merit of the wave-induced motion characteristics of the 2000-ton HYSWAS with other types of marine vehicles for similar operational requirements.

5. In real operations of the ship, it appears that the foils should be activated to control roll motion. Since the present analysis is based on stationary foils, it should serve as a guideline for an eventual optimum system design of automatic foil control.

13

ACKNOWLEDGMENT

The author would like to express his thanks to Mrs. Margaret D. Ochi and Mr. John R. Meyer for their careful review of the manuscript and valuable suggestions. The author acknowledges the contribution of the necessary input data for this study by Mr. Meyer.

14

REFERENCES

1. Lee, C.M. and Martin, M., "Determination of Size of Stabilizing Fins for Small Waterplane-Area, Twin-Hull Ships," NSRDC Report 4495, 1974

2. Pitts, W.C., Nielsen, J.N., and Kaattari, G., "Lift and Center of Pressures of Wing-Body-Tail Combinations at Subsonic, Transonic, and Supersonic Speeds," NACA Report 1307, 1957
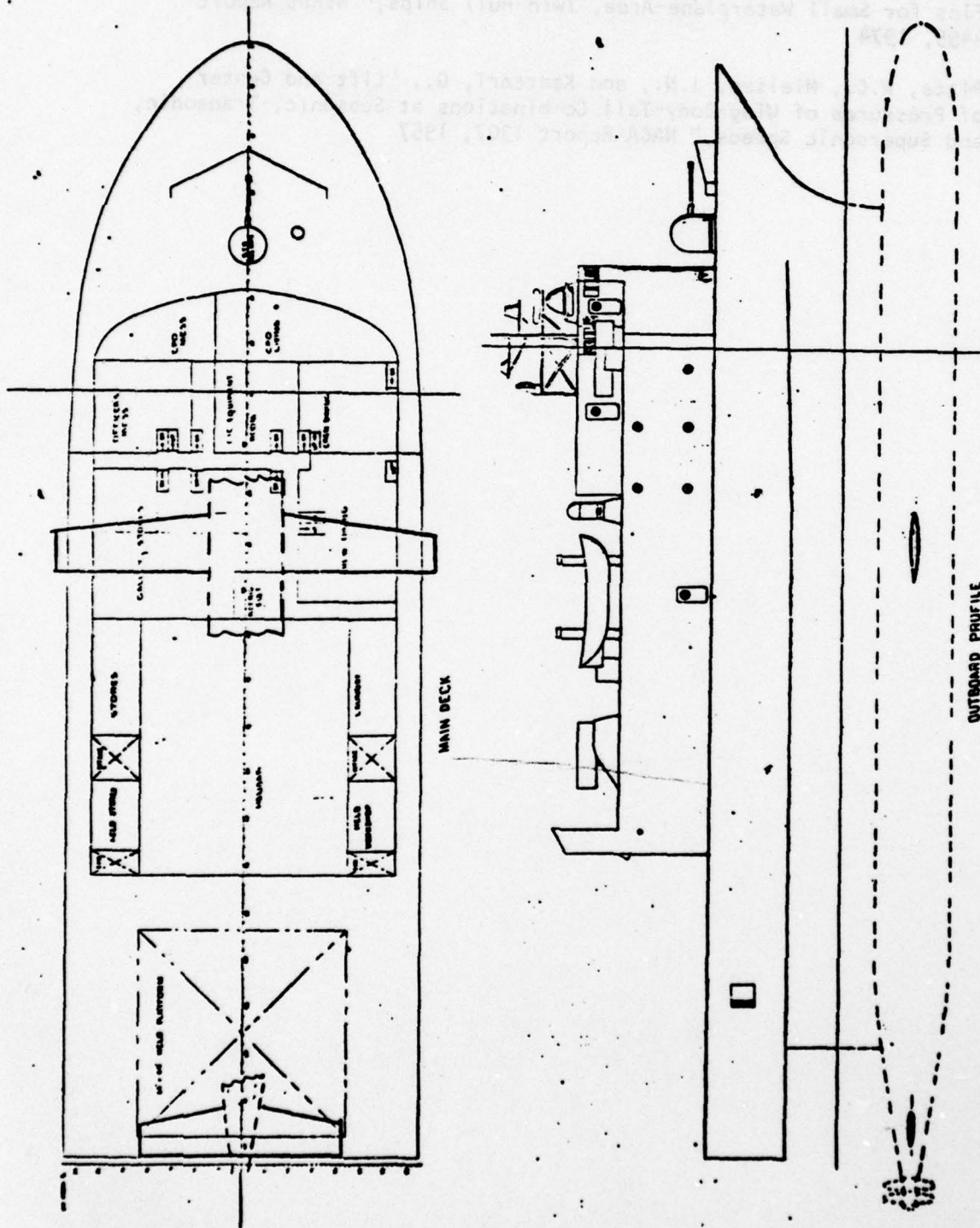
REFERENCES

1. McLeavy, C.M. and Martin, M., "Determination of Size of Stabilizing
   Fins for Small Waterplane-Area, Twin Hull Ships," NSRDC Report
   4677, 1974

2. Weiss, C.C., Wielgosz, J.R., and Kennard, E., "Lift of a Center
   of Pressure of Wing-Body-Tail Combinations at Subsonic, Transonic,
   and Supersonic Speeds," NACA Report 1307, 1957

OUTBOARD PROFILE

MAIN DECK

FIGURE 1 - General Sketch of Hydrofoil Small Waterplane Area Ship (HYSWAS) - 2000 ton
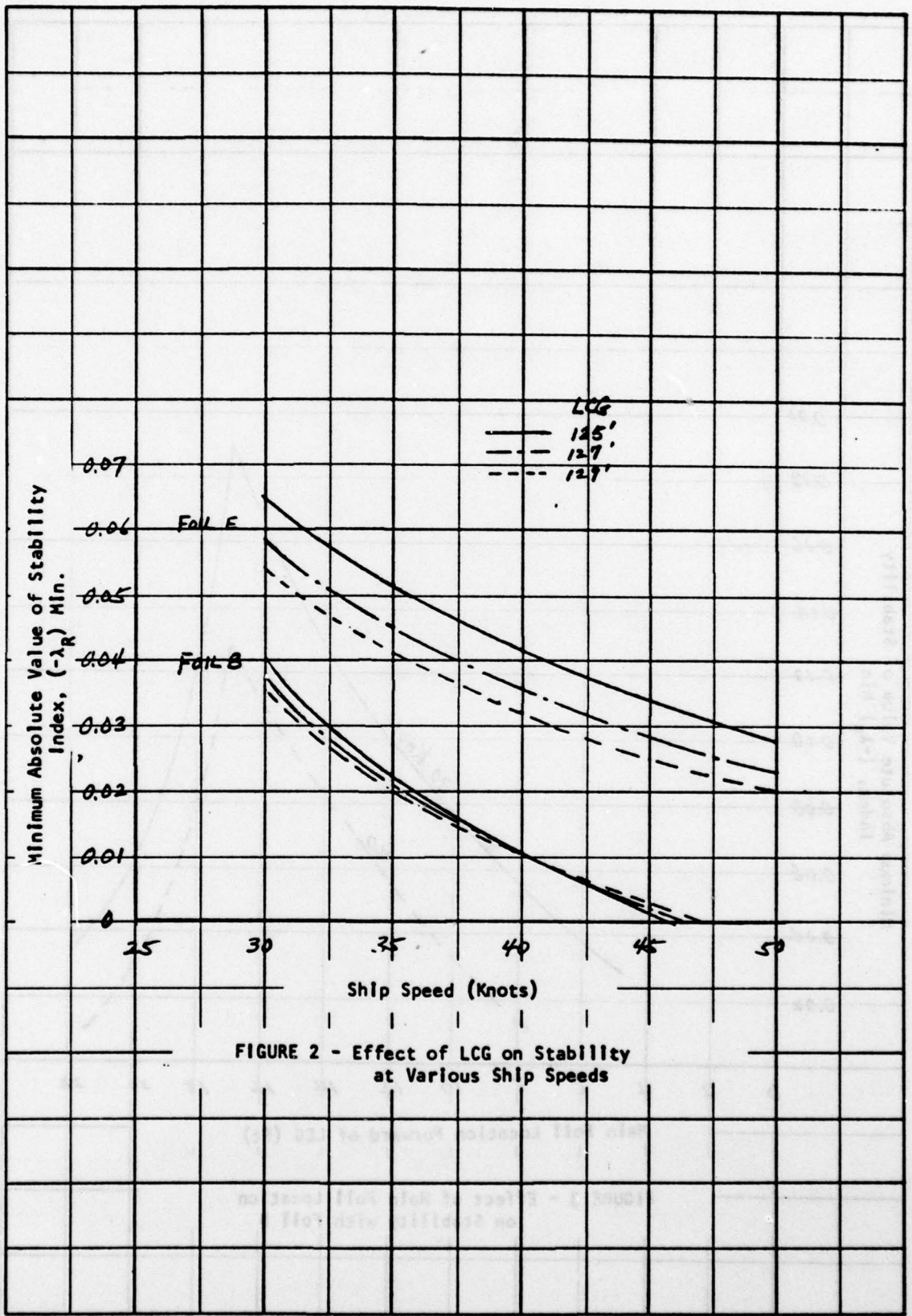
FIGURE 2 - Effect of LCG on Stability
at Various Ship Speeds

17
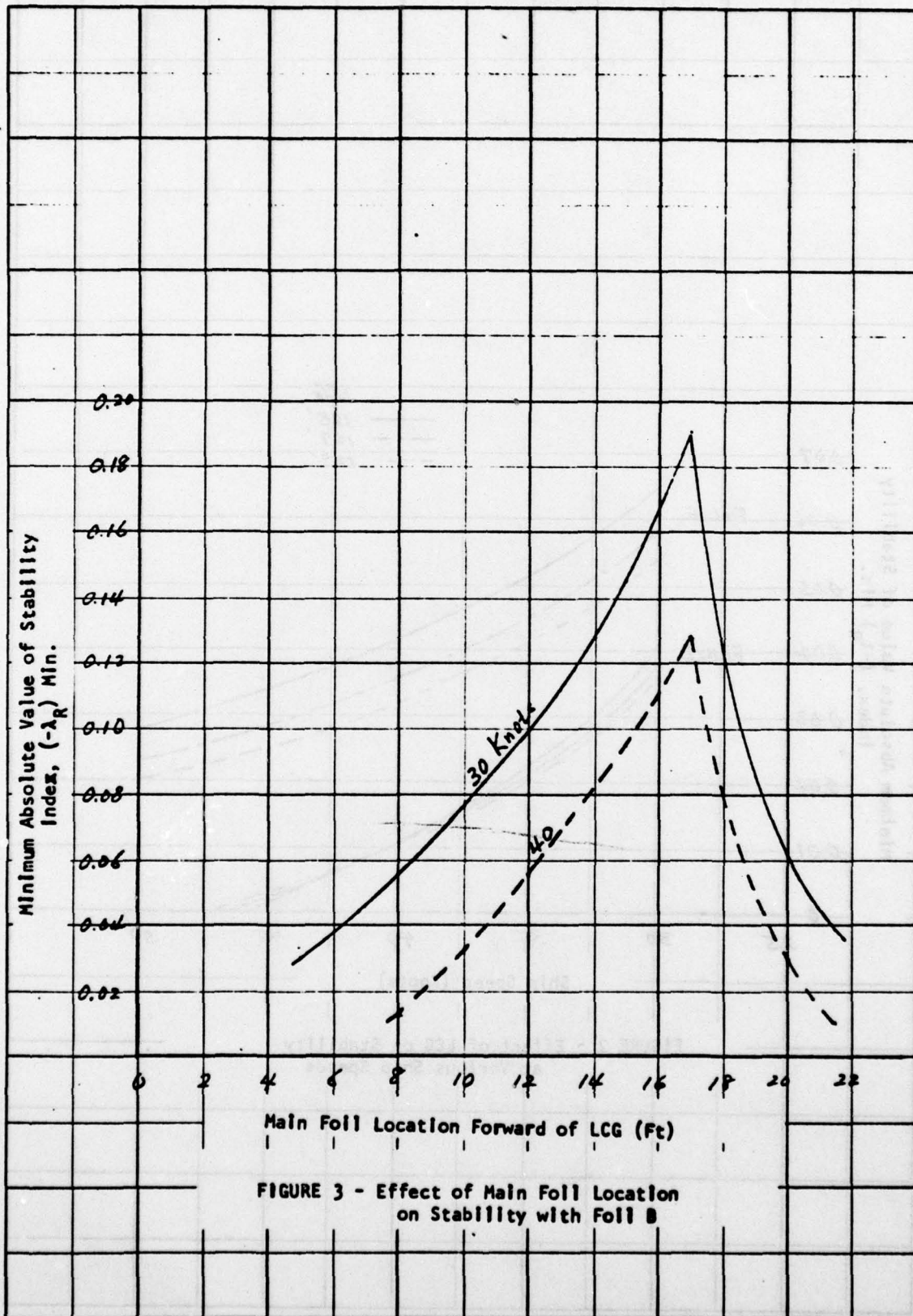
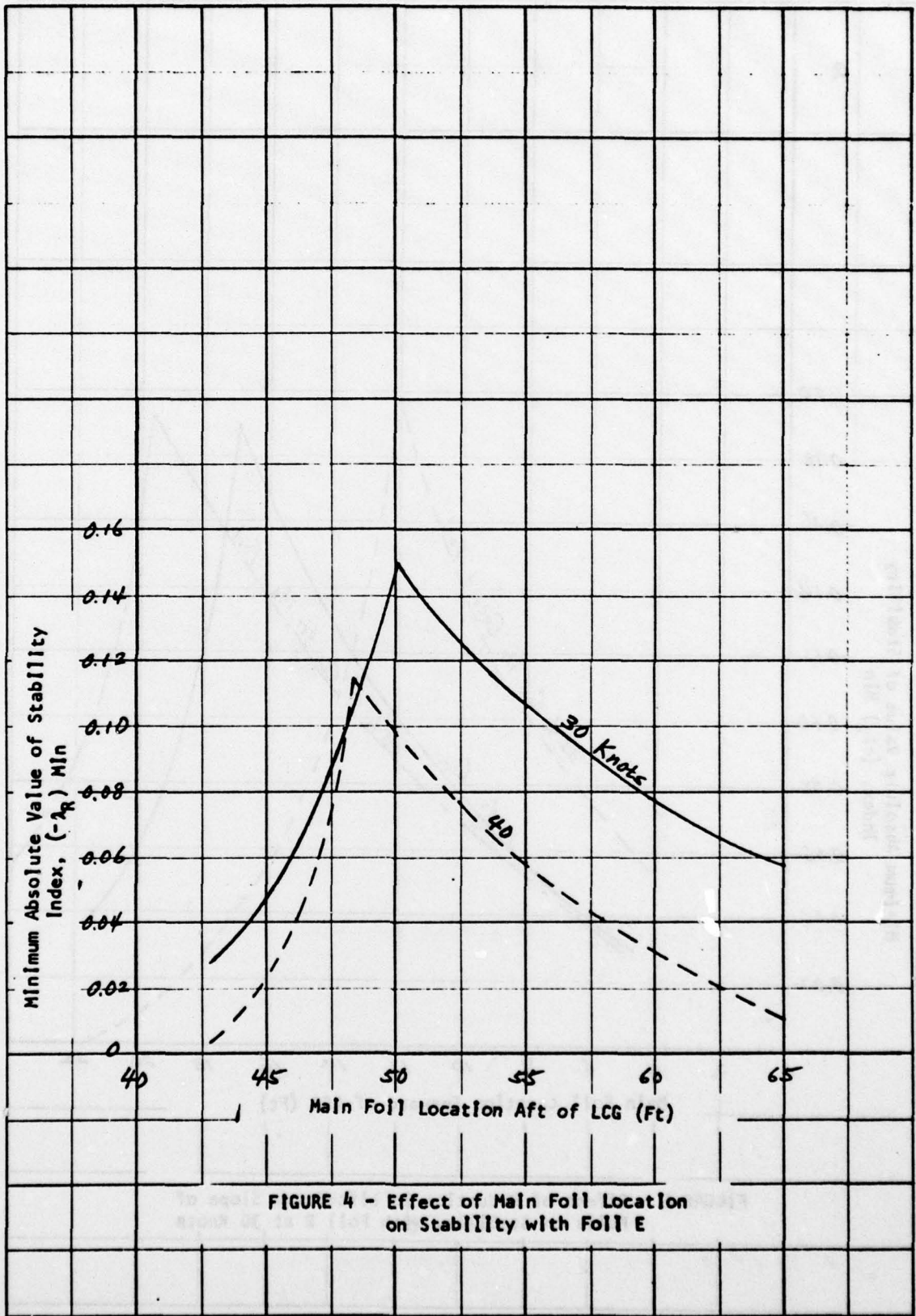FIGURE 3 - Effect of Main Foil Location on Stability with Foil B

18

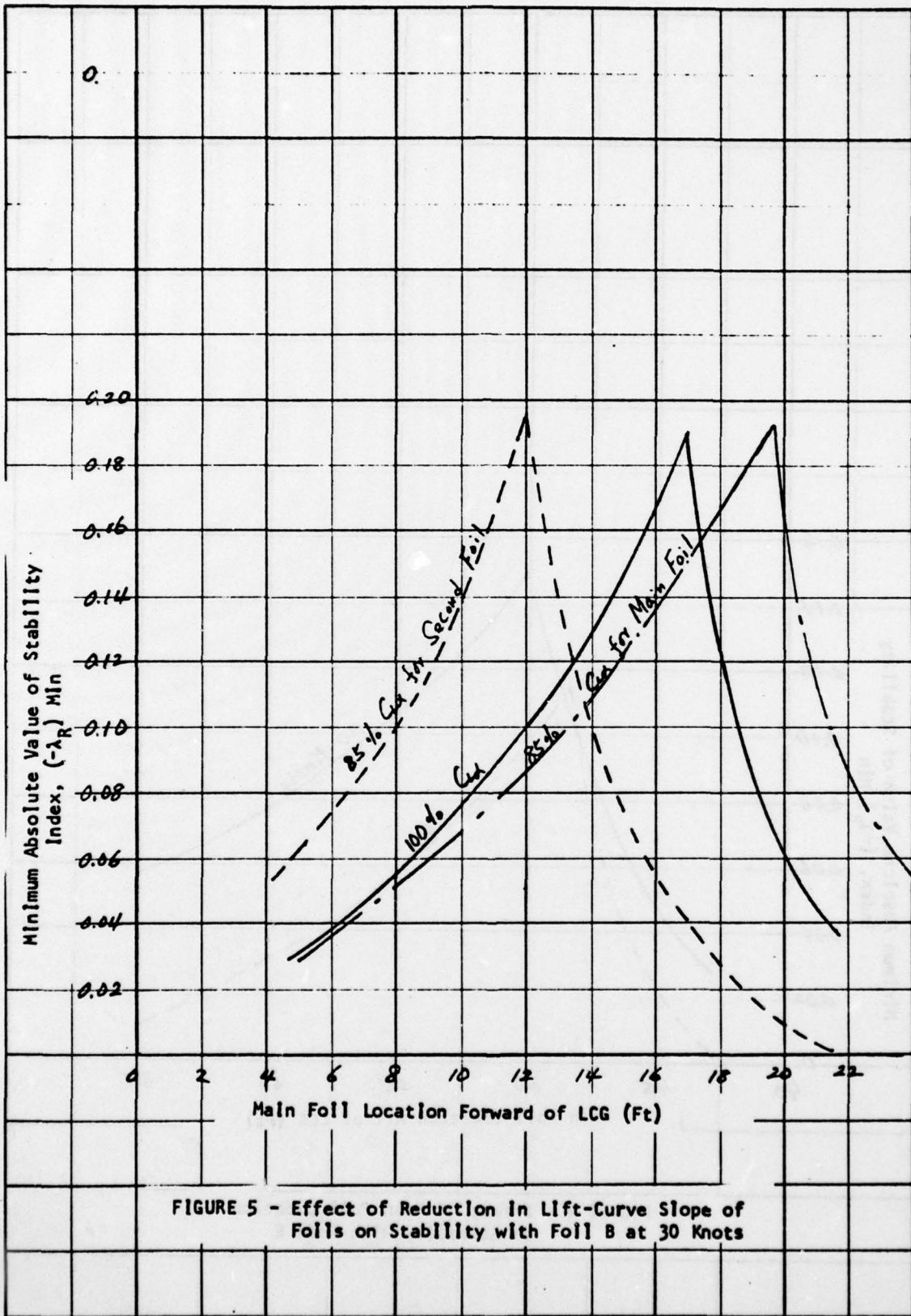FIGURE 4 - Effect of Main Foil Location on Stability with Foil E

FIGURE 5 - Effect of Reduction in Lift-Curve Slope of
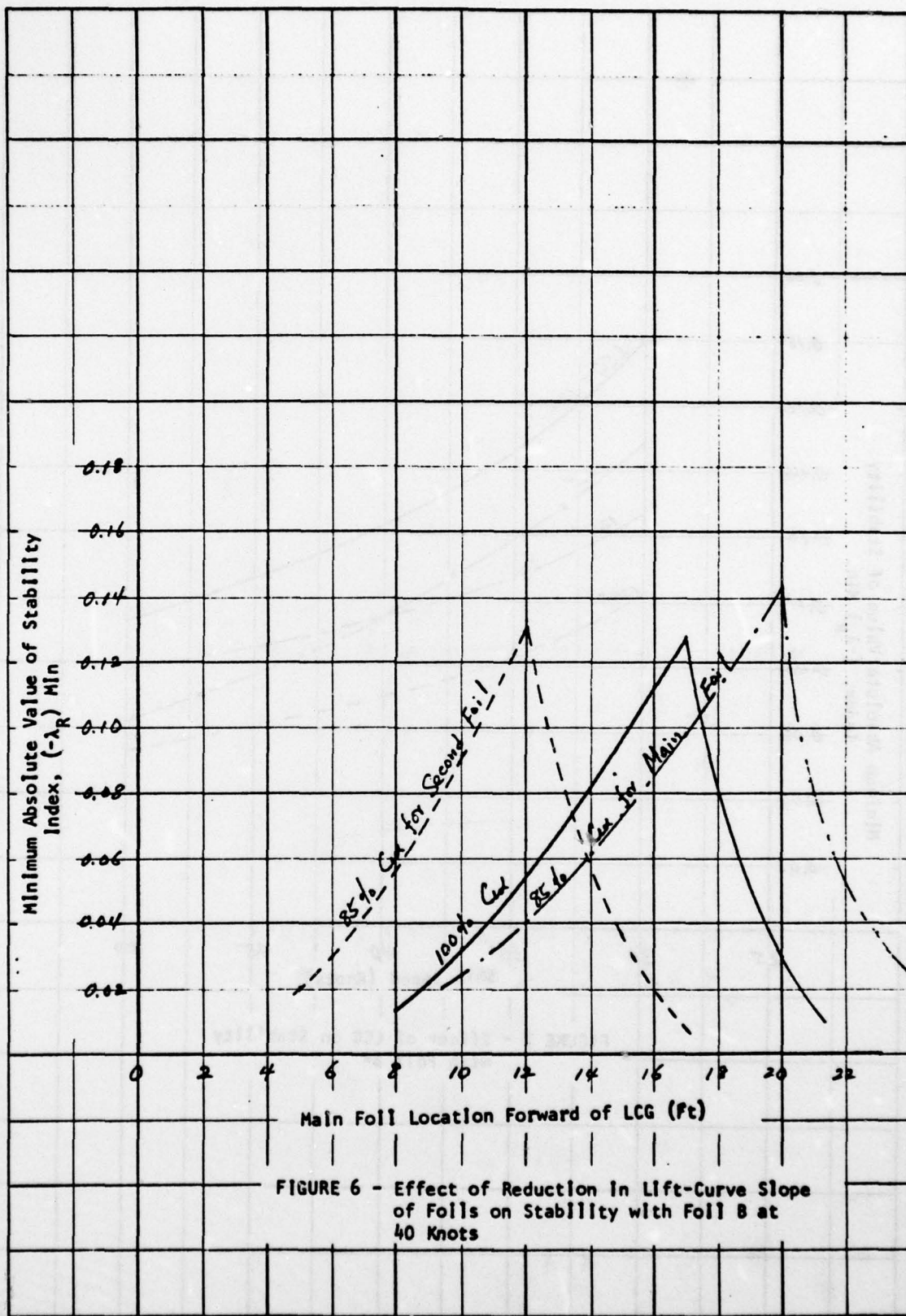Foils on Stability with Foil B at 30 Knots

20

FIGURE 6 - Effect of Reduction in Lift-Curve Slope of Foils on Stability with Foil B at 40 Knots
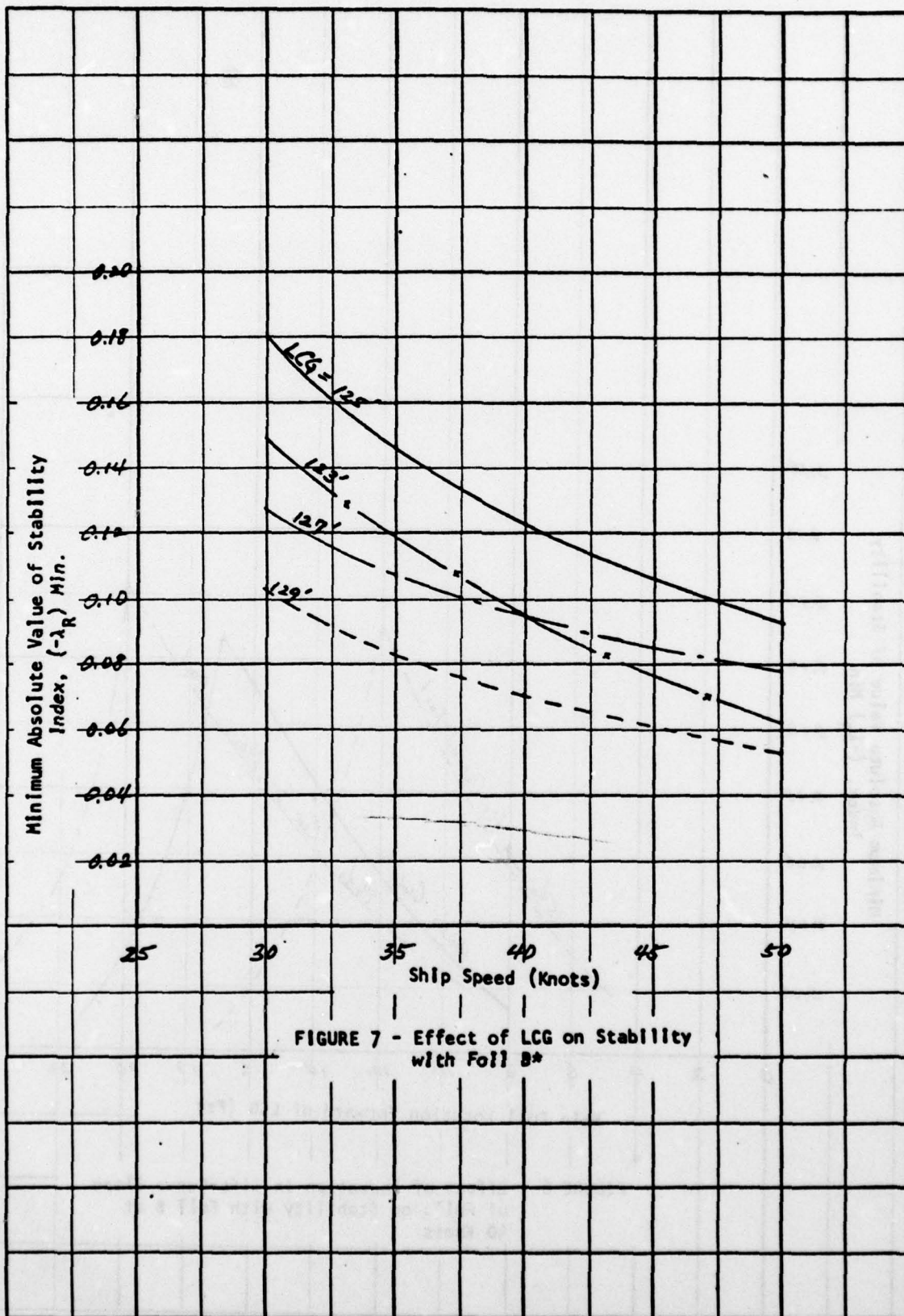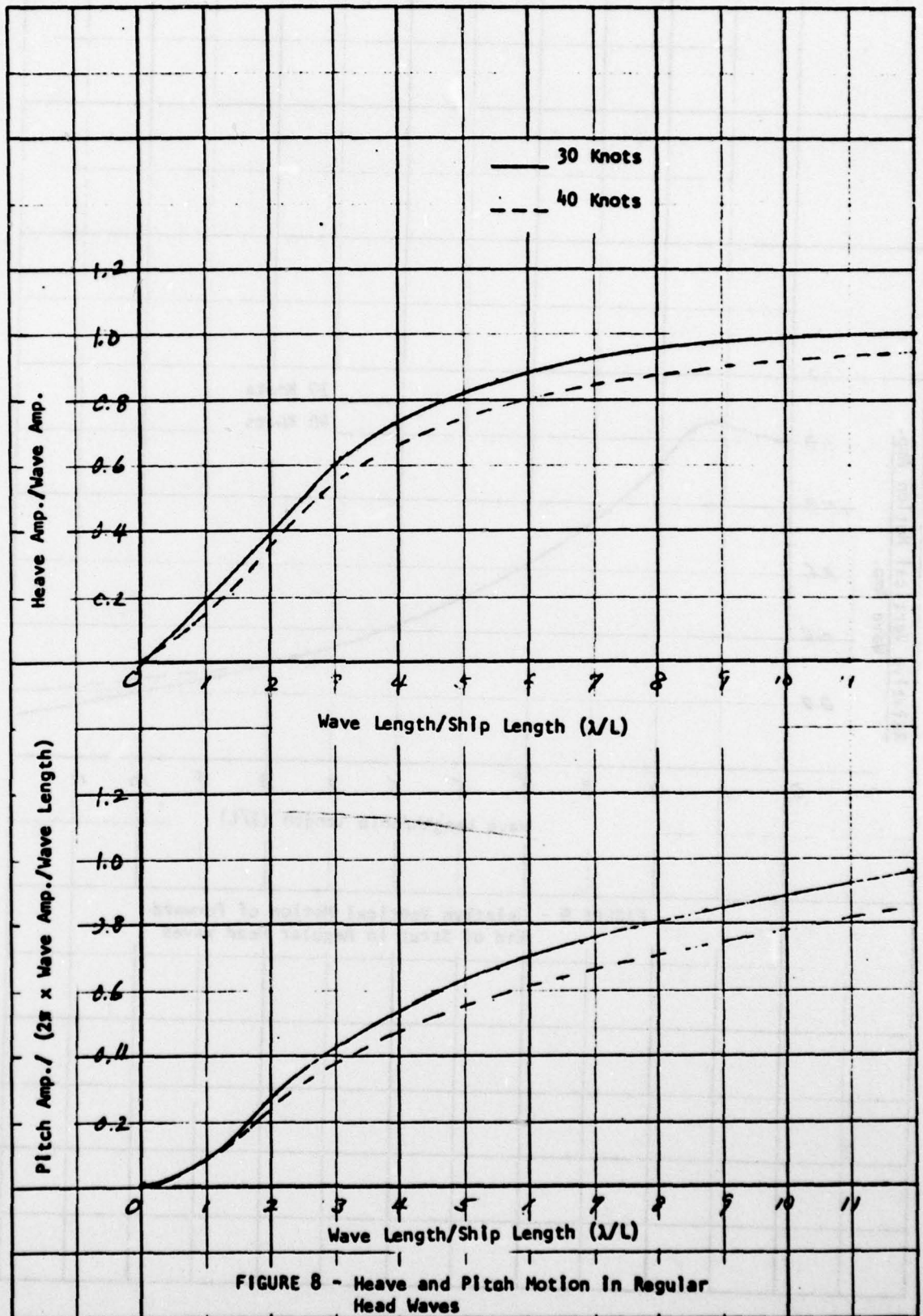
21

Minimum Absolute Value of Stability Index, $(-\lambda_R)$ Min.

0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02

LCG = 125'
123'
127'
129'

25   30   35   40   45   50

Ship Speed (Knots)

FIGURE 7 - Effect of LCG on Stability with Foil B*

22

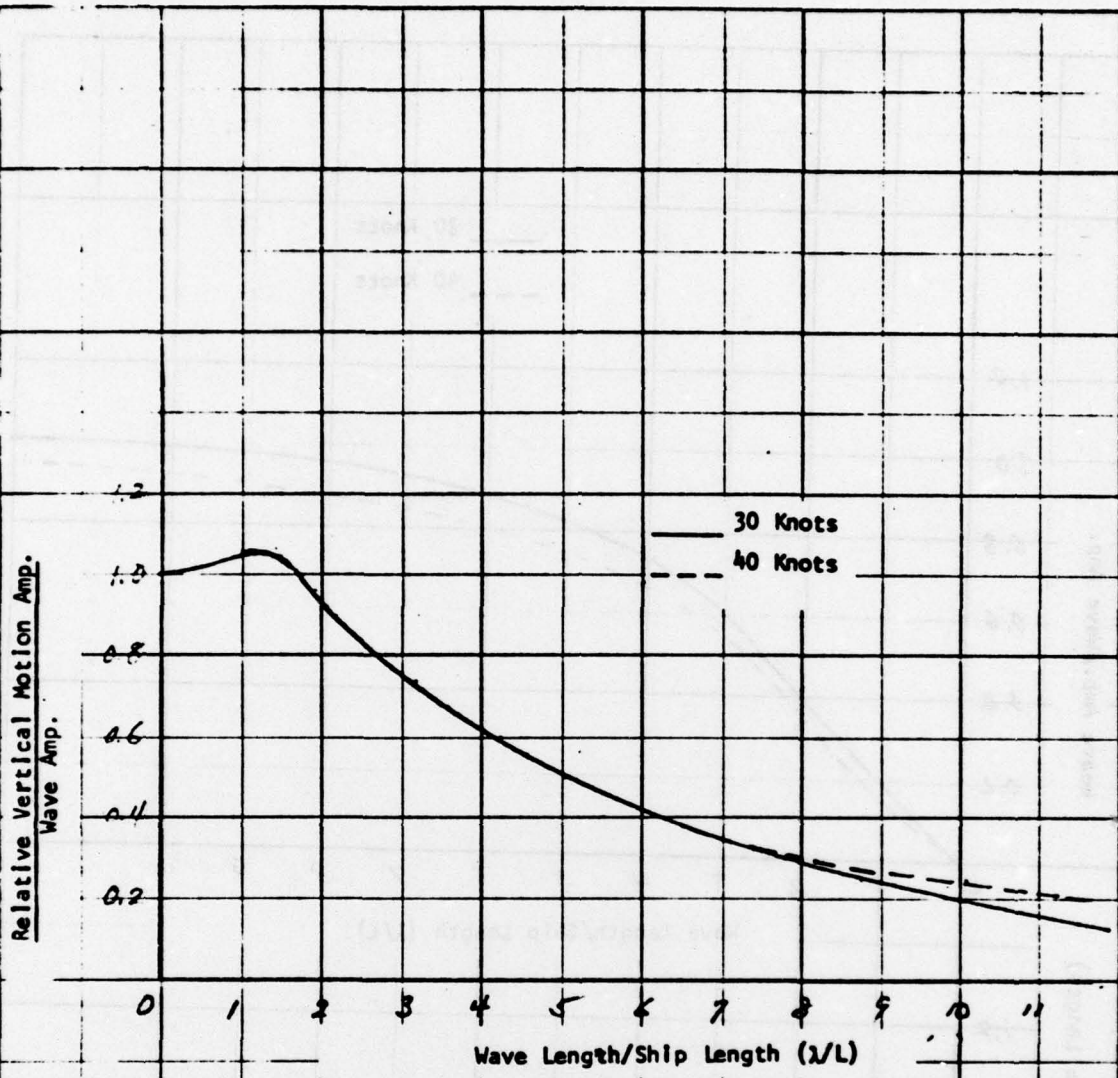FIGURE 8 - Heave and Pitch Motion in Regular Head Waves

FIGURE 9 - Relative Vertical Motion of Forward
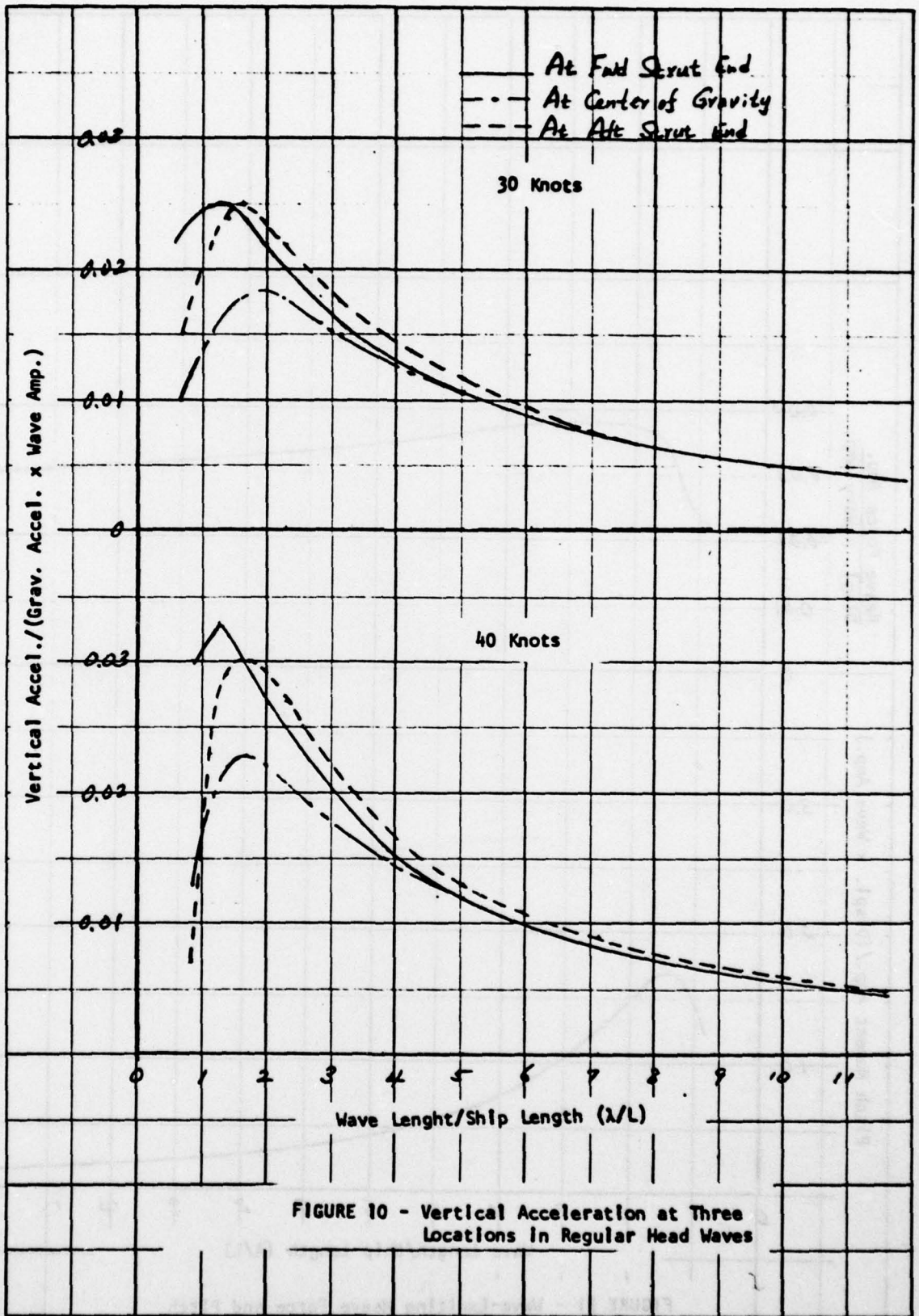End of Strut in Regular Head Waves

24

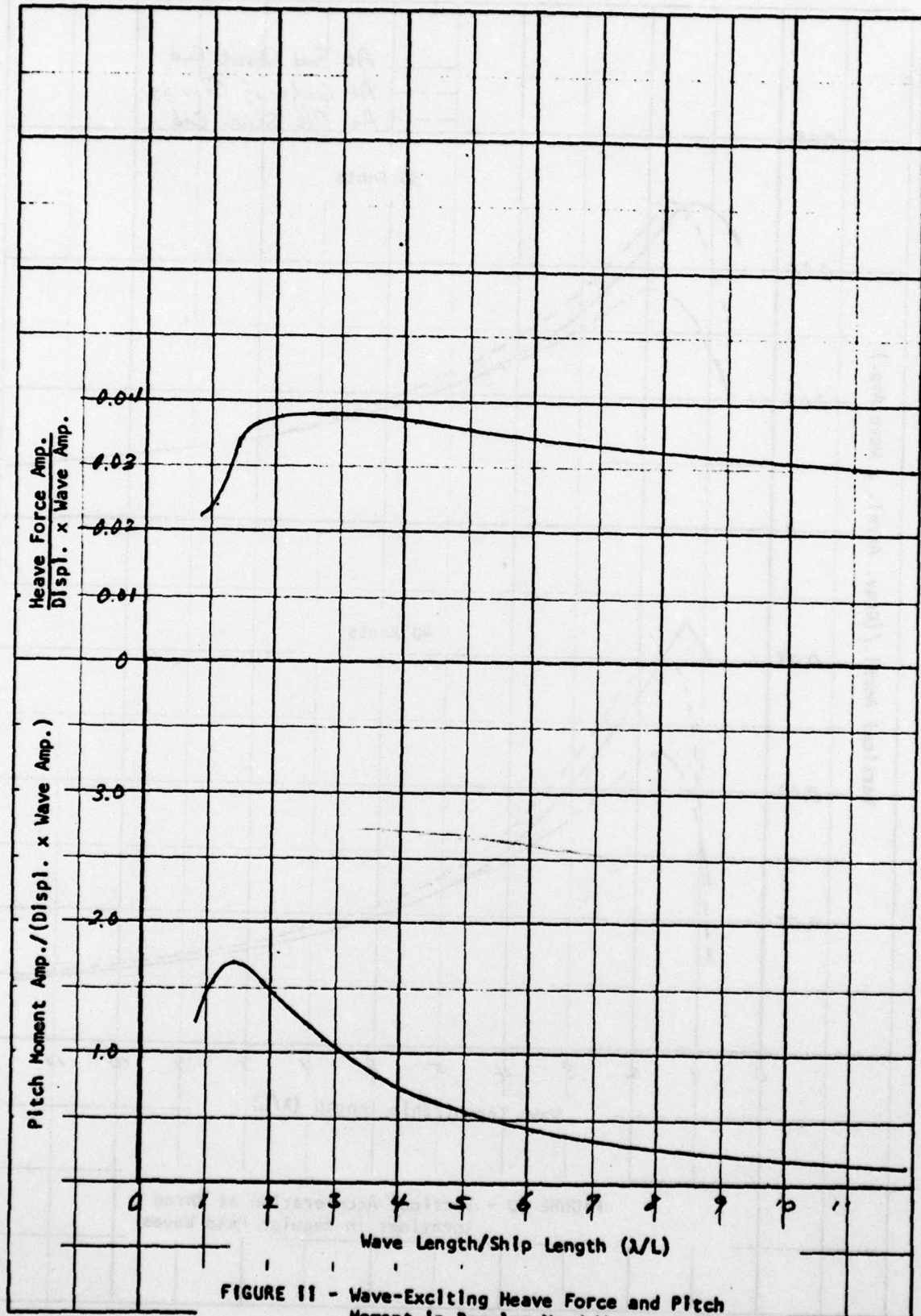FIGURE 10 - Vertical Acceleration at Three
Locations in Regular Head Waves

25

FIGURE 11 - Wave-Exciting Heave Force and Pitch
Moment in Regular Head Waves at 30 Knots

26

TABLE I

HULL GEOMETRIC CHARACTERISTICS

Full Load Displacement	2,000	Long Tons
Design Buoyancy	1,400	Long Tons
Design Foil Lift	600	Long Tons
Lower Hull Length	257	Feet
Lower Hull Maximum Diameter	15.2	Feet
Strut Length	180	Feet
Strut Maximum Thickness	7.2	Feet
Hullborne Draft	37.3	Feet
Foilborne Draft	24	Feet
Tons per Foot Immersion	30	Long Tons
Upper Hull Length	230	Feet
Upper Hull Maximum Beam	75	Feet
Upper Hull Clearance from Foilborne Waterline	11.3	Feet (At Chine)
Upper Hull Celarance from Foilborne Waterline	13	Feet (At Strut Centerline)
Longitudinal Center of Buoyancy from the Nose of Lower Hull	123	Feet
Vertical Center of Gravity from Keel	29	Feet

TABLE 2

FOIL GEOMETRY AND LOCATION
(CENTER OF BUOYANCY AT 123 FT IN FOILBORNE CONDITION)

Foil System	Foil Arrangement	Main (M) Secondary (S)	Lift Load Ratio	Semi* Span	Average Chord	Max** Thick-ness	FOIL LOCATION *** LCG= 123	LCG= 125	LCG= 127
			%	ft	ft	ft	ft	ft	ft
A	Airplane	M	70	34.2	11.4	1.14	75.0	84.0	93.8
		S	30	18.4	9.2	0.92	235.0	235.0	235.0
B	Airplane	M	75	35.6	11.9	0.19	85.7	94.2	103.5
		S	25	16.6	8.3	0.83	235.0	235.0	235.0
C	Airplane	M	85	38.1	12.7	1.27	103.2	111.0	119.0
		S	15	12.6	6.3	0.63	235.0	235.0	235.0
D	Canard	M	70	34.2	11.4	1.14	163.0	172.0	181.5
		S	30	18.4	9.2	0.92	30.0	30.0	30.0
E	Canard	M	75	35.6	11.9	1.19	154.0	162.0	171.2
		S	25	16.6	8.3	0.83	30.0	30.0	30.0
F	Canard	M	85	38.1	12.7	1.27	139.4	147.0	155.0
		S	15	12.6	6.3	0.63	30.0	30.0	30.0
G	Canard	M	90	39.0	13.0	1.30	133.3	141.0	148.2
		S	10	10.6	5.3	0.53	30.0	30.0	30.0
H	Airplane	M	90	39.0	13.0	1.30	110.6	118.0	125.5
		S	10	10.6	5.3	0.53	235.0	235.0	235.0
J	Airplane	M	100	40.9	13.7	1.37	123.0	129.2	136.3
		S	0	10.6	5.3	0.53	235.0	235.0	235.0

* Measured from lower hull surface
** Based on 10% thickness ratio at average chord stations
*** Distance in feet from forward end of lower hull to foil center of lift

28

TABLE 3

LOCATION OF FOIL SYSTEMS B AND E

Foil System	Distance from the Nose of Hull (ft)	
	Main	Secondary
B	103.5	235
E	171.2	30

TABLE 4

STABILITY INDICES AND HALF-DECAY TIME WITH FOIL

Speed	$(-\lambda_R)_{Min}$	T(1/2) (sec)
15	0.24	2.9
20	0.29	2.4
25	0.25	2.7
30	0.19	3.6
35	0.15	4.5
40	0.13	5.4
45	0.11	6.3
50	0.10	7.2

TABLE 5
TRANSIENT CHARACTERISTICS WITH FOIL B*

Speed Knots	Half-Decay Time sec		Natural Period sec		Damping Ratio	
	Heave	Pitch	Heave	Pitch	Heave	Pitch
15	2.9	2.1	27.7	14.2	0.72	0.59
20	2.4	1.5	46.7	18.7	0.91	0.80
25	2.7	1.0	107.9	29.7	0.97	0.95
30	3.6	0.8	152.6	39.7	0.98	0.99
35	4.5	0.6	116.5	46.0	0.94	0.99
40	5.4	0.5	105.6	54.0	0.91	1.00
45	6.3	0.5	100.4	67.8	0.87	1.00
50	7.2	0.4	97.4	106.6	0.83	1.00

DTNSRDC ISSUES THREE TYPES OF REPORTS