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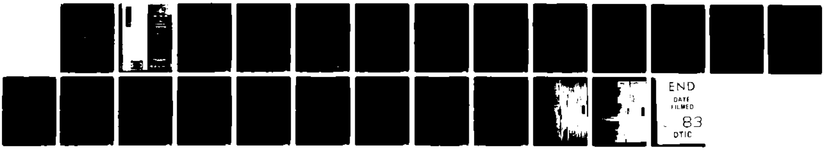

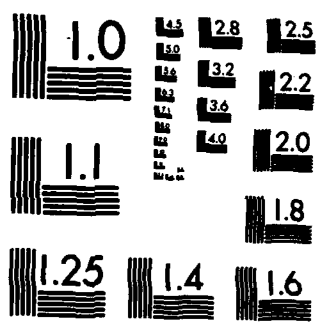

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER SIT-DL -81-9-2226	2. GOVT ACCESSION NO. AD-A123988	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ADDITIONAL SMOOTH AND ROUGH WATER TRIALS OF SKI-CAT		5. TYPE OF REPORT & PERIOD COVERED FINAL
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Gerard Fridsma and P. Ward Brown		8. CONTRACT OR GRANT NUMBER(s) N00014-79-C-0543 I.D. NO. NR 062-642
9. PERFORMING ORGANIZATION NAME AND ADDRESS DAVIDSON LABORATORY Stevens Institute of Technology Hoboken, NJ 07030		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Sea Systems Command Department of the Navy Washington, DC 20369		12. REPORT DATE August 1981
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) OFFICE OF NAVAL RESEARCH (Code 438) 800 N. Quincy Street Arlington, VA 22217		15. SECURITY CLASS. (of this report) Unclassified
		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)

Planing Hulls
Hydrofoils
Seakeeping
Marine Craft Performance
Propulsion

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

Further tests of SKI-CAT were made in smooth and rough water. Smooth water results confirmed the performance results of previous trials. An upper limit control boundary was established which restricts the flap angle to more negative angles as speed or RPM is increased. Rough water tests were a repeat also with performance and seakeeping results similar to those found earlier. Following seas account for small reductions in the accelerations and motions of SKI-CAT over against the head seas results.

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S/N 0102-014-6601

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

STEVENS INSTITUTE OF TECHNOLOGY
DAVIDSON LABORATORY
CASTLE POINT STATION
HOBOKEN, NEW JERSEY

Technical Report SIT-DL-81-9-2226
August 1981

ADDITIONAL SMOOTH AND ROUGH WATER TRIALS OF SKI-CAT

by
Gerard Fridsma
and
Peter Ward Brown

This Study was Supported
by
Naval Sea Systems Command
and Administered by
The Office of Naval Research
Contract No. N00014-79-C-0543 Nr 062-642
(Davidson Laboratory Projects 4737, 8, 9, 10/065, 6, 7, 8)

APPROVED: ____________
Daniel Savitsky
Deputy Director

INTRODUCTION

The hybrid marine vehicle known as SKI-CAT is a catamaran craft with high length-beam ratio planing hulls, a high aspect ratio hydrofoil, and bow hydroskis. Reference 1 gives a complete description of the physical craft including the geometry and instrumentation; and also reports the results of tests in calm water and waves. The significant conclusions reached, in comparing it to a modern day planing hull, were that SKI-CAT has superior lift/drag ratio in smooth water and reduced motions, accelerations, and minimal added resistance in waves.

Based on this evidence of good performance potential, it was recommended that additional seakeeping tests be conducted to extend the existing rough water data base to cover a wider range of parameters including higher sea states and various headings including beam seas, as a function of speed and hydrofoil flap setting.

Preparing SKI-CAT for tests, calibration of instruments and conducting the tests took place at Stevens Institute of Technology and in the Hudson River opposite the Stevens Campus and in upper New York Bay over a period of four months from July to October 1979.

PREPARING SKI-CAT FOR TESTS

After the two year hiatus since the earlier tests it was necessary to overhaul and re-furbish SKI-CAT and the support vehicles and equipment. The craft was surveyed and the following list of repairs put in hand:

- Repair chine strips
- Check foil/strut and strut/hull attachment
- Check water supply to main shaft bearings
- Check flap actuators
- Replace windshield motor
- Replace engine batteries
- Repair port engine water pump
- Replace points and plugs

Mount radar reflectors on mast and deckhouse

The catamaran hulls were re-painted and the struts and foils were cleaned, painted and rubbed down to a smooth finish.

Following a shake-down test on 8 August 1979, the following alterations were made to SKI-CAT. Large spray suppressors were fitted on the struts in between the existing ones (two per strut); these were 15.8 inches long by 4.2 inches wide. Spray originating at the struts had been observed in the previous tests[1] and was again evident in the shake-down tests. It was therefore decided to fit larger strut spray suppressors. Subsequently the strut spray was observed to be significantly reduced, although not quantitatively measured.

New transom height indicators were made and fitted to facilitate estimation of the draft of the transom. These consisted of contacts, similar to those embedded in the hydroskis, arranged vertically. There were four contacts per side spaced one inch apart.

INSTRUMENTATION

The instrumentation package was basically the same as used in the previous SKI-CAT trials. A gyro was installed for measuring the pitch (or trim) of the craft. Meters for the transom height indicators were installed on the dash.

The torque transducer package was sent back to the factory for overall and the Davidson Laboratory recalibrated them after they were returned later in August. All instruments were checked out and calibrated. A shakedown tests of SKI-CAT took place on 8 August. The craft operated well. The 400 Hz power supply for the gyro was noisy and needed an electronic filter to prevent interference with the instrument channels. Another problem which was never resolved, but could be tolerated, was cross-talk between CB transmission and the flap angle meters. This was solved by simply not using the CB while taking data.

On subsequent smooth water trials with the torque meters installed in SKI-CAT, additional instrumentation checks were made and corrected where necessary. The radar gun readings were checked against ground speed over the Stevens measured course. It proved to be insensitive to speeds below about 15 to 20 mph and was only accurate to within ±3 mph above these speeds.

TEST PROGRAM

Smooth Water

The smooth water test program was designed to check out previous data, but more importantly to develop a matrix of drag as a function of speed for fixed values of RPM and flap settings. The same craft displacement of 5,600 lb as in the 1977 tests was used, with the same propeller and hydroski setting. Measurements included speed over a timed course along the Stevens pier (946 ft), trim, radar speed, river current, and port and starboard torques, RPM's and flap angles.

Rough Water

With all systems working, the SKI-CAT was put on alert for rough weather in lower New York Bay. Contacts with the Coast Guard and a private weather service were established in order to provide a 24 hour lead time on launching the craft for wave tests. The objective of these tests was to extend the performance range to higher sea states, and establish the effect of sea direction, including beam seas.

On 25 October 1979, reports from the weather service indicated good rough water conditions in the bay with waves from 2 to 3 feet and winds of 10-15 knots with gusts up to 25 knots. SKI-CAT was launched and 23 runs were made over a three hour period. A calibrated wave strut was deployed from the support craft DOUBLET four times during this test interval and five minute tape recordings taken of the sea conditions. In addition to taking mean data as reported in the smooth water tests, time histories were obtained of the bow and cg accelerations and pitch or roll motions.

Tests were run in head, following, beam and quartering seas at speeds from 20 to 30 knots. In the beam sea tests the gyro was yawed 90° so as to measure roll instead of pitch. The speed of SKI-CAT was observed by radar from a chase boat loitering near the mid-point of SKI-CAT's run; multiple readings were taken of each run and averaged to determine the speed.

DATA PROCESSING

In smooth water the data was collected by "sample and hold" averaging electronic circuits, one for each data channel. On completion of each test run the various channels were selected manually and the stored readings displayed in digital form were recorded. The measured quantities included the port and starboard engine RPM and torque, the port and starboard flap setting and the trim. These were subsequently converted to engineering units by means of calibrations obtained for each channel.

In rough water the instrumentation was augmented by bow and cg accelerometers and these signals together with that from the pitch gyro were recorded as time histories on analog magnetic tape. The remaining quantities were averaged as in the smooth water tests.

Known calibration signals and zeros were entered on the tape recorder prior to the test session and then played back into the Davidson Laboratory's PDP-83 computer for appropriate processing. Spectral analysis was performed on the wave time history and peak/trough analysis performed on the acceleration and pitch/roll time histories. The latter analysis computes and tabulates the mean and rms values together with the average, average of the 1/3 highest and average of the 1/10 highest peaks and troughs on each channel.

RESULTS AND DISCUSSION

Smooth Water

The smooth water results are presented in Table 1 and include the water speed (corrected for current) the engine speed (average of the port and starboard rpm), trim angle, the hydrofoil flap deflection, positive for a downward deflection tending to increase the lift (average of the port and starboard angles) and the total thrust.

The smooth water tests were run at a series of constant engine speeds, nominally 1,500, 2,000, 2,500, 3,000, 3,500 and 4,000 rpm, and the tabulated results from the three days of testing (12, 18 and 27 August 1979) have been grouped accordingly. The first two digits of the run numbers indicate the test date, the second two are the sequence run for that date, and the direction of the run (north or south in the Hudson River off the Stevens' pier) is indicated.

The smooth water drag is shown as a function of speed on Figure 1. The data has been coded to show the magnitude of the foil flap angle, as being either less that -2°, between -2° and $+2^{\circ}$, or greater than 2°. At any given RPM and speed there is a tendency for the drag to be reduced with increasing flap angle, as found in the earlier tests. This trend is more marked at higher speed. However it is not possible to realize the full benefit of positive flap at high speed on the existing SKI-CAT.

Observation of SKI-CAT operating at fixed throttle and foil flap angle, δ_f, indicates that the craft becomes difficult to fly steadily when the combination of RPM and flap angle becomes too high. SKI-CAT may roll over on one hull or the skis come off the water and the craft broaches, after which she trims down and lands back on the skis and demi-hulls. This occurs when most of the weight of SKI-CAT is being carried by the foil. This observations does not imply that the craft is unstable, but it does suggest that an improved means of adjusting flap angle is desirable.

The limit on the maximum flap angle that can be used at any engine speed is shown on Figure 2 for speeds over 1,500 RPM:

$$\delta_f = 12 - \text{RPM}/250, \qquad \text{RPM} \geq 1{,}500$$

As shown on Figure 3 there is a linear relationship between engine speed and boat speed above 10 knots. The relationship:

$$V_k \text{ knots} = (\text{RPM} - 800)/97, \qquad V_k \geq 10$$

may be used to estimate water speed from engine speed, within ±2 knots.

Rough Water

The spectral analysis of the wave probe shown on Figure 4, resulted in a significant wave height of 14 inches. While observers in both SKI-CAT and the support craft had estimated a higher sea state, it is recognized that estimating wave height from a moving platform is very subjective and difficult to predict.

This means that the present data should be quite similar to that of the 1977 tests when SKI-CAT was tested in 16 inch significant height waves. This is borne out by comparison of the accelerations and motions for the two series of tests.

The results obtained in rough water in head, following, beam and quartering seas are presented in Tables 2, 3 and 4. Table 2 shows the water speed, engine speed, trim, flap angle and thrust, while Table 3 shows the acceleration statistics at CG and Bow and Table 4 presents the pitch motions.

Comparison of the acceleration and motion data in head seas, beam seas and bow quartering seas show very similar results as shown on Figure 5. In following seas and stern quartering seas the motions and accelerations are reduced as would be expected.

The low level of the 1/10 highest CG acclerations are noteworthy. Considering the SKI-CAT as a 1/3-scale manned model of a full-size 70 ton vessel, the data show 1/10 highest accelerations of less than 1/2 g at speeds of 54 knots in a low sea state 3.

In beam seas the significant double amplitude roll motion amounts to 12 degrees at 29 knots (Table 4).

The observed rough water drag given in Table 2, for speeds from 19 to 31 knots, shows no significant increase over the calm water drag. The results are somewhat scattered as would be expected in rough water. It is concluded that the added drag in waves of the SKI-CAT configuration is negligible.

During the return from the rough water test area, south of Governor's Island in lower New York Bay, to the Stevens' pier, the opportunity was taken to evaluate the controllability of SKI-CAT in rough water. Various members of the crew, who had few if any hours driving SKI-CAT, put the craft through various maneuvers including speed runs and turns into and out of wind. The strong opinion was developed as a result of this exercise that SKI-CAT is highly controllable with a minimum of familiarization.

CONCLUDING REMARKS

Photographs taken during the calm water trials are included as Figures 6 and 7. They show SKI-CAT operating in the Hudson River off the Stevens Campus with New York City in the background.

The intention of these trials was to extend the rough water data previously collected to higher sea states, at the same time repeating some of the calm water runs for continuity. Unfortunately the weather in the late summer of 1979 refused to co-operate. SKI-CAT was on stand-by ready to launch from the middle of August, through September and October. During September the calm water tests were conducted under exceptionally fine conditions. Finally at the end of October, with the testing season running out, reports were received of large waves in lower New York Bay with winds gusting to 25 knots. Nonetheless, measurements of the waves showed that they were no bigger than in the previous tests.

The findings of the previous report were confirmed. In smooth water, the lack of hump drag, the magnitude of the drag and the reduction of drag with increasing foil flap deflection was confirmed. The stick-fixed tests used to demonstrate the beneficial effect of increasing flap angle also showed that at high speed there was a maximum flap angle beyond which stick-fixed operation was not possible.

In rough water the low level of the bow and cg accelerations was again observed together with the small pitch motions and negligible added drag in waves. The general sea-kindliness and manageability of the craft in waves was re-confirmed.

ACKNOWLEDGEMENT

The SKI-CAT manned model is a large craft for a model, weight 2 1/2 tons and big enough (30 ft x 12 ft) to be difficult to maneuver out of its storage hanger and launch. Everyone who has participated in trials will appreciate the amount of effort by the support personnel needed to keep the craft operational especially during the trying time of waiting for rough water. Thanks are due to Mr. Aldo Sori of the Davidson Laboratory who took charge of the boat, arranged all maintenance of the boat and engines, supervised the launches and most importantly acted as test pilot for all the trials.

Mr. Richard Krukowski of the Davidson Laboratory did an outstanding job in planning, installing, and maintaining the instrumentation. Messers. Richard Tweitman and Donald Zurick of Davidson Laboratory skillfully handled the launching and docking of the craft and Mr. Tweitman piloted a support craft during the rough water trials. The Ocean Engineering Department students, under the supervision of Professor Richard I. Hires, provided the chase boat and back-up services.

REFERENCE

1. Savitsky, Daniel; Fridsma, Gerard and Brown, P. Ward: Smooth and Rough Water Trials of SKI-CAT (Manned Model), Davidson Laboratory Report 2004, December 1978.

TABLE 1

CALM WATER RESULTS

RUN	WATER SPEED knots	MEAN ENGINE SPEED rpm	TRIM deg	MEAN FLAP ANGLE deg	TOTAL THRUST lb
		1500 rpm			
1819S	3.5	1460	-	-0.1	890
1211N	4.3	1470	-	-4.4	840
1210S	5.7	1490	-	-4.2	760
1810N	5.9	1550	-	-2.6	820
1818N	6.2	1480	-	-0.1	700
1809S	8.5	1560	-	-2.6	620
		2000 rpm			
1213N	11.6	2000	-	-4.1	950
1821S	11.9	2020	-	-0.2	950
1820N	12.1	2010	-	-0.2	920
1811S	12.2	2030	-	-2.4	930
1812N	12.4	2020	-	-2.5	900
1212S	12.6	2040	-	-4.2	910
		2500 rpm			
2740S	16.5	2380	3.5	-2.0	1010
1215N	16.5	2550	-	-4.2	1320
2736N	16.6	2460	4.1	-4.4	1140
2734N	17.9	2480	3.1	3.7	1000
1813S	18.4	2570	-	-2.4	1090
1814N	18.7	2550	-	-2.4	1021
2739N	18.7	2590	4.2	-2.0	10[illegible]
1214S	19.5	2630	-	-0.2	1050
2733S	19.5	2530	2.9	3.2	880

TABLE 1
(cont'd)

CALM WATER RESULTS

RUN	WATER SPEED knots	MEAN ENGINE SPEED rpm	TRIM deg	MEAN FLAP ANGLE deg	TOTAL THRUST lb
		3000 rpm			
2720N	22.9	3030	2.9	-3.5	1340
2726N	22.9	2960	2.4	-1.0	1190
2730N	23.0	2890	2.3	0.6	1040
1815S	23.9	3040	-	-2.5	1200
2725S	24.1	2970	2.7	-1.0	1020
2719S	24.3	3010	3.0	-3.2	1070
1816N	24.6	3090	-	-2.3	1180
2732N	24.6	3100	2.3	0.4	1200
2731S	25.0	3040	2.1	1.2	1020
		3500 rpm			
2722N	27.0	3390	2.8	-3.5	1420
2721S	27.3	3450	2.5	-3.6	1500
2727S	27.9	3440	2.3	-1.3	1380
2728S	28.2	3530	2.2	-2.8	1530
		4000 rpm			
2717S	30.8	3790	2.2	-4.6	1640
2724N	31.1	3870	3.1	-3.6	1800
2723S	32.0	3950	2.3	-3.3	1810

TABLE 2

ROUGH WATER RESULTS - DRAG

RUN	WEIGHT lb	WATER SPEED knots	MEAN ENGINE SPEED rpm	TRIM deg	MEAN FLAP ANGLE deg	TOTAL THRUST lb
			HEAD SEAS			
1	5800	19	2470	3.9	2.9	830
3		24	3020	3.3	-0.9	1130
5		29	3710	2.9	-2.5	1810
7		30	3780	3.8	-4.0	1790
13	5960	20	2590	3.5	3.3	910
15		26	3090	3.5	-0.7	950
17		29	3450	3.6	-2.2	1180
19		31	3830	3.4	-2.6	1710
			FOLLOWING SEAS			
2	5800	19	2520	3.0	2.9	920
4		26	3270	2.7	-0.7	1320
6		29	3700	3.4	-2.7	1780
8		29	3710	3.6	-4.0	1800
14	5960	18	2470	3.1	2.5	960
16		23	3030	3.5	-2.3	1310
18		28	3630	3.6	-3.4	1800
20		29	3690	3.7	-4.4	1760
			BEAM SEAS			
				roll		
10	5800	25	3010	0	-0.8	960
11		29	3630	0	-2.5	1600
12		28	3610	0	-4.3	1740
21	5960	24	3000	0	-0.8	1060
			STERN QUARTERING			
22	5960	26	3080	3.9	-0.8	930
			BOW QUARTERING			
23	5960	28	3660	4.0	-2.5	1880

TABLE 3

ROUGH WATER ACCELERATIONS

RUN	SPEED knots	CG Acceleration RMS g	CG Acceleration AVG. g	CG Acceleration 1/3 g	CG Acceleration 1/10 g	Bow Acceleration RMS g	Bow Acceleration AVG. g	Bow Acceleration 1/3 g	Bow Acceleration 1/10 g
				HEAD SEAS					
1	19	0.11	0.23	0.30	0.37	0.18	0.45	0.69	0.91
3	24	0.11	0.21	0.29	0.38	0.23	0.45	0.70	0.94
5	29	0.14	0.26	0.36	0.45	0.32	0.60	0.99	1.38
7	30	0.13	0.25	0.36	0.47	0.31	0.58	0.98	1.39
13	20	0.11	0.23	0.30	0.35	0.18	0.43	0.63	0.86
15	26	0.13	0.25	0.35	0.45	0.24	0.51	0.81	1.10
17	29	0.12	0.24	0.35	0.43	0.28	0.55	0.91	1.18
19	31	0.13	0.25	0.37	0.48	0.30	0.57	0.93	1.36
				FOLLOWING SEAS					
2	19	0.09	0.19	0.23	0.26	0.12	0.35	0.44	0.50
4	26	0.10	0.22	0.28	0.31	0.20	0.45	0.67	0.86
6	29	0.10	0.22	0.29	0.33	0.24	0.49	0.73	0.89
8	29	0.12	0.25	0.34	0.43	0.25	0.52	0.80	1.04
14	18	0.08	0.19	0.23	0.26	0.11	0.35	0.45	0.53
16	23	0.09	0.20	0.25	0.28	0.17	0.42	0.58	0.77
18	28	0.11	0.22	0.29	0.36	0.25	0.53	0.84	1.18
20	29	0.10	0.22	0.27	0.32	0.22	0.47	0.70	0.91
				BEAM SEAS					
10	25	0.11	0.25	0.34	0.43	0.21	0.50	0.80	1.13
11	29	0.11	0.24	0.34	0.42	0.21	0.49	0.72	1.00
12	28	0.11	0.25	0.32	0.39	0.25	0.51	0.80	1.09
21	24	0.09	0.22	0.29	0.36	0.19	0.46	0.69	0.94
				STERN QUARTERING					
22	26	0.09	0.19	0.25	0.28	0.18	0.42	0.58	0.73
				BOW QUARTERING					
23	28	0.12	0.24	0.32	0.36	0.27	0.54	0.85	1.14

TABLE 4

ROUGH WATER DOUBLE AMPLITUDE PITCH MOTIONS

RUN	SPEED knots	RMS deg	AVG deg	1/3 deg	1/10 deg
		HEAD SEAS			
1	19	0.56	1.7	2.9	-
3	24	0.71	2.4	3.7	-
5	29	0.55	1.8	2.7	3.5
7	30	0.63	1.9	3.1	-
13	20	0.74	1.8	3.2	-
15	26	0.78	2.2	3.5	-
17	29	0.76	2.0	4.0	5.2
19	31	0.60	1.7	2.8	-
		FOLLOWING SEAS			
2	19	0.42	1.5	-	-
4	26	0.54	1.5	2.5	-
6	29	0.53	1.5	2.4	-
8	29	0.69	1.7	3.0	4.1
14	18	0.34	1.4	1.9	-
16	23	0.43	1.5	2.2	-
18	28	0.41	1.4	2.0	-
20	29	0.43	1.4	2.1	-
		BEAM SEAS-ROLL MOTIONS			
10	25	2.20	3.1	6.9	-
11	29	3.46	4.8	12.0	-
12	28	1.52	2.7	5.5	-
21	24	-	-	-	-
		STERN QUARTERING			
22	26	0.69	1.9	3.5	-
		BOW QUARTERING			
23	28	0.68	1.8	3.4	-

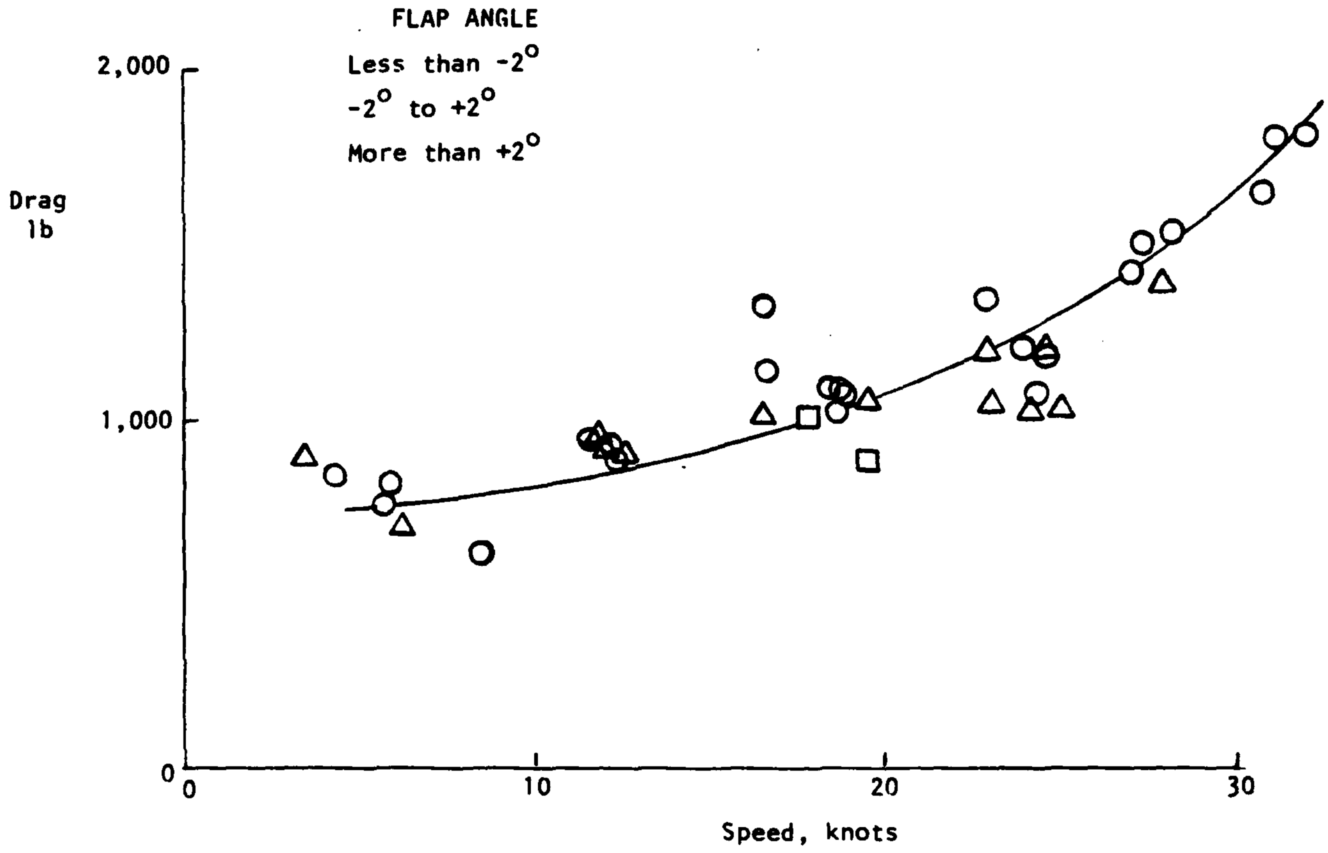

FIGURE 1 CALM WATER DRAG

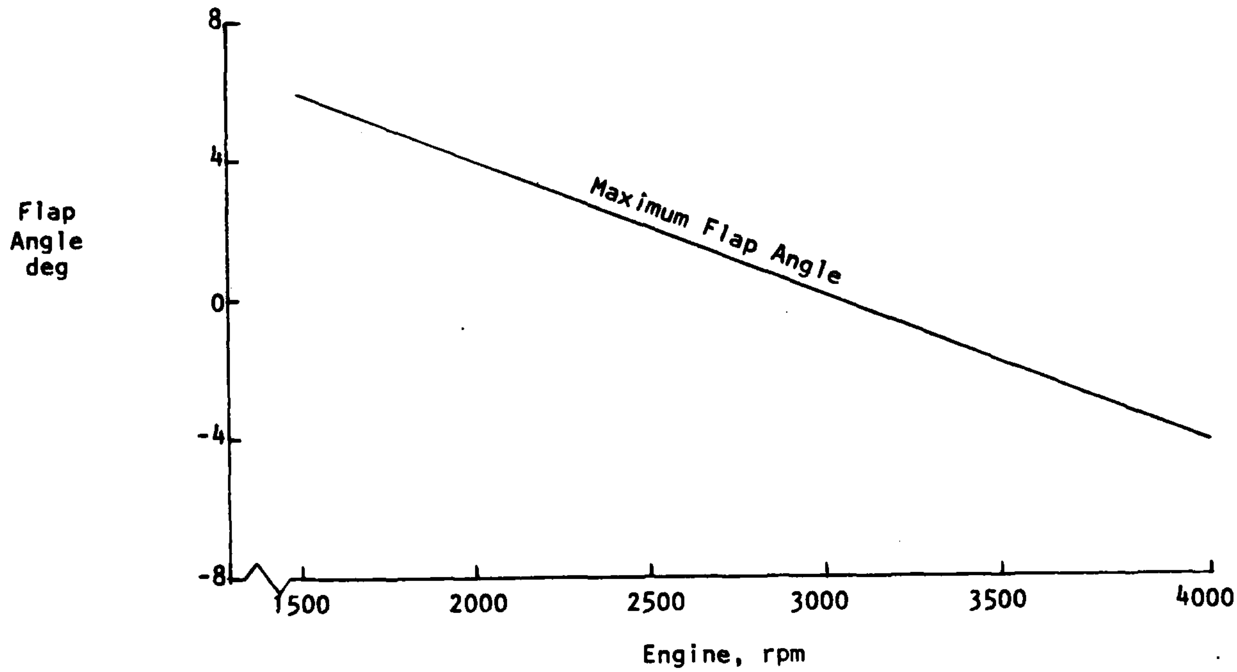

FIGURE 2 MAXIMUM "STICK-FIXED" FLAP ANGLE

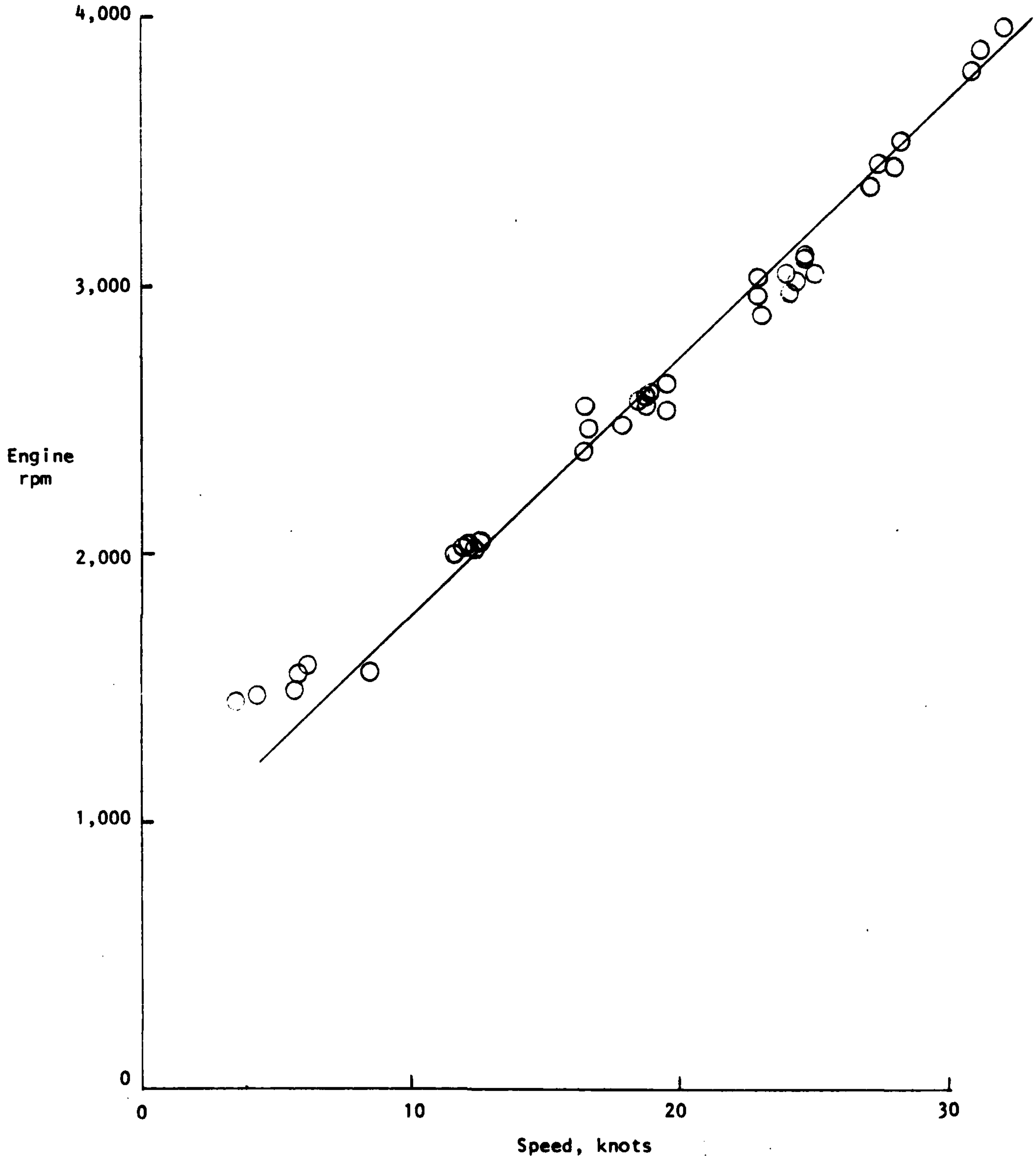

FIGURE 3 CALM WATER ENGINE SPEED

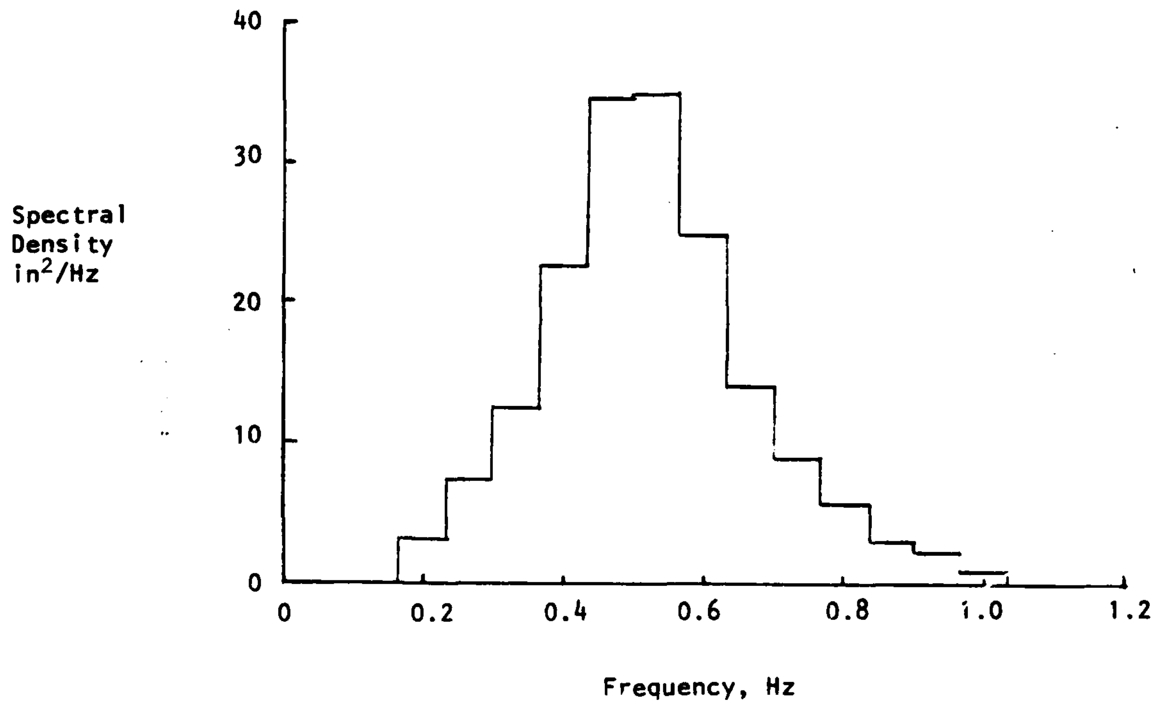

FIGURE 4 AVERAGE WAVE SPECTRUM, 14 INCH SIGNIFICANT HEIGHT

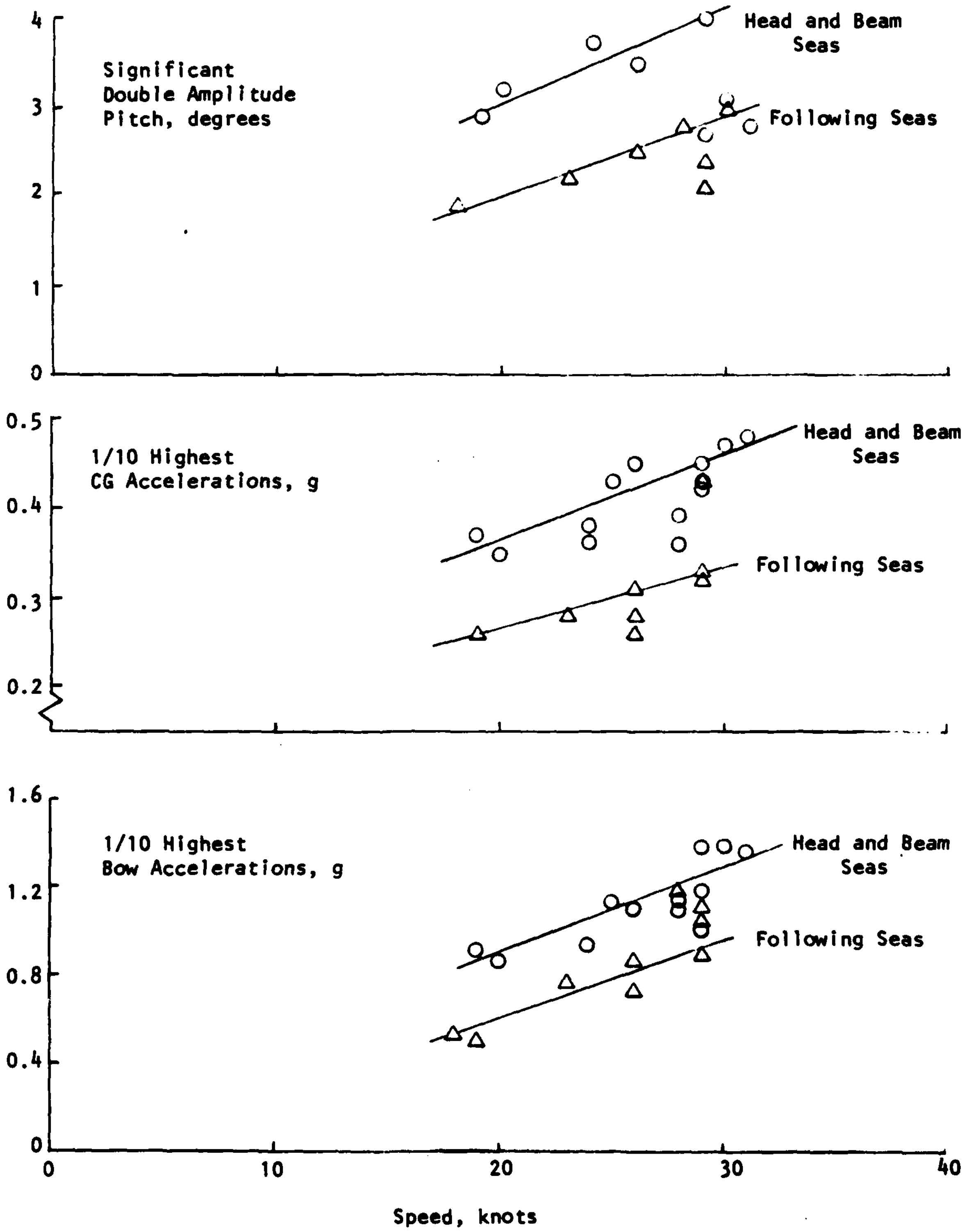

FIGURE 5 ROUGH WATER MOTIONS AND ACCELERATIONS

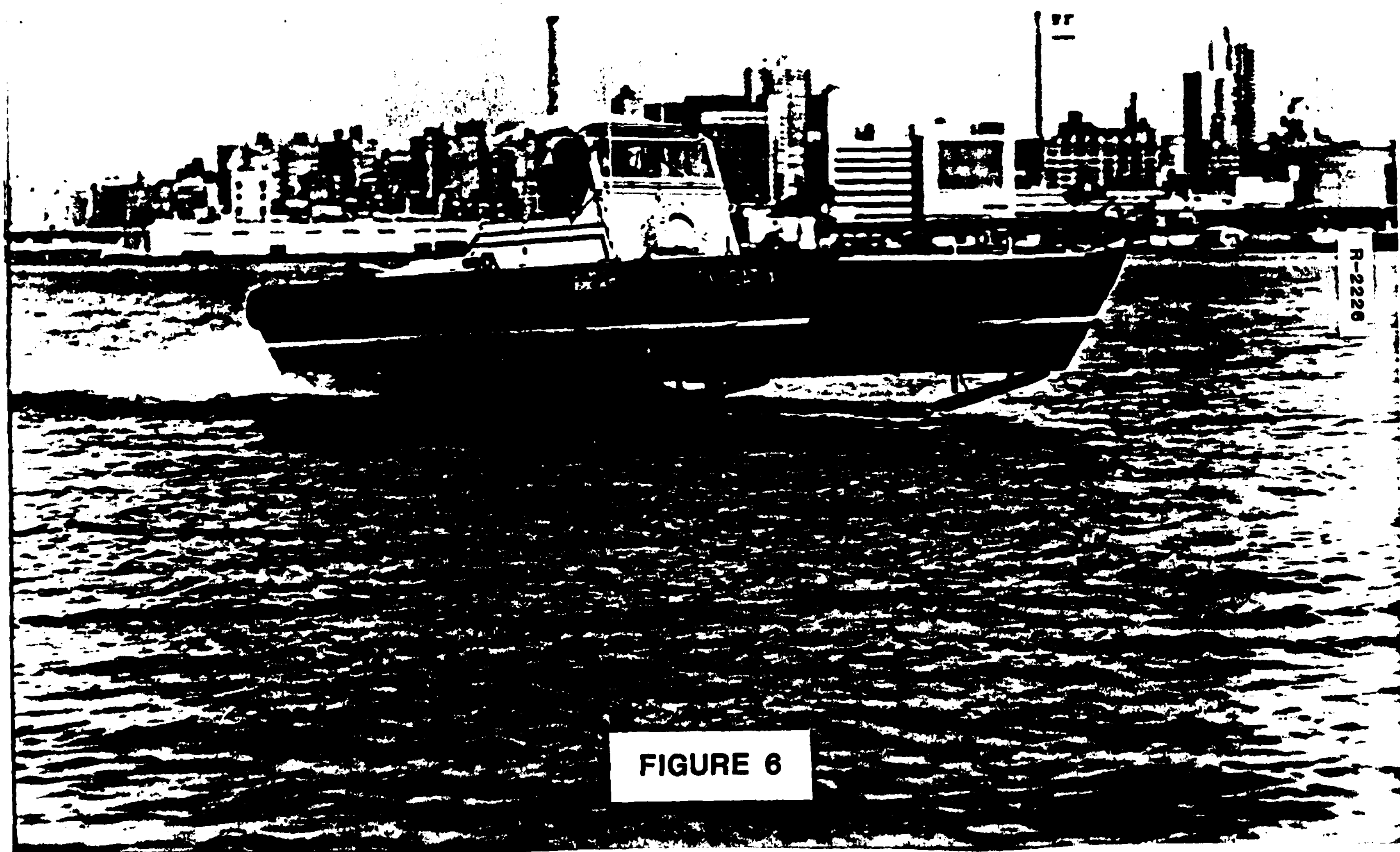

FIGURE 6

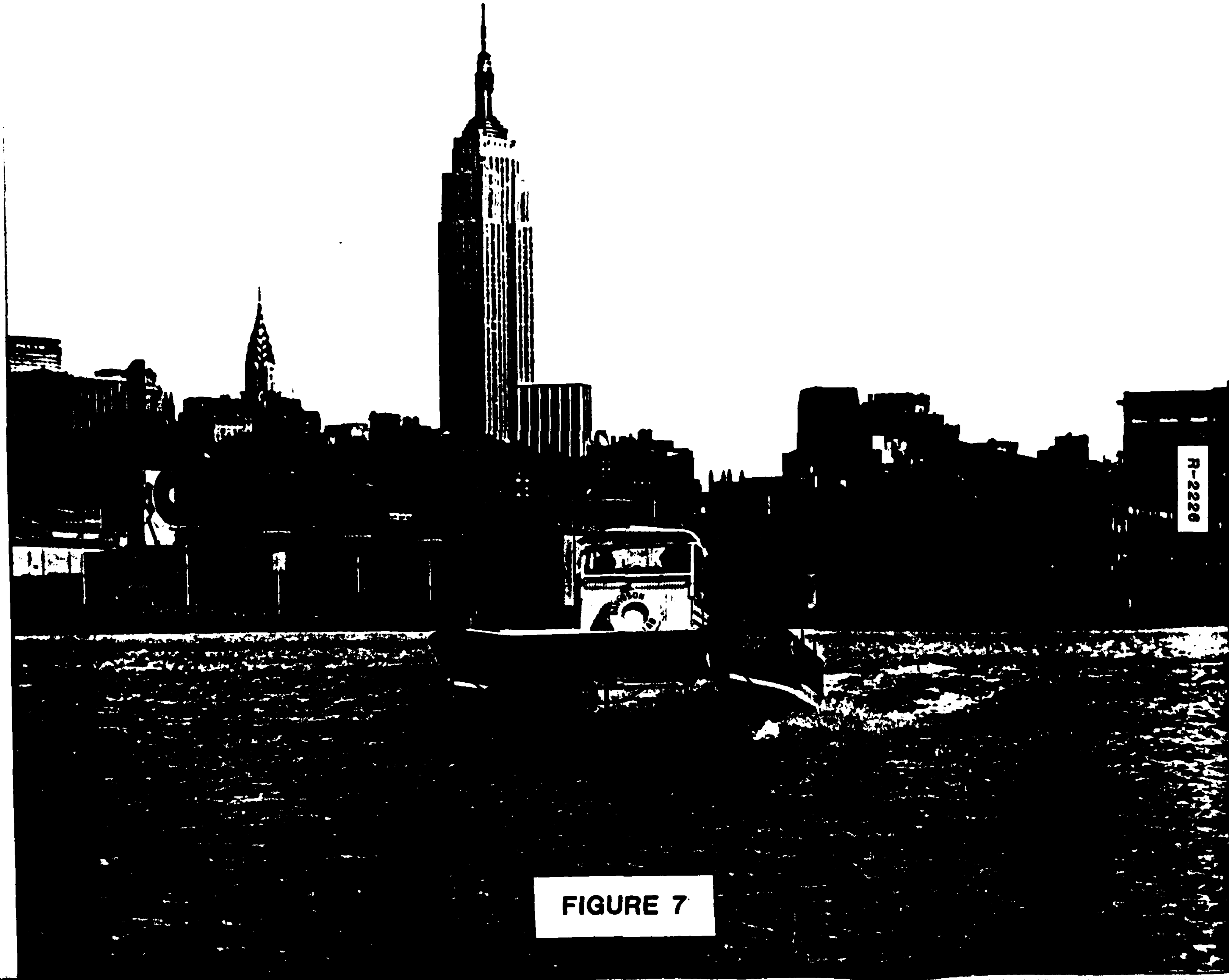

FIGURE 7

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