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Technical Characteristics Verification of the Prototype 47 FT MLB

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16. Abstract

The results of Design Technical Characteristics Verification Testing of the prototype USCG 47 FT MLB are reported. This boat is planned as the replacement for the Coast Guard's aging fleet of 44 FT MLB heavy weather rescue boats. The testing was conducted in September 1991 by the U.S. Coast Guard Research and Development Center to provide technical data required by the Motor Lifeboat Replacement Acquisition Project Manager. The report compares the performance of the prototype 47 FT MLB with two proven Coast Guard rescue boats, the 44 FT MLB and the 41 FT UTB. Included is an assessment of the boat's strengths and weaknesses relative to its required technical characteristics.

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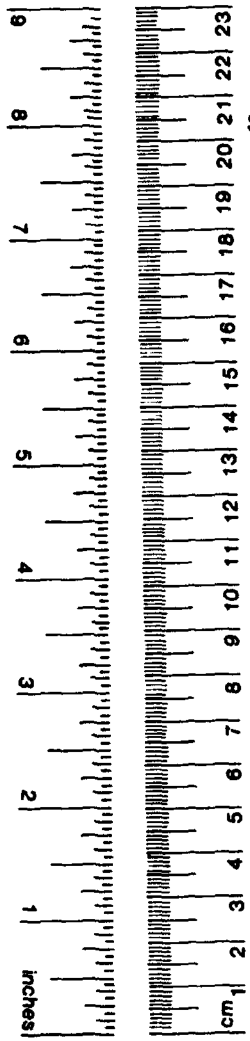
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

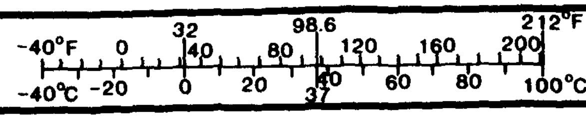
Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (WEIGHT)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (EXACT)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25. SD Catalog No. C13.10.286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (WEIGHT)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (EXACT)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



ACKNOWLEDGMENTS

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This report is made possible thanks to many hours of dedicated work by the R&D Center Marine Engineering Branch technical staff. The contributions of Mr. Orin Stark, Mr. Edward Purcell, Mr. James Bellemare, Mr. Bert Macesker, Ms. Elizabeth Weaver, MK2 Brian Elliot and BM2 Dave Harding are gratefully acknowledged. Special recognition is due to Mr. Robert Desruisseau for an outstanding job throughout the developmental testing of the 47FT MLB. Thanks also to Mr. Blaine Bateman, who filmed and produced the video documentation which accompanies this report.

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INTRODUCTION

This report provides the results from fifteen Technical Characteristics Verification Tests of the prototype 47FT MLB (47200). The U.S. Coast Guard Research and Development Center completed this testing in September 1991 at Cape Disappointment, Washington. The tests were conducted in accordance with the requirements of the Motor Lifeboat Replacement Test and Evaluation Master Plan (TEMP) [1][1] and the Developmental Test and Evaluation Plan Motor Lifeboat Replacement [2]. Test procedures follow the General Test Plan for Marine Vehicle Testing [3] and the Small Boat Test Plan [4], except as noted in test descriptions.

The report is part of the evaluation of the 47FT MLB as a replacement for the Coast Guard's primary heavy weather rescue boat, the 30-year-old 44FT MLB. Technical Characteristics Verification Testing made accurate measurements of technical performance independent of builder's trials and preliminary acceptance testing. The testing provided data requested by the Motor Lifeboat Replacement Project Manager. The purpose was to reduce the risk involved in the acquisition project by insuring that design goals were achieved and that the project was ready to proceed beyond developmental testing. Additional developmental testing, Design Performance Verification, was conducted by the Motor Lifeboat Replacement Test Team and was reported separately. Results from the two reports are combined in the Motor Lifeboat Replacement Project Manager's Developmental Test Report, a top-level document used in the acquisition project decision-making process.

Technical Characteristics Verification Tests are listed in Table 1. These tests were conducted for the prototype 47FT MLB, a 44FT MLB and a 41FT UTB. The latter two vessels are proven, successful Coast Guard boats with many years of operational service. Test procedures and results for these two boats are described in detail by [5]. Results from the proven designs provide a comparative baseline for assessing the 47FT MLB's performance.

Surf testing was not conducted during this phase of the project [1]. Evaluations of the boat's operation in surf are part of Design Performance Verification and are reported separately by the Replacement Project Test Team.

The 47FT MLB configuration employed in the Technical Characteristics Verification was a modification of the original design. During developmental testing, the prototype's rudders were changed to 1.9 square foot vertical rudders (vice the original 2.7 square foot canted rudders). This modification eliminated excessive transient rolls during high-speed maneuvers

[1] Numbers in brackets denote references at the end of the report.

and provided acceptable handling characteristics in following seas. Test results for various configurations leading to this modification are documented in the USCG R&D Center report, "Testing of the Prototype 47FT MLB with Various Skegs and Rudders" [6]. The propellers used during Technical Verification Tests were a set of 28 inch diameter, 33 inch pitch (28x33) propellers rather than the original 26x34 props. During earlier developmental testing the boat made better speed with the 28x33 propellers, therefore this set was used for the tests in this report.

TABLE 1
LIST OF TESTS

Test TC-1	Principal Characteristics
Test TC-2	Photographic Documentation
Test TC-3	Video Documentation
Test TC-4	Speed vs Power
Test TC-5	Trim vs Speed
Test TC-6	Righting Arm vs Heel Angle
Test TC-7	Bollard Pull
Test TC-8	Minimum Turning Radius
Test TC-9	Acceleration
Test TC-10	Sea Height vs Maximum Speed
Test TC-11	Fuel Consumption vs Speed
Test TC-12	Range vs Speed
Test TC-13	Maneuverability (Spiral Test)
Test TC-14	Maneuverability (Zig Zag Test)
Test TC-15	Motion in Waves

The next section of this report describes test procedures in detail. It is followed by a presentation of the test results in the format required by [2]. After the results is an analysis of the data comparing the prototype 47FT MLB to the 44FT MLB and the 41FT UTB. The analysis section identifies strengths and weaknesses of the prototype boat and points out any anomalies in the test results. The final section of the report is a summary that synopsizes all aspects of Technical Characteristics Verification. Two appendices are included. Appendix A is especially noteworthy as it includes results of an R&D Center Hull Structural Evaluation test which measured the stress levels in various parts of the boat during rough weather testing.

TEST DESCRIPTION

This section describes the test procedures used during 47FT MLB Technical Characteristics Verification. Test requirements are specified with considerable detail in [2], and are only paraphrased by this report. Test procedures follow the outlines of [3] and [4], except for various improvements in instrumentation or technique applied to the 47FT MLB testing. Detailed descriptions of test instrumentation are included in Appendix B.

TC-1 **Principal Characteristics:** Data for the required table were obtained from the design drawings and operator manuals.

TC-2 **Photo Documentation:** The prints and slides required by [2] were taken by Authur Chan Studios, professional photographers from Astoria, Oregon, under government contract. A USCG HH-65 Helicopter from USCG Air Station Astoria was used as the platform for the aerial shots.

TC-3 **Video Documentation:** A professional video photographer recorded and edited the footage used in the videotape required by [2].

TC-4 **Speed vs Power:** This test measured speed versus power at half load displacement (design full load with half fuel expended) and at full load displacement plus approximately 2000 pounds of additional weight in three locations of the longitudinal center of gravity (LCG). The additional load condition tests apply for the 47FT MLB only. To minimize the effects of wind and sea conditions the tests were conducted in the Columbia River near of Astoria, Oregon, with wind less than 15 knots and seas less than 1 foot. Water depth at the test site was 40 feet. To minimize the effects of current, tests were conducted near the time of slack tide. Measurements were taken on two reciprocal courses and the results averaged. Data was collected according to a randomized test sequence to reduce the effects of systematic errors from changing environmental conditions [7]. Repeated tests were used to estimate the precision of measurements, and the results were averaged to increase the confidence in final results.

Boat speed was measured by observing the elapsed time to transit a known distance. Two test ranges shown in Figure 1 were employed, a 1.58nm course on the Astoria Range and a 0.95nm course on the Tansy Point Turn and Range. Average speed over the ground was also measured using the boat's installed Furuno LC-90 LORAN-C receiver. Back-up data from the boat's speed log, a Datamarine Dart, was also recorded. The boat's speed log measures speed through the water to within 1 knot accuracy (after applying corrections), and was used to detect biases in speed over the ground measurements between reciprocal courses. Overall accuracy of the boat speed from the combined measurements is ± 0.5 knots.

Power was measured using an Accurex model 1642A horsepower meter on each propeller shaft. This instrument measures shaft torsional strain with a strain gage and transmits the reading from the rotating shaft via an FM antenna. The torsional strain measurement is converted to a torque measurement, based on the shaft manufacturer's statement of the shaft's modulus of rigidity. A shaft torque calibration was not conducted, and this reflects in the overall accuracy of the horsepower measurements. Despite the limitations on absolute accuracy, relative comparisons between 47FT MLB power measurements at various load conditions are not degraded. The horsepower meter system includes a tachometer accurate to within 0.25% of actual RPM. The shaft RPM and torque measurements are automatically multiplied by the horsepower meter to obtain shaft horsepower, accurate to within 3-5% of the actual shaft horsepower. This 3-5% accuracy statement includes the instrument errors and the uncertainty in the actual shaft modulus value, since the shaft was not torqued. The output was recorded continuously on a TEAC model RD-200T Digital Audio Tape (DAT) format recorder. The recorded signals were filtered and averaged to obtain shaft horsepower for the run. Horsepower for a given speed is the average of the horsepower for two directions on the test course at the same engine RPM. Power measurements from the two shafts were summed to provide total horsepower.

47FT MLB tests were conducted in four load conditions as described in Table 2 and in Figure 2. The baseline full load of the 47FT MLB, including four crewmembers is 40,410 LBS (18.0LT) ± 500 lbs. The baseline full load LCG is at 16.5 FT forward of the aft perpendicular (AP) ± 0.2FT. The half load displacement is defined as 17.5LT, including the weight of the boat, outfit, half fuel (200 gallons) and four crew members. Instrumentation and test personnel loads placed additional weight on the boat. To maintain the half load displacement condition, the test was conducted with less than half fuel in the tank as detailed in Table 2.

In the tests with full load plus additional weight, fresh water ballast was loaded into the aft buoyancy lockers and the forepeak tank. The weights were distributed as shown in Table 2 to maintain the boat in the required LCG conditions. The load variation between additional weight test conditions is only about 200 pounds, less than ½% of the boat's total displacement.

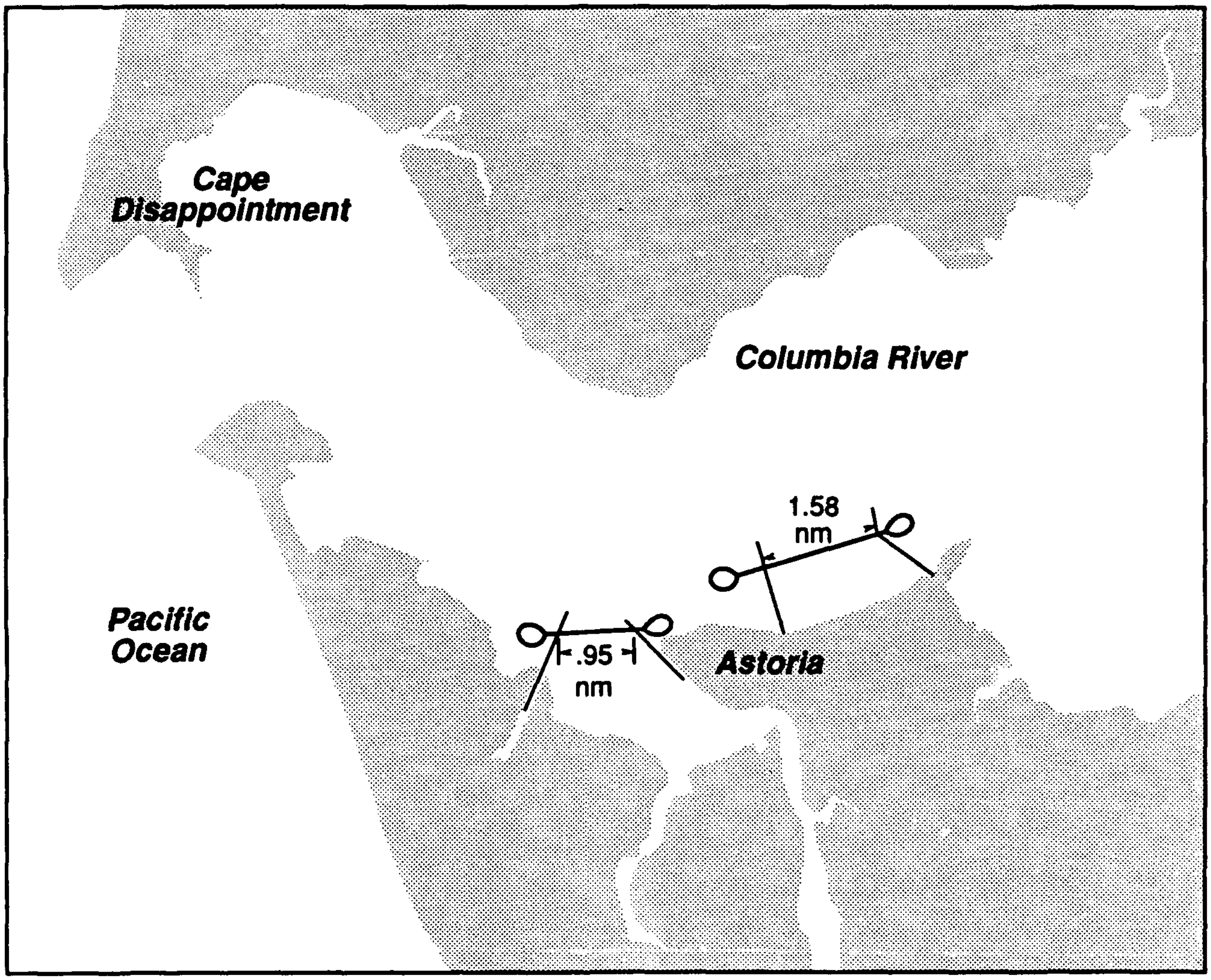


FIGURE 1. SPEED TRIAL RANGES

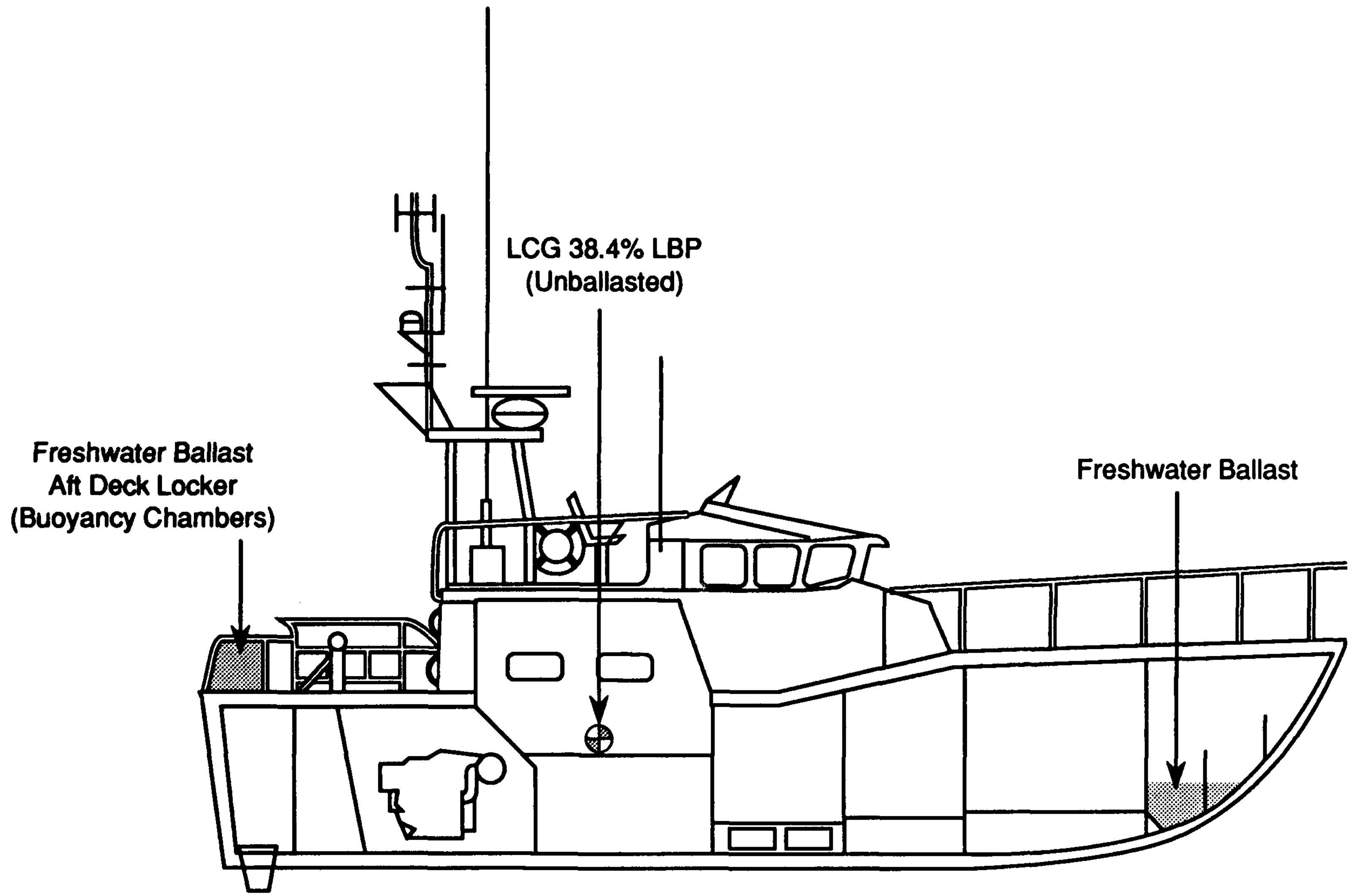


FIGURE 2. TEST CONDITION WEIGHT DISTRIBUTIONS

TABLE 2
BALLAST LOAD PLAN

BASELINE FULL LOAD

40,410lbs (18.0LT) w/LCG 16.51FT forward of AP (38.4% LBP)
Includes full outfit, 400 gallons fuel and four crewmembers
Baseline load known within ± 500lbs, LCG known within ± 0.2FT

	HALF LOAD	FULL +2000 AFT	FULL +2000 MID	FULL +2000 FWD
AVERAGE FUEL(GAL)	154	362	350	355
LOAD CORRECTIONS	WT(LBS)/MOMENT ARM(FT)			
FUEL	-1,700/N	-260/N	-345/N	-310/N
TEST EQUIPMENT	+200/N	+200/N	+200/N	+200/N
TEST PERSONNEL	+360/N	+360/N	+360/N	+540/N
FRESHWATER BALLAST				
AFT BUOYANCY LOCKERS	0/0	+1,515/-15.2	+920/-15.2	0/0
FOREPEAK	0/0	0/0	+595/+23.9	+1,515/+23.9
NET LOAD CHANGE (LBS)	-1,140	+1,815	+1,730	+1,945
NET MOMENT (FT-LBS)	N	-23,000	-236	+36,200
DISPLACEMENT(LBS)	39,270	42,225	42,140	42,355
DISPLACEMENT(LT)	17.5	18.85	18.81	18.91
LCG (FT FWD OF AP)	16.5	15.96	16.52	17.37
LCG (% LBP)	38.4%	37.1%	38.4%	40.4%

LEGEND

Load Changes are +/- weight in pounds referenced to Baseline Full Load
Moment Arms are measured in feet relative to the Baseline Full Load LCG (see Figure 2)
"+" Moment Arm is weight added the given distance Forward, "-" Moment Arm is Aft
Change in Moment is in Foot-Pounds, (Positive trims the bow down, Negative trims bow up)
*Note: "N" denotes negligible moment arm

TC-5 **Trim vs Speed:** Trim angle versus speed data were obtained concurrently with the speed versus horsepower measurements. Identical procedures were used to minimize the effects of wind, waves and current, and to measure boat speed.

Trim angle was measured using a digital inclinometer, mounted on a structural member in the survivors' compartment. This inclinometer was accurate to within ± 0.1 degree and has a response time constant less than 1 second. The inclinometer was zeroed to measure relative to the boat's static trim in the 17.5LT, LCG 38.4% LBP load condition. By the boat's curves of form (drawing 47MLB-801-012) this load condition results in a trim of approximately 1 inch by the stern, for a static trim angle of about 0.1 degree, bow up. Because this trim angle is very near the measurable limit of the inclinometer, the baseline was assumed parallel to the zero set at the 17.5LT, 38.4% LCG load condition. The instrument was read continuously by the data taker during the test and the reported trim angle is the average angle observed during the test run.

The test was conducted in the same load conditions described in Test TC-4 and Table 2.

TC-6 **Righting Arm vs Heel Angle:** These curves were taken from existing data provided by Coast Guard Headquarters Naval Engineering Division [G-ENE-5].

TC-7 **Bollard Pull:** This test measured the bollard pull (static thrust at the tow bitt) as a function of engine RPM. The test was conducted at Tongue Point Buoy Depot in Astoria, Oregon. Environmental conditions were not ideal during this test with winds up to 20 knots, waves of 1-2 feet and approximately 1 knot flood current, but the test period did not allow for rescheduling on a calmer day. The effect of these conditions is not known, but 44FT MLB bollard pull testing conducted at the same time agrees within 12% to data collected on a different 44FT MLB under better conditions [8]. The water depth at the test site was 20 feet. A tow hawser was led from the boat's tow bitt to a bollard on the pier. A 20,000-pound rated load cell was placed in line between the bollard and the tow hawser. The load cell was calibrated to within 1% of the indicated reading. Engine RPM was measured using the boat's installed tachometers on the starboard side of the flying bridge, which are accurate to ± 50 RPM. Bollard pull measurements were recorded at nine engine RPMs between idle and 1600 ERPM. The test was halted at this point for safety's sake because of the heavy loads on the tow hawser and the less-than-ideal weather conditions.

TC-8 **Minimum Turning Radius:** This test measured the minimum turning radius (at 30 degrees rudder angle) as a function of speed. The tests were conducted in the Columbia River, west of Astoria in light winds (10 knots) and seas less than 1 foot. Turn radius was measured from data output by a Global Positioning System (GPS) tracking system and the TACMAN_II tactical diameter tracking software developed at the R&D Center. The GPS tracking system measured the boat's track over the ground. To minimize the effects of current, the TACMAN_II software was used to remove set and drift from the boat's track. An example of this set and drift correction is shown in Figure 3. The boat executes a right turn, and continues turning five circles in her own wake. The GPS recorded track over the ground appears on the left as a trochoidal curve because of the effects of 1.2 knots of steady current. The corrected track on the right appears as a set of five nearly concentric circles, indicating the true path of the vessel through the water. The turning radius may be measured directly from the corrected track and is accurate to within 15 feet of the actual turn radius. Vessel speed for these tests was measured using the GPS tracking system, the boat's speed log and the Speed vs Engine RPM curve plotted from the results of test TC-4.

The 30 degree rudder angle was held until the vessel completed 720 degrees turning to allow a good check against the applied set-and-drift corrections. The time to turn 360 degrees (instead of 180) was recorded because this resulted in improved accuracy. Turns at a given speed were repeated for left and right rudder and the results averaged. Turns were repeated twice to estimate precision and repeatability.

TC-9 **Acceleration:** This test measured the boat's acceleration to full speed from a standing stop. The boat's speed log, corrected by a calibration curve obtained during test TC-4 was used to measure boat speed at 5-second intervals up to full speed. The results are accurate to ± 1 knot. The test is repeated in two directions, and the results averaged to reduce any effects from wind, waves and current. The test is conducted at full load displacement (18.0LT at LCG 38.4%) and at full load plus an additional 2000lbs (18.81LT at LCG 38.4% LBP).

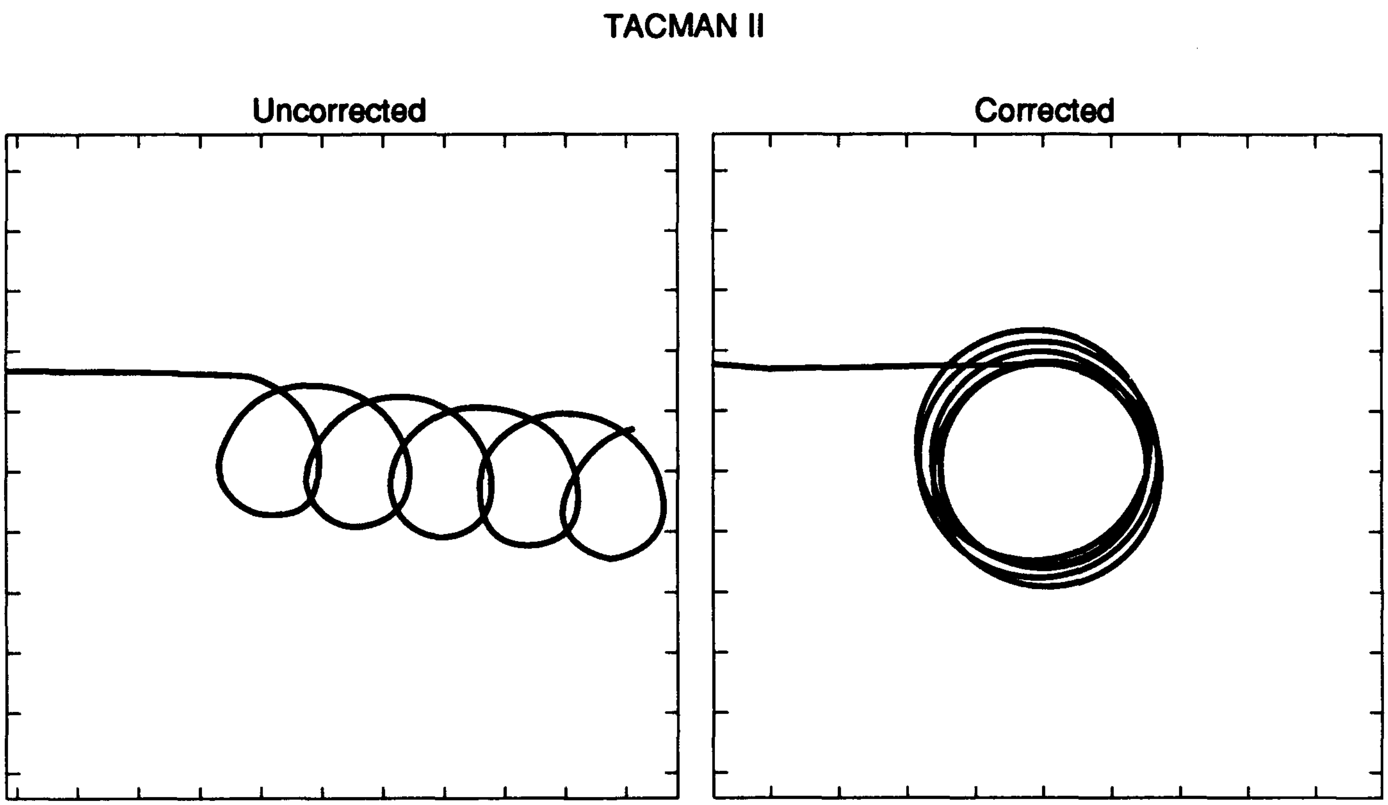


FIGURE 3. SET AND DRIFT CORRECTIONS

TC-10 **Sea Height vs Maximum Speed:** This test measured the maximum safe operating speed of the boat as a function of sea height for head seas operation, which is generally considered the slowest heading. Speed was measured with the boat's speed log, and/or LORAN-C speed over the ground. These speed measurements are presumed accurate to within ± 1 knot based on calm water comparisons with measured mile and GPS speed measurements. The test required a variety of sea conditions, up to 15-foot significant wave heights. Three different methods were used to measure the sea height depending on the severity of conditions and the availability of equipment. On some tests an Endeco Wave Buoy was used to measure directional wave heights near the test site. In more severe weather or during actual boat operations, the wave buoy was not available and the sea state was obtained from the NOAA wave buoy data near the mouth of the Columbia River (NOAA Buoy Station 46010) or by visual estimates by the boat's crew and weather reports.

The maximum throttle applied in head seas was determined by the coxswain and the crew rather than by the method of [2], (a measurement of vertical accelerations at the coxswain station). The threshold limit of "the point of exceeding 1.5g at the coxswain station" was not evaluated. Single slam events in lower sea states occasionally resulted in peak vertical accelerations exceeding 1.5g, but these random events were not used as the speed-limiting measurements because they did not affect safe operation. Test equipment was not installed during the higher sea conditions when vertical accelerations may have approached 1.5g RMS. Instead, the coxswain's operating discretion was relied on as a subjective, but meaningful measure of the boat's and the crew's speed limitations in head seas.

TC-11 **Fuel Consumption vs Speed:** Fuel consumption as a function of speed was measured concurrently with Test TC-4. The same procedures as in the Speed vs Power measurements were used to minimize the effects of wind, waves and current. Speed was measured as in Test TC-4 with averaged results reciprocal courses over a measured distance. A Fluidyne measurement system designed for precision determination of diesel fuel consumption of light to heavy duty vehicles was installed on board the 47FT MLB. Fuel consumption was measured using a single positive displacement fuel meter to record the amount of make-up fuel added to the recirculating fuel system. Care was taken to cool and settle the recirculating fuel before measuring the flow volume. The meter was calibrated at the factory to 0.5% accuracy with 0.1% repeatability. This same system was used successfully for precision fuel flow measurements on a 41FT UTB, as reported in [9]. The test was conducted at Half Load Displacement (17.50LT at LCG 38.4% LBP) for the 47FT MLB. Half load was selected because as the boat consumes fuel and becomes lighter, its speed increases. The Half Load condition represents the boat's average load state during a long mission, and results in improved accuracy for range computations in test TC-12.

TC-12 **Range vs Speed:** Maximum range as a function of speed was calculated based on an assumed 400 gallons available fuel for the 47FT MLB. The fuel consumption for computing range was measured at Half Load, as described in test TC-4, TC-11 and Table 2. Speed was measured as in Test TC-4.

TC-13 **Maneuverability (Spiral Test):** The spiral test is a definitive ship trial for measuring calm water directional stability characteristics. The test was conducted in the Columbia River, west of Astoria, in approximately 40 feet of water. The test was conducted with seas less than 1 foot, and wind less than 10 knots. The rudder angle was measured using the boat's rudder angle indicator, which was calibrated prior to the trial to within 1 degree accuracy. Yaw rate was measured using a Humphrey motions package yaw rate gyro. The test was conducted at two speeds, 10 knots and maximum. Starting from Left 30 degrees rudder, and increasing rudder angle by increments specified in [4], the yaw rate was recorded and then averaged over a 1-minute period of steady turning for each rudder angle. Heading change over the 1-minute period was also measured using the boat's compass as a check. The process was repeated for decreasing rudder angles starting at right 30 degrees rudder.

TC-14 **Maneuverability (Zig Zag Test):** The zig-zag test is a definitive ship trial for measuring the rudder's ability to control the boat in calm water. The test was conducted in the Columbia River, west of Astoria, in approximately 40 feet of water. Wind during the test was less than 10 knots, seas less than 1 foot. The rudder angle was measured using a string potentiometer attached to the rudder quadrant and calibrated to within 1 degree accuracy at the dock. Heading was recorded using the yaw gyro of the Humphrey motions package installed at the boat's center of gravity. The boat's track was recorded using the GPS tracking system with the TACMAN_II software to correct for the effects of set and drift from the 2-3 knot flood current. The test was conducted at two speeds, 10 knots and maximum. The test was conducted in two directions, up and down current. Data for the two directions was compared to ensure there was no bias in the results from the effects of set and drift.

Starting on a steady course and speed, the rudder was put to right 20 degrees, and held until the course changed 20 degrees from the base course. When the boat's heading was 20 degrees right of the base course, the rudder was shifted to left 20 degrees, and held until the heading changed to twenty degrees left of base course. The zig-zag pattern was repeated four times for each trial.

TC-15 **Motions in Waves:** This test measured the boat's response in heave, pitch and roll in a measured sea state. Seakeeping tests of the 47FT MLB with 1.9 square foot vertical rudders were conducted on 14 September 1991 in the Pacific Ocean, 5 to 15 nm southwest of Cape Disappointment. Water depth at the test site was greater than 200 feet. Winds were less than 5 knots during the seakeeping test. Seas were measured with the Endeco wave buoy in position 46-04.6N, 124-11.3W in the middle of the 3-hour test period. The significant wave height during the test was 4.8 feet and the average wave period was 8.6 seconds. Details of the wave buoy recorded data are given in Table TC-15.1 A normalized directional wave spectrum contour plot is shown in Figure TC-15.1. The direction of the major swell was from approximately 305T. The test was conducted at two speeds, 10 knots and maximum engine RPM. The boat's response in heave, surge, sway, pitch, roll and yaw was measured using a Humphrey inertial motions package located at the boat's center of gravity. The motions package provides an "earth-fixed" coordinate system for motions measurement through the use of gyro-stabilized sensors. Motions package outputs were recorded on magnetic tape for processing ashore. The test was conducted at two speeds in five directions: head seas, bow, beam, quarter and stern. Each test run was eleven minutes or longer, to collect a statistically significant sample of wave encounters.

TEST RESULTS

Test results are presented in this section in the format required by [1] and [2]. Analysis of the test results follows the data presentation. Photographic and Video Documentation are a separate enclosure to the report, and are included only in the distribution to Commandant, U.S. Coast Guard [G-AMB]. Copies of the video and photographs may be requested through the U.S. Coast Guard R&D Center Marine Engineering Branch.

TEST TC-1
PRINCIPAL CHARACTERISTICS

	BOAT TYPE		
BOAT CHARACTERISTIC	47FT MLB	44FT MLB	41FT UTB
LENGTH OVERALL (FT)	47' 11"	44' 1"	40' 8"
BEAM (FT)	14' 0"	12' 8"	13' 6"
DRAFT (FT)	4' 4"	3' 6"	4' 0"
FULL LOAD DISPLACEMENT (LBS)	40,000	39,680	30,700
HULL MATERIAL	ALUMINUM	STEEL	ALUMINUM
CABIN MATERIAL	ALUMINUM	N/A	FIBERGLASS
MAXIMUM SPEED (KTS)	27.1	13	23.0
IDLE SPEED (KTS)	5.7	2	5-10
FUEL CAPACITY (GAL)	400	334	450
ENGINE MODEL	DETROIT 6V-92TA	DETROIT 6V53	CUMMINS VT903
TOTAL BOAT HORSEPOWER	850	370	640
CREW SIZE	4	3-4	3
HEIGHT OF EYE (FT)	*9'10"/14'6"	10' 2"	8' 3"
VISIBLE HORIZON (NM)	*3.6/4.4	3.7	3.3

*Enclosed Bridge/Flying Bridge

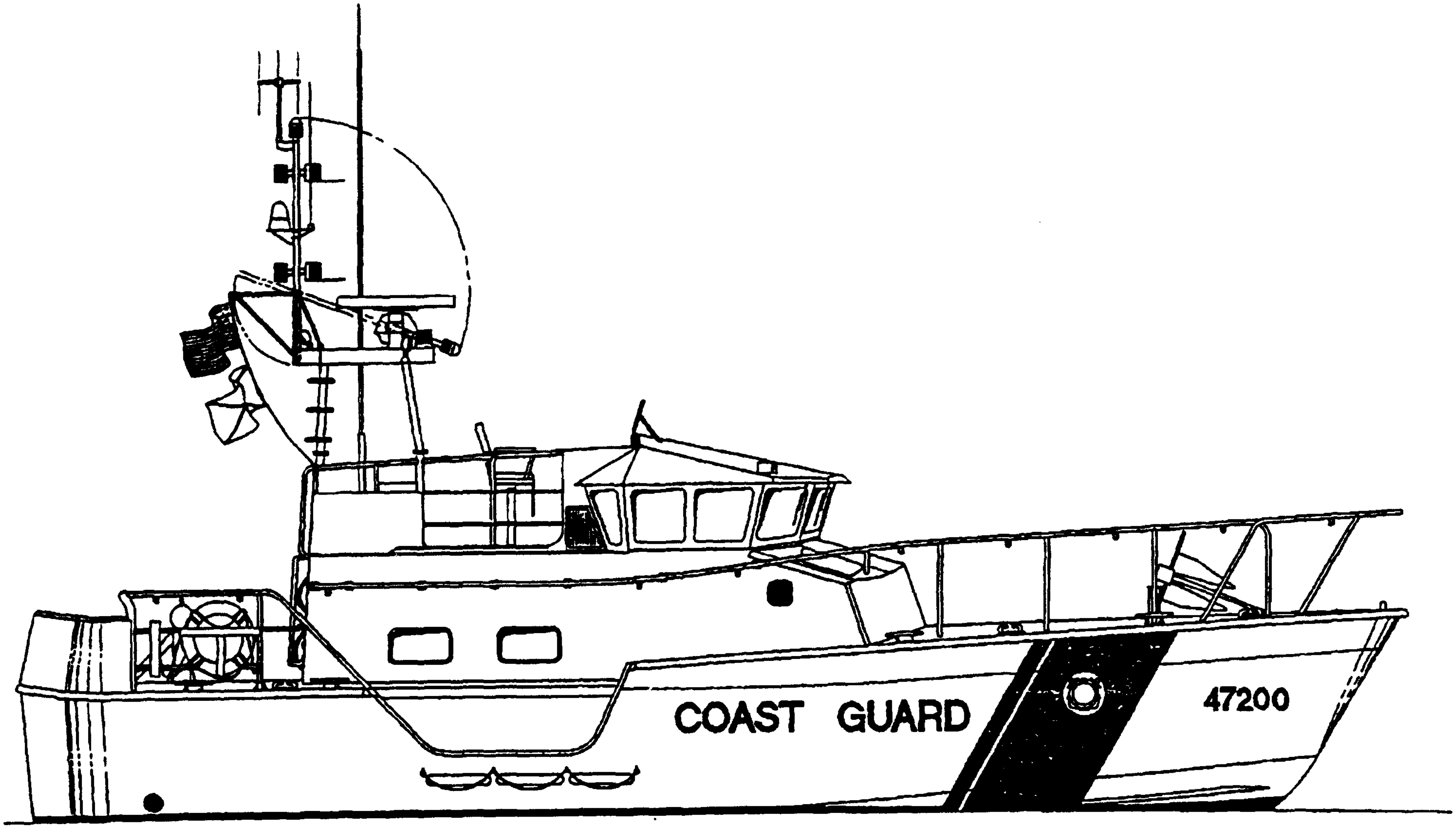


FIGURE TC-1.1. 47FT MLB OUTBOARD PROFILE

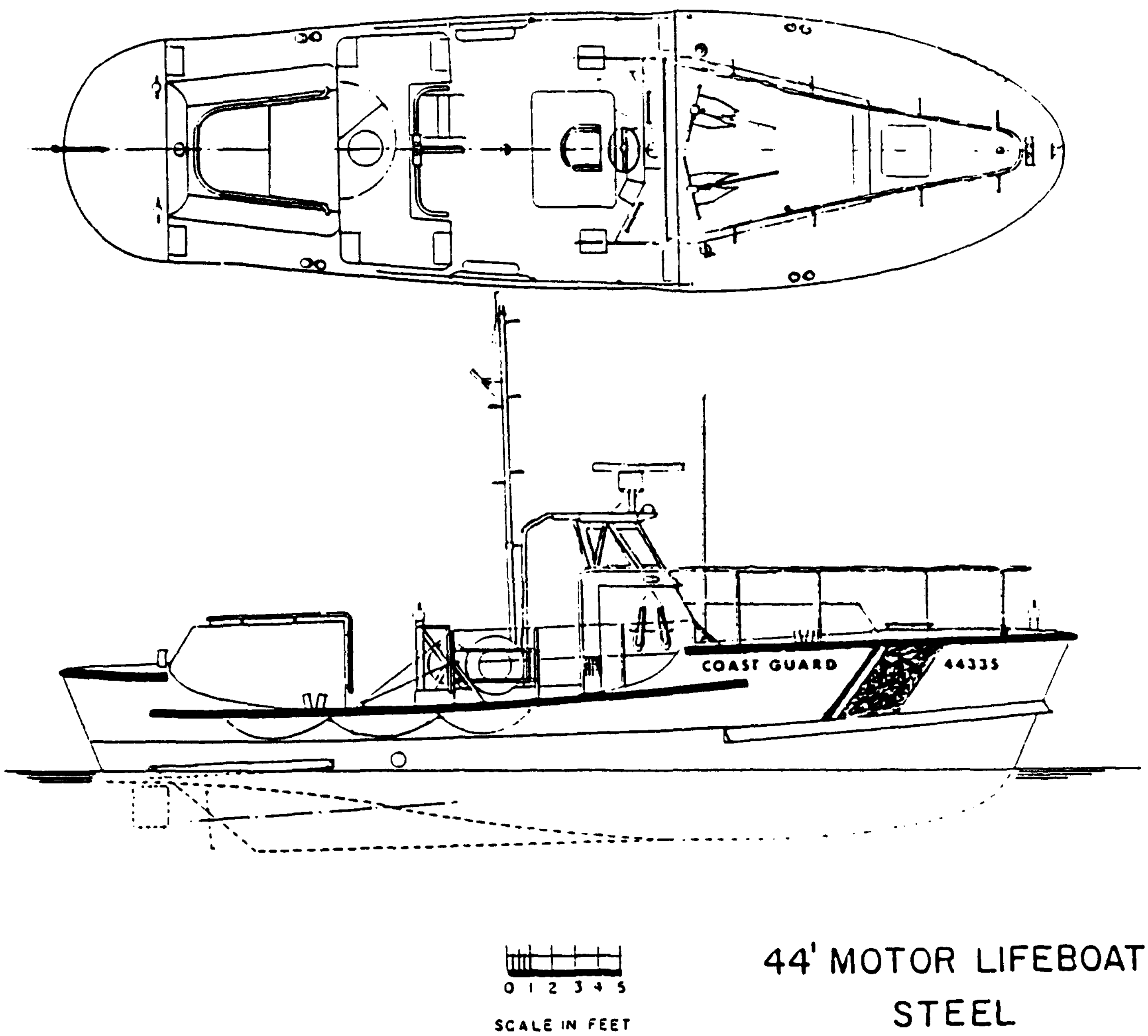
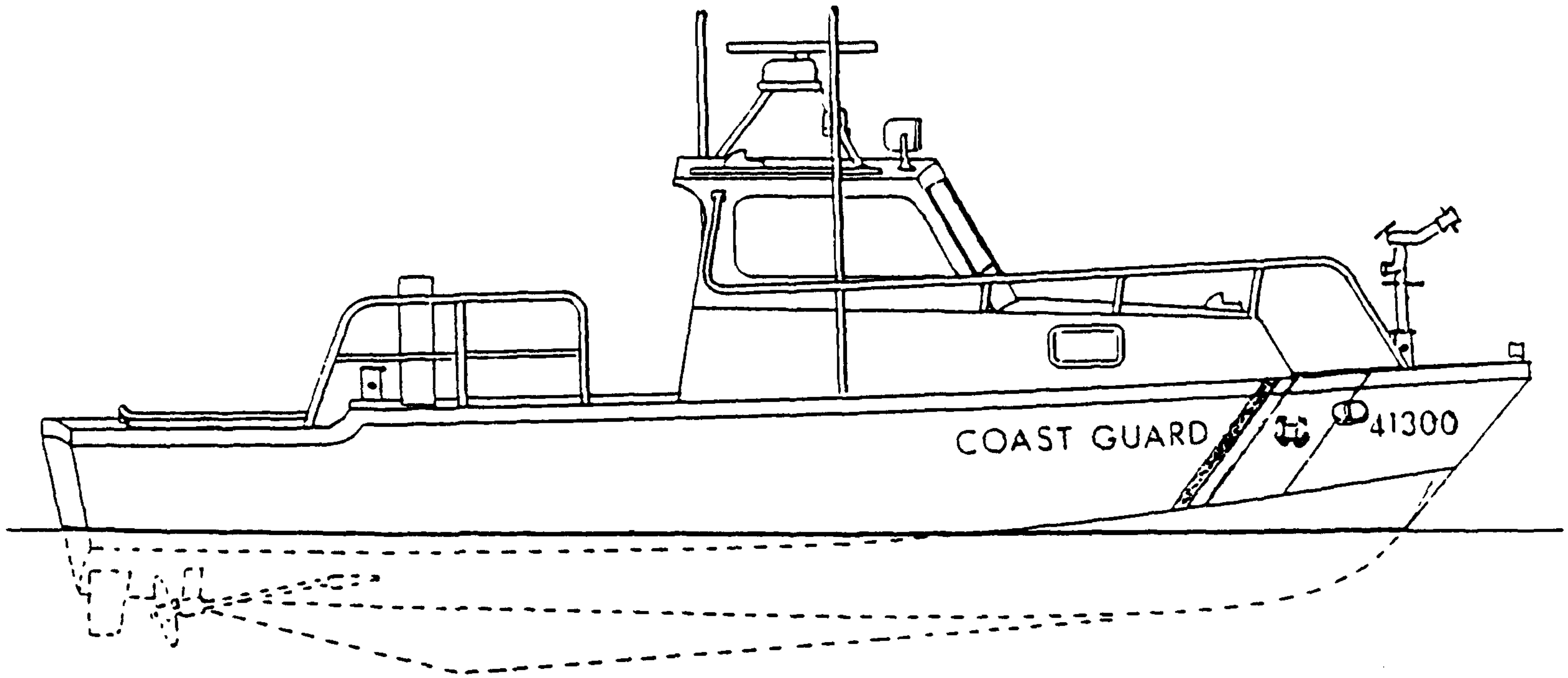


FIGURE TC-1.2. 44FT MLB OUTBOARD PROFILE



41' UTILITY BOAT

FIGURE TC-1.3. 41FT UTB OUTBOARD PROFILE

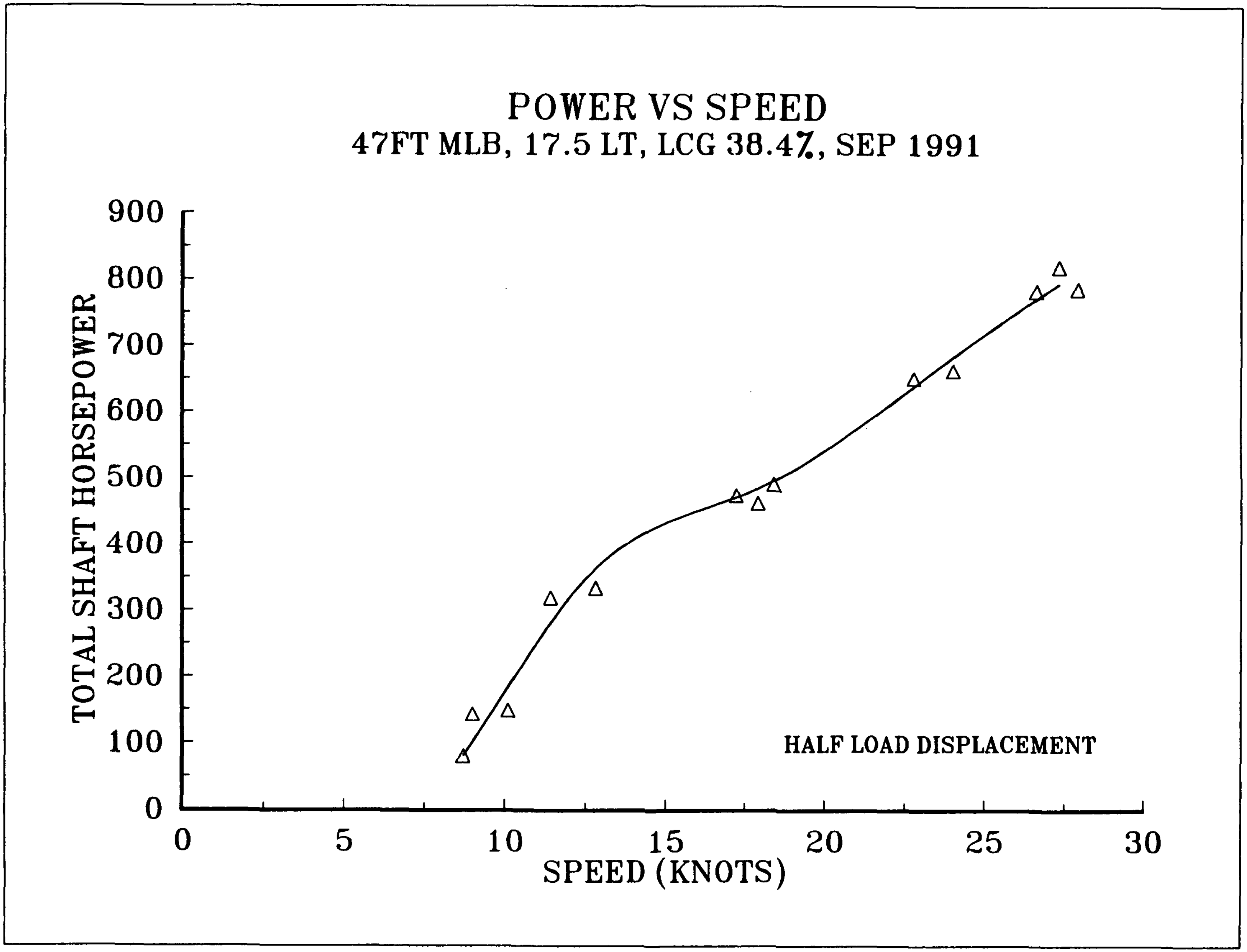


FIGURE TC-4.1. 47FT MLB POWER VS SPEED 17.5LT WITH LCG 38.4%

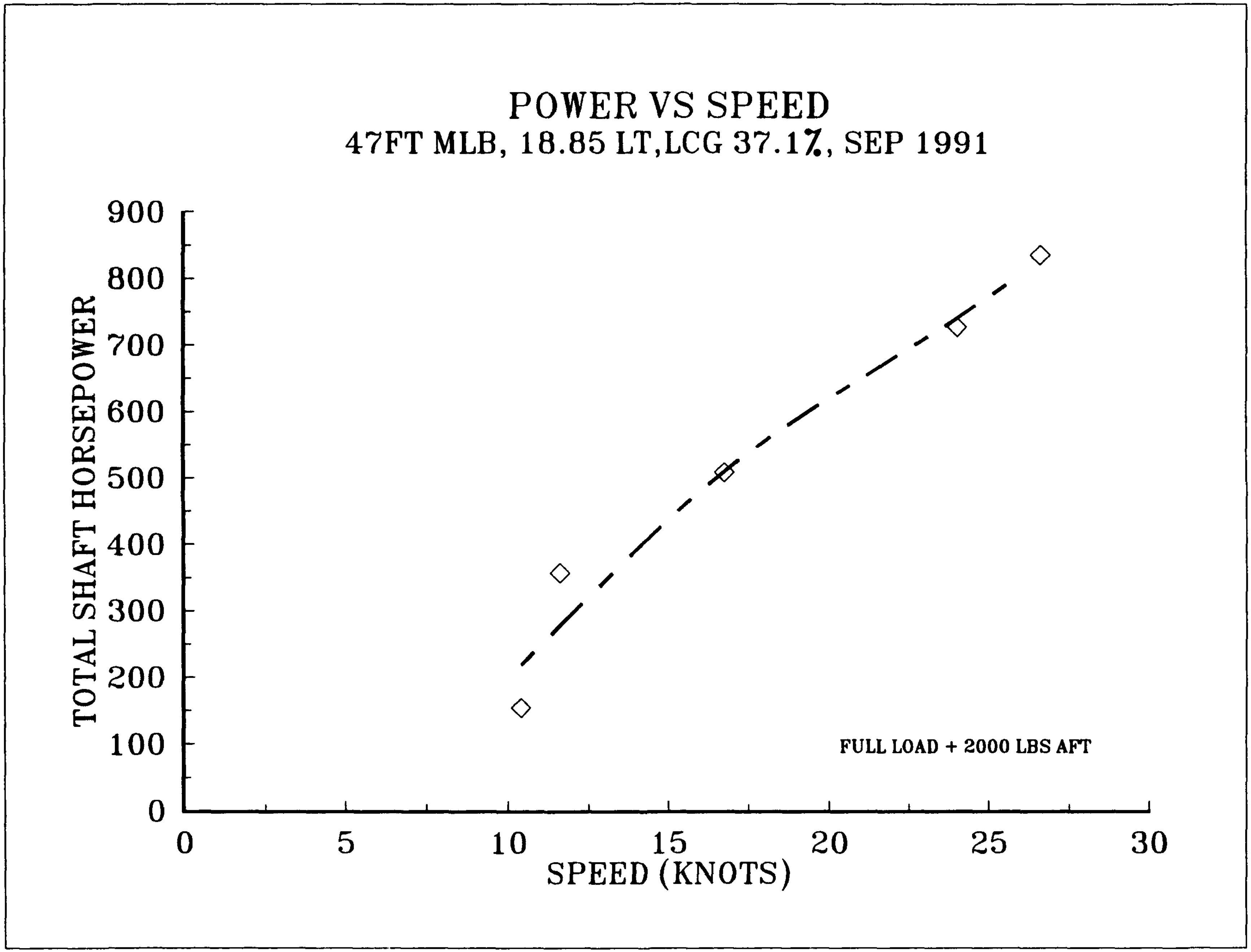


FIGURE TC-4.2. 47FT MLB POWER VS SPEED, 18.85LT WITH LCG 37.1%

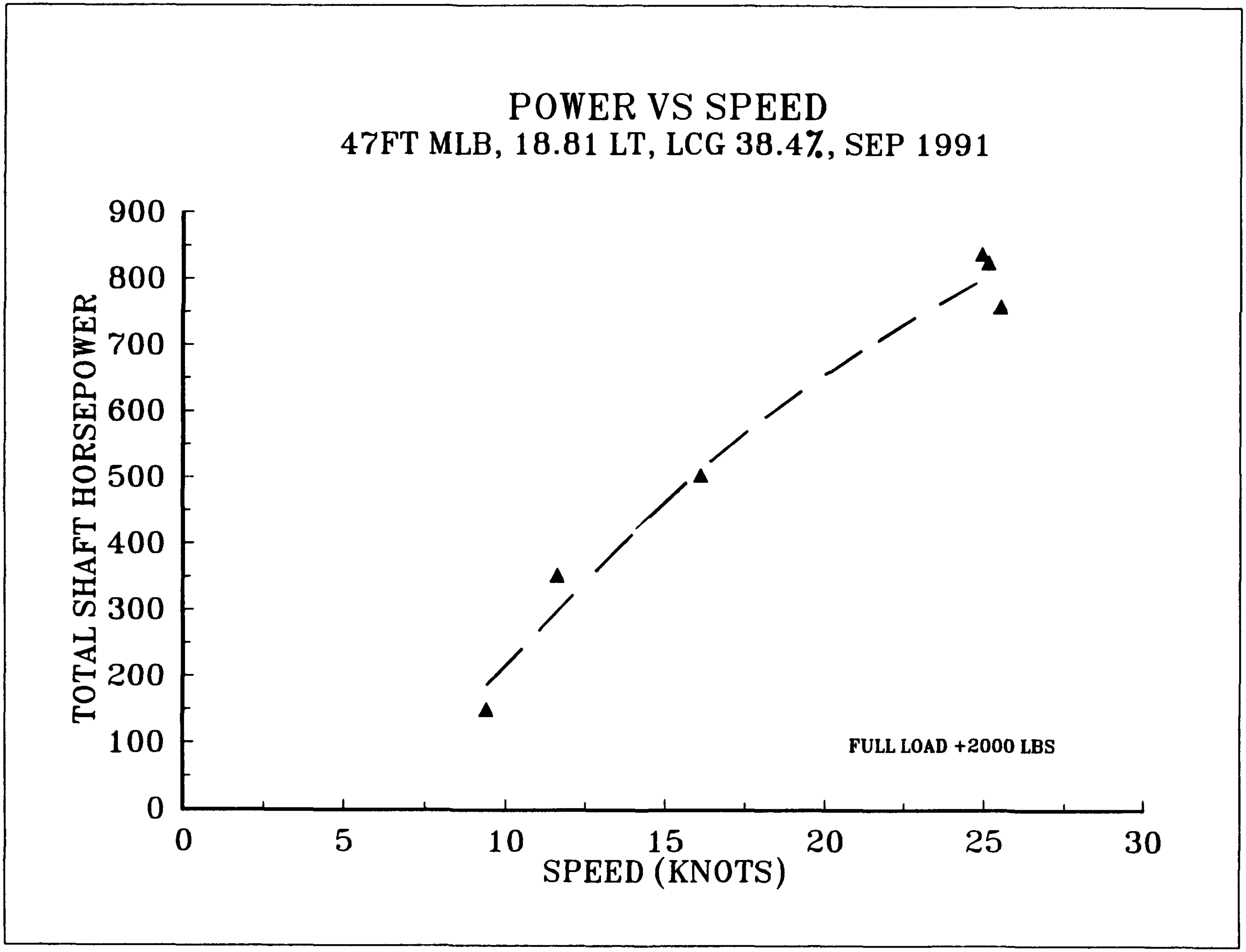


FIGURE TC-4.3. 47FT MLB POWER VS SPEED 18.81LT, LCG 38.4%

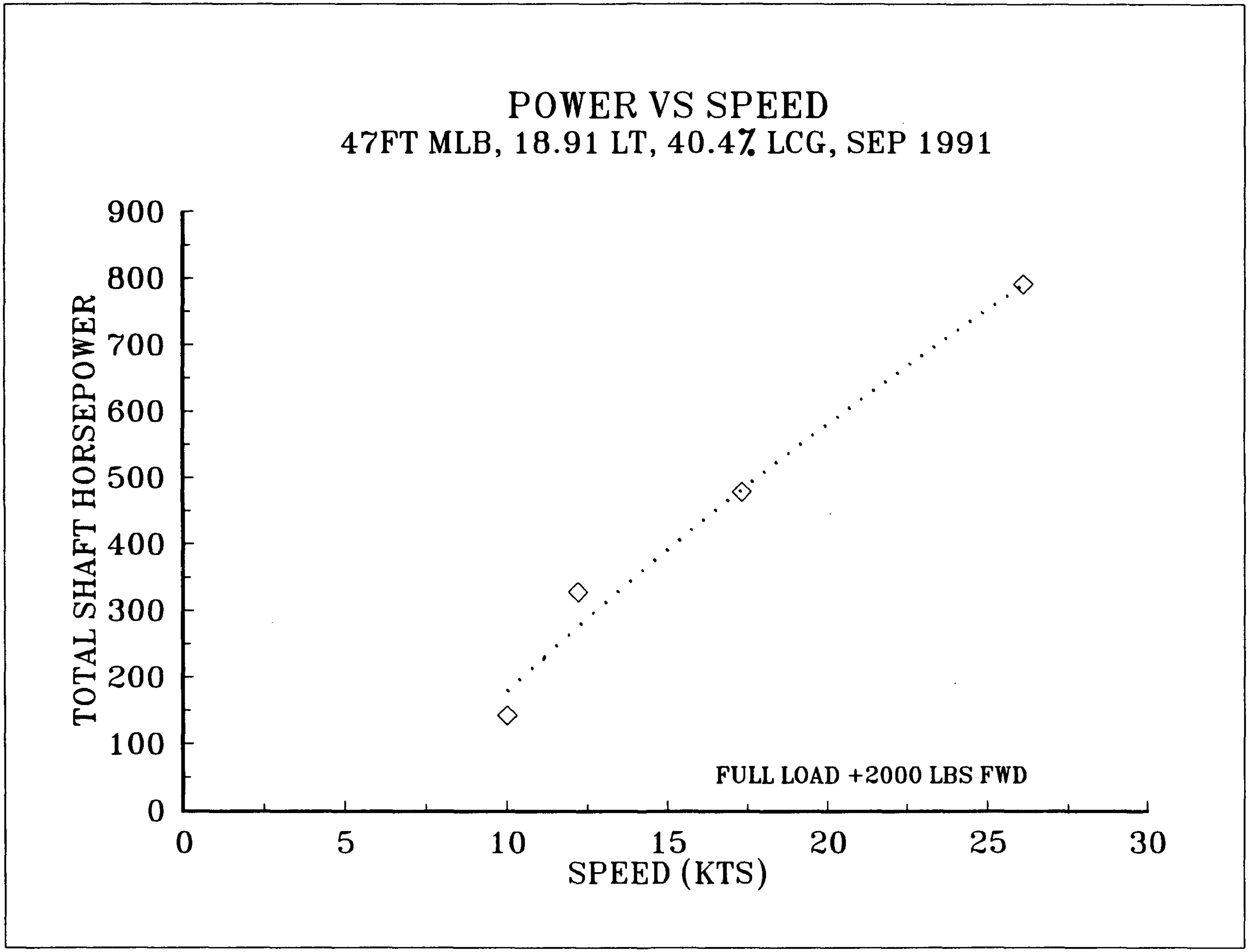


FIGURE TC-4.4. 47FT MLB POWER VS SPEED 18.91LT WITH LCG 40.4%

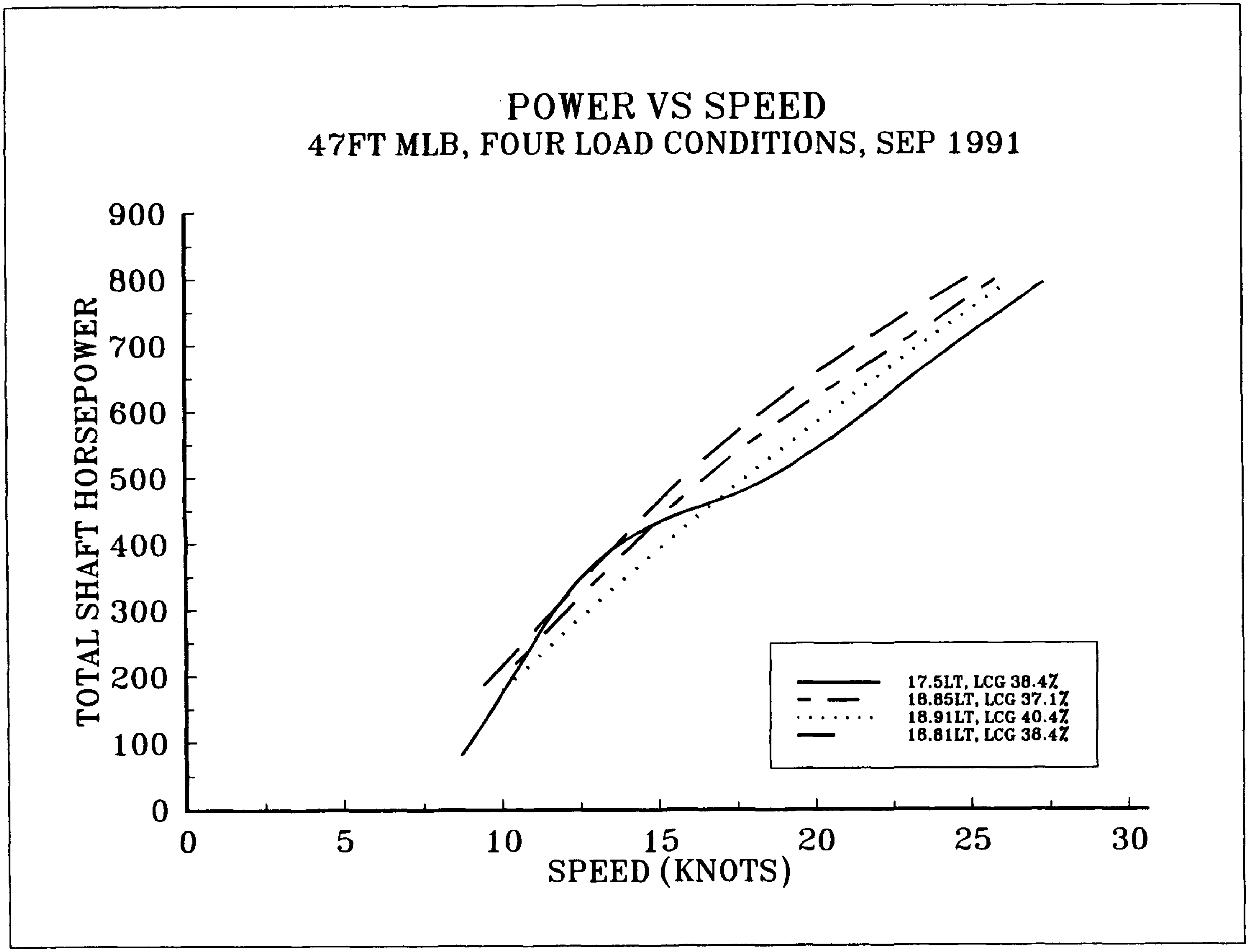


FIGURE TC-4.5. 47FT MLB POWER VS SPEED WITH LOAD/LCG VARIATIONS

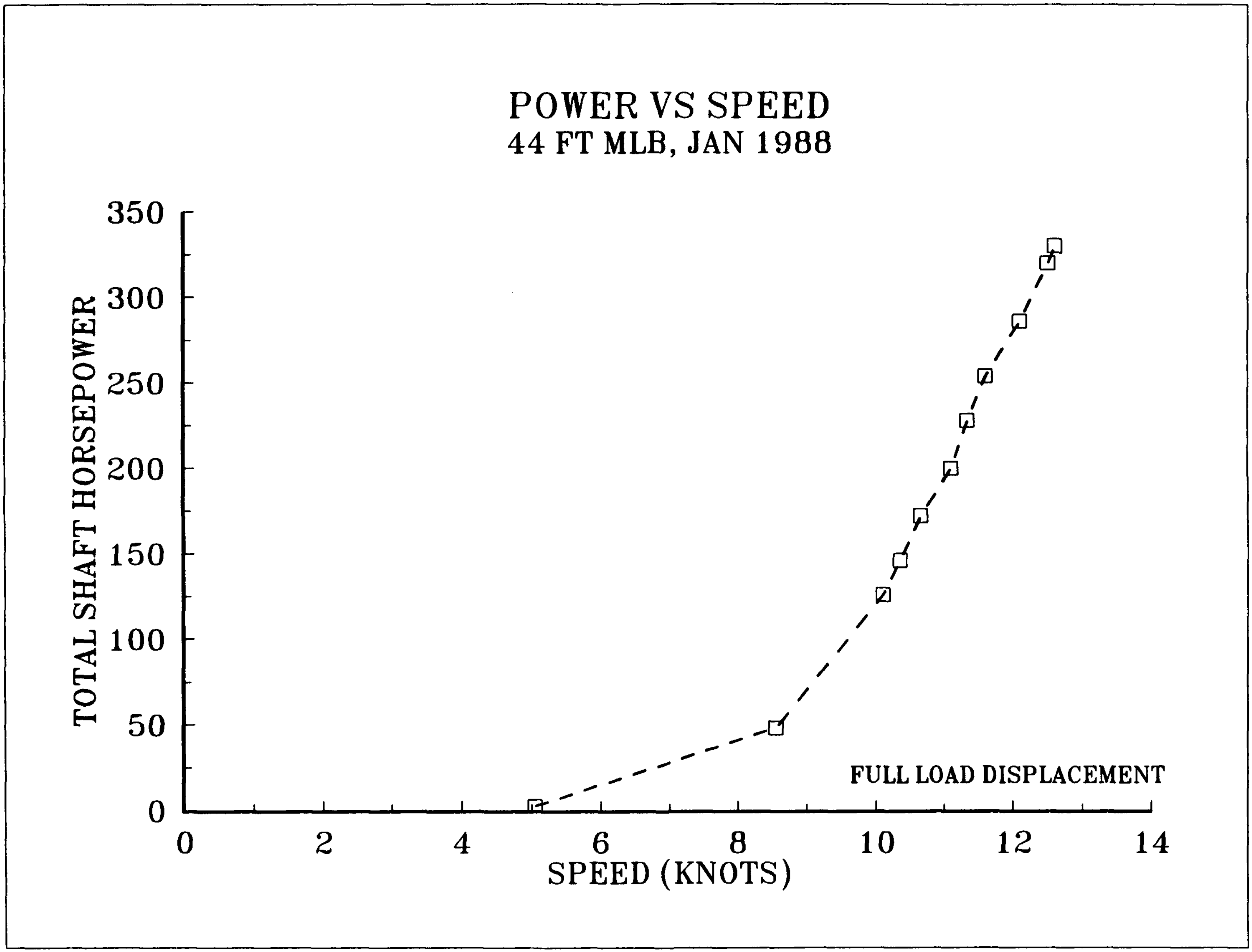


FIGURE TC-4.6. 44FT MLB POWER VS SPEED

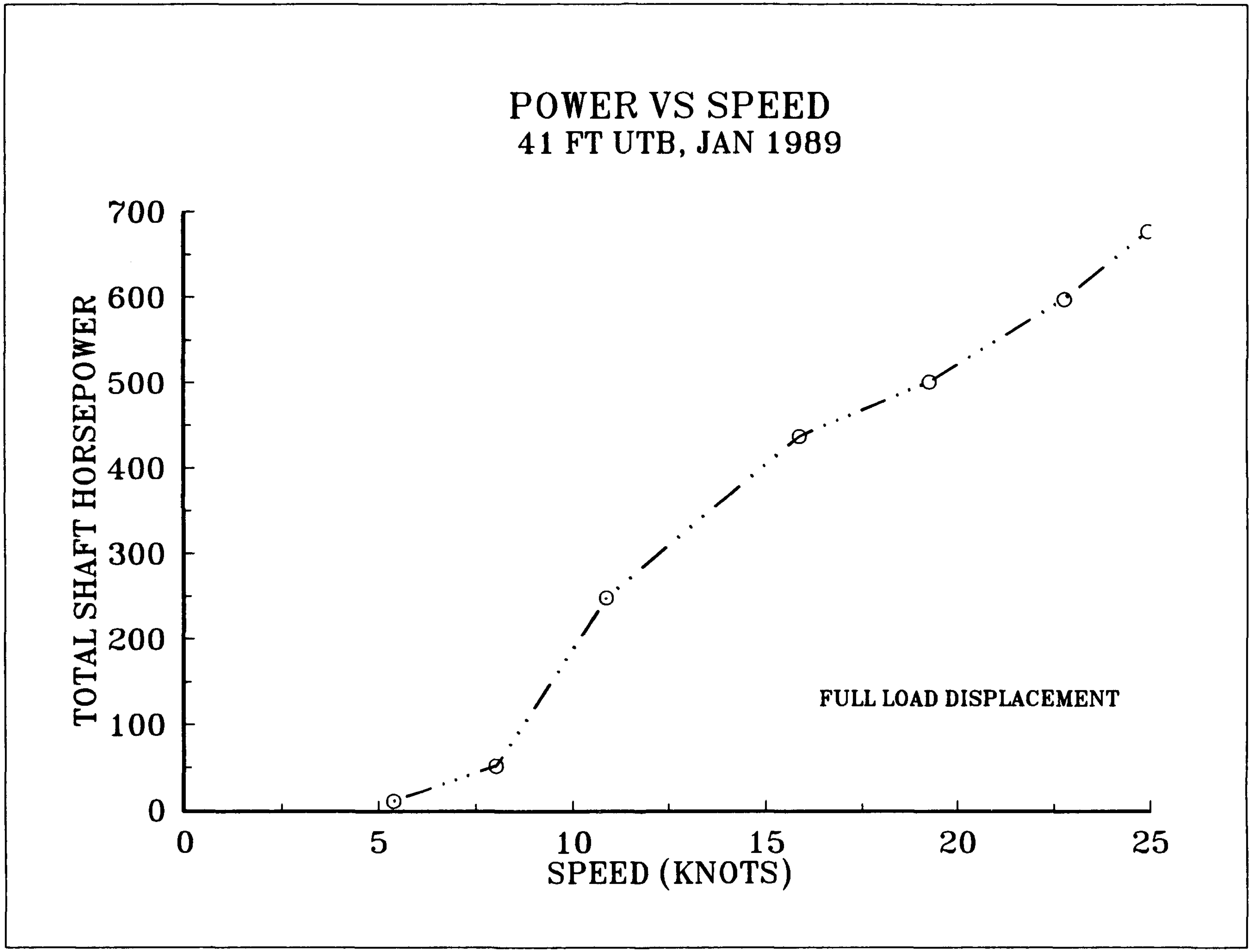


FIGURE TC-4.7. 41FT UTB POWER VS SPEED

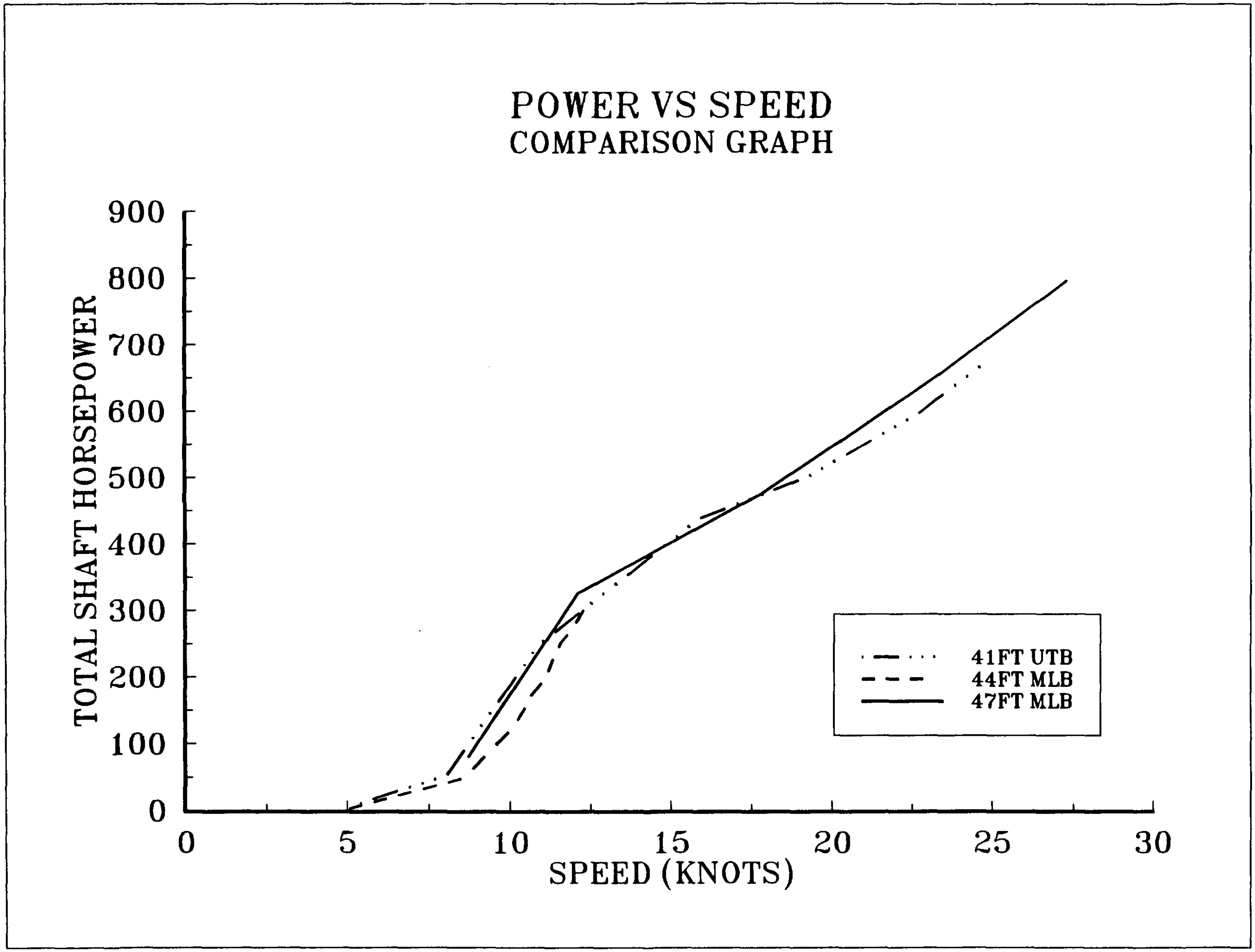


FIGURE TC-4.8. COMPARATIVE POWER VS SPEED

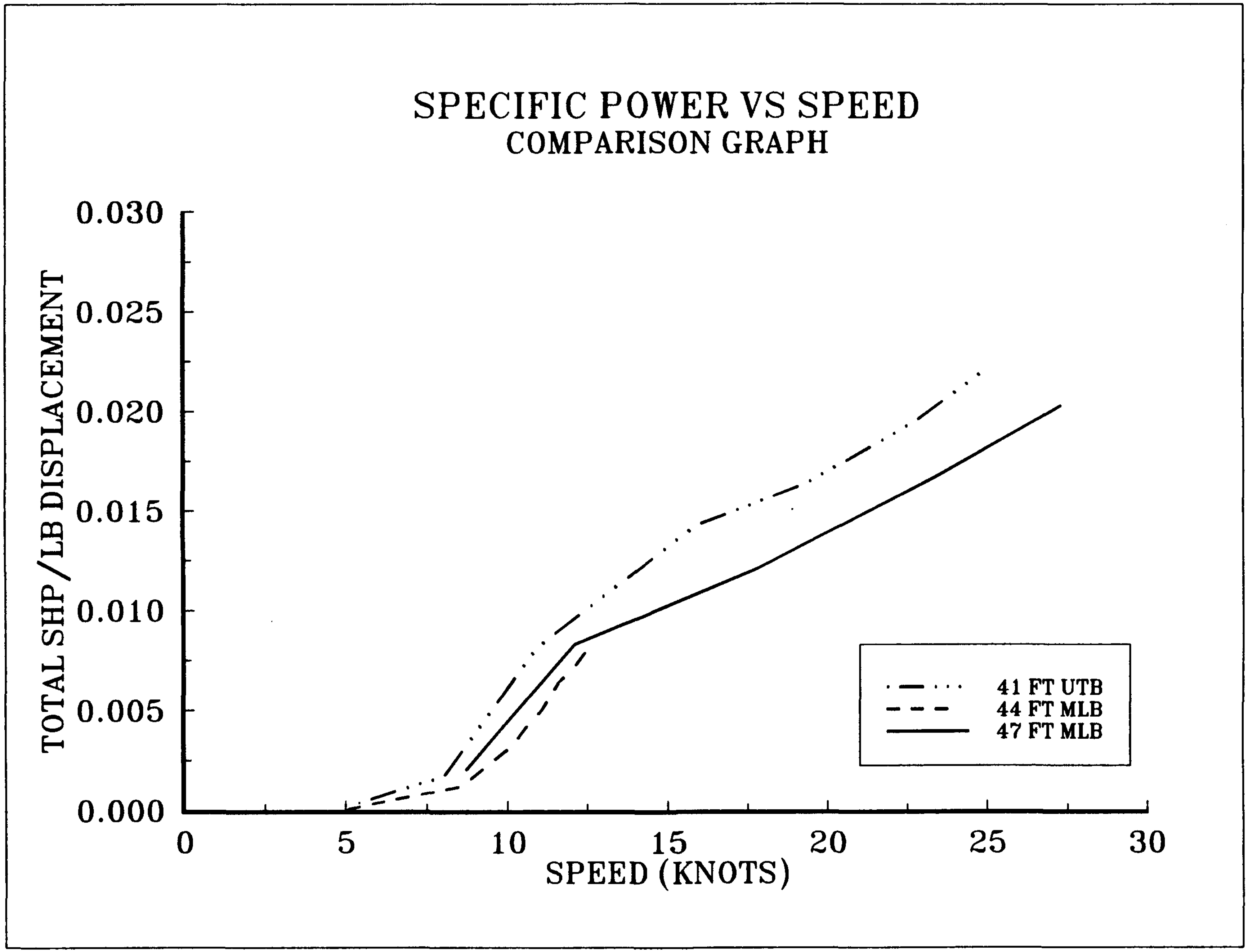


FIGURE TC-4.9. COMPARATIVE SPECIFIC POWER VS SPEED

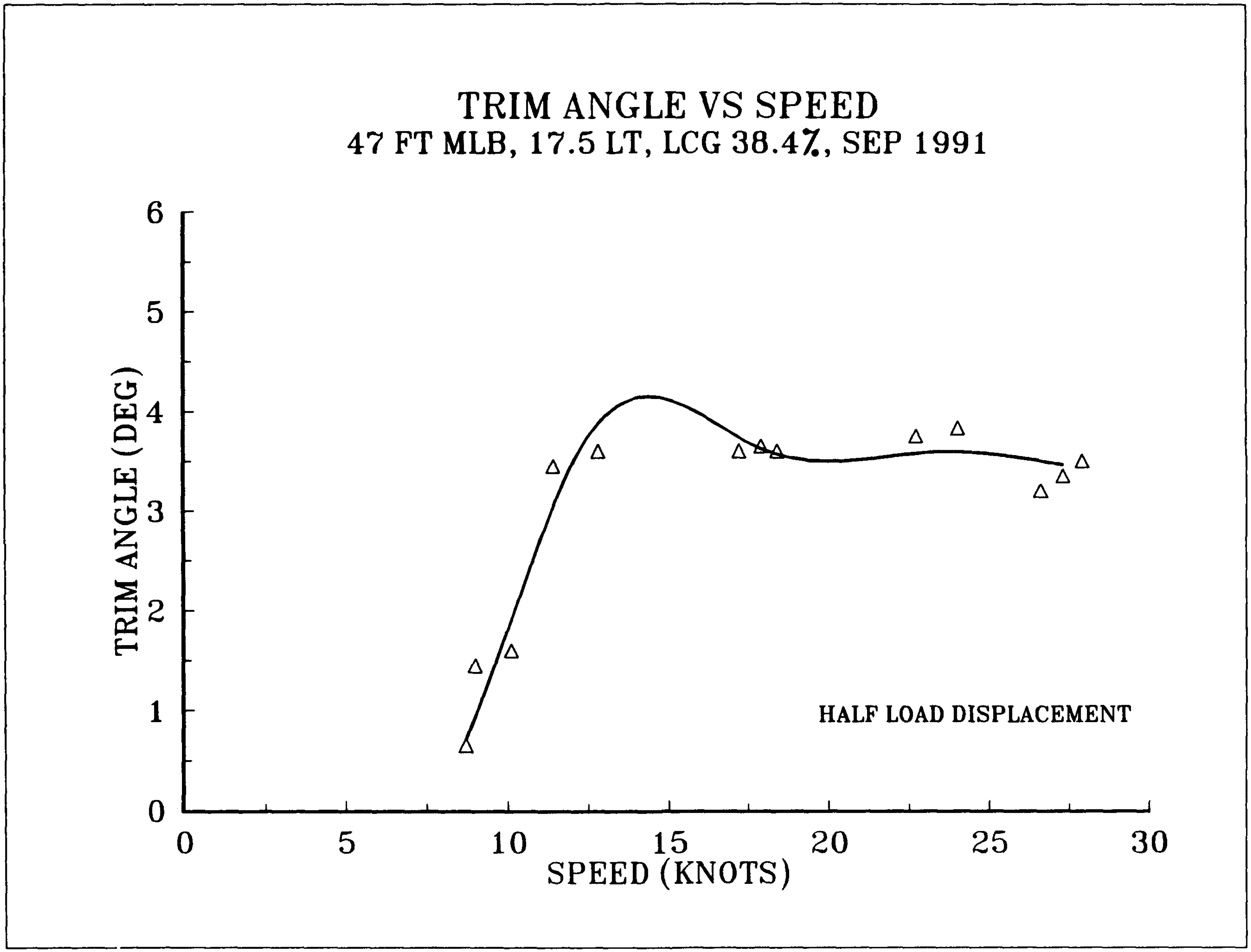


FIGURE TC-5.1. 47FT MLB TRIM VS SPEED 17.50LT WITH LCG 38.4%

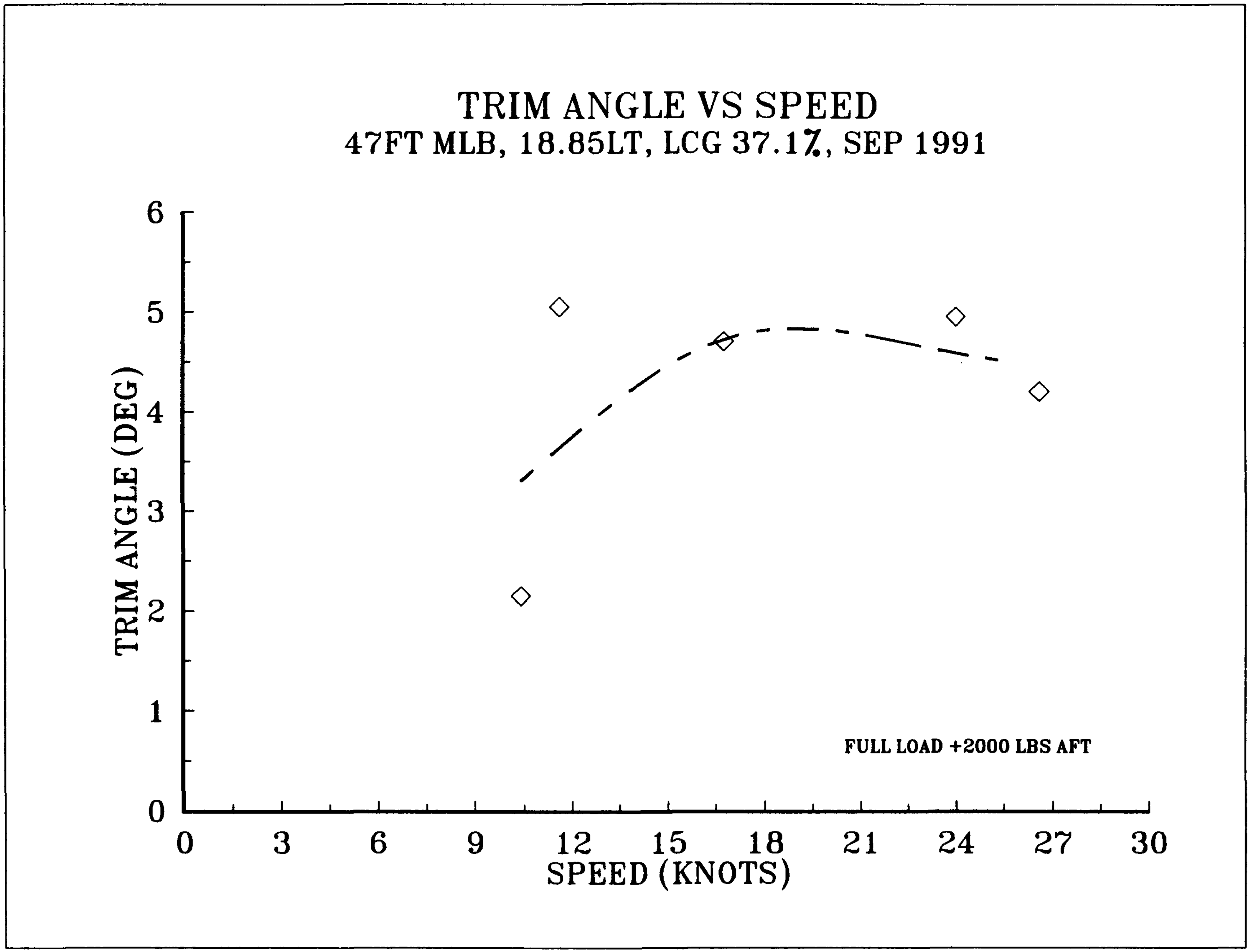


FIGURE TC-5.2. 47FT MLB TRIM VS SPEED 18.85LT WITH LCG 37.1%

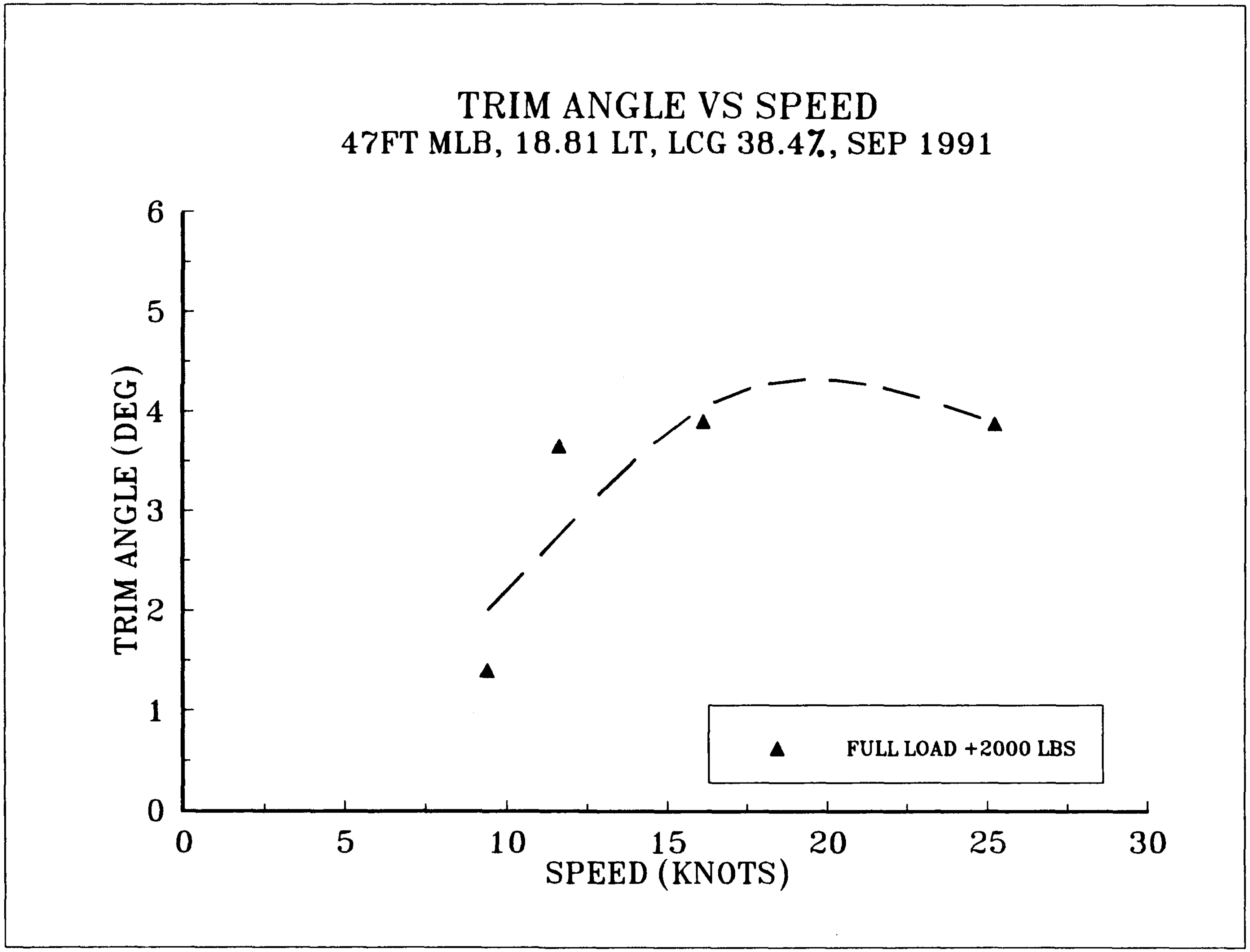


FIGURE TC-5.3. 47FT MLB TRIM VS SPEED 18.81LT WITH LCG 38.4%

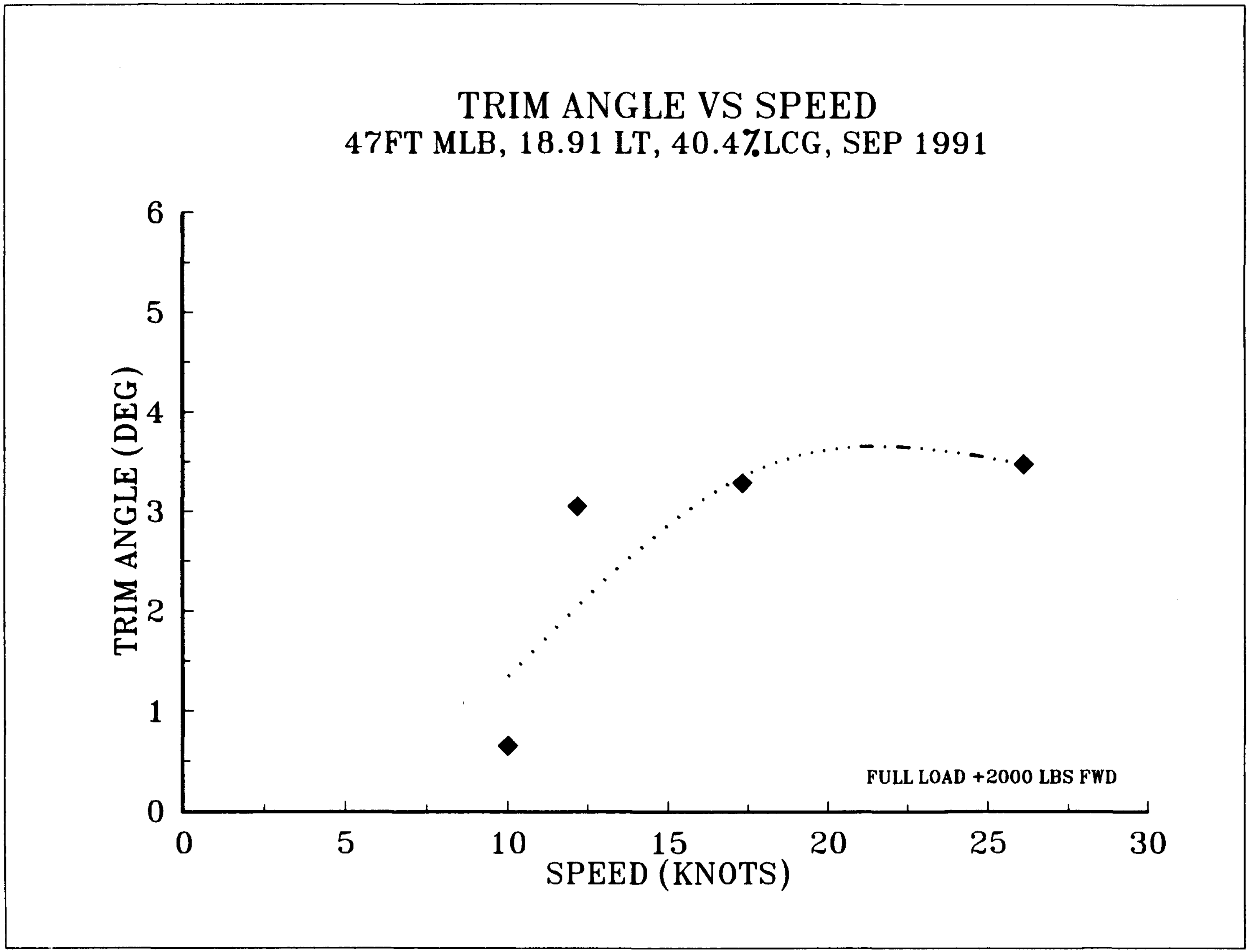


FIGURE TC-5.4. 47FT MLB TRIM VS SPEED 18.91LT WITH LCG 40.4%

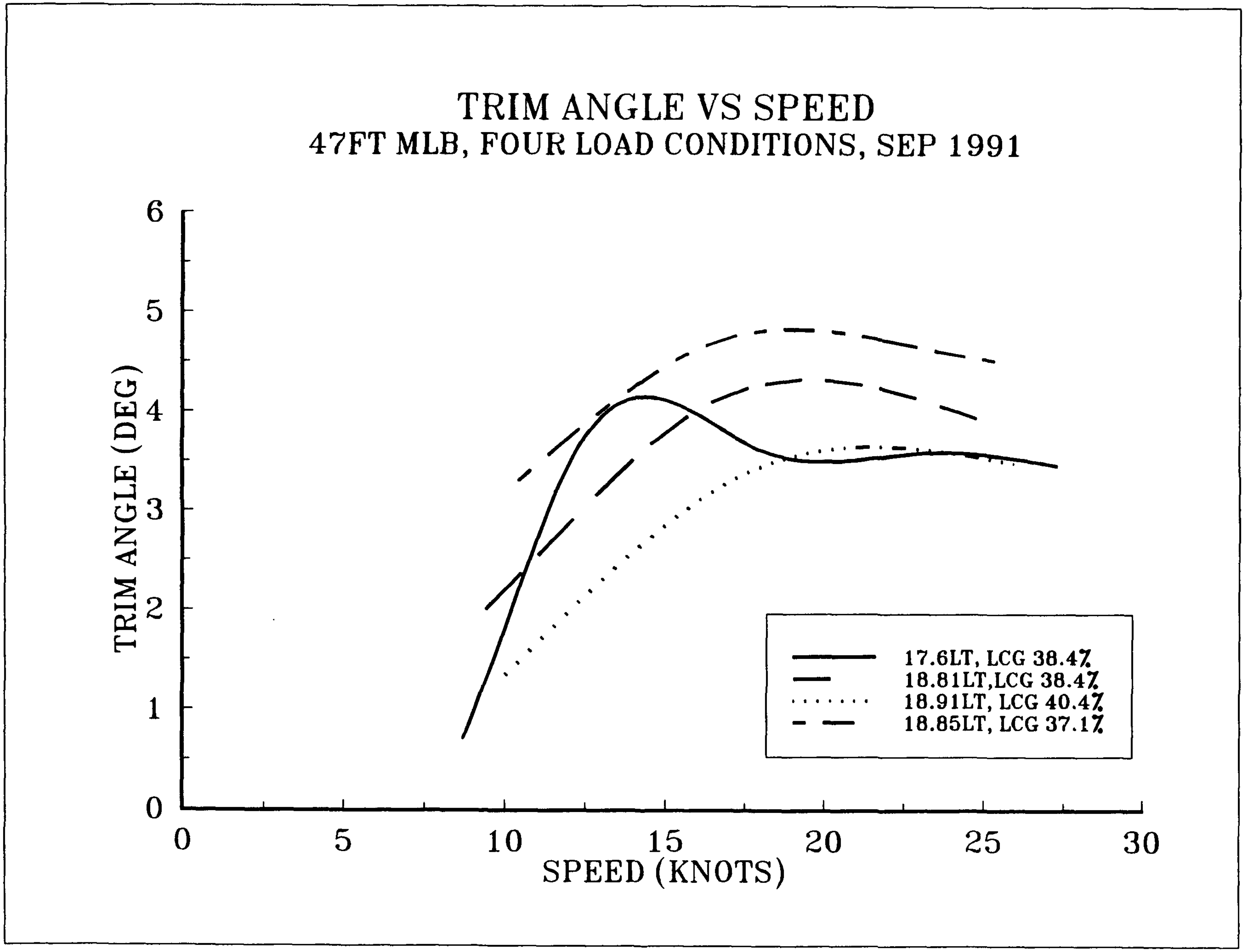


FIGURE TC-5.5. 47FT MLB TRIM VS SPEED WITH LOAD/LCG VARIATIONS

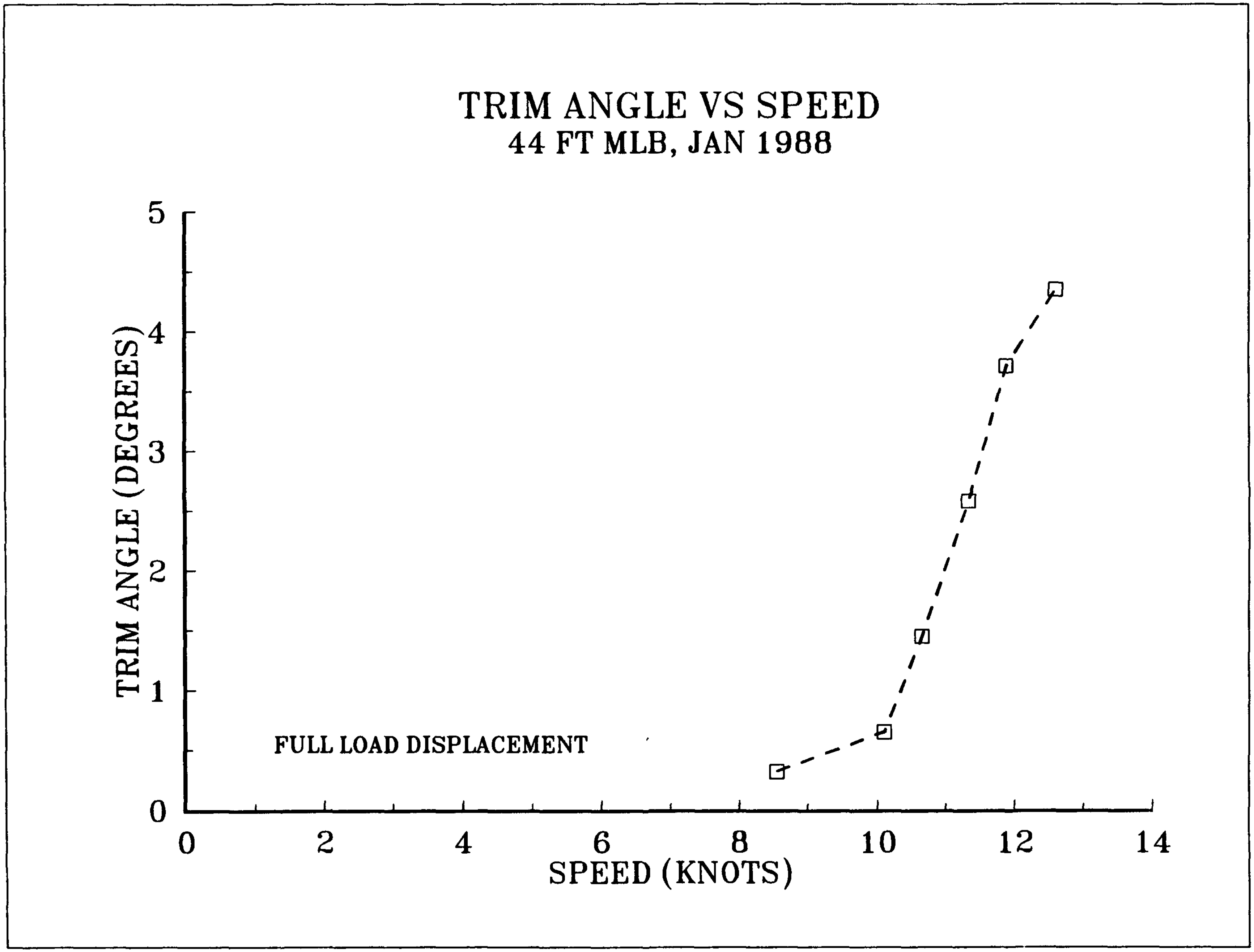


FIGURE TC-5.6. 44FT MLB TRIM VS SPEED

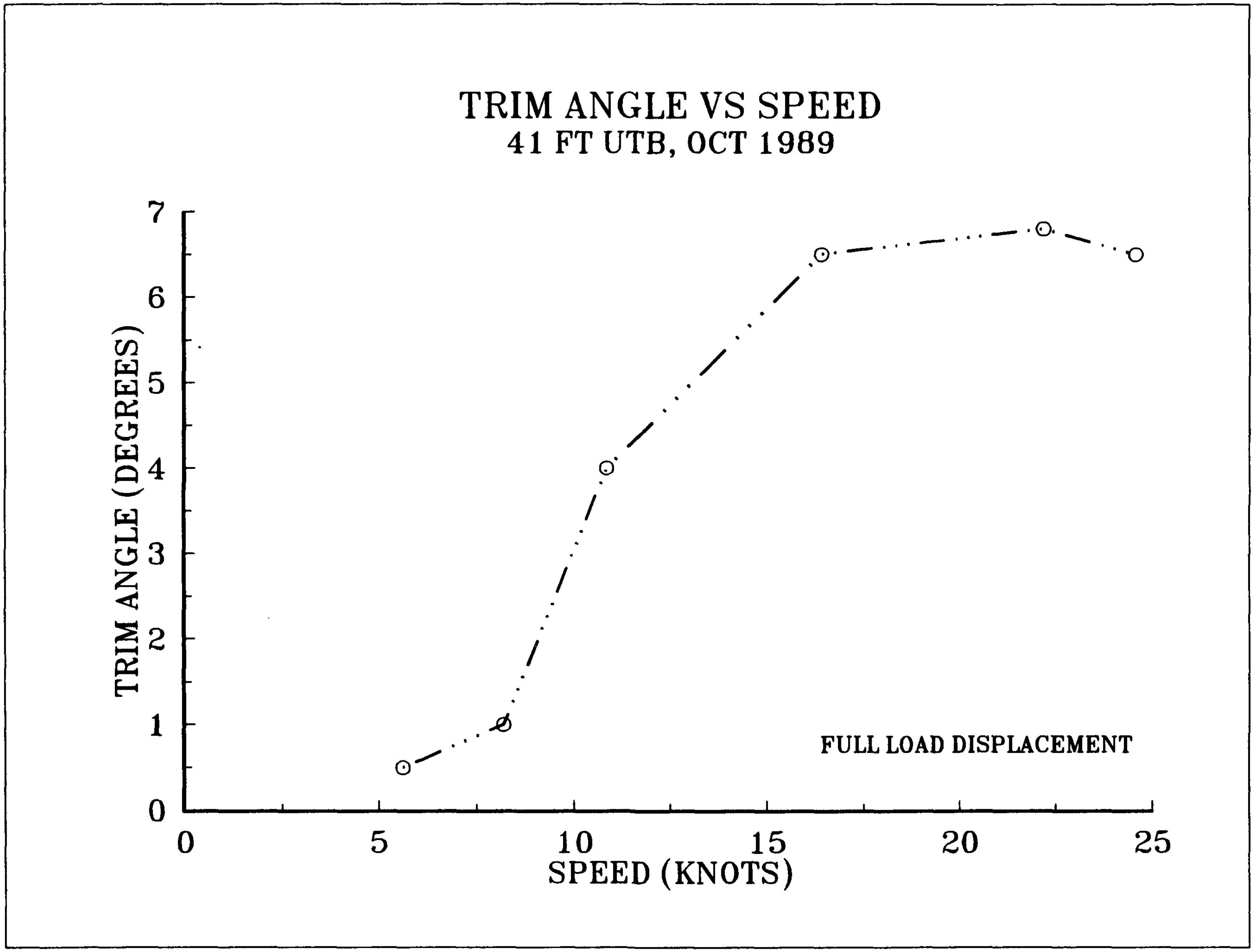


FIGURE TC-5.7. 41FT UTB TRIM VS SPEED

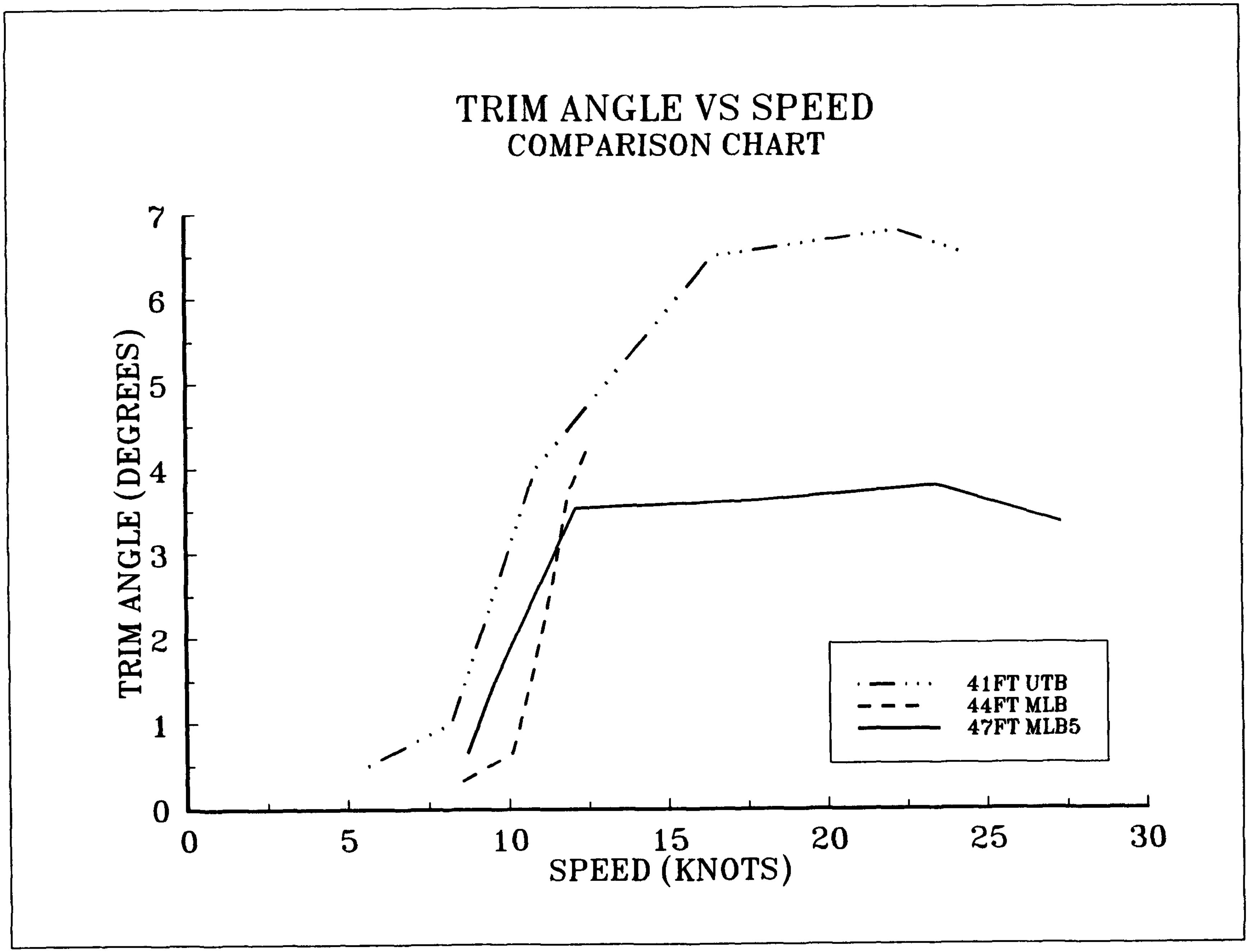


FIGURE TC-5.8. COMPARATIVE TRIM VS SPEED

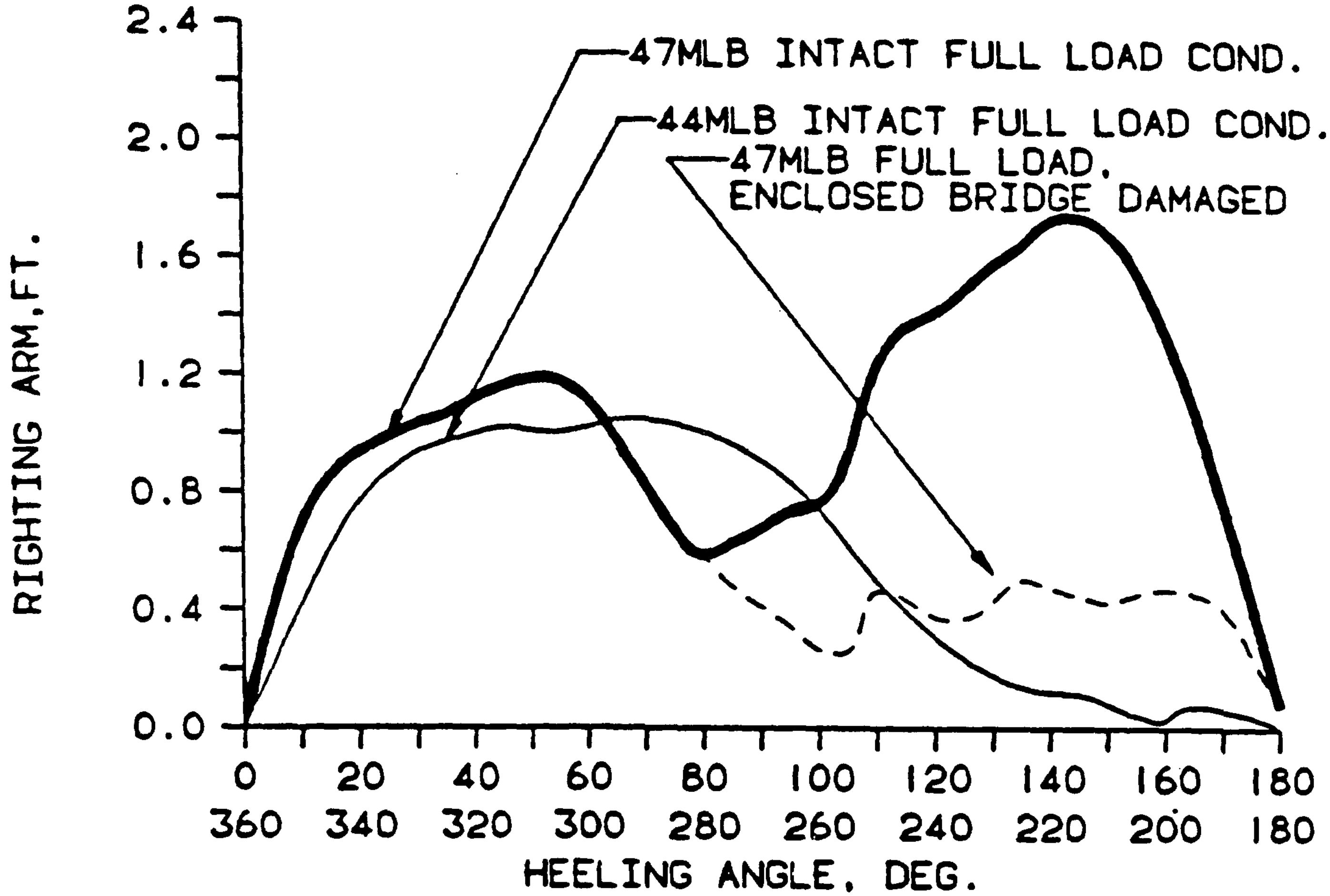


FIGURE TC-6. RIGHTING ARM VS HEEL ANGLE

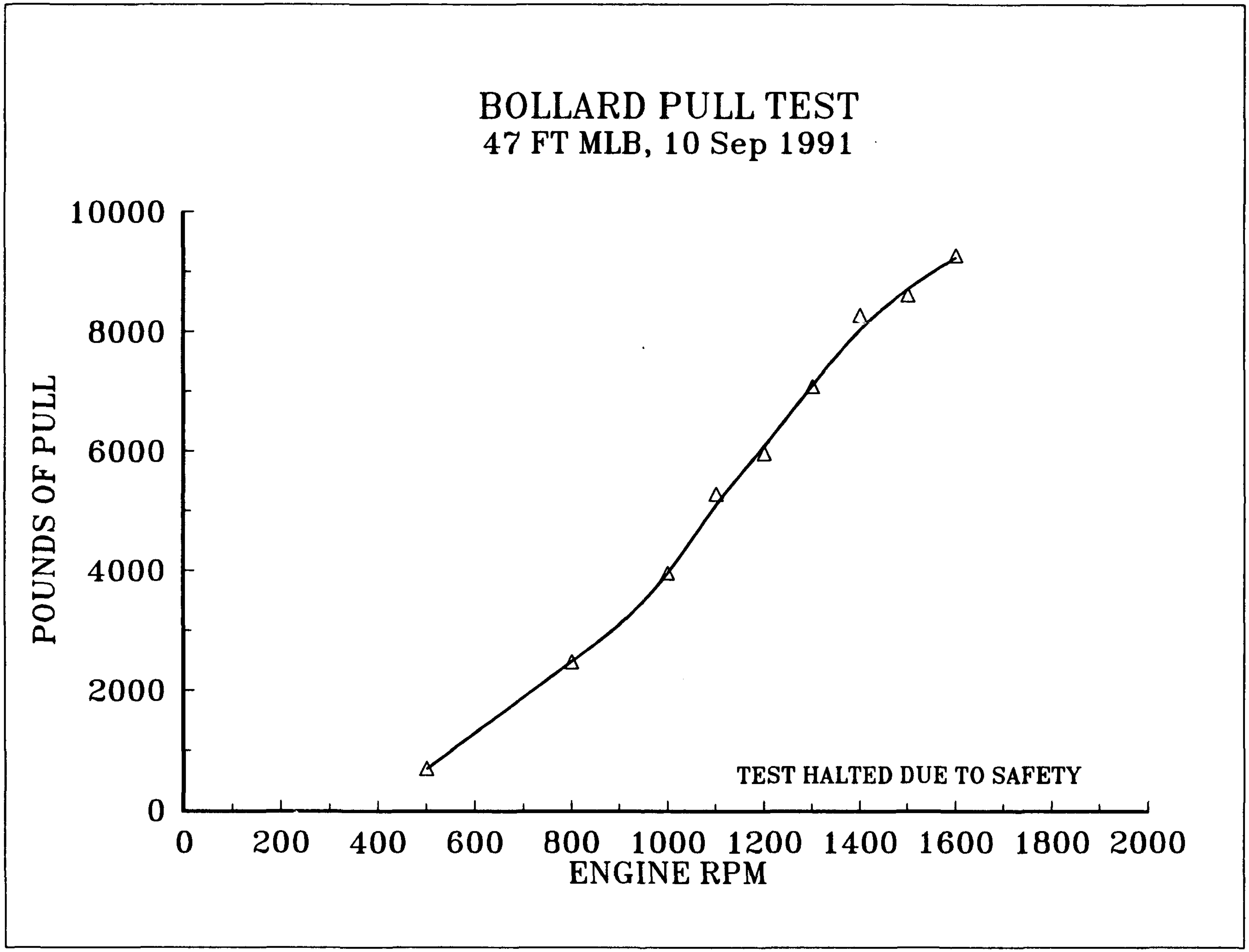


FIGURE TC-7.1. 47FT MLB BOLLARD PULL

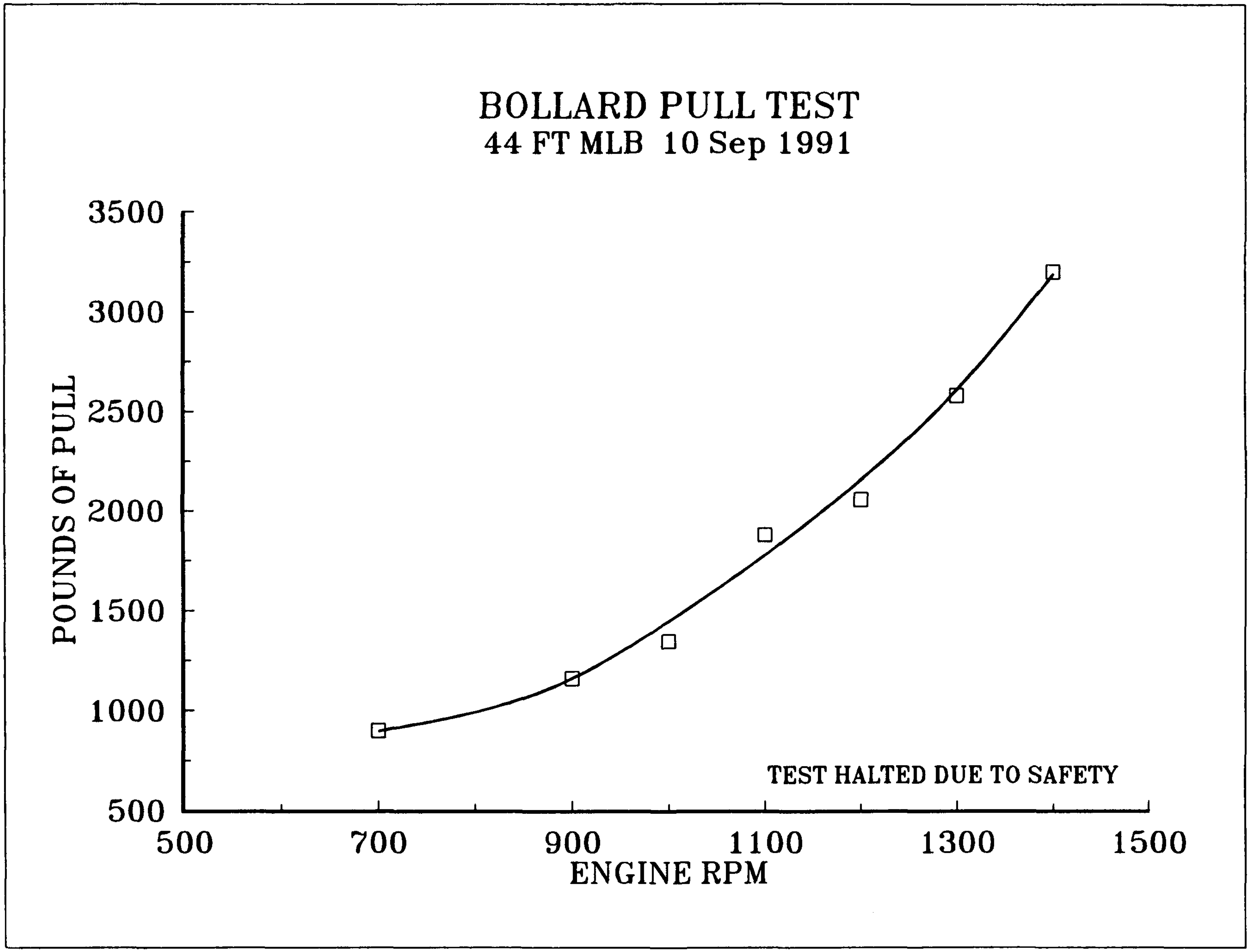


FIGURE TC-7.2. 44FT MLB BOLLARD PULL

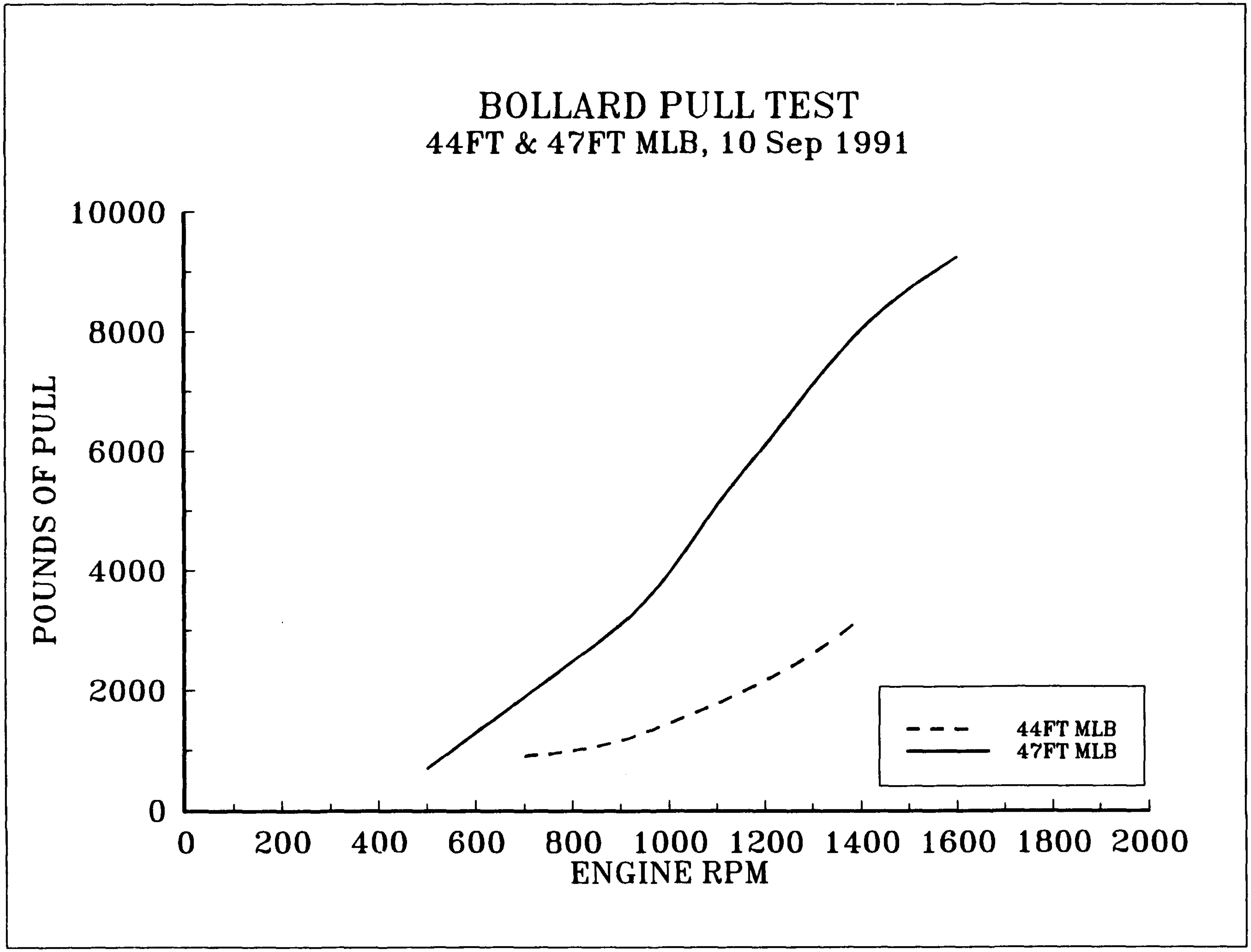


FIGURE TC-7.3. COMPARATIVE BOLLARD PULL

TEST TC-8
MINIMUM TURNING RADIUS

SPEED	BOAT TYPE 47FT MLB	44FT MLB	41FT UTB
10KTS	35yds(53sec)	18yds(28sec)	35yds(31sec)
20KTS	56yds(43sec)	(EXCEEDS MAX SPD)	43yds(31sec)
MAXIMUM	65yds(44sec) @27.2KTS	22yds(26sec) @12KTS	39yds(25sec) @23KTS

All turns at 30 degrees rudder

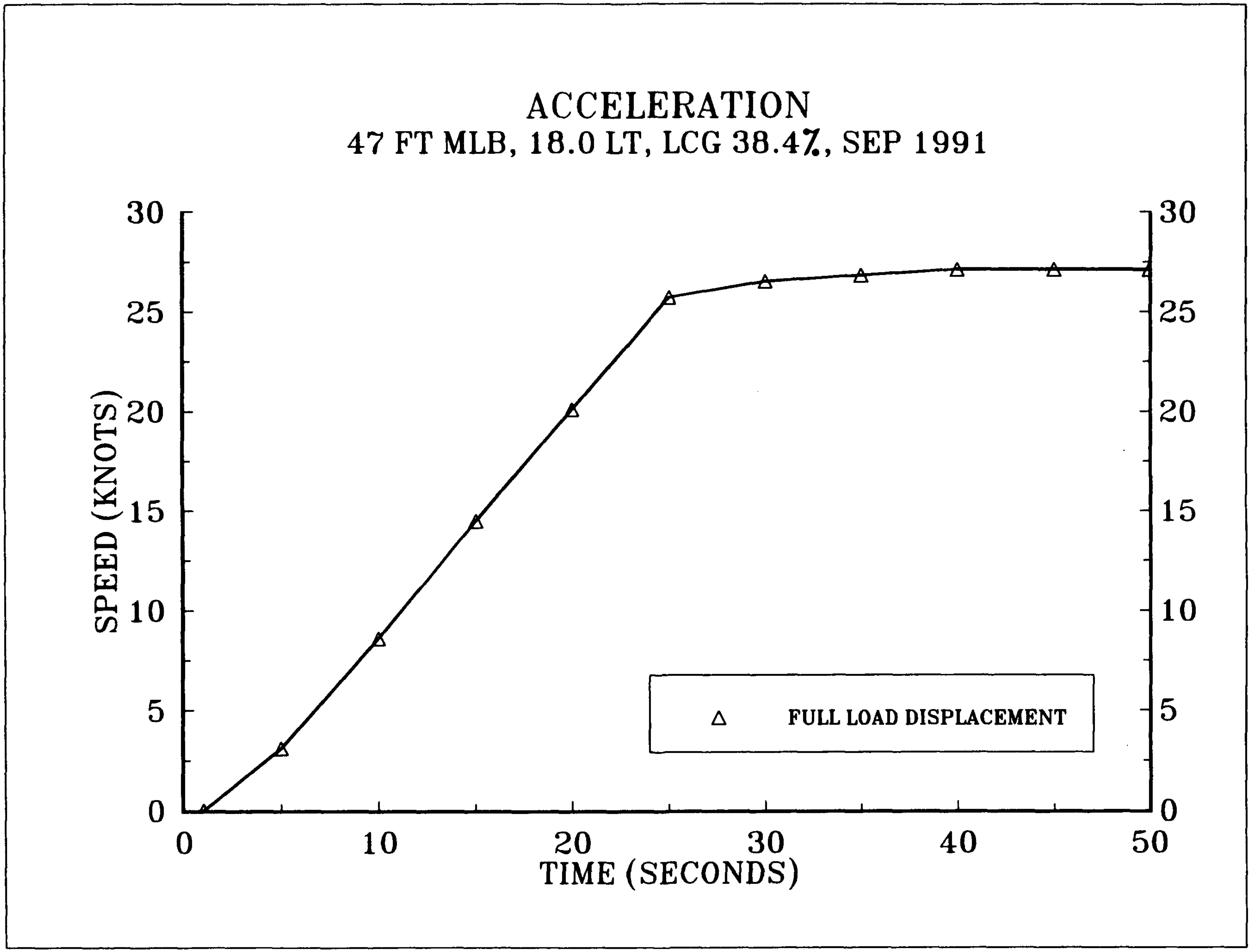


FIGURE TC-9.1. 47FT MLB ACCELERATION FULL LOAD

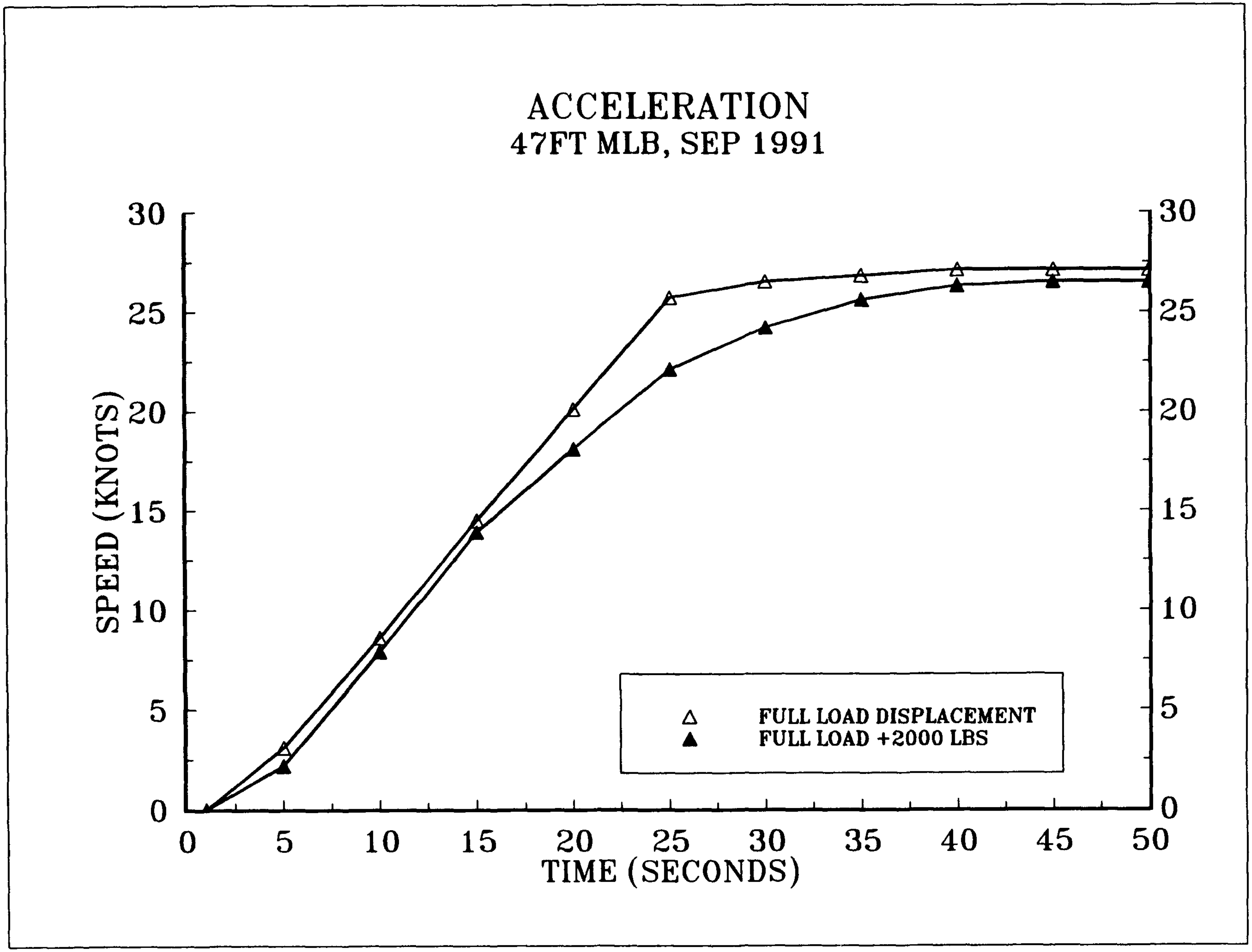


FIGURE TC-9.2. 47FT MLB ACCELERATION FULL LOAD PLUS 2000LBS

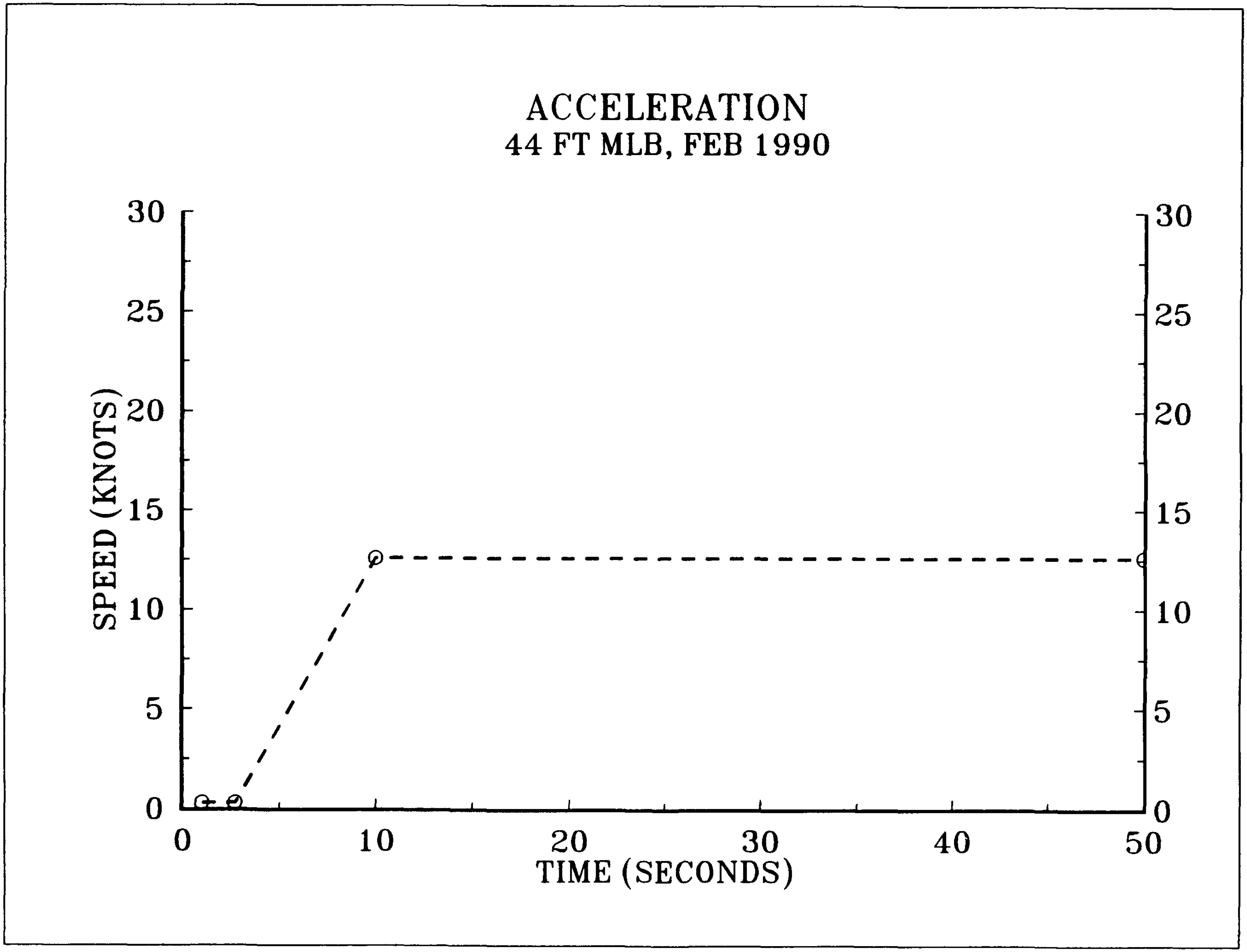


FIGURE TC-9.3. 44FT MLB ACCELERATION

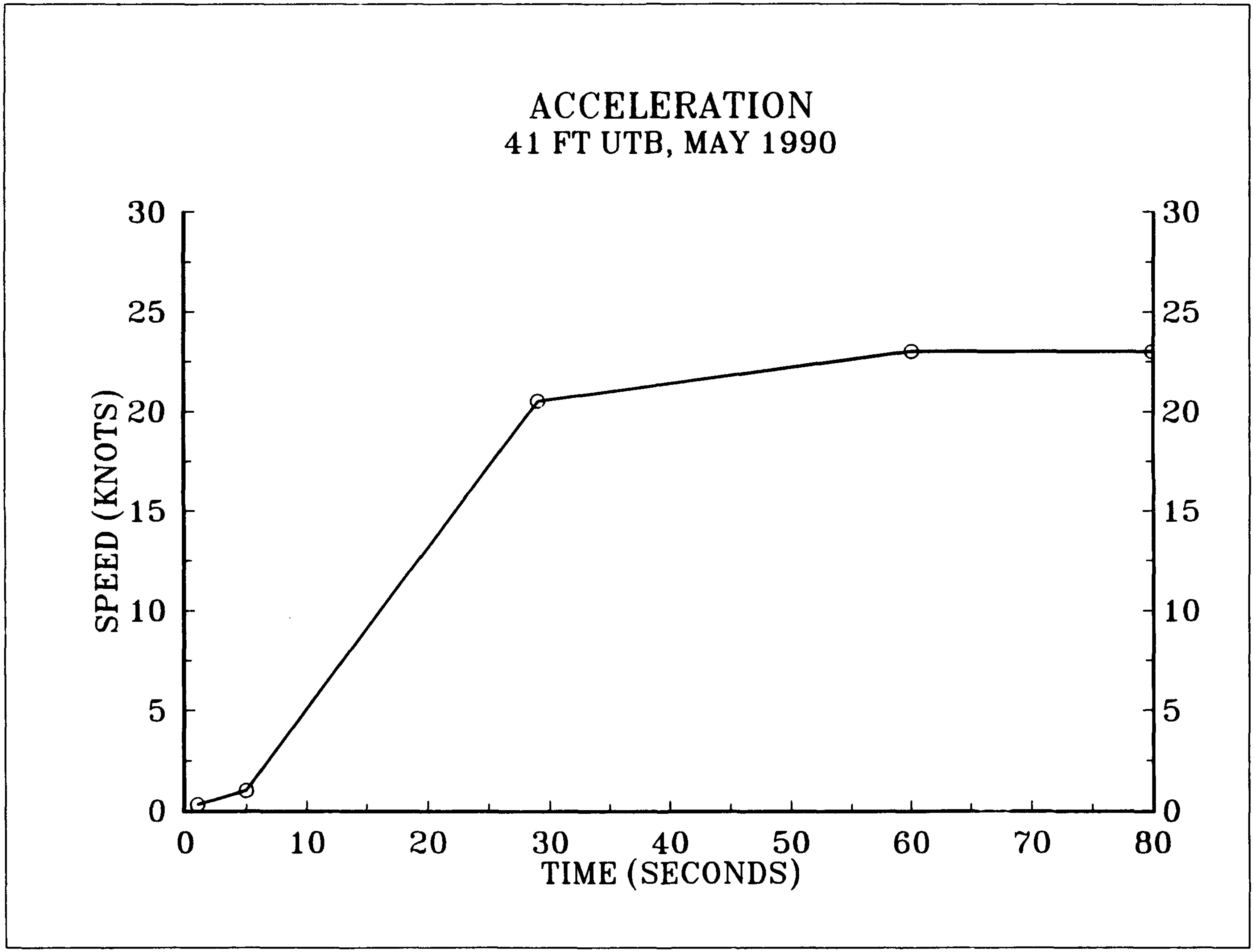


FIGURE TC-9.4. 41FT UTB ACCELERATION

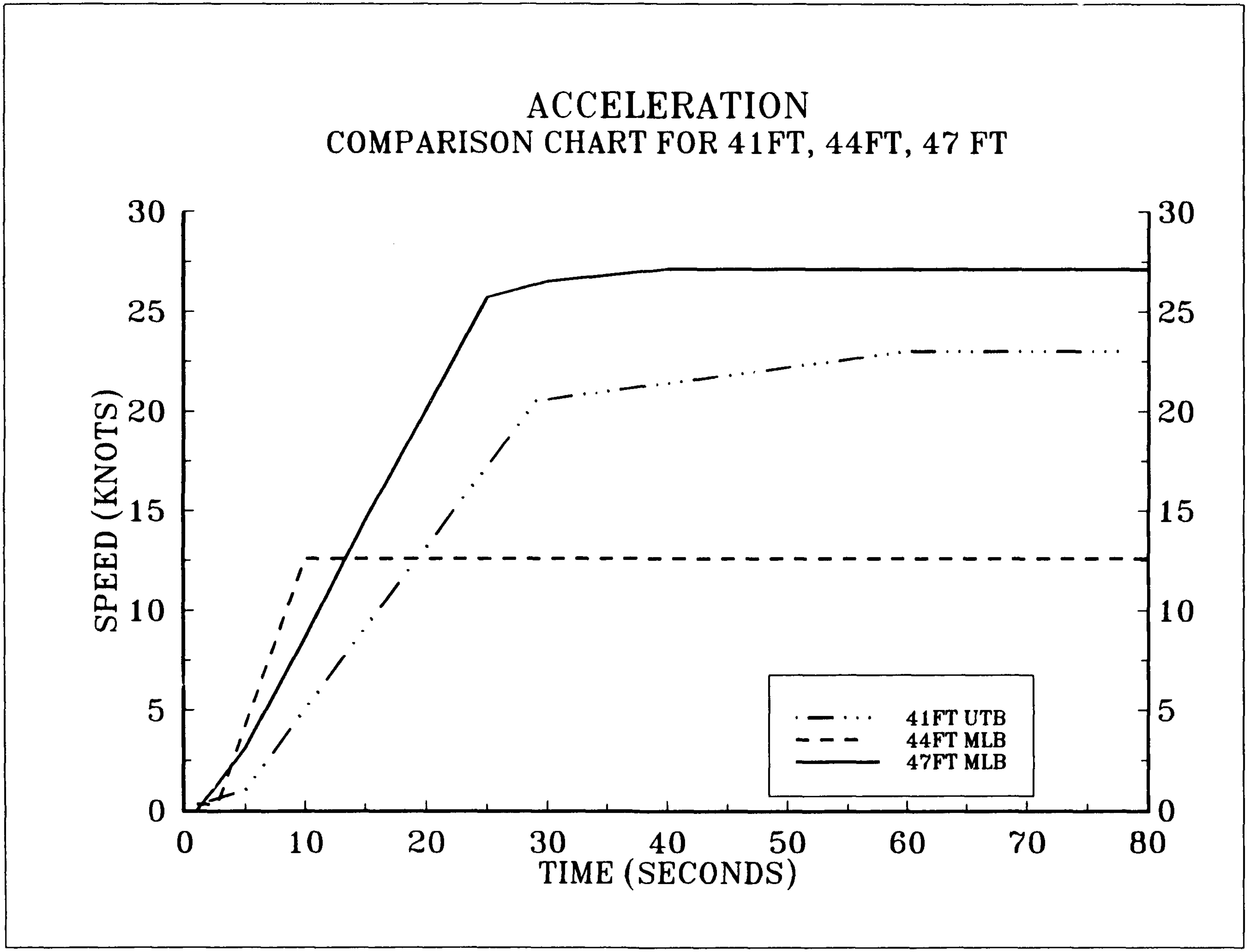


FIGURE TC-9.5. COMPARATIVE ACCELERATION

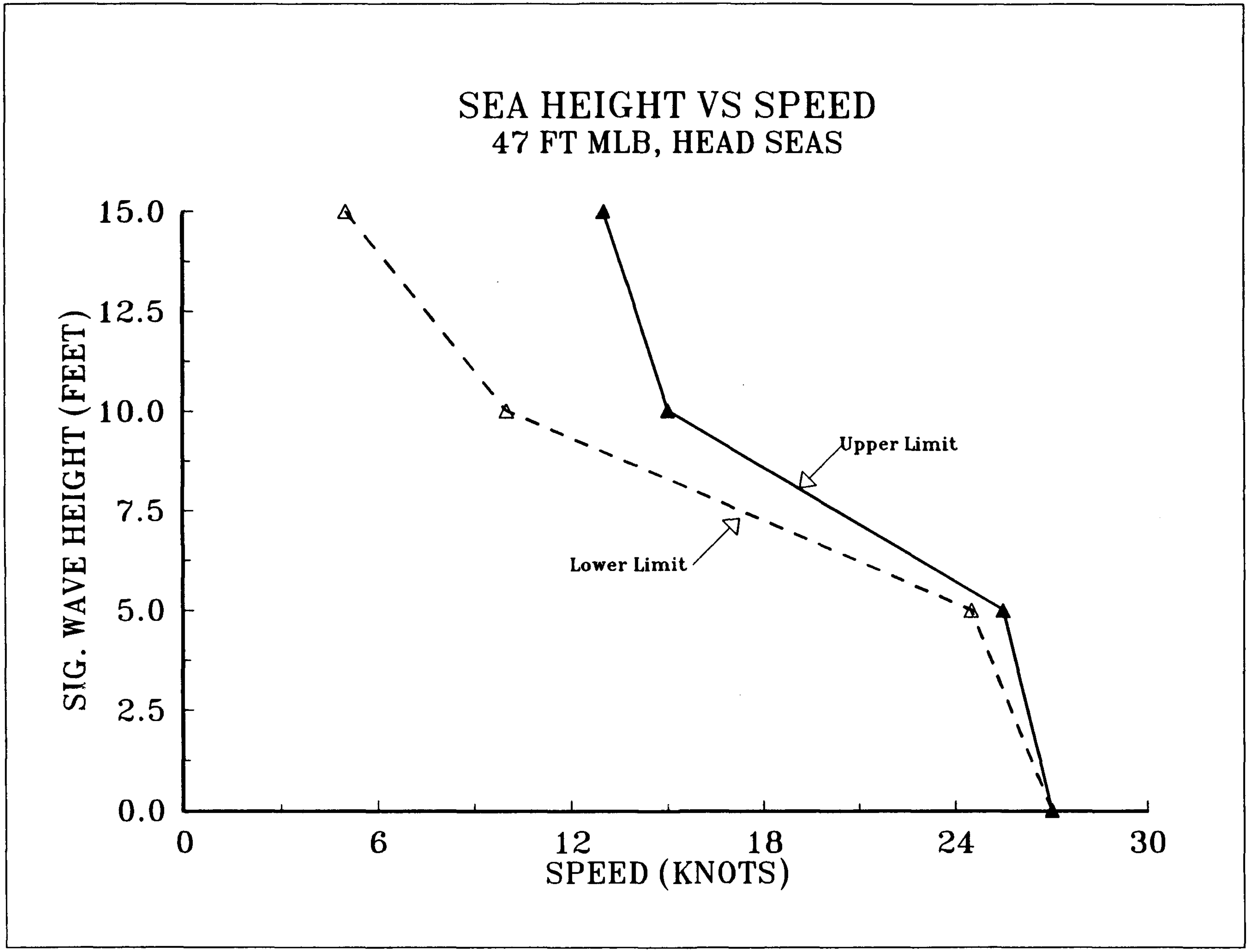


FIGURE TC-10.1. 47FT MLB SEA HEIGHT VS MAXIMUM SPEED

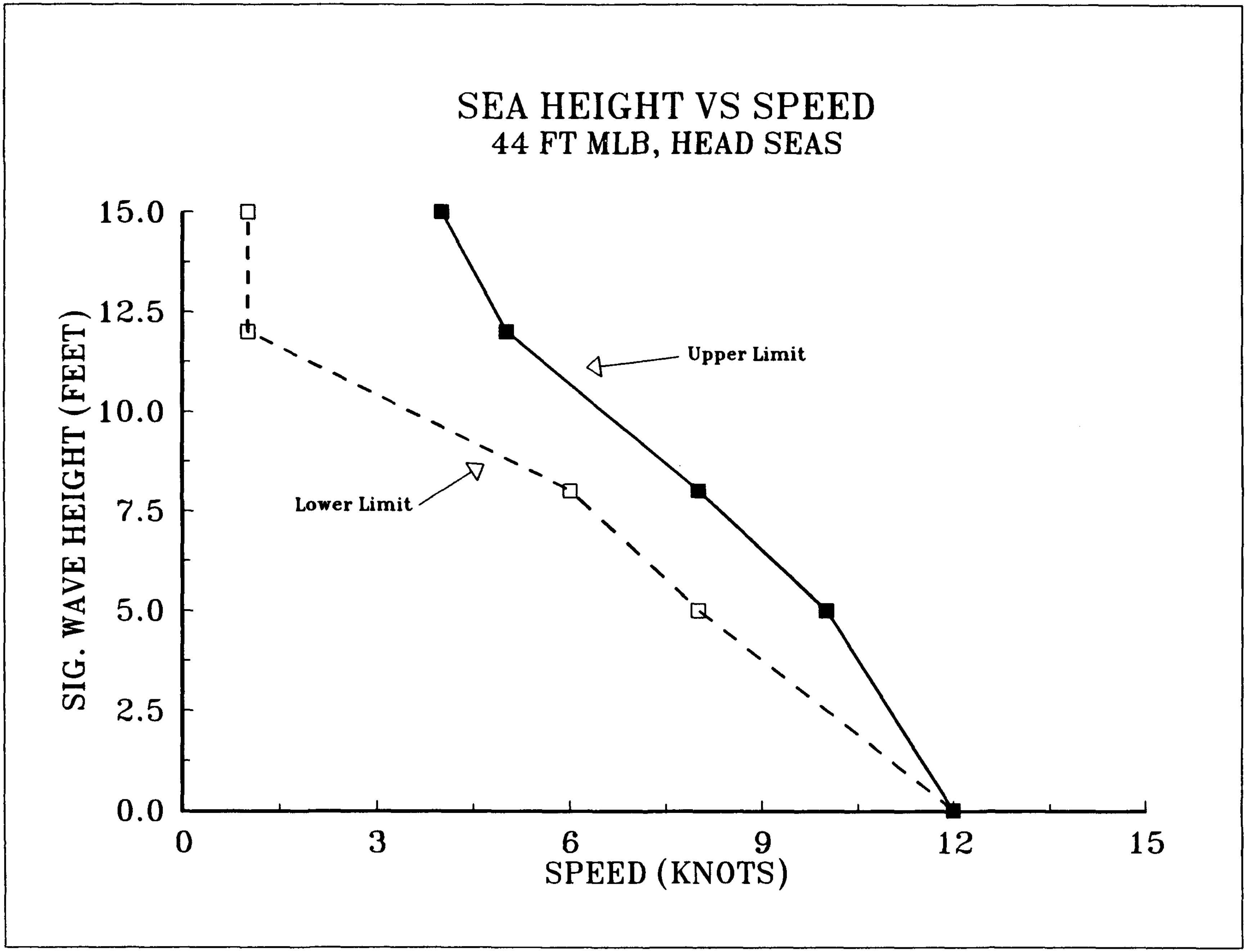


FIGURE TC-10.2. 44FT MLB SEA HEIGHT VS MAXIMUM SPEED

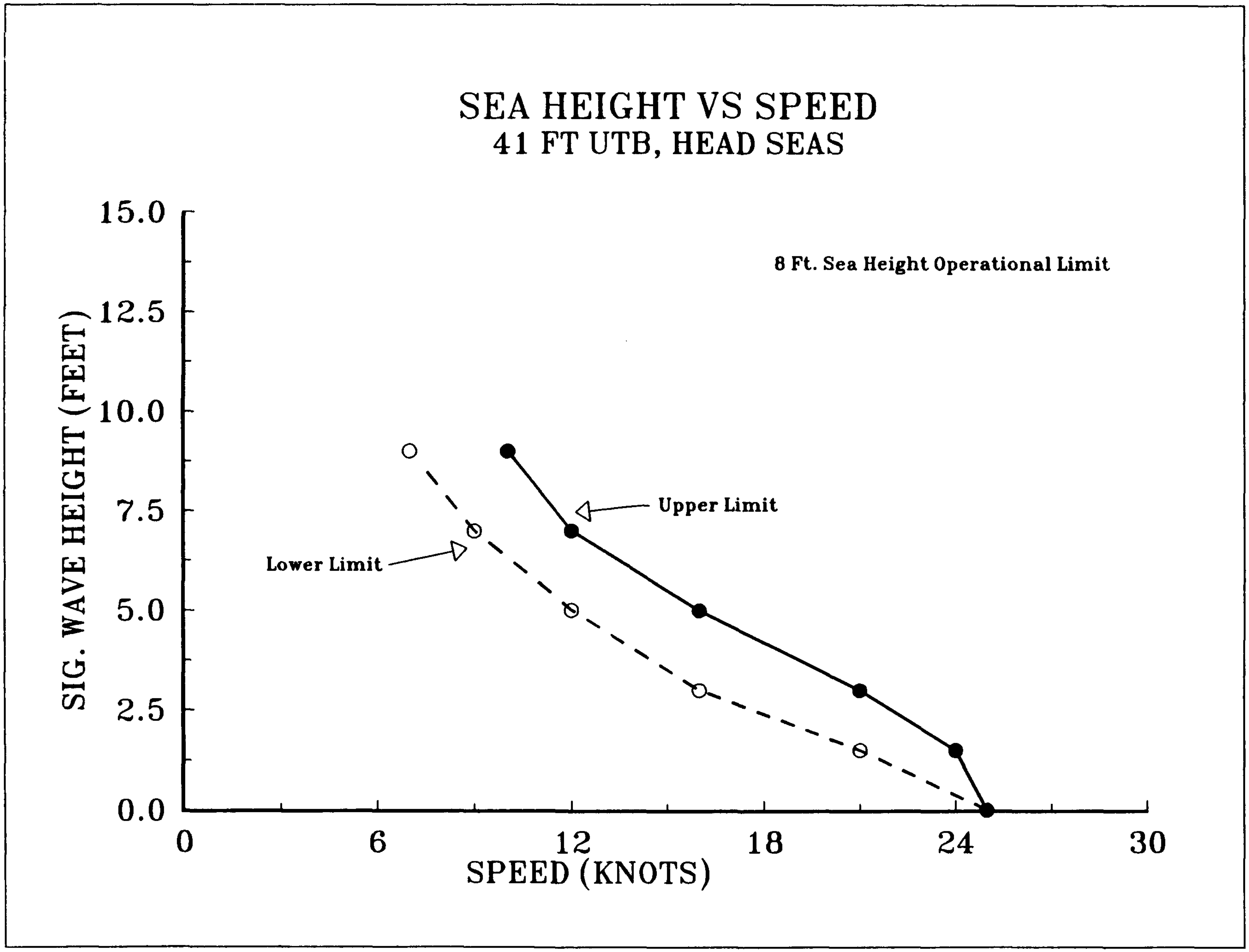


FIGURE TC-10.3. 41FT UTB SEA HEIGHT VS MAXIMUM SPEED

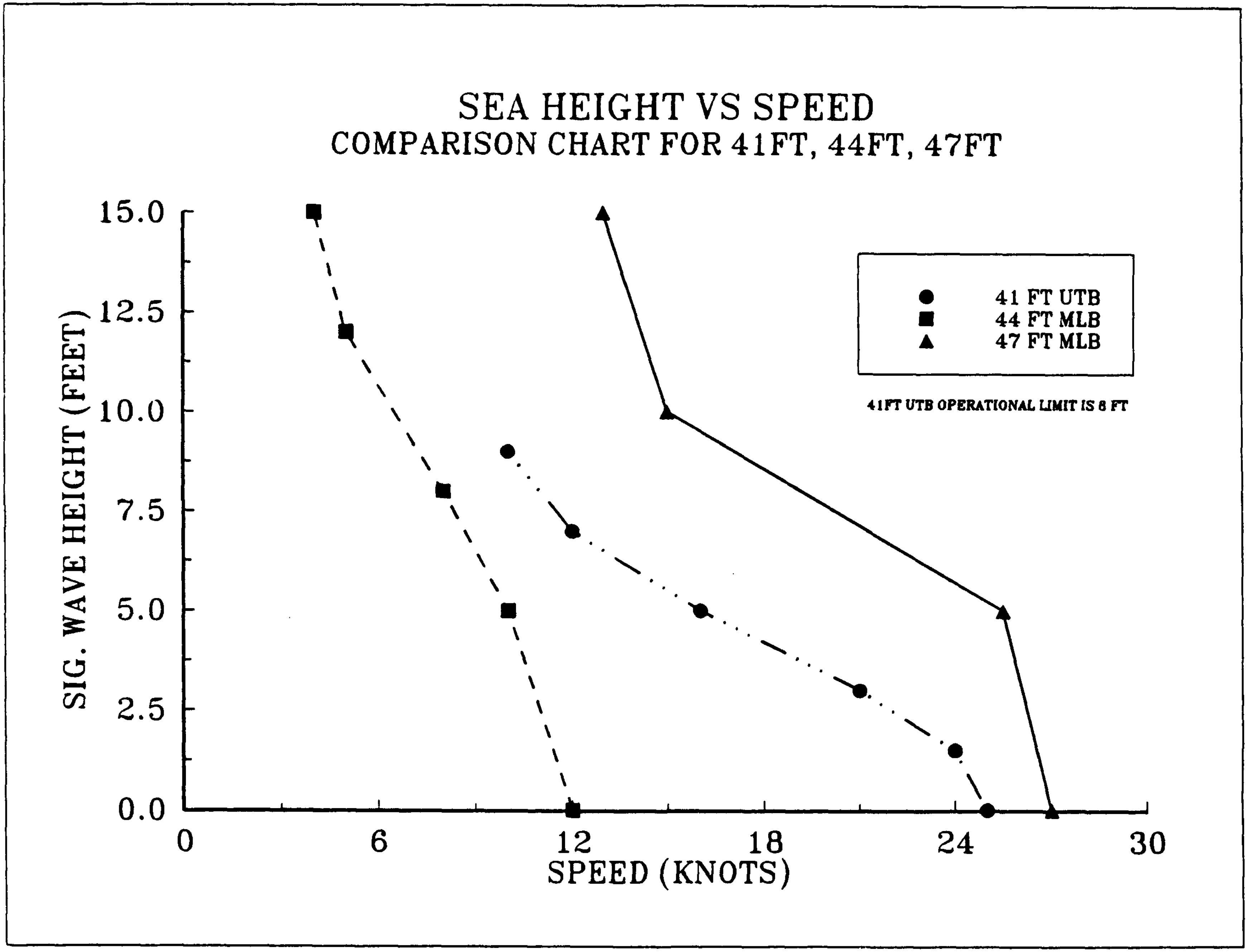


FIGURE TC-10.4. COMPARATIVE SEA HEIGHT VS MAXIMUM SPEED

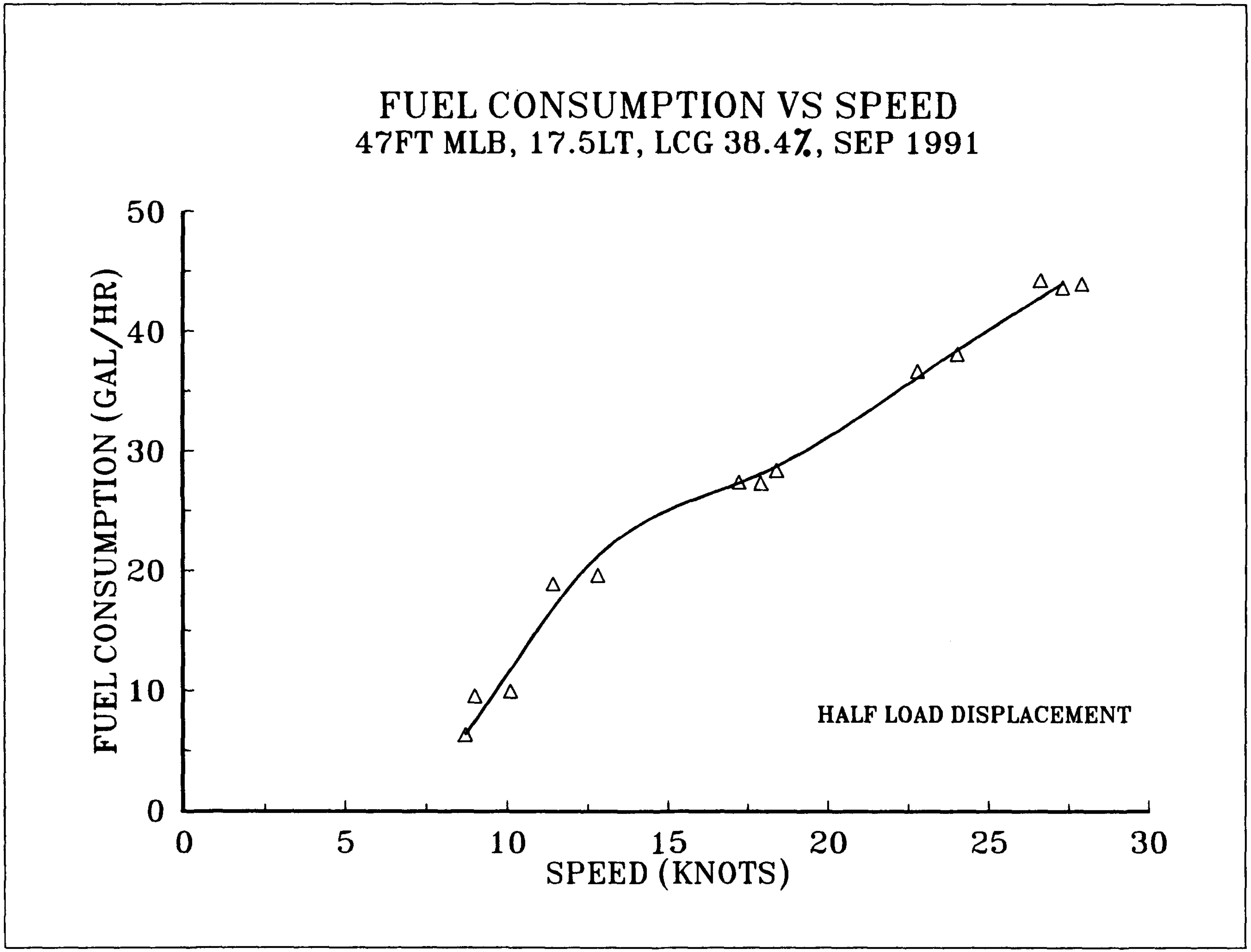


FIGURE TC-11.1. 47FT MLB FUEL CONSUMPTION VS SPEED

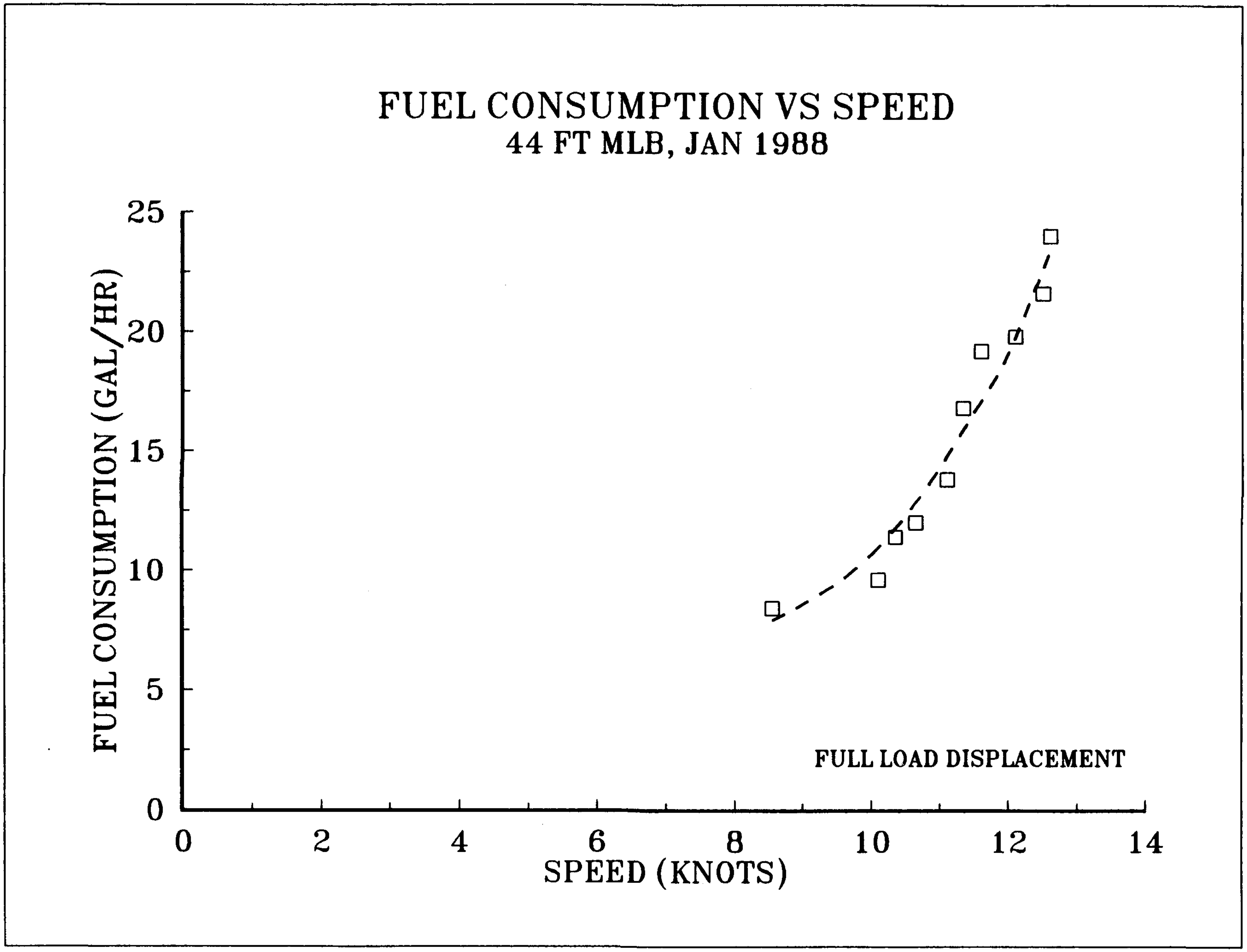


FIGURE TC-11.2. 44FT MLB FUEL CONSUMPTION VS SPEED

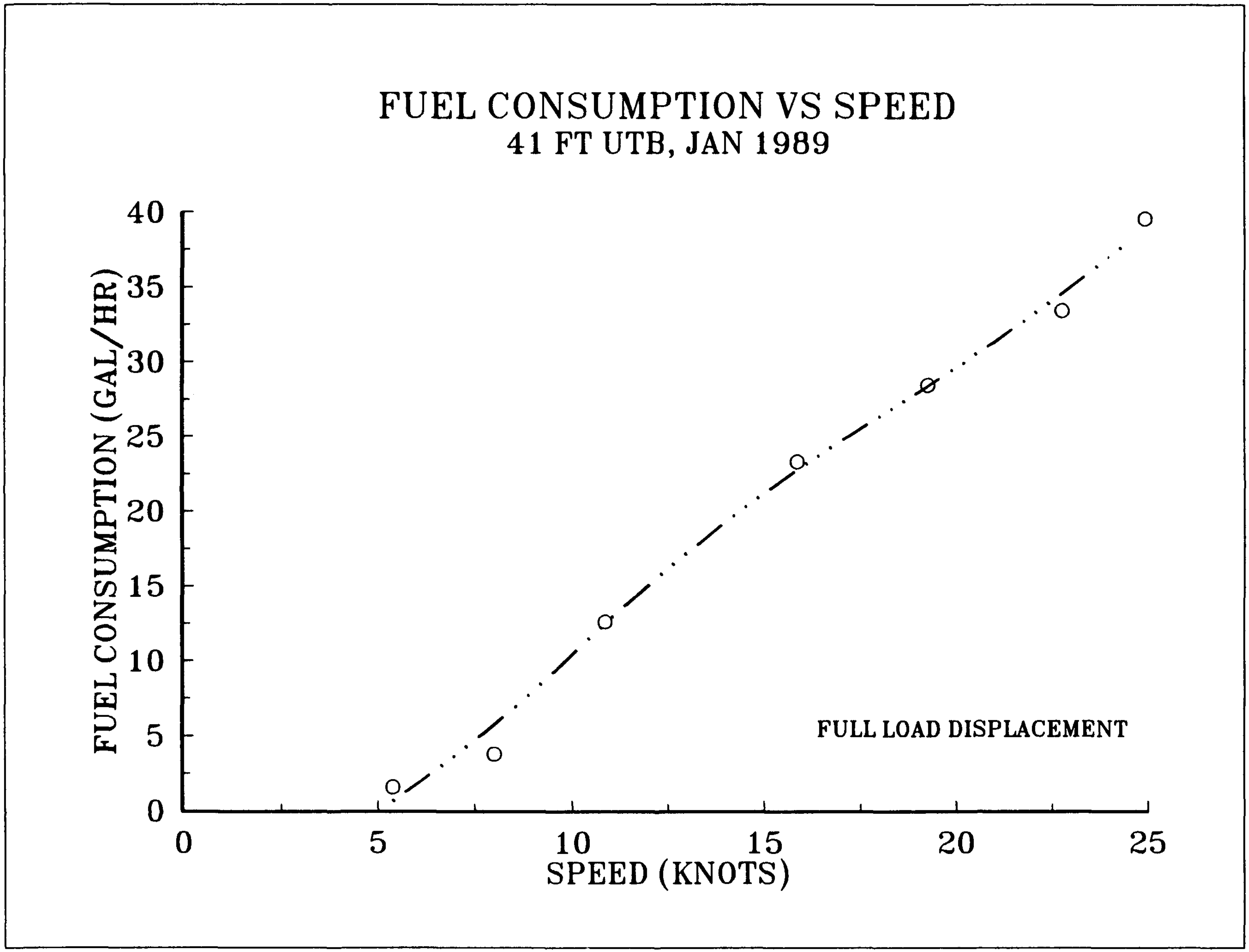


FIGURE TC-11.3. 41FT UTB FUEL CONSUMPTION VS SPEED

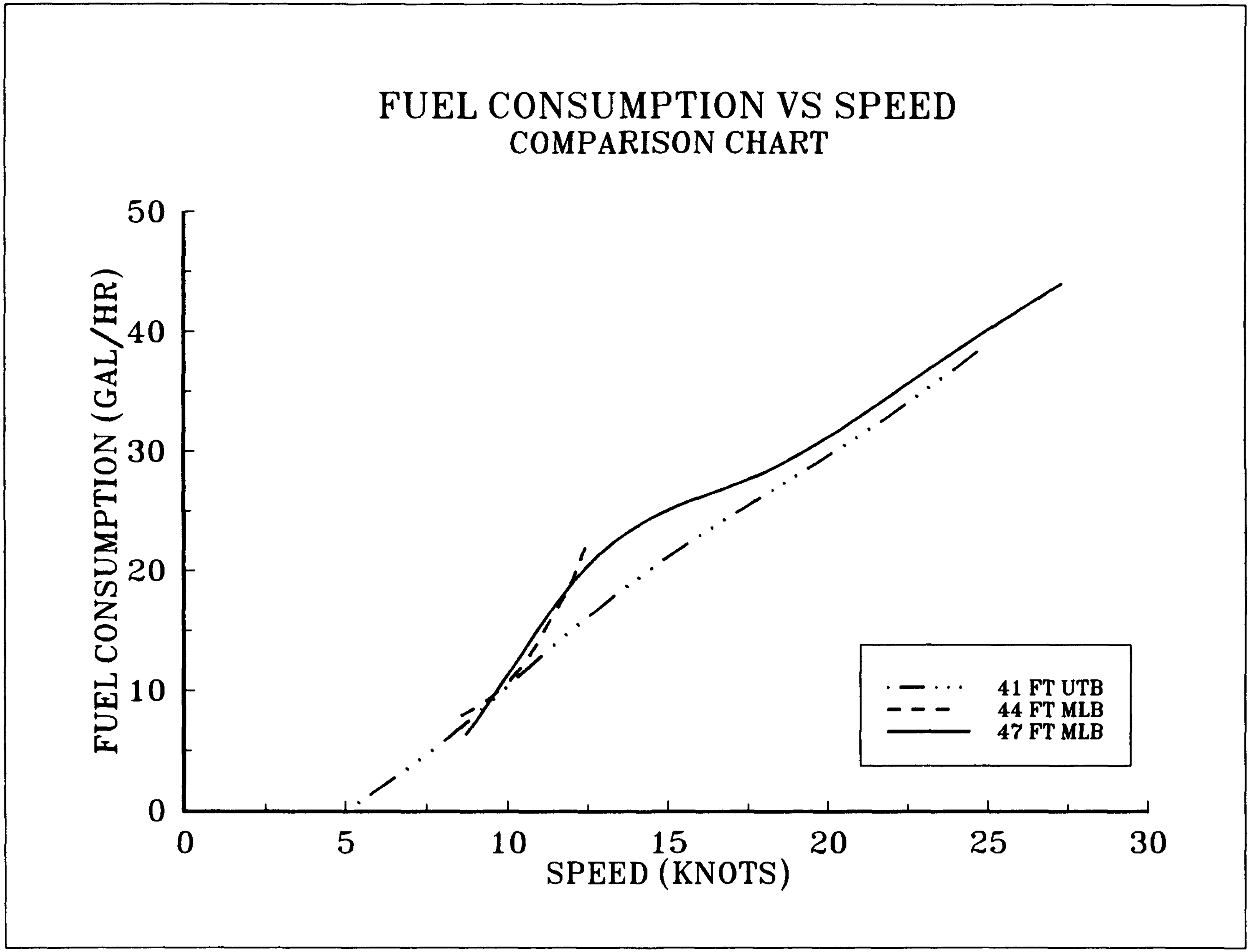


FIGURE TC-11.4. COMPARATIVE FUEL CONSUMPTION VS SPEED

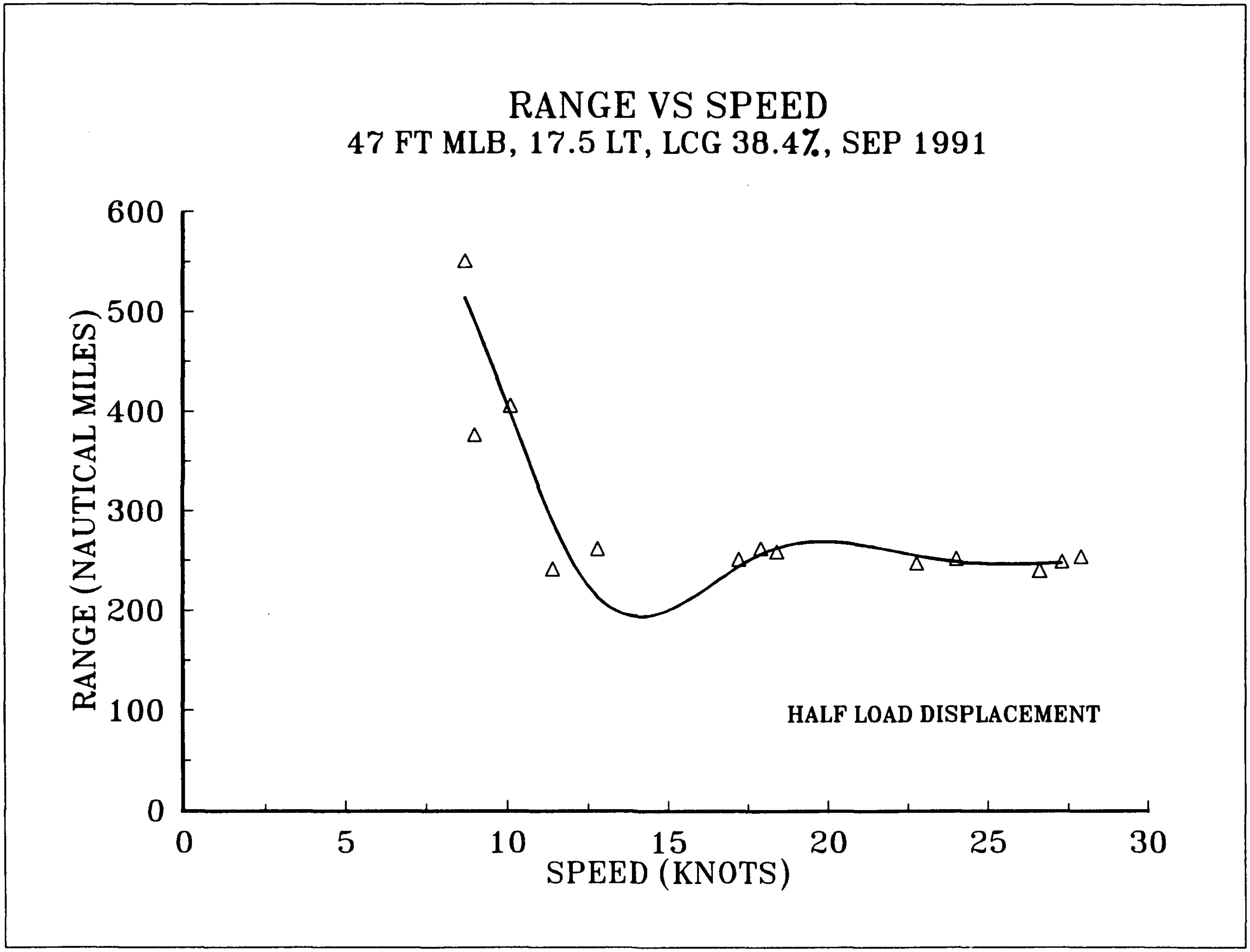


FIGURE TC-12.1. 47FT MLB RANGE VS SPEED

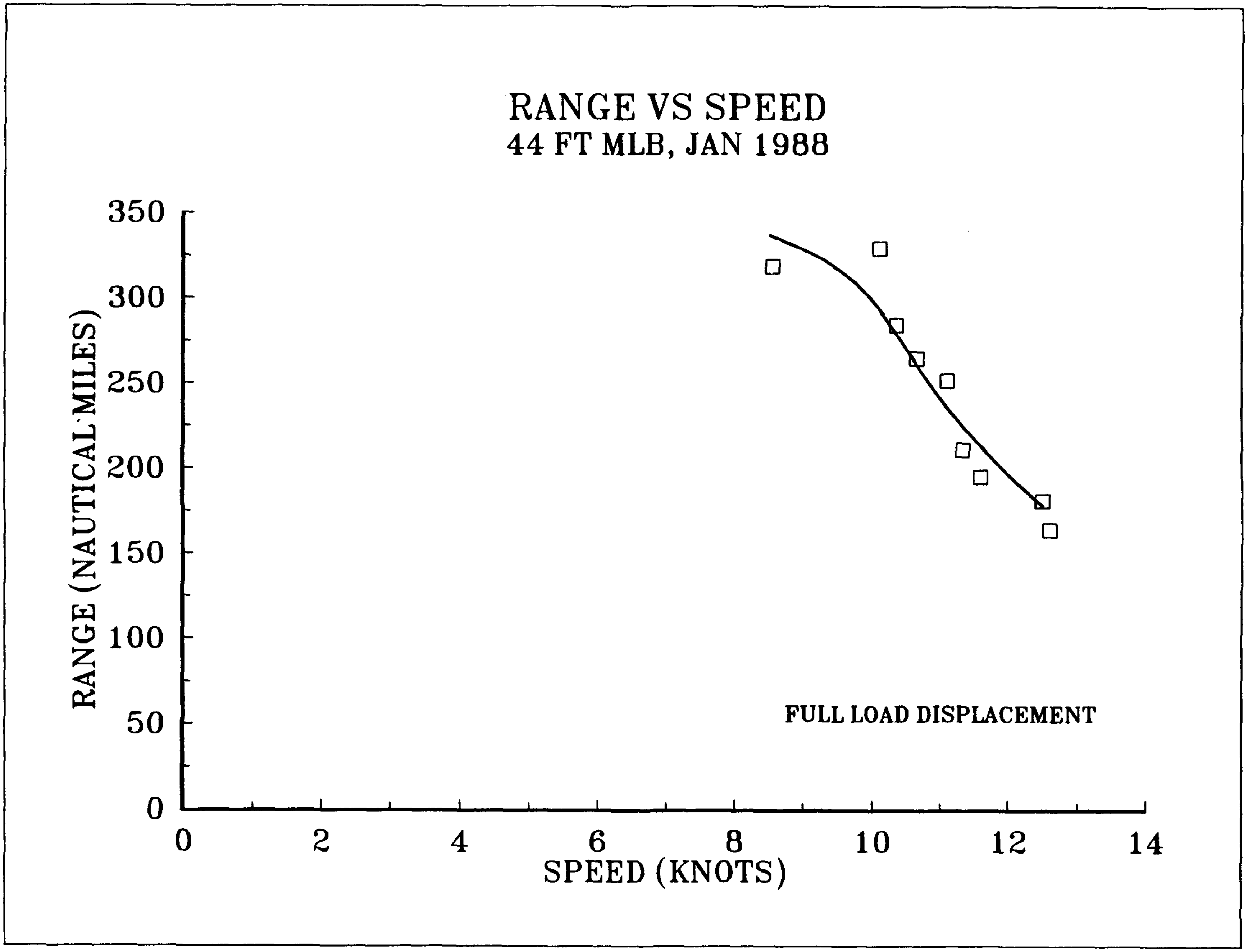


FIGURE TC-12.2. 44FT MLB RANGE VS SPEED

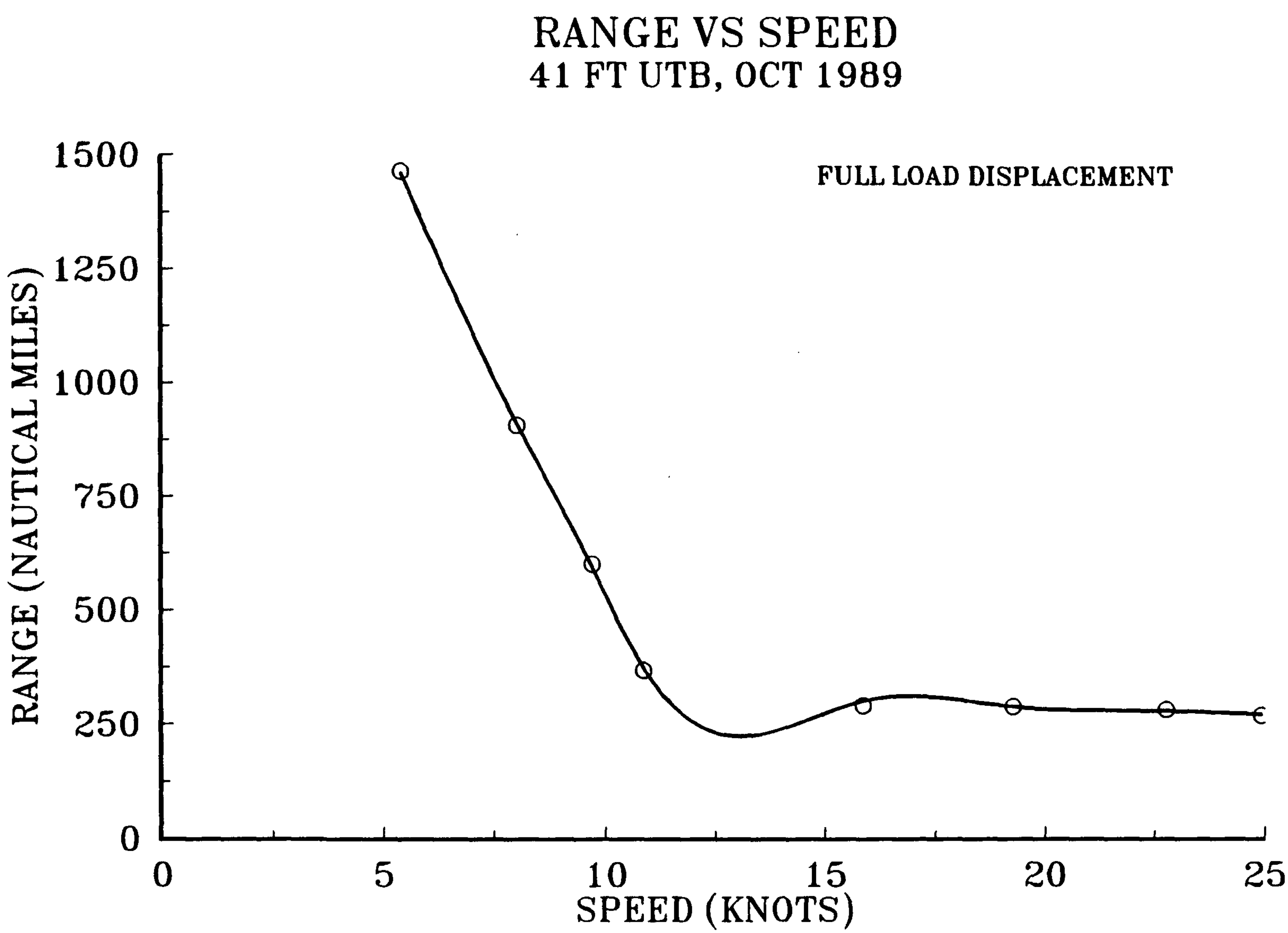


FIGURE TC-12.3. 41FT UTB RANGE VS SPEED

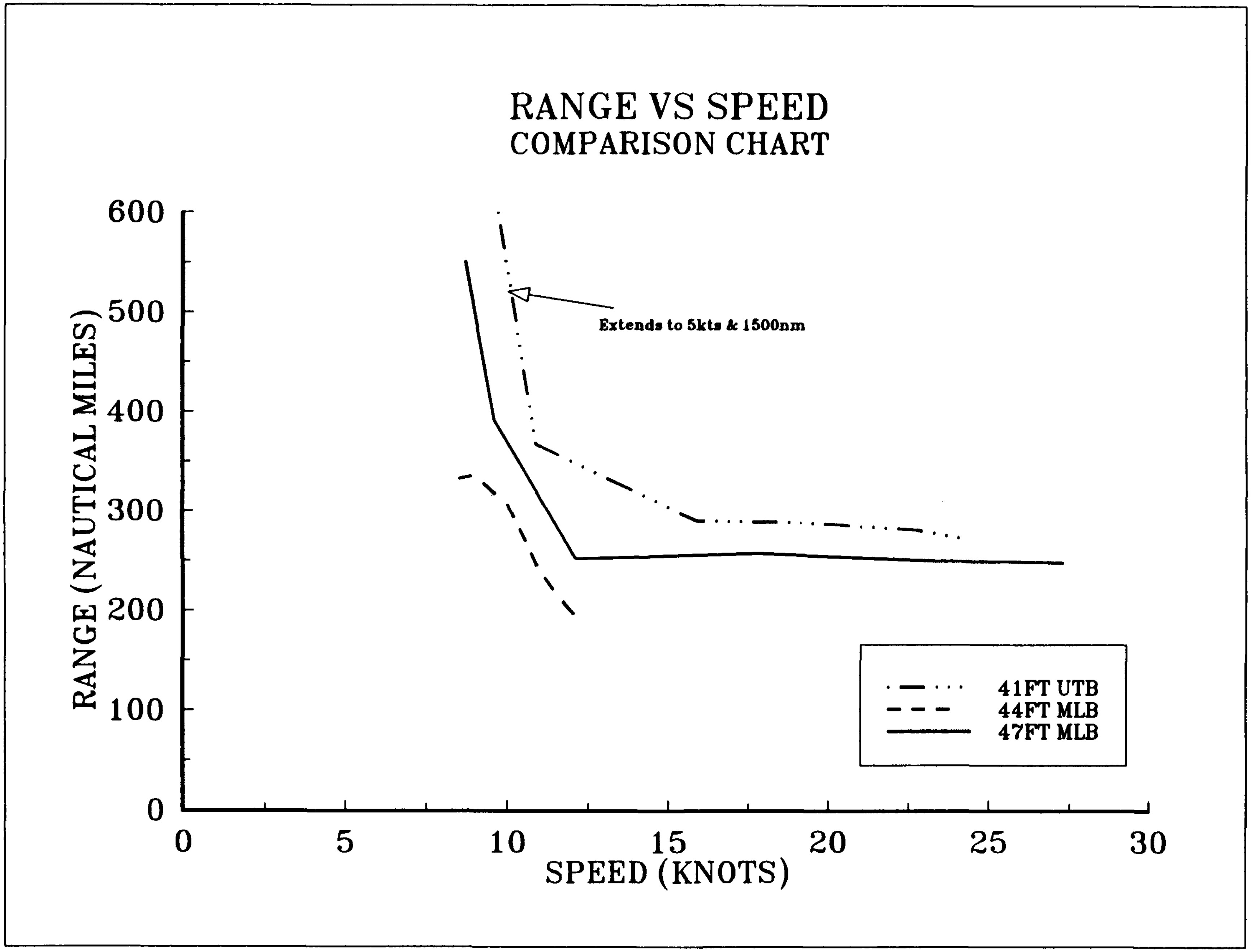


FIGURE TC-12.4. COMPARATIVE RANGE VS SPEED

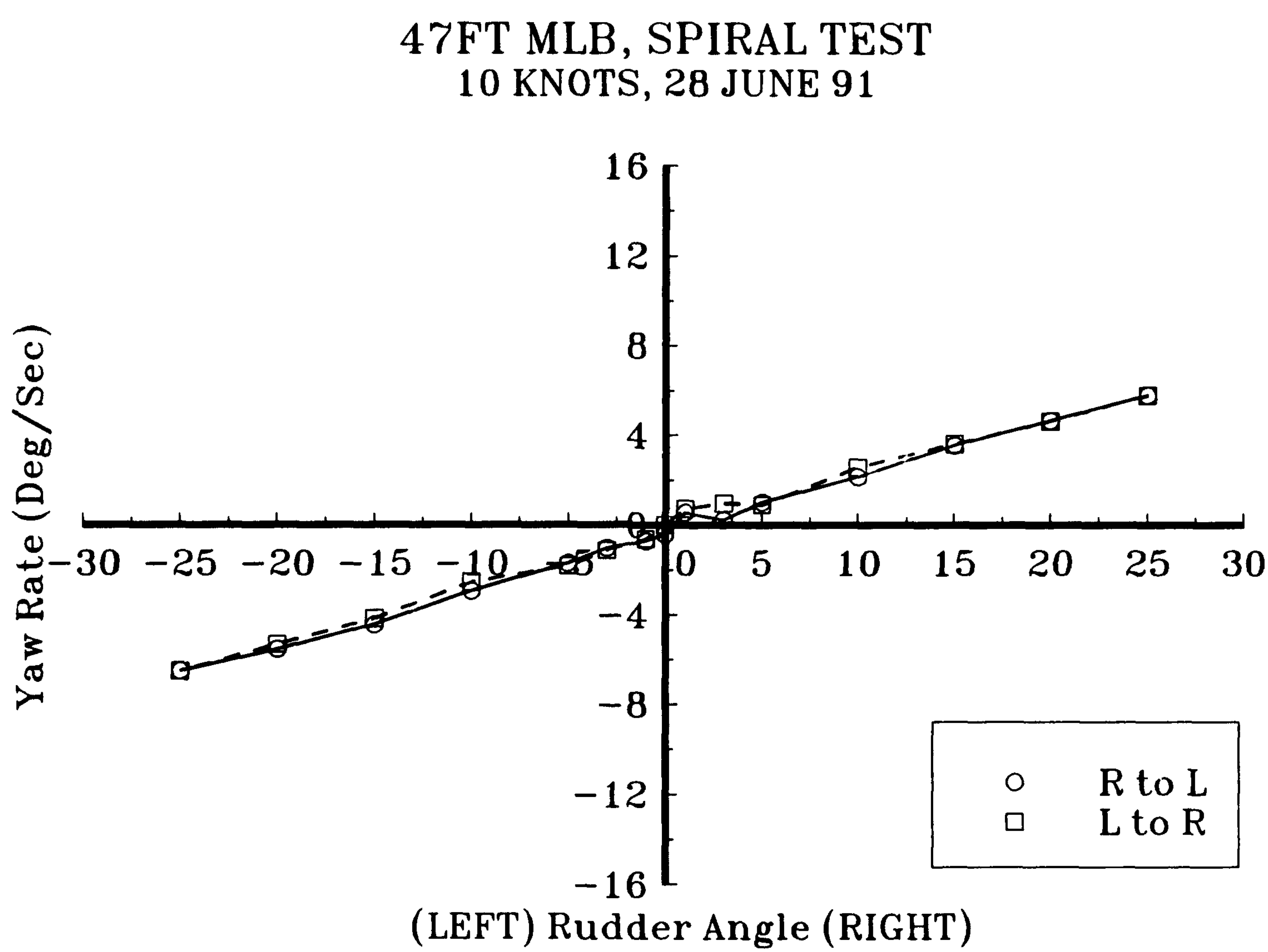


FIGURE TC-13.1. 47FT MLB SPIRAL TEST, 10 KTS

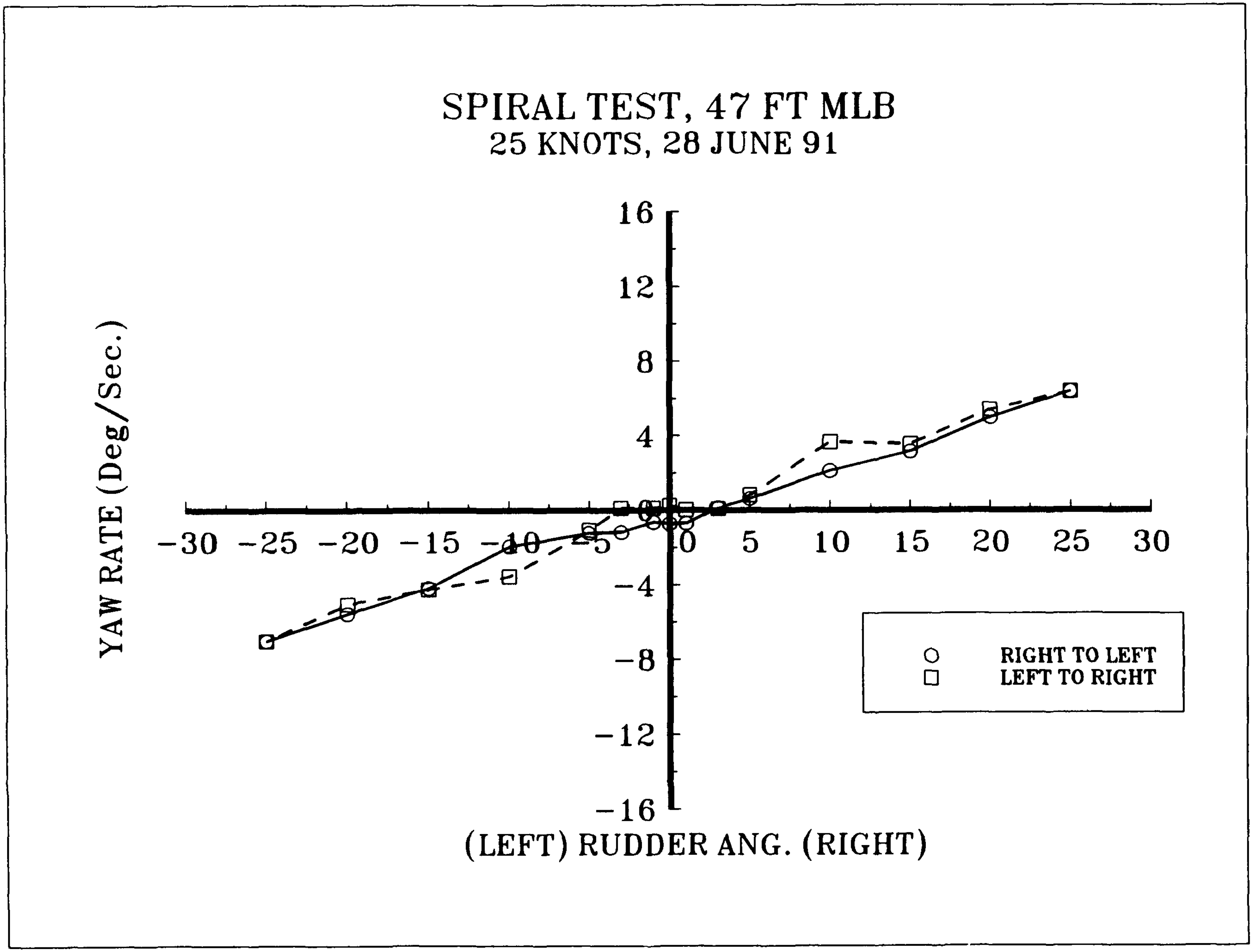


FIGURE TC-13.2. 47FT MLB SPIRAL TEST, 25 KTS

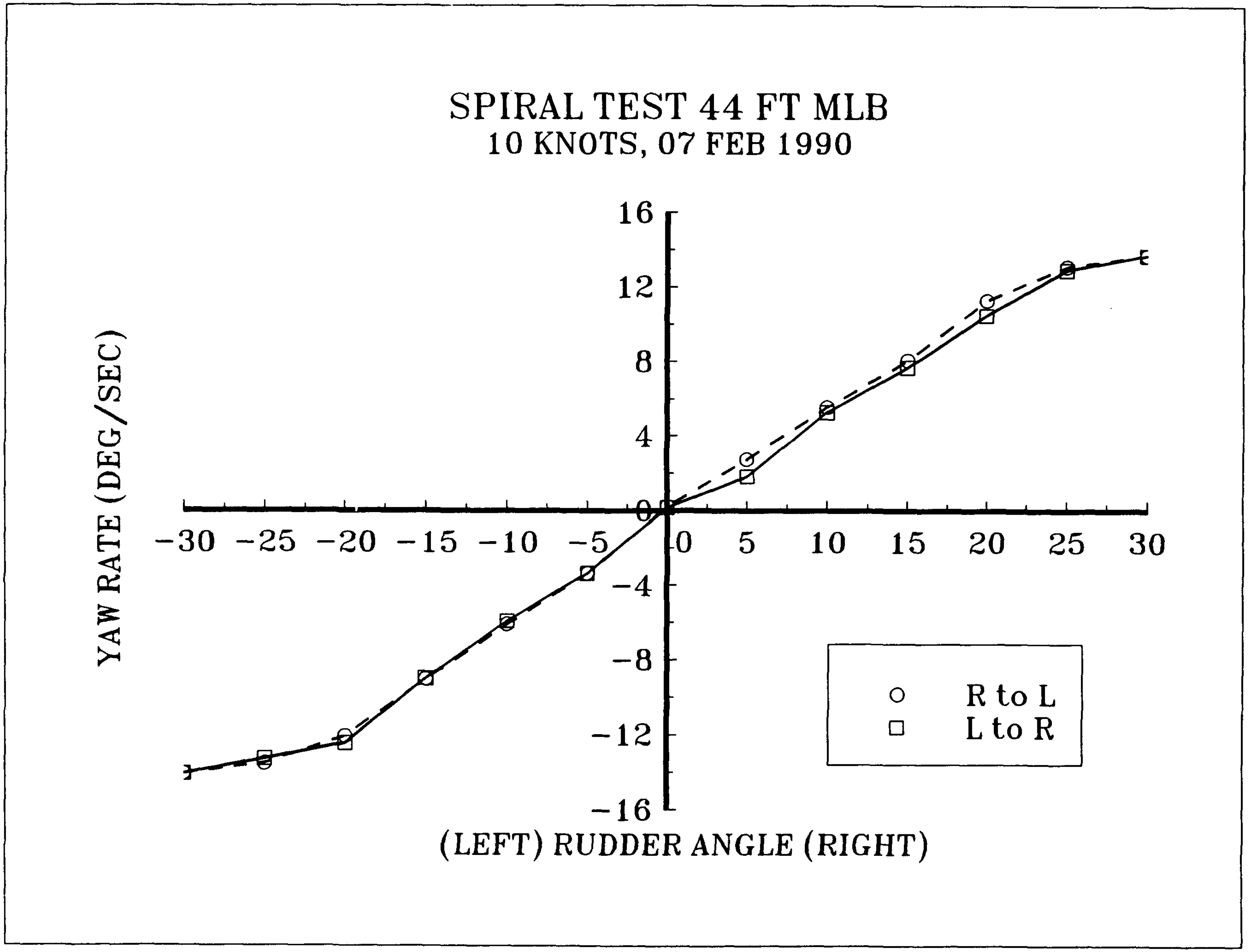


FIGURE TC-13.3. 44FT MLB SPIRAL TEST, 10KTS

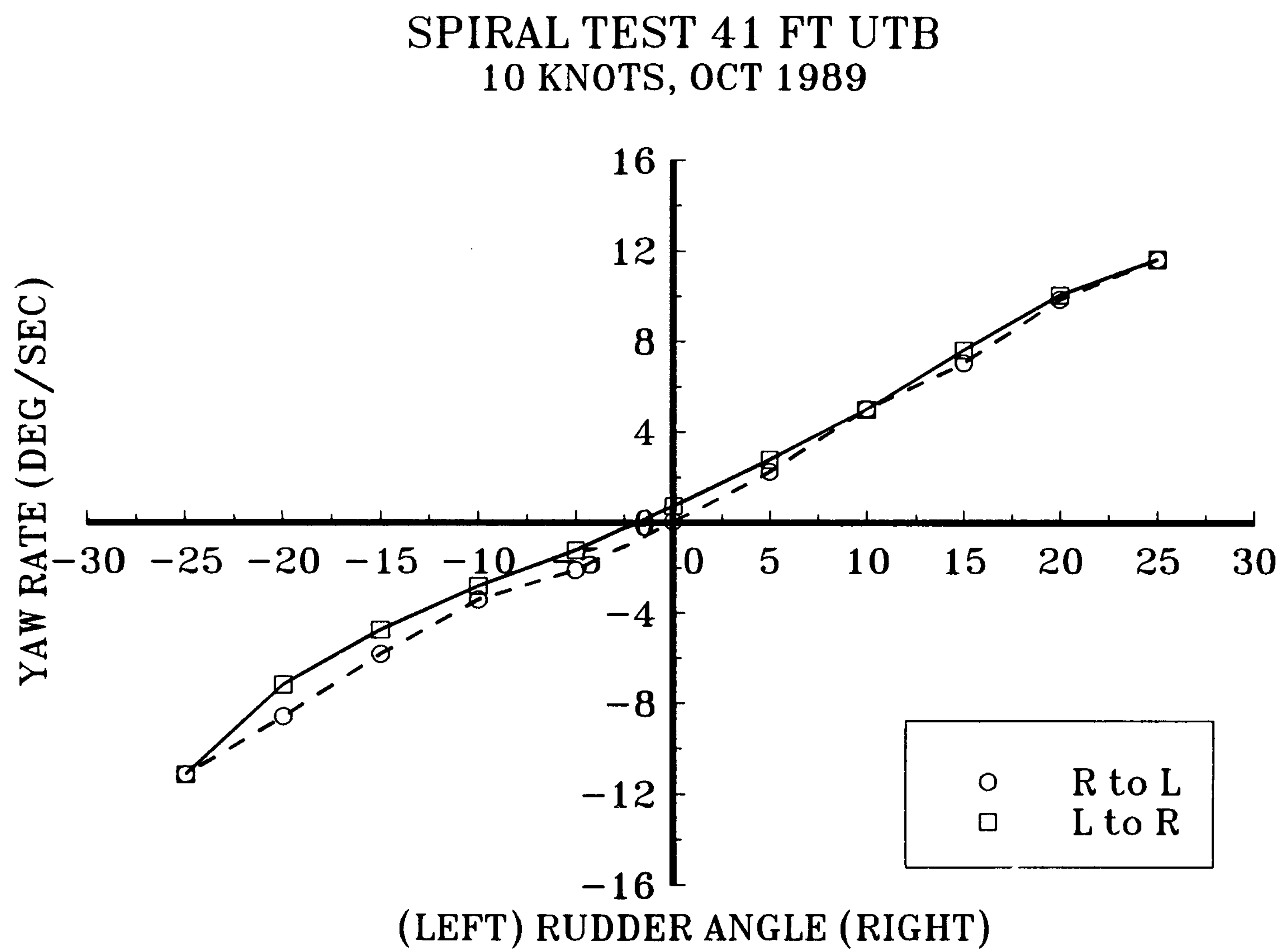


FIGURE TC-13.4. 41FT UTB SPIRAL TEST, 10 KTS

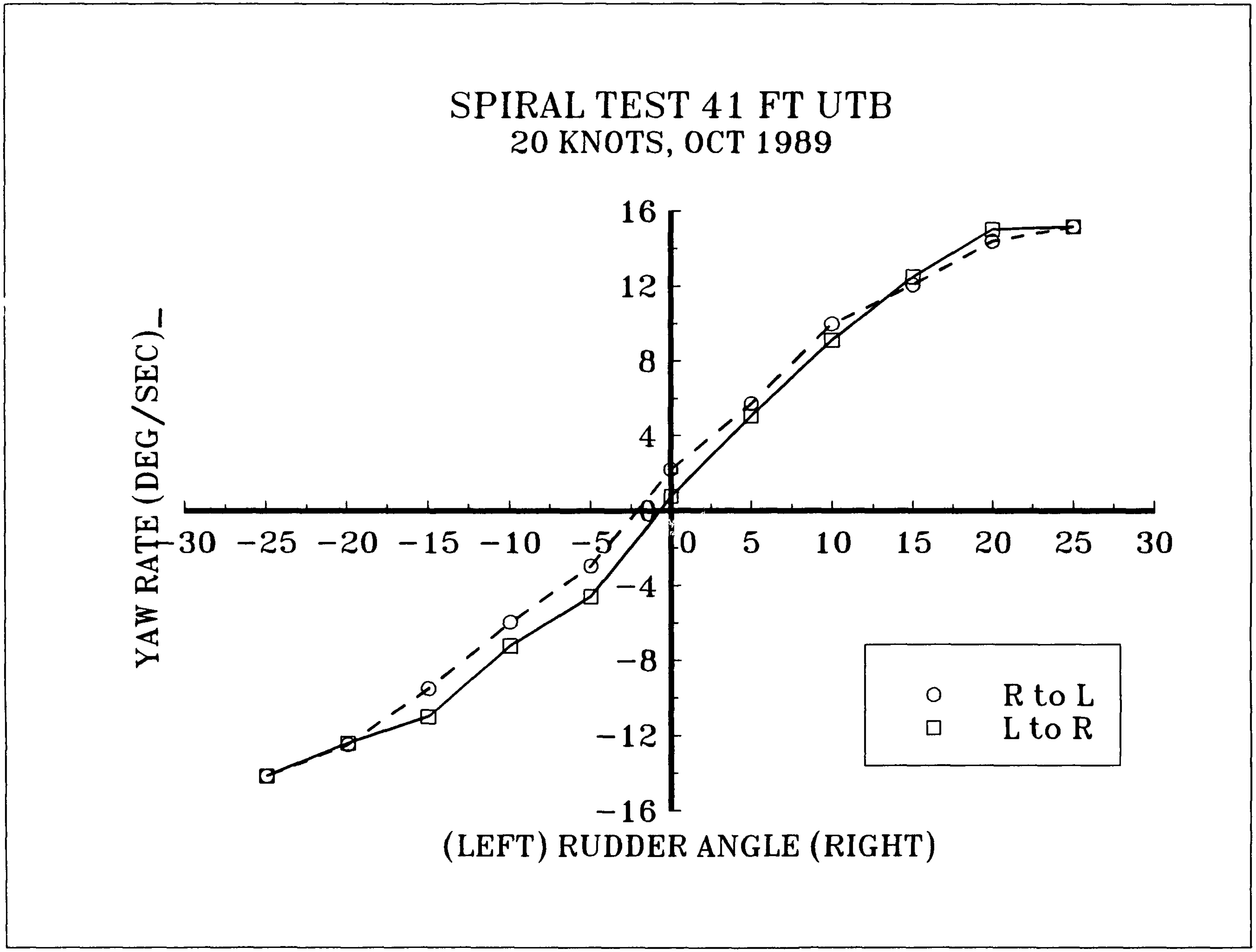


FIGURE TC-13.5. 41-FT UTB SPIRAL TEST, 20 KTS

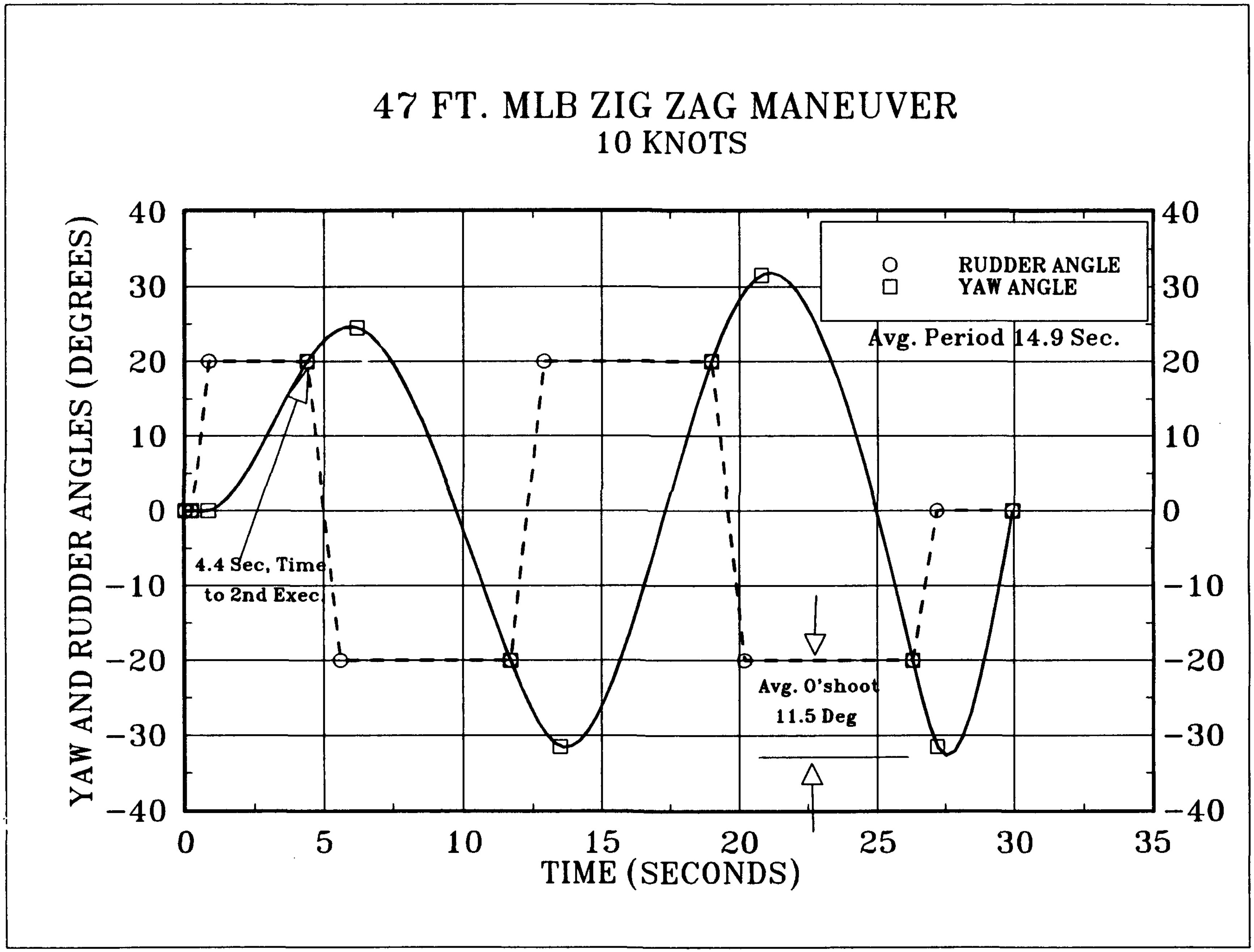


FIGURE TC-14.1. 47FT MLB ZIG-ZAG TEST, 10 KTS

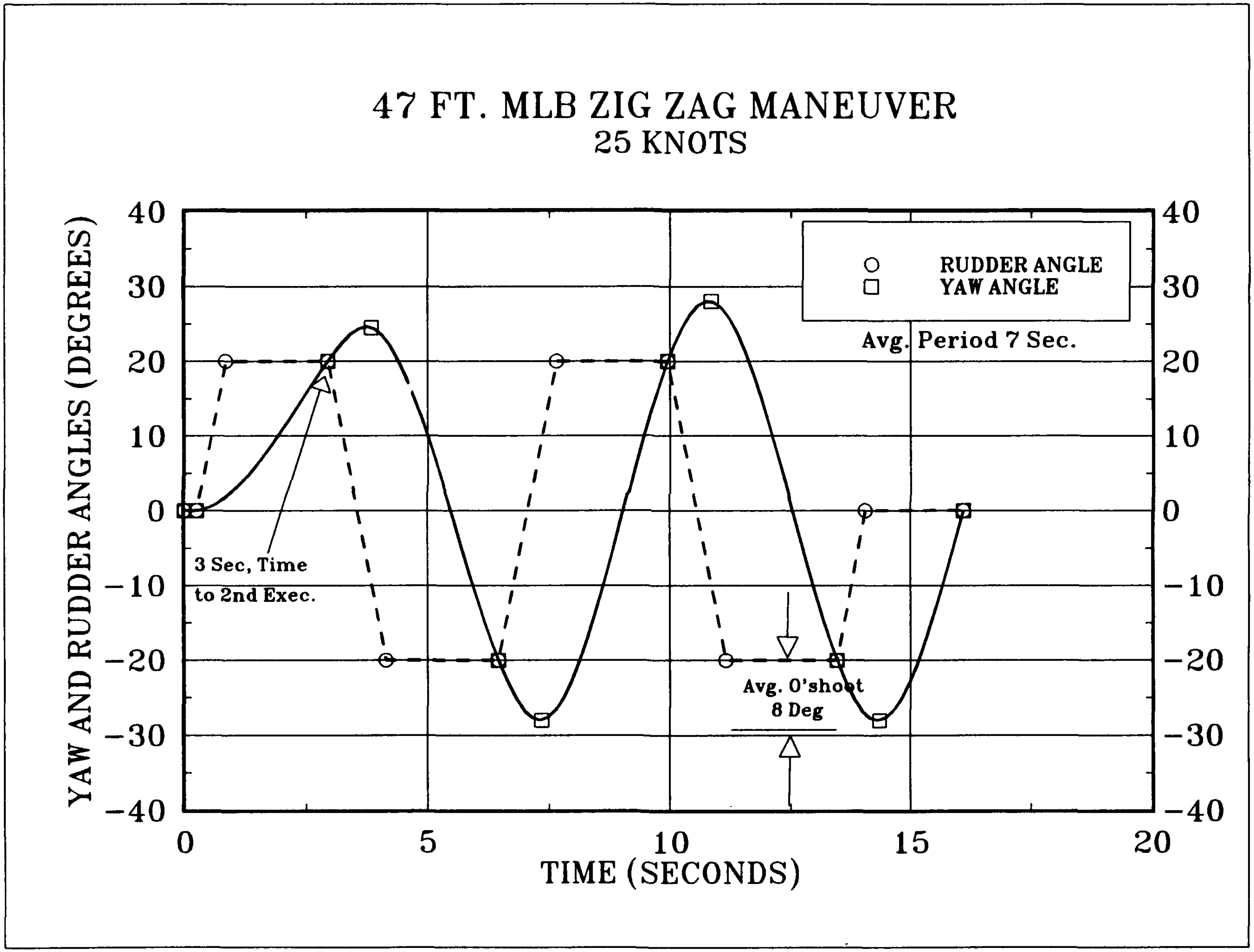


FIGURE TC-14.2. 47FT MLB ZIG-ZAG TEST, 25 KTS

44MLB ZIG-ZAG MANEUVER 10 KNOTS

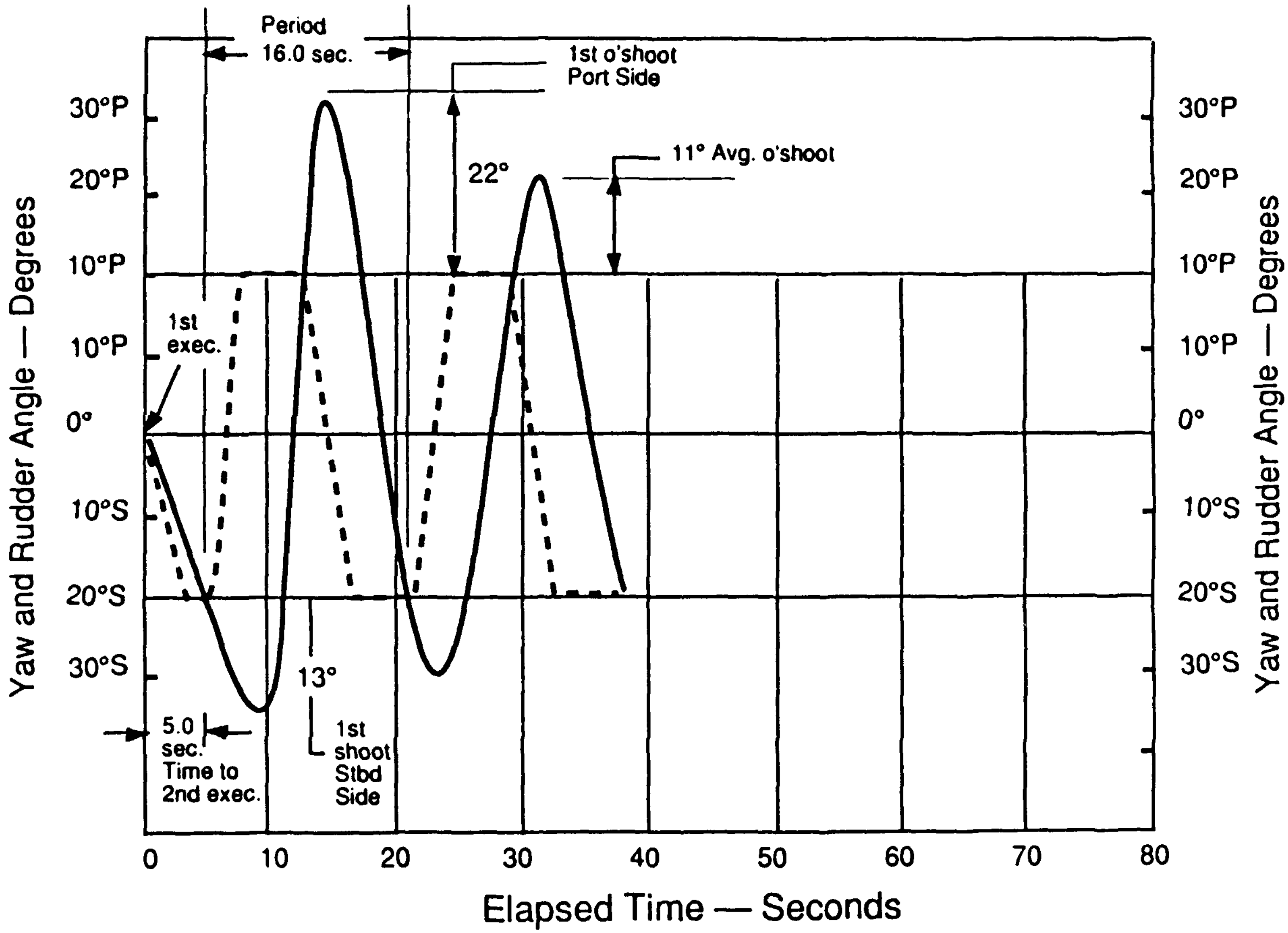


FIGURE TC-14.3. 44FT MLB ZIG-ZAG TEST, 10 KTS

41 UTB ZIG ZAG MANEUVER 10 KNOTS

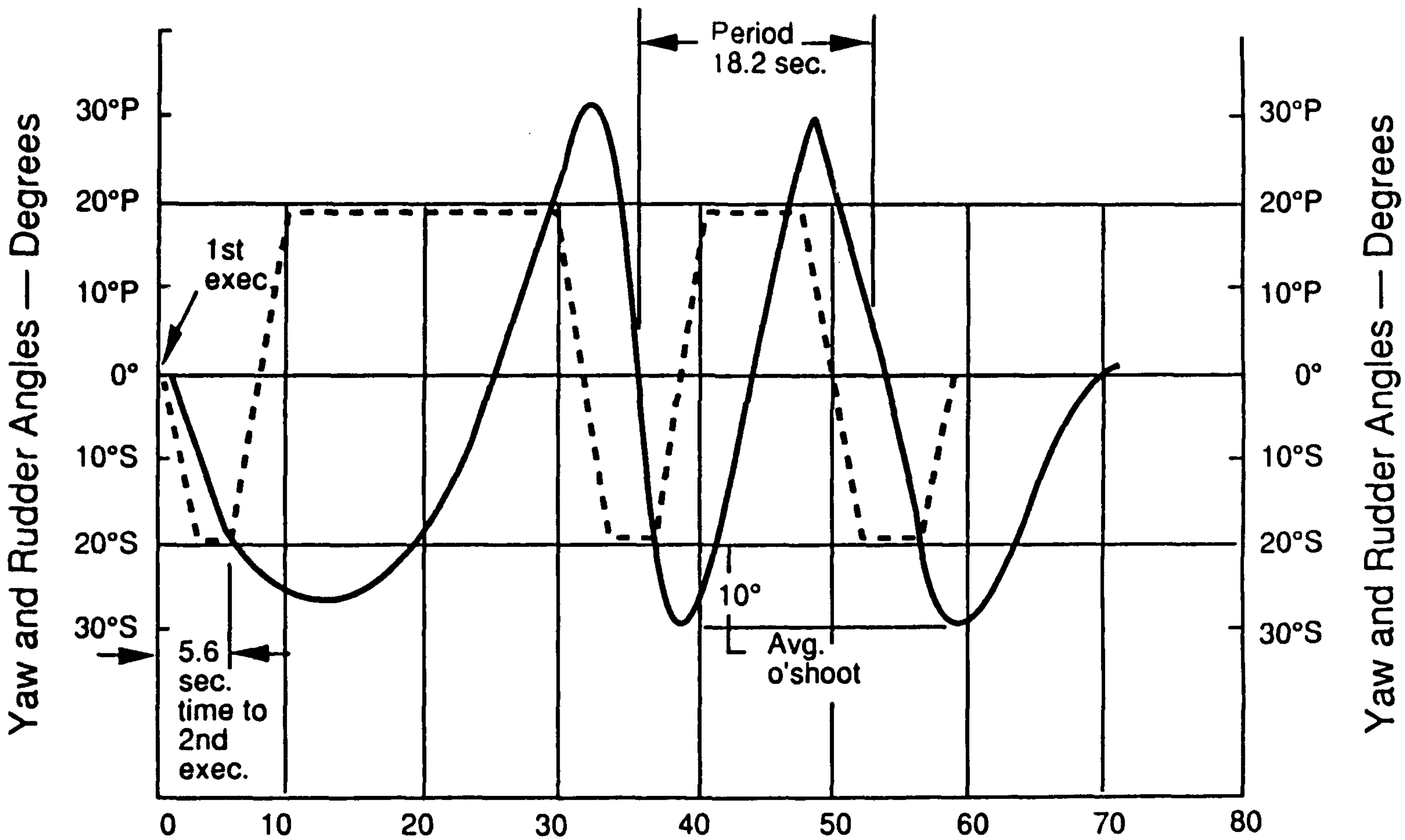


FIGURE TC-14.4. 41FT UTB ZIG-ZAG TEST, 10 KTS

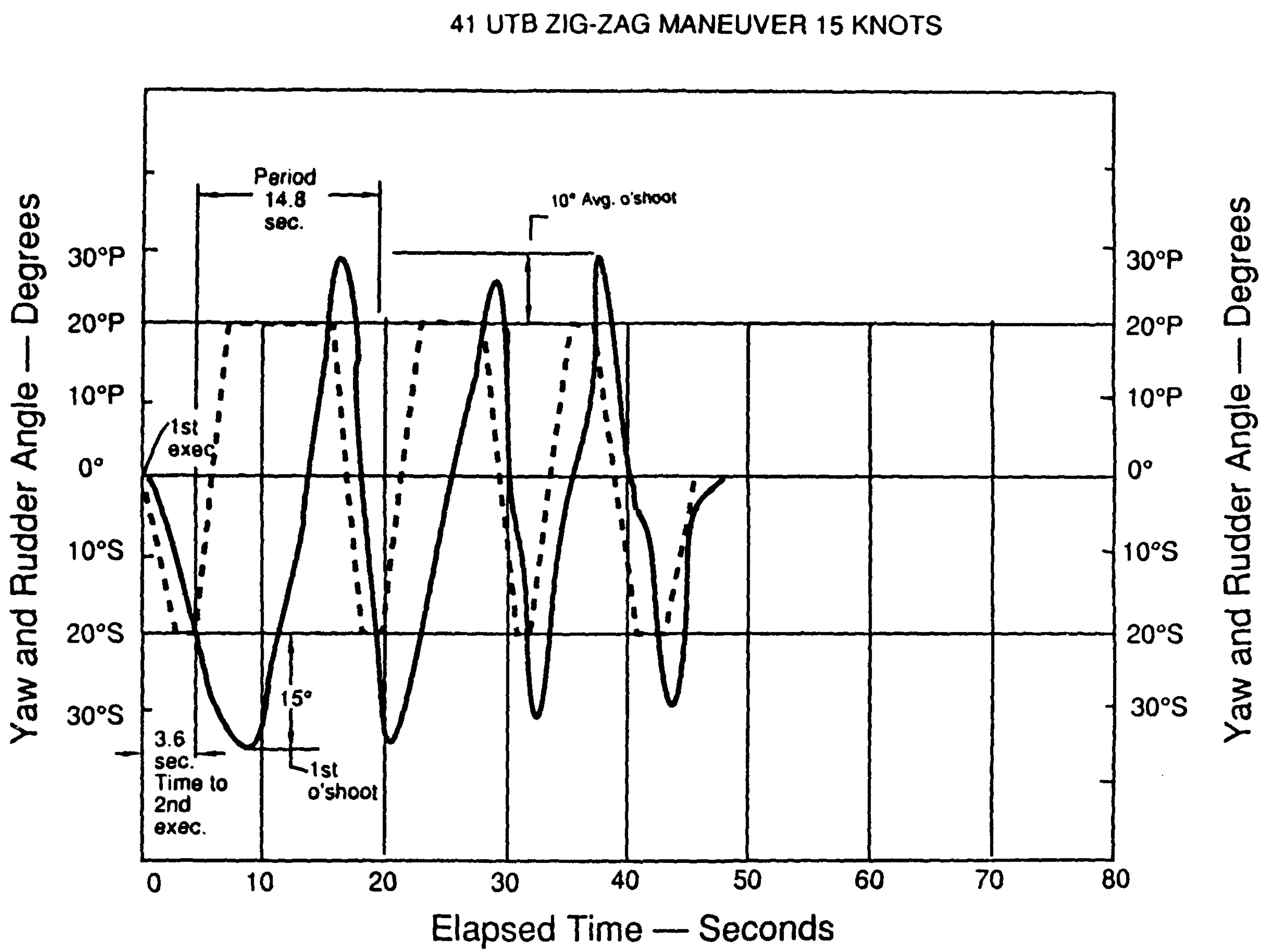


FIGURE TC-14.5. 41FT ZIG-ZAG TEST, 15 KTS

TABLE TC-15.1
47FT MLB WAVE BUOY DATA

ENDECO Inc.
Type 956 Directional Wave-Track Buoy
Digital Bandpass Filtering Method

47FT MLB ILWACO WA

Instrument 9560118 File 10091411
14-SEP-91 AT 11:38:03 Sample Length : 1024

******************** ZERO-CROSSING STATISTICS ********************

NBR WAVES	MAX PERIOD (S)	PERIOD OF MAX HEIGHT (S)	MAX HEIGHT (FT)	SIGNIFICANT PERIOD (S)	SIGNIFICANT HEIGHT (FT)	MEAN PERIOD (S)	MEAN HEIGHT (FT)	H 1/10 PERIOD (S)	H 1/10 HEIGHT (FT)
129	23.0	9.0	6.0	9.2	4.4	7.8	2.9	8.8	5.2

PROFILE OF MAXIMUM WAVE AT 1.00 SECOND INTERVALS

-1.0 1.4 2.7 2.9 2.3 .4 -.4 -.8 -3.1 -2.0 .4

****************** SPECTRAL ANALYSIS STATISTICS ******************

SIGNIFICANT WAVE HEIGHT (H 1/3) ... 4.8
ROOT-MEAN-SQUARE WAVE HEIGHT 3.4
AVERAGE PERIOD 8.6
AVERAGE ZERO CROSSING 7.9

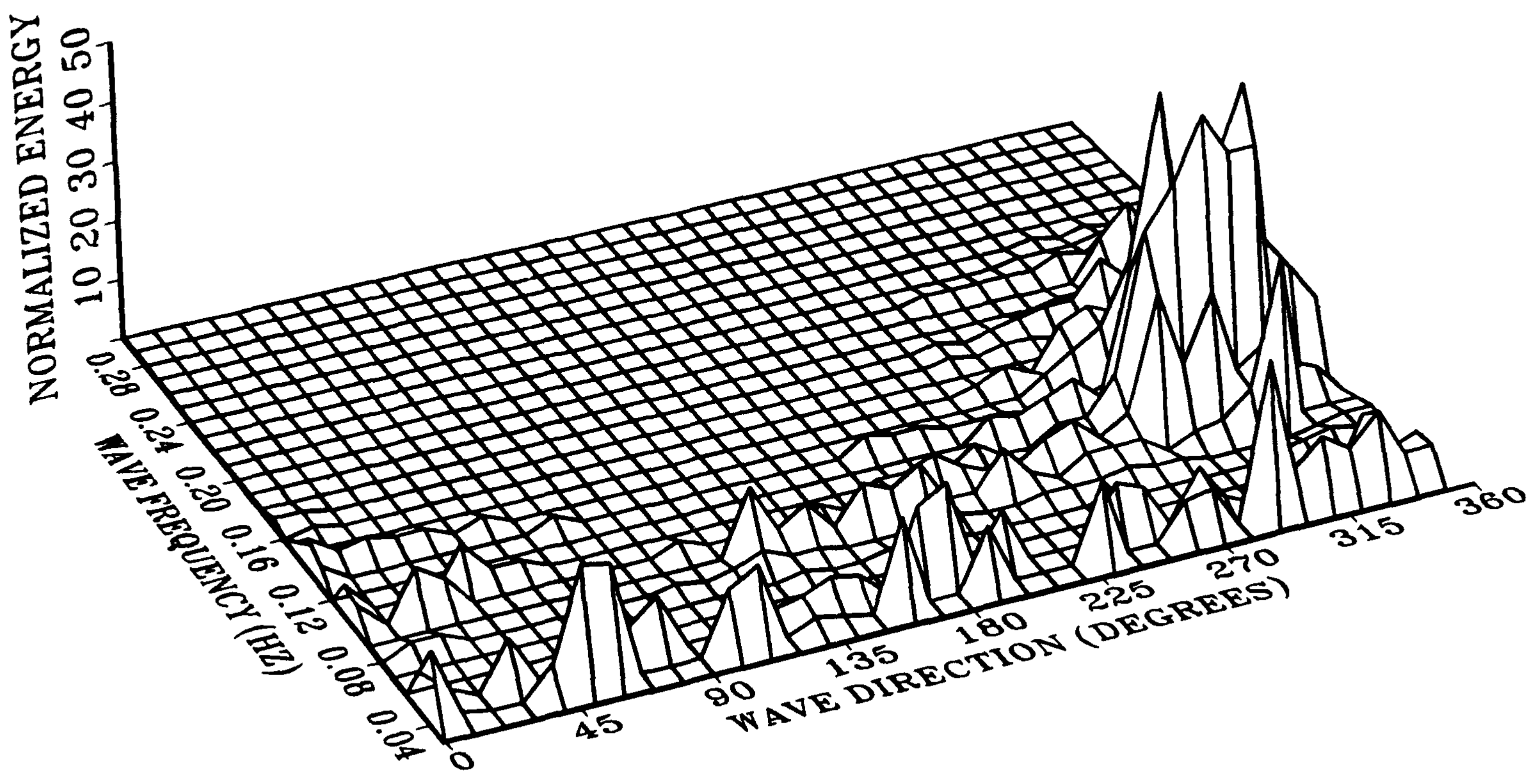
FREQUENCY BANDNUMBER	CENTER FREQUENCY (HZ)	CENTER PERIOD (S)	ENERGY DENSITY (FT-SQ/HZ)	MEAN DIRECTION (DEG)	STANDARD DEVIATION (DEG)
1	.030	33.3	.00	143.	10.0
2	.040	25.0	15.97	341.	13.7
3	.050	20.0	11.43	167.	14.7
4	.060	16.7	.52	71.	10.4
5	.070	14.3	1.78	288.	9.6
6	.080	12.5	2.66	276.	10.7
7	.090	11.1	8.48	241.	7.7
8	.100	10.0	11.34	291.	6.1
9	.110	9.1	18.46	303.	3.1
10	.120	8.3	17.39	306.	2.6
11	.130	7.7	10.75	311.	4.1
12	.140	7.1	15.25	314.	2.7
13	.150	6.7	7.12	305.	2.5
14	.160	6.3	5.65	320.	2.4
15	.170	5.9	3.77	322.	2.8
16	.180	5.6	2.81	291.	2.6
17	.190	5.3	1.18	313.	2.7
18	.200	5.0	2.32	319.	1.0
19	.210	4.8	1.70	294.	2.3
20	.220	4.5	2.05	323.	3.3
21	.230	4.3	.91	316.	4.0
22	.240	4.2	.37	351.	4.2
23	.250	4.0	.49	270.	5.4
24	.260	3.8	.75	240.	4.9
25	.270	3.7	.57	325.	5.2
26	.280	3.6	.30	327.	5.7
27	.290	3.4	.21	348.	5.7
28	.300	3.3	.39	15.	4.9

NOTE: Energy calculated for band #1 contains frequency components outside the range of the buoy.

47ft MLB SEAKEEPING SEASTATE

4.8 FT SIG WAVE HT, 8.6 SEC AVG PERIOD, 14 Sep 1991

Normalized Energy =50= spectral density of 0.348 (FT-sq/Hz*deg)



POSITION 046-04.6N, 124-11.3W

FIGURE TC-15.1. 47FT MLB NORMALIZED DIRECTIONAL SEA SPECTRA

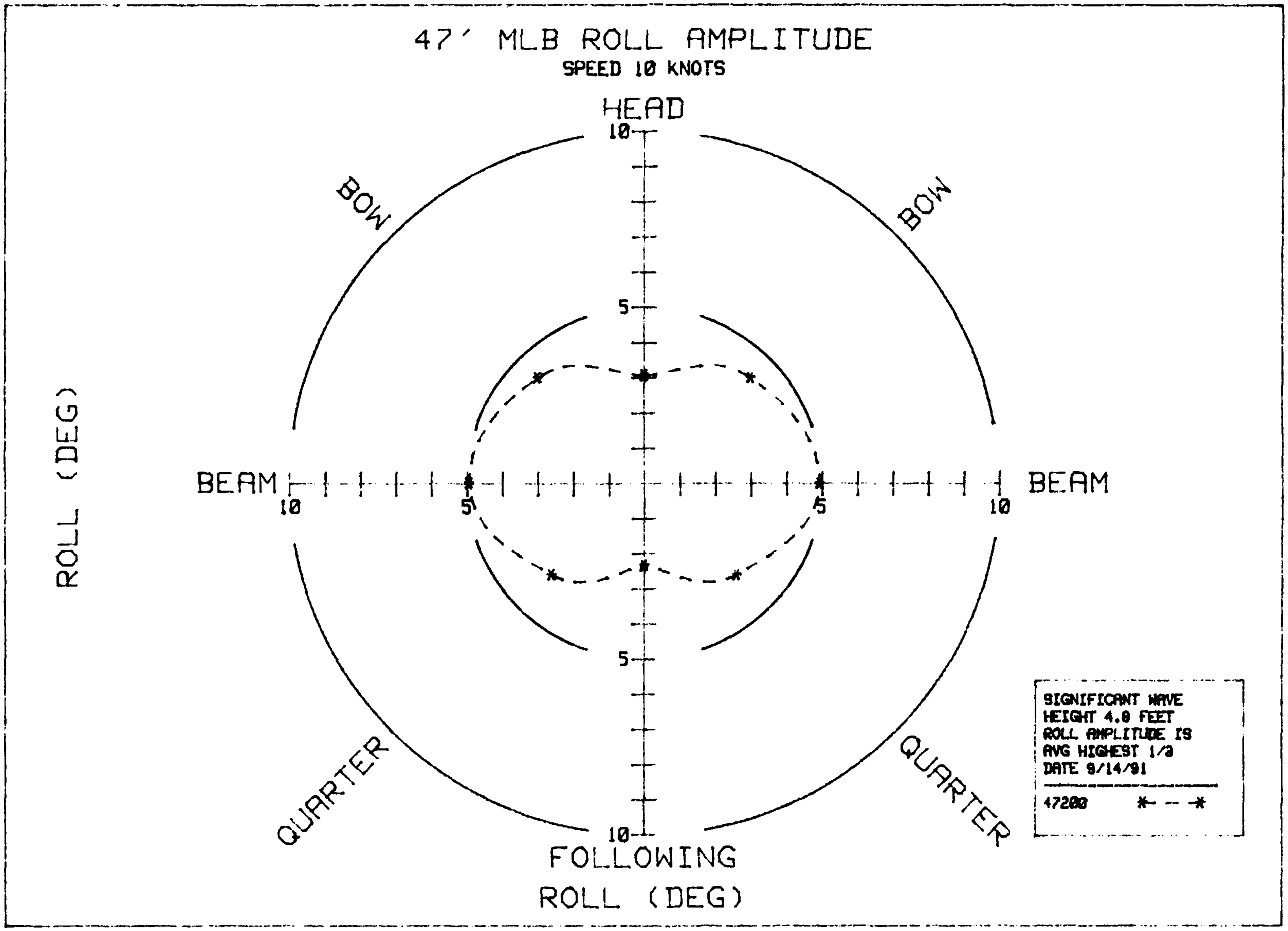


FIGURE TC-15.2. 47FT MLB ROLL AMPLITUDE, 10 KTS

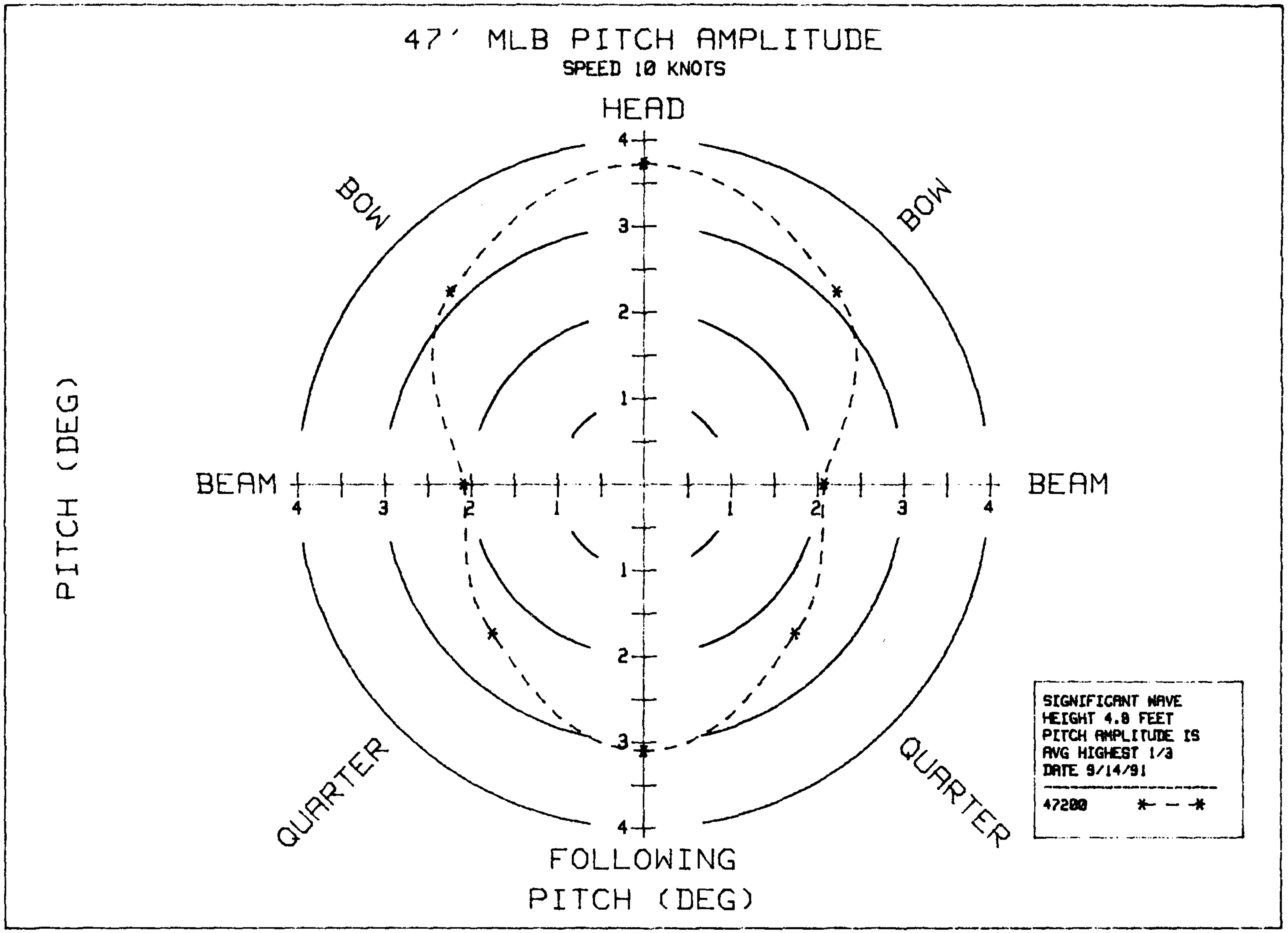


FIGURE TC-15.3. 47FT MLB PITCH AMPLITUDE, 10 KTS

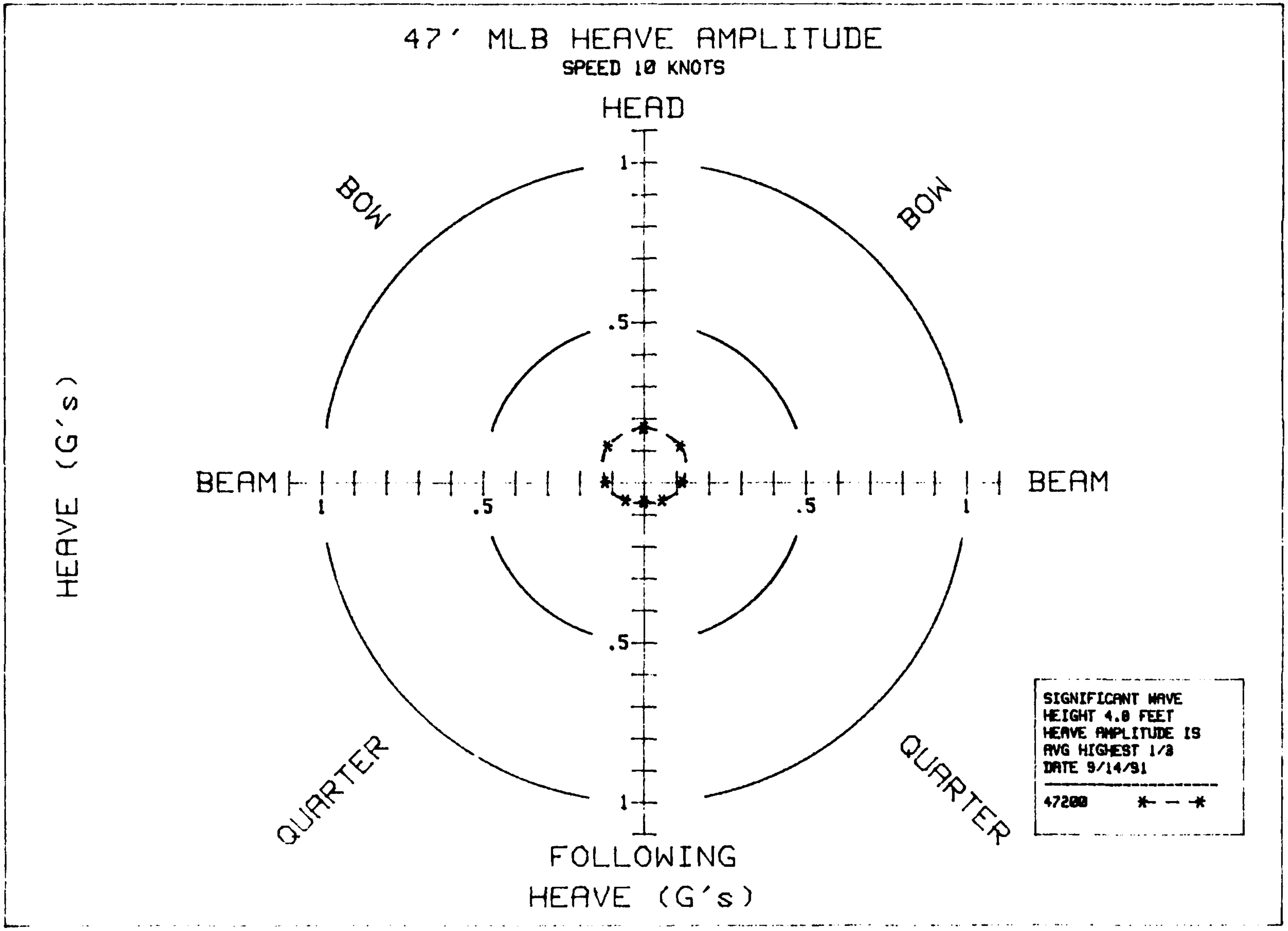


FIGURE TC-15.4. 47FT MLB HEAVE AMPLITUDE, 10 KTS

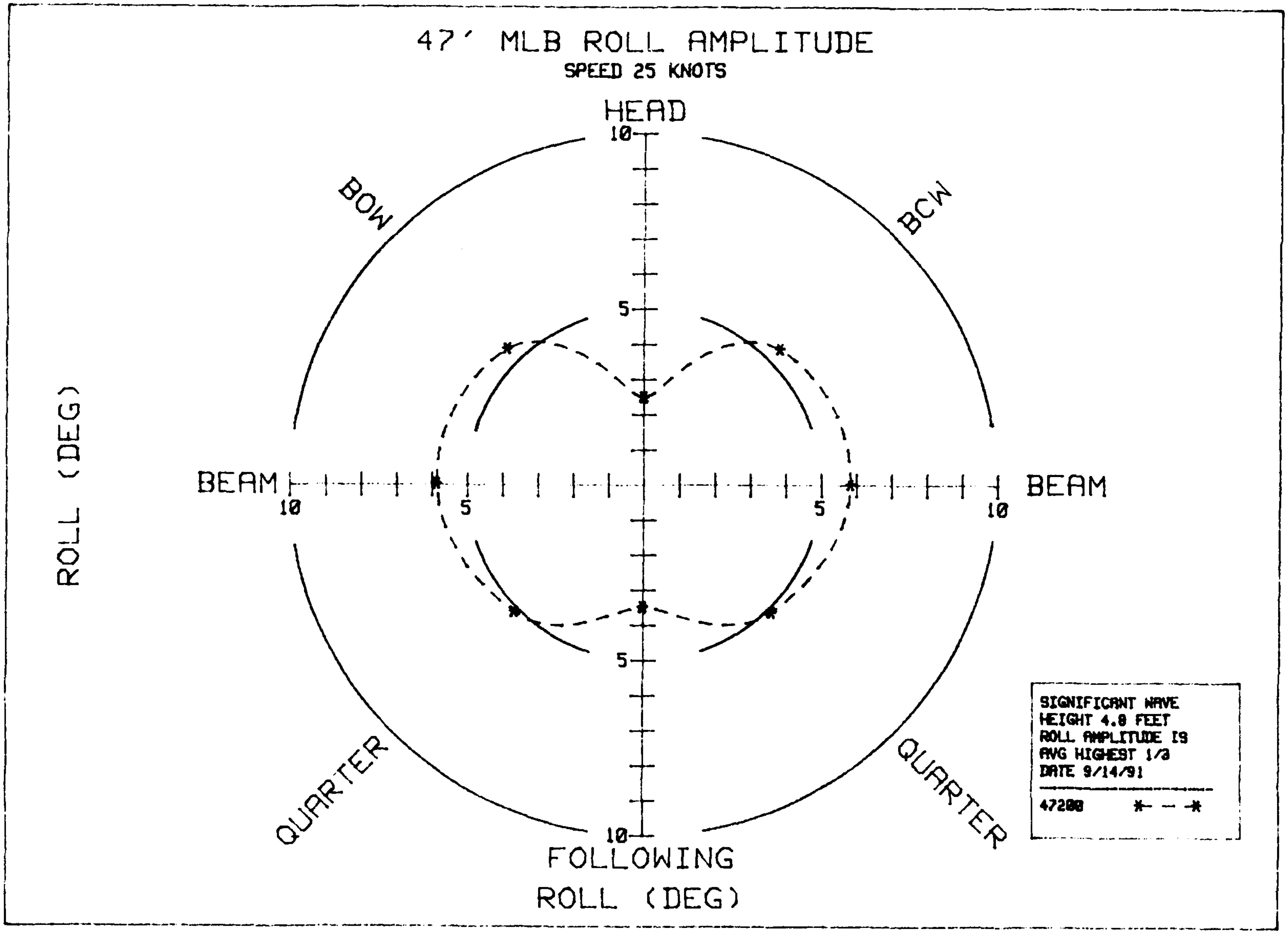


FIGURE TC-15.5. 47FT MLB ROLL AMPLITUDE, 25 KTS

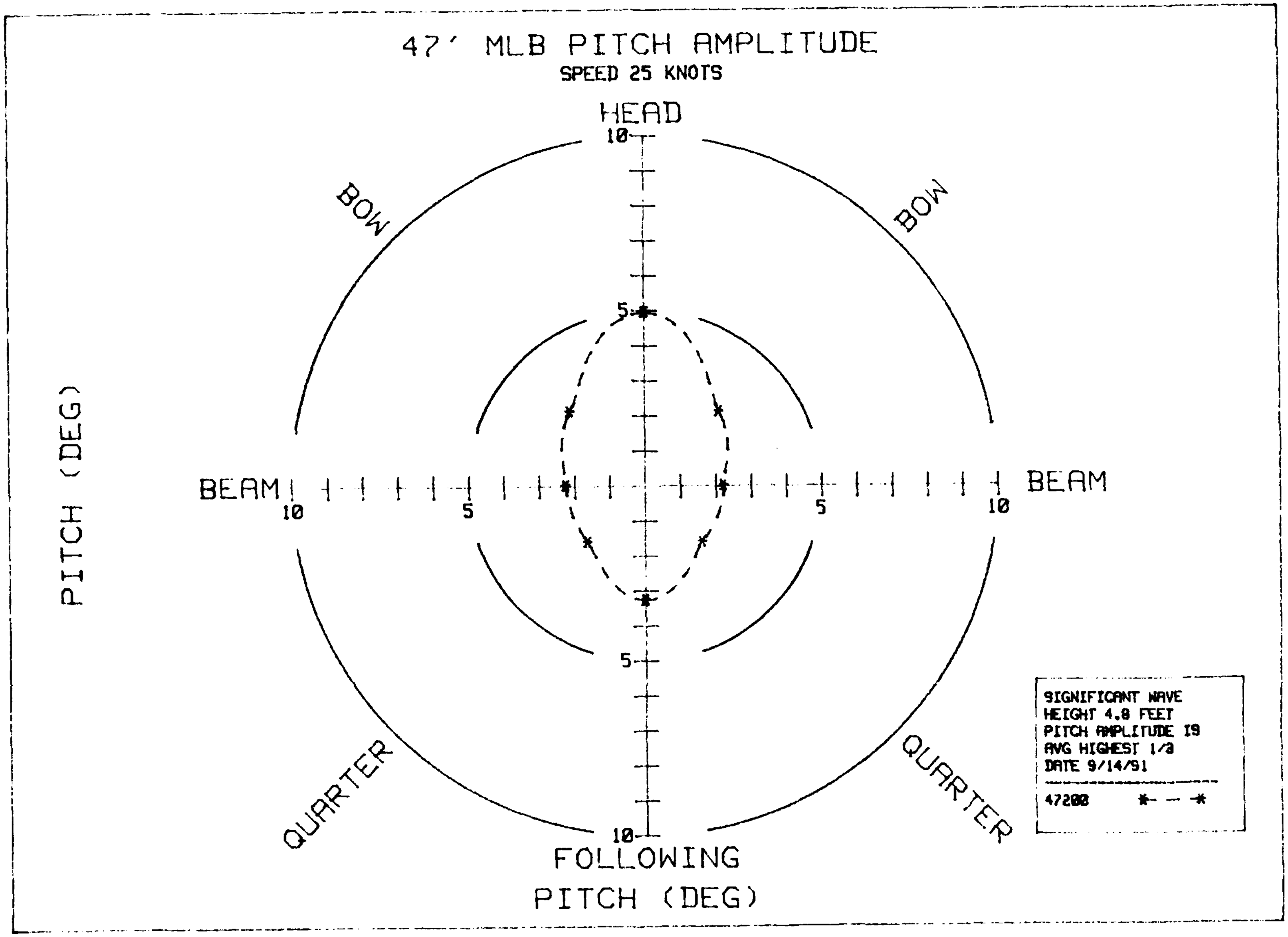


FIGURE TC-15.6. 47FT MLB PITCH AMPLITUDE, 25 KTS

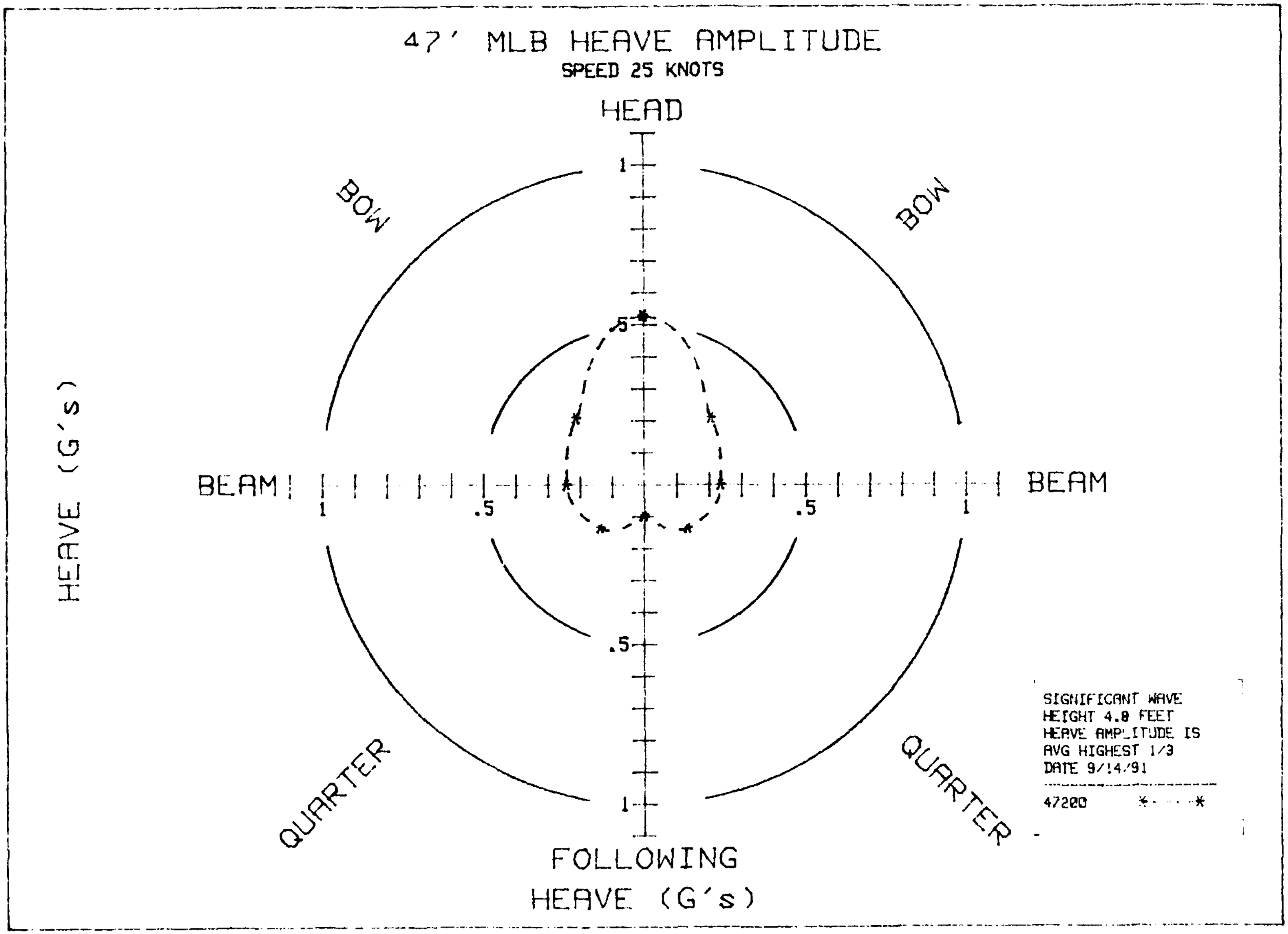


FIGURE TC-15.7. 47FT MLB HEAVE AMPLITUDE, 25 KTS

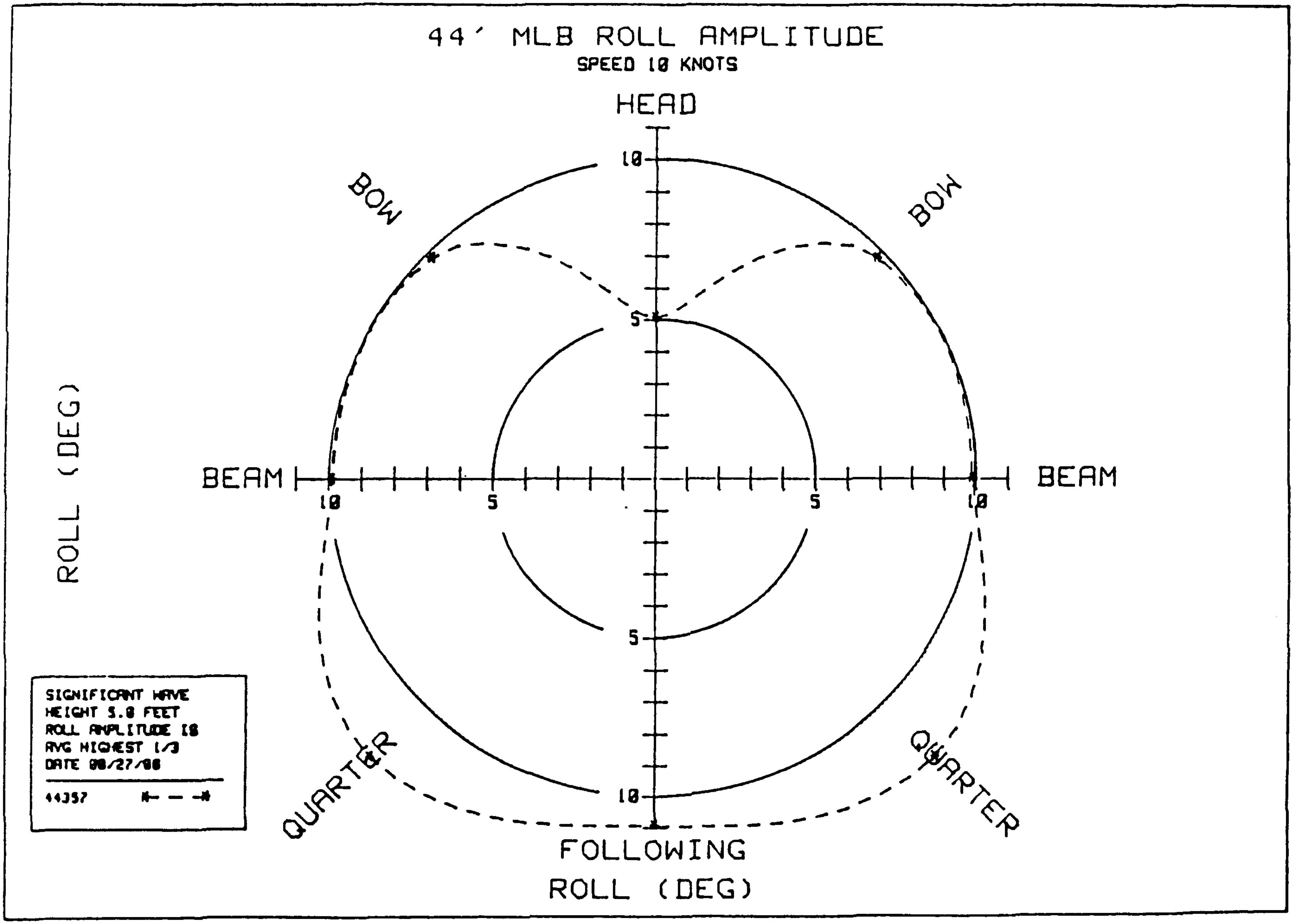


FIGURE TC-15.8. 44FT MLB ROLL AMPLITUDE, 10 KTS

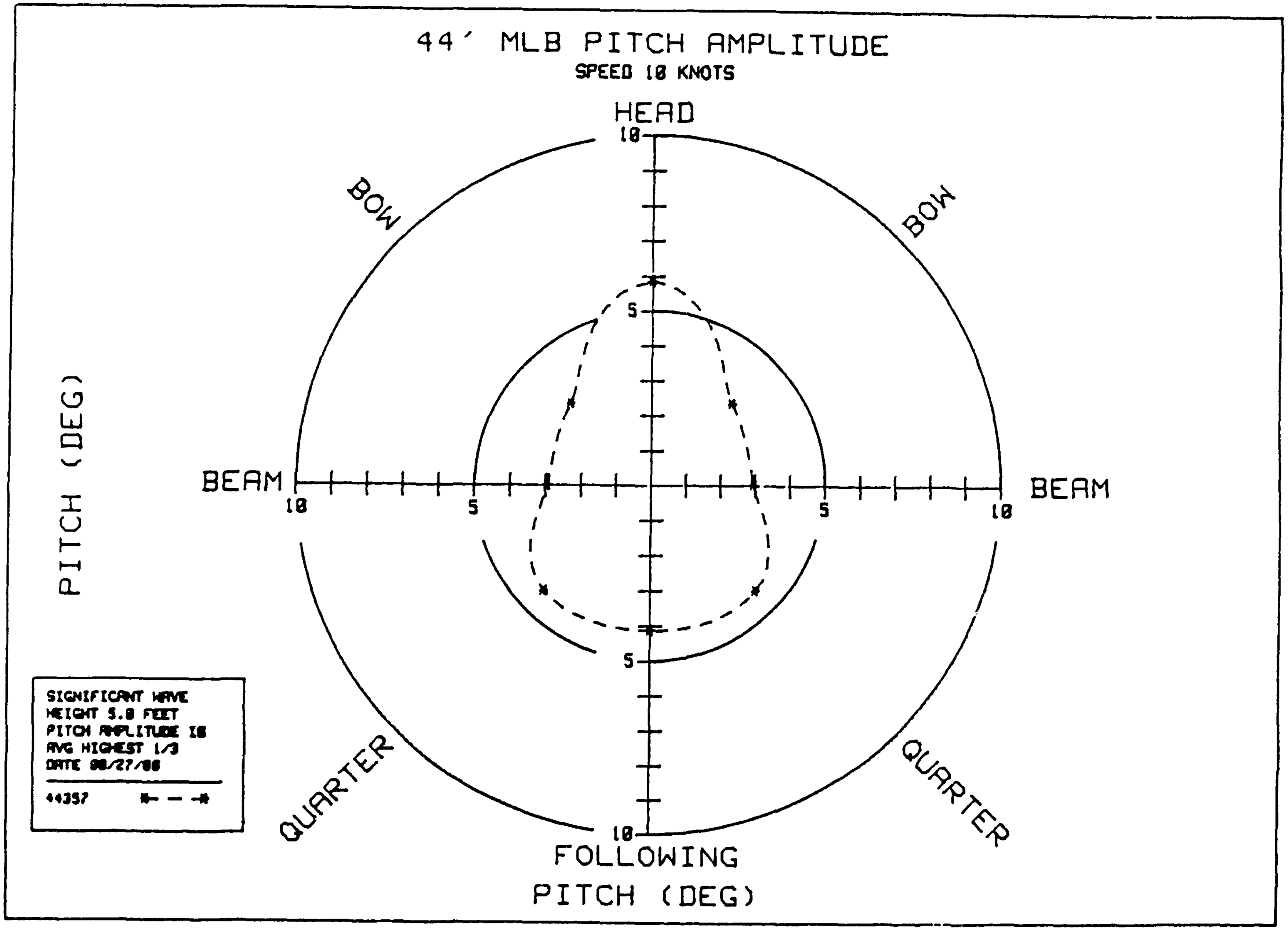


FIGURE TC-15.9. 44FT MLB PITCH AMPLITUDE, 10 KTS

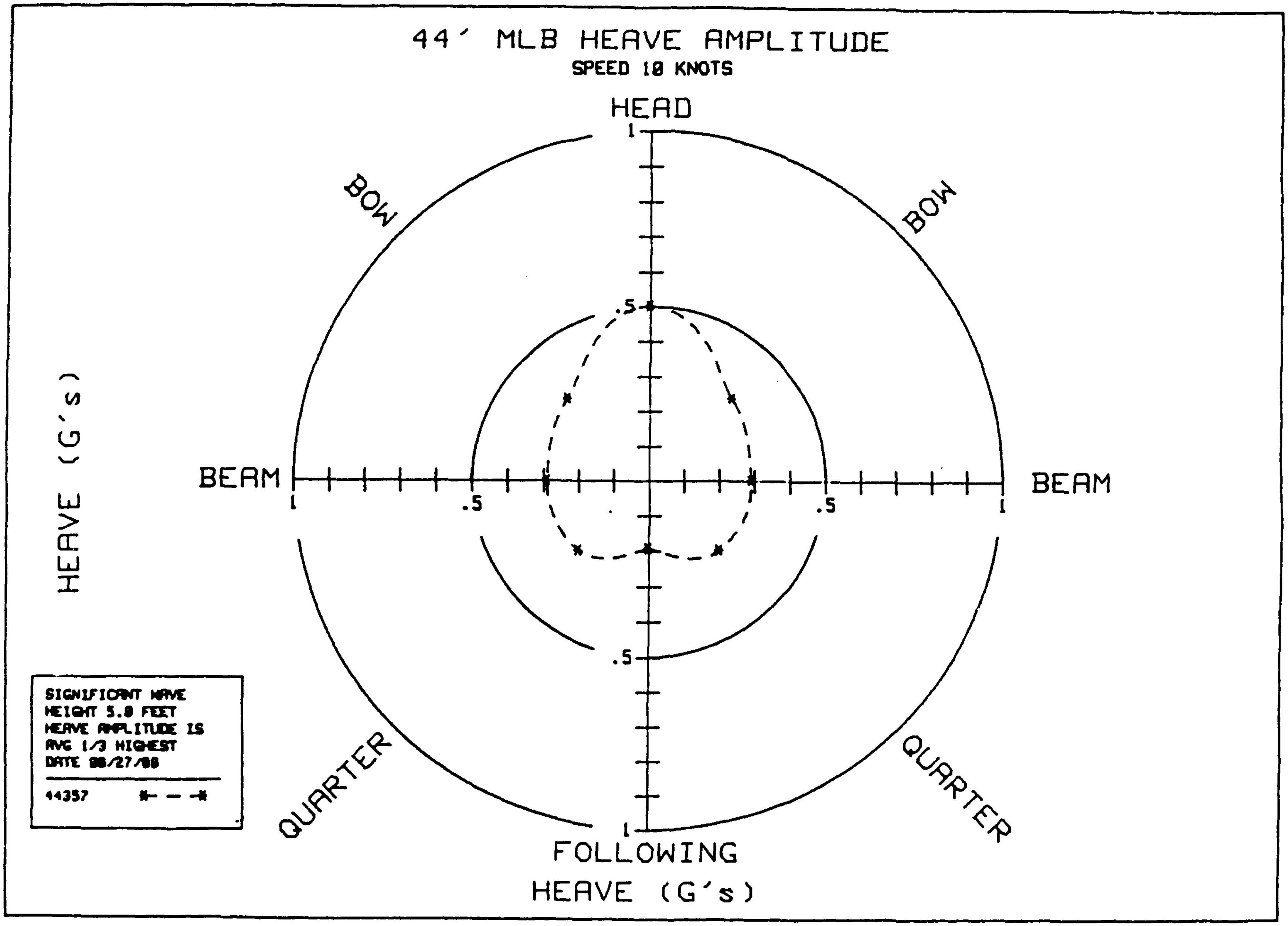


FIGURE TC-15.10. 44FT MLB HEAVE AMPLITUDE, 10 KTS

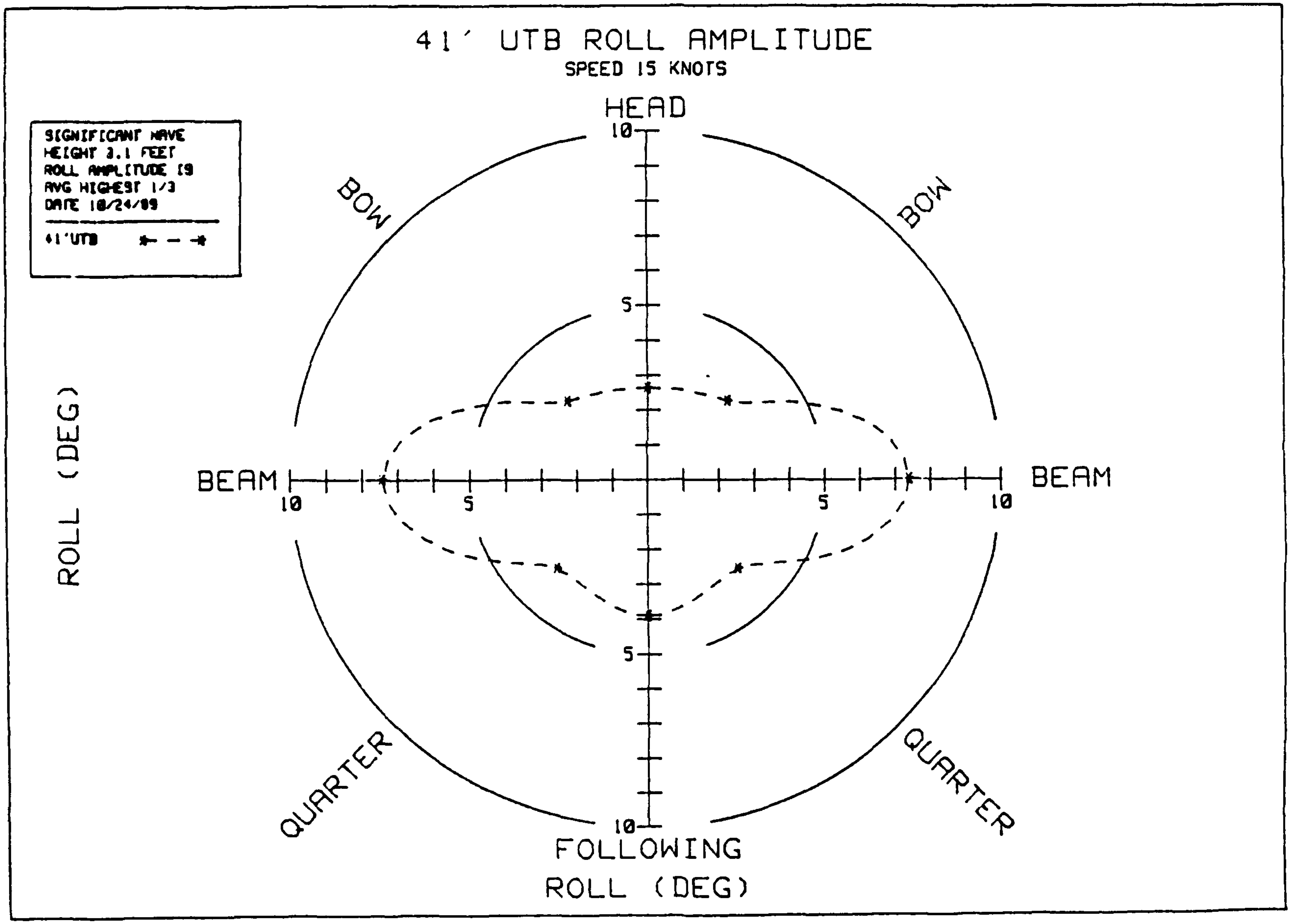


FIGURE TC-15.11. 41FT UTB ROLL AMPLITUDE, 15 KTS

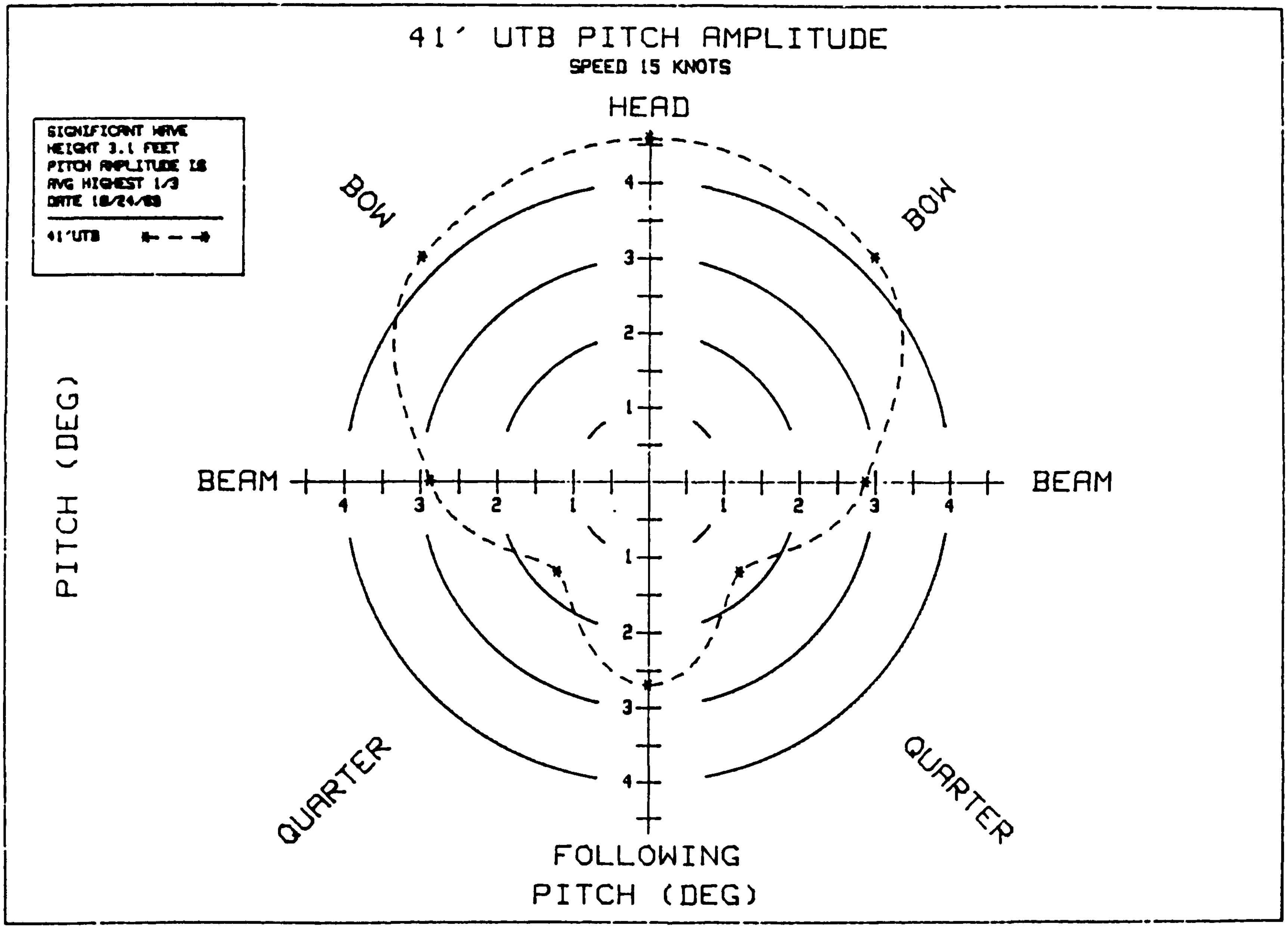


FIGURE TC-15.12. 41FT UTB PITCH AMPLITUDE, 15 KTS

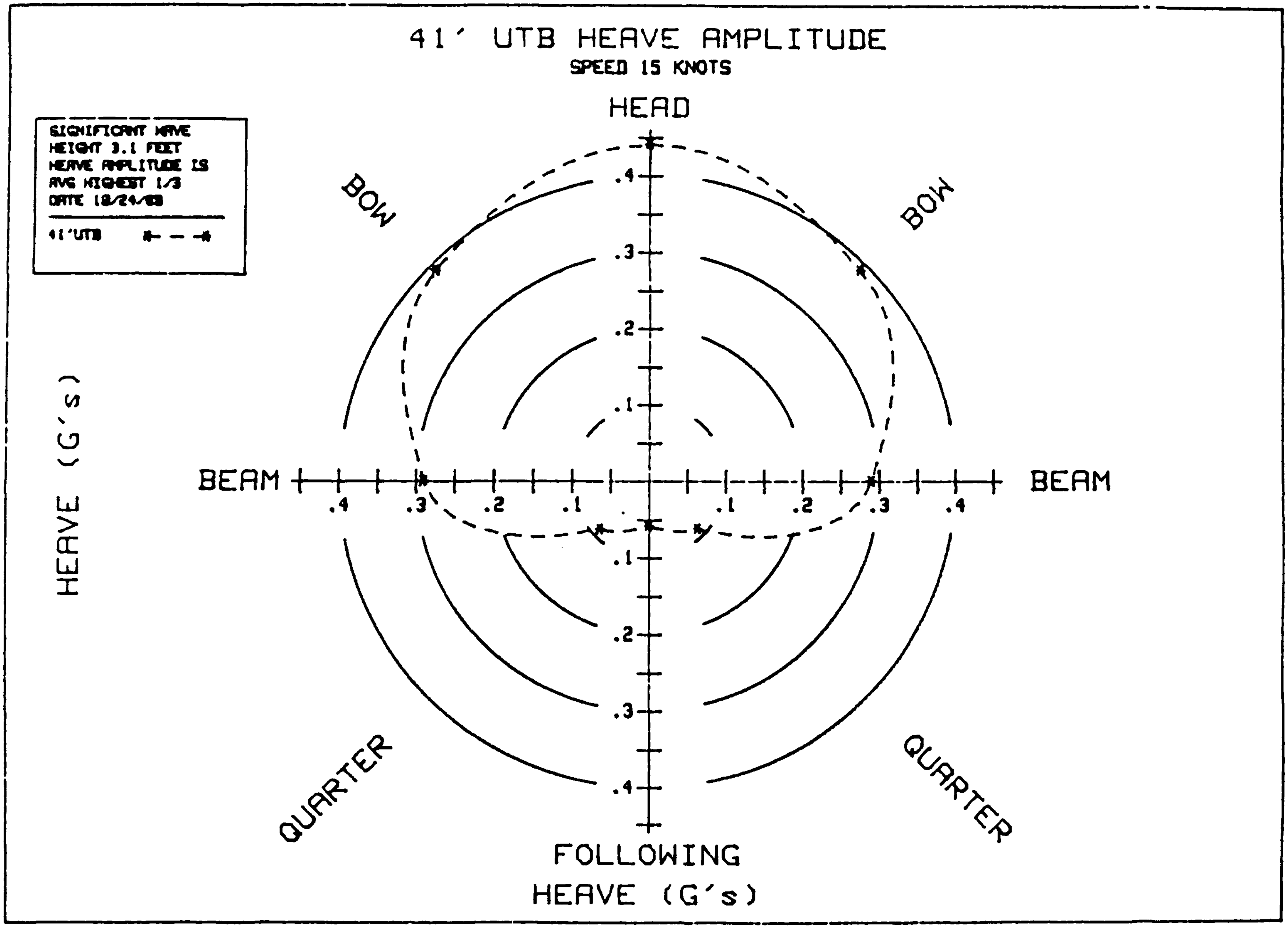


FIGURE TC-15.13. 41FT UTB HEAVE AMPLITUDE, 15 KTS

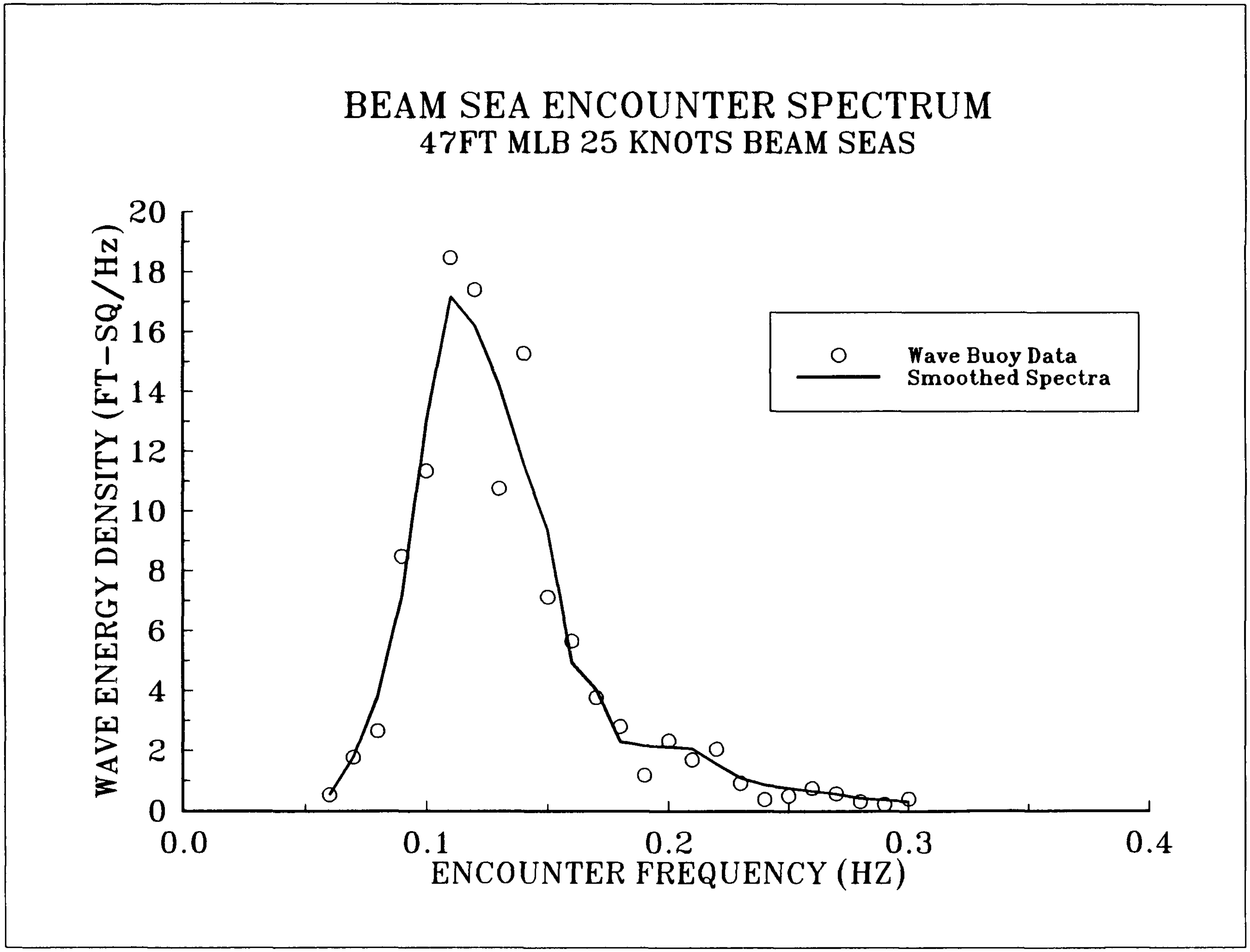


FIGURE TC-15.14. 47FT MLB BEAM SEAS ENCOUNTER SPECTRUM

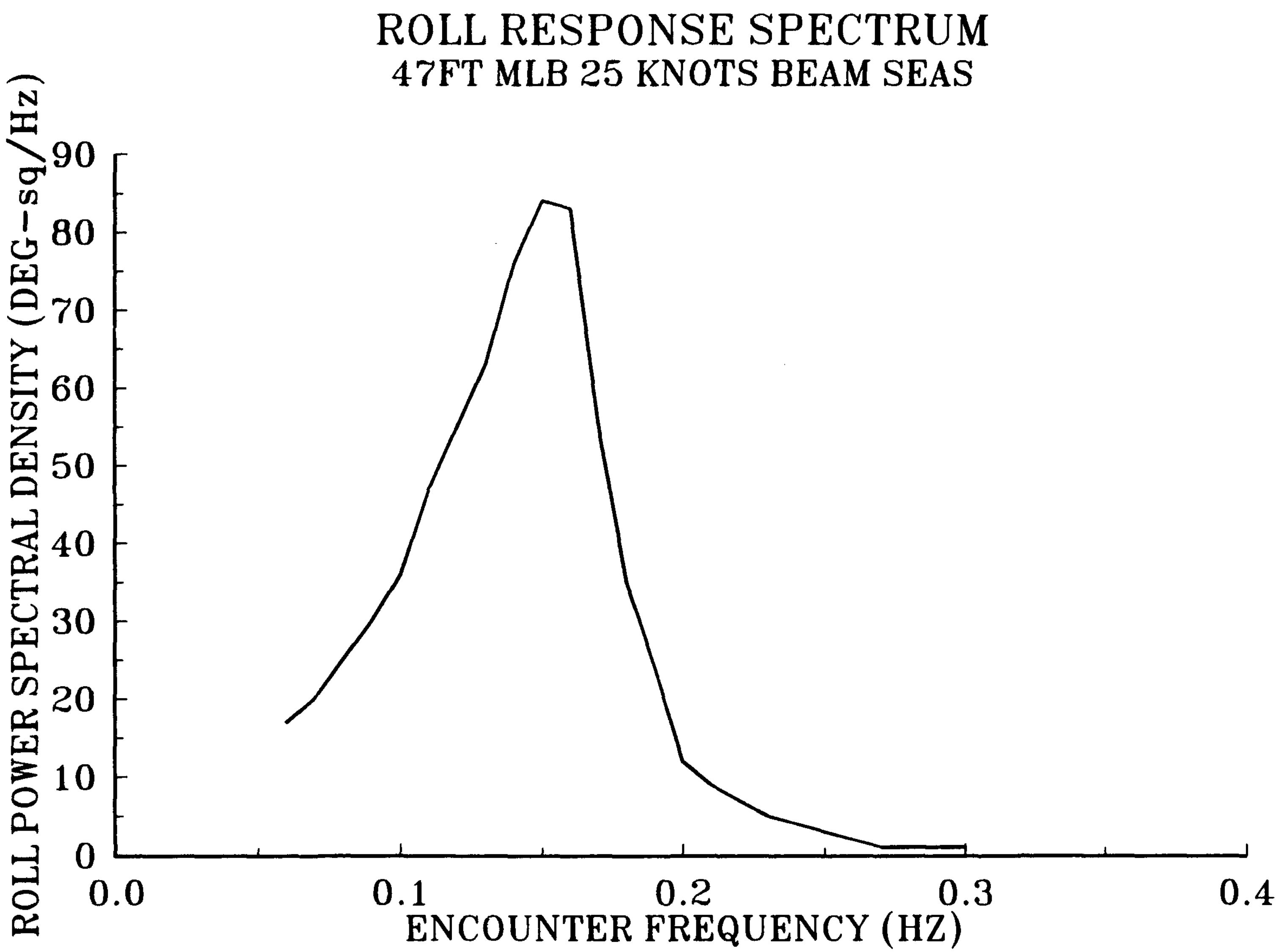


FIGURE TC-15.15. 47FT MLB ROLL RESPONSE SPECTRUM

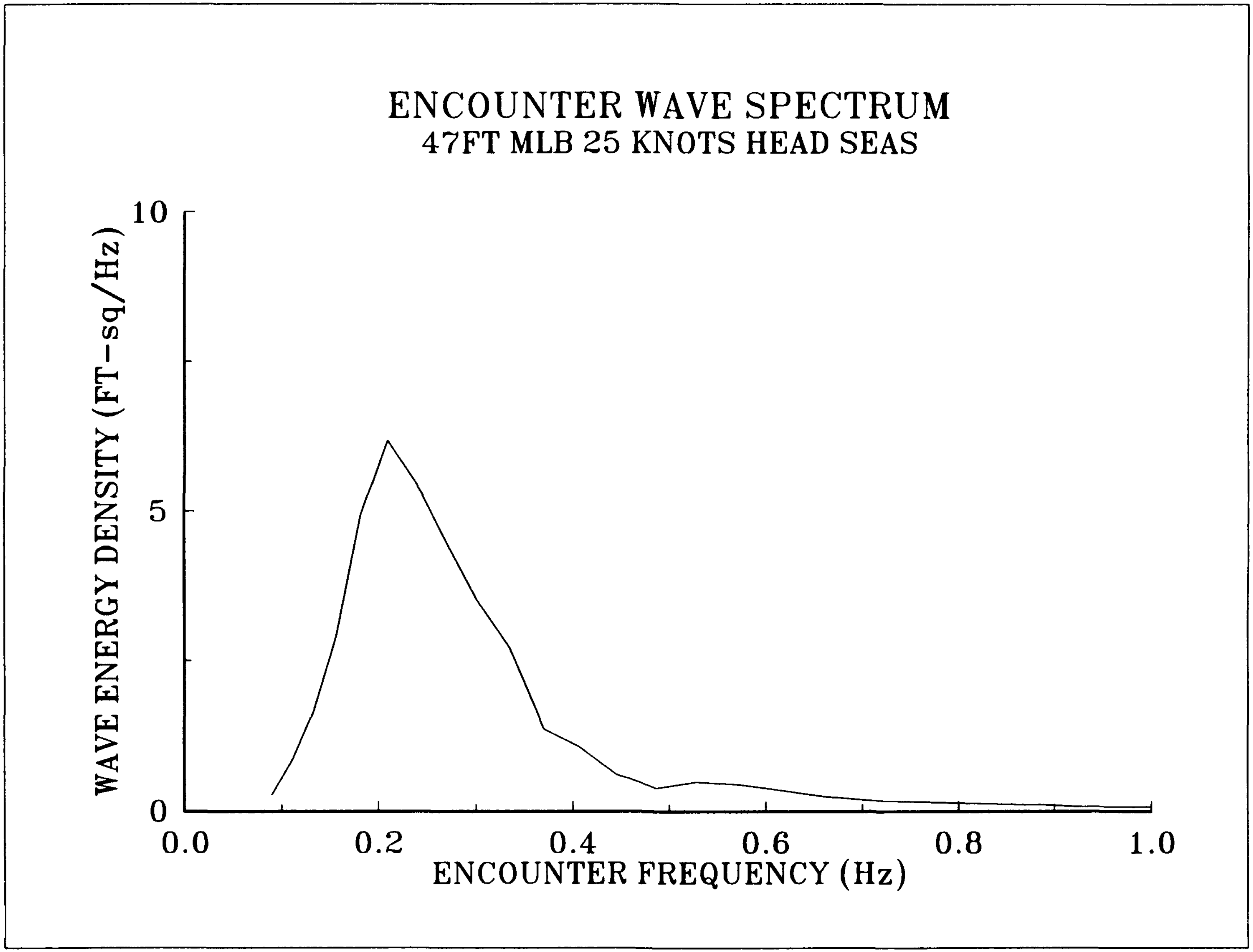


FIGURE TC-15.16. 47FT MLB HEAD SEAS ENCOUNTER SPECTRUM

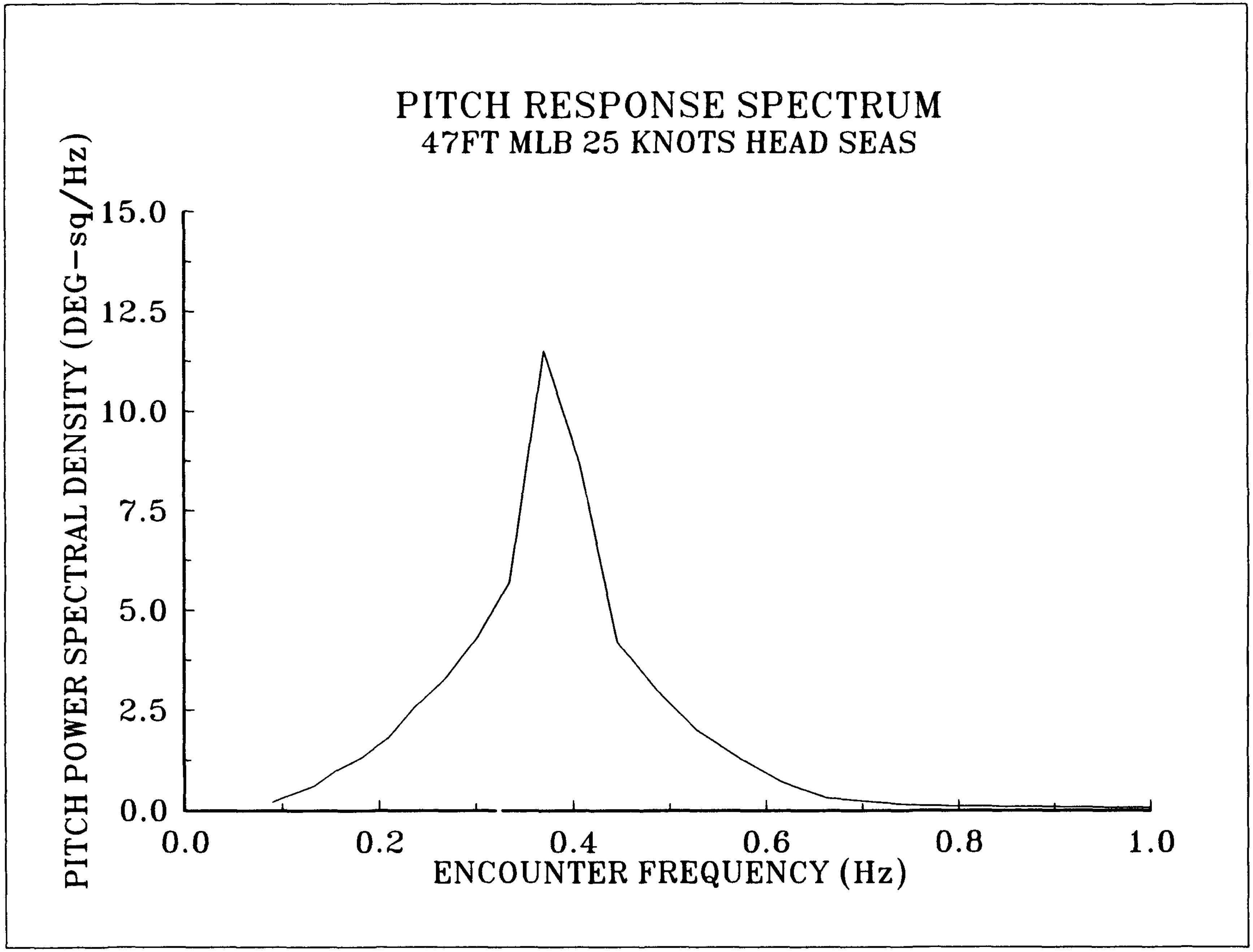


FIGURE TC-15.17. 47FT MLB PITCH RESPONSE SPECTRUM

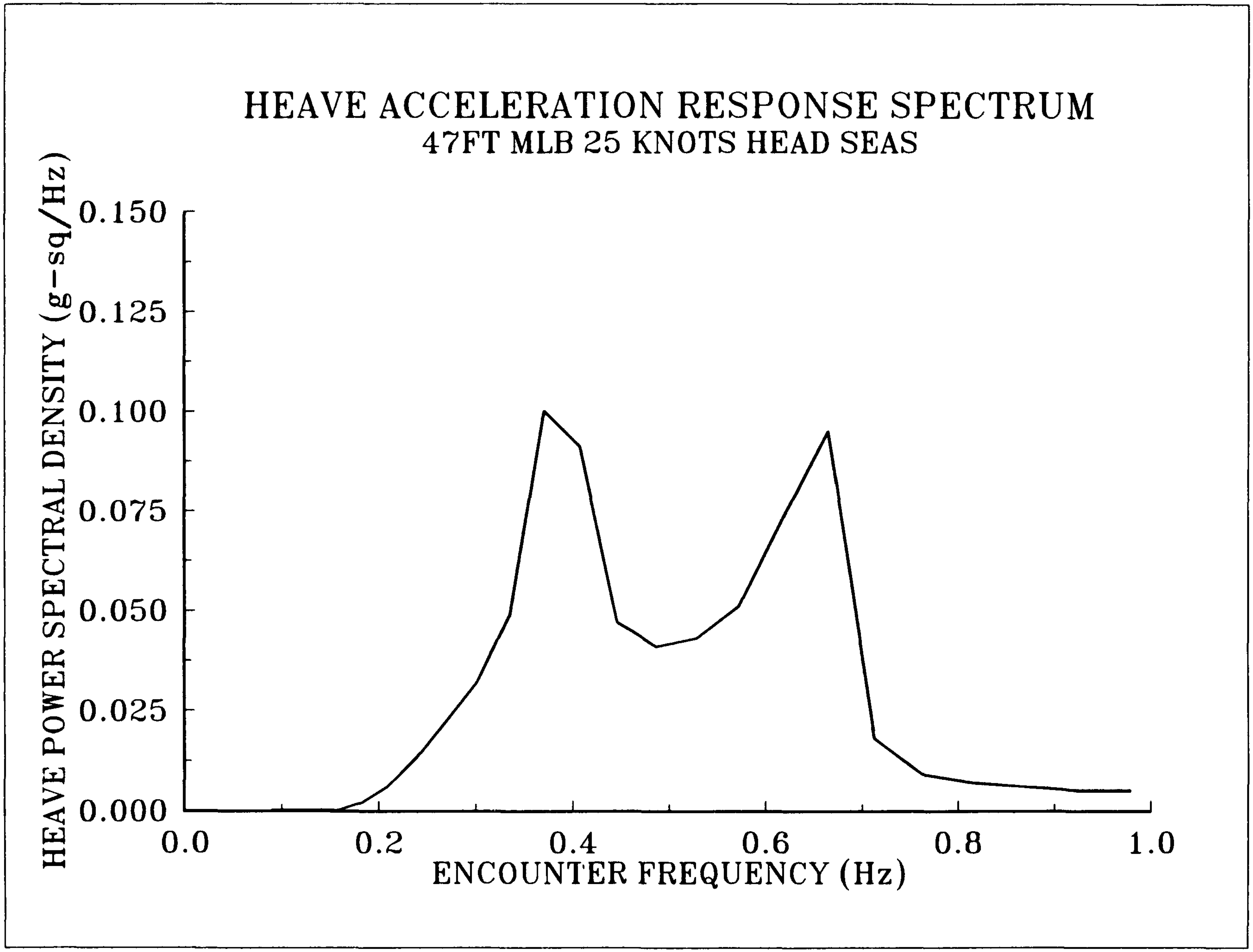


FIGURE TC-15.18. 47FT MLB HEAVE ACCELERATION RESPONSE SPECTRUM

ANALYSIS

In this section, results of the various tests are analyzed and the strengths and weaknesses of the 47FT MLB are compared with the two operationally proven Coast Guard boat designs. Anomalies in test results are also identified and discussed in this section.

Principal Characteristics

As listed in Table TC-1, the 47FT MLB is physically larger than the other two boats. The longer length provides for a more efficient, more easily driven hull form when scaled for displacement. The wider beam helps contribute to good stability characteristics. The 47FT MLB has greater draft than the other two boats. The draft of the boat is within the limitations imposed by [1], but restricts the shallow water operations of the 47FT MLB relative to the 44FT MLB. In addition, the lowest point in the boat's draft is at the propellers. The rudders and propellers of both the 44FT MLB and the 41FT UTB are protected from grounding damage by large centerline skegs extending from the keel. An engineering change proposal (ECP) to add protective extensions to the propeller struts of the prototype 47FT MLB is planned for evaluation on the prototype during the fall of 1991.

The 47FT MLB is made entirely of aluminum. With this high strength, lightweight material, the 47FT MLB's displacement is almost equal to the smaller 44FT MLB, which is made of steel. The 41FT UTB has proven the viability of aluminum as a material for Coast Guard small boat service. The 47FT MLB hull is stoutly constructed with conservative factors of safety (see Appendix A, Hull Structural Evaluation).

The 47FT MLB is designed for four crew members. As currently configured, the prototype arrangement of the enclosed bridge and the flying bridge do not comfortably accommodate four persons. This, and a number of other human factors-related issues, were identified in [10]. The congested enclosed bridge configuration is being addressed by an ECP, which includes recommendations from the Naval Biodynamics Laboratory Human Engineering Assessment.

The combination of the enclosed bridge and flying bridge in the 47FT MLB design offers many substantial advantages over both the 41FT UTB and the 44FT MLB. On the 41FT UTB, the coxswain is constrained to a single operating station, amidship in an enclosed cabin. This can hamper visibility while operating alongside. The 44FT MLB has no enclosed operating stations, leaving all of the crew exposed to the elements and increasing their rate of fatigue. The 47FT MLB is controllable from four operating stations, one on each side of the enclosed and flying bridges. This feature provides great flexibility for the crew in both normal operations and during close maneuvering situations.

A significant advantage of the 47FT MLB design is the increased height of eye of the enclosed bridge and flying bridge operating stations. Increased height of eye translates to a wider visible horizon for search targets and an improved perspective for operating in high sea states.

Speed vs Power

This test measures the speed of the boat as a function of the propeller shaft horsepower output from the propulsion system. The 47FT MLB engines are rated to produce 435 shaft horsepower each at 2300 engine RPM, more horsepower than either the 41FT UTB or the 44FT MLB. The increased shaft horsepower, coupled with the longer, deep-vee hull, result in increased maximum speed. The top speed of the 47FT MLB at full-load displacement exceeds the requirements of [1] with a 2.1 knot margin. The maximum calm water speed of the 47FT MLB is twice the speed of the 44FT MLB, and 2 knots faster than the 41FT UTB.

Figure TC-4.8 compares the speed versus horsepower characteristics of the three vessels. Note on this figure, the 47FT MLB is tested at half-load displacement and with the lighter load the boat's top speed is 27.3 knots. At speeds less than 10 knots, both the 47FT MLB and the 41FT UTB require 10 to 20% more horsepower than the displacement hull 44FT MLB. These speeds (less than 10 knots) occur before the 47FT MLB and 41FT UTB begin planing. The top speed of the 44FT MLB is only 13 knots. At speeds above 20 knots, the 47FT MLB only requires about 6% more power than the 41FT UTB to drive its additional 30% displacement thanks to the boat's longer waterline, no skeg and more optimal trim angle. Figure TC-4.9 emphasizes this comparison between the two boats. This figure plots horsepower per pound displacement as a function of calm water speed. ("Specific" power in this case refers to "Shaft Horsepower per unit weight".) The 47FT MLB requires 18% less horsepower per pound displacement at 25 knots than the 41FT UTB.

Figures TC-4.1-5 show the effects of increased load and different LCG locations on the 47FT MLB. This data can be combined with results of the 1/8th scale resistance modeling conducted during preliminary design reported in [11] to estimate propulsive efficiency. In the tow tank, effective horsepower (not shaft horsepower) was measured as a function of speed for several load conditions which correspond with the full-scale tests reported here. The propulsive coefficient of the hull (the ratio of effective horsepower to shaft horsepower) estimated from model and full-scale tests at speeds between 20 to 25 knots is in the range of 0.59 to 0.52, depending on loading condition. This is a reasonable efficiency range for a planing hull boat operating at this speed-to-length ratio [12].

The tests of the prototype at various positions of the LCG help indicate to designers the load condition for optimal powering efficiency. Some minor gains in efficiency of between 1 to 3% may be possible by moving the boat's LCG forward slightly without adding additional weight. The results of this test are not conclusive in this regard because of practical limits in measurement accuracy (+/-0.5 knots speed, +/- 3% power). The approximate position of the prototype's LCG is 38.4% of the LBP, ± 0.5%. In the full load displacement plus additional weight trials, the 18.91LT, LCG 40.4% condition required 5% less horsepower than the 18.81LT, LCG 38.4% case. When the LCG is moved further aft, as in the 18.85LT, LCG 37.1% case, about the same power is required as for the 40.4% LCG, but the top speed is reduced 0.5 knots. Moving the LCG slightly further forward from the 38.4% location (without adding additional weight to the boat) could optimize the boat's speed and power performance. This conclusion is also supported by [11], which reports LCG 39% as optimal. An anomaly in the data is the apparent improvement in efficiency by moving the LCG aft to 37.1%. This conclusion is not supported by [11], which indicates performance degrades as LCG is moved aft to 38%. The reader is cautioned that the relative differences between speed and power in these various load condition tests approaches the limit of accuracy for the test equipment.

At full throttle, the average engine RPM of the 47FT MLB was 2350 RPM. This is 50 RPM over the engine's maximum rated RPM. Governing the engines to 2300 RPM will reduce the top speed of the boat to approximately 26 knots at full load. At 2350 RPM, the engines developed an average of 418 SHP each for the +2000 pounds load conditions and 406 SHP for the half load condition. This is 4 to 6% less than the manufacturer's rated 435 SHP at 2300 RPM. At the rated RPM, the engines develop about 400 SHP. This leaves a 10% power margin with the engines for the effects of fouling, weight growth, and added resistance of waves. This service margin is in keeping with recommended design practice for commercial marine diesel engines on large ships [13].

Figure TC-4.4 also shows advantages to carefully controlling the weight growth of the 47FT MLB pre-production boats. About 14% more power is required at 25 knots to drive the 18.81LT loaded boat than the 17.5LT boat with the LCG at 38.4%. The top speed of the boat with 2,870 pounds more weight is decreased 2.2 knots.

An unusual phenomenon observed with the 47FT MLB prototype during developmental testing and the speed power trials was the boat's tendency to heel 3 to 6 degrees to port while running at speeds greater than 20 knots. The boat does not carry any list while at rest, nor while operating at speeds less than 20 knots. At higher speeds, the boat always tends to heel to port, regardless of the trim, load, skeg or rudder configuration. At times it has been observed that the coxswain must use 1 to 3 degrees left rudder to maintain a steady course at speeds over 20 knots. Left rudder causes a roll moment which heels the boat to port. The observation of the rudder angle at higher speeds has not been as consistent as the port list, but the two do seem correlated. There do not appear to be any serious consequences to this peculiar behavior and it has not yet been investigated. Two theories have been postulated by test personnel. The slight lateral curve in the boat's keel as a result of a construction flaw (1½ inches over 43 feet) may cause a tendency to turn at higher speeds, requiring left rudder to correct. The other theory is that the stern fixed wedges appear asymmetric port to starboard, which may also induce a running heel. If these theories are correct, then a straight keeled, symmetric stern wedge pre-production boat would not display the port heel tendency.

Trim Angle vs Speed

The 47FT MLB carries less trim at all speeds compared to the planing hull 41FT UTB. The low speed trim angles of the 47FT MLB are comparable to the trim angles of the displacement hull 44FT MLB. Figure TC-5.8 shows the trim angles as a function of speed for all three boats. The lower trim angle of the 47FT MLB has several advantages. Generally, for planing hull boats, optimal trim while planing translates into decreased running resistance and improved operating efficiency. In addition to reduced efficiency, the relatively large trim angle of the 41FT UTB (nearly 7 degrees at speeds greater than 20 knots) can impede the coxswain's visibility under the bow.

The speed versus trim results shown in Figures TC-5.1-5 for various load conditions are also useful for validating the preliminary design model test results in [11]. The full-scale trim versus speed results for all speeds and load conditions tested agrees within 5% for most of the model scale tank tests and better than 10% for nearly all of the tank results. This good correlation between 1/8-scale model preliminary design tests and full-scale trials confirms the validity of the model for predicting the calm water trim of the prototype. The good agreement will allow engineers to validate potential design modifications for pre-production and follow-on MLBs using a model with increased confidence in the validity of predictions.

Righting Arm

No physical measurements of righting arms were required for this test by [2]. Instead, calculated righting arm curves, provided by U.S. Coast Guard [G-ENE-5] are analyzed. The method used to calculate these curves was validated by righting arm measurements made during a full-scale static rollover test conducted during builder's trials.

The increased righting arm of the 47FT MLB is a significant improvement in the design. The 47FT MLB has a substantially greater metacentric height than the 44FT MLB, resulting in greater initial stability and a shorter natural roll period. The effects of the increased stability on seakeeping is discussed in the analysis of motions test results TC-15. The 47FT MLB has a larger righting arm than the 44FT MLB for all roll angles, except between 70 to 100 degrees. The righting arm of the 47FT MLB is especially larger for angles greater than 130 degrees. The area under the righting arm curve is one measure of dynamic stability, or the energy required to roll a boat. From Figure TC-6.1 it is apparent that the 47FT MLB has considerably greater righting energy than the 44FT MLB. In a static, beam-to-the-seas condition, the 47FT MLB should be much more resistant to capsize than the 44FT MLB. If capsized, the large righting arms available with the 47FT MLB will help the boat self-right more quickly than the 44FT MLB.

Despite the tremendous static stability of the 47FT MLB, the boat's high-speed dynamic stability is an area for further study. Early developmental tests with the prototype in different rudder configurations identified a problem with the roll response of the 47FT MLB at high speeds as described in [6], [14] and [15]. A change in the rudder configuration eliminated high-speed "snap roll" and reduced "hang roll" broach problems discussed in the references. Since the rudder change, no dynamic stability problems have been observed in technical or operational testing. Extensive heavy weather testing of the prototype was conducted during the fall of 1991 by the MLB Test Team. The tests indicated that all the previous dynamic stability problems have been corrected in the prototype.

The early high-speed problems with the original prototype configuration are of technical interest to ensure there is no potential for recurrence in pre-production and follow-on MLBs. Developmental testing indicated that these high-speed roll motions were directly related to large rudder roll moments. The problems were solved by changing the rudder configuration to reduce rudder rolling moments at high speeds. The problems could potentially return if the boat's vertical center of gravity (VCG) increases too much as a result of design modifications. Care must be exercised during detail design of the pre-production vessels to prevent excessive increases in the position of the VCG from changes in the boat's weight distribution.

The developmental test references also note that when a roll angle of about 20 degrees was exceeded at speeds greater than 20 knots, significant broaching events were likely to occur. Broaches greater than 20 degrees roll angle could be prevented by keeping the boat's speed less than 20 knots while running down the face of a large following sea, and by limiting the maximum rudder angle (and therefore rudder rolling moment). In the current rudder configurations, no broaches exceeding 20 degrees roll angle have occurred in seas up to 15-foot significant wave height and breaking surf. Down-wave performance of the modified prototype has been satisfactory in to date.

Bollard Pull

The bollard pull test measures the static thrust of the boat as a function of engine RPM. Greater bollard pull indicates an increased capacity for towing and maneuvering at low speeds. Figure TC-7.3 shows the comparative results of tests with the 47FT MLB and the 44FT MLB. The 47FT MLB's improved bollard pull will likely make the boat well suited for towing and maneuvering with a tow alongside. The greater bollard pull also indicates more power available for operating the boat at low speeds in extremely heavy weather conditions.

Minimum Turning Radius

Table TC-8 shows the results of minimum turning radius tests for the three boats. The turning performance of the 47FT MLB is adequate for safe navigation and maneuvering, but is not as good as the 41FT UTB and the 44FT MLB. Turn radius varies as a function of boat speed and boat length. A faster, longer boat like the 47FT MLB is expected to have a greater turn radius than the other two boats. To allow a better comparison of relative performance, the non-dimensional ratio of turn radius to boat length is used. Measured results for the three boats are compared to the performance prediction technique of Denny and Hubble [16]. Figure 4 shows the comparison of the meaured turn radius of the three boats to the predicted turn radius with 30 degrees rudder at maximum speed. The 41FT UTB and the 44FT MLB both have a non-dimensional turn radius not more than 25% greater than the theoretically predicted performance. The turn radius of the 47FT MLB at full speed is 50% greater than predicted when scaled for length, speed and displacement. The predicted turn radius is 42 yards, compared to the actual 65 yard radius of the 47FT MLB. The 47FT MLB non-dimensional turn radius at 20 knots is also more than twice the radius of the Royal National Lifeboat Institute (RNLI) Mersey Class [17] from Great Britain and the Danish Kattegat Class [18]. Time to turn 360 degrees with these other boats is 10-20% less than the 47FT MLB.

Previous tests with the canted 2.7 square foot rudder configuration and a skeg resulted in extremely good turning radius for the prototype (time to turn 23 seconds, turning radius 40 yards at 25.5 knots) [15]. The drawback to this highly maneuverable configuration was an increased tendency to "hang roll" broach. As a result, the configuration was modified to the current 1.9 square foot vertical rudders with no skeg. The change has proven satisfactory in every respect except for the turn rate and radius. Experiments with various skegs and different rudders are planned for 1992 to optimize the turning radius and time to turn on the prototype with vertical rudders, as was done with the canted rudder configuration during the previous year.

In rescue and emergency situations coxswains will primarily maneuver the boat using the engines, not by high-speed maneuvers using only the rudder for control. Turning ability in tight quarters maneuvering is not a problem for the twin screw 47FT MLB. The boat has excellent maneuverability at speeds less than 10 knots using opposed engines. It is able to spin around in its own length, rotating through 360 degrees in less than 30 seconds by pivoting about with one engine ahead and one in reverse. The high bollard pull thrust of the boat, combined with adequate lateral separation between the propellers gives this very good maneuverability characteristic.

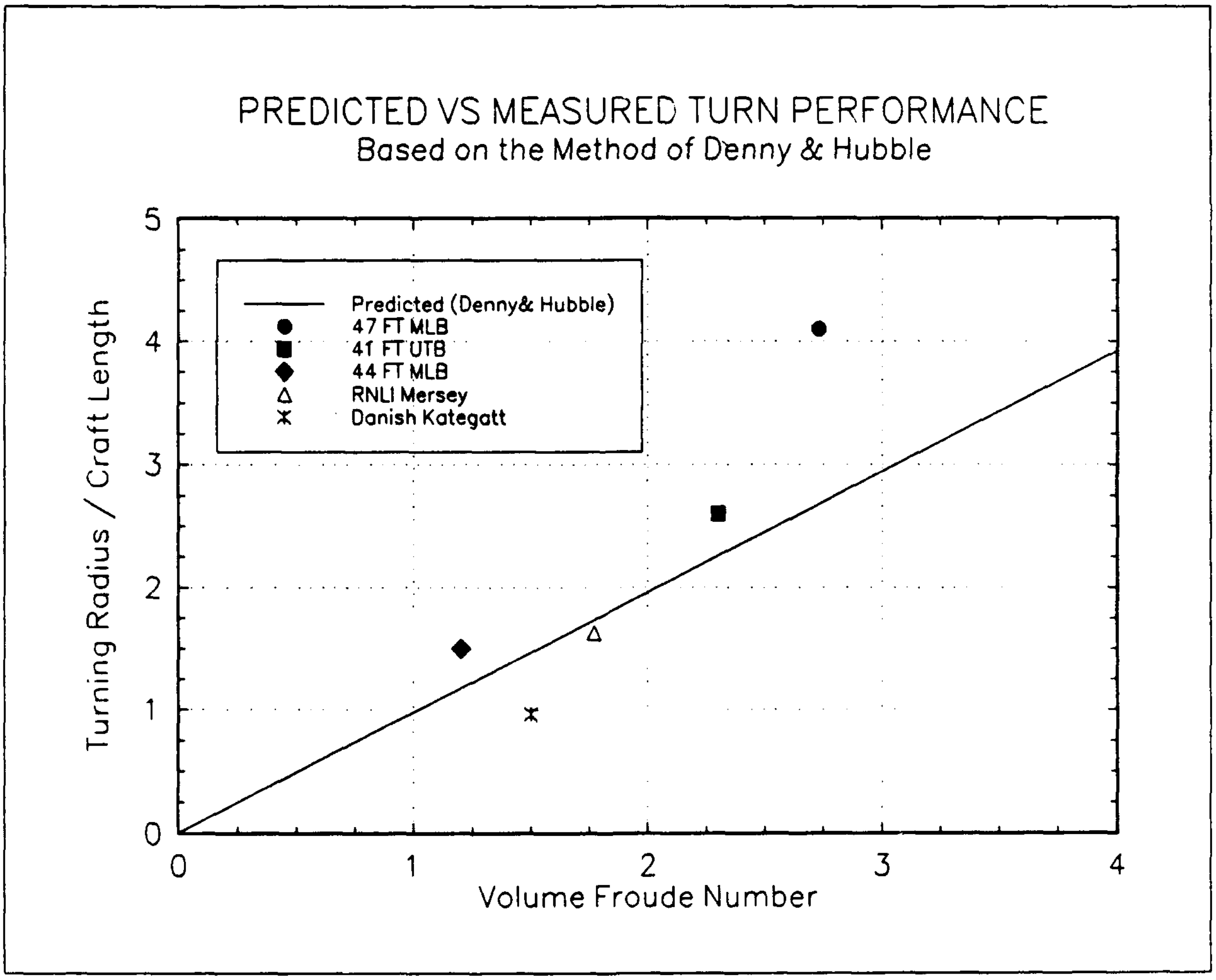


Figure 4. Comparison of Actual and Predicted Turn Performance

Acceleration

The calm water acceleration from a dead stop to maximum speed is measured in this test. Figure TC-9.5 shows a comparison of the acceleration of the three boats. The 47FT MLB and the 44FT MLB get "off the starting" line at about the same rate, but after 10 seconds, the 44FT MLB has reached its top speed, and the 47FT MLB quickly outruns the slower boat. The data in figure TC-9.4 and TC-9.5 for the 41FT UTB was obtained from a test of a Station New London 41FT UTB and represents performance of a typical boat. During a side by side trial with a 41FT UTB from Station Cape Disappointment, the 41333 pulled away from the 47FT MLB from a standing stop and remained ahead for 50 seconds until being overtaken. The Station Cape Disappointment 41FT UTB had been recently overhauled and tuned. Data of speed versus time was not recorded for the 41333, but it must be noted that a well tuned 41FT UTB can be faster off the line than the 47FT MLB.

The responsive acceleration of the 47FT MLB is advantageous for operating in heavy weather. The boat has low speed acceleration comparable to that of the maneuverable 44FT MLB, but has twice the top speed of the old MLB. The coxswain will have an increased ability to maneuver quickly for avoiding large waves. The top speed of the 47FT MLB prototype, at full load displacement, was measured in this test at 27.1 knots, which exceeds the requirements defined in [1] with a 2.1 knot margin. Propeller studies are planned for the winter of 1992 to optimize the performance of the 47FT MLB's propulsion system. An improved propeller design may result in increased acceleration and top speed.

Comparing Figure TC-9.1 to TC-9.2 shows the effects of adding 2000 pounds of weight to the 47FT MLB. The acceleration of the boat is decreased by nearly 10% with the additional load, and the top speed of the boat is reduced by 0.5 knots. The results of test TC-4 indicate a 2.2 knots reduction in speed with the addition of 2870 pounds to the Half Load condition. Also note that speed measurements in test TC-4 do not rely on the boat's speed log, which is only accurate to +/- 1 knot.

Speed vs Sea Height

Maximum speed attainable in head seas was observed for the 47FT MLB prototype in a wide variety of sea conditions up to a maximum of 15-foot significant wave height. The measure used to determine the maximum attainable speed for a given sea height was a subjective one which relied on the discretion of the coxswain operating the vessel. Nonetheless, the method is an accurate one, since ultimately the coxswain is responsible for the safety of the boat and the accomplishment of the operational mission.

The area between upper and lower limits on Figure TC-10.1 is indicative of the random nature of the waves and a difference in operation of the boat by various coxswains. For instance, it was much more difficult to make high speed in steep, short-crested seas than longer period waves with the same significant wave height. Also, some coxswains were extremely experienced and adept at controlling the boat's throttles to avoid serious slam impacts with big waves while still maintaining very high average speeds made good. Overall the speed in seas compares well with design predictions presented in [19].

The 47FT MLB can make much better speed in far worse sea states than either the 41FT UTB or the 44FT MLB (compare Figure TC-10.1 to TC-10.2-3). This is another significant advantage of the 47FT MLB. The boat is capable of arriving on scene more quickly, in more severe conditions than the other two rescue boats. The 41FT UTB has operational safety limitations on maximum wave height of 8 feet and no breaking waves. Heavy pounding of the 41FT UTB hull requires a voluntary speed reduction in waves greater than 5 feet. The 44FT MLB has proven its operational capability in seas exceeding 15 feet, but cannot achieve more than 10 knots in waves greater than 5 feet.

An area for further study with the prototype and pre-production boats is the potential effect on the crew of high-speed operations in rough conditions. High speed may result in crew fatigue and possibly physical injuries. A few instances of minor injuries occurred during developmental testing. Many of the human factors modifications proposed for the prototype in [10] are planned for evaluation on pre-production 47FT MLBs. These design changes are necessary to reduce the danger of injury and increase the comfort of the crew during high-speed head seas operations. Operational limit testing and human factors fatigue studies will help further refine the operational envelope for heavy weather head seas operation. In light of future testing, the upper limit speed for sea states higher than 5-feet significant wave height may be reduced (except for the most urgent emergencies). Rational operational limits derived from future studies could help further increase the comfort of the crew and reduce risk of injury in heavy weather operations.

Fuel Consumption and Range

The 47FT MLB meets the range requirements of [1] with a 250nm range at 27.3 knots based on half-load fuel consumption measurements. This range calculation assumes the boat has 400 gallons usable fuel and initial displacement of 18.0LT. A convenient check on these assumptions could be conducted at some point during future testing by running the boat until the fuel suction is lost and measuring the actual usable fuel.

The fuel consumption of the 47FT MLB and the 41FT UTB are within 10% of the fuel consumption of the 44FT MLB at speeds less than 10 knots. Figure TC-11.4 compares the fuel consumption rates as a function of speed for the three boats. The 41FT UTB uses about 15% less fuel at speeds greater than 20 knots than the 47FT MLB, but the 41FT UTB also is being driven by about 6% less horsepower than the 47FT MLB in that same speed range.

The estimated range as a function of speed for all three boats is shown in Figure TC-12.4. These range estimates are based on assumed values of usable fuel for each boat. 400 gallons usable is assumed for the 47FT MLB, 313 gallons for the 44FT MLB and 425 gallons for the 41FT UTB. Both the 41FT UTB and the 47FT MLB exceed the range of the 44FT MLB at all speeds. The 41FT UTB carries more fuel than the 47FT MLB and runs at a slightly lower consumption rate (see Figure TC-11.4). As a result, the 41FT UTB's range is about 10% greater than the 47FT MLB's range at speeds over 15 knots.

Spiral Test

The spiral test provides a measure of the directional stability of a vessel. If a boat is directionally unstable, it may possibly turn at two different rates for a given rudder angle, depending upon the initial conditions. The boat may be difficult to keep on a steady course. A severely directionally unstable boat may turn with no input from the helm, or even turn against the rudder. If a boat has too much directional stability, it may suffer reduced maneuverability, always tending to maintain a straight course.

The 47FT MLB possesses good directional stability as indicated by Figures TC-13.1-2. A small area of hysteresis appears in the 25-knot test condition, but because of the very low yaw rates at the low rudder angles, this may be due to data scatter.

An anomaly which appears in the 47FT MLB spiral results is the relatively low yaw rates, even at large rudder angles compared to the 41FT UTB and the 44FT MLB. Both of the other boats have a more steeply sloped yaw rate versus rudder angle curve. This indicates both vessels change heading more quickly than the 47FT MLB in steady turns.

Zig-Zag Test

Figure TC-14.1 shows the zig-zag maneuver of the 47FT MLB at 10 knots. The 47FT MLB has a first overshoot angle of 4.5 degrees, and an average overshoot angle of 11.5 degrees. The 47FT MLB has a 7.3 time-to-second execute, and a 14.9 second maneuver period.

Figure TC-14.3 shows the zig-zag maneuver performance of the 44FT MLB at 10 knots. The 44FT MLB has a first overshoot angle of 13 degrees, and an average overshoot angle on the three executes of 15 degrees. The 44FT MLB has a 5-second time-to-second execute and a 16-second maneuver period.

The 41FT UTB average overshoot angle at 10 knots is 9 degrees. The time-to-second execute for the 41FT UTB is 5.6 seconds and the average period of the maneuver at 10 knots is 18 seconds.

In the 10-knot trials, the 47FT MLB has a 50% smaller overshoot angle than the other two boats. This indicates the 47FT MLB has better turn-checking ability than both the 41FT UTB and the 44FT MLB. The decreased overshoot angle may also indicate the 47FT MLB has better directional stability than the 44FT MLB and the 41FT UTB, and/or that the 47FT MLB has a less effective rudder [20]. The 47FT MLB has a 30% greater time-to-second execute than the other boats at 10 knots. The increased time-to-second execute indicates the 47FT MLB has a less effective rudder and/or greater directional stability. The 47FT MLB has a 10% shorter average period at 10 knots than the other two boats. The shorter maneuver period may indicate the 47FT MLB's overshoot angles are less than the other boats, and that the swept path of the 47FT MLB is less.

At Maximum speed, the 47FT MLB has a 5-second time-to-second execute and a 7-second maneuver period. The first overshoot distance is 4.5 degrees, and the average overshoot is 8 degrees. In general the time-to-second execute and the maneuver period are expected to decrease with increasing speed and the overshoot angle generally increases [20]. For the 47FT MLB, the time-to-second execute decreases by 30% at the higher speed, and the overshoot angle decreases. This indicates improved yaw-checking ability for the 47FT MLB at higher speeds.

At 15 knots the 41FT UTB has only a 3.6 second time-to-second execute, but a 14.8 second maneuver period. The 15 knot initial overshoot angle is 15 degrees. The average overshoot angle is 10 degrees. At the higher speeds, the 47FT MLB has a longer time-to-second execute and a lesser overshoot angle. This again indicates the 47FT MLB has greater directional stability and/or a less effective rudder than the 41FT UTB.

Motions in Waves

This test compares the amplitudes of motion for the three boats on five headings in similar moderate sea states. The motions of the 47FT MLB at 10 knots and at 25 knots are less than or equal to the motions of the other two boats on all headings. Figures TC-15.2-13 show polar diagrams of the various motions of the boats. The plots show the magnitude of the average of the 1/3 highest (H 1/3) amplitude motions as a function of heading. The H 1/3 motions are determined by counting the peaks (amplitude, not peak to trough height) appearing in a time series of motions data, determining the peak amplitude exceeded by 1/3 of the motions and taking the average of the amplitudes in the highest 1/3. The headings are the direction of the boat relative to the predominate direction of the seas during the test. "Head" seas is running directly into the waves. "Bow" seas is at a 45 degree angle relative to the approaching waves. "Beam" seas is running parallel to the wave crests. "Quarter" seas is with the ships head at a 135 degree angle relative to the head seas direction. "Following" seas is when the boat runs down wave in the direction of the major seas.

Figure TC-15.1 shows the sea state measured by the wave buoy during the 47FT MLB trials. The majority of wave energy was concentrated coming from the direction of 305T. This course was the "Head" seas direction for the 47FT MLB. The wave energy was mostly concentrated in a 90 degree band centered on this direction. The significant wave height (the H 1/3 of the waves) was 4.8 feet. The average wave period from Table TC-15.1 was 8.6 seconds.

The other two boats were tested off the east coast, in Block Island Sound and Fishers Island Sound. The significant wave height for the 44FT MLB tests was 5.0 feet and the significant wave height for the 41FT UTB tests was 3.1 feet. The average wave period for the 41FT UTB tests was 4.8 seconds. Wave periods for Atlantic Coast waves are typically in the range of 4 to 8 seconds, whereas U. S. Pacific Coast waves typically range from 7 to 15 second period. The difference in wave periods between the tests of the different boats is not accounted for in this report. Wave period can have important effects on the motions of a boat and Atlantic Coast tests of the prototype or a pre-production boat are needed to completely evaluate the motions of the 47FT MLB in all of its future operating areas.

Figure TC-15.5 shows the roll amplitude of the 47FT MLB at 25 knots. The cardioid shape of the polar plot is typical of roll response. In head seas and following seas, the boat has an H 1/3 roll less than 4 degrees, because little wave energy or coupling effects act to make the boat roll. Roll amplitude is greatest in beam seas, about 6 degrees. Roll amplitude is slightly less in bow and quartering seas. Figure TC-15.2 shows the roll response of the 47FT MLB at 10 knots in the same sea condition. The magnitude of the motions is 1 to 2 degrees less at the slower speed, but still in the same general shape. Compare these two results to figure TC-15.8, roll response of the 44FT MLB. The 44FT MLB test is at 10 knots, and the roll amplitude on all headings is twice the H 1/3 roll of the 47FT MLB on all headings. In the 44FT MLB, quartering and following seas rolls have the greatest amplitude, 12 to 13 degrees H 1/3. The reduced roll motions of the 47FT MLB relative to the 44FT MLB represent a good improvement of the new design. Large amplitude roll motions can cause large lateral accelerations, which have an adverse effect on crew performance.

Figure TC-15.10 shows the roll response of the 41FT UTB in 3.1 foot seas. The 41FT UTB roll motions in beam seas are 2-3 degrees greater than the 47FT MLB's, but the motions in quartering and following seas are slightly less. Overall, the 41FT UTB and the 47FT MLB have similar roll response amplitudes.

The pitch response of the 47FT MLB at 10 knots is shown in figure TC-15.3 and at 25 knots in TC-15.6. Note that the two figures are plotted on different scales. At both speeds, the H 1/3 amplitude of pitch motions is about the same, 5 degrees in head seas and about 2 to 3 degrees on other headings. The figures do not show the period of pitch motions, which decreases to a sometimes uncomfortable level during high speed head seas runs. During the 25 knots head seas run, the peak response of the pitch motions had a period of 2.6 seconds. This is shown in figure TC-15.17, the pitch response spectrum. The pitch motions of the 44FT MLB are shown in figure TC-15.9. The 44FT MLB has 1 to 2 degrees greater pitch motions in head, beam quartering and following seas. The 41FT UTB pitch response is shown in figure TC-15.12. The pitch motions of the 41FT UTB at 15 knots are about equal to the motions of the 47FT MLB for all but bow seas. In bow seas, the 41FT UTB motions are about 2 degrees greater. Reference [5] notes that the reason 15 knots was selected as the test speed for the 41FT UTB seakeeping run was because any higher speed resulted in unacceptable slamming in head seas. Although the frequency and amplitude of pitching motions on the 25 knot head seas run of the 47FT MLB were not comfortable, the boat did not experience severe slamming.

The heave motions of the 47FT MLB are shown in figure TC-15.4 and TC-15.7. These figures show the heave (vertical) accelerations at the center of gravity measured by a gyro-stabilized accelerometer. At 10 knots, the H 1/3 accelerations are between 0.1 to 0.2 g (1 g is equal to acceleration of 32.2 feet/sec-sq) for beam, bow and head seas. Heave accelerations are between 0.1 to 0.05 g for quartering and following seas. At 25 knots, heave accelerations are greater on all headings. In head seas, the H 1/3 heave accelerations are about 0.5 g, three times the amplitude for the same heading at 10 knots. The 44FT MLB at 10 knots has similar heave acceleration response amplitude as the 47FT MLB has at 25 knots. The 41FT UTB has greater heave accelerations in bow seas at 15 knots, but about 0.1 g less response in quartering and following seas.

The best method to compare the relative motions of three different boats is to conduct the test side-by-side in the same waves and at the same speeds. This was not possible for this test because complete instrumentation is required for all three boats at the same time. In addition, the 47FT MLB can operate at significantly higher speeds than the 44FT MLB, making meaningful comparisons difficult. Response Amplitude Operators (RAOs) are sometimes used to compare the motions of different craft tested in different sea conditions. Difficulty was encountered during computation of the RAOs for the 47FT MLB. To avoid potential publication of incorrect results, RAOs are not presented here. Several references caution against placing too much confidence in motion predictions for different sea states derived from RAOs [3], [4], [21], so lack of these results does not detract much from the outcome of this analysis.

If motions are assumed to follow a Rayleigh probability distribution, the H 1/3 response may be related to the variance of the response spectrum [21]. The variance of a response spectrum is the area under the spectrum curve. The H 1/3 amplitude response is given by 2.0 times the square root of the spectral variance. Wave encounter and motions response spectra for beam seas roll and head seas pitch and heave at 25 knots are provided for the 47FT MLB in figures TC-15.14-18. The beam seas roll response at 25 knots has a large peak at about 0.15 Hz. The area under the spectrum is 8.2 deg-sq. The Rayleigh distribution assumed H 1/3 is 5.7 degrees, which agrees well with the beam seas roll H 1/3 of 5.8 degrees in Figure TC-15.5.

The pitch response spectrum for head seas at 25 knots has a peak at 0.39 Hz and a spectral variance of 2.2 deg-sq. The Rayleigh distribution assumed pitch H 1/3 is 3.0 degrees, which about 2 degrees less than the measured H 1/3 given in figure TC-15.6. The head seas heave response has a peculiar "double hump". This spectrum does not follow the classical Rayleigh distribution. The estimated H 1/3 from applying the Rayleigh distribution principles regardless is 0.35 g, about a 30% under-prediction of the actual response.

There appears to be good agreement between head seas pitch and heave H 1/3 responses for the 47FT MLB seakeeping model tests conducted at the U.S. Naval Academy [22] and the prototype trials. The model tests were conducted at 20 and 30 knots scale speed in irregular seas with 2.9 foot scale height and a 7.5 second modal period and 15 and 20 knots in 9.12 foot height with a 9.0 second modal period. The H 1/3 amplitude (average of peak and trough) responses from [22] are linearly interpolated to compare with the prototype head seas 25 knots with 4.9 foot significant wave height. The interpolated model vertical acceleration at the center of gravity is 0.49 g compared with 0.52 g observed during the prototype trials in 4.9 foot seas at 25 knots. The H 1/3 pitch of the model interpolated to the full scale head seas is 4.2 degrees, compared to 5 degrees for the prototype. This good agreement of results helps increase a designer's confidence in the validity of model tank tests for predicting the full scale heave and pitch characteristics of the boat in head seas.

Time series data of motions of the 47FT MLB and of the other two boats are stored on magnetic tape at the U. S. C. G. Research and Development Center. Readers interested in further analysis of the motions in waves data may contact the Marine Engineering Branch to discuss access to the data.

SUMMARY

The purpose of the tests described by this report was to independently measure technical aspects of the boat's performance. The results of this evaluation have been very positive. The 47FT MLB meets or exceeds all of the technical characteristics requirements outlined in [1]. The tests in this report do not include an important aspect of the boat's operation, performance in surf. Surf testing results are reported in the Design Performance Verification Report from the MLB Replacement Project Test Team. Table 3 summarizes the performance of the prototype relative to its required operational characteristics and critical technical characteristics.

The prototype exceeds its operational requirements for maximum speed with a 9% margin, and exceeds its continuous speed requirement with an 11% margin. The maximum range of the prototype at full speed is 248 nautical miles, meeting the 200-nm range requirement with a 50-gallon fuel reserve, or a 48-mile range reserve. The endurance of the boat at 25 knots is 10 hours. The boat meets the 8-hour endurance limit at 25 knots with a 75-gallon fuel reserve. Please note that range and endurance calculations are only accurate to within ± 10% because of the combined effects of a ± 0.5 knot uncertainty in speed measurements and a ± 1% instrument accuracy in total fuel consumption measurements.

The prototype meets its operational requirements for stability based on a positive righting arm through 360 degrees heel angle. The boat meets its requirements for crew size, number of survivors, length, beam, draft and hoisting weight. The draft requirement of the prototype 47FT MLB was extended to 4 feet, 4 inches and the overall length to 47 feet, 11 inches. The extreme limits of the 47FT MLB's operational envelope will be tested during Design Limit Testing. During earlier developmental testing, the prototype was operated successfully in head seas up to 15 feet significant wave height and winds up to 40 knots.

TABLE 3
REQUIRED OPERATIONAL AND
CRITICAL TECHNICAL PERFORMANCE SUMMARY

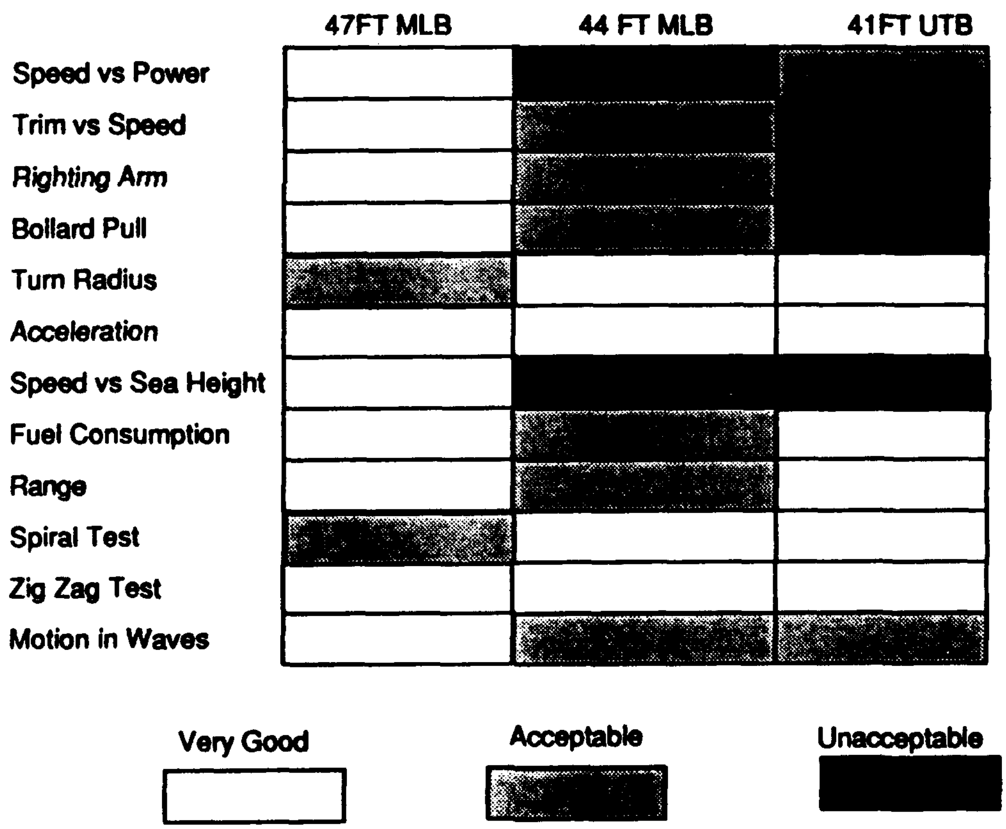
CHARACTERISTIC	REQUIREMENT	TEST	PERFORMANCE	RATING
Speed (MAX)	25KTS	TC-4,9	27.1KTS	++
Speed (CONT)	20KTS	TC-4,10	22.3KTS	++
(SS2)				
Range	200nm	TC-12	248nm	++
(At MAX SPD)				
Endurance	8hrs	TC-11,12	8hrs w/	><
(MAX SPD w/			75 gals Res	
20% Fuel Res)			(25 knots)	
Stability	360deg	TC-6	360 Positive	><
	Self-Right		Stability	
Operating				
Environment	20FT Seas/	Design	Up to 15FT	*
Sea State	20FT Surf	Limits	NOT TESTED	*
Wind	50KTS	Testing	UP TO 40KTS	*
Standard Crew	4	TC-1	4	><
Survivors	5	TC-1	5	><
Haul Out Limits				
Length	47FT	TC-1	47FT 11IN	><
Beam	14FT	TC-1	14FT	><
Draft	4FT 4IN	TC-1	4FT 4IN	><
Weight(Hoist)	40,000LBS	TC-1	40,000LBS	><

- RATING SCALE-

++ Exceeds Requirement
>< Meets Requirement
-- Fails requirement
* Pends Design Limit Testing

The 47FT MLB prototype meets or exceeds the performance of the two proven Coast Guard boat designs in all aspects except minimum turning radius and turn rate using the rudder only. The turn radius and rate of the 47FT MLB is acceptable for safe navigation and maneuvering. Design Performance Verification Testing and Operational Evaluation will test the 47FT MLB's performance in light of operational effectiveness. Table 4 summarizes the 47FT MLB's performance on technical characteristics tests compared to the 44FT MLB and the 41FT UTB. The performance ratings in this summary are subjective ratings of the relative performance of the three boats on the technical characteristics tests, judged against the requirements for the new motor lifeboat.

TABLE 4
COMPARISON OF TECHNICAL CHARACTERISTICS PERFORMANCE



The analysis section of this report evaluates the strengths and weaknesses of the 47FT MLB in light of Technical Characteristics Verification test results. Table 5 summarizes the strengths and weaknesses of the boat detailed in the analysis section. The 47FT MLB has many advantages which will enhance rescue and other operations. The combination of the boat's increased speed with good righting arm and a strong hull should make it suitable for service as a motor lifeboat. The combination enclosed bridge/flying bridge with multiple control stations is an important feature, offering great flexibility to the crew. The increased height of eye from the flying bridge and enclosed bridge provides better visibility for the crew. The boat's increased horsepower, high bollard pull and twin screw maneuverability provide good low speed control and improved towing capability.

The weaknesses of the prototype 47FT MLB do not substantially detract from the boat's capabilities. An ECP to improve the enclosed bridge arrangements and Human Factors Engineering is planned for evaluation on pre-production MLBs. An ECP to add protective strut extensions for the propellers to prevent grounding damage will be evaluated on the prototype later in 1991. Full-scale tests with various skegs and vertical rudders to optimize the turn performance of the prototype are also planned for later in 1991.

TABLE 5
STRENGTHS AND WEAKNESSES OF THE 47FT MLB

STRENGTHS

Increased Speed In Rough Seas
Greater Maximum Speed
Reduced Motions In Waves
Excellent Righting Arm
Strong Hull
Multiple Control Stations
Combined Enclosed/Open Bridge
Increased Height of Eye
Increased Horsepower
Increased Bollard Pull
Twin Screw Maneuverability
Lower Running Trim Angles
Full Scale Agrees with Model Test
Adequate Range
Good Directional Stability
Good Zig-Zag Performance

WEAKNESSES

Greater Draft
Exposed Propellers
Enclosed Bridge Arrangements
Human Factors Engineering
Adequate but Marginal Turn Radius
Low Turn Rate

Several areas are recommended for further study and evaluation based on developmental test results. These studies should proceed concurrently with pre-production efforts. The optimization of the design from recommendations of further studies could be accomplished through ECPs and Boat Alterations if required.

Early developmental testing with other skeg and rudder configurations revealed a high-speed dynamic stability problem resulting in large roll angles and significant broaches when full rudder was applied at high speeds. These problems were thought to be related to large rudder rolling moments, and were corrected by changing to smaller vertical rudders. The reduced rudder rolling moment has reduced to tolerable levels the earlier "snap roll" and "hang roll" problems in the prototype. The high-speed roll response of the 47FT MLB was not expected because of the boat's conventional hull form and good static stability. Similar design problems and future recurrence of earlier high-speed roll problems could be prevented by a detailed study into the hydrodynamics of the prototype's roll behavior.

The port list carried by the boat while operating at speeds greater than 20 knots has been a continuing anomaly during developmental testing. There do not appear to be any serious consequences to this curious behavior, but the situation should be investigated through comparisons between the prototype and pre-production boat running heel angles.

The range calculations in this report are subject to errors up to 10% from the combined effects of uncertainties in speed, fuel consumption and useable fuel capacity. A fairly quick and easy verification of the range calculations could be accomplished by operating the boat at full speed until it is out of fuel, and then measuring the distance travelled. This test would remove any shadow of doubt regarding the boat's range and would provide project managers further data about the boat's performance at the extremes of its envelope. The study could occur any time during design limit testing or pre-production boat testing, and will help avoid the potential of a boat unexpectedly running out of fuel on a long mission some day.

Reference [10] noted many human factors engineering issues for resolution on the prototype 47FT MLB. The 47FT MLB Test Team has gained additional experience with the layout and human factors detailing of the boat. The recommendations of both [10] and the Test Team are incorporated in an ECP for the pre-production 47FT MLBs. As pre-production boats are constructed, the human factors engineering evaluation of these changes should continue, so that the best possible arrangement can be developed before the boats go into full production.

The high speed attainable by the 47FT MLB in rough sea conditions could potentially result in crew fatigue. As the 47FT MLBs are brought into operational service, rational doctrine must be developed to reduce any potential risks on the boat crews. Standards for limits on speed or mission length in various sea states should be based on a study of crew fatigue on the new boats. This testing could be accomplished during the operational evaluation of pre-production boats, so that operational doctrine and training will be in place as 47FT MLBs are introduced to full service.

The motions response of the 47FT MLB should be evaluated in typical Atlantic Coast wave conditions to ensure the boat has acceptable characteristics in all operating areas. The motions in waves test indicated the boat has reduced motions in longer period waves, but was unable to measure the motions in shorter period waves typical of east coast operating areas. This test could be conducted when the first east coast pre-production boat is delivered.

CONCLUSION

The 47FT MLB prototype technical performance was evaluated during the Technical Characteristics Verification Testing. The boat meets or exceeds all of its Critical Technical Requirements. These test requirements do not include surf testing, which is reported separately by the MLB Replacement Project Test Team. The boat outperforms the 41FT UTB and 44FT MLB, two proven Coast Guard rescue boats, in almost every way. The prototype 47FT MLB has many strengths including increased speed, decreased motions, better seakeeping, increased height of eye and multiple control stations. The weaknesses of the prototype are addressed in ECPs or are planned for optimization during the coming winter season. Several areas for further study, concurrent with the pre-production testing program, are recommended in the preceding section of this report.

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APPENDIX A

STRUCTURAL EVALUATION OF THE 47-FT MOTOR LIFEBOAT

MARCH 1991

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SUMMARY

The USCG Research and Development Center, in response to a request from the Office of Naval Engineering (G-ENE), conducted structural testing of the 47-FT Motor Lifeboat (47' MLB) at Cape Disappointment, Washington, during the first two weeks of March 1991. Strain gauges were placed on the interior of the hull in various locations to measure stress level in the structure, simultaneous with the measurement of vertical acceleration during a variety of sea states and vessel speeds.

In general, stress levels were very low. Specifically, at the design condition of 25 knots, in Sea State 3, the average (RMS) stress level in the forward bottom plating was less than 1,000 psi, relative to the as-welded yield strength of 26,000 psi. The extreme stress value, recorded after the boat went airborne off a wave and slammed back to the surface, was about 5,000 psi, for a nominal factor of safety of 5 on the yield strength. By comparison, most high speed patrol boats are designed with a factor of safety between 1.0 and 1.5.

Structurally, this is a very well designed vessel, which should withstand the rigors of the heavy weather service for which it was intended.

TEST PROCEDURE

Strain gauges and accelerometers were placed on the hull at locations mutually agreed to by R&DC and G-ENE-5A, as shown in Figure A-1 and listed in Table A-1. The strain gauges were applied when the boat was out of the water. The effect of a still-water bending moment should be negligible. Single strain gauges were placed on various plating panels such that the gauge was perpendicular to the longest edge and as close to the weld as possible. Strain gauge rosettes were placed in the center of one bottom plating panel and on the interior flange of the main deck near the recovery well. Single-axis fixed accelerometers were placed at the bow, stern, bridge and center of gravity as shown. Signals from all sensors were properly amplified and shielded, then recorded on digital tape for later analysis. Test runs were made in calm water at two speeds, in Sea State 3 at two speeds and in Sea State 4 at maximum possible speed, all in head seas. An additional run was made in stern seas at maximum possible speed. The calm water runs were made in the Columbia River in water depths of about 40-50 FT and other runs were made offshore in water depths of 80-100 FT. Speed was measured by the boat's speed log, since GPS was not available. Wave heights were estimated from NOAA reports and seaman's eye due to failure of the wave buoy. Videotapes recorded wave conditions and slamming events. The boat was intentionally slammed in waves and occasionally was airborne before slamming. On any given test run, a minimum number of 100 wave encounters were recorded. A test matrix is shown in Table A-2 with a summary of stress levels.

TABLE A-1
STRAIN GAUGE AND ACCELEROMETER LOCATIONS

S.G. 1,2,3	Rosette on bottom plating in center of panel bounded by Fr. 10 and 11, CVK and L-1.
4	Bottom plating panel bounded by Fr. 13 and 14, L1 and L2, center of long edge, perpendicular to L2.
5	Same as 4, but between Fr. 12 and 13.
6	Same as 4, but between Fr. 11 and 12.
7	Same as 4, but between Fr. 10 and 11.
8	Bottom plating panel bounded by Fr. 10 and 11, L3 and L4, center of long edge, perpendicular to L4.
9	Same as 4, but between Fr. 8 and 9.
10,11,12	Rosette on main deck extension inside the Survivor's Compartment, between Fr. 6 and 7.
13	Deckhouse locker forward panel, between Fr. 11 and 12, perpendicular to vertical seam on centerline.
14	Side plating panel between Fr. 14 and 15, just above chine, center of long edge.
15	Bottom plating panel bounded by Fr. 7 and 8, L2 and L3, center of long edge, perpendicular to tank side.
16	Same as 14, but between Fr. 12 and 13.
Accel. 17	On centerline, aft face of BHD 15, 8 FT ABL.
18	On centerline, about Fr. 9, on overhead of enclosed bridge, about 14FT ABL.
19	On centerline, about Fr. 8, under the step through the WT Door, about 2FT ABL.
20	On centerline, aft face of BHD 1, 5 FT ABL.

TABLE A-2
TEST MATRIX

Test No.	Sea State	Boat Speed	Test Time	Stress (RMS) (psi)	Stress (Extreme) (psi)
4791	Calm	25.0 k	7 min.	120	200
4792	Calm	27.3 k	7 min.	120	250
4793	SS-3	25.0 k	5 min.	300	4,800
4794	SS-3	26.5 k	5 min.	300	5,300
4795	SS-4	24.0 k*	5 min.	200	320
4711	SS-4	20.0 k**	7 min.	300	4,600

* This test was in stern seas; all other tests in head seas. Speed estimated by LORAN; full throttle for 5 minutes.

**Speed was variable, depending on coxswain's choice on large waves.

DATA PROCESSING

After the data are gathered on digital tape, processing is completed at the R&D Center using techniques developed jointly with NAVSEA Combatant Craft Engineering Station, Norfolk, Virginia. Acceleration signals are analog-filtered with a 10 hz low-pass Butterworth filter, to remove extraneous high frequency content due to engine and propeller vibrations and hull resonance. This results in "rigid body" acceleration values, which can be digitized at different sampling rates. Generally, 50 samples per second is sufficient to capture most events, but occasionally slamming events are sampled at 1,000 hz and even 20,000 hz if there is a need to describe the shape of the rise curve of the event.

Strain gauge signals are conditioned while being amplified and no further filtering is required. These signals are digitized at 50 hz and processed using standard statistical programs.

TEST RESULTS

In general, stress levels were very low, as compared with the as-welded yield strength of 26,000 psi for this aluminum (5456). A typical sample of the 25-knot run in Sea State 3 is shown in Figure A-2 (stress) and Figure A-3 (acceleration). Near the end of the run, a slamming event produces a peak acceleration at the C.G. of 3.1G, corresponding to a peak stress of 5,000 psi (compressive) near the edge of the panel with Strain Gauge 7. The RMS value of stress for the entire run is about 250 psi and the RMS acceleration is 0.24G. The 1/10th highest acceleration is 1.34G.

An example of the benefit of using tape which can be digitized at various sampling frequencies is shown in Figure A-4. Here the sampling frequency is increased to 1,000 hz and the "flat" stress curve is obvious when the boat is airborne. The peak stress again is about 5,000 psi (compressive) near the edge of the panel with Strain Gauge 8. The acceleration at the C.G. for this event is 5.1G, but the duration of the impulse is only about three-thousandths of a second (3 msec). Although the event produces physical discomfort for the operator (and test team), the effect is not prolonged. It is worthy of note that the bow accelerometer measured 9.7G during this event, verified by an independent accelerometer just below on the same bulkhead, which measured 9.8G.

The stress level at strain gauge 15 in the bottom plating near the C.G. is generally less than in the forward bottom plating, except during one slamming event when it was slightly greater. The stress in the side plating (gauges 14 and 16) is generally less than 1,000 psi during all runs, except for one major slam when it reached 4,000 psi on gauge 16. No stress in excess of 300 psi was measured in the deck locker (gauge 13).

Figure A-5 shows the traces of the four accelerometers during a slamming event. Note the time lag of the stern accelerometer and the similar values of the C.G. and bridge accelerometers which are only a few feet apart longitudinally.

For the strain gauge rosettes, the individual readings of the three gauges are processed through software that produces the Von Mises equivalent uni-axial stress. Examples of stress plots from the rosettes are shown in Figures A-6 and A-7. Rosette 1,2,3 on the bottom plating between Frames 11 and 12 measured stresses as shown in Figure A-6, generally lower than the corresponding stresses at the edge of the panels, such as gauges 7 and 8. Figure A-7 shows the stress in the main deck from rosette 10,11,12 leading up to a major slam. The RMS stress for the entire run is about 140 psi and the slam is about 2,200 psi, both quite low.

CONCLUSIONS AND RECOMMENDATIONS

The 47-FT Motor Lifeboat should withstand the rigors of the heavy-weather service for which it was intended. Stress levels are well within the design limits for the material and the infrastructure is rugged and well-built. A nominal factor of safety of at least 5 has been found in all plating. Transient accelerations at the bow in the order of 10 G have not damaged any structure or auxiliary equipment. The only recommendation concerning the structure is to take greater care during construction to achieve a fair hull. There are many indentations and weld deformations that could be avoided through better craftsmanship.

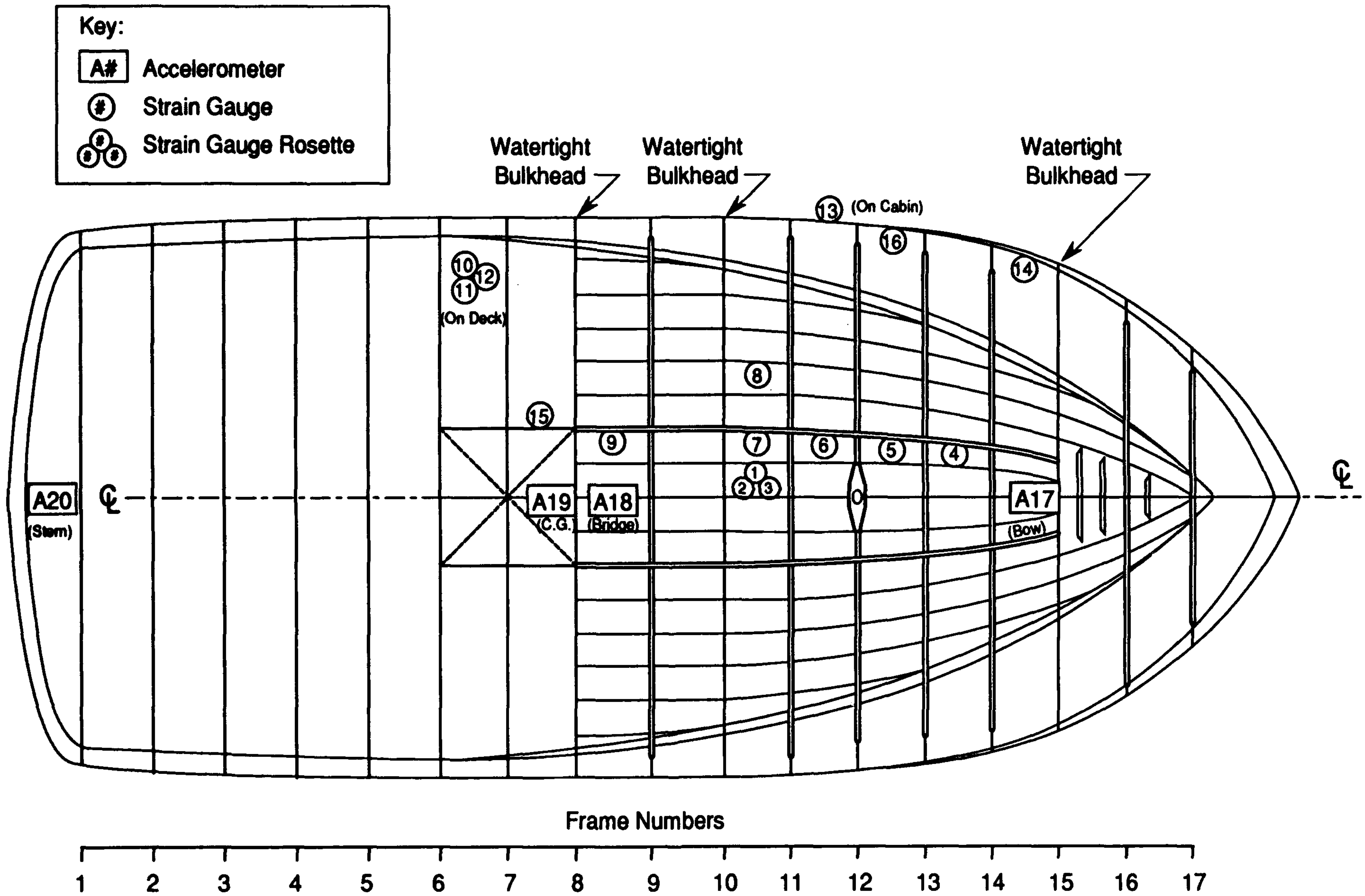

FIGURE A-1 47-foot MLB Structural Evaluation; Strain Gauge and Accelerometer Locations

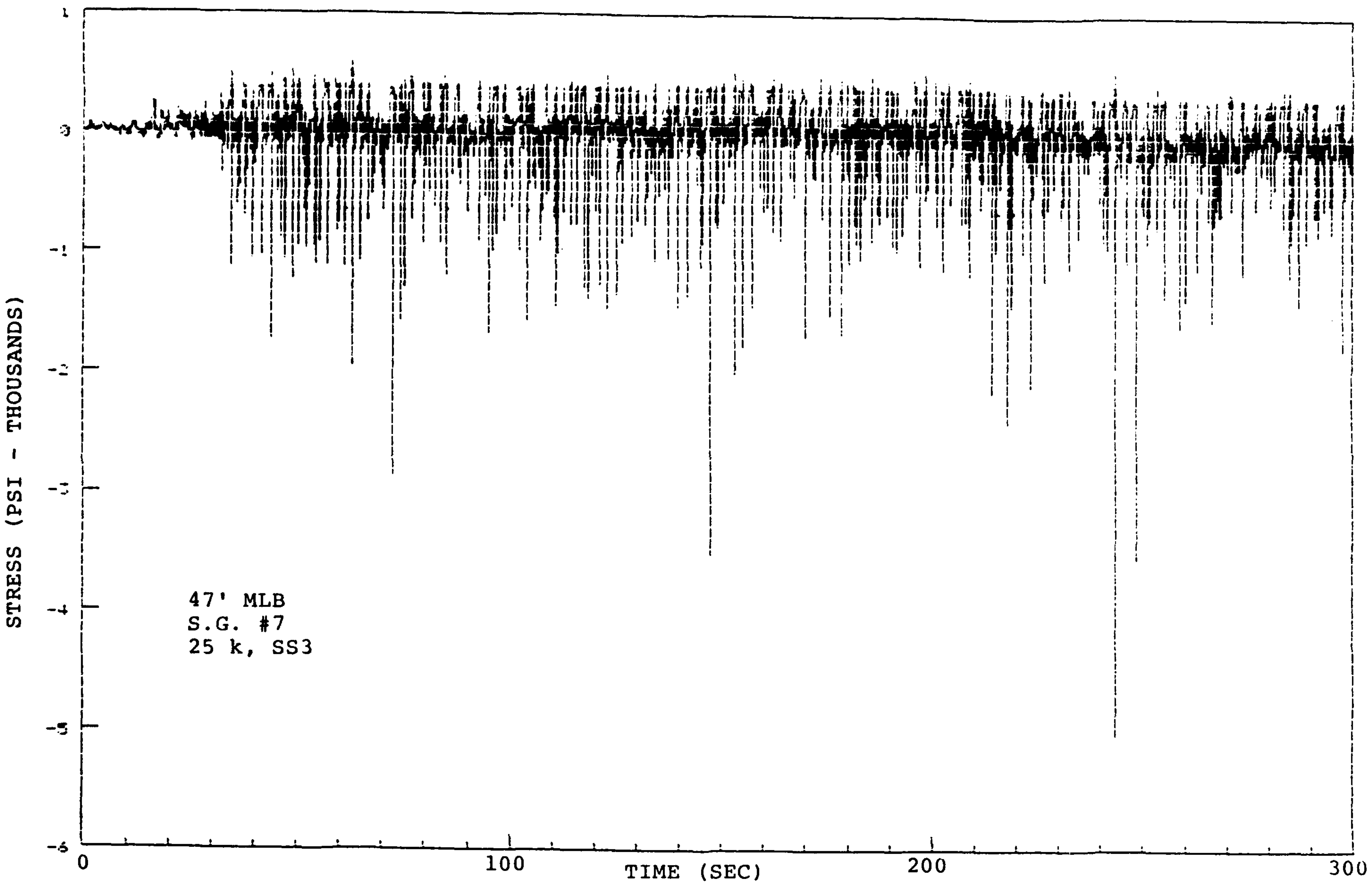

FIGURE A-2. BOTTOM PLATING STRESS, TEST 4793

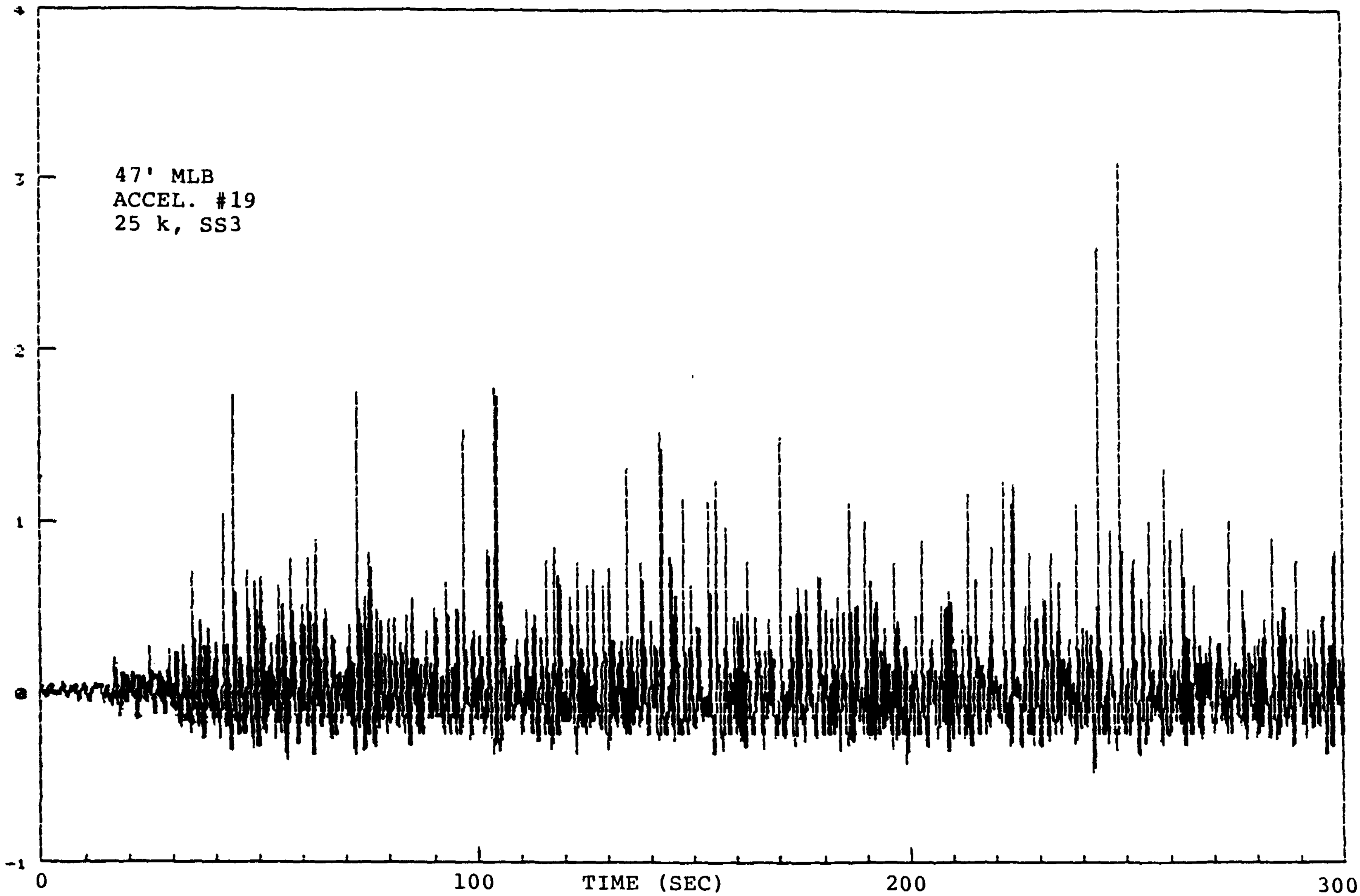

FIGURE A-3. ACCELERATION AT C.G., TEST 4793

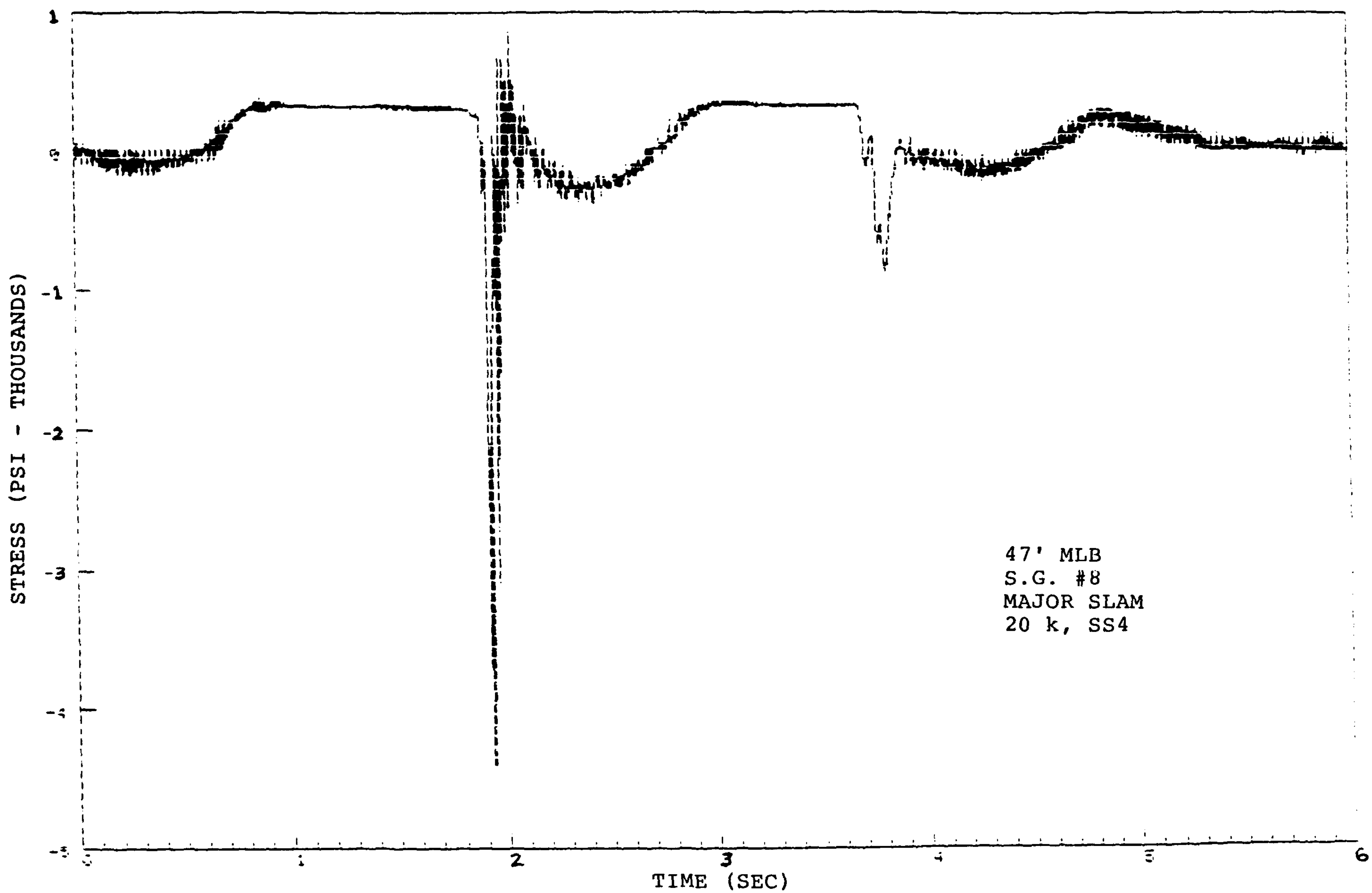

FIGURE A-4. BOTTOM PLATING STRESS, TEST 4711

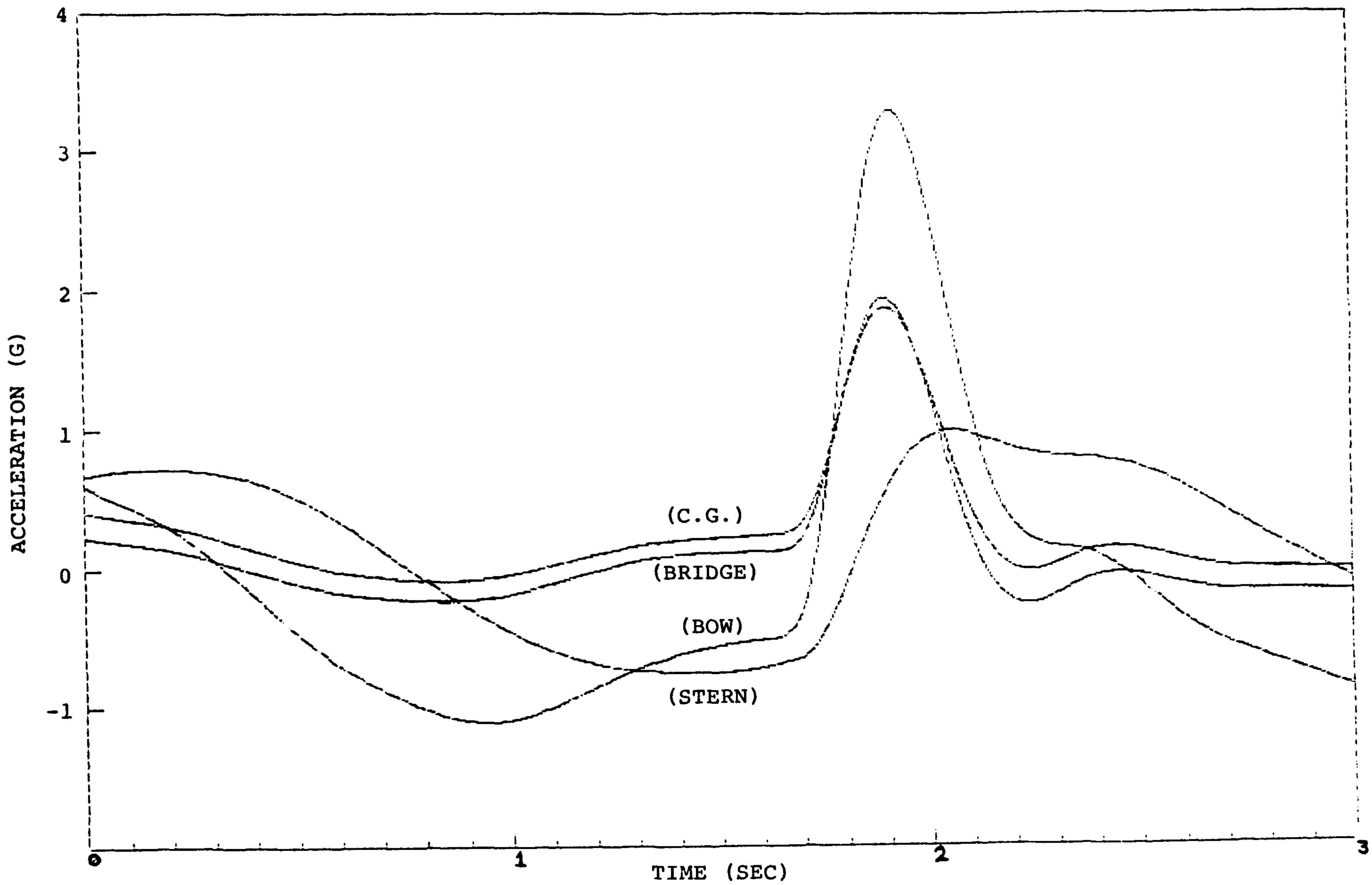

FIGURE A-5. ACCELEROMETER RESPONSE TO SLAMMING

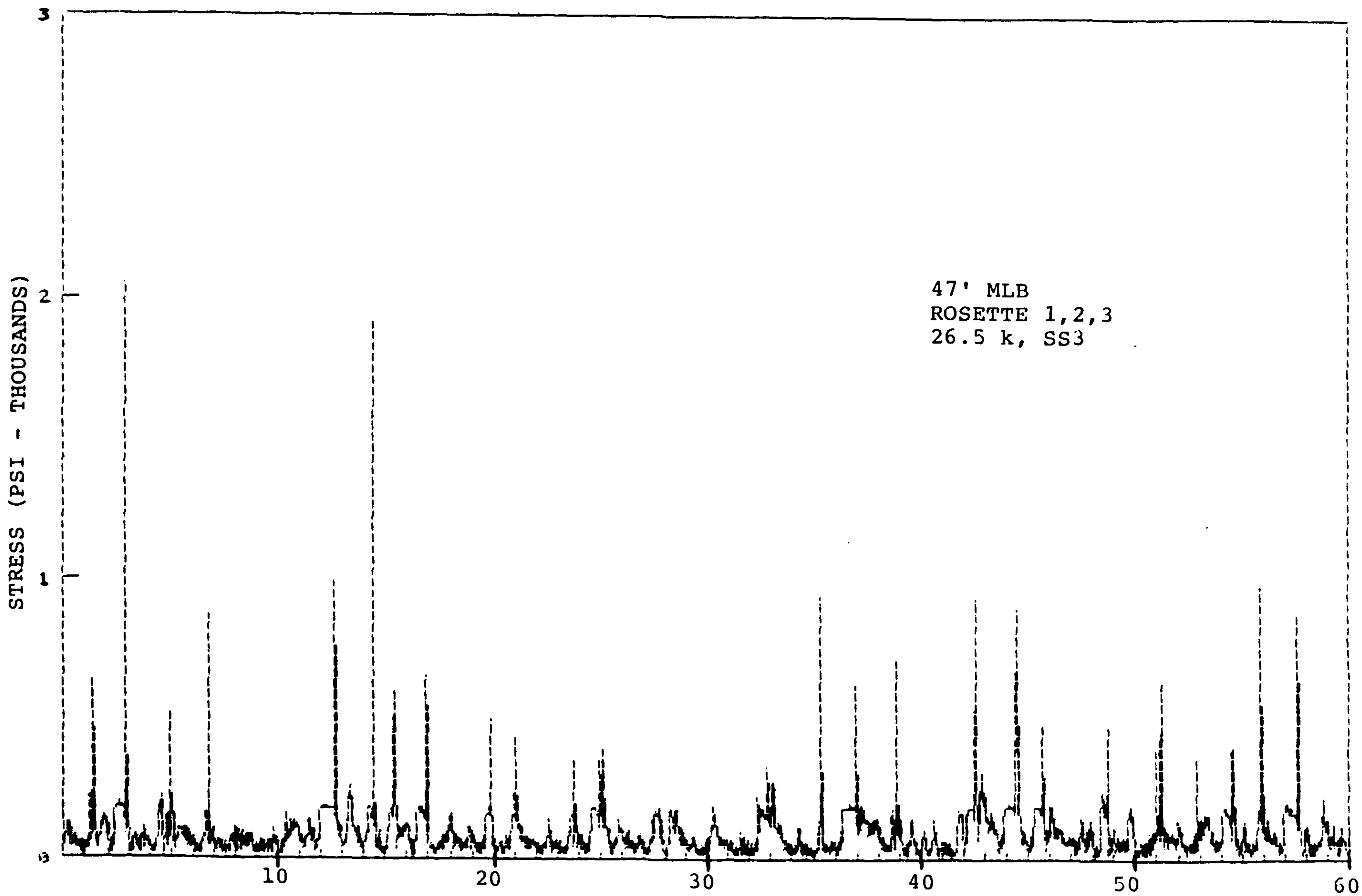

FIGURE A-6. BOTTOM PLATING STRESS, TEST 4794

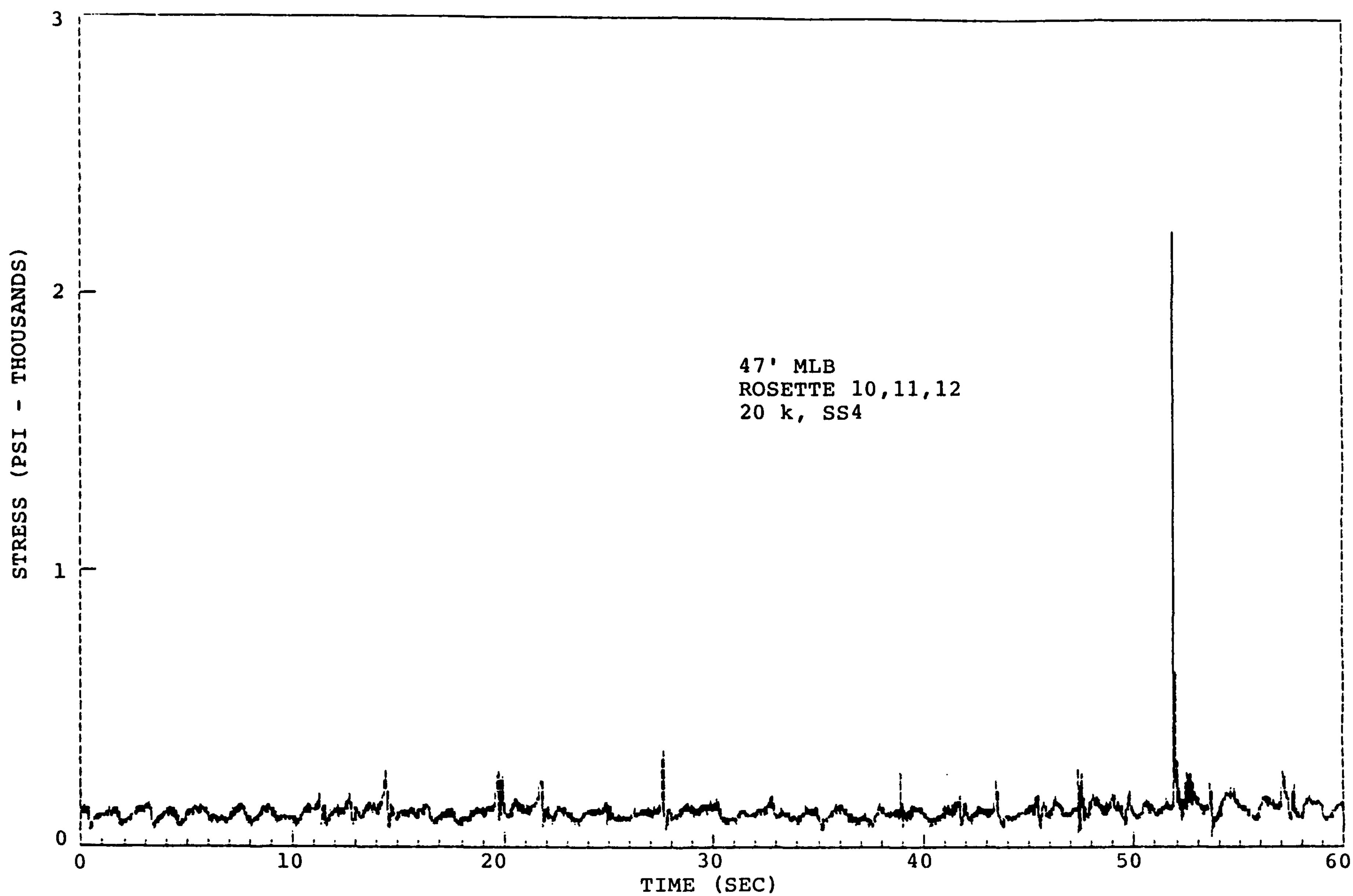

FIGURE A-7. DECK PLATING STRESS, TEST 4711

APPENDIX B

TEST EQUIPMENT

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LIST OF TEST EQUIPMENT - 47FT MLB

FLUIDYNE Diesel Fuel Economy Measurement System 1214D/1228, modified for Coast Guard marine use (Mfg: EMCO)

TEAC RD 200T PCM Data Recorder, 16 channel

TEAC MR-30, data recorder, 7 channel

ENDECO Type 956 Directional Wave Track Buoy (with Zenith laptop Supersport 286e)

HUMPHREY Motion Package with 9 parameters (Angle: roll, pitch, yaw); (Acceleration: heave, surge, sway); (Rate: roll, pitch, yaw)

EDR-1 data recorder for acceleration and shock (with Zenith laptop Supersport 286e)

B&K accelerometer charge amplifier, Types 2635 and 2651

B&K accelerometer, Type 4368

MEASUREMENT GROUP 2310 signal conditioner for strain gauges

Strain gauges M.G. CEA-13-250 UR-350 rosettes

Strain gauges M.G. CEA-13-250 UW-350 single element

Ships clinometer Type 11 - heel angle

SPERRY Angle Star protractor (digital inclinometer)

HUMPHREY potentiometer, cable-operated (analog rudder angle indicator)

TRIPLITE 24-volt inverter, 1000-watt, PV-1000 FC/24

B&K 2231 modular precision sound level meter, used with Type 1624 octave filter

MOTOROLA GPS System, Eagle VIII, 8-channel GPS receiver (with Zenith Supersport 286e laptop controller)

Data Reduction

AP CIRCUIT, 4-channel low-pass filter

HP 9000 series computer

HP 3497A data acquisition control unit

HONEYWELL Test Management System (HTMS) 3000 (now KINETIC SYSTEMS)