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AT-SEA EVALUATION OF THE COAST GUARD VOSS, NOFI-V AND FIOCS OIL RECOVERY SYSTEMS

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16. Abstract

At-sea evaluations of the U.S. Coast Guard Vessel of Opportunity Skimming System (CG VOSS) were conducted to determine its seaworthiness, handling and towing characteristics. The M/V TROJAN, a 225 ft offshore supply vessel, was used to evaluate the CG VOSS, the NOFI-V Sweep, and the FIOCS systems during trials off the coast of Groton, CT and near Montauk Point, Long Island. The system outriggers were instrumented to measure strain during standard operations and maneuvers. Load cells were attached to handling lines to determine tensions in the various systems during operations. Depth gauges were placed along the CG VOSS boom skirt and the NOFI-V Sweep boom skirt to determine the dynamics of these booms in calm water and heavy seas through their maximum operational speeds. Hydrodynamic and structural performance of the systems were presented.

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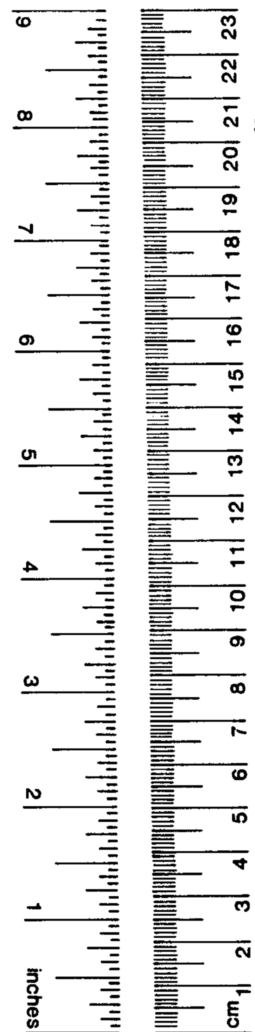
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

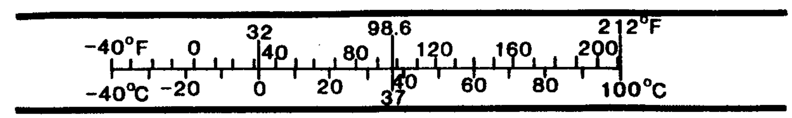
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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).



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



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ABSTRACT

At sea evaluations of the U.S. Coast Guard Vessel of Opportunity Skimming System (CG VOSS) were conducted to determine its seaworthiness, handling and towing characteristics. The M/V TROJAN, a 225 ft offshore supply vessel, was used to evaluate the CG VOSS, the NOFI V Sweep, and the FIOCS systems during trials conducted off the coast of Groton, CT and near Montauk Point, Long Island. The system outriggers were instrumented to measure strain during standard operations and maneuvers. Load cells were attached to handling lines to determine tensions in the various systems during operations. Depth gauges were placed along the skirt of the CG VOSS boom skirt and NOFI V Sweep boom skirt to determine the dynamics of these booms in calm water and heavy seas through their maximum operational speeds. Hydrodynamic and structural performance of the systems are presented.

ADMINISTRATIVE INFORMATION

The work described in this report was sponsored by the United States Coast Guard Research and Development Center under Military Interdepartmental Purchase Request (MIPR) Z 51100-1-E41A28. The work was performed by the Carderock Division, Naval Surface Warfare Center under Work Unit 1541-710.

1.0 INTRODUCTION

The Carderock Division of the Naval Surface Warfare Center, (CDNSWC) was tasked by the United States Coast Guard Research and Development Center to evaluate the performance of the Vessel of Opportunity Skimming System (VOSS) procured by the USCG and referred to as the CG VOSS. The CG VOSS is designed to be a rapid response oil spill recovery system that can be deployed from both sides of any suitable and available ship near a spill site. The CG VOSS system is shown in a plan view in Fig. 1. The equipment necessary to configure one side of a vessel of opportunity is comprised of the following components:

1. Three sections of outrigger attached orthogonally to a ships rail via a gimballed fixed point and various tensioning lines, Fig. 2,

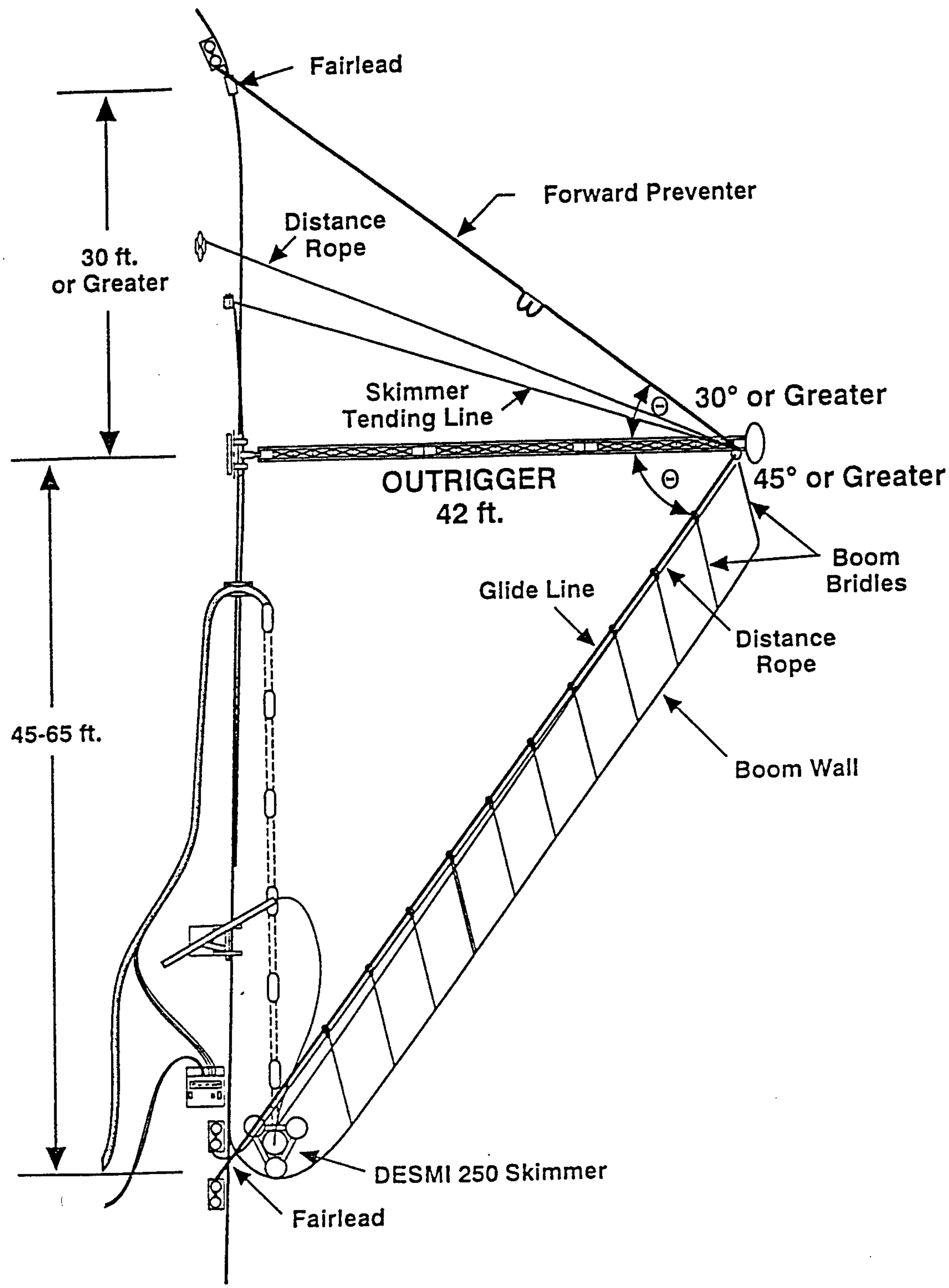


Fig. 1. CG VOSS system as viewed from above (ref. operations manual)

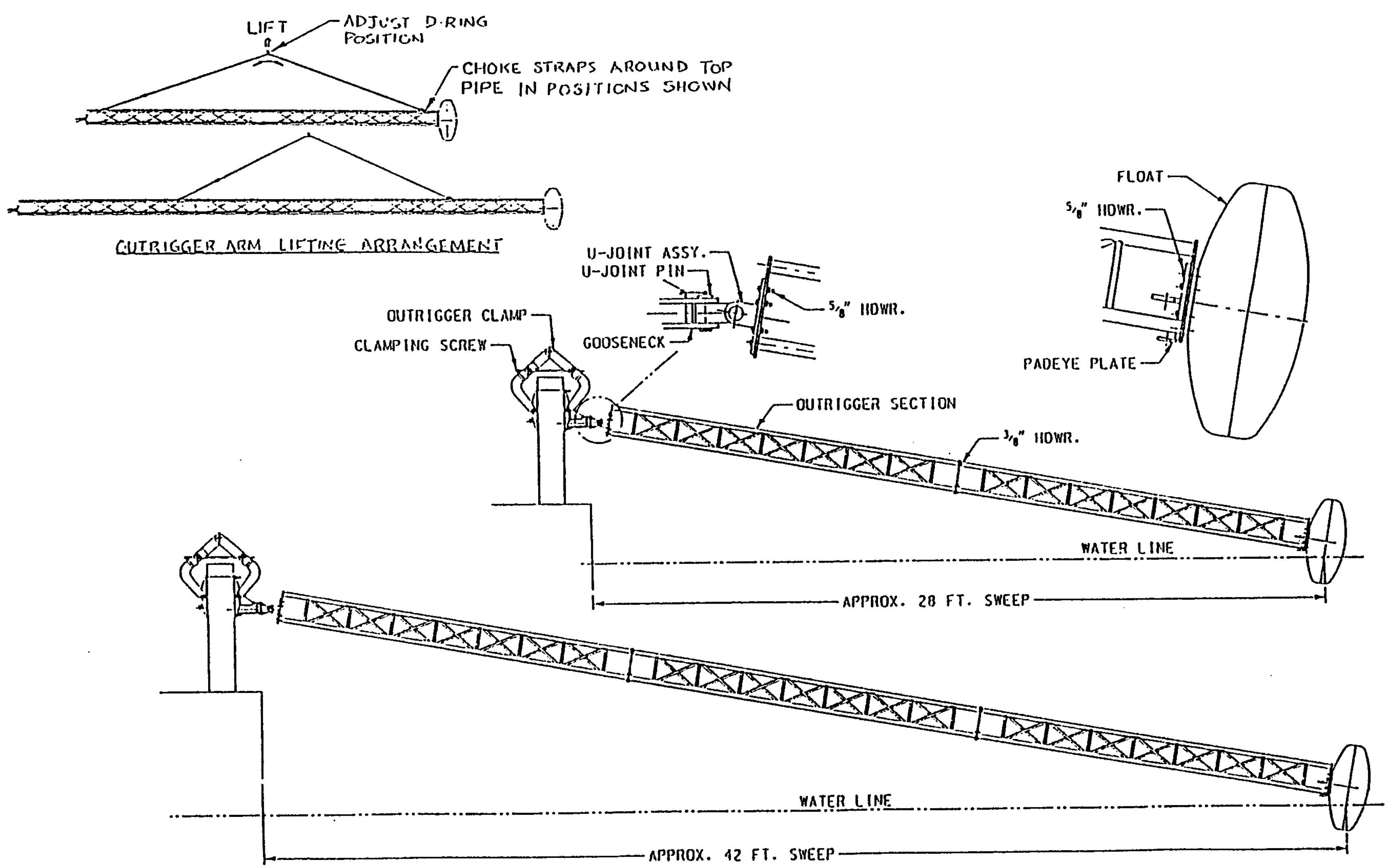


Fig. 2. CG VOSS outrigger attached to ship's rail via gimballed outrigger clamp (ref. operations manual)

2. An ocean going Hyde products boom,
3. A DESMI 250 skimmer, hydraulic power pack, and hoses, Figs. 3 and 4 and,
4. A portable lifting davit arm for deployment and retrieval of the skimmer, Fig. 5.

The results of tests performed in FY92 combined with input from actual field usage has exposed areas of concerns with the CG VOSS. These areas include:

1. Forces on the outrigger section,
2. Stability of the CG VOSS boom,
3. Handling and deployment techniques and,
4. Investigation for different sea states, boat speeds and the boom towing orientation of the boom relative to the sea state.

In response to these concerns, an evaluation program addressing the primary objectives of development, seaworthiness, handling and towing forces was initiated to assess the towing characteristics of the system under various sea conditions, to make a determination of problem areas, to ascertain the magnitude of the forces that would be encountered during operation and to instrument the system for evaluation purposes. This instrumentation package was installed on the CG VOSS system by CDNSWC and used during sea trials for performance data acquisition.

In addition to the CG VOSS towing boom, two other boom configurations were evaluated. These boom systems were the NOFI V Sweep utilizing the CG VOSS outrigger and the Fully Integrated Oil Collection System (FIOCS), which is an extended version of the NOFI V Sweep.

This report contains the results of the three boom evaluations that were conducted at sea and are presented separately for each system for various speeds and sea states. The three boom configurations, equipment, instrumentation and set-up are described. The measurement data in the form of line tensions, boom depths, and outrigger motions for the various speeds and sea states are also presented. Program conclusions with recommendations are made on a limited analysis of the data obtained at sea.

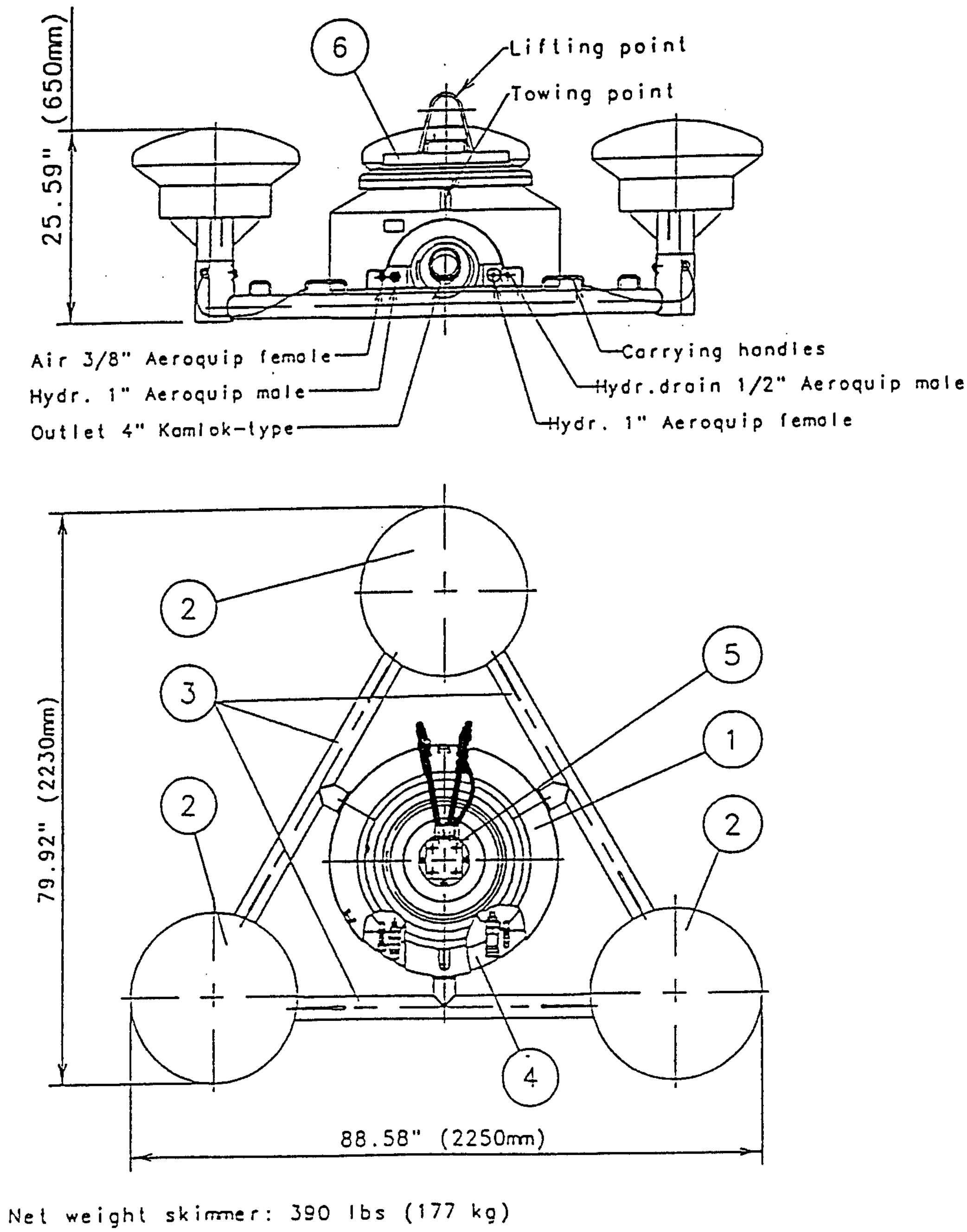


Fig. 3. DESMI DS-250, Destroil Skimmer (ref. operations manual)

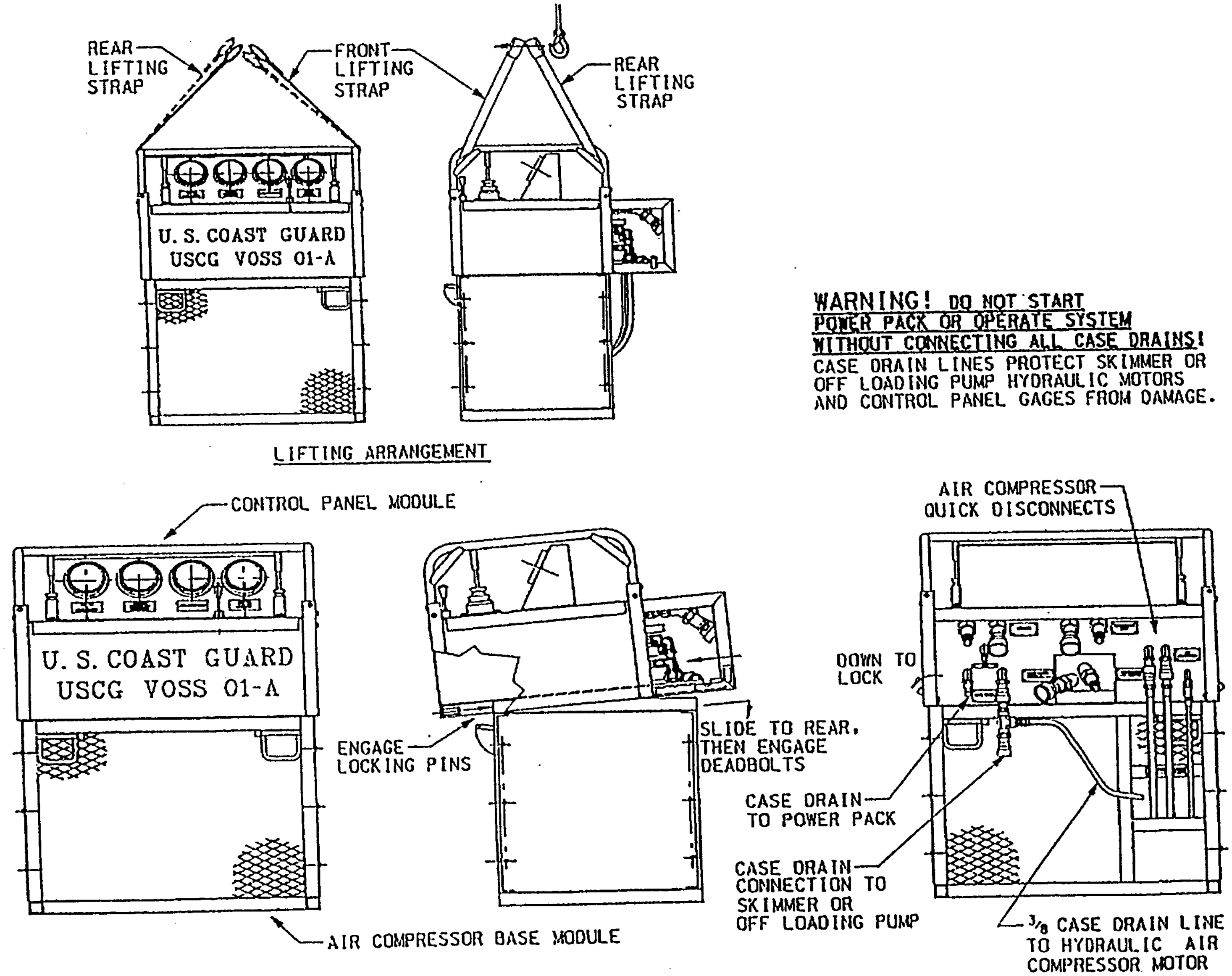


Fig. 4. USCG VOSS 01-A Hydraulic Power Unit (ref. operations manual)

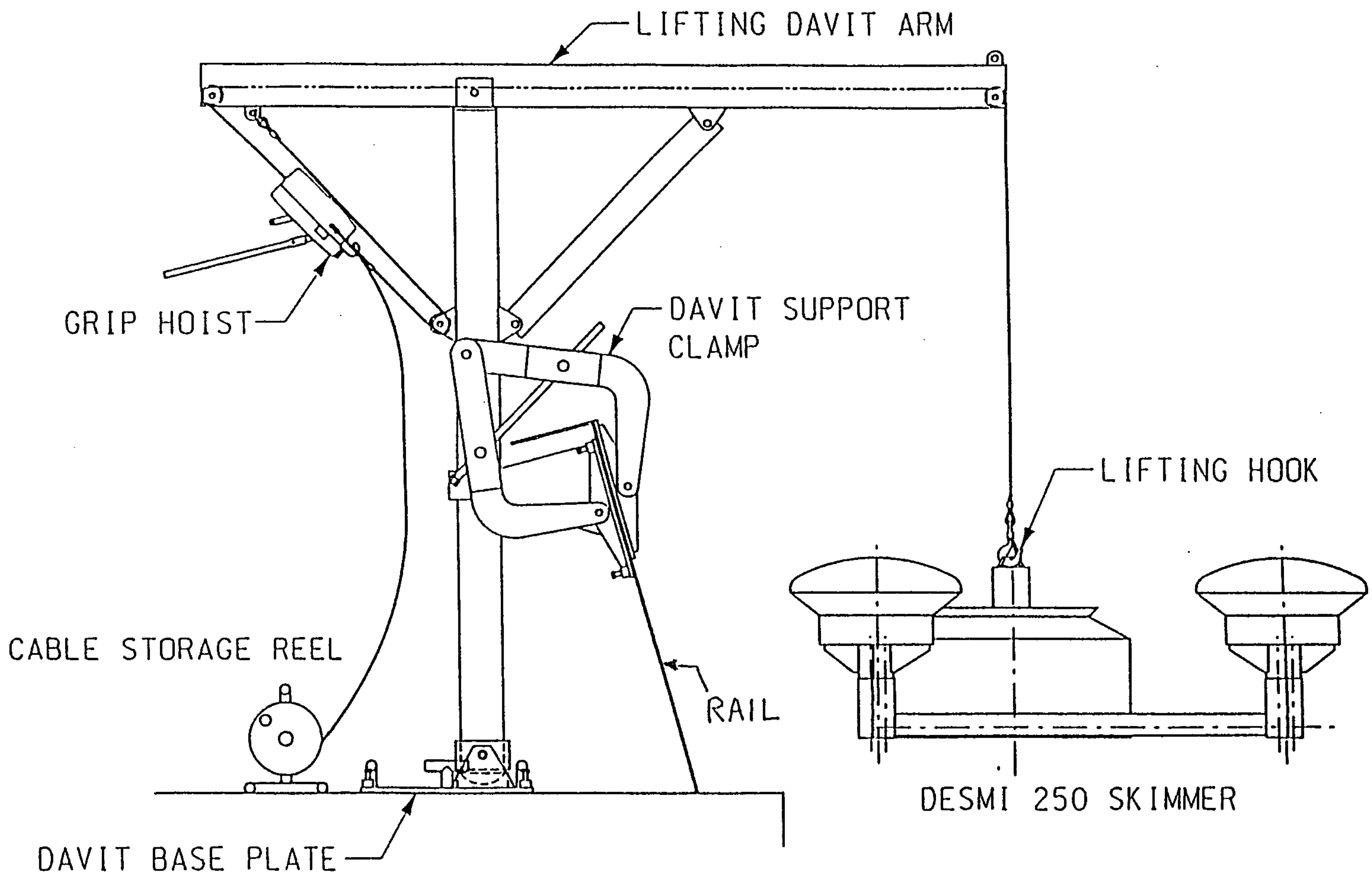


Fig. 5. Lifting davit and rail outrigger clamp (ref. operations manual)

2.0 TEST OBJECTIVES

The objective of the sea trial was to evaluate the deployment, seaworthiness, handling, and towing characteristics of the CG VOSS, NOFI V Sweep, and FIOCS systems at various speeds, in various sea states and at different headings relative to the sea direction. Additionally, the trials were conducted to gain experience and to identify problem areas with the handling characteristics of the three systems.

3.0 DESCRIPTION OF TEST SET UP

The at-sea evaluation was conducted out of the Naval Undersea Warfare Center facility (NUWC) in New London, CT during the first two weeks of May in 1993. The vessel used was the M/V ENSCO TROJAN out of New Orleans, LA. The TROJAN is a tug/supply vessel operated by Ensco Marine and was leased by NUWC for Anti-Submarine Warfare research and other related oceanographic services. Physical dimensions and detailed specifications of the vessel are contained in Table 1 and a sketch of the vessel is shown in Fig. 6. Daily operations were conducted off the coast of Montauk, LI which was approximately a two-hour transit from New London, CT. Figure 7 shows the onloading of the CG VOSS and NOFI containers onto the deck of the TROJAN prior to the start of operations.

Responsibilities during the sea trial were distributed among several government agencies and private companies. The participating agencies and companies are listed in Table 2 with their respective responsibilities. Prior to the start of the sea trial, CDNSWC provided a test plan with a proposed run matrix. The actual run matrix performed was modified by the test director and Coast Guard representative due to weather conditions and other factors as discussed later in this report.

Prior to the first deployment, discussions were held with all the agencies involved with the evaluation. The Captain of the vessel was also briefed with respect to schedule and ship requirements and included in the discussions. At the end of each test day, there was a meeting to discuss the test procedures and results and to plan for the following day.

Table 1. ENSCO TROJAN ship specifications.

M/V ENSCO TROJAN

Specifications

GENERAL

Length Overall	228 ft.
Beam	41 ft.
Depth	17 ft.
Maximum Draft	14 ft.
Tonnage	500 Gross Tons
Endurance	30 days @ 13 kts.
Deck Load	~850 LT
Deck Space	32 x 136 ft.
Speed	17 knots
Year Built	1974
Builder	Halter Marine

NAVIGATION EQUIPMENT

Main	MARISAT/INCA Nav/comm System
Auto Pilot	Sperry - 8T
Fathometer	Data Marine Model 3000
Loran	Furuno LC - 90
Radars	(1) Micrologic ML 220 (2) furuno 805
Radios	(1) ICOMM - 100 (VHF) (2) Stephens SEA - 222 (SSB) w/ Necode Ringer
Telephone	Motorola Cellular Phone
Call Letters	WTE 5093

CAPACITIES

Fuel Oil	173,000 US Gal
Lube Oil	2,000 US Gal
Bulk Tanks	5,000 Cu Feet
Potable Water	14,000 US Gal
Drill Water	217,000 US Gal
Liquid Mud	1,928 Barrels

SPECIAL EQUIPMENT

Engine Alarm	36 pts.
Welding Machine	one
Rescue Boat	14' Duracraft w/ 9 hp motor

MACHINERY

Main Engine (2)	EMD 20-645E5
Brake Horsepower	7240 Hp
Bollard Pull	110 Tons
Propellers (2)	120 Var Pitch
Generators (2)	150 Kw
Bow Thruster	500 Hp 12V71
Anchors (2)	2500# Danforth
Winch	SMATCO 72 Dbl Drum Waterfall
Line Pull	400,000#
Chain Lockers(2)	4,000'of 3.5' Chain Ea. Side

ACCOMODATIONS

Stateroom/Berth	8
Galley	All Electric
Certified to Carry	22
Walk-in cooler	350 Cu.Feet
Walk-in Freezer	350 Cu.Feet

REGISTRATION

Class	ABS:A-1, All Ocean Service

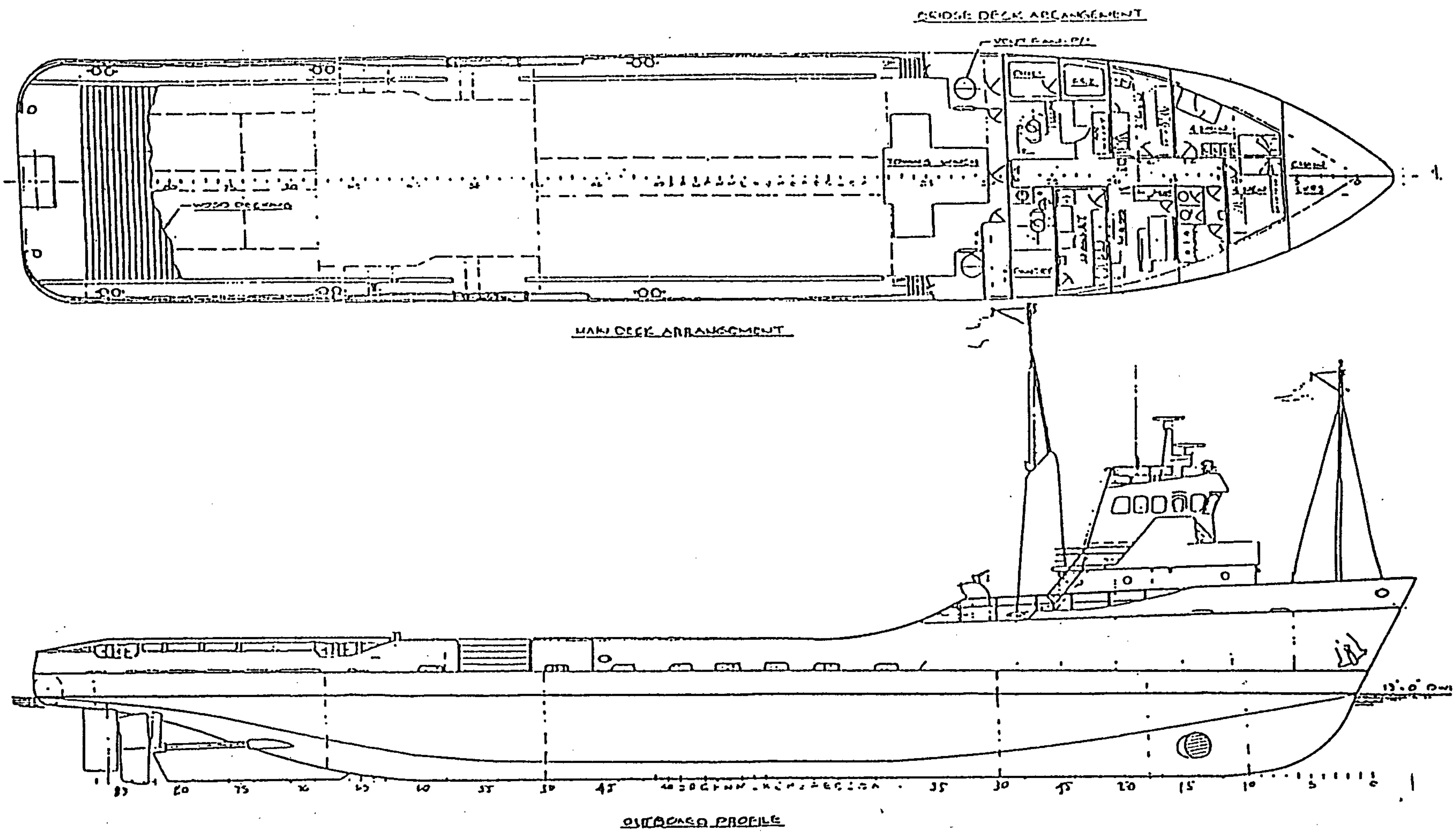
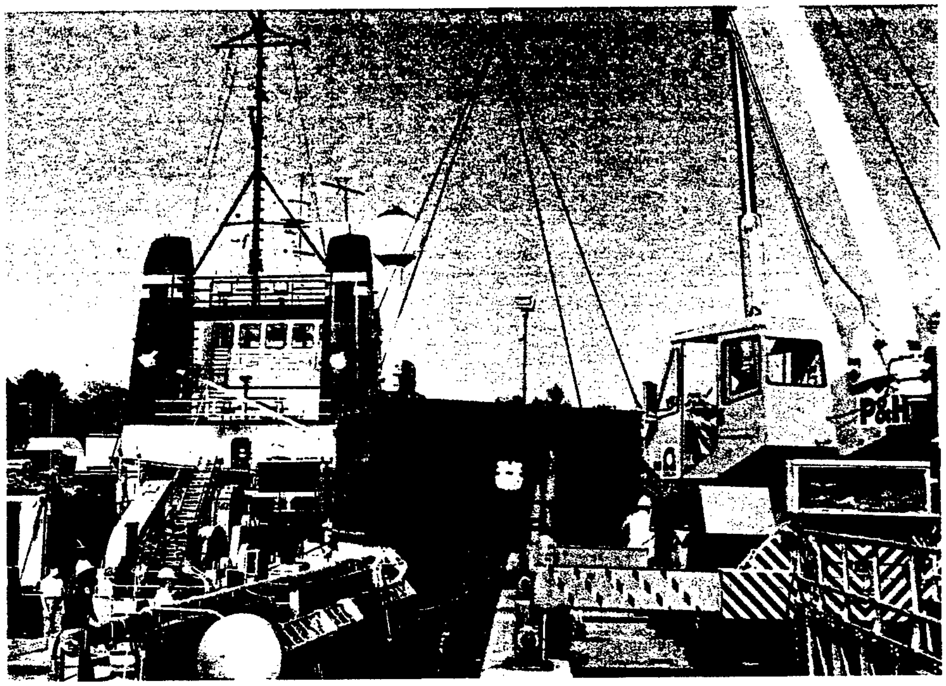


Fig. 6. Sketch of the M/V TROJAN showing outboard profile and deck arrangement.



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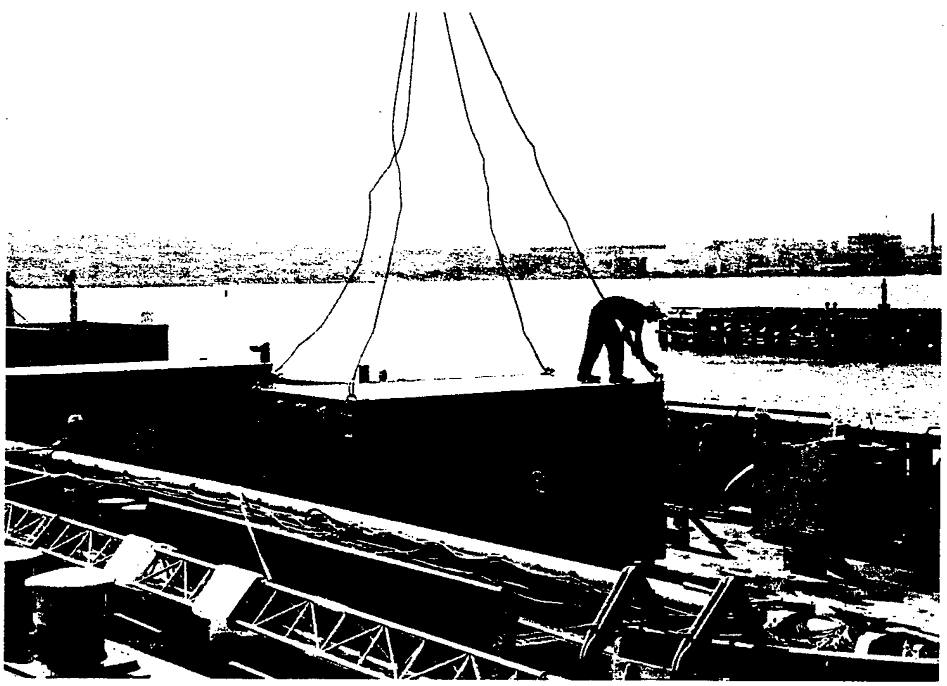

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Fig. 7. Photographs of the onloading process at the NUWC/NL dock.

Table 2. Organizational responsibilities during VOSS sea trial.

ORGANIZATION	RESPONSIBILITIES
AllMaritim Bellvue, WA	Consultant for NOFI and FIOCS boom. Responsible for teaching deployment of system.
AllMaritim Norway	Consultant for NOFI and FIOCS boom. Involved in design of system.
Applied Fabrics Orchard Park, NY	Consultant for NOFI and FIOCS boom. Manufactured boom assembly.
National Strike Force Coordination Center, (NSFCC) Elizabeth City, NC	Provided U.S. Coast Guard personnel who were responsible for deploying all boom systems. They worked previously with CG VOSS, but had to be trained on site to deploy NOFI and FIOCS.
Carderock Division Naval Surface Warfare Center Bethesda, MD	Provided the sea trial director, instrumentation package, and photographer. Prepared Test Plan. Performed data analysis and prepared report.
New London Detachment Naval Undersea Warfare Center New London, CT	Provided the point of contact for all agencies involved in the test and provided many of the necessary hardware items and support required for conduct of the sea trial.
NOFI Norway	Consultant for NOFI and FIOCS. Provided technician that had worked previously with the equipment.
U. S. Coast Guard, Hdqtrs. Washington, D.C.	Provided technical assistance on CG VOSS system and assisted with the preparation of the test plan.
U.S. Coast Guard R & D Center Groton, CT	Sponsor of the sea trial. Provided technical assistance with the preparation and conduct of the trials.

All agencies were present for these meetings and provided input and recommendations for the next day of testing.

The location of Montauk Point, LI, lends itself to shifting currents, waves, and wind conditions. Often a long and regular swell may be moving in one direction with small short crested surface waves resulting from changing wind conditions moving in a different direction. The decision on how to orient the ship relative to the sea to best represent the test matrix was made by the ship captain and the sea trial director. The various sea states encountered during the sea trial were estimated visually and recorded via a wave buoy system provided by the Coast Guard.

The trial set for each of the three boom configurations will be described in the sections that follow. Instrumentation and the trial or test matrix will give details of each test configuration.

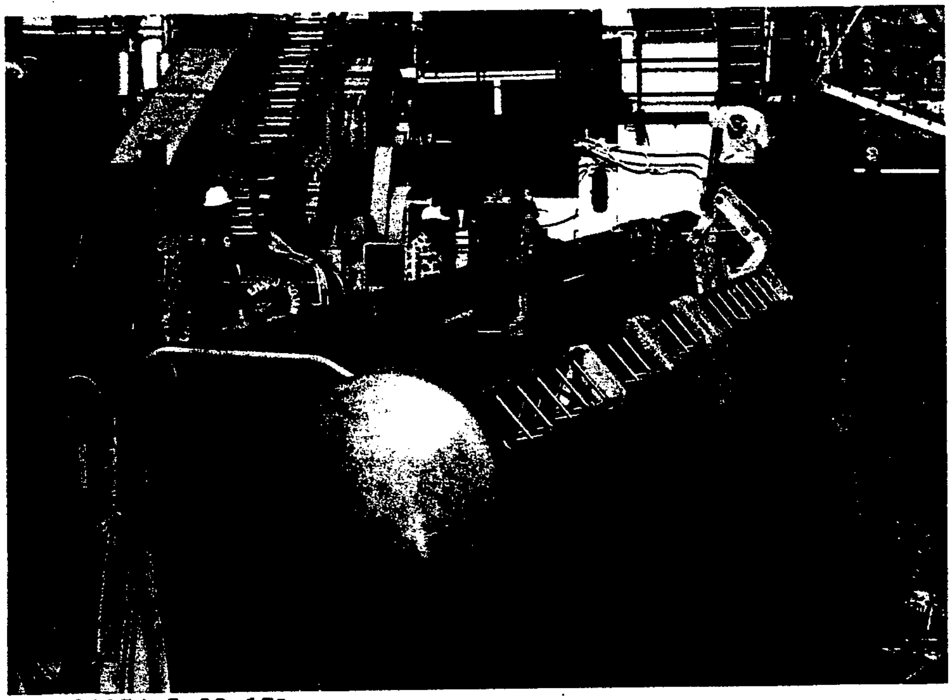
3.1 CG VOSS SET-UP

The sea trial for the CG VOSS configuration was performed using the CG VOSS outriggers with both the CG VOSS Hyde Products boom and the NOFI V sweep boom. The system configurations allowed both systems to be deployed and to be operated simultaneously. The outriggers are made of three sections of triangulated aluminum tubing of the kind typically used in radio mast and antenna supports bolted together and fitted to a rail on the ship as shown in Fig. 8. The outriggers are fitted to a clamp which is fastened to the rail. These clamps are shown fitted to the TROJAN in Figs. 9 and 10. The CG VOSS boom was deployed on the port side as shown in Fig. 11. The glide lines and restraining bridles supporting the CG VOSS boom are shown in Figs 12 and 13.

3.2 NOFI V SET-UP

The NOFI V Sweep was deployed on the starboard side as shown in Fig. 14. The NOFI V Sweep is constrained into a V-shape by underwater netting of various strengths and grid sizes. The netting is attached to the boom skirt constraining the boom into a "V" shape rather than allowing the boom to take a more standard parabolic shape due to hydrodynamic forces. The boom is shown laid out on the aft deck where NOFI personnel attached the skirt netting to the base of the boom in Figs. 15 and 16.

The flotation chambers of the NOFI V boom were filled by NOFI and Coast Guard personnel using portable air pumps and the boom was pulled over the stern by a small workboat which brought the boom around to the starboard outrigger for installation. This sequence of events is shown in Figs. 17



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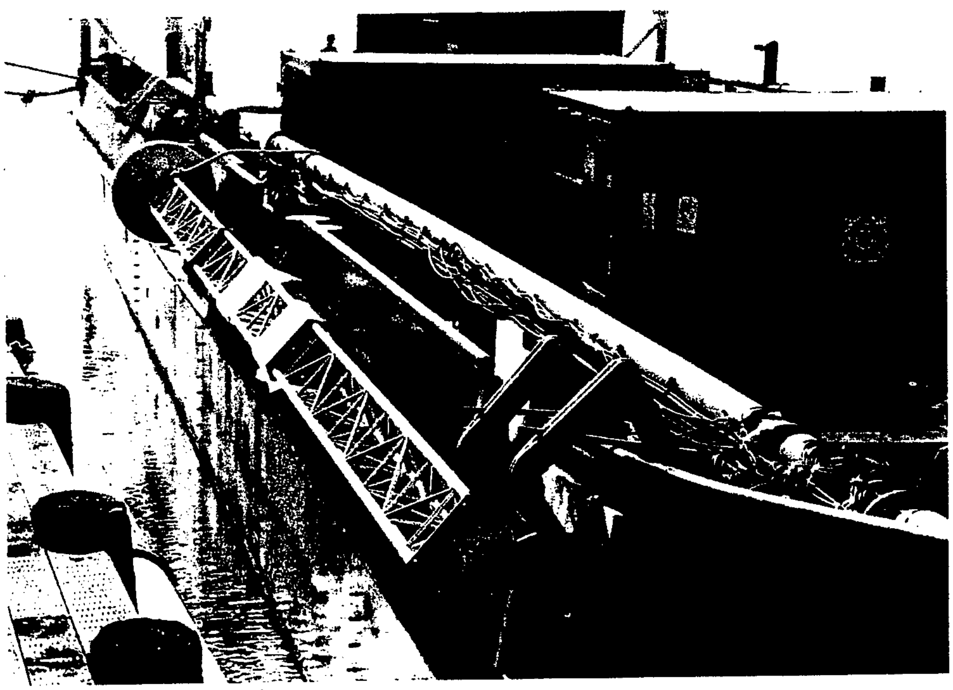

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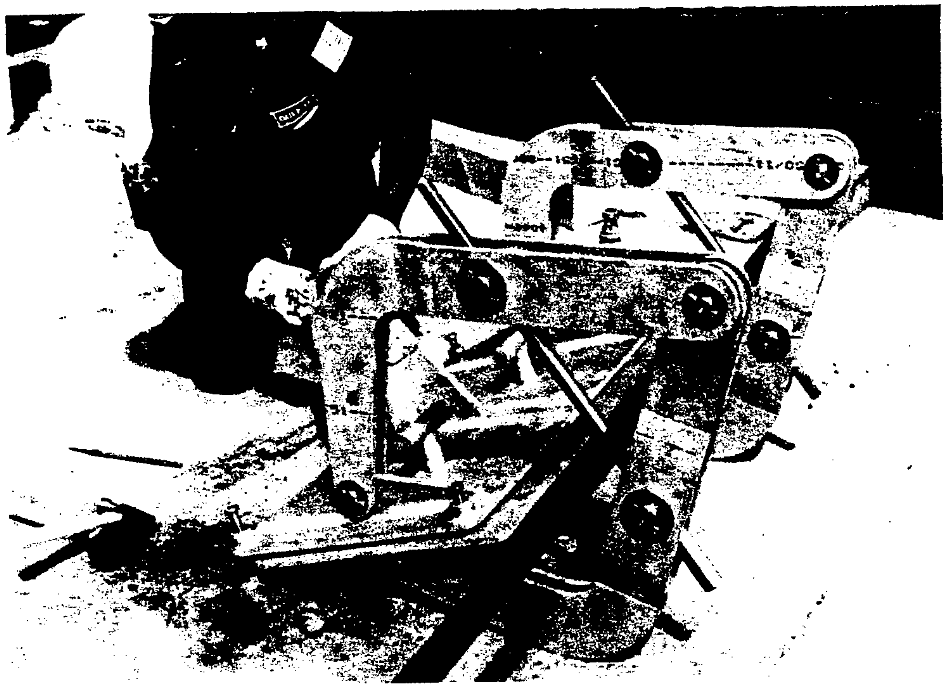
Fig. 8. Photographs of CG VOSS outriggers in stowed position at TROJANS gunwales.



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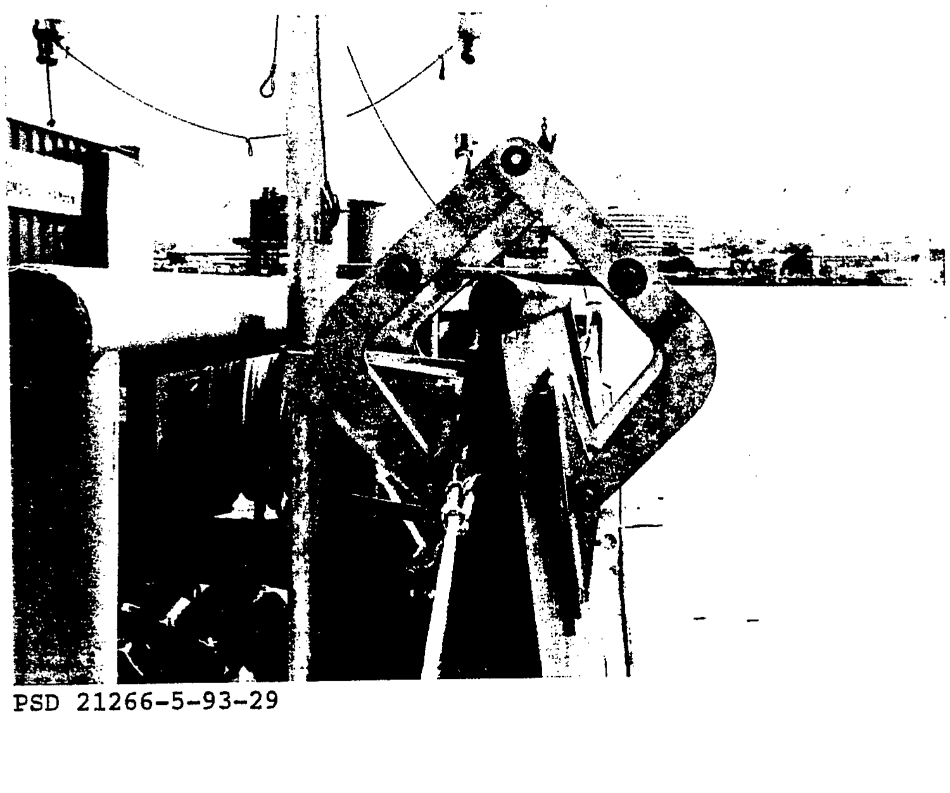

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Fig. 9. Photographs of the CG VOSS outrigger clamp fitted to TROJANS port rail.

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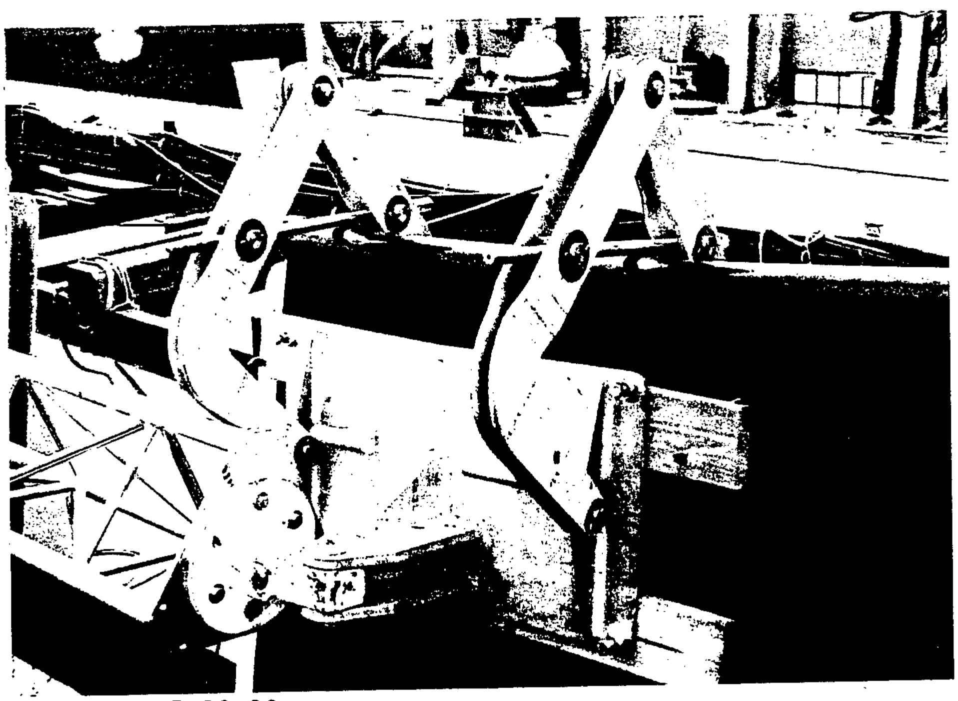

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Fig. 10. Photographs of the CG VOSS outrigger and gimbal fitted to the starboard rail clamp .

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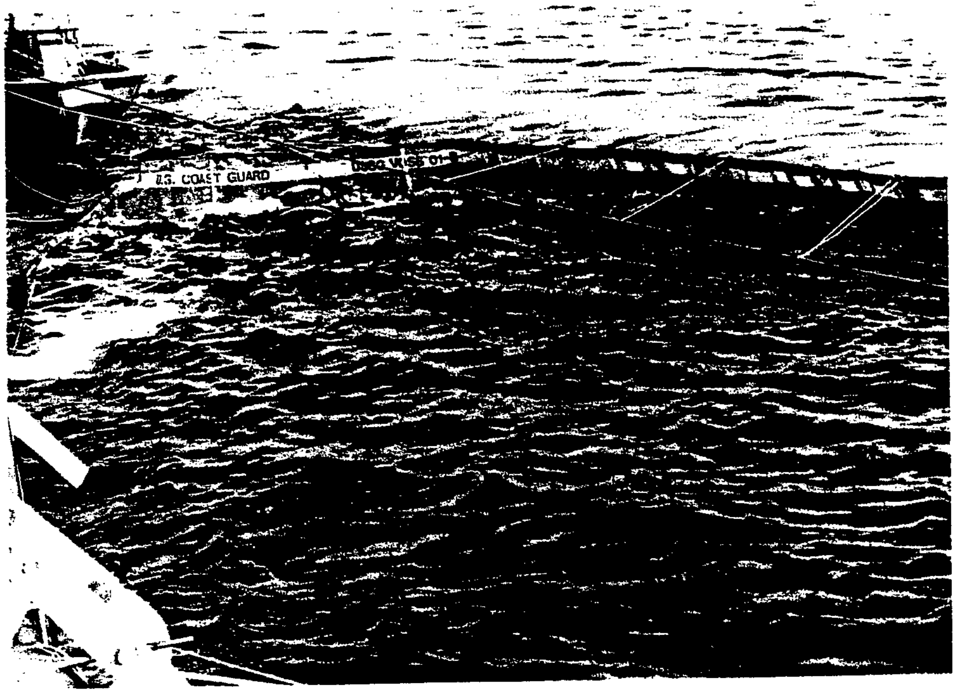
Fig. 11. Photographs of CG VOSS deployed on the port side of the TROJAN.



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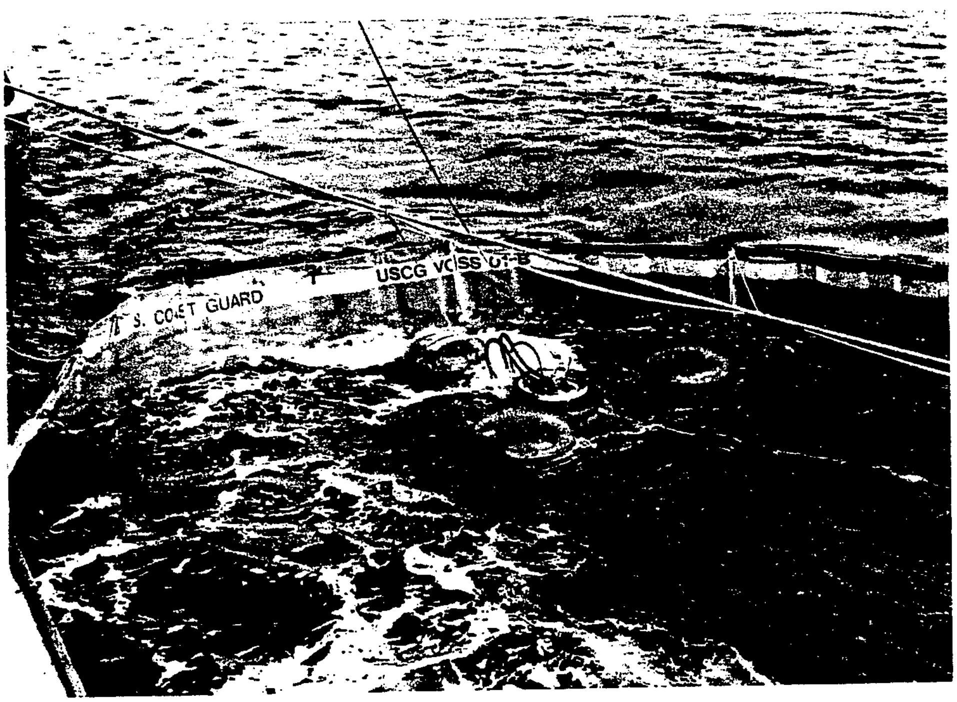

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Fig. 12. Photographs of the CG VOSS glide line and restraining bridles.

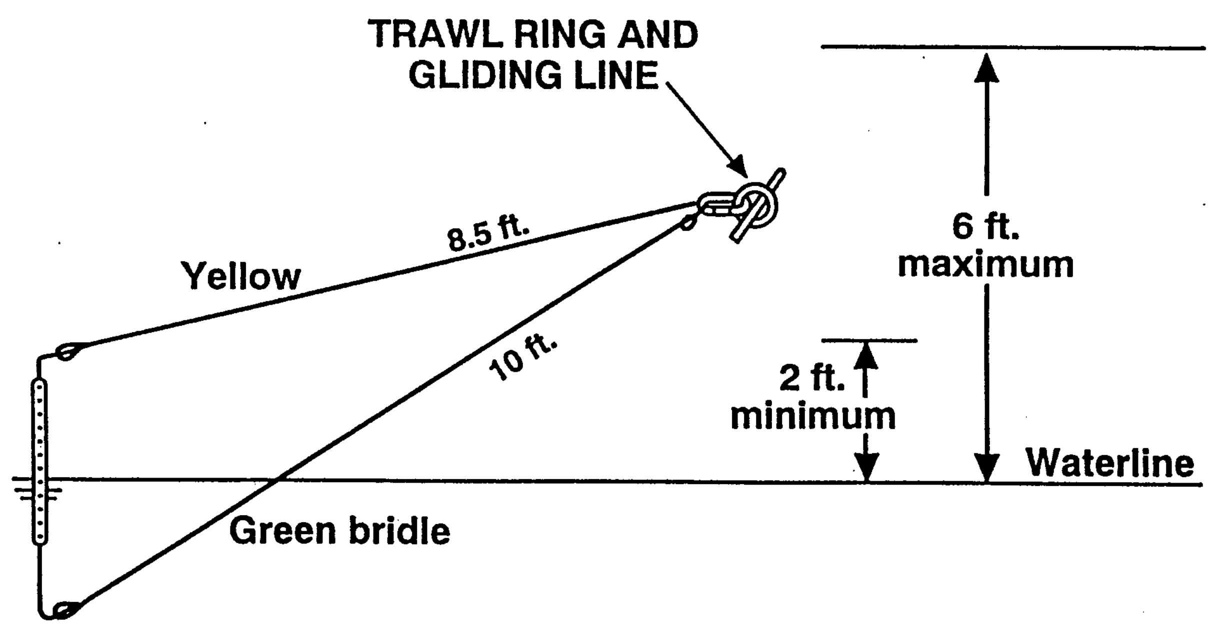
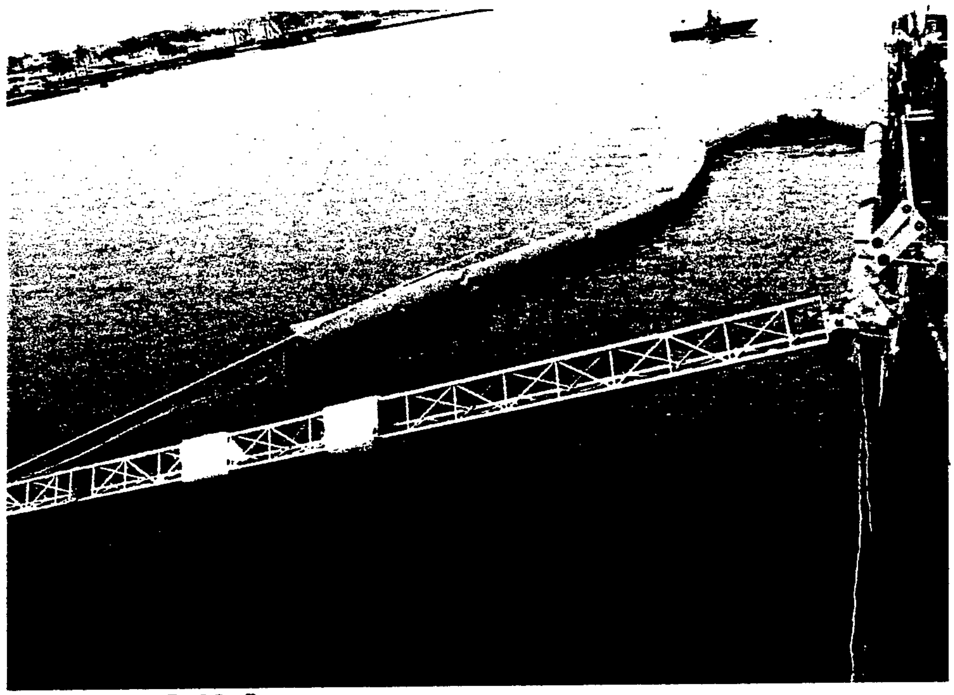


Fig. 13. Glide line and bridle arrangement for support of the CG VOSS.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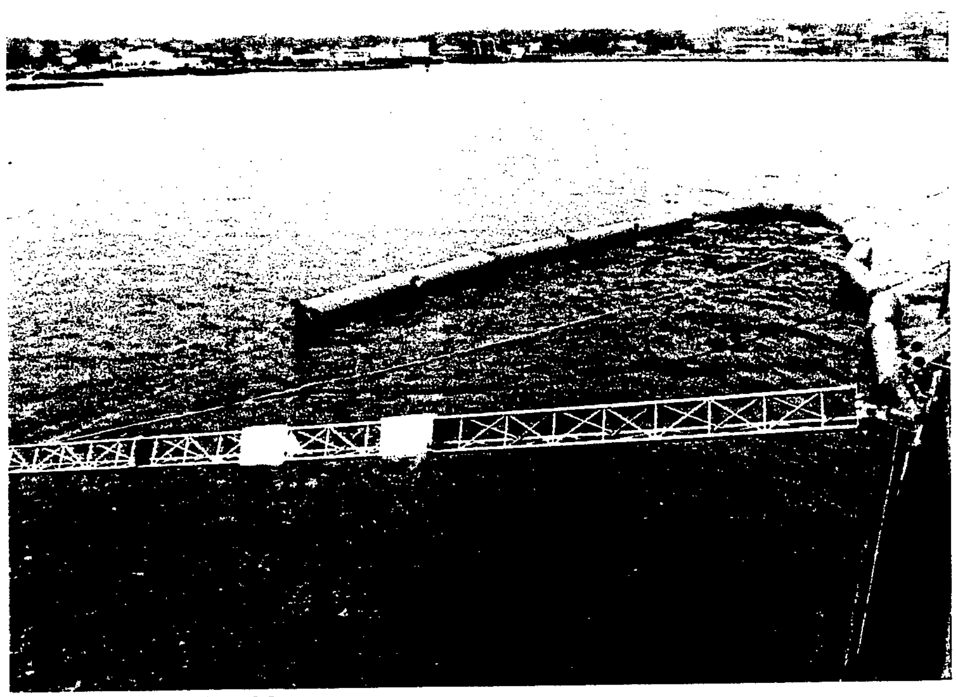
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Fig. 14. Photographs of the NOFI V Sweep deployed using the CG VOSS outrigger.

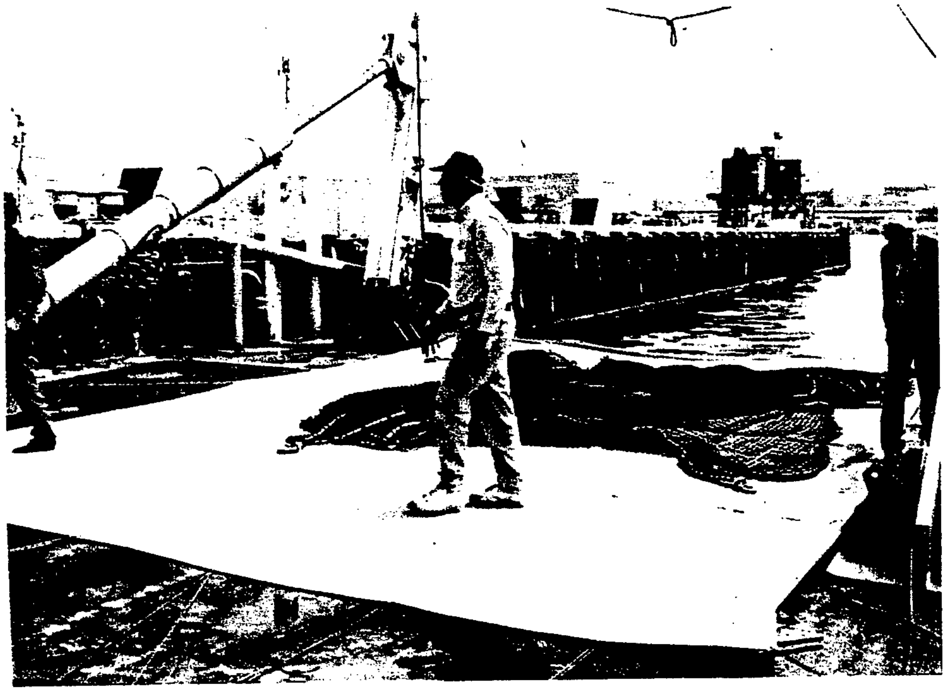

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Fig. 15. Photographs showing the skirt netting and NOFI V Sweep boom on TROJAN aft deck.

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Fig. 16. Photographs of NOFI personnel attaching the skirt netting to the boom.

and 18. The workboat was necessary for installation since the NOFI boom had not been designed for use with the CG VOSS outrigger and had no pre-designed deployment scheme. This boom is typically towed by two vessels, as in the Fully Integrated Oil Collection System (FIOCS) arrangement, but was re-configured to use the CG VOSS outrigger for this evaluation. The outboard section of the boom is attached to the outboard portion of the outrigger while the inboard section of the boom is pulled close to the ship through a block and tackle arrangement and secured in the forward section of the ship as shown in Fig. 19.

3.3 FIOCS SET-UP

The FIOCS utilizes the NOFI V Sweep in its standard two ship configuration with an extended boom length as shown in Fig. 20. The second vessel was the U.S. Coast Guard cutter POINT WELLS. The NOFI boom was pulled from a reel inside its standard shipping container by the second vessel. NOFI and Coast Guard personnel filled the buoyancy bladder sections with portable blowers as the boom went over the stern. The POINT WELLS then towed the sweep forward and away from the main tow vessel in order to form a J-shaped sweep path. A three point bridle is used in place of the outrigger section to maintain stability in the boom arrangement near the recovery ship. The bridle was routed over the starboard rail to a hardpoint on the deck so that a load cell could be installed to measure bridle tension. The FIOCS deployment is shown in Figs. 21 - 27. Radio communication was maintained at all times between the two vessels during deployment and while data runs were conducted to maintain the ship positions relative to one another.

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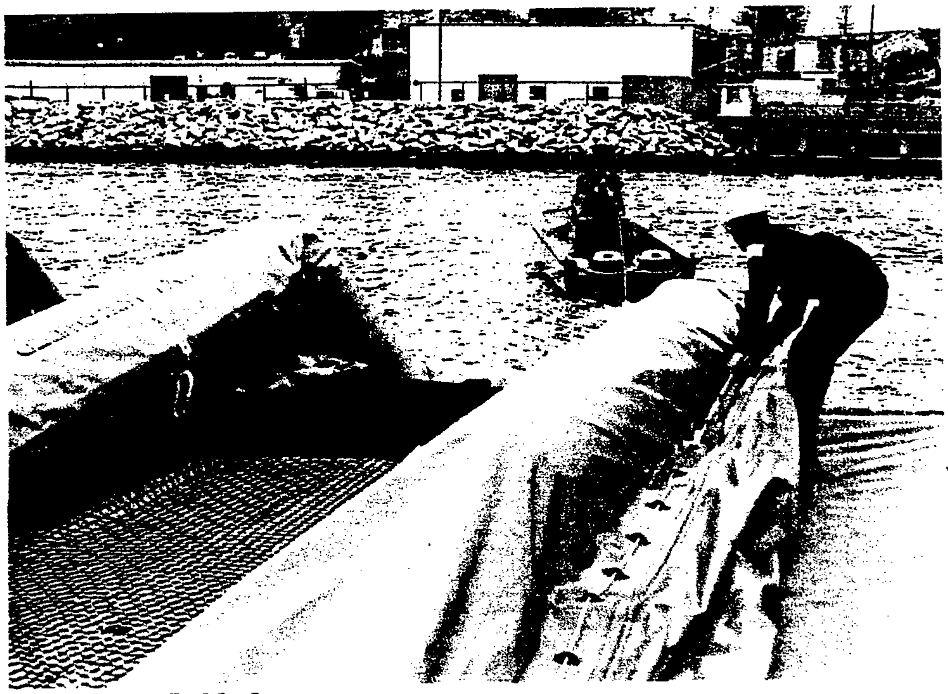
Fig. 17. Photographs of the NOFI V chamber inflation process and the inflated boom.



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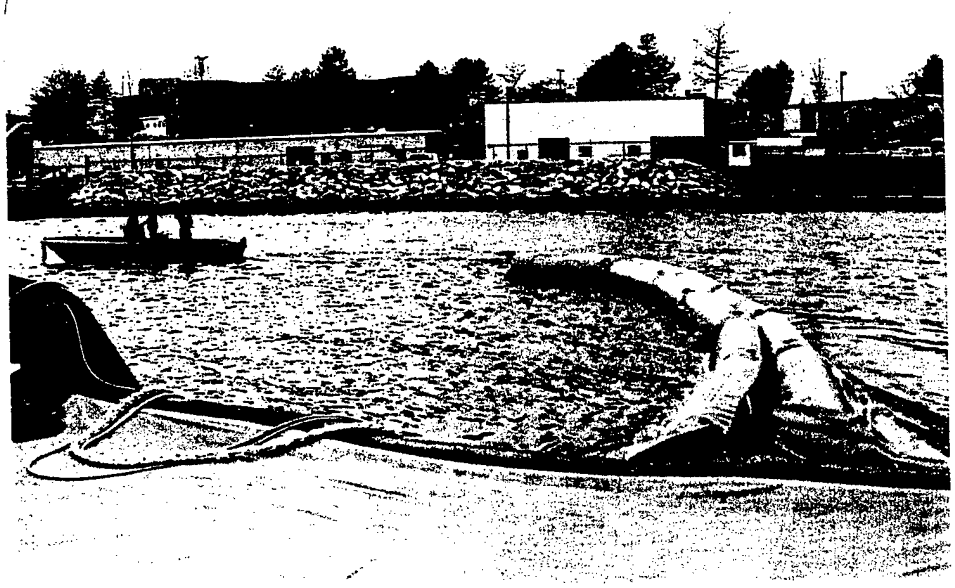

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Fig. 18. Photographs of the NOFI V Sweep being deployed over the stern by the workboat.

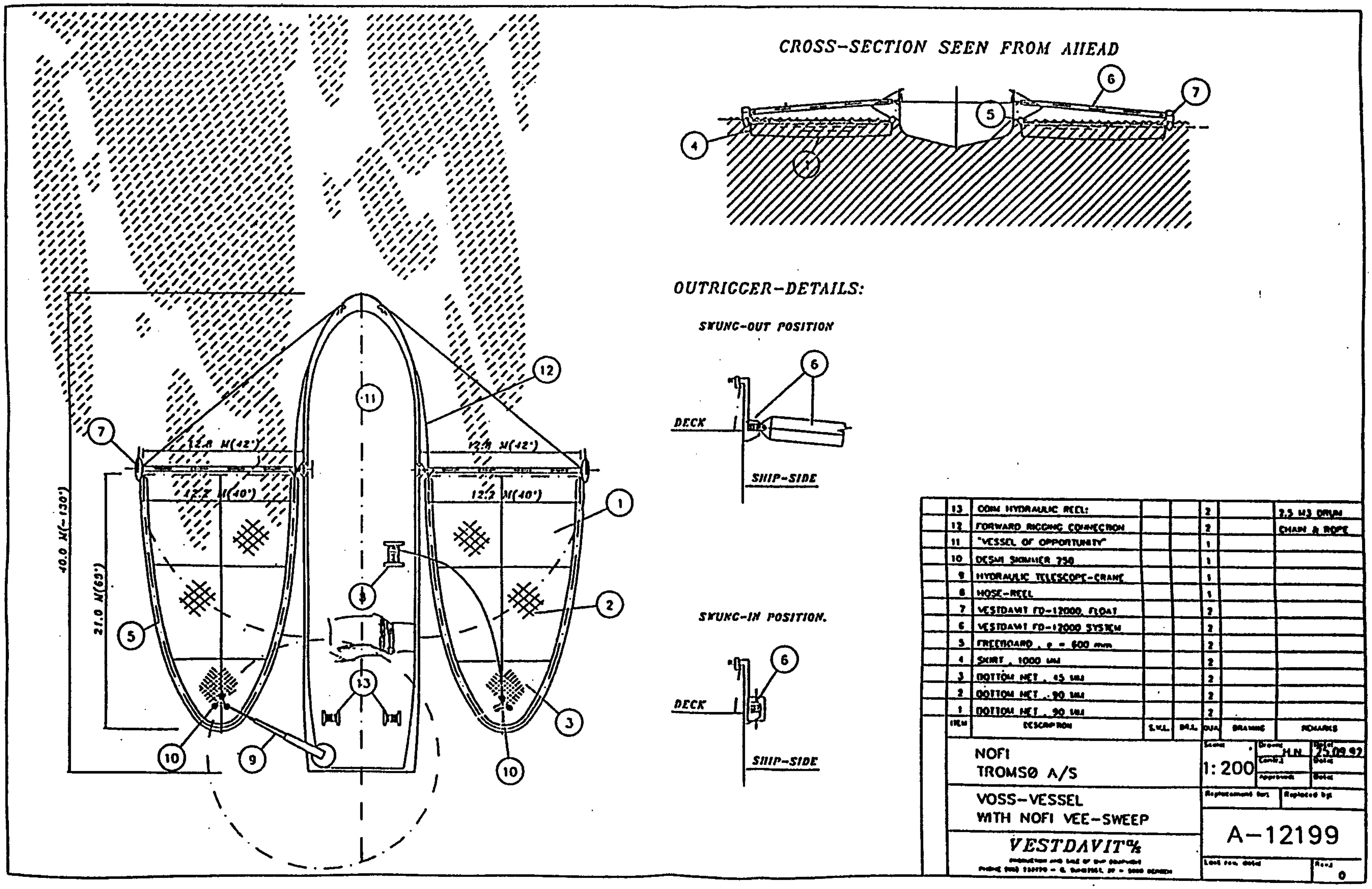


Fig. 19. NOFI V Sweep/CG VOSS outrigger rigging arrangement.

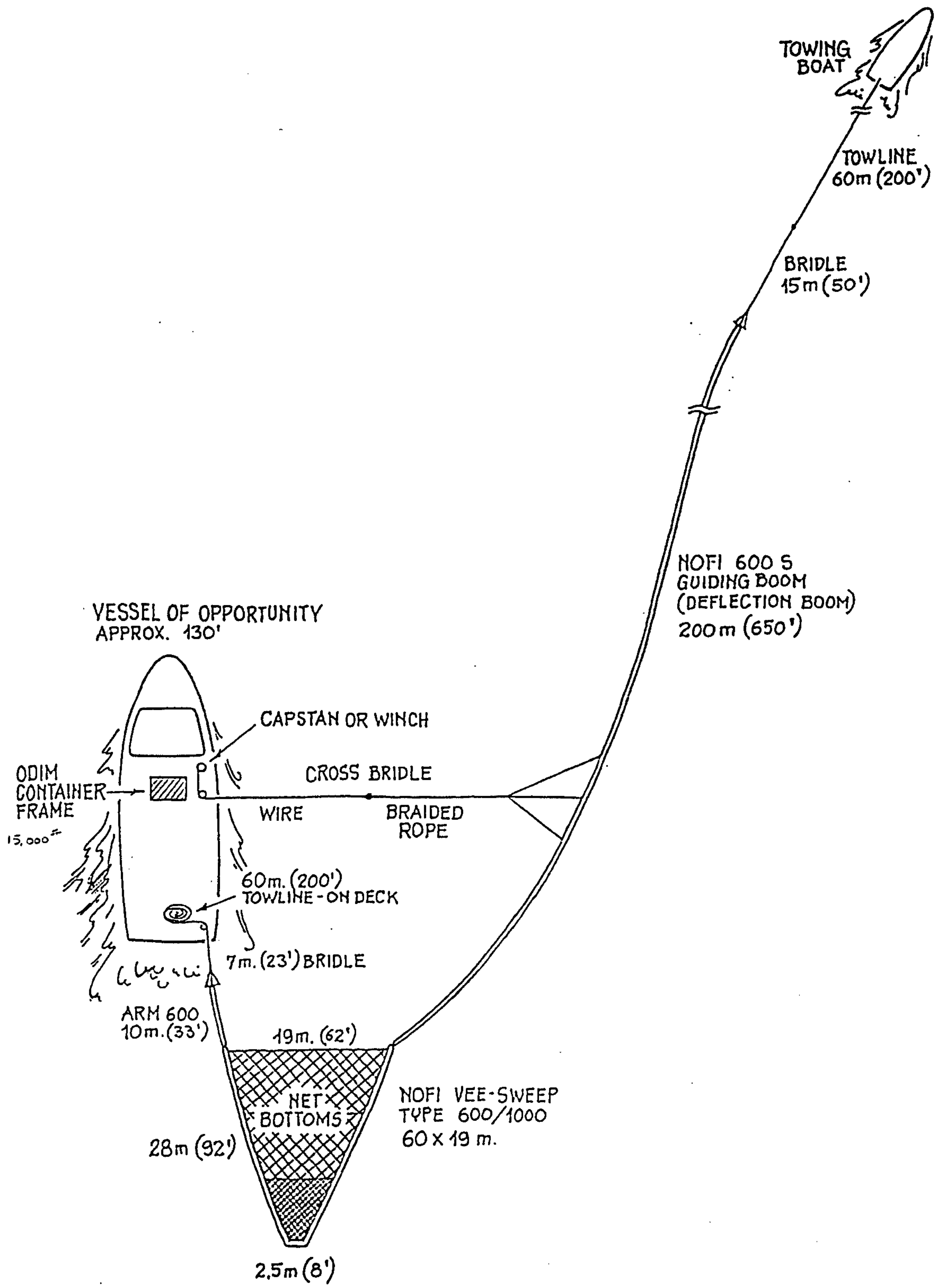
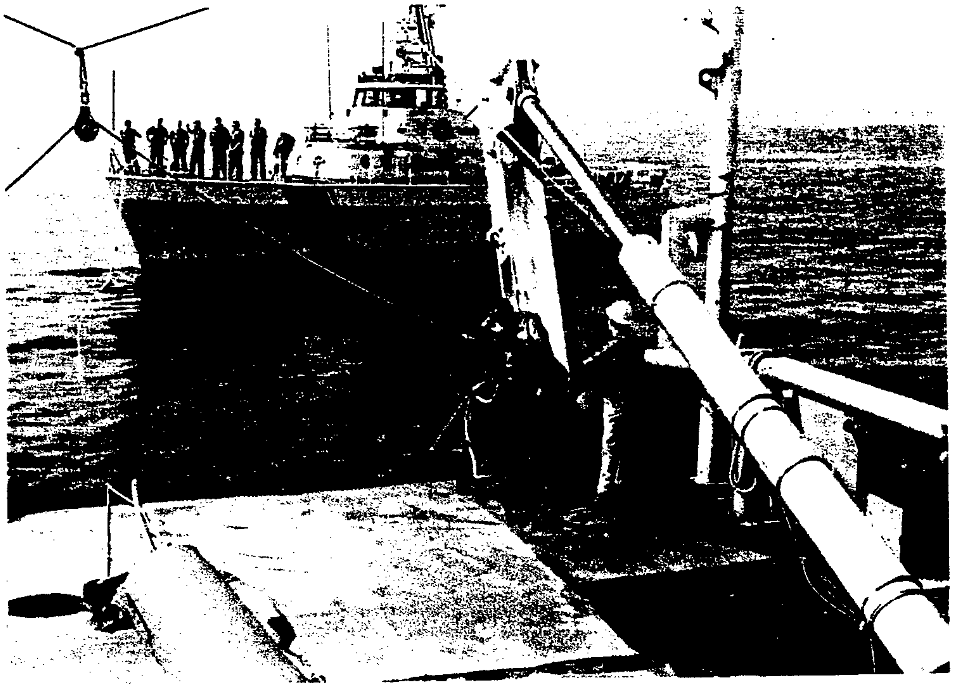


Fig. 20. FIOCS towing sketch showing Trojan's stern line and bridle arrangement.



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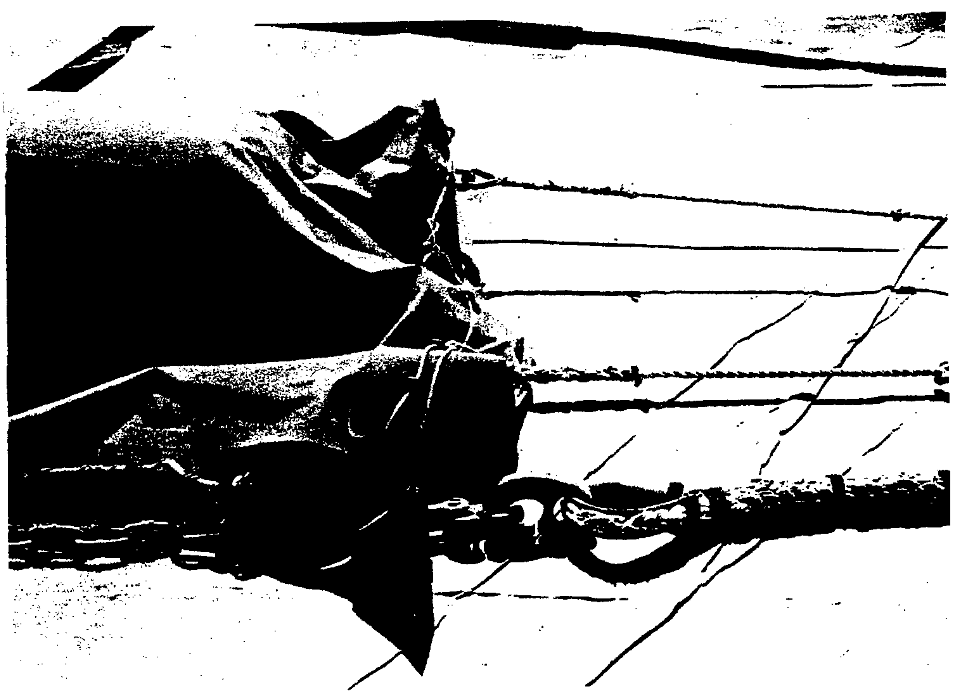

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Fig. 21. Photographs of Coast Guard Cutter POINT WELLS and FIOCS boom towline.

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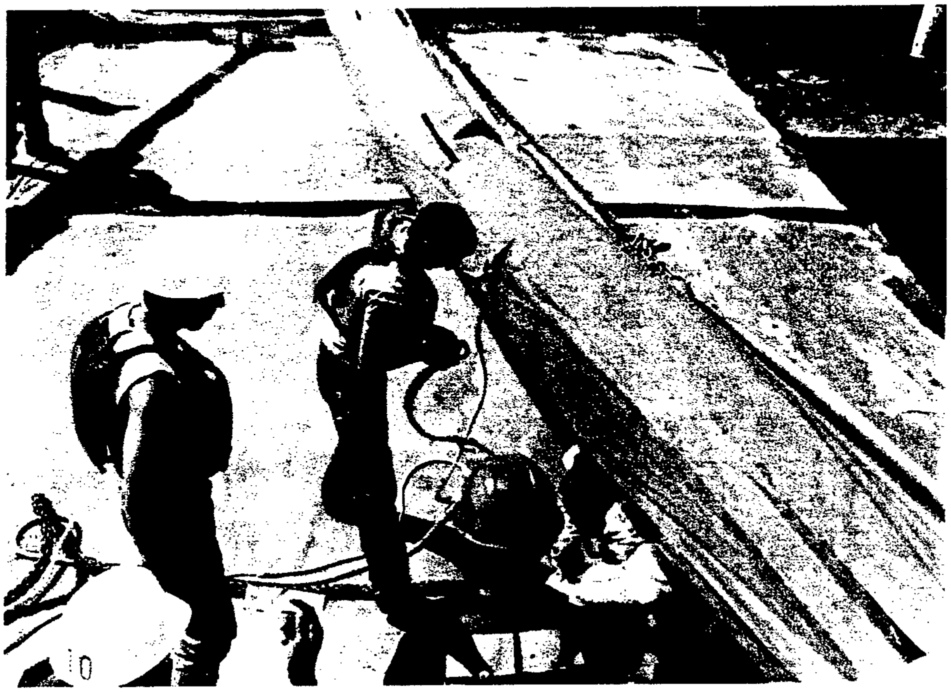
Fig. 22. Photographs of NOFI V Sweep deployment over the TROJAN stern.



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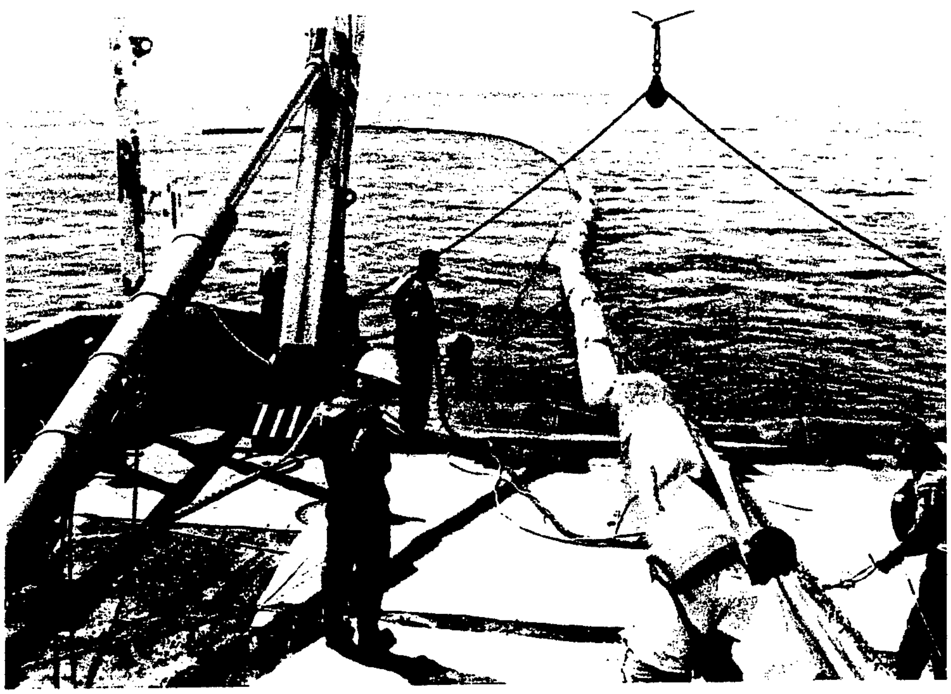

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Fig. 23. Photographs of 3-line bridle and view of the NOFI V boom beginning to be towed forward along the TROJAN's starboard side.

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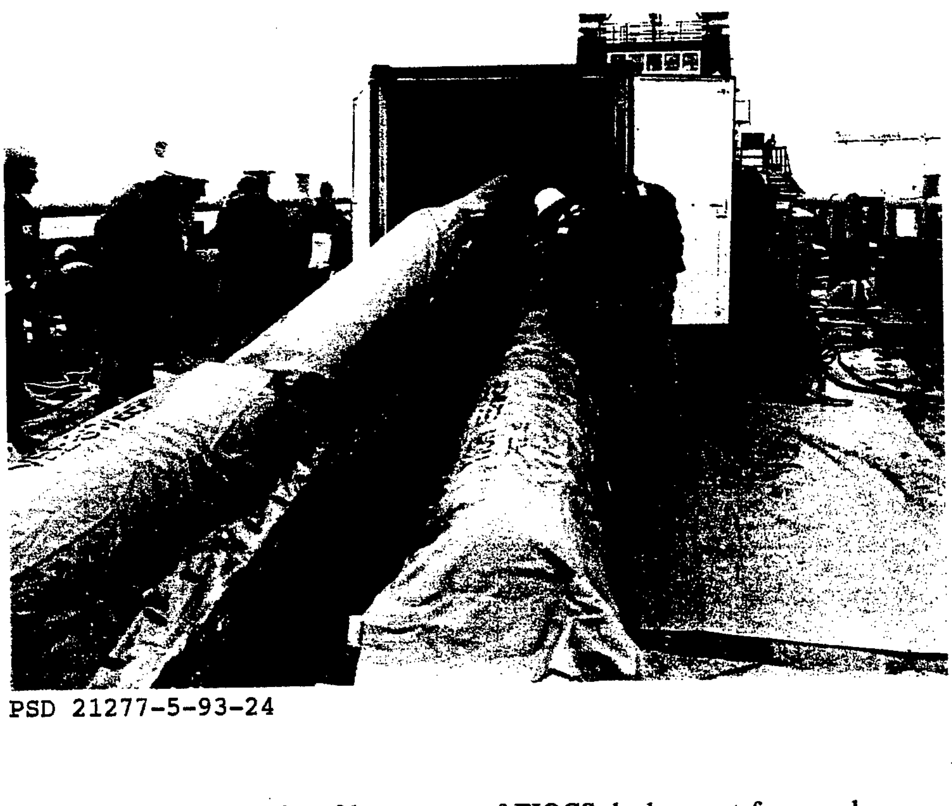

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Fig. 24. Photographs of last stages of FIOCS deployment from reel showing 'V' pocket and skirt netting.

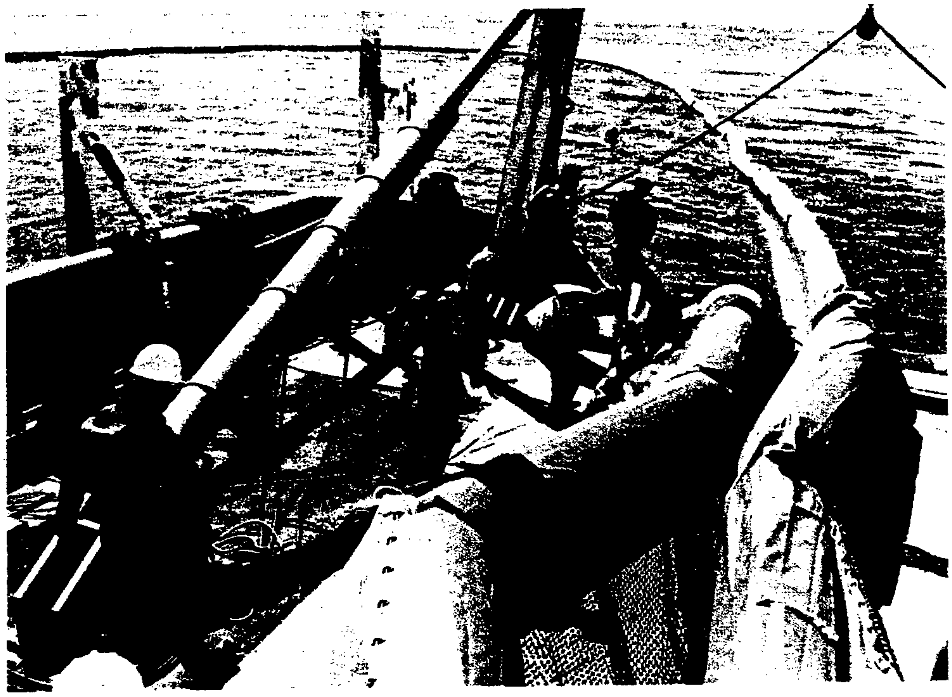

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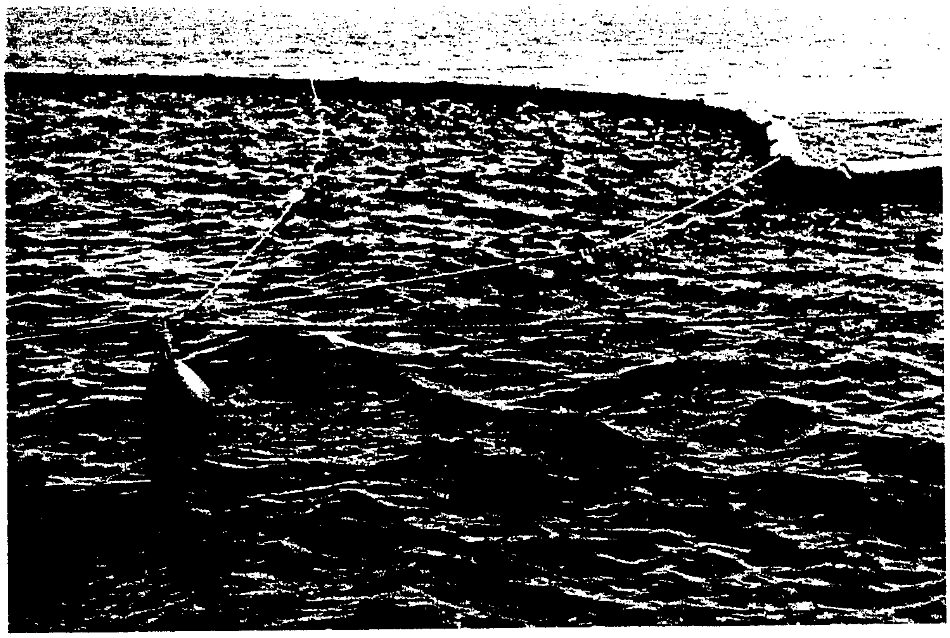
Fig. 25. Photographs of final boom sections going over the stern and being placed into position on the TROJAN's starboard side.



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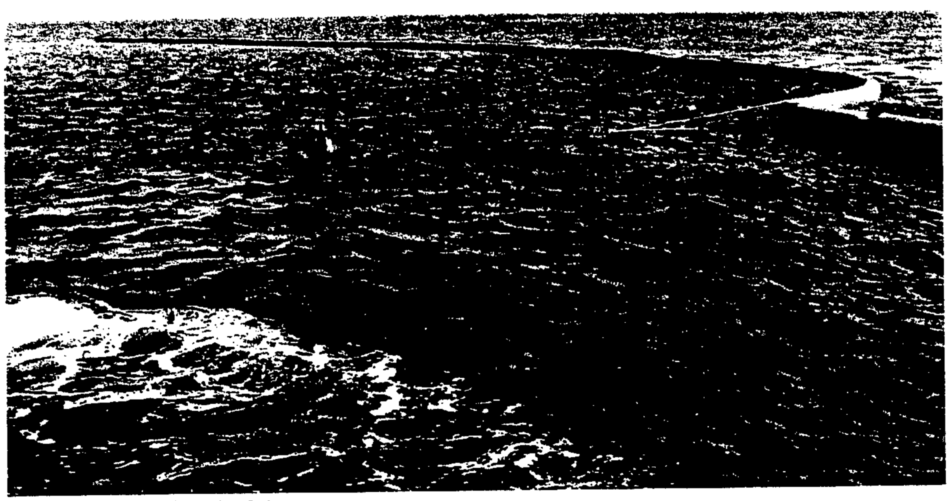

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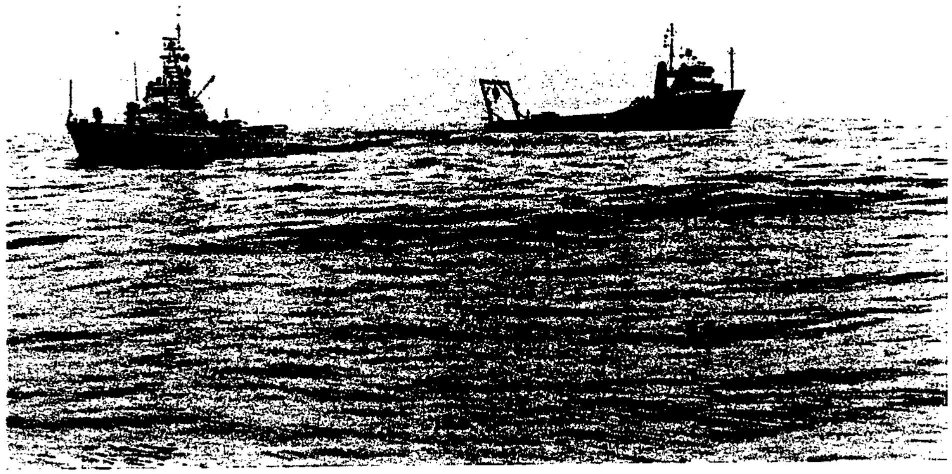
Fig. 26. Photographs of 3-line bridle in position along the TROJAN's starboard side.



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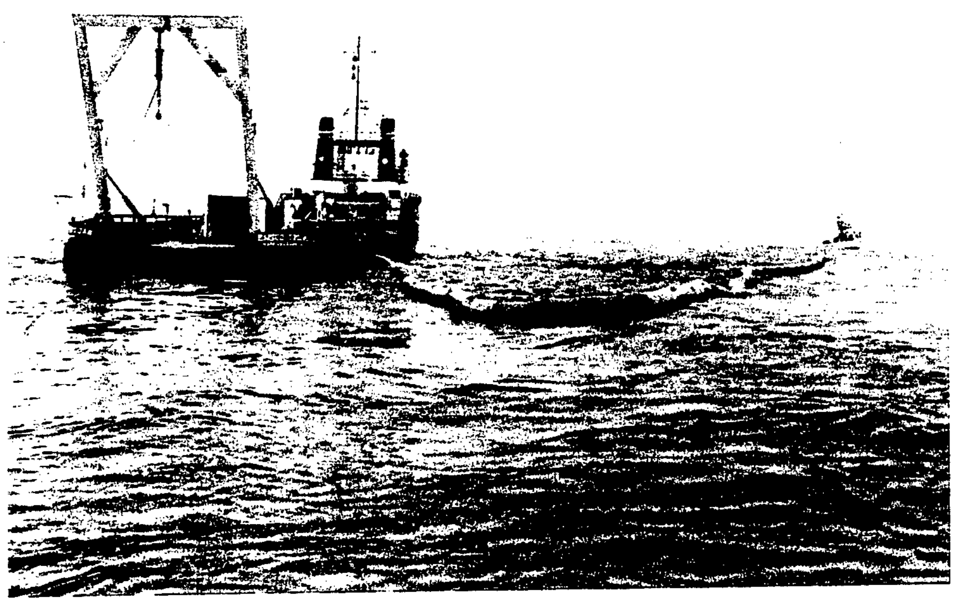

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Fig. 27. Photographs of TROJAN and POINT WELLS in towing position.

4.0 INSTRUMENTATION

4.1 CG VOSS INSTRUMENTATION

Instrumentation on the CG VOSS system consisted of three load cells, three pressure gages and a set of strain gages as shown in Fig. 28. Two load cells, shown in Figs. 29 and 30, were located on the outboard end of the outrigger where the forward preventer and glide line attach to the float. The highest loads were expected to occur at those locations. A third load cell was placed in one of two different locations to measure either the skimmer handling line tension or the distance rope tension. These tensions were expected to be low and were used to provide information about the system. Strain gauges, shown wrapped in bubble wrap in Fig. 31, were positioned in the center of the outrigger to indicate the bending moments and deflection of the outrigger during towing operations. Pressure gauges were positioned on the bottom of the boom using the fiberglass skirt stiffeners as mounting points. These gauges were placed around the apex or belly of the boom to determine changes in boom depth resulting from varying sea states and speed. The consistency or variation in the pressure transducer output is indicative of how well the boom follows the motion of the water surface; a steady output indicates a constant depth while a varying output indicates the boom is moving relative to the surface. Figures 32 - 33 show the pressure gauge placement on the CG VOSS boom.

4.2 NOFI V SWEEP INSTRUMENTATION

Instrumentation of the NOFI V Sweep boom consisted of three load cells, three pressure gages and a set of strain gages. One load cell was located on the outboard end of the outrigger where the forward preventer attaches to the float. A second load cell was attached to the outboard section of the NOFI V Sweep boom where the top, middle, and bottom lines of the boom come together. These lines link into a single towline which is then routed through a pulley on the float to the bow of the ship. A third load cell was placed on the inboard section of the boom where it was secured to the forward section

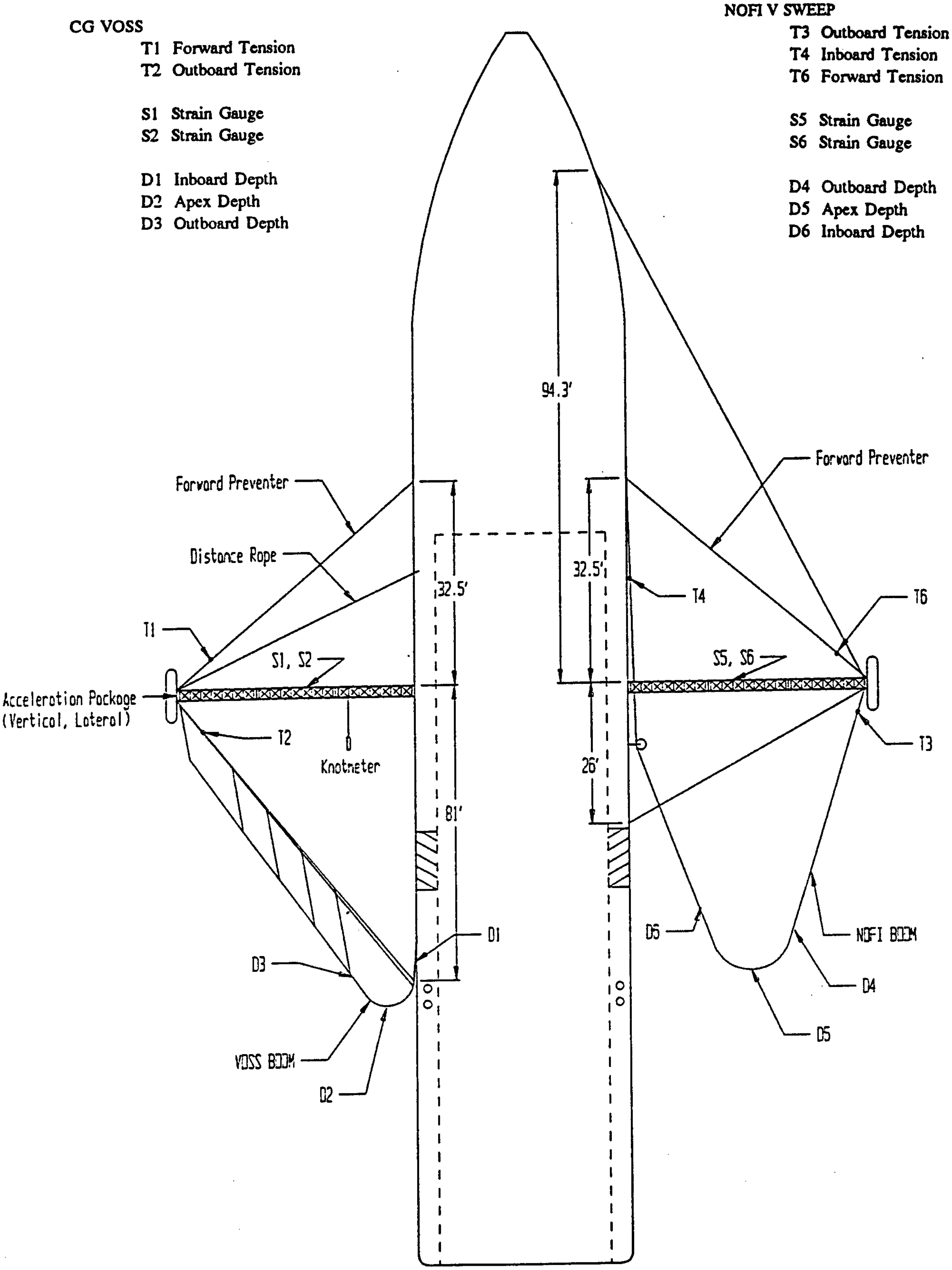

Fig. 28. Instrumentation setup on CG VOSS and NOFI V Sweep systems.

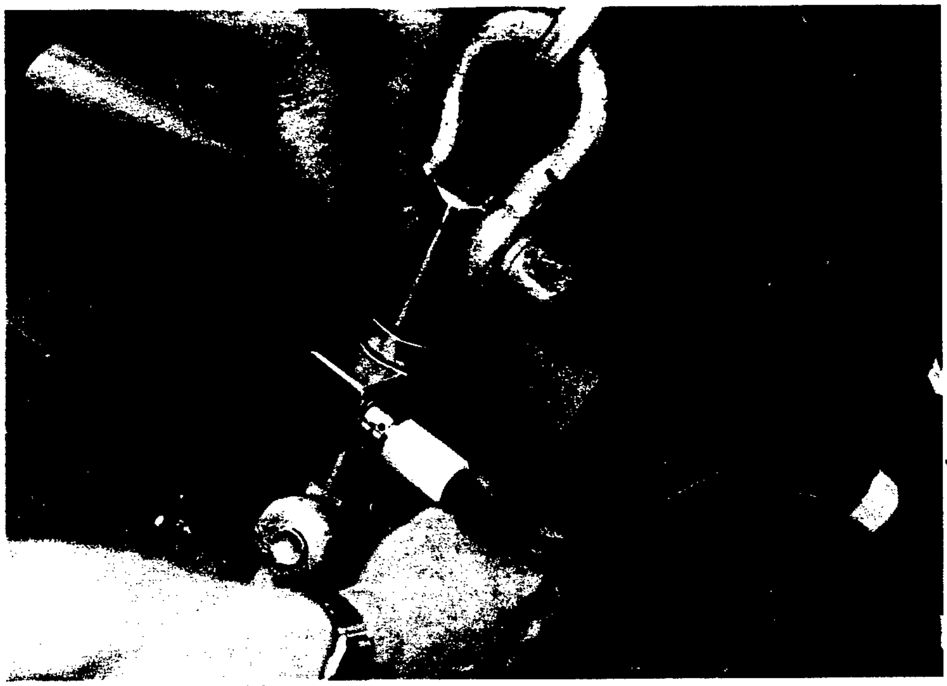

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Fig. 29. Photographs of load cells being protected prior to installation at the outboard end of the outrigger.

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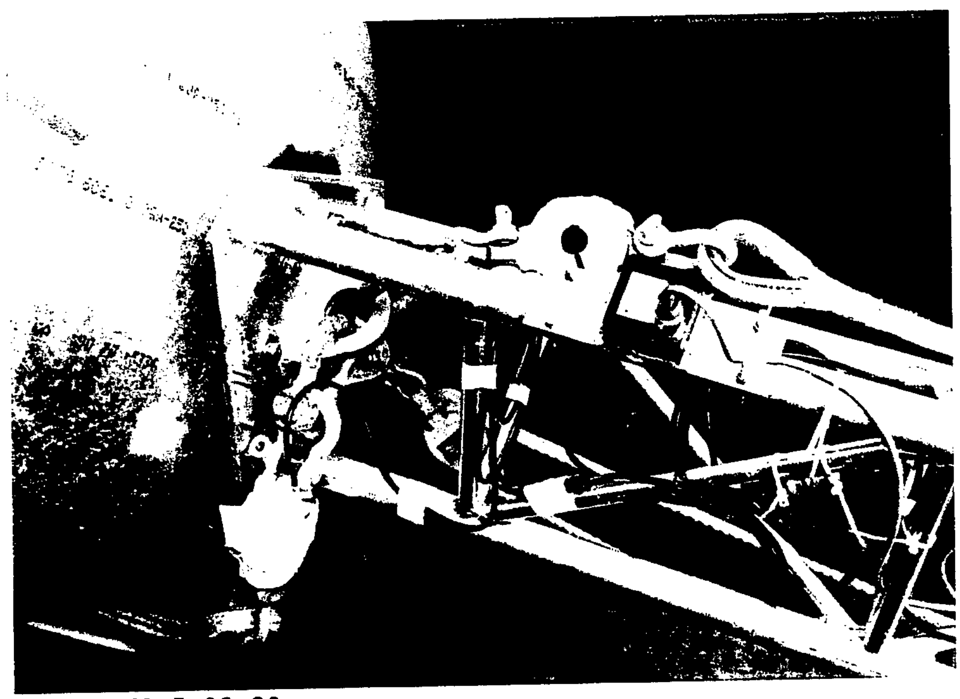

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Fig. 30. Photographs of load cells and accelerometer package being installed near outrigger float.

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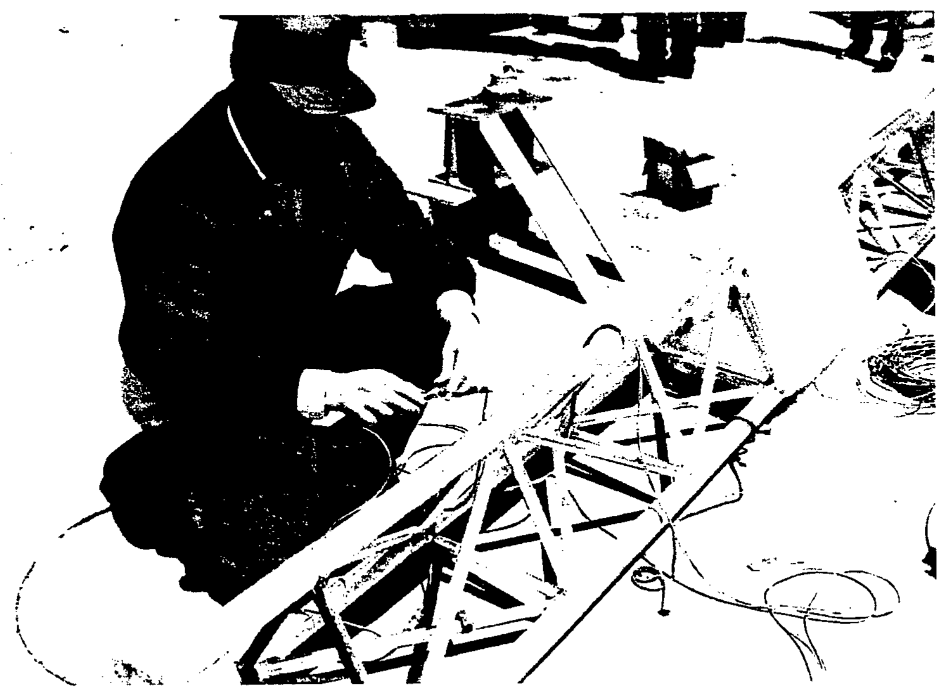

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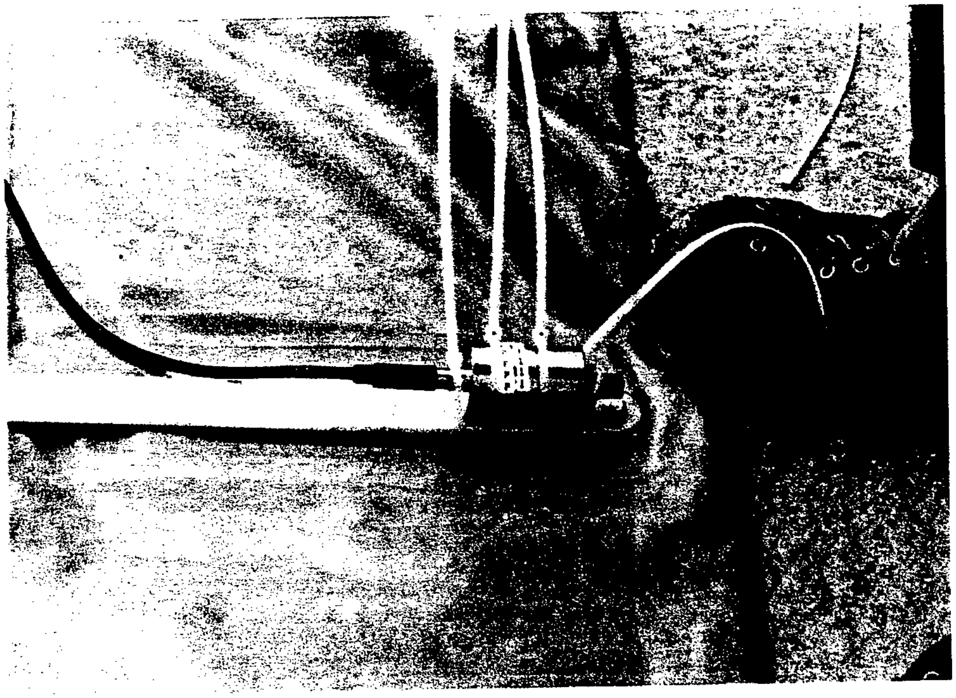
Fig. 31. Photographs of strain gauged outrigger sections (protected areas) being wired prior to deployment.



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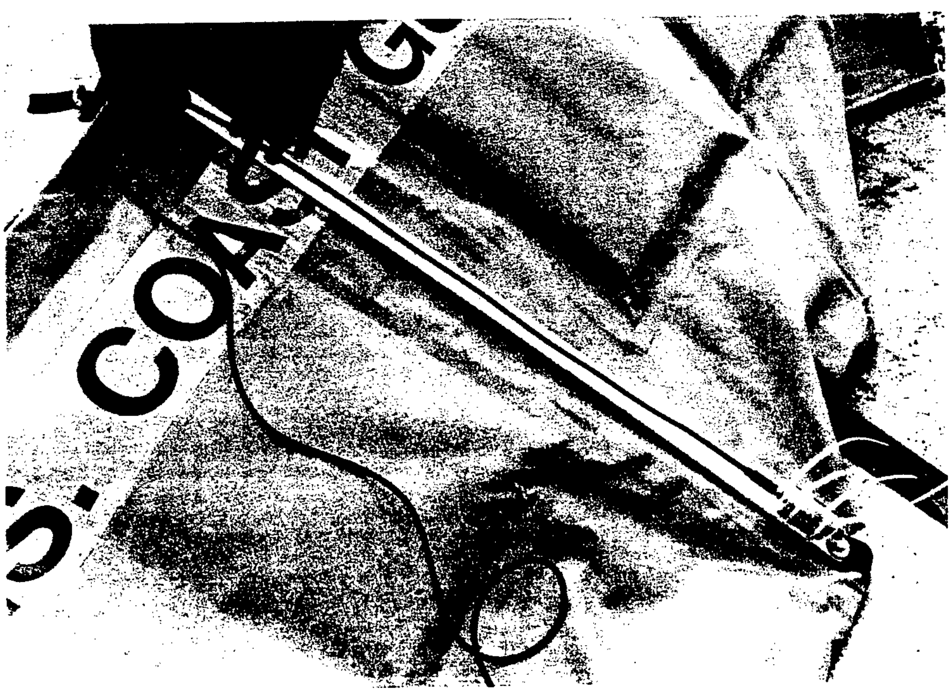

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Fig. 32. Photographs of pressure gauges being installed along CG VOSS boom skirt.

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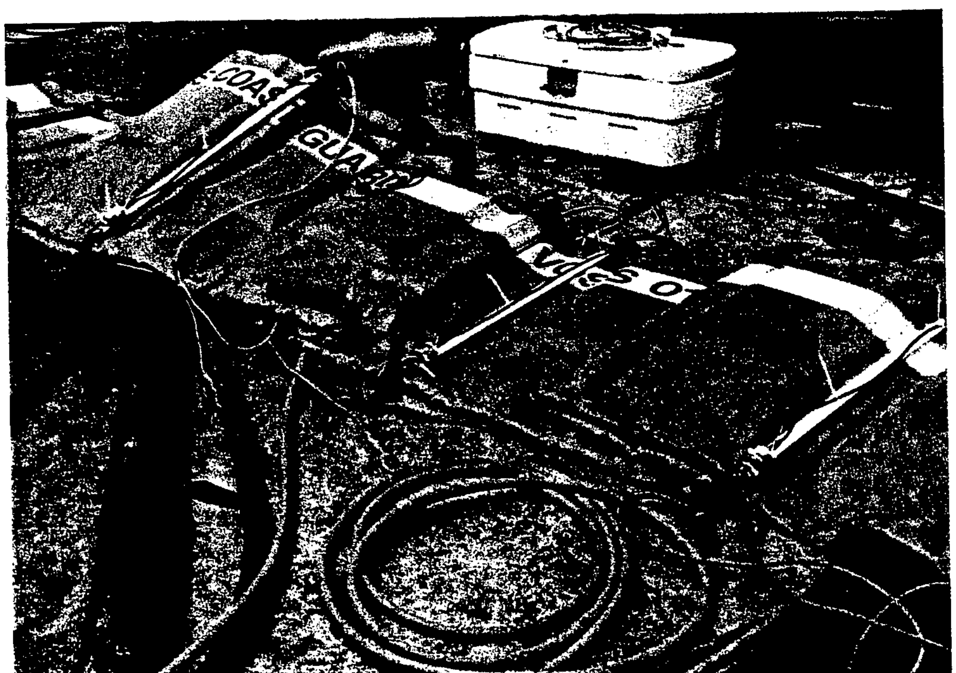


PSD 21269-5-93-28

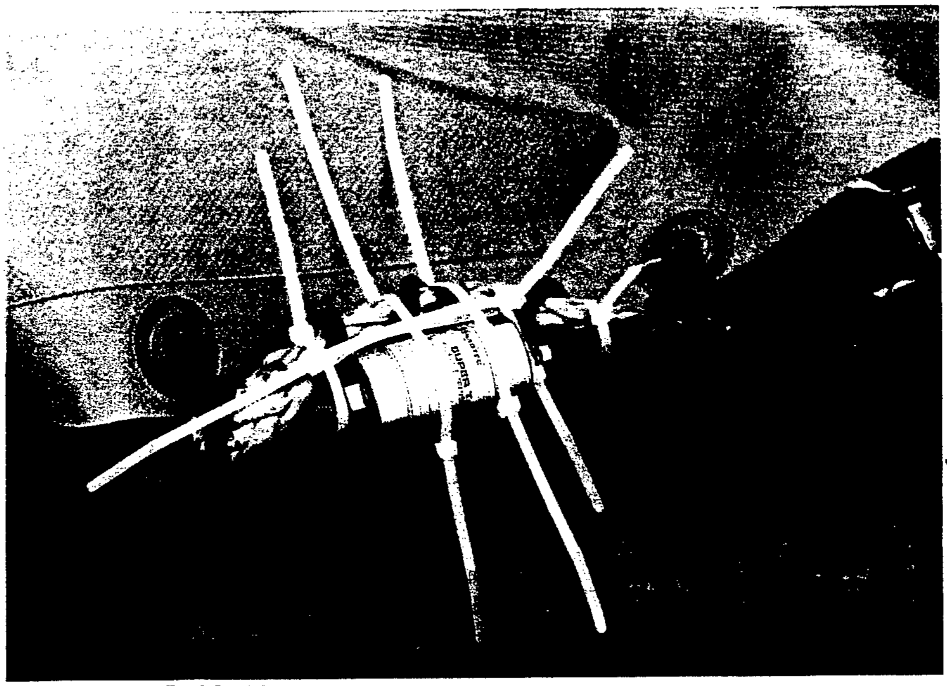
Fig. 33. Photographs of inboard, apex, and outboard pressure gauges being wired along CG VOSS boom.

of the ship. Refer to Fig. 28 for complete configuration information. The strain gauges and pressure gauges were mounted on the outrigger section and the NOFI V Sweep boom in a similar fashion as the CG VOSS side. Figure 34 illustrates how the pressure gauges were attached to the NOFI V sweep boom.

4.3 OUTRIGGER INSTRUMENTATION

The strain gauges were configured to measure strain in locations expecting to experience maximum bending moments. The port and starboard outriggers were each strain gauged at two outboard locations using a 4-arm Wheatstone bridge configuration. The first one was located at the center of the middle (1 of 3) outrigger section and the second was at the inboard end of the middle section as shown in Fig. 35. The spanwise locations were chosen so that strain could be measured near the center of the span using the first bridge if 3 sections of outrigger were used and using the second bridge if two sections were used. The second gauge provided a backup set of gauges if a failure in the bond, wiring or waterproofing occurred. The outriggers were strain gauged as full 4-arm bending bridges. The four arm design allows for compensation of temperature and asymmetrical loads. Ideally, the absolute magnitude of the output of all gauge elements should allow for any desired load to be measured as long as the load is aligned with the gauge axis. However, if some cross load is applied, the resulting signals will be of opposite sign in opposite legs of the bridge and cancel. Gauges designated C1, C2, T1 and T2 (C for compression and T for tension) made up one bending bridge in the vertical plane and gauges C3, C4, T3 and T4 made up a second bridge in the horizontal plane. The strains were reduced to micro-inches per inch and are related as follows:

1. S1, CG VOSS outrigger vertical bending strain,
2. S2, CG VOSS outrigger longitudinal strain,
3. S5, NOFI V outrigger vertical bending strain, and
4. S6, NOFI V outrigger longitudinal bending strain.



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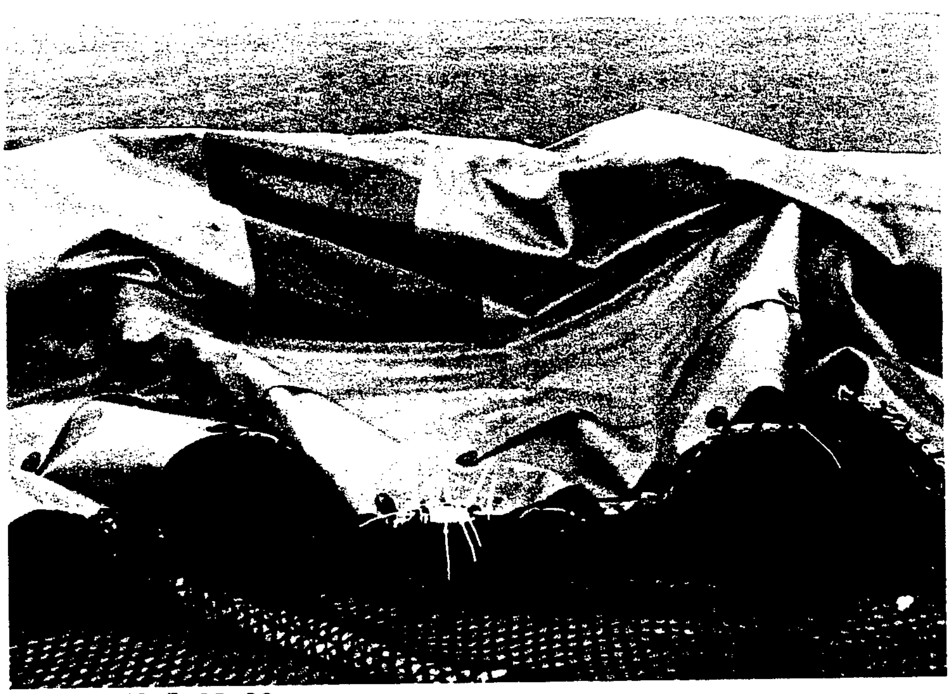

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Fig. 34. Photographs of pressure gauge installation along NOFI V Sweep boom skirt.

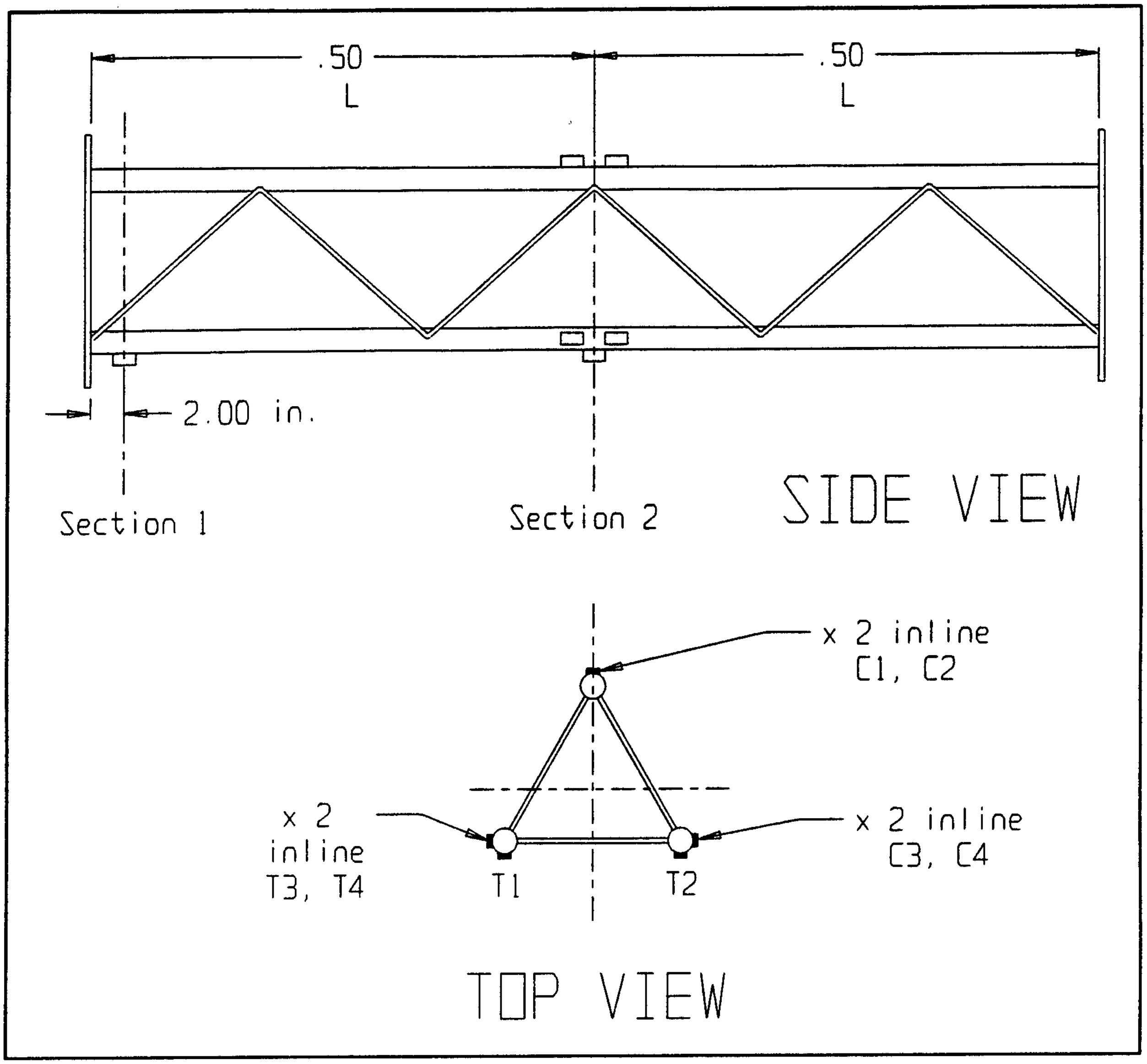


Fig. 35. Strain gauge installations on outrigger sections.

4.4 SHIP AND SEA INSTRUMENTATION

The speed of the tow was monitored using a knotmeter. The knotmeter was positioned in the apex of the CG VOSS boom. A line and pulley arrangement allowed positioning of the knotmeter at various positions in the boom pocket, but was, in practice, rarely repositioned so as to maintain a common speed reference position.

Additional instrumentation included the floating wave buoy of the Coast Guard for measuring wave height and a ship motion package for measuring ship motions. The wave buoy could not be deployed for long periods of time without being lost and presented somewhat of a handling problem due to its weight and awkward shape. However, the wave buoy was deployed at various times throughout the trial and data were recorded for later analysis. The ship motion package typically measures roll and pitch and three axes of acceleration (heave, sway and surge). However, since sea conditions were moderate for a ship of this size the accelerometer package was placed on the CG VOSS outrigger float, as seen in Fig. 30, so that the outboard outrigger accelerations could be monitored for comparison with the tension fluctuations and depth variations of the boom skirt.

Data were recorded on strip chart recorders and a 486 pc computer using a data collection program developed for the Naval Surface Warfare Center. Data were collected at 30 hertz and run times were typically on the order of 4 minutes per run. Video recording was performed throughout the trial during all deployments and during selected segments of each run.

5.0 TEST MATRIX

The test plan included the evaluation of three system configurations in various sea conditions ranging from flat calm seas through a sea state 2 as could best be accommodated by geographic location and weather conditions. Configuration 1 refers to the CG VOSS system, Configuration 2 refers to the NOFI V sweep boom with CG VOSS outrigger and Configuration 3 refers to the FIOCS system. The speeds were to range from one knot to a maximum of three knots. The duration of each run was 4 minutes. Table 3 summarizes the trial schedule and run log into the three sea condition variations and lists the runs that were conducted under those conditions. Weather conditions prevented a simple, well controlled evaluation as might occur in a test tank; however, all the desired test objectives (sea conditions, speeds and relative ship headings) were achieved. Additional runs were conducted for training, calibration and equipment checkout; however, only those runs whose conditions were best controlled are included for detailed evaluation and comparison.

Table 3. Test matrix for evaluation of three configurations for VOSS sea trial.

DATE	CONFIG	SEA STATE	HEADING	SPEED, kn	RUNS
5/5	1,2	0	0	1.0 2.0	22,23
5/7	1,2	1 (1-2 ft)	0,180	1.0 2.0	41-44
5/6	1,2	1 (1-3 ft)	0,180	1.0 2.0 3.0*	25-27
5/6	1,2	2 (2-4 ft)	0,45P,45S	1.0 2.0	28-36
5/11	1,2	2 (3-5 ft)	0,45P,45S	1.0 2.0 3.0	48-55
5/11	3	3 (5-7 ft)	0,180	1.0 2.0 3.0	67-68 71-72 74-77

* NOFI only

6.0 RESULTS

The results of the at-sea evaluation are presented below for each of the systems tested. Data were collected simultaneously on the CG VOSS and NOFI V sweep boom. Selected data runs for each system will be presented. Because these systems were operating together under identical conditions, a table summarizing the statistical information on the tensions as seen by each system for comparison, is included. Information on all other data runs is included in the appendices. Appendix A is a run log of those CG VOSS and NOFI V runs referenced in this report and Appendix B is a compilation of the run averages, maxima, minima and standard deviations of all the applicable recorded engineering parameters. The FIOCS was tested separately and all these data are presented in the body of the report.

Data were collected in calm seas, sea state 1 and sea state 2. The wave buoy data were collected to get a statistical representation of the sea state. Figures 36, 37, and 38 are time history samples of significant wave heights for sea states 1 and 2. The data show significant wave heights of 2.23 ft (sea state 1), 3.3 ft (sea state 2), and 3.9 ft (sea state 2).

6.1 SUPPORT LINE TENSIONS

6.1.1 CG VOSS SUPPORT LINE TENSIONS

Tension data presented for the CG VOSS system were measured using load cells T1 and T2 which correspond to the forward preventer and glide line (see Fig. 28). In general, the forward preventer on the CG VOSS had loads which were twice that of the glide line. The time histories for the tensions measured in the CG VOSS support lines are presented graphically in the figures that follow.

The calm water test was performed just outside the NUWC facility on the Thames River, New London, CT. The wave buoy was not deployed in the river, but the conditions were determined to be a very calm sea. The runs for this day were intended as a check out procedure for deployment, handling, and recovery observations. However, after the deployment was completed, data were recorded at various

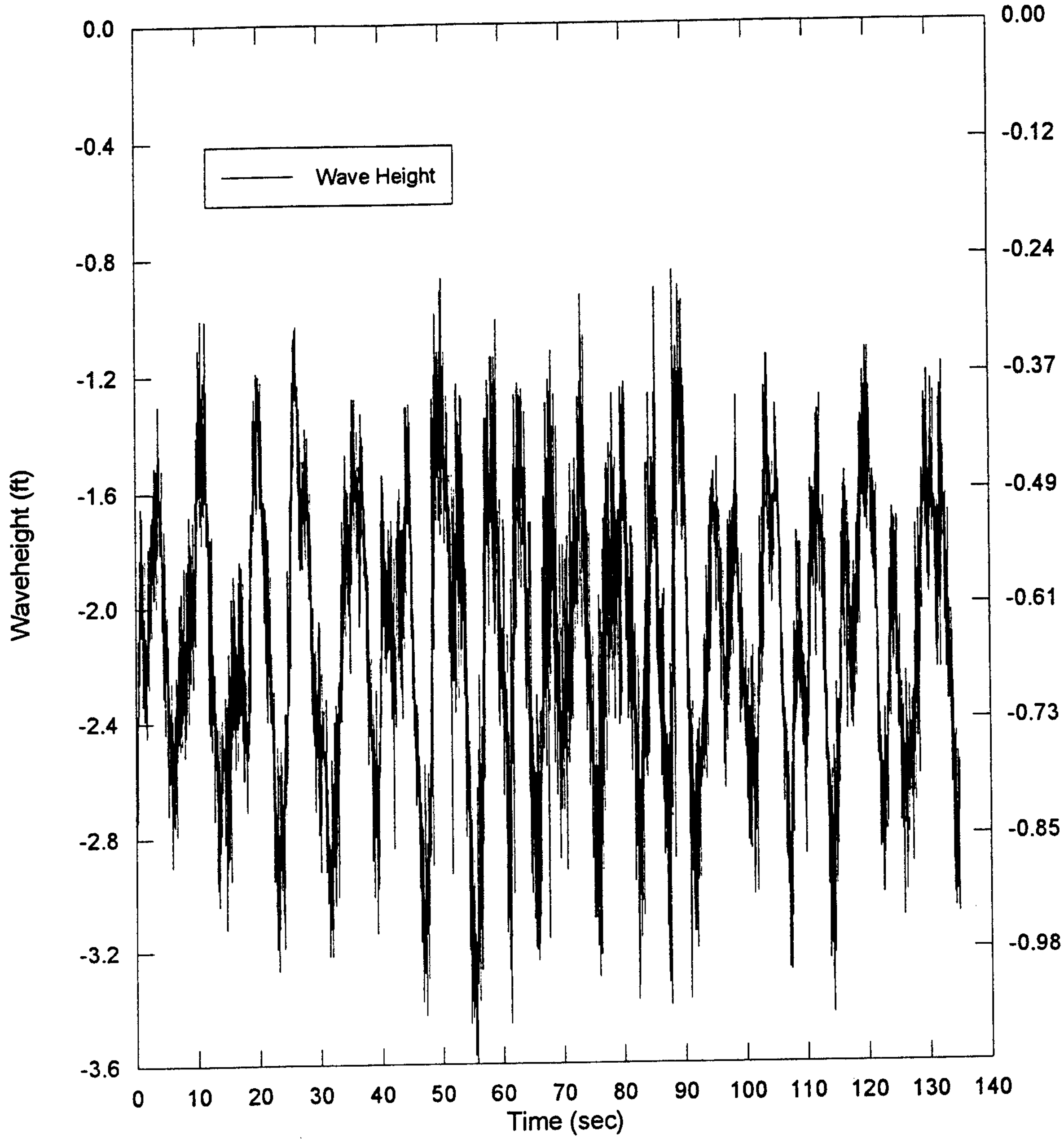


Fig. 36. Wave height data on May 7th corresponding to Sea State 1. (Run 40)

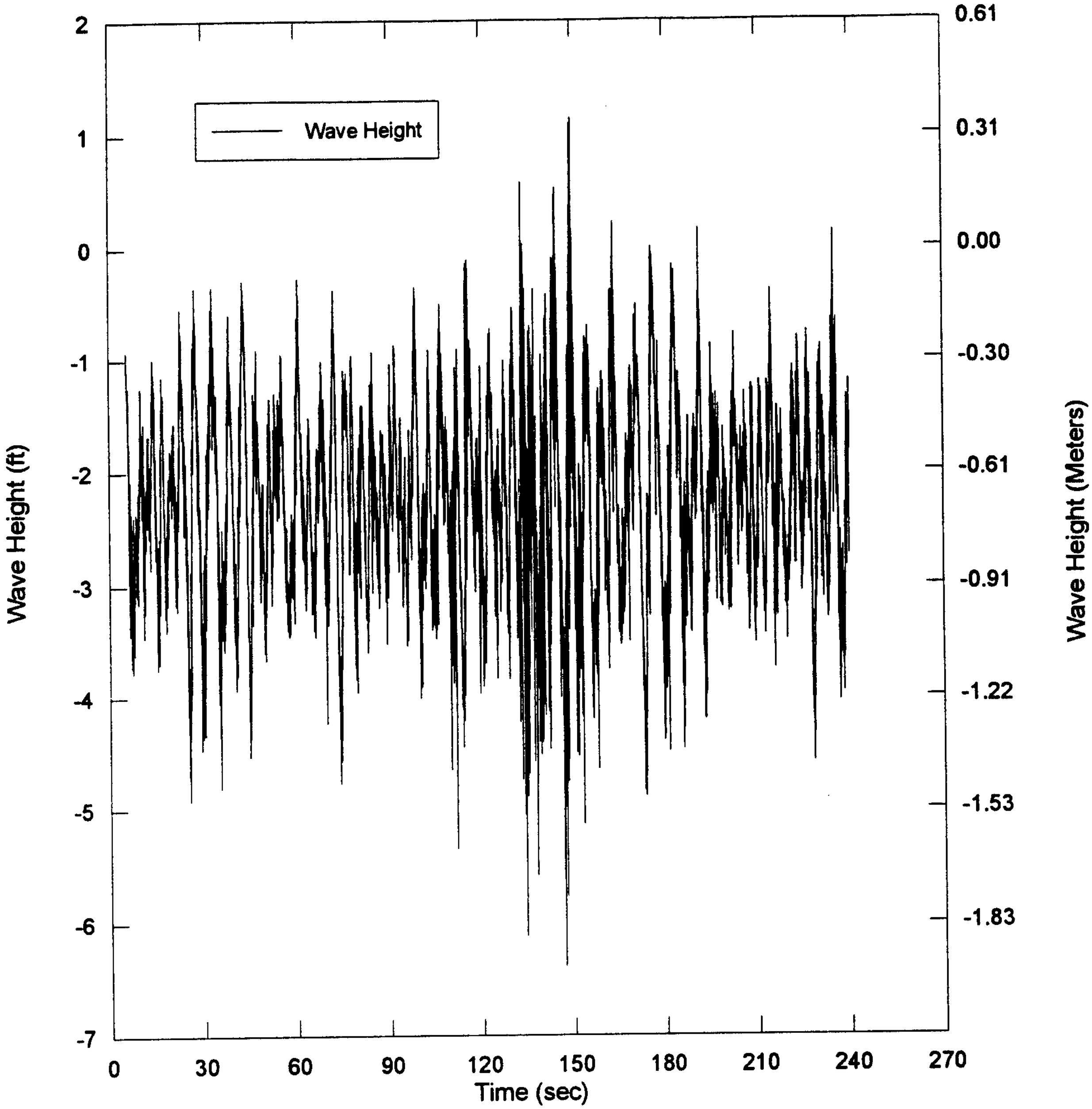
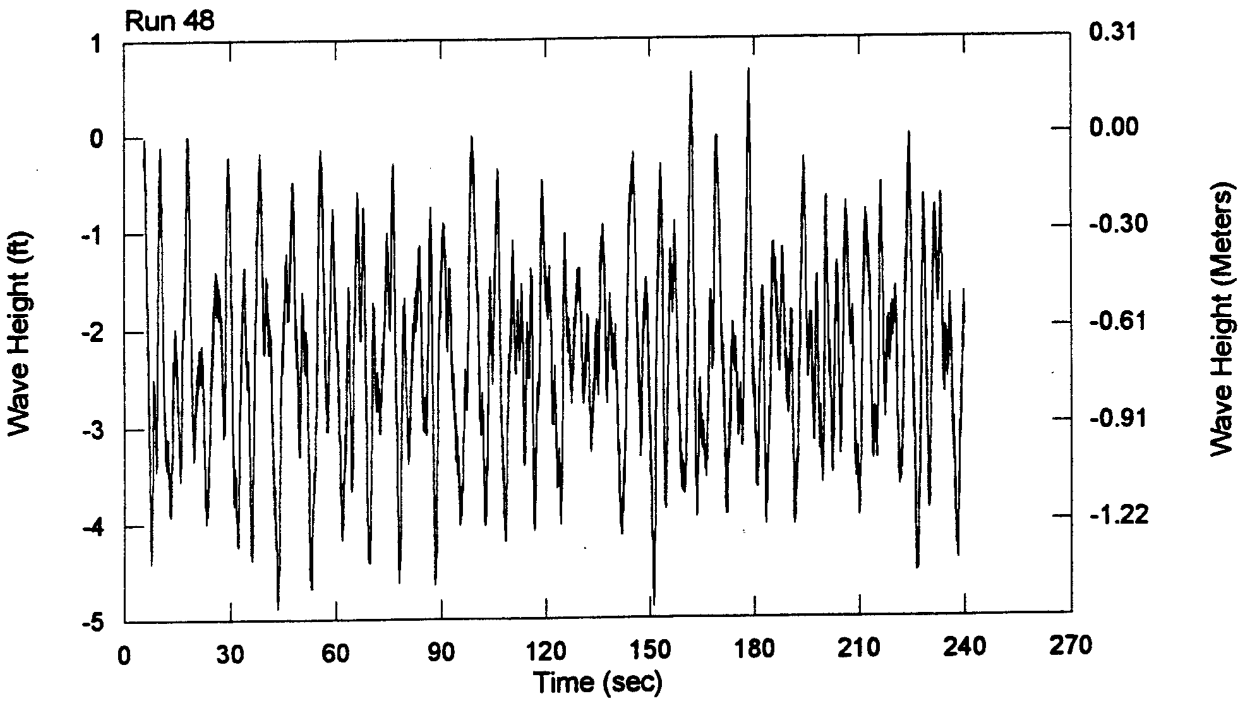


Fig. 37. Wave height data for May 6th corresponding to Sea State 2 (Run 32).



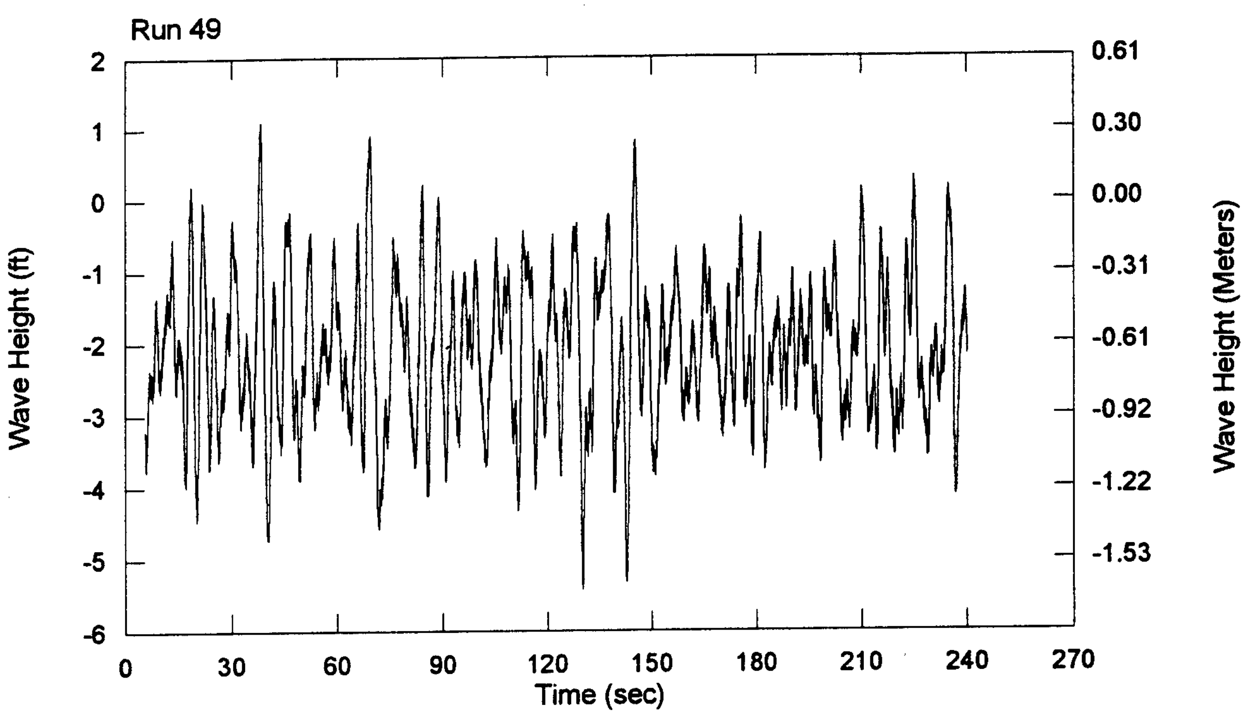


Fig. 38. Wave height data for May 11th corresponding to Sea State 2 (Run 48 & 49).

speeds since it was not likely that calm seas would be found outside the mouth of the river. Deployment began around mid afternoon leaving a limited amount of time to perform the test so the skimmers were not deployed. The time history of the tension data for the CG VOSS in calms seas are shown in Figs. 39 and 40. There was approximately a one Hz oscillation in the Forward Preventer tension measurement and a 2 Hz oscillation in glide line tension measurement at one knot. The amplitude fluctuations were on the order of 50 lb and the measurements tracked each other consistently at a given speed. This indicates that these oscillations are related to the natural frequency of the system under tension and not to environmental dynamics.

Sea state 1 testing was done on May 6th and 7th. Wave buoy data were taken on the morning of the 7th and indicated a significant wave height of 2.23 ft (see Fig. 36). Sea conditions were estimated to be about the same throughout the day of testing. The sea conditions were slightly higher on May 6th than on May 7th but were still considered a sea state 1. Therefore, the May 6th runs are considered 1 - 3 ft seas rather than the 1 - 2 ft experienced on May 7th.

Figures 41 - 46 present the tension time histories for the CG VOSS in a sea state 1 condition. Tension variations increased significantly in this moderate sea state over those seen in calm seas. Maximum to minimum tension ratios were as high as 23:1 in a following sea conditions at one knot for the CG VOSS system. The most significant periodic motion seen by the system was directly related to the period of maximum energy of the sea which was around 5 - 6 seconds. There was a slight change in the dominant frequency seen in the tension data due to ship speed and direction changes. However, the wave celerity (speed of the wave front) dominates the encounter frequency at these low ship speeds and small changes in speed do not cause major frequency shifts in the tension data. The high frequency variations seen in calm water runs were not visible in the CG VOSS data under the significantly higher tensions observed during a sea state 1. A secondary oscillation at about three times the frequency of the maximum wave energy does appear in the CG VOSS tension data but is dominated by the 5 - 6 second

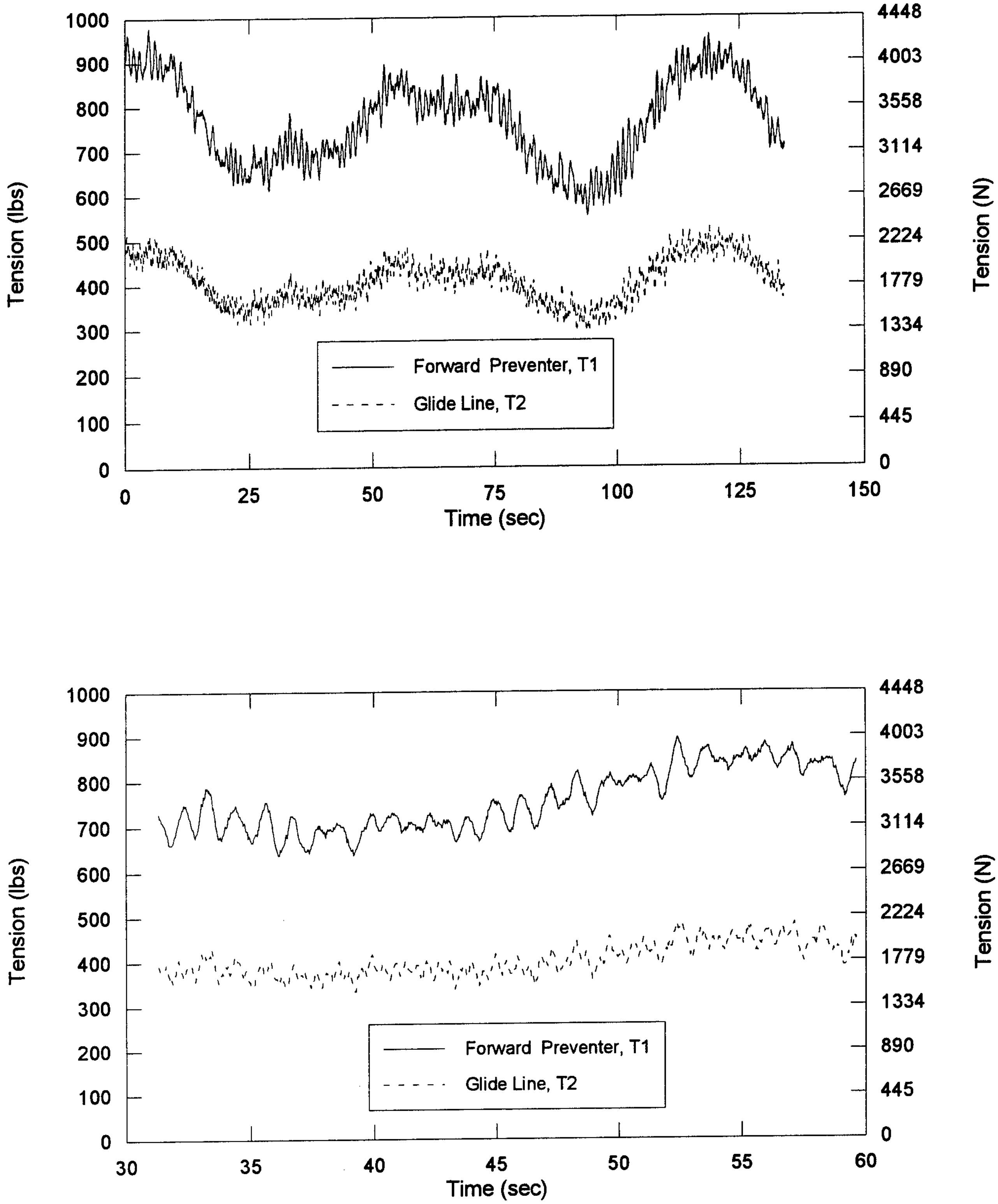
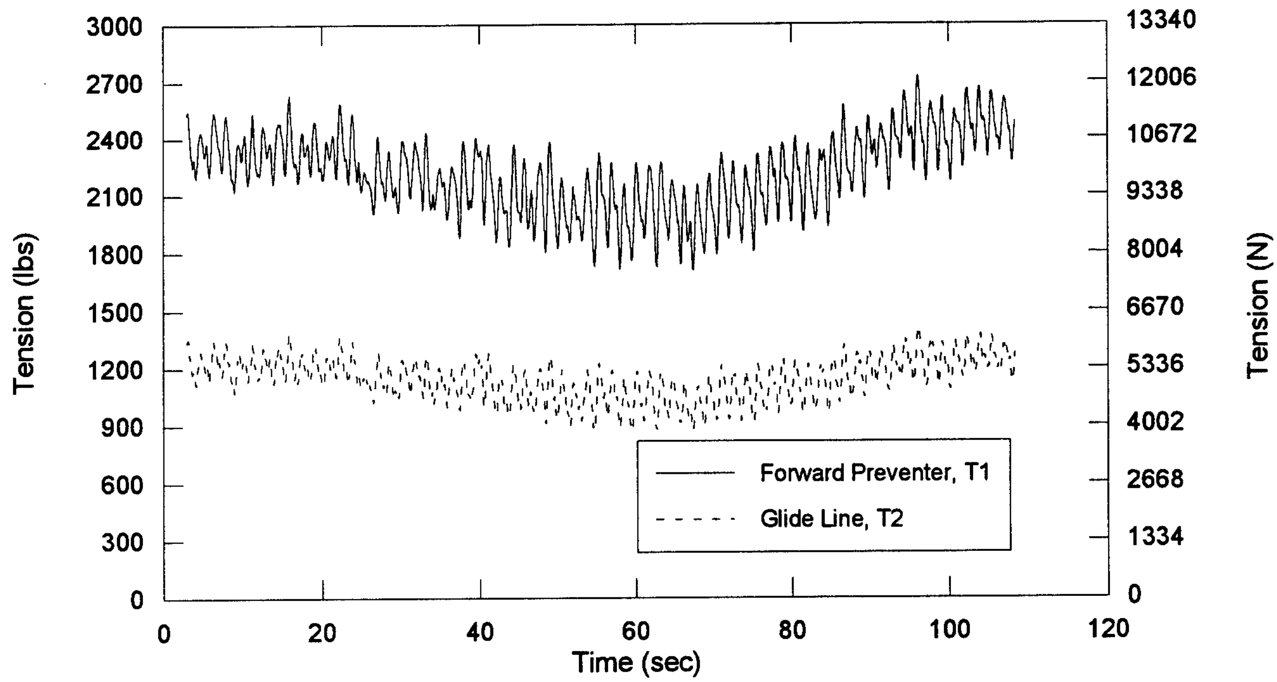


Fig. 39. Tension in CG VOSS support lines at 1 knot in calm seas, without skimmer. Bottom graph is a closeup of the period from 30 to 60 seconds. (Run 22, 5/5/93)



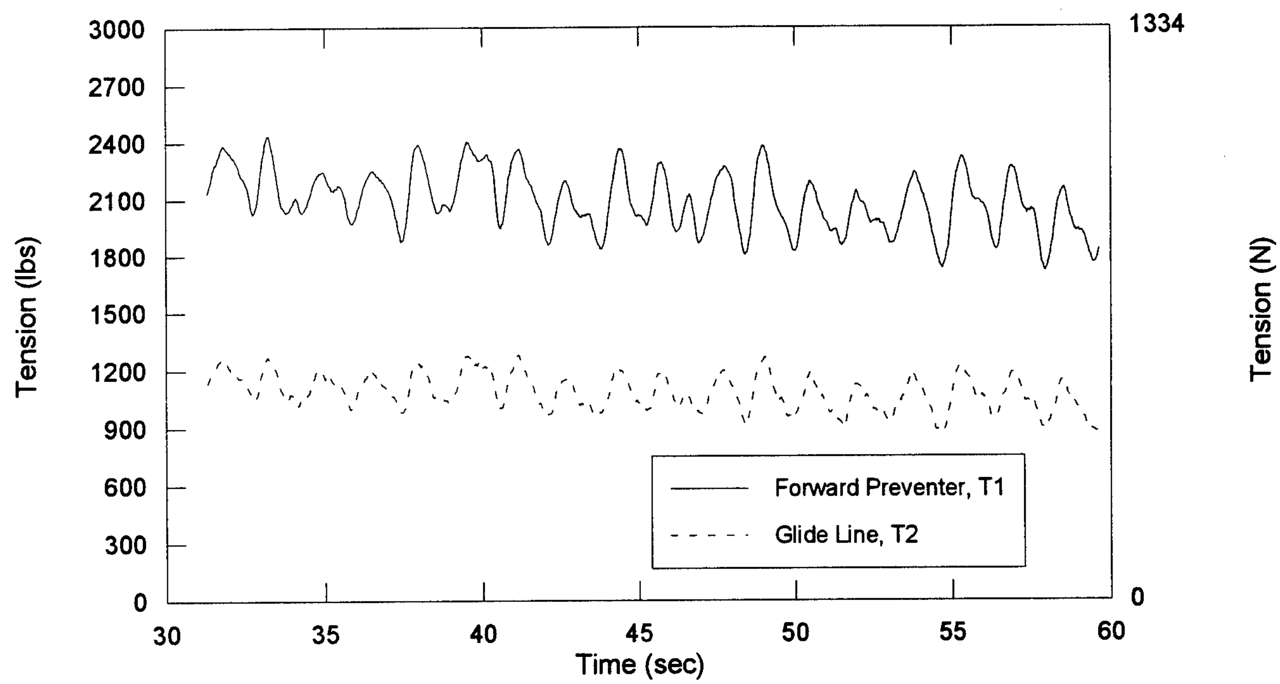
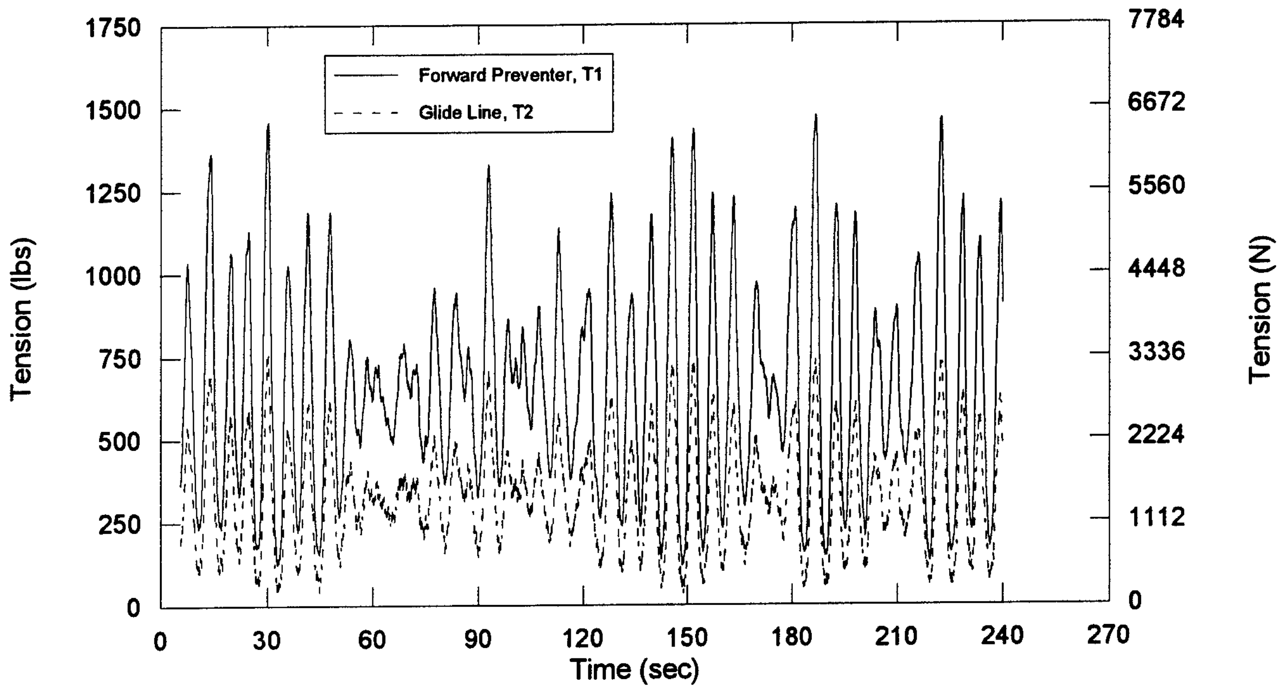


Fig. 40. Tension in CG VOSS support lines at 2 kt in calm seas, without skimmer. Bottom graph is a closeup of the period from 30 to 60 seconds. (Run 23, 5/5/93)



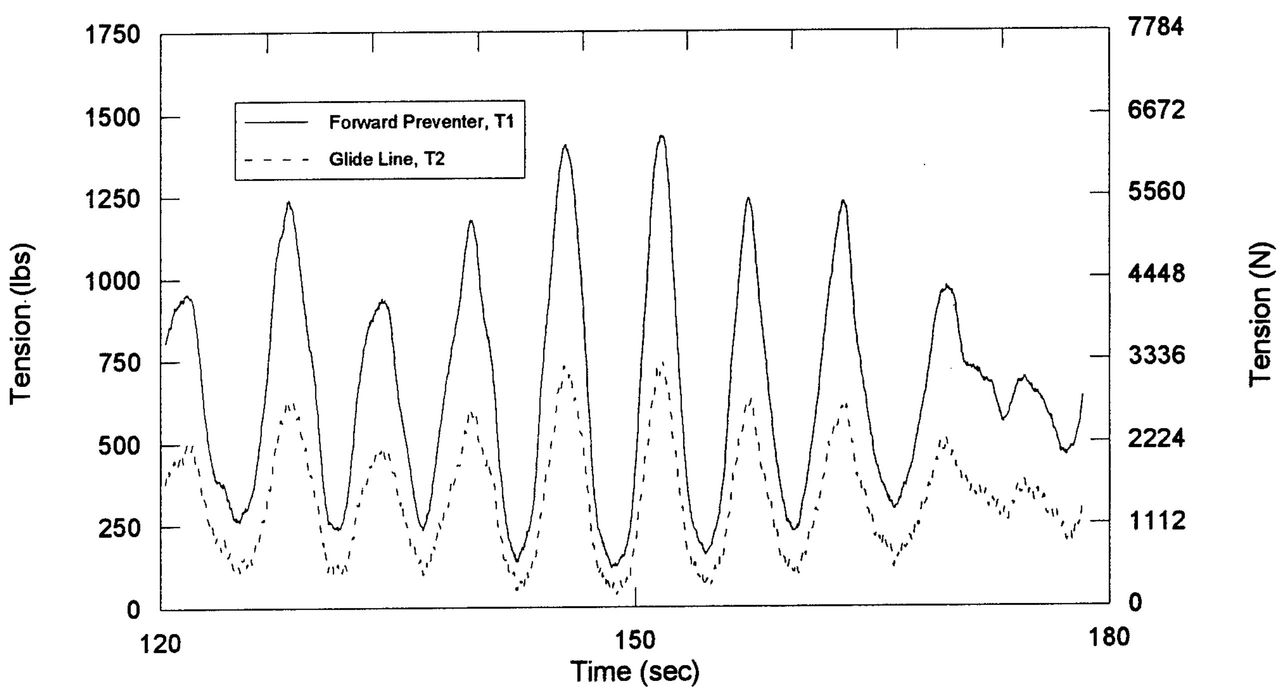


Fig. 41. Tension in CG VOSS support lines at 1 knot in 1 - 2 ft head seas with skimmer. Bottom graph is a closeup of the period from 120 to 180 seconds. (Run 41, 5/7/93)

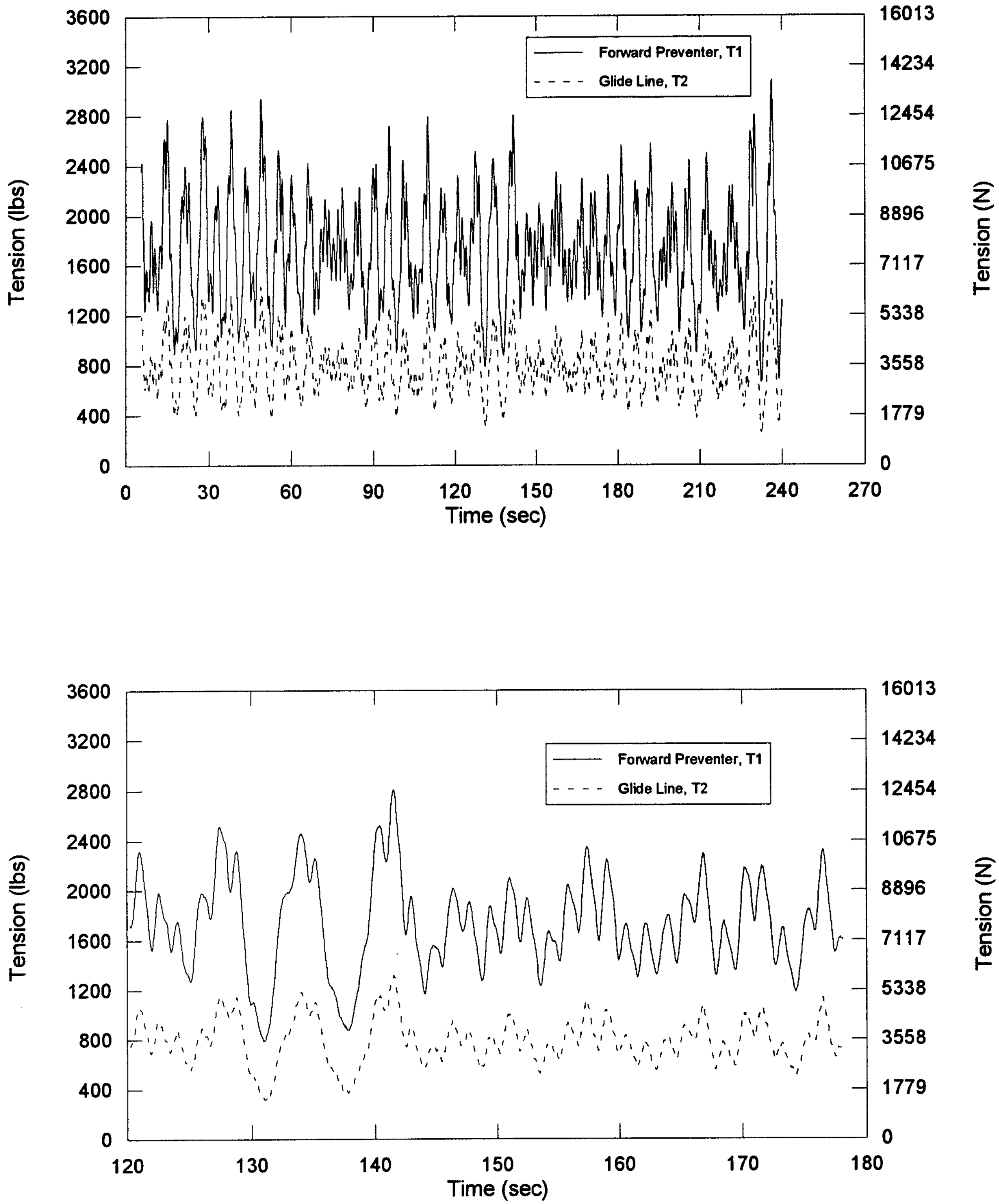
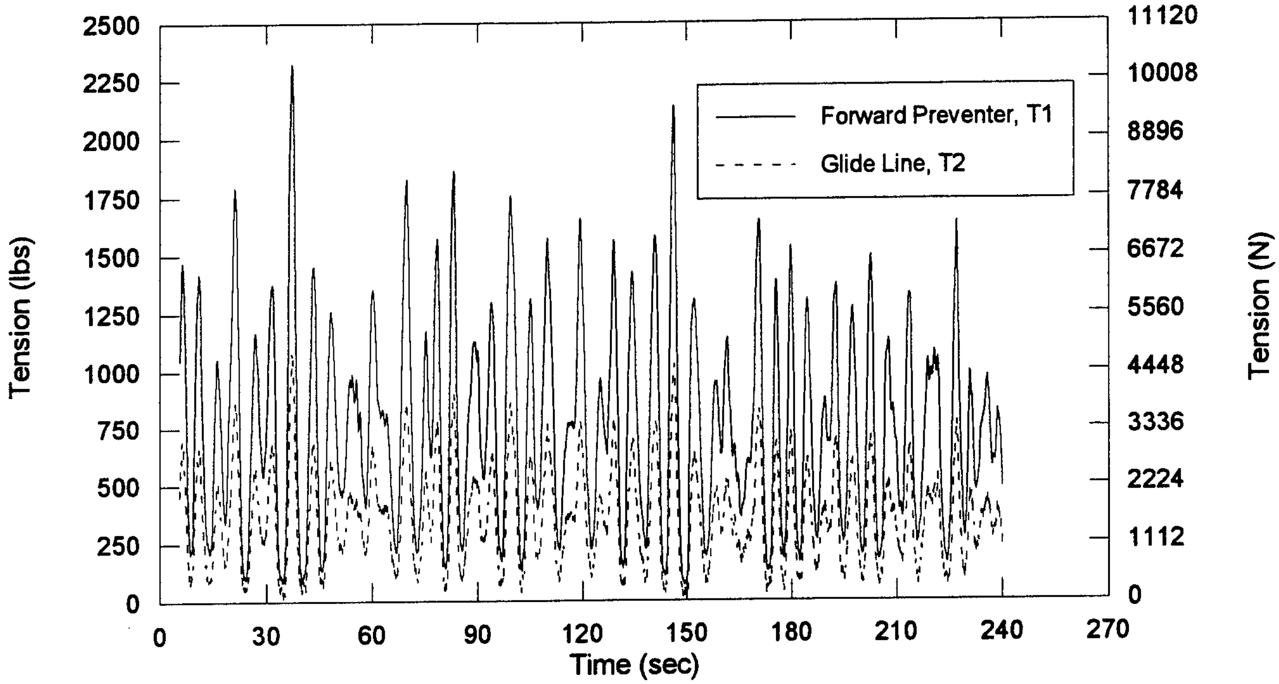


Fig. 42. Tension in CG VOSS support lines at 2 knots in 1 - 2 foot head seas with skimmer. Bottom graph is a closeup of the period from 120 to 180 seconds. (Run 42, 5/7/93)



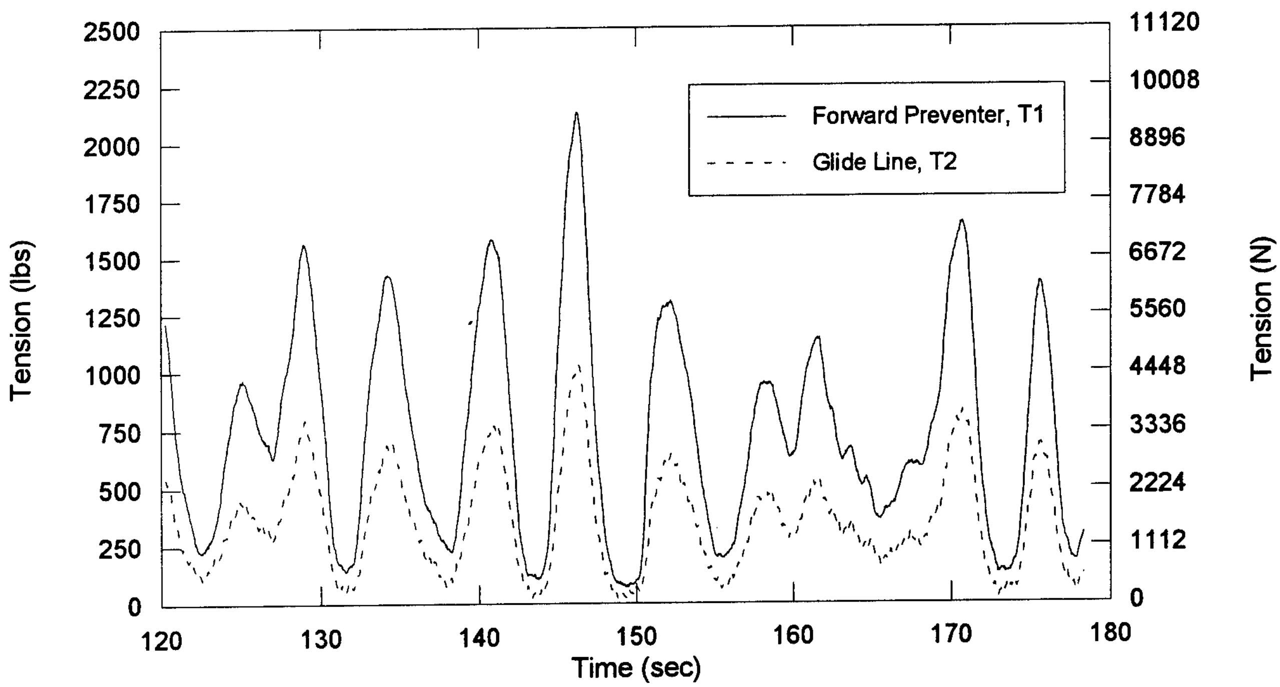
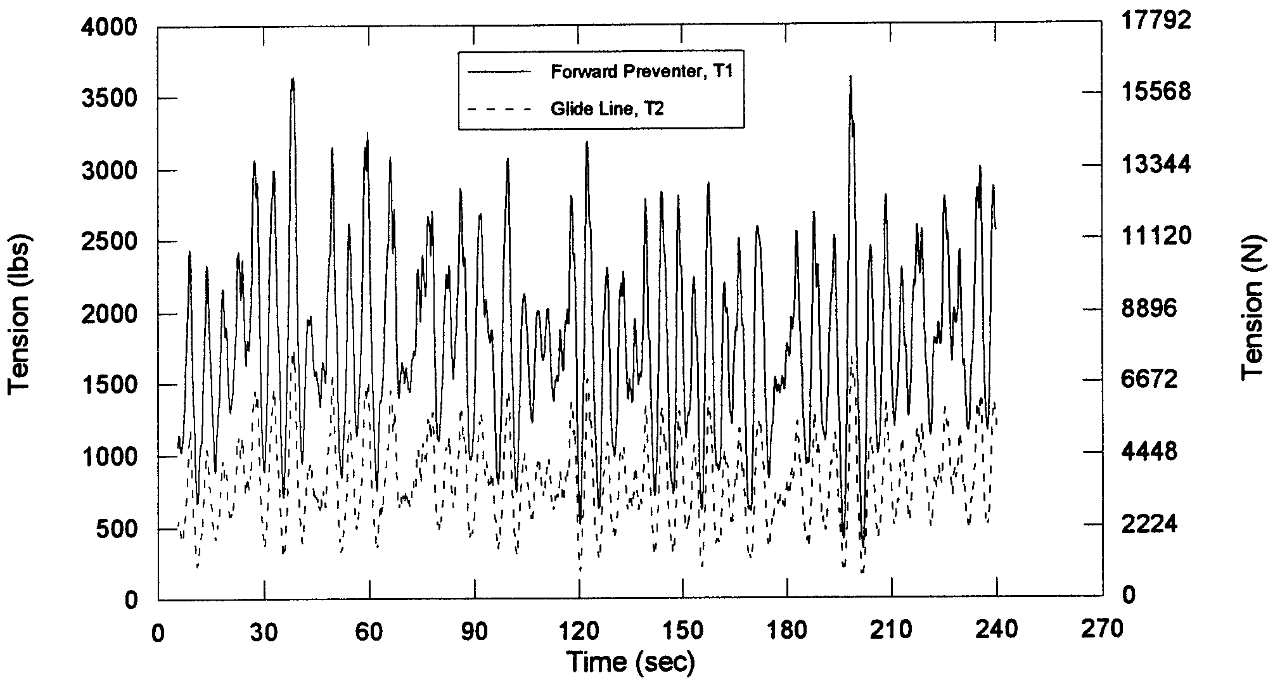


Fig. 43. Tension in CG VOSS support lines at 1 knot in 1 - 2 ft following seas with skimmer. Bottom graph is a closeup of the period from 120 to 180 seconds. (Run 43, 5/7/93)



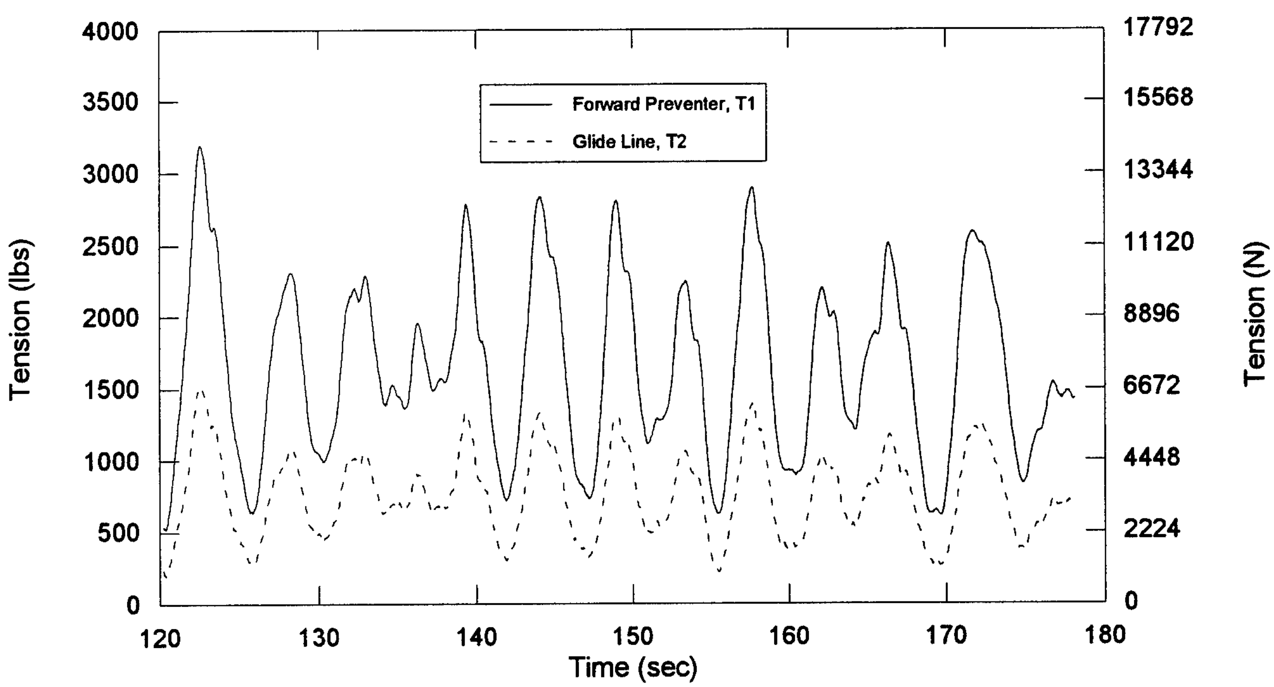
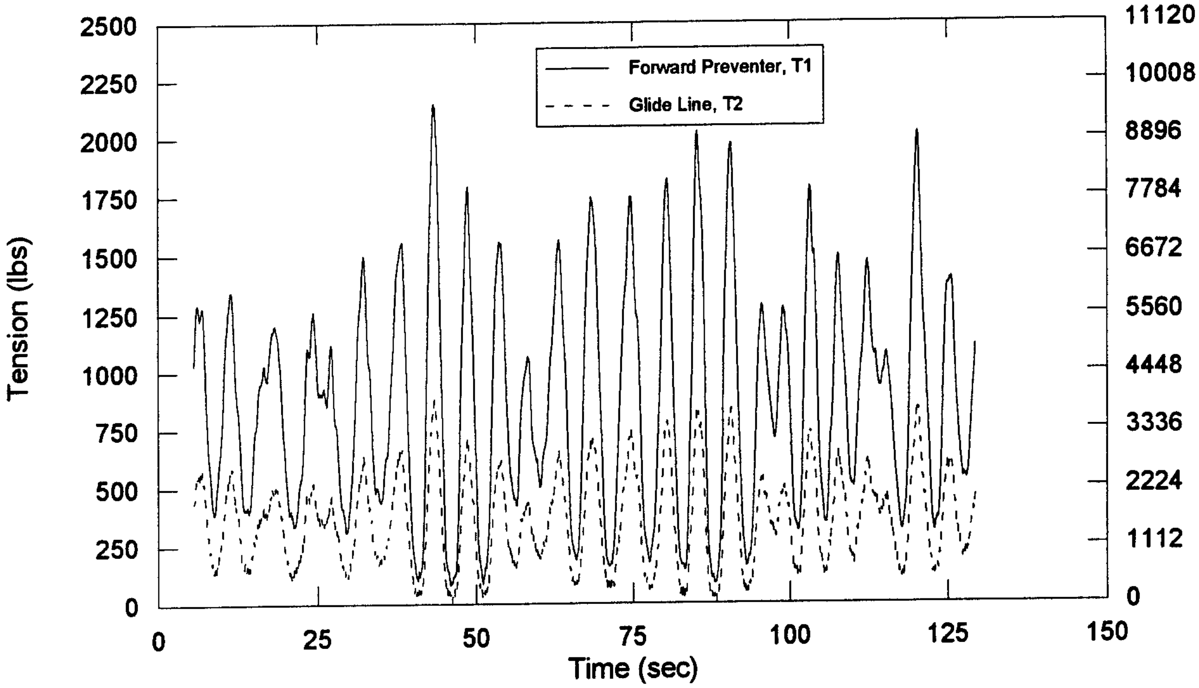


Fig. 44. Tension in CG VOSS support lines at 2 knots in 1 - 2 ft following seas with skimmer. Bottom graph is a closeup of the period from 120 to 180 seconds. (Run 44, 5/7/93)



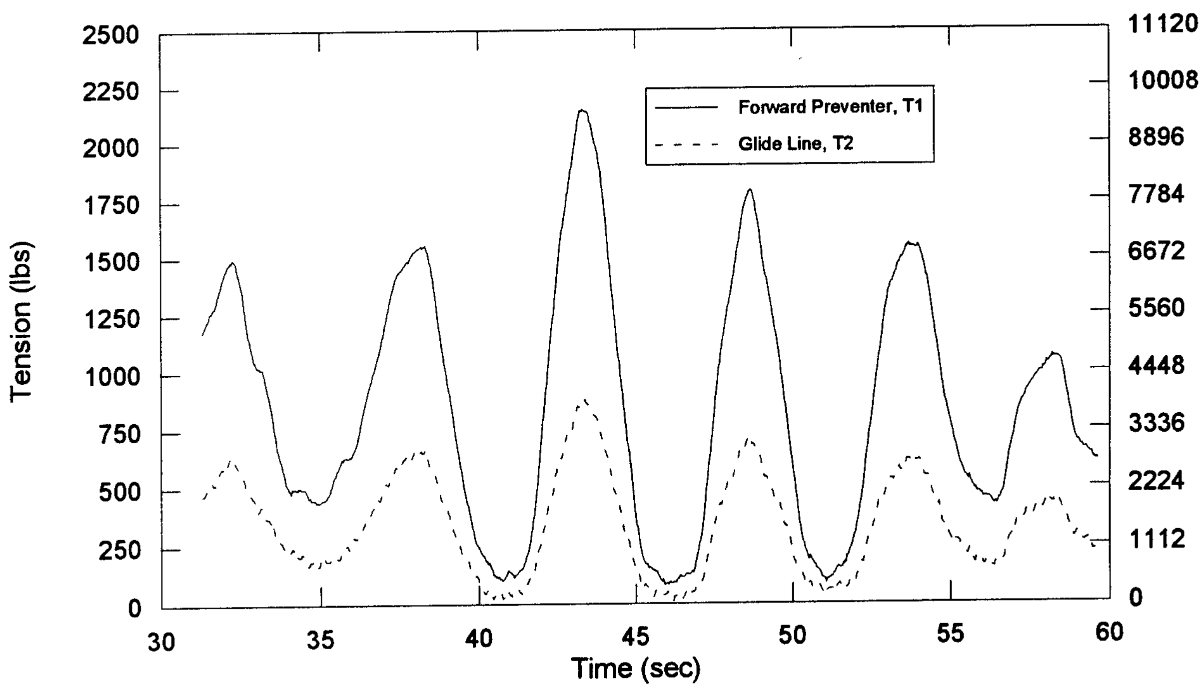
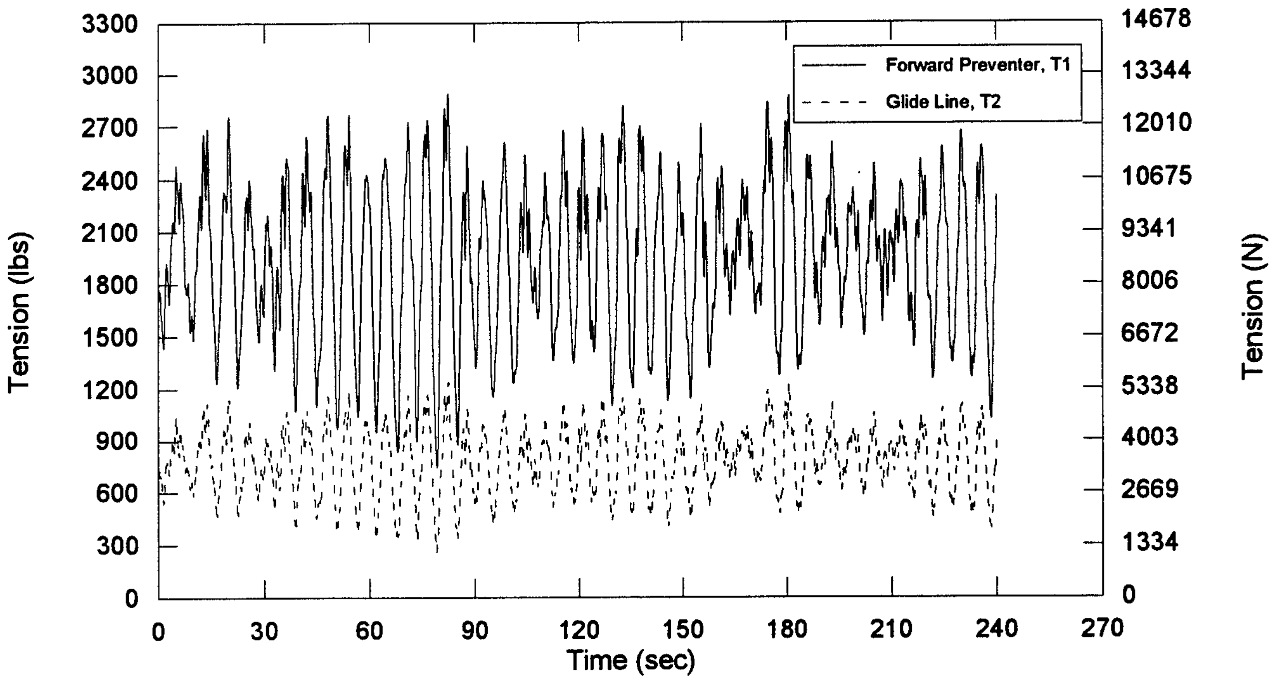


Fig. 45. Tension in CG VOSS support lines at 1 knot in 1-3 foot following seas (w/ skimmer). Bottom graph is a closeup of the period from 30 to 60 seconds. (Run 26, 5/6/93)



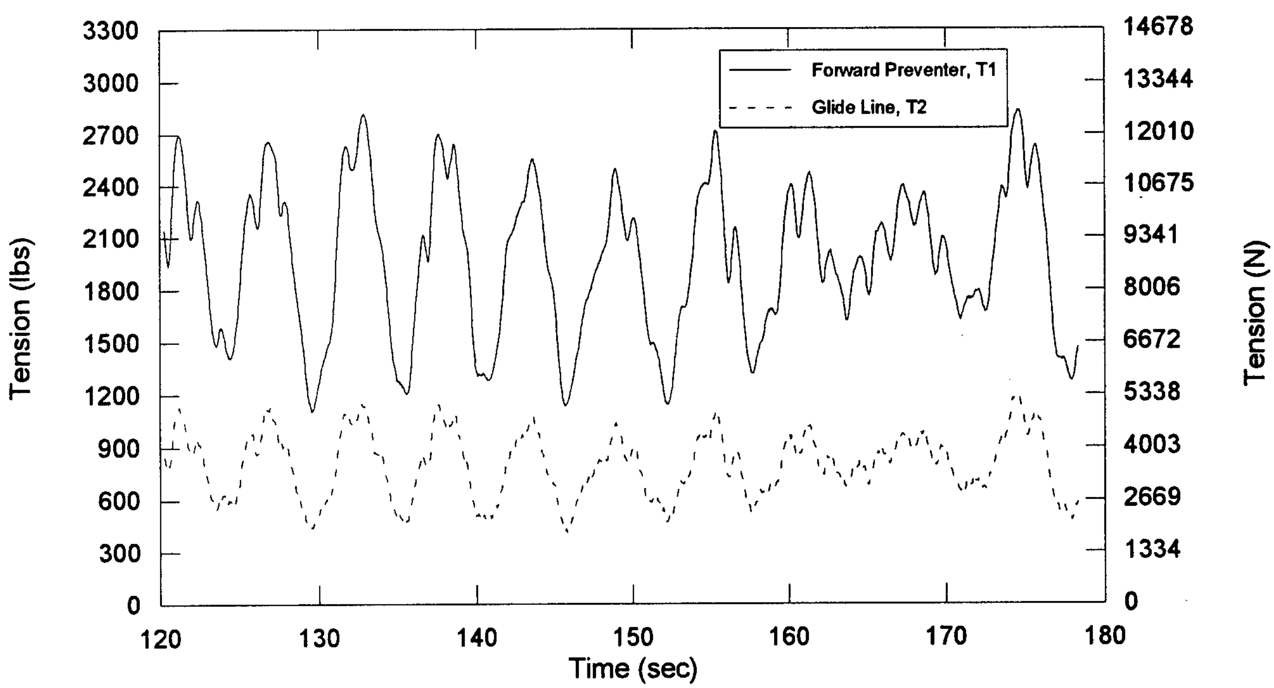


Fig. 46. Tension in CG VOSS support lines at 2 knots in 1-3 foot following seas (w/ skimmer). Bottom graph is a closeup of the period from 120 to 180 seconds. (Run 27, 5/6/93)

period fluctuation.

The CG VOSS boom came out of the water in Run 27 at a speed of 2.1 kn and rode on top of the waves. However, the sea condition was approaching a sea state 2. After Runs 26 and 27, the vessel turned to do a reciprocal course and the seas were still considered a sea state 2. A load cell (T5) was used to record the tensions of the skimmer during these runs. At 1.25 kn, the load was 24 lb and at 2.08 kn, the load was 81 lb which indicates a velocity squared loading relationship. The skimmer tensions were considered to be so low that skimmer tension was no longer measured after Run 31.

Sea state 2 testing was performed on May 6th and 11th, with significant wave heights of 3.3 - 3.9 ft (See Figs. 37 and 38). The wave buoy was deployed after Run 31 on the May 6th and prior to Run 50 on the May 11th. The behavior of the CG VOSS boom was fair in head sea conditions during Runs 28 and 29 and in the starboard seas of during Runs 30 and 31. Starboard seas corresponded to the TROJAN heading 45 deg to port relative to the seas. However, the head sea condition of Runs 28 and 29 was actually a combination of a wind driven sea from the starboard quarter and a slight swell from the port quarter. This was accepted as a head sea condition for lack of congruence between the sea and swell. However, this condition actually put the CG VOSS system in a more protected position than on earlier head sea conditions since the swell had less of an effect on the boom dynamics than the wind driven seas. Tensions were actually lower than in the lower sea state conditions of Runs 26 and 27.

The CG VOSS boom began to behave erratically in the port seas condition (TROJAN turned to starboard relative to the seas) where it was more directly exposed to the brunt of the wave onslaught and tensions increased markedly. Run 34, a 2-kn run, was cut short due to severity of the boom dynamics and the CG VOSS was recovered. The tension time histories for Runs 28 through 34 are shown in Appendix C.

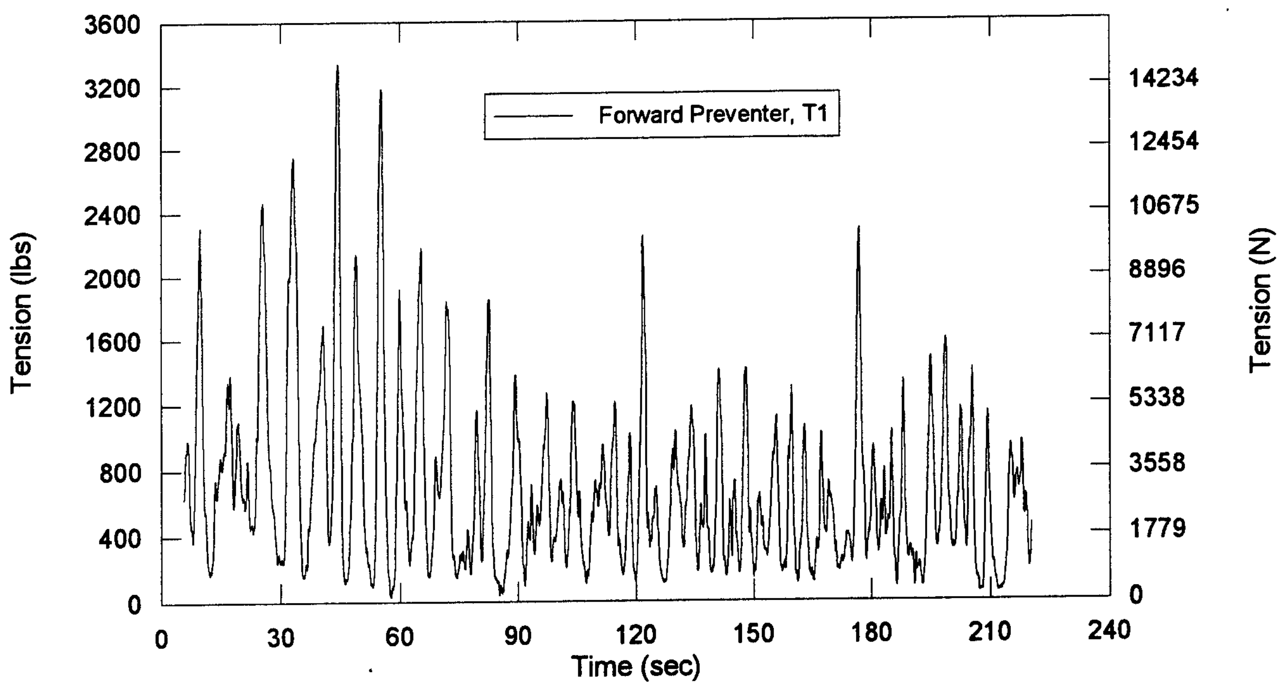
The seas were running slightly higher on the morning of the May 11th and continued to build all day. The first run of the day, Run 50, was made at 1.48 kn when the CG VOSS boom became unstable, with the boom skirt flipping out and laying on the water surface. The boom dynamics became so severe that damage to the system was expected to occur and the CG VOSS was retrieved. The time history of the tension for the CG VOSS forward preventer taken in the sea state 2 condition is shown in Fig. 47.

6.1.2 NOFI V SWEEP SUPPORT LINE TENSIONS

The NOFI V Sweep measurements were measured using gauges T3 and T4 which correspond to the outboard and inboard restraining lines (again see Fig. 28). The operational conditions are the same as for the CG VOSS since the two systems were operating simultaneously, except under those conditions when the CG VOSS had to been recovered due to severe boom dynamics. Some operational occurrences should be noted. During the two-knot calm sea runs the NOFI V Sweep boom entrapped some lobster pots from local fisherman and the run was shortened. However, the tension and depth data did not appear to be affected. The forward preventer (T6) and the outboard support (T3) load cells were periodically disabled. A table indicating measurements taken for each run are indicated in Appendix B. It should also be noted that the outrigger float used for the NOFI V Sweep began to take on water as soon as it was deployed and lost much of its buoyancy early in the testing. Figure 48 shows the starboard float after the first day of testing in a semi-submerged condition. This caused the float to plow through the oncoming waves rather than ride over them as originally designed and intended.

The NOFI V Sweep behaved extremely well in calm seas. Figures 49 and 50 show time histories of the tensions in the support lines of the NOFI V Sweep for one and two knot speeds in calm seas. The inboard and outboard loads are comparable and do not vary significantly. However, there is a very high frequency of oscillation present in the data not related to the sea motion. These fluctuations are believed to be due to the natural frequencies of the system.

Sea state 1 testing was done on May 6th and 7th, as for the CG VOSS (refer to previous section for information on sea conditions). Figures 51 - 56 present the tension time histories for the NOFI V



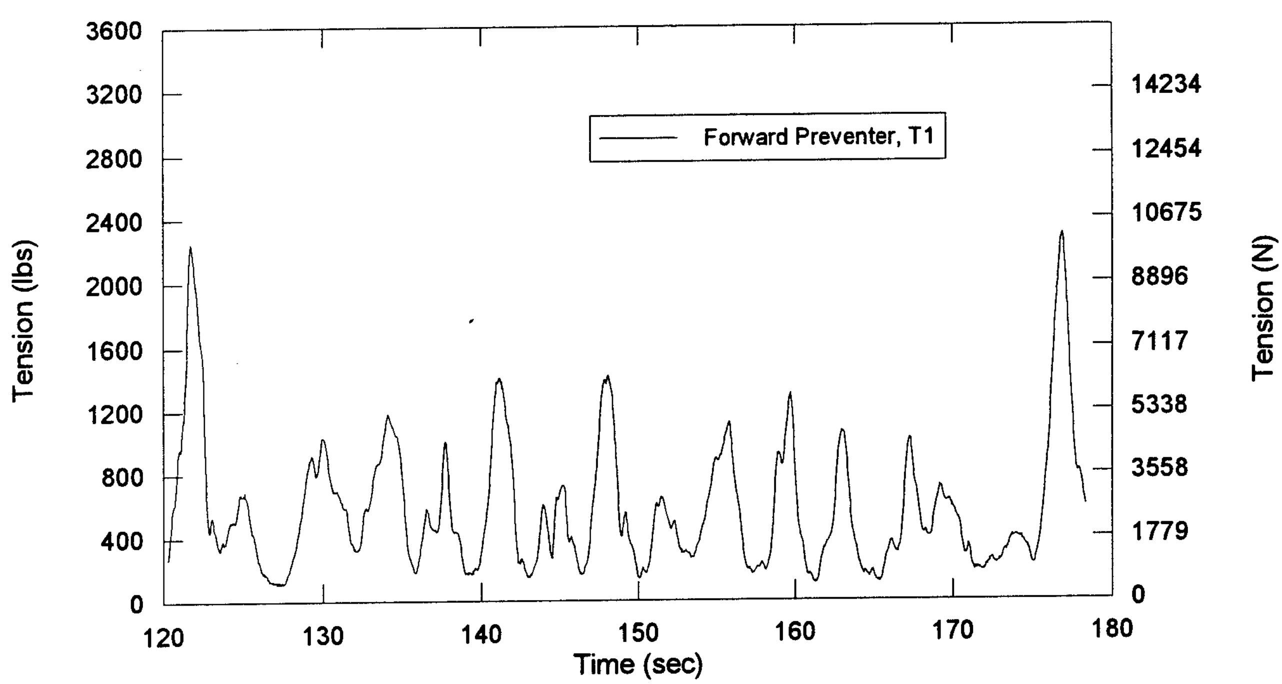
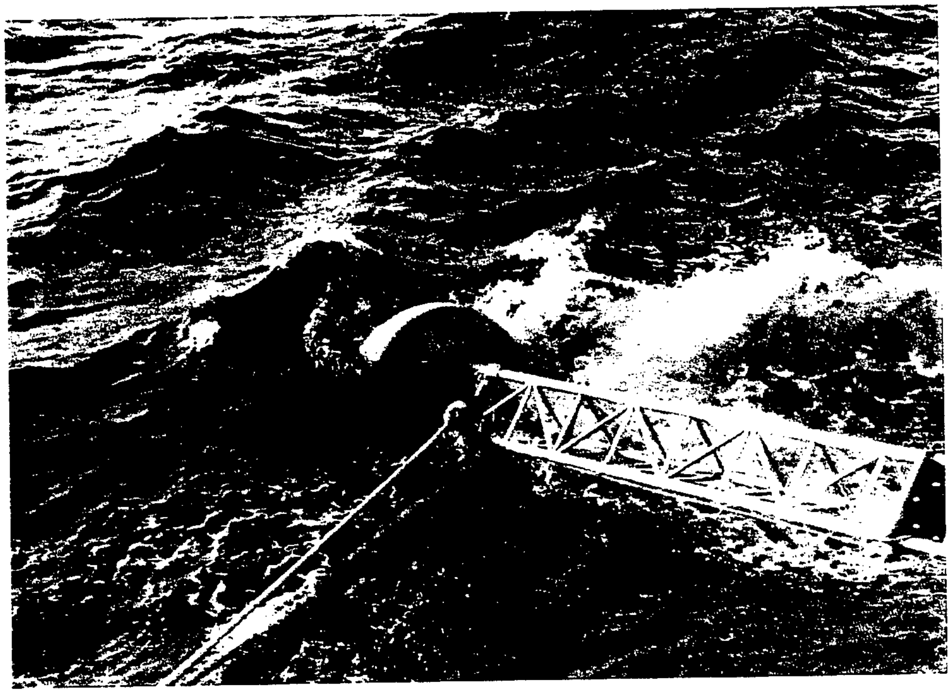


Fig. 47. Tension in CG VOSS support lines at 1 knot in 3-5 foot head seas (w/ skimmer). Bottom graph is a closeup of the period from 120 to 180 seconds. (Run 50, 5/11/93)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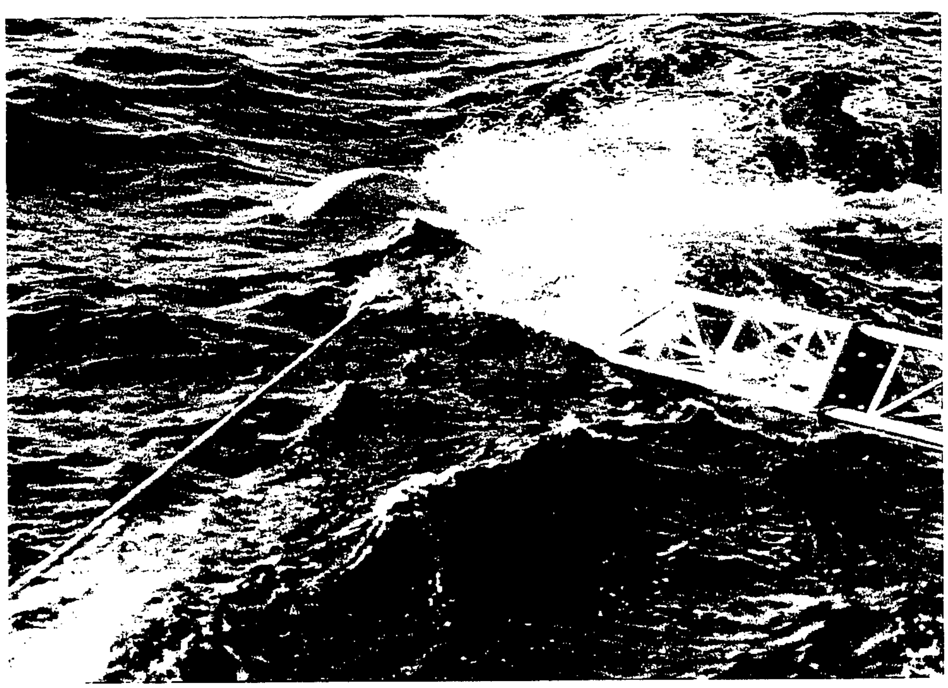
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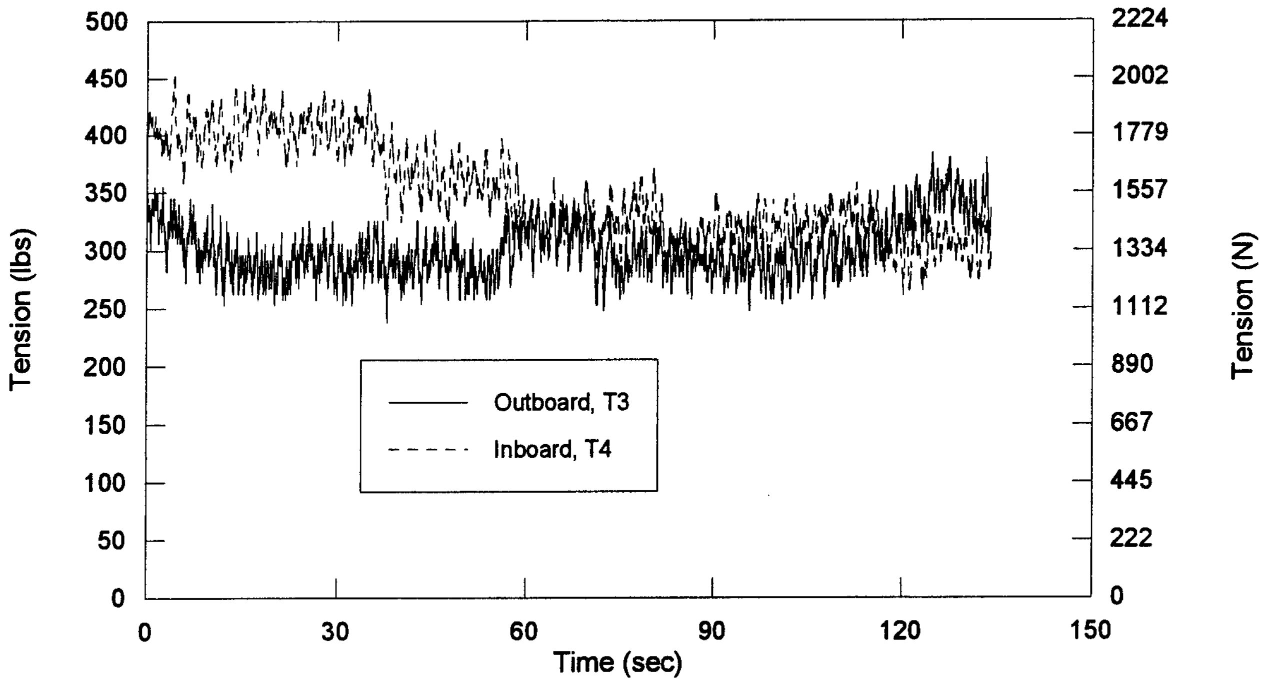
Fig. 48. Photographs of starboard outrigger float in semi-submerged condition after taking on water.



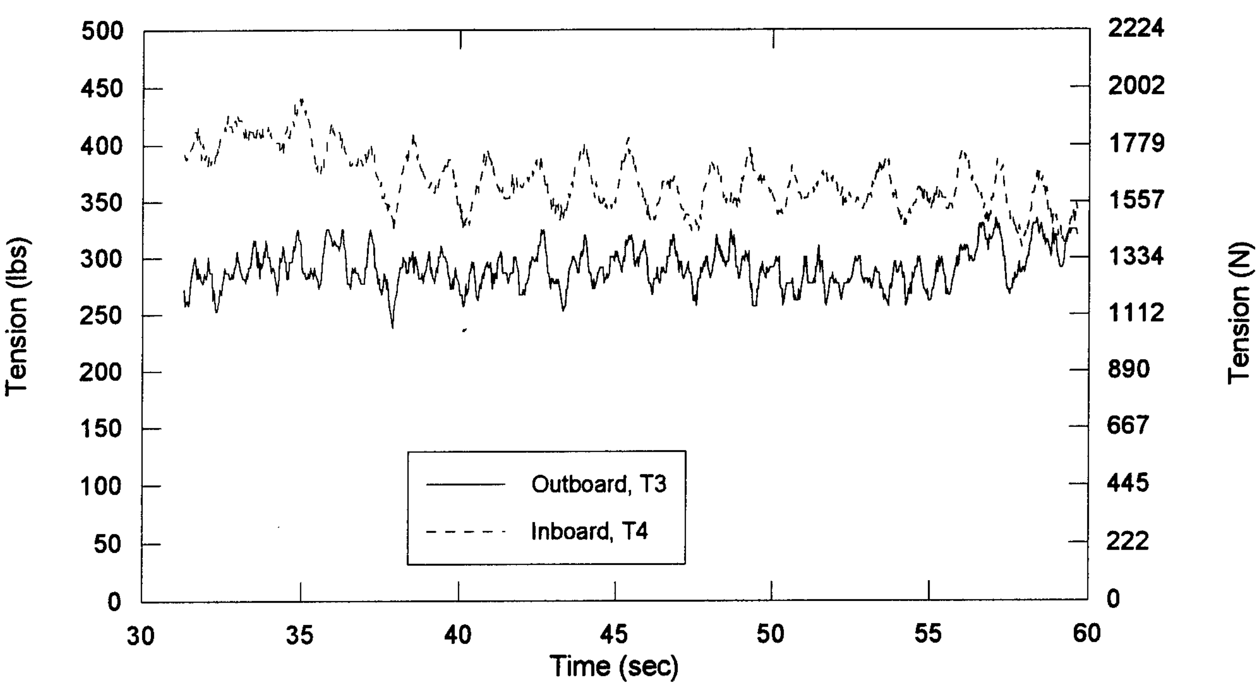
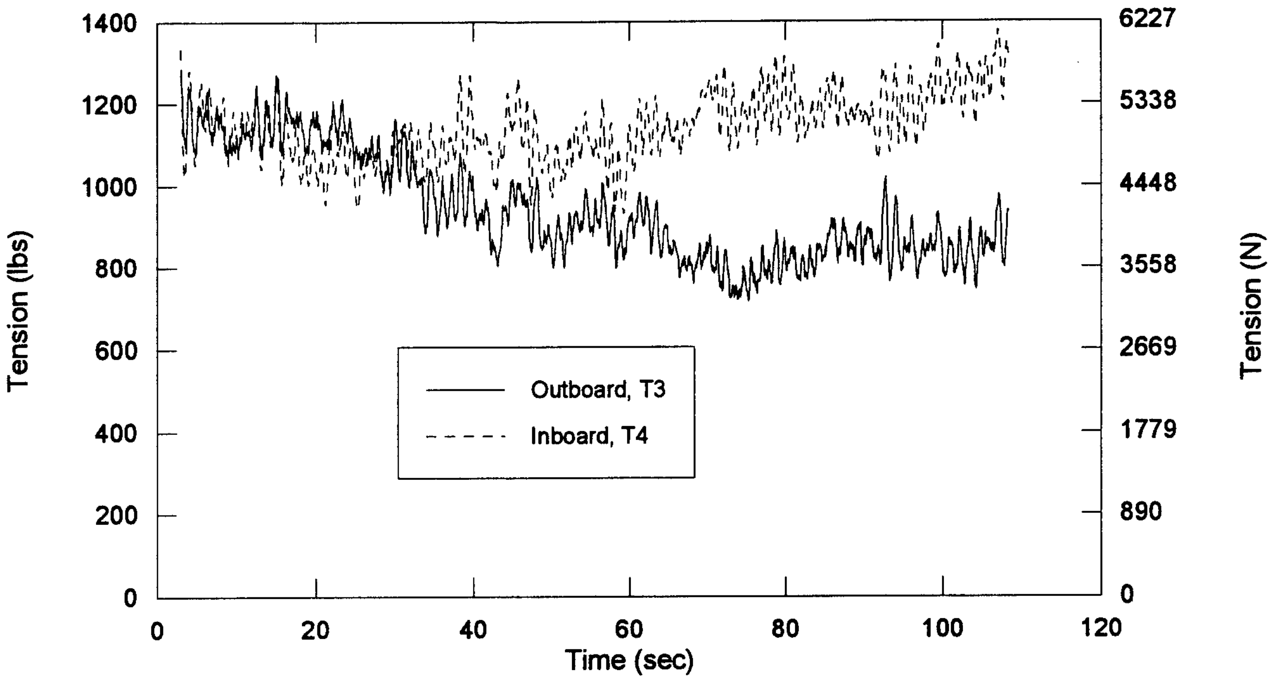


Fig. 49. Tension NOFI V SWEEP support lines at 1 knot in calm seas, without skimmer. Bottom graph is a closeup of the period from 30 to 60 seconds. (Run 22, 5/5/93)



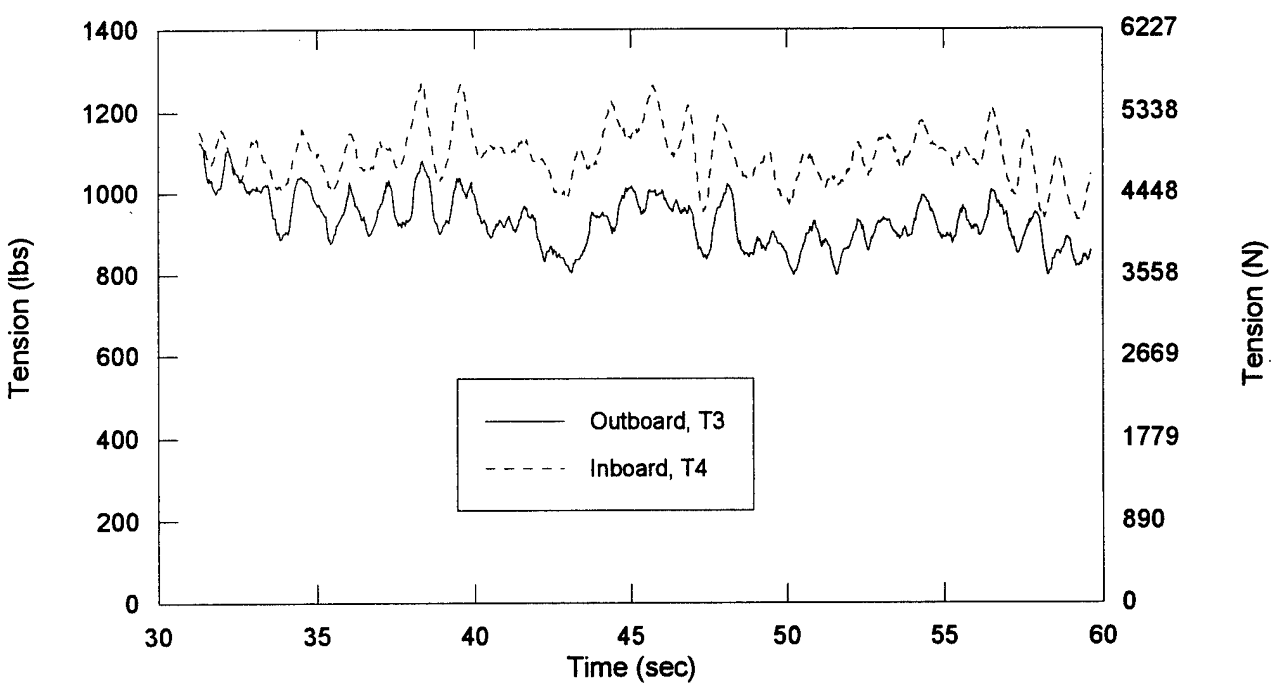
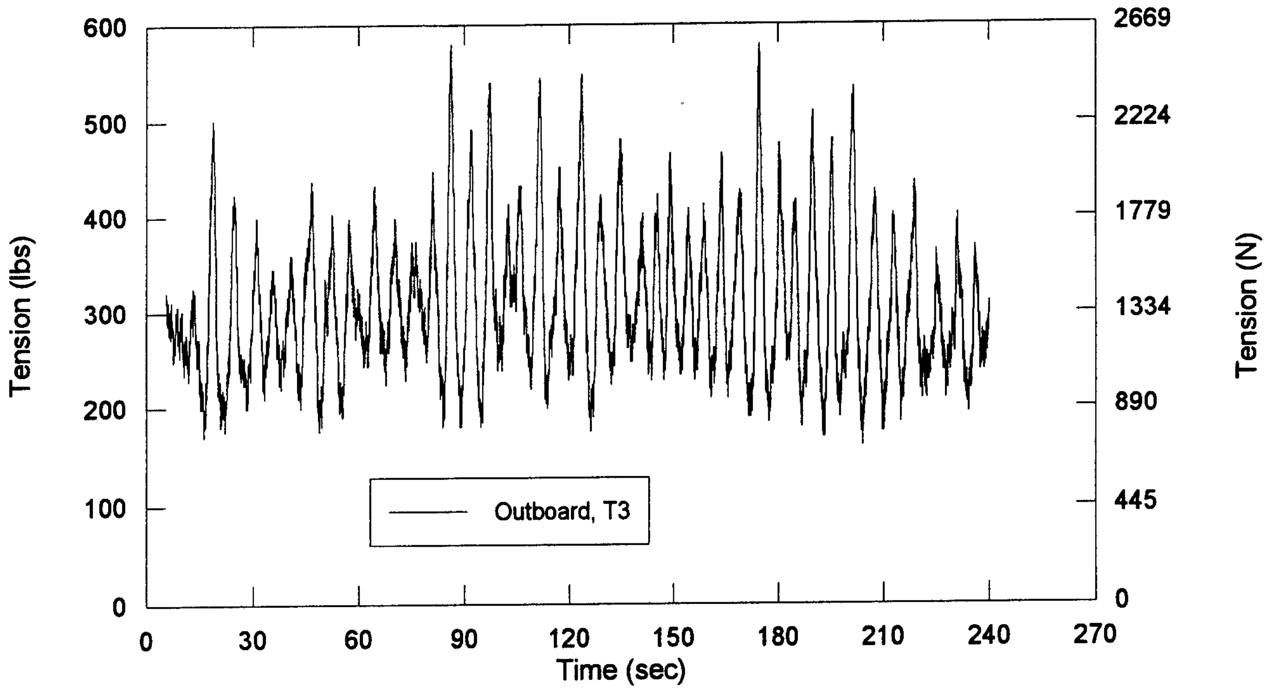


Fig. 50. Tension in NOFI V SWEEP support lines at 2 kt in calm seas, without skimmer. Bottom graph is a closeup of the period from 30 to 60 seconds. (Run 23, 5/5/93)



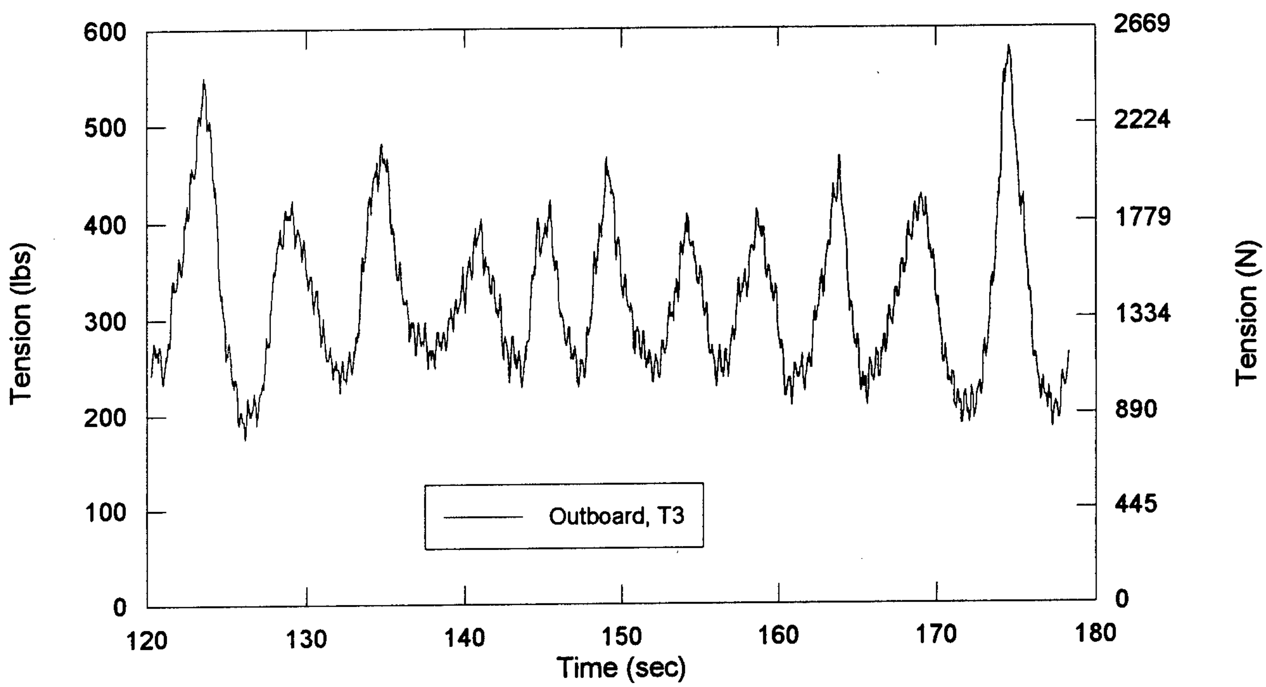
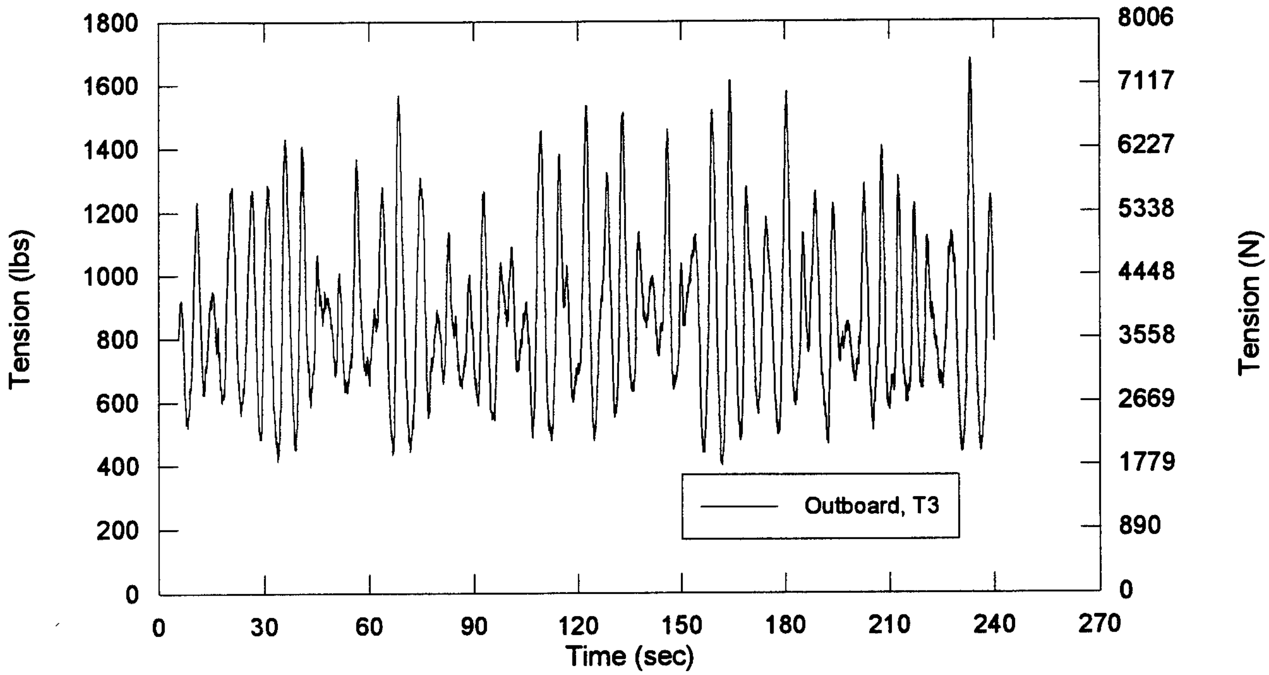


Fig. 51. Tension in NOFI V SWEEP support lines at 1 knot in 1 - 2 ft head seas. Bottom graph is a closeup of the period from 120 to 180 seconds. (Run 41, 5/7/93)



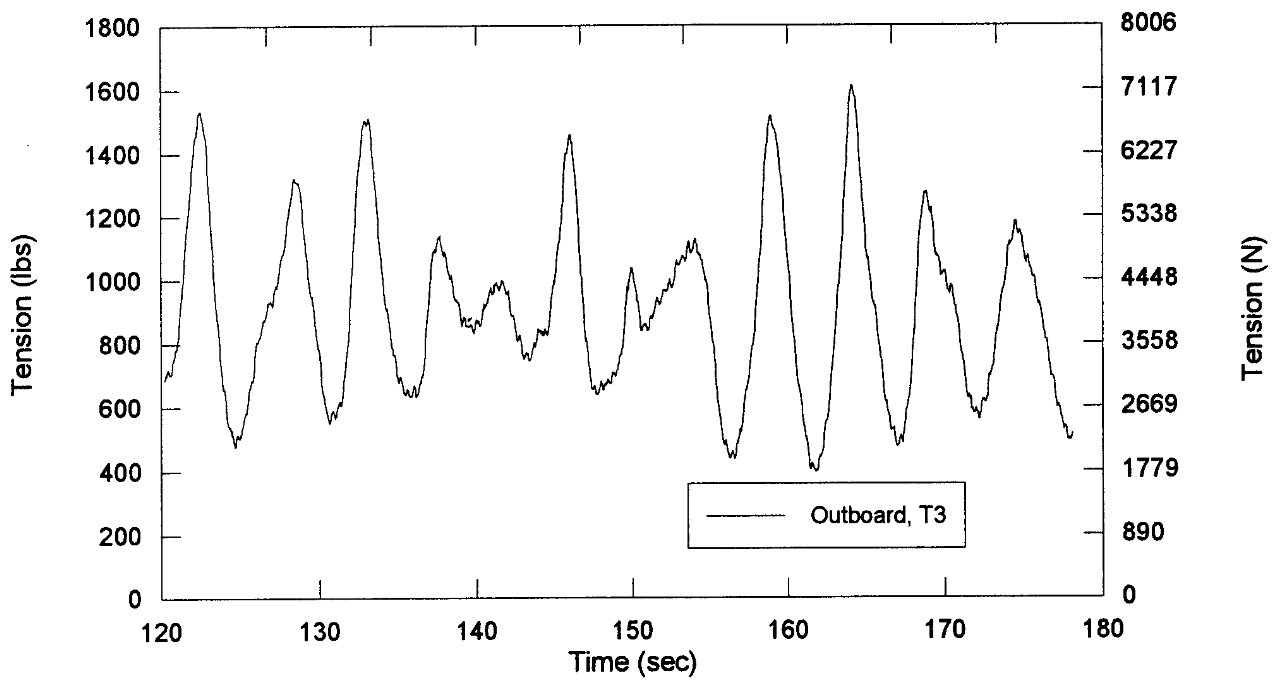
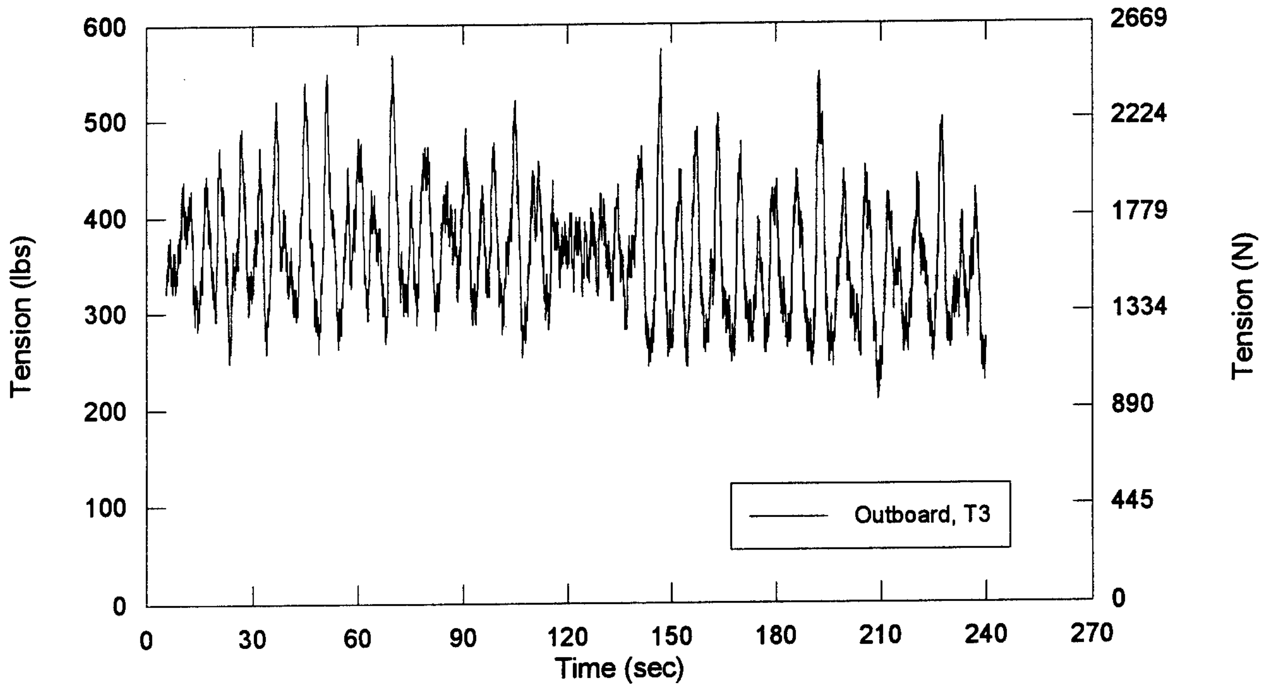


Fig. 52. Tension in NOFI V SWEEP support line at 2 knots in 1 - 2 foot head seas. Bottom graph is a closeup of the period from 120 to 180 seconds. (Run 42, 5/7/93)



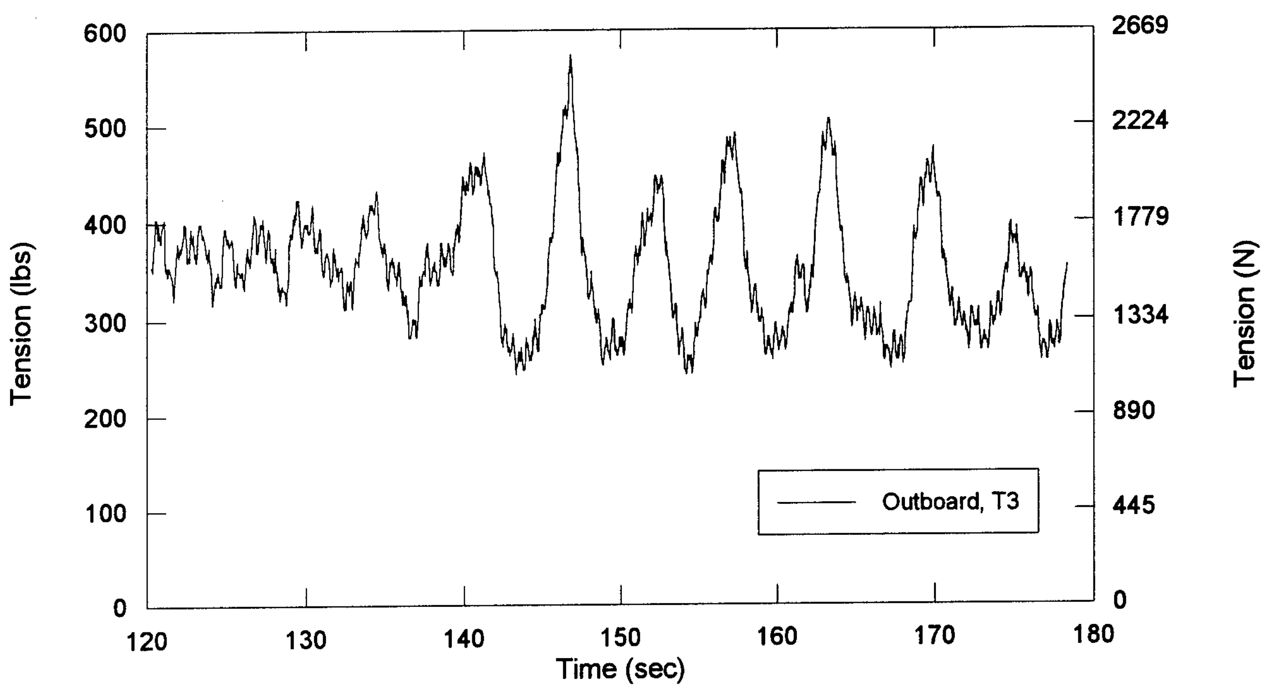
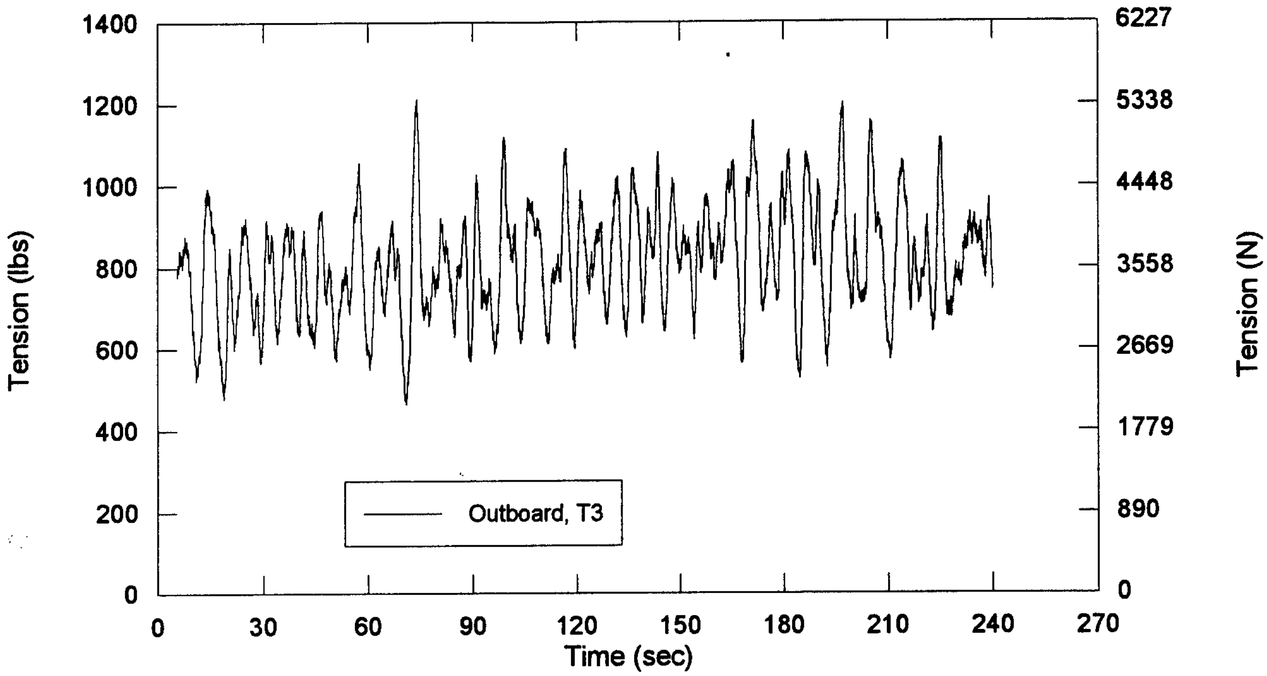


Fig. 53. Tension NOFI V SWEEP support line at 1 knot in 1 - 2 ft following seas. Bottom graph is a closeup of the period from 120 to 180 seconds. (Run 43, 5/7/93)



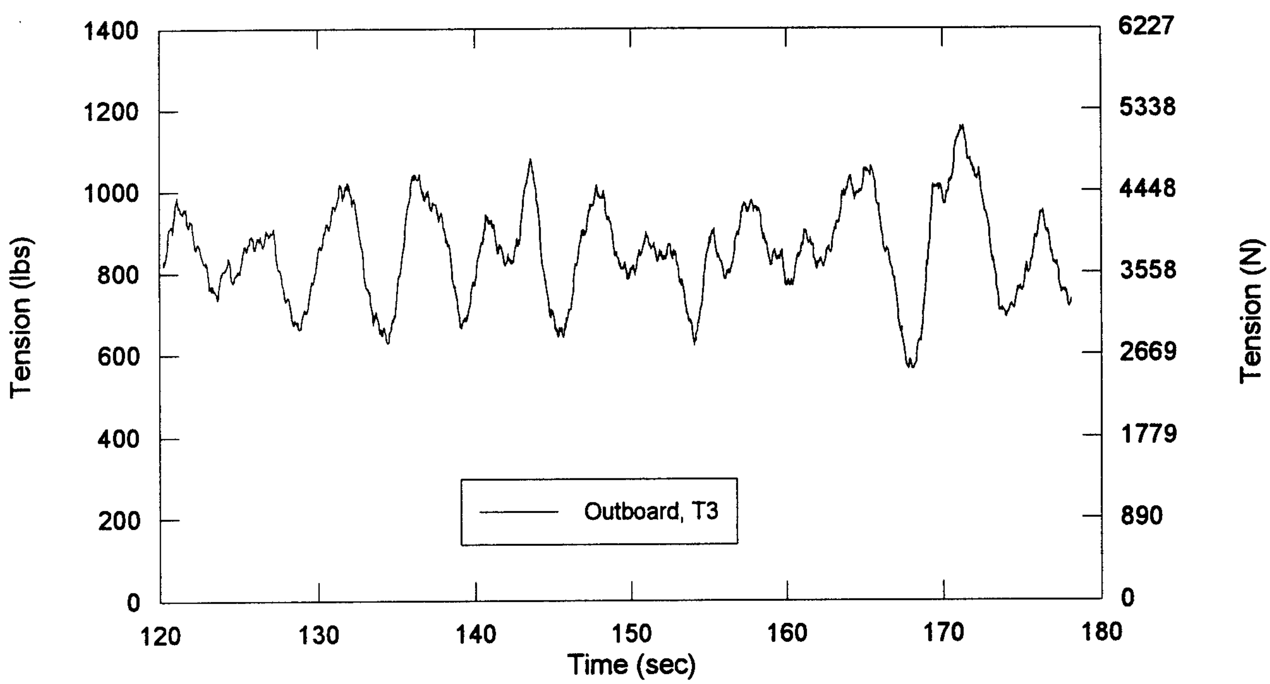


Fig. 54. Tension in NOFI V SWEEP support line at 2 knots in 1 - 2 ft following seas. Bottom graph is a closeup of the period from 120 to 180 seconds. (Run 44, 5/7/93)

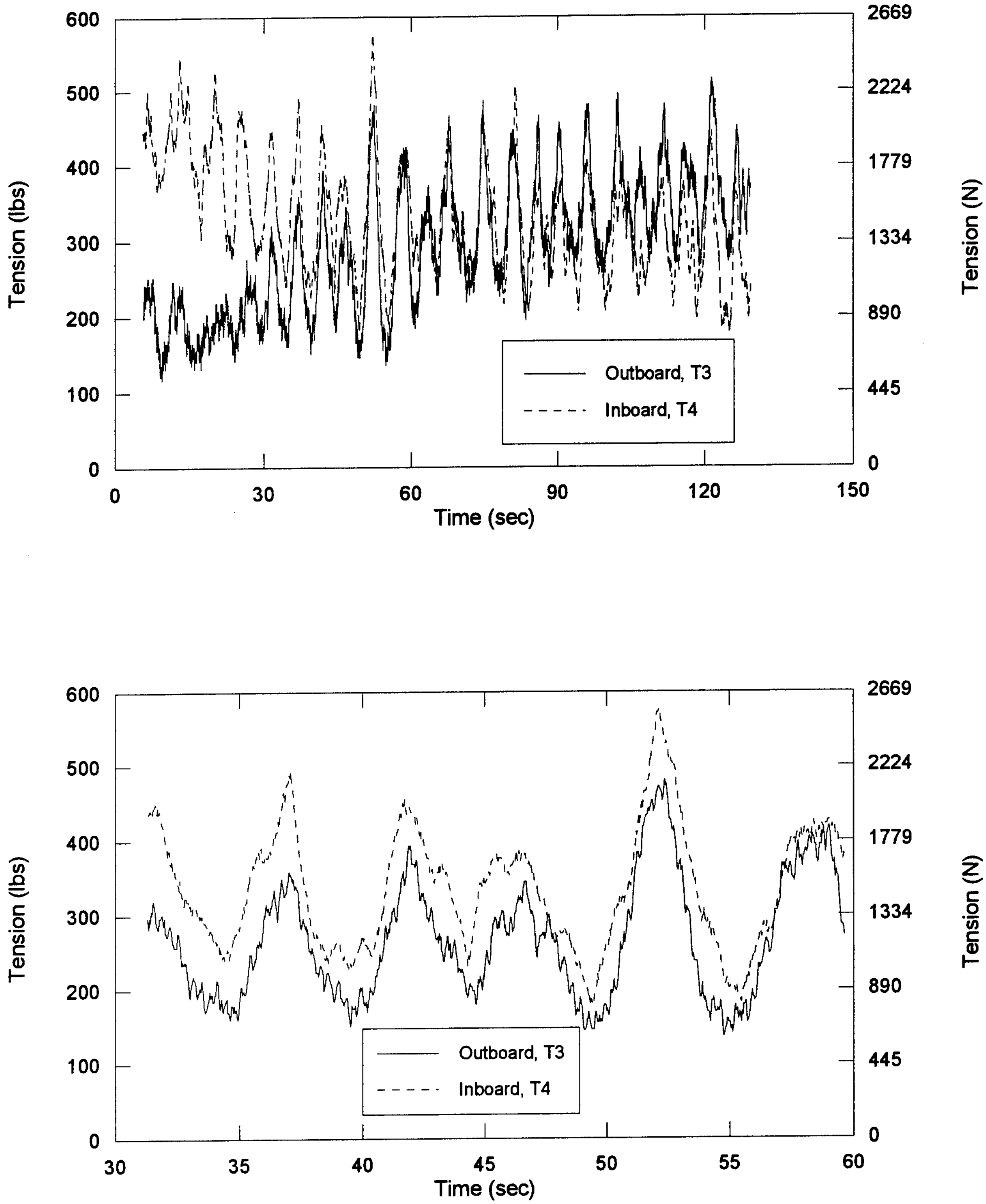
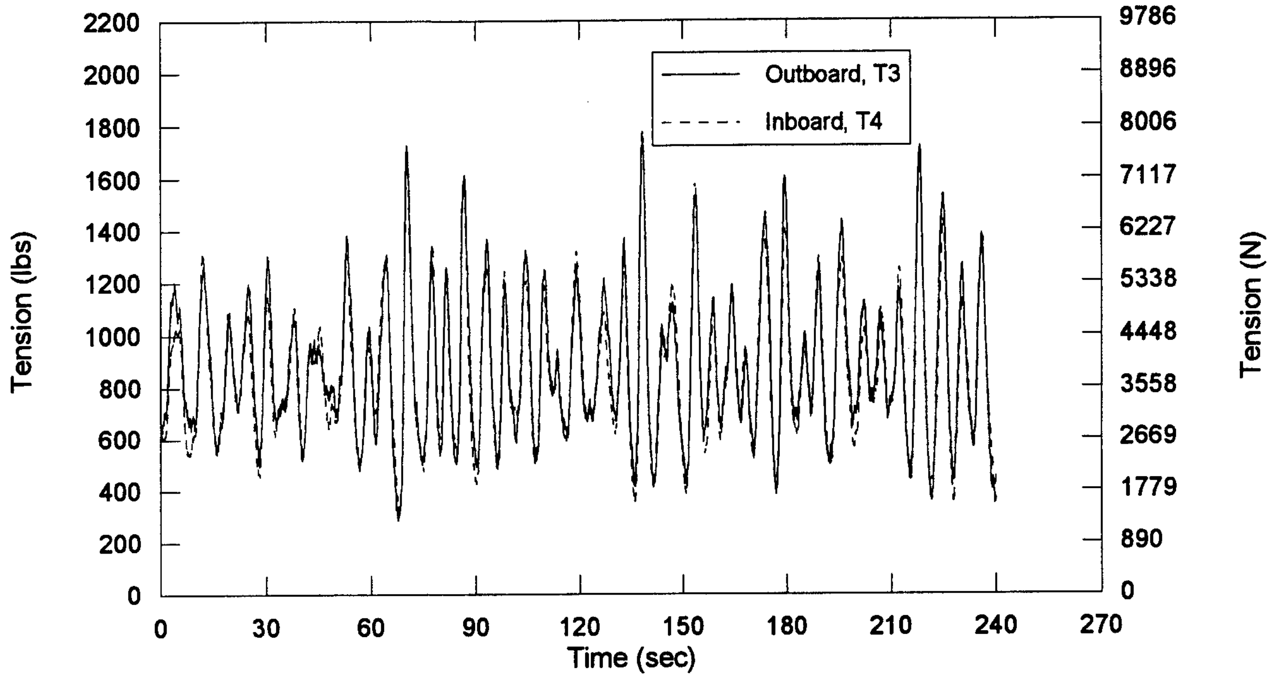


Fig. 55. Tension NOFI V SWEEP support lines 1 knot in 1-3 foot following seas. Bottom graph is a closeup of the period from 30 to 60 seconds. (Run 26, 5/6/93)



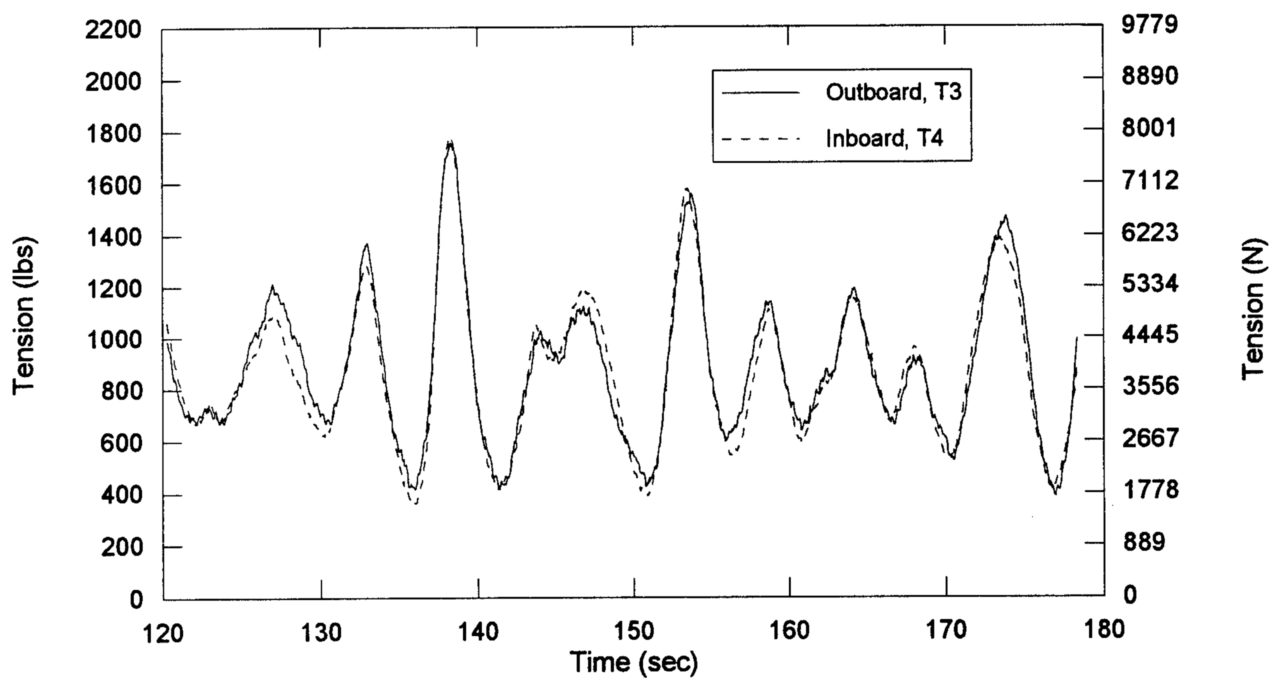


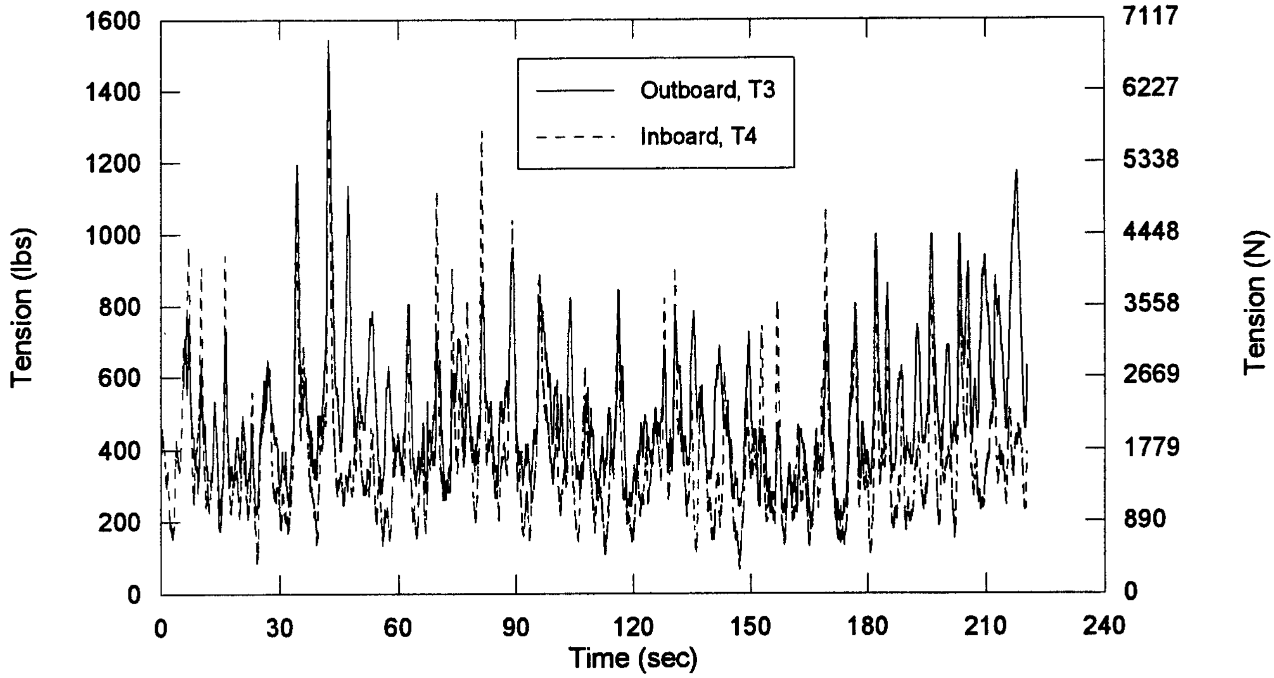
Fig. 56. Tension in NOFI V SWEEP support lines at 2 knots in 1-3 ft following seas. Bottom graph is a closeup of the period from 120 to 180 seconds. (Run 27, 5/6/93)

Sweep operating under sea state 1 conditions. The tension time histories show a very good correlation between the outboard and inboard loadings. As seen with the CG VOSS, tension variations increased significantly over those seen in calm seas. Maximum to minimum tension ratios were as high as 4:1 for the NOFI V Sweep in head seas at two knots (Fig. 52). The most significant periodic motion for the NOFI V Sweep system was 5 - 6 seconds as with the CG VOSS, this being the period of maximum energy of the seas. There were only slight changes in this frequency due to ship speed and direction changes as mentioned previously. The high frequency variations seen in the calm water runs were visible in the low speed NOFI V Sweep data.

Sea state 2 testing of the NOFI V Sweep was performed coincidentally with the CG VOSS. Figures 57 - 61 show the time histories of the tensions seen by the NOFI V Sweep support lines for this operating condition. Additional time histories for this system are included in Appendix C. The NOFI V Sweep boom did not appear to be significantly affected by the sea conditions though peak tensions did reach twice the peak tensions reached in calm seas. The performance was stable and the system did not exhibit any erratic behaviors as the sea state increased. The data collected for 1, 2, and 3 kn indicate the increase in mean tension as a function of speed and averaged 300, 750, and 1500 lb respectively (Figs. 57, 58, and 59-61). Due to the high seas, the depth gauges for this boom could not be hooked up and T3, the outboard load cell, was inoperative. The measured tensions for the various speeds indicate that the NOFI V Sweep system drag curve follows a velocity squared relationship.

6.1.3 COMPARISON OF CG VOSS AND NOFI V SWEEP TENSION LOADS

In general, the average loads on the CG VOSS are two to three times higher than the loads on the NOFI V Sweep. However, the distribution of loads is very different between the two systems. The NOFI V Sweep directly loaded the inboard and outboard restraining lines while the forward preventer in the CG VOSS was keeping the outrigger in place and, due to the angle of its pull, was putting the



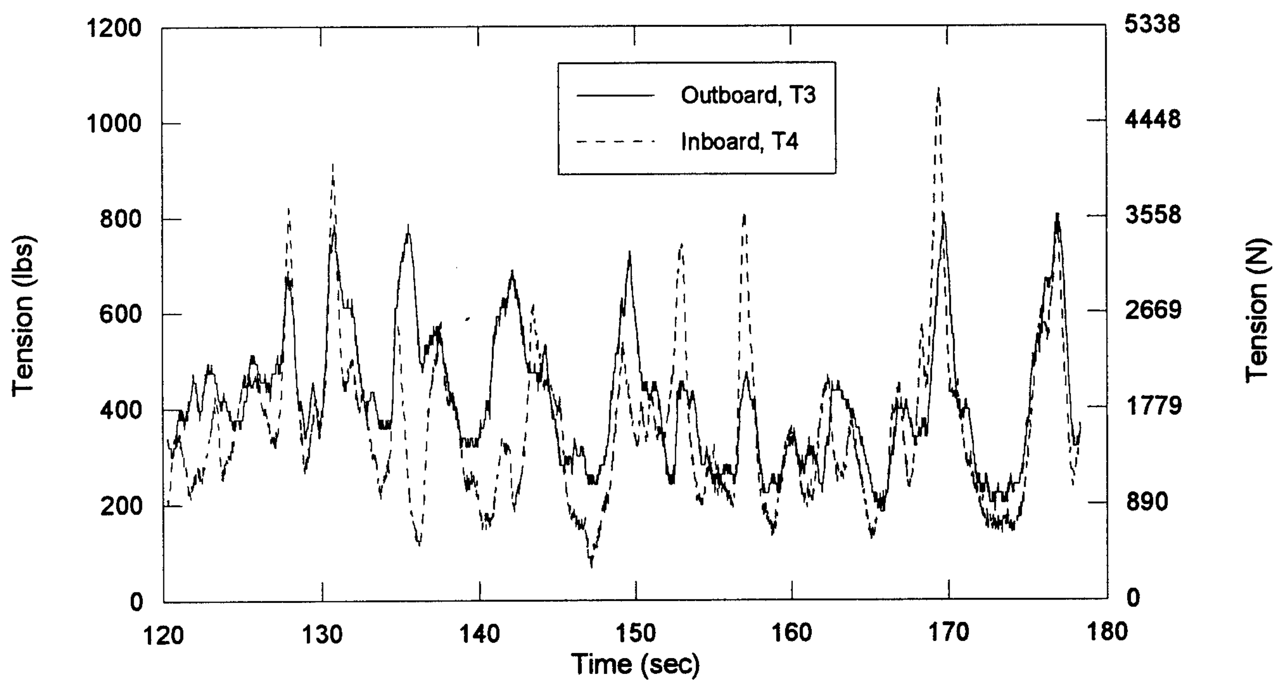
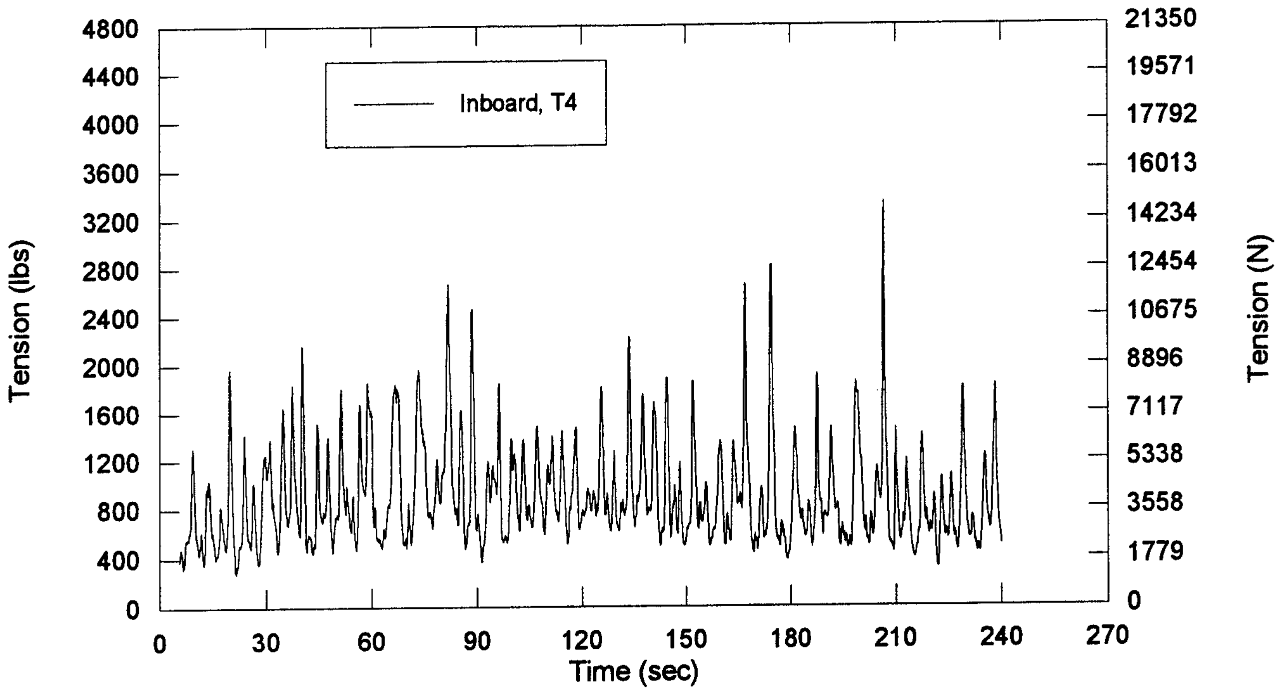


Fig. 57. Tension in NOFI V SWEEP support lines at 1 knot in 3-5 ft head seas. Bottom graph is a closeup of the period from 120 to 180 seconds. (Run 50, 5/11/93)



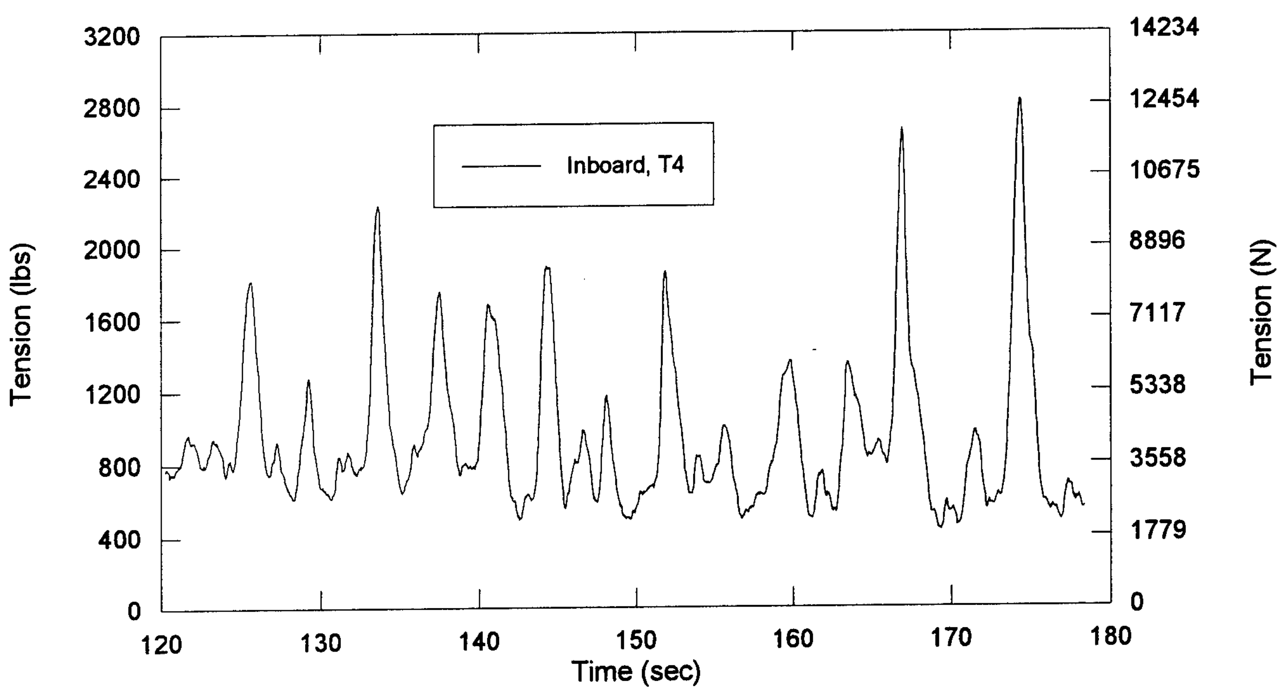
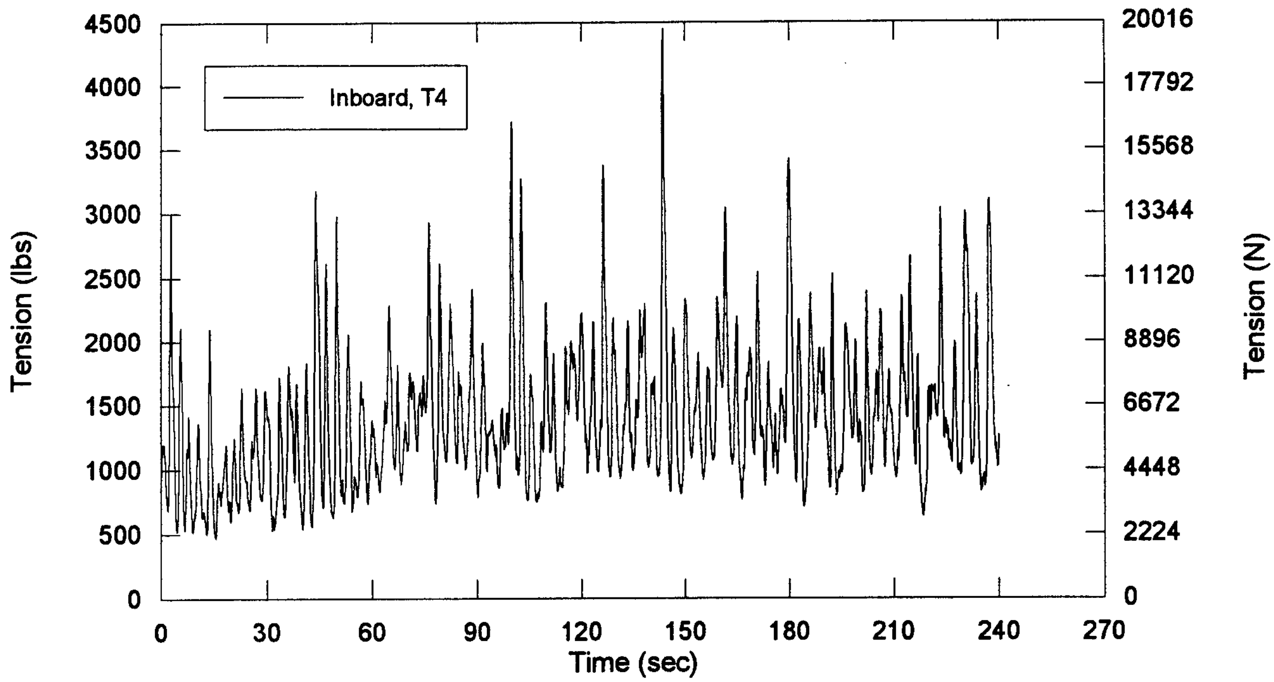


Fig. 58. Tension in NOFI V SWEEP support lines at 2 knots in 3-5 foot head sea conditions. Bottom graph is a closeup of the period from 120 to 180 seconds. (Run 52, 5/11/93)



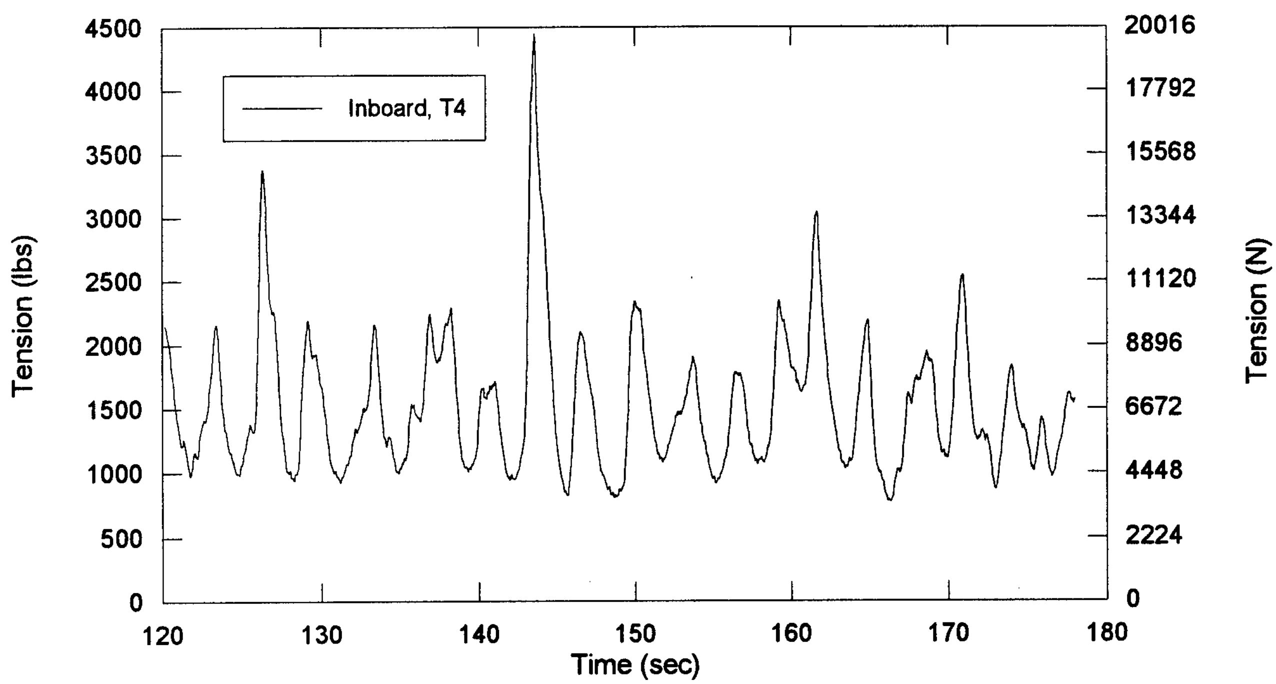
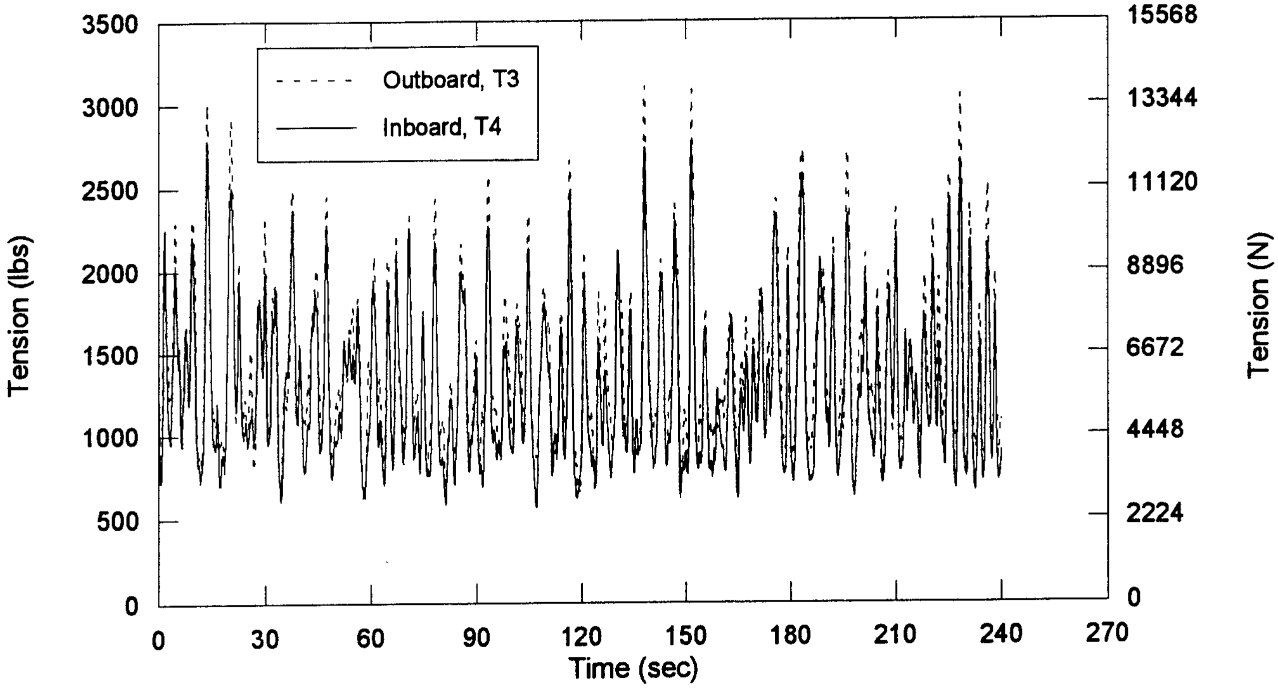


Fig. 59. Tension in NOFI V SWEEP support lines at 3 knots in 3-5 foot head sea conditions. Bottom graph is a closeup of the period from 120 to 180 seconds. (Run 53, 5/11/93)



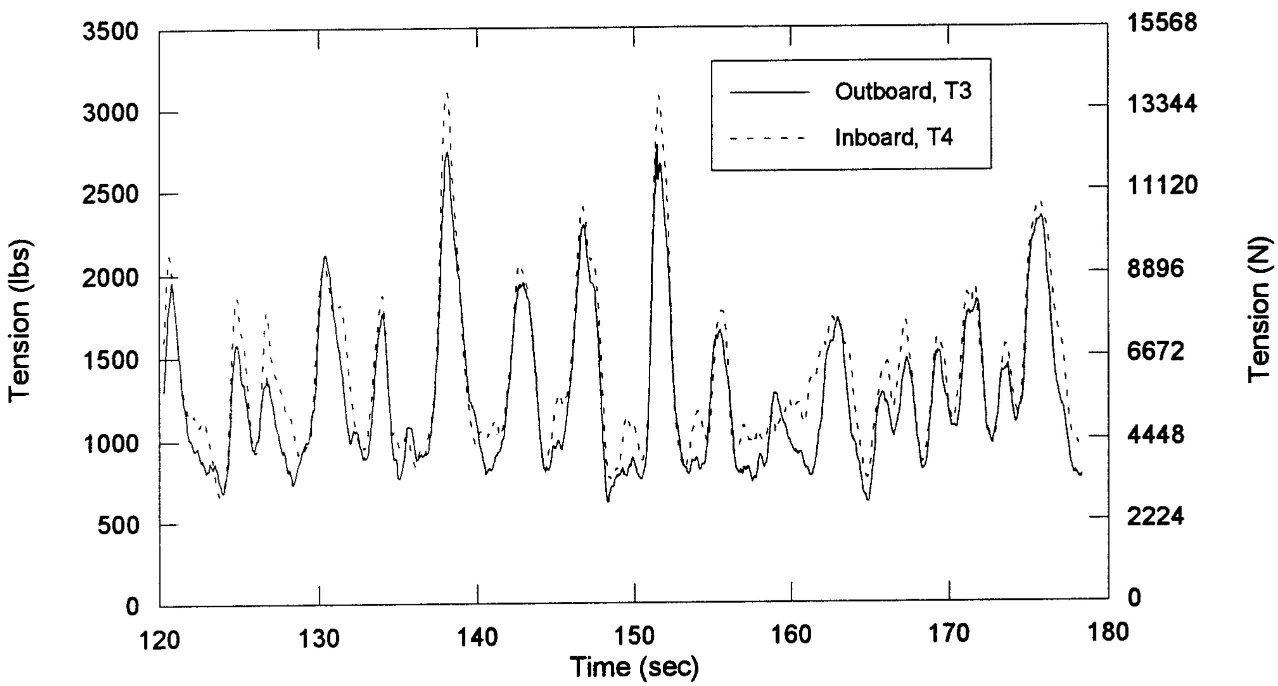
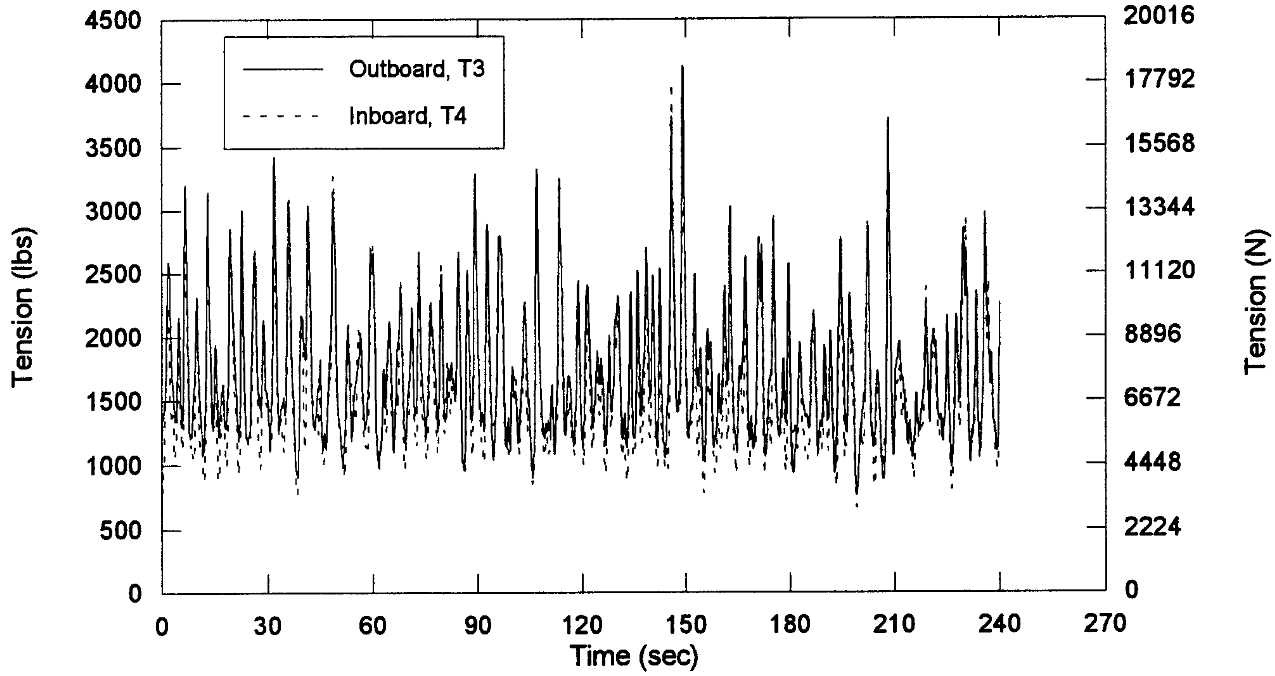


Fig. 60. Tension in NOFI V SWEEP support lines at 3 knots in 2 - 4 foot head sea condition. Bottom graph is a closeup of the period from 120 to 180 seconds. (Run 35, 5/6/93)



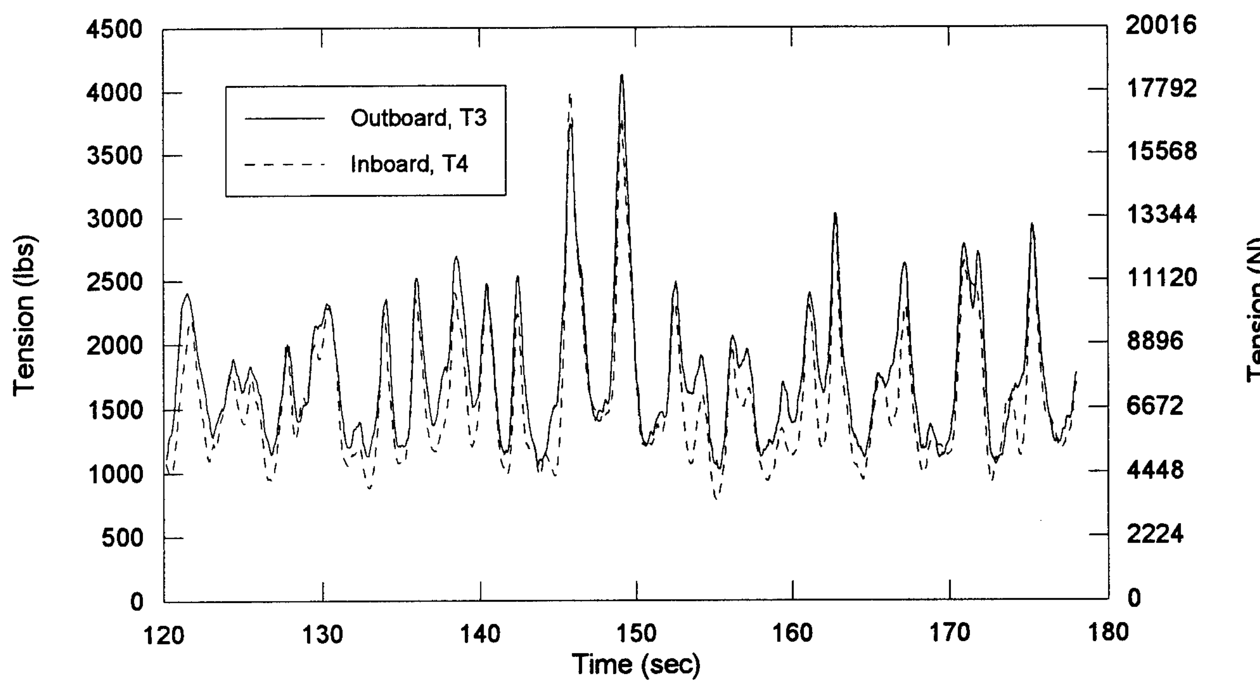


Fig. 61. Tension in NOFI V SWEEP support lines at 3 knots 2-4 foot 45 degree starboard seas. Bottom graph is a closeup of the period from 120 to 180 seconds. (Run 36, 5/6/93).

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outrigger in compression, (See Fig. 28). There was very little difference between outboard and inboard measurements on the NOFI V Sweep so either value can be used for comparative purposes.

Table 4 lists the average, maximum, and minimum of the calm water tension data. For the calm conditions, the standard deviations for each system were approximately ±50 and 135 lb for the CG VOSS system and ±18 and 54 lb for the NOFI V Sweep at one and two knots, respectively.

Table 4. Tension of CG VOSS and NOFI V SWEEP restraining lines in calm water.

Run	Speed (kn)	CG VOSS Forward Preventer Guide Line (lb)			NOFI V Outboard NOFI V Inboard (lb)			Observed Sea Conditions, Orientations & Comments
	mean	mean	max	min	mean	max	min	
22	1.13	770 412	979 529	554 289	301 348	384 456	238 260	dead calm
23	2.13	2208 1139	2727 1412	1711 870	955 1136	1339 1348	715 934	dead calm

At increased sea states, the tension values and standard deviation values greatly increased. Table 5 shows the average, maximum, and minimum tension values measured in each system in a sea state 1. Tension variations increased significantly over those seen in calm seas with even a moderate increase in sea state. Maximum to minimum tension ratios were as high as 23:1 in for the CG VOSS system and 3:1 for the NOFI V Sweep when operating in a following sea at one knot. For the NOFI V Sweep, this ratio reached the maximum value of 4:1 in a head sea at two knots.

An effect on the oscillatory behavior of each system can be seen on the time histories with an increased in speed. The CG VOSS has a decrease in the higher frequency components. There is a slower oscillation on the order of the wave period due to the large amounts of water in front of the CG VOSS boom skirt dominating the forces felt by the system. The NOFI V Sweep, however, primarily rode atop the waves at all speeds and the higher frequency components remained.

Table 5. Tension of CG VOSS and NOFI V SWEEP restraining lines in a sea state 1.

Run	Speed (kn)	CG VOSS Forward Preventer Guide Line (lb)			NOFI V Outboard NOFI V Inboard (lb)			Observed Sea Conditions, Orientations & Comments
	mean	mean	max	min	mean	max	min	
41	1.16	651 326	1472 758	119 36	305 ND	579 ND	160 ND	1 - 2 ft head seas
42	2.08	1721 786	3078 1466	665 255	866 ND	1680 ND	399 ND	1 - 2 ft head seas
43	1.14	765 359	2326 1080	70 11	360 ND	574 ND	209 ND	1 - 2 ft following seas
44	1.89	1770 809	3640 1730	353 153	811 ND	1212 ND	462 ND	1 - 2 ft following seas
25	1.26	724 293	2024 856	75 1	251 359	408 607	131 187	1 - 3 ft following seas
26	1.24	867 353	2151 880	80 1	292 334	516 577	116 177	1 - 3 ft following seas
27	2.08	1941 784	2888 1242	744 260	882 860	1758 1777	287 309	1 - 3 ft following seas; VOSS boom comes out of water.

In sea state 2, the severity of the sea greatly influenced the performance of each system. Both booms were behaving well in head sea conditions, Runs 28 and 29, and in the starboard seas, Runs 30 and 31. Starboard seas correspond to the TROJAN heading 45 deg to port relative to the seas leaving the CG VOSS system protected from experiencing the full impact of the waves. Tensions were less than in the lower sea state conditions of Runs 26 and 27. However, for port seas the CG VOSS behaved erratically since it was now directly exposed to the brunt of the wave onslaught and tensions increased markedly. Therefore, the CG VOSS operational envelop would be limited at two knots in a sea state 2 while the NOFI V boom did not appear to be significantly affected by the sea conditions though peak tensions did increase. The loads incurred during these runs are included in Table 6, showing the mean, maximum, and minimum tension values.

Table 6. Tension of CG VOSS and NOFI V Sweep restraining lines in a sea state 2.

Run	Speed (kn)	CG VOSS Forward Preventer Guide Line (lb)			*NOFI V Outboard (lb)			Observed Sea Conditions, Orientations & Comments
	mean	mean	max	min	mean	max	min	
28	0.94	239 100	597 275	65 -13	282 267	633 485	121 124	2 - 4 ft head seas
29	2.12	1399 582	2448 1006	646 221	754 963	2051 2494	301 373	2 - 4 ft head seas
30	2.19	1191 501	2204 1017	431 123	734 868	1666 2265	262 251	3 - 5 ft 45 deg stbd. seas
31	0.96	207 73	573 280	46 -13	475 424	1193 1129	160 90	3 - 5 ft 45 deg stbd. seas
33	0.93	920 340	2854 1217	NA NA	256 141	1178 1080	N/A N/A	3 - 5 ft 45 deg port seas
35	2.91	ND	ND	ND	1282 1404	2786 3104	564 621	3 - 5 ft head seas
36	3.01	ND	ND	ND	1705 1574	4131 3997	759 665	3 - 5 ft 45 deg stbd. seas
50	1.48	686 0	3340 748	31 0	495 382	1540 1360	183 65	4 - 6 ft head seas; VOSS boom comes out of water.
51	1.10	ND	ND	ND	NA 255	NA 1400	NA 2	4 - 6 ft head seas
52	2.05	ND	ND	ND	NA 895	NA 3340	NA 280	4 - 6 ft head seas
53	2.72	ND	ND	ND	NA 1403	NA 4450	NA 470	4 - 6 ft head seas

NA - Not Available
ND - Not Deployed

6.2 SURFACE FOLLOWING

As an indicator of the surface following characteristics, the readings from the pressure transducers were translated into depth measurements. The depth of the boom is resolved from the pressure transducers located in the skirt which indicate higher static pressure for deeper depths of submergence. For example, a continuous value output from the depth sensors would indicate a very good surface following characteristic in which the depth sensor remained at the same depth and was merely following in a parallel path with the surface. For conciseness, the time histories for the two systems are presented concurrently. Because the values for each are sufficiently different, the curves for each system are distinguishable.

6.2.1 CG VOSS SURFACE FOLLOWING

The surface following or depth keeping characteristics of the CG VOSS boom was strongly influenced by the hydrodynamic forces exerted on the submerged portion of the boom. In calm seas, the CG VOSS skirt experienced an oscillation with approximately a 1.5-second period as shown in Fig. 62. The amount of depth variation ranged from 14 in. at the outboard depth gauge to 8 - 10 in. at the boom apex and to only a few inches at the inboard gauge. This oscillation was less visible at one knot but increased in amplitude significantly at two knots in a head sea state 1. The amplitude increased to approximately 24 in. with the skirt getting very close to the surface at the outboard section and staying deeper near the ship as shown in Fig. 63. At one knot, the CG VOSS boom stayed between the water surface and a depth of 2.0 ft for calm seas, sea state 1 and even sea state 2. However, at 2.0 kn, the boom was very susceptible to coming out of the water in sea states other than a calm sea and in all vessel positions other than one which protects the boom. The oscillation may occur because of a combination of an oscillatory hydrodynamic force on the boom and the restraining forces acting on the boom or a combination of these forces that allowed it to rotate about the glide

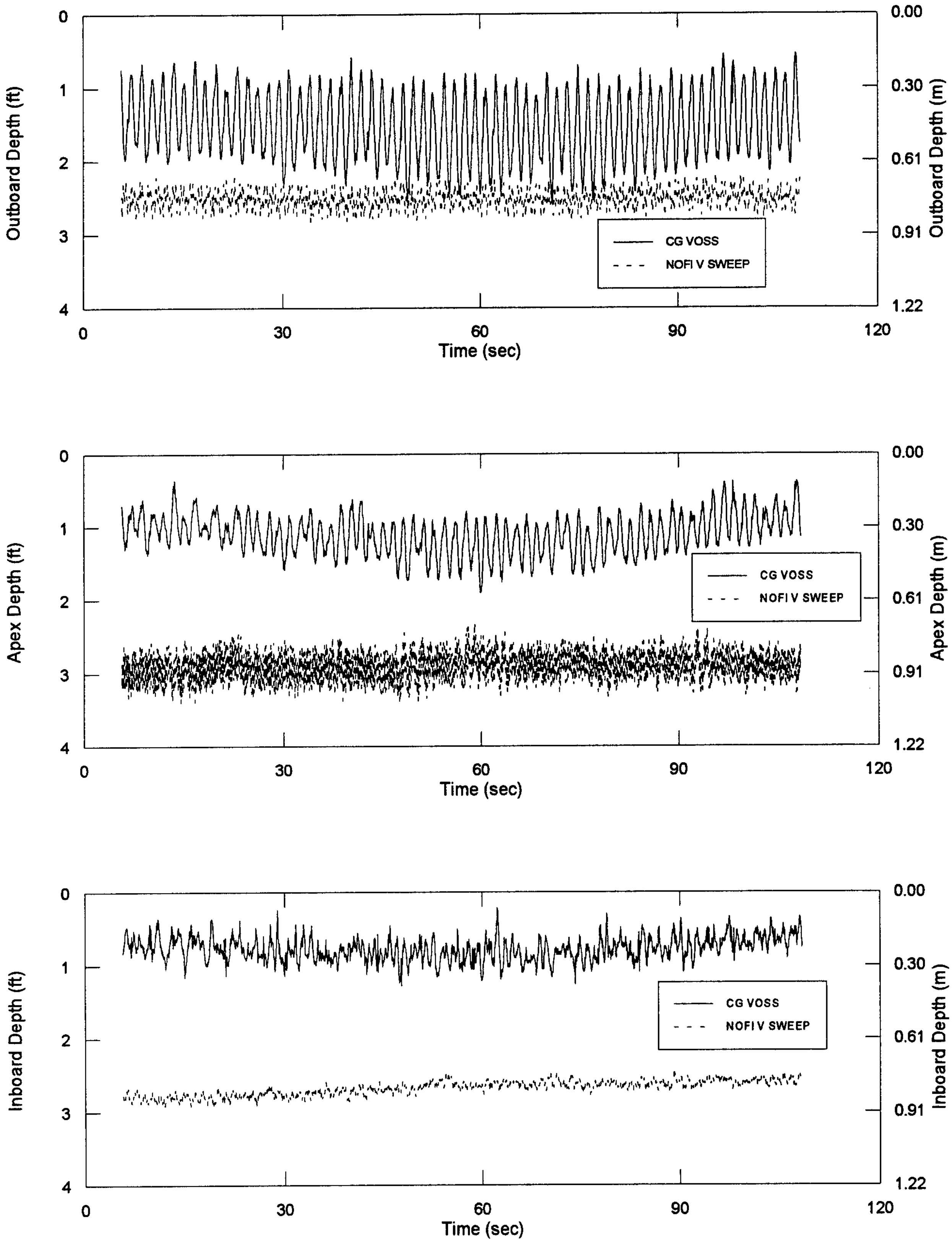


Fig. 62. CG VOSS and NOFI V SWEEP boom skirt depths at 2 knots in calm seas. (Run 23, 5/5/93)

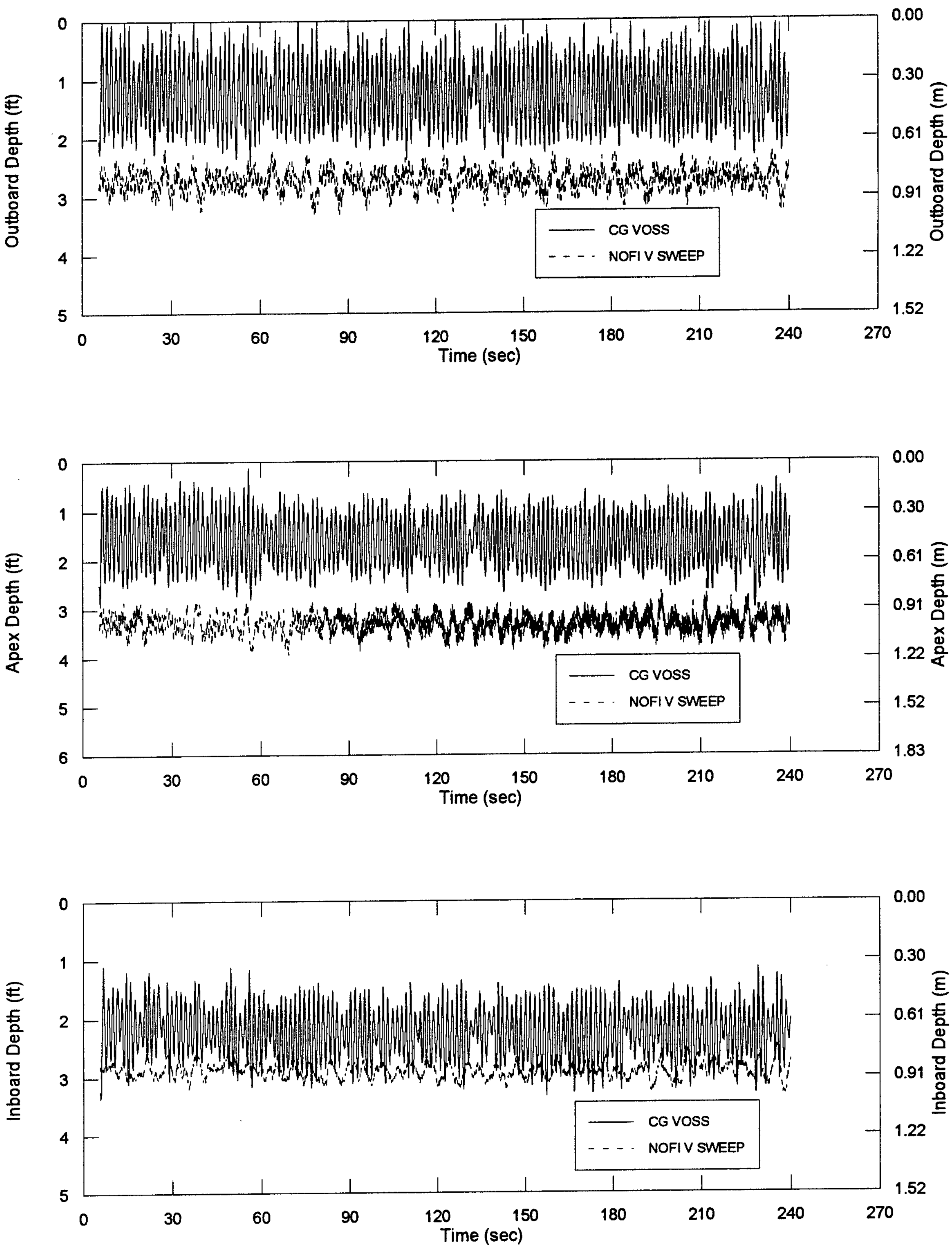


Fig. 63. CG VOSS and NOFI V SWEEP boom skirt depths at 2 knots in 1-2 foot head seas. (Run 42, 1993)

line on the end of its bridle (see Fig. 13).

6.2.2 NOFI V SWEEP SURFACE FOLLOWING

The NOFI V Sweep demonstrated good surface following or depth keeping capability. Figures 62-64 show the curves for surface following for the NOFI V Sweep. The curves, oscillating about the 2-3 ft depth, show that the NOFI V Sweep experiences a high frequency oscillation but maintains depth very well. Figure 62 shows the performance in a calm sea. The inboard sensor experiences the least variations while the apex sensors experiences the most. However, all three curves average near 3.0 ft of depth and the time histories indicate a relatively steady depth for surface following. Figure 63 shows the performance in a sea state 1 and shows an increase in the variations about the mean value. Again, the inboard sensor has the fewest high frequency components and the smallest amount of variation. In Fig. 64, a peak to peak value of ± 2.0 ft was achieved for a sea state 2. Under all conditions, the NOFI V Sweep demonstrated very good surface following characteristics since it is made primarily of floatation devices. Depth as a function of time for the various speeds and sea states is presented in Appendix D for many significant data runs.

6.3 STRAIN ON OUTRIGGERS

The yield strength of Aluminum is approximately 40,000 psi. However, since portions of the outrigger section were welded it is possible that failure in the structure could occur earlier if stress levels approached the annealed yield strength of aluminum which is closer to 15,000 psi. This corresponds to a maximum strain limit of 1500 μin/in. Therefore, for safe operation of these systems the outrigger should never experience a strain approaching this limit. Figures 65 and 66 show the mean and maximum vertical and horizontal stresses and strains encountered during the evaluation for the CG VOSS and NOFI V Sweep configurations for several runs operating at one and two knots. At

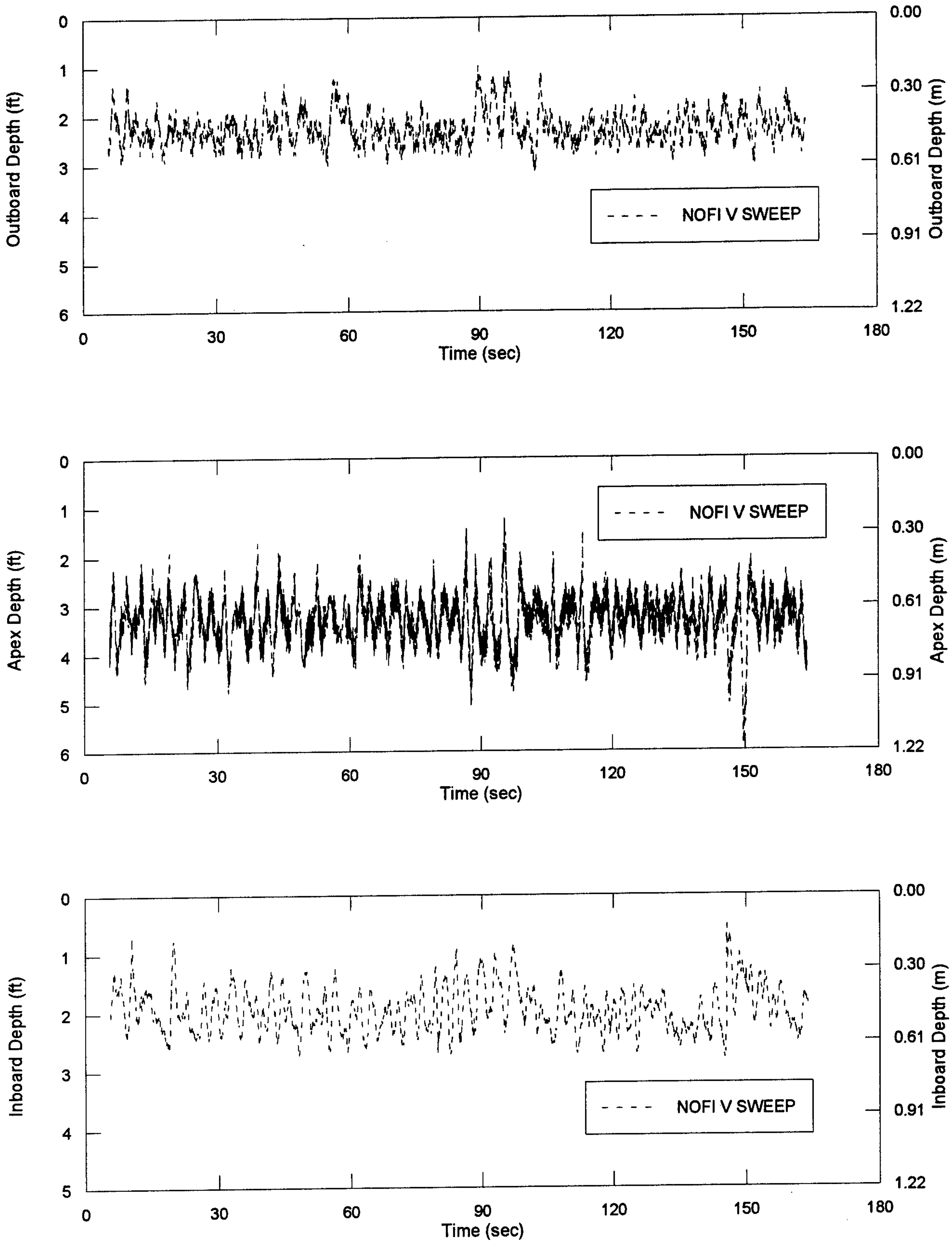


Fig. 64. NOFI V SWEEP boom skirt depth at 3 knots in 2-4 foot 45 degree starboard seas. (Run 36, 5/6/93)

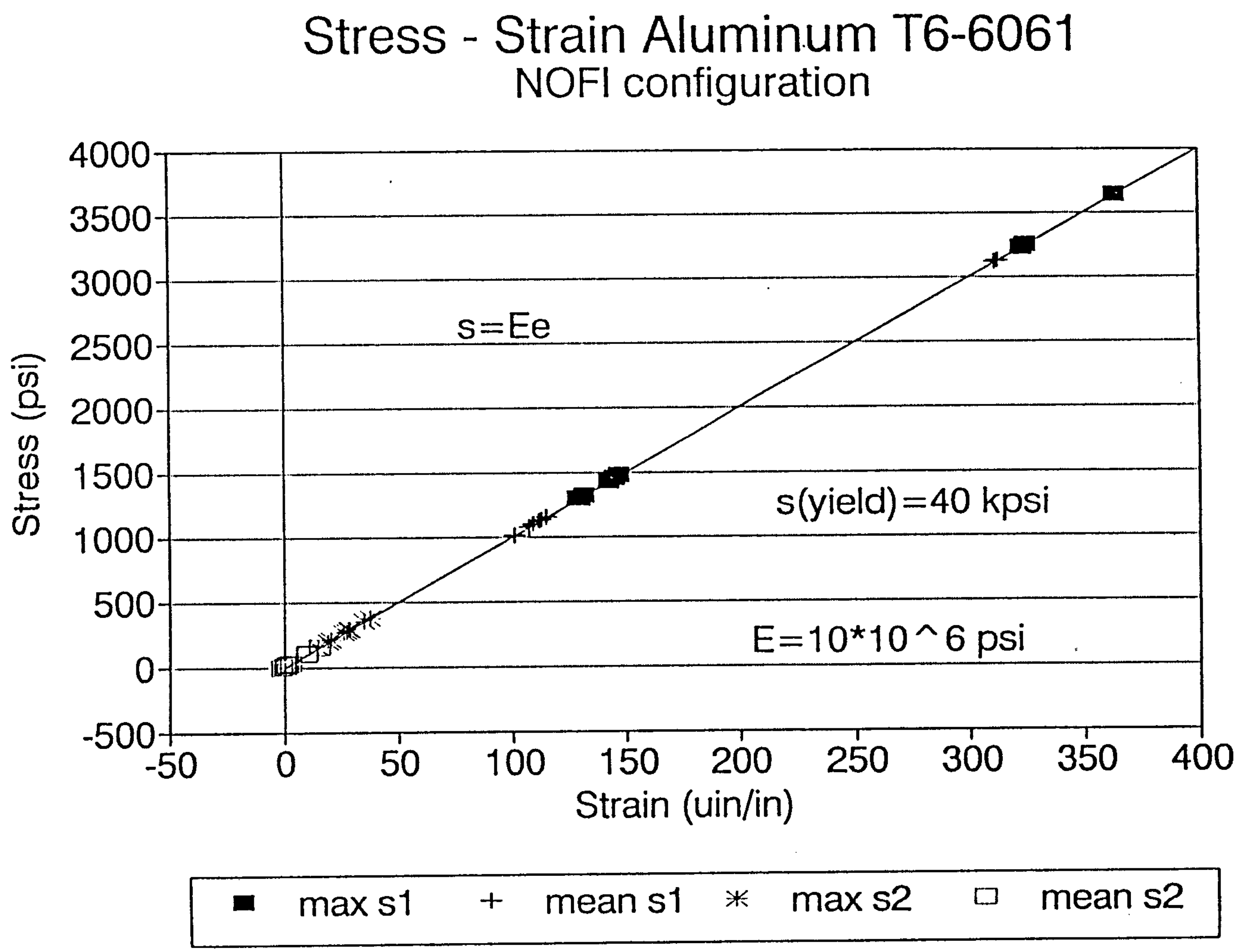


Fig. 65. Stress versus strain for starboard outrigger with NOFI V Sweep.

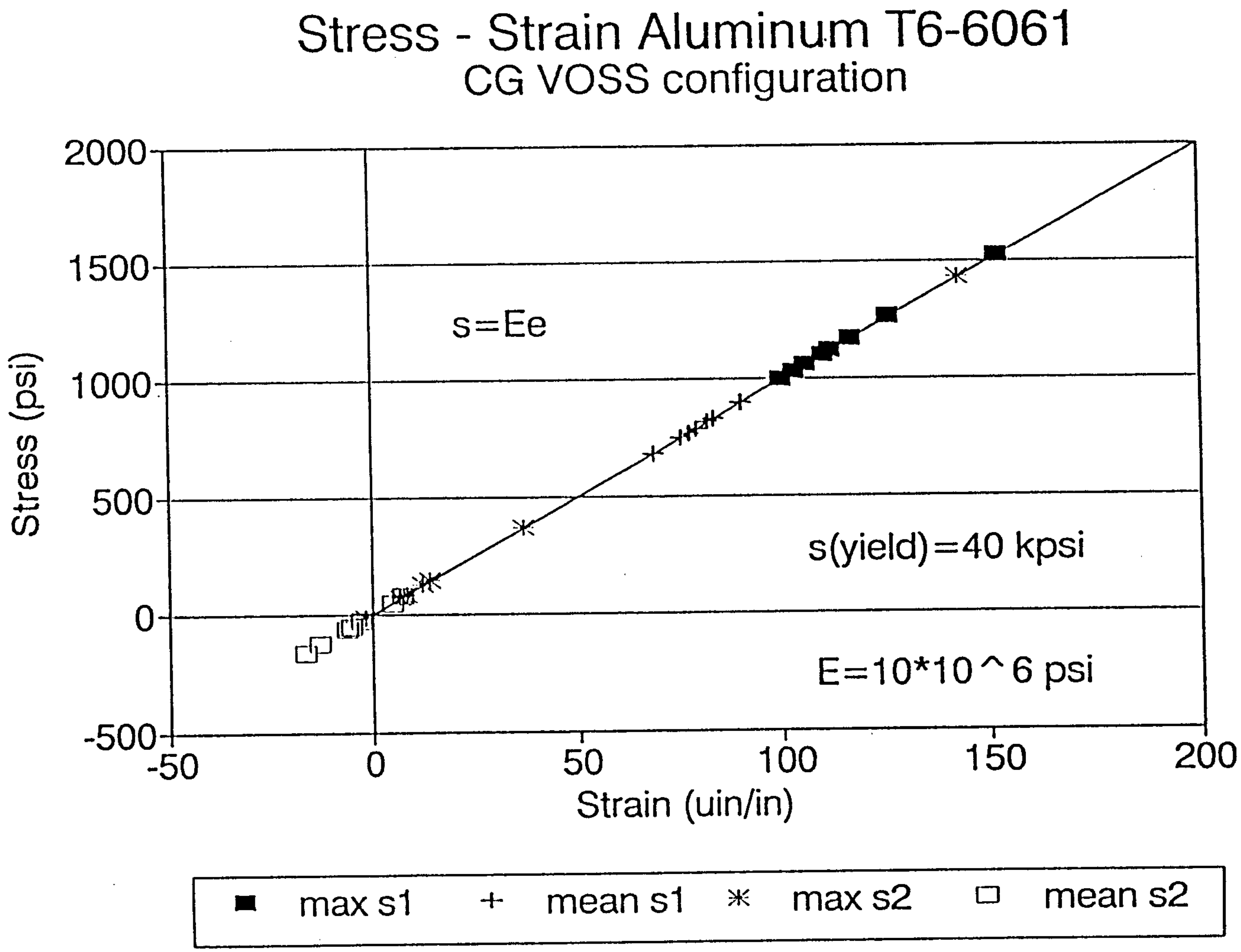


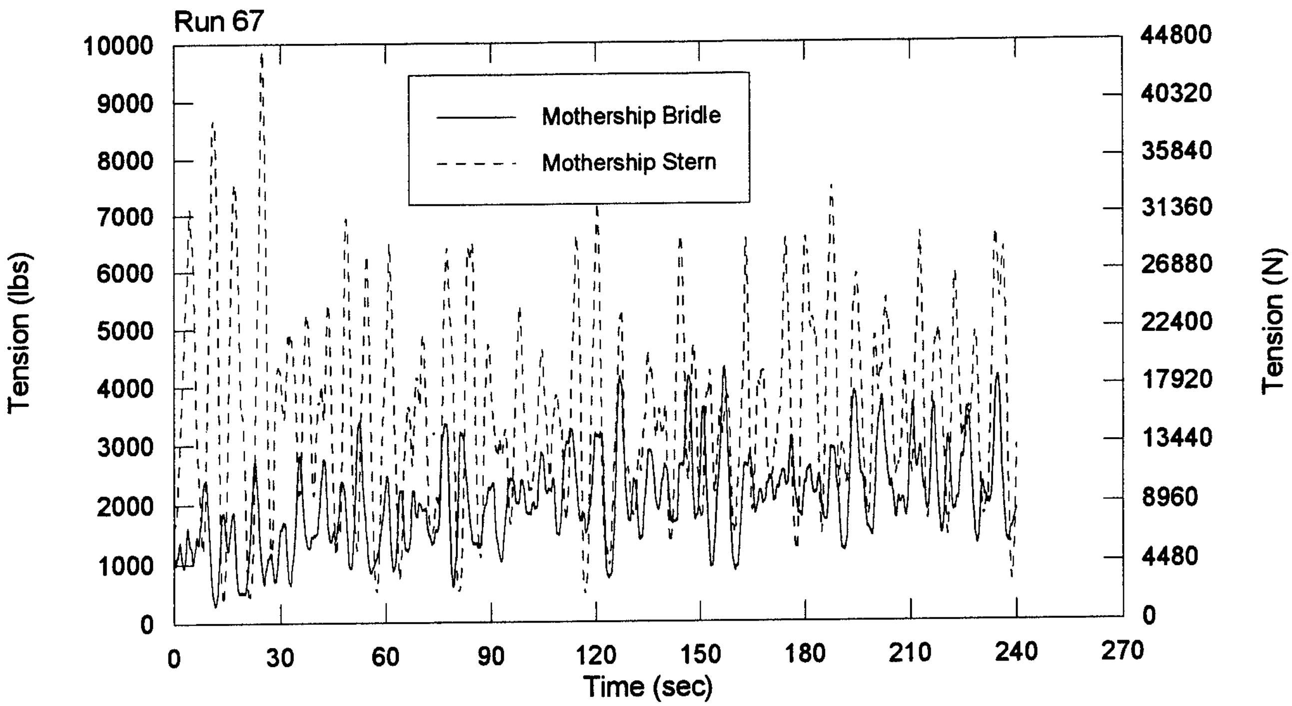
Fig. 66. Stress versus Strain for port outrigger with CG VOSS .

no time did the level of stress approach this limit. The NOFI V Sweep outrigger developed peak stresses which were nominally 20% higher than those in the CG VOSS outrigger except for the two calm water low speed runs which experienced peak stresses of 3500 psi. These higher stresses were believed to be caused by the slightly different methods of rigging the two systems. The NOFI V Sweep system was stable up to a higher operational speed (3 kn) than the CG VOSS. However, average stresses did not increase by more than 1000 psi. at this speed. Stress in the outrigger may be a better measure of the absolute loading than comparisons of the load cell tensions, but this method is still hampered by the differences in rigging arrangements.

6.4 FIOCS RESULTS

The FIOCS system was evaluated on May 13th and was configured as indicated in Fig. 20. Seas were running at 5 - 7 ft. The wave buoy was not deployed since handling the buoy over the stern in the higher sea conditions without a crane, davit or A-frame became a safety concern.

Time histories of the tension data corresponding to a head sea condition at 3.0 kn are shown in Figs. 67 and 68. The average stern line tensions and peak values were higher than those for the bridle arrangement at both 2.0 and 3.0 kn in a head sea condition. However, the bridle tensions were higher than the stern line tensions in all following sea conditions as shown in Figs. 69 - 74 and in Table 7. This is believed to be an artifact of the varying mothership to second vessel relationship rather than a head/following sea phenomena. This relative positioning is critical for successful operation of the system. The highest tension of 9900 lb occurred in the stern line in a head sea as seen in Fig. 67. Large maximum to minimum tensions were seen in all the runs with the stern line tensions dropping to zero as shown Figs. 71 - 74. Both the bridle and stern tensions appeared to oscillate at approximately the same frequency of 5.5 - 6 seconds in head seas and 7 - 7.5 seconds in following seas. There was some correlation between the two tensions; however, they easily went in



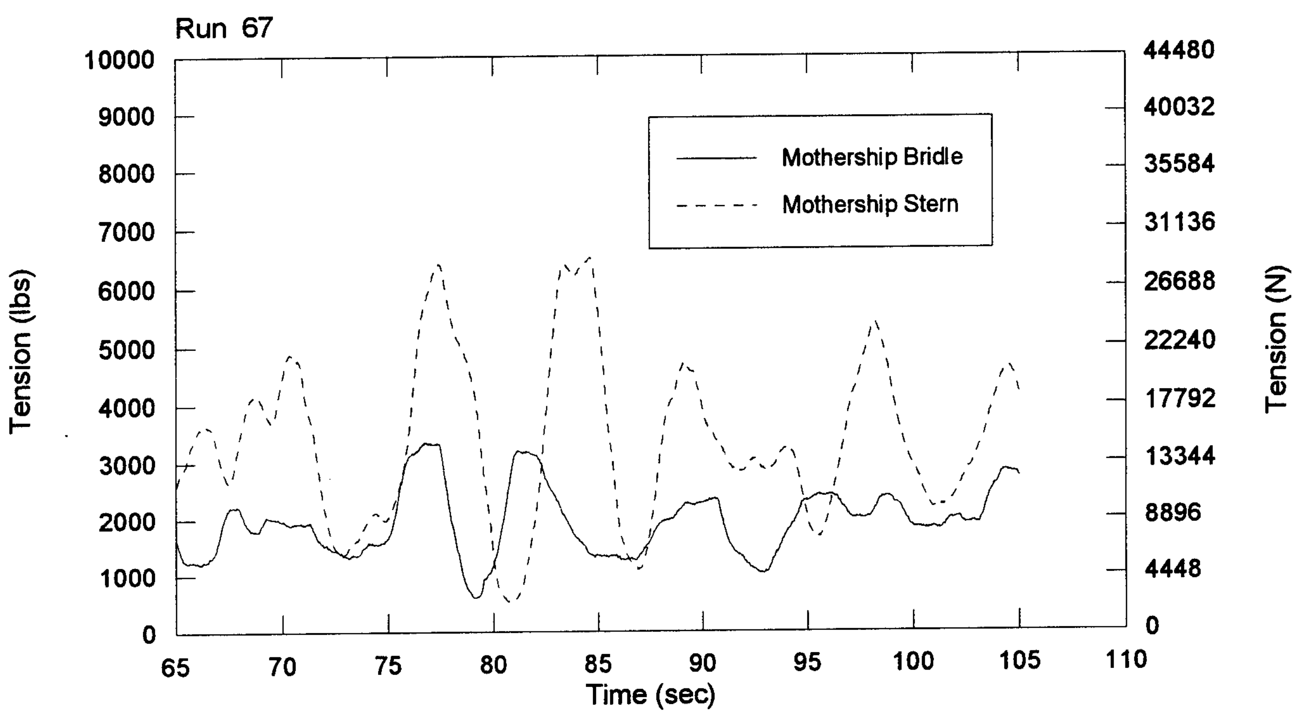
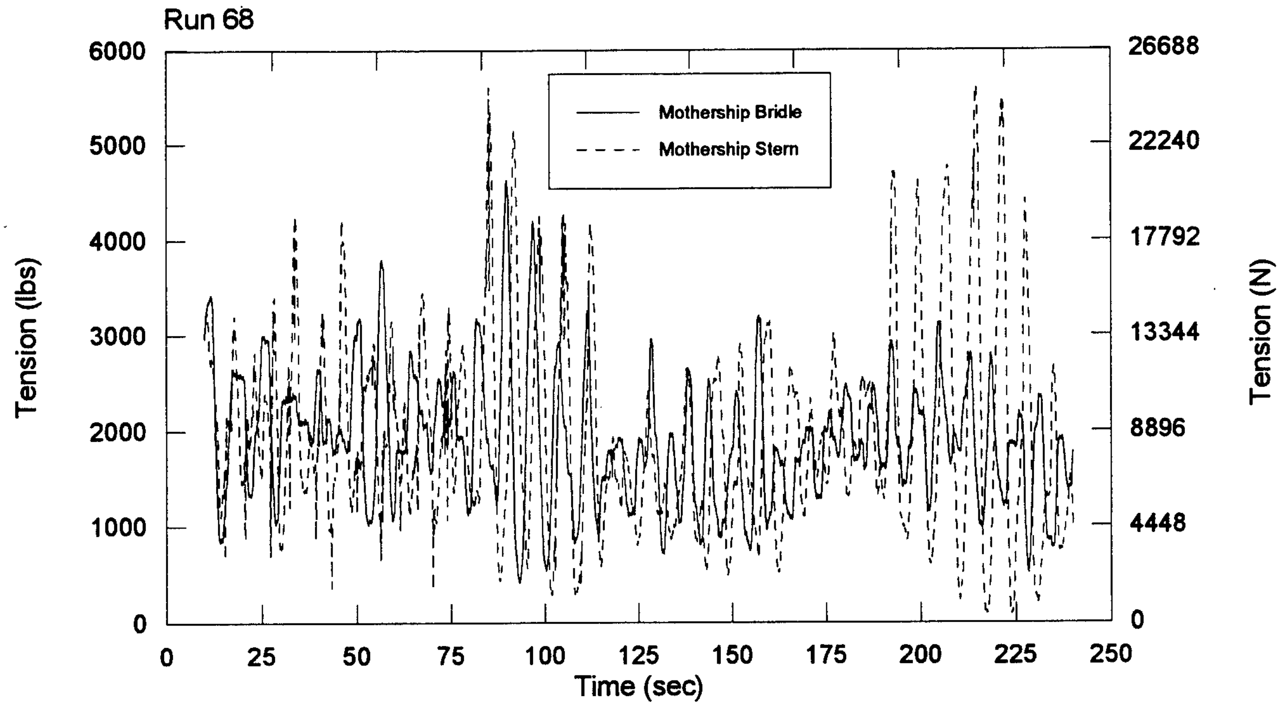


Fig. 67. Tension in FIOCS resstraining lines at 3 knots in 5 - 7 foot head seas. (Run 67, 5/13/93).



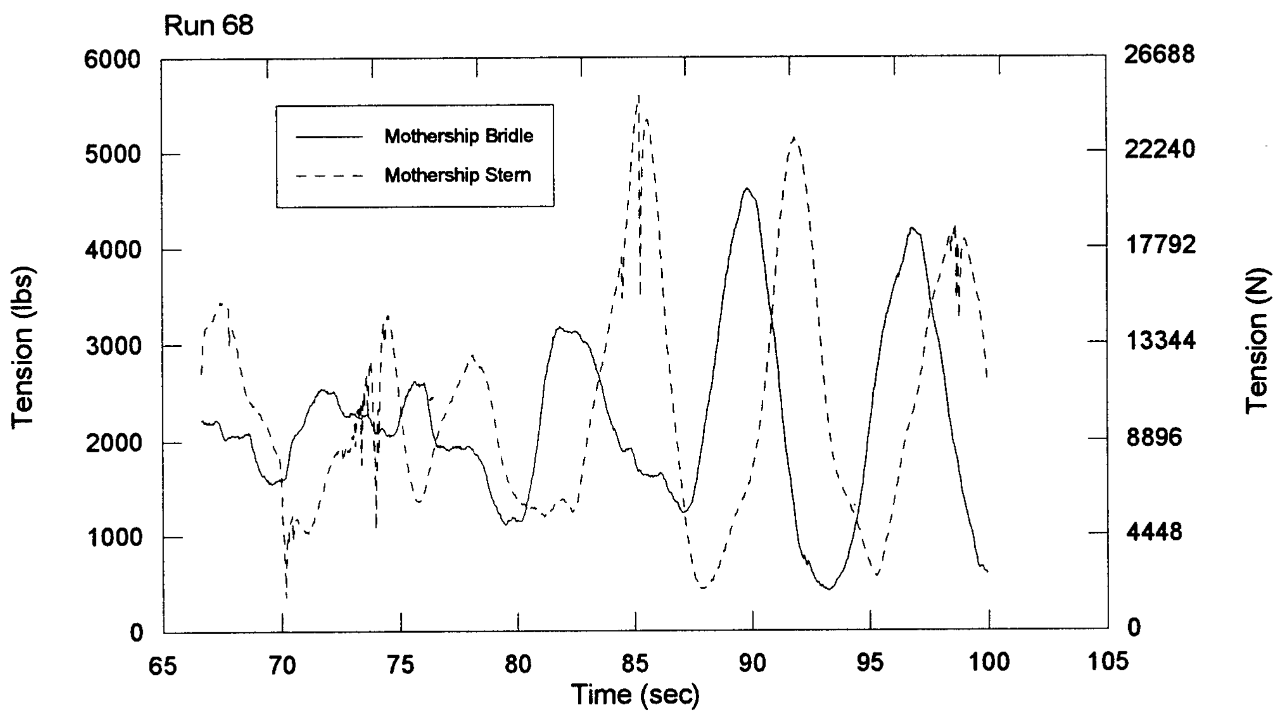


Fig. 68. Tension in FIOCS restraining lines at 3 knots in 5 - 7 foot head seas. (Run 68, 5/13/93).

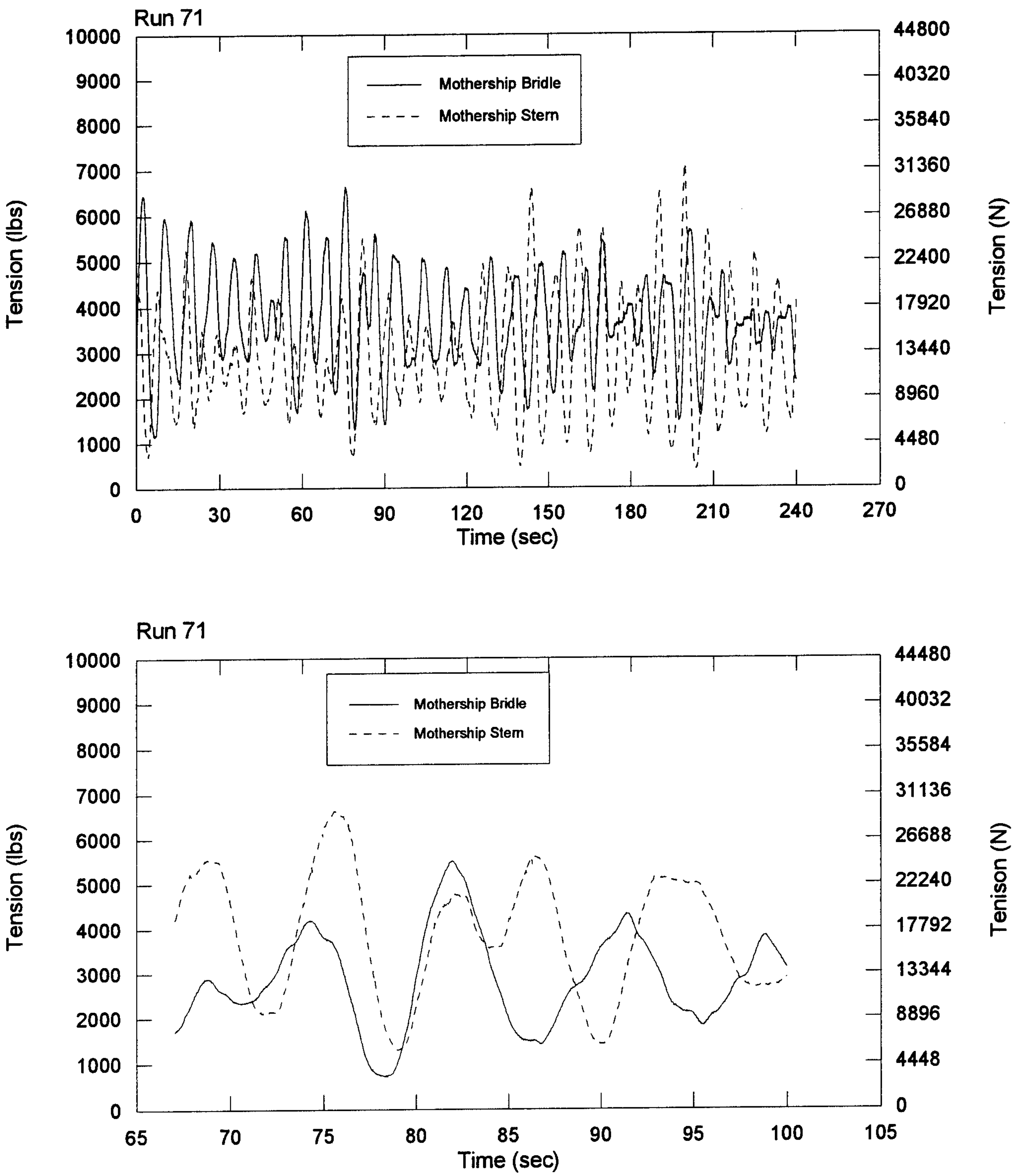
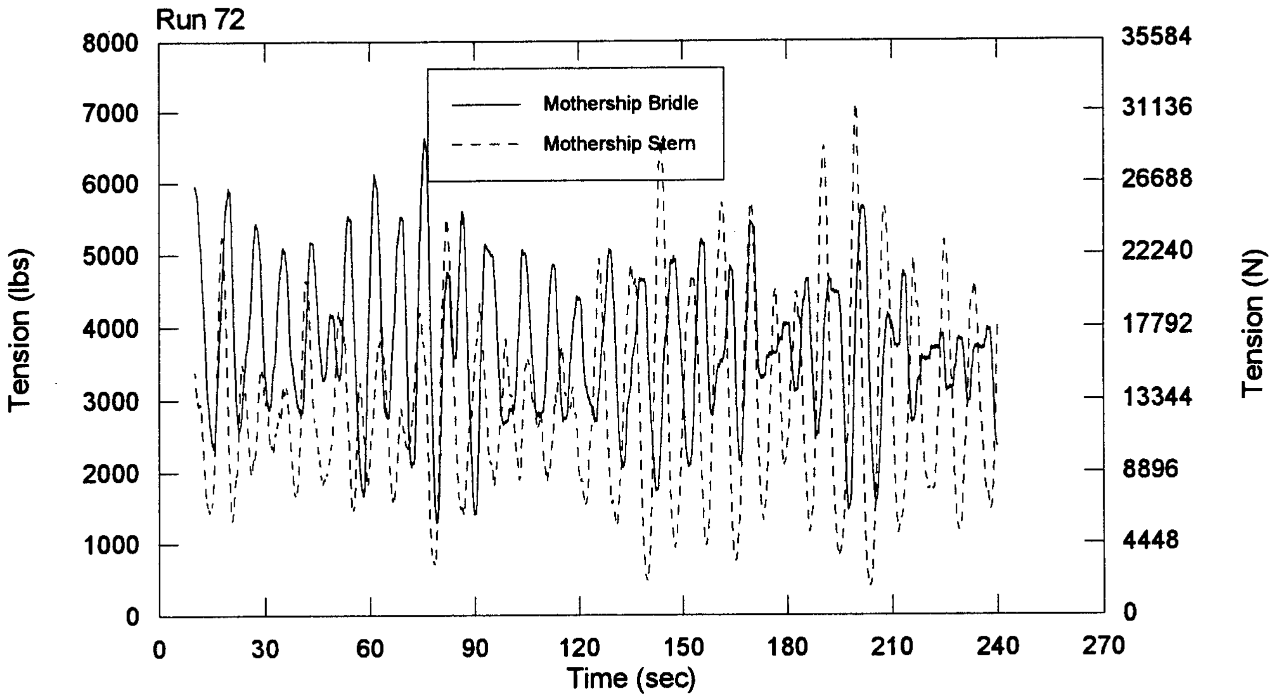


Fig. 69. Tension in FIOCS restraining lines at 3 knots in 5 - 7 foot following seas. (Run 71, 5/13/93)



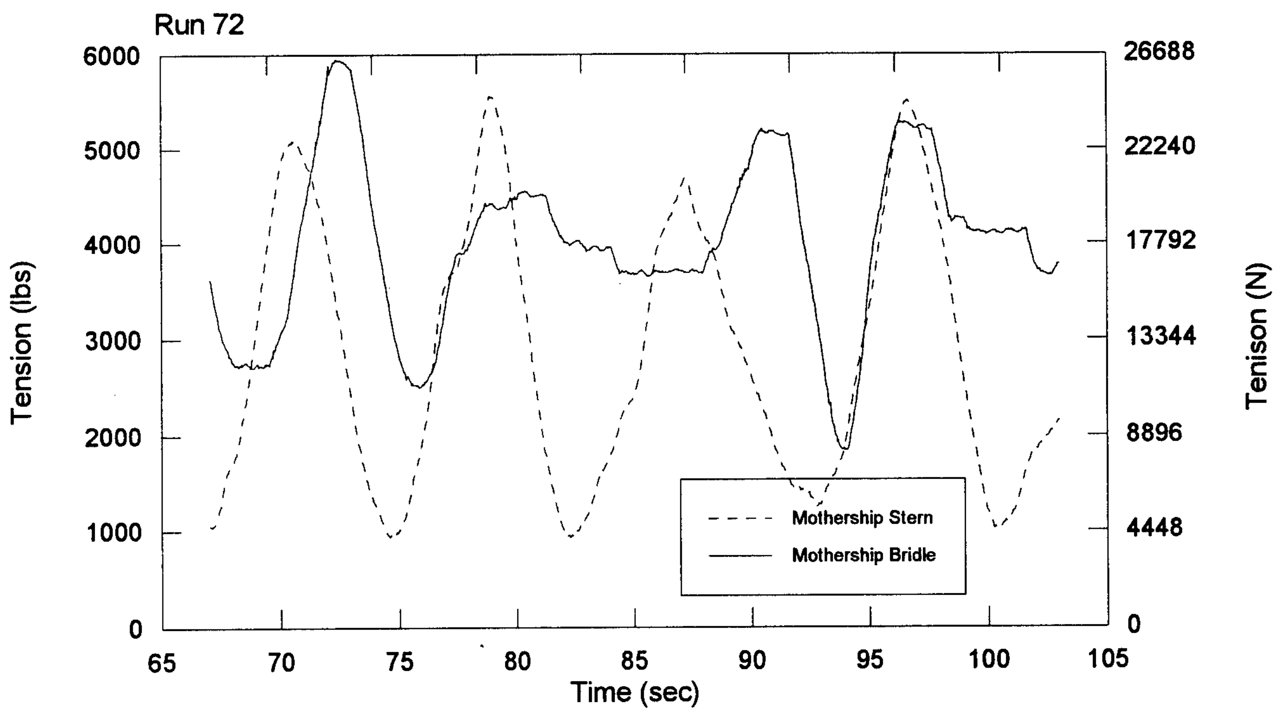
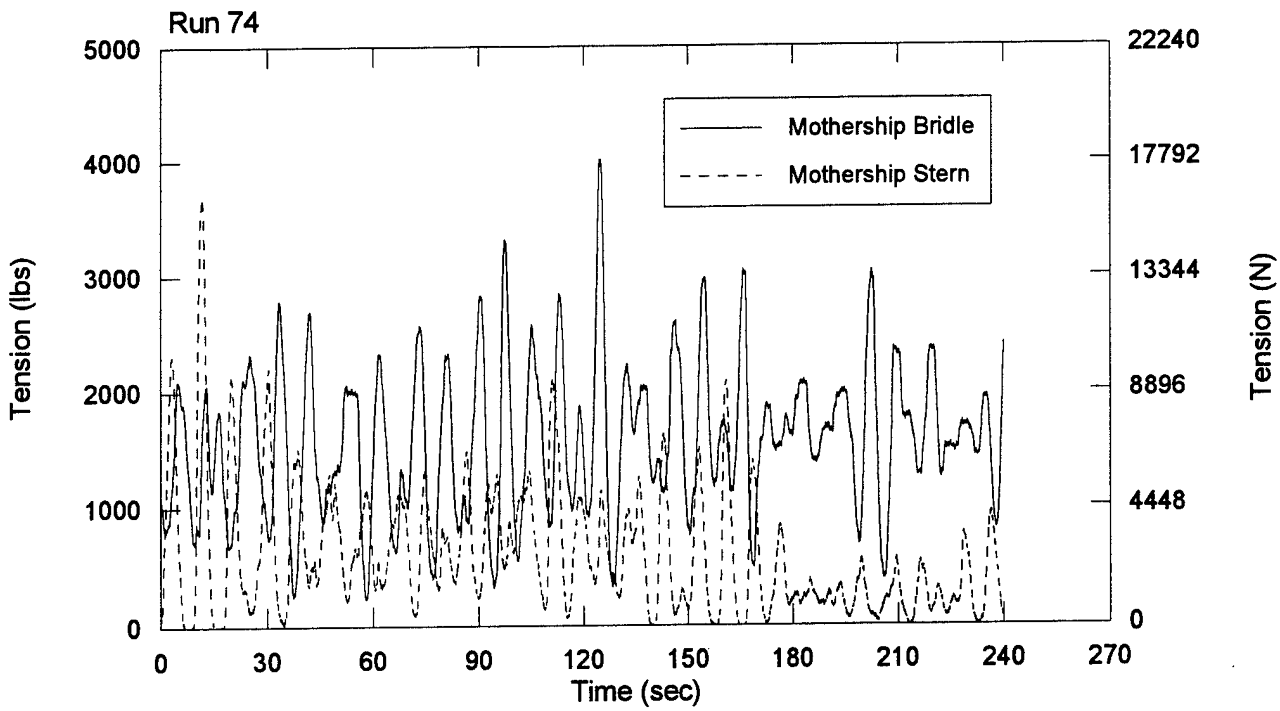


Fig. 70. Tension in FIOCS restraining lines at 3 knots in 5 - 7 foot following seas. (Run 72, 5/13/93)



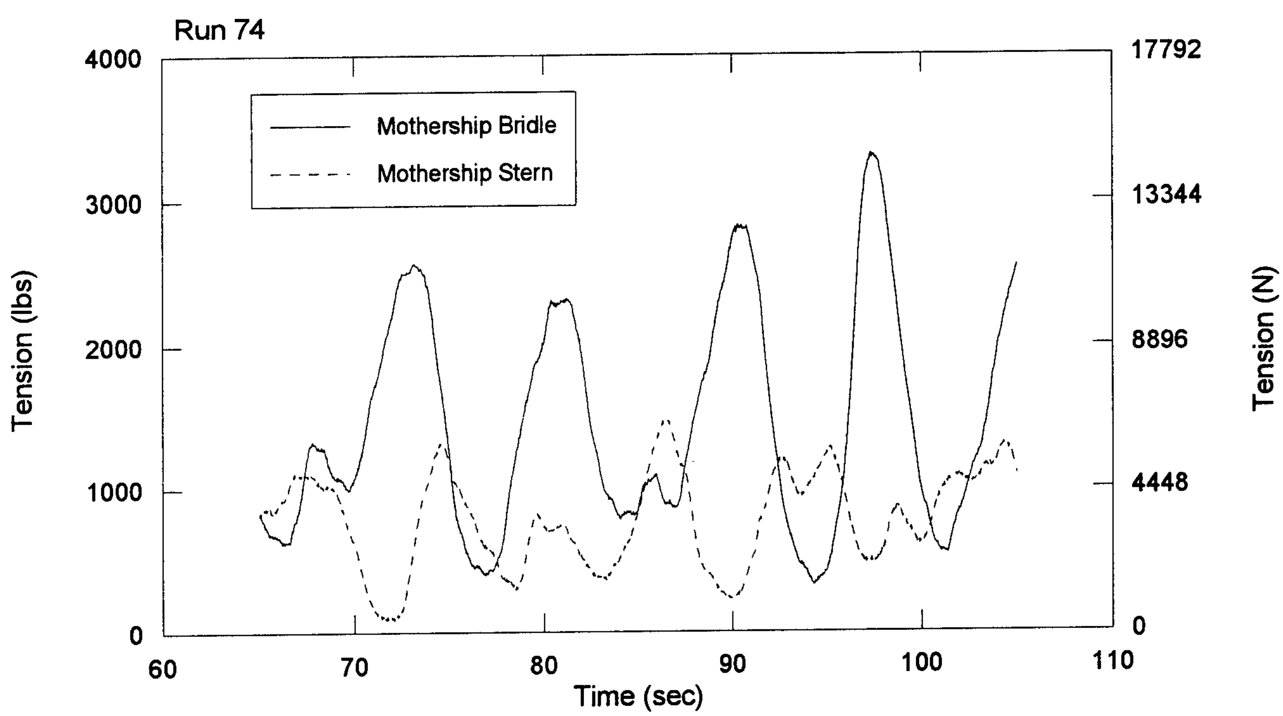
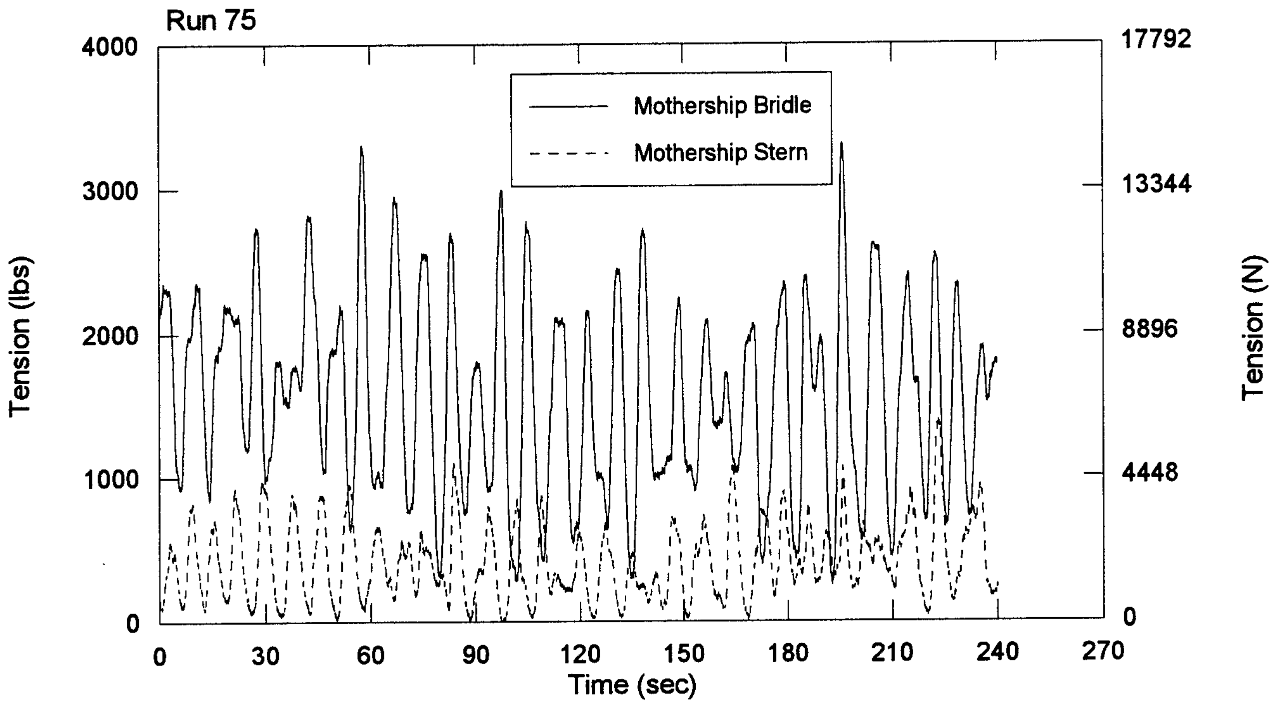


Fig. 71. Tension in FIOCS restraining lines at 2 knots in 5-7 foot following seas (Run 74, 5/13/93).



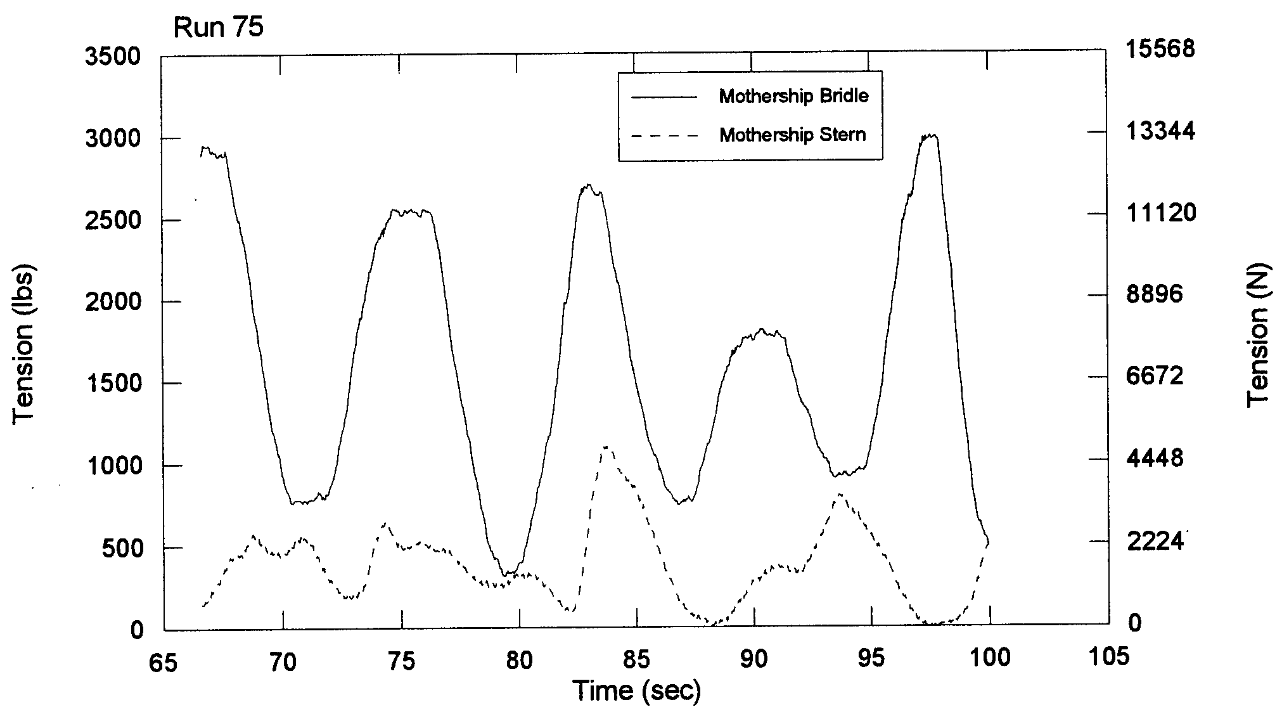
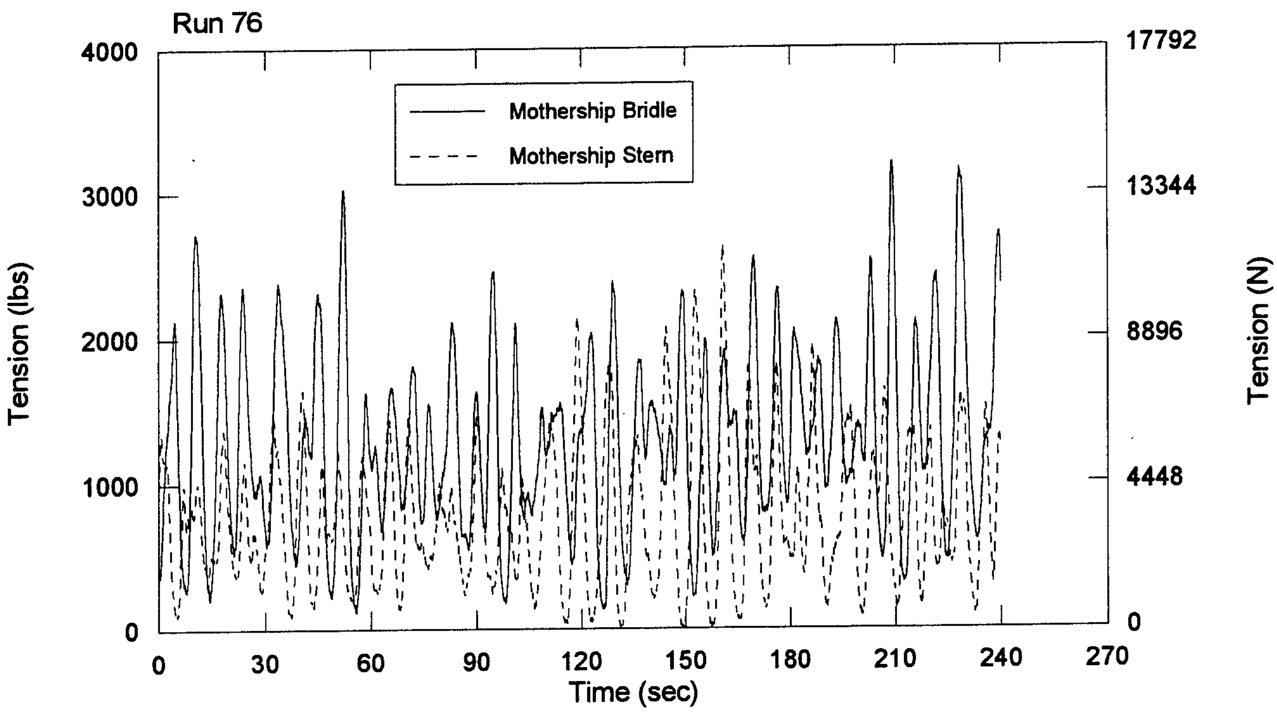


Fig. 72. Tension in FIOCS restraining lines at 2 knots in 5 - 7 foot following seas (Run 75, 5/13/93).



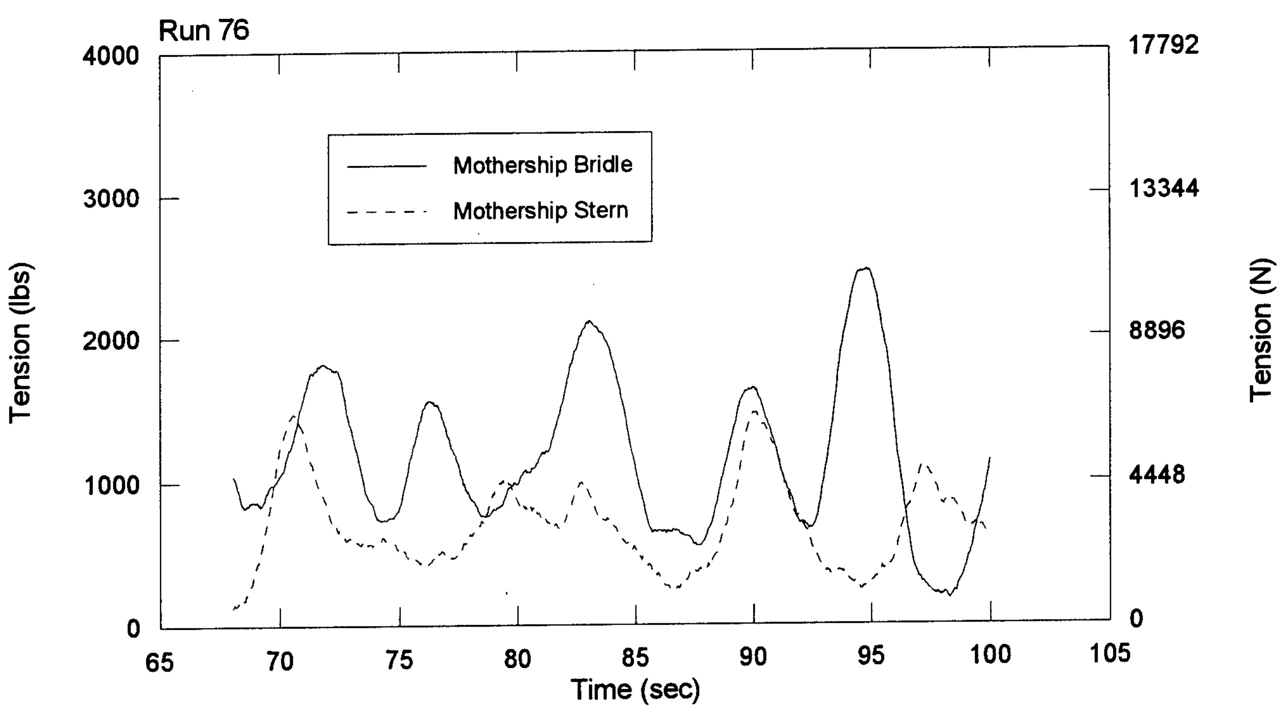
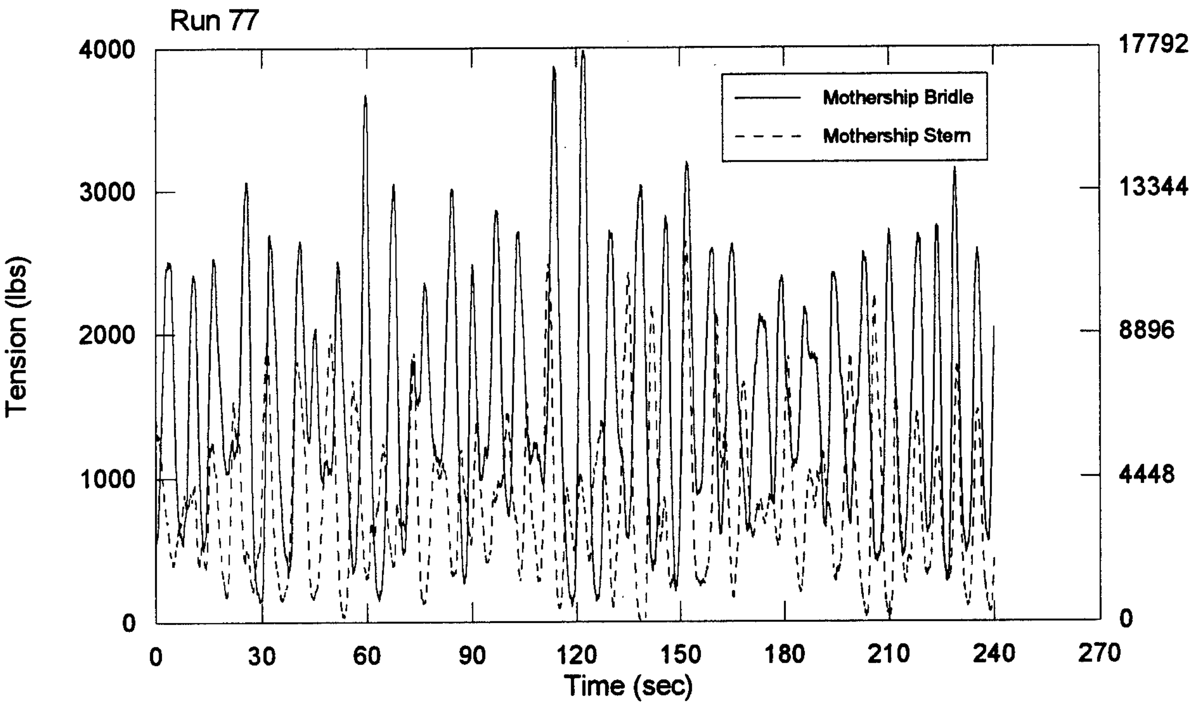


Fig. 73. Tension in FIOCS restraining lines at 1.5 knots in 5-7 foot seas (Run 76, 5/13/93).



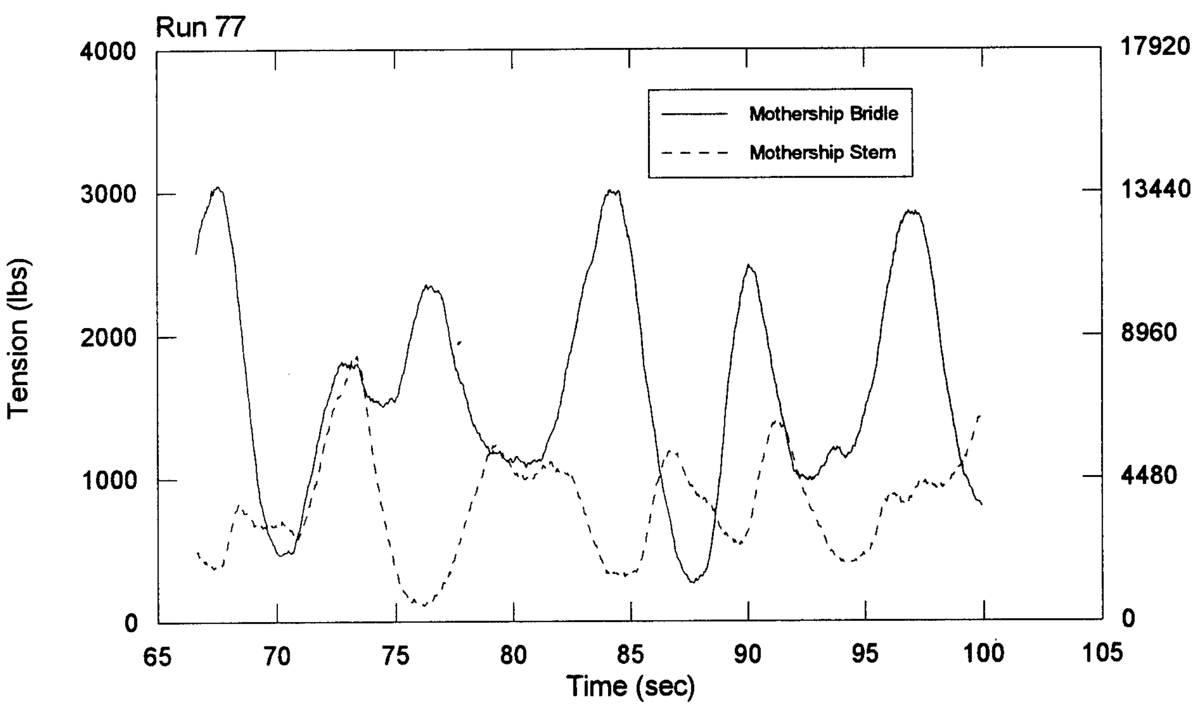


Fig. 74. Closeup of Tension in FIOCS restraining lines at 1.5 knots in 5-7 foot seas (Run 77, 5/13/93).

and out of phase so there is no direct coupling relationship that can be established. The tension data for the second vessel in Table 7 were obtained from analog strip chart recordings.

Table 7. Tension of FIOCS restraining lines.

Run #	Trojan Speed (kn)	Mothership Bridle Tension Stern Tension (lb)			POINT WELLS Observed tension (lb)			Observed Sea Conditions, Orientations & Comments
	mean	mean	max	min	mean	max	min	
67	2.71	2050 3620	4310 9900	285 382	4200	6500	2000	head seas
68	2.61	1920 1980	4620 5610	416 90	4400	6900	2300	head seas
71	3.07	3750 2930	6630 7100	1150 407	5200	8300	2500	following seas
72	3.06	3840 2900	7050 6240	1010 480	5200	8400	2500	following seas
74	2.00	1570 609	4040 369	226 0	3150	5500	1700	following seas
75	1.96	1560 415	3320 1390	250 0	3150	5650	1050	following seas
76	1.55	1300 768	3200 2640	119 0	1950	4600	420	following seas
77	1.48	1520 829	3990 2650	104 0	1950	4200	850	following seas

6.5 OUTRIGGER MOTIONS

The time histories for the motions of the outrigger float, the bending strain and the skirt depth are presented together to show the relationships between motions and resulting forces. The vertical accelerations of the outrigger float were obtained by means of the accelerometer package. The outrigger float accelerations, the depth of the apex pressure gauge and vertical bending strain of the boom as a function time are illustrated for several data runs in Figs. 75-77 for the CG VOSS and in Figs. 78-80 for the NOFI V Sweep.

There is a tendency for the CG VOSS depth and strain curves to have similarities in their profiles, as seen in Fig. 76 for the 1.0 kn condition. Figure 77 also shows this tendency with some evidence of a phase shift in the response of these measurements. There is some correlation between the strain and acceleration curves. Figure 75 demonstrates that regions of small oscillatory accelerations correspond to regions of small oscillatory behavior in strain; the same is true for large oscillations.

There appears to be a strong correlation between strain and depth for the NOFI V Sweep, as can be seen in Figs. 78-80. The long period fluctuations (approximately 6 seconds) in the strain measurements shown in Fig. 80 are clearly seen in the depth information but is not evident in the accelerometer data. The responses move in and out of phase and the damping effects appear to vary over time.

A similar comparison was performed for the longitudinal (fore/aft) direction with the longitudinal bending strain and the boom load cell data. Because the longitudinal accelerometer was insensitive to the small longitudinal accelerations, this data is not included on the figures. Figures 81 - 83 show the CG VOSS forward preventer and glide line tensions over time for head and following seas for sea state 1 and head seas for sea state 2. Figure 84 shows the NOFI V Sweep forward and aft restraining line tensions and the strain of their respective outriggers over time for a sea state 2. From the CG VOSS data, there is a correlation between the outrigger bending strain and the load cell data. The profiles for each, as seen clearly in Figs. 81 and 82, are 180 deg out of phase. It is clear from comparing Figs. 81 and 82 with Fig.83 how the dominant frequency changes with increasing sea state. For the NOFI V Sweep, there does not appear to be a correlation between its outrigger strain and the load information seen in Fig. 84. There is a low frequency periodicity

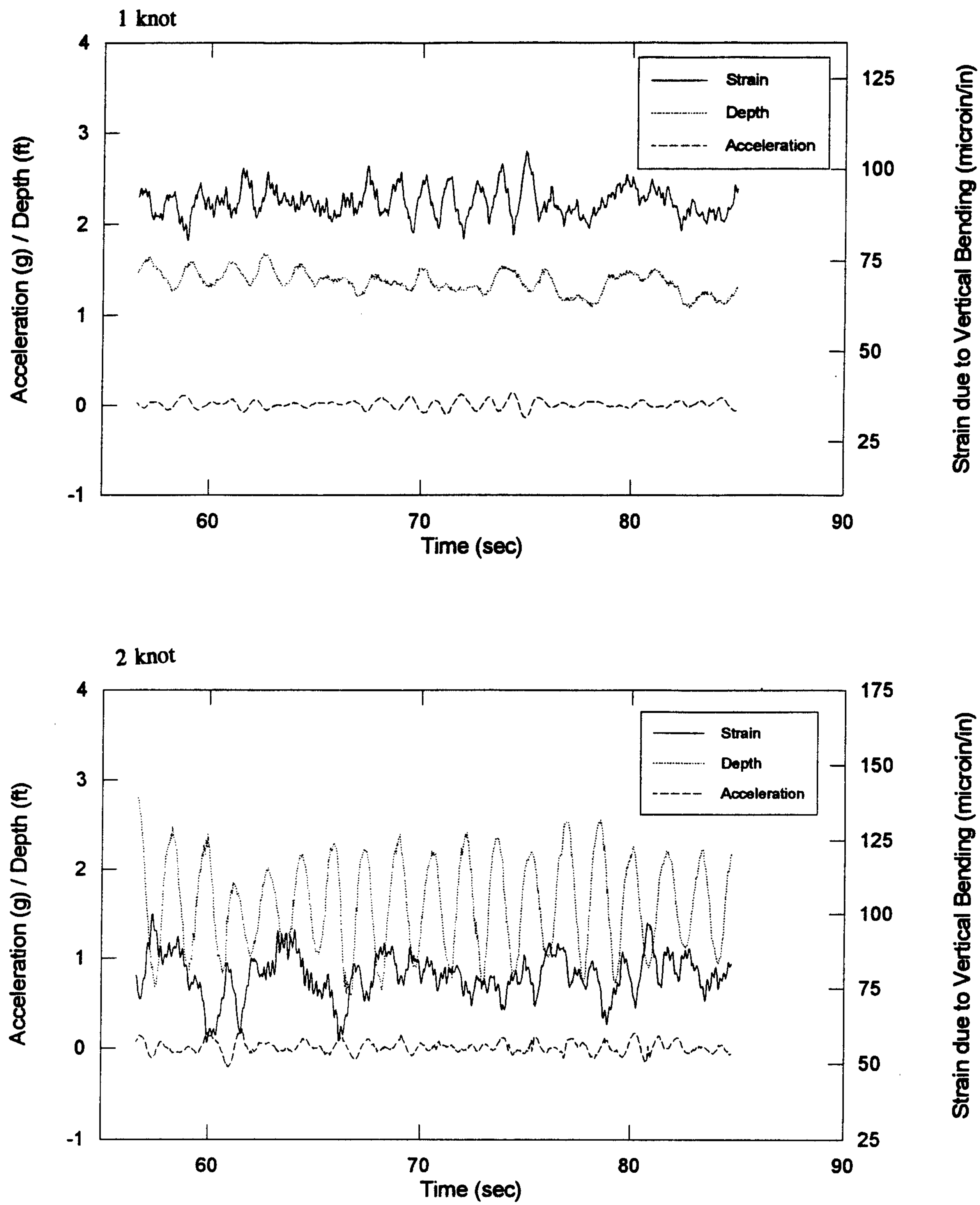
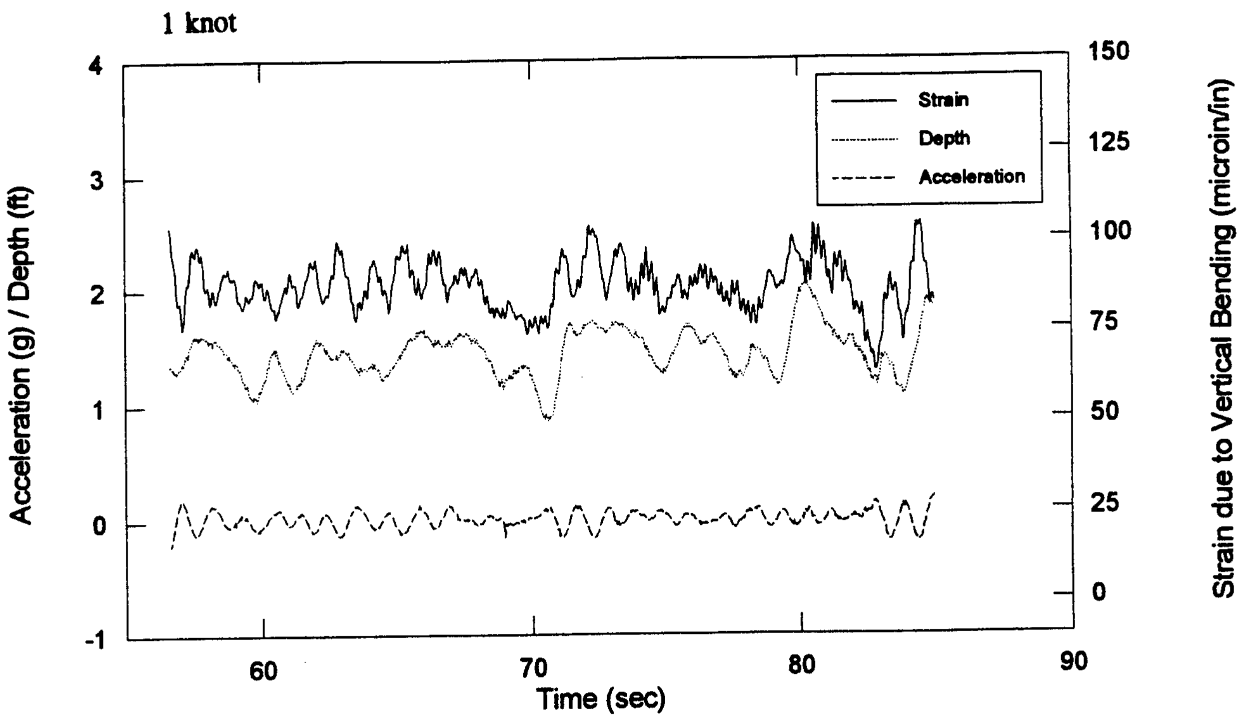


Fig. 75. Acceleration, depth and strain due to vertical bending of CG VOSS system at 1 and 2 knots in 1 - 2 foot head seas. (Run 41 & 42, 5/7/93)



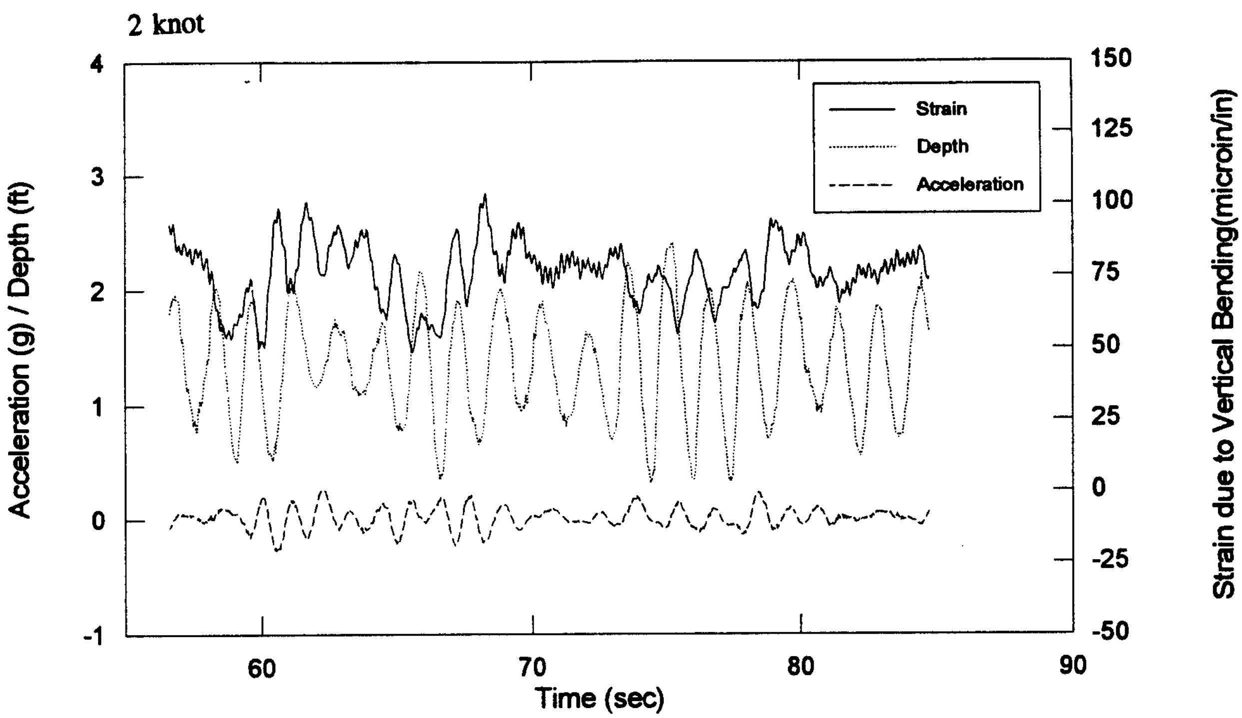
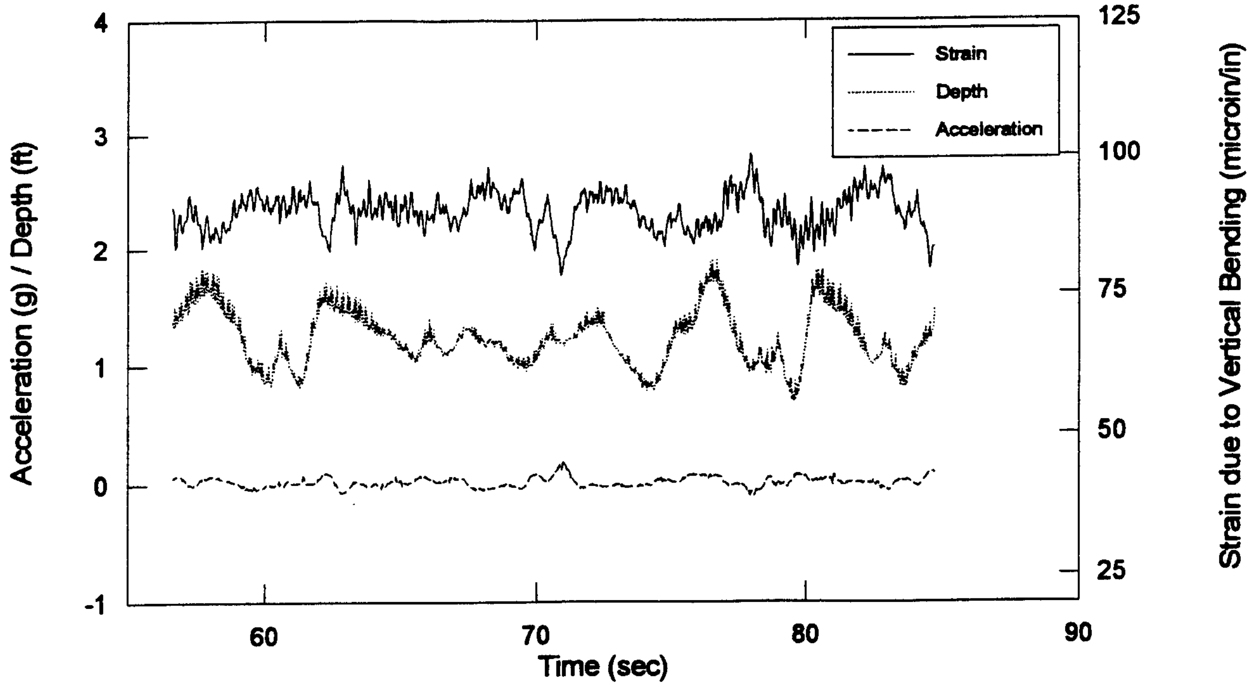


Fig. 76. Acceleration, depth and strain due to vertical bending of CG VOSS system at 1 and 2 knots in 1 - 2 foot following seas. (Run 43 & 44, 5/7/93)

1 knot



2 knot

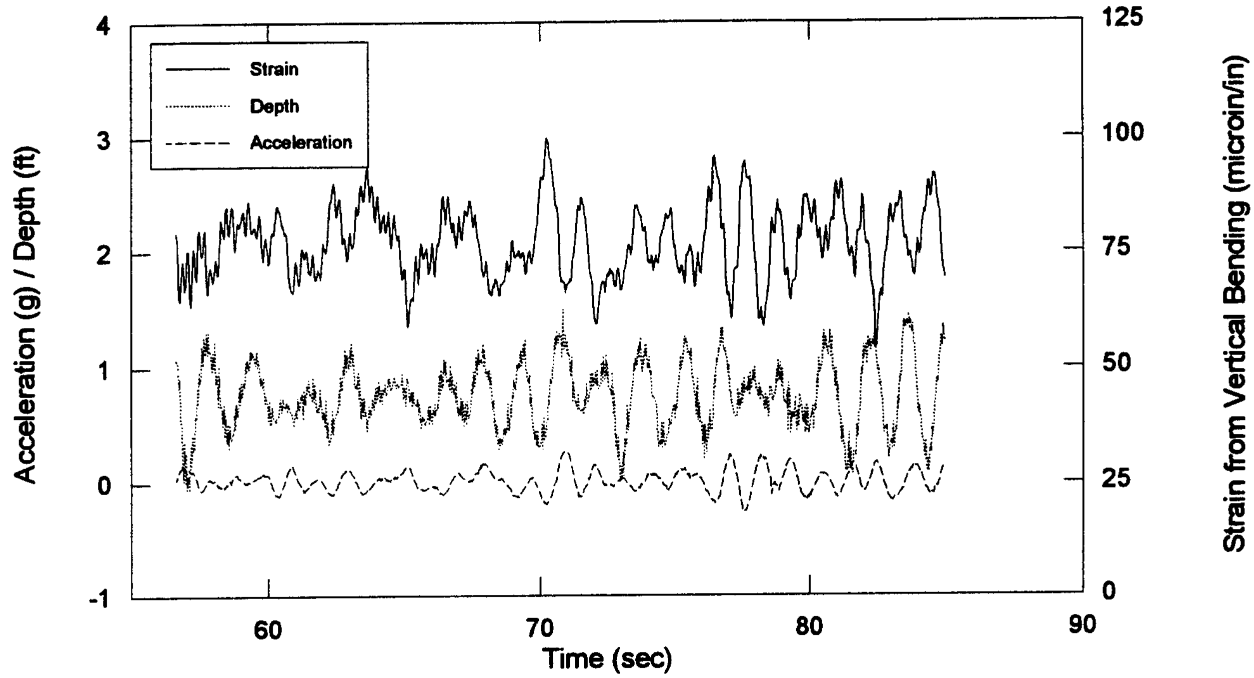


Fig.77. Acceleration, depth and strain due to vertical bending of CG VOSS system at 1 and 2 knots in 2 - 4 foot head seas. (Run 28 & 29, 5/6/93)

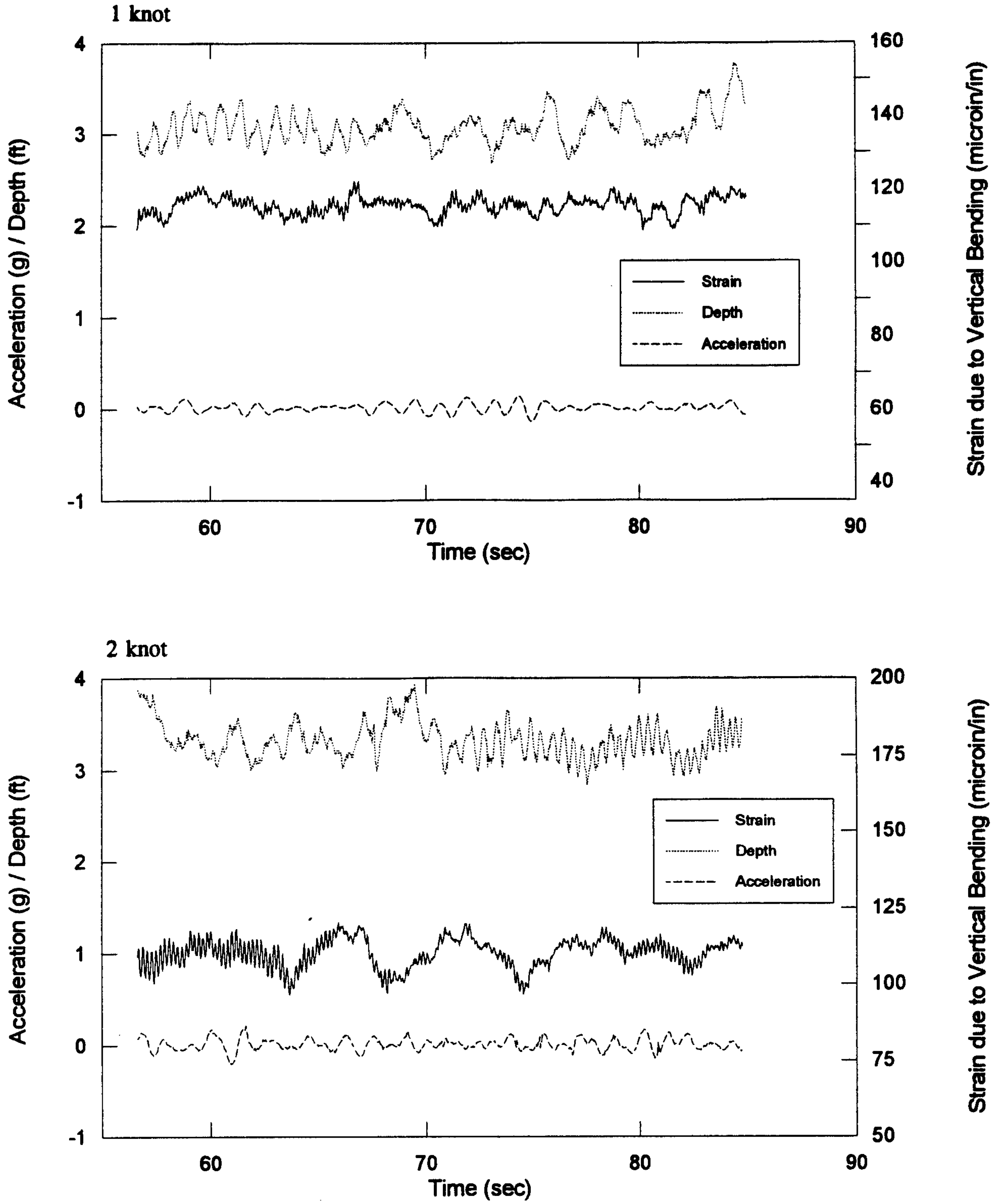
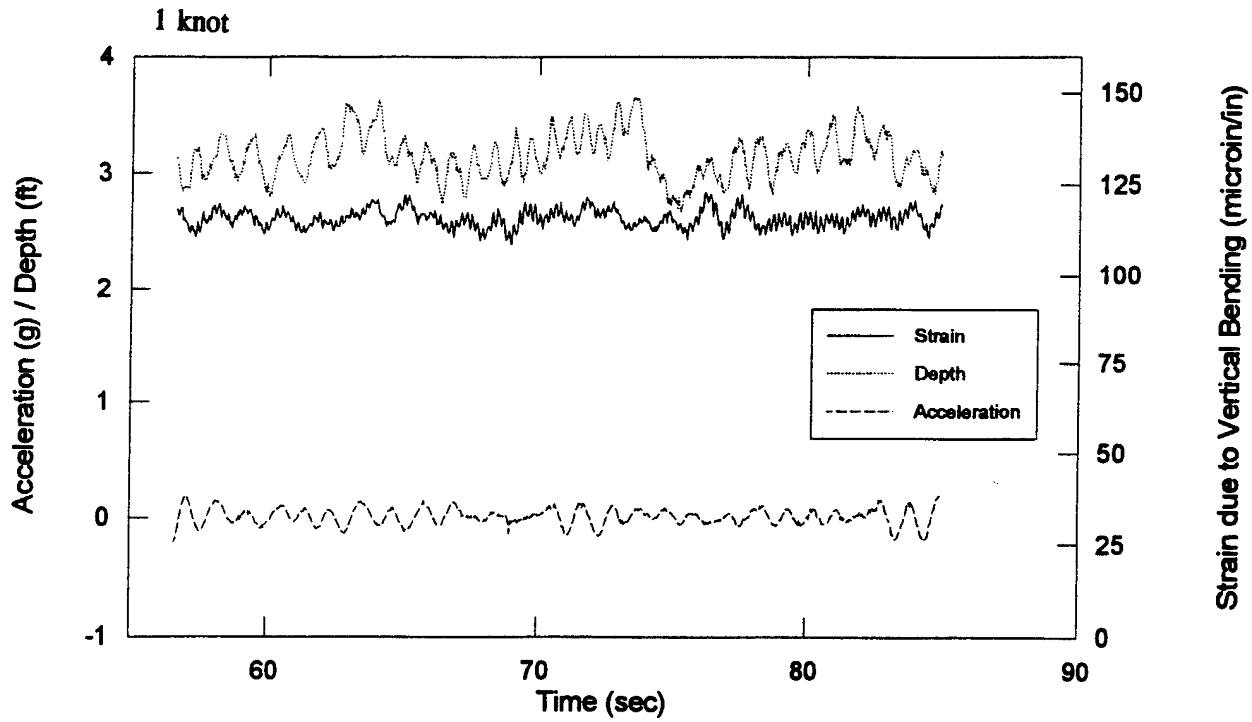


Fig.78. Acceleration, depth and strain due to vertical bending of NOFI V Sweep system at 1 and 2 knots in 1 - 2 foot head seas. (Run 41 & 42, 5/7/93)



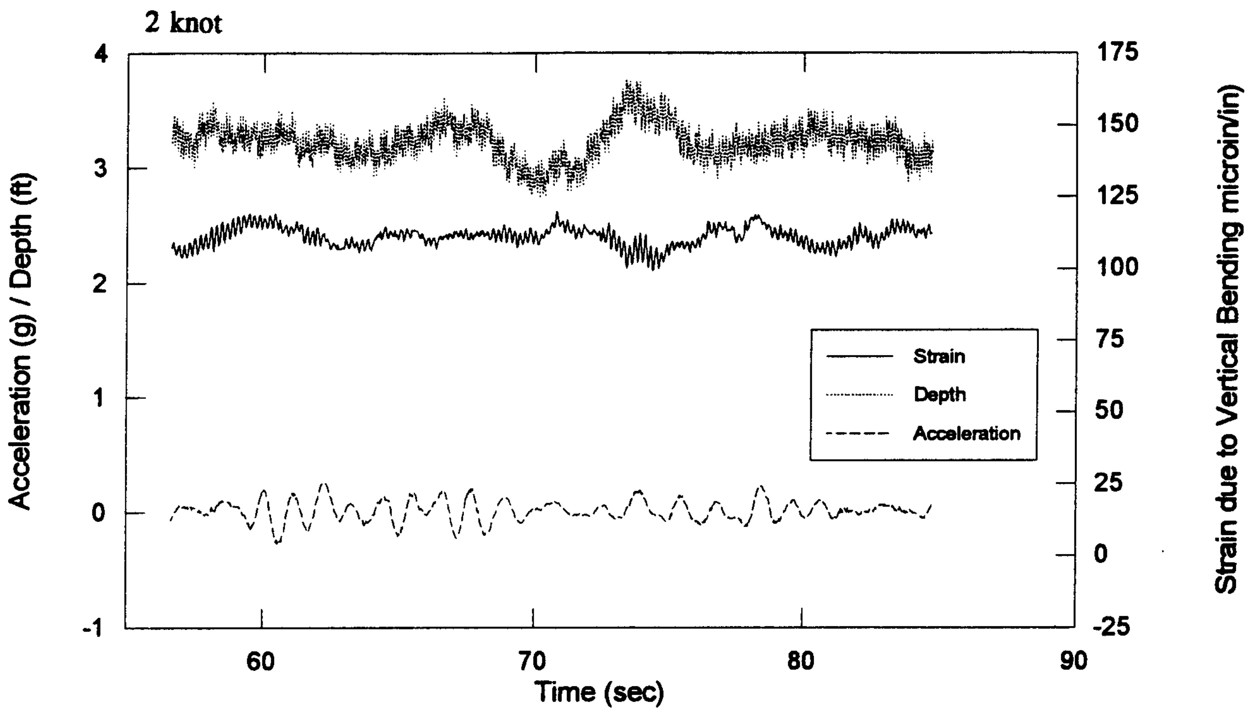


Fig. 79. Acceleration, depth and strain due to vertical bending of NOFI V Sweep system at 1 and 2 knots in 1 - 2 foot following seas. (Run 43 & 44, 5/7/93)

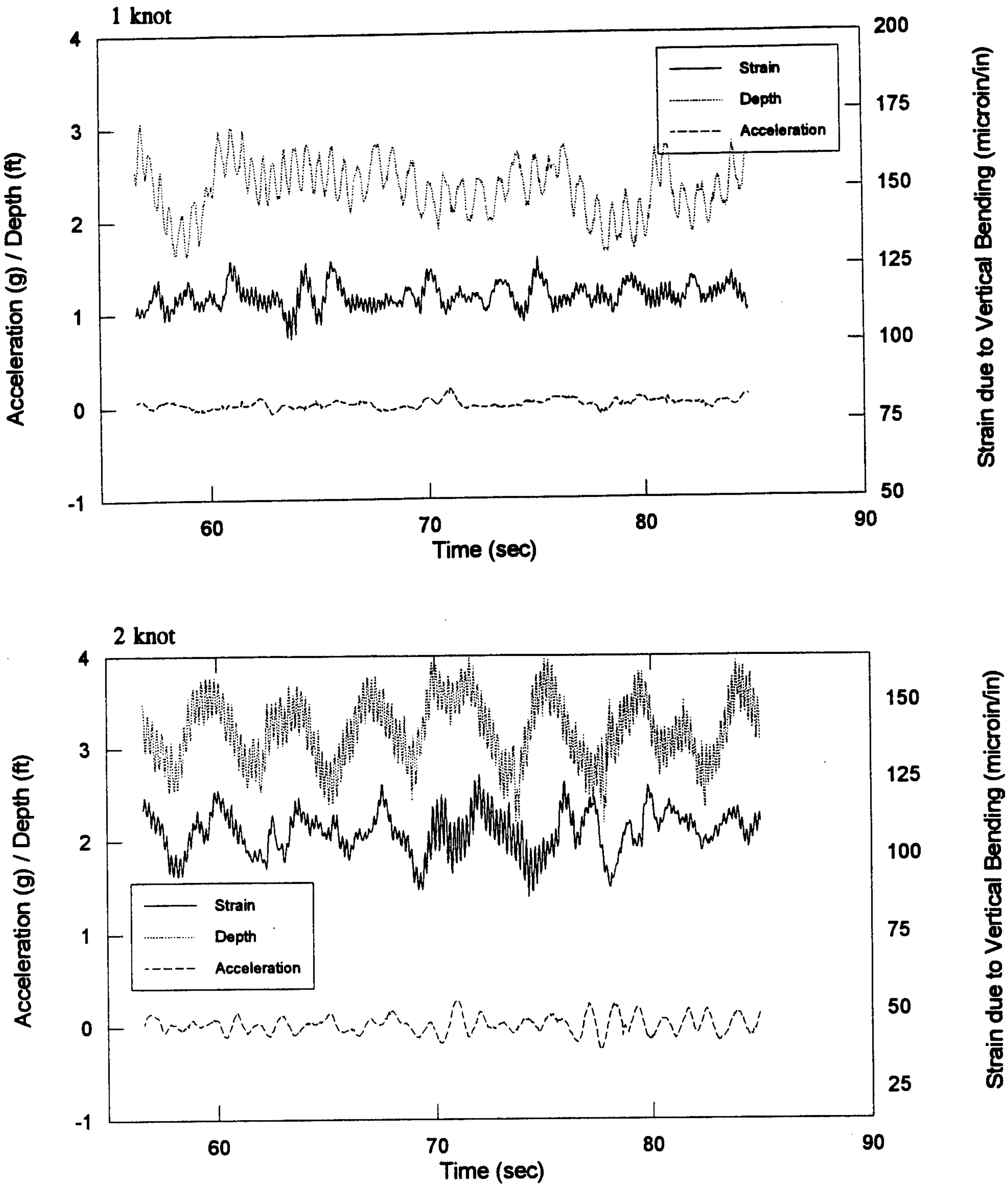


Fig. 80. Acceleration, depth and strain due to vertical bending of NOFI V Sweep system at 1 knot in 2 - 4 foot head seas. (Run 28 & 29, 5/6/93)

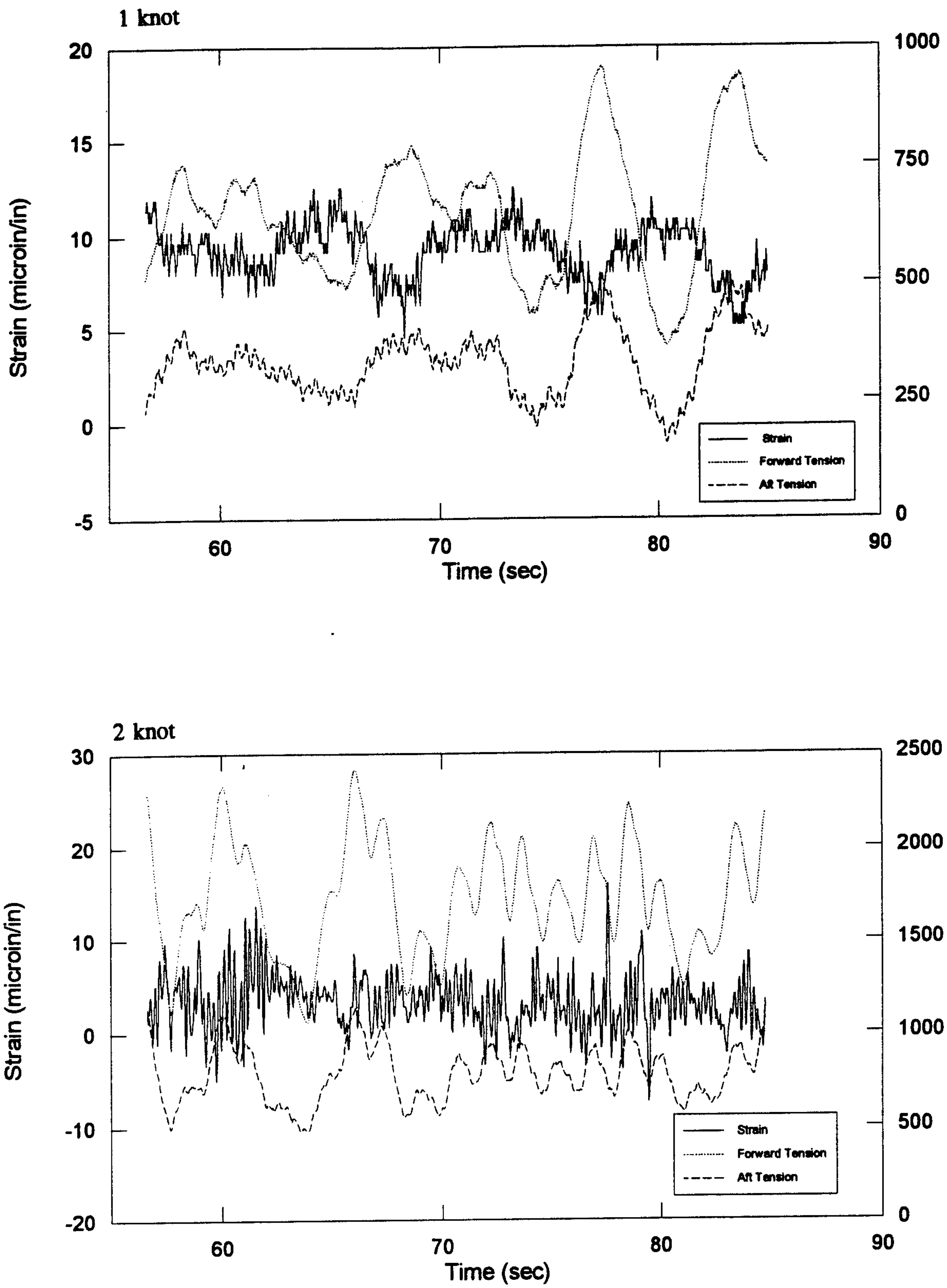
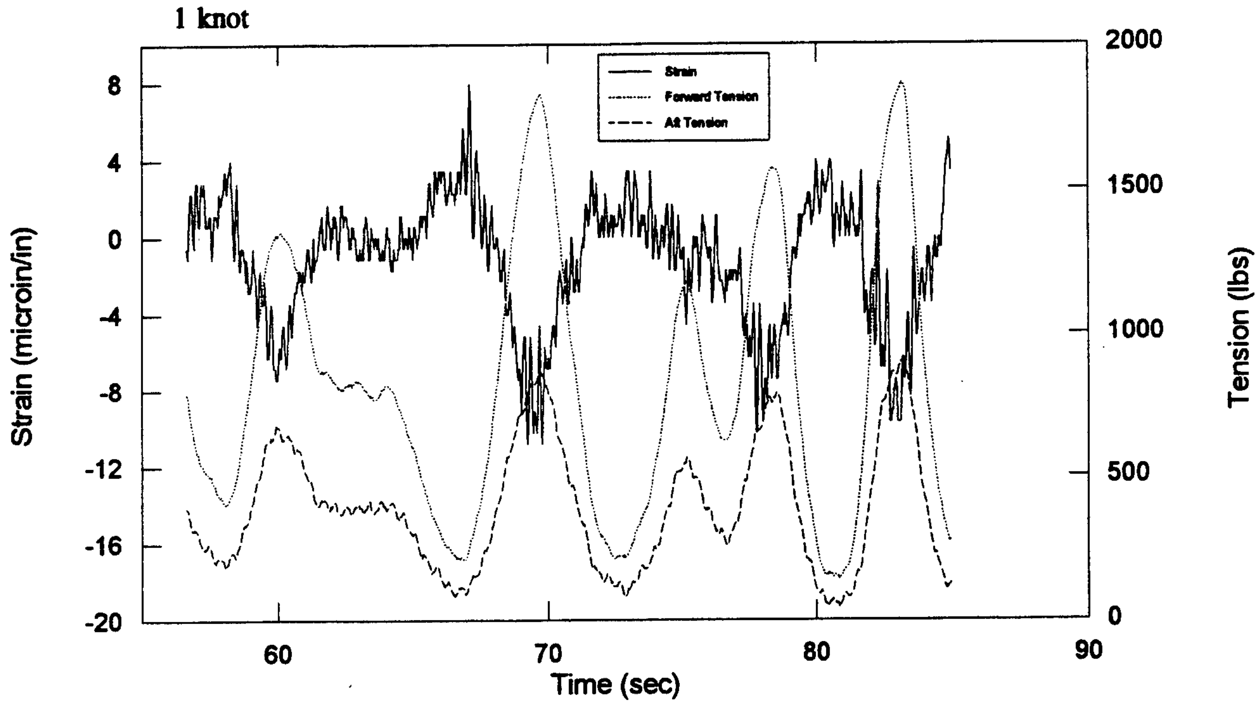


Fig. 81. Tensions and strain due to longitudinal bending of the CG VOSS outrigger with skimmer at 1 and 2 knots in 1 - 2 foot head seas. (Run 41& 42, 5/6/93)



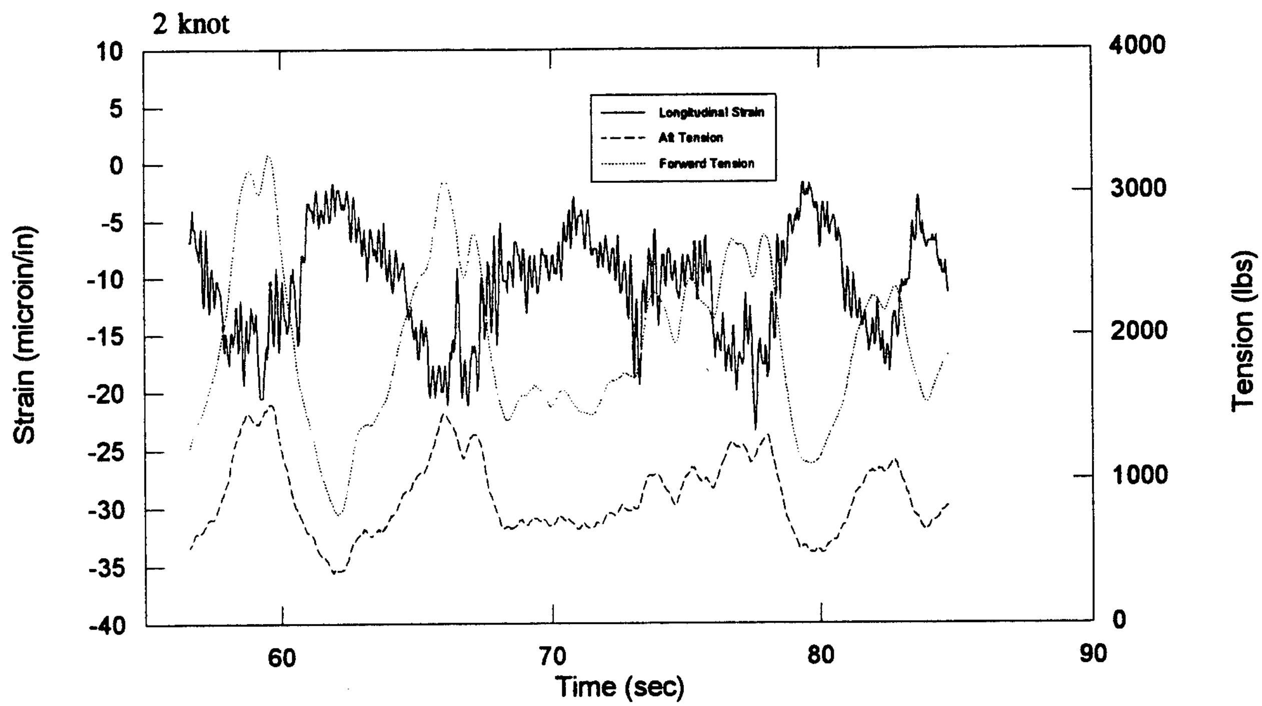
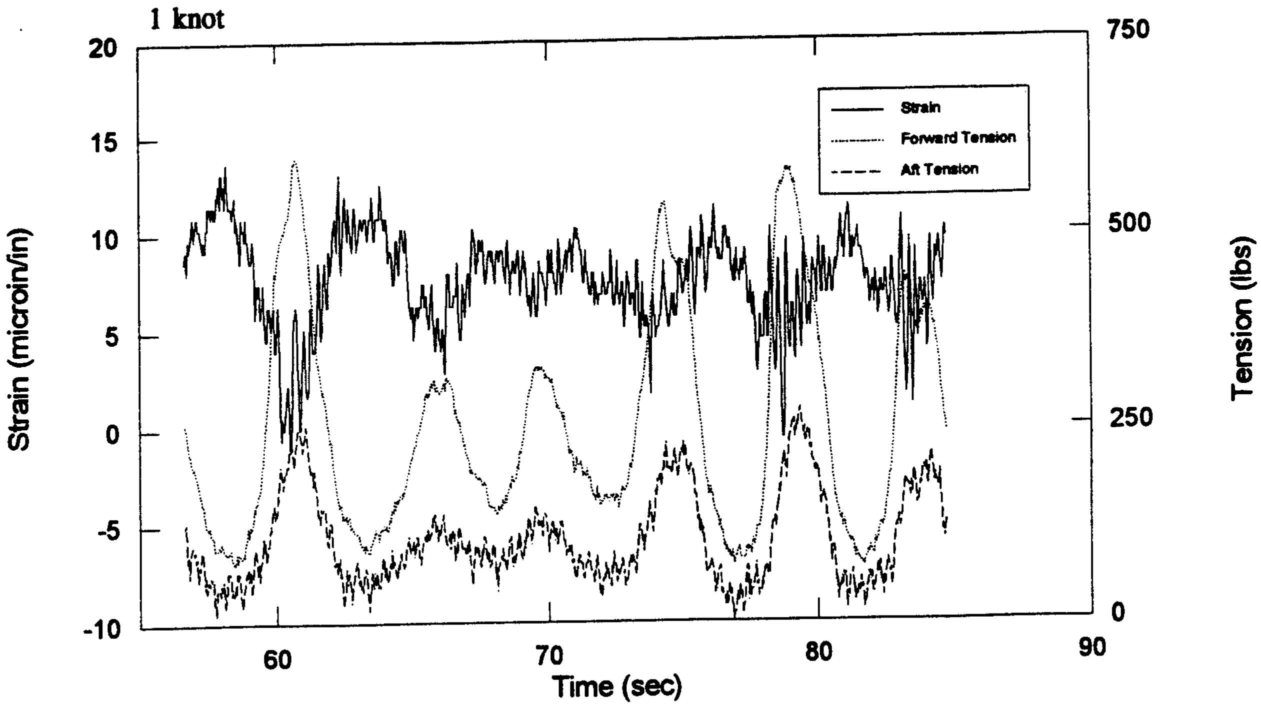


Fig. 82. Tensions and strain due to longitudinal bending of the CG VOSS outrigger with skimmer at 1 and 2 knots in 1 - 2 foot following seas. (Run 43 & 44, 5/6/93)



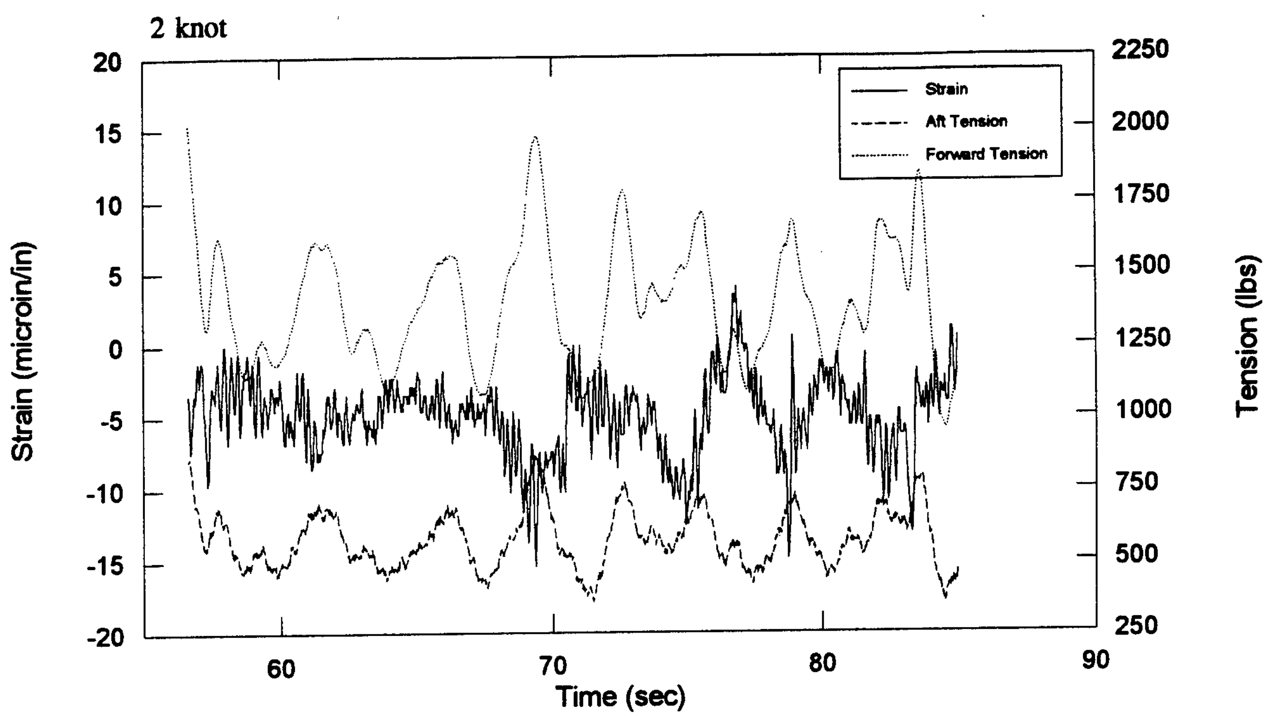
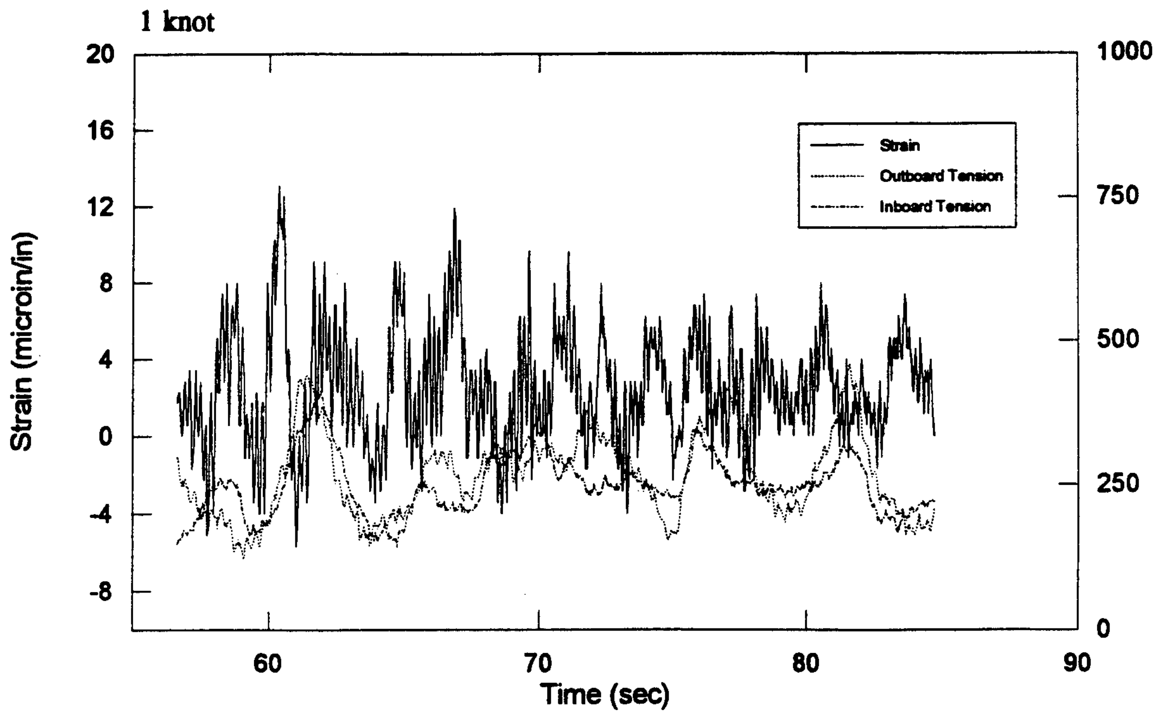


Fig. 83. Tensions and strain due to longitudinal bending of the CG VOSS outriggers at 1 and 2 knots in 2 - 4 foot head seas. (Run 28& 29, 5/6/93)



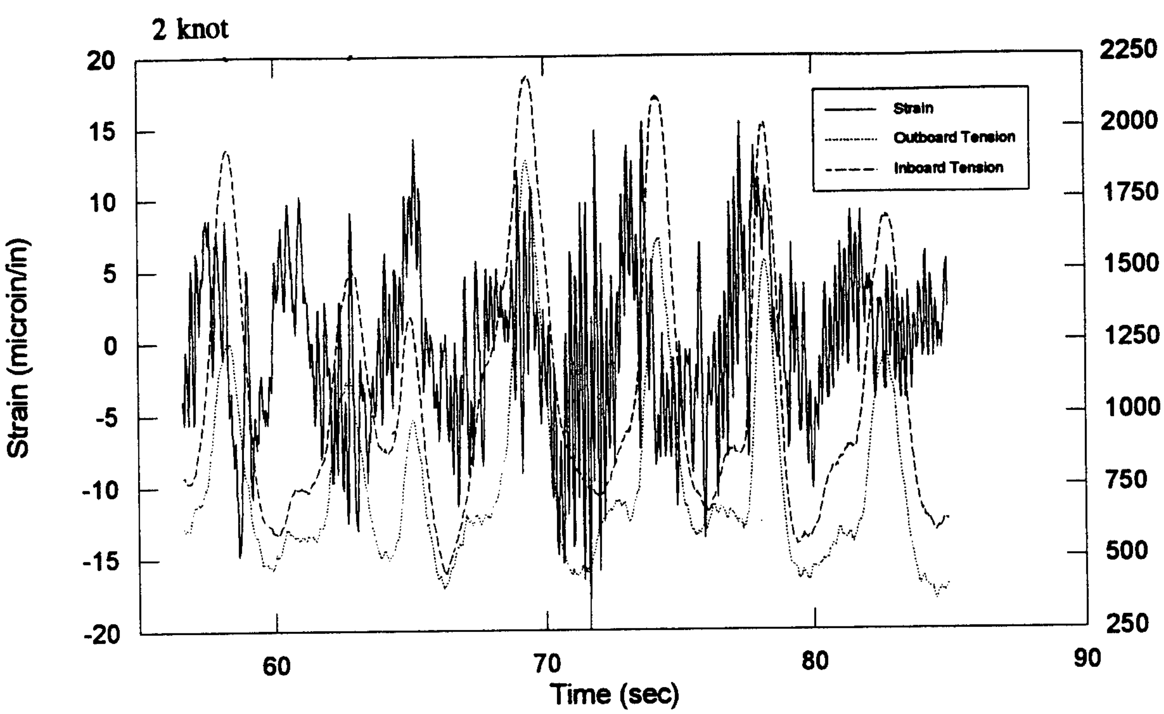


Fig. 84. Tensions and strain due to longitudinal bending of the NOFI V Sweep outriggers at 1 and 2 knots in 2 - 4 foot head seas. (Run 28& 29, 5/6/93)

which does seem to be of a similar magnitude for the strain and tension data but only the strain data experience the high frequency oscillations which are of a significant amplitude compared to its mean value.

7.0 HANDLING

Deployment and retrieval of both systems were performed by U.S. Coast Guard (USCG) personnel. The Coast Guard was familiar with the CG VOSS boom and had worked with this system in the field. They had to be trained on site for deploying the NOFI V Sweep boom. The training was done by NOFI representatives. Taking this into account, the NOFI V Sweep appears to be an easier boom to deploy and retrieve, especially in higher sea states.

The FIOCS deployment is very similar to the NOFI V Sweep deployment but with an additional vessel. The unknown variable with the FIOCS is the ability of the two vessels to properly communicate and be able to maneuver accordingly at slow speeds at all times. This is a very significant point because slow speeds can be very difficult for many types of vessels.

Observations relative to the handling of these systems are stated below.

7.1 CG VOSS SYSTEM

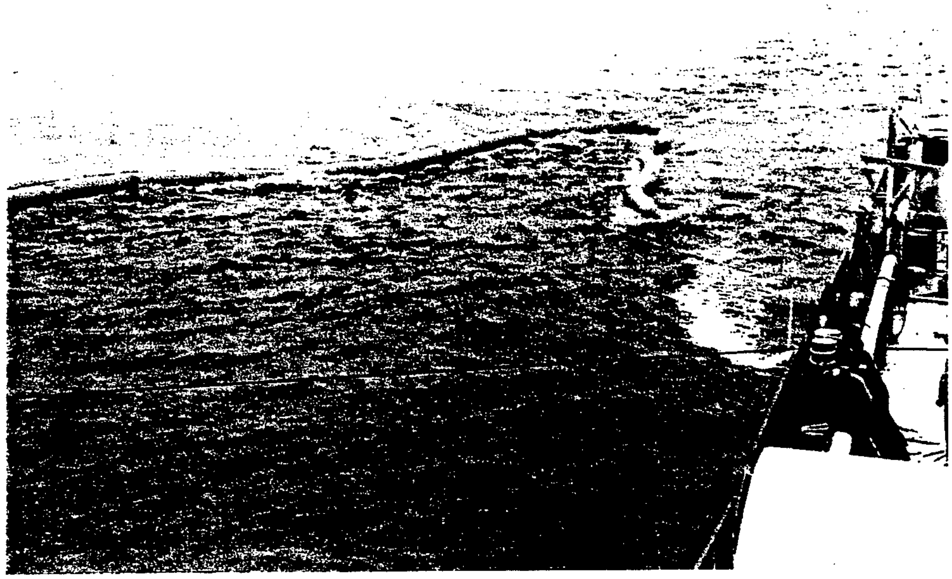
1. The CG VOSS system has more parts to assemble and more lines to work with.
2. The CG VOSS requires the use of different bridle sizes depending on freeboard height of ship. This could become awkward at times.
3. The CG VOSS boom is not as strong structurally as the NOFI boom. The VOSS boom is designed for 1 knot, 4 ft seas while the NOFI boom is designed for 2+ knots, 4 ft seas.
4. The CG VOSS is deployed off the side of the vessel and exposes personnel to some dangerous motions of the ship in rough seas.
5. The CG VOSS boom has low reserve buoyancy and thus limited to use in 1–4 ft seas.
6. The CG VOSS boom adjusts easily to different outrigger lengths while the NOFI boom width is fixed due to the bottom net shape and requires the outrigger to be the width of the boom mouth.

7.2 NOFI V SWEEP SYSTEM

1. The NOFI V Sweep is easy to rig with only an inboard and outboard tending line.
2. The NOFI V sweep hardware is designed for high loads and can handle 6–foot seas due to its high reserve buoyancy.
3. The NOFI V Sweep is deployed from the back of the ship which is believed to be a safer deployment method than from the side of the ship.
4. The NOFI V Sweep requires a second vessel for easier deployment.
5. Placement of the skimmer in the NOFI V Sweep configuration requires a lifting davit boom with a longer reach due to the buoyancy bladder of the NOFI V Sweep.
6. The NOFI V Sweep tended to pull away from the starboard side of the TROJAN during turns and port seas as shown in Figure 85. Another method of restraint may be necessary to maintain the proper orientation relative to the vessel. This needs to be considered carefully to avoid constraining the system in ways that would reduce its effectiveness and compliance.

7.3 FIOCS SYSTEM

1. The FIOCS extended length created tracking problems. This may be due primarily to limited training and experience working with this system.
2. The FIOCS bridle system placed high tension lines across deck of the TROJAN. This safety hazard could be alleviated by repositioning the tensioning winch.
3. The FIOCS Sweep requires another winch to be mounted on the ship for tending the cross bridle.
4. Placement of skimmer in the FIOCS configuration requires a lifting davit boom with a longer reach due to the buoyancy bladder of the boom or placement of the davit forward of the V Sweep boom mouth.



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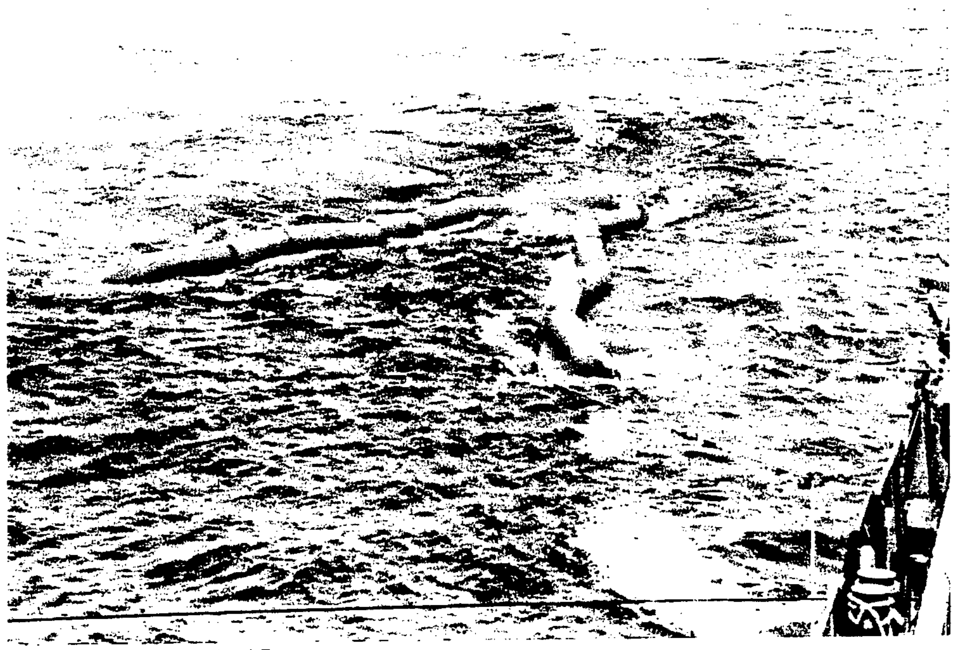

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Fig. 85. Photographs of NOFI V Sweep moving away from the starboard side of the vessel in a turn.

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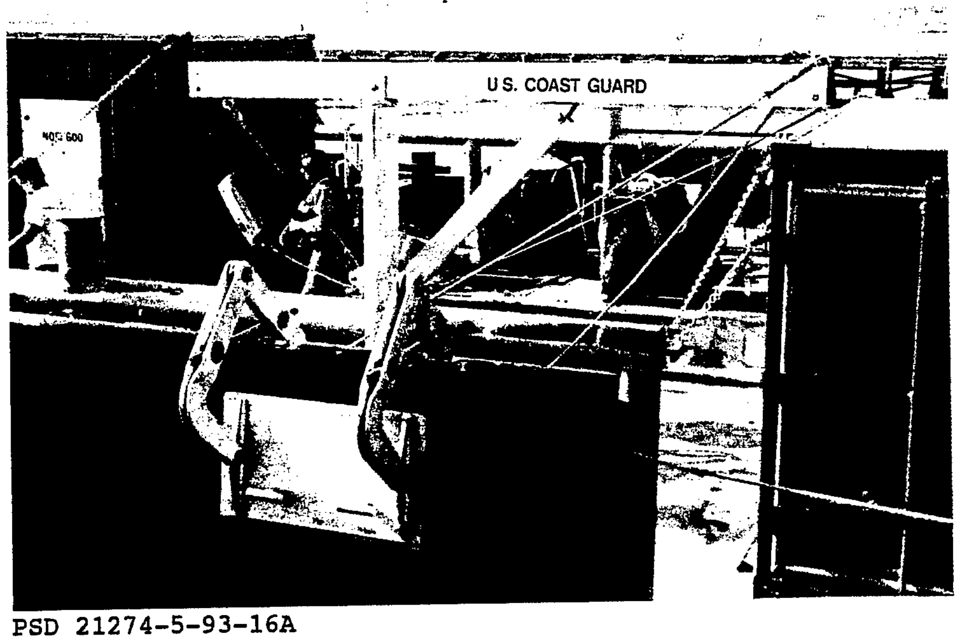

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Fig. 86. Photographs of lifting davit and davit base being welded to the deck.

8.0 CONCLUSIONS

8.1 CG VOSS SYSTEM

Deployment procedures for the CG VOSS are well defined and the system is relatively simple to deploy. However, there is a safety concern with deploying from the side of the ship causing the crew to be exposed to any rough sea. The CG VOSS operates well in low sea states and low speeds. However, the system begins to behave erratically in a sea state 2 when operating at speeds higher than 1.8 knots. This makes it a very inefficient recovery system in rough sea conditions. There was evidence of a dominant period of oscillation between five and six seconds. This corresponds to the period of maximum energy for the seas encountered which indicates the system is directly responsive to excitations due to wave motions. The CG VOSS configuration shape is determined by the outrigger and glide line bridles. These lines are fixed to the outrigger and the support vessel providing a rigid foundation. This rigidity and low reserve buoyancy apparently hinders the CG VOSS system from conforming to the wave action so the tensions in the system are characteristic of a stiff, lightly damped system with large maximum to minimum tension ratios. In addition, this rigidity has an effect on the system stability. Since the boom is constrained from moving aft by the upper and lower bridles, it rotates on the rear support line to absorb sudden wave loading and flips out onto the water surface at speeds above 2 knots.

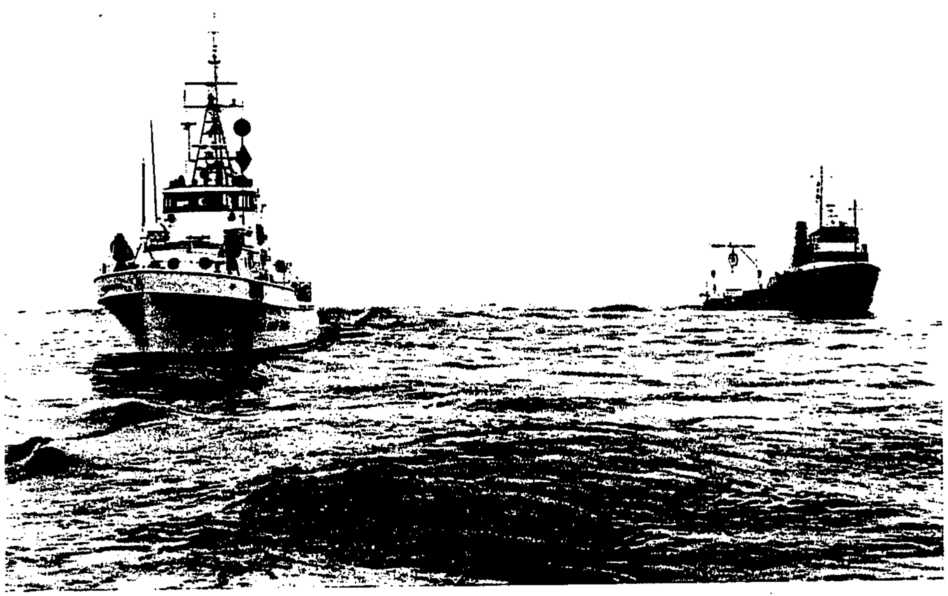
8.2 NOFI V SYSTEM

Deployment for the NOFI V Sweep system is safe and was uncomplicated. However, it did require a second vessel when used with the extended outrigger. The NOFI V Sweep system appeared to operate well in all conditions. The system maintains its shape and stability by virtue of its skirt netting and surface flotation. This decouples the boom from the ship motions and allows it to be more compliant with the sea. The NOFI appears to be large enough and compliant enough along its length, due to its individually filled float chambers, that it conforms to the vertical wave motion adequately with some significant vertical skirt motion in higher sea states but no broaching or violent motion. There was also evidence of a dominant period of oscillation between five and six seconds, this being the period of maximum energy for the seas encountered and indicating that this system is responsive to excitations due to wave motions. Higher frequency oscillations in skirt depth were also noticed but they did not appear in the tension data.

8.3 FIOCS SYSTEM

The FIOCS system deployment is very similar to the NOFI V Sweep and is relatively safe and uncomplicated except as stated in the previous discussions. Performance of the FIOCS section was similar to that of the NOFI V Sweep configuration, very compliant to the sea and stable in most conditions. The difficulty in operation is from the dependence of the system shape and line tensions on the location of the mothership and second vessel relative to one another. The shape of the boom is critical to its effectiveness, as well as to the magnitude of the loads experienced. A belly can develop in the outboard portion of the boom between the outermost bridle attachment point and the second vessel if the two vessels are not oriented correctly and are not making the same speed. This would cause oil entrainment prematurely. Radar and voice communications appeared to be a reasonable way for a vessel of opportunity to keep track of the relative positions of the ships without having to develop a more elaborate method. Figure 87 shows a photograph of the radar display of the TROJAN during the FIOCS tow. The gain had to be turned up significantly to catch the boom shape in its current configuration. However, some economical radar reflectors may be added to the boom every 20 ft or so to allow the ship operators to turn down the gain and get better definition of the image.

PSD 21282-5-93-1



PSD 21279-5-93-32A

Fig. 87. Photographs of the TROJAN's radar display during FIOCS tow and FIOCS tow underway.

9.0 ACKNOWLEDGEMENTS

All participating personnel from the organizations listed in Table 1 are to be commended for their support of this trial and for their assistance to the Trial Director. In particular, the authors would like to express their appreciation and gratitude to:

1. The Coast Guard Strike Force team members for their participation and invaluable experience,
2. Captain Allan Strunk and the crew of the ENSCO TROJAN,
3. The Captain and crew of the Coast Guard Cutter POINT WELLS and
4. Mr. Sandy Traggis and Mr. Dan Dinsmore of NUWC/NL for arranging for the use of the TROJAN, making the NUWC/NL facilities available to us and for their engineering support.

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APPENDIX A

RUN LOG OF REFERENCED SEA TRIAL RUNS

Data log for the VOSS sea trial.
May 1 - 15, 1993
Includes All Referenced Runs

Run No.	Date	Config 1 VOSS 2 NOFI 3 FIOCS	Speed (kt)	Comments
22	5/5	1,2	1	Calm water deployment in river.
23	5/5	1,2	2	Calm water deployment in river.
25	5/6	1,2	1	Moved knotmeter during run; repeat run; 1-2 ft swell; heading not significant, but following seas.
26		1,2	1	
27		1,2	2	VOSS boom is bouncing out of water, data OK.
28		1,2	1	Swell building to 2-4 ft; TROJAN turns 180 deg to head into swell
29		1,2	2	
30		1,2	2	TROJAN turns 45 deg to port; swell at 3-5 ft
31		1,2	1	
32		1,2		Wave buoy data
33		1,2	1	TROJAN turns 45 deg to stbd
34		1,2	2	VOSS boom comes out of water; run is shortened
35		2	3	TROJAN at 0 deg heading to waves; 3-5' swell
36		2	3	TROJAN turns 45 deg to port
38	5/7	2	3	1-2 ft swell
39				Wave buoy data
40				Wave buoy data
41		1,2	1	Head seas, T4 and T5 are questionable for rest of day. T5 on skimmer.
42		1,2	2	VOSS come out of water?? Check video!
43		1,2	1	TROJAN does 180 deg.; following seas
44		1,2	2	

Run No.	Date	Config 1 VOSS 2 NOFI 3 FIOCS	Speed (kt)	Comments
45	5/10		0	Zero speed run but some inst. were not on; repeat run
46			0	Zero speed run; T3 is bad; replace with 20K
47	5/11	1,2	0	Zero speed run
48				Wave buoy data
49				Wave buoy data; 3-5 ft swell
50		1,2	1	Head seas; VOSS boom ineffective; End run early to retrieve boom!!! P4,P5,P6 (depth) not hooked up due to high seas. T3 not working!
51		2	1	
52		2	2	
53		2	3	
56	5/12		0	Instumentation checkout for FIOCS
57			0	Instumentation checkout for FIOCS
58			0	Instumentation checkout for FIOCS
59	5/13	3		Calibration check, C1, C2, ZC
60		3	0	Zero speed run
61		3		Swells at 5-7 ft; Deployment being done; Head seas
62		3		Deployment being done
63		3		Deployment being done
64		3	2	Cals performed during run but data is still good; repeat run just in case
65		3	2	Comment 2 is incorrect, cals were not done.
66		3	3	
67		3	3	
68		3	3	

Run No.	Date	Config 1 VOSS 2 NOFI 3 FIOCS	Speed (kt)	Comments
69		3		Turn data
70		3		Turn data
71		3	3	Following seas
72		3	3	
73		3	2	This run was performed as a speed check; data taken again on next run
74		3	2	Comment 2 is wrong, this was not a speed check
75		3	2	
76		3	1.5	
77		3	1.5	

APPENDIX B

SPREADSHEET OF CG VOSS/NOFI V DATA

(SPREADSHEET SHOWS DATA AVERAGES, MAXIMA, MINIMA, AND STANDARD DEVIATIONS FOR REFERENCED RUNS)

VOSS/NOFI Sea Trial, May 1 - 15, 1993; Referenced Run Data

RUN NO	SEA STE	HDG DEG	SPEED (KTS)	SPEED (KTS)			TENSION, T1 (LBS)				TENSION, T2 (LBS)			
			MEAN	MAX	MIN	S.D.	MEAN	MAX	MIN	S.D.	MEAN	MAX	MIN	S.D.
22	0	0	1.13	1.67	0.71	0.12	770	979	554	51	412	529	269	26.4
23	0	0	2.13	2.35	1.84	0.07	2206	2727	1711	136	1139	1412	870	80
25	1	180	1.26	2.81	0.62	0.25	724	2024	75	423	293	856	1	178
26	1	180	1.24	1.86	0.79	0.17	867	2151	80	448	353	880	1	189
27	1	180	2.08	2.85	1.34	0.21	1941	2888	744	418	784	1242	260	180
28	1	0	0.94	1.20	0.64	0.09	239	597	65	113	100	275	-13	50
29	1	0	2.12	2.66	1.88	0.14	1399	2448	646	300	582	1066	221	139
30	2	45S	2.19	2.60	1.78	0.14	1191	2204	431	295	501	1017	123	151
31	2	45S	0.96	1.37	0.62	0.10	207	573	46	96	73	280	-13	43
32	2	45S	0.86	1.53	0.38	0.15	802	2470	60	468	325	1100	-8	203
33	2	45P	0.93	1.57	0.36	0.15	920	2654	BAD	624	340	1217	BAD	343
34	2	45P	2.27	2.97	1.67	0.22	1760	4850	378	773	725	2140	69	353
35	2	0	2.91	3.88	2.17	0.25	ND	ND	ND	ND	ND	ND	ND	ND
36	2	45S	3.01	4.02	2.19	0.30	ND	ND	ND	ND	ND	ND	ND	ND
38		0	2.80	3.72	2.13	0.23	ND	ND	ND	ND	ND	ND	ND	ND
39	0.0	N/A	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB
40	0.0	N/A	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB
41	1	0	1.16	1.51	0.67	0.09	651	1472	119	289	326	756	36	146
42	1	0	2.08	2.56	1.63	0.13	1721	3078	666	414	786	1466	255	207
43	1	180	1.14	1.74	0.77	0.11	765	2326	70	424	359	1060	11	203
44	1	180	1.89	2.95	1.28	0.21	1770	3640	353	578	809	1730	153	280
48	2	0	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB
49	2	0	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB
50	2	0	1.48	2.62	0.69	0.32	886	3340	31	477	-18	748	-716	467
51	2	0	1.10	1.68	0.52	0.16	ND	ND	ND	ND	ND	ND	ND	ND
52	2	0	2.05	3.06	1.18	0.27	ND	ND	ND	ND	ND	ND	ND	ND
53	2	0	2.72	4.54	1.78	0.35	ND	ND	ND	ND	ND	ND	ND	ND

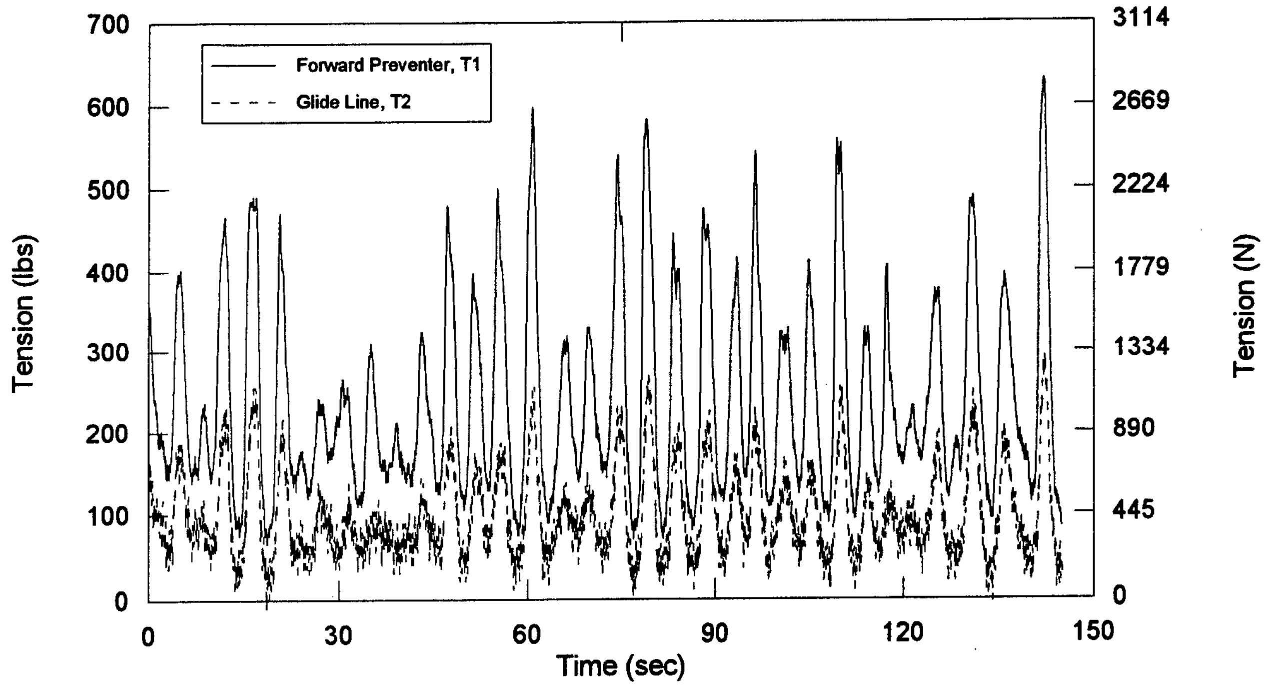
RUN NO	TENSION, T3 (LBS)				TENSION, T4 (LBS)				TENSION, T5 (LBS)				TENSION, T6 (LBS)				DEPTH, D1 (FT)	
	MEAN	MAX	MIN	S.D.	MEAN	MAX	MIN	S.D.	MEAN	MAX	MIN	S.D.	MEAN	MAX	MIN	S.D.	MEAN	MAX
22	301	364	238	18	348	456	260	18	65	15	35	13	ND	ND	ND	ND	1.59	1.88
23	955	1339	715	54	1136	1348	934	58	193	303	98	31	ND	ND	ND	ND	0.78	1.28
25	251	408	131	57	359	607	187	65	29	84	0	17	108	252	0	37	1.47	2.14
26	292	516	116	56	334	577	177	62	24	103	0	20	126	428	0	54	1.52	2.16
27	862	1758	287	264	860	1777	309	256	81	186	1	34	402	1053	0	171	1.18	2.23
28	282	633	121	76	267	485	124	71	2	54	0	20	-3	174	0	40	1.78	2.28
29	754	2051	301	250	963	2494	373	316	49	167	0	32	279	1131	0	184	1.55	2.54
30	734	1666	262	265	868	2265	251	328	62	152	0	29	295	1287	0	213	1.64	2.73
31	475	1193	160	186	424	1129	90	174	14	108	0	20	BAD	BAD	BAD	BAD	1.77	2.42
32	280	876	111	81	200	658	70	75	ND	ND	ND	ND	BAD	BAD	BAD	BAD	1.46	2.16
33	256	1178	BAD	216	141	1060	BAD	203	ND	ND	ND	ND	BAD	BAD	BAD	BAD	1.43	3.30
34	1110	2340	511	342	956	2300	441	340	42	303	0	43	407	1420	0	269	1.14	5.20
35	1282	2786	564	434	1404	3104	621	449	ND	ND	ND	ND	564	1639	0	317	ND	ND
36	1705	4131	759	496	1574	3997	665	497	ND	ND	ND	ND	789	2322	0	375	ND	ND
38	1570	2494	998	207	BAD	BAD	BAD	BAD	ND	ND	ND	ND	BAD	BAD	BAD	BAD	ND	ND
39	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	BAD	BAD	BAD	BAD	WB	WB
40	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	BAD	BAD	BAD	BAD	WB	WB
41	305	579	160	69	ND	ND	ND	ND	ND	ND	ND	ND	BAD	BAD	BAD	BAD	2.02	2.54
42	866	1680	399	241	ND	ND	ND	ND	ND	ND	ND	ND	BAD	BAD	BAD	BAD	2.26	3.37
43	360	574	209	57	ND	ND	ND	ND	ND	ND	ND	ND	BAD	BAD	BAD	BAD	2.04	2.59
44	811	1212	462	124	ND	ND	ND	ND	ND	ND	ND	ND	BAD	BAD	BAD	BAD	2.00	2.80
48	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB
49	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB
50	495	1540	183	154	382	1460	65	171	ND	ND	ND	ND	BAD	BAD	BAD	BAD	1.20	3.18
51	BAD	BAD	BAD	BAD	255	1403	2	138	ND	ND	ND	ND	BAD	BAD	BAD	BAD	ND	ND
52	BAD	BAD	BAD	BAD	895	3340	280	363	ND	ND	ND	ND	BAD	BAD	BAD	BAD	ND	ND
53	BAD	BAD	BAD	BAD	1403	4450	470	496	ND	ND	ND	ND	BAD	BAD	BAD	BAD	ND	ND

RUN NO	SEA STE	HDG DEG	SPEED (KTS)			DEPTH, D2 (FT)				DEPTH, D3 (FT)				DEPTH, D4 (FT)				DEPTH, D5 (FT)				DEPTH, D6 (FT)				STRAIN, S1 (UIN/IN)				STRAIN, S2 (UIN/IN)		
			MEAN	MIN	S.D.	MEAN	MAX	MIN	S.D.	MEAN	MAX	MIN	S.D.	MEAN	MAX	MIN	S.D.	MEAN	MAX	MIN	S.D.	MEAN	MAX	MIN	S.D.	MEAN	MAX	MIN	S.D.	MEAN	MAX	MIN
22	0	0	1.13	1.28	0.07	1.56	1.85	1.33	0.07	1.33	1.67	1.06	0.09	2.41	2.75	2.06	0.12	2.67	3.15	2.23	0.21	2.81	3.10	2.62	0.05	92.7	120.0	67.3	6.2	1.3	7.2	-5.1
23	0	0	2.13	0.21	0.14	1.11	1.90	0.36	0.24	1.52	2.56	0.55	0.44	2.52	2.64	2.18	0.12	2.91	3.46	2.30	0.19	2.69	2.96	2.41	0.05	90.3	120.4	43.9	11.1	-7.1	14.8	-23.4
25	1	180	1.26	-0.02	0.34	1.03	1.71	-0.38	0.36	1.15	1.76	0.09	0.33	2.74	3.17	2.06	0.15	2.87	3.37	2.27	0.17	2.71	2.98	2.44	0.08	83.1	116.4	43.4	10.3	-5.6	7.4	-23.4
26	1	180	1.24	-0.02	0.29	1.02	1.73	-0.26	0.34	1.09	1.88	-0.17	0.33	2.70	3.17	2.13	0.14	2.94	3.49	2.23	0.17	2.88	3.24	2.48	0.06	81.6	116.9	41.6	11.0	-6.3	8.6	-25.7
27	1	180	2.08	0.06	0.39	0.63	1.69	-0.78	0.43	0.69	1.59	-0.46	0.40	2.58	3.12	2.06	0.15	3.15	4.06	2.46	0.22	2.93	3.22	2.65	0.08	68.4	110.1	29.7	11.6	-16.3	-1.7	-34.8
28	1	0	0.94	1.45	0.12	1.23	1.90	0.69	0.19	1.26	1.76	0.82	0.14	2.73	3.27	2.18	0.19	2.39	3.18	1.32	0.29	2.81	3.19	2.34	0.12	90.1	100.4	78.1	3.5	7.6	14.3	-1.1
29	1	0	2.12	0.52	0.35	0.78	1.90	-0.40	0.35	0.71	1.57	-0.32	0.30	2.33	3.01	1.28	0.24	3.12	4.27	1.92	0.31	2.36	2.93	1.63	0.17	77.2	103.2	42.8	8.3	-5.3	6.8	-25.1
30	2	45S	2.19	0.64	0.35	0.83	2.02	-0.40	0.37	0.73	1.69	-0.39	0.30	2.36	3.10	1.42	0.25	3.06	4.22	1.75	0.32	2.11	2.77	1.07	0.22	78.8	105.5	49.1	8.3	-5.1	6.0	-24.5
31	2	45S	0.96	1.19	0.16	1.21	1.85	0.67	0.17	1.22	1.76	0.72	0.14	2.65	3.55	1.75	0.24	2.43	3.56	0.92	0.38	2.61	3.28	1.75	0.21	89.6	111.8	65.6	5.9	4.9	12.5	-8.6
32	2	45S	0.86	-11.90	0.39	1.07	2.06	-0.36	0.38	1.23	2.25	-0.07	0.34	2.70	3.57	1.47	0.24	2.87	3.99	1.18	0.36	2.85	3.36	2.11	0.17	85.0	119.0	41.1	11.1	72.0	26.2	-20.0
33	2	45P	0.93	-0.12	0.42	1.05	2.30	-0.40	0.40	1.18	2.03	-0.22	0.36	2.60	3.29	1.44	0.24	2.84	4.15	1.16	0.36	2.84	3.36	1.96	0.18	83.1	126.1	40.5	12.1	-2.7	36.5	-56.5
34	2	45P	2.27	0.00	0.60	0.60	2.25	0.00	0.55	0.72	2.27	0.00	0.48	2.36	3.08	1.11	0.26	3.17	4.34	1.49	0.36	2.64	3.22	1.51	0.27	74.9	152.0	22.2	17.2	-12.8	143.0	-202.0
35	2	0	2.81	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.18	3.08	0.54	0.30	3.29	4.82	1.87	0.45	1.63	2.48	0.06	0.31	ND	ND	ND	ND	ND	ND	ND
36	2	45S	3.01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-2.60	9.82	-48.47	4.12	3.27	5.91	1.23	0.51	1.92	2.93	0.52	0.36	ND	ND	ND	ND	ND	ND	ND
38		0	2.80	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.75	3.17	2.30	0.14	3.52	4.51	2.92	0.20	2.78	3.12	2.41	0.10	ND	ND	ND	ND	ND	ND	ND
39	0.0	N/A	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB
40	0.0	N/A	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB
41	1	0	1.16	1.62	0.11	1.42	1.99	0.88	0.17	1.48	2.20	0.80	0.24	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	91.1	107.8	71.3	4.9	8.9	14.8	1.1
42	1	0	2.08	0.76	0.44	1.61	2.99	0.12	0.54	1.24	2.37	-0.46	0.56	2.73	3.31	2.15	0.18	3.31	3.94	2.37	0.19	2.90	3.31	2.44	0.12	79.1	102.1	50.2	7.8	3.0	57.6	-59.9
43	1	180	1.14	1.57	0.14	1.49	2.04	0.67	0.20	1.50	2.15	0.65	0.25	3.02	3.38	2.63	0.12	3.15	3.70	2.68	0.18	3.22	3.52	2.86	0.06	87.2	110.1	62.7	7.6	-1.3	44.5	-45.6
44	1	180	1.89	1.12	0.27	1.30	2.42	0.14	0.41	1.21	2.22	0.02	0.40	2.80	3.17	2.41	0.13	3.22	3.77	2.73	0.16	2.99	3.26	2.70	0.06	77.4	106.5	38.2	9.5	-9.4	20.0	-81.6
48	2	0	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB
49	2	0	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB
50	2	0	1.48	-0.62	0.44	1.77	3.42	0.00	0.41	1.25	2.71	-0.44	-0.45	0.08	0.21	-0.02	0.03	0.00	0.09	-0.10	0.03	0.19	0.29	0.10	0.29	86.5	145.0	240.0	16.0	3.5	197.0	-84.4
51	2	0	1.10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
52	2	0	2.05	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
53	2	0	2.72	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

RUN NO	SEA STE	HDG DEG	SPEED (KTS)		STRAIN, S5 (UIN/IN)				STRAIN, S6 (UIN/IN)				ROLL DEG				PITCH DEG				VERT G				LAT G				WVHGHT M			
			MEAN	S.D.	MEAN	MAX	MIN	S.D.	MEAN	MAX	MIN	S.D.	MEAN	MAX	MIN	S.D.	MEAN	MAX	MIN	S.D.	MEAN	MAX	MIN	S.D.	MEAN	MAX	MIN	S.D.	MEAN	MAX	MIN	S.D.
22	0	0	1.13	1.6	111.0	120.0	100.0	3.0	-3.1	4.6	-1.1	1.7	1.32	1.43	1.14	0.05	-0.8	-0.66	-1	0.93	1.11	1.12	0.95	0.01	-0.12	0.003	-0.13	0.008	ND	ND	ND	ND
23	0	0	2.13	4.6	99.1	125.5	76.4	5.7	-2.5	12.0	-17.1	3.5	1.31	1.43	1.14	0.04	-0.64	-0.61	-1.05	0.10	1.11	1.12	0.78	0.01	-0.12	0.11	-0.13	0.01	ND	ND	ND	ND
25	1	180	1.26	5.2	312.7	322.9	297.8	2.2	10.5	26.0	-9.7	3.6	1.33	5.62	-2.75	1.63	-0.12	0.73	-1.31	0.22	0.01	0.42	-0.39	0.12	-0.04	0.30	-0.33	0.04	ND	ND	ND	ND
26	1	180	1.24	5.0	312.4	324.6	275.5	2.3	9.8	35.4	-2.9	3.3	1.33	6.11	-3.84	1.84	-0.13	0.54	-0.92	0.22	0.02	0.40	-0.41	0.12	-0.05	0.12	-0.29	0.03	ND	ND	ND	ND
27	1	180	2.08	4.4	312.1	363.9	244.7	3.5	15.4	35.4	-5.1	5.0	1.37	3.74	-1.13	0.60	-0.13	0.30	-0.77	0.17	0.02	0.45	-0.48	0.15	-0.06	0.11	-0.24	0.04	ND	ND	ND	ND
28	1	0	0.94	2.0	115.3	128.9	101.5	4.2	2.6	14.8	-6.3	2.8	1.50	3.10	0.00	0.57	-0.15	0.98	-1.55	0.37	0.02	0.49	-0.24	0.04	-0.03	0.16	-0.23	0.02	ND	ND	ND	ND
29	1	0	2.12	3.6	107.4	131.8	83.3	5.7	-0.9	19.4	-22.2	5.0	1.56	4.19	-1.23	0.75	-0.14	0.78	-0.92	0.29	0.02	0.39	-0.30	0.10	-0.05	0.12	-0.29	0.04	ND	ND	ND	ND
30	2	45S	2.19	4.0	109.5	130.1	81.6	6.6	1.1	27.4	-30.8	6.1	1.58	6.65	-3.98	1.59	-0.16	1.22	-1.60	0.39	0.02	0.35	-0.32	0.10	-0.05	0.15	-0.29	0.04	ND	ND	ND	ND
31	2	45S	0.96	2.5	114.9	143.2	89.0	5.8	1.9	26.5	-22.2	4.2	1.57	7.14	-3.30	1.68	-0.15	0.93	-1.40	0.36	0.02	0.36	-0.42	0.08	-0.04	0.33	-0.39	0.03	ND	ND	ND	ND
32	2	45S	0.86	4.8	113.0	147.0	84.4	7.9	-0.9	20.5	-20.5	4.6	1.50	5.66	-3.39	1.75	-0.14	0.97	-1.50	0.32	0.02	0.53	-0.42	0.13	-0.04	0.18	-0.32	0.04	-0.678	0.3467	-1.948	0.2529
33	2	45P	0.93	5.4	111.9	144.9	78.1	7.4	1.3	26.2	-27.4	4.9	0.88	7.34	-31.45	2.95	-0.78	0.88	-33.55	1.59	0.04	1.28	-0.48	0.16	-0.05	0.24	-0.71	0.06	ND	ND	ND	ND
34	2	45P	2.27	105.0	101.0	129.0	70.7	8.7	0.1	37.6	-44.5	8.4	1.48	5.62	-2.36	1.63	-0.14	0.78	-1.11	0.32	0.02	0.60	-0.08	0.19	-0.05	1.27	-1.16	0.09	ND	ND	ND	ND
35	2	0	2.91	ND	99.6	138.6	57.0	10.3	-11.1	21.1	-89.0	10.1	1.60	4.48	-1.28	0.92	-0.14	0.98	-1.36	0.40	0.02	1.20	-1.54	0.17	-0.03	1.01	-1.15	0.09	ND	ND	ND	ND
36	2	45S	3.01	ND	91.7	126.6	30.2	12.5	-13.3	47.3	-105.0	13.7	1.52	6.70	-3.15	1.90	-0.14	0.88	-1.26	0.26	0.00	0.07	0.07	0.03	0.03	0.12	-0.06	0.03	ND	ND	ND	ND
38		0	2.80	ND	98.5	117.5	63.3	8.3	35.0	60.5	12.0	7.5	1.27	4.48	-2.36	1.28	-0.14	0.44	-0.77	0.20	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
39	0.0	N/A	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	-0.66	-0.20	-1.21	0.15
40	0.0	N/A	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	-0.65	0.24	-1.52	0.17
41	1	0	1.16	2.2	ND	ND	ND	ND	ND	ND	ND	ND	1.34	5.37	-3.15	1.63	-0.17	0.59	-1.06	0.24	0.01	0.17	-0.16	0.05	-0.03	0.08	-0.17	0.01	ND	ND	ND	ND
42	1	0	2.08	3.9	109.9	126.1	86.7	4.9	7.2	34.2	-16.0	5.2	1.37	5.22	-2.66	1.33	-0.17	0.69	-1.11	0.26	0.01	0.26	-0.21	0.07	-0.04	0.37	-0.28	0.05	ND	ND	ND	ND
43	1	180	1.14	3.7	116.3	124.9	106.7	2.5	14.1	22.8	5.7	2.5	1.24	5.81	-3.34	1.48	-0.15	0.30	-0.82	0.17	0.01	0.31	-0.38	0.08	-0.03	0.25	-0.27	0.03	ND	ND	ND	ND
44	1	180	1.89	5.1	110.7	122.1	97.5	3.2	19.8	38.2	5.7	4.6	1.31	4.58	-2.46	1.20	-0.15	0.30	-0.67	0.14	0.01	0.32	-0.28	0.08	-0.04	0.40	-0.43	0.04	ND	ND	ND	ND
48	2	0	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	-0.71	0.21	-1.49	0.30
49	2	0	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	WB	-0.65	0.33	-1.66	0.30
50	2	0	1.48	10.6	116.0	151.0	7.6	7.9	-7.0	16.5	-82.1	5.9	0.97	5.96	-3.69	1.55	-0.21	0.66	-1.55	0.30	0.016	0.8	-1.54	0.2	-0.04	0.70	-0.94	0.09	ND	ND	ND	ND
51	2	0	1.10	ND	117.0	176.0	89.6	7.7	117.0	163.0	7.9	5.9	0.86	5.57	-3.98	1.68	-0.23	0.76	-1.35	0.29	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
52	2	0	2.05	ND	118.0	169.0	47.9	10.2	116.0	156.0	5.2	8.2	0.82	4.73	-3.44	1.61	-0.24	0.34	-1.35	0.27	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
53	2	0	2.72	ND	113.0	1520.0	27.4	10.4	112.0	144.0	47.3	8.8	0.80	4.34	-3.30	1.25	-0.24	0.69	-1.01	0.27	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

APPENDIX C

ADDITIONAL TIME HISTORIES FOR REFERENCED RUNS



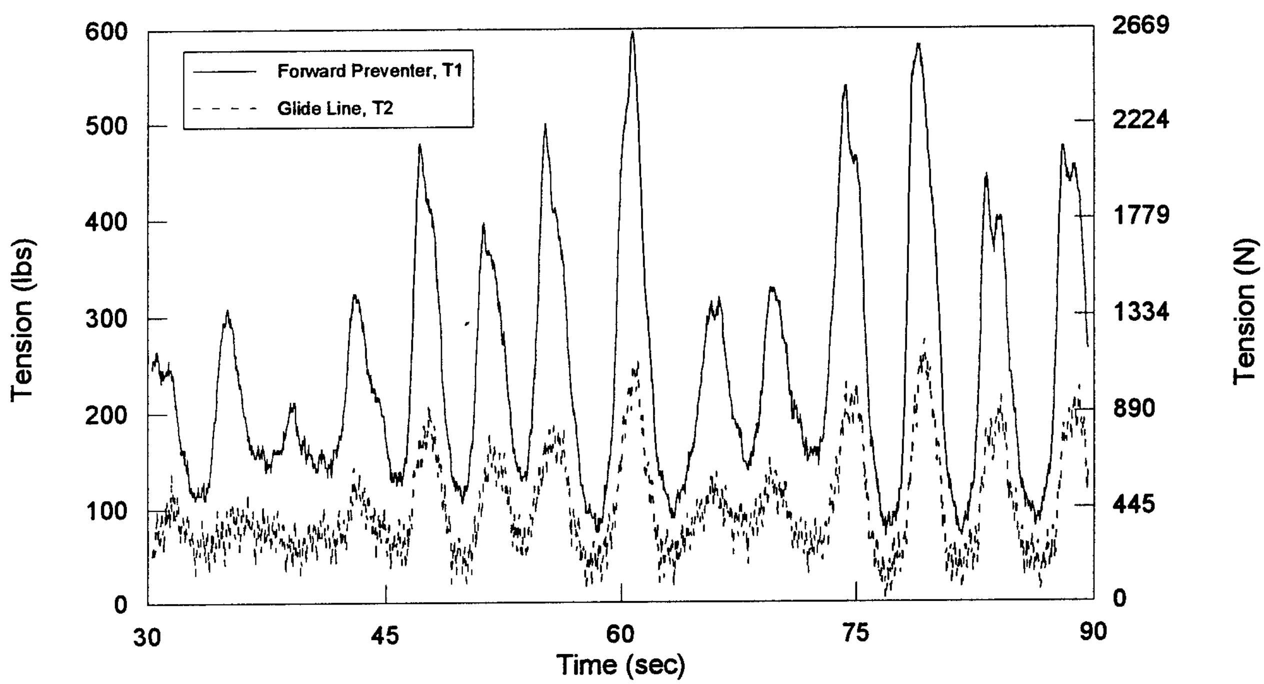
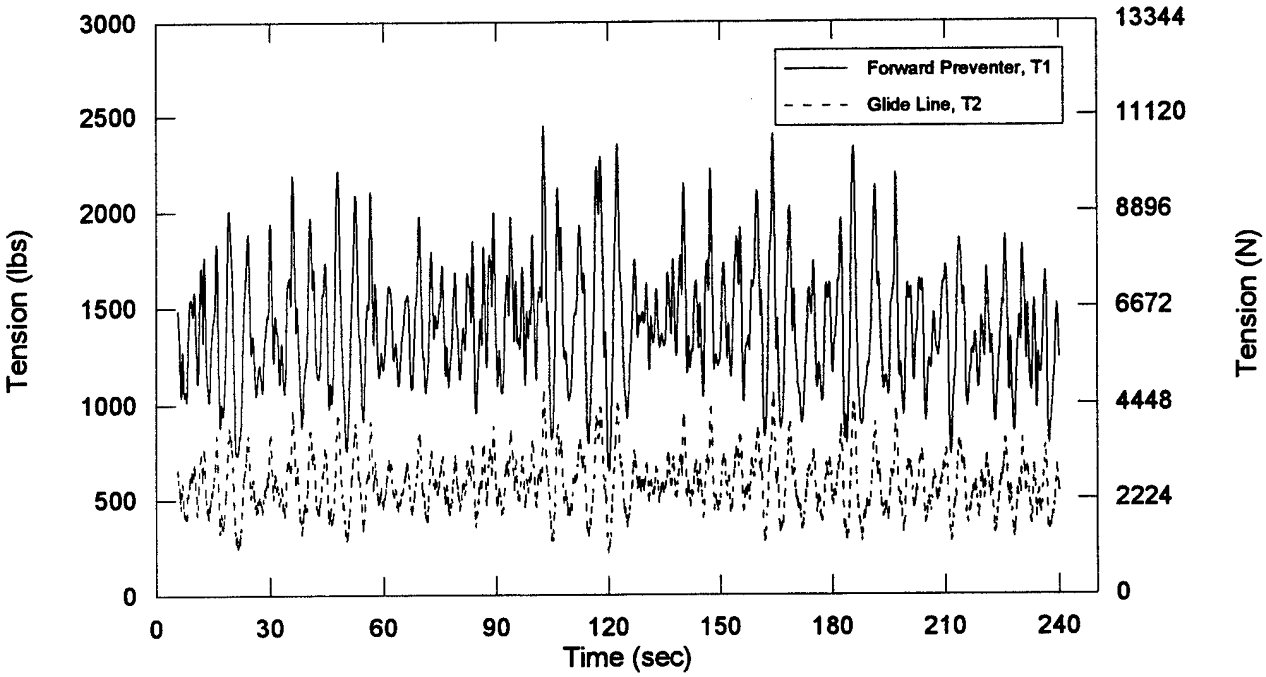


Fig. C.1. Tension in CG VOSS support lines at 1 knots in 2 - 4 foot head seas. Bottom graph is a closeup of the period from 30 to 90 seconds. (Run 28, 5/6/93).



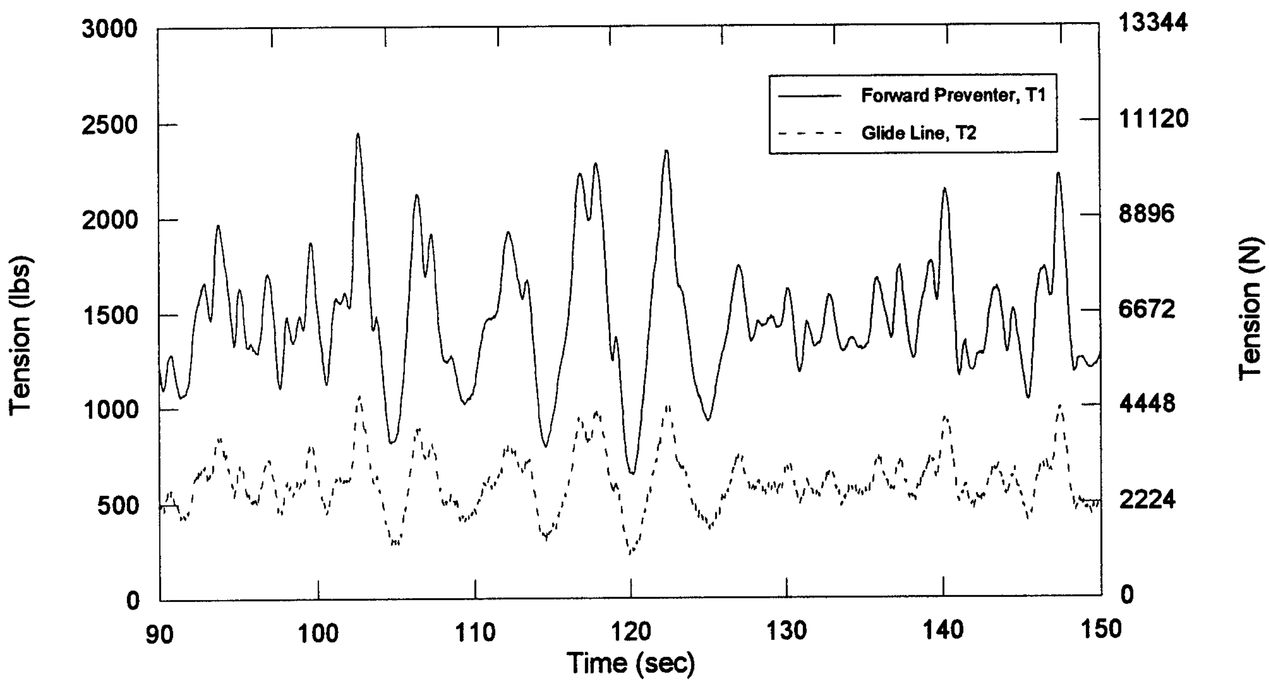
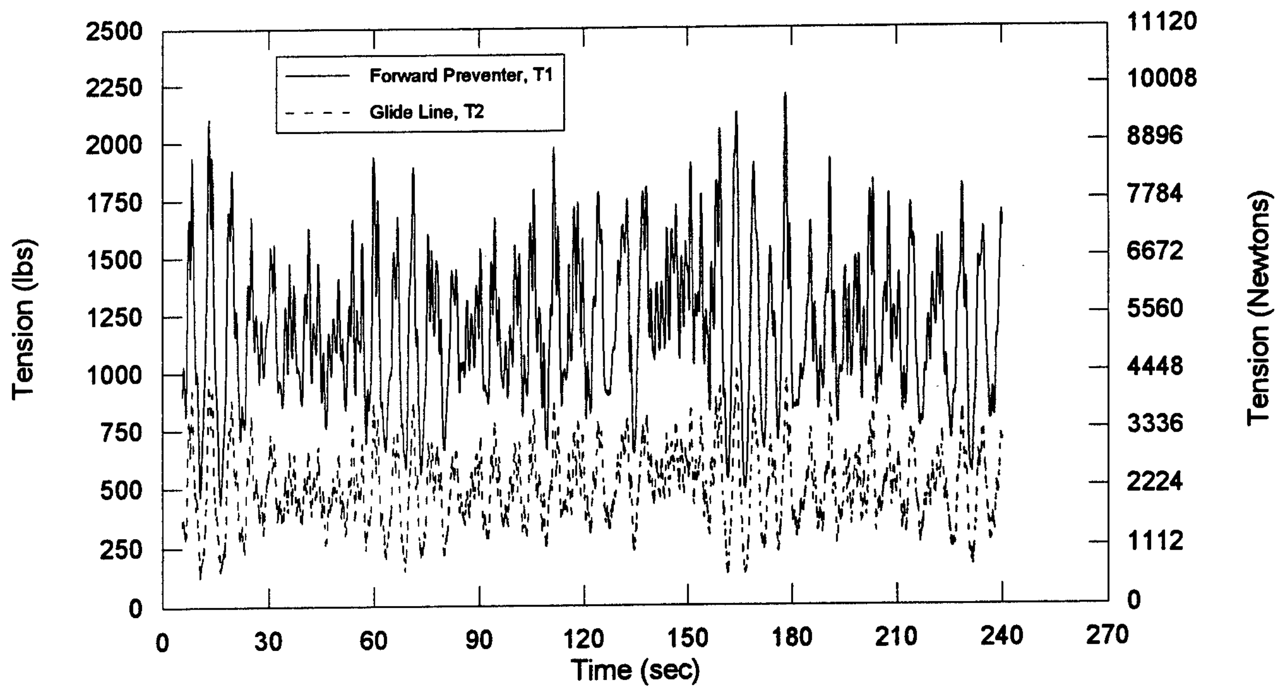


Fig. C.2. Tension in CG VOSS at 1 knot in 2 - 4 foot head seas. Bottom graph is a closeup of the period from 90 to 150 seconds. (Run 29, 5/6/93)



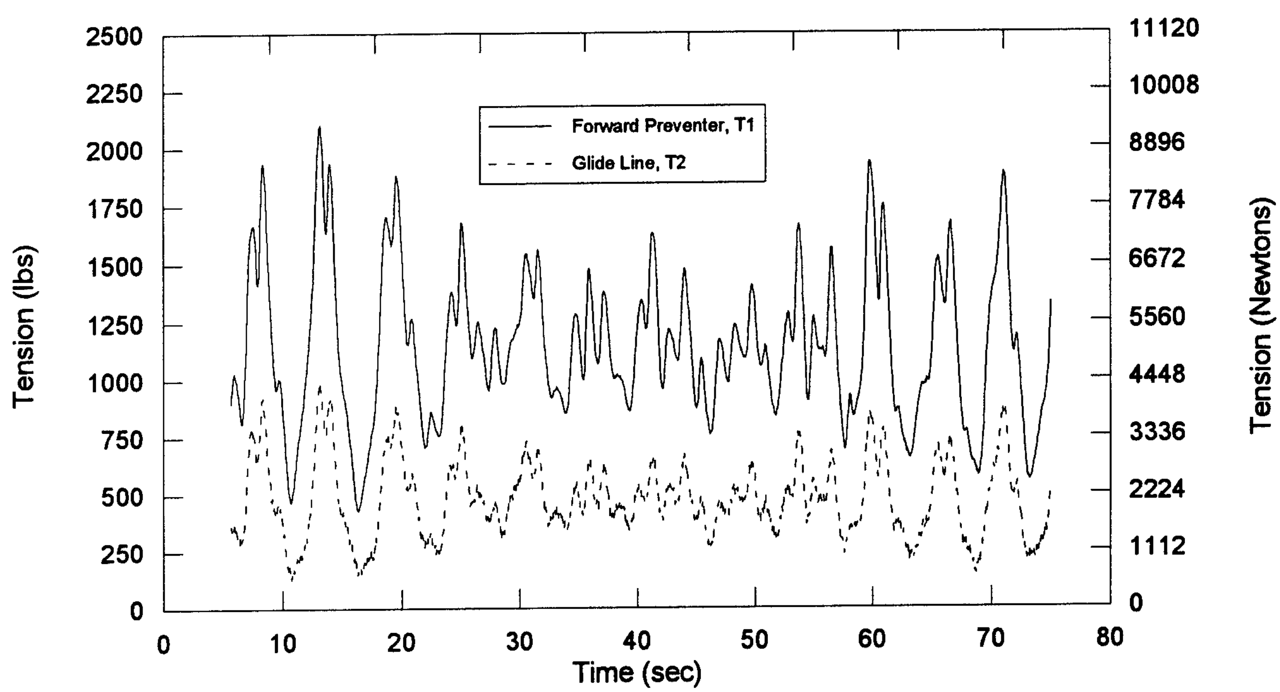


Fig. C.3. Tension in the CG VOSS support lines in 2 - 4 foot 45 degree stbd. seas. Bottom graph is a close up of the period from 10 to 70 seconds. (Run 30, 5/6/93)

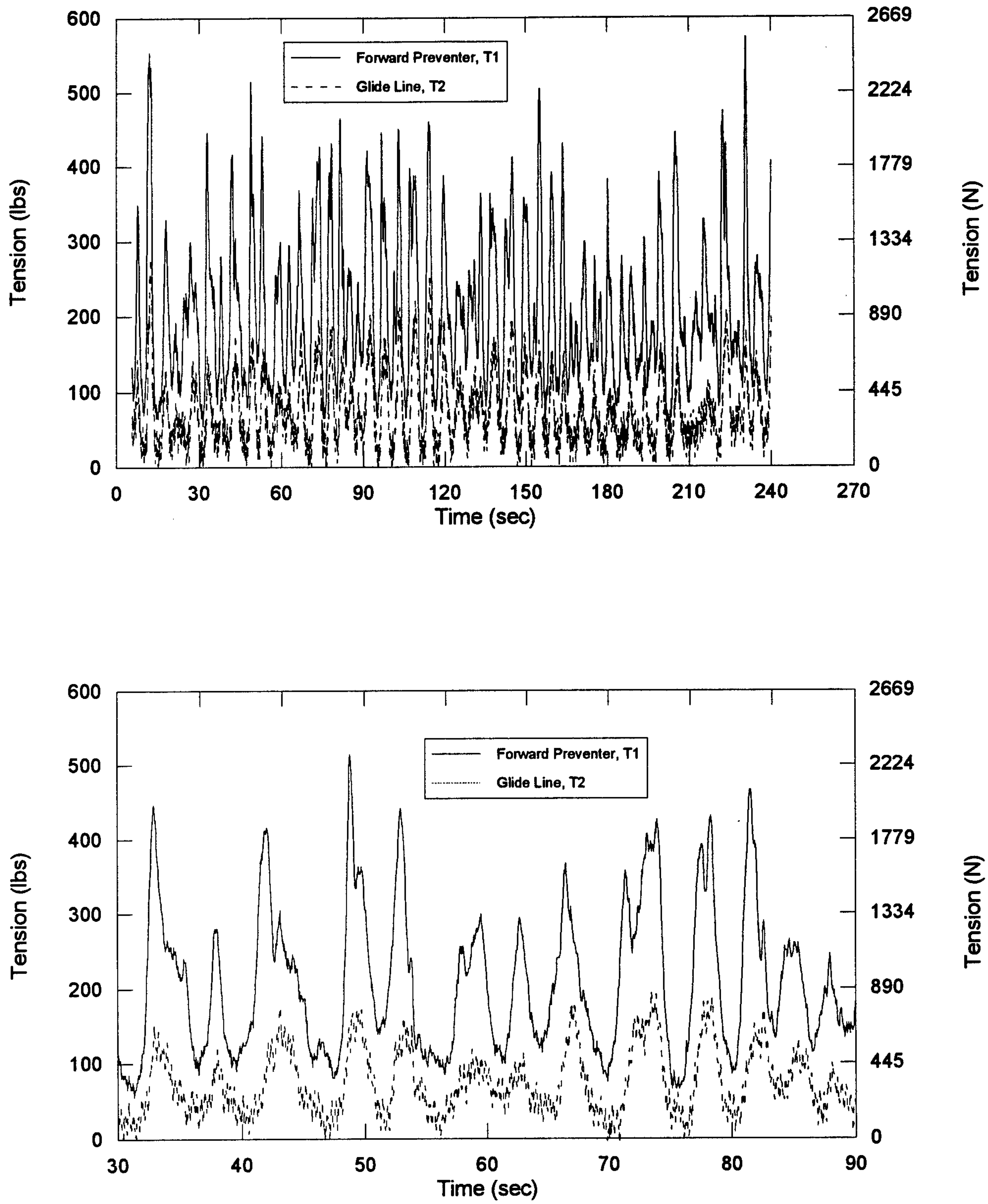
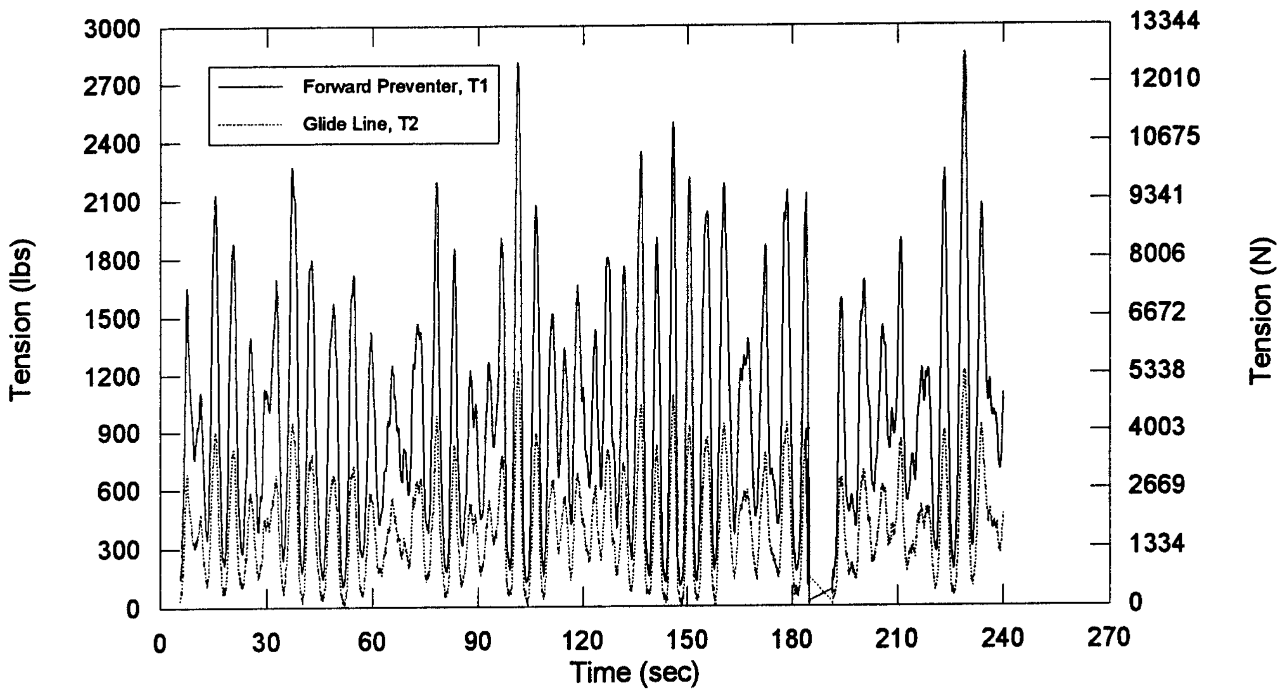


Fig. C.4. Tension in CG VOSS support lines at 1 knot in 2 - 4 foot 45 degree stbd. seas. Bottom graph is a closeup of the period from 30 to 90 seconds. (Run 31, 5/6/93)



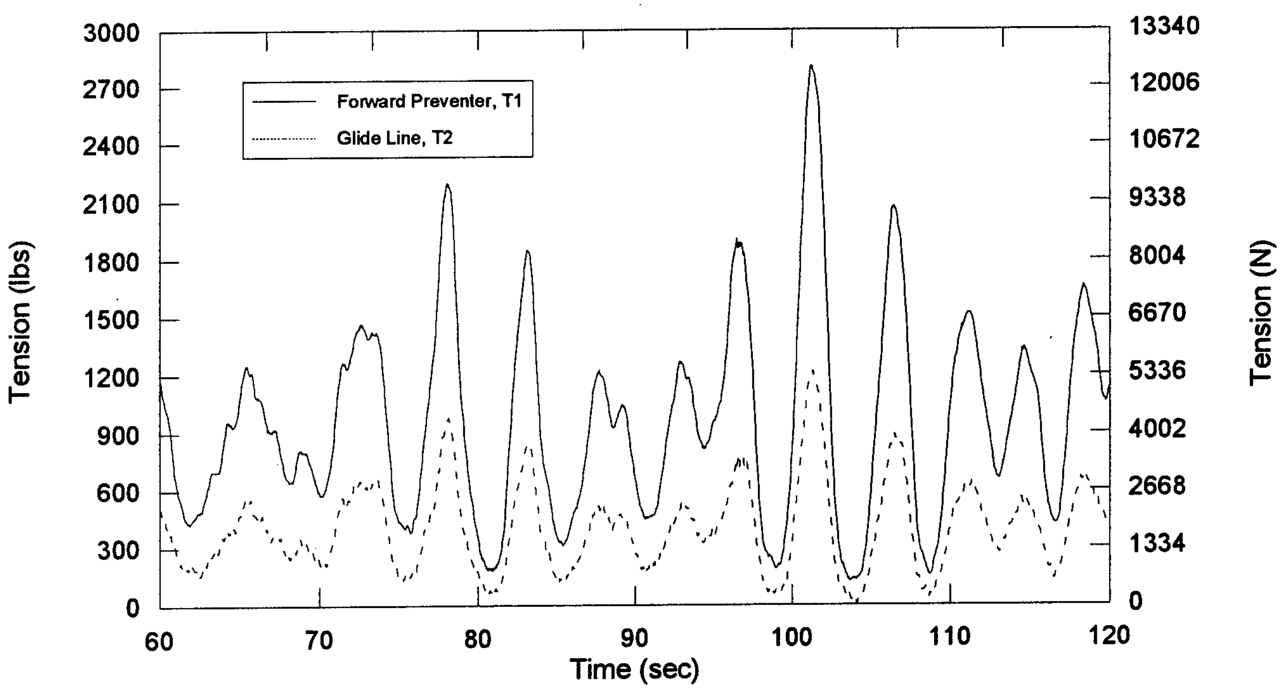
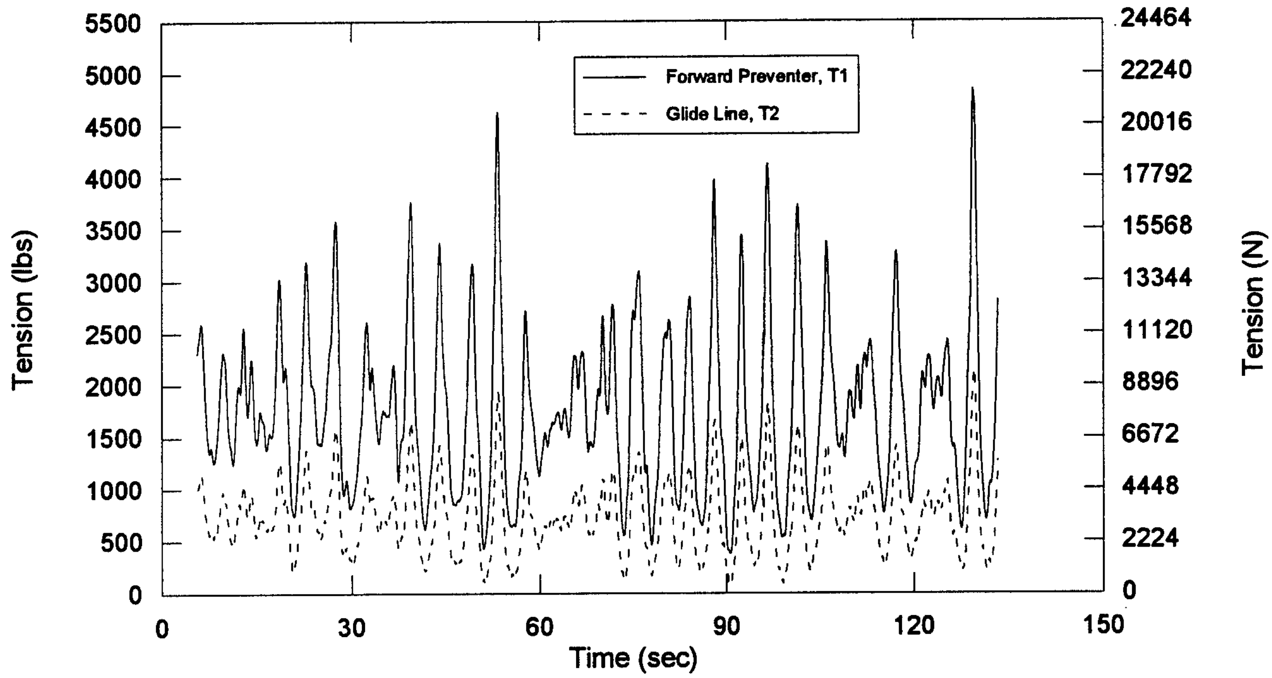


Fig. C.5. Tension in CG VOSS support lines at 1 knot in 2 - 4 foot 45 degree port seas. Bottom graph is a closeip of the period from 60 to 120 seconds. (Run 33, 5/6/93)



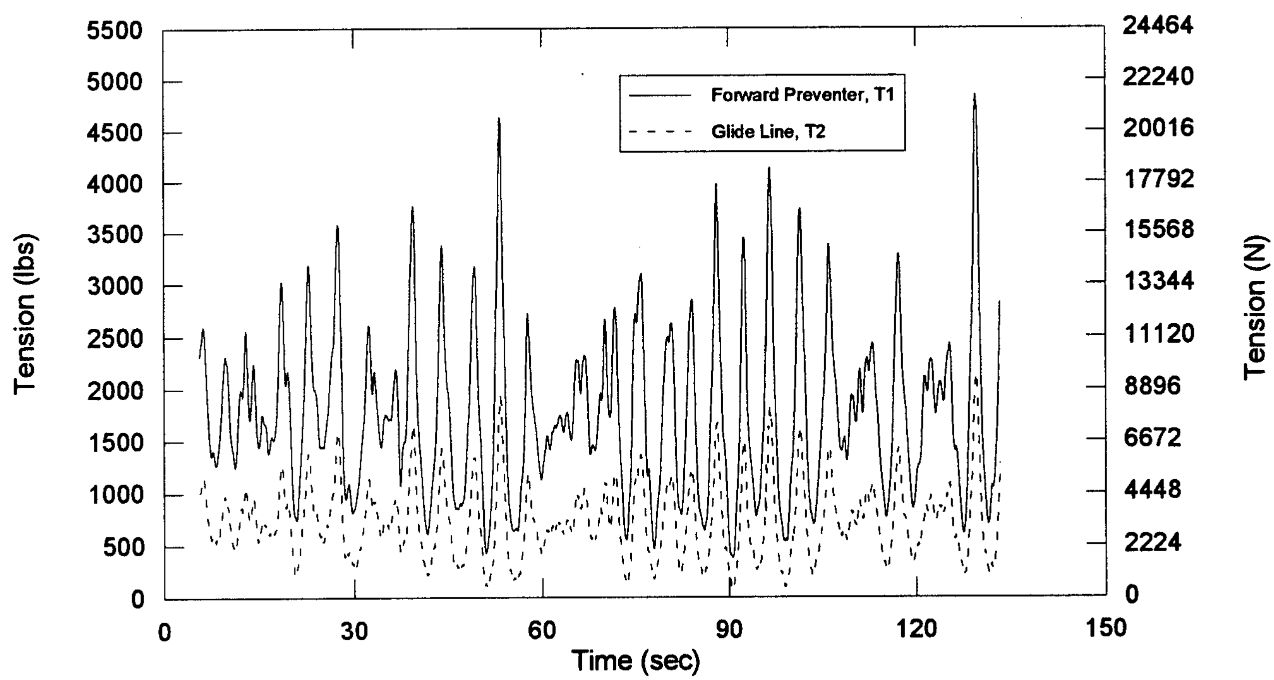
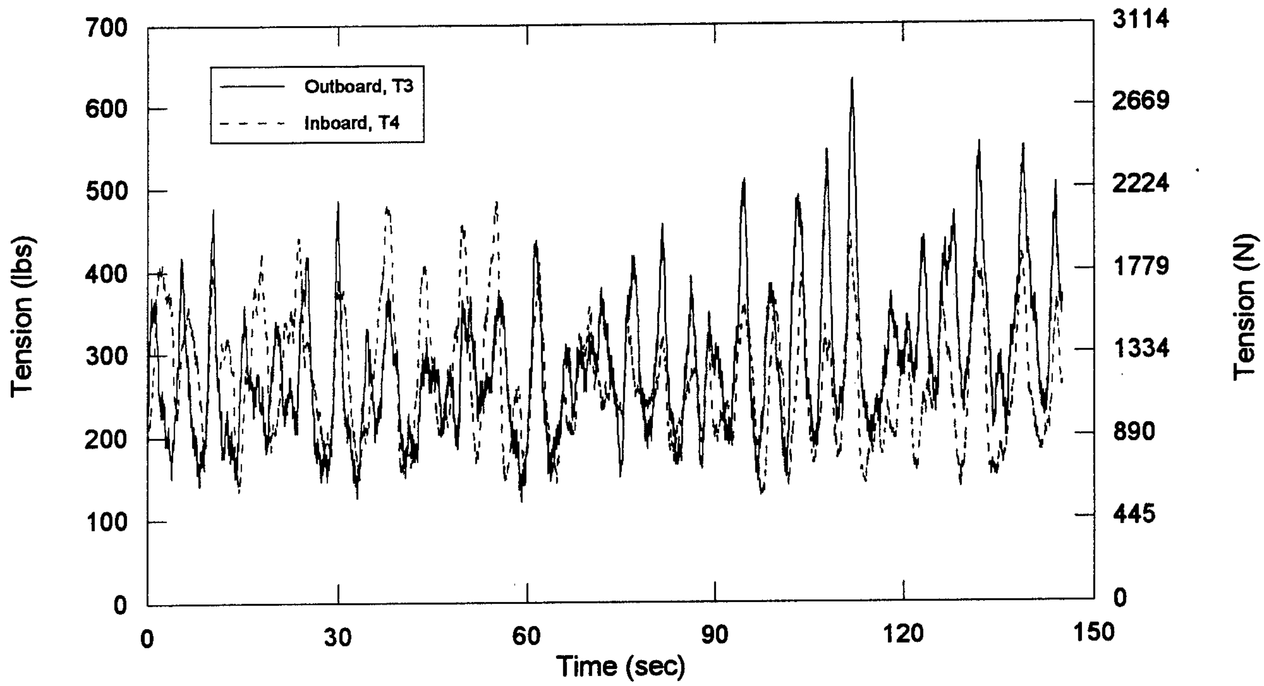


Fig. C.6. Tension in CG VOSS support lines at 2 knots in 2 - 4 foot 45 degree port seas. Bottom graph is a closeup of the period from 30 to 90 seconds. (Run 34, 5/6/93)



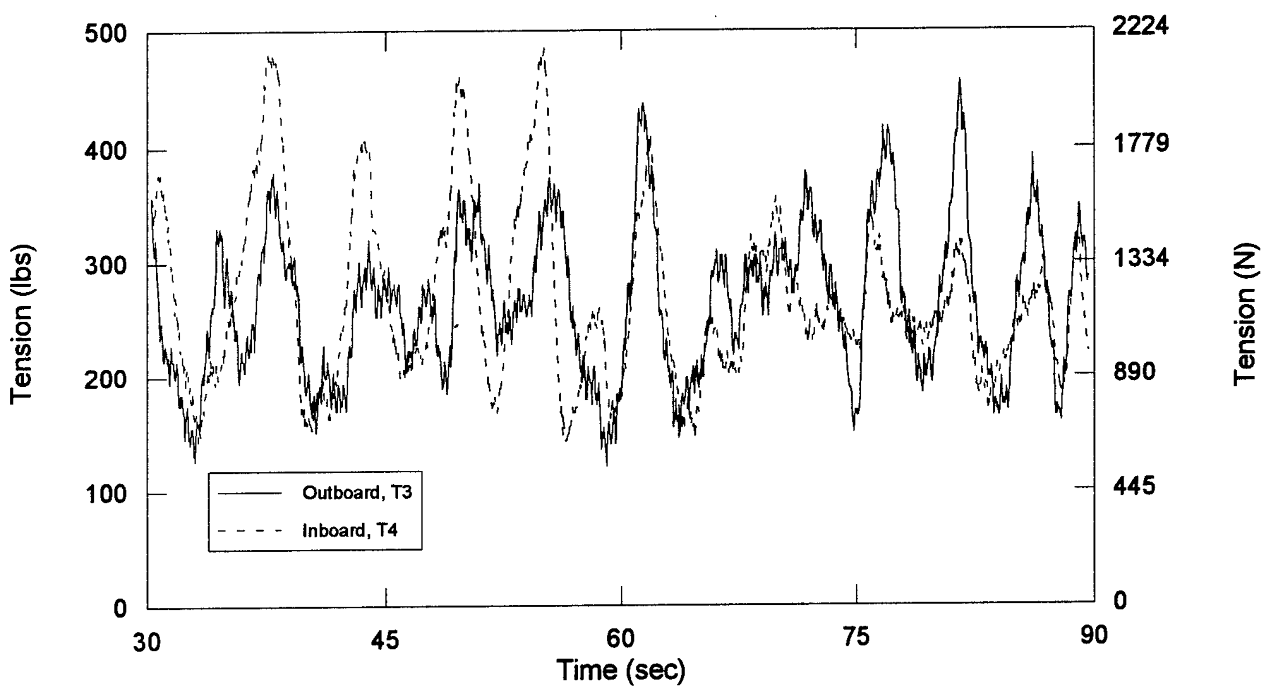
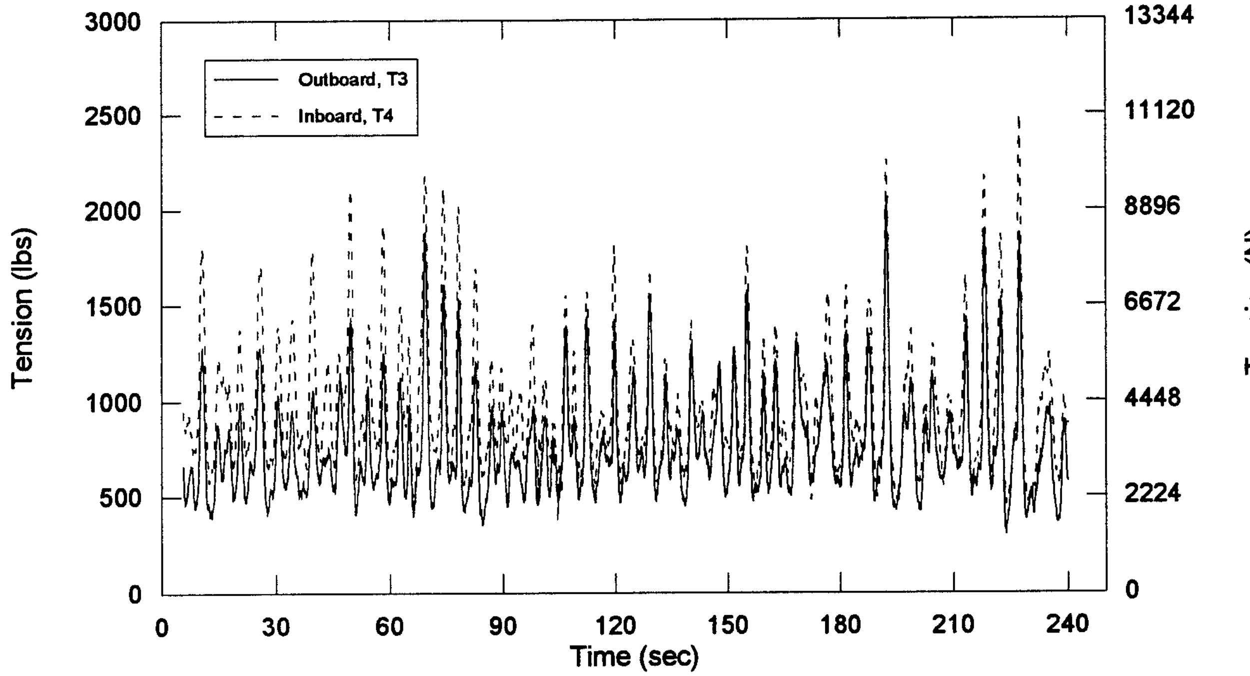


Fig. C.7. Tension in NOFI V Sweep at 1 knot in 2 - 4 foot head seas. Bottom graph is a closeup of the period from 30 to 90 seconds. (Run 28, 5/6/93)



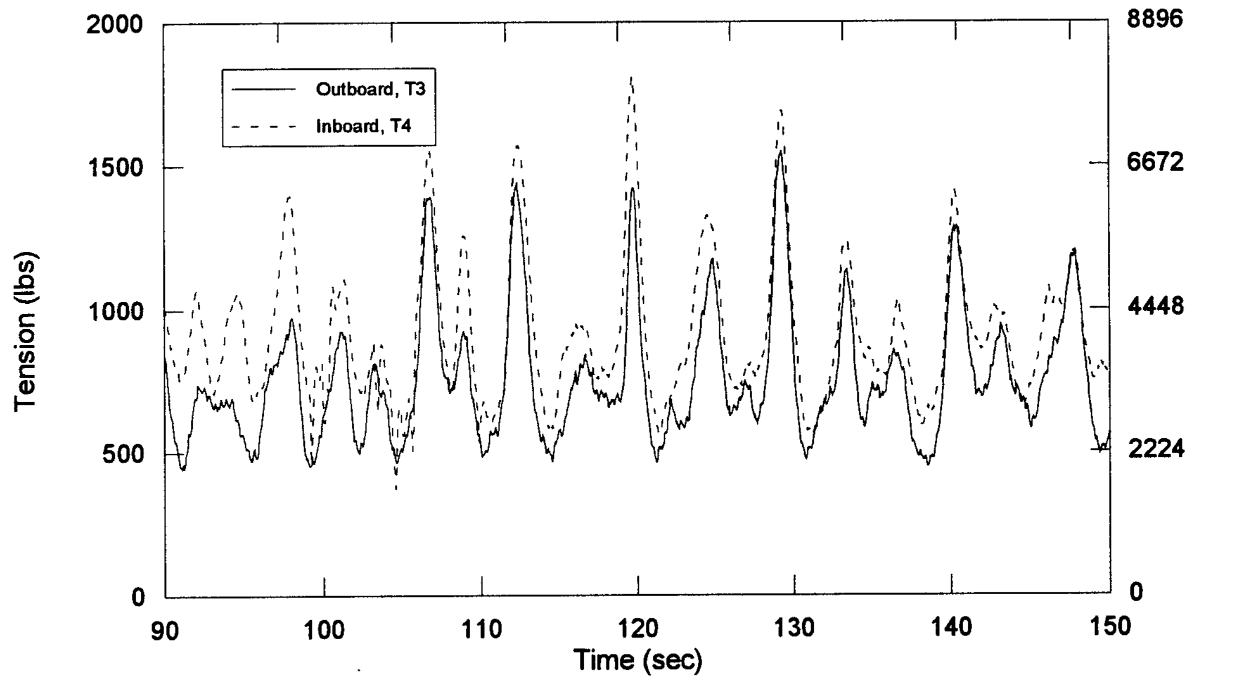
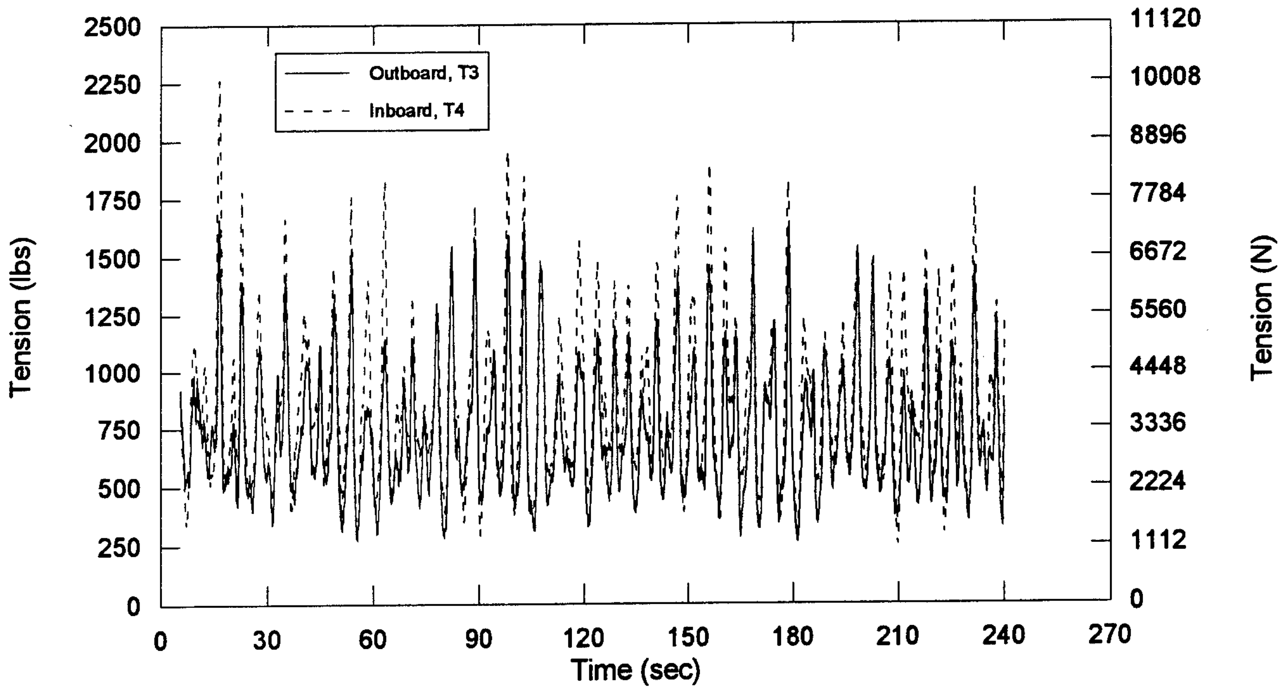


Fig. C.8. Tension in NOFI V Sweep at 1 knot in 2 - 4 foot head seas. Bottom graph is a closeup of the period from 90 to 150 seconds. (Run 29, 5/6/93)



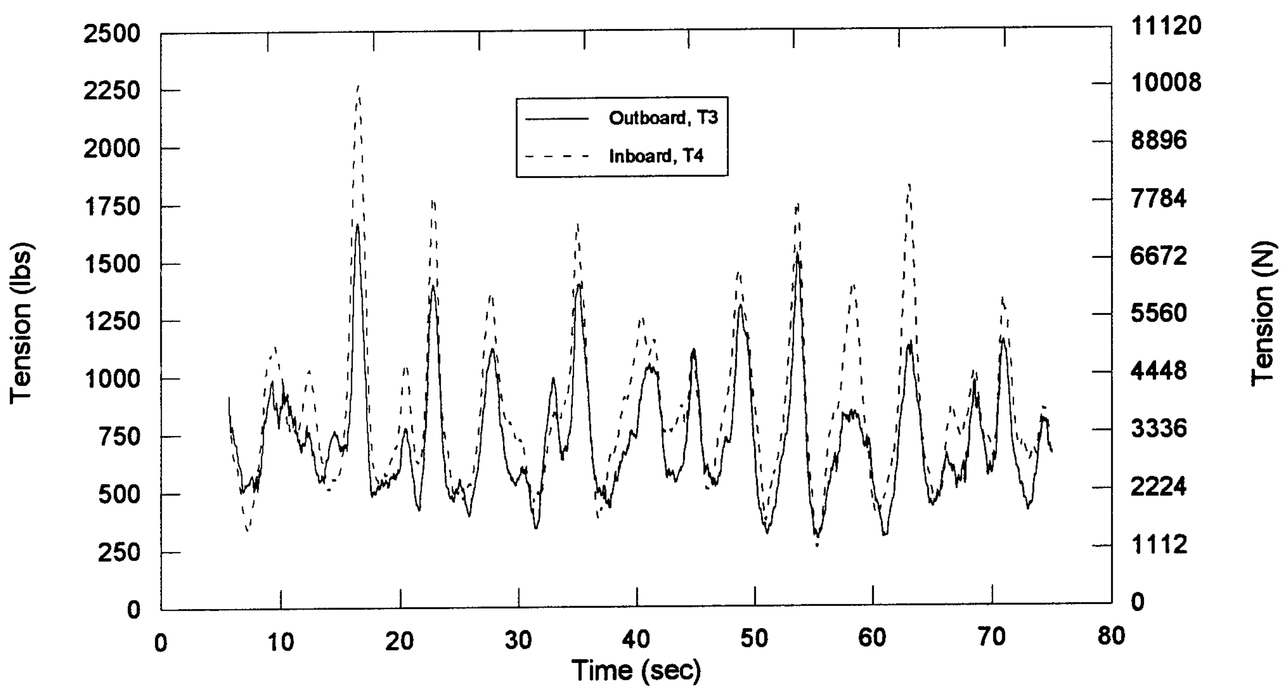


Fig. C.9. Tension in NOFI V Sweep at 2 knots in 2 - 4 foot 45 degree stbd. seas. Bottom graph is a close up of the period from 10 to 70 seconds. (Run 30, 5/6/93)

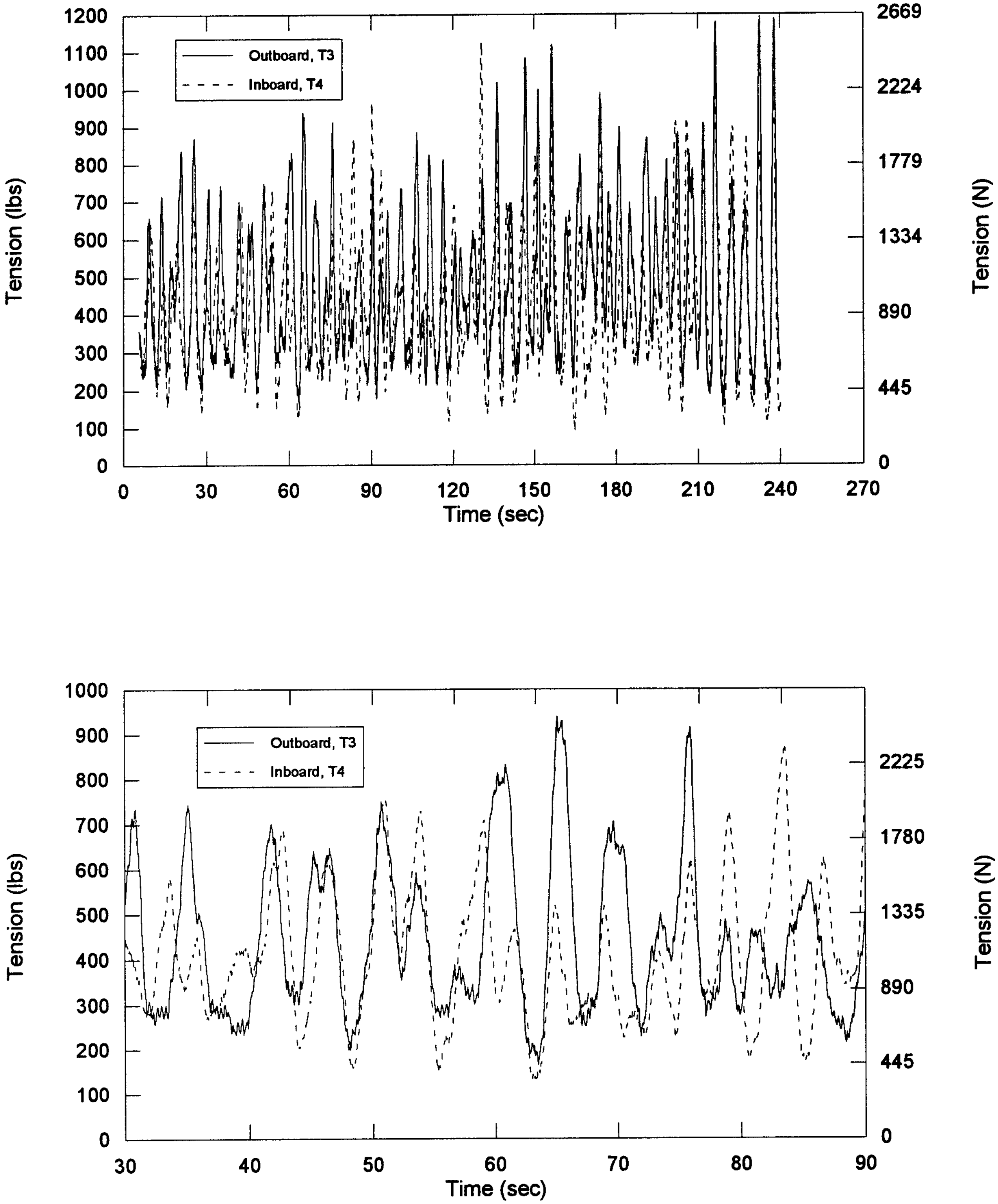
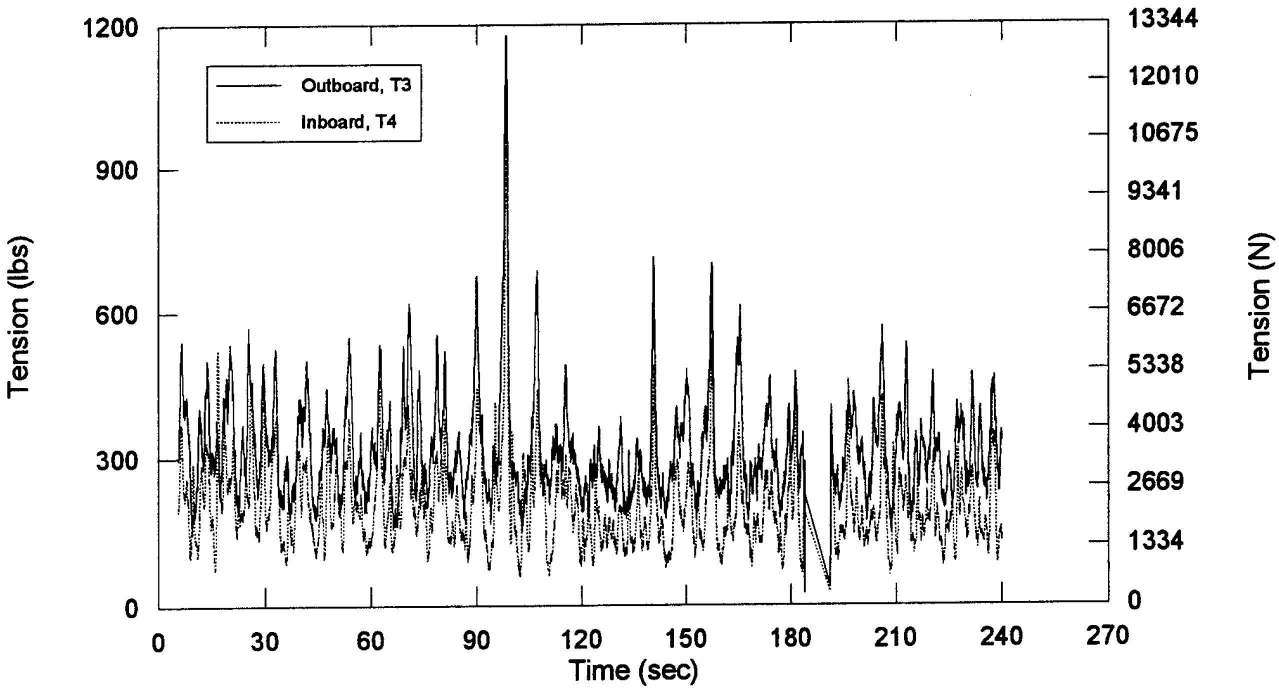


Fig. C.10. Tension in NOFI V Sweep at 1 knot in 2 - 4 foot 45 degree stbd. seas. Bottom graph is a closeup of the period from 30 to 90 seconds. (Run 31, 5/6/93)



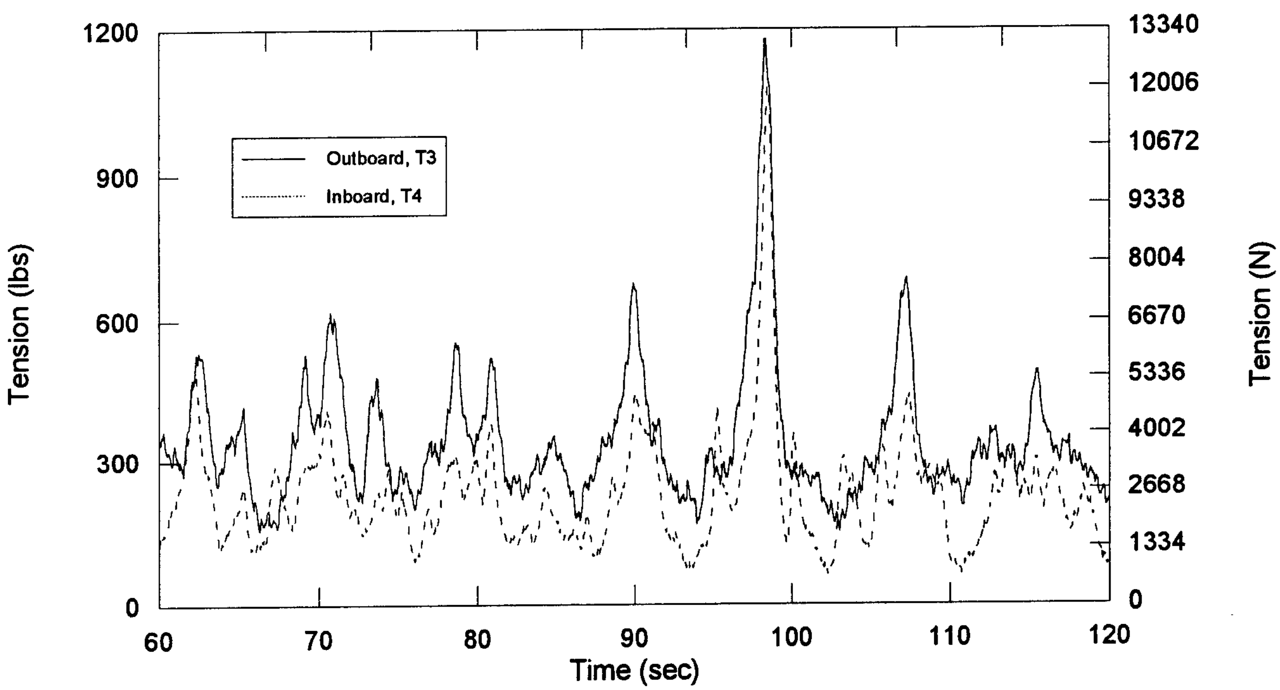
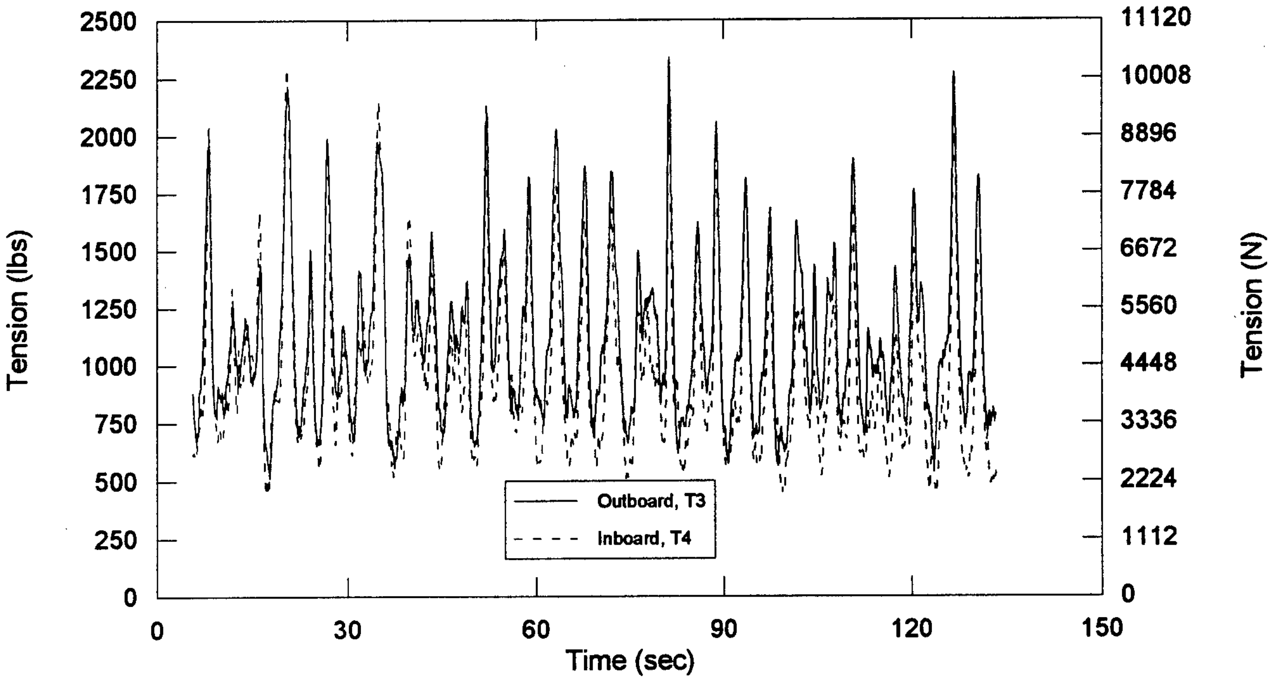


Fig. C.11. Tension in NOFI V Sweep at 1 knot in 2 - 4 foot 45 degree port seas. Bottom graph is a closeip of the period from 60 to 120 seconds. (Run 33, 5/6/93)



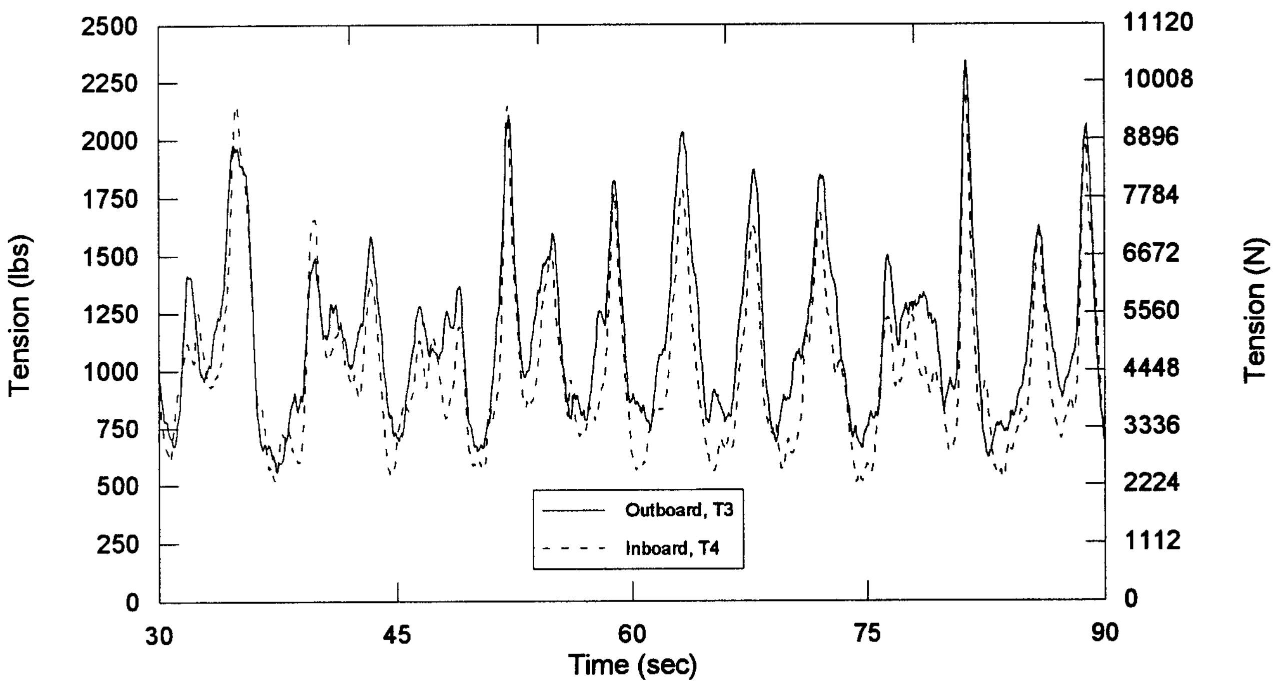


Fig. C.12. Tension in NOFI V Sweep at 2 knots in 2 - 4 foot 45 degree port seas. Bottom graph is a closeup of the period from 30 to 90 seconds. (Run 34, 5/6/93)

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APPENDIX D

ADDITIONAL DEPTH TIME HISTORIES FOR REFERENCED RUNS

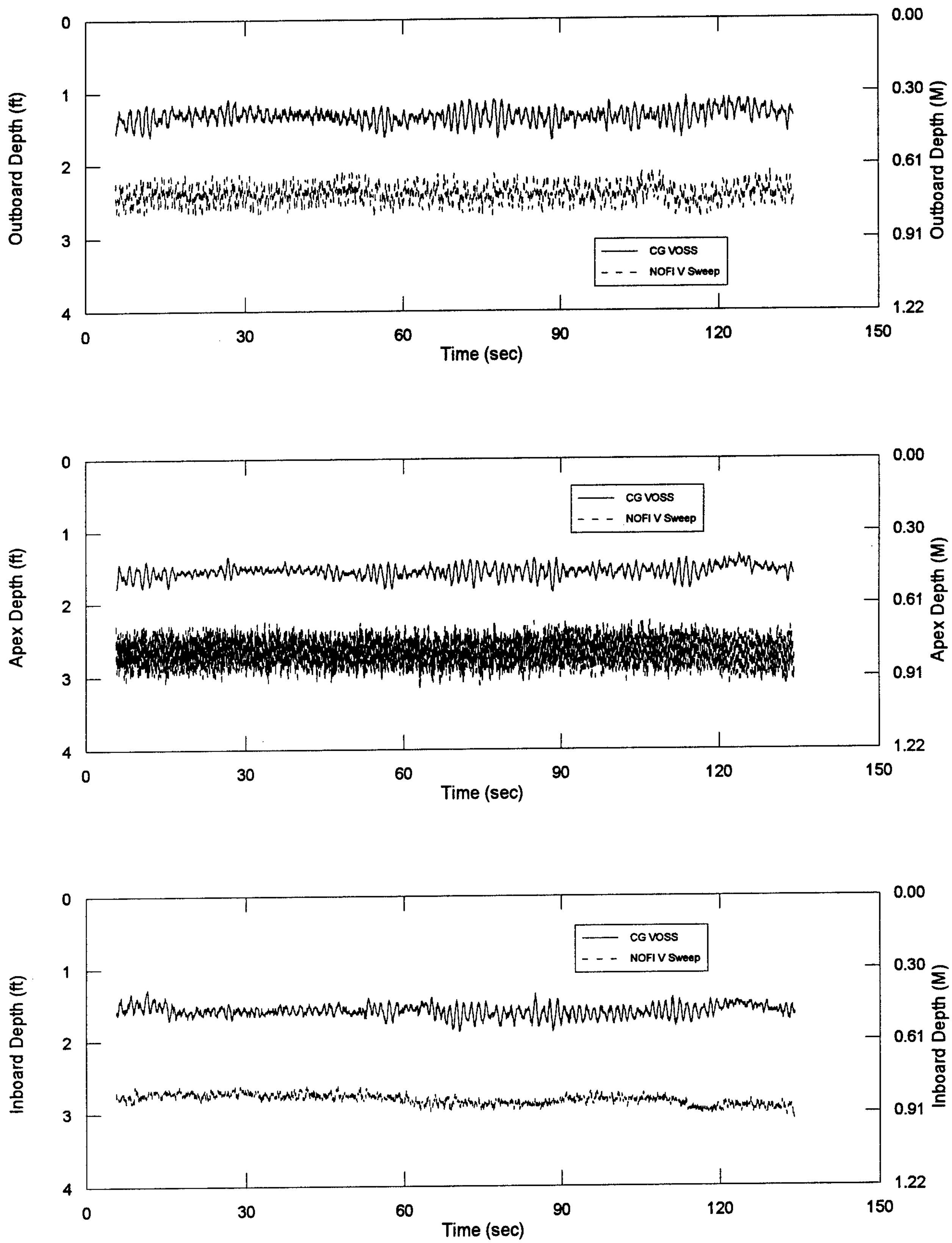


Fig. D.1. CG VOSS and NOFI V Sweep boom skirt depths at 1 knot in calm seas. (Run 22, 5/5/93)

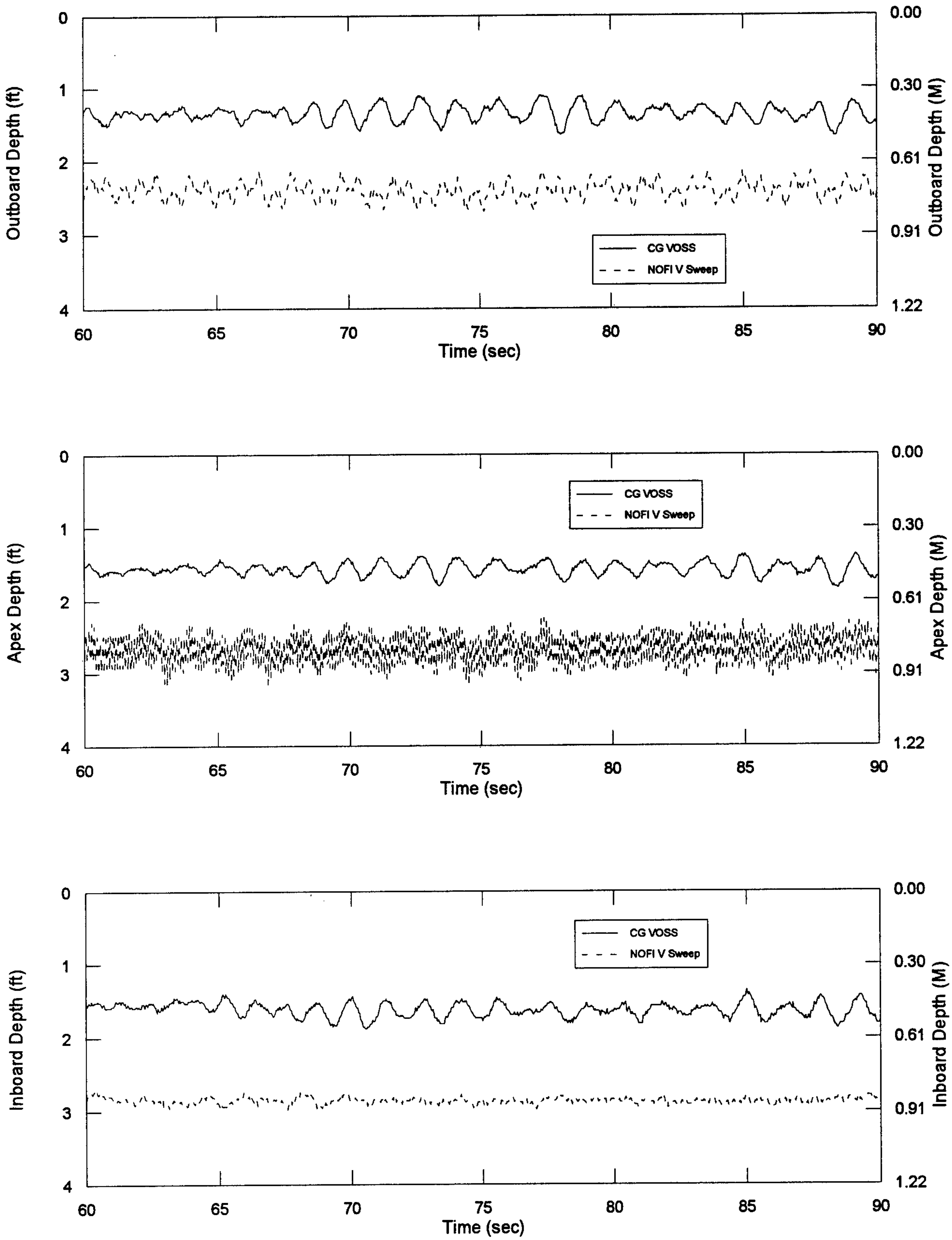


Fig. D.2. Closeup of CG VOSS and NOFI V Sweep boom skirt depths at 1 knot in calm seas. (Run 22, 5/5/93)

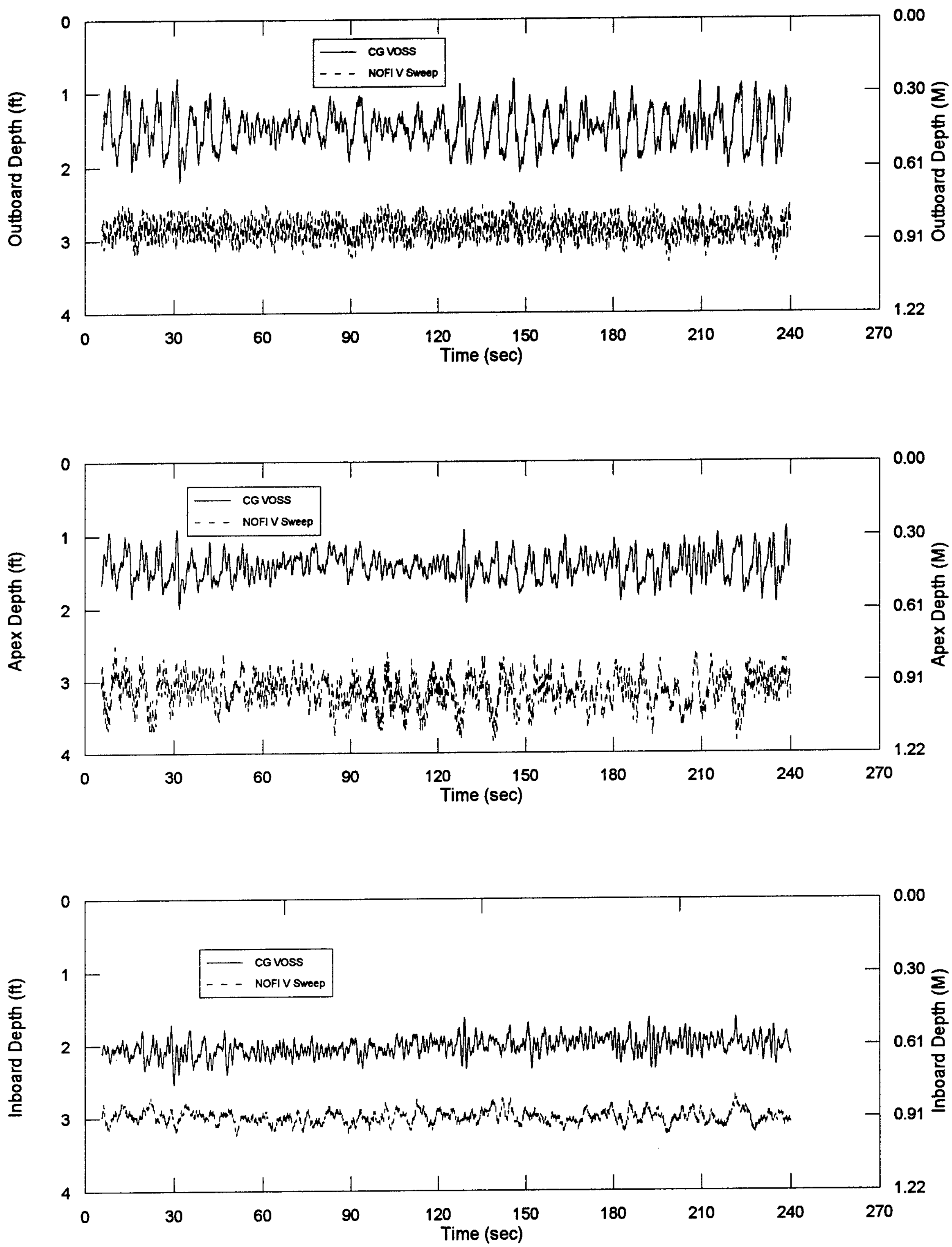


Fig. D.3. CG VOSS and NOFI V Sweep boom skirt depths at 1 kt in 1 - 2 foot head seas. (Run 41, 5/7/93)

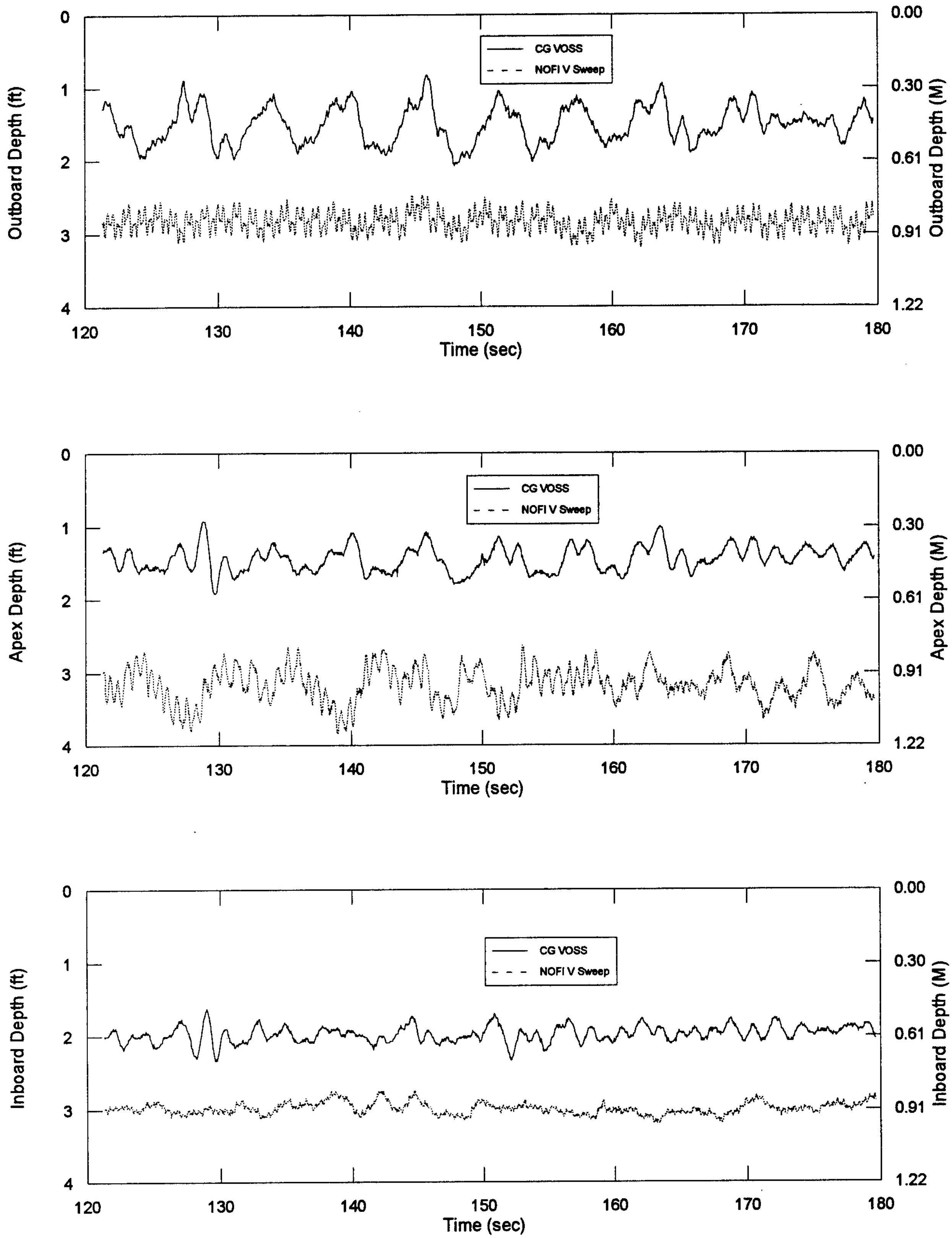


Fig. D.4. Closeup of CG VOSS and NOFI V Sweep boom skirt depths at 1 knot in 1 - 2 foot head seas. (Run 41, 5/7/93)

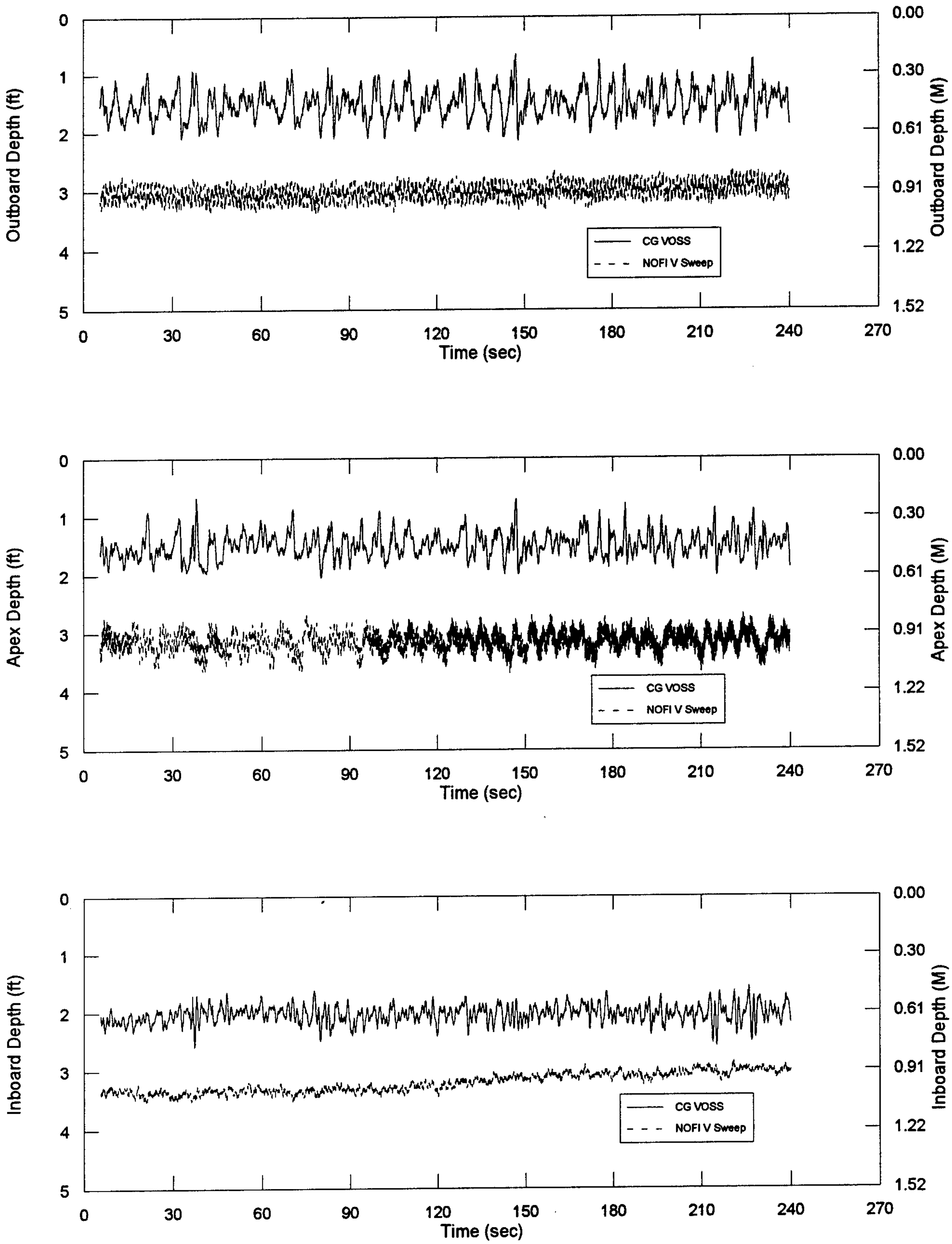


Fig. D.5. CG VOSS and NOFI V Sweep boom skirt depths at 1 kt in 1 - 2 ft following seas. (Run 43, 5/7/93)

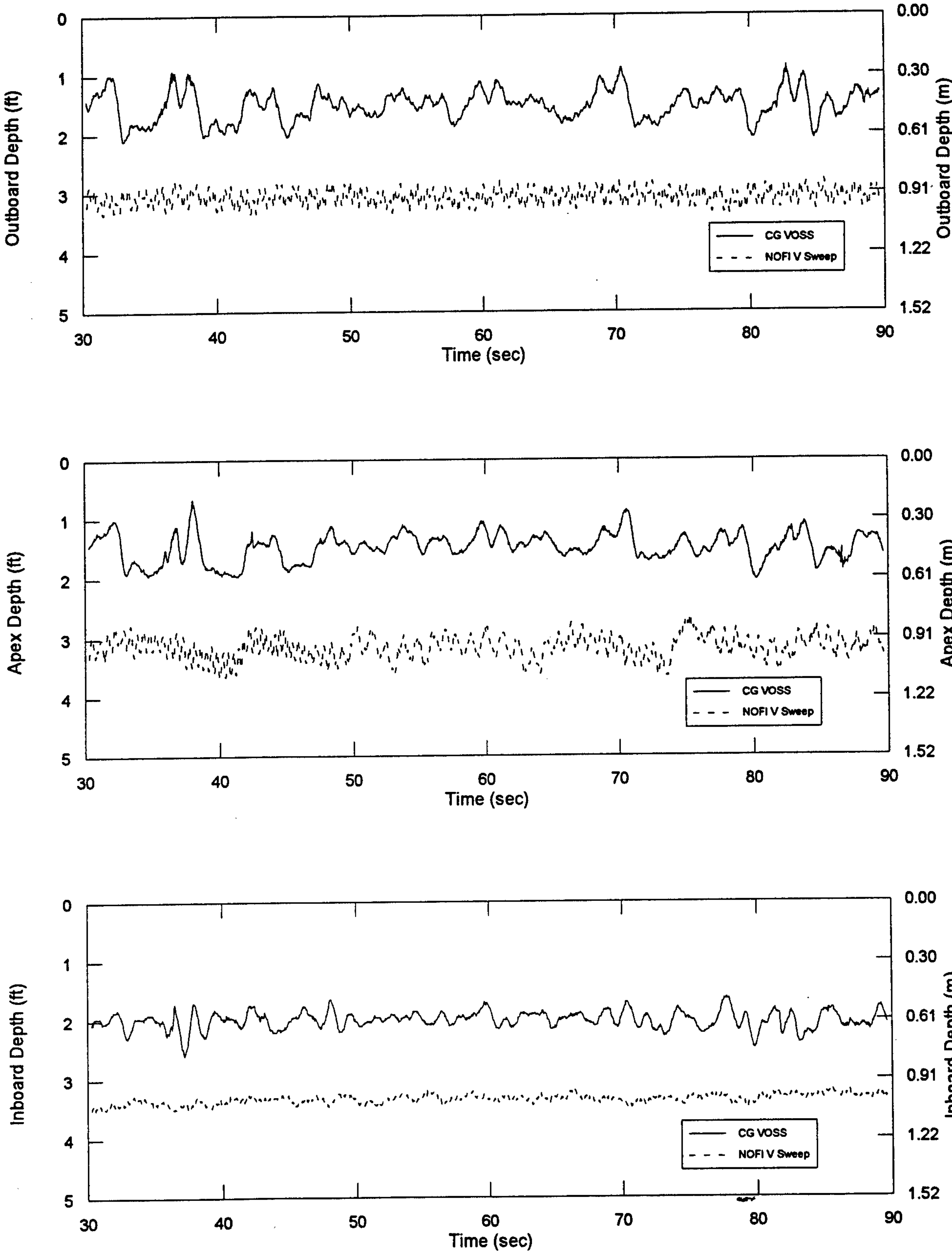


Fig. D.6. Closeup ofCG VOSS and NOFI V Sweep boom skirt depths at 1 knot in 1 - 2 foot following seas. (Run 43, 5/7/93)

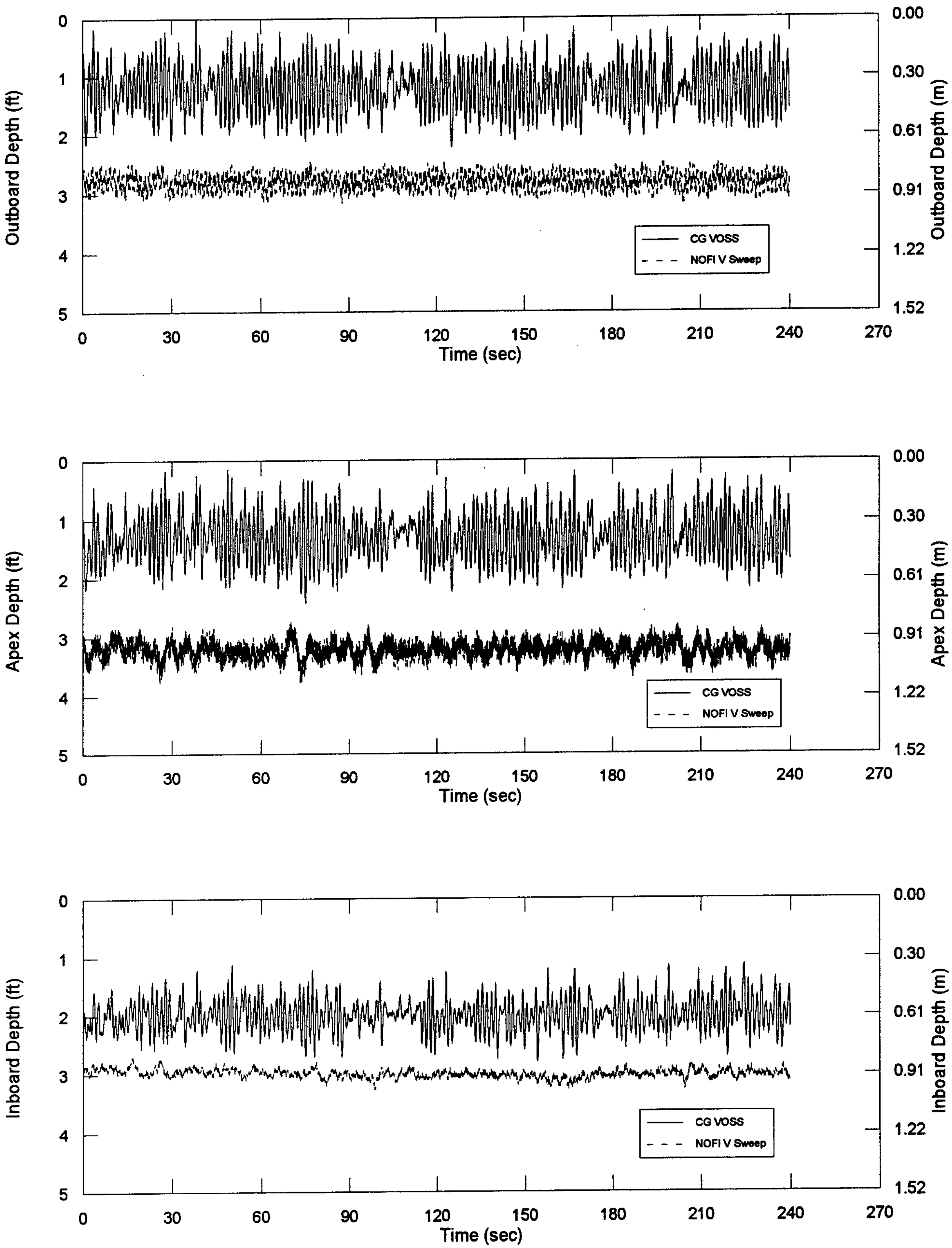


Fig. D.7. CG VOSS and NOFI V Sweep boom skirt depths at 2 knots in 1 - 2 foot following seas. (Run 44, 5/7/93)

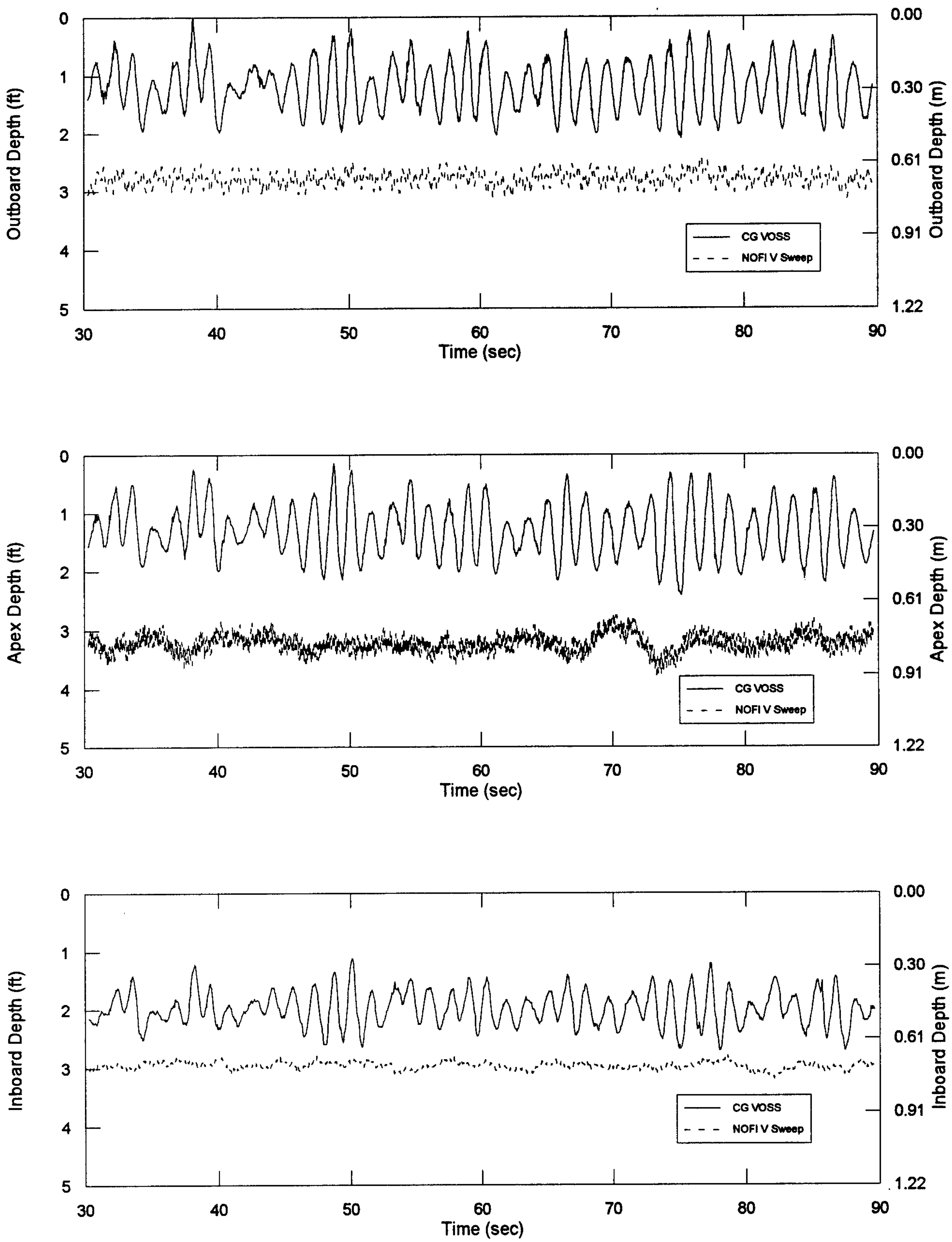
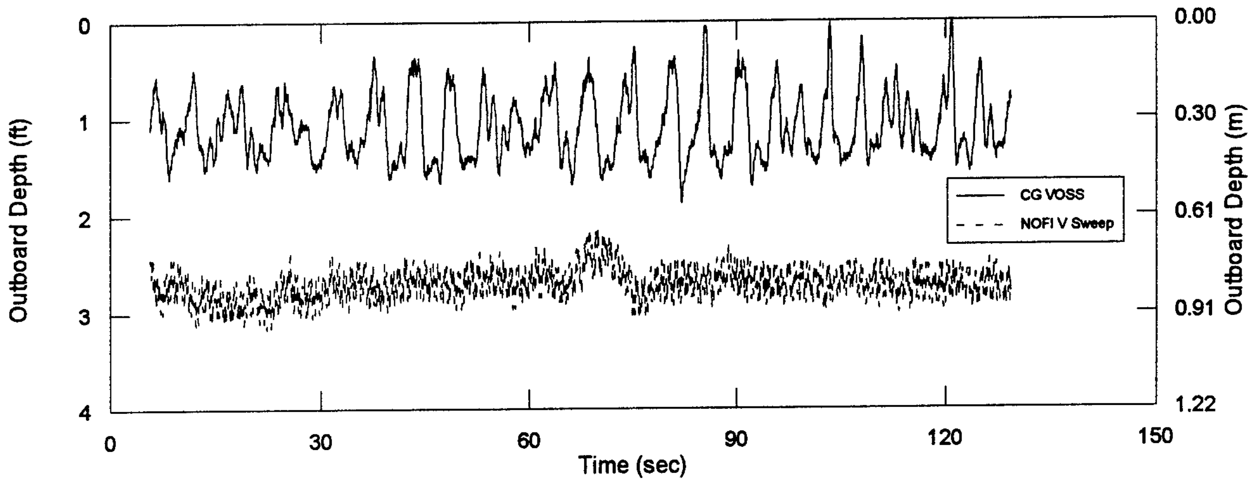
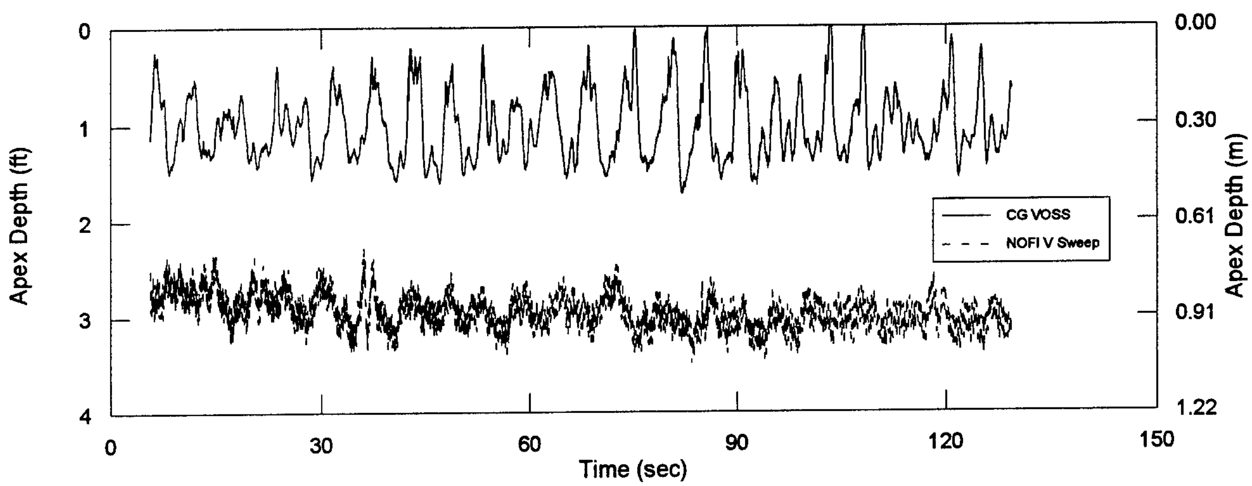


Fig. D.8. Closeup of CG VOSS and NOFI V Sweep boom skirt depths at 2 knots in 1 - 2 foot following seas. (Run 44, 5/7/93)





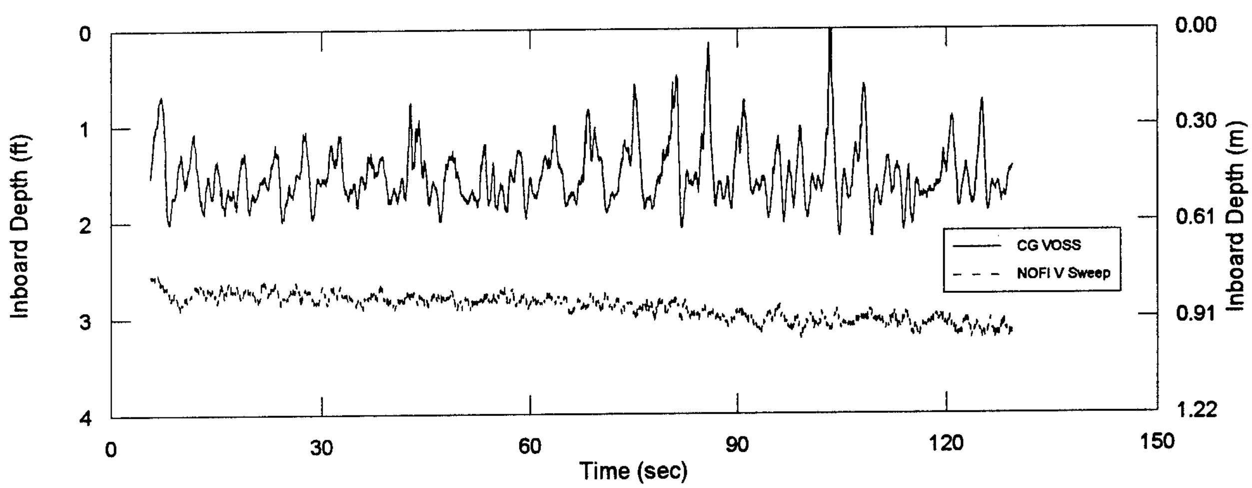
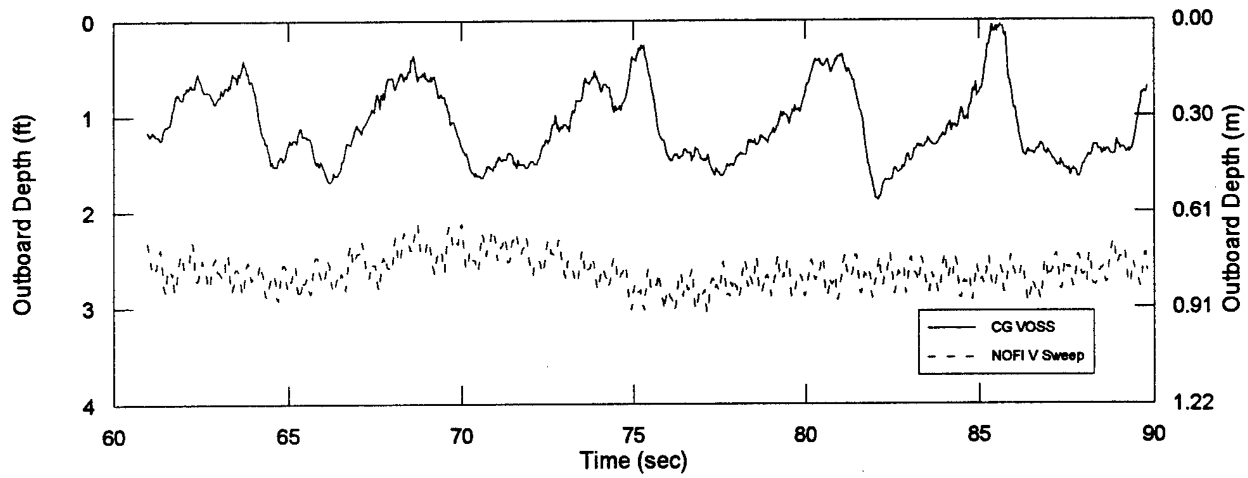
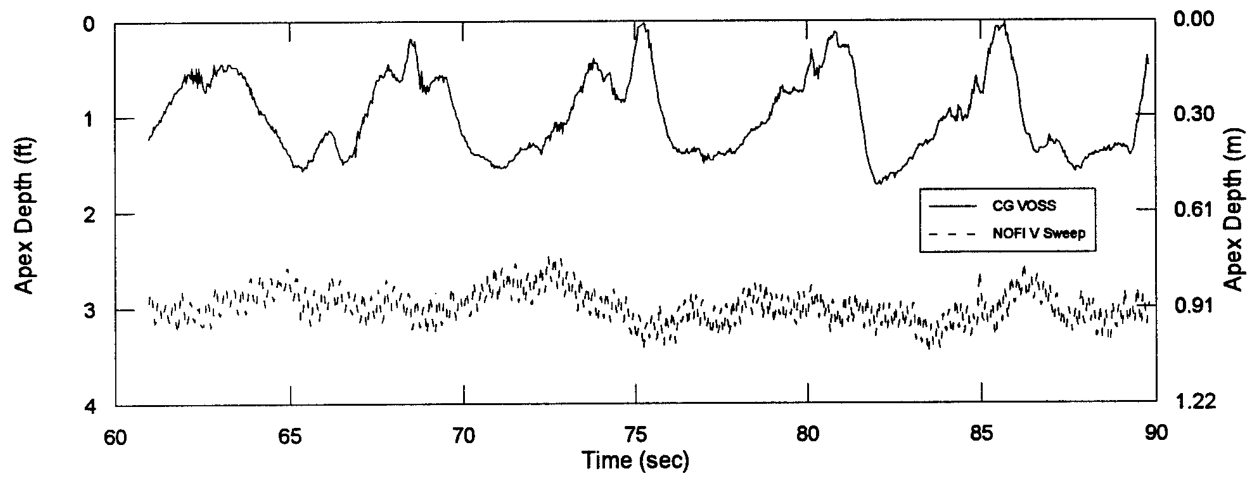


Fig. D.9. CG VOSS and NOFI V Sweep boom skirt depth at 1 knot in 1-3 ft following seas. (Run 26, 5/6/93)





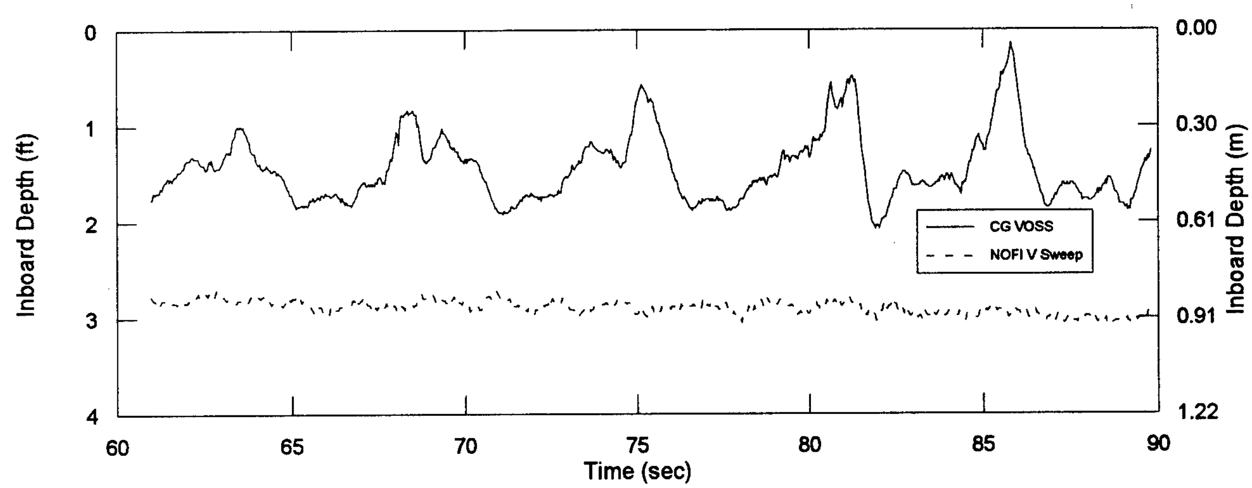


Fig. D.10. Closeup of CG VOSS and NOFI V Sweep boom skirt depths at 1 knot in 1 - 3 foot following seas. (Run 26, 5/6/93)

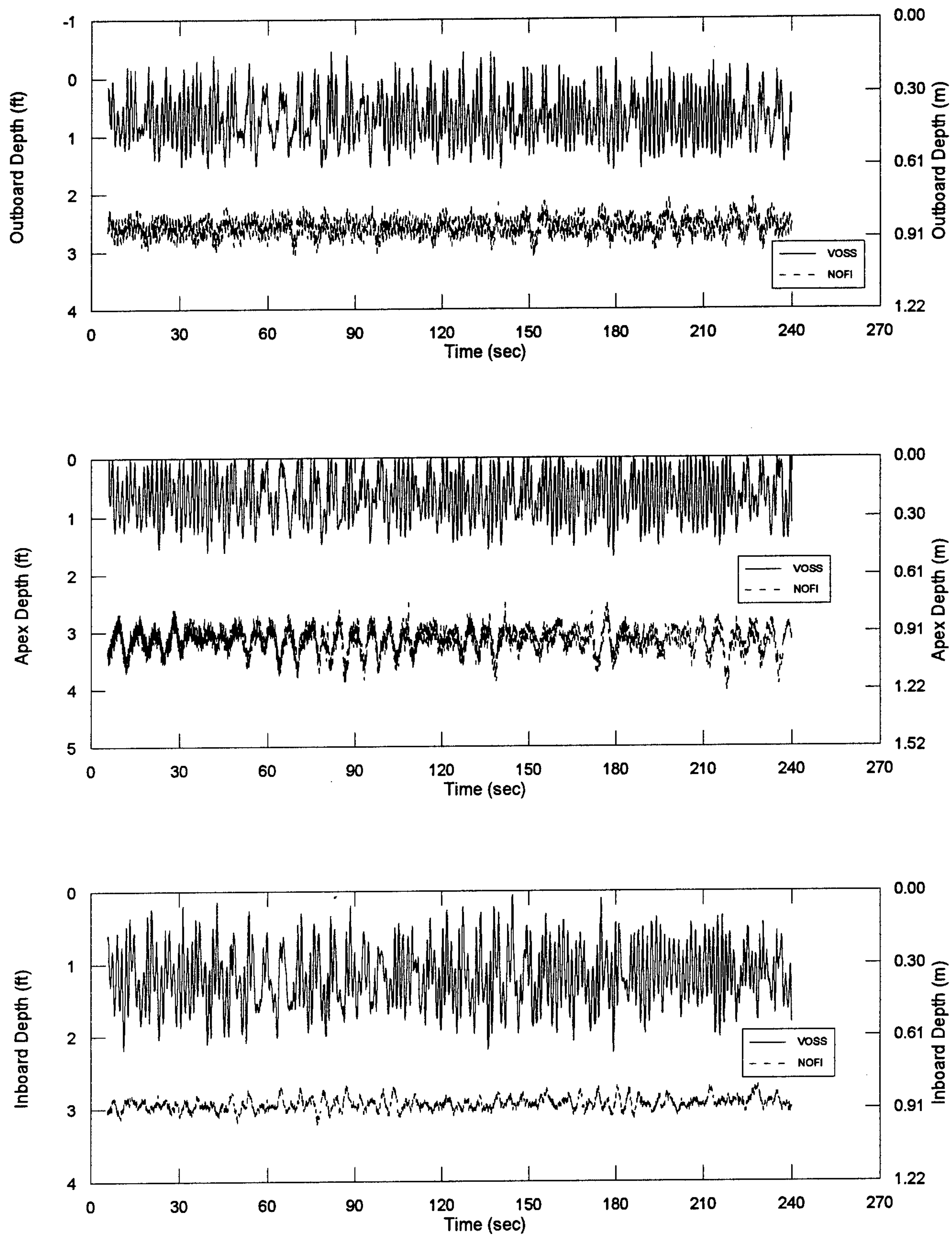


Fig. D.11. CG VOSS and NOFI V Sweep boom skirt depth at 2 knots in 1 - 3 foot following seas. (Run 27, 5/6/93)

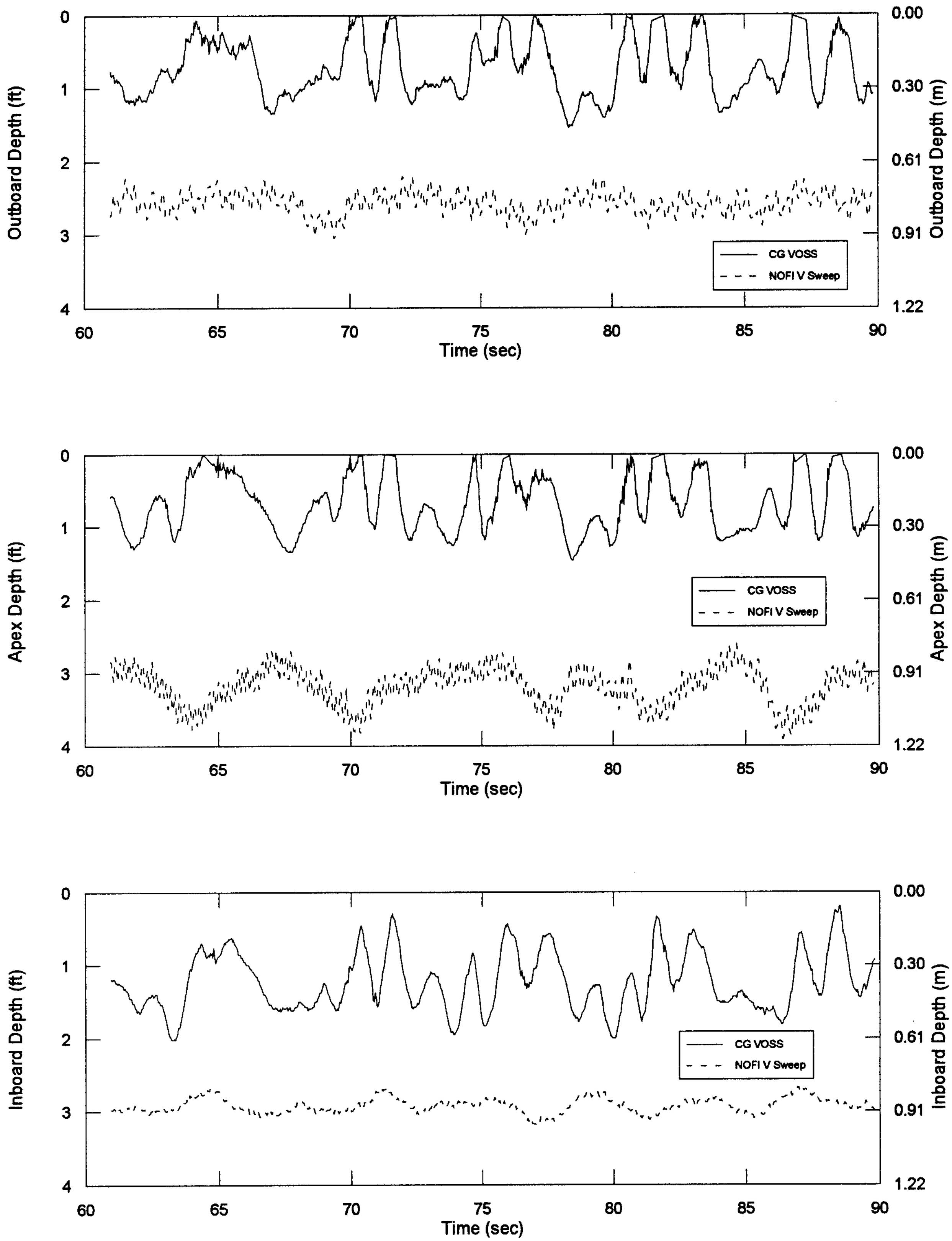


Fig. D.12. Closeup of CG VOSS and NOFI V Sweep boom skirt depths at 2 knots in 1 - 3 foot following seas. (Run 27, 5/6/93)

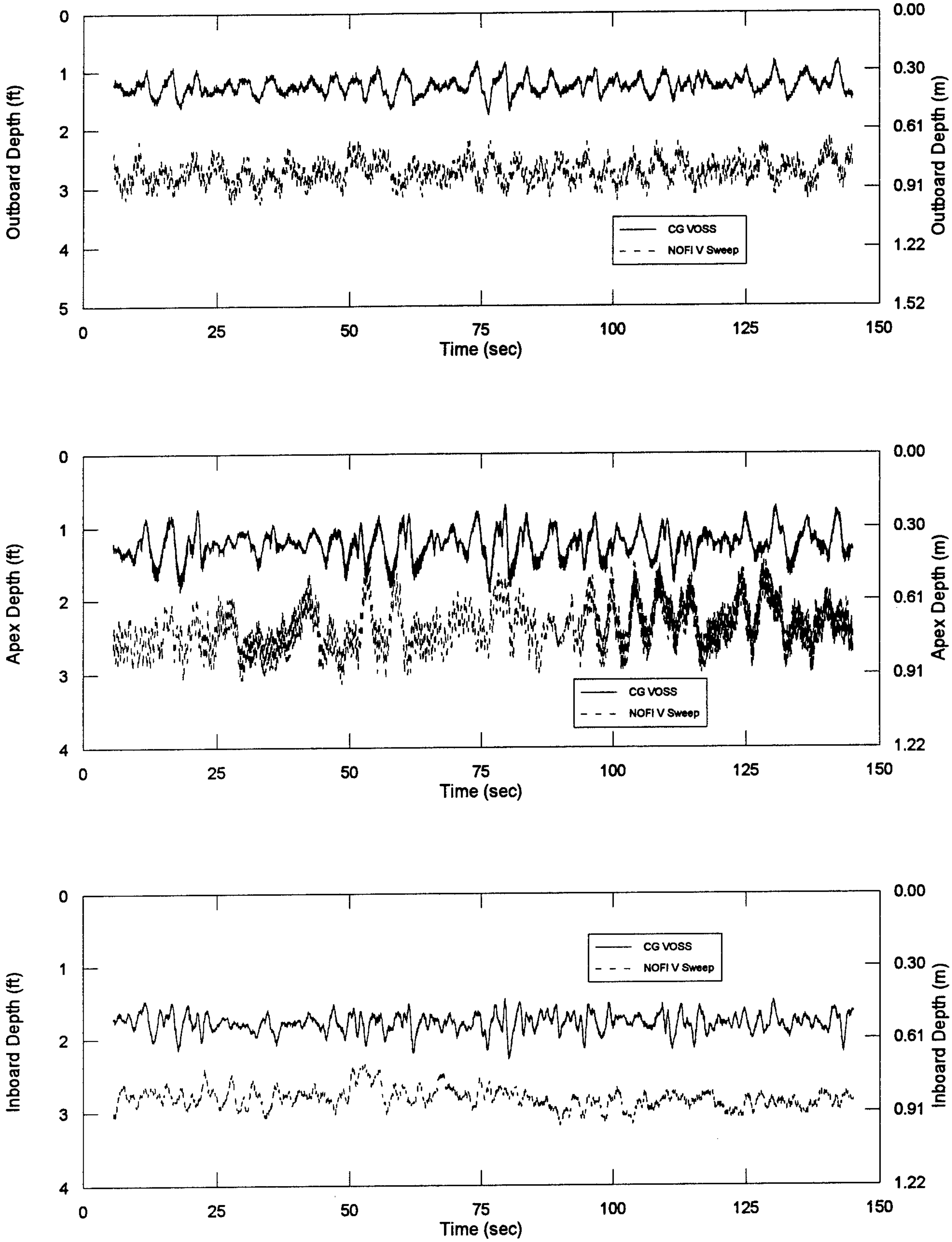
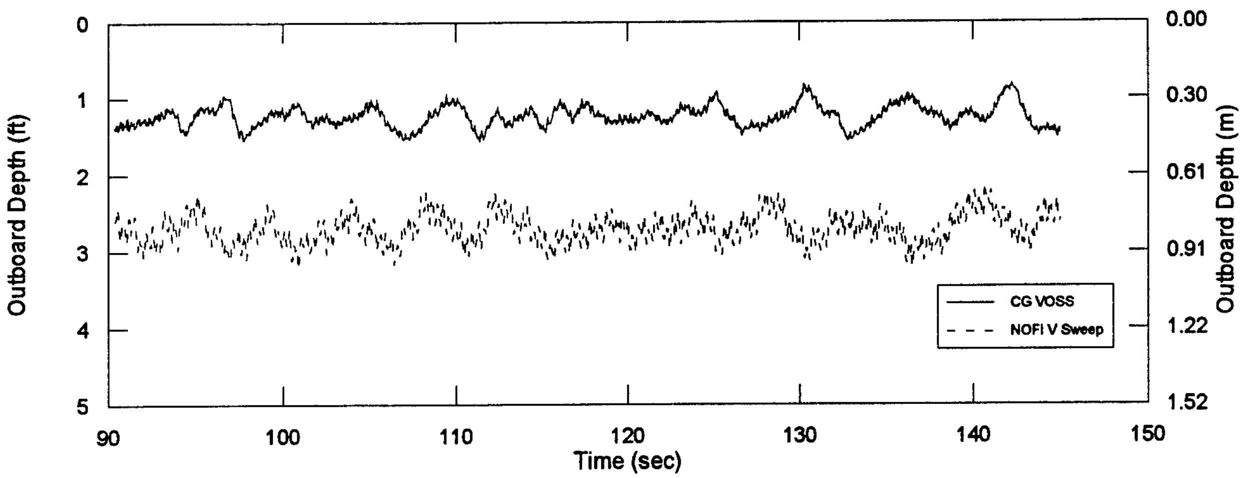
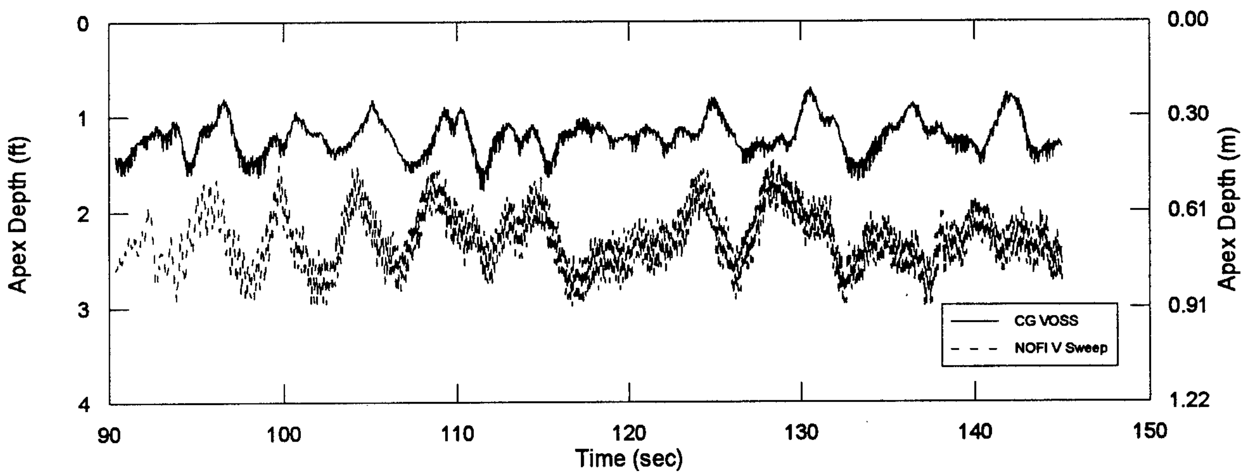


Fig. D.13. CG VOSS and NOFI V Sweep boom skirt depths at 1 knot in 2 - 4 foot head seas. (Run 28, 5/6/93)





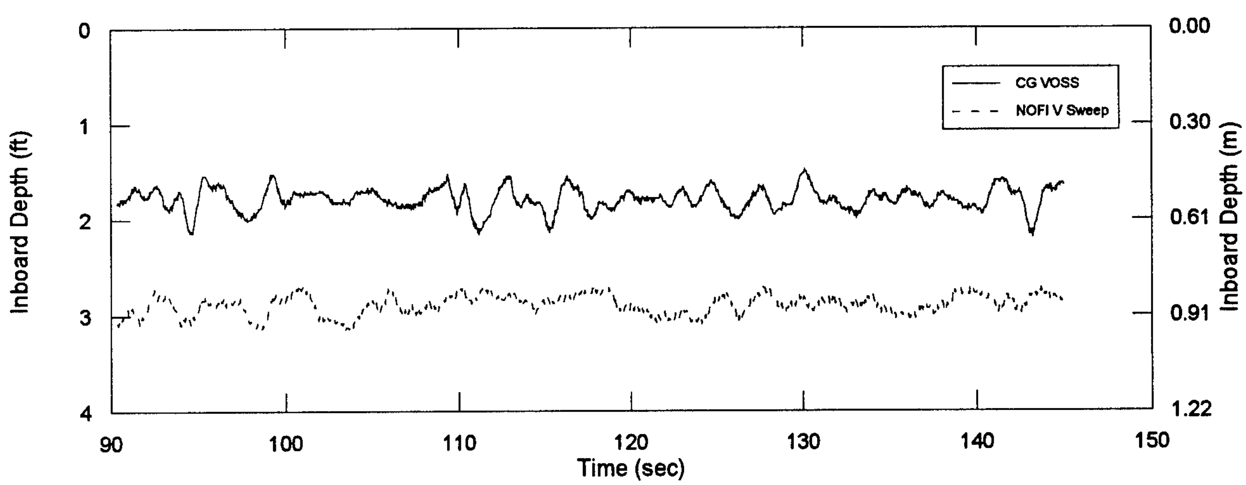


Fig. D.14. Closeup of CG VOSS and NOFI V Sweep boom skirt depths at 1 knot in 2 - 4 foot head seas. (Run 28, 5/6/93)

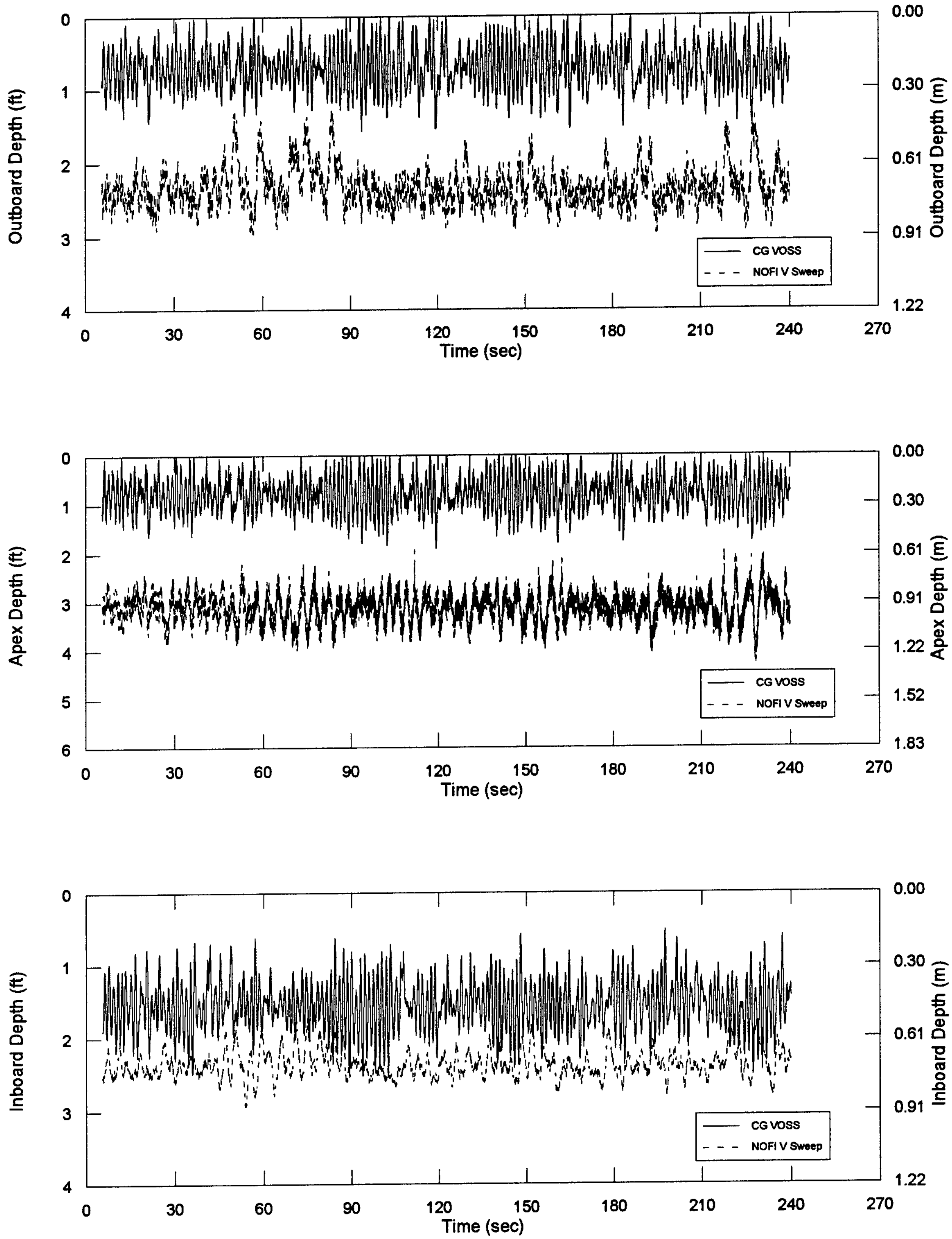


Fig. D.15. CG VOSS and NOFI V Sweep boom skirt depths at 2 knots in 2 - 4 foot head seas. (Run 29, 5/6/93)

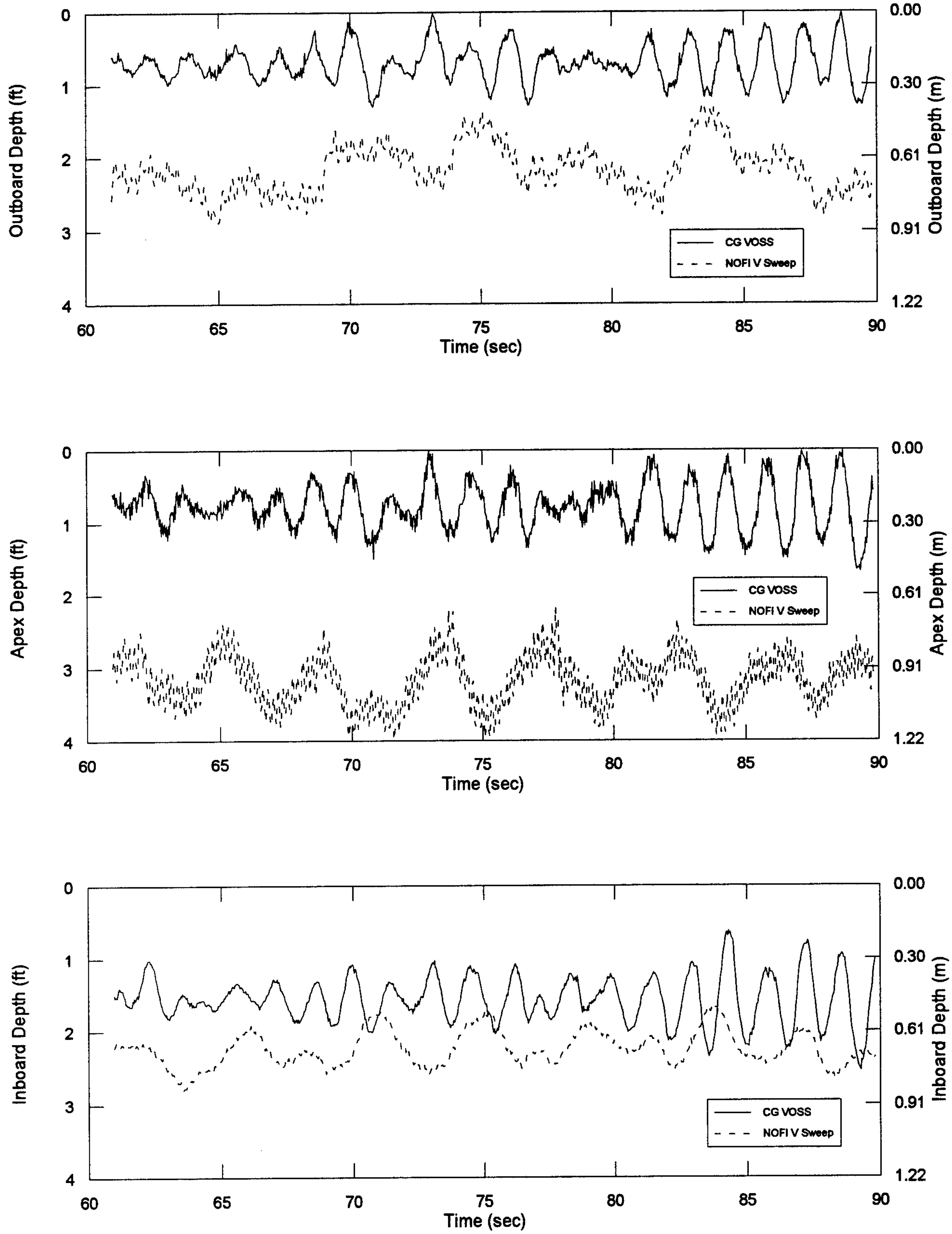


Fig. D.16. Closeup of CG VOSS and NOFI V Sweep boom skirt depths at 2 knots in 2 - 4 ft head seas. (Run 29, 5/6/93)

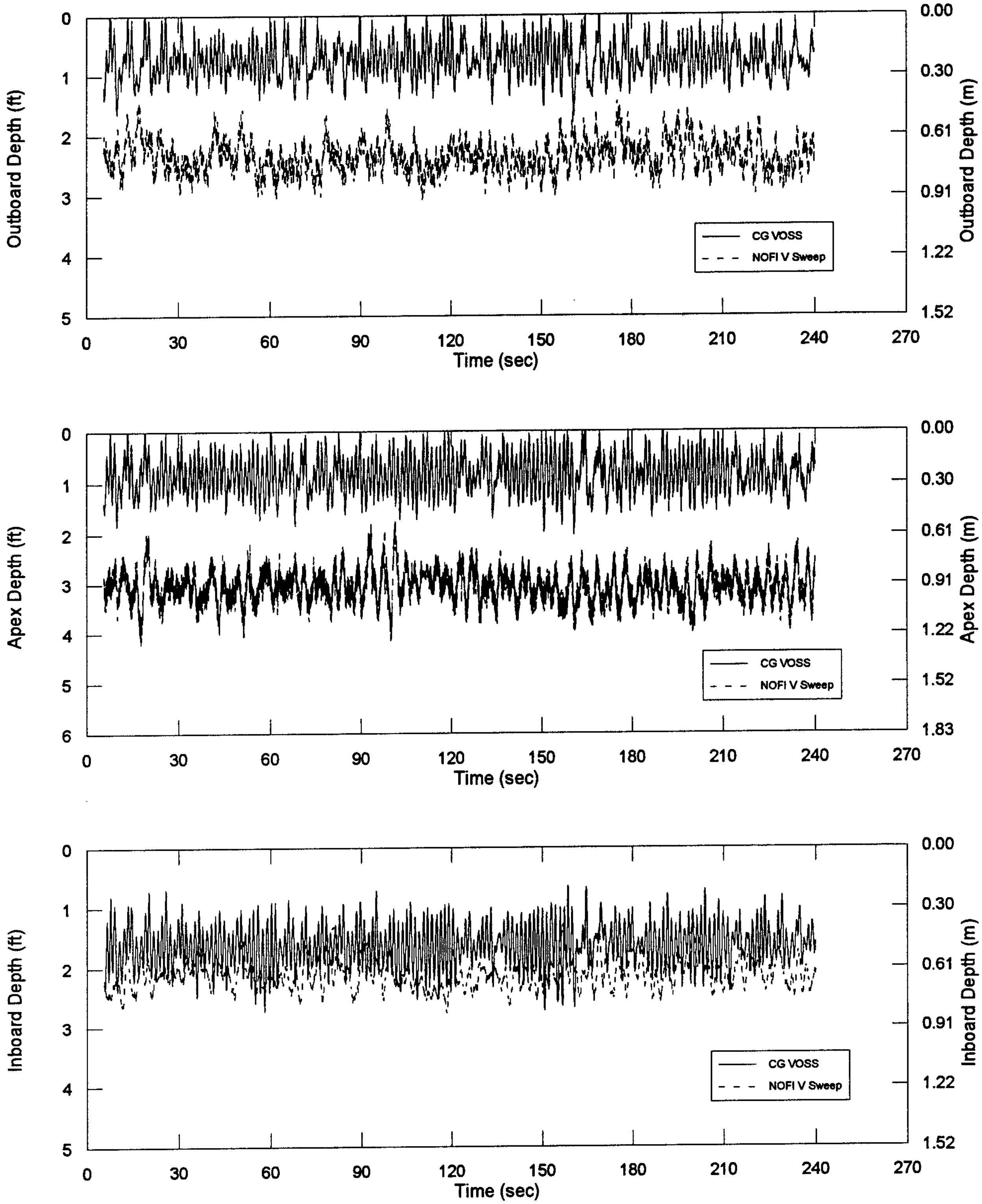


Fig. D.17. CG VOSS and NOFI V Sweep boom skirt depths at 2 knots in 2 - 4 foot 45 degree stbd. seas. (Run 30, 5/6/93)

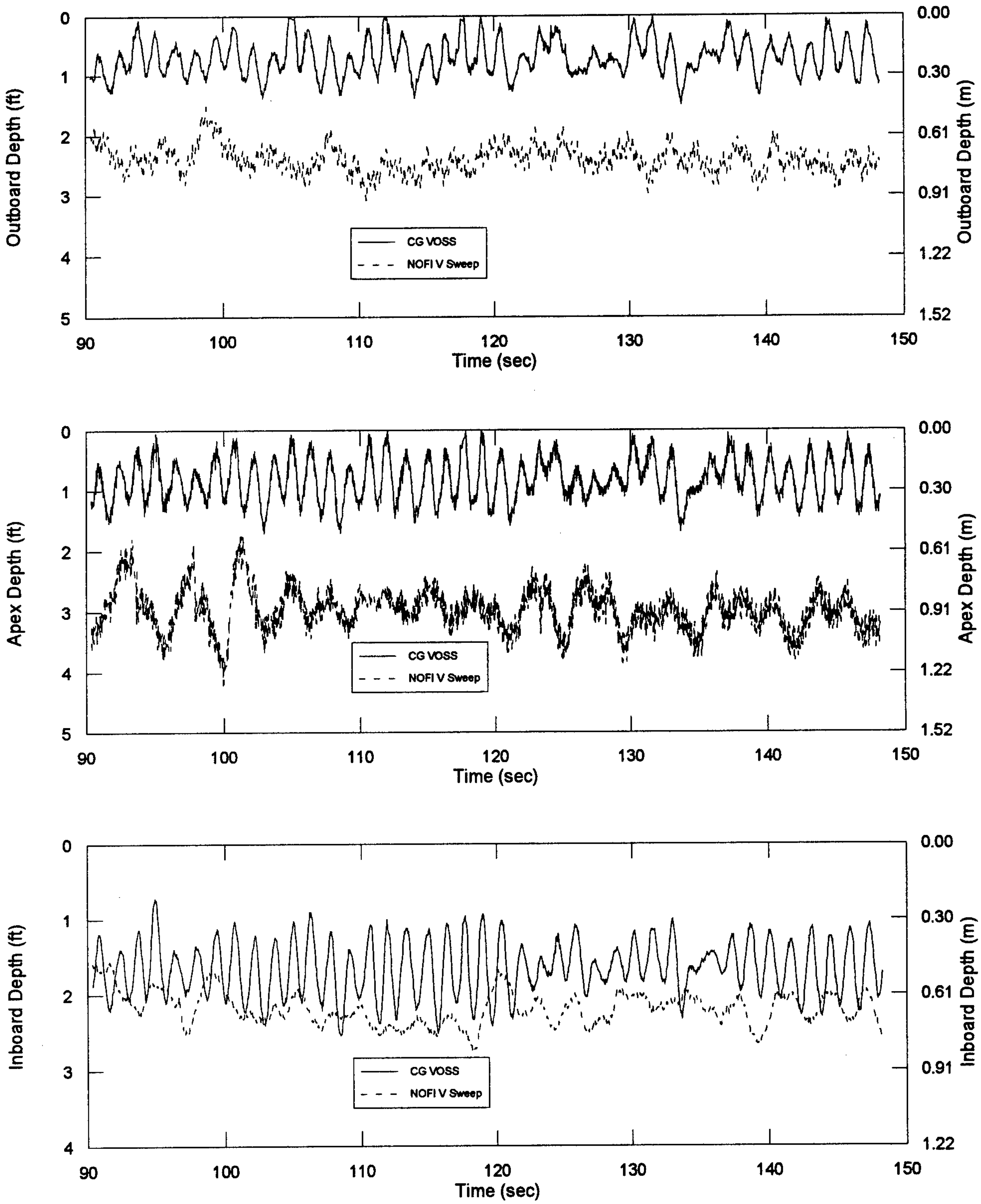


Fig. D.18. Closeup of CG VOSS and NOFI V Sweep boom skirt depths at 2 knots in 2 - 4 foot 45 degree stbd. seas. (Run 30, 5/6/93)

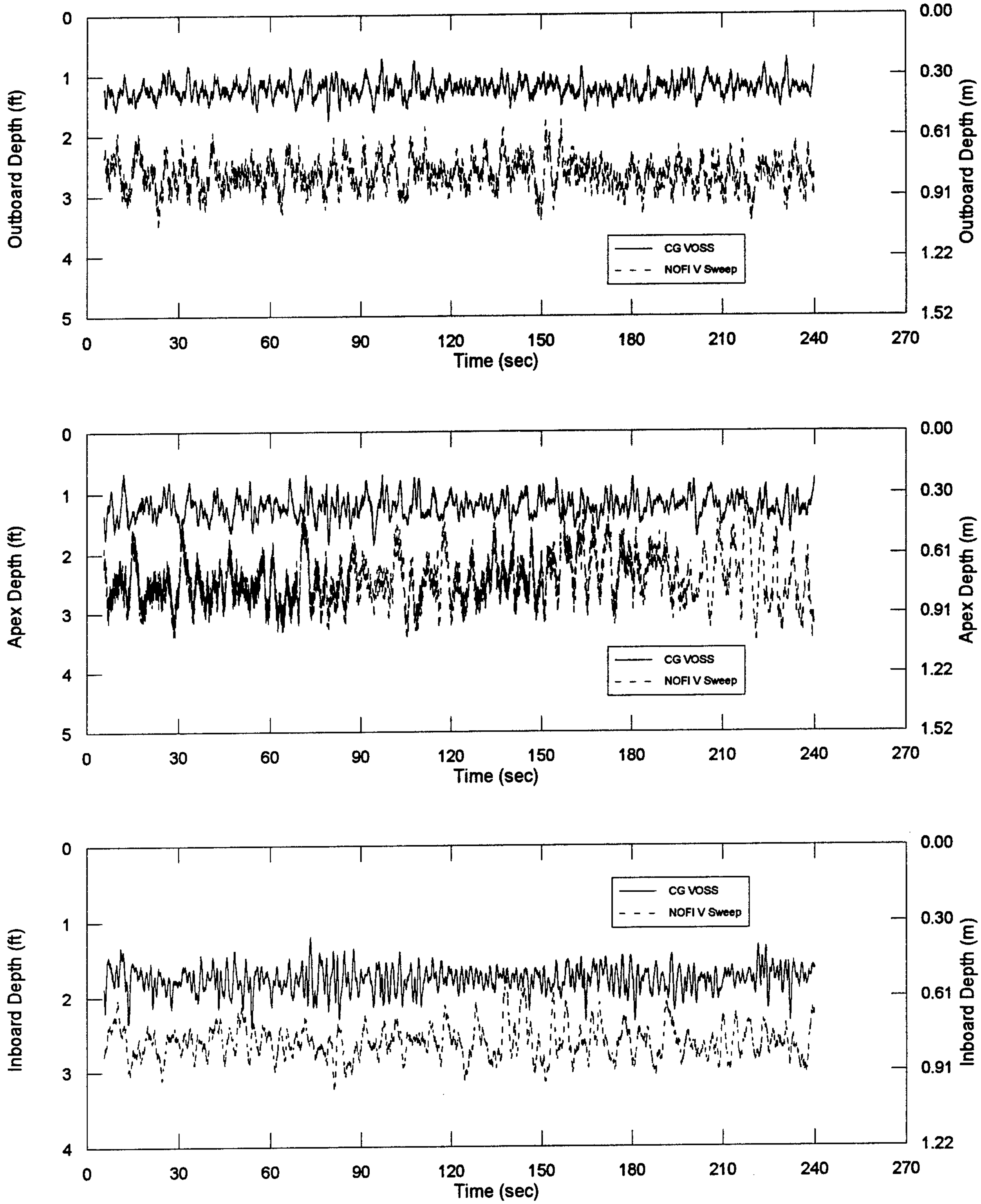


Fig. D.19. CG VOSS and NOFI V Sweep boom skirt depths at 1 knot in 2 - 4 foot 45 degree stbd seas. (Run 31, 5/6/93)

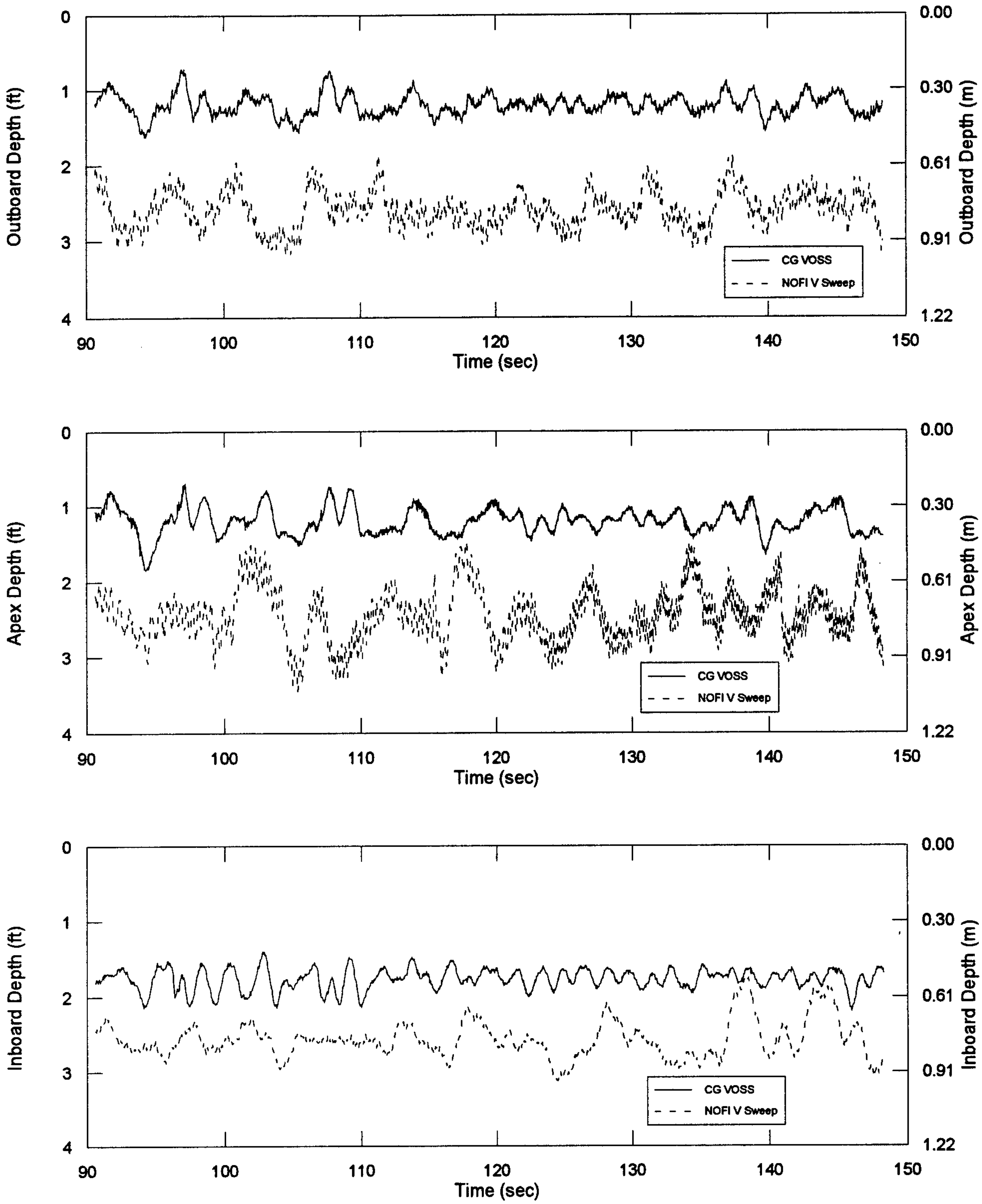


Fig. D.20. Closeup of CG VOSS and NOFI V Sweep boom skirt depths at 1 knot in 2 - 4 foot 45 degree stbd. seas. (Run 31, 5/6/93)

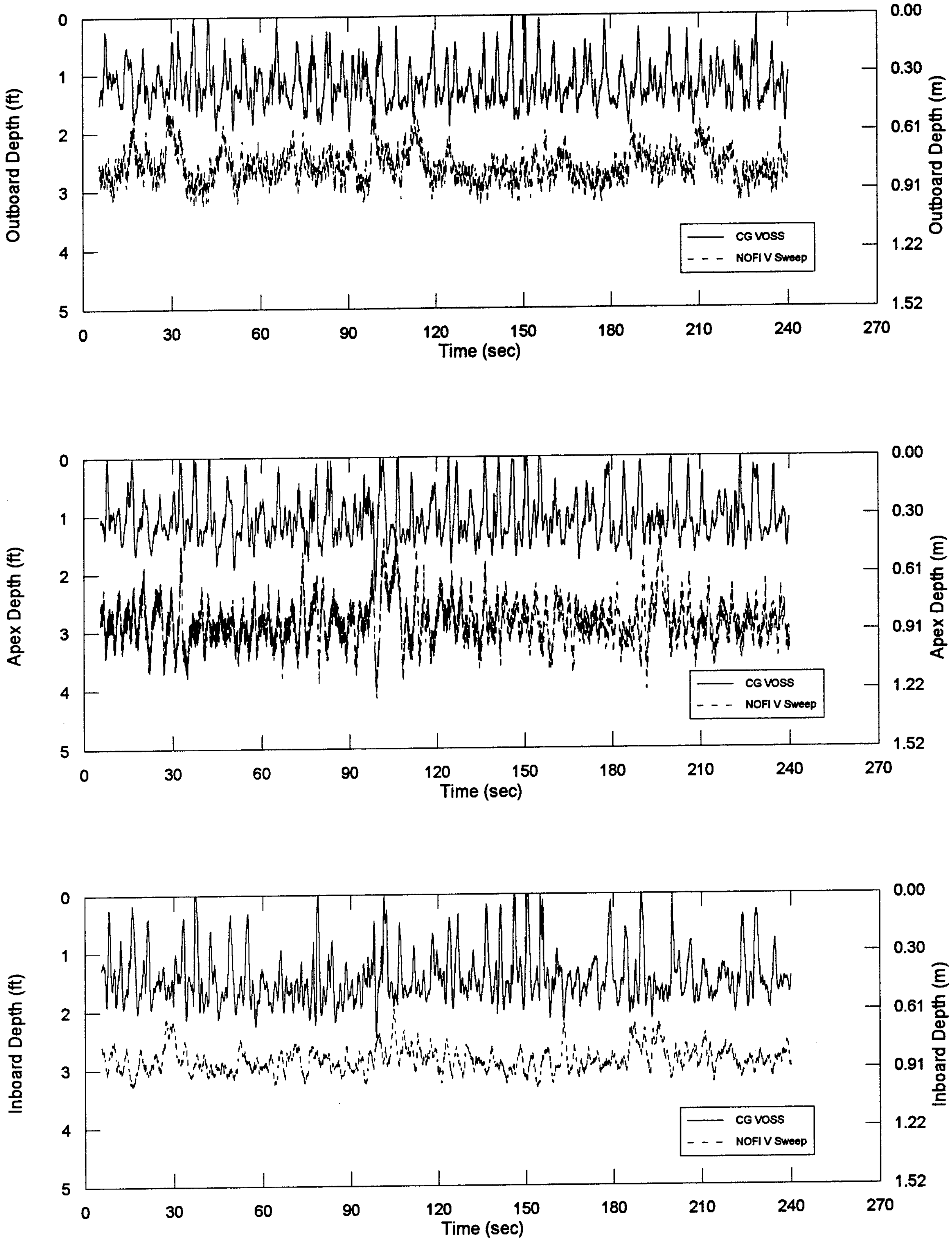
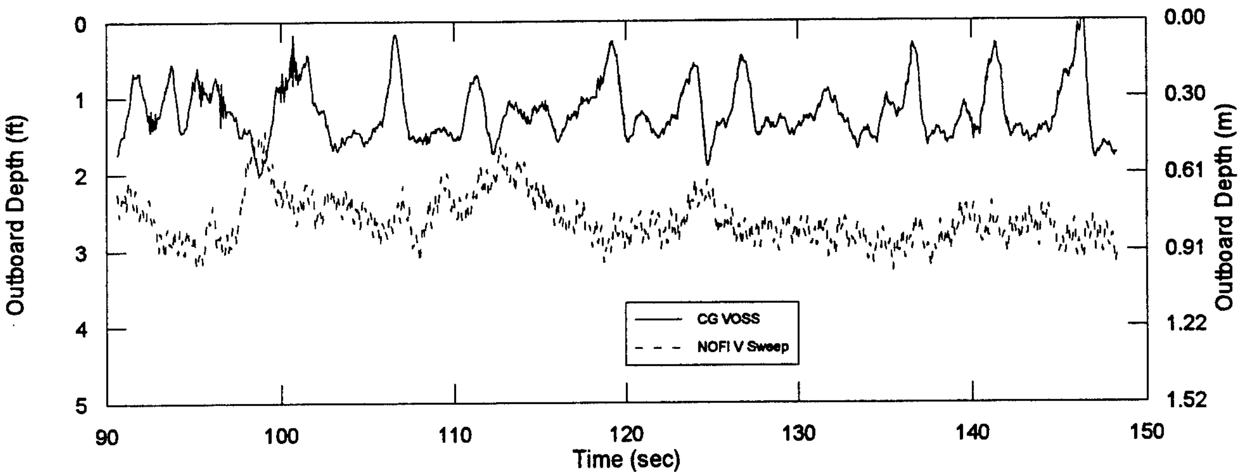
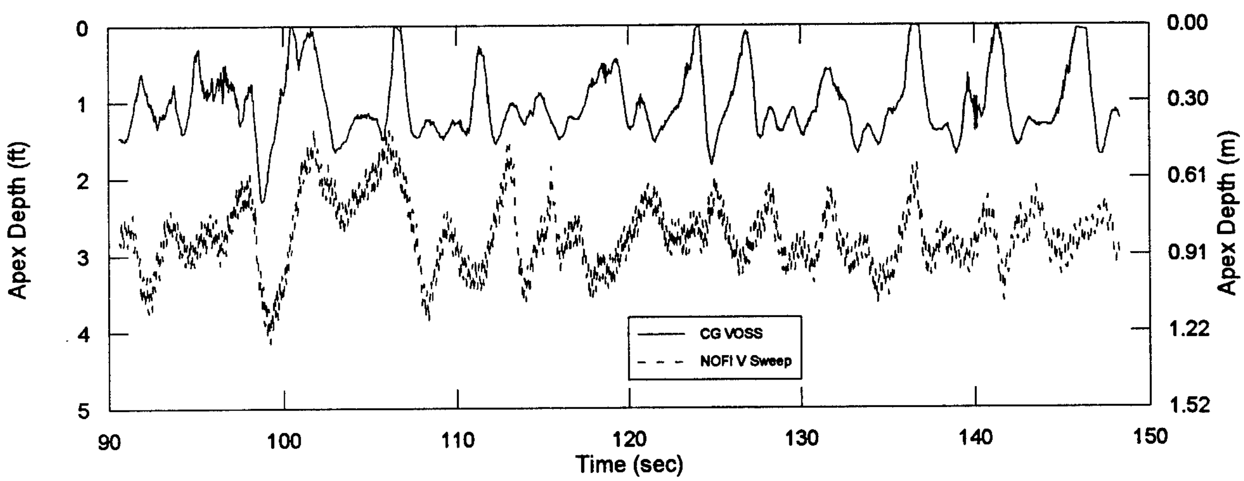


Fig. D.21. CG VOSS and NOFI V Sweep boom skirt depths at 1 knot in 2 - 4 foot 45 degree port seas. (Run 33, 5/6/93)





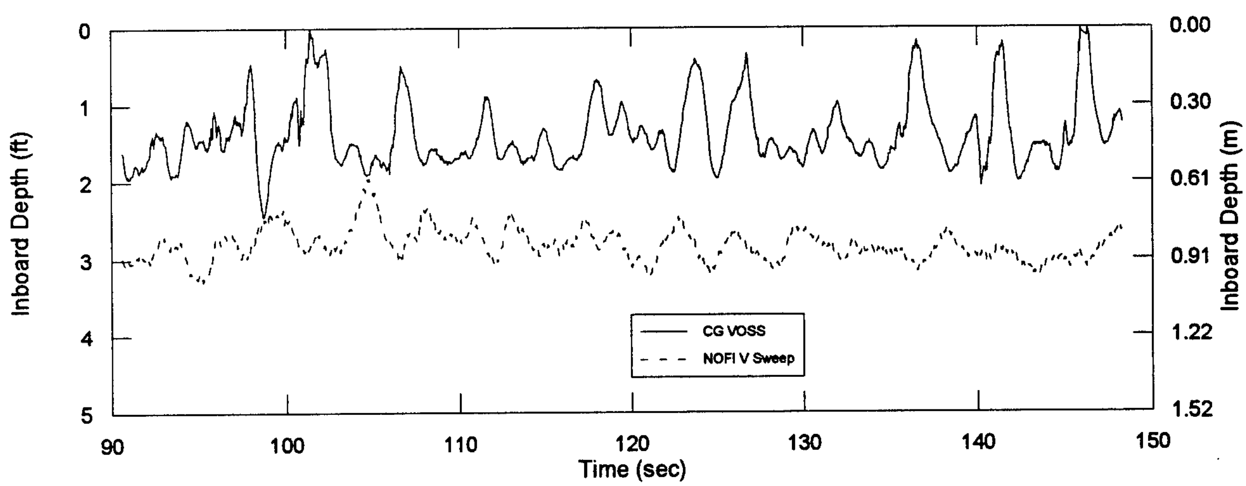


Fig. D.22. Closeup of CG VOSS and NOFI V Sweep boom skirt depths at 1 knot in 2 - 4 foot 45 degree port seas. (Run 33, 5/6/93)

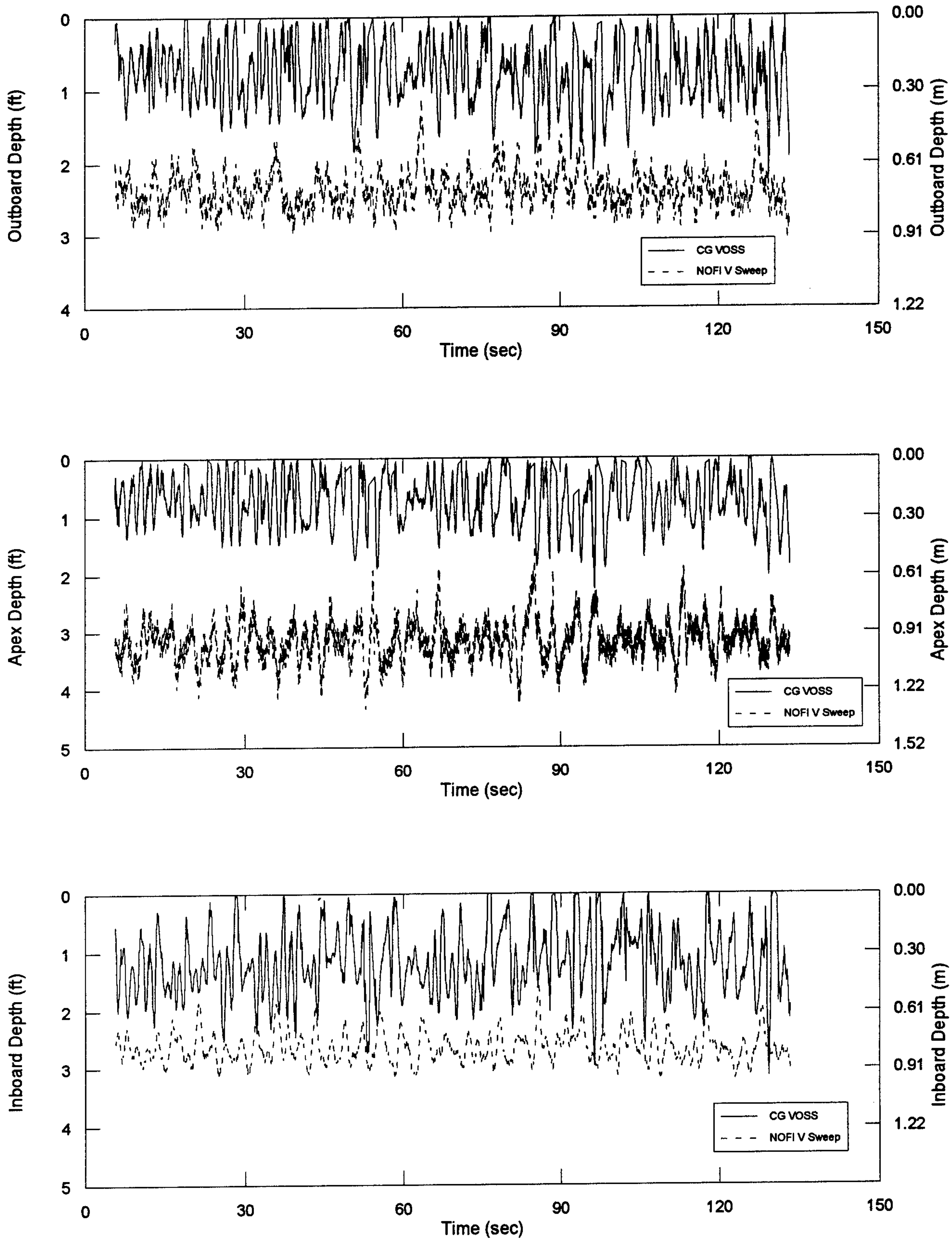


Fig. D.23. CG VOSS and NOFI V Sweep boom skirt depths at 2 knots in 2 - 4 foot 45 degree port seas. (Run 34, 5/6/93)

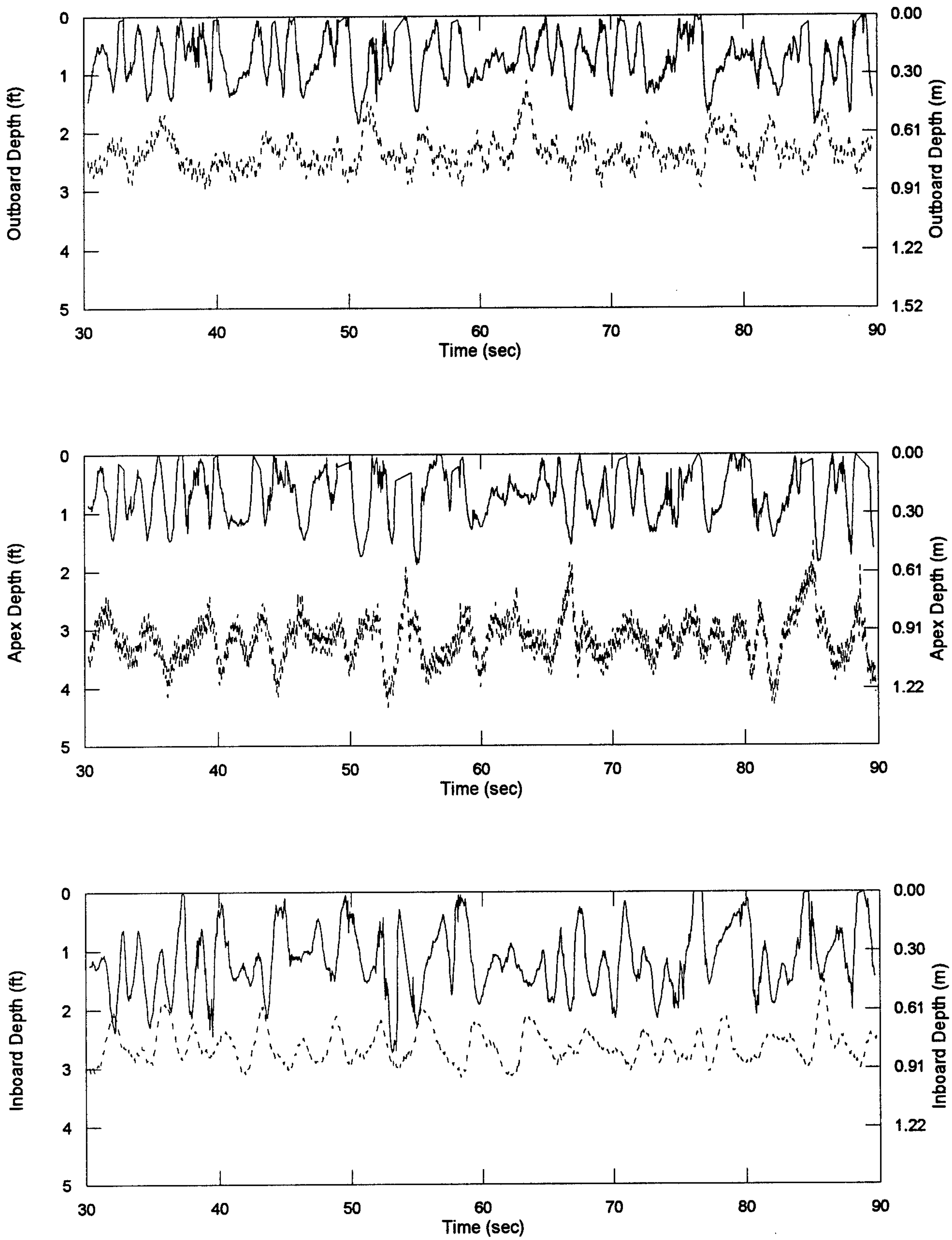


Fig. D.24. Closeup of CG VOSS and NOFI V Sweep boom skirt depths at 2 knots in 2 - 4 foot 45 degree port seas. (Run 34, 5/6/93)

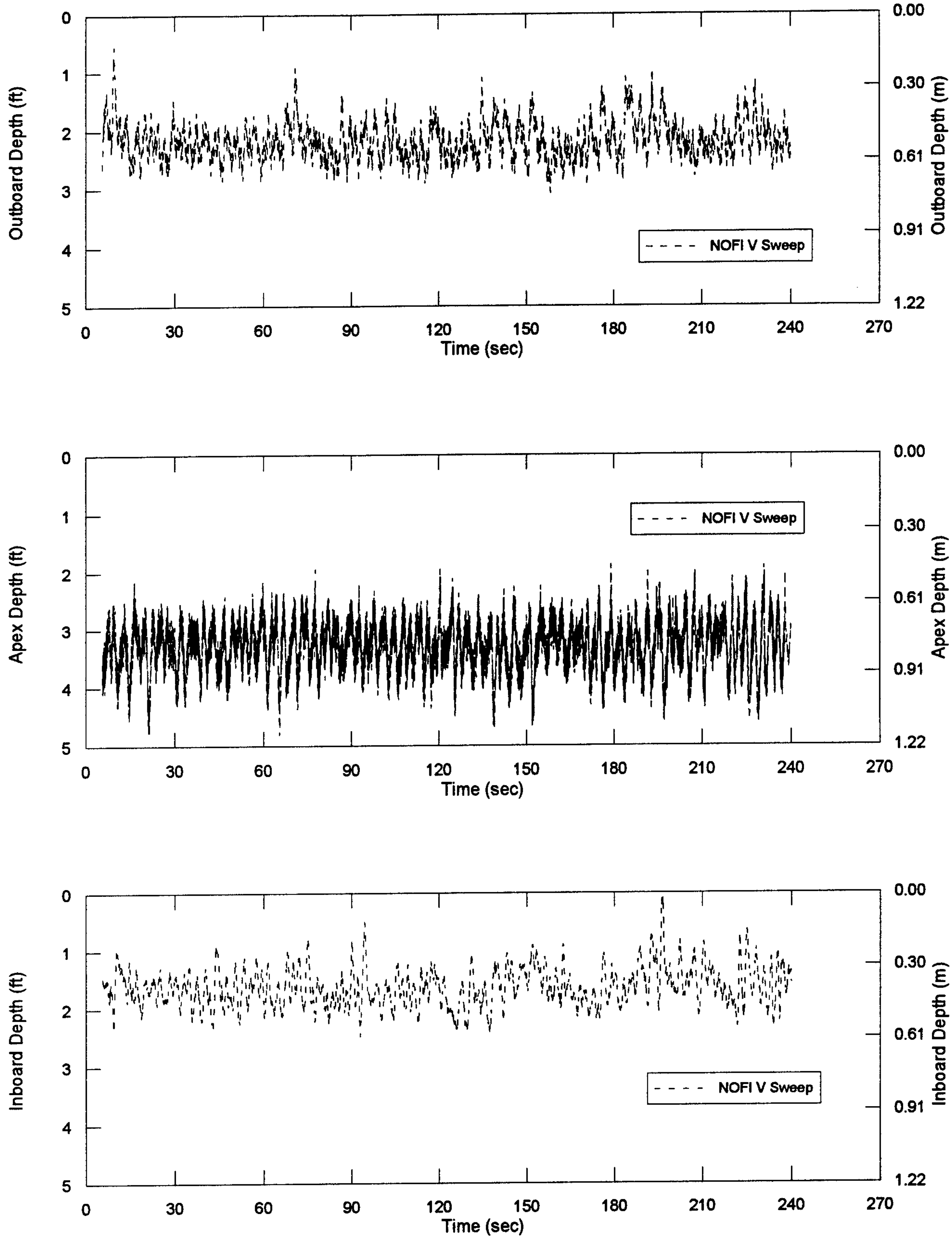


Fig. D.25. NOFI V Sweep boom skirt depth at 3 knots in 2 - 4 foot head seas. (Run 35, 5/6/93)

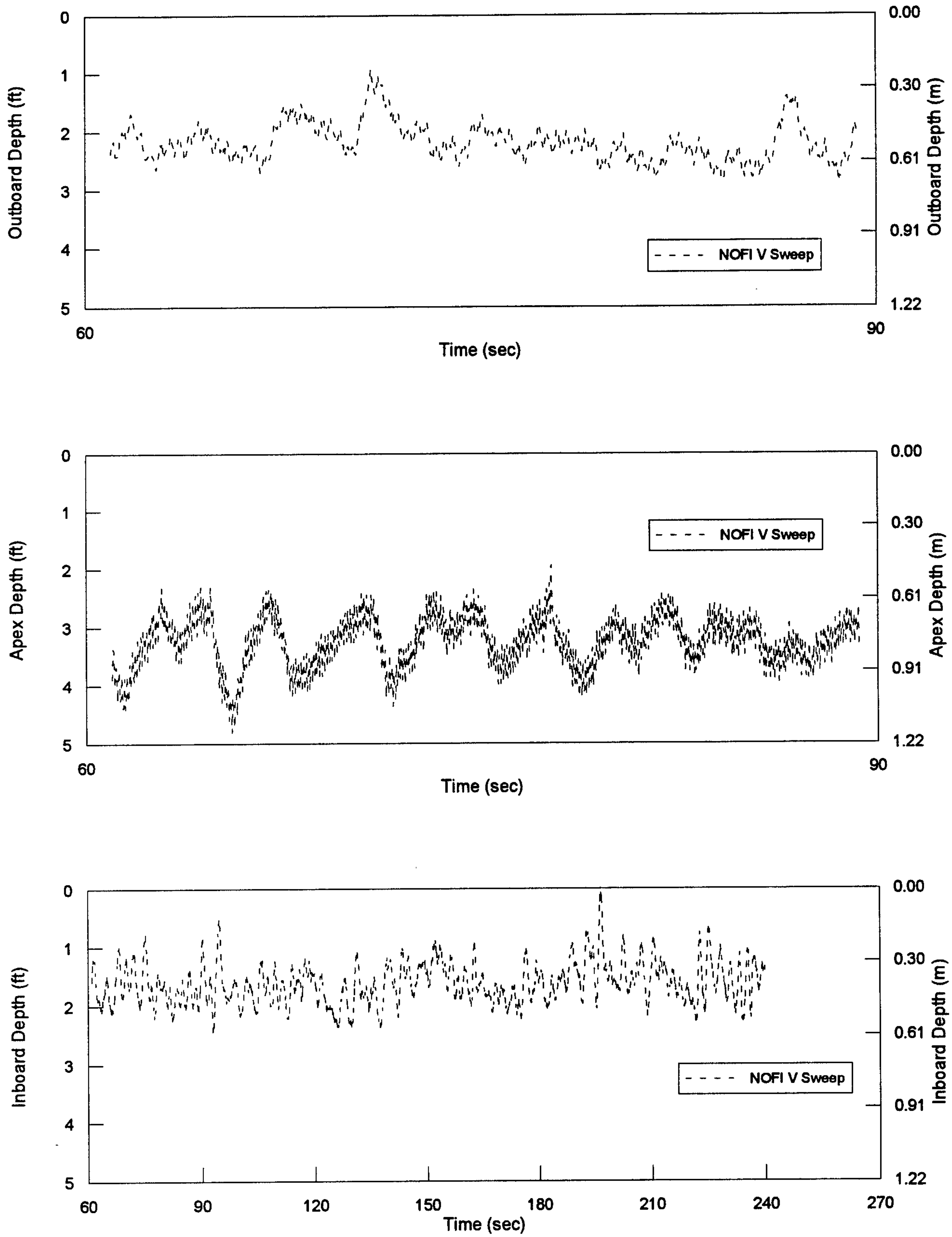


Fig. D.26. Closeup of NOFI V Sweep boom skirt depths at 3 knots in 2 - 4 foot head seas. (Run 35, 5/6/93)

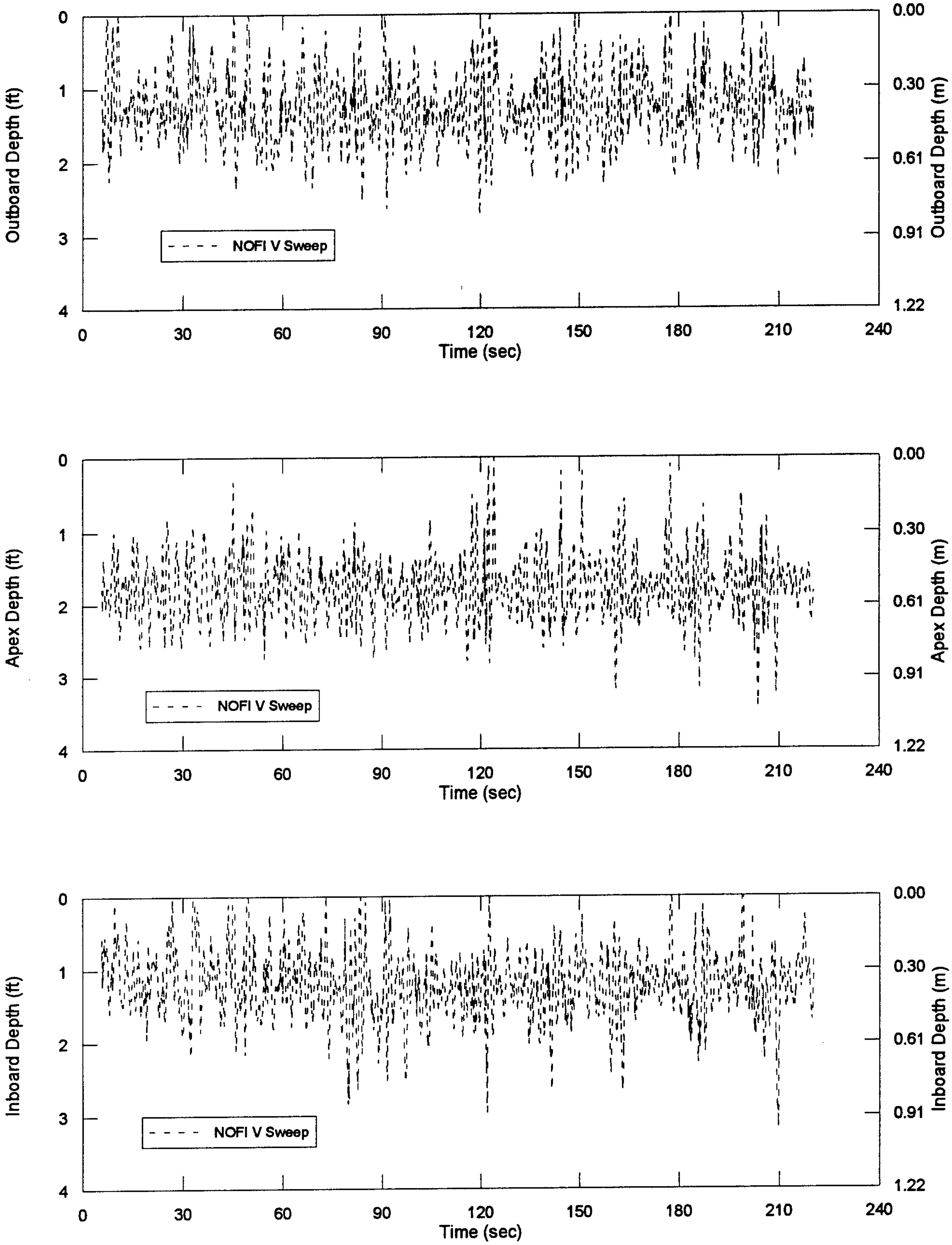


Fig. D.27. NOFI V Sweep boom skirt depth at 1 knot in 3 - 5 foot head seas. (Run 50, 5/11/93)

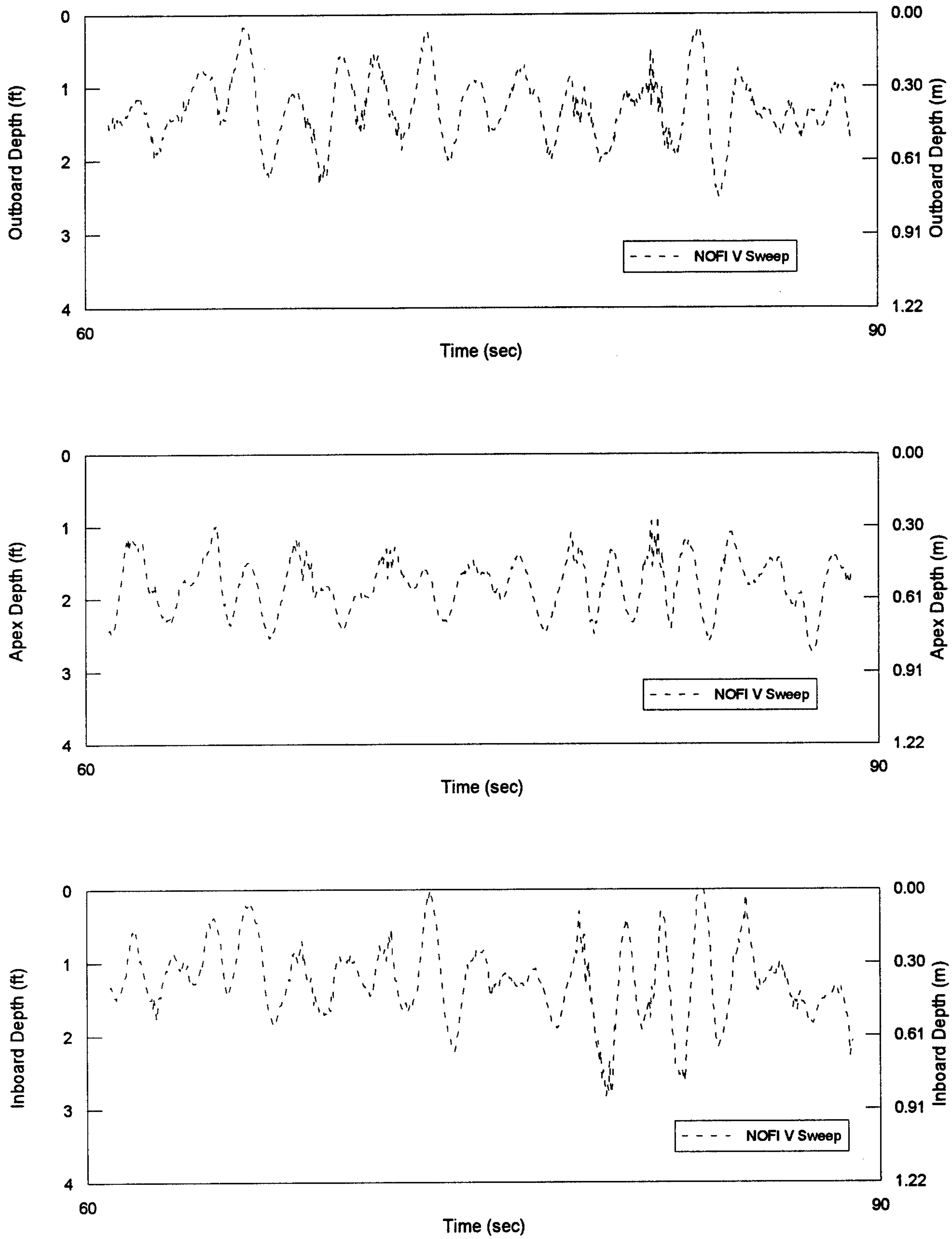


Fig. D.28. Closeup of NOFI V Sweep boom skirt depth at 1 knot in 3 - 5 foot head seas. (Run 50, 5/11/93)