UNIVERSITY - NATIONAL OCEANOGRAPHIC LABORATORY SYSTEM

RESEARCH VESSEL TECHNICAL ENHANCEMENT COMMITTEE

MEETING MINUTES

November 11, 12, 13, 1996

J. Seward Johnson Marine Education and Conference Center
Harbor Branch Oceanographic Institution
Ft. Pierce, FL

RESEARCH VESSEL TECHNICAL ENHANCEMENT COMMITTEE
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MEETING MINUTES

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Monday, 11 November

Introduction

The meeting was called to order by Chair, Rich Findley, at 0900 on Monday, 10 November, 1996 at the J. Seward Johnson Marine Education and Conference Center, Harbor Branch Oceanographic Institution, Ft. Pierce, FL. Tim Askew, HBOI Director of Marine Operations, welcomed the group to HBOI. Participants introduced themselves and Rich Findley reviewed the meeting agenda. The agenda and list of participants are included as ***Appendix I*** and ***Appendix II***. Rich Findley briefly reviewed the history of RVTEC and its accomplishments since the inception of the committee in 1992.

Communications (Appendices III, IV)

Rich Findley presented information on the MSAT service (also known as satellite cellular telephone). MSAT is an all digital communications system, primarily used on land, and in coastal regions. Coverage is coastal US, Alaska, Hawaii and central America. There are several providers, including American Mobile Satellite Corporation, Cruise Phone Communications International (CPCI), MarineSat and Seven Seas. The system provides data transmission (2400 baud, 4800 baud testing), fax (2400 baud testing) and packet data transmission. Charge rates vary from $1.29 to $2.00 per minute for voice, data and fax. Rich outlined a rate plan for UNOLS vessels with CPCI. One-time charges include activation ($50) and PIN service ($30). Incremental rates include voice service ($40/month), fax and data service ($15/month) and airtime

($1.29/minute). Entry cost on an MSAT system runs $6,000 - $10,000 depending on specific ship requirements.

Rich also gave a short presentation on DirectPC, a downlink-only communications link. DirectPC works in a similar fashion to DirectTV, using a small dish antenna. DirectPC provides a high-speed downlink to the ship (400 kbps), but no uplink capability. Information on DirectPC can be obtained at:

http://www.direcpc.com

Andy Clark (HBOI) gave a brief overview of OceanNET, a cooperative venture between HBOI and Harris Corp, see ***Appendix III***. Andy introduced Ray Kohler of Harris Corp., who gave a short overview of the system. OceanNET is a ship or buoy-based high-speed data transmission system, capable of 1 Mbit/sec transfer rates from ship to shore. It has been deployed on a 5m buoy with onboard diesel power plant. Transmission is via IntelSat, a geostationary satellite. The uplink requires an 18-inch antenna. A spread-spectrum technique is used to reduce interference and allow multiple access to the same bandwidth. The OceanNET buoy can be communicated with via Inmarsat-C for command and status functions. The OceanNET concept is used in the Gulf of Mexico for aircraft VHF-FM communications relay. OceanNet is useful primarily for high-speed ship-shore communications. Communications from shore-ship are much slower. Coverage is available worldwide.

Following a short break, Chris Riffe (LUMCON) posed a question about data communications via HF radio. A short discussion of HF packet communications followed.

Rich Findley presented information on the MerLAN system under development by the Marine Technician Group at HBOI, see ***Appendix IV***. MerLAN is an integrated shipboard and underwater system designed to provide 10 Mbit ethernet communications to lowered or towed packages. The underwater unit was displayed. The heart of the system is a PC-104 board stack in the underwater unit. The system is designed to operate over a single-mode optical fiber up to 20km long. Both power and fiber signals and power are transferred through the winch by copper or mercury slip rings. Fibers are terminated in the winch hub with standard fiber optic terminators (FOTs). All control and I/O software are available off-the-shelf. The cable presently being used for MerLAN is a Rochester 0.322" diameter, 3-conductor cable with one optical fiber within each conductor stranding. This cable has the same form factor and working load specifications as UNOLS standard CTD cable. The fiber optic version of this cable is Rochester # A-304059. This cable costs about seven times the cost of UNOLS cable ($10/m versus $1.50/m) due to the much closer tolerances required for the single mode fiber.

Autonomous Underwater Vehicles (AUVs, Appendix V)

Dan White (HBOI Engineering Division) gave a short presentation on AUVs, see ***Appendix V***. Dan outlined the different types of AUVs, and gave background information on the strengths and weaknesses of each.

Morning Wrap-up

The floor was opened to discussion of the morning's presentations. Several topics were discussed, including file transfer protocols on the World Wide Web, TCP/IP address conflicts encountered by scientists moving computers from shore labs to ships, TCP/IP as a standard networking protocol for ships, file transfers by FTP versus NFS, various WWW topics including Java, the impact of NetPCs, and HTML delivery of real-time data displays. Rich Mueller (MLML) posed a question about running SeaBird CTD software under Windows'95. There was a short discussion of other software conflicts under Windows95.

Conducting Cable Workshop - I (Appendices VI, VII, VIII)

Following a lunch break, Rich Findley introduced Don Moller (WHOI) who gave a short history of the UNOLS wire pool system. Don then introduced Phil Gibson of Tension Member Technology.

Phil began his presentation with an analysis of the UNOLS 0.322" CTD cable which was recently completed for UNOLS. Copies of the plots resulting from this analysis are included in ***Appendix VI***. Following this presentation, Phil began discussing topics of interest to the committee, and answering questions from the committee. ***Appendix VII*** is a complete copy of the Cable Workshop Notes as prepared by Mr. Gibson. The following topics were addressed. These comments are from Phil Gibson, as transcribed by the Vice-Chair. Any errors are NOT Mr. Gibson's.

Fleet Angle: Operating wires at high fleet angles will cause twist in the cable by a rolling action on the cheeks of the sheave.

Snap Loading: UNOLS 0.322" cable is generally not sensitive to loading rate, but is sensitive to maximum load achieved.

Ends-Fixed Towing or Lowering: In the ends-fixed case (no swiveling of package, e.g., MOCNESS or SeaSoar), there is a large twist gradient at the sheave end of the cable, and a small twist gradient at the lowered or free end. Between these areas, there is an area of zero torque in the cable. When the cable is lowered, there is a tension gradient but no net torque is induced in the cable. Once a cable has been spooled, there is little additional twist induced in the cable in an ends-fixed application.

Preconditioning of cable: Cables should be preconditioned under the same conditions (or as close as practical to them) as they will be operated. Many cable manufacturers will "prestress" a cable, but this is not necessary.

Definition of Breaking and Safe Working Loads (SWL): Breaking load is defined as the load required to cause a mid-cable break of a sample. Safe Working Load is usually a very conservative downrating of the breaking load. There is no standard calculation of SWL; it is determined by the manufacturer. Safe Working Load may be more dependent on the yield point of the copper conductors than the yield point of the armor.

Dynamic Loading: The important factor in dynamic or "snap" loading is the maximum tension reached. The speed at which one arrives at the maximum tension is relatively unimportant. Every effort should be made to measure peak tensions in dynamic situations.

Spooling Cables and Spooling Tension: Winding cables under tension is also known as profile winding. When spooling cables, one should try to match the tension profile through the drum which the cable will experience during use. This technique will also "pre-yield" the copper conductors. One possible problem with traction winches is that the cable is stressed when hauled over the traction device, then stored under low tension, i.e., the storage tension profile does not match the use profile.

This ended the proceedings of 11 November.

Tuesday, 12 November

Conducting Cable Workshop - II (Appendices VI, VII, VIII)

The meeting was reconvened at 0830 on 12 November. Phil Gibson resumed his discussion of cables with topics which had come up the previous evening.

Waterblocking: Copper and other wire cores need waterblocking for waterproofing, for radial stability and to accommodate squeeze by tension or pressure. Void fillers are not necessarily waterblockers.

Optical Fiber Cable Considerations: Within a hybrid (copper-fiber) cable, the copper conductors have the lowest yield, with the optical fibers having a higher yield tension. The main problem with fibers is long-term storage under tension. The copper surrounding the fibers must have a higher yield strength because of the small helix angles of the copper bundles. This small helix angle does not strain relieve the copper conductors.

Cable Helix Angles: The helix angle is defined as the angle between the AXIS of the cable and the helix. Low helix angles give high strength and low stretch. However, low angle cables are susceptible to armor wire displacement and crossovers, especially in multiple layer winding and where cables are repeatedly run over sheaves. Slightly higher helix angles will give slightly lower strength and higher stretch, but perform better in multiple layer applications and where cables are repeatedly run over sheaves.

Lay Length: Lay length is defined as the down-cable distance of one rotation around the cable.

Sheave Treads and Lebus Shells: Sheave treads should conform as closely as possible to the wire diameter. If treads do not match closely, wires should be watched closely for signs of bending fatigue. Flat-treaded sheaves provide little support for cables. Narrow-treaded sheaves cause pinching of cables. UNOLS 0.322" cable is nominally 0.324" (0.322-0.325). According to Don Moller (WHOI) all UNOLS winch drums are Lebus grooved for 0.327" wire. Lebus grooving must match cable diameter as well as cheek-to-cheek distance, and are made to very close tolerances.

Bending Cycle: One bending cycle is defined as one cycle of cable straight-cable bent-cable straight.

Levelwind Rollers: Rollers on levelwinds may be significant if fatigue failure is a problem. Soft plastic rollers have certain advantages in supporting the wire. Flat-faced rollers cause problems because the wire is supported for less of its circumference. These problems are worse with 3x19 cable because its triangular cross-section provides less support for the cable. Small diameter rollers cause excessive bend fatigue.

Cable Lubrication: Heavy, thick tar-like lubricants do not assist cable lubrication. A low viscosity, penetrating lubricant is required to penetrate and lubricate between cable components.

End-for-Ending Cables: This is not recommended. End-for-ending puts the wire in best condition at the working end, but puts the wire in worst shape at the point of highest tension. If this practice is followed, one must closely monitor the amount of wire overboard so that cable which was previously stressed does not bear the full load of a lowering. Additionally, end-for-ending reverses the tension profile of the wire, and subjects the cable to new and different stresses, which may result in premature conductor or cable failure.

Kevlar and Synthetics: Synthetics currently available are:

> Technora: This is an Aramid (Kevlar) synthetic made by a different process. Technora is 30% higher in strength, and Technora fibers are 15% stronger than comparable Kevlar fibers. Bending fatigue is 50% better than Kevlar, and strength efficiency is better. Technora suffers from the same failure problems as Kevlar (abrasion and transverse loading).
>
> Vectran: This is an expensive (twice the cost of Kevlar) synthetic with a larger filament than Kevlar. It is more tolerant of transverse loading, but has similar stretch and strength as Kevlar. Bending fatigue performance is better than Kevlar.
>
> Spectra: This synthetic is not useful for EM cables. Spectra creeps under load and has too much stretch for EM cables.

Kevlar Stretch: Braided Kevlar is more stretchy than served Kevlar. Kevlar cables must be designed to protect the core components.

Kevlar Strain and Loading: Tensions on Kevlar cables must be kept relatively high. Bending fatigue is worse at low tensions because of tension/compression differences and puckering on the inside of a bend. Kinks at joints of mylar inner jackets can break the adjacent Kevlar strands.

Cable Terminations: Mr. Gibson discussed several terminations, including the PMI Deadend grip (known as the "finger grip"), the PMI Dyna-Grip and its bending strain relief, Kellum grips (these are NOT recommended) and Resin Sockets.

Resin Socket Terminations: Resin sockets (or Crosby Sockets) are useful for multiple cyclic loading applications. "Socket Fast" resin (ESCO Corp.) is recommended. The socket must have a conical insert. Cone angles should not exceed 15 degrees total angle. Such shallow cone angles are needed for maximum wedging action. Likewise, the bore of the cone should be smooth, not annulated. The smooth bore provides maximum surface area for wedging with the resin plug. The socket should have a keyway in the wall to prevent rotation.

Following the cable discussion, Don Moller (WHOI) began a discussion of specifications for the next generation of UNOLS cables. Don began by giving a history of the UNOLS wire pool, and a historical review of the design of the 0.322" UNOLS cable, see ***Appendix VIII***. Phil Gibson (TMT) interjected some comments on the design process. He noted that the design should be driven by performance, not detail. Mr. Gibson also commented that a hybrid (copper-fiber) cable is not necessarily the best approach, as one might end up with the worst of both types, or a cable which does neither very well.

Following this introduction, the committee discussed some of the requirements and specifications for a new cable. There was also some discussion about writing specifications which included or allowed synthetic cables. The possibility was raised that there might be two specifications, one for steel, one for synthetic. This discussion concluded with the appointment of a Subcommittee on Cable Specifications. Subcommittee members are: Don Moller (WHOI), Rich Findley (U.Miami/HBOI), John Freitag (RVTEC Chair, URI) and Mike Webb (NOAA PMC).

Tour of Harbor Branch and R/V SEWARD JOHNSON

Following a lunch break, Rich Findley presented an introduction to the R/V SEWARD JOHNSON, and a short film outlining HBOI activities. The rest of the day was spent touring HBOI facilities and R/V SEWARD JOHNSON.

Wednesday, 13 November

The meeting was reconvened at 0840 on 13 November. Rich Findley introduced attendees from NAVOCEANO who joined the meeting that morning.

Database Subcommittee Report

Database Subcommittee Chair, Tom Wilson (SUNY-Stony Brook), gave an update on the activities of the Database Subcommittee. He demonstrated the latest version of the RVTEC homepage, and invited comments on where the subcommittee should go next. Tom outlined the weaknesses of the current server at URI, and stressed the need for a more-capable server. The committee at large discussed what items should be made available at the homepage. Suggestions for a searchable database of equipment and personnel, and on-line equipment request forms. UNOLS is going to on-line forms for most of its business, and RVTEC might do the same. Barrie Walden (WHOI) offered to work with Tom on finding a new server for the homepage, possibly at WHOI. Actions items for the Database Subcommittee are: 1) Advertise more widely on the web; 2) Find a more capable host for the homepage; 3) Develop a searchable database on a more capable host (when found).

The URL for the RVTEC homepage is:

http://www.gso.uri.edu/unols/rvtec/rvtec.html

Data Interchange Subcommittee

Data Interchange Subcommittee Chair Marc Willis (OSU) gave a historical review of the effort to incorporate netCDF as a standard data delivery format for UNOLS vessels, and gave some thoughts on future directions for this effort. Steve Poulos (U.Hawaii) agreed to take over as Subcommittee Chair.

Steve Poulos outlined his thoughts about where the effort should go next. He requested that all participating institutions send sample copies of their shipboard data files to him. Steve will use this information as background for development of a proposal to fund a person to facilitate the transition from current formats to netCDF. The committee discussed at length the best method for transitioning from current formats to netCDF, and the consensus was that one highly-skilled person helping all institutions is probably the best approach. The Data Interchange Subcommittee was tasked with developing an implementation plan for netCDF on UNOLS vessels.

National Science Foundation (Appendix IX)

Following a short break, Sandy Shor (acting NSF-OCFS Instrumentation and Technical Services Program Director) outlined the current budget situation at NSF, see ***Appendix IX.***

Sandy then reported on a meeting he had attended the previous week about the Marine Advanced Technical Education initiative, an effort of the Monterey Peninsula College. Based on feedback from RVTEC and other marine technical communities, it appears that there is a need for this type of training, both for academia and for industry. Development of this program will continue.

Sandy advised RVTEC that the International Ship Operators Meeting (ISOM) had held an International Marine Technicians Workshop at Southampton, England in late September, 1996. ISOM is interested in holding a joint meeting of International Marine Technicians and RVTEC in 1998. The next chair (John Freitag, URI subsequently elected) is charged with contacting the organizer of the 1996 Workshop (Ken Robertson, Research Vessel Services, UK) to discuss a joint meeting.

NAVOCEANO Requirements

Cindy Kelly and Dennis Kyman (NAVO) were introduced, and outlined the requirements for the NAVOCEANO cruises scheduled on UNOLS vessels for 1997. Dennis Kyman reviewed the operational plans for the various surveys, including equipment requirements, personnel requirements, data processing requirements, water sampling and coring. The point of contact for institutions performing NAVO research is Gordon Wilkes.

Salary Survey

Rich Findley noted that it has been some years since a salary survey was done for Technicians. RVTEC will conduct the survey, with the UNOLS office coordinating to preserve confidentiality. The plan is to provide the survey form on the web page, and have it returned in hard copy to UNOLS.

Long-Range Instrumentation Planning

Rich Findley proposed the establishment of a Long Range Instrumentation Planning Subcommittee. Rich agreed to serve as chair.

Election of Chair

Rich Findley has served two terms, the maximum allowed by the RVTEC charter. One nomination was received, John Freitag (URI). The nomination was moved by Chip Maxwell and seconded by Carroll Baker. John Freitag was elected chair by acclamation. John will serve a two year term.

Subcommittees

Database Subcommittee - This Subcommittee was renamed the On-line Resources Subcommittee, and Tom Wilson will continue as chair.

Data Interchange Subcommittee - This Subcommittee was renamed the Data Standards and Exchange Subcommittee. Steve Poulos will take over as chair replacing Marc Willis.

Wire and Cable Specifications Review Subcommittee - This new Subcommittee will be chaired by Don Moller.

Next Meeting

Neil Bogue (UW) agreed to host the next annual meeting of RVTEC. The meeting is tentatively scheduled for 20-22 October 1997 at the University of Washington, Seattle.

Other Business

Comments are requested on the University of Hawaii SWATH vessel designs. Comments should be sent to UNOLS.

Tom Wilson has come up with an RVTEC logo design. This will be posted on the web page. Members are encouraged to vote yea or nea on this design, and to submit other designs.

There was a short discussion of possible workshop topics for the next meeting. Some of the ideas are: Marine Corrosion, SeaBird CTD, ADCP.

Rich Findley asked members to think about collaborating on an RVTEC CD-ROM to distribute commonly-used software, manuals, etc.

Rich Findley reminded members to distribute their Technicians and Instrumentation Proposals to UNOLS members.

The SeaNET Group was not represented at the meeting, but sent a written update. This is included as ***Appendix X***.

Adjournment

Adjournment was moved by Tom Wilson, and seconded by Tim Deering (U.Delaware). The meeting was adjourned at 1240 on Wednesday, 13 November.

APPENDIX I

Agenda

Research Vessel Technical Enhancement Committee

November 11 - 13, 1996
8:30 AM to 5:00 PM
Harbor Branch Oceanographic Institution, Inc.
J. Seward Johnson Marine Education & Conference Center
2nd Floor, East Conference Room

MONDAY	Agenda topics
8:30 AM	Informal Networking
9:00 AM	Meeting Called to Order
	---Welcome by Tim Askew
	---Introductory Remarks by Chair
9:15 AM	Participant Introductions
9:30 AM	Communications:
	---OceanNET SEANET, MSAT, DIRECT PC
10:15 AM	Break
10:30 AM	New Instrumentation
	---MerLAN
	---AUVs
12:00 PM	Lunch
1:00 PM	Conducting Cable Workshop
3:00 PM	Break
3:15PM	Conducting Cable Workshop (continued)

TUESDAY

8:30 AM	Meeting Called to Order
8:15 AM	Conducting Cable Workshop (continued)
10:15 AM	Break
10:30 AM	Conducting Cable Workshop (continued)
12:00 PM	Lunch
1:00 PM	Tour of HBOI Facilities
	---Orientation
	---Video
	---Facilities tour
4:00 PM	Tour of R/V SEWARD JOHNSON
5:00 PM	Reception Hosted by HBOI

Wednesday

8:30 AM	Sub committee Reports
	---Technician & Equipment Database Subcommittee Report
	Database workshop
	---Data Standards Introduction; Mark Willis followed by;
	Data Standards Workshop
10:00 AM	Break
	Development Of Curricula Or Training Of Marine Technicians
	International Marine Technician Training Course- Workshop
	NAVO Technician requirements
	Salary Survey
	Long Range Instrumentation Planning
	Election of Chair
	Updating of Action Plans
	Scheduling of Next Meeting
	New Business
1:00PM	Adjournment
	Presentation by International Comunications Group

APPENDIX II

1996 RVTEC Meeting Attendees

First Name	Last Name	Organization	Address	City, State, Zip	Phone	Fax	Email
Anthony	Amos	University of Texas Marine Science Institute	750 Channelview	Port Aransas, TX 78373	512-749-6720	512-749-6777	afamos@utmsi.zo.utexas.edu
Douglas	Anderson	NOAA/AOML/PHOD	4301 Rickenbacker Csy	Miami, FL 33149	305-361-4510	305-361-4392	
Norman	Andresen	University of Michigan	2200 Bonisteel Blvd - CGlas	Ann Arbor, MI 48109-2099	313-647-2734	313-647-2748	andresen@umich.edu
Dwight	Arrants	Duke/UNC	135 Duke Marine Lab Road	Beaufort,NC 28516	919-504-7583	919-504-7651	dwighta@duncoc.ml.duke.edu
Tim	Askew	Harbor Branch Oceanographic Institution	5600 U.S. 1 N.	Ft. Pierce, FL 34946	561-465-2400	561-465-2116	taskew@hboi.edu
Carroll	Baker	Skidaway Institute of Oceanography	10 Ocean Science Circle	Savannah, GA 31411	912-598-2464	912-598-2310	
Neil M.	Bogue	University of Washington School of Oceanography	Box 357940	Seattle, WA 98198-7940	206-543-4485	206-685-7436	bogue@ocean.washington.edu
Kenneth	Bottom	Texas A & M University	B04 Eller O&M Bldg	College Station, TX 77843-4146	409-845-8385	409-845-6331	ksb@larry.tamu.edu
Andrew	Clark	Harbor Branch Oceanographic Institution	5600 U.S. 1 N	Ft. Pierce, FL 34946	561-465-2400	561-464-9094	aclark@hboi.edu
Cecil	Crosby	University of Miami RSMAS	8821 NW 14th Ave	Miami, FL 33147	305-693-4108	305-361-4174	ccrosby@rsmas.miami.edu
Don	Cucchiara	University of Miami RSMAS	4600 Rickenbacker Cswy	Miami, FL 33149	305-361-4175	305-361-4174	dcucchiara@rsmas.miami.edu
Tim	Deering	University of Delaware	700 Pilottown Rd	Lewes, De 19958	302-645-4338	302-645-4006	deering@brahms.udel.edu
Matt	Denny	LUMCON Louisiana	8124 Hwy 56	Chauvin, LA 70344	504-851-2816	504-851-2874	mdenny@lumcon.edu
Annette	DeSilva	UNOLS	P.O. Box 392	Saunderstown, RI 02874	401-874-6825	401-874-6486	desilva@gso.uri.edu
Jon	Erickson	United States Geological Survey	599 Seaport Blvd	Redwood City, CA 94063	415-329-5885	415-365-9841	erickson@usgs.gov
Rich	Findley	University of Miami RSMAS	4600 Rickenbacker Cswy	Miami, FL 33419	305-361-4175	305-361-4174	rfindley@rsmas.miami.edu
John	Freitag	University of Rhode Island	Narragansett Bay Campus	Narragansett, RI 02882-1197	401-874-6579	401-874-6578	jfreitag@gsosun1.gso.uri.edu
Phil	Gibson	Tension Member Technology					
Steven	Hartz	University of Alaska	Box 730	Seward, AK 99664	907-224-5261	907-224-3392	frsjh@aurora.alaska.edu
Dave	Hogg	United States Geological Survey	599 Seaport Blvd	Redwood City, CA 94063	415-329-5864	415-365-9841	dhogg@usgs.gov

1996 RVTEC Meeting Attendees

First Name	Last Name	Organization	Address	City, State, Zip	Phone	Fax	Email
Tim	Holt	Rogue Wave	8510 SW 35th	Corvalis ,OR 97331	541-754-4089		holt@roguewave.com
Cindy	Kelly	Naval Oceanographic Office	1002 Balch Blvd (code N3112)	Stennis Space Center MS 39522	601-688-4276	601-688-4729	cynthia%n31%navo.@navol. Navo.navy.mil
Ray	Kolar	Harris Corporation P.O. Box 98000	MS 5450, Bldg. 25	Melbourne, FL 32902	407-727-6462	407-729-7980	rkolar@iu.net
Dennis	Krynen	Naval Oceanographic Office	1002 Balch Blvd	Stennis Space Center MS 39522-5001	601-688-4427	601-688-5778	dkrynen@msrcnavo.navy.mil
Chip	Maxwell	University of Miami RSMAS	4600 Rickenbacker Cswy	Miami, FL 33149	305-361-4175	305-361-4174	cmaxwell@rsmas.miami.edu
Miguel	McKinney	University of Miami RSMAS	4600 Rickenbacker Cswy	Miami, FL 33149	305-361-4175	305-361-4174	mmckinney@rsmas.miami.edu
Don	Michaelson	Antarctic Support Associates	61 Inverness Dr., E., Ste 300	Englewood, CO 80112	303-790-8606	303-792-9006	michaelson.asa@asa.org
Don	Moller	Woods Hole Oceanographic Institution	WHOI	Woods Hole, Ma 02543	508-289-2277	508-457-2185	dmoller@whoi.edu
Paul	Moylan	University of Delaware	700 Pilottown Rd.	Lewes, DE 19958	302-645-4048	302-645-4006	
Richard	Muller	Moss Landing Marine Labs	P.O. Box 450	Moss Landing, CA 95039	408-633-3534	408-633-4580	rmuller@mlml.calstate.edu
David	Nelson	URI/GSO	South Ferry Road	Narragansett, RI 02882	401-874-6840	401-874-6578	nelson@gsosun1.gso.uri.edu
Scott	Olson	Harbor Branch Oceanographic Institution	5600 U.S. 1 N	Ft. Pierce, FL 34946	561-465-2400	561-465-2116	olson@hboi.edu
Eugene	Olson	Florida Institute of Oceanography	830 1st Street South	St. Petersburg, FL 33701	813-893-9100	813-893-9109	olsone@mail.firn.edu
Steve	Poulos	University of Hawaii	2525 Correa Rd. RM-PH	Honolulu, HI 96822	808-956-6650		poulos@soest.hawaii.edu
Pierluigi	Pozzi	University of Hawaii	2525 Correa Rd	Honolulu, HI 96822	808-956-9064	808-956-2538	luigi@poha.soest.hawaii.edu
Michael	Rawson	Lamont Observatory Oceanographic Institution	Rte 9W	Palisades, NY 10964	914-365-8367	914-359-6817	rawson@ldeo.columbia.edu
Chris	Riffe	LUMCON Louisiana	8124 Hwy 56	Chauvin, LA 70344	504-851-2816	504-851-2874	criffe@coco.lumcon.edu
Dan	Schwartz	Harbor Branch Oceanographic Institution	5600 U.S. 1 N	Ft. Pierce, FL 34946	561-465-2400	561-465-2116	dschwartz@hboi.edu
Alexander	Shor	National Science Foundation	4201 Wilson Blvd., Room 725	Arlington, VA 22230	703-306-1578	703-306-0390	ashor@nsf.gov
Jim	Sullivan	Harbor Branch Oceanographic Institution	5600 U.S. 1 N	Ft. Pierce, FL 34946	561-465-2400	561-465-2116	jsullivan @hboi.edu

1996 RVTEC Meeting Attendees

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Woody	Sutherland	Scripps Institute of Oceanography	UCSD/SIO/STS	LaJolla, CA 92093-7383	619-534-4425	619-534-7383	woodys@ucsd.edu
Barrie	Walden	Woods Hole Oceanographic Institution	86 Water Street, MS #17	Woods Hole, MA 02543	508-289-2407	508-457-2107	bwalden@whoi.edu
Rob	Walker	Florida Institute of Oceanography	830 First St. South	St. Petersburg, FL 33701	813-893-9100	813-893-9109	rwalker@seas.marine.usf.edu
Mike	Webb	Pacific Marine Center NOAA	1801 Fairview Ave E	Seattle, WA 98102-3722	206-556-0192	206-553-8348	michael.d.webb@noaa.gov
Edward	Webb	Texas A & M University	B04 Eller O&M Bldg	College Station, TX 77843-3146	409-845-7237	409-845-6331	erw@larry.tamu.edu
Dan	White	Harbo Branch Oceanographic Institution	5600 U.S. 1 N	Ft. Pierce, FL 34946	561-465-7400	561-464-9094	white@hboi.edu
Gordon	Wilkes	Naval Oceanographic Office	1002 Balche Blvd	Stennis Space Center MS 39522-5001	601-688-4376	601-688-5607	gwilkes@navo.navy.mil
Marc	Willis	Oregon State University	Ocean. Admin. 104	Corvallis, OR 97331	541-737-4622	541-737-2470	willis@oce.orst.edu
Tom	Wilson	SUNY Marine Sciences Resource	State University of NY	Stony Brook, NY 11794	516-632-8706	516-632-8820	twilson@ccmail.sunysb.edu

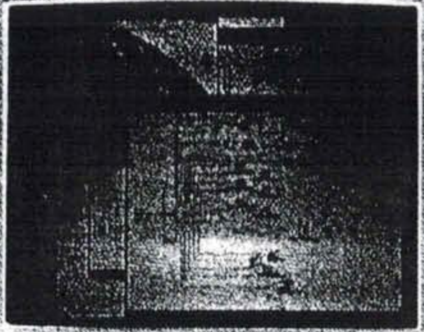
APPENDIX III

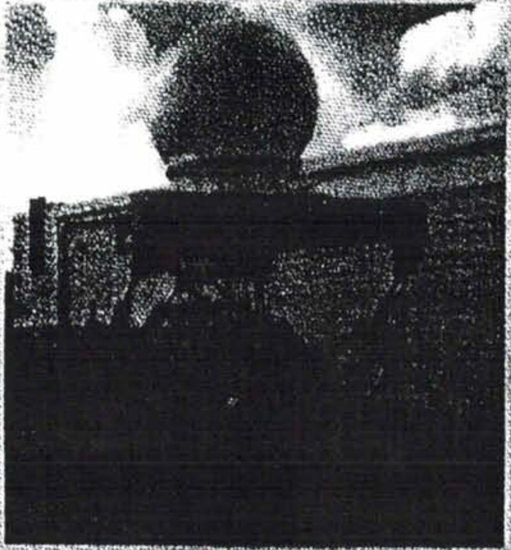
HARRIS

Buoy Communications Enabling Technologies

Buoy Modeling

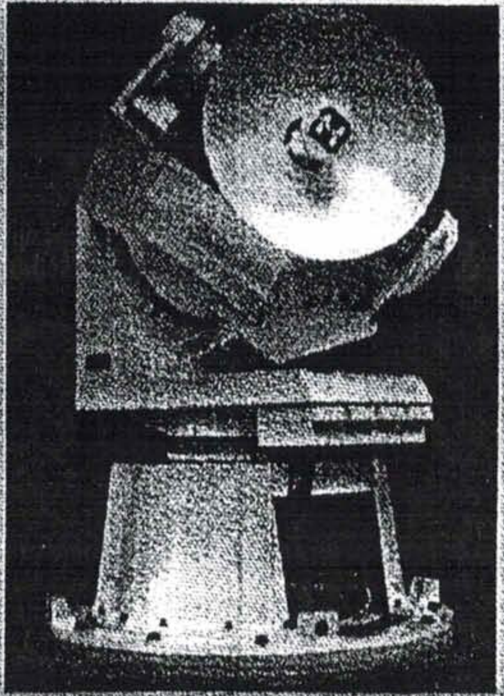
- Buoy design
- Environmental and platform response
- Antenna positioner response
- RF link calculator





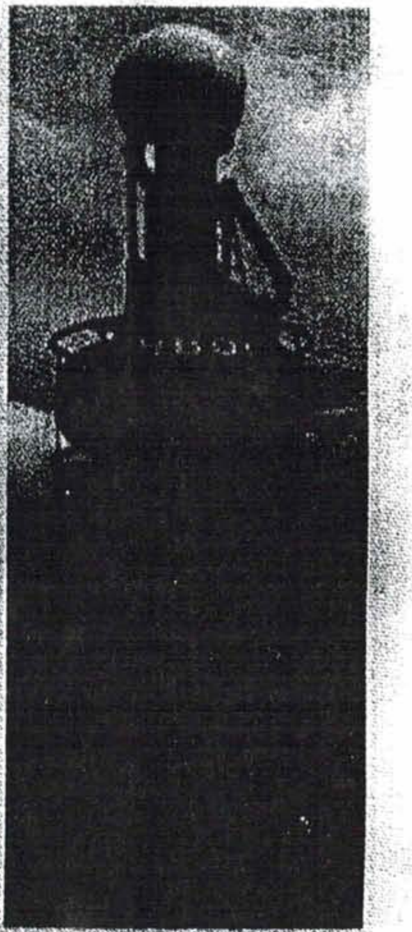
Motion Simulator

- 6 degree of freedom simulator
- Driven by model or collected parametric data
- Motions to > Sea State 6



Positioner and Antennas

- High dynamic positioner
- Simple K-band reflector
- Tested on motion simulator to Sea State 6



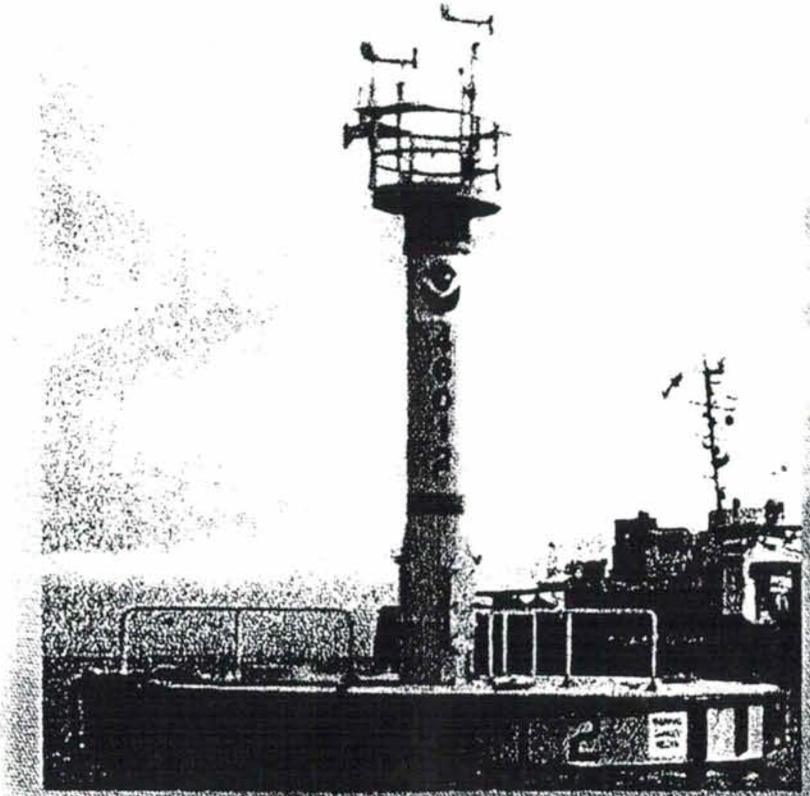
Tuned 2.3 meter buoy

- Dampened "wave following" platform
- Light payload capacity (~2 tons)

HARRIS

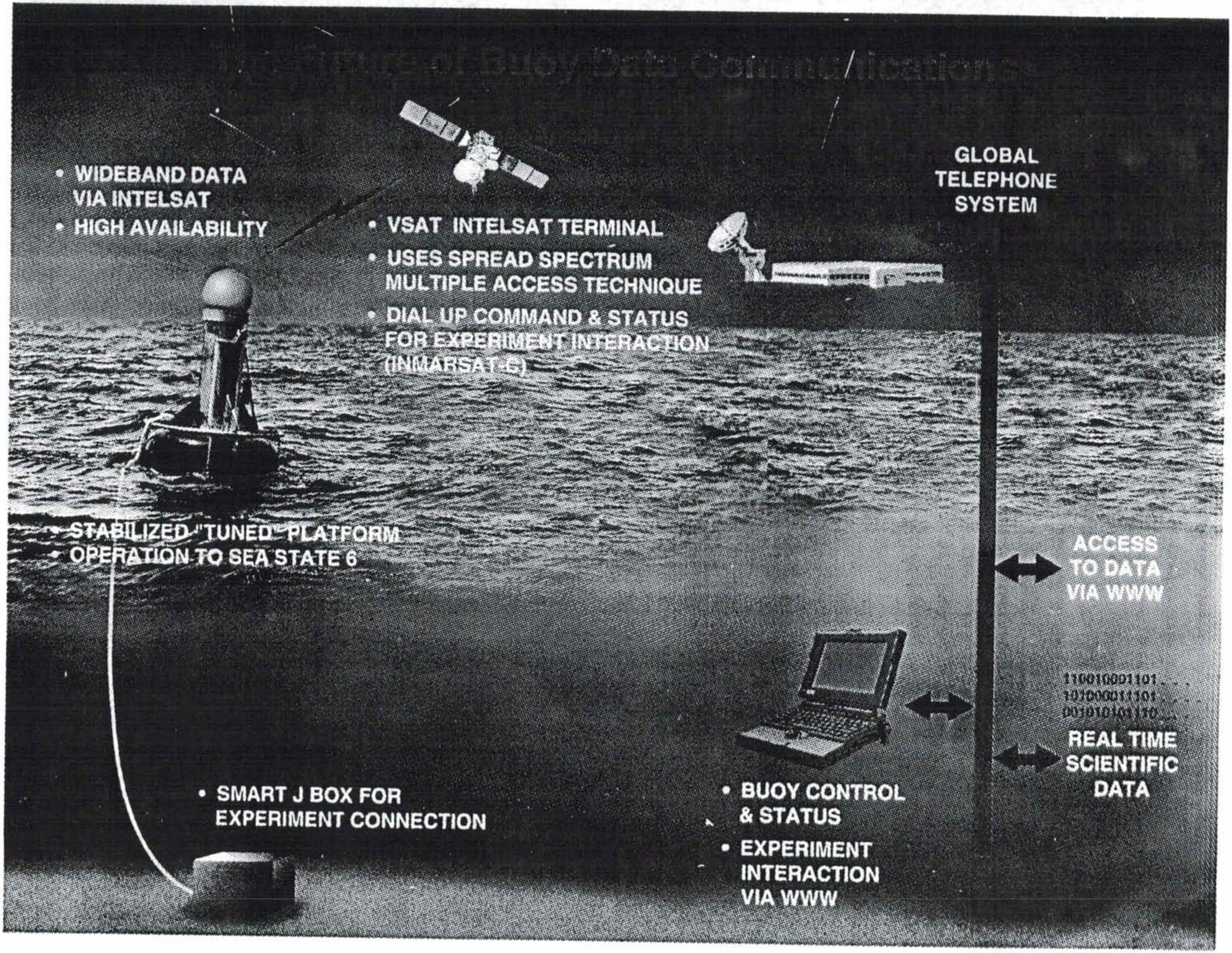
An Example of Buoy Data Communications: the FAA Gulf of Mexico Buoy Communications System

The BCS allows for more frequent and safer flights over waterways by providing seamless air to ground communications between pilots and controllers



- First system developed for FAA in the Gulf of Mexico
- VHF/AM A/G communications system
- Redundant Ku-band satellite links
- 0.99999 system availability
- High-dynamics antenna pedestal
- Extensive redundancy and remote monitoring capability
- INMARSAT emergency control capability
- More direct routes over waterways reduce flight time and fuel consumption

Future of Buoy Data Communications



- WIDEBAND DATA VIA INTELSAT
- HIGH AVAILABILITY

- VSAT INTELSAT TERMINAL
- USES SPREAD SPECTRUM MULTIPLE ACCESS TECHNIQUE
- DIAL UP COMMAND & STATUS FOR EXPERIMENT INTERACTION (INMARSAT-C)

GLOBAL TELEPHONE SYSTEM

- STABILIZED "TUNED" PLATFORM
- OPERATION TO SEA STATE 6

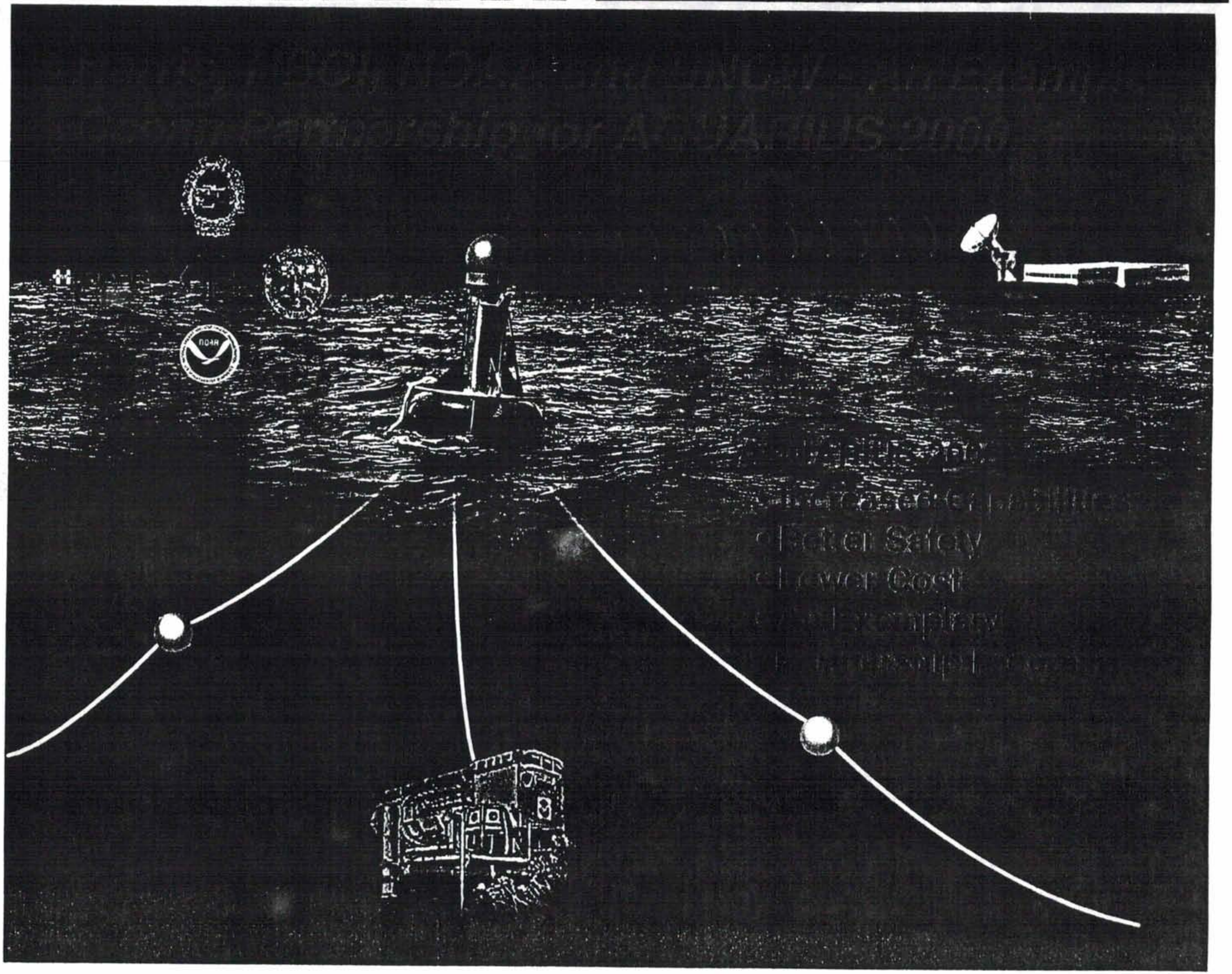
ACCESS TO DATA VIA WWW

110010001101. . .
101000011101. . .
001010101110. . .

REAL TIME SCIENTIFIC DATA

- SMART J BOX FOR EXPERIMENT CONNECTION

- BUOY CONTROL & STATUS
- EXPERIMENT INTERACTION VIA WWW



[illegible]

Partnership for AQUARIUS 2000

AQUARIUS 2000

- Increased Capabilities
- Better Safety
- Lower Cost
- An Exemplary
- Partnership [illegible]

APPENDIX IV

MerLAN

Enabling Technology

- Allow rapid development of new lowered sensors
- Simple configuration
- Simple programming
- Built from off the shelf components
- Operates at full duplex ETHERNET transmission speed (10 mbit/sec)
- Seperates power transmission and signal transmission

PC/104 Standard

- Adaption of regular PC bus (IEEE P996)
- Compact Form-Factor
  - Size reduces to 3.6 by 3.8 inches
- Self-stacking
  - Can eliminate cost and bulk of backplanes and card cages
  - Pin-and Socket connectors
- Relaxed bus drive (4 mA.)
  - Lowers power consumption (1-2 watts per module) and minimizes component count

The PC 104 Standard

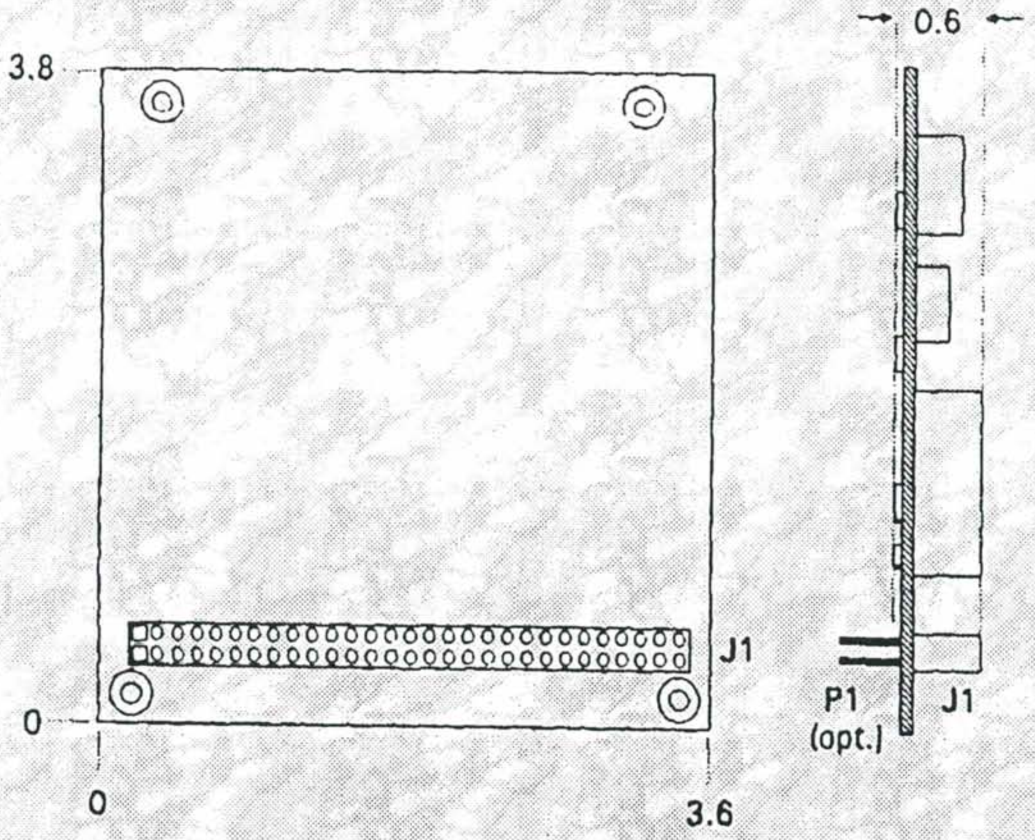


Figure 1. Basic Mechanical Dimensions (8-bit Version)

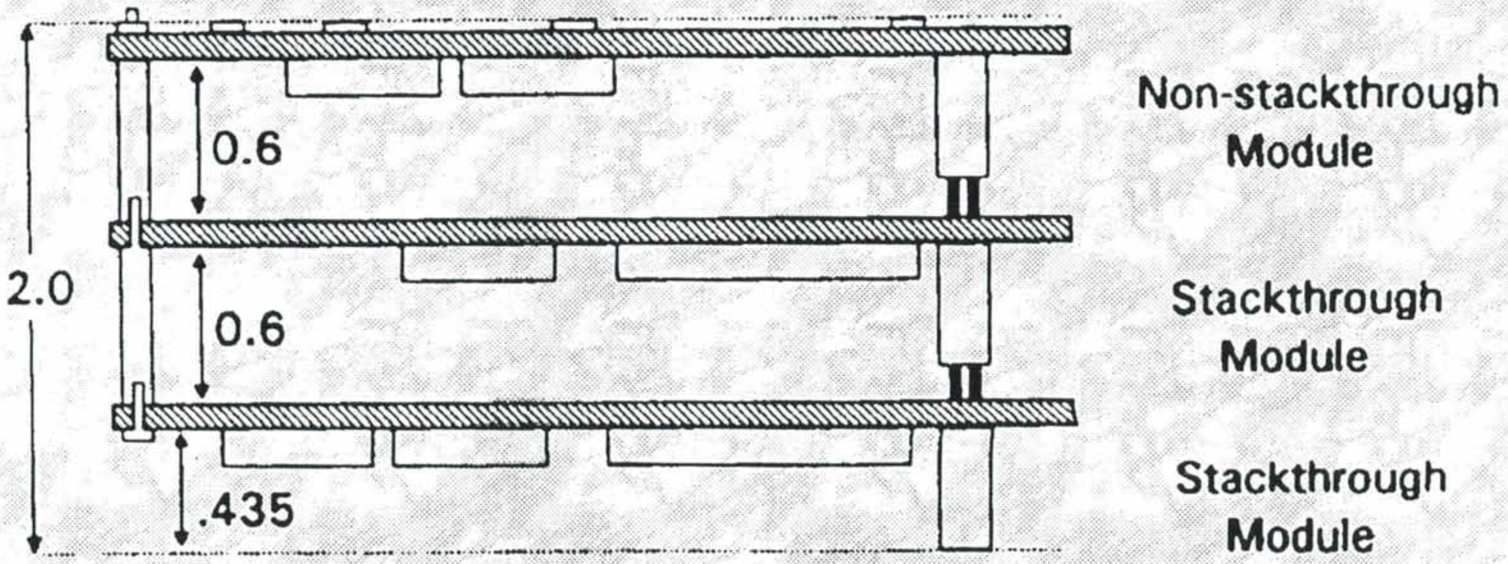


Figure 2. Standalone Module Stacks

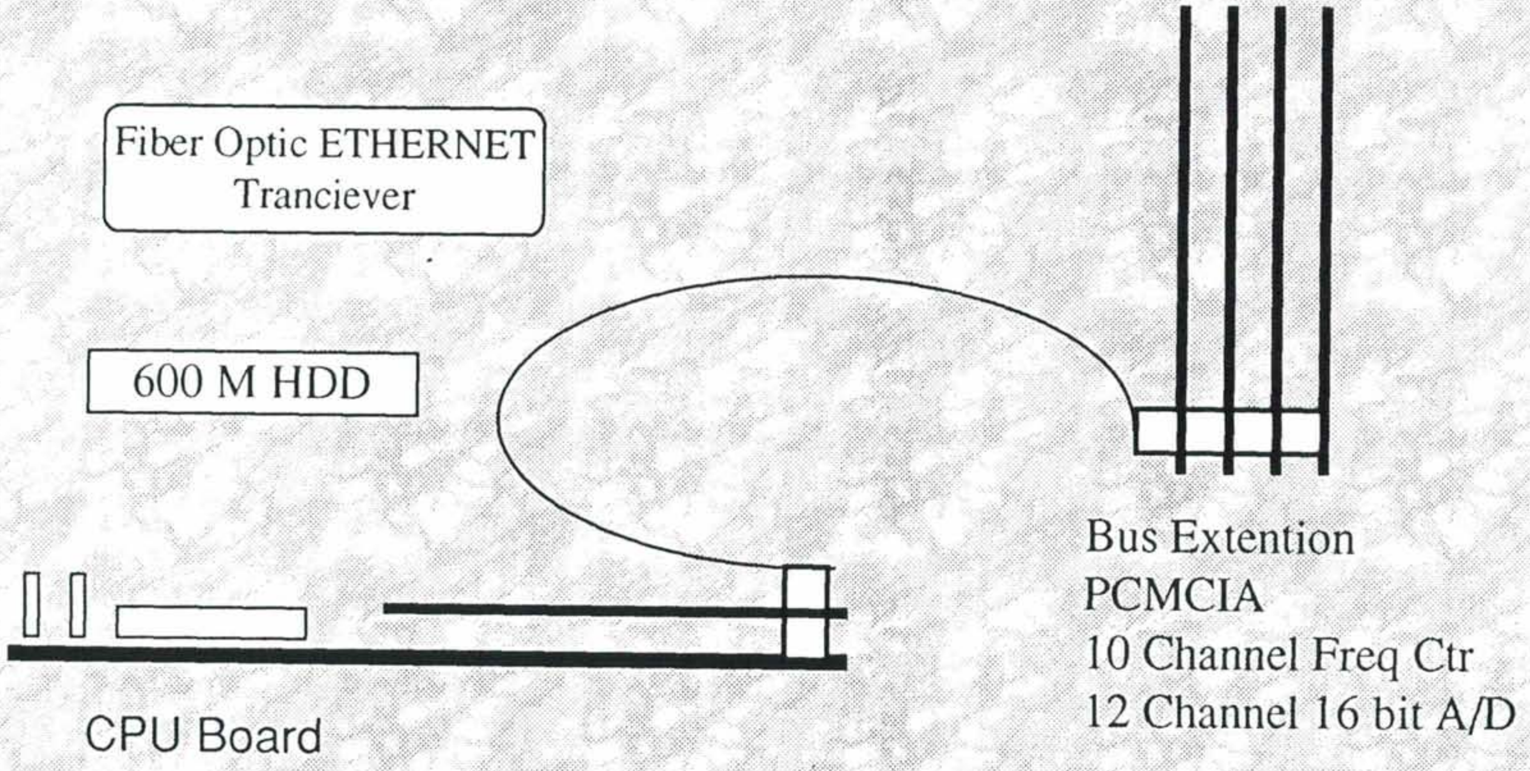
Two Different Types of PC/104 Boards

- PC/104 Form-Factor
  - Fits dimensional 3.8" x 3.6" criteria
- PC/104 Expandable
  - Allows PC/104 Form-Factor boards to be pluged into it

Typical PC/104 Boards Available

- CPU's
  - 386
  - 486
  - 586 (expandable only)
- Network Interfaces
- Modems
- Motor Controllers
- PCMCIA
- Serial Port Expansion
- SCSI Interfaces
- A/Ds
  - 12 bit 16 channel
  - 16 bit 16 channel
  - 22 bit single channel
- Counter/Timmers
- Digital Signal Processing
- Video Capture
- Syncro/Resolver
- Speech & Sound Modules

MerLAN Architecture

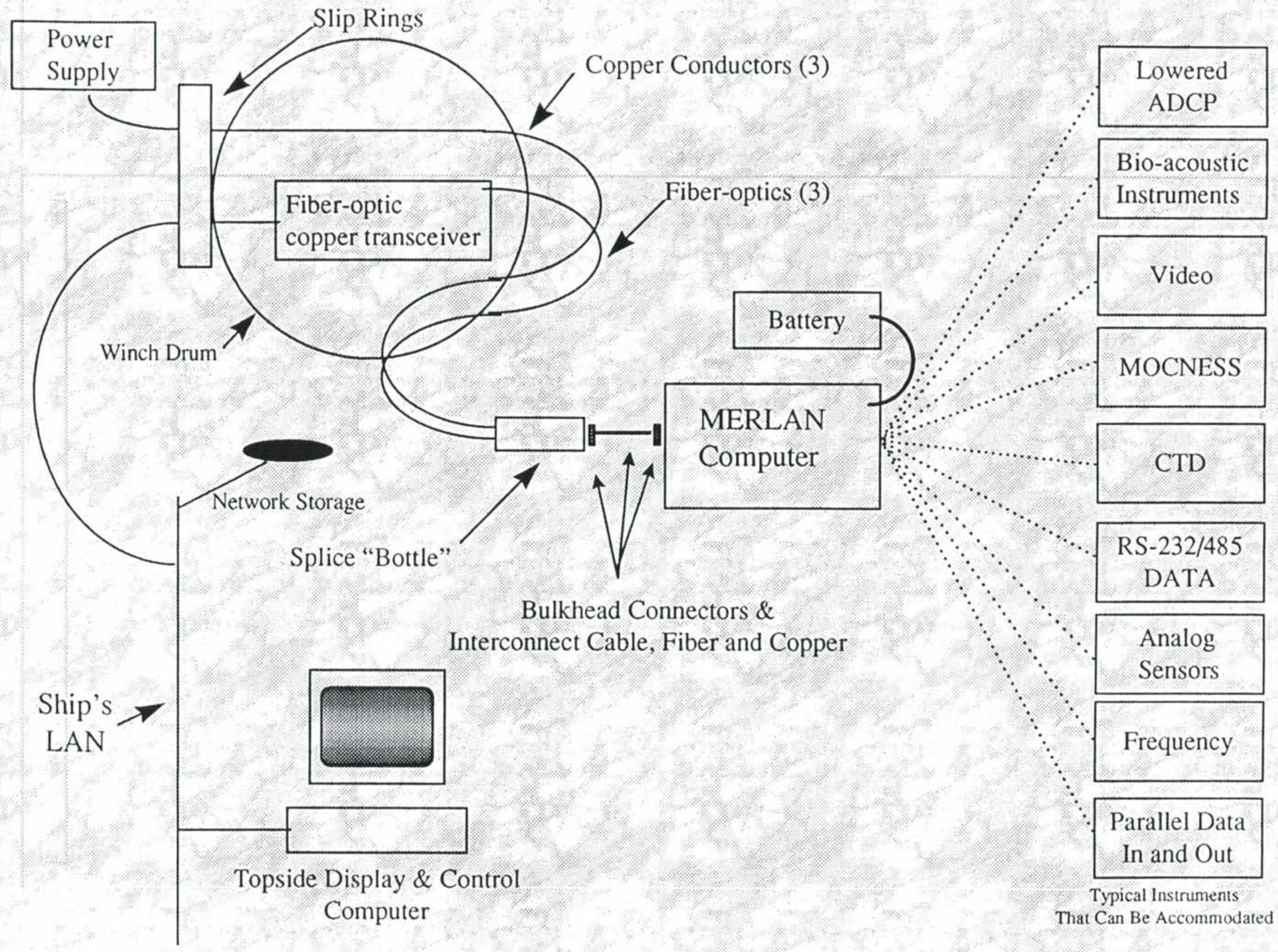


Fiber Optic ETHERNET
Tranciever

600 M HDD

CPU Board

Bus Extention
PCMCIA
10 Channel Freq Ctr
12 Channel 16 bit A/D


Power Supply
Slip Rings
Copper Conductors (3)
Fiber-optic copper transceiver
Fiber-optics (3)
Winch Drum
Battery
MERLAN Computer
Network Storage
Splice "Bottle"
Bulkhead Connectors & Interconnect Cable, Fiber and Copper
Ship's LAN
Topside Display & Control Computer
Lowered ADCP
Bio-acoustic Instruments
Video
MOCNESS
CTD
RS-232/485 DATA
Analog Sensors
Frequency
Parallel Data In and Out
Typical Instruments That Can Be Accommodated

Operating System Software

- Windows 95*
  - Remotly controlled by PC Anywhere
- Windows NT
  - Remotly controlled by PC Anywhere or X-Windows
- UNIX
  - Remotely controlled by X-Windows

Acquisition Software

- LabTech CONTROL*
- LabView
- Control Point

APPENDIX V

WHY CONSIDER AUVS?

THERE ARE MISSIONS THAT ONLY AUVS CAN PERFORM EFFECTIVELY

AND

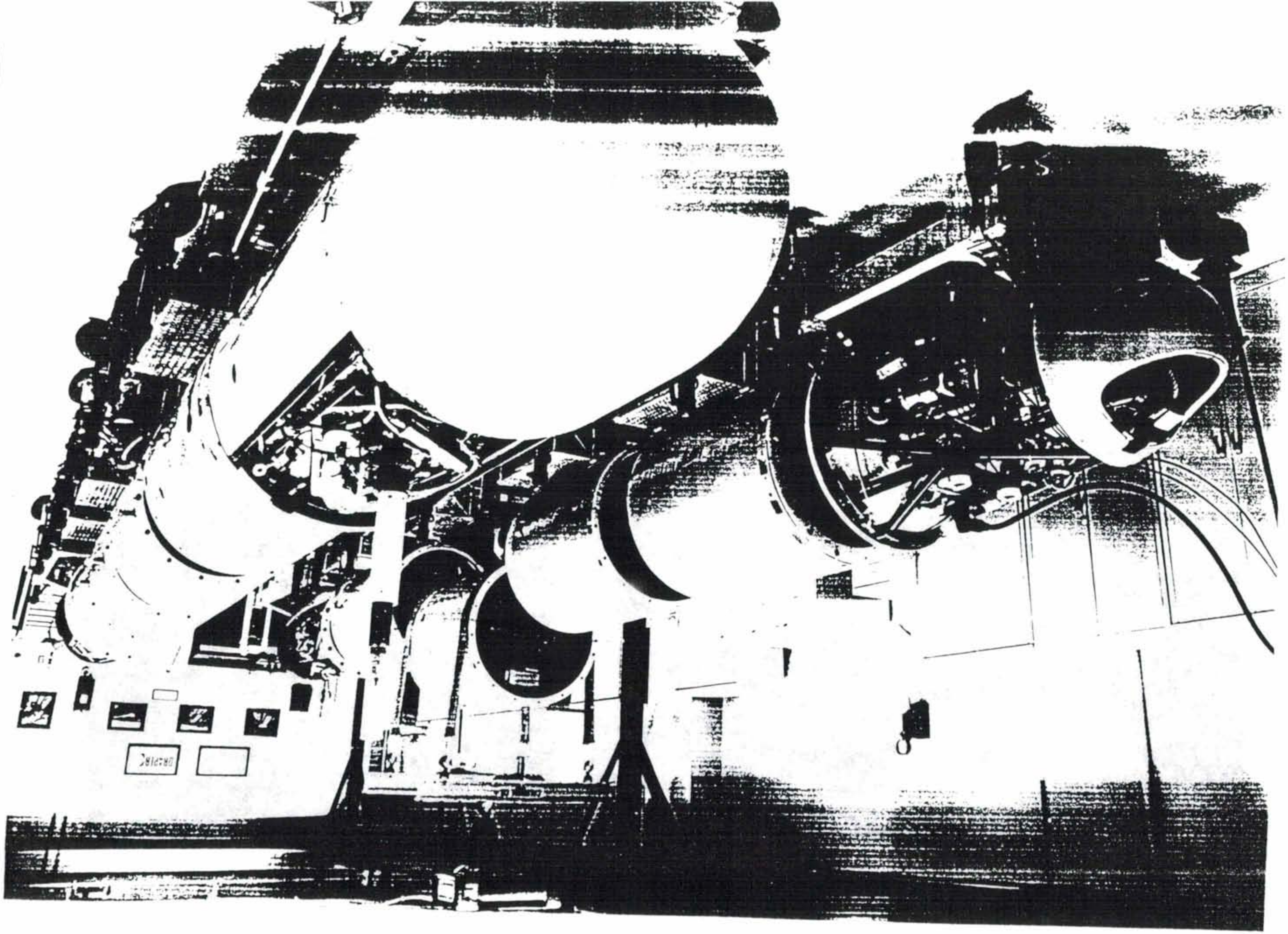
CAN REDUCE THE COST OF OPERATIONS SIGNIFICANTLY

THESE MISSIONS WILL HAVE TO BE PERFORMED FIRST IN ORDER FOR AUVS TO GAIN ACCEPTANCE

Harbor Branch Oceanographic Institution, Inc.

DUAL-USE APPLICATIONS

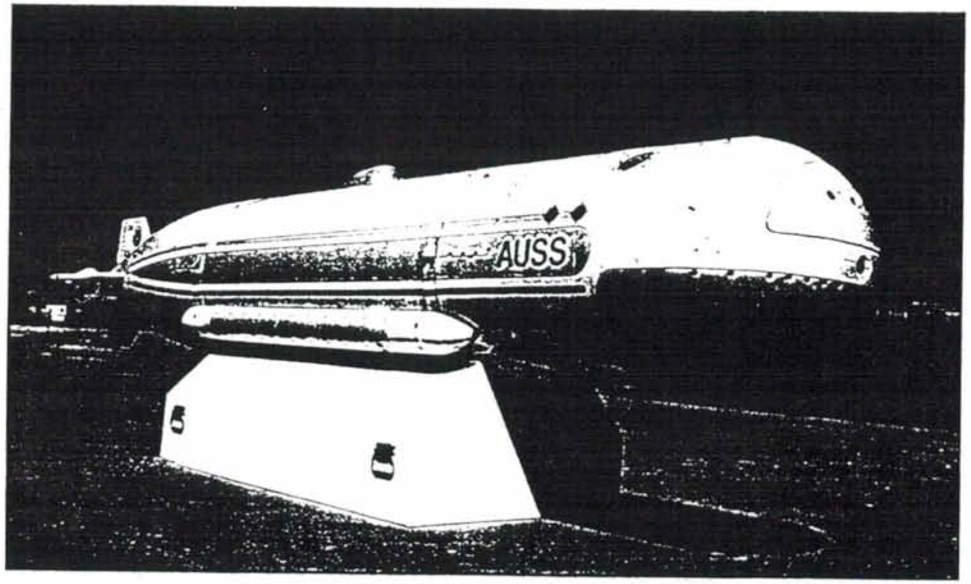
APPLICATION	COMMERCIAL USE	MILITARY USE
Long Horizontal Excursions	• Under ice survey • Seafloor mapping • Oceanographic data • Routine surveys	• Under ice surveillance • Mine countermeasures • Reconnaissance missions • Search missions
On-Site for Long Periods	• Hydrothermal vents • Biological sites • Dump sites • Seismic/volcanic sites • Platform/riser inspection	• Harbor entrances • Mine countermeasures • Surveillance • Weapon delivery • Decoy
Rapid Response	• Oil spills • Seismic/volcanic activity • Lost plane/ship/sub	• Acquire intruder • Drug interdiction • Lost plane/ship/sub
Weather Tolerant	• Storm monitoring • Coastal site monitoring	• Storm monitoring • Coastal surveillance
Very Hazardous Inspection	• Hazardous waste sites • Oil field blowout	• Mine field survey • Sunken nuclear sub

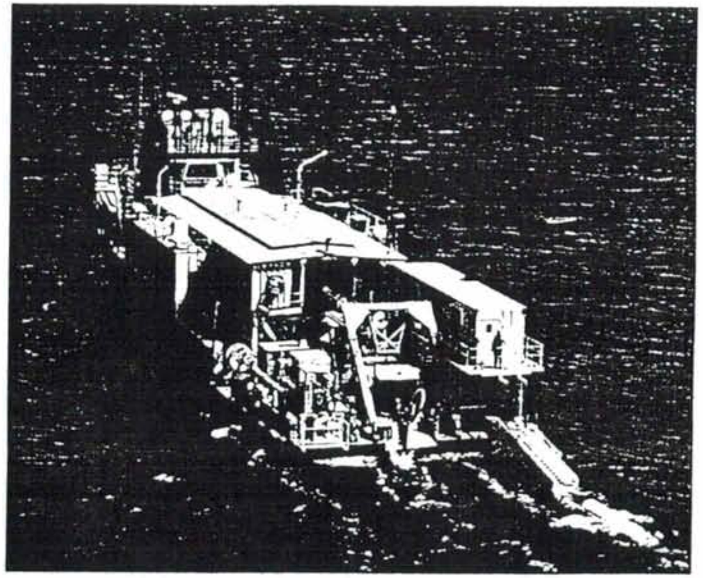


Naval Command.
Control and Ocean
Surveillance Center RDT&E Division

San Diego, CA
92152-5000

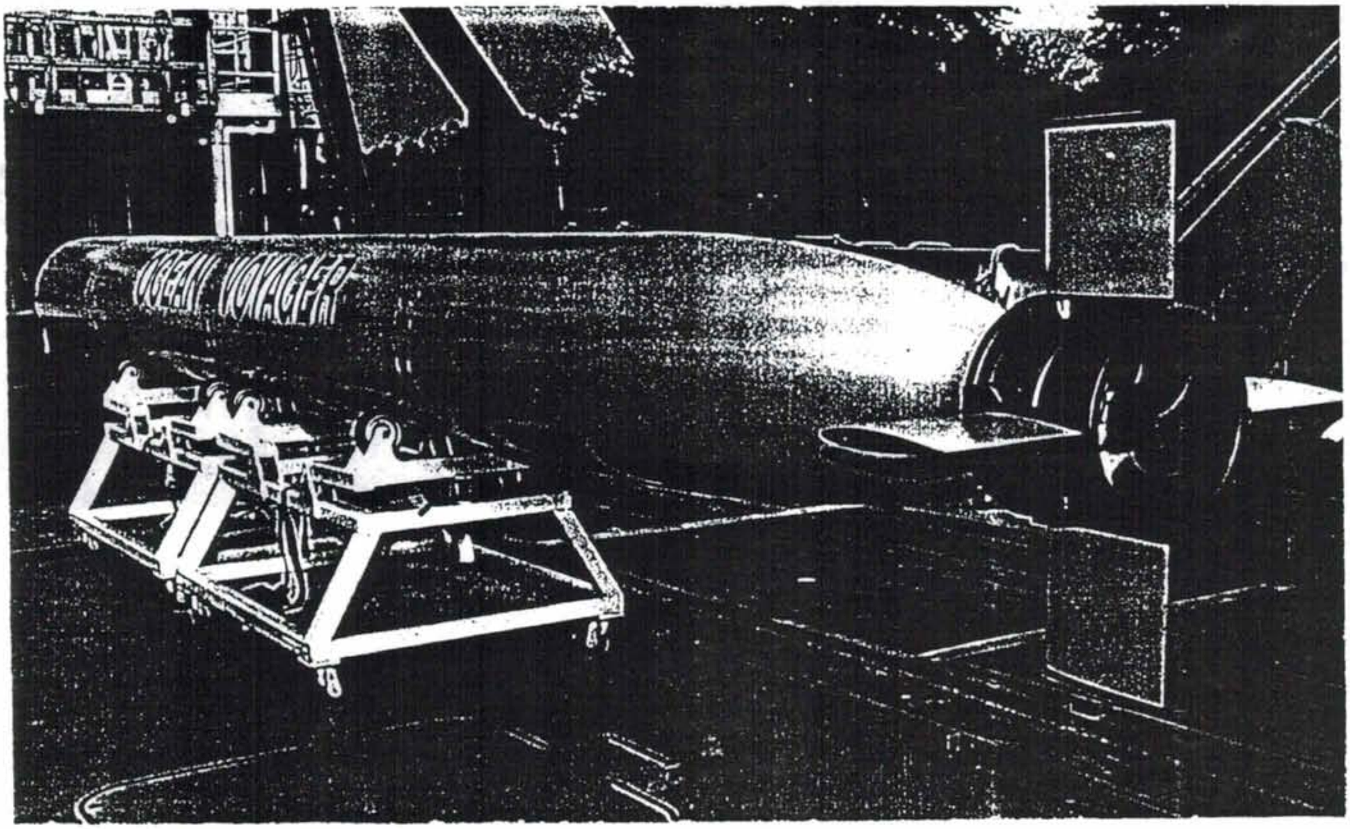
ADVANCED UNMANNED SEARCH SYSTEM





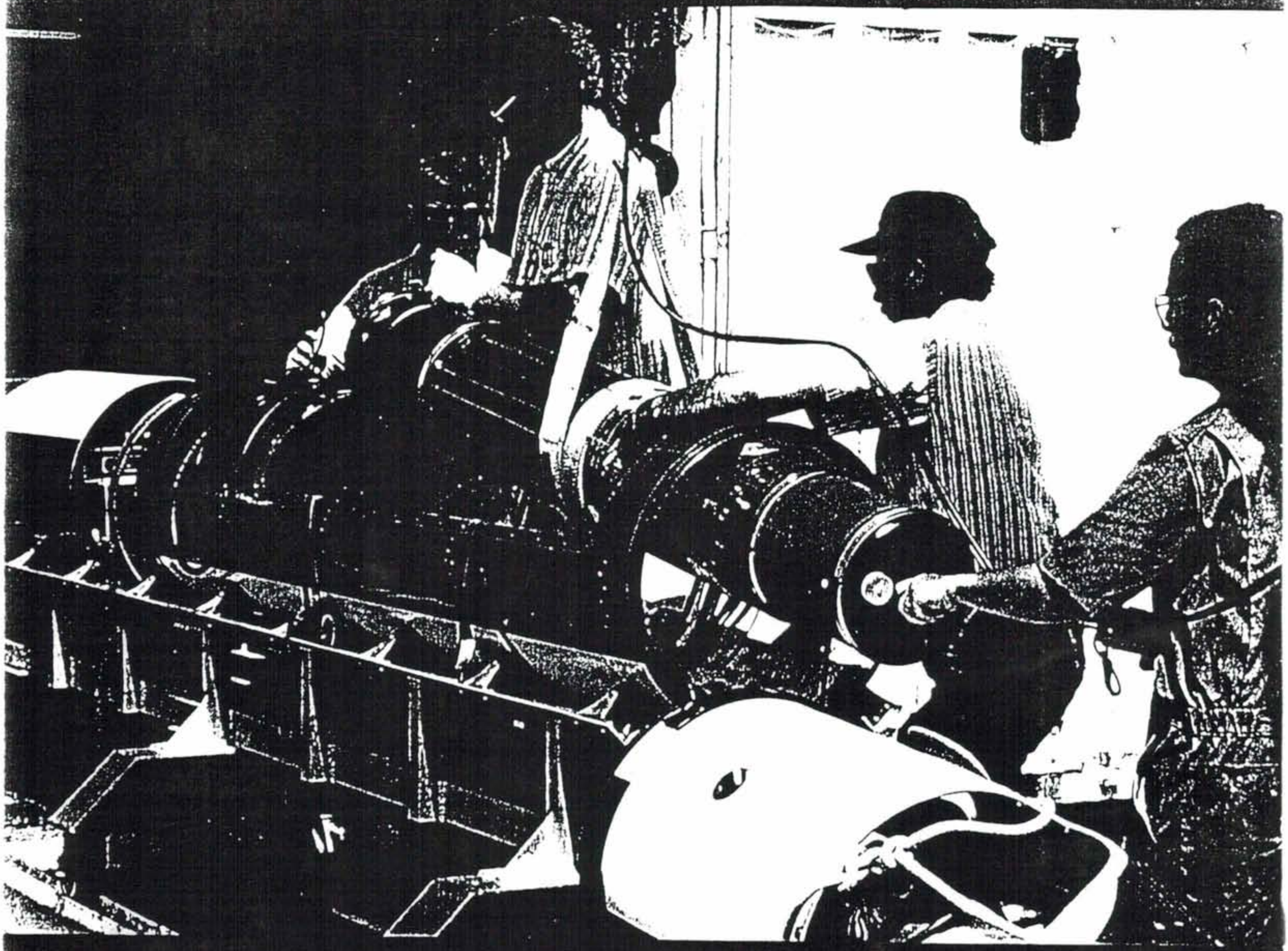
OCEAN VOYAGER I

Autonomous Undersea Vehicle

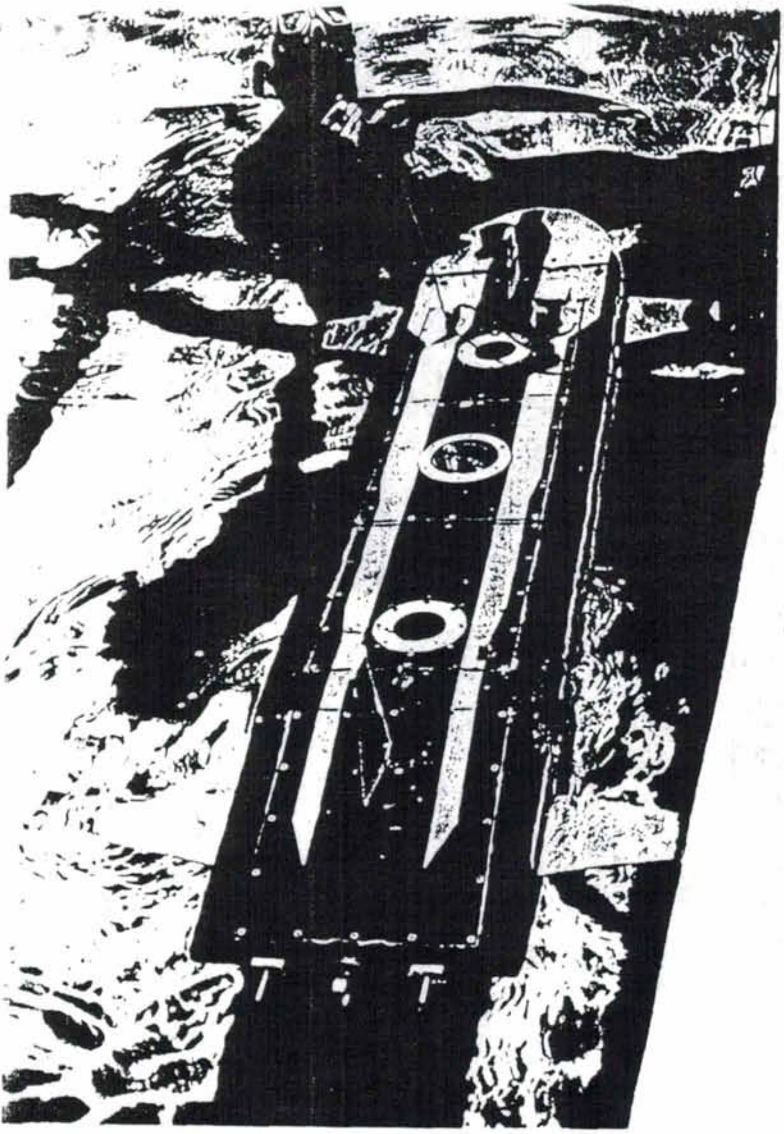


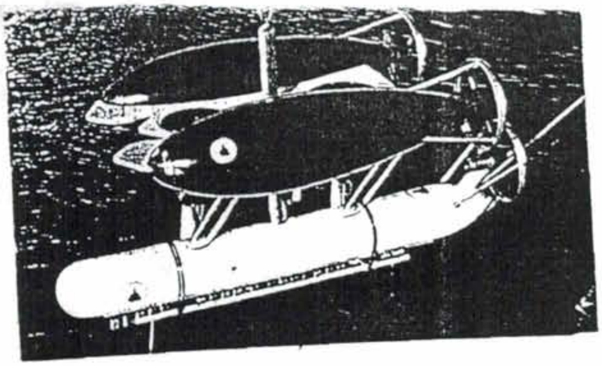
Ocean Voyager I aboard ship

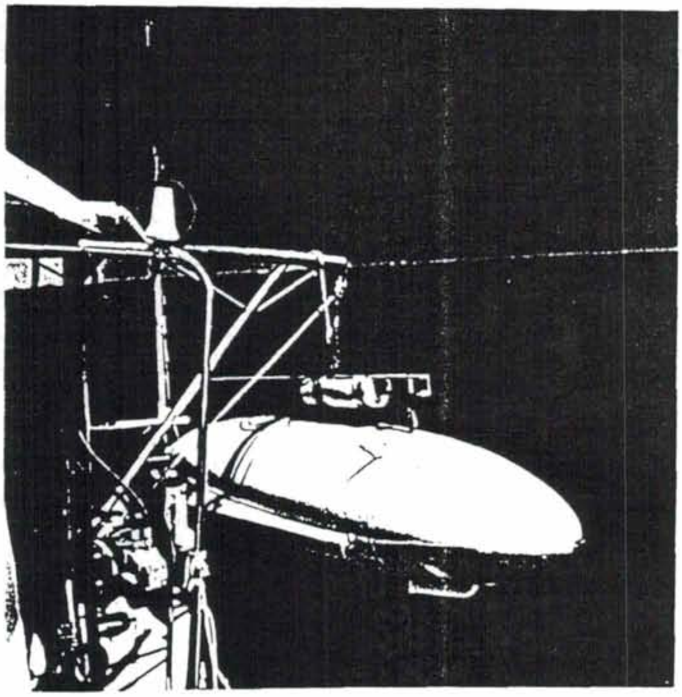
ART's sea trials of LS-4096 laser system in XP-21

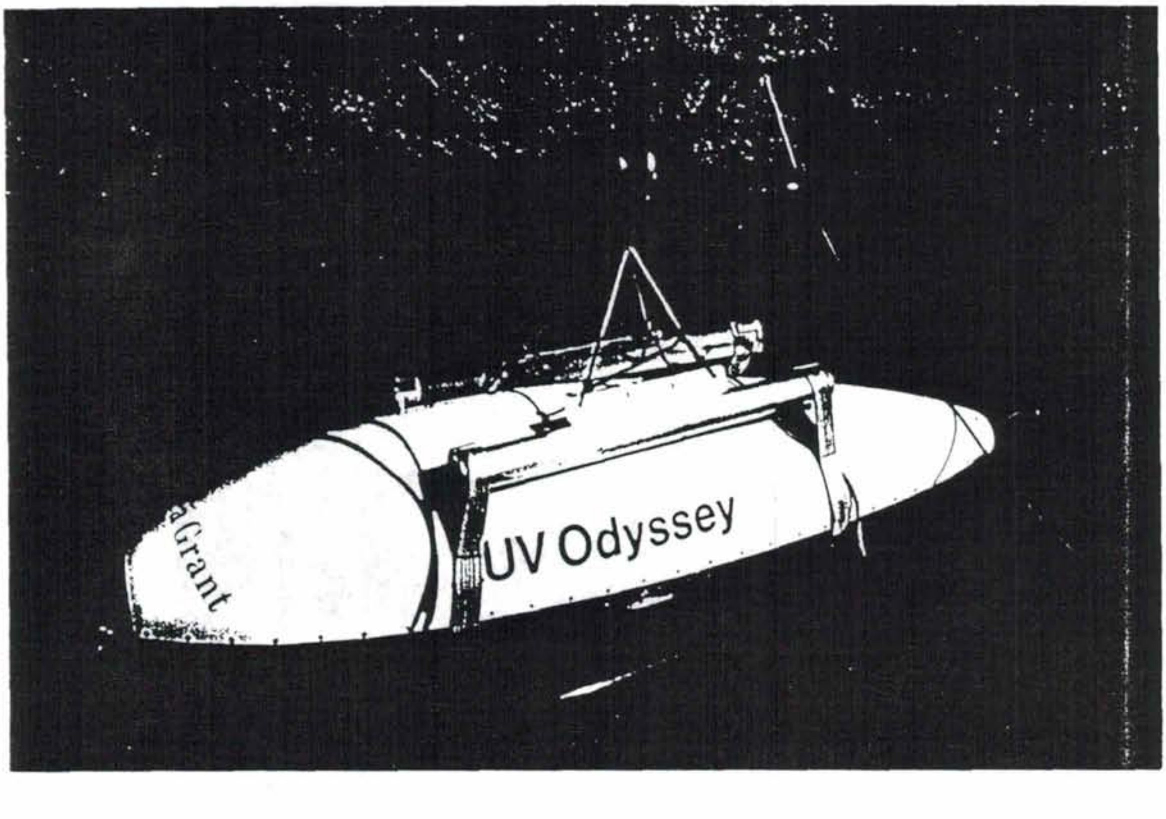


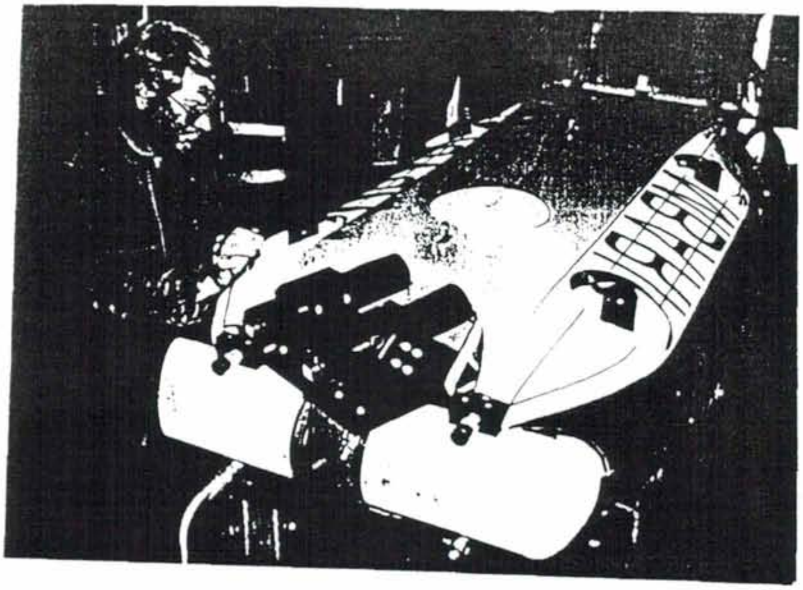
The International Underwater Industry Magazine

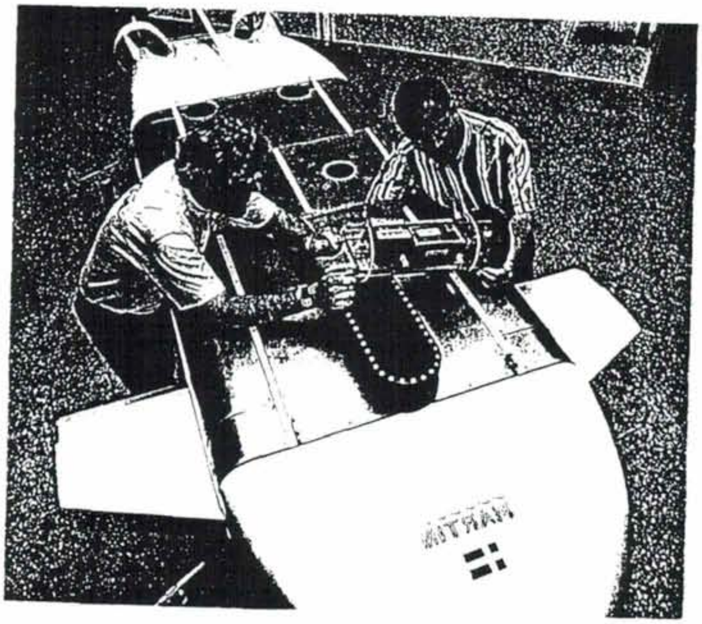


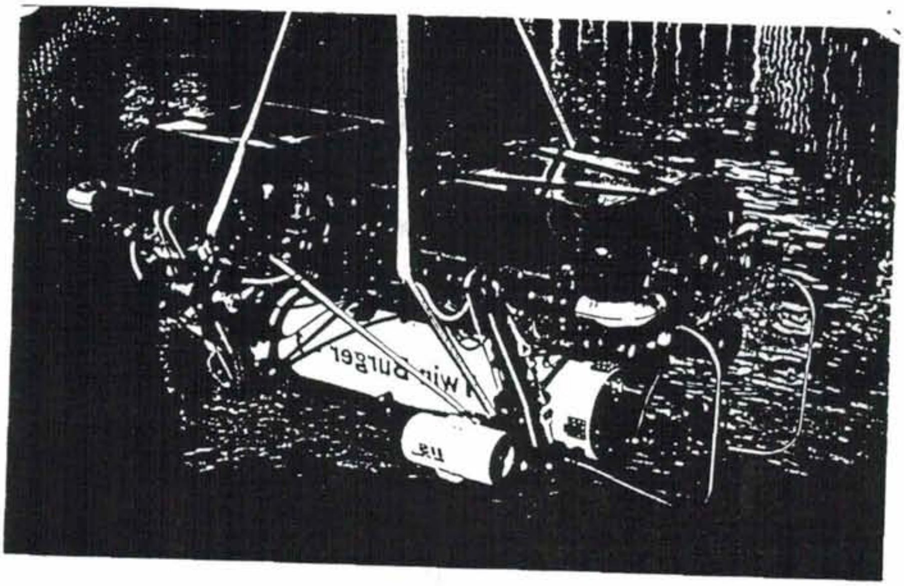





Grant
UV Odyssey




MARTIN


Win Burger

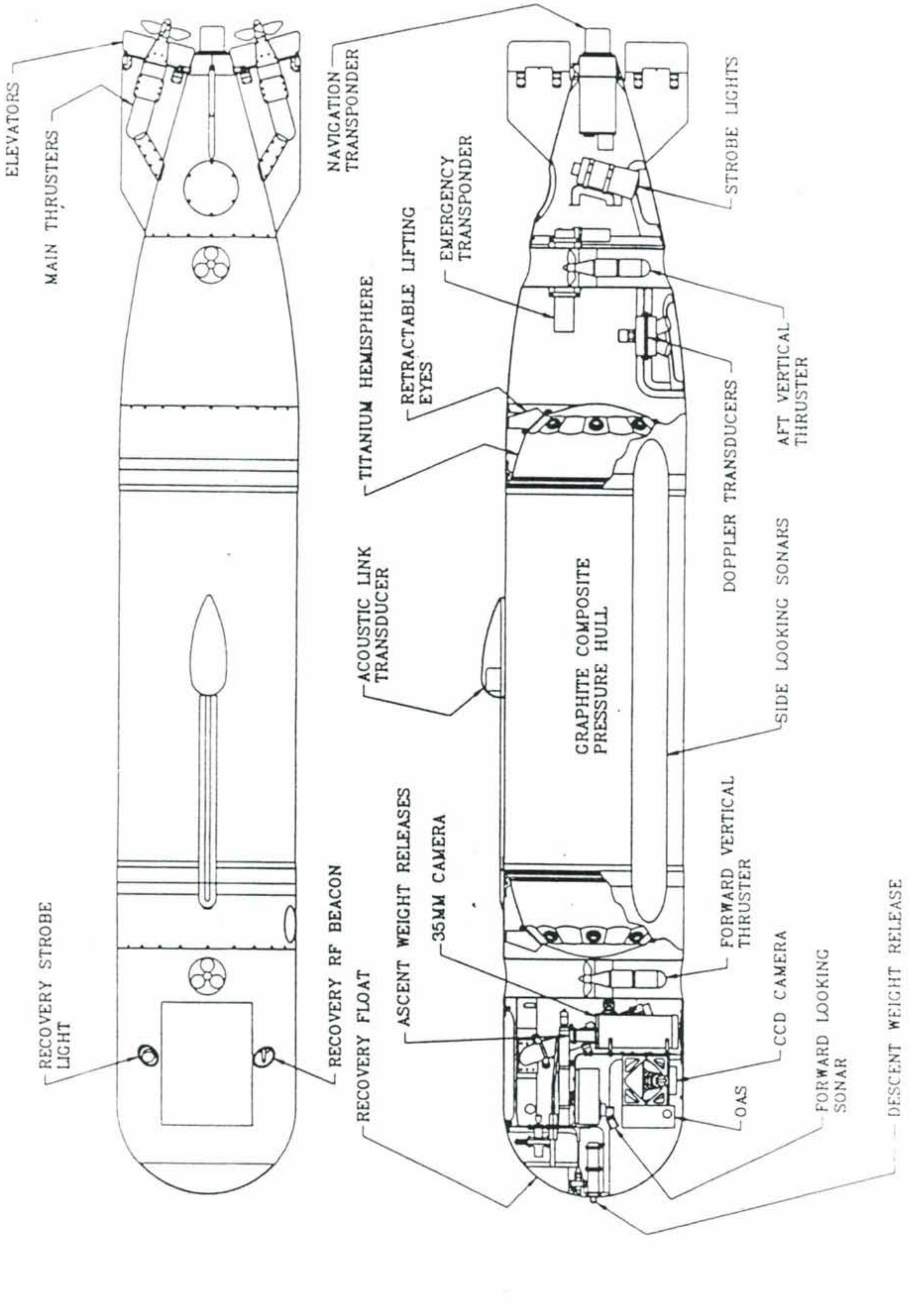


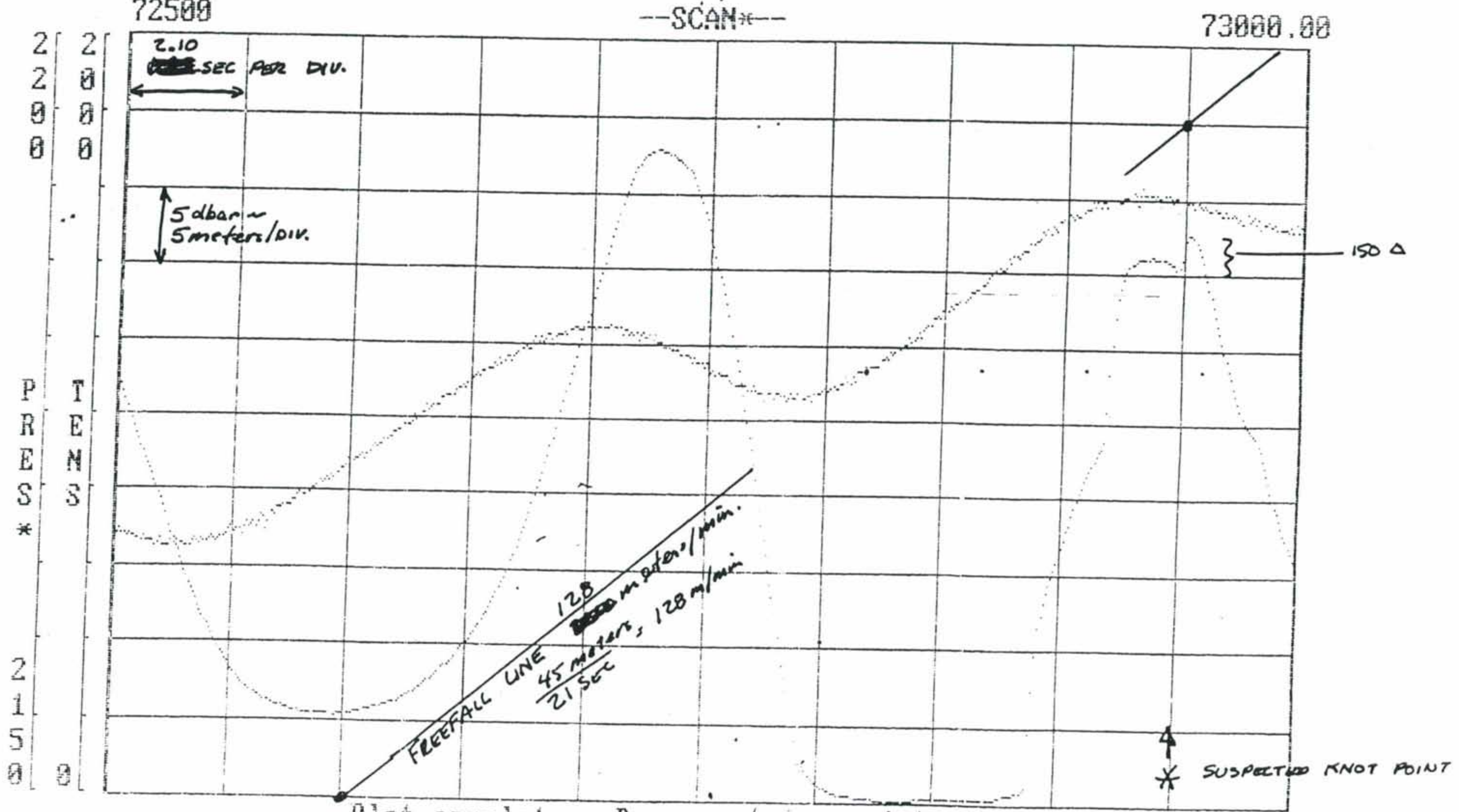
Figure 1. AUSS vehicle.

APPENDIX VI

96-10-30 TEST STATION 992 DOWNTRACE @ 75m/min.
USING WHOI CTD 4-L x24 BOTTLE FRAME
WITH CTD9

M. Swartz 96-10-31

File - KN47D992.EDT
--SCAN*--



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Plot complete.  Do you want a printout ? [Y/N]
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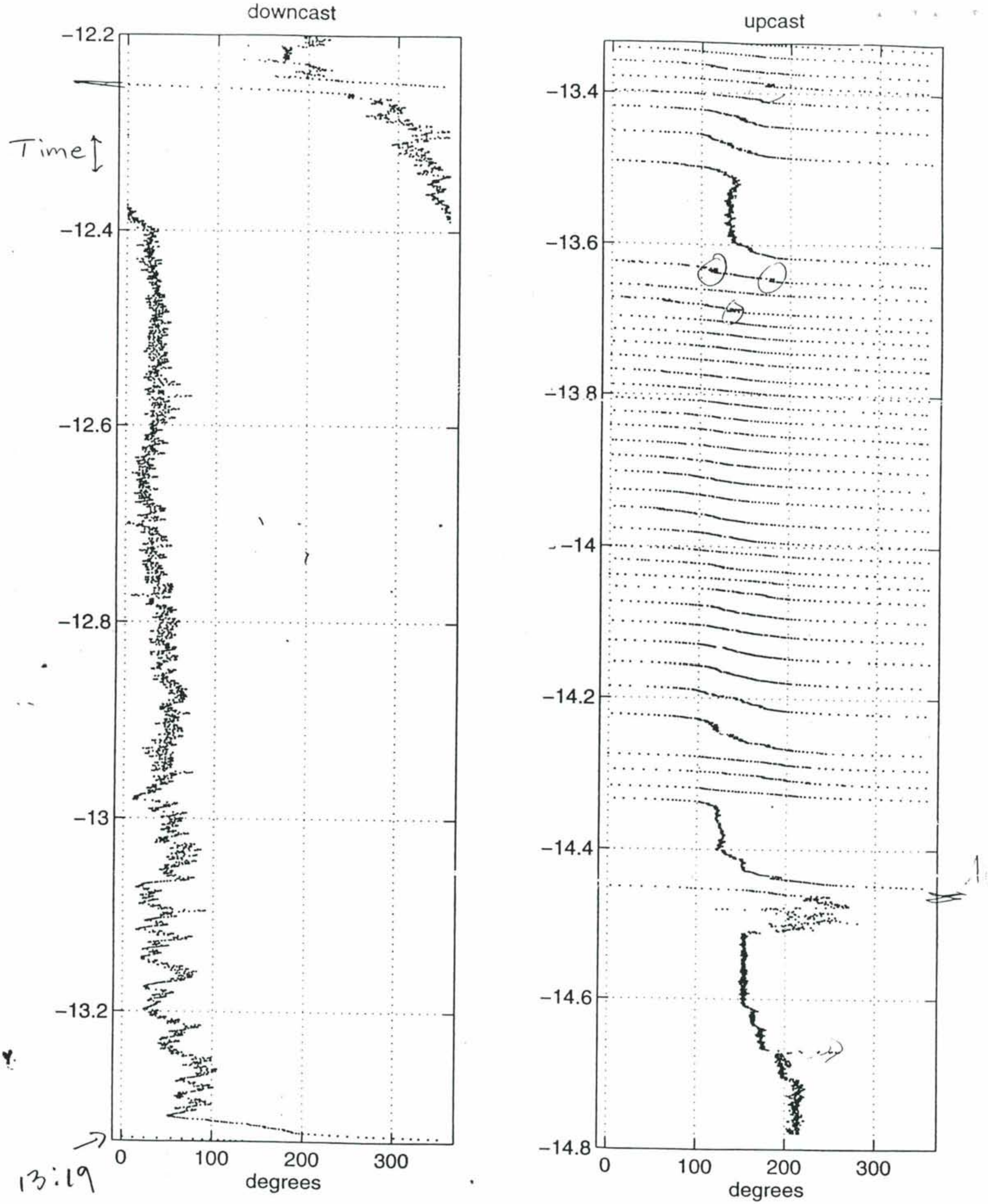
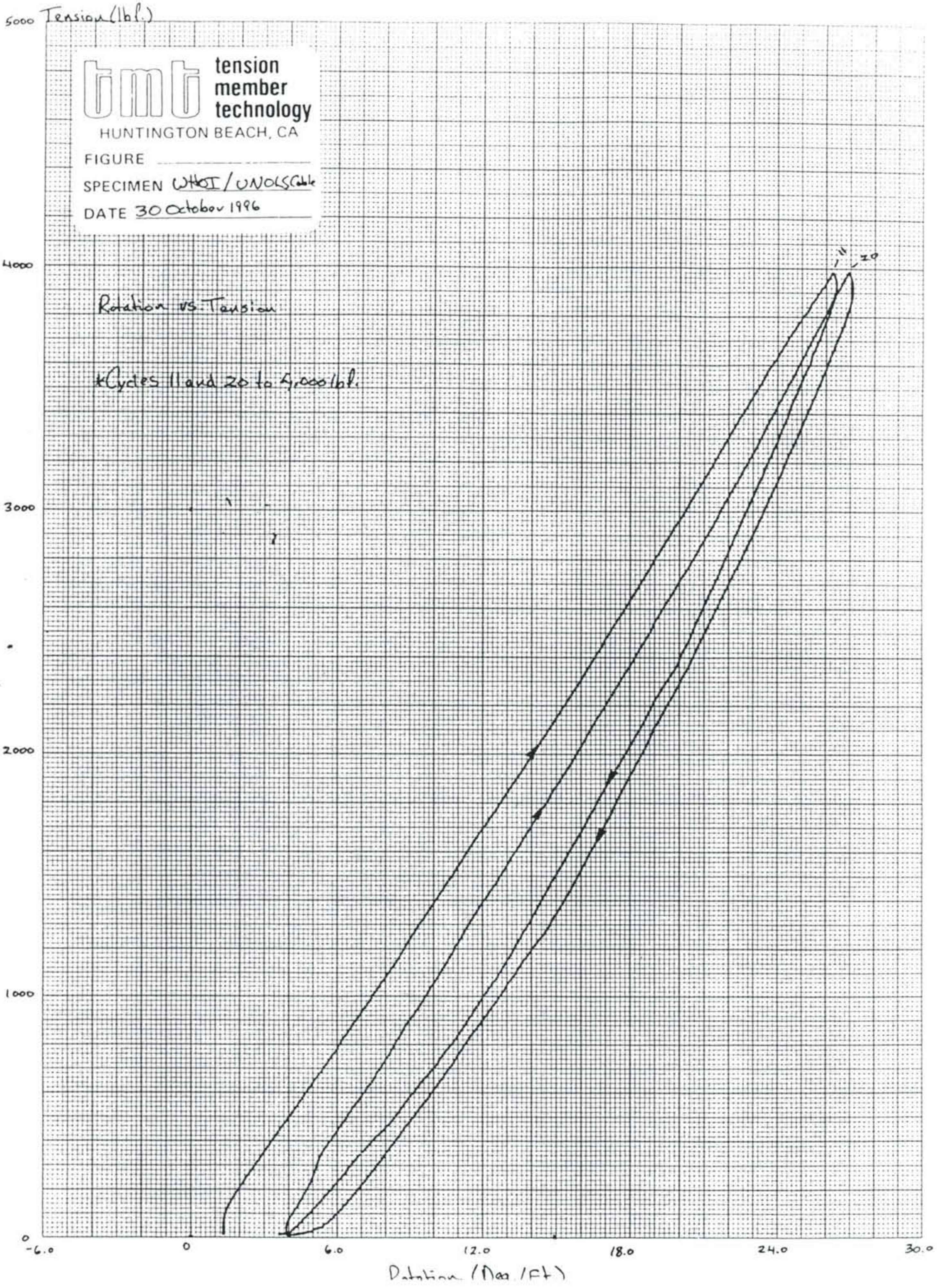


13:19

transit: test cast k992

Kinky

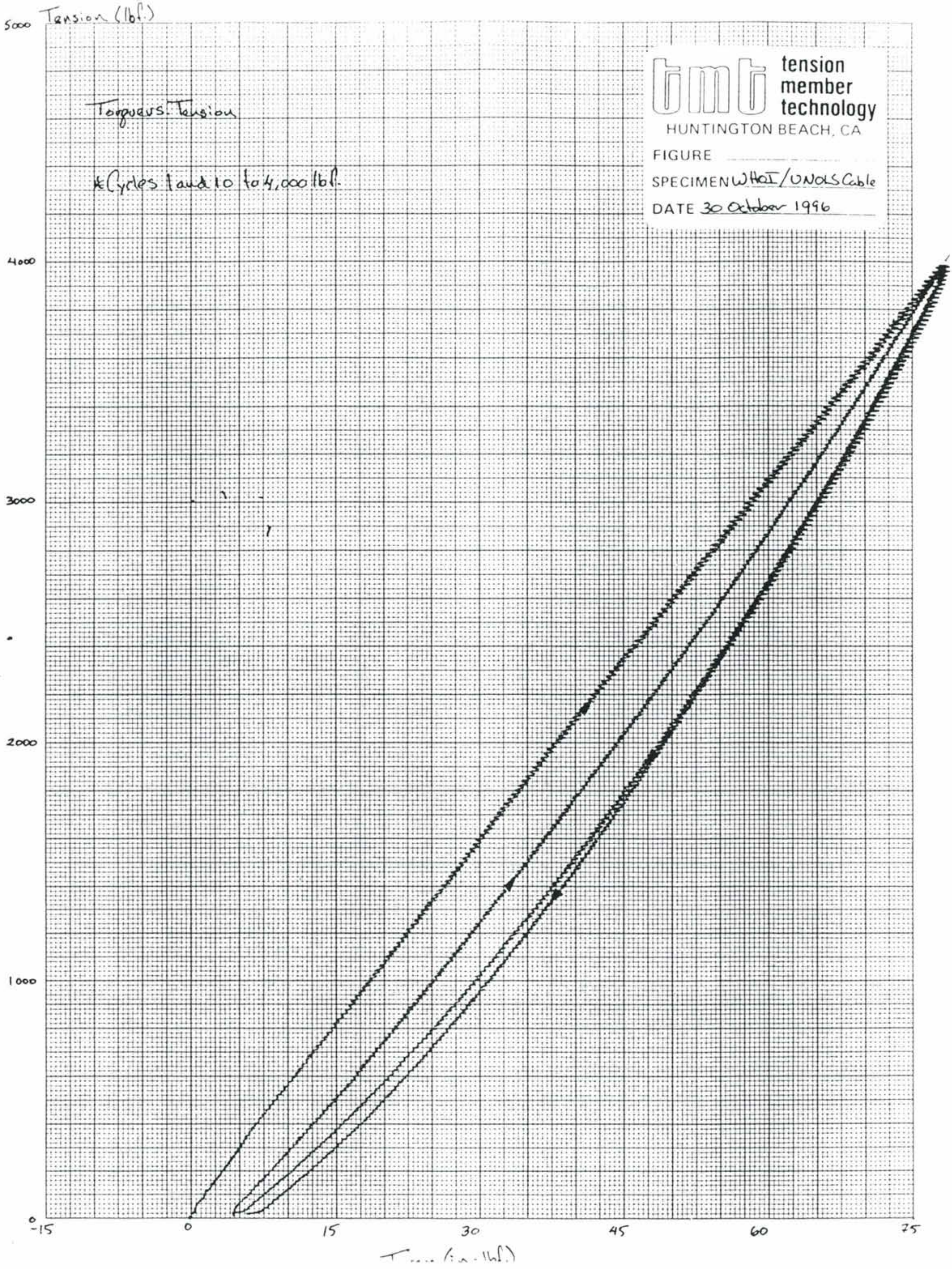


tension
member
technology
HUNTINGTON BEACH, CA

FIGURE
SPECIMEN WHOI/UNOLS Cable
DATE 30 October 1996

Rotation vs. Tension

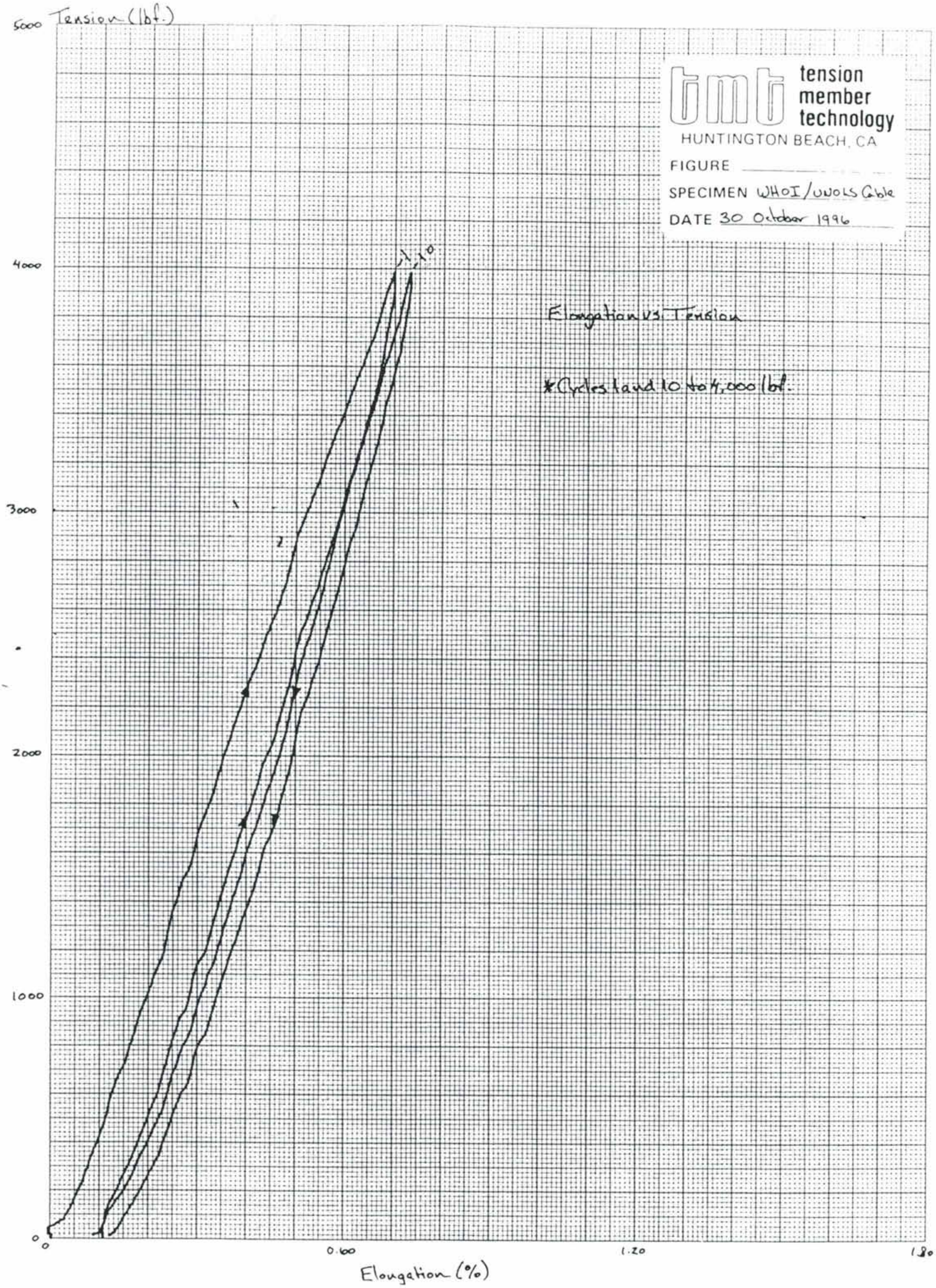
*Cycles 11 and 20 to 4,000 lbf.



Torque vs. Tension

* Cycles 1 and 10 to 4,000 lbf.

tension member technology
HUNTINGTON BEACH, CA
FIGURE
SPECIMEN WHOI/UNOLS Cable
DATE 30 October 1996



tension member technology
HUNTINGTON BEACH, CA
FIGURE
SPECIMEN WHOI/UNOLS Cable
DATE 30 October 1996

Elongation vs. Tension

*Cycles 1 and 10 to 4,000 lbf.

```
DESIGN: UNOLS-1
DESCRIPTION: 0.322-inch Diameter 3-Conductor Cable

LAYER  1      #19 AWG Conductors

   LAYER DESIGNATION                                 -> CONDUCTOR
   NUMBER OF CONDUCTORS                               = 3
   CONDUCTOR DIA. (in)                                = 0.0349
   CONDUCTOR INSULATION DIA. (in)                     = 0.0710
   LAYER O.D. (in)                                    = 0.1530
   LAY LENGTH (in)                                    = 1.300
   LAY DIRECTION                                     -> LEFT
   TENSILE MODULUS (Mpsi)                             = 15.000
   ULTIMATE STRESS (kpsi)                             = 40.0
   YIELD STRESS (kpsi)                                = 30.0
   POISSON'S RATIO                                    = 0.33
   THERMAL EXPANSION COEF (10^-6/deg F)               = 9.0
   SPECIFIC GRAVITY                                   = 8.90
   SPECIFIC GRAVITY OF INSULATION                     = 0.90

LAYER  2      Core Jacket

   LAYER DESIGNATION                                 -> NON-HELICAL
   ROD OR TUBE                                       -> TUBE
   TUBE I.D. (in)                                     = 0.1300
   TUBE O.D. (in)                                     = 0.1800
   TENSILE MODULUS (Mpsi)                             = 0.100
   ULTIMATE STRESS (kpsi)                             = 5.0
   YIELD STRESS (kpsi)                                = 3.0
   POISSON'S RATIO                                    = 0.45
   THERMAL EXPANSION COEF (10^-6/deg F)               = 70.0
   SPECIFIC GRAVITY                                   = 0.96

LAYER  3      Inner Armor

   LAYER DESIGNATION                                 -> ARMOR
   NUMBER OF WIRES                                    = 16
   WIRE DIA. (in)                                     = 0.0375
   LAYER O.D. (in)                                    = 0.2500
   LAY LENGTH (in)                                    = 1.596
   LAY DIRECTION                                     -> RIGHT
   TENSILE MODULUS (Mpsi)                             = 28.000
   ULTIMATE STRESS (kpsi)                             = 300.0
   YIELD STRESS (kpsi)                                = 265.0
   POISSON'S RATIO                                    = 0.30
   THERMAL EXPANSION COEF (10^-6/deg F)               = 6.0
   SPECIFIC GRAVITY                                   = 7.80

CABLE SOLVER 1  V4.09  CS1000  11-07-1996
Copyright 1987-1993 Tension Member Technology
```

```
DESIGN: UNOLS-1
DESCRIPTION: 0.322-inch Diameter 3-Conductor Cable

LAYER  4      Outer Armor

   LAYER DESIGNATION                                       -> ARMOR
   NUMBER OF WIRES                                          = 22
   WIRE DIA. (in)                                           = 0.0375
   LAYER O.D. (in)                                          = 0.3250
   LAY LENGTH (in)                                          = 2.685
   LAY DIRECTION                                           -> LEFT
   TENSILE MODULUS (Mpsi)                                   = 28.000
   ULTIMATE STRESS (kpsi)                                   = 300.0
   YIELD STRESS (kpsi)                                      = 265.0
   POISSON'S RATIO                                          = 0.30
   THERMAL EXPANSION COEF (10^-6/deg F)                     = 6.0
   SPECIFIC GRAVITY                                         = 7.80

CORE           Belt Over Power Conductors

   INITIAL CORE I.D. (in)                                   = 0
   INITIAL CORE O.D. (in)                                   = 0.1800
   BULK MODULUS (kpsi)                                      = 100.0
   VOID VOLUME (%)                                          = 0
   SPECIFIC GRAVITY OF VOID FILLER                          = 0
   THERMAL EXPANSION COEF (10^-6/deg F)                     = 0

MAXIMUM CUSP FILL (%)                                       = 90
CUSP FILL PRESSURE PARAMETER (psi)                          = 1000
HERMETIC CABLE JACKET                                      -> NO

CABLE SOLVER 1  V4.09  CS1000  11-07-1996
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```

```
DESIGN: UNOLS-1
DESCRIPTION: 0.322-inch Diameter 3-Conductor Cable

  LAYER                        DESCRIPTION

  LAYER  1         #19 AWG Conductors
  LAYER  2         Core Jacket
  LAYER  3         Inner Armor
  LAYER  4         Outer Armor
  CORE             Belt Over Power Conductors

CABLE SOLVER 1  V4.09  CS1000  11-07-1996
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```

```
DESIGN: UNOLS-1
DESCRIPTION: 0.322-inch Diameter 3-Conductor Cable

  MATERIAL PROPERTIES TABLE
---------------------------------------------------------
LAYER NUMBER                1         2         3         4
LAYER DESIGNATION        COND       NHL     ARMOR     ARMOR
---------------------------------------------------------
TENSILE MOD (Mpsi)     15.000     0.100    28.000    28.000
ULTIMATE (kpsi)          40.0       5.0     300.0     300.0
YIELD (kpsi)             30.0       3.0     265.0     265.0
SHEAR MOD (Mpsi)        5.639     0.034    10.769    10.769
POISSON'S RATIO          0.33      0.45      0.30      0.30
TEC (10^-6/deg F)         9.0      70.0       6.0       6.0
SPECIFIC GRAVITY         8.90      0.96      7.80      7.80
SG OF INSULATION         0.90       n/a       n/a       n/a
---------------------------------------------------------

CABLE SOLVER 1  V4.09  CS1000  11-07-1996
Copyright 1987-1993 Tension Member Technology
```

```
DESIGN: UNOLS-1
DESCRIPTION: 0.322-inch Diameter 3-Conductor Cable

INITIAL DESIGN

CORE: INITIAL CORE I.D. (in)                  = 0
      INITIAL CORE O.D. (in)                  = 0.1800
      BULK MODULUS (kpsi)                     = 100.0
      VOID VOLUME (%)                         = 0                     (4.6)
      SPECIFIC GRAVITY OF VOID FILLER         = 0
      MASS OF VOID FILLER (lbm/ft)            = 0
      THERMAL EXPANSION COEF (10^-6/deg F)    = 0

LAYER OVER CORE                               = LAYER  3
INITIAL CUSP FILL (%)                         = 74
MAXIMUM CUSP FILL (%)                         = 90
CUSP FILL PRESSURE PARAMETER (psi)            = 1000
NO HERMETIC CABLE JACKET

  CONFIGURATION TABLE
---------------------------------------------------------
LAYER NUMBER                  1        2        3        4
LAYER DESIGNATION          COND      NHL    ARMOR    ARMOR
---------------------------------------------------------
NO. OF ELEMENTS               3        1       16       22
ELMNT DIA. (in)          0.0349      n/a   0.0375   0.0375
INSLTN DIA. (in)         0.0710      n/a      n/a      n/a
LAYER I.D. (in)          0.0110   0.1300   0.1750   0.2500
LAYER P.D. (in)          0.0820   0.1550   0.2125   0.2875
LAYER O.D. (in)          0.1530   0.1800   0.2500   0.3250
DELTA O.D. (in)               0        0        0        0
DIA. BIAS (in)                0        0        0        0
LAY LENGTH (in)           1.300      n/a    1.596    2.685
LAY ANGLE (deg)           11.21        0    22.70    18.59
LAY DIRECTION              Left      n/a    Right     Left
R OF CURV (in)              1.1      n/a      0.7      1.4
COVERAGE (%)              100.8      n/a     97.8     96.6
STRENGTH (lb)               110       60     4890     6910
MASS (lbm/ft)              0.01     0.01     0.06     0.09
---------------------------------------------------------
STRAIN (%)          = 0          CORE PRESSURE (psi)          = 0
TENSION (lb)        = 0          TENSILE STRENGTH SUM (lb)    = 11970
TORQUE (lb-in)      = 0          MASS SUMMATION (lbm/ft)      = 0.17
ROTATION (deg/ft)   = 0

CABLE SOLVER 1  V4.09  CS1000  11-07-1996
Copyright 1987-1993 Tension Member Technology
```

```
DESIGN: UNOLS-1
DESCRIPTION: 0.322-inch Diameter 3-Conductor Cable

INITIAL TENSION (lb)                        = 0
FINAL TENSION (lb)                          = 4000
INCREMENT OF TENSION (lb)                   = 500
END CONDITION                              -> FIXED (NO ROTATION)
COMPRESSIBLE CORE MODEL
TENSION DEPENDENT CUSP FILL
NO BIAS

CORE: INITIAL CORE I.D. (in)                = 0
      INITIAL CORE O.D. (in)                = 0.1800
      BULK MODULUS (kpsi)                   = 100.0
      VOID VOLUME (%)                       = 0                     (4.6)
      SPECIFIC GRAVITY OF VOID FILLER       = 0
      MASS OF VOID FILLER (lbm/ft)          = 0

LAYER OVER CORE                             = LAYER  3
INITIAL CUSP FILL (%)                       = 74
MAXIMUM CUSP FILL (%)                       = 90
CUSP FILL PRESSURE PARAMETER (psi)          = 1000
NO HERMETIC CABLE JACKET

  PERFORMANCE TABLE
-------------------------------------------------------------------------------
 TENSION   STRAIN   TORQUE   ROTATION   DIAMETER    PRESSURE   TEMPERATURE
   (lb)      (%)   (lb-in)   (deg/ft)      (in)       (psi)      (deg F)
-------------------------------------------------------------------------------
      0        0        0         0      0.3250         0            0
    500     0.10       15         0      0.3240         0            0
   1000     0.20       27         0      0.3232         0            0
   1500     0.28       38         0      0.3225         0            0
   2000     0.37       49         0      0.3219         0            0
   2500     0.46       60         0      0.3212         0            0
   3000     0.54       71         0      0.3206         0            0
   3500     0.63       81         0      0.3200         0            0
   4000     0.71       91         0      0.3194         0            0
-------------------------------------------------------------------------------

CABLE SOLVER 1  V4.09  CS1000  11-07-1996
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```

```
DESIGN: UNOLS-1
DESCRIPTION: 0.322-inch Diameter 3-Conductor Cable

INITIAL TENSION (lb)                        = 0
FINAL TENSION (lb)                          = 4000
INCREMENT OF TENSION (lb)                   = 500
END CONDITION                              -> FREE TO ROTATE
COMPRESSIBLE CORE MODEL
TENSION DEPENDENT CUSP FILL
NO BIAS

CORE: INITIAL CORE I.D. (in)                = 0
      INITIAL CORE O.D. (in)                = 0.1800
      BULK MODULUS (kpsi)                   = 100.0
      VOID VOLUME (%)                       = 0                        (4.6)
      SPECIFIC GRAVITY OF VOID FILLER       = 0
      MASS OF VOID FILLER (lbm/ft)          = 0

LAYER OVER CORE                             = LAYER  3
INITIAL CUSP FILL (%)                       = 74
MAXIMUM CUSP FILL (%)                       = 90
CUSP FILL PRESSURE PARAMETER (psi)          = 1000
NO HERMETIC CABLE JACKET

  PERFORMANCE TABLE
-----------------------------------------------------------------------------
 TENSION    STRAIN    TORQUE   ROTATION    DIAMETER    PRESSURE  TEMPERATURE
   (lb)       (%)    (lb-in)   (deg/ft)       (in)        (psi)     (deg F)
-----------------------------------------------------------------------------
       0         0         0          0     0.3250          0            0
     500      0.13         0        5.8     0.3237          0            0
    1000      0.24         0       10.6     0.3227          0            0
    1500      0.34         0       15.0     0.3219          0            0
    2000      0.44         0       19.3     0.3211          0            0
    2500      0.54         0       23.6     0.3204          0            0
    3000      0.64         0       27.9     0.3196          0            0
    3500      0.74         0       32.3     0.3188          0            0
    4000      0.84         0       36.6     0.3181          0            0
-----------------------------------------------------------------------------

CABLE SOLVER 1  V4.09  CS1000  11-07-1996
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```

```
DESIGN: UNOLS-1
DESCRIPTION: 0.322-inch Diameter 3-Conductor Cable

TENSION (lb)                                  = 4000
END CONDITION                                -> FIXED (NO ROTATION)
COMPRESSIBLE CORE MODEL
TENSION DEPENDENT CUSP FILL
NO BIAS

CORE: INITIAL CORE I.D. (in)                  = 0
      INITIAL CORE O.D. (in)                  = 0.1800
      EFFECTIVE CORE O.D. (in)                = 0.1749
      DELTA CORE O.D. (in)                    = -0.0051
      BULK MODULUS (kpsi)                     = 100.0
      VOID VOLUME (%)                         = 0                         (4.6)
      SPECIFIC GRAVITY OF VOID FILLER         = 0
      MASS OF VOID FILLER (lbm/ft)            = 0

LAYER OVER CORE                               = LAYER  3
INITIAL CUSP FILL (%)                         = 74
MAXIMUM CUSP FILL (%)                         = 90
CUSP FILL PRESSURE PARAMETER (psi)            = 1000
CUSP FILL (%)                                 = 90
NO HERMETIC CABLE JACKET

  CONFIGURATION TABLE
---------------------------------------------------------
LAYER NUMBER                 1        2        3        4
LAYER DESIGNATION         COND      NHL    ARMOR    ARMOR
---------------------------------------------------------
NO. OF ELEMENTS              3        1       16       22
ELMNT DIA. (in)         0.0349      n/a   0.0375   0.0375
INSLTN DIA. (in)        0.0710      n/a      n/a      n/a
LAYER I.D. (in)         0.0107   0.1263   0.1694   0.2444
LAYER P.D. (in)         0.0797   0.1506   0.2069   0.2819
LAYER O.D. (in)         0.1487   0.1749   0.2444   0.3194
DELTA O.D. (in)        -0.0043  -0.0051  -0.0056  -0.0056
DIA. BIAS (in)               0        0        0        0
LAY LENGTH (in)          1.309      n/a    1.607    2.704
LAY ANGLE (deg)          10.83        0    22.02    18.14
LAY DIRECTION             Left      n/a    Right     Left
R OF CURV (in)             1.1      n/a      0.7      1.5
COVERAGE (%)             101.4      n/a    100.0     98.3
STRENGTH (lb)              110       60     4890     6910
MASS (lbm/ft)             0.01     0.01     0.06     0.09
---------------------------------------------------------
STRAIN (%)          = 0.71     CORE PRESSURE (psi)         = 4870
TENSION (lb)        = 4000     TENSILE STRENGTH SUM (lb)   = 11970
TORQUE (lb-in)      = 91       MASS SUMMATION (lbm/ft)     = 0.17
ROTATION (deg/ft)   = 0

CABLE SOLVER 1  V4.09  CS1000  11-07-1996
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```

```
DESIGN: UNOLS-1
DESCRIPTION: 0.322-inch Diameter 3-Conductor Cable

TENSION (lb)                                 = 4000
END CONDITION                               -> FIXED (NO ROTATION)
COMPRESSIBLE CORE MODEL
TENSION DEPENDENT CUSP FILL
NO BIAS

CORE: INITIAL CORE I.D. (in)                 = 0
      INITIAL CORE O.D. (in)                 = 0.1800
      EFFECTIVE CORE O.D. (in)               = 0.1749
      DELTA CORE O.D. (in)                   = -0.0051
      BULK MODULUS (kpsi)                    = 100.0
      VOID VOLUME (%)                        = 0                        (4.6)
      SPECIFIC GRAVITY OF VOID FILLER        = 0
      MASS OF VOID FILLER (lbm/ft)           = 0

LAYER OVER CORE                              = LAYER  3
INITIAL CUSP FILL (%)                        = 74
MAXIMUM CUSP FILL (%)                        = 90
CUSP FILL PRESSURE PARAMETER (psi)           = 1000
CUSP FILL (%)                                = 90
NO HERMETIC CABLE JACKET

  STRESS/STRAIN TABLE
---------------------------------------------------------
LAYER NUMBER                1        2        3        4
LAYER DESIGNATION         COND      NHL    ARMOR    ARMOR
---------------------------------------------------------
TEN STRESS (kpsi)         39.7      0.7     61.6    124.2
TEN STRAIN (%)            0.58     0.71     0.22     0.44
SHR STRESS (kpsi)            0        0      0.4      0.1
SHR STRAIN (%)               0        0        0        0
MXTOR STRESS (kpsi)        2.0        0      1.8      0.8
MXTOR STRAIN (%)          0.04        0     0.02     0.01
MXBEN STRESS (kpsi)        *0*        0     22.5     10.4
MXBEN STRAIN (%)           *0*        0     0.08     0.04
MXEFF STRESS (kpsi)       39.8      0.7     84.1    134.6
TENSION (lb)               110       10     1010     2870
TORQUE (lb-in)               1        0      -41      132
RAD FORCE (lb/in)          100        0     1570     2180
RAD PRESS (psi)            410        0     2420     2460
---------------------------------------------------------
 LAYER(S)  1  MXEFF STRESS ABOVE YIELD.
STRAIN (%)            = 0.71      CORE PRESSURE (psi)          = 4870
TENSION (lb)          = 4000      TENSILE STRENGTH SUM (lb)    = 11970
TORQUE (lb-in)        = 91
ROTATION (deg/ft)     = 0

CABLE SOLVER 1  V4.09  CS1000  11-07-1996
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```

```
DESIGN: UNOLS-1
DESCRIPTION: 0.322-inch Diameter 3-Conductor Cable

TENSION (lb)                                    = 4000
END CONDITION                                  -> FREE TO ROTATE
COMPRESSIBLE CORE MODEL
TENSION DEPENDENT CUSP FILL
NO BIAS

CORE:  INITIAL CORE I.D. (in)                   = 0
       INITIAL CORE O.D. (in)                   = 0.1800
       EFFECTIVE CORE O.D. (in)                 = 0.1734
       DELTA CORE O.D. (in)                     = -0.0066
       BULK MODULUS (kpsi)                      = 100.0
       VOID VOLUME (%)                          = 0                        (4.6)
       SPECIFIC GRAVITY OF VOID FILLER          = 0
       MASS OF VOID FILLER (lbm/ft)             = 0

LAYER OVER CORE                                 = LAYER  3
INITIAL CUSP FILL (%)                           = 74
MAXIMUM CUSP FILL (%)                           = 90
CUSP FILL PRESSURE PARAMETER (psi)              = 1000
CUSP FILL (%)                                   = 90
NO HERMETIC CABLE JACKET

  CONFIGURATION TABLE
---------------------------------------------------------
LAYER NUMBER                 1        2        3        4
LAYER DESIGNATION         COND      NHL    ARMOR    ARMOR
---------------------------------------------------------
NO. OF ELEMENTS              3        1       16       22
ELMNT DIA. (in)         0.0349      n/a   0.0375   0.0375
INSLTN DIA. (in)        0.0710      n/a      n/a      n/a
LAYER I.D. (in)         0.0106   0.1252   0.1681   0.2431
LAYER P.D. (in)         0.0790   0.1493   0.2056   0.2806
LAYER O.D. (in)         0.1474   0.1734   0.2431   0.3181
DELTA O.D. (in)        -0.0056  -0.0066  -0.0069  -0.0069
DIA. BIAS (in)               0        0        0        0
LAY LENGTH (in)          1.325      n/a    1.588    2.771
LAY ANGLE (deg)          10.61        0    22.13    17.65
LAY DIRECTION             Left      n/a    Right     Left
R OF CURV (in)             1.2      n/a      0.7      1.5
COVERAGE (%)             101.5      n/a    100.7     98.5
STRENGTH (lb)              110       60     4890     6910
MASS (lbm/ft)             0.01     0.01     0.06     0.09
---------------------------------------------------------
STRAIN (%)          = 0.84     CORE PRESSURE (psi)         = 6410
TENSION (lb)        = 4000     TENSILE STRENGTH SUM (lb)   = 11970
TORQUE (lb-in)      = 0        MASS SUMMATION (lbm/ft)     = 0.17
ROTATION (deg/ft)   = 36.6

CABLE SOLVER 1  V4.09  CS1000  11-07-1996
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```
DESIGN: UNOLS-1
DESCRIPTION: 0.322-inch Diameter 3-Conductor Cable

TENSION (lb)                                   = 4000
END CONDITION                                 -> FREE TO ROTATE
COMPRESSIBLE CORE MODEL
TENSION DEPENDENT CUSP FILL
NO BIAS

CORE: INITIAL CORE I.D. (in)                   = 0
      INITIAL CORE O.D. (in)                   = 0.1800
      EFFECTIVE CORE O.D. (in)                 = 0.1734
      DELTA CORE O.D. (in)                     = -0.0066
      BULK MODULUS (kpsi)                      = 100.0
      VOID VOLUME (%)                          = 0                    (4.6)
      SPECIFIC GRAVITY OF VOID FILLER          = 0
      MASS OF VOID FILLER (lbm/ft)             = 0

LAYER OVER CORE                                = LAYER  3
INITIAL CUSP FILL (%)                          = 74
MAXIMUM CUSP FILL (%)                          = 90
CUSP FILL PRESSURE PARAMETER (psi)             = 1000
CUSP FILL (%)                                  = 90
NO HERMETIC CABLE JACKET

  STRESS/STRAIN TABLE
------------------------------------------------------------
LAYER NUMBER                1         2         3         4
LAYER DESIGNATION         COND       NHL     ARMOR     ARMOR
------------------------------------------------------------
TEN STRESS (kpsi)         39.8       0.8     119.7      82.7
TEN STRAIN (%)            0.63      0.84      0.43      0.30
SHR STRESS (kpsi)          0.1         0       0.3       0.2
SHR STRAIN (%)               0         0         0         0
MXTOR STRESS (kpsi)        7.0       0.2       9.0       8.6
MXTOR STRAIN (%)          0.12      0.46      0.08      0.08
MXBEN STRESS (kpsi)        *0*         0      10.8      27.3
MXBEN STRAIN (%)           *0*         0      0.04      0.10
MXEFF STRESS (kpsi)       41.6       0.9     131.5     111.0
TENSION (lb)               110        10      1960      1920
TORQUE (lb-in)               1         0       -82        82
RAD FORCE (lb/in)          100         0      3130      1370
RAD PRESS (psi)            400         0      4850      1550
------------------------------------------------------------
 LAYER(S)  1  MXEFF STRESS ABOVE YIELD.
STRAIN (%)          = 0.84      CORE PRESSURE (psi)          = 6410
TENSION (lb)        = 4000      TENSILE STRENGTH SUM (lb)    = 11970
TORQUE (lb-in)      = 0
ROTATION (deg/ft)   = 36.6

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APPENDIX VII

CABLE WORKSHOP NOTES

Prepared for

Research Vessel Technical Enhancement Committee

1996 Annual Meeting

November 11 - 13, 1996

at

Harbor Branch Oceanographic Institution, Inc.
J. Seward Johnson Marine Education & Conference Center
Ft. Pierce, Florida

by

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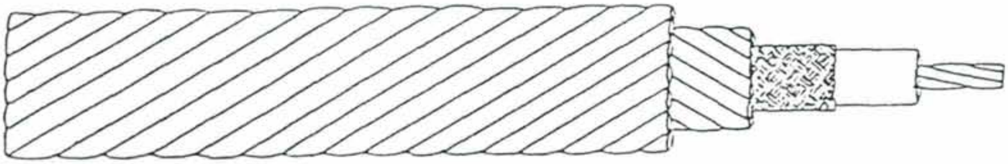
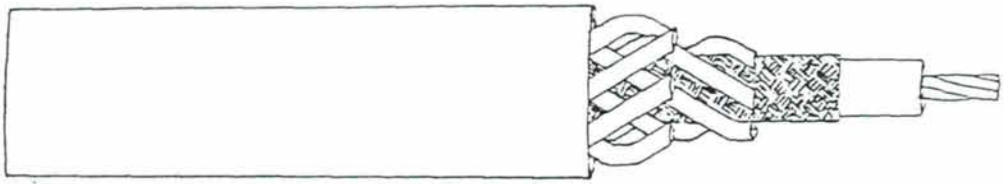
A



Double Steel Wire Armor

B

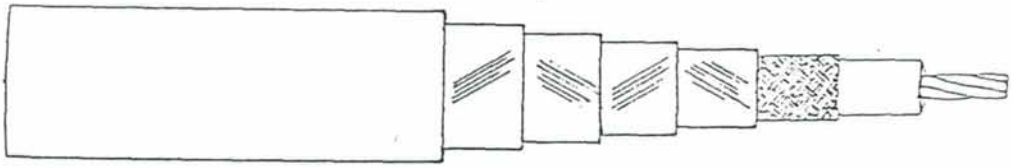


Spaced Armor and Integral Extruded Jacket

C

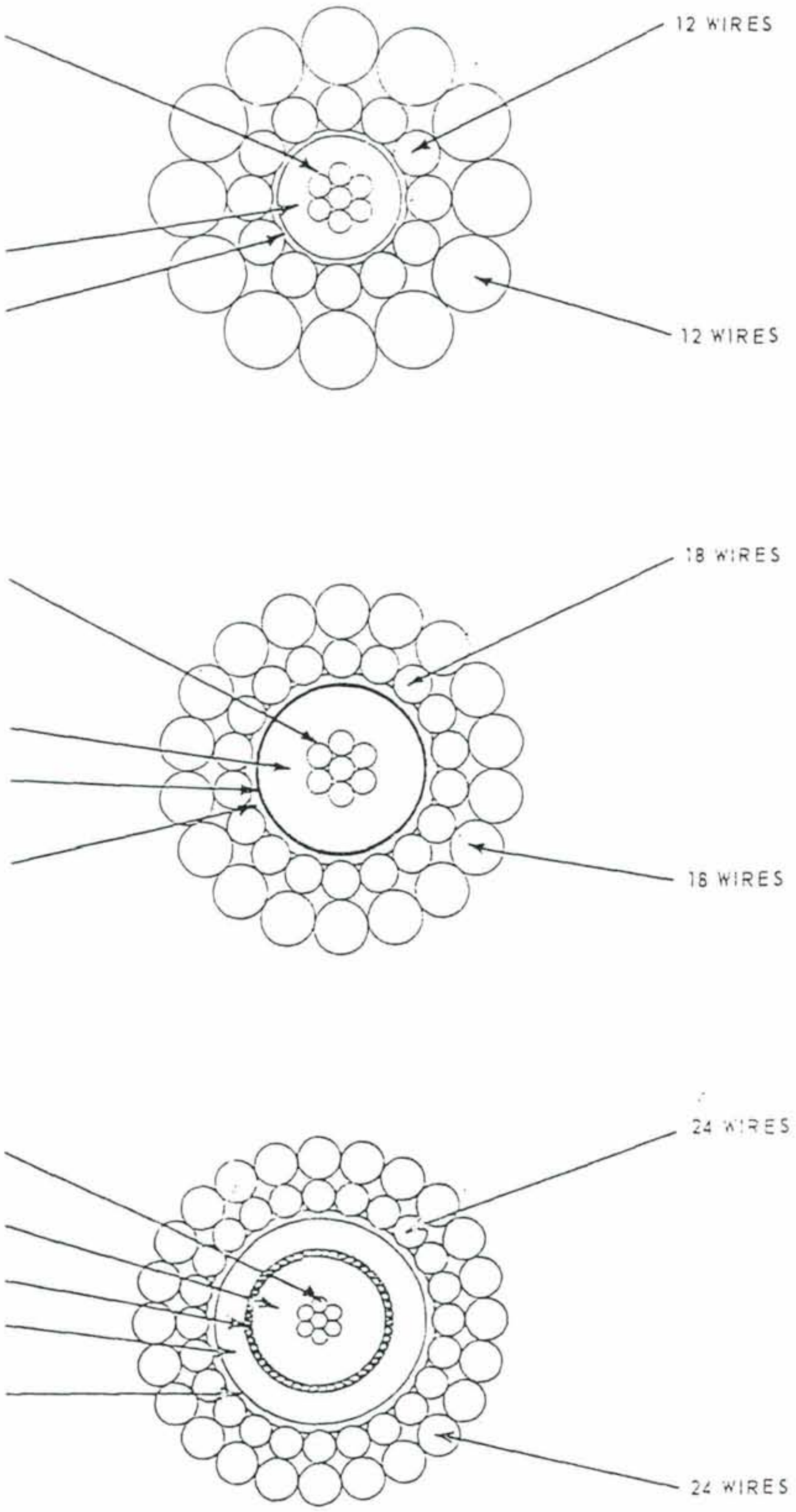
Braided Kevlar and Overall Jacket

D

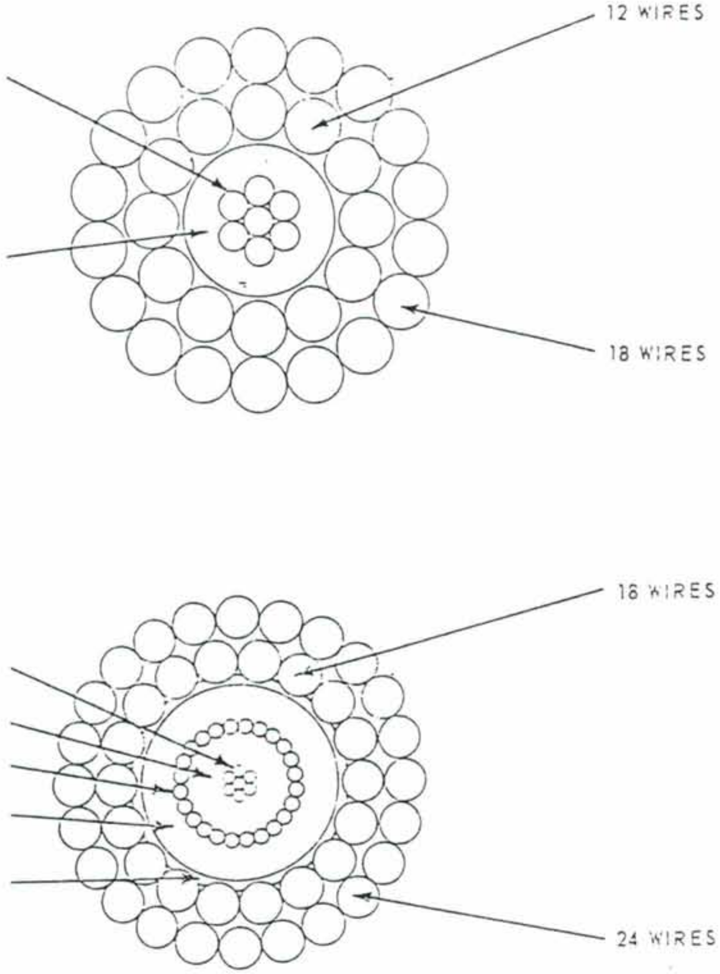


Served Kevlar and Overall Jacket

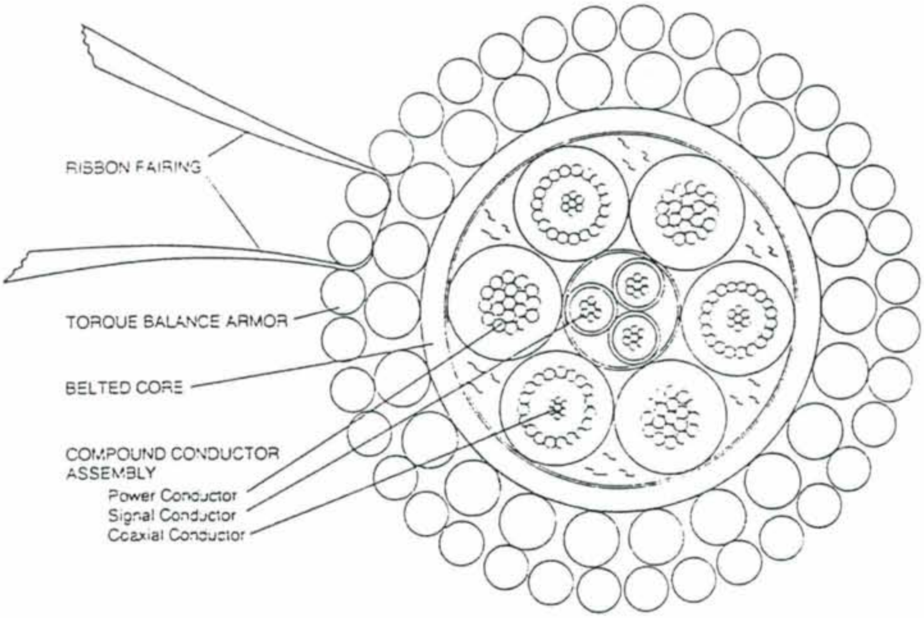
TYPICAL CONFIGURATIONS OF CABLES HAVING
EXTERNAL STRENGTH MEMBERS



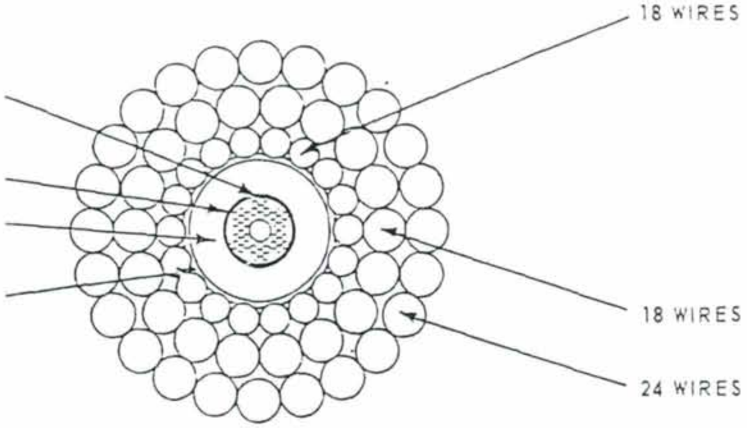
CABLES WITH EQUAL NUMBERS OF WIRES IN BOTH LAYERS



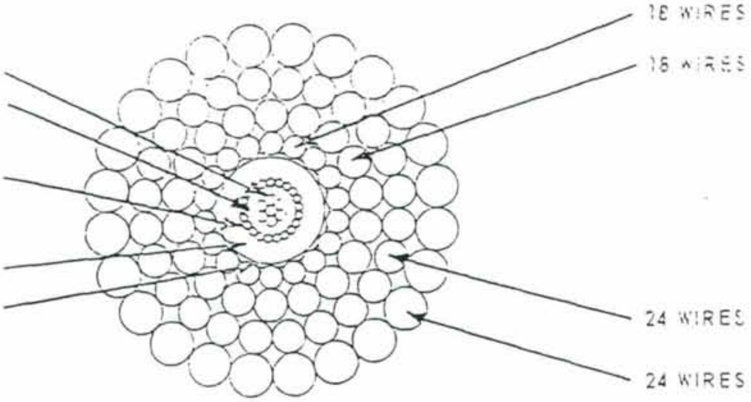
CABLES WITH EQUAL SIZE WIRES IN BOTH LAYERS



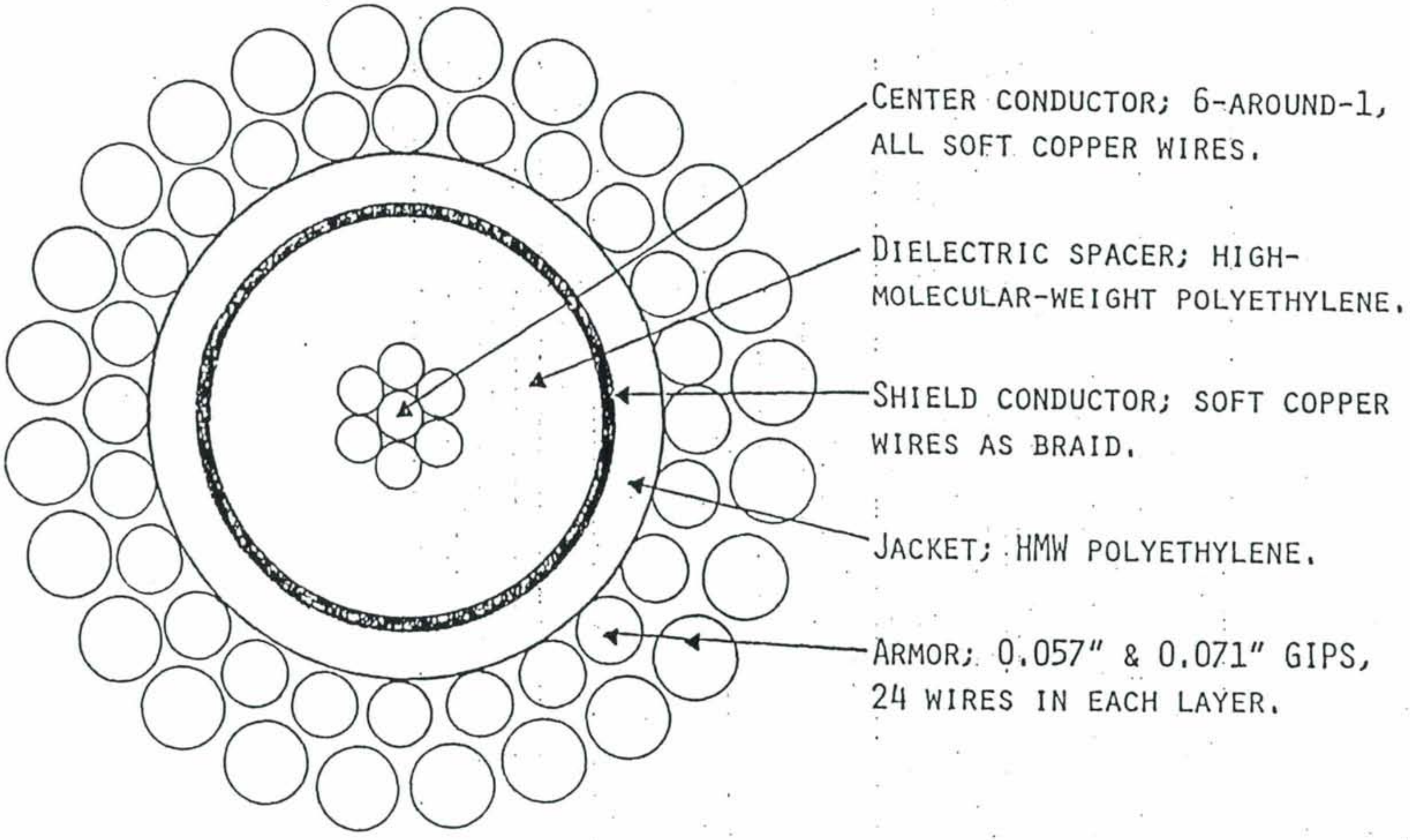
A Typical Compound Cable
(TORQUE BALANCED)



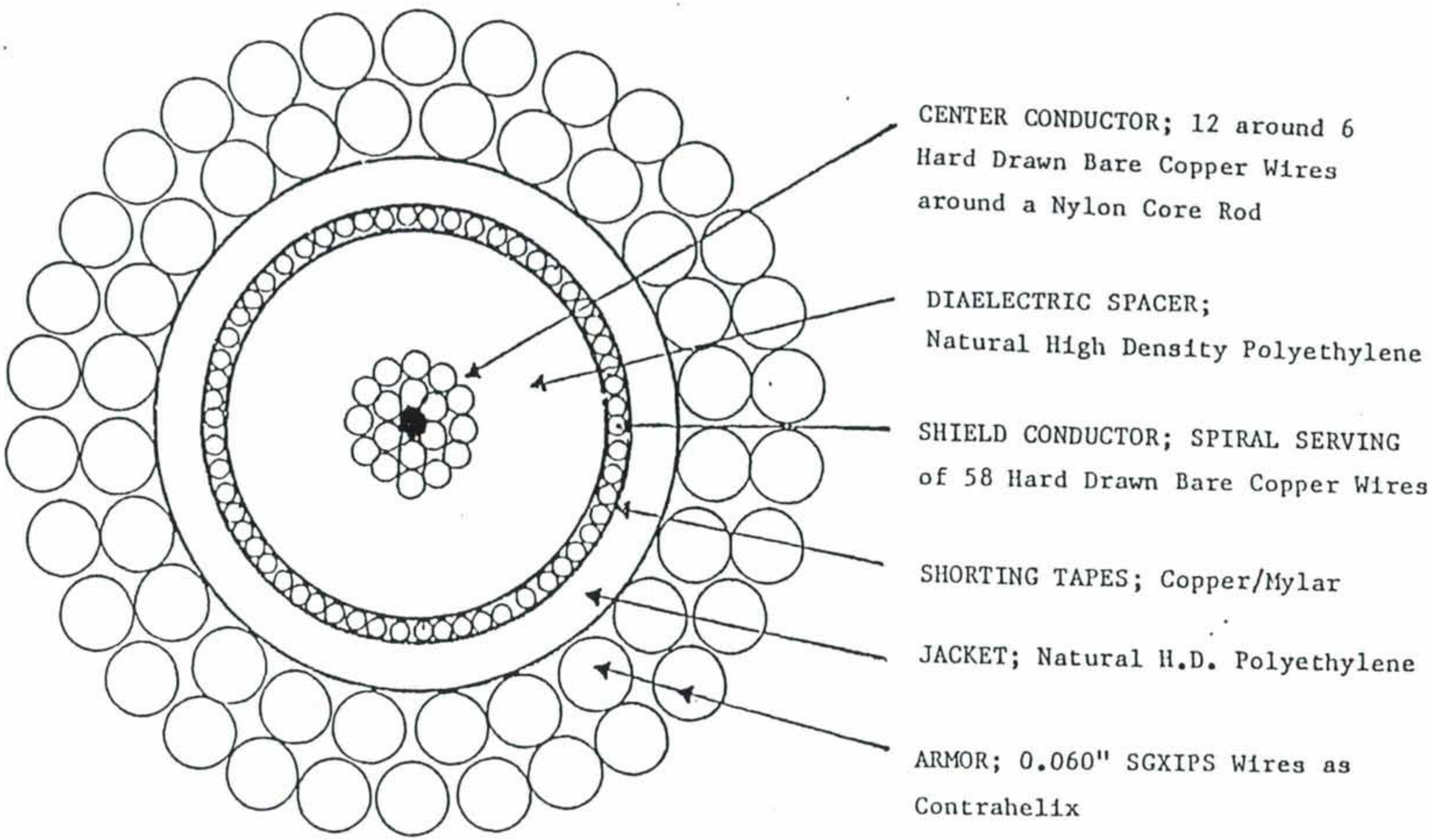
THREE LAYERS OF ARMOR



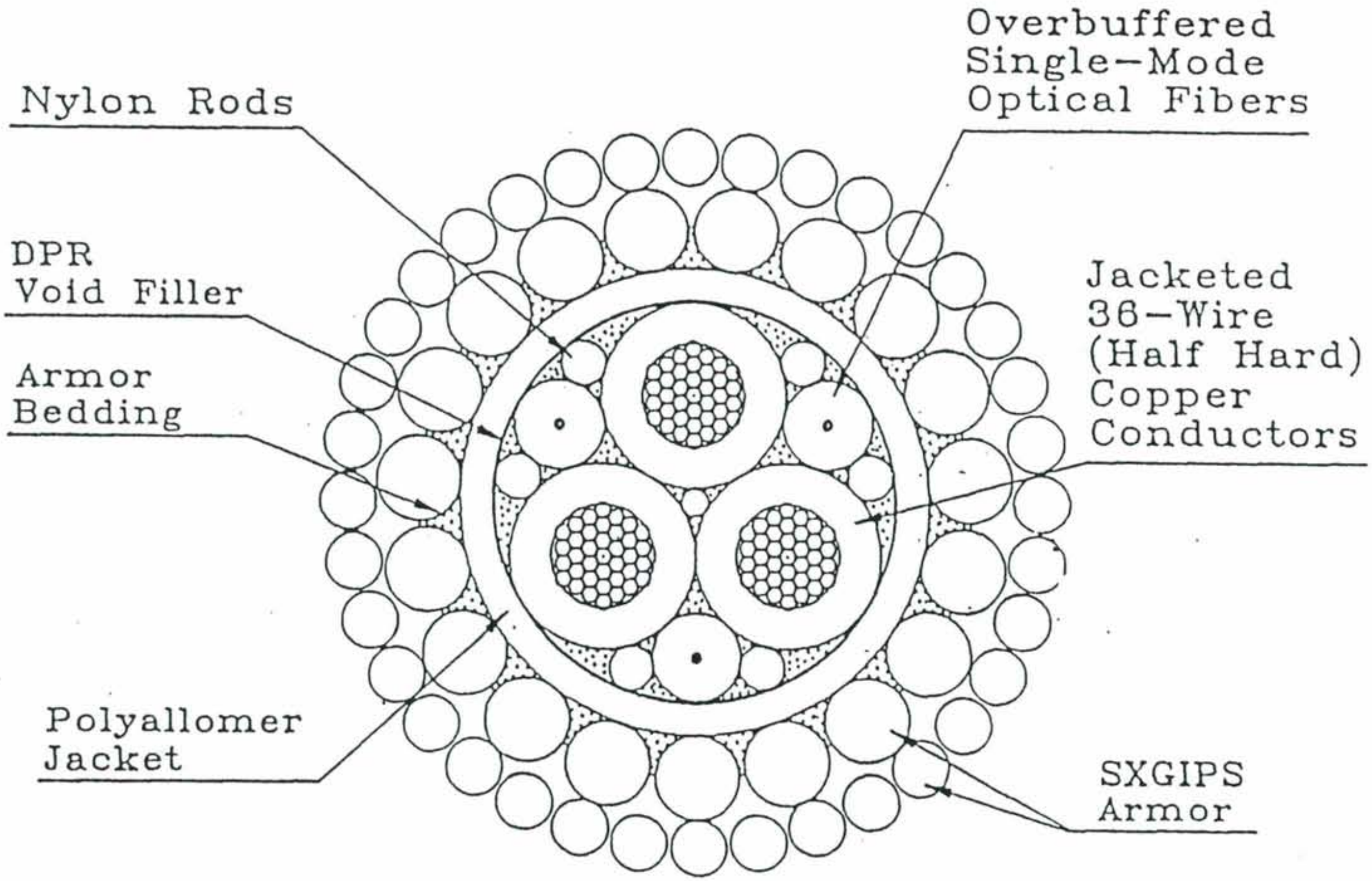
FOUR LAYERS OF ARMOR



EARLY (CA 1972) NAVY VERSION OF MPL/WHOI CABLE.

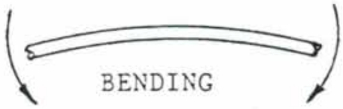


CROSS SECTION OF SPECIFICATION ARMORED COAXIAL CABLE.
(ALL VOIDS IN THE CABLE CORE ARE FILLED.)



Prototype Deepsea E-O Tether Cable

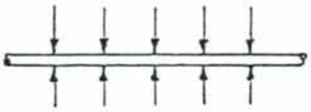
TENSION



BENDING

TORSION

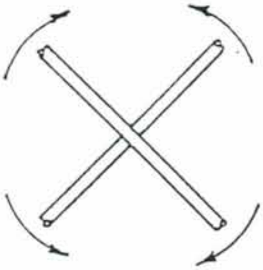
SHEAR



UNIFORM COMPRESSION

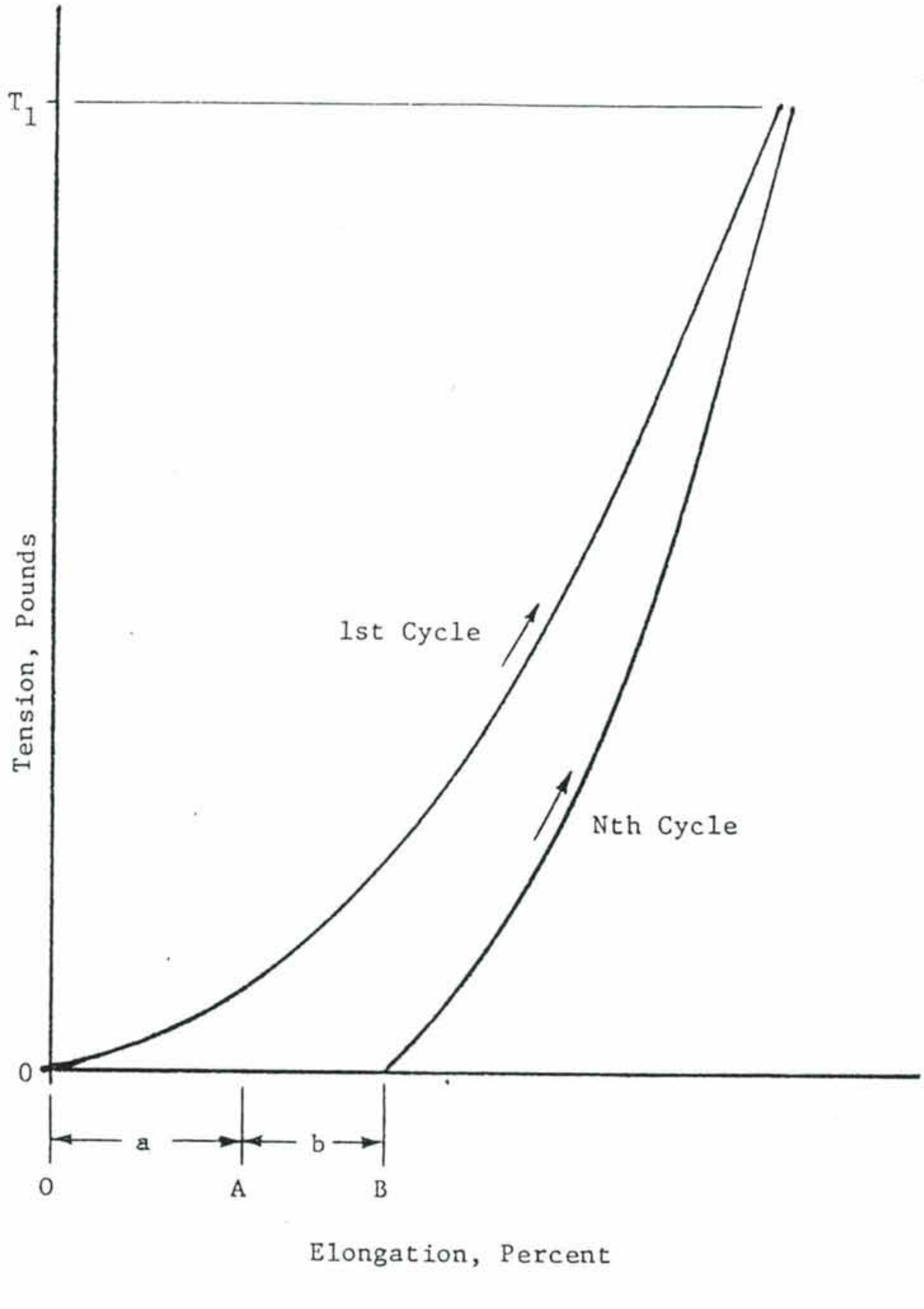
LOCALIZED COMPRESSION

FIBER ABRASION
DUE TO
ROPE BENDING

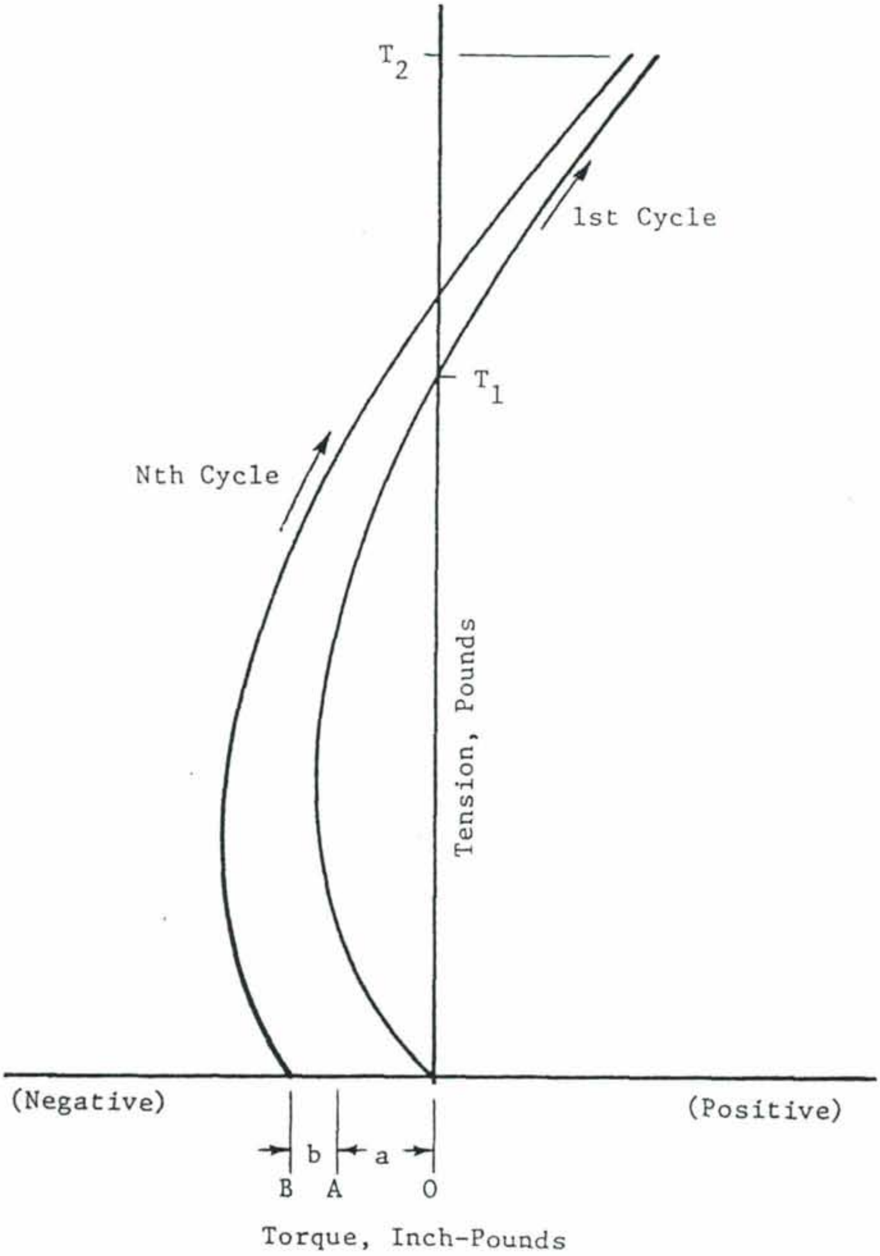


FIBER ABRASION
DUE TO
ROPE ELONGATION

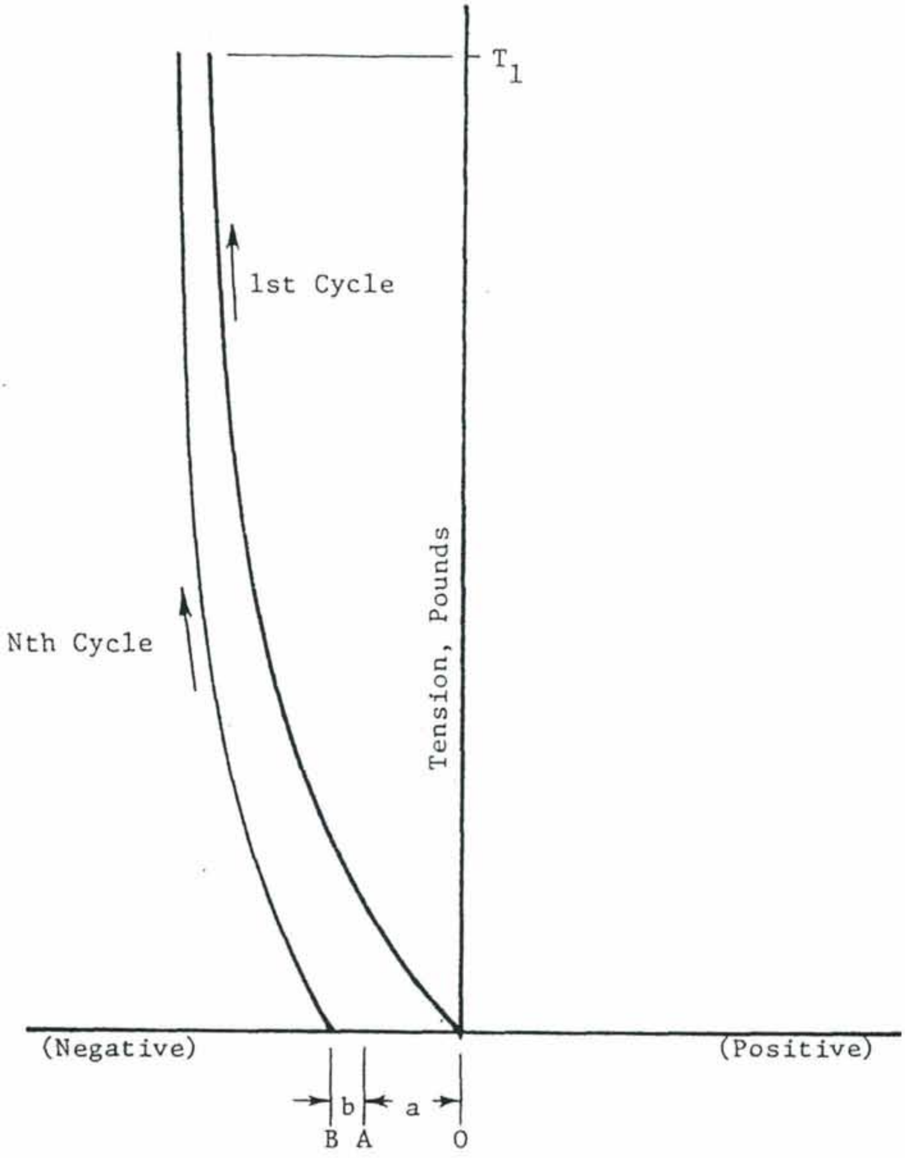
FORCES AND MOTIONS AFFECTING INDIVIDUAL ELEMENTS WITHIN A ROPE OR CABLE



TYPICAL ELONGATION VERSUS TENSION CURVES FOR
FOR A DOUBLE STEEL-WIRE ARMORED ELECTRO-
MECHNICAL CABLE

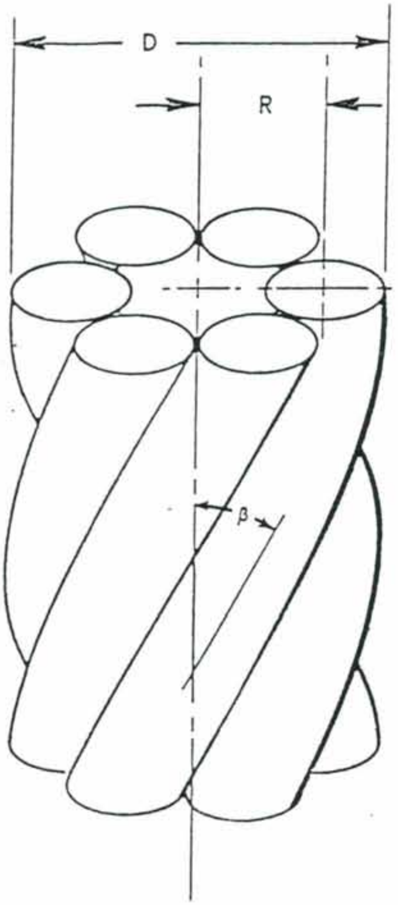


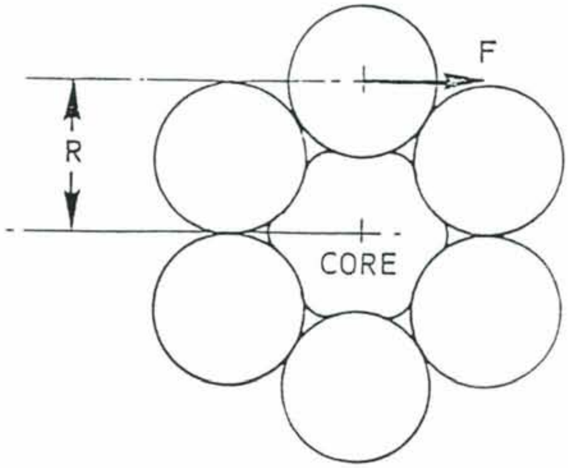
TYPICAL TORQUE VERSUS TENSION CURVES FOR A 'TORQUE-BALANCED' DOUBLE STEEL-WIRE ARMORED ELECTROMECHANICAL CABLE

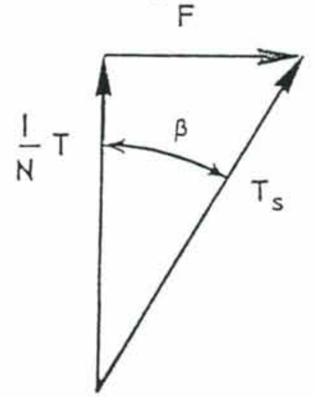


TYPICAL ROTATION VERSUS TENSION CURVES FOR
A 'TORQUE-BALANCED' DOUBLE STEEL-WIRE
ARMORED ELECTROMECHANICAL CABLE

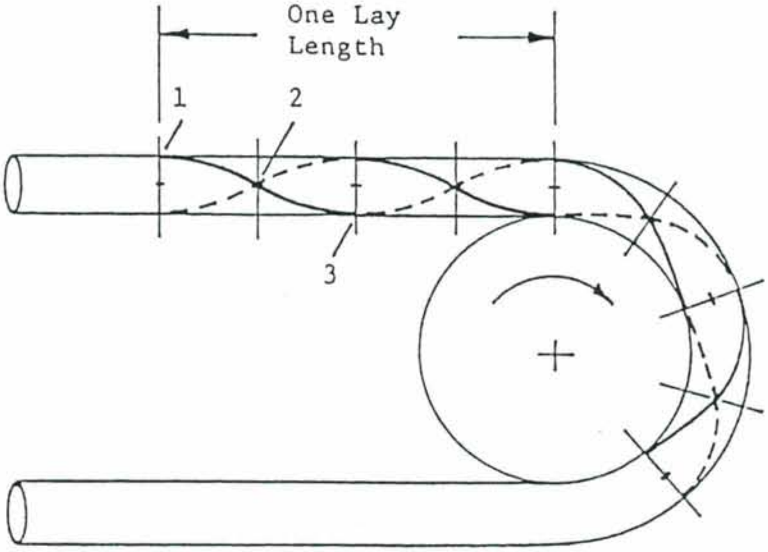
CABLE TORQUE COMPONENTS



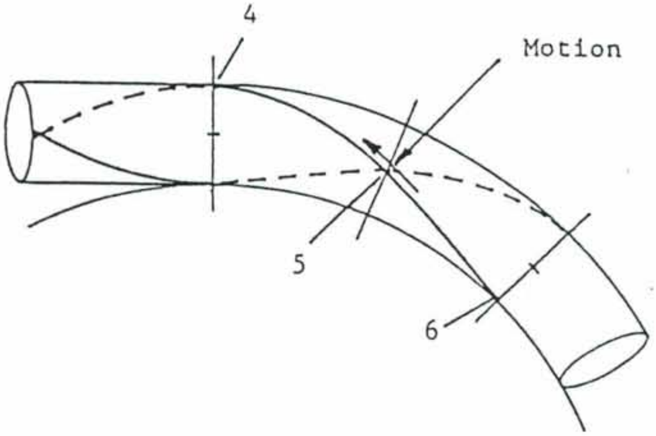




COMPONENT MOTIONS DURING CABLE BENDING



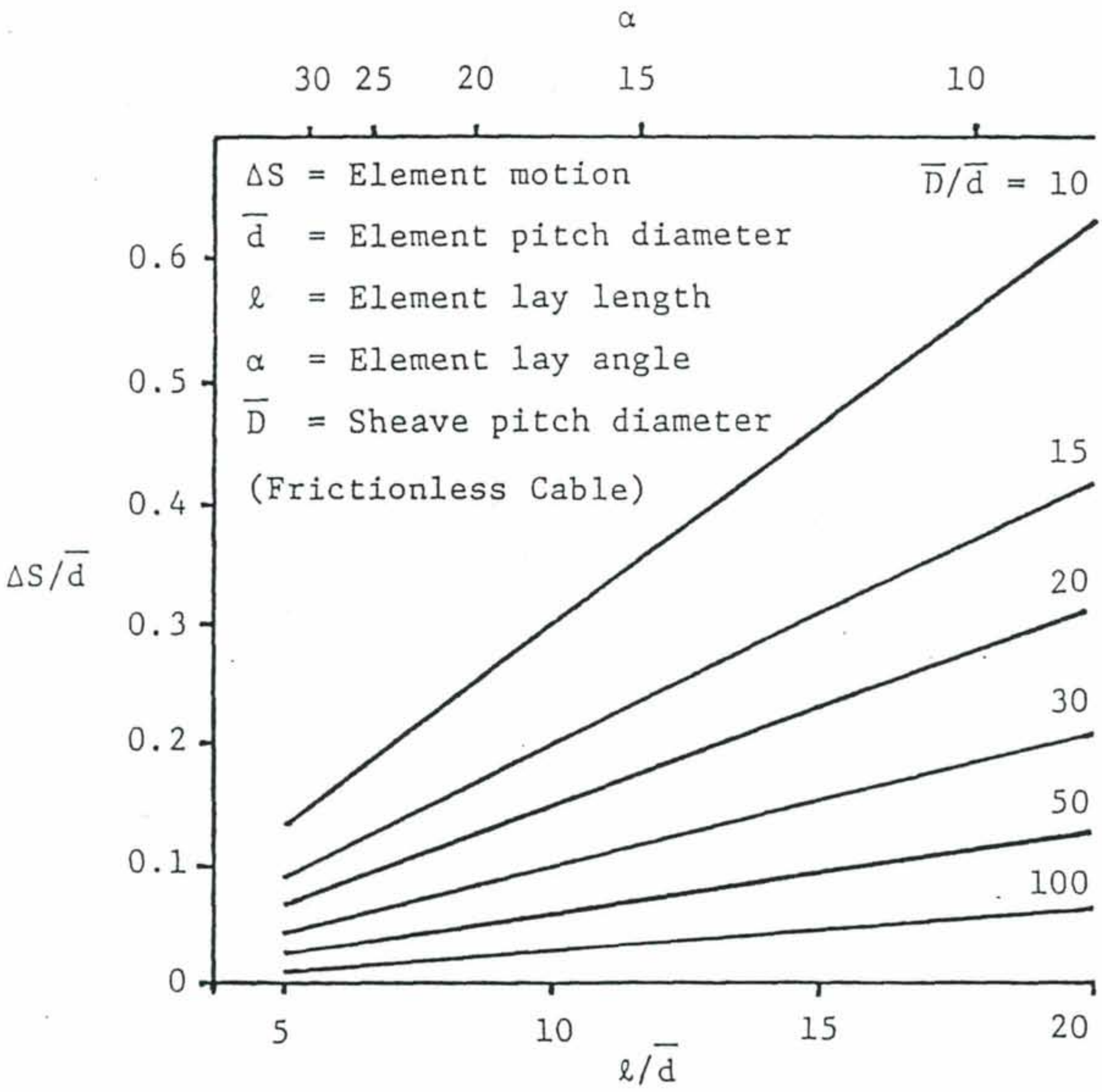
Deformations of Component Helices

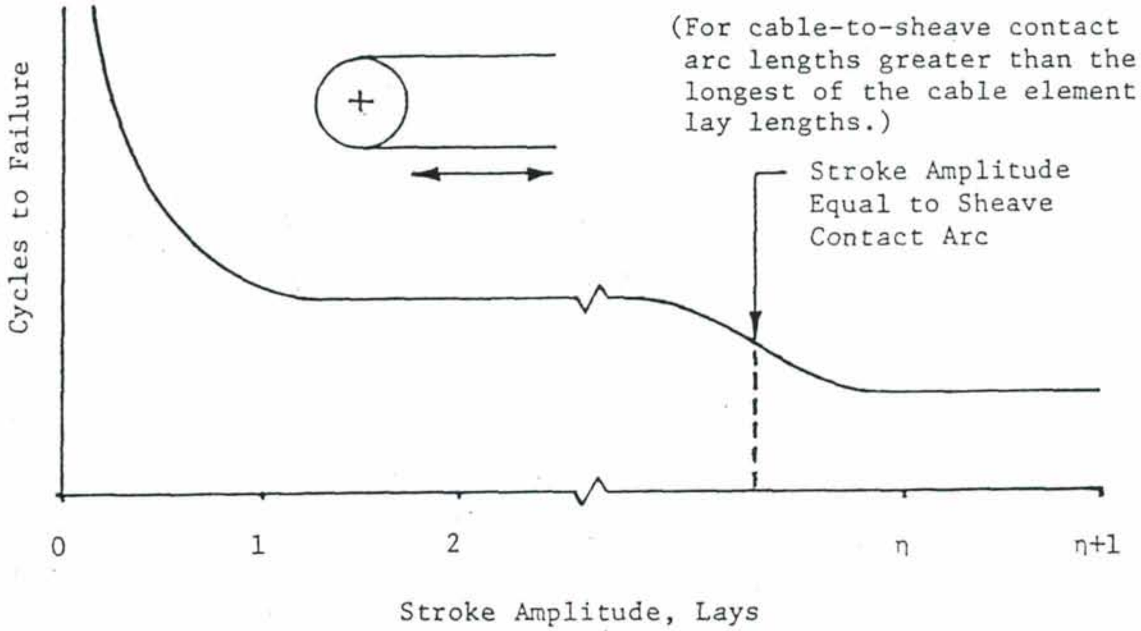


Component Motions

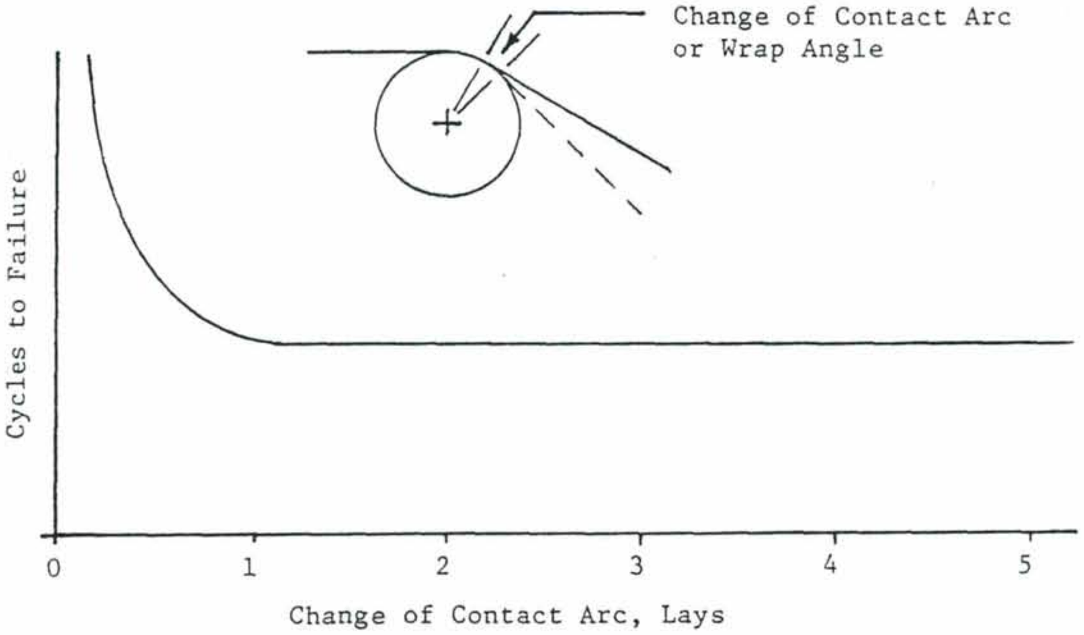
COMPONENT MOTIONS DURING CABLE BENDING

$\bar{d}$ = diam fm. center of cable to center of component
$\bar{D}$ = diam fm center of sheave to center of cable

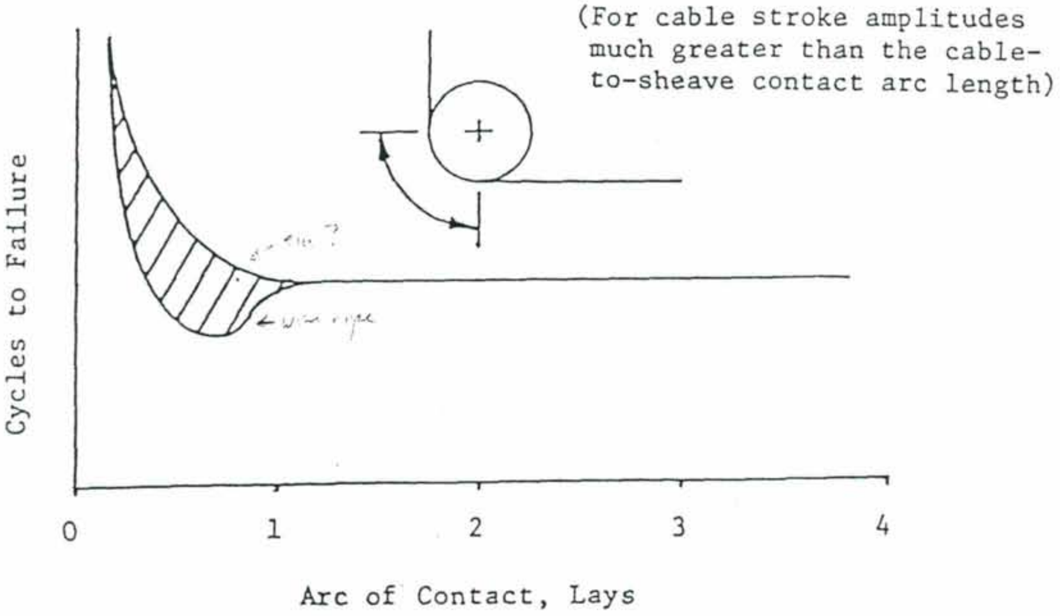




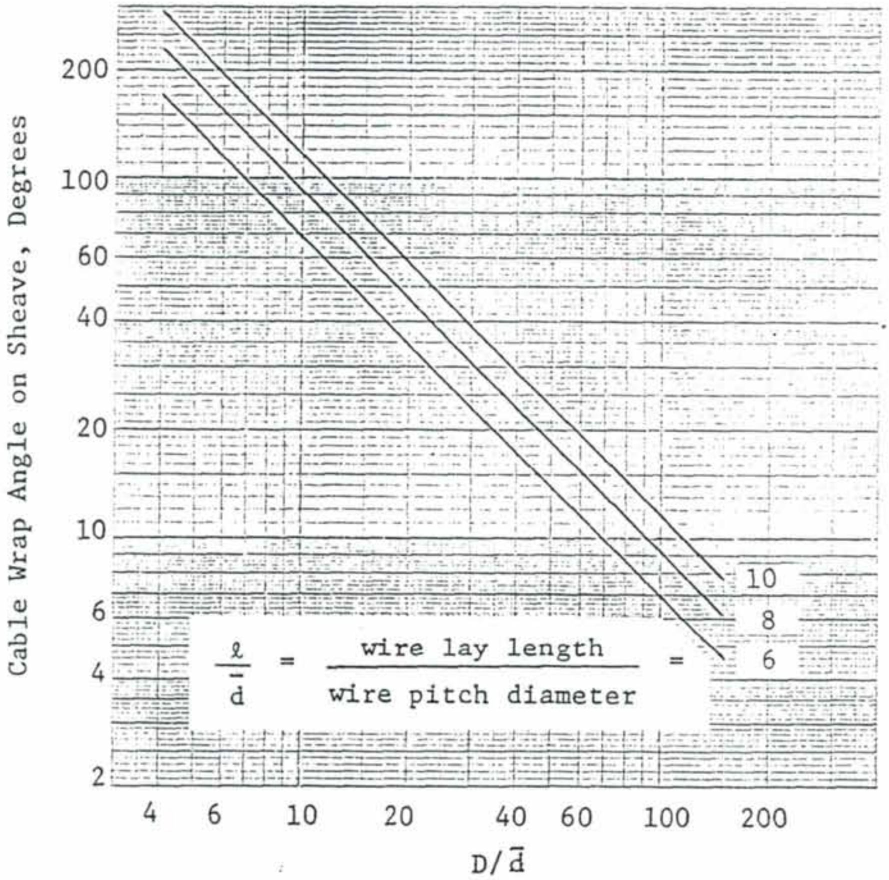
EFFECT OF CYCLING STROKE AMPLITUDE ON CABLE BENDING FATIGUE LIFE



EFFECT OF BENDING AMPLITUDE AT OUTBOARD SHEAVE ON CABLE BENDING FATIGUE LIFE



EFFECT OF SHEAVE CONTACT ARC ON CABLE BENDING FATIGUE LIFE



WRAP ANGLE OF A CABLE ON A SHEAVE CORRESPONDING TO A CONTACT ARC OF ONE LAY LENGTH OF THE OUTER LAYER OF STRENGTH MEMBERS

SECTION 3

HANDLING SYSTEM CONSIDERATIONS

A. Single-drum winches

1. Potential sources of cable damage
    a. Crushing due to winding many layers at high tension
    b. Crushing due to uneven winding
    c. Pinching at drum flange
    d. Cutting in
    e. Electrical resistive heating
2. Drum configurations
    a. Flat faced
    b. Spiral grooved
    c. Lebus grooved
3. Spooling aids
    a. Fillers
    b. Risers
    c. False flanges
4. Level wind systems

B. Traction winches

1. Single-drum capstan (not recommended)
2. Double-drum capstan
3. Linear puller

C. Sheave design considerations

1. Tread diameter
2. Groove diameter, depth, and flange angle
3. Groove material, hardness, and surface finish
4. Type of bearings

D. Reeving configurations

1. Safety considerations
2. Number of sheaves (minimize)
3. Reverse bends (avoid)
4. Fleet angles (minimize)
5. Sheave spacing (maximize for systems with motion compensation)
6. Cable wrap angles on sheaves (maximize for systems with motion compensation)
7. Use of guide rollers (avoid)

   Caution: never use a series of small rollers to replace a sheave!!

8. Use of swivels (to facilitate vehicle docking)
9. Special fairleads (wide-flange sheaves, rollers, chutes, bellmouths)

E. Motion compensation systems

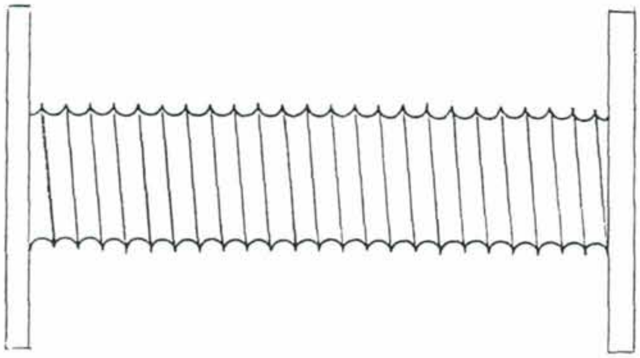
1. Active drum
2. Active traction winch
3. Ram tensioner system

4. Nodding (or bobbing) boom system
    a. Inflicts minimal cable flexure damage
    b. Can be used with a "stopper" to reduce cable flexure damage
5. Cable temperature rise
    a. Effects of sheave size, cable tension, and stroke amplitude
    b. Effects of cable jackets and sheave liners

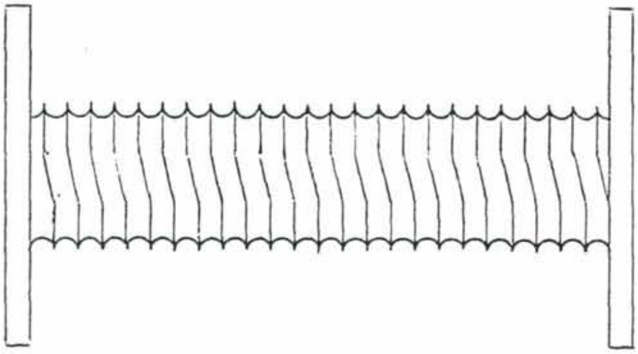
F. Use of operating logs to extend cable life by distributing wear
    1. Length of cable deployed
    2. Cable tension amplitude and frequency
    3. Cable motion amplitude and frequency
    4. Elapsed time

G. Tension measuring devices
    1. Load cell at termination
    2. Sheave axle or suspension system
    3. Winch suspension system
    4. Three-sheave device
    5. Vibration monitor

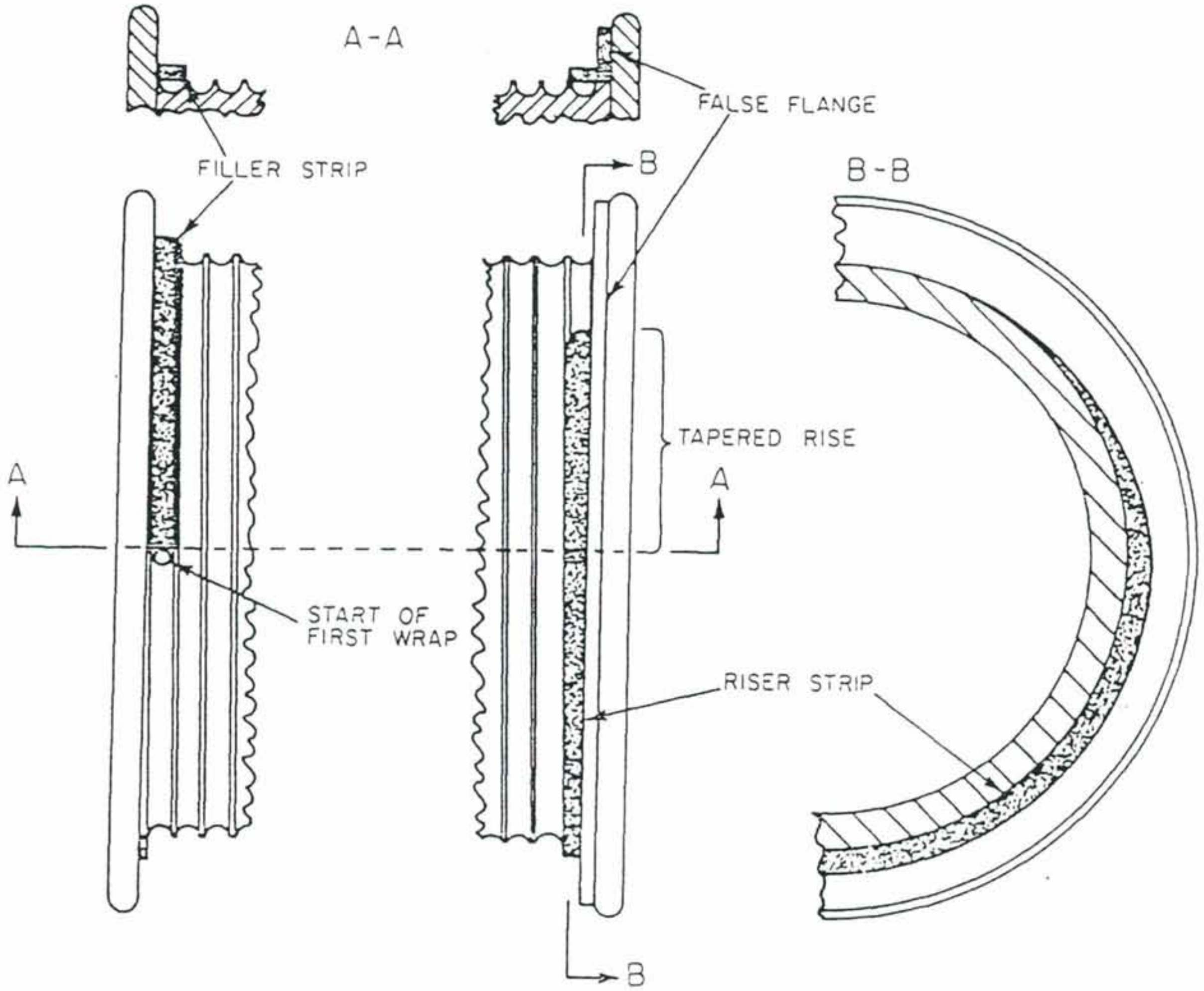
H. Cable storage
    1. Drum (low tension versus high tension)
    2. Basket or cage (with induced twist)
    3. On deck (figure eight)



SPIRALLY-GROOVED DRUM



LEBUS-GROOVED DRUM

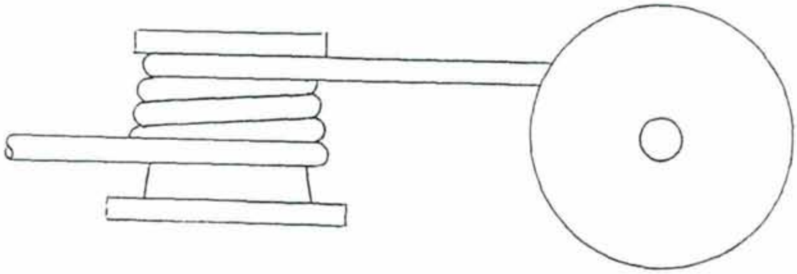


SPOOLING AIDS

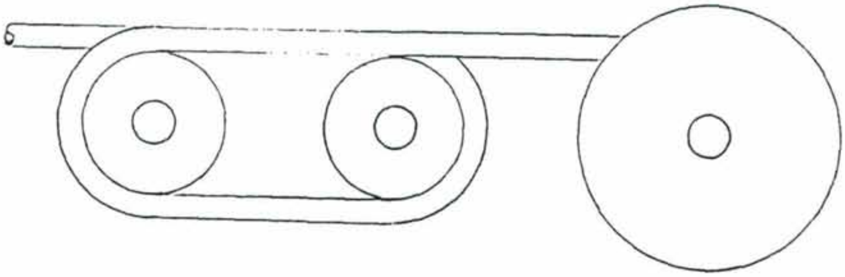
DRUM GROOVING CONSIDERATIONS

The following combinations are generally most effective:

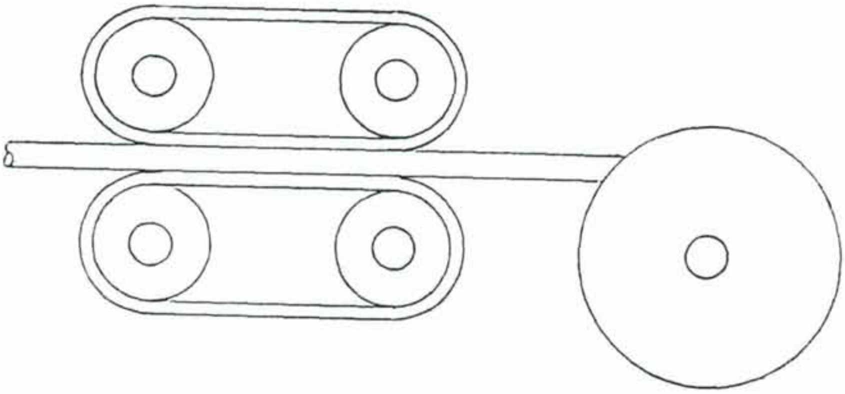
- For single layer winding, helical grooving is best.
- For two layer winding, either helical grooving with a riser or LEBUS grooving with a riser is satisfactory.
- For three layer winding, LEBUS grooving is preferred over helical grooving, but in either case riser and filler strips are needed.
- For more than three layer winding, LEBUS grooving should be used with riser and filler strips; helical grooving is not recommended.



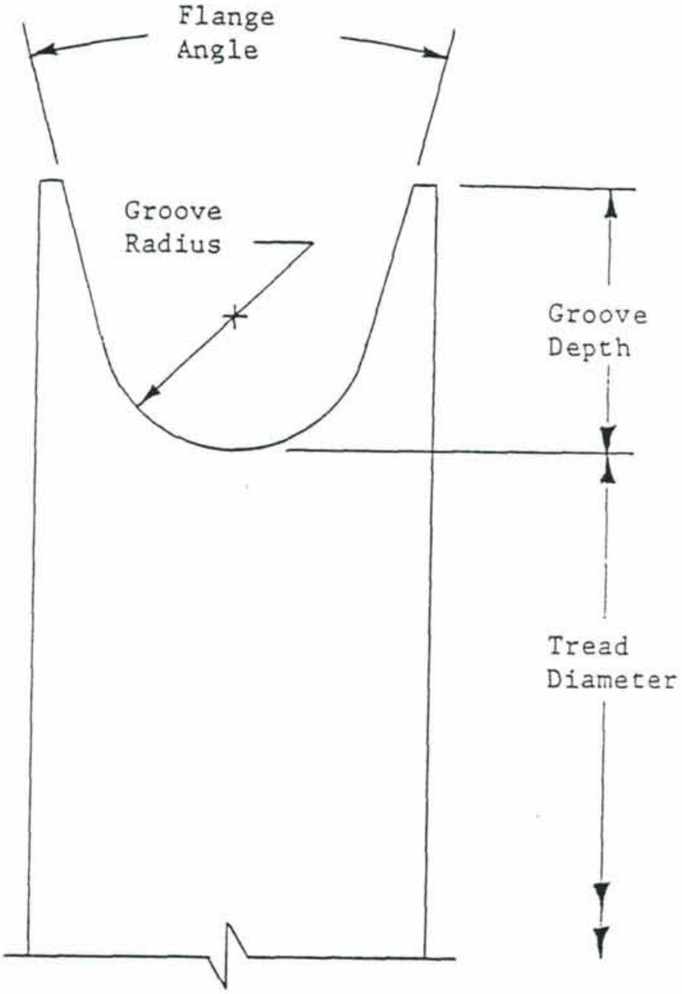
SINGLE-DRUM CAPSTAN



DOUBLE-DRUM CAPSTAN



LINEAR TRACTION UNIT

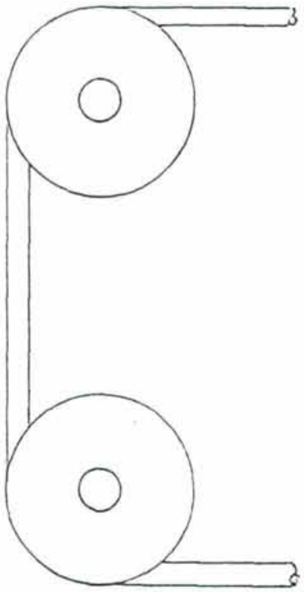


Material: ___________

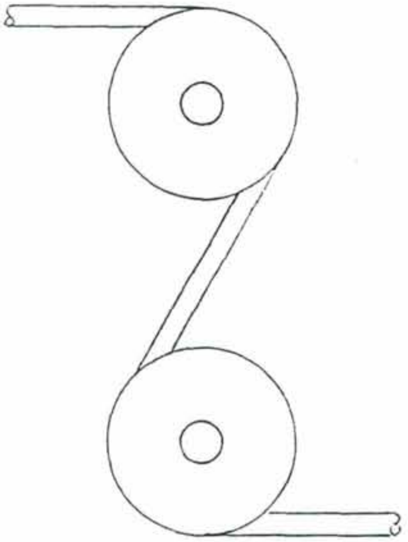
Hardness: ___________

Surface Finish: ____

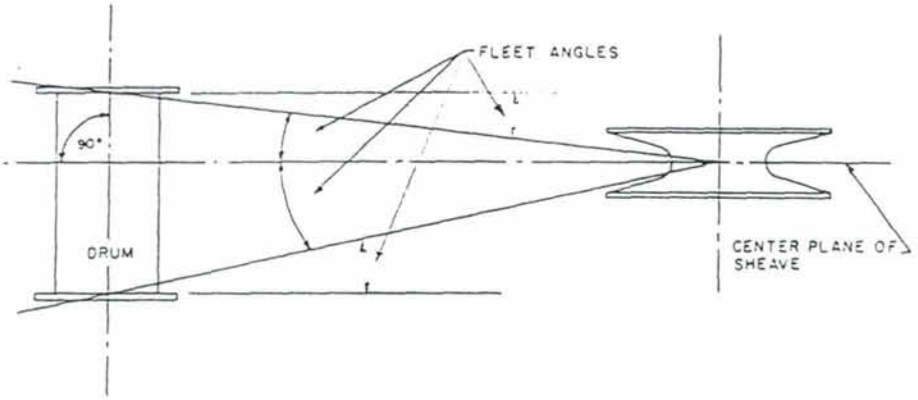
SHEAVE DESIGN PARAMETERS



BENDING IN THE SAME DIRECTION
OVER TWO SHEAVES



REVERSE BENDING OVER TWO SHEAVES



FLEET ANGLES

SECTION 4

TERMINATIONS

A. Considerations in termination selection
  1. Size and weight limitations
  2. Compatibility with the cable design details
    a. Central versus external strength member
    b. Metallic versus nonmetallic strength member
    c. Potential impact on cable design
  3. Required strength and fatigue performance
  4. Requirement for field installation
  5. Load transfer mechanism

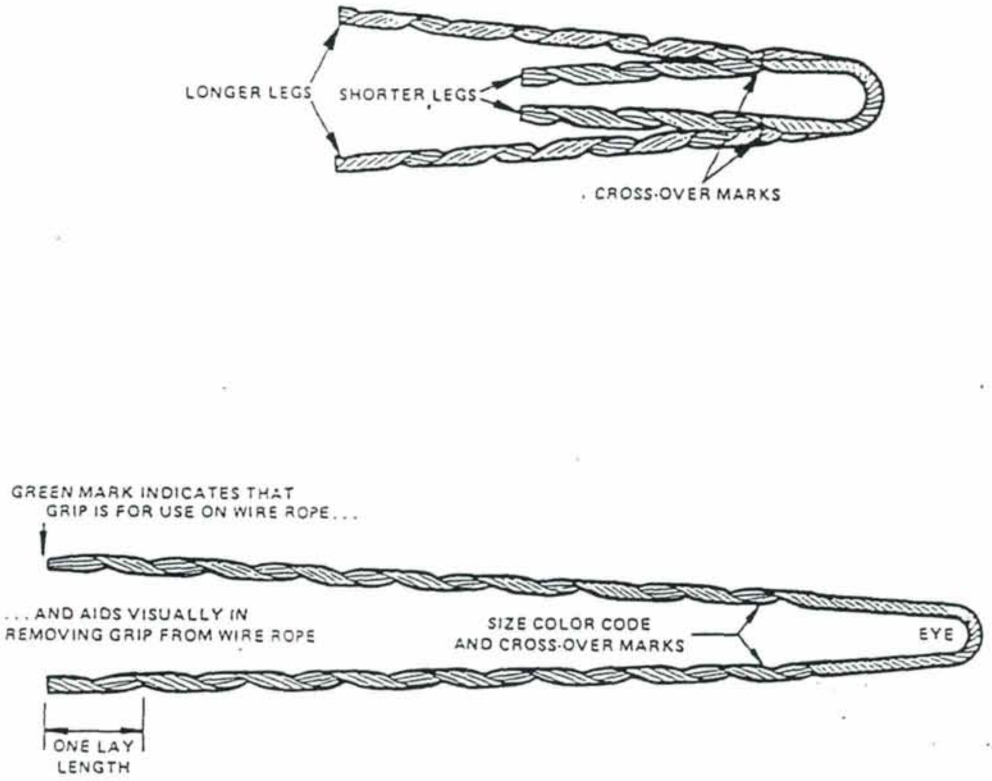
B. Externally applied cable terminations
  1. Capstans, bollards, and drum grips
  2. Twisted wire rod grips
    a. Single layer versus double layer
    b. Cable diameter sensitivity
    c. Bending strain relief
  3. Flexible mesh grips
  4. Split pipe grips
  5. Stoppers

C. Terminations integrated with strength members
  1. Resin sockets
  2. Mechanical compression fittings with conical wedge inserts
  3. braid-splice terminations

D. Bending strain relief considerations

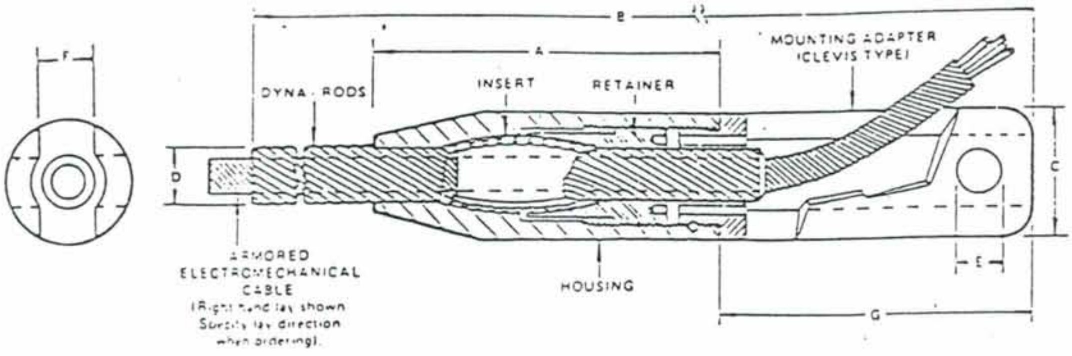
E. Specifics of resin terminations

   1. Load transfer mechanism
   2. Cavity shape and surface finish
   3. Resin matrix material
   4. Suitability for steel versus nonmetallic cable strength members
   5. Installation procedures



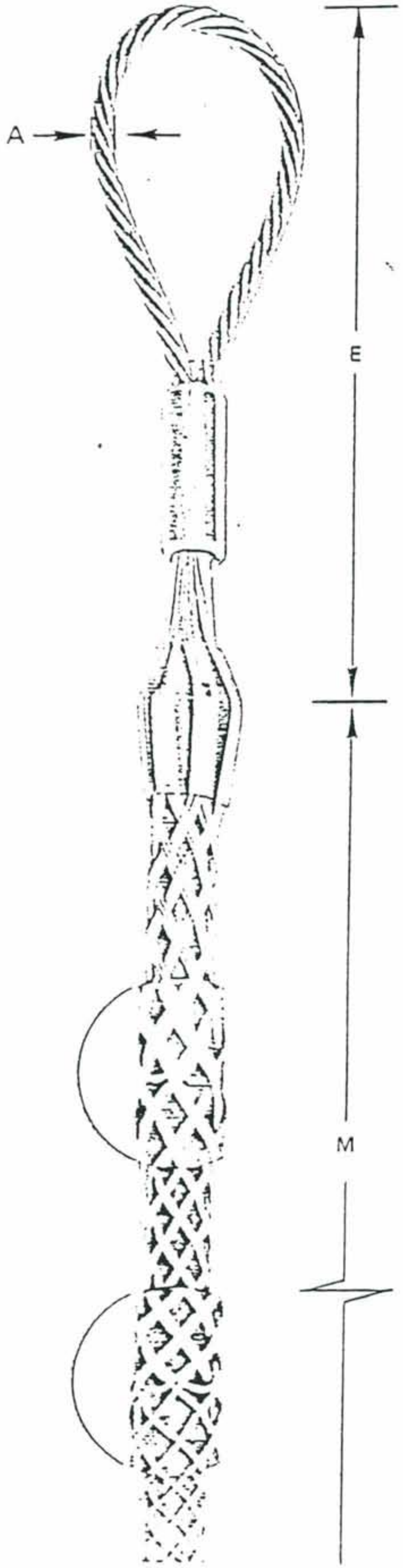
* Courtesy of Preformed Marine Cleveland, Ohio.

TWISTED WIRE ROD GRIPS



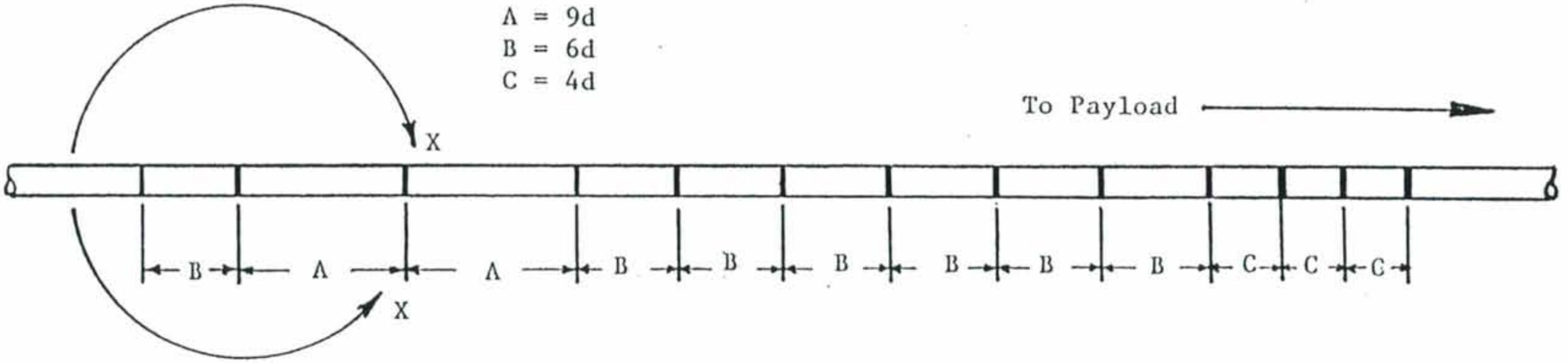
DYNA-GRIP TWISTED WIRE ROD TERMINATION

(Courtesy of Preformed Marine, Cleveland, Ohio)

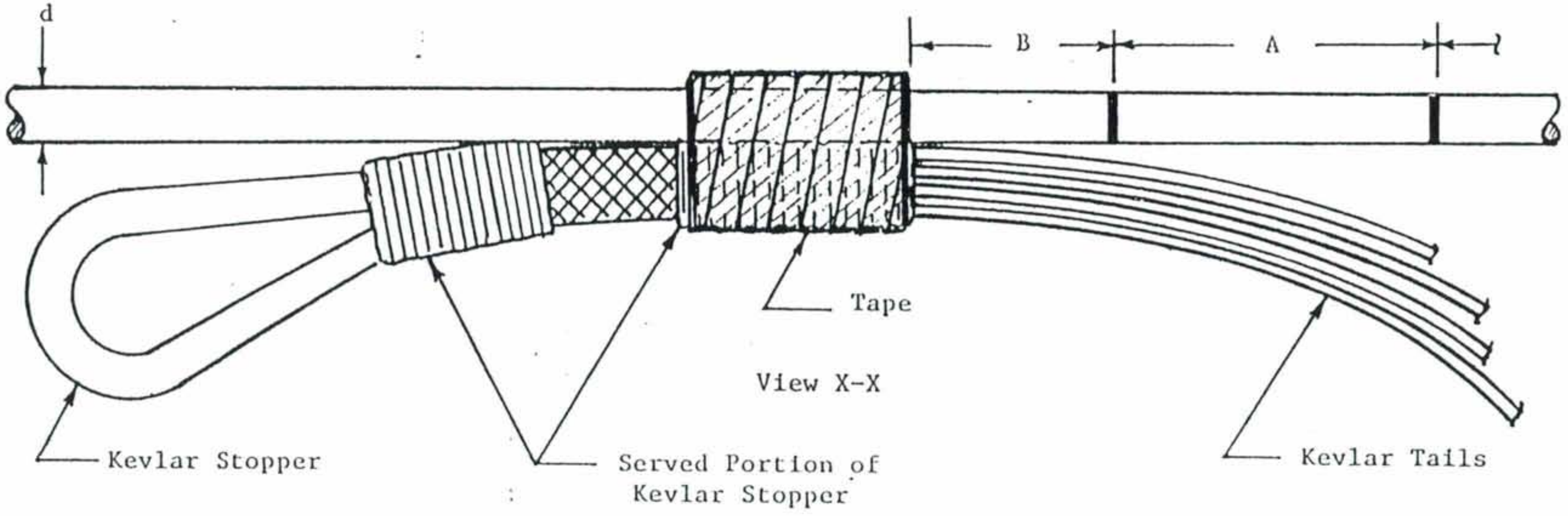


WOVEN WIRE MESH GRIPS

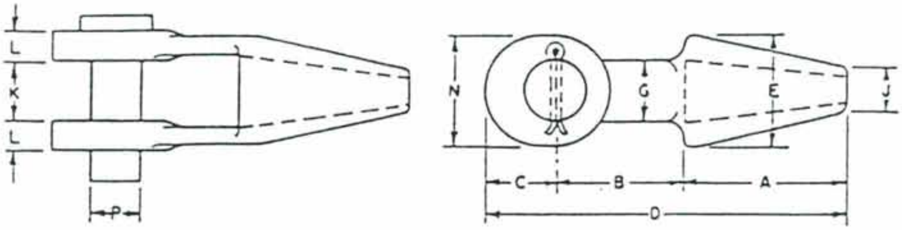
Tension Member Technology
(714) 898-5641
5721 Research Drive
Huntington Beach, Ca 92649



Premarking of Cable for Stopper Tail Crossover Points

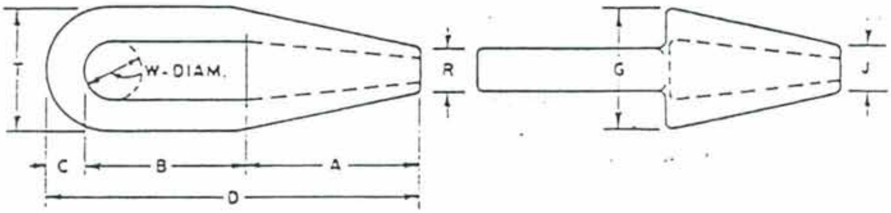


ONE POSSIBLE CONFIGURATION FOR A CABLE STOPPER



Rope Diam.	A	B	C	D	E	G	J	K	L	N	P	Approx. Wt Lb
³⁄₁₆ & ¼	2	1⁹⁄₁₆	¾	4⁵⁄₁₆	1⁵⁄₁₆	¾	⁹⁄₁₆	¹¹⁄₁₆	⁵⁄₁₆	1⁵⁄₁₆	¹¹⁄₁₆	0.9
⁵⁄₁₆ & ⅜	2	1¾	⅞	4⅝	1⁹⁄₁₆	¹³⁄₁₆	¾	¹³⁄₁₆	¹⁵⁄₃₂	1½	¹³⁄₁₆	1.1
⁷⁄₁₆ & ½	2½	2	1¹⁄₁₆	5⁹⁄₁₆	1⅞	1	¹⁵⁄₁₆	1	½	1⅞	1	2.3
⁹⁄₁₆ & ⅝	3	2½	1¼	6¾	2¼	1¼	1⅛	1¼	⁹⁄₁₆	2¼	1⁵⁄₁₆	3.8
¾	3½	3	1⁵⁄₁₆	7¹³⁄₁₆	2⅝	1½	1¼	1½	⅝	2⅝	1⅜	6.0
⅞	4	3½	1¾	9¼	3⅛	1¾	1½	1¾	¾	3⅛	1⅝	10.0
	4½	4	2¹⁄₁₆	10⁹⁄₁₆	3⅝	2	1¾	2	⅞	3¾	2	15.0
⅛	5	4½	2⁵⁄₁₆	11¹³⁄₁₆	4	2⅜	2	2¼	1	4⅛	2¼	23.0

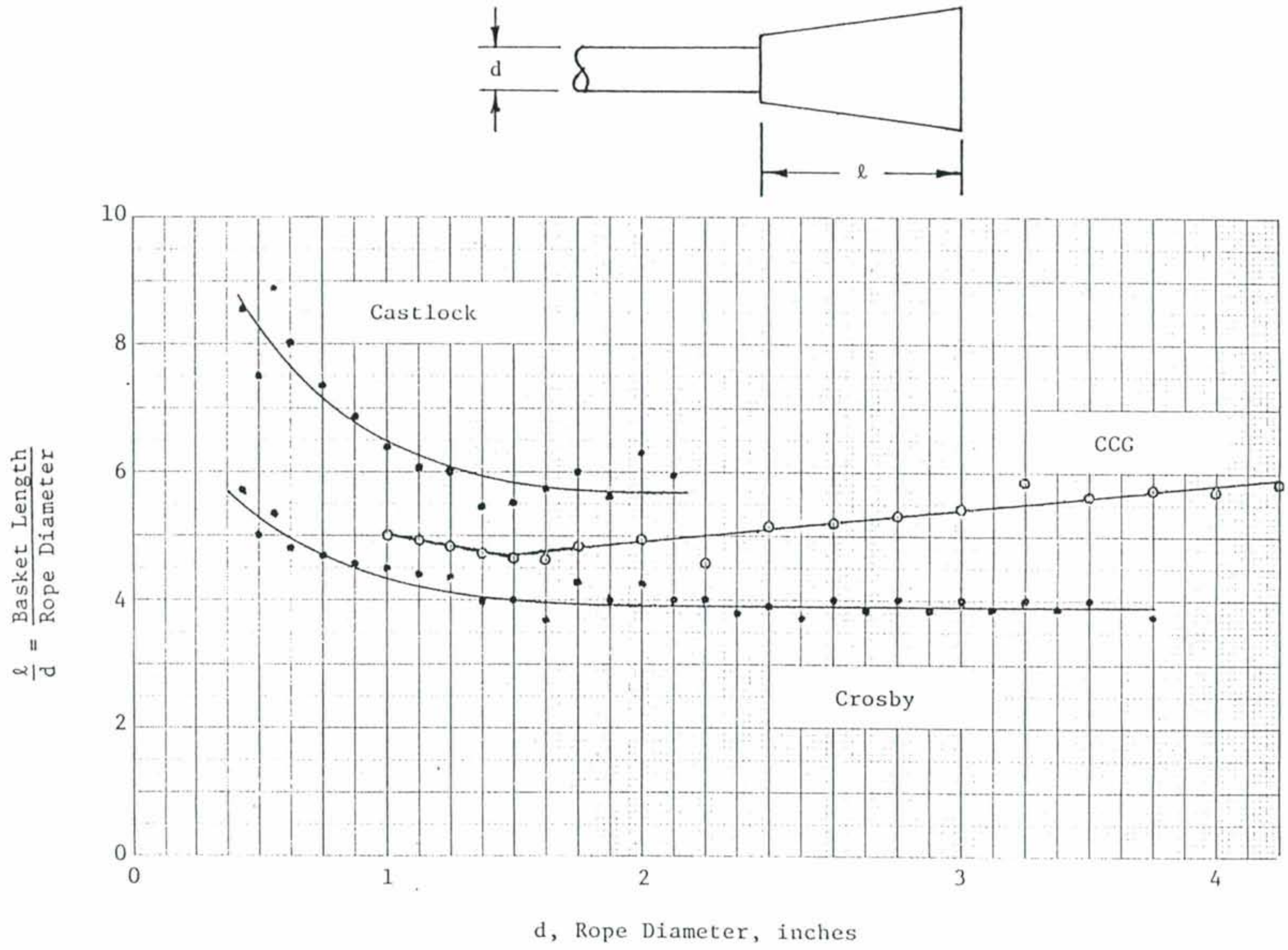
OPEN SOCKETS FOR USE WITH POURED RESIN



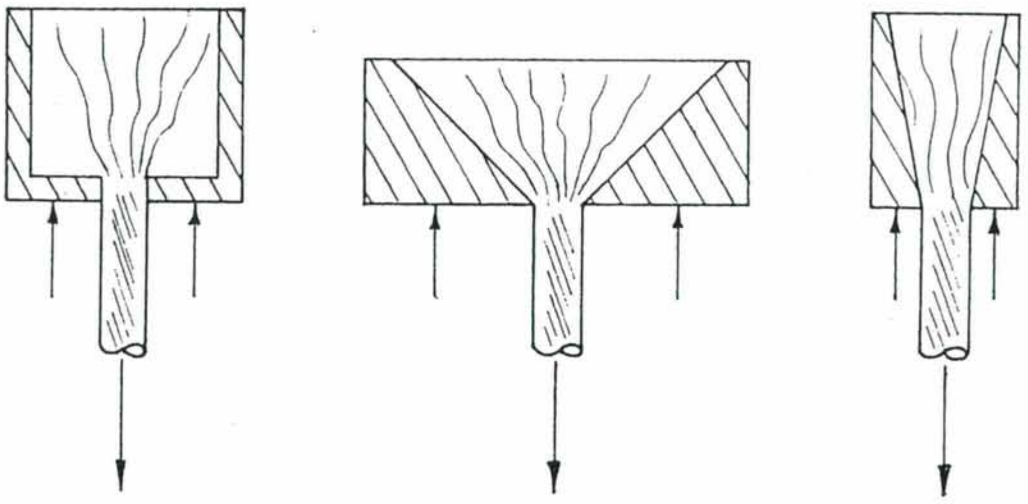
Rope Diam.	A	B	C	D	G	J	R	T	W	Approx. Wt Lb
³⁄₁₆ & ¼	2	1¾	⁷⁄₁₆	4³⁄₁₆	1⁵⁄₁₆	⁹⁄₁₆	½	1⁵⁄₁₆	¹³⁄₁₆	0.5
⁵⁄₁₆ & ⅜	2	2	⁹⁄₁₆	4⁹⁄₁₆	1⁹⁄₁₆	¾	⅝	1¹¹⁄₁₆	¹⁵⁄₁₆	0.9
⁷⁄₁₆ & ½	2½	2¼	¹¹⁄₁₆	5⁷⁄₁₆	1⅞	¹⁵⁄₁₆	⅞	2	1⅛	1.5
⁹⁄₁₆ & ⅝	3	2½	¹³⁄₁₆	6⁵⁄₁₆	2⅜	1⅛	1	2⅝	1⅜	3.0
¾	3½	3	1¹⁄₁₆	7⅝	2¾	1¼	1¼	3	1⅝	4.5
⅞	4	3½	1¼	8⅞	3¼	1½	1½	3⅝	1⅞	7.0
	4½	4	1⅜	9⅞	3¾	1¾	1¾	4⅛	2¼	11.0
⅛	5	4½	1½	11	4⅛	2	2	4½	2½	16.0

CLOSED SOCKETS FOR USE WITH POURED RESIN

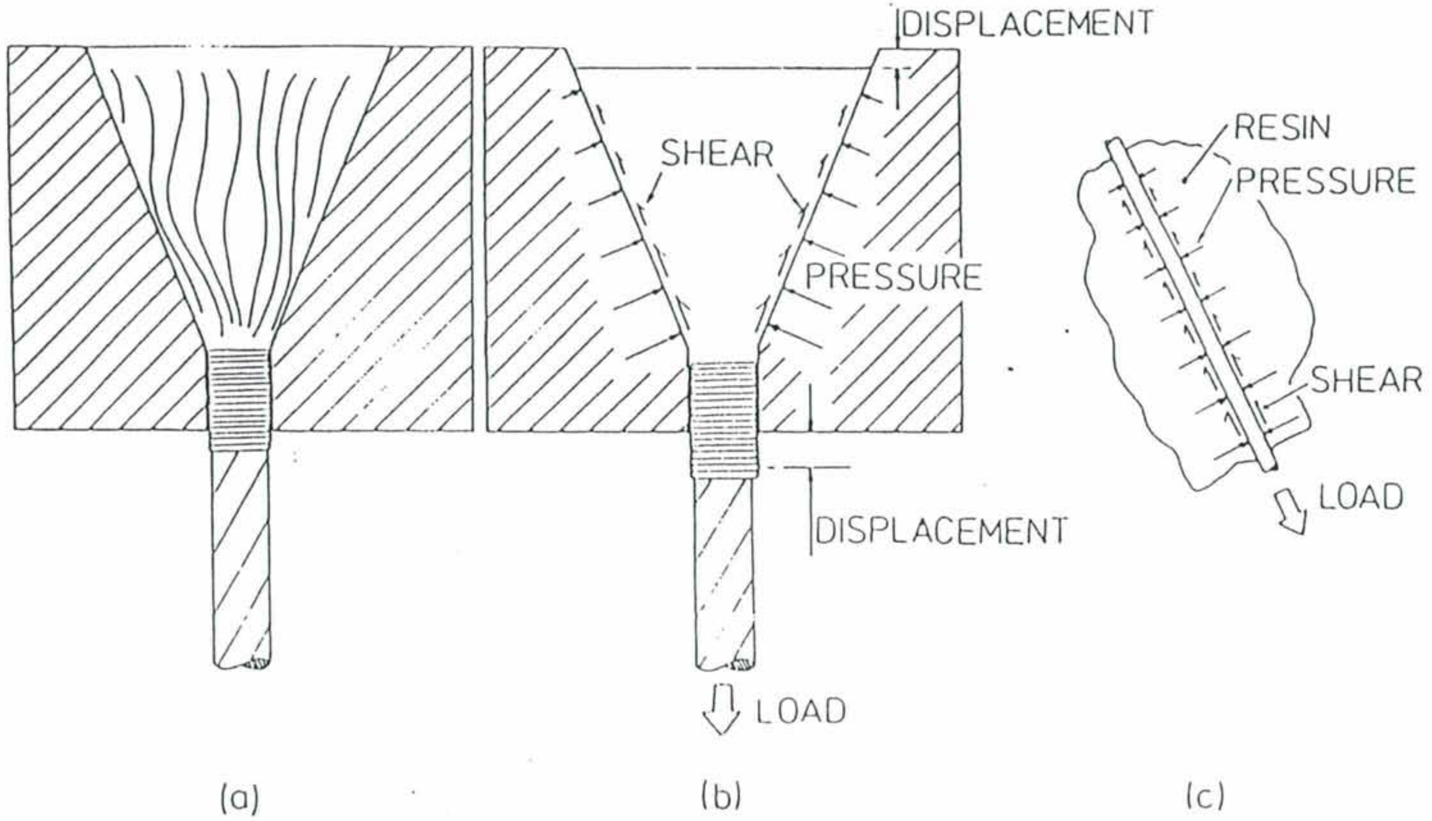
Tension Member Technology
(714) 898-5641
5721 Research Drive
Huntington Beach, Ca 92649



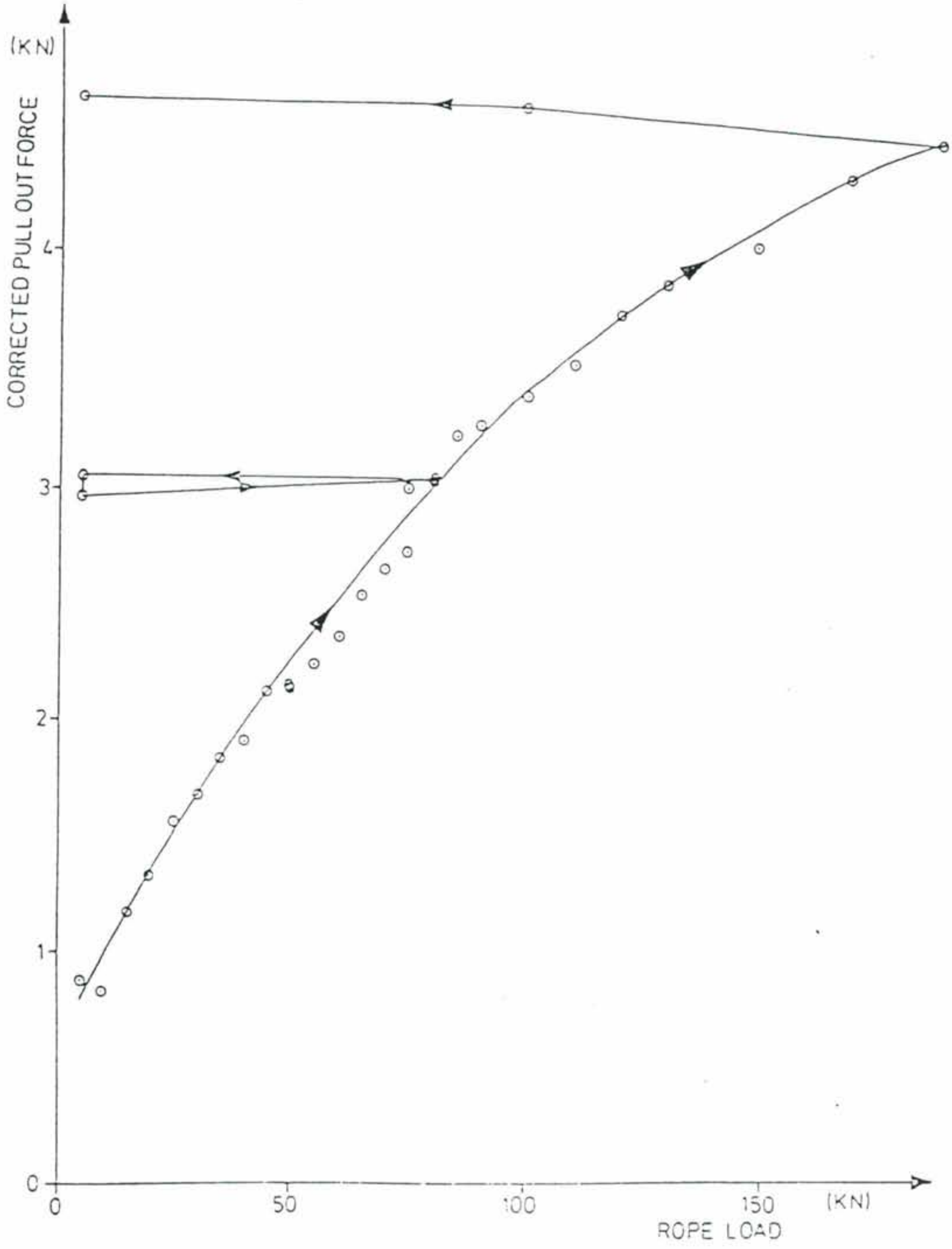
TYPICAL ROPE SOCKET BASKET CONFIGURATIONS



VARIATIONS OF SOCKET BASKET GEOMETRY



Schematic cross-section of termination showing:
(a) unloaded termination, (b) the effect of a load to produce an axial displacement of the rope relative to the socket generating transverse pressure and surface friction, (c) a similar situation at the wire/resin interface.



Pull-out force as a function of axial tensile load in the rope.

PERFORMANCE CHARACTERISTICS OF ROV TETHER CABLES

James A. Walther and Philip T. Gibson

Tension Member Technology
15202 Pipeline Lane
Huntington Beach, CA 92649

ABSTRACT

This paper describes some of the general operational characteristics of ROV tether cables which must be taken into consideration to achieve good cable service life. The reaction of a cable to tensile loading is discussed with regard to the component stresses and changes in cable elongation and diameter. Cable torque and twist characteristics are described, including design considerations for achieving torque and twist balance, the effect of twist on cable performance, and causes of cable hockling and kinking. The reaction of a tether cable to bending is discussed, including comments on how cable performance is affected by the details of the cable design and by the geometry of the components within the cable handling system.

Cable terminations are discussed with reference to the ease of installation and the strength efficiency achievable. Finally, typical cable failure mechanisms are reviewd and suggestions are included on ways to improve the mechanical and electrical performance of ROV tether cables.

CABLE REACTION TO TENSILE LOADING

The initial application of a tensile load to a new tether cable produces cable elongation which consists of a constructional stretch component and an elastic stretch component. The constructional stretch of the cable, a more or less permanent cable elongation (a portion of this elongation may dissipate if the cable is allowed to remain at zero tension for a period of time), is most evident in cables having external strength members and is primarily the result of core compression and strength member compaction.

External cable strength members, either steel or Kevlar, are wrapped helically around the cable core in either a braided construction or in one or more separate layers. As a tensile load is applied to the cable, the strength members exert a radial pressure on the cable core. In response to this pressure, the cable elements and filler materials experience deformations due to their own compressibility and due to material displacements associated with the elimination of voids within the cable structure. The result of this process is a reduction in cable diameter and a corresponding increase in cable length. Cables having Kevlar strength members typically exhibit a greater amount of strength member compaction than do cables having steel strength members. When the tensile load is removed from the cable, there is some recovery of cable diameter and a corresponding reduction in cable length. However, a significant portion of the core compression and strength member compaction may be relatively permanent, and, as a result,there will be some permanent increase in cable length.

This permanent change in cable length must not be overlooked, because its magnitude may actually be greater than the elastic stretch the cable exhibits under normal operating tensions. Obviously, the total strain experienced by the cable conductors (copper wires or optical fibers) will be a function of both the constructional and elastic cable elongation. Cables which experience a large amount of constructional stretch may impose strains on optical fibers which may, in the long term, contribute to fiber failures under quite moderate cable operating tensions or even during storage of the cable between missions.

CABLE TORQUE AND TWIST CHARACTERISTICS

Another consequence of changes in cable diameter with applied tension load relates to the cable torque characteristics. Any change in diameter of a cable having an external strength member (with the exception of a braided strength member) alters the load sharing among the strength member layers. As the stress balance among strength member layers changes, so does the torque contribution of each layer. Typically, reductions in diameter of double armored cables cause a small shift in tensile stresses from the inner to the outer layer of wires. As a result, the outer wires experience a proportionally higher tensile stress and, thus, produce a portionally higher torque component. In fact, most of the so-called torque-balanced double-armored cables which have been tested in the Tension Member Technology laboratory have exhibited a small amount of torque and rotation in a direction to unlay the outer wires due to an excessive torque component in that layer. On the other hand, cables which have two or more layers of served Kevlar strength members may experience a reduction in the tensile load and torque contribution of the outer layers.

Another consequence of cable constructional stretch is an increased torque contribution of the cable core due to an increase in the tensile strain on the core elements. This torque can be quite large in cables which incorporate one or more layers of large power conductors located just beneath the insulated jacket of the core assembly. To quantify the torque contribution of the cable core as well as the contribution of each layer of strength member elements, it has become common practice in the Tension Member Technology laboratory to conduct torque/dissection tests. During this test, a cable specimen is repeatedly loaded to the same total strain while continuous traces of cable torque versus tension are recorded after the removal of successive layers of cable elements. (A precision friction-compensated swivel is required to obtain accurate cable torque data.) The results of this test indicate how much tension load and how much torque is produced by each layer of elements within the cable. These data can then be used to determine how the cable geometry may be altered to achieve a design having better torque and twist balance.

The torsional stiffness of a cable (the amount of cable rotation which will be produced by a given amount of internal or external torque) is highly directional, especially for double-armored cables. A cable will typically rotate much more easily in the direction to loosen the outer layer of wires. Thus, to produce a cable with a minimum amount of rotation, it is desirable for any amount of torque imbalance to be in the direction which causes a tightening of the outer layer of wires.

It is usually desirable for a tether cable to have good torque and twist balance to minimize the possibility of cable hockling and kinking in service. A hockle is a loop which forms in a cable and then becomes twisted so that the portions of the cable on either side of the loop become helically wrapped around each other. The hockle itself may not seriously damage the cable, but it renders the cable useless where a tension load must be transmitted to a tethered vehicle. Any application of tension to a hockled cable may cause the hockle to tighten, thereby producing permanent cable deformation and kinking. In a double steel wire armored cable, the outer armor wires may become badly displaced or birdcaged as a result of this hockling and kinking.

The generation of a hockle in a cable requires only that a slack loop of sufficient size be allowed to form in a cable which contains a sufficient amount of stored torsional energy. If a cable contains no torsional energy, then the formation of a slack loop is not likely to produce a hockle. Similarly, if even a small amount of tension is maintained on the cable so that a slack loop cannot form, then no hockling will occur even if the cable contains a rather large amount of torsional energy.

If a cable is not of a torque-balanced design and if it is negatively buoyant and is suspended in long lengths in the ocean, then the cable may develop a significant amount of internal torque due to the tension produced by cable self weight. Should a slack loop be allowed to form at the lower end of the cable, then hockling is likely to occur.

Even if a cable has been designed to have good torque balance, the cable may still exhibit some torsional energy if any twisting has been induced in the cable. Such twisting can occur during the lowering or raising of a nonsymmetrical vehicle, by maneuvering of a vehicle so as to accumulate turns in the cable, or by the cable handling techniques. For example, if a tether cable which is deployed manually is allowed to pull out of a coil which is lying on the deck, the cable will develop one turn of twist for each wrap in the coil. Similarly, a cable handling system which does not incorporate a drum, but which allows the cable to lie in a cage or basket, will produce one complete twist of the cable for each loop of cable in the basket. Depending on the diameter of the tether cable and on its inherent torsional stiffness, the resulting twisting of the cable may be sufficient to produce hockling if a slack loop should be allowed to form.

The twisting of a cable has a number of adverse effects other than the potential formation of hockles. One of the major consequences of twisting is a reduction in cable breaking strength. This effect is most significant in cables having external contrahelical strength members arranged in either a braid or in multiple layers. When a cable is twisted, the strength members which are wrapped in one helical direction are tightened, while the strength members which are wrapped in the opposite helical direction are loosened. The resulting stress imbalance not only reduces the cable breaking strength but also reduces the cable fatigue performance. Kevlar strengthened cables, in particular, exhibit a dramatic reduction in breaking strength as a result of small amounts of induced twist.

Another potential consequence of cable twisting is the rapid failure of conductors within the cable core. Most cables having a complex core design incorporate several layers of conductors which are typically assembled with alternately right and left lay helical directions. With this type of core design, no matter which way the cable is twisted some of the conductors will tend to tighten while the others tend to loosen. Since cables having external strength members tend to become shorter no matter in which direction they are twisted (assuming that the strength members are either braided or are assembled in two or more contrahelical layers), then the conductors which tend to tighten will experience some strain relief due to shortening of the cable. However, those conductors which tend to loosen as a result of cable twisting experience even more loosening due to shortening of the cable, and they rapidly develop z-kinks which lead to conductor or insulation failure.

If it is known that a cable will be twisted in service due to the characteristics of the cable handling system, it is possible to design the cable to be twist tolerant. Such a cable must have all conductor layers arranged in the same helical direction so that they will all tighten and loosen together in response to cable twisting. Furthermore, the helical direction of the conductors should be such that the cable twisting induced by the handling system tends to tighten the conductors. Finally, the lay angle of each layer of conductors should be carefully chosen to minimize the additional conductor strain induced by cable twisting. Extensive cable twist tests have revealed that properly designed tether cables can survive many thousands of cycles of severe cable twisting without electrical or mechanical failure. Conversely, tether cables which have not been designed for twist tolerance may survive only a few cycles of moderate twisting.

Of course, whenever possible, cable twisting should be avoided so as to achieve maximum cable breaking strength and fatigue performance. In some systems, it may be necessary to employ a swivel to decouple a torque-balanced cable from a twisting payload. Conversely, it may be equally important to eliminate a swivel in a system which uses a nontorque-balanced cable with a stable and nonrotating payload. Regardless of the details of the service conditions for a specific cable,it is usually quite helpful for the cable to be manufactured with an obvious and permanent stripe positioned longitudinally along the cable jacket. This stripe will allow any cable twisting to be identified and quantified so that measures can be taken to minimize the number of accumulated twists.

CABLE REACTION TO BENDING

The bending of the cable around a sheave or other curved surface obviously produces a change in the radius of curvature of each cable element and a corresponding change in the bending stress in each element. In addition, cable bending produces relative motions among the various cable components.

Consider for example, the path followed by a single outer armor wire on a cable which is wrapped around a sheave. (See Figure 1.) Assume that the 12 o'clock position corresponds to the location on the cable furthest from the sheave centerline. It is apparent, then, that the path length of the wire as it moves from the three o'clock to the nine o'clock position is shorter than the path length of the wire as it moves from the nine o'clock past the 12 o'clock and back to the three o'clock position. If all of the wires within the cable were locked together so that no relative motion could occur, then the individual wires would experience high tensile strains on the side of the cable away from the sheave throat and compressive buckling strains on the side of the cable adjacent to the sheave throat. However, the mobility of the individual wires within the cable structure allows the excess wire length on the side of the cable toward the sheave throat to make up for the deficiency in wire length on the side of the cable away from the sheave throat. As a result, the tensile stress remains much more uniform along the length of each wire than would be the case if all wires were locked up so that no relative motions could occur.

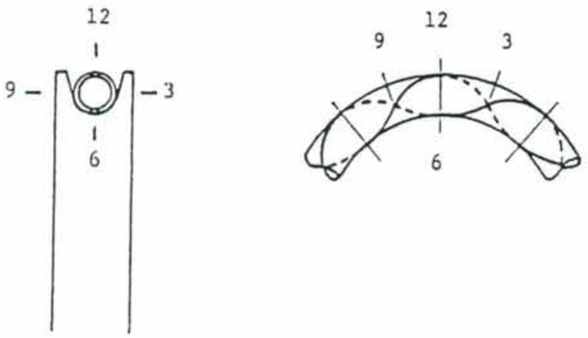


FIGURE 1. ARMOR WIRE GEOMETRY

As a cable is repeatedly flexed over a sheave, the largest magnitudes of relative motion among the cable elements occur at the three o'clock and nine o'clock positions. For example, when a cable having a braided Kevlar strength member is moved back-and-forth over a sheave during a laboratory fatigue test, the Kevlar strands within the braid become most severely worn at the three and nine o'clock positions, with very little Kevlar wear occurring at the six and twelve o'clock positions.

All of the bending-induced changes in bending stress and in the relative motions among the cable components as described above take place in the vicinity of the cable-to-sheave tangent point. Because of the internal friction within the cable structure, the affected portion of the cable is approximately one lay length either side of the tangent point. In other words, portions of the cable which are more than approximately one lay length away from a sheave, or portions of a cable which are on a sheave but are more than approximately one lay length away from a sheave tangent point, experience no changes in internal stresses or motions and thus are not influenced by the bending of other portions of the cable. If the arc of contact between the cable and sheave exceeds approximately one lay length, then there will be a certain portion of cable in contact with the sheave which, having undergone stress changes in the vicinity of one sheave tangent point, will experience no further changes in its state of stress until it approaches a second tangent point.

The conclusion which can be drawn from the previous discussion is that for typical deployment and retrieval operations, the bending fatigue life of a cable is not influenced by the wrap angle on a sheave as long as at least one lay length of the cable is in contact with the sheave. Tether cables which experience many deployment and retrieval cycles through a series of fairlead sheaves will provide a certain bending fatigue life which will be the same regardless of whether the cable wrap angles on the sheaves are 180 degrees or 90 degrees or any other angle which produces a cable contact arc equivalent to one lay length or more. For contact arcs of less than one lay length, the bending fatigue damage produced by the sheave is typically reduced, but there are notable exceptions to this rule. Depending on the specific cable design, the sheave-to-cable diameter ratio, and the cable safety factor, a cable contact arc of one-half lay may be more damaging than a longer contact arc. One of the important conclusions which can be drawn from these considerations is that a sheave diameter should not be arbitrarily reduced just because a cable happens to have a relatively small wrap angle on that sheave. A single, small deflection sheave or roller can produce more cable damage than all of the other sheaves in the fairlead system. Even worse is the replacement of a sheave with a series of small rollers in the interest of saving space. This procedure can quickly destroy a tether which supports any significant tensile load.

In cable systems which employ active motion compensation and which induce repeated flexure of the cable over one or more sheaves, special consideration must be given to cable wrap angles and sheave spacing. Obviously, such a system should employ as small a number of sheaves as possible to minimize the bending fatigue damage to the cable. Furthermore, these sheaves should be spaced as far apart as necessary to assure that during each heave cycle no single section of the cable comes into contact with more than one sheave. Should a single section of cable pass over two sheaves with each heave cycle, the total bending fatigue life of the cable will obviously be one-half of that which could be achieved if the sheaves were further apart.

Another important, but less obvious, factor which influences the total achievable cable fatigue life in a motion compensation system is the arc of contact between the cable and each sheave in the fairlead system. (It should be noted that the previous discussion of cable contact arc effects applied to typical deployment and retrieval operations and not to motion compensation.) During active motion compensation, if the cable stroke amplitude is less than the cable arc of contact with a sheave, then each heave cycle will produce one straight-bent-straight cable bending cycle. If, on the other hand, the amplitude of cable motion should exceed the length of the cable arc of contact on the sheave, then during each heave cycle a single section of the cable will pass onto, completely around, and off of the sheave as the cable strokes in one direction, and will then return to its original position as the vessel completes one heave cycle. Under these conditions, a section of the cable receives two straight-bent-straight bending cycles during each heave cycle. Thus, it is obvious that using a cable wrap angle of 180 degrees will allow cable motions (heave amplitudes) twice as large as could be accommodated with a wrap angle of 90 degrees before each heave cycle of the vessel produces two cable bending cycles. In the long term, a motion compensation system which employs larger cable wrap angles will accumulate fewer cable bending cycles and will enjoy a longer cable service life.

With regard to the sheaves which are used in the cable handling system, the sheave diameter should be as large as practical in order to maximize cable service life. In addition, the sheave grooves must be smooth, and the groove diameter should be the same as the cable diameter when measured at zero tension. It is also important that each sheave be properly aligned so that the cable experiences little or no fleet angle. Any sheave misalignment will cause cable wear due to rubbing on the sheave flanges.

Plastic lined or nylon sheaves may offer some advantage for double steel wire armored electromechanical cables in terms of cable wear and wire-to-sheave contact stress. However, in situations where a highly loaded cable passes back-and-forth over a sheave in a motion compensation system, especially when transmitting large amounts of electrical power, it may be advantageous to avoid the use of nonmetallic sheaves or sheave liners because of cable heating considerations. Cable heating which is produced by repeated high load flexure and by electrical power dissipation can sometimes be reduced by heat transfer into a metal sheave.

In general, cables which are required to experience repeated bending over sheaves will provide better total fatigue life with increasing helix angles for the individual cable components. Although large helix angles for the strength members tend to slightly reduce the achievable cable breaking strength, they greatly reduce the amplitude of relative motions among the components and, to a limited extent, reduce the component bending stresses. For example, two electromechanical cables which differ only in the helix angles of the strength members will typically exhibit significant differences in fatigue performance; the cable having the larger helix angles will provide the best fatigue life. And, of course, good cable lubrication is essential to good flexure performance.

It is important for any electromechanical cable to be properly void filled to minimize the change in diameter during tensile loading and the associated constructional elongation. However, for any cable which is to be operated over sheaves, the void fillers used within the core must not be of the type which remain liquid, no matter how high the viscosity may appear to be. Repeated cycling of the cable over a sheave will cause such void fillers to be milked away from the sheave contact zone due to the increased pressures produced by cable contact with the sheave. The void filling material will then accumulate just beyond the sheave contact zone and will produce bulging of the cable or even total rupture of the core jacket. Elastomeric void fillers, such as DPR, are much preferred.

TERMINATIONS

The ideal tether cable termination restrains the cable core and external strength members in such a manner as to duplicate the stress distribution in the cable elements which would be present in an undisturbed continuation of the original cable. Compression of the cable core by the strength members when the cable is under tension prevents the core from slipping longitudinally inside the cable and allows the core to extend through the strength member termination without affecting the stress distribution in the strength members.

Four basic types of cable terminations are in common use on ROV tether cables. The drum-grip termination is simplest in concept. It consists of a wide sheave having either a flat face or a helical, conformal groove upon which are wrapped several turns of cable. The friction between the cable strength member and the drum face provides a means for transferring the stress in the cable strength member to the drum grip. A portion of the cable tension is transferred to the drum for each wrap of cable, and the low tension end of the cable is anchored with a suitable secondary termination which can accommodate the lower tension level. The drum grip is particularly effective for steel wire armored cables, it works well with certain Kevlar-strengthened cables, and it may be easily installed in the field.

To maintain the greatest termination strength efficiency, the same geometry requirements as mentioned for sheaves must be met: i.e. a large drum-to-cable diameter ratio, a groove diameter equal to the cable diameter at zero tension, and a small fleet angle. (Termination efficiency is defined as the ratio of terminated cable breaking strength to unterminated breaking strength expressed as a percent.) Drum-grip terminations are usually large in diameter and are relatively heavy. Termination efficiencies of near 100 percent are achievable on steel wire armored cables without external jackets. However, jacketed tether cables having steel or Kevlar strength members can encounter problems when terminated with drum grips. If the coefficient of friction between the cable strength member and the jacket is less than the coefficient of friction between the jacket and the face of the drum grip, the strength members will slip inside the jacket, and upon repeated load cycling the entire load will eventually appear at the secondary termination resulting in cable failure. (If the secondary termination is capable of handling the entire load, then the drum grip is superfluous.) This same internal slippage problem can occur in systems utilizing traction sheaves, and total jacket delamination is the final result.

The resin-filled socket termination is a proven technology used successfully with steel wire armored cables. The large diameters of the individual tensile elements in steel wire cables (approximately one millimeter diameter) as compared to those in Kevlar-strengthened cables (0.012 millimeter diameter) has a great bearing on the strength efficiencies achievable with resin terminations. In Kevlar-strengthened cables, good wetting of the individual Kevlar strands by the potting compound is essential for high strength efficiency. Termination efficiencies of 100 percent are commonly achieved on steel wire armored cables, but efficiencies of as little as 60 percent are often encountered for Kevlar-strengthened cables.

A factor contributing to the low strength efficiency of resin terminations when used on Kevlar is the fact that, unlike steel wires which can yield under tension and allow all wires to share the load, Kevlar fibers fail without yielding. Thus, careful preparation of the Kevlar before pouring the resin in the socket is essential for good fiber load sharing and a high strength efficiency.

External compression-type terminations apply radial compression over some length of the cable and transfer the stress in the cable tension elements to some type of external tension elements. Woven wire mesh "Chinese finger" grips, single-layer and double-layer helical wire grips, and split-pipe grips fall into this termination category. They are quite effective on steel strength member cables and may work well on externally jacketed cables if the coefficient of friction between the jacket and the strength members is high enough. If this is not the case, the termination and a section of the jacket will pull off of the cable at a rather low tension. In cables which have multiple layers of Kevlar strength members (double-layer Kevlar braids and multiple layers of contrahelically served Kevlar), the friction between layers must be sufficient to allow the load transfer to take place from the inner to the outer layers to provide uniform loading of the cable strength members by the termination. Isolation tapes, if used between Kevlar layers to prevent layer-to-layer abrasion during cable flexing, must be specially selected to isolate while still providing adequate friction between layers if terminations of this type are to be utilized successfully.

Spliced eye terminations made of Kevlar fiber which is braided back into the end of Kevlar-strengthened cables are being used quite successfully. They circumvent the jacket-to-strength-member and layer-to-layer coefficient of friction problems by terminating all Kevlar fibers directly. The elasticity of the braided section provides some load sharing among the fibers so that good stress distribution is maintained. Spliced eye terminations are readily applied to braided Kevlar strength members and, with some judicious rearrangement of the geometry of the fibers in the cable strength member, they may also be applied to cables having multiple layers of braided or served Kevlar. Although somewhat time consuming to apply, they are light in weight and give strength efficiencies approaching 100 percent. The lay lengths of the braid tucks must be carefully engineered for each specific cable to provide uniform core compression over the length of the splice to avoid damage to the cable core. Premade splice eyes can be applied in the field and are also effective on cables having optical fibers in the cable core.

FAILURE MECHANISMS AND RETIREMENT CRITERIA

ROV tether cables seldom "wear out" in the same sense that, for example, elevator cables do. Elevator cables are used under a set of conditions which vary little from day to day. The environment is clean and dry, and the handling system is optimized to provide a long cable life. The cables wear out as a result of bending fatigue and are retired prior to failure by means of some experience-based retirement criteria. Catastrophic failure due to cable damage or fatigue is a rare exception to normal elevator operating procedures.

ROV tether cables have several modes of failure which may occur if the tether does not encounter accidental damage such as entanglement with propellers or slipping off of the handling system sheaves. One common operational mode of failure is tensile overload due to a snap load induced during docking of the vehicle with a surface ship or underwater garage. If the two masses involved have different motions, the snap loads induced in a short deployed length of tether cable can be large enough to produce a tensile failure.

Internal failure mechanisms are present in the tether cable itself and can be the cause of cable failure if the tether receives enough use. In tether cable designs which utilize several layers of contrahelically served Kevlar for the strength member, circumferential migration of the Kevlar may occur. The cable corkscrewing which results can cause internal damage to the cable core. This type of failure occurs most commonly at sheave and drum tangent points where the cable stops repeatedly, such as when the vehicle is secured in its cage or on deck.

If the tether cable receives sufficient use, the internal wear on the cable elements will be the ultimate cause of failure. Either the strength members will wear and degrade in strength allowing a tensile failure to occur at some lower tension, or the core elements will break or short out causing a failure in the power, communications, or control systems.

Another factor contributing to cable failure is heating of the cable power conductors due to IR losses. The conflicting requirements of neutral buoyancy, small diameter, high strength, and high power capability result in cables which operate at elevated temperatures. Usually, once the cable is underwater, the heat dissipation into the water column is sufficient to keep the internal cable temperatures within acceptable limits. When the tether is in air or rolled up on a drum, severe heating problems often exist.

Increasing the thermal conductivity of the Kevlar strength member by impregnating it with thermally conductive grease can be an effective means of lowering cable core temperatures, but the lubrication effect of the grease on the Kevlar has been shown to increase the probability of Kevlar migration and corkscrewing of contrahelically served strength members.

Since ROV tethers are usually retired from service following, rather than prior to, some cable failure, it is desirable to limit the damage to a localized area of the cable. The failure of communication or control system elements in the cable may scrub the mission, but will allow the vehicle to be retrieved by means of the tether cable strength member. If the failure occurs near one end of the tether cable, and particularly if it is due to an external cause rather than general internal wear, cutting off the damaged section and retermination of the cable is a reasonable approach. This technique also applies when opens in the power conductors cause loss of power to the vehicle.

Perhaps the worst type of cable failure is a shorting of the power conductors where the system does not have adequate safeguards to prevent additional cable damage. Cables particularly susceptible to thermal heating damage during short circuits are those which use several power conductors in parallel to achieve the required conductor cross-sectional area. If, for example, three power conductors are used in parallel to carry 15 amperes and are protected by a single 15 ampere circuit breaker, shorting of one of the three conductors to a return conductor at a damage site in the cable can cause that conductor to carry the full 15 amperes with virtually no current being carried by the two remaining power conductors. Since the 15 amperes is the design current, this situation can exist without blowing any circuit breakers and can allow the insulation on one conductor to be thermally damaged along the entire length of the cable between the power source and the short circuit, forcing early retirement of the cable.

ROV power systems should be designed to accommodate shorts and opens in tether power conductors without causing any additional local damage such as arcing at the location of the cable short circuit. This approach will prevent additional damage from occurring along the length of the cable and will allow a failure analysis to be performed on the damaged section. The addition of conductive blocking compounds and drain wires to the cable core allows the use of ground-fault detector circuits at the power source. These circuits disconnect the power to the cable upon detection of electrical leakage above a predetermined level to either seawater or the cable drain wires. This system prevents power surges from passing through a shorted section of cable and heating the entire length of the power conductors sufficiently to thermally damage the conductor insulation.

The importance of failure analysis cannot be over emphasized. In any tether failure, a 10-meter section of cable including the failure location should be saved for analysis. The end toward the vehicle should be marked, and a cable map prepared showing the location of the failed section in relationship to the handling system sheaves. The cause of failure, if known, the sea state, and other operating conditions should be recorded.

It is important to determine whether the failure is due to externally or internally induced cable damage. If externally induced, then an examination of the operational procedures is in order. If internally induced, the cable may be worn out or have design deficiencies which make it unsuitable for use under existing conditions. A change in operational procedure may reduce the cable stresses to a level which will allow the tether to perform satisfactorily.

Operational Characteristics of Electromechanical Cables

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During the past decade, there has been a proliferation of operational systems which include electromechanical (or electro-optical-mechanical) cables as vital system components. Examples of such systems include: 1) unmanned remote operated vehicles (ROVs) used for subsea exploration, inspection, recovery, or repair; 2) towed arrays or towed electronic packages used for subsea maping, exploration, or surveillance; 3) moored subsea systems used for surveillance or acquisition of environmental data; 4) tethered aerostats used for communication and surveillance; 5) data acquisition systems used in oil, gas, and geothermal wells. For each of these systems, the success of the mission is contingent upon the reliable operation of the electromechanical (EM) cable which provides the strength, power, and communications link. As the applications for EM cables have become more varied and as the operational conditions for these cables have become more demanding, there has been a corresponding increase in the sophistication of cable design and manufacturing methods. Most contemporary EM cables are highly complex machines which are designed specifically for the intended application. Unfortunately, the complexities and the operational idiosyncrasies of these cables are often misunderstood by the cable user with the result being less than optimum cable performance. As cable technology continues to advance, it becomes increasingly important that cable users devote ample engineering and monetary resources to the development of cables and cable handling systems which are required for critical applications. This paper discusses many of the operational characteristics of typical EM cables and highlights the important points which must be considered during cable design. Examples are given of how cable designs may be tailored to achieve specific performance goals in terms of cable strength, elasticity, torque and rotation characteristics, bending fatigue life, and twist tolerance. The paper also compares and contrasts the operational characteristics which are achievable with cables having metallic strength members versus cables having nonmetallic (typically Kevlar) strength members. The advantages and shortcomings of these two basic classes of cables are described for various strength member configurations. A list of references is provided to assist the reader in further investigations into cable response to tension, bending, and twisting.

Typical Cable Configurations

Electromechanical cables typically fall into one of three basic design categories. The most common configuration is one in which the power and/or data transmission elements are contained within the center of the cable with the strength member elements being placed on the exterior. The cable may include an overall extruded or braided jacket. Another cable configuration has a centrally located strength member around which the power and/or data transmission elements are helically wrapped. This type of cable requires an overall extruded or braided jacket. Finally, a cable may have a separate strength member which lies along side of and is attached to a second component which contains all of the power and/or data transmission elements. A large number of design and material variations are available within each of these basic cable design categories.

Operational systems which subject cables to high tension loads combined with bending over sheaves and drums typically use cables which have an external strength member and, perhaps, an overall jacket. This cable configuration provides the best protection and service life for the internal conductors, it is easily handled using conventional winch systems, and it can be designed to provide high strength, good torque balance, and good cyclic tension and cyclic bending fatigue performance. Because of its widespread use, this cable configuration will be the main subject of the following discussion. However, many of the concepts which are described in the forthcoming may also be applied to cables

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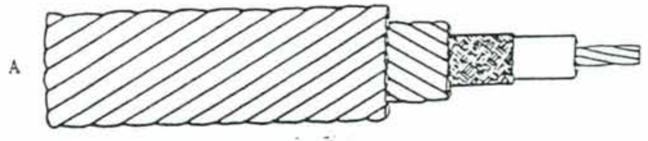
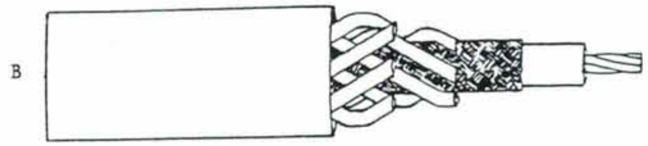
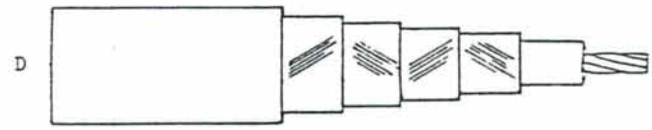


Double Steel Wire Armor



Spaced Armor and Integral Extruded Jacket

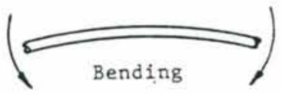
Braided Kevlar and Overall Jacket



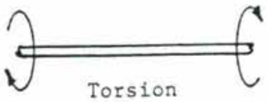
Served Kevlar and Overall Jacket

Fig. 1 Typical configurations of cables having external strength members

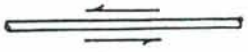
Tension



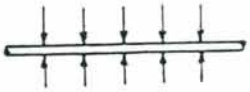
Bending



Torsion



Shear



Uniform Compression

Localized Compression

Fig. 2 Forces and deformations affecting individual cable elements

having center strength members or strength members which are separate from the cable component which contains the power and/or data transmission elements.

Typical configurations of cables having external strength members are shown in Fig. 1. Cable design A is a double steel wire armor cable which incorporates two contrahelically wrapped layers of steel wires. More than two layers of armor wires can be used if increased cable strength or weight is required.

Should a cable require a large core assembly with many conductors, then a full double armor design may provide excessive cable weight and more strength than required. The alternative is a spaced armor design represented by Cable B in Fig. 1. In this case, the armor wires within each layer are widely spaced and are held in position by an integral extruded jacket.

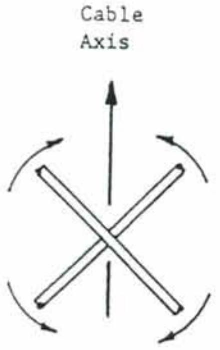
Cables which use Kevlar fibers rather than steel wires as the strength member elements typically have the Kevlar applied as a braid or in several contrahelically served layers as represented by Cables C and D in Fig. 1. In some cases, two or more layers of braided Kevlar are used, perhaps with isolation tapes separating the layers. However, higher strength, lower stretch, and better flexure performance can typically be achieved with a multiple layer, contrahelically served Kevlar strength member with the various fiber layers separated by some type of isolation tape. In either case, the cable typically includes an overall extruded or braided jacket.

All of the cables shown in Fig. 1 have a simple insulated conductor as the core element. However, most conventional operating cables require complex cores containing power conductors, twisted pairs, twisted quads, and coaxial conductors. Other cables which are beginning to be used more widely contain power conductors and optical fibers within the core. With few exceptions, all elements of an operating cable (power conductors, data transmission elements, and strength members) are assembled with helical paths within the cable structure to accommodate bending of the cable. Any conductor which is located in the very center of the cable core so as to have no helix, itself, is typically manufactured from helically wrapped copper filaments. While the discussion which follows is directed primarily at cable strength members, it applies to all helically wrapped elements within the cable structure.

Forces Affecting Cable Elements

The forces which act upon the elements within a cable structure are described in Fig. 2. The application of a tensile load to a cable produces cable elongation which imposes a longitudinal strain and, therefore, a tensile force on each of the cable elements. In addition, the slight tension-induced changes in cable geometry (increase in length and reduction in diameter) produce minor amounts of bending and torsion in the individual cable elements.

Whenever a cable is bent, the individual elements experience changes in curvature which produce bending stresses within these elements. In steel wire strength members, the resulting bending stresses may be quite high if the cable bending diameter is small. However, in the case of cables having Kevlar strength members, no matter how small the



Element Motion Due
To Cable Elongation

Element Motion Due
To Cable Bending

Fig. 3 Motions affecting individual cable elements

cable bending diameter, the bending stresses within the individual fibers are negligible due to the very small diameter of these fibers.

Bending and twisting of a cable also induces torsional stresses in each of the individual components. However, these stresses are typically small relative to other critical stresses within the structure.

The bending of a cable also produces significant shear forces among the elements within each helical layer and at the interface between layers. As described in the forthcoming, the magnitude of these shear forces is dependent upon the cable bending diameter and the helix angles of the elements within the cable structure.

Elements within a cable which are in parallel contact with each other or which contact extruded materials experience more or less uniform compressive forces along their length as a result of the tension load which is applied to the cable or as the result of externally applied hydrostatic pressure. The combination of compression and shear forces acting on individual elements is frequently the cause of element deterioration.

At the interface between contrahelically wrapped layers of elements within a cable structure, the individual elements experience localized compressive loading at locations where they contact each other. These localized contact forces produce high contact stresses which can lead to the rapid deterioration of cable conductors or strength members.

Motions Affecting Cable Elements

Whenever a cable is subjected to tensile loading, the resulting increase in length and reduction in diameter causes a slight reduction in the helix angle of each element within the cable. At the interface between contrahelically wrapped elements, this change in helix angle produces localized abrasion of the cable elements as described in Fig. 3. This effect is more pronounced in cables having greater stretch due to higher initial helix angles, compressibility of the cable core, or high elasticity of the individual strength members.

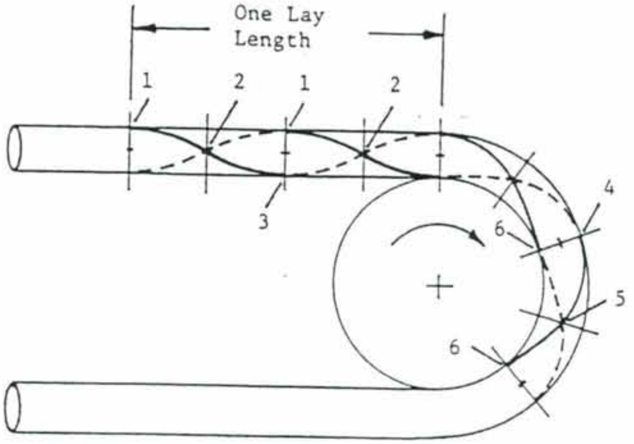


Fig. 4 Element geometry in a bent cable

Whenever a cable is subjected to bending, the individual elements experience a small amount of movement along their individual axes as the helical cable structure deforms to accommodate the change of cable curvature. The result is localized abrasion of the elements at the interface between contrahelically wrapped layers. To a lesser extent, bending of the cable also produces small amplitude relative motions among the elements within each layer.

Cable Behavior in Bending

When a cable is subjected to combined tension and bending, the forces and motions which are imposed upon the individual elements, as described above, are responsible for the deterioration and final retirement of the cable. It is useful to understand the factors which affect the magnitudes of these forces and motions so that cables may be designed and used properly to avoid premature failure.

Consider a cable which is passing over a sheave as shown schematically in Fig. 4. Within the straight portion of the cable, all elements within a given layer (for example, all outer armor wires) have precisely the same length within a given length of cable. Furthermore, if the straight portion of cable is divided into sections of equal length (for example, one-fourth lay length increments as shown in Fig. 4), then the elements in one cable section have the same length as the elements in another cable section. In other words, the length of an element between Positions 1 and 2 is the same as the length of that same element between Positions 2 and 3.

However, after the cable has been bent onto a sheave, the length of an element from Position 4 to Position 5 is greater than the length of the same element from Position 5 to Position 6. Thus in the process of being bent onto the sheave, the cable experiences relative motions among its individual elements to accommodate the distortion of the helical geometry. As the cable passes onto the sheave, the high contact forces at the sheave-to-cable interface prevent element motions in this region (Position 6). To accommodate the length differences described in the foregoing, each cable element experiences a small amount of motion relative to adjacent layers as shown in Fig. 5. Little or no motion actually occurs among elements located at Position 4.

This behavior is often observed in the laboratory during cyclic-bend-over-sheave fatigue tests of cables having braided Kevlar strength members. During repeated bending over sheaves with normal operating tensions, such cables eventually fail mechanically due to Kevlar fiber abrasion in the vicinity of Position 5, with little abrasion being apparent in the vicinities of Positions 4 and 6. Of course, similar motions

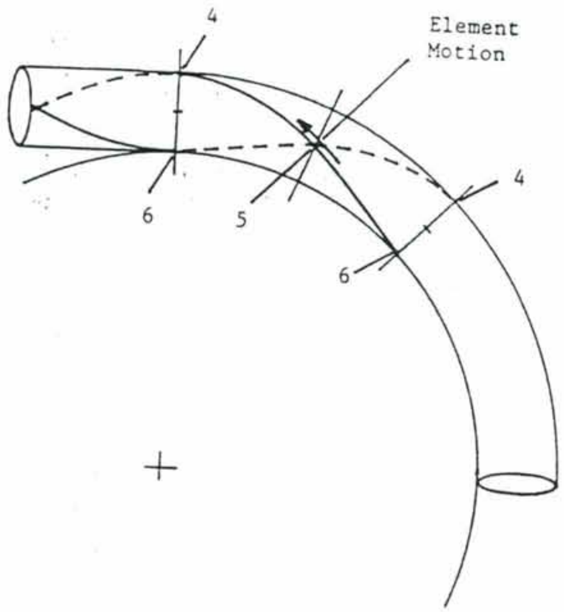


Fig. 5 Element motion induced by cable bending

and wear patterns are exhibited to a greater or lesser degree by all helically wrapped elements within a cable.

To determine the magnitude of these element motions, a mathematical model was developed which, with the aid of a digital computer, allows the analysis of any helical structure which is deformed to any desired bending diameter. While the details of this analysis are beyond the scope of this paper, the results are summarized in Fig. 6 (Reference [18]).

Consider, for example, a double steel wire armored cable having an outside diameter of 25 mm. Assume that the diameter of each outer armor wire is 2 mm and, therefore, the pitch diameter of this layer of wires is 23 mm. Also assume that the lay length of the outer armor wires is 230 mm or 10 times the wire pitch diameter. If this cable is bent over a sheave which provides a 690-mm bending pitch diameter for the cable (30 times the pitch diameter of the outer armor wires), then the motion of each outer armor wire relative to the inner armor wires is approximately 0.10 times the pitch diameter of the outer wires or approximately 2.3 mm. Physical measurements of cable specimens during bending at zero tension (a condition which approaches a frictionless cable) have confirmed that the actual element displacements are approximately the same as the displacements predicted in Fig. 6.

It is this relative motion between and within element layers which gives rise to the shearing forces and abrasive deterioration discussed earlier. In general, increasing the number of elements in a given layer decreases the relative motion between any two adjacent elements within that layer. However, the motion of an element relative to an adjacent layer is affected only to a small degree by the number of elements and the element diameters in a given layer.

As discussed in the foregoing, the dominant failure mechanism in a braided Kevlar strength member is fiber-to-fiber abrasion at the braid crossover points. Improved performance is obtained if the Kevlar strength member is applied in contrahelically served layers separated by low-friction isolation tapes (such as mylar). The isolation tapes all but eliminate the layer-to-layer abrasion. Furthermore, since the individual Kevlar fibers have a diameter of only approximately 0.012 mm and the number of fibers in each layer is enormous, the relative motion and, thus, the abrasive wear between adjacent fibers within a given layer is negligible. In the absence of significant fiber wear within and between Kevlar layers (and due to the insensitivity of Kevlar to cyclic tension, bending, and torsional stresses which promote fatigue crack growth in metallic strength members), outstanding cable flexure performance may be achieved.

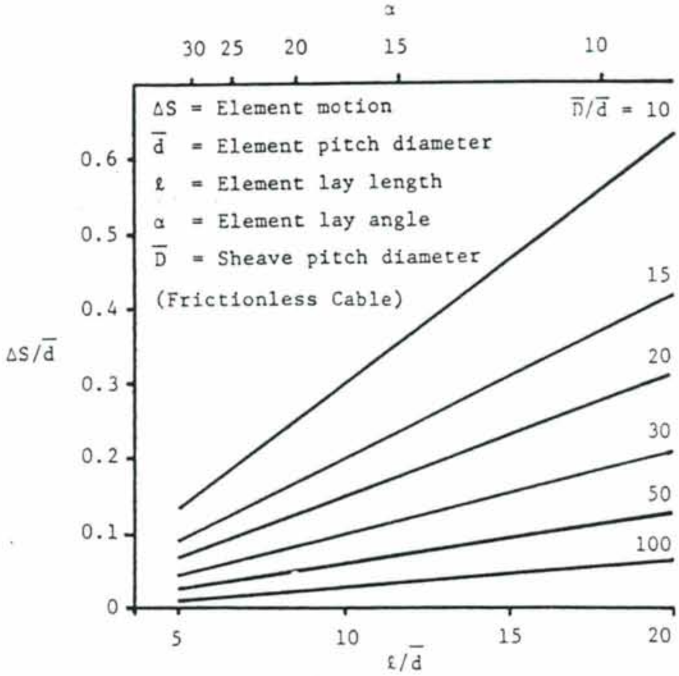


Fig. 6 Cable element motions due to cable bending over a sheave

In the case of cables which have steel wire strength members, the relative motions within and between the armor layers contribute to some degree of wear which may remove the protective zinc coating on galvanized wires and, thus, promote the corrosive deterioration of the armor. However, wire armored cables usually do not exhibit a significant strength loss due to internal wear per se. Rather, they develop fatigue failures of individual wires due to variations in the tension, bending, torsion, and localized compressive contact stresses produced by cable tension, bending, and twisting.

An examination of Fig. 6 reveals that the element motions within a cable can be reduced by decreasing the element lay length (increasing the element helix angle) or by increasing the bending diameter of the cable. Both Kevlar and steel-strengthened cables exhibit improved bending fatigue performance with larger helix angles and/or larger bending diameters. Of course, an increase in element helix angles usually produces an increase in cable diameter, a reduction in elastic modulus, and a decrese in the maximum achievable breaking strength for a given quantity of load bearing wire or fiber. However, since the useable service life of a cable is determined by the residual breaking strength after some period of flexure cycling and not by the original breaking strength, the use of higher helix angles to improve fatigue performance is usually advantageous if the corresponding increase in cable diameter can be tolerated.

When a cable is subjected to tensile loading, each of the helically wrapped elements exerts a radial force on the portion of the cable around which it is wrapped. This radial force acts in conjunction with the internal cable friction to impede the element motions described in the foregoing. As a consequence of the friction forces which exist within a cable, each element experiences a variation in tension along its length as the cable is bent. For example, referring to Fig. 5, the portion of an element between Positions 4 and 5 experiences an increase in tensile loading while the adjacent portion of the same element between Positions 5 and 6 experiences a decrease in tensile loading as internal friction forces impede the motion of that element. Only in ideal frictionless cable would the tensile loading remain uniform along the length of a given element.

Thus, a second factor which contributes to cable deterioration during bending, in addition to element wear, is a variation in the effective tensile load experienced by each element. The resulting variation in tensile stress acts to accelerate fatigue crack initiation and propagation in metallic components.

Another consequence of the element motions and friction forces within a cable is a distortion of the geometry of that portion of cable immediately adjacent to a sheave tangent point. Because of the nonuniform tensile load distribution in the strength members around the cable circumference (higher element tensions away from the sheave and lower element tensions toward the sheave), the cable does not remain a smooth circular cylinder, but rather developes a helical distortion or corkscrew over a short section of its length adjacent to the sheave. Close observation of a cable which is passing over a sheave will reveal a small standing wave at each sheave tangent point as a consequence of this helical deformation. Cables which have small helix angles for the individual strength member elements experience greater element motions and larger element tension variations and, therefore, exhibit more obvious helical deformation during bending. In extreme cases, this helical deformation can lead to the circumferential migration of the strength members which exposes the inner layers of cable elements and leads to gross deformation of the cable structure. Experience in the laboratory has shown, for example, that a cable with 48 outer armor wires will operate satisfactorily over a sheave which is 20 times the cable diameter if the armor wires have a helix angle of 23 deg, but very rapid cable distortion and destruction occurs with armor wire helix angles of approximately 18 deg. Larger sheaves are required for the latter cable to reduce armor wire motions and tension variations.

The element displacements and friction forces described above also give rise to cable heating during flexure over sheaves. Such heating is of little consequence during normal deployment and retrieval operations where the cable may experience bending over several sheaves, but only infrequently. On the other hand, if a cable is subjected to repeated bending over the sheaves of a motion compensation system while sustaining a high tension load, then the friction-induced temperature buildup in the cable can be quite significant and, when added to any electrical resistance heating, can lead to accelerated failure of certain insulation materials. The application of a lubricant to a cable to reduce the internal friction and to improve the heat transfer away from the cable will reduce these heating effects.

When a cable is subjected to bending, either steel or Kevlar strength members have sufficient tensile strength and elastic modulus (low stretch) to accommodate the induced element motions, although with some resulting variation in tensile loading as discussed above. Should a cable be manufactured with highly elastic strength members, then the internal cable friction would impede element motions to the extent that the motions would be minimal, and, instead, the cable strength members would experience changes in length to accommodate the induced deformations due to cable bending. A consequence of this behavior would be a reduction in abrasion between element layers. However, most high performance electromechanical cables have relatively inelastic strength members and, thus, they experience element motions approaching the theoretical values for a frictionless cable as described in Fig. 6.

The electrical conductors or optical fibers within the core of a cable also experience similar element motions and friction forces. However, in this case the elements themselves may be of insufficient tensile strength to accommodate the induced element motions in the presence of high internal cable friction. As a consequence, small copper conductors may experience strains far in excess of their yield point between Positions 4 and 5 in Fig. 5, while the same conductors may experience column buckling loads and z-kinking between Positions 5 and 6. Then, if the same section of cable passes over a sheave so as to be bent in the opposite direction, the reverse situation will occur, and that portion of the wire which was previously strained beyond its yield point will be forced into longitudinal compression, while the adjacent section of wire which was previously compressed will be strained beyond its yield point. The consequence of this behavior will be rapid failure of the conductor and insulating materials. This type of deterioration is frequently observed in cables which incorporate small interstitial conductors at locations well away from the cable centerline.

On the other hand, larger power conductors which have ample tensile strength can accommodate the induced motions without rapid failure. However, even these conductors may eventually exhibit cup and cone tensile failures (rather than classical fatigue failures) as the result of the large strains induced in the conductors during cable bending.

There are several steps that can be taken to avoid premature failure of small conductors which must be located at a significant distance from the cable centerline. One approach is to combine several small conductors together into a twisted pair, triad, or quad so that the assembly has ample extensibility to accommodate the length changes imposed by cable bending without exceeding the yield point of the conductor material. If it is not possible to combine small conductors into complexes, then it is necessary to either use a very high conductor helix angle so as to minimize the motions within the cable structure or to fabricate an elastic conductor by wrapping one or more layers of copper filaments around a small diameter nylon rod. In any case, careful attention must be paid to the design of a cable core so that all elements within the core have sufficient strength, elasticity, and helix angle to accommodate the deformations which occur as the result of cable bending.

Cable Reaction to Twisting

Many cables must survive not only combined tension and bending but also a certain amount of twisting. There are several potential sources of twisting including the maneuvering of a tethered vehicle, the use of a cable handling system which places the cable in a cage or basket rather than on a drum (in this case the cable experiences one complete 360-deg twist for each wrap in the basket), or the use of a nontorque-balanced cable with a swivel or with an unrestrained payload. The twisting of the cable always increases the strain on the helical elements which are wrapped in one direction while it decreases the strain on the elements which are wrapped in the opposite direction. The result is often a decrease in cable breaking strength (particularly in the case of Kevlar strengthened cables) and a reduction in the cable flexure performance. Of course, any excess strain which is induced in the individual elements due to cable twisting will compound any problems associated with the excess strain induced by cable bending.

Since most cables have strength members which are assembled with both right and left-hand helices, the cables tend to become shorter no matter in which direction they are twisted. Any conductors within the cable core which tend to experience increased strain due to cable twisting will be relieved to some extent by this shortening of the cable. On the other hand, any conductors which experience a decrease in length due to cable twisting will experience a further decrease in length due to cable shortening and may then fail due to column buckling and z-kinking. Thus, any cable which is likely to experience a significant amount of twisting in service must be carefully designed with the proper conductor lay direction and lay angles to accommodate the twisting without inducing excessive strains on the core elements. Experience has shown that careful attention to such design details can result in electromechanical cables which are highly twist tolerant, although they may have a preferred twist direction. In any case, designing for twist tolerance must be undertaken in light of the additional element strains and motions which must be accommodated due to cable bending.

Cable Torque and Rotation

The preceding discussion describes the influence of cable element helix angles on certain cable parameters such as breaking strength, elasticity, twist tolerance, conductor survivability, and cable flexure life. However, this discussion would be incomplete without some mention of cable torque and rotation characteristics and how these parameters are influenced by the selection of component helix angles.

For many applications, it is very important that a cable be well torque-balanced and free from rotation to avoid rotation of a payload or to decrease the chance of hockles and kinks should a slack loop form in a deployed cable. To achieve good stress balance among the cable strength members as well as good torque balance for the complete cable assembly, it is necessary that certain relationships exist between the helix angles of various layers within the cable structure. Should it become necessary to alter the helix angle of one layer of elements (perhaps to avoid a premature mode of failure), then it may also be necessary to alter the geometry of other components in order to preserve torque balance. This is especially true for Kevlar strengthened cables where cable elongation often imposes significant strains and tension loads on copper conductors within the cable core. Should the core contain a number of large power conductors, then the torque contribution of these elements may be quite large. A change in the helix angle of these conductors may require a redesign of the cable strength member to preserve the desired torque balance. This redesign may be in the form of changes in the helix angles of the strength members or changes in the load bearing area of the strength members in each layer, or a combination of the two. Of course, the final selection of the helix angles for all cable elements must be made with consideration for the cable flexure performance and twist tolerance, as well as for the torque balance.

Conclusions

To achieve satisfactory cable performance under conditions of bending and/or twisting, careful attention must be paid to the helical geometry of all elements within the cable structure and to the strength and stretch characteristics of these elements. Slight variations in cable geometry can have a dramatic effect on the useful service life of the cable. The survivability of electrical and/or optical elements is contingent upon the selection of a cable design which imposes neither excessive tensile strains nor column buckling loads on delicate cable components. The survivability of the cable strength member is contingent upon the selection of a cable design which, in the case of Kevlar strength members, avoids excessive fiber-to-fiber compressive loads and relative motions and, in the case of steel wire armored cables, avoids excessive bending and contact stresses which promote fatigue crack initiation and growth. While the evolution of a satisfactory cable design may require actual operational experience or properly executed laboratory tests, significant cable performance improvements are often possible through careful failure analyses and slight variations in cable geometry to delay or avoid the dominant failure mechanisms.

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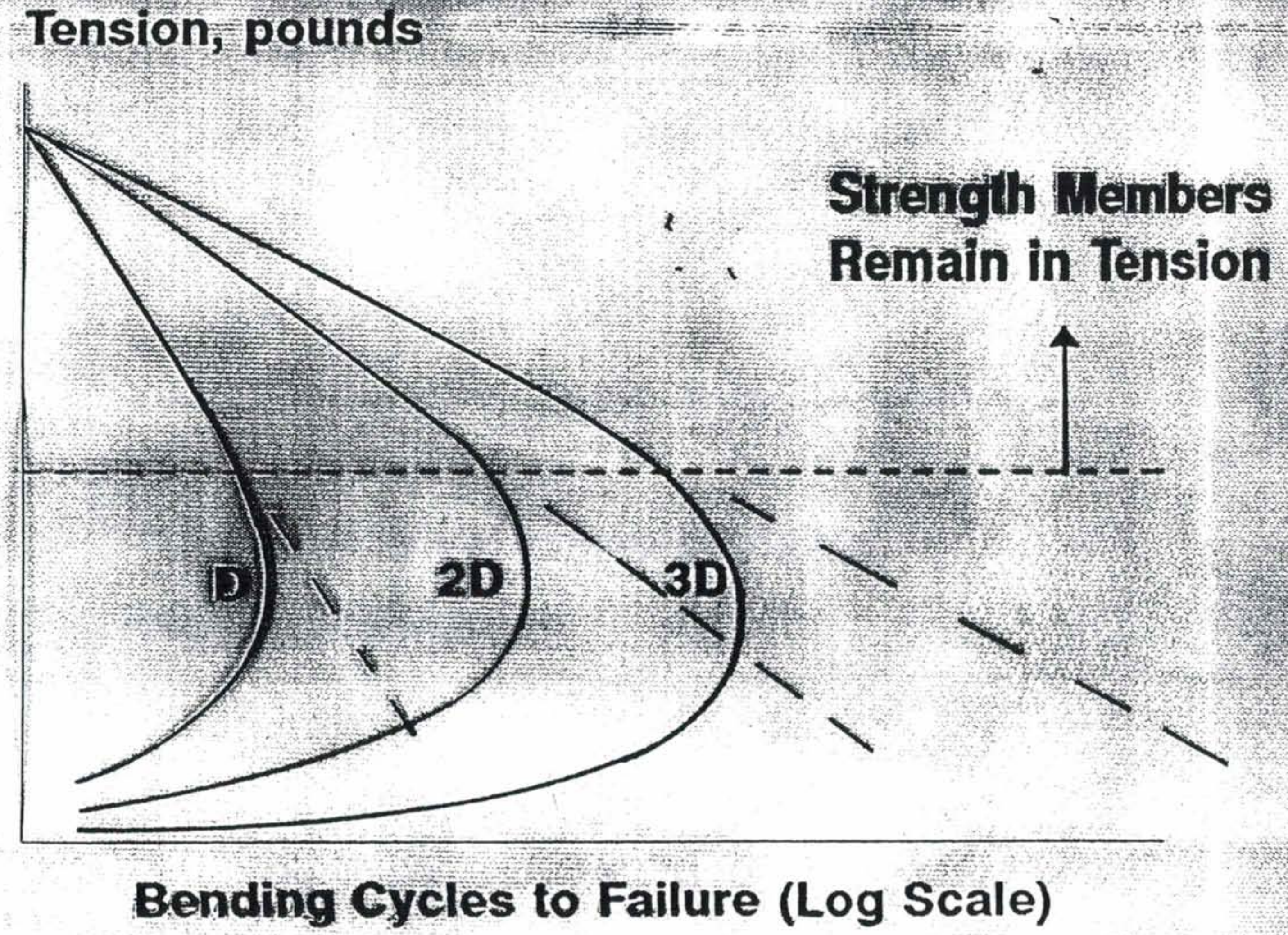
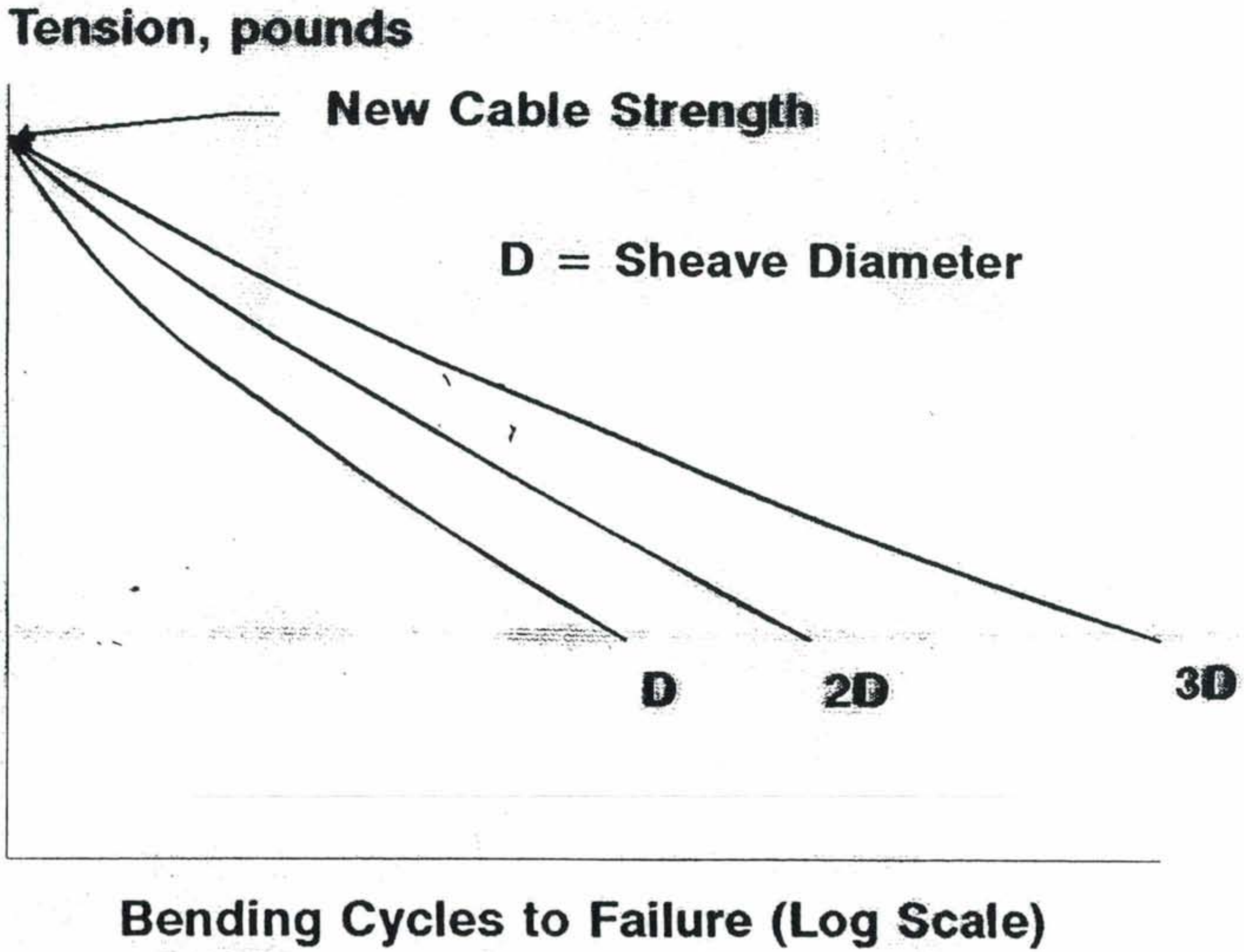
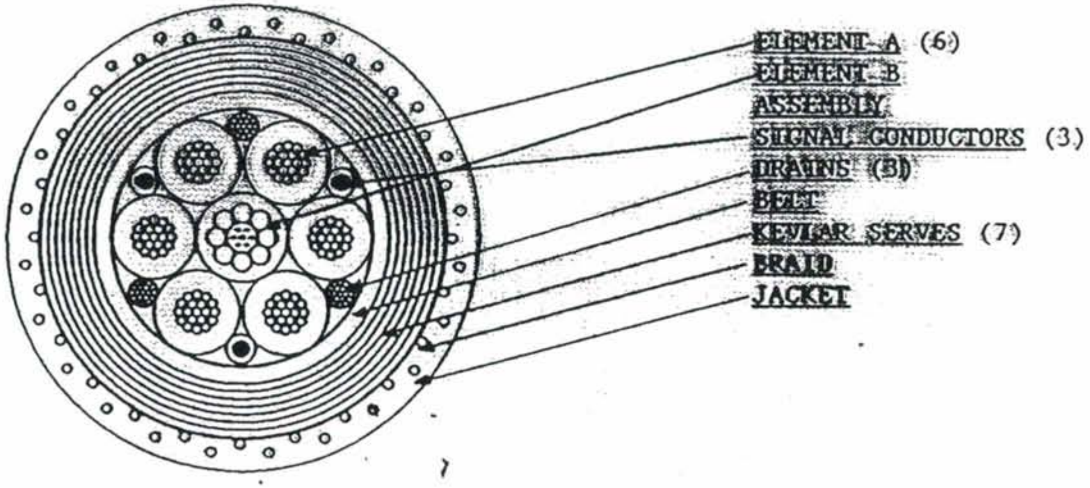
Typical Bending Fatigue Performance of Cables Having High-Modulus-Fiber Served Strength Members



Typical Bending Fatigue Performance of Cables Having Steel-Wire Strength Members (Armor)





OPTICAL MATRIX ROV CABLE

FIGURE 2

APPENDIX VIII

OCEANOGRAPHIC CABLE POOLS
GENESIS

Before 1982:

- Each institution purchased cable to meet its own requirements.
- Characteristics varied through fleet (Electrical and mechanical)
- CTD became dominant user of E-M cable

Problems:

- User: unable to pick R/V of choice
- User: unpredictable cable performance (multiple designs/vendors)
- Many annual proposals for funds
- High cost per unit length
- Inefficient maintenance of reserve cables

Solutions:

- Standardize cable type/design/length
- Provide uniform winch capability
- Bulk-purchase cable
- Pool reserve cables

D.A.M.- 3/94

HISTORICAL REPLACEMENT OF CABLE

Too Short	• **75-80%**
Age/corrosion	• 15-20%
Loss	• 5-10%

Reason: Electrical failure - cut at sea

Causes:
Crushing due to poor level-wind
Z-kinking (cyclical overloading)
Slack wire hockle (cyclical "0" load)

Solutions:

- Multiple conductor cable - redundancy
- Improve strength/weight ratio
- New winch/level-wind systems
- Improve payload characteristics
- Define operating limits:
  - Sea state
  - Vessel motion
  - Lowering speeds
  - Payload limits (weight/bulk)
- Education

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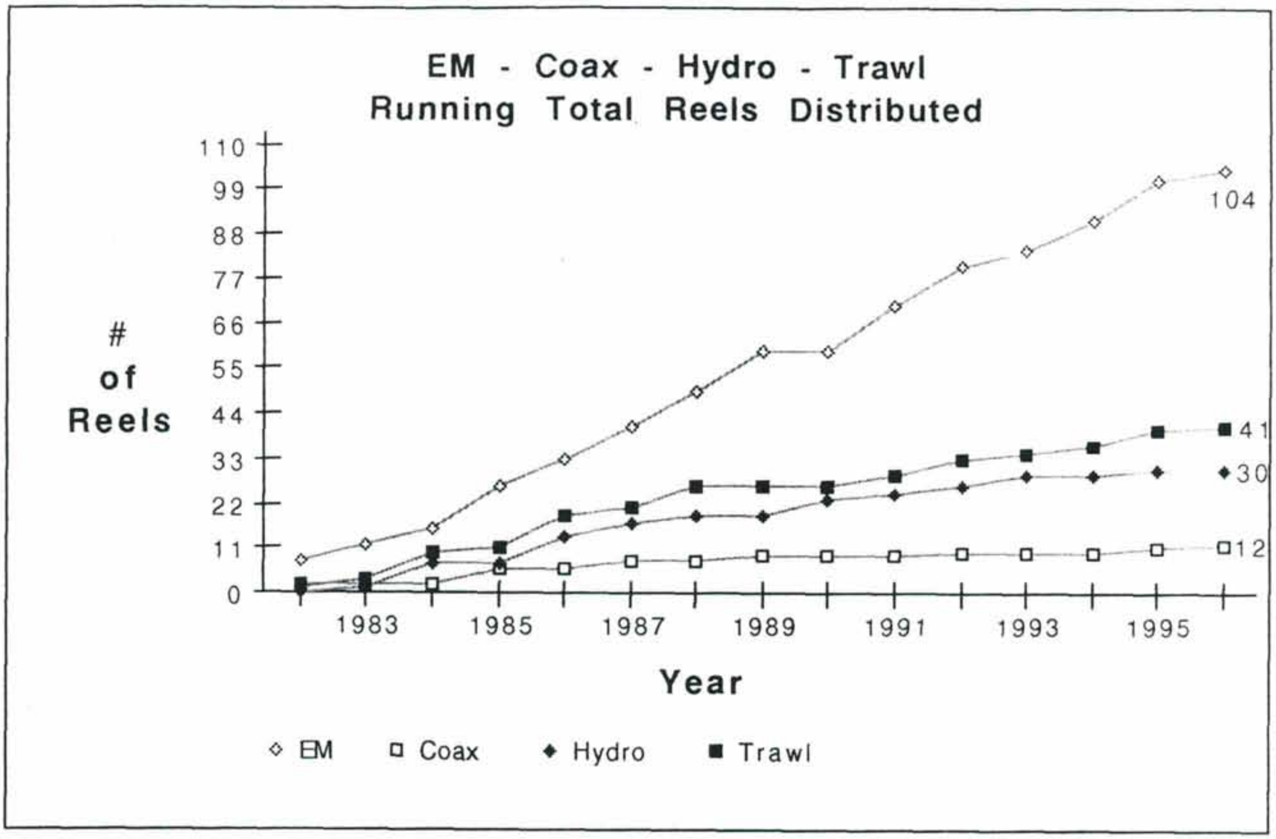
UNOLS
Oceanographic Cable 'Pools'

Total Purchases since Inception

	No. of Reels	Total Length (x1000)	Total Cost (x1000)
EM- .225"	18	457.1'	$ 132.7
.303"	5	132.4'	91.7
.322"	100	3,174.2'	1,853.3
Total	123	3,764.0'	$2,077.7
Coaxial - .68"	13	359.9'	$959.9
Hydro - 3/16"	9	271.2'	$ 73.4
(3x19) 1/4"	25	742.1'	340.7
Total	34	1,013.3'	$414.1
Trawl - 1/2"	27	811.3'	$ 608.3
(3x19) 9/16"	22	845.6'	993.2
Total	49	1,656.9'	$1,601.5
Grand Total	219	6,794.1'	$5,053.2

D.Moller -11/1/96

UNOLS Oceanographic Cable 'Pools'



D.Moller-11/1/96

UNOLS E-M CABLE

Requirement: A long cable with data transmission capability used to lower varied instrumentation from R/V on the High Seas

GENERAL SPECIFICATIONS

- Payload weight: >1000# (450kg.)
- Operating Depth: 6,000m.
- Lowering rates: >60m./min.

- Dynamic environment
- Continuous operation
- Intermediate sized winch systems
- "Well logging" cable design
- Multiple conductors
- Low powered telemetry
- Minimal power capacity

CHARACTERISTICS

- Nominal .322"(8.2mm) diameter
- 10,000 meter length
- Best weight to strength ratio
- Highest elastic limit
- Best abrasion resistance
- Best corrosion resistance
- High rotational stability
- Armor stress balance
- Well preformed (resist unlaying)
- Service life >3 years
- Survival: >40% RBS for 70% life
- Survival: Periodic loading >50% RBS
- Withstand cyclical loading
- Flexure: operate over sheaves 40X cable dia.
- Galvanized
- Storage under tension to 40 layers
- Lubricated

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UNOLS E-M CABLE
PERFORMANCE SPECIFICATIONS

Diameter:	.322" (+/-.003") at 15% RBS <2% Change at 50% RBS Uniform over length
Length:	10,000 meters, w/o splices
Strength:	RBS >9,000# w/ one-end-free
Rotation:	<20°/ft. at 40% RBS
Flexure:	>50,000 cycles, sheave 40X O.D. at 40% RBS without failure
Tension cycling:	as above, 10% to 40% RBS
Min.Sheave size:	<15" tread diameter
Armor:	Strength ≥ XIPS Ductility ≤ XIPS Min. outer wire dia.=.032" (.81mm)
Electrical:	3 cond.,stranded copper wire >#20AWG Conductor: DC resist <10Ω/1000', <40pf/ft.@1kHz, Rated >600 VDC Primary circut: 1 conductor to armor Telemetry: optimize freq <20kHz (5kHz+10kHz) Copper yield >65% RBS of cable
Lubrication:	Low vicosity, water displacing During armoring

D.A.M.- 3/94

May '1986

SPECIFICATIONS
FOR
A UNOLS "CTD" CABLE

The academic oceanographic community, represented collectively by the University and National Oceanographic Laboratory System (UNOLS), has for many years used Electro-mechanical cables in general purpose applications to lower various scientific instruments over the side of oceangoing research vessels. The cables, which are handled with intermediate-sized hydrographic winches, support the instruments and provide the medium for electronic telemetry to the vessel. This type of cable has come to be known as "CTD wire".

Since 1982 a community wide effort has been made to "standardize" E-M cables to a single design to provide commonality on UNOLS vessels. A triple conductor .322" diameter cable of 33,000 ft. length has been selected for this application. In 1984,1985 and 1986 several reels of this cable were purchased. Winch systems have been replaced or upgraded to accommodate cables of this size.

The E-M cable is of the general type developed for the well logging industry. Although this type cable continues to be suitable for oceanographic applications, operating conditions and scientific applications aboard research vessels differ from those of the oil industry. These differences are significant enough to warrant the design of a cable that will specifically meet the needs of the UNOLS laboratories.

The following specifications describe in general terms the significant characteristics a UNOLS E-M cable design MUST have. No priority is implied by the order given.

GENERAL:

An Electro-mechanical cable is required to lower various scientific instruments over the side of oceangoing research vessels. The cable must be capable of safely lowering an instrument to a 20,000 foot water depth in the dynamic environment caused by ship and wave motion, and lowering/raising speeds of 300 ft./min. Multiple conductors are required for the real time transmission of electrical data and control signals and for redundancy. The cable must be capable of being stored under tension for long periods of time on single drum winches to a depth of 40 layers. Resistance to crushing, as occurs when level winding is faulty, is desirable. It is expected, that regardless of the Ultimate and Yield Strengths of the cable, payloads will evolve to a point that loading of the cable (static + dynamic) will frequently approach 50% of RBS.

CHARACTERISTICS:

1) Maximum strength attainable-- identified as the best possible ratio of strength to weight. The ability of a cable to "survive" under extreme conditions is a function of its Rated or Ultimate Breaking Strain.

2) Highest elastic limit attainable-- identified as the best possible ratio of elastic limit to weight. This characteristic controls the mix of payload size, wire out, wire speed and environmental conditions at which the cable can operate with safety. This applies to both strength and electrical components of the cable.

3) High rotational stability-- identified as a minimal amount of axial rotation under loads cyclically varying from 0% to 45% of RBS. Low rotation is considered necessary to avoid looping/hockling the cable on bottom contact or "Zero" tension conditions and to prevent excessive spinning of lowered instruments. (A 'trade off' with Item 15)

4) High degree of armor stress balance -- identified as the absence or near absence of variations to the relative loading on inner and outer armors that produce strength degradation when one end of the cable is free to rotate.

5) Minimum service life of 3 years-- the useful life in "normal" service assuming reasonable care and proper handling.

6) Cable must be capable of operating at:
>30% RBS for 90% of expected life;
>40% RBS for 70% of expected life.

7) Withstand occasional loading to 50% RBS without significant, if any, reduction in strength or change in electrical characteristics.

8) The cable must be galvanized.

9) The cable must have a finished O.D. of .322". This is to avoid modifications to existing winch/sheave train systems.

10) The cable must be in an unbroken length of 33,000' (without splices).

11) The cable must be capable of operation with single drum winch systems where the cable is stored under tension.

12) Operate continuously (useful life) over sheaves NLT 40X cable diameter without degradation in strength.

13) The cable must be capable of withstanding repeated flexures over sheaves at the nominal working loads given in Item 6 without degradation in strength or change in electrical characteristics.

14) The cable must be capable of withstanding cyclical loading in tension as results from ship motion without degradation in strength or change in electrical characteristics.

15) Exhibit the best possible resistance to abrasion, both internal and external, consistent with the need for high rotational stability. (A 'trade off' with Item 3)

16) Exhibit the best possible resistance to corrosion, particularly crevice corrosion and hydrogen imbrittlement.

17) The cable must not unlay when cut, i.e., it must be well preformed.

18) The cable should be lubricated for abrasion and corrosion protection. The lubricant should not extrude in use.

19) The cable must have multiple electrical conductors capable of efficient transmission of low power telemetry signals at frequencies <20kHz. Cable design should be optimized to permit simultaneous transmission of 5kHz and 10 kHz signals in a single conductor to armor circuit. There is no requirement for power transmission.

PERFORMANCE SPECIFICATIONS:

1) Finished Diameter: The finished diameter shall be .322" at a loading of 15% of RBS. The diameter shall be uniform over the length of the rope with tolerances of (±0.003"). This specification permits the use of existing winch/sheave train systems without modification.

2) Working Diameter: The change in cable diameter due to a change in cable loading shall not exceed 2% of the finish diameter. At a loading of 50% RBS the cable diameter shall not be less than .316". This specification is to assure the cable stays within limits necessary for proper level winding.

3) Rotation: The finished rope should not rotate about its axis more than 20° per foot at 40% of Rated Breaking Strength. It is recognized that this requirement may not be met given the specified outer armor wire size and minimum sheave diameter.

4) Rated Breaking Strength: >9000# with 1 end free to rotate.

5) Flexure Tolerance: Withstand ≥50,000 flexure cycles over sheaves 40X wire O.D. at 35-40% of RBS without failure of individual wires or degradation of electrical performance. Degradation in strength shall not exceed 5% of RBS. This is estimated to be 150% of flexures in a sheave train for 500 casts to oceanic depths including flexures at the overboarding sheave due to ship motion.

6) Tension Cycling: Withstand ≥50,000 cycles in tension from 10% to 40% of RBS at an 8 sec. period without failure of individual wires or degradation of electrical performance. Degradation in strength shall not exceed 5% of RBS. This value is considered to be representative of tension variations due to ship motion and pay-out/haul-in speeds for 500 casts to oceanic depths.

7) Sheave Size: The cable shall be capable of operation with sheaves of tread diameter ≤15".

8) Cable Length: The cable shall be of an unbroken length of 33,000 ft. without splices.

9) Armor Wires: The armor wires shall be galvanized and have the following characteristics:

Tensile strength: ≥ xtra Improved Plow Steel
Ductility: ≥ of XIPS
Outer armor: wires to have a diameter ≥.032".

10) Electrical: The cable shall be constructed with 3 stranded copper wire conductors sized #20 AWG or larger, each of which shall have the following electrical characteristics:

Resistance: <10 ohms/1000ft.
Capacitance: <40 pf./ ft. at a freq. of 1 kHz.
Voltage Rating: ≥ 600 VDC

11) Yield Strength: Construction shall be such that the conductors shall not yield at a cable loading equal to 70% of RBS.

12) Lubrication: The cable should be lubricated for abrasion and corrosion protection at the armor closing process during manufacture. The lubricant shall be of a low viscosity, water displacing type that does not extrude in use.

APPENDIX IX

Ocean Sciences Division Budget
(in $M)

	FY 1995	FY 1996	FY 1997*	% Change 96 to 97
Research Section	102.60	104.92	109.32	+4.2%
Facilities Section	50.45	48.91	52.26	+6.8%
Drilling Program	39.76	39.85	40.25	+1.0%
TOTAL	$192.81	$193.68	$201.83†	+4.2%

†Includes $4.47M which is committed to the centrally managed Academic Research Infrastructure program. Excluding these funds the OCE total is $197.38M for 1997, a 1.9% increase over 1996.

*** unofficial estimate.**

NSF OCEAN SCIENCES DIVISION

Ocean Sciences

- Budget estimate is $193.7 Million
- Increase of $0.9 Million or .5%

	FY 1994	FY 1995	FY 1996
Ocean Sciences Research	$100.0 M	$102.6M	$104.9M
Oceanographic Centers & Facilities	50.3M	50.4M	48.9M
Ocean Drilling Program	38.7M	39.8M	39.9M
	$189.0M	$192.8M	$193.7M

- Major Research Initiatives

	FY 1994	FY 1995	FY 1996
Global Change Programs	$53.7M	$57.7M	$57.6M
Biotechnology	4.0M	3.6M	3.0M
High Performance Computing	0.4M	0.8M	0.8M
Environmental Research	7.3M	7.7M	7.3M
SMETE (EHR)	2.1M	2.9M	3.1M
	$67.5M	$72.7M	$71.8M

- Other Research Activities	$121.5M	$120.6M	$121.9M

(June 1996)

NSF OCEAN SCIENCES DIVISION

	FY 1994	FY 1995	FY 1996
Ocean Sciences Research	$100.0 M	$102.6M	$104.9M
Oceanographic Centers & Facilities	50.3M	50.4M	48.9M
Ocean Drilling Program	38.7M	39.8M	39.9M
	$189.0M	$192.8M	$193.7M

Oceanographic Facilities Detail

	FY 1994	FY 1995	FY 1996
Operations			
Ship Operations*	$32.2M	$35.1M	$31.1M
ALVIN, Aircraft, etc.	2.2M	2.1M	2.4M
Marine Techs	4.2M	4.4M	3.8M
	$38.6M	$41.6M	$37.3M
Infrastructure			
Science Instruments	2.5M	1.9M	1.9M
Shipboard Equipment	2.1M	1.1M	1.6M
Ships, Upgrades	2.1M	0.2M	1.5M
UNOLS, Misc.	0.5M	0.5M	0.3M
	$7.2M	$3.7M	$5.3M
Centers and Reserves			
AMS	1.2M	1.0M	1.4M
IAI	1.3M	2.0M	1.9M
Cross Directorate/Reserves	2.0M	2.1M	3.0M
	$4.5M	$5.1M	$6.3M

*Plus $1.6M from ODP (1994), $1.8M (1995), $2.1M (1996)

(June 1996)

NSF OCEAN SCIENCES DIVISION

Facilities Planning (1997-2001)

- Context of geosciences Long-Range Plan
  - Earth Sciences
  - Ocean Sciences
  - Atmospheric Sciences

- Financial Context
  - Budget levels comparable to fiscal years 1995/1996
  - Possible reductions in ocean sciences support by other agencies
  - Prioritization

- Academic Research Fleet planning
  - Support operation of academic research fleet at levels that will enable scientific needs to be met
  - Upgrades and replacements of vessels may be undertaken in conjunction with possible lay-up of vessels not needed at times
  - Capital improvements and operations costs combined must stay within budget levels comparable to FY1995/96

- Priorities if additional funds
  - All-season access to Arctic Ocean
  - Upgrading ocean drillship
  - Coastal research vessel

(June 1996)

OCEANOGRAPHIC CENTERS & FACILITIES

- Staff Change
  - * Lisa Rom, Instrumentation and Technical Services (ITS)
    - - one year leave. August 1996-August 1997
  - * Sandy Shor, ITS Program Director
    - - IPA, University of Hawaii, August 1996-August 1997

- Program Addition
  - * Interamerican Institute (IAI)
  - * Line budget in OCFS ($1.6M)
  - * OCE "center" management
  - * Global Change Program

- UNOLS Liaisons

  Unols Council - Don Heinrichs
  RVOC
  Ship scheduling Dolly Dieter
  DESSC
  RVTEC - Lisa Rom/Sandy Shor
  FIC - Richard West

APPENDIX X

SeaNET update

November 11, 1996
Andy Maffei and Dale Chayes

The SeaNet Communications Node (SCN)/INMARSAT-B system which has been on the R/V Thompson was moved to The Joides Resolution (SEDCO-471) during a regularly scheduled port stop in San Diego at the end of October. This move would not have been possible without the able assistance of Mike Realander who handled the removal and packing on the Thompson end and the SEDCO crew. who managed to find time to assist with the installation in the middle of replacing both of their radars.

The installation on the Resolution was done to allow wire line logging data to be transferred ashore for analysis with the results to be sent back out to the onboard science party during the drilling leg 170. The Borehole Research Group which leads the wireline logging effort on the resolution has been using a VSAT system courtesy of Schlumberger to do this for some time. The SCN/INMARSAT-B system was installed for the current leg because the drilling site was expected to be beyond the reach of the existing VSAT capability.

As with all INMARSAT A installations, there are still problems with antenna masts (and the drill rig!) blocking the view of the satellite on certain headings. This problem is somewhat lessened by SEDCO-471 remaining stationary for much of the time during a cruise. High Speed connections to shore need to be coordinated for a time when the ship is pointed towards the equator (more or less). We are working on a software module that calculates good headings based on a ship's above deck profile and the predicted azimuth and elevation to an INMARSAT satellite. Careful planning of the antenna location can reduce the impact of obstructions. One of the things we have learned about INMARSAT B is that voice connections are more robust in the fact of obstructions than for INMARSAT A. However, HSD connections require a clear line of site to the satellite. For shipboard applications where continuous HSD service is critical and a single location can't be found, consideration of two antennas might be an alternative.

We are now getting ready to help with some periodic transfers of wireline logging data from the SEDCO-471 after the first hole is finished and logged which we expect within the next week. There are some ISDN problems to be worked out and some software to be tweaked in support of their efforts to transmit some fairly large seismic files over the INMARSAT-B SeaNet system installed on the Resolution.

It is likely that we will see on the order of half a dozen large (multi-megabyte) file transfers during this leg and we expect to be able to monitor the transfer characteristics and hope to be able to improve the throughput over time while providing a useful service to the science community at the same time.

When it became clear that the our INMARSAT B system with High Speed Data (HSD) was going to be installed to support the wireline logging effort, TAMU expressed interest in using the link to transfer their cc:Mail messages between ship and shore. We are working with them to develop and implement a test plan. One of the problems is that the ship is currently using an network number that is already in use on the TAMU campus. A "simple" TCP/IP routing scenario is not an option. A lesson to be learned from this is that even for ships (or remote sites) that do not anticipate a direct Internet connection, now is the time to allocate legitimate network addresses.

Our hope is that when (if) UNOLS vessels move to using INMARSAT-B more then we will have an attractive communications hub for them to use for various Internet type tasks. We should have some hard numbers to report by the end of the year concerning optimal file transfer rates and costs. We are also hoping to port the software to a Linux platform soon and make it available as a development platform for other shipboard applications.

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