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Curly Wurly Concept Analysis Phase I Report

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1. SCOPE

1.1 INTRODUCTION

1.1.1 Objective

This effort's objective was to perform a concept analysis of a mechanical deployment and recovery technique for neutrally buoyant underwater cable systems. A Scottish company, Deep Water Recovery and Exploration, Ltd. (DWRE) developed a prototype system, the Curly Wurly. This technique uses an approach where individual outer cables are helically wrapped around a central strength member during deployment and separated during recovery. Phase 1 of this study investigated and analyzed the trade-offs of using such a system and determined potential application areas.

1.1.2 Approach

In the Phase 1 effort described in this document, similar systems and techniques were investigated and compared. Important performance attributes were evaluated, including feasibility, reliability, and applicability to desired application areas. Engineering analyses were conducted comparing candidate material characteristics, cable dynamics, and overall system trade-offs. Candidate application areas were then proposed as a result of the analysis.

1.1.3 Need

Cables used in oceanographic applications are generally custom-made, incorporating the strength members, power conductors, and data lines required for a specific application. These cables are typically heavy and cumbersome, requiring specialized handling equipment, particularly for deep-water applications. They are also expensive and vulnerable to damage (e.g., when a single component of the cable such as a data line is broken, the entire cable must be discarded). If smaller, lighter cables with interchangeable components could be used, there could be cost and operational benefits for a range of applications.

1.2 CURLY WURLY SYSTEM

1.2.1 Motivation

DWRE performs deep-water salvage using a 4.5-ton grabber attached to a surface-mounted winch. This winch grabs and recovers payloads. Because of the deep water (up to 3000 meters), the resultant lift cable (up to 4.5 tons) has a great impact on the amount of payload possible per lift. Conventional mechanical and electromechanical cables are less than satisfactory, showing high wear and lasting less than a year. Synthetic cables with external power and data lines could achieve the desired low-cost access to the deep-water salvage applications.

1.2.2 System Description

The Curly Wurly System combines a synthetic strength member with a data or power cable on a regular, repeatable basis. This is done by wrapping the data and/or power cable around the strength member in a helical fashion. Figure 1 shows the basic design of a main lifting winch going through a sheave and vertical fairlead with a secondary spool rotating about the fairlead axis. It uses two winches arranged with the secondary "wrapping" spool rotating about the payout axis of the primary lifting winch. The primary lifting winch can be a standard deck-mounted winch while the secondary one is mounted in the Curly Wurly configuration. A dedicated strength member can then be used for the main lifting function, and power and/or data cables can be wrapped around it as desired. For the initial demonstration, slip rings were not used, as the signal connection was only required once the desired amount of cable was paid out. In future systems, slip rings will be incorporated to permit continual data and/or power transmission during operations.

Figure 1. Curly Wurly System.

(photo courtesy of Deep Water Recovery & Exploration, Ltd.)

1.2.3 System Development

As of February 1999, an initial Curly Wurly System prototype had been built, with two systems currently under construction. One of these will be used for salvage operations in the Mediterranean at depths of up to 3000 meters. A two-reel towed system is under development whereby both power and fiber-optic data cables will wrap around the strength member. These reels will be offset by 180 degrees and will rotate in unison, resulting in a parallel wrap of the two external cables.

1.3 SYSTEM APPLICATIONS

Section 3 details conceptual design applications of the Curly Wurly System.

1.3.1 Salvage

As described in Section 1.2, DWRE developed the Curly Wurly System to provide cost-effective, deep ocean salvage operations. The driving requirement was to minimize the lifting cable weight while providing the required power and/or data capability at depth. Generally, these needs are basic—power and data for a light and a video camera. The cable dynamics are somewhat extreme: a rapid payout at 1000 ft/min, impact of the grabber at the salvage site, and haul-in at up to 1000 ft/min. These desirable speeds minimize the cycle time required for the salvage process.

1.3.2 Towed

Towed systems add some complexity to the salvage system, as they are moved horizontally as well as vertically. The power and data requirements may range from simple camera systems to highly instrumented tow sleds with high power and data requirements, such as the Towed Oceanographic Survey System (TOSS). Section 3.2 discusses the design implications of such a system.

1.3.3 Free Swimming

Finally, a free-swimming system, such as a Remotely Operated Vehicle (ROV) adds the third dimension of motion. As discussed in Section 3.3, these systems tend to have relatively high power and data requirements.

2. CABLE TRADE-OFF ANALYSIS

The externally wound cable assembly resulting from the Curly Wurly process is a marked departure from conventional unified cables for oceanographic applications. To evaluate the externally wound cable, three major areas of analysis were performed: mechanical characteristics, dynamic behavior, and electrical characteristics. Three cable types of comparable strength were compared: a 0.75-inch-diameter, torque-balanced wire rope, a 0.75-inch-diameter JETSTRAN I-A kevlar line, and the TOSS System unified cable. Appendix A provides the specific characteristics of each cable type.

2.1 MECHANICAL CHARACTERISTICS

2.1.1 Size/Weight

Initial system analysis concentrated on the weight/strength trade-offs of candidate materials and the properties of the resulting helically wound cable. As expected, synthetic rope as the strength member may provide significant weight savings over the unified cable currently used with the TOSS system (figure 2). As figure 2 shows, weight still decreases when a power cable is added to the kevlar (*kevpwr)*.

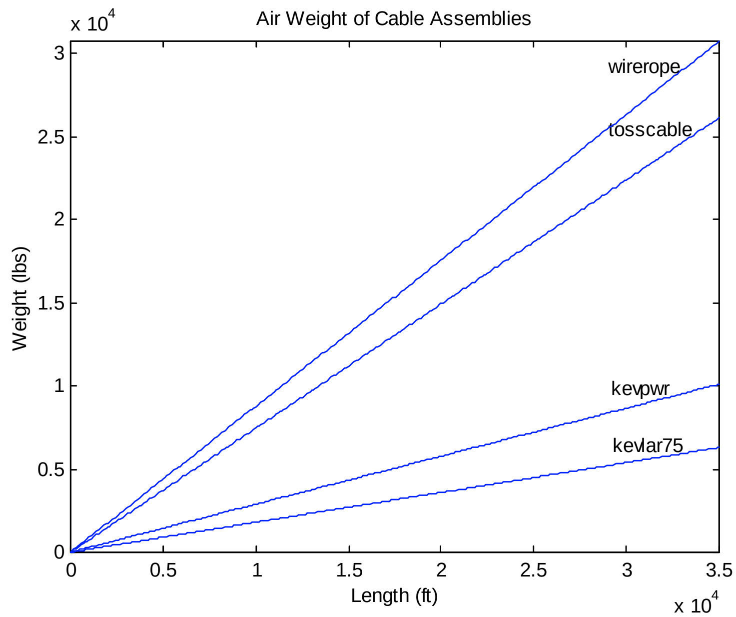

Figure 2. Cable assembly weight as a function of length.

2.1.2 Payloads/Working Strengths

As described in Section 1.2.1, one of the primary motivations in the Curly Wurly design was to increase the system payload capacity by minimizing the self-weight of the cable. Payload analysis shows the maximum payload possible for a given length with a built-in safety factor of two. For the negatively buoyant materials (wire rope and the TOSS cable), the payload capability goes down as length goes up because of the self-weight of the cable (figure 3). For the essentially neutral kevlar strength member, the cable weight itself is not a factor in the payload capability.

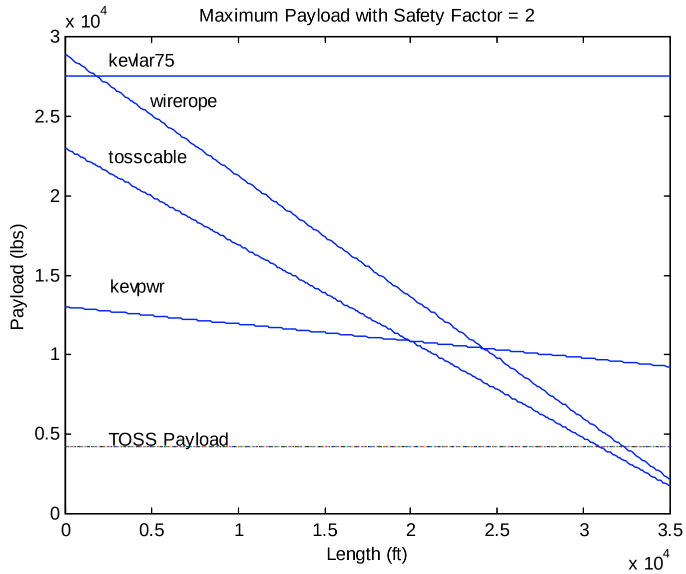

Figure 3. Payload capacity as a function of length.

2.1.3 Elongation/Diameter Variation

Cable designers must consider the elongation and diameter variation of the cable components under load, whether unified or compound as in the Curly Wurly System. For loads of up to 20,000 pounds, the elongation is less than 1 percent (figure 4). For the cables wrapped around the outside, this is even less of an issue, as the wrapping provides some strain relief proportional to the cosine of the pitch angle. To accommodate a strength member stretch of 1 per cent, the pitch angle must be less than 89.4 degrees, which is readily achievable (Section 2.1.6).

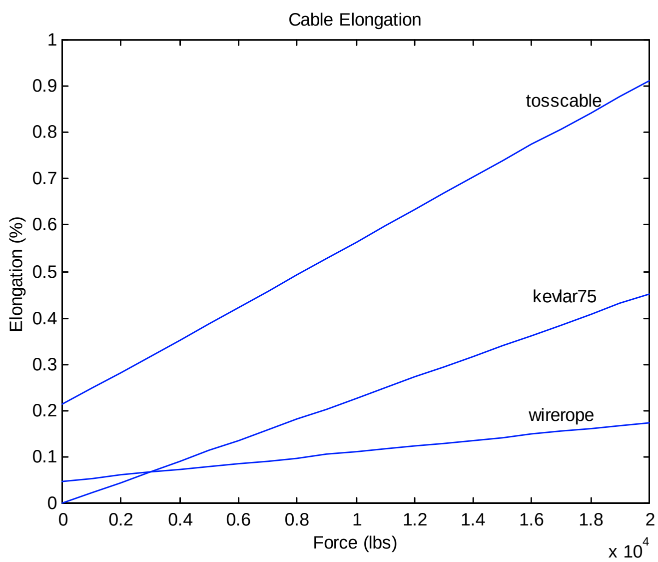

Figure 4. Elongation of cable under load.

When one cable is wrapped around another, there is also concern of the "necking down" of the interior cable under tension. While this varies greatly with material, braid, and type of cable construction, DWRE experience indicates that this is not generally a problem. A basic analysis of the diameter reduction (figure 5) confirms this, with less than a 0.003-per-cent reduction in diameter for loads up to 20,000 pounds.

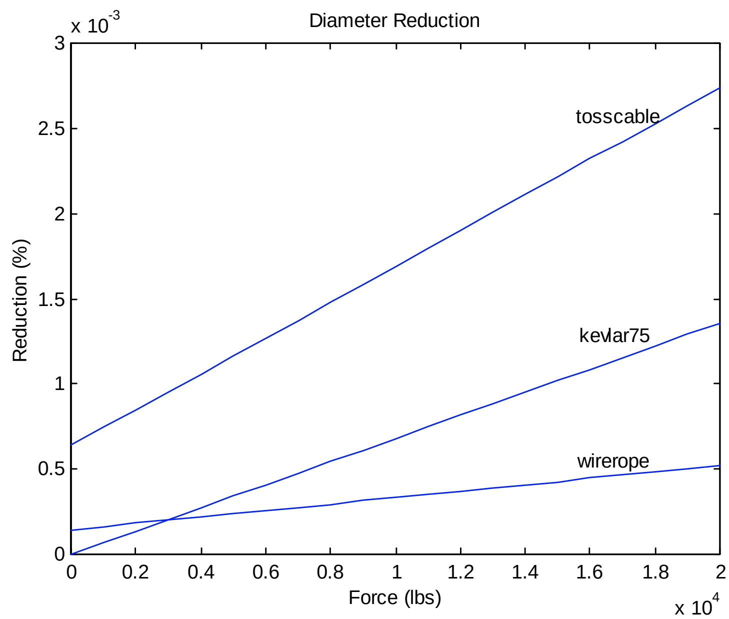

Figure 5. Diameter reduction under load.

2.1.4 Fatigue/Work Hardening

The wrapping and unwrapping of the external cable may result in some fatigue or work hardening. In the case of a copper wire, the critical parameter is to maintain the overall elongation experienced during loading at less than 0.1 per cent. Because of the stress relief provided by the wrapping process (Section 2.1.3), no appreciable fatigue or work hardening would be expected with the Curly Wurly System.

2.1.5 Torque

The torque characteristics of the cable are driven by that of the internal lifting cable. DWRE experience[1] shows there may be up to 42 wire rope rotations over a 6000-foot span. As a given helical cable is torque-balanced only for specific loading conditions, care must be taken to choose a cable suited for the application. When the Curly Wurly System is used, one must observe the degree of torque to prevent excessive tightening or slacking of the externally wound cable.

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[1] A. Crawford. 1999. Discussions held at SSC San Diego, CA, 10 February.

2.1.6 Wrapping Geometry

The wrapping geometry of one cable wrapped about another may be described by the pitch length and pitch angle (figure 6). These parameters are driven in the Curly Wurly System by the relative speeds between the strength member payout and the rotation speed of the wrapping winch. For the existing Curly Wurly System, the strength member's payout speed and the auxiliary cable's wrapping speed may be adjusted independently, providing great flexibility in the resultant cable configuration. Both the pitch angle of the wrapped cable and the relative length ratio of the wrapped cable to the strength member are simple functions of the payout/wrapping speed ratio (figure 7). As currently deployed, DWRE pays out cable at 1000 ft/min with a wrapping rate of 13 rpm, resulting in a speed ratio of 75.

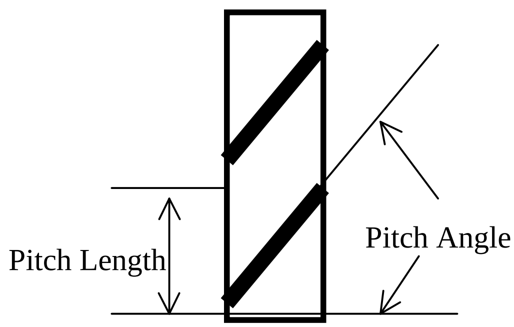

Figure 6. Pitch length and angle of wrapped cable.

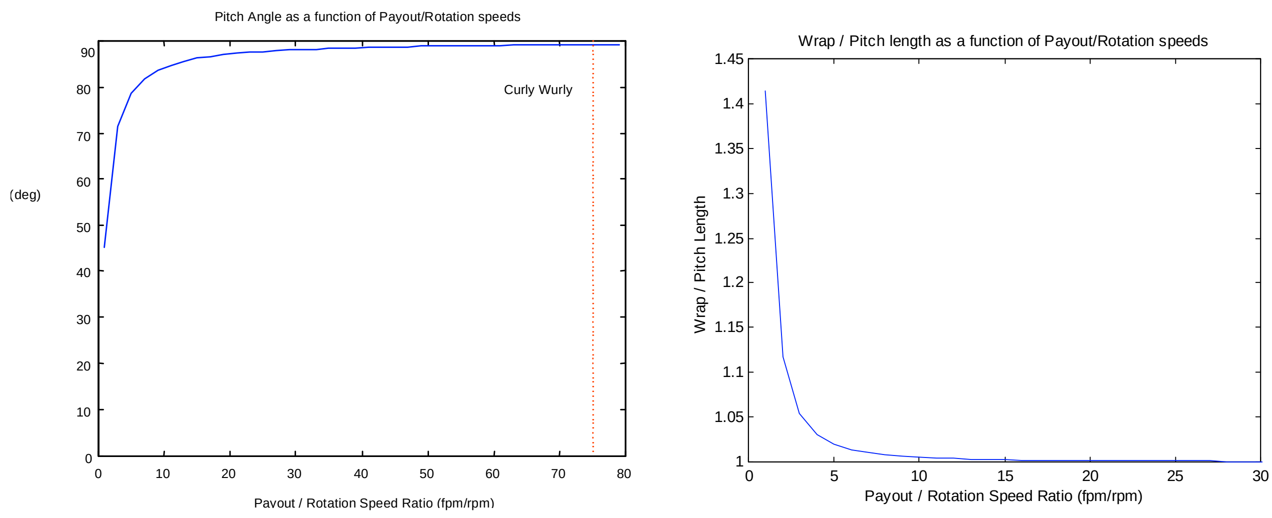

Figure 7. Pitch angle and pitch length as a function of payout versus wrapping speeds.

Figure 8 shows a range of helices possible with the system as a function of the speed ratio. Because of plotting limitations, these are not shown to scale, but rather in a foreshortened view to show the relative packing density of the wrapped cable. All of these fall within the operating parameters under consideration for the system application.

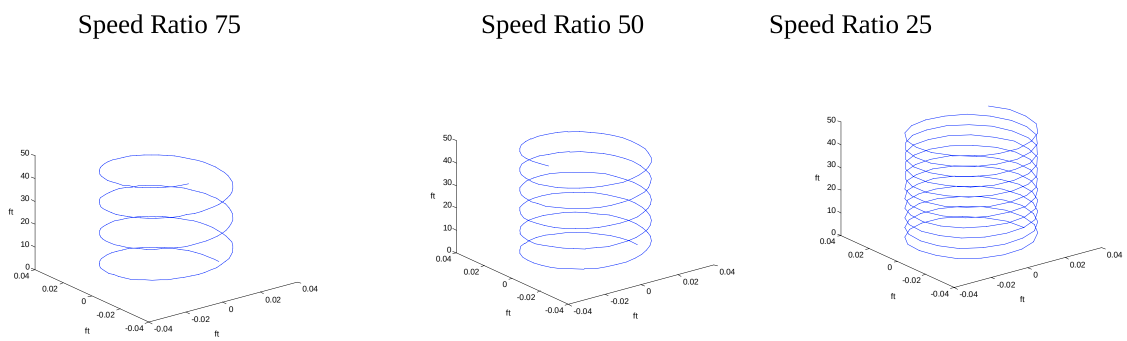

Figure 8. Relative wrapping densities as a function of speed ratios of 75, 50, and 25. Note that the speed ratio is proportional to the actual pitch length.

2.1.7 Bend Radius

The resultant wire bend radius of the wrapped cable is a function of both the speed ratio and the core cable diameter. This is a critical parameter in optical fibers, where the bend radius must generally be greater than 5 to12 inches to avoid significant signal loss. As figure 9 shows, this does not appear to be an issue, as the resultant wire-bend radii quickly exceed the minimum for any speed ratio under consideration. The three curves shown are for core cable diameters of 0.5, 0.75, and 1.0 inches.

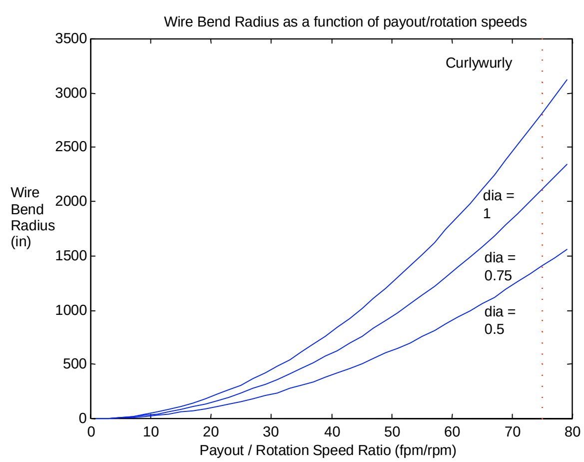

Figure 9. Effective bend radius of wrapped cable.

The bend radius only becomes an issue when the wrapping speed is very high compared to the payout speed. Figure 10 shows that acceptable bend radii are generally achieved for any speed ratio greater than 6 (i.e., with a 6-foot or greater pitch length).

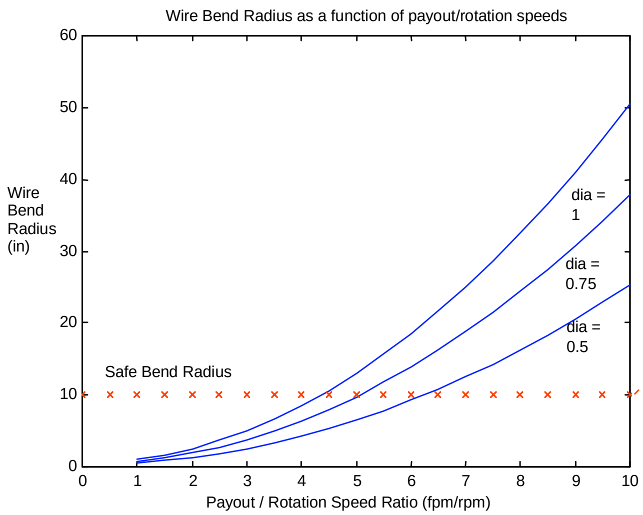

Figure 10. Detailed effective wrapped cable bend radius.

2.2 CABLE DYNAMICS

The cable system's critical dynamic characteristics vary between the applications. For instance, a high-speed payout is highly desirable for the salvage grab operations where slow speeds are the norm for towing applications. Some of these critical parameters such as payout speeds, towing characteristics, and relative tensions are described below.

2.2.1 Winch Speeds

With the high payout speeds possible with the Curly Wurly System (up to 1000 ft/min, 17 ft/sec), operators must be careful not to exceed the payload terminal velocity, which results in slack cable. Figure 11 shows the terminal velocities as a function of weight for various payload cross-sectional areas. During payout, these speeds should not be exceeded to avoid a slack cable situation. Similarly, to avoid excessive tensioning, these speeds should not be exceeded during haul-in.

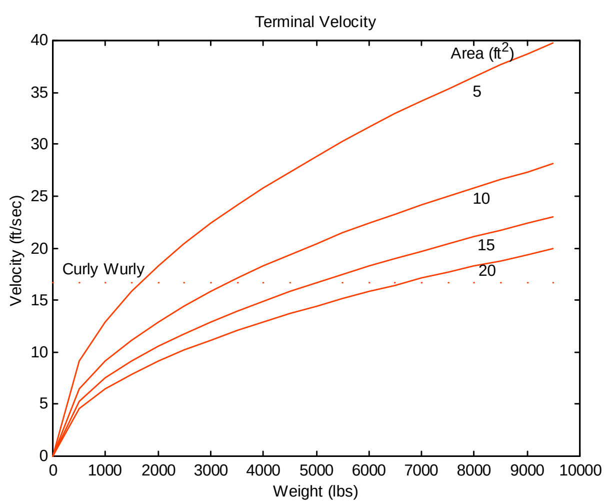

Figure 11. Maximum desired winch speeds.

2.2.2 Towing Characteristics

The choice of cable, in particular both the weight and the diameter, greatly affects the dynamic behavior of the system. In many towing applications, the cable weight is a significant part of the system weight, greatly affecting the position of the tow body, both in the desired depth and in the distance behind the ship. To evaluate system impact, the towing formation of a 30,000-foot cable was plotted as a function of cable type and towing speed, using cable dynamics software developed at SSC San Diego[2]. A line has been drawn at the 20,000-foot mark to show the relative depths achieved. The impact on the system performance varies with both towing speed and payload weight as described below.

2.2.2.1 Towing Speed. Figures 12, 13, and 14 show the resultant towline position at speeds of 1, 2, and 5 knots, respectively, for a payload representative of the TOSS system (in-water weight of 3200 pounds). Several factors are immediately apparent:

1. The near-neutral kevlar towline requires a much broader scope to achieve the same depth as the TOSS cable or a wire rope.
2. Higher towing speeds exacerbate this tendency, requiring even more cable to achieve a desired depth.

Table 1 summarizes the numerical impact of the speed on towline position.

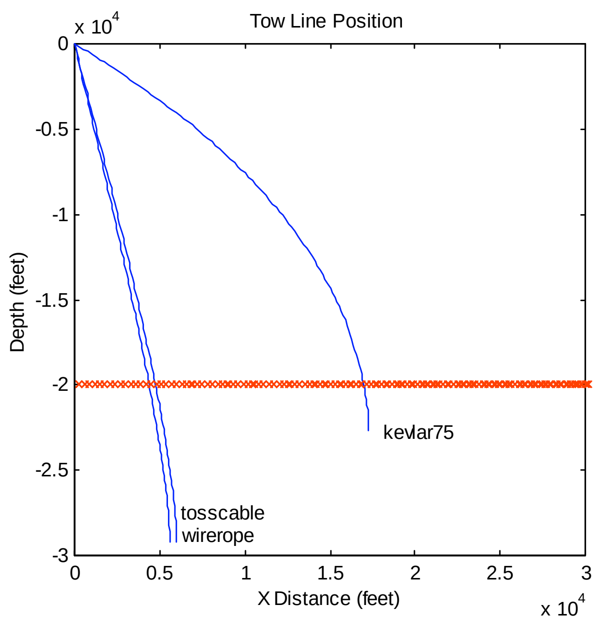

Figure 12. Towline position at 1 knot.

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[2] R. Buecher and R. Yumori. 1999. REM 2-D Cable Statics—Towing. BASIC Software Program. SSC San Diego, CA.

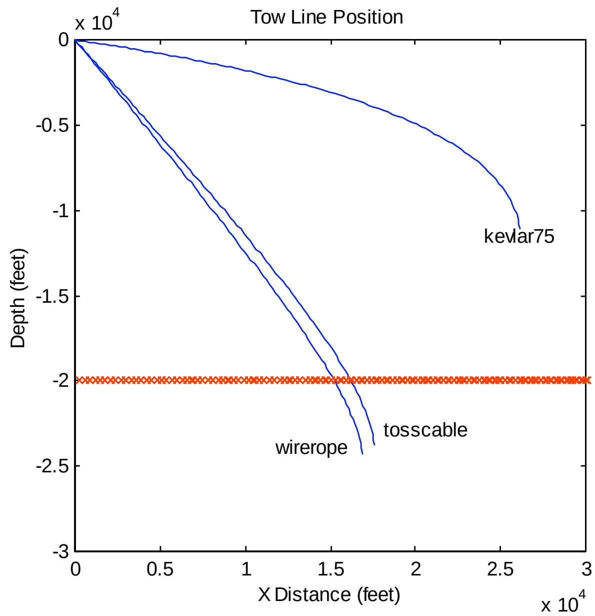

Figure 13. Towline position at 2 knots. Note that the neutral kevlar cable does not reach the desired 20,00-foot depth.

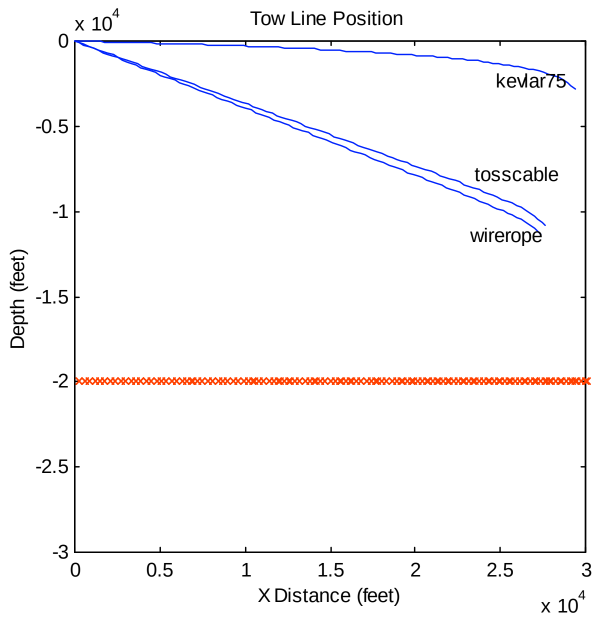

Figure 14. Towline position at 5 knots. Note that no payloads reach the “desired” 20,000-foot depth.

Table 1. Effect of speed on towline position.

Speed (knots)	Material	Depth (feet)	X Distance (feet)
1	Wire rope	29,481	5639
	TOSS cable	29,477	6031
	Kevlar	22,956	17,288
2	Wire rope	24,545	16,921
	TOSS cable	24,066	17,623
	Kevlar	11,422	26,159
5	Wire rope	11,633	27,559
	TOSS cable	11,103	27,808
	Kevlar	3063	29,532

2.2.2.2. Payload Weight. The overall effect of the payload weight varies with the weight of the chosen cable. Figure 15 shows the relative positions of 1000- and 5000-pound payloads on the TOSS cable and the kevlar line. With the lighter kevlar line, the effect of payload weight is much more pronounced than with the heavier TOSS cable. Even with the 5000-pound payload (roughly twice that of the TOSS sled), there is insufficient weight to achieve the desired depth. Table 2 summarizes numerically the effect of payload weight.

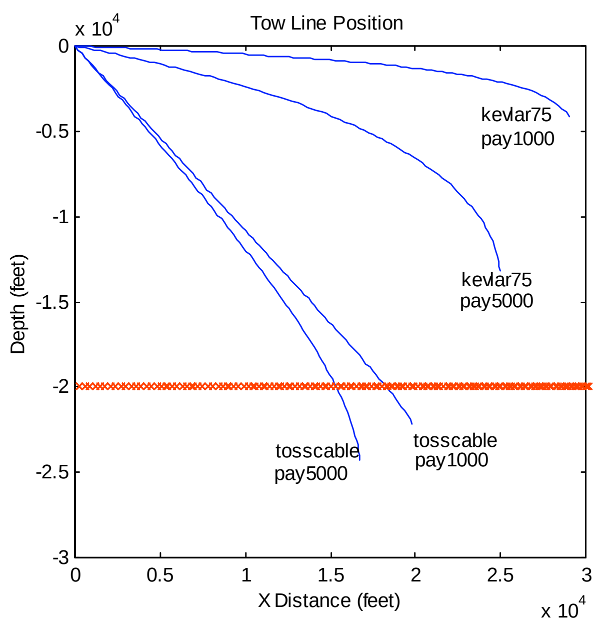

Figure 15. Towline position at 2 knots as a function of payload weight.

Table 2. Effect of payload weight on towline position (2-knot speed).

Payload In-water Weight (pounds)	Material	Depth (feet)	X Distance (feet)
1000	TOSS cable	22,492	19,892
	Kevlar	4441	29,097
2800	TOSS cable	24,066	17,623
	Kevlar	10,612	26,365
5000	TOSS cable	24,624	16,766
	Kevlar	13,521	24,991

2.2.3 Cable Tensioning

The tension in the towline is directly proportional to the cable weight (figure 16). This not only affects the overall payload capacity of the system (Section 2.1.2), but it is also a consideration in the dynamics of the composite cable. The external cable tends to unwind when the tension on an externally wound cable is lessened. Under operational conditions, this could occur many ways, such as the ship making a turn or the payload hitting the bottom. This could be a serious flaw, as the wound cable may separate from the core cable, a phenomena known as "birdcaging," rendering it vulnerable to damage and snap loading. As this cannot be easily analyzed, empirical trials with desired cable configurations are recommended before any large-scale deployment.

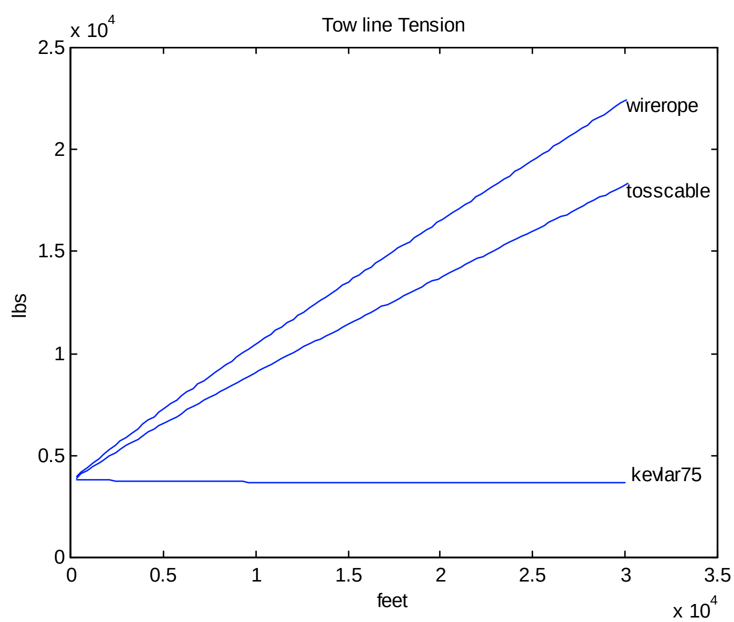

Figure 16. Towline tension at 2 knots.

2.2.4 Strumming

Cable strumming occurs when the vortices of the flow around the cable are shed in alternately clockwise and counterclockwise directions (Berteaux, 1991). This can create greatly increased drag on the cable, with resulting changes in the tow body position. Figure 17 shows the effect of this increase in drag coefficient, where the effect of drag coefficients of 1.0, 1.5, and 2.0 are seen on the existing TOSS cable (the standard being 1.2). This phenomenon has been noted with a number of deep-water systems, including the Advanced Tethered Vehicle. For this system, effective drag coefficients exceeding 2.0 were determined by curve-fitting to cable position data[3]. It is unclear whether a composite helically wound cable would produce similar effects. Anecdotal evidence suggests that the helix formed by the externally wrapped wire might actually aid in vortex shedding, thus reducing strumming behavior. While in-depth analytical modeling might be possible, some empirical testing of desired cable configurations is the most expedient means of assessing this issue.

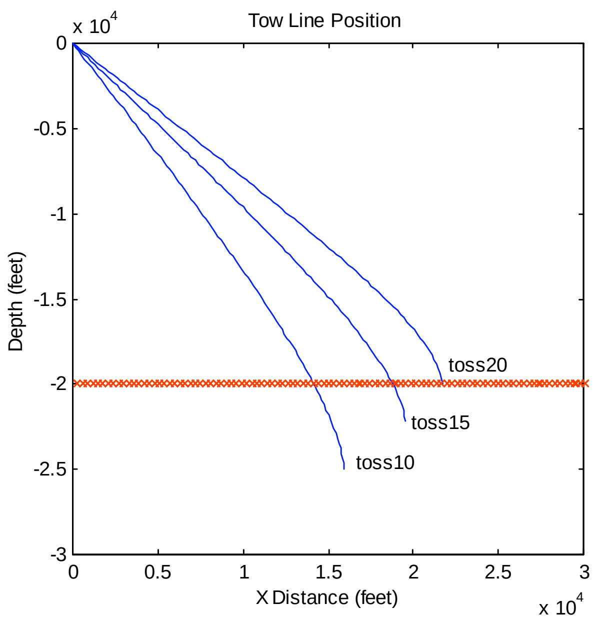

Figure 17. Effect of increasing cable drag coefficients on tow body position. Toss10 has a Cd of 1.0, toss15 has a Cd of 1.5, and toss20 has a Cd of 2.0.

2.3 ELECTRICAL CHARACTERISTICS

The flexibility of the cable components available with the Curly Wurly System produced several implementation concepts. These concepts include using a single-conductor DC power source and various data/signal transmission options.

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[3] R. Yumori. 1998. Discussions held at SSC San Diego, CA, November 1998 to February 1999.

2.3.1 Power

To minimize the number of power conductors required, a seawater return for the power system has been suggested. This would be a DC system using a single power conductor, with the return to ground occurring through the water. A literature search revealed no undersea systems using this approach, particularly none with the high power and data requirements considered in this effort. There are many reasons to be wary of this approach: safety considerations when high currents are involved, cathodic corrosion between dissimilar metals, and electrical interference with signals. When in-water returns happen accidentally, various adverse consequences occur. Personnel may experience electrical shocks, signals are degraded, and corrosion products may accumulate on metals, particularly aluminum. If a seawater return system were implemented, the system would require design or redesign specifically for that feature, with careful choice of materials, connectors, and isolation techniques. Therefore, while such a system is possible, there is no overriding reason to pursue such a design.

2.3.2 Signal

In the typical Curly Wurly application foreseen, a data cable will be wrapped around the strength member. Aside from the minimal effect of work hardening discussed in Section 2.1.4, this should not present any difficulty with conventional coaxial cables. It is of greater concern when fiber optics are used as the primary signal carrier. Not only must the gross bending of the wrap be considered (Section 2.1.6), but also the microbending that occurs as the central cable moves. Microbending can severely reduce the bandwidth, depending on the magnitude of the bending and the cable type. As with the other dynamic characteristics of slack and strumming, this phenomenon is likely to be a function of cable types, length, and payloads under consideration. Empirical testing of desired combinations is recommended to determine the magnitude of this effect.

3. HARDWARE TRADE-OFF ANALYSIS

The ability to conveniently join cable components provides great flexibility when applied to various ocean systems. In addition to the DWRE Curly Wurly hardware, an alternative approach, the spinning reel, was also examined and compared as a technique for wrapping cables together.

3,1 CURLY WURLY SYSTEM

3.1.1 Concept

The basic concept behind the Curly Wurly System is that of moving one or more spools of cable around the lift line (Section 1.2.2). Data and/or power cables are contained on these secondary spools and are paid out in synchronization with the lift line.

3.1.2 Hardware Design

Curly Wurly uses one lift line winch arranged with one or more secondary "wrapping" spools rotating about the payout axis of the primary lifting line (figure 18). The primary lifting winch can be a standard deck-mounted winch, sized and configured to meet the lifting application needs. The secondary winch(es), containing data and/or power cables, are mounted on the Curly Wurly winder. This mechanism provides winch rotation around the lift line. The secondary winch(es) are sized to match the cable being wound. DWRE is currently building two winding systems (table 3).

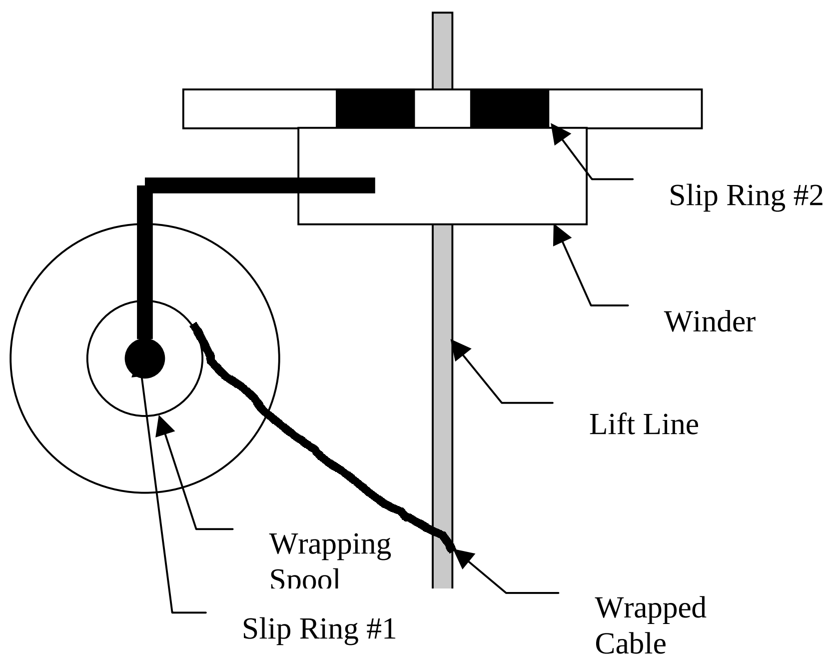

Figure 18. Curly Wurly configuration (front view).

Table 3. DWRE Curly Wurly Systems[4].

	Large	Small
Cable		
Length	2000 m (6500 ft)	3500 m (11,000 ft)
Diameter	12 mm (0.3 in)	Fiber optic
Winder		
Drive	Hydraulic	Hydraulic or electric
Weight	Approx. 1900 pounds	Approx. 1000 pounds
Speed	1000 ft/min	330 ft/min
Winder Power	6 hp (4.5 kW)	1.75 hp (1.3 kW)
Winch Power	20 hp (15 kW)	2 hp (1.5 kW)

Two slip rings are required to maintain continuous power and data transmission through a Curly Wurly cable. One would be used on the payout axis on the secondary winch, mounted in the conventional manner. The second would be mounted on the rotational axis, with the lift line passing through its center. In the case of multiple spools, each spool would have its own axial slip ring, but only one slip ring assembly would be required on the rotational axis.

3.1.3 Assessment

A prototype Curly Wurly System has been demonstrated successfully, and two additional units are currently under construction. One of the greatest perceived disadvantages is the requirement for multiple slip rings on the system. This is not a significant issue for conventional electromechanical slip rings, as they are commonly used in shipboard applications similar to those proposed in this document. The question becomes more complex when considering optical fibers. Optical slip rings are more complex and delicate, and do not yet have a proven track record for offshore applications. The need for an optical slip ring with a central hole for the lift line also poses some design challenges. Currently, no such unit is commercially available. One approach would be to use an electrical slip ring with electro-optical converters at each end[5].

3.2 ALTERNATIVE DESIGN APPROACH: SPINNING REEL

3.2.1 Concept

As opposed to the Curly Wurly System, the spinning reel approach does not rotate the spool around the lift cable, but rather the lift cable runs through the center of the spool and the external cable unwinds around it. The twist of the cable on the spool is therefore transferred to the wrap on the lift line without a need for slip rings.

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[4] Phone conversations with Moya Crawford, November 1998 to February 1999.

[5] Phone conversations with Jim Snow of Focal Technologies, March 1999.

3.2.2 Hardware Design

In the spinning reel design concept, a bail would rotate about a stationary spool, unwinding the cable off the spool and simultaneously winding it about the lift line (figure 19). While accomplishing the same end-product as the Curly Wurly, this approach has several important differences. The wrapped cable would pay out directly off its storage reel rather than using a winch for handling. The diameter of its reel thereby determines the pitch length of cable wrapped about the lift line. There would be no simple way to control or adjust the pitch; in fact, it would vary continually as the cable came off its reel and the diameter diminished. To get the desired pitch lengths of 10 or more feet, reels exceeding the 3-foot diameter would be required. In most cases, this would require custom building of cable reels.

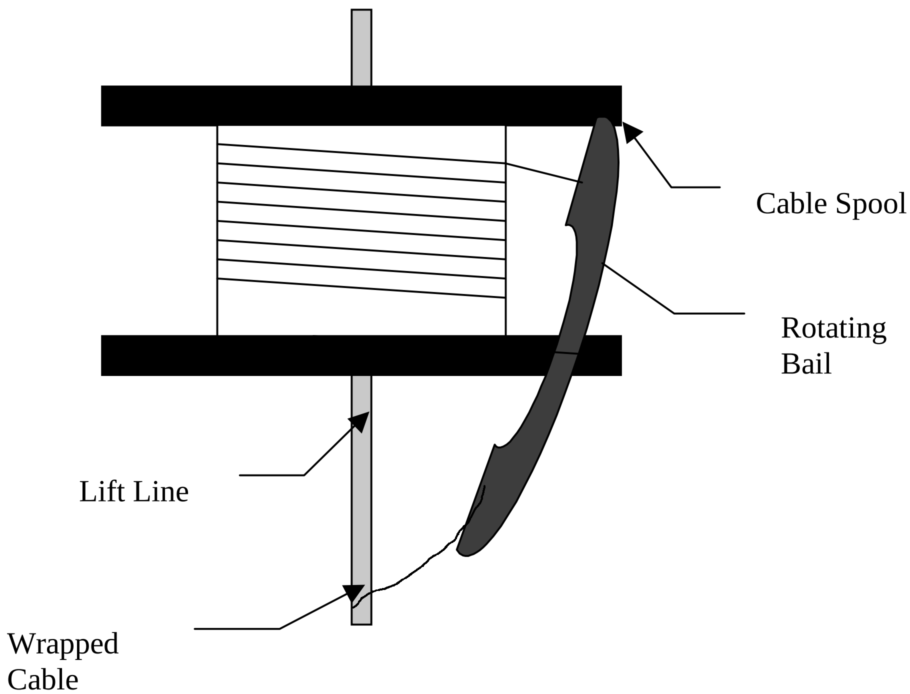

Figure 19. Spinning reel configuration.

3.2.3 Assessment

The primary advantage in the spinning reel design concept is that it minimizes the need for slip rings, particularly when using optical fibers. However, other hardware design aspects become more complicated. Several factors must be considered to ensure that the cable is wrapped securely about the lift line. First is the issue of the cable reels, which would require custom reels for each wrapped cable of the necessary size with the means of running the lift line through the center. Depending on the hardware at the end of the lift line, this could be somewhat difficult to accomplish. To ensure a consisten wrap tension, it would also be necessary to monitor the tension of the wrapped cable and control the payout speed of the lift line accordingly. It is difficult to envision a system where two different cables could be wound this way, as it would not be possible to adjust the payout speed to match the changing payout requirements of two separate reels of varying diameters.

Initial concepts for implementing a spinning reel design appear significantly more complicated than the Curly Wurly approach. While the ability to avoid the use of slip rings may be appealing in some instances, the limitations of a single cable combination and the control ramifications would be major disadvantages of this approach.

4. TARGET APPLICATIONS

There is potential for flexibility in applying the Curly Wurly System to various ocean systems. Three different types of applications are examined in this section, including some system trade-offs.

4.1 SALVAGE: DWRE

4.1.1 Description

As described in Section 1.2, DWRE developed the Curly Wurly System as an economical deep-water salvage technique. The system operates predominantly in one dimension—the straight up and down of the recovery cable. One planned system modification is the addition of a thruster on the recovery cable at a point approximately 100 feet above the grabber. Working within a transponder net, this will position the grabber without the need for dynamic positioning of the surface ship.

4.1.2 Requirements

The driving requirement in the salvage application is the strength and payload capacity of the cable. The current capacity of the salvage system is approximately 12.8 tons, of which the grabber itself is 4.5 tons, and the conventional lift line is 4 tons. With the use of a lighter synthetic lift line, the payload available can be increased substantially.

A 30-kW thruster will be added to implement the thrust capabilities. A cable wrapped about the lift line will power the thruster. As it will be automatically controlled using feedback from the transponder network, the thruster system needs no additional data cables.

4.1.3 Cable Design

The cable design for this application is relatively straightforward—a high-strength lift line wrapped with an appropriate power conductor. DWRE plans to use a 28-mm Dynamo fiber rope, providing a total lift capacity of 12.8 tons with a safety factor of 5. Choosing the power/data conductor will depend on the thruster chosen and the data that will be transmitted to the surface. The power cable used in the analysis in Section 2.1.1 would likely be representative of the cable type to be used.

4.1.4 Hardware Design

Hardware required for this application would be the basic Curly Wurly System with a single spool rotating about the lift line. The size of the lifting winch would be driven by the size and length of the chosen lift line. Similarly, the length and size of the chosen conductor would determine the size of the rotating reel. Initial operation of the Curly Wurly System by DWRE has shown the need for a level wind on the rotating winch. Two electrical slip rings would be required to maintain control and action of the thruster during winch operations: one slip ring about the axis of the cable spool and one about the rotational axis around the lift line. Such slip rings are commonly used in the shipboard environment and pose no great concerns regarding feasibility or reliability.

4.1.5 Assessment

Based on present DWRE experience, the Curly Wurly appears well-suited to the deep-water salvage application. Using a synthetic, neutrally buoyant rope for lifting provides a great increase in the amount of available payload. Joining a power/signal conductor to the synthetic lifting member provides additional flexibility previously available only with electro-mechanical cables. The ability to both monitor and move the grabber position without corresponding precision ship motion will greatly enhance the salvage operation.

4.2 TOWING

4.2.1 Description

As mentioned in Section 1.2.3, DWRE is developing a Curly Wurly for use with a simple towed system. Looking at other more complex, towed systems, TOSS has been suggested as a possible application for the Curly Wurly System. This is a full ocean depth (20,000 feet) sled, carrying a full configuration of oceanographic instruments. These include the following items:

- Four video cameras
- Two electronic still cameras
- Two 35mm cameras
- Dual-frequency, side-scan sonar
- Acoustic Doppler current profiler
- Attitude measurement unit
- Acoustic tracking system
- Sub-bottom profiler
- Transmissometer
- Optical back scatter sensor
- Hydrophones
- Compass
- Forward-looking CTFM sonar
- Two thrusters
- Thallium iodide and HMI lights
- Strobe lights
- Conductivity, pressure, and temperature sensors

4.2.2 Requirements

The TOSS System is a full ocean depth system, towed 0 to10 feet above the bottom at 1 to 1.5 knots. This precision flying often requires continual winch operation to maintain the desired altitude off the bottom. Typical winch speeds are on the order of 300 feet/minute, roughly one-third of the DWRE winch speeds. The sled is 16.2 feet long, 5.6 feet high, and 3.5 feet wide, with an in-water weight of approximately 3800 pounds. These characteristics were used as the representative payload in the analyses (Section 2).

The driving requirement on the TOSS cable is the vast amount of data generated and transmitted by the instruments on the sled. Currently, the system uses three optical fibers to handle the data flow: an uplink, a downlink, and video. Power is also a consideration as the system is supplied with 1500 to 1660 V at 400 cycles down the cable.

4.2.3 Cable Design

The current TOSS cable design is a unified cable containing three #11 AWG conductors and three optical fibers with three layers of steel armoring. This cable has a breaking strength of 46,000 pounds with a working load of 10,000 pounds. These capabilities could be matched using a synthetic lift line wrapped with a power cable and one or more fibers.

A candidate configuration would be to use a 0.5-inch kevlar line as the strength member, a Bostrig 125 three-conductor cable for the power, and three micro-fibers for the data. Appendix A lists the characteristics of each of these components. The interaction of these multiple elements on the lift line are of concern, particularly entanglement. Two methods of winding the cables are possible (figure 20), parallel winding and counterwinding. On initial evaluation, the parallel winding approach is the most appealing as this would minimize crushing and abrasion between the wound cables. An alternative would be to counterwind the cables in an effort to minimize slippage and birdcaging. This would not be recommended for use with fiber-optic cables because of the likelihood of pinching and breakage.

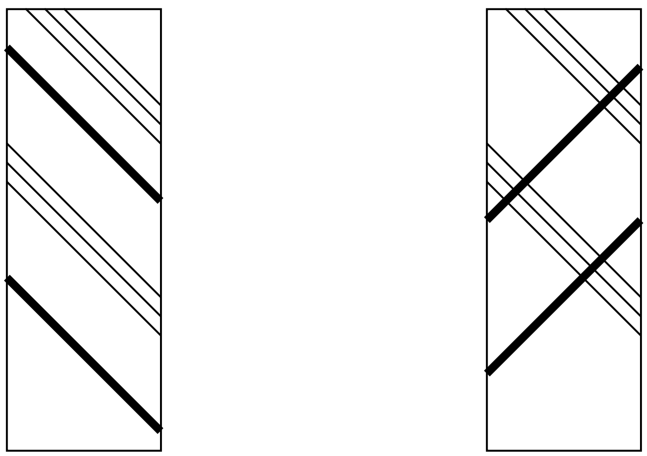

Figure 20. Parallel and counter winding.

4.2.4 Hardware Design

The hardware required to implement the Curly Wurly approach for the TOSS System would be appreciably more complex than that currently used by DWRE. A minimum of two winding reels would be required: one for the power conductor and one for the fibers.

Handling of the multiple fiber-optic cable itself requires special attention. The three fibers could be spooled on a single mandrel and paid off all together. Tangling of the cable is problematic, given the additional wrapping motion. The power cable requires two electrical slip rings as well as two optical slip rings, each cable of supporting the three fibers. These are expensive, precision items, adding to the system’s complexity.

4.2.5 Assessment

While Curly Wurly may be useful for simple towed systems (Section 1.2.3), its use is questionable for systems such as TOSS. As shown in the analysis in Section 2.2.2, a heavier cable is actually desirable to achieve the towing depths desired without undue scope. The number of power and data cables required in this instance make the Curly Wurly deployment technique ungainly at best, with questionable benefit.

4.3 FREE SWIMMING: ROV

4.3.1 Description

Another candidate for use of the Curly Wurly System would be that of a free-swimming Remotely Operated Vehicle (ROV). Unlike the TOSS system described above, an ROV is self-propelled and generally can maneuver in all three dimensions.

4.3.2 Requirements

These vehicles cover a full range of sizes and capabilities, but share many common features including the need for power and data transmission. Generally, ROVs move slowly, at speeds less than 2 knots, and are consequently greatly affected by current flow. Deeper diving vehicles are becoming available, with capabilities of 10,000 feet not uncommon. With these factors, ROVs do expend a great deal of power overcoming tether effects, so efforts to minimize tether size and weight are a primary concern.

4.3.3 Cable Design

As with the TOSS System described above, a minimum suite of cables would be a strength member, power conductor, and data conductor(s). While these would vary greatly with the specific ROV size, the general configuration would be very similar to that proposed for the TOSS system in Section 4.2. If warranted, the design could be somewhat simplified by replacing the three fiber-optic cables with a cable containing many coaxial or other data wires. In this way, two relatively simple copper-based cables, one for power and one for data, could be wrapped about the strength member.

4.3.4 Hardware Design

As with the cable design, the hardware configuration would be very similar to that described for the TOSS System (Section 4.2). Most likely, a two-reel system would be desired, with the ramifications discussed above. The slip ring assemblies could be somewhat simplified if the optical cables were replaced by copper as described above.

4.3.5 Assessment

There are many cables available for ROVs today, including many neutrally buoyant ones. While these are generally of greater diameter than the corresponding negatively buoyant cables, the trade-off to the complexity of the Curly Wurly does not seem worthwhile for most operational applications. In addition, the free-swimming dynamics of an ROV may prove problematic as the turning of the vehicle may tend to twist or untwist the externally wound cable.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCEPT ADVANTAGES AND DISADVANTAGES

5.1.1 Advantages

The major advantage of the Curly Wurly System is the flexibility it offers in combining cable's lift, power, and data elements. As discussed in Section 2.1.1, a synthetic lift line can provide for appreciable weight savings when payload capacity is a major consideration. For many in-field activities, such as the DWRE salvage operations, the flexibility to add a data or power line can result in significant added capabilities. This interchangeability can also lead to cost savings as individual cable components can be replaced as necessary, rather than having to replace an entire unified cable. These advantages are particularly clear in cases where one or two capabilities are required on an irregular basis, thus making it particularly beneficial to be able to change items in and out at will.

5.1.2 Disadvantages

The Curly Wurly System does not appear to be particularly well-suited for those applications requiring multiple conductors and/or data lines. Winding of two or more cables around the lift line poses some design questions that require testing in actual application. Handling of multiple spools quickly becomes complex with a high risk of entanglement and breakage. While it is possible to avoid this somewhat by using cables with multiple conductors and/or fibers, using a unified cable provides the best solution. The unified cable design has been well-proven for many applications (specifically, the towing and ROV systems discussed here), and there does not appear to be any overriding reason to replace these systems.

5.2 RECOMMENDED APPLICATIONS

Based on the results of this concept analysis, two application areas appear particularly well-suited to the capabilities and advantages of the Curly Wurly system: salvage and prototyping.

5.2.1 Salvage

Not surprisingly, the Curly Wurly System appears well-suited for its designed purpose, that of adding some capabilities to a salvage system. For the relatively simple dynamics of the drop and lift, the cable interactions appear relatively straightforward. The big payoff, as discussed in Sections 2.1.2 and 3.1, is the greatly increased payload capacity available with a synthetic lift line. The ability to supplement the basic grabber with video or a thruster also adds significant system operational capabilities.

5.2.2 Prototyping

The flexibility of the Curly Wurly System is also well-suited for rapid prototyping of oceanographic systems. In the initial design validation of many systems, it is highly desirable to take various components and test them in an operational environment. Often, appropriate cables are not immediately available and multiple cables must be joined together for the testing. While this is customarily done by hand with tie-wraps and duct tape, the Curly Wurly system offers a more elegant approach to the problem. In cases of deep-water testing where long cables are the norm, it certainly offers an appealing and efficient alternative to joining cables together by hand. Similarly, the system provides an expedient manner of rapidly configuring lift and data lines for salvage and rescue operations that require a quick response time.

5.3 RECOMMENDED FUTURE INVESTIGATIONS

The Phase 1 effort discussed in this document determined some of the characteristics and trade-offs of using the Curly Wurly system. As described, the utility of the Curly Wurly System is largely dependent on the intended application. The characteristics of the resultant cable depend on the components chosen, with virtually unlimited combinations. It is best to make these choices by empirical testing of the combinations of interest in future efforts.

5.3.1 Mechanical Characteristics

Many of the mechanical characteristics of combined cables do not lend themselves to precise analytical determination (Section 2.1). Nonetheless, many of these characteristics should be determined before full-scale deployment. Prospective cable combinations should be tested empirically to confirm mechanical characteristics such as elongation under load, the effect of bending on the wrapped cables, and the wrapped cables' torque tolerance. Hydrodynamic characteristics should also be evaluated including the effective coefficient of drag and the effect on the cable behavior, including strumming.

5.3.2 Field Testing

In addition to determining the mechanical characteristics of the cables of interest, small-scale field-testing should be performed to determine the feasibility of use in the ocean environment. During these tests, the operational behavior of the cable can be evaluated, including its tendency to snag or become entangled. Field-testing will also provide a first-level assessment of the cable's durability and reliability.

5.3.3 Engineering Cost Analysis

Phase 1 of this effort, discussed in this document, covered the technical feasibility and applicability analysis of using wrapped cable assemblies. The cable results apply to both the existing Curly Wurly device and the alternative spinning reel design concept. Phase 2, as proposed, would include an engineering cost analysis of implementing one or both of these systems. This would include examining the cost of developing, building, testing, and certifying the cost of a new cable system as compared to that of using existing cable systems. Special attention would be paid to the need for modification of hardware and support platforms to accommodate a new system.

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APPENDIX A

CABLE CHARACTERISTICS

Table A-1 lists cable characteristics used in the analysis in this document.

Table A-1. Cable characteristics.

Cable	TOSS Cable	3x19 Oceanographic Wire Rope	Kevlar 29 JETSTRAN I-A	Bostrig 125 10 AWG Power Conductor	Fiber-Optic Microcable
Diameter (in)	0.681	0.75	0.75	0.520	0.031
Air Weight (pounds/ft)	0.747	0.879	0.180	0.2	0.0007
Water Weight (pounds/ft)	0.608	0.764	0.000	0.105	0.0003
Breaking Strength (pounds)	46,000	57,800	55,000	1800	100
Modulus of Elasticity (psi)	7,844,000	20,300,000	10,000,000	N/A	3,785,000

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This effort’s objective was to perform a concept analysis of a mechanical deployment and recovery technique for neutrally buoyant underwater cable systems. A Scottish company, Deep Water Recovery and Exploration, Ltd. (DWRE) developed a prototype system, the Curly Wurly. This technique uses an approach where individual outer cables are helically wrapped around a central strength member during deployment and separated during recovery. Phase 1 of this study investigated and analyzed the trade-offs of using such a system and determined potential application areas.

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