RSI

U.S. Coast Guard Research and Development Center

1082 Shennecossett Road, Groton, CT 06340-6048

Report No. 5643

Shoulder-Fired Portable Entanglement Net (PEN)

FINAL REPORT
JANUARY, 2007

This document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161

Prepared for:

U.S. Department of Homeland Security
United States Coast Guard
Research and Development Center
1082 Shennecossett Road, Groton, CT 06340-6096

N O T I C E

This document is disseminated under the sponsorship of the Department of Homeland Security in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

This report does not constitute a standard, specification, or regulation.

Marc B. Mandler, Ph.D.
Technical Director
United States Coast Guard
Research & Development Center
1082 Shennecossett Road
Groton, CT 06340-6048

1. Report No.	2. Government Accession Number	3. Recipient's Catalog No.
To be filled in by R&DC	To be filled in by R&DC	N/A

4. Title and Subtitle
Shoulder-Fired Portable Entanglement Net (PEN)

5. Report Date
AUGUST 30, 2006

6. Performing Organization Code
Project No. 2406326E69001

7. Author(s)
Jim Fitzmaurice (541) 504-9300 jim@resqmax.com

8. Performing Organization Report No.
R&DC UDI # (provided by COTR)

9. Performing Organization Name and Address
Rescue Solutions Int'l, Inc.
2234 S.W. 2nd CT.
Redmond, OR 97756

U.S. Coast Guard
Research and Development Center
1082 Shennecossett Road,
Groton, CT 06340-6048

10. Work Unit No. (TRAIS)
N/A

11. Contract or Grant No.
HSCG32-06-R00005

12. Sponsoring Organization Name and Address
U.S. Department of Homeland Security
United States Coast Guard
Research and Development Center
Washington, DC20593-0001

13. Type of Report & Period Covered
FINAL

14. Sponsoring Agency Code
Commandant (G-)
Sponsor 3-ltr designation
U.S. Coast Guard Headquarters
Washington, DC 20593-0001

15. Supplementary Notes
The R&D Center point of contact is Robert Sedat, (860) 441-2684, Robert.D.Sedat@uscg.mil.

16. Abstract (MAXIMUM 200 WORDS)

The USCG requires a portable, non-lethal system for interdicting non-compliant propeller-driven watercraft. This report presents a system designed to disable propeller-driven watercraft by means of entanglement, and evaluates the use of a commercially available, line-throwing appliance to deploy this system.

A variety of evolving entanglement payloads were tested by deploying the payloads across the path of propeller-powered boats at speeds up to 35 mph. Of the entanglement designs tested, the preferred design had an interdiction success rate of 100 percent when deployed against propeller-driven craft with engines up to 115 in hp, at speeds up to 35 mph. The preferred entanglement system might be successfully deployed using an existing, commercially available, line-throwing appliance. Performance of the launching system might be enhanced by using prototype projectiles.

The portable entanglement net (PEN) system developed under this contract has proven to be highly successful against most outboard-powered craft. Further work is needed to develop more-robust entanglers and more-powerful launchers for defeating higher-powered outboards, inboard/outboards, and direct-drive craft.

17. Key Words
Non-lethal
Entanglement
Propeller
Interdict
Non-compliant
Running gear
RGES
Outboard engine

18. Distribution Statement
Approved for public release; distribution is unlimited. This information is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161

19. Security Class (This Report)	20. Security Class (This Page)	21. No of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	39	

EXECUTIVE SUMMARY

Small watercraft are involved in a wide variety of unlawful pursuits, including illegal immigration, fishing violations, drug smuggling, and terrorism. When watercraft involved in illegal activities are encountered by enforcement officials while underway, they often take evasive action.

Historically, enforcement officials had to choose between firing upon fleeing watercraft or allowing them to escape; there were few non-lethal means to compel compliance. The U.S. Coast Guard (USCG) has developed various devices intended to entangle the propellers of small outboard or inboard/outboard craft that do not comply with an order to stop. However, the existing system, the Running Gear Entanglement System (RGES), has many shortcomings.

The USCG has determined it needs a portable entanglement device that can successfully entangle the running gear of non-compliant watercraft a high percentage of the time. Toward fulfilling this need, the USCG issued a Broad Agency Announcement (BAA) soliciting concept designs, proposed modifications of existing systems, and/or working prototypes of small portable interdiction-effective devices. In response to this BAA, the Contractor conducted a study:

- To experiment with various types of interdicting payloads, including conducting water trials, to establish the design of a reliable entanglement payload.
- To establish what modifications would be necessary to an existing, commercially available launching system to make it suitable for use by enforcement officials in deploying the above-referenced interdicting payload across the path of a fleeing non-compliant watercraft.

Experimentation with launchable entanglement payloads under this study were undertaken by the Contractor in conjunction with the Home Office Scientific Development Branch (HOSDB) at the Royal Navy Dive Training Center located on Horsea Island in Portsmouth, England. Concurrent experimentation took place at and nearby the Contractor's facilities, located in Redmond, OR.

A wide variety of experimental entanglement designs were constructed for field-testing. The majority of these entanglement prototypes were constructed using ultra high-molecular-weight polyethylene (UHMWPE) fiber, due to its high strength-to-weight ratio. This is advantageous as it permits the most flexibility in the mass, length and weight of the payload to be delivered.

Of a variety of payloads tested, two variations of entanglement payloads showed a high rate of success: The Type 1 payload consisted of weighted loops along a header line, with weighted hanging tentacle-like strands lashed on the header line between and at mid-span of the hanging loops. This payload had a success rate of 100 percent, entangled propellers in 18 consecutive deployments, on outboard engines ranging in size from 75 hp to 115 hp, at speeds to 35 mph.

The type 2 payload consisted of tentacle-like lines lashed to a header line spaced at approximately 12 in. Flat washers were lashed to the tentacles, to induce flutter and add weight. This payload also had a success rate of 100 percent, entangling propellers in 11 consecutive deployments at various speeds against outboard engines up to 200 hp.

The existing commercially available launching system selected for this application is a modular system using compressed air as a power source. The off-the-shelf components of this system include a projectile launcher with a folding stock, a compressed air projectile cylinder with a service pressure of 3,000 psi. and variously sized payload containers that each interlock on the

underside of the launcher assembly. The tail of the projectile cylinder is fitted with a nozzle that incorporates a valve and pressure relief assembly, and a connecting point for bridle lines.

The performance of the launching system – that is, the delivery distance – is principally controlled by the weight of the projectile, the pressure charge in the projectile, the internal volume of the projectile cylinder, and the weight of the payload being delivered. Other external factors, such as wind load, can also have an effect on the delivery distance.

Based on the Contractor's pre-study experience with launching entanglement systems, it was anticipated that the final weight of the entanglement payload under development would require an enhancement to the performance capacity of the existing launching system. No suitable compressed-air cylinder compatible with the existing launcher system was commercially available. This required manufacture of a custom-made projectile cylinder that included a larger internal volume and a higher service pressure. A unique nozzle was also developed, to maximize the thrust generated by the increased volume and pressure of the compressed air.

The volume of early entanglement payloads suggested that a larger payload container might be needed. Prototype payload containers were constructed and used in various field tests. However, the payload determined to be most effective was compatible with the largest commercially available container. Thus, there was no need to develop larger containers.

The prototype projectiles developed increased the payload delivery capacity of the existing launching system by approximately 45 percent. The commercially available launcher, equipped with the prototype projectile and nozzle, was able to deliver leading end of the Type 2 payload approximately 135 ft under calm conditions. This capacity allowed miscellaneous modifications to be made to the Type 2 payload, without requiring any further modifications to the payload launching system. As noted previously, a currently commercially available payload container is adequate for the Type 2 entanglement payload.

The prototype projectile and unique nozzle assembly, as developed, optimizes the performance of the launching system selected.

The launching system used in conjunction with the prototype projectile and the type 2 payloads meet all requirements of the Broad Agency Announcement, and has proven effective against engines of up to 200 hp. The payload, consisting of tentacle-like strands, incorporating flutter-inducing devices and/or weights, proved to be highly successful in generating propeller entanglement, and provided the best effectiveness-to-weight ratio. Damage to the tentacle payload during entanglement of high-horsepower inboard/outboard drives indicated need for additional study to determine maximum efficiency of the payload in relationship to the length, spacing, and material used for the tentacles, together with the material, size, weight, location, and quantity of flutter-inducing washers on the tentacles, and the overall length of the payload.

The results of the information presented by this study indicate that refinements and modifications in the systems developed remain to be performed. Historically, substantial difficulty has been experienced in deliberately entangling small propeller-powered watercraft on a reliable basis. The high success rate in creating entanglement, as outlined by this study, should be built on in order to expand the applications for which this technology is suitable.

The portable entanglement net (PEN) system developed under this contract has proven highly successful against most outboard-powered craft. Prototypes should be deployed for operational testing by the USCG. Further work is needed to develop more-robust entanglers and more-powerful launchers to defeat higher-powered outboards, inboard/outboards, and direct-drive craft.

TABLE OF CONTENTS

LIST OF FIGURES

Not attached, but incorporated by reference – Compact Disc containing video footage.

LIST OF ACRONYMS

Assy.	Assembly
CG	Coast Guard
BAA	Broad Agency Announcement
DHS	Department of Homeland Security
HOSDB	Home Office Scientific Development Branch
MK 10	Mark 10 RGES Mounting Launching System
NLWD	Non-Lethal Weapons Directorate
NSWG	Naval Special Warfare Group
OB	Observers Boat
PB	Pursuit Boat
PEN	Portable Entanglement Net
R&DC	Research & Development Center
RGES	Running Gear Entanglement System
RHIB	Rigid-Hulled Inflatable Boat
RSI	Rescue Solutions International, Inc.
SCBA	Self Contained Breathing Apparatus
SCUBA	Self Contained Underwater Breathing Apparatus
TB	Target Boat
TBD	To Be Determined
UHMWPE	Ultra-High Molecular Weight Polyethylene
U.K.	United Kingdom of Great Britain
USCG	United States Coast Guard
UTB	Utility Boats (USCG)
DOT	Department of Transportation

1. INTRODUCTION

Background

Small watercraft are involved in a wide variety of unlawful pursuits, including illegal immigration, fishing violations, drug smuggling, and terrorism. When watercraft involved in illegal activities are encountered by enforcement officials while underway, they often take evasive action to escape or to continue in their purpose, rather than follow instructions to stop.

Historically, enforcement officials had to choose between firing upon fleeing watercraft or allowing them escape, as there were few non-lethal means to compel compliance. The vast majority of the watercraft employed in these illegal activities are propeller driven.

The U.S. Coast Guard (USCG) has developed various devices intended to entangle the propellers of small outboard or inboard/outboard craft that do not comply with an order to stop. An existing system, the Running Gear Entanglement System (RGES), consists of a header-line with U-shaped loops suspended below it. This has proven effective as a static barrier when manually deployed in advance across the path of a small watercraft. The RGES can also be deployed using the Mark 10 RGES (MK 10) launcher, a deployment system installed on a 50-caliber gun stand. However, the current MK 10 can only be deployed from one side of an enforcement vessel, can only be fired a single time during a mission, and displaces the 50-caliber gun from its mount and thereby removes it from possible use. Further, when deployed in a pursuit situation, the current RGES will often affix itself to the lower drive unit of the non-compliant vessel, but will not consistently entangle the propeller blades.

The USCG has determined, based on field experience to date, that small craft, such as its rigid-hulled inflatable boats (RHIB), port-security boats, and utility boats (UTB), have a need for a more-portable launchable system that can be hand-fired and reloaded quickly, and that can deploy a payload that is successful in entangling the running gear of a non-compliant watercraft a high percentage of the time.

Project Requirement

The USCG has determined, based on field experience to date, that small craft, such as its rigid-hulled inflatable boats (RHIB), port-security boats, and utility boats (UTB), have a need for a more-portable launchable system that can be hand-fired and reloaded quickly.

Furthermore, when an interdicting payload is deployed against a non-compliant vessel in a pursuit situation, this device should not only affix itself to the lower drive unit of the non-compliant vessel, but should also consistently entangle the propeller blades or otherwise retard the progress of the non-compliant vessel to afford enforcement personnel the opportunity to board the fleeing craft.

The USCG issued a Broad Agency Announcement (BAA) soliciting concept designs, proposed modifications of existing systems, and/or working prototypes of small portable interdiction-effective devices. The desired requirements of these devices were:

- The interdicting payload shall be at least 50 ft in length
- It shall be effective against an outboard-powered, single-propeller planing watercraft of at least 15 ft in length

- The interdicting payload shall be easily recoverable
- If the interdicting payload is projectile-powered the projectile shall pose minimum risk of injury to persons on board the vessel to be entangled
- The leading end of the of the interdicting payload shall be capable of being propelled at least 100-ft from the launcher
- The system shall be re-loadable with a new payload and delivery charge within 30-sec
- The system shall be capable of surviving in a marine environment
- Compatibility with commercially available line throwers, or standard issue firearm is desirable, but not required
- Recoil shall be as low as possible to allow firing by an unsupported individual
- Exhaust gases, if any, shall not pose a hazard to those behind the shooter
- Total weight of the system shall be less than 30 lbs, and shall be able to be held and fired by a normal-sized person from a 25-ft long boat in "at sea" conditions

Contractor's Related Experience

The contractor is a manufacturer of a range of commercially available compressed air-powered delivery devices. This equipment is used in the marine, military, industrial and rescue environments for line deployment, swift-water rescue, man-overboard recovery, ship-to-ship and ship-to-shore line deployment, and various additional industrial and tactical applications.

The contractor has background experience in the design and manufacture of components used in the USCG MK 10 system, and has designed and delivered the launching platform for the fixed Naval Special Warfare Group (NSWG)-RGES launching system.

The contractor, Rescue Solutions International, Inc. (RSI) has done field trials with various U.S. Government agencies including the USCG using experimental interdiction payloads, and presently serves as a Technical Advisor to the United Kingdom Home Office Scientific Development Branch (HOSDB) on related projects.

The contractor made a proposal to respond to the above-referenced requirements, and was awarded a contract under which the work embodied in this study was performed.

2. DELIVERY SYSTEM

Commercially Available System

The contractor currently manufactures the ResQmax line-throwing appliance. The principal components of this system consist of:

- A launcher assembly
- A compressed air projectile cylinder assembly
- A payload container
- A filler hose assembly

The launcher assembly has an internal mechanism made principally from stainless steel, and a handle, barrel and folding stock made from injection-molded polycarbonate. Also integrated into the launcher is a pressure gauge, a pressure relief assembly, and a bleed screw to relieve excess pressure as required. The launcher assembly has been designed for use in marine environments to meet the requirements of its various existing commercial applications. The launcher is designed for use at service pressures to 6,000 psi. The launcher is compact and lightweight, being 18-in long with the stock in the collapsed position, 30-in in length with the stock extended to the firing position, and weighing less than 4 lbs (Figure B-8).

The standard projectile assembly includes a compressed air projectile cylinder is made from 6061-T6 powder-coated aluminum, has a liquid volume of 29-cu-in and has a service pressure of 3,000-psi. This is the highest pressure, largest volume commercially available cylinder that is compatible with the ResQmax launcher. The cylinder is fitted with a stainless steel nozzle that itself incorporates a pressure relief device, and a drum valve, permitting each projectile to be pre-charged prior to use. The projectile cylinder has an external diameter of 2.375-in and the projectile assy. weighs 1.8-lbs and has an overall length of 13.25-in. Two bridle lines pass through the body of the projectile nozzle assembly and are used to provide a connection between the projectile cylinder assembly and the desired payload (Figure B-5).

The payload container is made from rotary molded polypropylene, has an irregular geometric shape, and measures internally 18-in at it longest point, 9-in at its widest point, and 7.25-in at its highest point. It has a usable internal cubic volume of 10.9-cubic liters, and weighs 2.9-lbs. The container is fitted with a door of the same material designed to open at the moment of firing (Figure B-6). Existing available payloads include messenger lines, rescue lines, climbing lines, ascending ladders and special purpose lines. Existing accessories include auto-inflating flotation devices, grappling hooks and special purpose fixtures.

The filler hose assy. is made from 6061-T6 anodized-aluminum fittings fixed on either end of a hydraulic hose. The service pressure of this assembly is 5,000-psi. Incorporated in this assembly are optional fittings compatible with various air sources, together with a pressure gauge and a pressure bleed screw. The assembly has an overall length of 43-in and weighs 2.15-lbs (Figure B-7).

Launcher Operation

The filler hose assembly is connect on one end to an air source, and at the other end to the projectile cylinder nozzle assy. High pressure air is decanted, through the filler hose assy., compressor, self contained breathing apparatus (SCBA) cylinder, or other source, into the projectile cylinder. When the service pressure of the projectile has been reached as indicated by the pressure gauge fitted to the filler hose assy., the supply source of the air is closed off, and the drum valve in the nozzle of the projectile is closed, sealing in the charged air. Opening the bleed screw relieves pressure from the filler hose assy., and the projectile is disconnected from the filler hose assembly. The projectile cylinder is now charged, and ready for use. This sequence is repeated to fill multiple projectile cylinders as desired.

The launcher assy. interlocks to the top of the payload container using a forward sliding motion, engaging the line catch on the launcher assy. through the corresponding opening in the line container. The line, or interdicting payload, is stored inside the container. Once installed the container, with payload inside, becomes an integral part of the launcher device (Figure B-8).

To load the system a charged projectile cylinder assembly is inserted into the launcher assembly with bridle lines draped out of the mouth of the launcher barrel. Hand pressure is applied to the end of the projectile. The safety mechanism on the launcher engages automatically, indicating that the projectile is correctly loaded. The bridle lines on the projectile are connected to the leading end of the payload, which protrudes through a notch on the payload container door. The launcher itself is pressurized by depressing the valve key on the sidewall of the launcher, engaging the stem on the drum valve of the installed projectile cylinder nozzle, and rotating it clockwise 90 degrees. The pressure gauge on the launcher assembly will now indicate a positive pressure reading, indicating that the launcher is charged.

To fire, extend the folding stock, determine your target, disengage the safety by depressing the safety button on the launcher, support the stock against your shoulder, elevate the launcher to approximately 30 degrees above horizontal, and squeeze the trigger. The projectile, fueled by the discharging compressed air, is propelled in the direction of the target. As it leaves the barrel the attached bridle lines apply tension to the leading end of the payload protruding from the payload container, which in turn disengages the container door. The projectile cylinder acts as a rocket, discharging compressed air as it travels through the air at high speed, and towing the payload behind it in the direction of the target. Recoil is approximately 2 ft-lbs of energy.

The system is reloaded by disengaging the line catch below the mouth of the launcher barrel, and sliding the launcher assy. rearward. A new, full payload container and pre-charged projectile cylinder assy. may now be loaded in preparation for a successive shot, following the steps outlined above. An experienced operator can reload the system in less than 30-seconds.

Possible Modifications Required to Existing System

Factors affecting the delivery distance of the system include:

- The volume, weight, and service pressure of projectile cylinder, which in aggregate reflect the gross deployment energy available, and
- The weight and geometry of the payload, reflecting the mass that the energy must project.

Other factors such as sea condition and wind loads also effect system performance, but are beyond the ability of the manufacturer to control.

The contractor's pre-study experience was that various experimental payloads using the available system have shown promise, but have not been consistently successful. Pre-study data gathered indicated that enhanced interdiction effectiveness is more likely to be achieved on a consistent basis by implementing payload design changes that would increase the mass of the payload beyond both the volumetric capacity of the payload container, and the delivery energy available from the projectile cylinder.

These requirements would create the need to modify two of the principal components of the existing system as follows:

- A larger payload container, capable of containing a payload with a larger mass, and
- A projectile cylinder with a larger cubic volume and/or higher service pressure.

Design Considerations

Enlarged Payload Container

The current payload containers are manufactured using a rotary molding process. This process begins with the costly and time consuming manufacture of a set of molds, one for the body of the part, and one for the door. It would not be possible to determine the actual internal volumetric requirement of an enlarged payload container until:

- The delivery energy of an enhanced projectile cylinder was determined
- The mass of the successful interdicting payload has been determined

Therefore the final design of the enlarged payload container could only be determined at the conclusion of this testing. Two prototype non-production containers accommodating the contractor's experimental payloads were provided. The final size and shape of this payload container was intended to evolve in conjunction with the experimental payload testing, and was expected to be an enlarged version of the existing payload container (Figure B-6).

Enhanced Projectile Cylinder

As noted above, the current projectile cylinder is both the largest, and the highest-pressure cylinder commercially available, and compatible with the existing launcher. In order to enhance the performance of the projectile cylinder it was necessary to manufacture a purpose-built cylinder that was compatible with the existing launching system.

The current projectile cylinder has a service pressure of 3,000 psi. Commonplace industrial compressed air service pressures reach 4,500 psi, and are common to SCBA cylinders used by fire & rescue teams, both civilian and military. They are also common to modern carbon fiber wrapped self contained underwater breathing apparatus (SCUBA) dive tanks, again in use by both civilian and military organizations. Similarly, a wide range of high-pressure compressors, both portable and stationary, with capacities up to 4,500 psi are commercially available. Additionally, a service pressure for the projectile cylinder of 4,500 psi is within the design service pressures of both the existing launcher assembly, and filler hose assy. It is therefore practical to consider service pressures up to 4,500 psi.

The internal volume of the cylinder is affected by the external diameter, the required wall thickness, and the practical length. The external diameter of the projectile cylinder is controlled by the internal diameter of the launcher barrel. The wall thickness of the cylinder is controlled by the mechanical properties of the material selected. The practical length, based on the contractors experience with other hybrid, high-pressure projectile cylinders, is aerodynamically limited to 16-in or less.

Using these factors, it was practical to consider a projectile cylinder (with an external diameter of no more than 2.5 in (as limited by the internal diameter of the launcher barrel), and a length of no more than16 in as having a cubic volume of 50 cu in and a service pressure of 4,500 psi.

This represents an increase to existing service pressure of 50-percent, and a volumetric increase of 60-percent. A range of materials with suitable mechanical properties may be used for the production of this cylinder with only a modest increase in weight above that of the cylinder currently used. For the purposes of prototyping a 7000-series aluminum alloy was selected (examples in Figure B-9, Figure B-10, Figure B-11, and Figure B-12).

While actual performance characteristics may only be accurately determined by live field-testing, higher pressure and greater fuel volume will predictably result in greater delivery distances with any given payload. This in turn creates greater flexibility in the mass of the payload it is possible to deploy from the shoulder-fired system, and will enhance the deployment performance in pursuit situations, which may include significant wind loads.

While these modifications could be made if future designs require increased launching power, the standard ResQmax projectile proved nearly able to launch the recommended payload to the required distance, and may prove suitable for most field situations.

3. PAYLOAD DESIGN

General Considerations

The USCG experience with launched entanglement payloads of all types to date indicates that many payloads simply engage or hang up on the lower unit of the engine above the anti-ventilation plates, fail to entangle the propeller, and sometimes slip off the lower unit due to greater payload drag on one side of the lower unit. Drag devices (e.g. small drogues) or diving planes on both ends of the net help to prevent the entanglement payload from slipping around the lower unit of an engine, and facilitate propeller entanglement, which is the desired end state. Payloads which mimic the successful static barrier RGES do not fully deploy quickly enough when launched in the path of an underway vessel to entangle the propeller, and are themselves often engaged on the lower drive unit and dragged behind the vessel. And payloads that, by mass alone, are substantial enough to slow or halt the passage of a vessel are too heavy to be successfully deployed by a portable system. Almost without exception, any payload put in the path of a propeller-driven underway watercraft becomes engaged on the lower drive unit protruding below the plane of the boat, but frequently the payloads do not successfully entangle the propeller.

Nets of various alternative configurations have also been evaluated in previous testing. Various length nets have been configured in 24-in and 30-in widths, with exterior frames made from 7-16ths, 3-8ths and 5-16ths in diameter material. The interior body of the nets have had various configurations, including diagonal hatched layouts on various centers, fine mesh patterns, vertical members connecting the outer frame of the nets in a ladder-like configurations.

The majority of these nets, and including the successful RGES static barrier nets have been manufactured with rope made from ultra-high molecular weight polyethylene fiber (UHMWPE). This material has been selected for its high strength, low stretch characteristics. With a specific gravity of 0.97, it is a buoyant material that has very high resistance to chemicals, water and ultraviolet light. It is able to resist high loads and high strain rates, has excellent flex fatigue and internal fiber-friction characteristics and outstanding toughness. Laboratory testing confirm that pound-for-pound it is stronger than steel by a multiple of 10. The failure of the nets to entangle or stop a vessel in previous testing has not been related to a failure of the UHMWPE, and we currently consider it to be the most suitable commercially available material for this purpose.

Our pre-study field experience indicates that drag devices such as drogues attached to a payload that engages the lower drive unit can apply a sudden and substantial force to the lower unit of a watercraft, and have caused outboard engines of up to 225 hp to stall. However an interdicting payload depending only on drag, without incorporating entanglement, is reliant solely on a beneficial effect from the initial shock load of the drogue on the lower unit. If the drogue or other drag device fails, or the target boat operator slows and "slips" the payload attached to the drogue off of his lower unit, or if the drogue is momentarily successful and the target boat operator is then able to restart his craft and resume his flight, then the drogue has not successfully incapacitated the non-compliant vessel.

When boating in a propeller driven vessel constant attention needs to be paid to your course, in part due to the constant danger of becoming entangled in naturally occurring marine hazards, such as kelp, or man-made debris such as fishing lines or trash bags.

The difficulties experienced in designing a device intended to deliberately entangle a propeller are therefore superficially puzzling. However the dynamics of the situation in dealing with a non-compliant vessel will in large measure explain the difficulties. The non-compliant vessel is underway, often at high speeds, and the coxswain, in flight, is constantly prepared to take evasive action. Successful interdiction therefore requires that a payload of adequate length is launched just forward of the bow of the fleeing vessel, eliminating the possibility of avoidance. The interval of time between deployment of the payload and contact with the non-compliant vessel's lower unit is a matter of only a few seconds.

The success of the RGES static barrier system is explained by the loops, at 16 in on center, hanging vertically from the main line, 30 in below the surface of the water. The same net, when launched as described above, does not have the time to assume the same static position, and seldom entangles the propeller. The velocity of the non-compliant vessel effectively tows the net on the surface of the water out of reach of the rotating propeller.

Kelp lies in strands below the surface of the water, and generally in beds of considerable density. While only a few strands of kelp can foul a propeller, it is a few of many. It is not practical to consider being able to so precisely deploy a short, dense, kelp bed-like payload as to entangle the propeller.

The alternative payload nets described earlier invariably hang up on the lower drive unit. Where the propeller does come into contact with a portion of these nets it does not draw the netting into itself, but rather cuts or abrades the contact portion of the net. This possibly results from the tension on the net caused by the forward motion of the non-compliant vessel in combination with the drag of the water.

It therefore seems logical to pursue entanglement designs that incorporate elements, such as loops or trailers, clustered in as close proximity and as lengthy as the launchable mass will allow, fastened along a header or "tow" line, that are isolated from the drag load of the entire net in the water. These semi-independent elements, incorporating weights and/or flutter inducers to enhance their motion "under tow" seem most likely to be caught up in the turbulence caused by the rotation of the propeller, resulting in entanglement.

Notwithstanding the challenges, successful entanglement, while difficult to achieve, is the surest means of interdicting the progress of a non-compliant vessel, as once entangled the vessel is incapacitated for the period of time required to clear the drive gear, affording enforcement officials adequate time to board the vessel.

Entangler Designs Tested

Payloads with the greatest probability of success based on our pre-study experience were expected to include some combination of the following elements:

- Hanging loops on maximum 16-in centers, with some weighting added at the extreme lower corners to accelerate settlement into the water and promote motion in the area of the propeller turbulence
- Trailing tentacle-like lines attached to a main spine, either with frayed ends, or weights added to promote interaction with the propeller

- Addition of flutter inducers on either the trailing lines or hanging loops to promote interaction with the propeller
- Use of either parachute or series drogues to introduce drag to slow the vessel, or to utilize the drag created to draw a specific portion of the payload into contact with the lower unit to enhance the probability of entanglement

Preliminary evaluation of various payloads including parachute and series drogues along the header line had been tested on dry land. The series drogues deployed at the moment of launching, adding significant load to the payload being delivered and proved to be impractical to deploy the required distance. Pre-trial experience with parachute drogues pointed to significant challenges in making the drogue adequately robust. And self-deploying drogues were anticipated to be potentially overly complex for use in the field. Therefore this payload type was not utilized in subsequent water trials.

Ultimately two payload designs were settled on for evaluation in formal underway testing.

Frayed Tentacle Style – A payload consisting of a 65-ft header line of 3,000-lb tensile strength UHMWPE with a 4.0-mm diameter with 60-in long tentacles of the same material hanging downward, and installed at 12-in on center. Lead weights of 0.5-oz were embedded in the tentacles immediately above the frayed portion of the tentacle (Figure B-1).

Theory – The target boat (TB) will engage the header line, and the forward motion will draw the payload along both sides of the lower drive unit. Motion induced by the propeller, in conjunction with the lead weights, will draw one or more tentacle strands into the propeller, initiating entanglement.

Loop Style – A payload consisting of a 50-ft long header line made from 7-16ths-in diameter UHMWPE with 21,000-lb tensile strength, with 8-in wide by 30-in long loops located at 16-in on center. Each loop was shaped with an embedded piece of vinyl coated flexible wire rope located at the loop's apex (Figure B-1).

Theory – The TB will engage the header line, and the forward motion will draw the payload along both sides of the lower drive unit. Motion induced by the propeller, in conjunction with the weighted loops, will draw one or more loops into the propeller, initiating entanglement.

4. ENTANGLEMENT TESTS

The contractor conducted multiple series of tests, both in the United Kingdom and nearby the Redmond, OR facility.

Test Series 1 –The first series of testing consisted of fabricating prototypes of these two types of payload for evaluation using the standard launcher configuration. The HOSDB, for whom RSI staff act as a Technical Advisor, conducted testing of these experimental payloads as a part of their ongoing interdiction program in the U.K. The nets were deployed in water trials conducted by HOSDB at the Naval Dive Training Center at Horsea Island, Portsmouth, U.K., in accordance with their testing protocols in place, commencing on April 11th. The TB used was 7.5-m rigid-hulled inflatable boats (RHIB) powered by single 75-hp outboard engines, used at speeds to 30-mph. RSI personnel were active participants in the testing and were present to monitor the performance and gather the test results.

Test Series 1 – Results – The frayed tentacle style payload, described above, proved only marginally effective, initiating entanglement in 1 of 8 attempts. The loop style payload, described above, also proved only marginally effective, initiating entanglement in 1 of 6 attempts. However when combined for testing on the following day the assembled payload proved to be effective, resulting in 100 percent entanglement on each of 8 successive shots (APPENDIX B).

Test Series 2 - Multiple additional water trials of payloads were conducted at Lake Billy Chinook, nearby the contractor's facility in Oregon between May 9th and May 16th. The payloads types evaluated, based of the results of Test Series 1, included two variations of the Type 1 payload as shown in Figure B-13. The TB used in this testing was a 17-ft speed boat equipped with a 115-hp outboard motor at speeds to 35 mph. Testing consisted of deploying payloads across the path of a planing watercraft from a platform vessel and/or pursuit vessel.

Test Series – 2 – Results - Test results achieved with the Type 1 payload (Figure B-13) were consistent with those realized in England. Entanglement occurred at a rate of 100 percent on 11 consecutive shots over during the test period. In each instance the individual strands of fiber, and not the loops, were wrapped closest to the propeller hub, indicating that the fiber strands, and not the loops were initiating the entanglement (Figure B-15).

A Type 1A prototype was also constructed with a view to making this effective payload lighter, and less costly (Figure B-14). The Type 1A payload was constructed including both the loops and the individual strands. However the individual strands were modified to eliminate the frayed tails, which were very labor intensive to produce, and which created considerable self-entanglement after each shot, making the payload slow to re-pack. The lead weight, previously embedded at mid-point, was now moved to the extremity of the strand. This payload also initiated entanglement, causing the target boat to lurch violently on impact. However the entanglement was short-lived, as the lead weights embedded in the tail of the strands was expelled by the rotational force of the propeller, allowing the craft to escape the payload. Entanglement was evident at the points of contact between the propeller and the payload. The strands showed significant abrasion, and the lead weights were conspicuous in their absence.

Dry land testing of the performance of the hybrid projectile cylinder also took place parallel to the Series 2 water tests. The original Type 1 payload, with a weight of 13 lbs was deployed on each of two occasions to a measured distance of 110 ft.

The watercraft used at the contractor's facility included two primary vessels. Vessel No.1, serving as the TB had a length of 17 ft. and was powered by a 115-hp outboard motor. Vessel No. 2 had a length of 20 ft and was powered by a 260-hp V8 inboard/outboard engine. The speeds of the craft was regulated relative to the progressive results achieved. Initially success at lower speeds was sought, with a view to gathering some meaningful data without permanently disabling the test watercraft. The objective was to evaluate the operational effectiveness of the various deployed payloads by increasing the craft to full speed at the conclusion of each day's trials.

Test Series 3 – Consisted of water trials testing the Type 1 payload that had evolved based on results from Test Series 1 and ongoing Test Series 2, and included the hybrid projectile and prototype enlarged payload container nearby the contractor's facility in conjunction with representatives of the USCG. Testing consisted of having two watercraft participate actively, and a third watercraft serving as an observer boat (OB). One of the active participants was the "target boat" and the second was the "pursuit boat" (PB). Shots were taken demonstrating the effectiveness of the Type 1 payload and equipment modifications (APPENDIX A).

Test Series 3 – Results - Testing began with dry land demonstration of the performance of the hybrid projectile cylinder delivering the Type 1 payload. On each of 3 successive shots the Type 1 payload, weighing 13.0 lbs was deployed less than the required distance of 100-ft. It was noted that gas continued to exhaust from the projectile after it have come to ground. A high friction tape, added to promote contact with the propeller, had been applied to the Type 1 payload subsequent to the dry land testing that had taken place during Test Series 2. It is possible that the friction generated by the tape on the inside of the payload container was responsible for the failure of the projectile to deliver the payload the required distance. This was the only conspicuous variable between the two separate dry land deployment tests.

The Type 1 payload performed successfully on three successive deployments (Figure B-15 and Figure B-16). Incorporated by reference, and accompanying this document, is a video record of this testing.

Test Series 4 – Consisted of water trials, in both Portsmouth, U.K. and nearby the contractor's facility in Redmond, OR of evolving entanglement payloads. At the conclusion of Test Series 2 and 3, based on the results achieved, a Type 2 payload was contemplated, including the elimination of the loops completely, increased diameter materials for the individual strands, and experimentation with weights, and flutter inducers fastened more robustly to the tails of the strands, to prevent expulsion during entanglement (Figure B-17 and Figure B-18).

The Type 2 payload deployed successfully and entangled at a rate of 100 percent (Figure B-20 and Figure B-21). Additional testing was performed in the United Kingdom, again achieving 100 percent success rate in multiple deployments. Some static testing was undertaken against 200-hp outboard motors. Incorporated by reference, and accompanying this document, is a video record of this testing.

Limited additional testing was carried out using the Type 2A payload (Figure B-19) on August 4th, using a 20-ft. boat with a 260-hp V8 engine and outdrive. Test speeds were approximately 45 mph. During these tests the payload did momentarily engage the propeller on the outdrive, however the torque of the engine, coupled with the forward momentum of the target boat defeated the entangling tentacle before the balance of the payload could be drawn into the propeller (Figure B-20).

5. CONCLUSIONS

The criteria laid out by the BAA has been met by the modifications made to a commercially available product, coupled with the development of the Type 2 payload, as follows:

- The interdicting payload as developed is 50 ft in length
- It is effective against an 115-hp outboard powered, single propeller driven planing craft of 17 ft in length traveling at speeds to 35 mph
- The interdicting payload is easily recoverable
- The projectile-powered interdicting payload poses minimum risk of injury to persons on board the vessel to be entangled
- The leading end of the of the interdicting payload is capable of being propelled at least 125 ft from the launcher
- The system can be re-loadable with a new payload and delivery charge within 30 seconds
- The system is capable of surviving in a marine environment
- The system is compatibility with commercially available line throwers,
- Recoil is approximately 3 ft-lbs, allowing firing by an unsupported individual
- Compressed air exhaust gases do not pose a hazard to those behind the shooter
- Total weight of the system, loaded and ready to fire, is less than 18 lbs, and is able to be held and fired by a normal-sized person from a 25-ft long boat in "at sea" conditions

The Type 2 payload appears to offer the best weight-to-efficiency of those payloads tested. It appears to be highly effective in entangling small propeller-drive watercraft. Failure of the payload to completely entangle the inboard/outboard target vessel during the Test Series 4 may indicate the need for longer tentacles, or more closely spaced tentacles, or tentacles with greater strength (that is, a larger diameter material) or some combination of the above. However, the fact that entanglement is occurring is a significant achievement.

6. RECOMMENDATIONS

The results of the information presented by this study indicate that necessary refinements and modifications in the systems developed remain to be performed. Substantial difficulty has been experienced historically in deliberately generating entanglement of small propeller-powered watercraft on a reliable basis. The high success in creating entanglement, as outlined by this study, should be built upon in order to expand the applications for which this technology is suitable.

The portable entanglement net (PEN) system developed under this contract has proven highly successful against most outboard-powered craft. Prototypes should be deployed for operational testing by the Coast Guard. Further work is needed to develop more robust entanglers and more powerful launchers to defeat higher-powered outboards, inboard/outboards, and direct drive craft.

APPENDIX A. SHOULDER-LAUNCHED RUNNING-GEAR ENTANGLEMENT SYSTEM TEST PLAN

Date/Time: May 17^{th}, 2006

Location: Lake Billy Chinook, Redmond, Oregon

Purpose: The purpose of this testing was to evaluate the performance of the modified ResQmax launcher system and experimental payloads as measured against the desired requirements of BAA HSCG32-05-R-R00020, with results as follows:

- The interdicting payload was 50 ft. in length
- It was effective against a 17-ft planing craft single engine 115-hp outboard powered craft
- The interdicting payload was easily recoverable
- The projectile-powered interdicting payload posed minimum risk of injury to persons on board the vessel to be entangled
- The leading end of the of the Type 1 interdicting payload was capable of being propelled at least 80 feet from the launcher (note: Type 2 payload can be delivered min. 125 ft)
- The system may be re-loadable with a new payload and delivery charge within 30 seconds
- The system is capable of surviving in a marine environment
- The system is compatible with commercially available line throwers
- Recoil was sufficiently low as to allow firing by an unsupported individual
- Exhaust gases, did not pose a hazard to those behind the shooter
- Total weight of the system was 23 lbs, and was able to be held and fired by a normal-sized person from a 25-ft. boat in at sea conditions

Procedures: Three small boats were used for the testing. The TB acted as the "simulated bad guy" boat. The PB was the platform from which the ResQmax is launched. A third boat, OB was used for USCG personnel to witness the testing. At all times the OB, was positioned so as to be out of the path of both the TB and PB, and out of the line-of-fire of the launching system.

Test: – The stopping power of one the Type 1 payload systems was tested in conjunction with items a-k (above). The PB was tested underway at a moderate speed, approximately 25 kts. Starting with both boats even, the PB accelerated and pulled ahead of the TB. The PB launched the net/line well forward of the TB, to minimize unnecessary risk to TB personnel. The TB maintained a course and speed, making adjustments as necessary in order to travel over the deployed payload. The TB did not reduce throttle. Entanglement/mechanical resistance was experienced immediately after contact with the Type 1 payload, killing the engine. The test was repeated with matching results. Type 2 Payloads evolved from the results of this testing, together with testing results gathered immediately prior to this testing.

Safety: RSI acted as the Safety Supervisor. RSI determined and authorized all aspects of this testing in regards to the positioning and speeds of the TB and PB. A safety briefing was conducted prior to getting underway.

Liability: RSI assumed all risk and liability for damage to watercraft employed in this test.

Documentation: RSI provided video personnel on the OB to record test exercise. A copy of the video footage taken accompanies this Final Report, and is incorporated by reference.

Participants:

OB

Leslie Shumway – Dept. of Homeland Security (DHS)
Robert Sedat – USCG Research &Development Center (R&DC)
Neal Armstrong – USCG – Non-Lethal Weapons Directorate (NLWD)
Video Personnel

PB

Craft Operator - RSI
Jim Fitzmaurice - RSI

TB

Craft Operator – RSI

APPENDIX B. HOSDB TRIALS 11-12 APRIL 2006: TYPE 1 PAYLOAD

Portable net modified to give 100-percent success in HOSDB Trials.

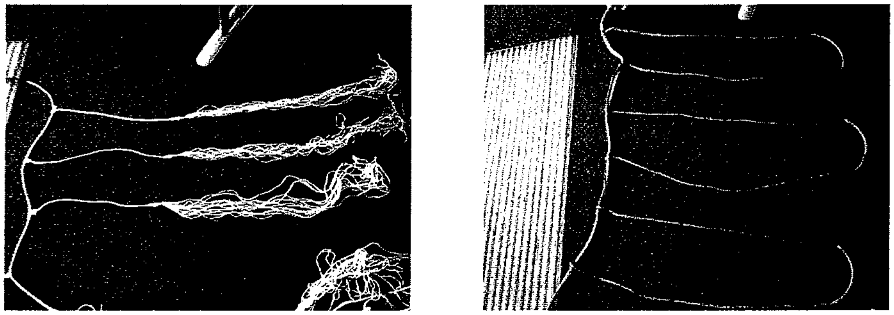


Figure B-1. Frayed tentacles and loops.

Frayed Tentacles	**Loops**
Embedded lead weights	Wire rope inserts at extremity
1 out of 8 Entanglements	1 out of 6 Entanglements

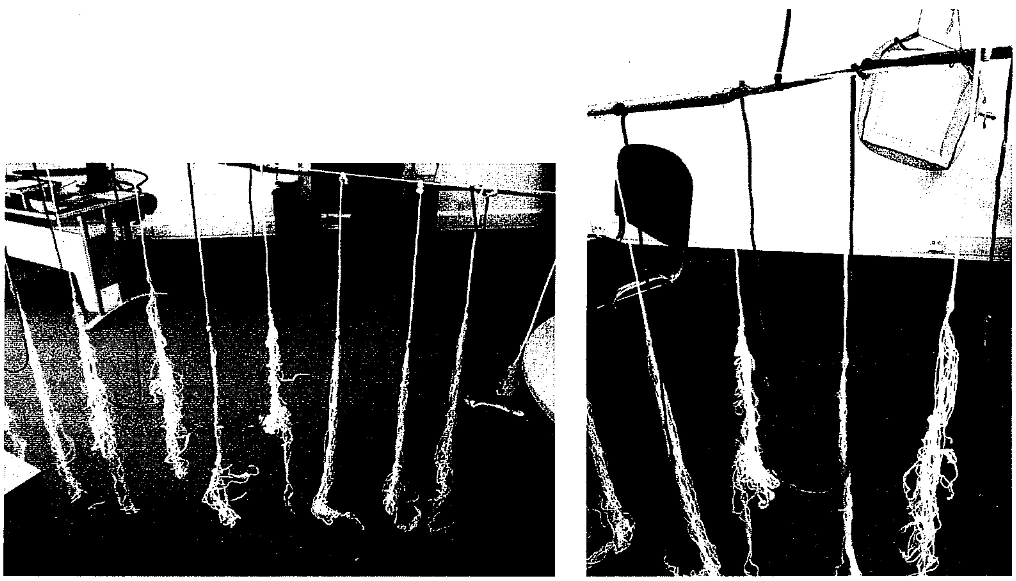


Figure B-2. Payload features combined to form type 1 payload.

Combined loops & tentacles together gave 8 out of 8 successes. Net has been deployed by ResQmax (UK) Ltd. with portable Launcher with a standard projectile at 300 Bar. Distance to outboard end of net: 36M.

Top line is positively buoyant; loops and strands weighted to assume deployed position in water.

- Internal loop width 8 in
- Distance between each loop 8 in

- Strands randomly along top line
- Weight 13.0 lbs in combined method

Entanglement Evidence

A combination of 'Tentacles and Loops' on the propeller hub. **Note**: Tentacles are below loops on hub, indicating tentacles initiated entanglement.

Figure B-3. Loop and strands around hub and gearbox leg, locking up of propeller.

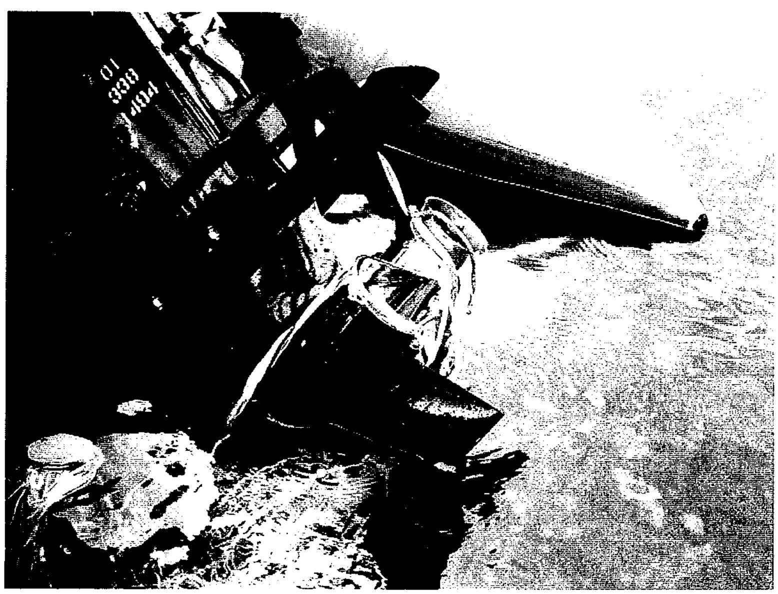
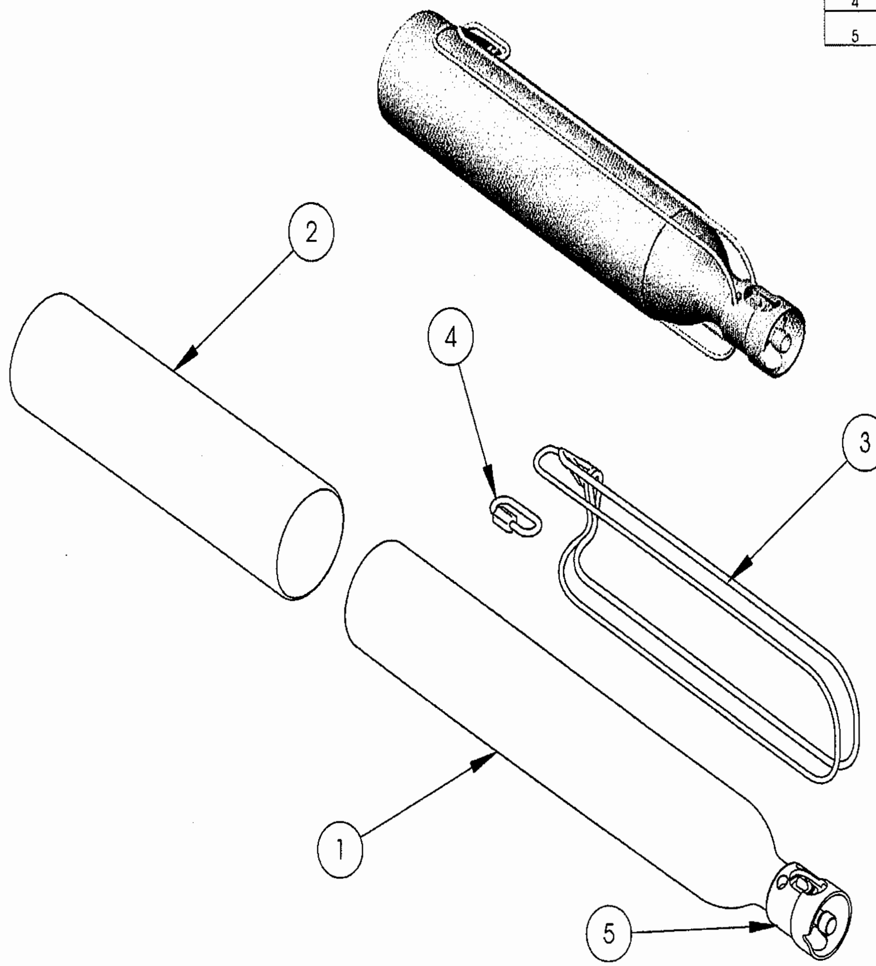


Figure B-4. An entanglement initiated by strands.

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF RESCUE SOLUTIONS INTERNATIONAL. ANY REPRODUCTION IN PART OR WHOLE WITHOUT THE WRITTEN PERMISSION OF RESCUE SOLUTIONS INTERNATIONAL IS PROHIBITED.

ITEM NO.	QTY.	PART NO.	DESCRIPTION
1	1	30001	Line Projectile Cylinder
2	1	30002	Line Projectile Protector
3	2	30003	Line Projectile Bridle Lines
4	1	30004	Projectile Quick Link
5	1	604	Nozzle Valve Assy.



RESCUE SOLUTIONS INTERNATIONAL
2720 LOKER Ave. W, Suite T Carlsbad, CA 92008
TEL: 760-602-9990 FAX: 760-602-9995

Line Projectile Assy.

SIZE	PART NO.		
A		R300	SHEET 1 OF 1

Figure B-5. Line projectile assembly.

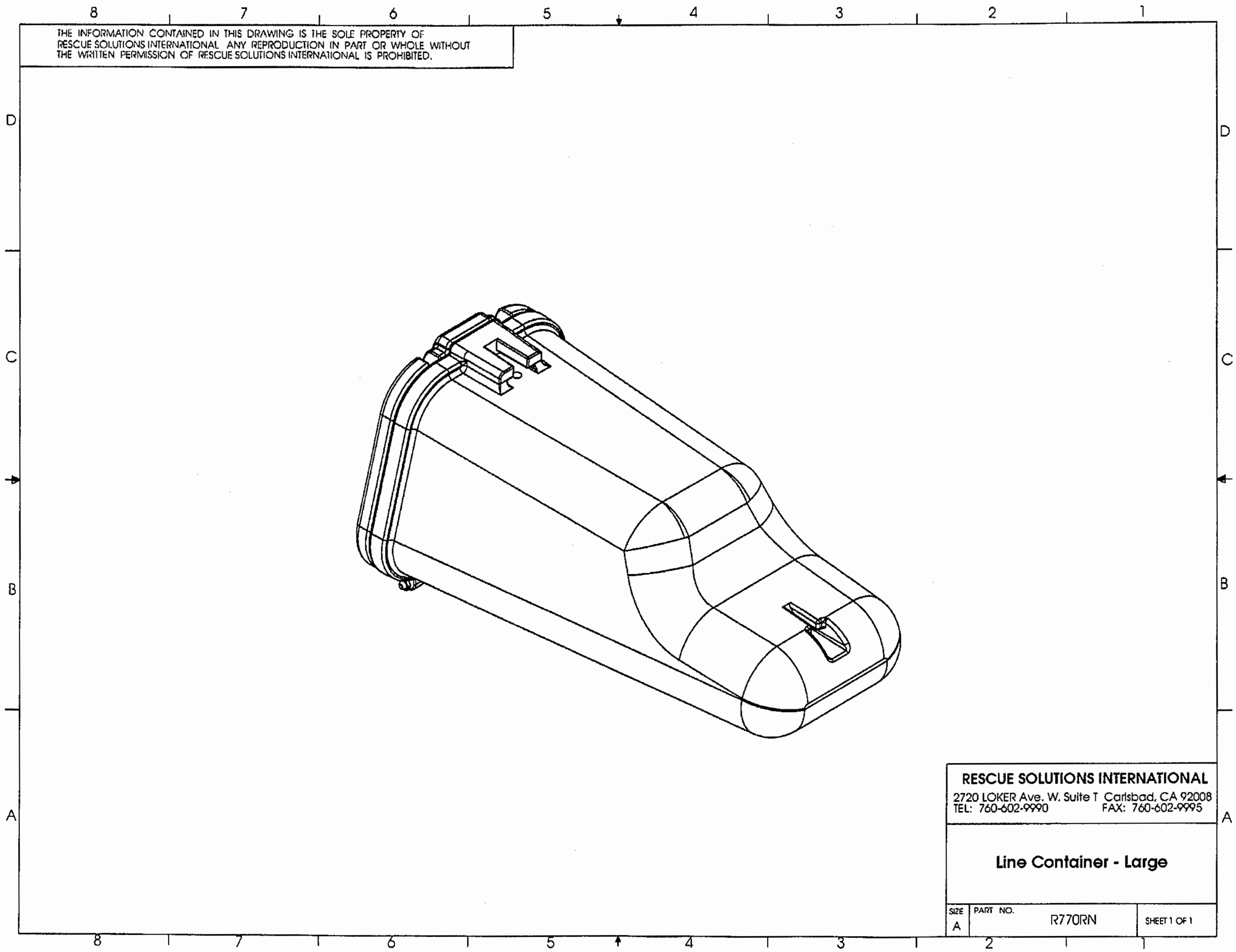


Figure B-6. Line container-large.

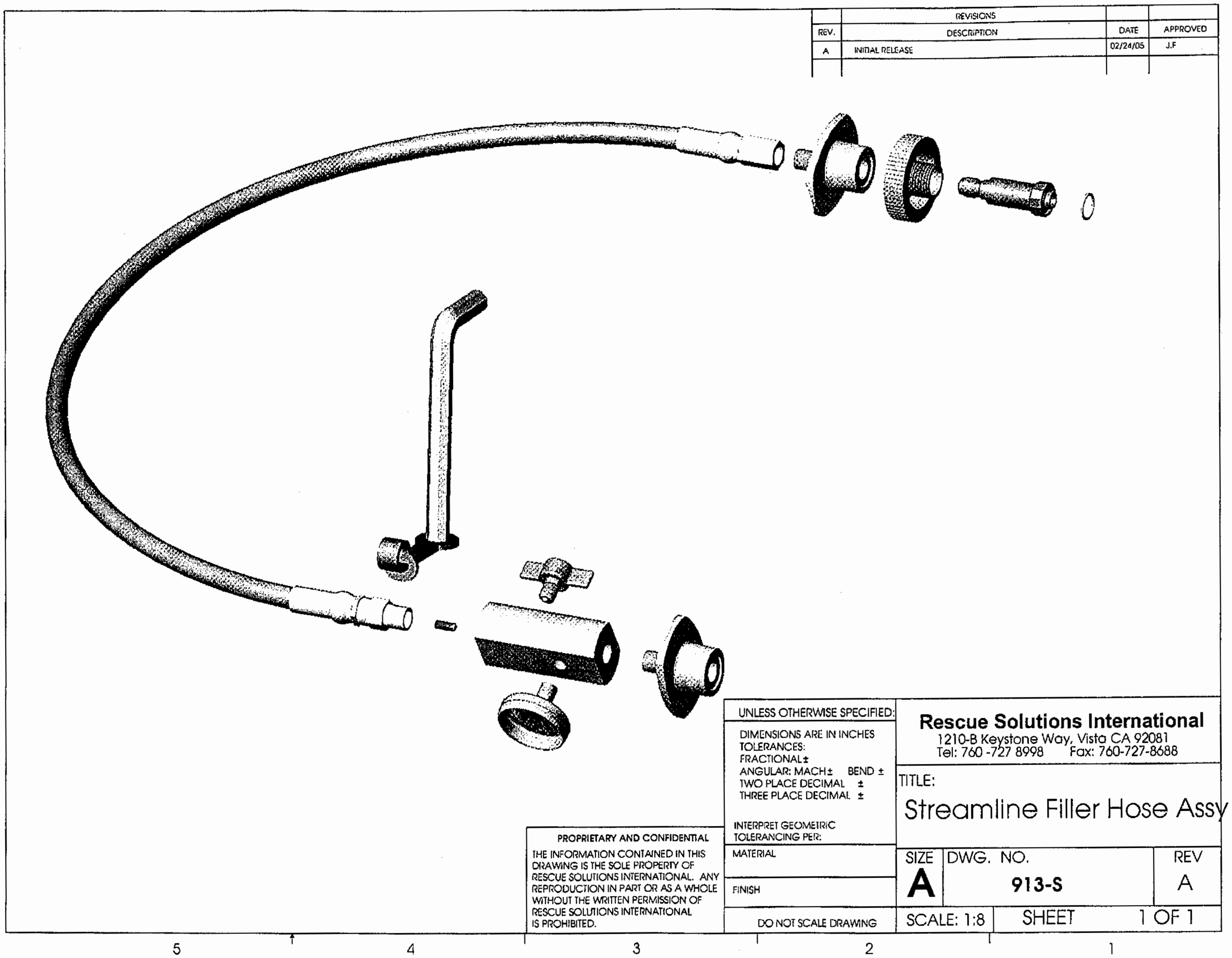


Figure B-7. Streamline filler hose assembly.

Figure B-8. ResQmax line-throwing appliance.

Aluminum 7075 - T6

14%	Elongation
	Rockwell

Rocket Projectile Cylinder Calculations

P = Pressure in Bottle	psi	Barlow's Formula for thin wall tubes
S = Allowable stress in wall	psi	
t = Wall thickness	ins	P = (2 * S * t)/D
D = Outer Diameter	ins	

WP = Working Pressure	psi	Reqd. Pressure =	***4,500*** psi
TP = Test pressure	psi	TP = (5/3)*WP =	7,500 psi
BP = Burst Pressure	psi	BP = 2.5*WP =	11,250 psi

Given data for material and bottle design

D =	***2.375*** ins
eqd. Vol. =	***50*** cu.ins.
Density =	***0.102*** lbs/cu. Ins.
SMYS =	***77,000*** psi
SMTS =	***86,000*** psi

Wall thickness required for Test Pressure, using SMYS

t = (P * D)/ 2* SMYS =	**0.116** ins	4500	46200

Wall thickness required for Burst Pressure, using SMTS

t = (P * D)/ 2* SMTS =	**0.155** ins	4500	34400

Wall stress in bottle at working pressure using thicker wall

S = (P * D)/(2 * t) = 34,400 psi

Estimated weight of bottle using thicker wall

ID = OD - 2*t =	2.064 ins
Cross Section area =	3.348 sq, ins
Total length incl ends =	15.281 ins
Area of ends = 4PiR^2=	13.393 sq, ins
Length of Cyclinder =	12.657 ins
Vol.of Cyclinder Matrl =	14.668 cu. Ins
Vol of end matrl =	4.159 cu. Ins
Wt of ends =	0.424 lbs
Wt. Of Threaded part =	0.060 lbs
Wt of Cyclinder =	1.496 lbs

Total estimated wt. of bottle = 1.980 lbs

Figure B-9. Rocket projectile cylinder calculations.