Redesign of a Tactical Backpack

Submitted to the
Faculty of

WORCESTER POLYTECHNIC INSTITUTE
In partial fulfillment of the requirements for the
Interactive Qualifying Project.

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C-Term, 2010
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ABSTRACT

Our project endeavored to improve upon the United States Marine Corps Pack System. At the onset of our work, our project group had aspired to design a completely new dry liner for the United States Marine Corps Improved Load Bearing Equipment (ILBE) pack design. USMC contracting departments, however, are currently discussing the possibility of soon phasing out the ILBE completely. Therefore, our focus was redirected towards improving a supplementary tactical system that would continue to be used regardless of the primary pack design later adopted. The compression dry sack currently used by active service marines (in particular Force Reconnaissance Marine dive units) is called the Marine Compression Stuff (MACS) Sack. This design, manufactured by Cascade Designs, Inc, has demonstrated one critical flaw when put to use during USMC recon diver operations: it doesn't fully deflate.

Our project has analyzed the control elements of this tactical pack and developed various means to improve its basic design with respect to this established problem. Our group reached a consensus that a renovation to the existing MACS Sack should come in the form of a more efficient compression method and the possible incorporation of a vacuum pump. With the addition of a "rip-cord" system, the time necessary to initially compress the waterproof pack around its contents would be significantly reduced. Moreover, the integration of a small, manually powered vacuum-pump would provide the means to remove any air remaining after initial compression. Intended for regular and rigorous use, these proposed additions would operate to significantly improve the function of the MACS Sack's current design. With the support of quantitative testing and a comprehensive literature review, this project proposes an effective and practical improvement of the Marine Corps Pack System as a whole.

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CHAPTER 1: PROJECT INTRODUCTION

From the onset of this project the underlying goal has never changed: to develop and propose an addition to the United States Marine Corps pack system which works to improve overall functionality and combat effectiveness. The marines are arguably one of the most elite and formidable fighting forces that this world has ever seen. The intense level of discipline and high personal standard that the Marine Corp holds should be reflected in the sophistication of their equipment. It was our groups' intention to analyze the present day pack system utilized by Marines and identify some aspect of function which might benefit from redesign. Simplicity in equipment design serves to protect from mechanical failure but can also inhibit efficiency and operational effectiveness. It has been our goal to keep these two considerations in balance while designing a tactical sub assembly which will serve those who serve. The sub assembly we have come to address is the standard issue dry sack: The MACS Sack.

The MACS Sack originally was not designed for underwater use, and because of this, purging air completely out if the sack during dive operations is a major problem. The issue arises when the MACS Sack is filled with the contents in such a way that the contents make air pockets that simple compression cannot solve. If any dive operations go to significant depths, any residual air in the MACS Sack severely hinders the movements of the diver as buoyancy compounds with depth. The MACS Sack will stay in production and use by the common Marine because it is effective in protecting materials from liquids. In the case of Marine Dive Units, however, a change in the dry liner technology has to be made to allow for more effective buoyancy control.

Currently the MACS Sack uses a one way pressure induced valve to purge any residual air in the sack. The valve is a two layer rubber disk fixed to a hollow disk forming an uncomplicated seal. The design is rudimentary but durable enough to function under all kinds of stress, but it is ineffective in the eyes of combat divers who must consider for all possible buoyancy forces. In straightforward terms, the MACS Sack is simply a Nylon bag with a roll-to-close top, sealed by the combination of the internal outward pressure and the friction between the layers of the coated material. The MACS Sack's soul mission was to simply keep water out and stand up to rigorous use and conditions. Although it achieves this mission with resounding success, Marine Reconnaissance Dive Units experience trouble diving when air within these dry liners are complicate buoyancy control at significant depths. The identified objective of our project is to provide a way to fully deflate the Marine issued MACS Sack.

Our design additions to the MACS Sack, consisting of a compression assist rip cord system and a manually-powered vacuum pump, are meant to reduce inhibiting buoyancy forces experienced by diving operations. Secondary objectives of our project continue to be to reduce system mass and production cost while maintaining system durability and operational simplicity. Our intended design will offer a direct solution to a very real and present problem. What's more, another aspect of seriousness comes to light when one considers who this project aspires to aid. The redesign of the Marine's tactical pack system, even in the slightest way, might someday offer the means to save a life – be it that of a recon diver or those he fights to protect.

This report will discuss the progress of our group's project. It will begin by touching upon all relevant background studies, then the project's design process and considerations. After this, the group's design methodology and testing procedures will be explained. The report will conclude with a analysis of group performance and the potential for extended work.

CHAPTER 2. LITERARY REVIEW

This chapter is meant to provide a detailed description of all background considerations relevant to our project's progress. By assessing these general concerns in more detailed, a higher understanding of our group's design process and decisions can be attained.

2.1 – Transition in Objectives

Our original objective for this project was focused on the standard Marine issued Improved Load Bearing Equipment (ILBE). In our initial assessment of the ILBE, we intended to determine a method to effectively waterproof the bag so as to protect contents from the elements. Based on our believed needs of the Marines, this appeared to be the quickest and most effective way to make the lives of Marines in service even just a little easier.

After looking into the variety of conditional and operational requirements experienced by the Marines (as well as the abuse that their equipment must endure) we concluded a couple of requirements. We surmised that the most efficient way to waterproof the ILBE was to add a waterproof liner that would be capable of being removed from the pack. This would allow for the waterproof liner to be taken out when not necessary, allowing for improved access to items that would, otherwise, be stored within the liner. We also determined that the material of this liner must be extremely tough and durable. This was of utmost importance so as to withstand the tremendous abuse that would be inflicted upon the liner while in use. This aspect of design arises from a phrase which we have held close to mind during our entire progress "it must be Marine proof".

Our group launched into this avenue of design and soon thought that making the liner inflatable, to allow for flotation, would be advantageous to the Marines. As well as acting to maintain watertight integrity, this design could act as a safety method in extreme operation conditions. With the understanding that the liner assembly would inherently be waterproof, it would not have been a stretch to continue the permeability limits of the material to prevent air from escaping.

After discussion with a contact, we were given contact information for the ILBE project engineer from the naval division at Natick Labs. We have been in communication with Mister Trevor Scott about our project, and he has provided insightful information for us in moving forward in our efforts. We have been able to ask him about the ILBE, and related matters, and he has been tremendously informative. We informed Mr. Scott of our intentions to design a waterproof and airtight liner for the ILBE, and he provided very helpful information.

More recently, we have discovered the availability of a waterproof pack liner, designed by Cascade Designs Inc. under their Seal Line brand, marketed as the MACS Sack. Four models of this liner are issued to every Marine to provide a waterproof protection for contents of their individual packs. To simplify our project, we decided to improve on this design, which meets our waterproof requirements, and focus on the design of an inflation method to apply to the MACS Sack.

Informing Mister Scott of our discovery of the availability of the MACS Sack, and original plan to make the current Marine ILBE floatable, he told us that a floatable pack is, currently, not a requirement. Additionally, he informed us that Marine Reconnaissance Units even report having difficulty submerging the issued dry packs during diving operations. With this epiphany, we realized that our project required a change of direction.

With knowledge of the MACS Sack, and understanding of the true problems experienced by the Marines relevant to in-water operations, we decided to focus on improving the MACS Sack. Based on Mister Scott's comment pertaining to the difficulty of submerging a full pack with the sack, we are, now, focusing on improving the complete air removal capabilities of the MACS Sack.

2.2 – Current Demands for USMC Pack System

To understand the demands of the USMC pack system today, one may look to the currently employed Improved Load Bearing Equipment (ILBE) system. The ILBE is a design evolved to support combat troops specifically and incorporates a high load capacity, a high-density foam backing, a lightweight internal rail support system, and even a hydration system. The ILBE is also made to coordinate specifically with the current Kevlar body armor systems, and to be broken down if necessary into a smaller assault pack and a larger main pack. Designed by Arc'teryx's LEAF (Law Enforcement and Armed Forces) program and manufactured by Propper Inc., the ILBE is made from Cordura 725 denier fabric, with pixilated MARPAT (MARine PATtern) printed onto it. The pack also bears a PALS grid (Pouch Attachment Ladder System) for smaller modular attachments, ("Military Backpacks: ILBE"). The PALS grid has directly made it possible to carry 61 mm and 80 mm motor rounds on the exterior of the pack. Being able to readily access ammunition during combat proves the ILBE's worth over other designs. The production of the ILBE has been met with many positive reviews since its introduction to active service in 2004. The aspects of its design speak to great lengths about the advantages it poses, such as its durability and ability to evenly distribute its contents weight.

In our correspondence with Mr. Scott from Natick laboratories, we were directed to the USMC's page for civilian contracting opportunities. Our attention was brought to a particular military notice posted in late October, 2010. In this posting, the Marine Corps has declared its intention to phase out the ILBE in favor of a system, yet to be designed, that resembles the functions of the old Army MOLLE pack system. The exact excerpt of relevance is read as follows:

> The Program Manager Individual Combat and Equipment (PM ICE), Marine Corps Systems Command (MARCORSYSCOM), is seeking industry input that identifies potential sources and best practice information regarding the manufacturing of a government-designed USMC Pack System. The USMC Pack System is similar to the US Army's MOLLE Large and Assault Packs. The resultant System must be Berry Amendment compliant and as well as be produced at a rate which will result in a total of 108,000 Systems being delivered within 12 months of contract awards. *(MARCORSYSCOM: "84--Industry Manufacturing Capability for the USMC Pack System Solicitation Number: M6785411I3002." [1])*

This posting is a testament to the Marine Corps' intention to stay on the cutting edge of the latest technology and equipment.

The MOLLE (Modular Lightweight Load-carrying Equipment) Pack System is an older generation platform formerly employed by both the United States Army and Marine Corps prior to the ILBE. The advantage of the modular system allowed for each soldier and Marine's pack assembly to be customized according to the individual mission at hand. The system was phased out in exchange for the ILBE because several material production problems arose with regular use. For example, in Afghanistan, troops noted that MOLLE zippers were bursting open when the bags were stuffed full. Another defect was that the straps weren't long enough to be easily adjusted over body armor (“Modular Lightweight Load Carrying Equipment (MOLLE)" [30]). The published intent expressed by the Marine Corps to re-integrate the modular systems seems to indicate that the various jobs within the Corps differ in their needs of a pack system.

In addition to this information, Natick Laboratories also turned our attention to another problem faced by the current pack system, but one that would likely continue despite future primary pack changes. Of late, it actually seemed that the Marine Corps is more concerned not with an inflatable, life-preserver-pack but instead with a method for more effectively sinking packs during reconnaissance dive operations. This problem, already described in better detail, is specifically derived from the use of dry bags that can’t be completely purged of contained air. In an effort to align our project according to objectives that will remain relevant, our project therefore turned to address this critical fault found in dry liners. This way, regardless of whether or not the ILBE continues to be used in the unseen future, our project’s proposal may continue to have a practical use and positive impact.

2.3 – Uses of MACS Sack as Supplementary Platform to Pack System

Action Reports from Operations Iraqi Freedom and Enduring Freedom emphasized a compelling need to supply a waterproof bag to protect personal gear from the elements, rain, sand, snow, and moisture. The Marine Compression (MAC) sack will provide marines a better method of waterproofing their personal gear stored inside Improved Load Bearing Equipment (ILBE).

The MACS sack is used to line Marine Corps backpacks and specifically made to shield the marine’s contents from water during marine diving operations. The sack was made to withstand the harshest environments. What makes this stuff sack useful to the marines is its dry-seal roll-down technology allows fast submersion. The MACS sack was primarily designed by the company of Cascade Designs and SealLine, who specialize in long-lasting and durable packing equipment for all weather conditions. (Cascade Designs, "Seal Line: MACS Sac" [36]).

Figure 1: Cascade Designs Logo

Figure 2: Sea Line Production Series Logo

They also exclusively make the unique sack for the marines. The pack’s simple design provides optimized functions for the marine to carry out the mission without any additional constraints. It comes in an olive green color providing a camouflage effect in any given environment. With no contents, the pack weighs 3.3 oz or 93 grams and a diameter of 7 inches or 18 centimeters. The marine can put fairly large objects in their pack and allowing them to carry their belongings for long periods of time. The MACS sack has a height of 13 inches or 33 centimeters and a volume of 549 cubic inches or 9 liters. (Water Sports Gear Protection, “Amphibious Backpack Liner: MACS Sack "[2]). These dimensions and rounded bottom allows the marine to fill the sack to capacity with objects of a variety of shapes and sizes. The marine compression stuff sack consists of an easy-access single strap. This flexible handle gives the marine an easier means in carrying their contents and provides enough space to carry it with gloves.

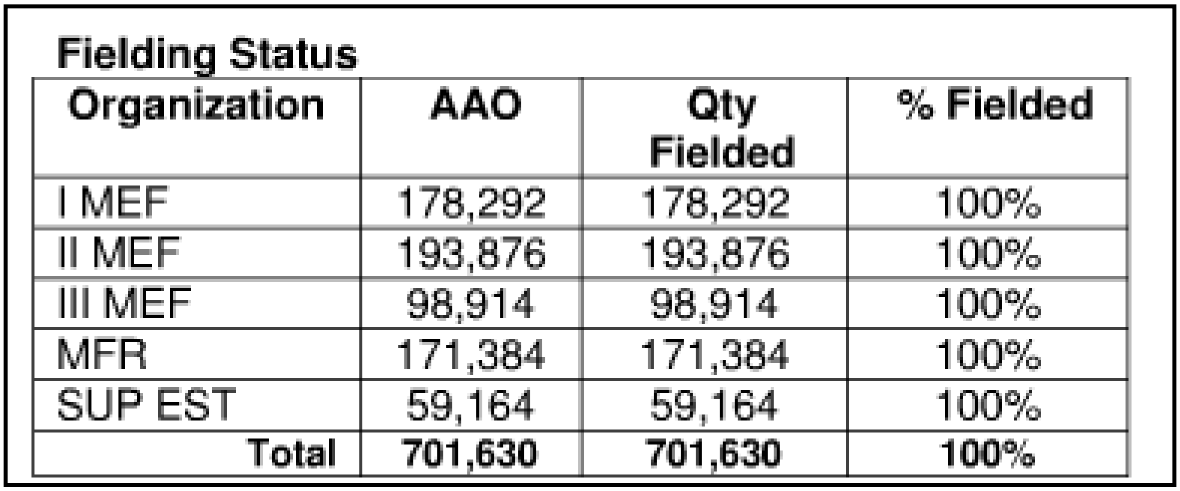
The “flush-mounted, hands-free check” valve located on the front of the pack gives the marine the option of releasing air out from the pack, as a result, reducing buoyancy and assisting the marine in the diving operation. Releasing the air requires pressing down the pack while rolling the top closure so the air travels through the one-way valve without any unwanted air entering the pack. The advantage of having a valve with no metal or hard plastic parts is it won’t give the marine any unnecessary disturbances and jeopardize the marine’s operation. A metal or hard plastic valve can get caught on something and affect the pack or more importantly restrict the movement of the marine. Also, the current design of the valve does not provide any disturbances for the marine due to the low surface area and material.

Figure 3: Cascade Design's MACS Sack seen with full contents (left) and deflated (right)

SealLine's exclusive 'Dry Seal’ roll-down top possesses continuous double sealing strips, making the roll-down closing method more waterproof (not-watertight) than any other. Making it easier to use, instructions are printed on the strip. To optimize this feature, simply fold the top edges of the Baja bag downward between the strips, squeeze out any trapped air inside the bag, fold a couple times, and then connect the buckle ends together to lock close. When rolled-properly, the 'dry seal' can withstand a quick submersion and act as a speedy float as seen in Figure 3.

Due to the MACS sack’s complex material, the 210D oxford nylon with “high tenacity” polyurethane coating fabric provides protection from the water, harsh environments and temperature changes. Its properties give it, yet lightweight voyage. The material is very durable is made to withstand even man-made elements that a typical marine would carry, such as insect repellent or weapon lubricants. The nylon consists of a smooth surface throughout and maximizes packing of the marine’s contents. The smooth surface reduces friction thus optimizing flexibility and compression of the pack. If a marine were to attempt to release air out of a MACS sack with a rough surface, an increase in friction and resistance would affect the time and amount of air coming out of the pack. The overall design is simple, as a result, allowing the marines to maximize the sack’s functions. (USMC Combat Equipment and Support Systems, "Marine Corps Stuff Sack" [26]).

Table 1: Fielding Status of MACS Sacks



Fielding Status

Organization	AAO	Qty Fielded	% Fielded
I MEF	178,292	178,292	100%
II MEF	193,876	193,876	100%
III MEF	98,914	98,914	100%
MFR	171,384	171,384	100%
SUP EST	59,164	59,164	100%
Total	**701,630**	**701,630**	**100%**

Each marine is given an ILBE to transport their belongings and with each one comes with four MACS sack. According to Marines Corps System Command, a total of 701,630 MACS sacks have been distributed so far, (USMC Combat Equipment and Support Systems, "Marine Corps Stuff Sack" [26]). As one can see from the table, there are several divisions of the Marine Corps, so a given quantity is given to each organization. The military has established a contract which demands an estimated quantity of 51,000 MACS Sacks produced for military purposes. There are different options within that contract which allows the military to decide if they need any additional sacks depending on the demand, (USMC Combat Equipment and Support Systems, "Marine Corps Stuff Sack" [26]).

The relationship between Cascade Designs, SealLine, and the military is quite well-maintained. They have also modified other equipment for them such as a lightweight tent, portable stove, and a small water purifier. There are many more devices they supply and signifies the trust the military, namely the Marine Corps, have towards these companies. Cascade design has over 30+ years of experience in innovating outdoor technology and with a rich history of successful inventions; they certainly have the credentials in supporting the military with their products.

In conclusion, the MACS sack function and properties match up well with the marine's needs as they dive and explore the harsh environments of the world. After quick background info on the manufacturers of the MACS sack, the Marine Corps seem like they're in good hands with Cascade Designs developing some of their equipment. The design is simple and easy to use, while its mechanical and material properties meet expectations, able to withstand abusive weather and still protect the marine's gear throughout extensive periods of times. It achieves its goal and doesn't become an obstacle for the marine. However, there is always room for improvement. We will use the methods and approach of Cascade Designs as a guideline in order for our group to come up with a design to improve upon their successful invention. Improving this invention would directly help the Marine Corps in achieving their goals more effectively, which would mean that our goals would be met. Who knows? Maybe we can agree on a contract with the military in the near future. No matter how well an invention is created, there would always be room for developments and Cascade Design has definitely demonstrated that. Hopefully, we'll be able to create a design that would set a higher standard for the next engineers to build up upon.

2.4 –Marine Reconnaissance Units

The United States Marine Corps (USMC) is a hard working group of individuals driven by what they fight for: the freedom of the American populace. This is why we strive to improve the equipment which they utilize to properly complete their missions. Our focus is the most extreme situation that will be experienced by the Marines, and this will, most often, fall upon the Reconnaissance Marine Battalion.

The Reconnaissance Marine Battalion is the Special Forces equivalent of the USMC. They are the most capable, most extensively trained Marines, with the motto "Swift, Silent, Deadly," ("Insignia" [21]) expected to undertake the most difficult and taxing missions. Members of the Reconnaissance Marines fall under the Marine Special Operations Command (MARSOC), which consists of the elite USMC groups, although primarily the Recon Marines. "As a member of MARSOC you'll fight the secret wars that never make the front page and you'll bring the highest level of expertise to every operation you are involved in," ("Military.com"

[28]). The Recon Marines are expected to accomplish the most difficult missions that no one will hear about.

Figure 4: 1st Recon Battalion Insignia

Officially existing as Reconnaissance Battalions since the Vietnam War, their roots lie much deeper. “Created during World War II as a raiding unit, known as the Raider Battalion, they provided the US forces with a group capable of providing a fast moving, hard hitting light force,” ("specwar.net" [42]). Through the remainder of the war, the Raider Battalion was limited in size, until the increase in the need for their services during the Korean War. The ability of the reconnaissance units to infiltrate enemy lines to procure intelligence, as well as provide a force for demolition of the Korean transportation network, was imperative.

Reconnaissance Marines remained a relevant force into the Vietnam War, when their ability to gather information about enemy forces became crucial. In small groups, the Recon Marines would travel with stealth to avoid the large volumes of enemy forces, being terribly outnumbered in the event of a conflict. “The small groups were preferred by the Recon members for they could be quieter, and avoid detection better than larger groups during the long, grueling missions," ("specwar.net" [42]).

The series of missions which Reconnaissance Marines are implemented in are more defined than they once were. The following list demonstrates the spectrum which their mission statements covered.

Missions:

Long-range reconnaissance and surveillance

T.R.A.P. (*Tactical Recovery of Aircraft Personnel*)

M.I.O. (*Maritime Interdiction Operations*)

Hydro-graphic surveys & beach reconnaissance

Small unit raids/selected prisoner snatches

Harbor reconnaissance

Underwater searches

Evacuation of American civilians from hostile environments (*countries*)

("specwar.net" [42])

This cornucopia of missions which the Reconnaissance Marines are subject to requires a multitude of training. This includes jump school training, SCUBA training, and learning of inflatable boat skills, to name a few.

With knowledge of the extreme environments the Reconnaissance Marines must endure, it is easy to understand that they must be proficient in all areas of training. They must exhibit strength and endurance in every environment from the mountains to the oceans. The standard Marine training, which all recruits must pass, consists of the Marine Recruit Training, and the School of Infantry. Although this training is beyond what many could manage, both physically and mentally, it is not rigorous enough for the Recon Marines.

To be qualified to become a Reconnaissance Marine, one must pass the standard Marine physical testing requirements with a total score of 285 out of 300 to just be considered for the recon "Indoc," and have three to four years of field experience, or be highly motivated and score at least 285. The score is based on three 100 point sections, with a three mile run, pull-ups from a dead-hang, and sit-ups for two minutes. To score 300 total points, the run must be completed in eighteen minutes, one must manage twenty pull-ups, and one must reach eighty sit-ups (Smith).

A military fitness trainer, US Naval Academy graduate, and former Navy SEAL wrote that for a Marine to pass the Marine Recon INDOC, he will be "required to perform two obstacle courses in less than two minutes each time, swim 500 meters in full cammies [uniform] in seventeen minutes, and other fun water activities, and a ten mile ruck [hike] with a fifty pound pack in under two hours," (Smith [38]).

Stew Smith, also, addresses a required a "Level Test" which must be performed.

> Max Pushups 2min
>
> Max Sit ups 2min.
>
> Max Pull ups 2min.
>
> Max Flutter Kicks 2min.
>
> Max 8 Count Pushups in 2:00
>
> Max scissors in 2:00
>
> *(Smith [38])*

Additionally, in a run portion of the INDOC requirement the recruits must accomplish:

Forced March (or "Hump") for 20 miles @ 4-5mph

Rucksack Run 3-4 miles timed (with 50 lb)

(Smith [38])

Passing the Marine Recon INDOC requires commitment and constant training, unique to the drive and commitment found in the members of the Special Forces, arguably some of the toughest soldiers in the world. Only after the recruit has completed the Amphibious Reconnaissance School (ARS) will he be, officially, a Reconnaissance Marine.

The amphibious portion of the Reconnaissance Marines’ training is integral in their ability to complete their missions. With a large portion of their operational tasks involving “amphibious-ground reconnaissance and underwater reconnaissance,” ("American Special Ops"[27]), the Recon Marines can spend large quantities of time in water. Naturally, what is not protected from the wet environment will become saturated. Only on missions intended to be entirely underwater are the Recon Marines wearing wetsuits and equipped with a load out of items intended for underwater use. The remainder of their water-based missions is of the amphibious variety. During these missions, they are most commonly deployed into the water via Spie Rig (Helicopter insertions), HALO (High Altitude/Low Opening), HAHO (High Altitude/High Opening), and CRRC (Combat Rubber Raiding Craft),” ("specwar.net" [9]). The latter method will not, necessarily, lead to total submersion, but the proximity to the water while in nothing more than a rubber boat would be cause enough for equivalent water protection to that of the former four methods of water insertion.

In the event of total submersion, the load out of the Reconnaissance Marines does contain items which can be sensitive to water, or sensitive when the addition of the water pressure due to depth is added, if one must submerge themselves to greater depth than is items may be rated at. The availability of a standardized water proofing solution for the Recon Marines was a major necessity.

With this necessity came the creation of the Seal Line MACS Sack. The MACS Sack is an airtight and waterproof dry bag designed by Seal Line, a Cascade Designs company based in Seattle, Washington. For the Recon Marines, this was a much needed answer to their problems.

Figure 5: Cascade Designs MACK Sack

“The MAC Sack is a special-issue compression dry sack designed exclusively for the U.S. Marine Corps. It’s the ideal solution for low-capacity, low-profile watertight protection in extremely abusive environments. It’s made to order for year-round guiding, daily abuse and for those who are particularly harsh of their gear,” (Cascade Design-Seal Line [36]).

The phrase “Marine proof” effectively describes the simplicity and durability of the MACS Sack. The durability is provided by the tough materials it is comprised of, in its 210D oxford nylon with a polyurethane coating. The simplicity is exemplified in its basic roll-down closure, secured by a standard two-piece buckle. In an effort to assure proper submersion of the MACS Sack in the event of their use during these dive operations, a one way purge valve is incorporated to allow for air to be squeezed from the bag.

The necessity for, and effectiveness in, keeping contained contents dry is evident in the "issue of four MACS Sacks to each Marine," ("Docstoc" [25]). The MACS Sack keeps the contents dry without any problems, but the inherent problem when the bag is filled with equipment is the creation of small openings caused by the uneven distribution of material within the bag. These gaps can harbor air, even after the bag has been sealed squeezed, to purge the air.

If a large enough volume of air remains within the MACS Sack, submersion of the bag, which will be contained within the ILBE pack of the Marine, can become a problem. When the success of the Reconnaissance Marines' mission relies on proper submersion of themselves and their equipment, being unable to evacuate enough air from the bag can be a matter of success or failure, life or death. With this in mind, we have set out in an effort to improve the air purging capabilities of the MACS Sack for the Marines fighting for our freedom.

2.5 – Material Properties Considered

Many aspects and uses for this bag had to be considered before fully deciding on the proper material which could be used to represent our design. Being a device which must be durable, but yet flexible, we considered nylon and polyester fabrics to be the most useful items. Nylon itself comes from a family of synthetic polymers known as polyamides (Hegde, "NYLON FIBERS" [15]). Its uses range drastically from the first nylon bristle toothbrush to machining screws cast in metal. Chemically, it is comprised of diamine and dicarboxylic acids so that amides may form at both ends of the monomer. Due to this composition the durability and strength of this material are increased tremendously. Along with having high durability, a nylon product can also maintain a flexible nature in which the product has the ability to stretch and deform greatly. These features are quite necessary in the design of a sack which will be carrying various items essential to a Marine's mission. Being flexible and durable, nylons also have certain resistive properties which include weatherproofing to a certain extent, abrasion resistance, and longevity.

The characteristics of a nylon product are really why they are so great to use in applications such as this. As a necessary part of a Marine's diving sack, the bag must definitely be waterproof and lightweight. However, these are not the only characteristics that you will get with a nylon product. Due to its chemical composition, nylon has a high resistance to heat. Once heat reaches above its melting temperature it then transforms into amorphous solids (also known as viscous fluids), (Hegde, "NYLON FIBERS" [15]). Therefore, the heating of a nylon product would not create a burning effect but however would allow the product to melt and conform to whatever may be inside or around the product. Based on this, the sack and its contents could be salvageable in a fire or explosion if rescued within a decent time interval. Wallace Carothers, the scientist who first produced nylon, developed a product known as nylon 6,6. Nylon Type 6,6 consists of hexamethylene diamine with six carbon atoms and adipic acid (Hegde, "NYLON FIBERS" [15]). This process allows the nylon to maintain better weathering properties. If the pack were to take on excessive sunlight or cold it could then expand or contract instead of heating up or cooling down to intense temperatures. As Nylon 6,6 was developed the scientists also discovered that the product would now have a greater resistance to insects, fungi, animals, molds, mildew, and many other chemicals (Hegde, "NYLON FIBERS" [15]). This feature can be very appealing to the design of a liner for the Marines. While on long and grueling expeditions Marines can encounter various forces of nature which may intrude on their belongings. If any sort of insects or mold were to infiltrate their food and belongings it would then become increasingly difficult for them to partake and survive for long periods of time. With the development of Nylon 6,6 - this has no longer become an issue.

Professor Carothers and DuPont Labs worked together to develop Nylon 6,6 and derived some great uses for it. During the Second World War DuPont Labs used its nylon product in many military applications. Throughout the majority of wars preceding World War II, asian silk and hemp were used instead of nylon. DuPont developed a way to use nylon in parachutes, tires, tents, ropes, ponchos, and other military supplies during the war (Hegde, "NYLON FIBERS" [15]). By allowing the military to use these new products would allow the world to see how useful and diverse nylon can be. If it is tough enough for the military to use then it is most definitely tough enough for the average individual to use. This was seen throughout the year of 1945 when manufactured fibers began to be used in twenty five percent more products while cotton began to drop in usage (Hegde, "NYLON FIBERS" [15]). It can be seen that nylon products have been on the rise since the early forties, and new usages and products using nylon are still being developed to this day. Based on its lightweight design and durability, nylon can be produced at a relatively cheap price which is appealing to the general public.

Based on the analysis of the product nylon, it is almost without a doubt that some sort of nylon product will be used in the making of this new MACKS Sack. Its properties and chemical composition are in no way a hindrance or danger to a Marine, but instead keep the Marine’s belongings safe and secure. Its characteristics include the ability to resist weathering and outside chemicals that may enter the bag and contaminate its belongings. With these abilities Marines can concentrate on their own fight instead of the natural occurrences which can create an attack without anyone ever noticing. Further research has shown that nylons properties also allow it to maintain a resistance against water and liquids which may attempt to penetrate it. Keeping the contents of the sack dry is at an utmost importance for the survival of our soldiers. Therefore a major objective for this project has been to discover a nylon or polymer which suits the needs and specifications of our design.

The current issued MACS Sack uses an Oxford Nylon for the material of the bag. According to an online source, Oxford Nylon is recognized as a stiff coarse nylon fabric with a basket-like weave and a durable finish ("What is ‘Oxford Nylon’” [45]). These nylons have been normally used in athletic style jackets. The MACS Sack, developed by SEAL Line, is also finished with a polyurethane coating to increase its durability. Based on our knowledge of shearing and stress in materials, the development of the Oxford Nylon was an ingenious invention. Based on its weaving basket-like design, the liner will have a greater strength than most nylon liners. This is true because the weave design allows the fabric to cross over and layer up on top of each other as would a homeowner’s lattice. With a weave the fabric gains strength in the tensile direction. As the fabric is stretched the weave expands and tightens around the other fabrics which cross over it. This design is far more durable than a liner that consists of a horizontal or vertical fabric weaving. With an increase in tensile strength, the pack gains the ability to pack more items inside itself without failure. Puncturing the bag from the outside would be the only chance of this bag failing a tensile test.

The design of Oxford Nylon can closely be compared to that of a truss system. In structural engineering a truss is clearly defined as a structure comprising of one or more triangle units which take on external forces in either the tensile or compressive direction (Martini, Kirk.

"Trusses: Classical Truss Theory" [29]). Due to them being designed as triangles the members can take the compressive and tensile loads on at every point therefore stabilizing the structure. This is common practice in the design of a building or bridge truss because it has been proven to be successful. As in the Oxford Nylon design a weave pattern is used. This weave pattern creates a set of triangles at each cross of the fabric. Based on this design and the design of trusses, the fabric will excel in taking on external forces.

With these assumptions in mind, it is almost necessary for us to discover a nylon or polymer which possesses some similar properties to that of Oxford Nylon. A nylon which contains the ability to repel external forces but yet is lightweight and has the characteristics mentioned earlier would be ideal for the use in the design of this new sack. As long as weight and price are kept in mind, a new design for the MACKS Sack could improve the overall quality of the product.

A new nylon material must be used to incorporate all the necessities of the United States Marines. As an objective to this projective the sack must remain waterproof and weather resistant, but must be able to remove air from inside itself at a decent rate. The current MACKS Sack contains a valve on the outside which removes air when the bag is compressed, but it does this rather inefficiently. As part of this new design a better pump or valve system will be integrated on the outside of the sack to increase the amount of air that is releases thus allowing the Marine's to dive deeper under water without being propelled to the service because their pack is too buoyant. The new nylon that seemed to be the best fit for this type of product was found to be one known as Weather MAX 65. This nylon is a

> "100% solution dyed polyester incorporates UV resistant characteristics for long-term color and strength retention along with excellent breathability and abrasion

> resistance. The Hydro MAX finish raises the bar of hydrostatic performance and delivers unsurpassed water repellency, mildew and oil resistance without relying on environmentally unfriendly coating compounds. Weather MAX 65 has anti-microbial properties and a minimum UV resistance of 1000 hours but only weighs 6.5 oz./sq. yard due to the use of a filament rather than a spun yarn like acrylic fabrics. Excellent for anything from horse blankets to tough outerwear to marine grade tarps."
>
> *(Seattle Fabrics, Inc., "Coated and Uncoated Nylons" [6])*

As can be seen in the description for this product, it has all the necessary aspects that nylon should have to endure what a Marine may go through. As described, this polymer only weighs 6.5 oz/sq. yard. This is a needed aspect since the dive op Marines will still need to pack all their necessary belongings but at the same time maintain a safe weight on their backs which allows them to swim and dive. This type of material also comes in various colors including burgundy, forest, pacific blue, navy, toast, charcoal, black, and white. My choice would be burgundy because of the famous recon Marine who was known as Ron Burgundy. The price of this material is around fourteen dollars and fifty cents per yard. Although this may not be the cheapest nylon per yard, it does have a greater strength and durability than other polymers which go for around nine dollars and fifty cents per yard. With the use of Weather MAX 65 polymers the liner would then be able to resist UV rays which could harm the contents of their MREs (Meals Ready to Eat). Allowing food to last longer allows the soldier to then stay out on his mission for a much longer period of time. Another interesting aspect of this material is that it is not coated with anything like the polyurethane that coats Oxford Nylon products. Without any coating this product resists cracking in severe cold temperatures (Lee Sail Covers, "Weather

MAX" [44]). The strength and resistance statistics of this material can be found in the table shown below.

Table 2: Oxford Nylon Material Properties

Tensile Strength (warp x fill)	ASTM D5034	Lbs.	492 x 370
Mullen Bust	ASTM D3786	psi	393
Tongue Tear (warp x fill)	ASTM D2261	Lbs.	20 x 18
Taber Abrasion	ASTM D3884	cycles	600
Hydrostatic Resistance	AATCC 127	cm	65
Spray Rating	AATCC 22	cm	100
Air Permeability	ASTM D737	cm	1.3
Circular Bend Stiffness	ASTM D4032	Lbs.	6.5

With the given size of the current MACS Sack, this new material can take on a huge load while at the same time maintaining its shape without tearing of puncturing because of the flexibility of this nylon. Comparatively to Oxford Nylon which costs between nine and ten dollars per yard the Weather MAX 65 polymer may be more expensive but has better properties for the situations that Marines, or any other military personnel for that matter, may encounter.

Other Materials to consider for this pack are the epoxy which will be applied to the bottom of the pack where a possible pulley system will be attached to help remove air from inside the pack at a higher rate. With that in mind, other changes to the outside of the pack may also include the addition of a handheld pump or vacuum system which will also help to remove air. All these additional systems must be economical and safe for the use by Marines at all times.

The materials, size, weight, and cost of these additional mechanisms must be considered to develop the greatest product possible. The use of pulley and pump systems will be discussed later in the design aspects of our newly designed bag liner. To design something is great, but to make something better that has already been proven to work is tremendous.

CHAPTER 3. PROJECT METHODOLOGY

3.1 – Analysis of Problem

Originally the MACS Sack was not designed for underwater use. The valve was placed to allow the user to push our air to make more use of room. While this allows for most of the air to be purged, the contents of the bag form natural air pockets inside of each other that simple compression cannot reach.

The force from residual air in the MACS Sack becomes greater with depth. Imagine a cubic meter of air in water, the way the upward force works is by the water pressure pushing in on it from all sides (remember pressure increases with depth) Archimedes principle says that the combined effect of the fluid pushing on the cube is the weight of the fluid it displaces. Therefore even a small amount of air in deep water dives can cause huge upward forces on the marines making them work harder or even be unable to get to their destination.

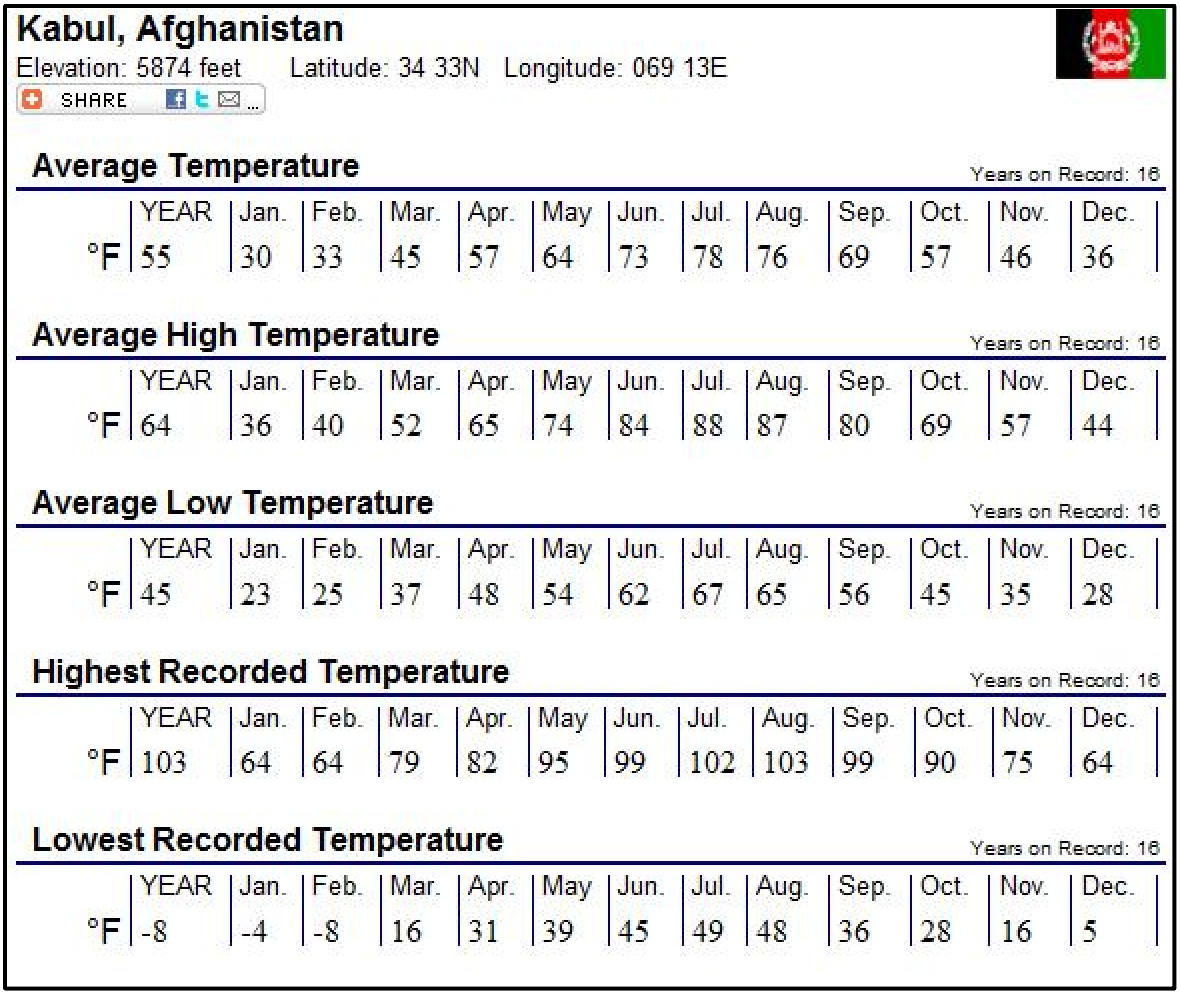
The air pockets in-between the contents is an issue at greater depths but it also hinders for pre dive manual compression. If the bag cannot be compressed before hand, it is uncertain the air will be purged. As mentioned earlier the valve is pressure induced. If the marines need to cross a river quickly or make a short dive operation, the pressure isn’t always great enough to purge the air. While this isn’t a major issue it still requires the marine to work harder and can hinder his operation time

Marines are always in constant danger and may need to leave in a moment’s notice. Ideally the system should be able to deflate the bag in as short as time as possible. An ideal solution would have to be as simple and light weight as possible.

When a job needs to be done, it is of utmost importance that the tools needed for the job function properly. For the United States Marine Corps, if the tools they use for their job do not work correctly, it can be the difference between life and death. For the Reconnaissance Marines, they face the most extreme conditions every day on the job. They operate in the most extreme environments, from deserts to mountains to oceans. Different environmental conditions which the Recon Marines must endure consist of a broad range of temperatures, extreme weather conditions, different operational requirements, even the simplicity of operation during both night and day.

Temperature can be a major factor in the function of the Reconnaissance Marines and their equipment. In Afghanistan, the location in which the majority of the Reconnaissance Marines are currently deployed, temperatures range from highs of nearly one hundred degrees, Fahrenheit to below thirty-two degrees, Fahrenheit ("Weatherbase" [23]), they encounter temperature at both ends of the spectrum (Table 3). Often times, from night to day, the temperature may swing in excess of thirty degrees, Fahrenheit. This requires the Recon Marines to be prepared for all temperature conditions.

Table 3: Temperature Chart of Kabul, Afghanistan



Kabul, Afghanistan

Elevation: 5874 feet Latitude: 34 33N Longitude: 069 13E

Average Temperature

Years on Record: 16

	YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
°F	55	30	33	45	57	64	73	78	76	69	57	46	36

Average High Temperature

Years on Record: 16

	YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
°F	64	36	40	52	65	74	84	88	87	80	69	57	44

Average Low Temperature

Years on Record: 16

	YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
°F	45	23	25	37	48	54	62	67	65	56	45	35	28

Highest Recorded Temperature

Years on Record: 16

	YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
°F	103	64	64	79	82	95	99	102	103	99	90	75	64

Lowest Recorded Temperature

Years on Record: 16

	YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
°F	-8	-4	-8	16	31	39	45	49	48	36	28	16	5

The range of temperatures experienced by the Reconnaissance Marines in Afghanistan may not even compare with the extremes which they may be required to endure elsewhere, where temperatures may be tremendously high, in excess of one hundred degrees, Fahrenheit, or tremendously low, much less than zero degrees, Fahrenheit. While in colder climates, the Recon Marines will require a larger amount of equipment, solely for the sake of remaining warm and being capable of functioning in extreme cold. The warmer climates would not require as much equipment for remaining warm, but would require the capability for consistent hydration.

In the event of being deployed in a region in which there are large temperature swings, such as in the deserts and mountains of Afghanistan, having necessary equipment to adjust to the temperature gradients is imperative. During daily operation, the recently employed, standard operational MARPAT uniforms (Figure 6) are sufficient for their purposes. They keep the sun off of the Marines' skin and insulate effectively in the event of a colder than normal day, on warm to mild temperature days. When the temperature of the region in which the Reconnaissance Marines are deployed is quite low, they will require heavier clothing, such as a jacket seen in Figure 7, heavier pants and a stocking cap.

Figure 6: Desert MARPAT

Figure 7: Thermal Desert MARPAT

Weather conditions can play a major role in the equipment load out of the Reconnaissance Marines. Whether deployed in the jungles of South America, or the deserts in the Middle East, the Marines experience weather conditions of all extremes. They must endure snow and rain and wind and intense heat. In dry environments, additional equipment may not be needed by the Marines. But in environments in which there are copious amounts of rain or moisture, the need arises to assure that the Marine can remain somewhat dry.

For the Reconnaissance Marines, maintaining a state of dryness is the least of their worries. The major problem with a wet environment is keeping equipment essential to the completion of a mission dry. With countries in Central and South America receiving rain, on average, sixty-seven percent of the year, two hundred and sixty-two out of three hundred and sixty-five days in Panama City, Panama ("Weatherbase" [23]), the probability of the Reconnaissance Marines encountering rain while deployed in these regions is very high.

The Marines, and, especially, the Reconnaissance Marines, are trained in the harshest conditions which can be achieved at locations such as Marine Corps Base, Camp Lejeune in Lejeune, North Carolina, and Marine Corps Base Quantico, which is in Quantico, Virginia. The equipment, on the other hand, cannot be trained like the Marines. The Marines are put through the toughest challenges to increase their tolerance to pain, fatigue, and weather conditions. With Reconnaissance Marines, you can make the comparison to a piece of steel stock being strained and beaten. Cold working steel will increase the strength of the steel stock, and the more it is worked, the stronger it will become (“Engineers Edge” [7]). The equipment which they are issued cannot be challenged, repeatedly, and hardened to resist conditions more extreme than it was designed for.

Unlike a piece of steel being cold hardened to increase its strength, the equipment issued to the Reconnaissance Marines has an established threshold for breakage or failure. Once pushed past this limit, the equipment will fail, and become useless. The failure of the equipment of a Recon Marine can be detrimental to the success of a mission, or even to the safety and survival of the Marine. The dependence upon the equipment which will, most likely, be contained within the Marine ILBE, is much too great for there to be any additional stresses placed on the Reconnaissance Marines' load out.

While deployed in any location, the Reconnaissance Marines will be subject to the change of the hours. They will be operating at all hours of the day and night, through hazy sun rises to moonless nights. With the different lighting conditions surrounding the Marines, having appropriate equipment to combat this is necessary. Many enlisted men and women carry sunglasses on them to fight the bright sun, often times relying on those provided by Oakley Incorporated (Figure 8) to our service men and women. The sunglasses used are, most often, polarized to reduce the glare present with sunlight reflecting off of the sandy desert surface. The eyewear provided by Oakley Incorporated is tested to extreme specifications ("Oakley" [33]), for

Figure 8: Oakley Tactical Sunglasses

impact resistance, scratch resistance, as well as for their hydrophobic qualities to prevent build up of liquid or moisture on the lenses to prevent obscured vision.

In addition to the sunglasses utilized by the service men and women, the presence of wind blowing sand around warrants the use of goggles. The goggles utilized are, essentially, winter goggles one would use whilst skiing or snowboarding (Figure 9). Also provided by Oakley Incorporated, these goggles prevent sand and dirt from affecting the vision of the soldiers in the extreme conditions they are currently subject to while deployed in the Middle East.

Figure 9: Oakley Goggles

During the nighttime, lighting conditions can range anywhere from several light bulbs to no light at all. While being indoors or in an area in which light is provided- even if just barely so- vision is not greatly impaired. In the worst case situation, the Reconnaissance Marines may need to enlist the assistance of a flashlight, such as those provided to our service men and women by Insight Technology ("Insight Technology" [20]).

Figure 10: Handheld Insight Flashlight

Figure 11: Weapon Mounted LIght

Insight Technology Incorporated, an L-3 company, produces flashlights for handheld use (Figure 10) and weapon mounting (Figure 11) which can be seen above. In addition to the tactical flashlights provided by Insight Technology, they also provide weapon mounted and handheld optics, such as red dot sights (Figure 12), laser range finders (Figure 13) and weapon mounted night vision optics (Figure 14) for the armed services.

Figure 12: Red Dot Sight

Figure 13: Laser Range Finder

Figure 14: Weapon Mounted NVO's

All of these items are utilized by the Reconnaissance Marines during their missions, and must be carried on their person in some fashion.

One factor which will affect the load out of the Reconnaissance Marines is the mission statements, and operational requirements. Although, after the infamous incident of the Battle of Mogadishu, which was part of the United States' Operation Gothic Serpent, in which a simple reconnaissance mission turned into an ongoing battle in the city of Mogadishu, in Somalia, many soldiers prepare for the worst possible scenario for the sake of always having an advantage.

A situation in which a mission encompasses less than twenty-four hours is very rare for the Reconnaissance Marines. Most often, they are deployed on lengthy operations which span weeks at a time. This length of time in which the Recon Marines must be out, and self sustaining, requires that they have all of the necessary equipment with them for completion of their mission.

The ILBE pack which every Marine is issued is designed to hold a maximum amount of equipment and supplies which can be crucial to the mission at hand. When extreme temperatures and weather conditions are presented to the Reconnaissance Marines, they must, also have a way to keep essentials at operable temperature, or, in many cases, dry. The necessity for preventing saturation of the ILBE pack contents led the Marine Corps to issue Marine Corps Stuff (MACS) Sacks (Figure 15) to every Marine. “Marines who were issued an ILBE will be issued four (4) Marine Corps Stuff Sacks, (“Doc Stoc” [25]). These dry bags allow for Marines to easily organize and waterproof the contents of their pack by placing the items into the MACS Sack, and properly closing the Sack.

Figure 15: Cascade Designs MACK Sack

The simplicity and ruggedness of the MACS Sack is precisely the function which Marines require in the use of all of their equipment. Designed to release air through a one way pressure valve, the Marine must close the Sack, and apply pressure to it. This pressure forces air to pass through the valve, allowing it to escape the Sack. The inherent problem with forcing air out of the MACS Sack is that when it is filled with equipment, there are spaces within that cannot be evacuated of air due to the combined structure of the contents of the Sack. When this occurs, incompressible pockets of air remain in the MACS Sack.

Normally, the air within the MACS Sack does not present any problems. This inclusion of air is not a factor during missions in which the Reconnaissance Marines operate on land, even if they must parachute to in to their destination. The major problem with the presence of air within the MACS Sack arises when the Recon Marines must submerge themselves and all of their gear.

The Reconnaissance Marines must operate on land, sea, and air. The Special Forces battalion for the Marine Corps, they are well versed in underwater operation. During these underwater operations, many times they are required to submerge themselves with the intentions of reaching a structure or land mass on which the use of equipment not intended for prolonged submersion will be necessity. Placing the equipment within the MACS Sacks, the Recon Marines must maintain possession of all gear issued while travelling underwater, dragging it all along with them for the duration of the swim, (“MARSOC Marines” [28]).

This is when the presence of the pockets of air becomes a nuisance to the Marine. When filled and compressed, the MACS Sack may harbor enough air to create a buoyancy force of approximately eight pounds. The eight pounds is an upward force that the Reconnaissance Marines must overcome to submerge themselves and their gear for the duration of their submersion. This may appear insignificant, but that value was tested for a single MACS Sack. With every Marine being issued four Sacks, this value is multiplied by that factor, and they are faced with a total buoyancy force of thirty-two pounds.

The buoyancy force of thirty-two pounds is more difficult to overcome than the eight pounds of a single MACS Sack. Additionally, this testing was done at a depth of approximately thirteen feet. Depending upon the requirement of the mission, the Reconnaissance Marines may need to dive to greater depths for the sake of stealth or avoiding obstacles. As the depth which they must reach increases, the buoyancy force of the MACS Sacks will become magnified.

After contacting a member of the naval division of Natick Labs in Natick, Massachusetts, we established that Marines have trouble, not only keeping their equipment with them, at depth, but that they have difficulty in the initial submersion of the pack, as well. With this in mind, we set out to determine a method to improve the ability to submerge the ILBE pack through the modification and alteration of the Marine Corps issued MACS Sack.

<u>3.2 – Design Restraints</u>

After much research and consulting of official sources, we were able to come to the decision of focusing on the MACS Sack. This would allow us the most reasonable direction for implanted design alteration in the realistic application. Given that the ILBE pack (Figure 16) is issued to every Marine in service, and is a recent design, any alterations or intended improvements to the design would be unreasonable were we to present them to the correct authorities.

Figure 16: USMC ILBE Main Pack System

To make modifications to the Marine issued ILBE would not be plausible due to the fact that there are already thousands in the field, and any design change would require that they all be replaced in a small amount of time to assure that all of the deployed soldiers utilizing it have the most recent equipment at their disposal. “Designed by Arc’teryx’s LEAF (Law Enforcement and Armed Forces) program and manufactured by Propper Inc., the USMC ILBE is made from

Cordura 725 denier fabric, with pixilated MARPAT (MARinePATtern) printed onto it," ("military-backpacks.com" [30]). Arc'teryx LEAF created the best possible load bearing pack that incorporated everything the Marines required for this purpose. The improved pack is designed to carry a greater volume of equipment, and to make it less strenuous for the Marines to carry the greater weight.

Made up of three main packs, the ILBE Assault Pack for missions of less than a week, the ILBE Main Pack for slightly longer missions, and the ILBE Hydration System (both the Assault Pack and Main Pack can be combined for extended time in the field), the ILBE could be adjusted to maximize the storage volume from one mission to the next. The versatility of the ILBE makes it optimal for the use of the Reconnaissance Marines. With such a great amount of work and time put into the design production of the Marine issued ILBE, the United States government, as well as Arc'teryx LEAF, would not want to stop producing the current, successful design to implement minor design alterations presented by a group of college students.

Understanding that the Cordura fabric implemented in the ILBE pack is porous, and far from air tight, and only water *resistant* (as opposed to waterproof), submersion of the ILBE would cause any air within the pack to be forced out by the water which will soak through the outer material of the pack. This knowledge allowed us to focus on a more direct approach to preventing air inclusion.

The MACS Sack issued to Marines is a simple dry bag. Designed and marketed by Cascade Designs-Seal Line, the Marine issued MACS Sack is closely related to the commercial dry bags (Figure 17) available to anyone looking to keep their belongings dry in a wet environment.

Figure 17: Cascade Designs' Sea Line Series

These bags can be purchased at any outdoor equipment distributor such as Eastern Mountain Sports® or REI. The commercial sale of dry bags can be affected by the improvement of the design in any way.

The application of designs for the military often times trickle down to the civilian market because there is a large amount of money available to design and produce the best equipment for the men and women fighting for our freedom. Once this has been accomplished, the technology has already been developed and can easily be implemented and assimilated into the civilian market. A good example of the assimilation of technology designed for the military into the civilian market is the Camelbak® hydration system.

Designed for improved hydration for the military, the Camelbak® design allowed for easy access to a larger amount of water than canteens had provided. The collapsible water bladder prevented splashing and noise, and the ease of use was tremendous with the bite valve which allowed the user to drink without slowing them down. The design utilized for the military (Figure 18) was easily carried over for outdoor enthusiasts (Figure 19)

Figure 18: Camelbak Dessert

Figure 19: Hydration Pack

Our goal was to come up with a design that would lead to, only, a minimal alteration for the MACS Sack that can impact the armed services, and possibly the commercial market. This design would need to be compatible with the size and shape of the MACS Sack, be easily added to the production of the Sack, and not be costly to the manufacturer or producer. We had basic restraints that would limit the final design of our modification to the Sack.

Focusing on the dimensions of the MACS Sack, we knew that we did not want to have to change the size and shape of the MACS Sack in any way. The dimensions of the MACS Sack are as follows:

	9L
Color	Olive Green
Weight	3.3 oz / 93 g
Diameter	7 in / 18 cm
Height	13 in / 33 cm
Volume	549 cu. in / 9 liters
PVC-Free	Yes
Country of Origin	Made in Seattle, USA

Table 4: Dimensions of Standard Model MACS Sack

The Sack has “an internal volume of nine liters, it has an expanded diameter of seven inches, and a sealed height of thirteen inches,” ("Cascade Designs-Seal Line" [36]). There is a single flexible purge valve on the side of the Sack, and we wanted to modify the bag so as to maximize the ability of this valve to allow air to escape the bag.

Considering different options for improved air removal, we did not want to implement anything that would require putting holes into the MACS Sack for fear of degrading the high level of toughness already built in to it. Any holes would create stress concentrations which could lead to premature failure of the Sack during use in the form of tearing of the nylon fabric. The only method in which this would be successful is if we were to securely fasten additional material over the hole, similar to the fashion in which the flexible valve currently on the MACS Sack is attached.

Because of the fashion in which the MACS Sack is filled, making changes to the interior could, also, lead to premature failure. When filling the Sacks, the Marines will be rapidly stuffing equipment inside with disregard for the material and layout of the Sack. If we were to modify the MACS Sack interior, it would create unwanted edges, lips, or seams which can be pulled at by every piece of equipment. Flush mounted attachments would be required, affixed by epoxies.

The simplicity of our modification would be proportionate to the ease of production and inclusion in the production of the MACS Sack. In an effort to make an alteration to the Sack, we considered methods that could attach directly to the outside of the bag without affecting the strength of the nylon fabric of the bag, or the “high-tenacity polyurethane coating,” (“Cascade Design-Seal Line” [36]).

In addition, using a design that would be simple and cost effective would be optimal. Placing an additional flexible valve would be simple due to the fact that the valves are already readily available during production, as well as the placing of the hole and proper epoxy. Minimizing the amount of material we must add to the MACS Sack would allow the smallest cost and possibility of obstruction when a filled Sack is forced into an ILBE pack. Also, less material to be added makes the plausibility of incorporating the inclusion of our modification into the production process of the MACS Sack.

The basic restraints to our design are inclusive of the original design of the MACS Sack. We were no able to make alterations to the shape or size of the Sack, limited to adding material to the bag. In keeping as close as possible to the exterior dimensions, we can only add a minimal amount of extra material in our design. Cost considerations and ease of inclusion of our improvement, though, will be the overshadowing factors that can only be swayed by positive results from our design.

The pack design cannot include external apparatuses, cannot include appendages that can easily become tangled, and cannot prove to be a significant cost increase from the existing design. Any integration of a pump design would have to have a small profile, and ideally be able to fold up without any levers or actuating arms protruding from the housing. The pumps would need to be painfully simple, as the more complicated you make a design, the harder it is to repair. Improvements such as a purging valve, ripcord compression system, and possible integration of elastic bungee cord provide low-cost and reasonable design changes to the pack, without needing any complicated overhauls of existing designs. The simplicity of the ripcord, elastic bungees and reverse purging valves allows for reliable operation in the field as well, which at the military level is a must.

3.3 – Solution Iteration – The Design Process

The thorough investigation of the current design flaws brought us to consider several areas of possible improvement. Through active conversation, which involved extensive sketching and deliberation, our group arrived at a consensus on how to solve the MACS Sack's excess buoyancy problem. Our proposed solution takes on two faces: a compression-assist rip cord system, and a compact, manually-powered vacuum pump. Our intentions for these additions are not complicated: make it possible to quickly deflate the pack through general compression, and then remove all excess air by a few short strokes of a compact vacuum. The conversations held by our group served to bounce ideas off of each other and make sure our final consensus posed a durable, realistic, and reliable solution to the problem.

3.4 – Rip Cord Compression Assist

The ideal implementation of the ripcord system is to surround the bag with a network of cord that can be drawn together with a single pull to purge excess air from the pack. The existing design requires air within the pack to be expelled to the best of the Marine's ability before even closing the case, which requires rolling the bag or squeezing it manually. This solution is inefficient and difficult in battle situations, so the ripcord solution provides benefits in both regards. The pull cords can be evenly distributed around the outside of the bag to effectively wrap the bag in compressive force. This allows odd shapes of tools or equipment to fall into gaps within the cords, and the air surrounding the edges of the tools will be forced out when the cords are drawn inward and up. The cords will join to form a single cord at the top of the pack, so individual cords would not need to be pulled separately. A single upward pull of the main cord will draw the others inward, and with ties on the bottom of the pack, the bottom would also compress to some degree for maximum compression of the pack, and efficient expulsion of air from within. Elastic banding, as mentioned before, can aid in the compression of the bag by providing a base level of compression by which internal equipment may settle prior to the ripcord being used. The purging valve will allow the air to escape during the compression process, and keep the bag compressed by not allowing air to return into the bag without opening the valve manually. This is many times more efficient than rolling an open bag to reduce air, or trying to squeeze and close it using only your hands as the current design allows for.

3.5 – Manually Powered Vacuum Pump

The incorporation of a pump operated vacuum poses a very significant level of complexity to the pack, one that might be dangerous in field operations given any unpredicted mechanical failure. This risk, however, ultimately does not out way the benefit that a in-place vacuum would serve to completely emptying the MACS Sack of any contained air. The established problem is a reality for one explicit problem: no matter the degree of compression applied, it the pack contents must assume some irregular configuration and consequently create air pockets- this air can only be accounted for via a vacuum force. If left unaddressed, any air in such a pocket would create increasing buoyancy force the deeper the pack is submerged.

The vacuum pump design our group had envisioned would be very compact, very durable, and as lightweight as possible. The pump assembly would likely have to be fixated to the MACS Sack's side with equally durably and waterproof adhesive. The assembly would have to be made with both a very slender profile and very small cross section. Additionally, there must be a way of securing the piston and ram in the closed position to limit the possibility of it extruding accidentally and getting somehow hooked. The material for the piston, pump casing, and ram will be selected among a range of very durable, yet light, plastics – as to do so otherwise would add unwanted weight to the assembly. The pump would be connected via a short hose connection directly to the interior of the MACS Sack. This connection would be encased withing the pump profile and not inhibit the interior of the pack.

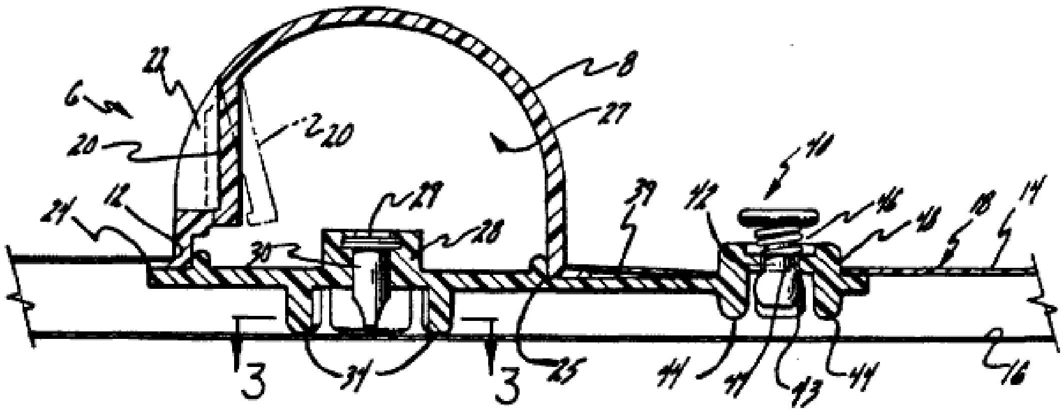
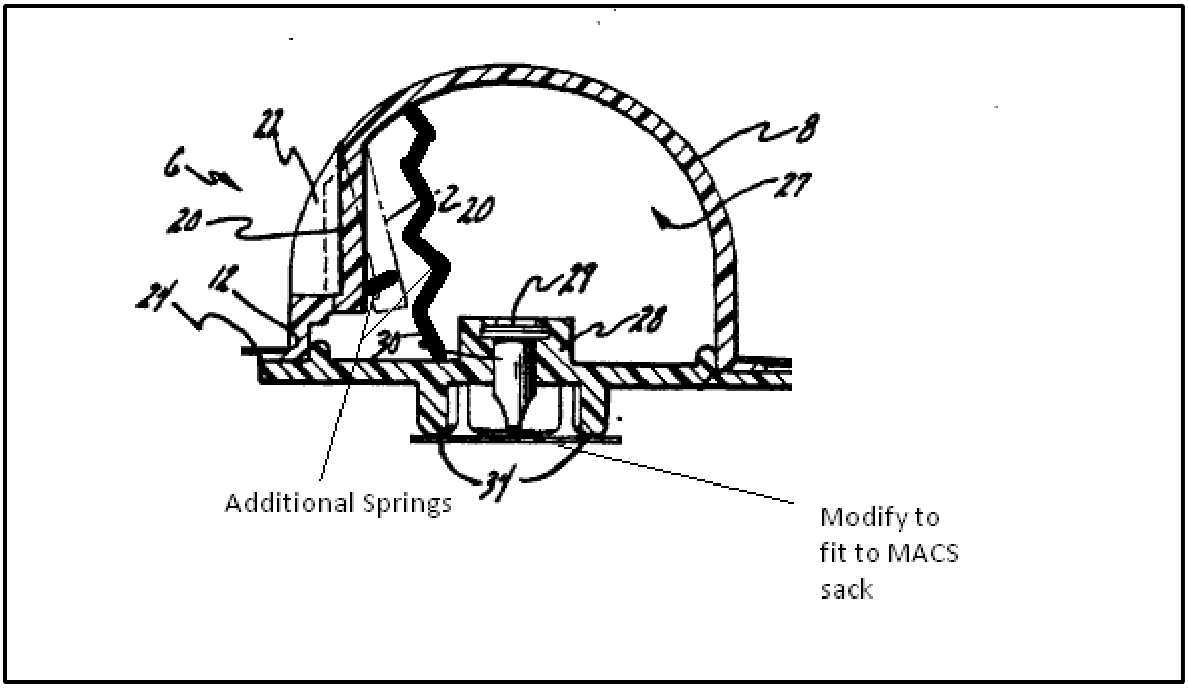


Figure 20: US Patent 5,074,765, Pekar, Dec 21, 1991

Another option to purge the air out of the MACS sack was the use of a pump. There are two main types of pumps, manual and mechanical. Since mechanical ones are often battery operated which would require carrying a power source in addition to the pump, and weigh significantly more, the team decided to stay with a manual design (See Figure 20 for a graphical explanation).

Show above would be a similar design to what we would use as a mechanical pump for our MACS sack. It is a dual valve design that would have to be modified for our use but the principal would remain the same. As you compress the bubble shown by the number 8, the latch 20 would open up allowing air to be released from the system. The pressure from the air flow would keep the first gasket 29 closed (Pekar). When you release the bubble, with the addition of springs forcing 20 to close and 8 to decompress, a vacuum would form pulling the gasket 29 open and air would travel from the high pressure system to the low pressure system. The opening 34 could be modified to form a seal to the valve on the MACS sack to allow air from it to be pulled out. (See Figure 21 for a preliminary modification).



Additional Springs

Modify to fit to MACS sack

Figure 21: US Patent 5,074,765, Pekar, Dec 21, 1991. Desired Points of Modification

There are ups and downs when using a pump to release air over manual compression. The first notable negative of a pump would be extra weight and storage space. The Marine carries an average of 100 pounds of gear, one of our goals was to create a system that minimized weight and the pump would add a decent amount. Even if they had the weight to carry the pump, there isn't necessarily the space to do it. The bags are already packed to the brim, and if the pump was damaged during transport it would become useless and much more of a hassle to replace then a simple manual system. If the pump isn't damaged by being crushed, you can tell from the design above if the dome (part #8) is punctured by anything, it immediately becomes useless thus making it somewhat of a fragile peace of equipment, not something that would stand up well in a fire fight.

Even though the negatives seem to rule out the pump all together, there are reasons to consider it. To start off the pump would require a lot less effort to use, instead of squeezing the bag with all you might, you would be able to just compress the bubble. It would also control the air coming out of the bag, as there are fewer factors affecting it. Strength would no longer be an issue, so everyone would be able to compress the bag to the same result. Since the pump would directly pull the air out of the valve, there should be less accidents preventing air from going through the valve. Since the air would naturally flow to the vacuum created, you would not have the issue where you compressed the bag at a poor angle resulting in little air being purged. If one Marines' vacuum broke, he/she could simply borrow another until it is replaced. Lastly and perhaps one of the most promising positive of the pump is the ability to purge more air than the manual compression. When a Marine packs the MACS sack, unless packed with the upmost care, there is a high chance that air pockets will be formed that manual compression would not be able to purge. The vacuum formed inside the pump would force the air from these air pockets out yielding better results.

The air pump for the MACS sack would consist of six major components:

1 – **Vacuum bubble**

This would have to be made of a malleable/flexible surface that is air tight and easily compressible with high shear strength to prevent puncture.

2 –**Gasket valve**

This would prevent the air from escaping back into the bag once the bubble is fully decompressed and would have to form a good seal to the base of the pump.

3 – **Spring Door Valve**

The main function of this would be to allow the air to be pressed out of the pump once the bubble is being compressed.

4 – **Spring Mechanism**

To assist in the decompression of the bubble and forming of the vacuum a spring could be inserted, in addition a spring could be inserted to seal the door valve once the bubble starts decompressing.

5 – **Base**

The base needs to be a strong light weight material that can support all the parts of the pump.

6 – Connecting mechanism to the MACS sack

This would be the most complicated part as we would have to make it air tight on the already existing MACS sack. Since the sack is already in production modifications to it would be counterproductive to the models already in service.

Key factors in deciding what the pump would be made out of included: durability, weight, and density. If the pump could not withstand the environments or daily activities of a Marine (which could range from a dive to a firefight while plummeting into the water from a helicopter), then it would be no use to the Marine. The Marine already has enough stress and weight in the equipment to begin with, if the density is lower than water then it would just add to the buoyancy issues, and if it weighs a decent amount then it will just add more strain than it's worth.

The first part to look at would be the base of the pump. This would have to have a high durability and be able to be formed to hold the rest of the pump together. Since the team has already looked at PVC before and seen its redeeming qualities it was decided to be the base material for the pump. The density is higher than water so buoyancy would not be affected, in addition it is resistant to weather and many chemicals and ultra-violated light so there wouldn't be a chance of corrosion due to the sea (Wilkes, et al [46].)

Attached to the top of the base would be the bubble that would form the vacuum to pull the air out of the sac. Due to its job, the material would have to prevent air from escaping, and form a good seal to the base. The first material we looked at was from a similar product, a plunger. The concept of a plunger is very similar to what we need our pump to do. When you press the plunger into a toilet all the air escapes from the dome of the base. When you pull up on, the air pocket from the pipes flows to the plunger unclogging the material blocking the path. The dome on a plunger is made of rubber. Rubber was first used in the industrial world in 1839. Its redeeming qualities were that of being a solid material that is weather resistant with a moderate resistance to many chemicals, and is easily deformed with high yield strength. With a density of about 1100 kg/m^3 rubber made an excellent choice for the dome of a pump.

Inside the rubber would be the spring door mechanism that would allow air out during compression of the dome. To accomplish this, a one way door of PVC material could be used that can only open outward from the dome. The pressure created from the air being compressed would open the valve allowing it to escape, and once released the spring would close the door shut. It is very important that the component is air tight, if there is an opening anywhere the pump will not work.

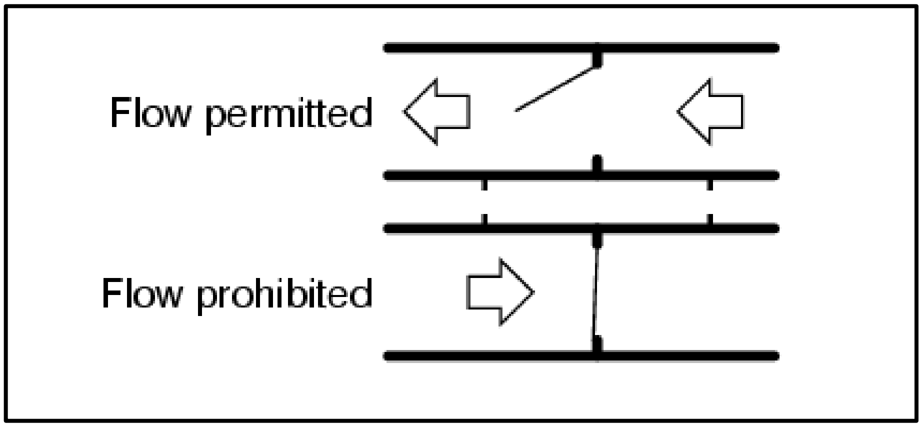


Figure 22: Check Valve Diagram. Different states of valve action.

The spring used to decompress the rubber bubble has to be strong enough to force the air out of the MACS sack, but weak enough so that a human hand can compress it. According to the NASA study, the average human hand has a gripping force of 134 lb for the right hand and 124 lb for the left hand (Jeeverajan “Human Performance” [22]). Using Hooke’s law and assuming the spring is being compressed 2 inches the spring constant for the spring being used would be 21602.319 lbs/in (2440.94 N/M). When you release the bubble, the compressed spring will return to its rest position forcing the rubber to decompress and pulling the air into the pump.

The gasket valve inside the rubber bubble would be the point of entry for the air from the MACS sack to the pump. When the vacuum is formed by the spring forcing the bubble to decompress, the force will open the valve and allow the air to travel to the low pressure system. When the bubble is being compressed, the pressure formed from the air pressing against the valve prevents the air from returning back into the sack.

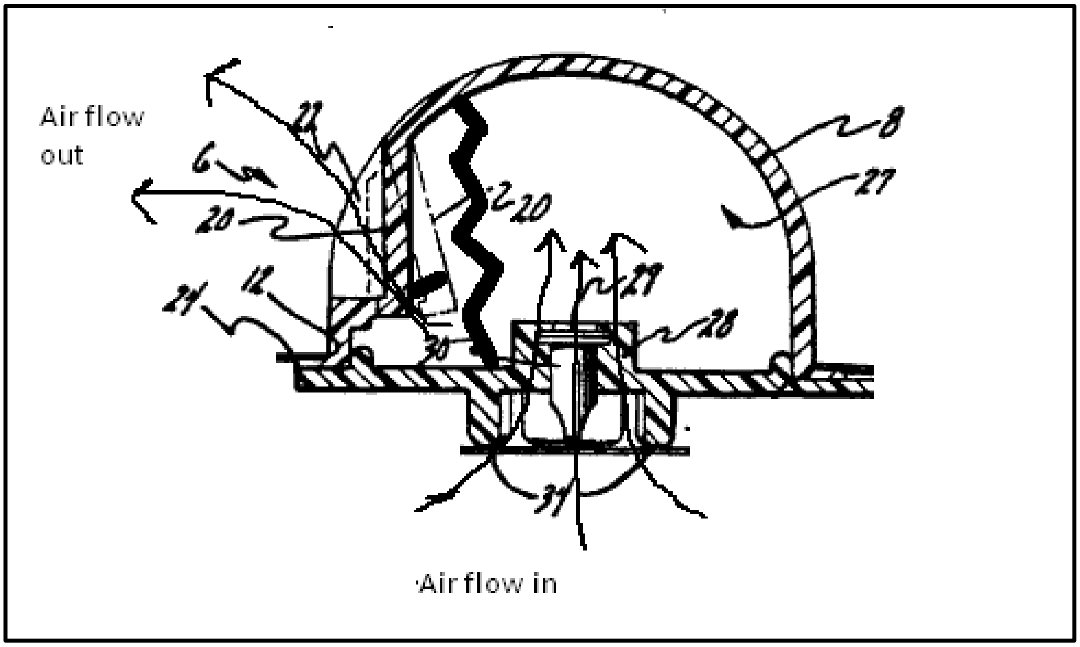


Figure 23: US Patent 5,074,765, Pekar, Dec 21, 1991

The material for the spring would be a light weight metal with a high elastic range and low density to reduce weight. Also even though the whole product will be air tight, they should be weather and corrosion resistant for good measure. The top and bottom should be fleshed out to increase surface area connection between the spring and the base and bubble to increase the efficiency.

The last part of the pump would be the seal between the pump and the MACS sack. This would provide the biggest challenge since the MACS sack would not be able to be changed. In order to create a tight seal onto the bag we searched for existing items already on the market. After doing research the best solution we found was rubber suction cups. They work very similar to the pump design we are using, instead of pulling the air out of an object, the vacuum is used to create a suction force that connects two objects together.

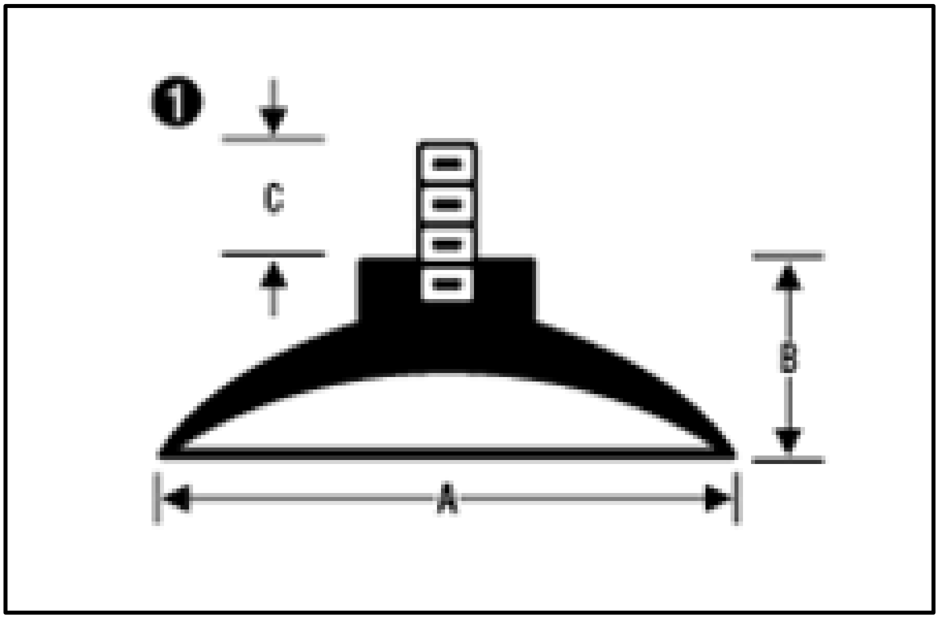


Figure 24: Suction Cup Cross Section

Since the gasket valve is already air tight at the top of the suction cup the seal will be formed the same way that it would if it was just a solid whole. If we extruded the bottom of the pump (presumably part of the base, so with PVC) we could attach a suction cup with a whole in the center that would seal it to the MACS sack. The sack is made of a flexible material so there would be no issue forming a seal.

As mention above the whole system would have to be air tight for it to perform to the tasks it is required to do. The whole system together could be quite small and easily fit into the bag of the Marines. One note to make, the bigger the dome for the bubble, the larger amount of air is moved per pump. With this in mind the sized would have to be optimized to the needs of the Marine. Since the densities of the parts are higher than water, the pump will not add to the buoyancy forces that we are trying to mitigate.

The most promising feature of the mechanical pump as mentioned earlier is the ability to remove more air out of the MACS sack than the manual system. The small amount of residual air inside the sack can produce large forces on the Marine when diving at deep depths (remember that each Marine carries four of these bags). Unfortunately due to the time and lack of materials we were never able to create and test the pump but we were able to do research on similar items such as vacuum pumps for vacuum sealing food.

While both solutions were viable, due to the extreme conditions a Marine has to go through, the manual system was chosen for the preferred choice. If something goes wrong with the pump during a combat situation, there is not enough time to find a replacement to use. Even if the nylon rope is damaged, unless it is torn completely through on each rope, it can still function. Also to note is the time difference, pumps could take at least 30 seconds to purge all the air out of the system. On the go the manual system can be used in the matter of a second or two, not to the success of a pump, but enough to release a large portion of the air.

3.6 – Solidworks Computer Modeling

The process of generating a SolidWorks model of our redesigned pack has been remarkably challenging. The nature of SolidWorks being a premier software choice for modeling rigid bodies hints at how difficult representing a soft body such as a nylon bag can be. While browsing the materials library within SolidWorks, the choices of different plastics and metals can be quite overwhelming. Especially so, when you must take into consideration the specific properties that this sack will require, such as relatively high ductility, and low weight.

The sack model will show the pack in its expanded, “inflated” form. The sack takes on a cylindrical shape, with a rounded bottom and an open top. The model features key additions from our redesign, including the cords lining the outside from the air purging system, and elastic stabilizing bands that add additional compressive force while also guiding the rip cords down the side of the pack for optimum compression.

The main body of the pack was made by generating a cross-sectional view of the sack in “inflated” form, and revolving half the shape to create the cylindrical body you would expect. The sketch was drawn on the front plane, and the revolved shape was drawn to a thickness of 1/10 inch to accurately represent the thin nature of the bag’s wall. After the body was revolved successfully, the exterior was given an olive-green military coloring to match our purchased bag as accurately as possible.

The ripcords were modeled by offsetting the original sketch from the revolved body to mimic the exact curves of the bag, and then placing a reference plane on top of the body, where the circular reference shape for the cords was sketched. This reference was lofted along the offset path, creating the first cord on the outside of the bag. This feature was then duplicated via circular pattern 5 times to create a network of six ripcords, joined at the bottom of the bag. The bottom of the bag was then mirrored to the top, completing the ripcord system’s main network of smaller lines, which upon sketching another line was finished by adding the final main ripcord at the top. The final cord was made a bit thicker to compensate for the additional force experienced during the air purging process, and to model what the cord may look like if the other minor cords are simply joined together to form the main cord instead of using an additional cord affixed to the others through adhesives or other methods.

The final feature added to the model was the elastic banding that would line the bag's exterior to compress the bag further, and guide the ripcord system for most effective compression. The process of creating this banding began by creating a mid-body reference plane parallel to the top plane by which the sketch could be drawn easiest. A circle was drawn over the exterior of the bag, to the exact diameter of the outer wall. This circle was offset by 0.15", which represents the thickness of the elastic banding around the outside of the bag. Additional circles were then added to the area around each ripcord to represent the lump the cords would create when the band is laid on top of each one. These circles were smoothed out by fillets, creating a

Fig 25: MACS Sack SolidWorks Model Rev. A

smooth looking band around the outside of the bag. This sketch was extruded 1.5” mid-plane to bring the banding to life. The finished band was then duplicated twice, top and bottom, to solidify the compression system with maximum stability. Three bands were used in the model, but cost considerations could allow for two thicker bands to be used in place of the triple banded system. There would be a minor loss in stability, but for the most part, the rigidity of the system would be maintained.

The importance of modeling the sack comes from the ability to convey the design aspects of the new sack improvements in a visual manner, helping others to realize any changes you’ve come up with in a quantitative way. Secondly, the model allows for testing within the SolidWorks environment itself, which when appropriate materials are applied, can provide incredibly important and valuable data to potential manufacturing companies or prototype designers without having to assemble a model at great cost of money and time. A virtual model saves the designers the hassle of potentially making a prototype that will fail, and allows for more thorough testing on a single model where a physical model would likely only be able to endure 1-2 tests at most. Multiple tests mean multiple prototypes, which also means more manufacturing time and money. So, by making this model in SolidWorks, we enable the design to materialize in the cheapest, most efficient way. As engineers, efficiency is key to the process with which we design our products, and being able to model in the virtual world allows us to have the best of both worlds: a model to test without significant financial or material risk.

More work will be conducted on the model in the near future, but for right now, the model we have will serve the purpose of getting our design strategy across to outside parties or other group members responsible for different design aspects. The model brings together many different design ideas, so everyone can collaborate more effectively while working towards the same goal.

3.7 – Means to Test Designs Experimentally

As a means of developing a more desirable way to sink the MACS Sack we have developed a series of tests. This testing will allow us to determine the sack's buoyancy when it is full and will also show what force is necessary (i.e. via draw string or vacuum pump) to remove enough air and sink the bag. First, we used a small controlled experiment to test the bag. The bag was filled with a common sweatshirt and not placed in water. Once sealed, we removed as much air as we could manually by squeezing the bag. We determined that other methods should be tested in order to see what was the most efficient manner of removing air from the bag.

The series of tests which will be conducted will isolate design variables such as the time devoted to sack compression, the volume of contents and remaining air space in the bag, the depths at which the bag will be submerged, and the combination of the various designs which we have come up with. Once we have finalized the designs we will then attach to the bag and begin the time tests. For example, we will take the unchanged bag, the rip cord idea, and the vacuum attachment separately and test how long it would take to remove the most air from the bag in the shortest interval of time. This, however, must then be compared to how practical the idea may be and how well the bag then sinks when the air has been dispersed. Once the bag has been tested with the same materials packed into the MACS Sack will then be tested with various different volumes of materials. This will help us to determine if one idea works better than the other. If the vacuum can suck the air out when there are clothes in the sack but cannot get the remaining air out when there are rigid food containers, then that idea may be plausible but not logical.

Next, the water testing will begin. We have considered testing the designs in various water types such as a chlorinated pool, freshwater lakes, and the ocean. At this point in time, the type of water, which the bag will be tested in, will not be worried about. We are mainly concerned with how the bag sinks or floats depending on which design has been used to remove the air. Also, once the bag has been submerged we will test its ability to remain buoyant or sink at different depths. This will show us how our bag will manage when a Marine dives deeper because as they go lower the pressure will be build and the bag will either want to rise to the surface or continue sinking. One of the final tests will be to combine some of our designs to decipher if having more than one is a better means of removing air from the sack. All tests described will be completed to calculate the buoyancy forces of the sack when it is filled with various materials.

Certain venues have also been chosen for the testing of our newly designed MACS Sack. The College of the Holy Cross swimming pool and Hart Center Diving Well have been considered for the testing because of the greater depths which we can utilize. The saltwater may add extra buoyancy to the bag and may also alter our results, and we would need to test the bag in different types of water. For freshwater, we have discussed taking a trip to Webster, MA and testing the sack in Webster Lake. Finally, for saltwater testing we could potentially take a trip to Falmouth, MA down in Cape Cod. These and other testing considerations will be discussed in further detail in later sections.

3.8 — SolidWorks Model Revisions.

As more design constraints and ideas were taken into consideration, the original revision of our SolidWorks model we had made earlier needed revamping to reflect these changes. The original model still adequately reflected the model we wished to create, with only slight changes made to appearances in order to better reflect design considerations regarding the ripcord system. These changes included lowering the structural elastic banding on the exterior of the bag so that the forces exerted on the bag could be better distributed along the entirety of the bag's outer surface, and not complicate or impede proper closing of the top of the sack.

Figure 26: Original MACS sack design created in SolidWorks, [Rev A]

To modify the model, the properties of the work planes within the original model needed to be lowered on the x-plane by 3 inches to provide ample room for the top flap to adequately fold over and seal properly. The middle plane provided a reference to not only the middle elastic band, but also the other two above and below the primary band as well. The references allow for only one plane shift to relocate all three bands without any additional modifications necessary.

This was great news, because this meant that the initially developed model was very close to what we would ultimately end up with in the prototyping phase, validating our design ideas and solutions and producing, ultimately, an excellent product.

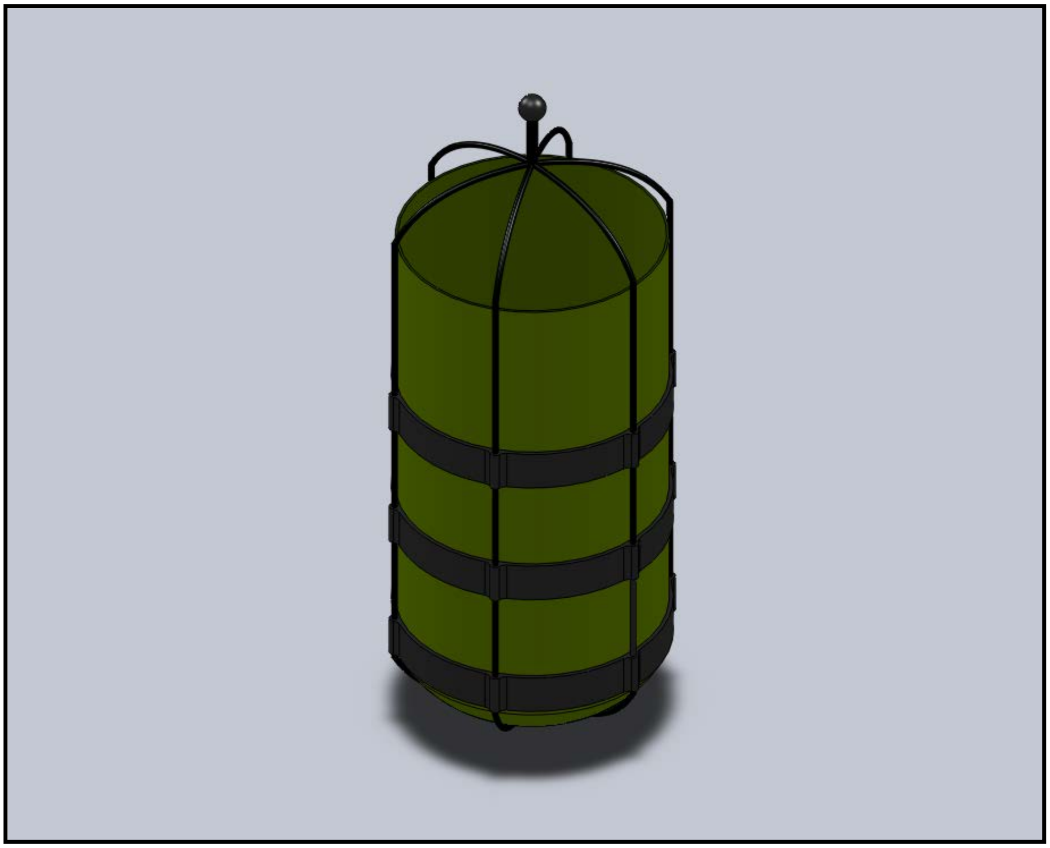


Figure 27: Redesigned SolidWorks MACS part (REV B)

Unfortunately, when adjusting the plane in the model, a few of the relations did not transition smoothly and required a rebuild to successfully propagate. After these minor adjustments, and editing of some other sketches within the part, the changes went through without a hitch, allowing me to create the drawing file attached below.

3.9 — From model to analog prototype.

Prototyping the MACS sack redesign on a limited budget was no easy task. The materials to modify a military-grade piece of equipment must be equally resilient, durable and, most importantly, inexpensive. The task laid out before us was not simple, but with the proper models developed in SolidWorks, and the physical MACS sack that we acquired, adapting our redesigned apparatuses became much simpler.

Our first step involved adapting our modeled changes within the virtual model (SolidWorks model) to the physical bag in our possession. The virtual model was based on high-end materials, which the military could feasibly use on a bag of this nature, which would naturally be difficult for the average college student to obtain. In place of such materials, suitable prototyping materials would have to be substituted with similar mechanical and physical properties. Obviously our limited budget would not allow the widest selection of prototyping components, but the design constraints were open enough to allow wiggle room in the prototype stage whereas significant data could be collected without severe loss of data resolution.

The bag lining itself did not need to be altered in any way, as the additions would only be external modifications fastened through adhesives in the absence of sewn elastic banding. The elastic banding outlined in the modeling phase was too difficult to obtain and fasten within budget and time constraints, so we actively began searching for a suitable analog to the banding. This analog would need to withstand significant moisture, pressure from deep water, and the forces generated by the rapid deflation of the sack. In addition, the banding would also need to replicate the elastic properties prescribed in the original design. The elasticity of the banding is crucial to obtaining complete compression, but adhering simple elastic bands alone would not accommodate the ripcord system from the design. For this reason, we decided to use a hybrid mix of both duct tape and elastic bands to achieve structural integrity as well as peak functionality.

The original design laid out in the SolidWorks drawing called for three bands to be used along the exterior of the bag, however this design would impede correct sealing of the bag under typical usage. The way the bag is currently designed takes into account a certain amount of rolling with the upper portion of the bag to enable a watertight, airtight seal. In the original design model, pictured below, the top-most elastic banding would be in the way of such a sealing action, effectively negating the point of a compression system if no proper seal can be attained. To counteract this impediment to properly sealing the bag, we decided upon moving the bands down on the bag to leave ample room for the bag to adequately close prior to compression. This also eliminates the potential problem of a large area of uncompressed air or mass settling at the bottom of the bag, leaving the sack misshapen and inherently buoyant. The shifted band location seeks to limit this from happening, with the compressive force of the elastics now focused more towards the bottom of the bag, as well as the compressive ripcord system centering lower for more evenly distributed pressure. The newer design, as mentioned in the previous section, took this into consideration by lowering the bands to more adequately spread the force over the contained area of the bag, rather than the upper region where only folding for a seal would occur.

The bands themselves were replicated with duct tape and elastic bands (explained in much more detail in the following section), and thin loops for the ripcord system to follow were adhered to the bag using hot acrylic glue. In this way, we were able to create the bands on the bag in a minimally invasive and cost effective way, to allow for testing of the bag in a quick and accurate manner.

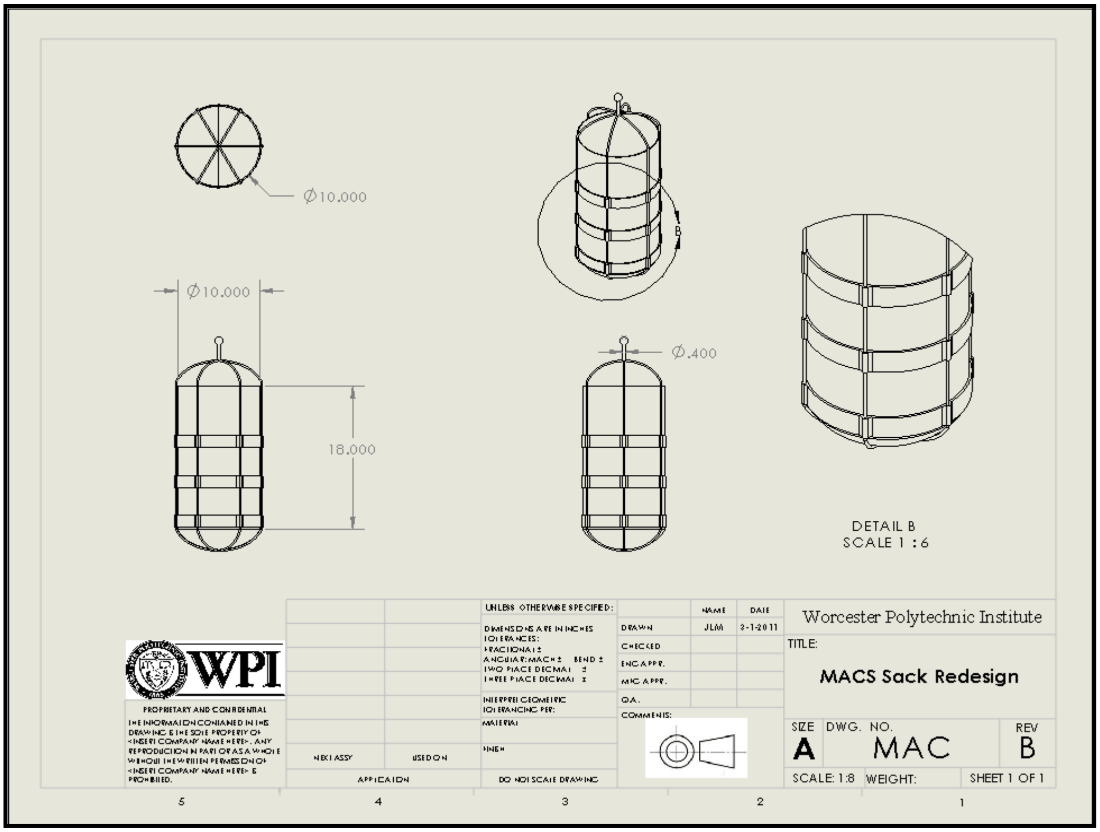


Figure 28: SolidWorks Drawing of redesigned bag (Rev B 3-1-2011)

3.10 — Testing impact on prototype sack.

The toll of testing in a prototyped product is essential to any objective testing. Our pack was no exception, where we would be subjecting the bag to extensive outside influence in and out of aquatic environments. The bag needed to withstand compressive forces, any deformation or damage from adhesive materials used in prototyping, and significant moisture and water pressure. Given these constraints, as well as a nearly non-existent budget, we embarked on creating our prototype as cheaply and structurally sound as possible.

As mentioned previously, our materials included rope, water ski cord, duct tape, ballpoint pen casings, and elastic bands. The rope and ski cord replicated the ripcord system, and could potentially be replaced with high strength, low cost variations made of nylon, tough composite plastics, or other cord materials used in military applications. The rope was initially used as a cheap option that was both readily available and in bountiful supply. Our haste in constructing the prototype bag led us towards using the rope for the prototype to conduct as many tests as possible; however it became immediately apparent that adverse effects from repeated usage and environmental factors (i.e. Excessive moisture from the pool or potential dive sites in the field) could render the rope ineffective. The quality of the rope originally selected was relatively poor compared to other, more expensive alternatives. It provided, however, very sound properties for creating compressive forces on the bag while maintaining minimal elastic characteristics. In essence, the rope would have been a good short-term testing analog for the cord, but we wished to test the bag multiple times to gather many data points, thus rendering the rope useless for testing.

The water ski cord presented us with a better option, albeit far more expensive and much less plentiful than the rope option. Luckily, one of our group members happened to have some on hand for the testing, thus allowing us to conduct testing of much higher accuracy to what we intended to design. The ski cord’s surface is much smoother than the rope, and can withstand considerable wear and tear given its applications for extreme sports. Skiing provides a harsh environment for sporting goods; meaning products such as the ski cord are made to very tough specifications. These specifications allow for excellent mechanical properties and rugged construction, making water ski cord an excellent candidate for our prototyping purposes. The ski cord was made from a Nylon composite material, making it extremely durable and exceptionally waterproof. The Nylon makes up the main body of the bag as well, and in a real unit would be used for the cloth portion of the elastic banding running along the outside in strips. The cord we used is primarily used to secure water skiing handles, or other water sports equipment, to a boat for towing along the surface of the water. The towing of an individual on skis, wakeboards, tubes or other equipment is an inherently stressful application of force on the cord. Knowing this, and what the cord is capable of, we deemed the cord a perfect solution to our ripcord system in all sorts of adverse conditions.

Figure 29: Ski Chord Similar to the type utilized

The moisture and exerted forces present in extreme water sport (wakeboarding, knee boarding, water skiing, etc.) conditions are particularly harsh on ropes of this type after repeated usage in varying surf conditions (calm vs. rough) and non-skiing activities. These activities could include such added weight as if one were to ride on an adapted inner tube towed behind a boat, possibly even with another person on board as well. With this taken into consideration, the cords were designed exceptionally well to deal with such adverse environments, making it a prime candidate for our testing purposes as well. In fact, the cord performed so admirably, and a true-to-design mock up of our bag could likely feature cord of similar properties in a final production design. For now, though, our rough prototype needed only to demonstrate the mechanisms we had developed, and truly adverse conditions and forces would not need to be tested to any great extent.

The role of duct tape in our prototype was pivotal in providing sound structural rigidity to the core of the ripcord system. The duct tape was used primarily as the analog for the elastic banding on the original design, but provided additional benefits as well. The first of which was the added adhesive from the back of the tape, which helped to secure the guide loops for the ripcords to the side of the bag. The second added benefit to the tape was the cost factor in relation to elastic banding, whereas duct tape is much less expensive and more readily available than the proper fabric-based bands. In addition to providing significant adhesion for the cost, the bag also suffers no significant damage during the testing due to the non-invasive or destructive application to the bag compared to the sewing necessary to effectively fasten the banding to the bag. Penetrating the bag with a needle during sewing would also potentially compromise the watertight and airtight qualities of the liner. Duct tape is known for its versatility in almost all repair applications, mostly due to its watertight, airtight and strong physical properties. Its stellar reputation, coupled with our tiny budget, made the selection of duct tape for our prototype an easy decision.

Elastic bands were also a necessary component in putting together our prototyped design. The original plan prescribed elastic fabric-based banding around the circumference of the exterior of the bag. The bands were replaced structurally with duct tape, but this did not provide the added elastic compression we desired from the bands to help the ripcord system with compression. The elastic bands are not the ideal solution for an exact analog, due to their smaller surface area compared to the larger bands, but in the area of cost, they present the best alternative to other methods such as rigid string or rope solutions. The combined forces between the ripcord system and the elastics provide a total compressive force on the bag, both horizontally and vertically. The rubber that makes up the rubber bands was also considered in the selection of

Figure 30: Example of typical rubber bands used in prototype

materials, as rubber does not easily break down in water, meaning as a proof-of-concept analog, elastic bands would do just fine for our short term testing. The inexpensive nature of elastic bands also meant that testing with the bands would fit within our budget, and provide plenty of extra materials should any break or deform in construction or testing.

In order to create smooth lanes for the cord system to pass through, we needed some sort of medium through which the rope or ski cord could slide easily and reliably. Once again, we weighed cost against what we had readily available, and decided upon using BIC™ ballpoint pen casings for our loop guides. The cases provide a consistent inner and outer diameter for testing, and also allowed us to vary the length of the guides, as we deemed necessary during the build process.

Figure 31: Common Pen Casing Utilized in Prototype

The pen casings were acquired cheaply, and we went about sizing out the individual loops for the bands to surround the bag. The portion of the pen that we utilized was the main body, consisting of a simple long white plastic tube (See Figure 31). We estimated the loops would need to be about 1-2 inches to be consistent with the banding outlined in our original design, and to accurately fit the width of the duct tape as well. A combination of hot glue and the adhesive backing from the duct tape held the loops in place securely to the sides of the bag. The hot glue was chosen so as to not melt, deform, or puncture the outer lining of the bag as sewing or riveting may have done. While the main design calls for a stitched seal between the bag and elastic banding, we decided upon hot glue for the prototype to save the original bag from harm, as we only had the one to test with. The hot glue held plenty securely, and the duct tape helped make sure there was no give in the positioning of the loops. The inner diameter of the pens (1/4" on average, minor variations between pens), matched the test rope and the ski cord outer diameters with plenty of tolerance for free movement within the tubes. While movement within the tubes was necessary for the rope and cord to contract the bag properly, minimal space was required to accomplish adequate compression. What began as a bargain-oriented blind guess ended up being a lucky break for our group, as the prototype loops worked like a charm with minimal modification necessary (besides the length of the loops, of course).

In general the majority of our materials worked very well in aquatic environments, and would hold up fine under normal conditions. However, despite being very adhesive above the surface of the water, we quickly realized that the hot glue lost much of its ability to hold securely when submerged. This was accounted for with the addition of duct tape, and what went from a potential disaster for the design ended up making for a successful test after all. The ski cord performed admirably in its test, and for simple functional evaluation even the rope held fairly well in preliminary testing. The rope material did not make the dive, as the ski cord would be the obvious choice for moisture-laden atmospheres, and was thus substituted at the time of the testing. The bag itself was known to be watertight prior to testing, and the separate evaluation done was without modification to the exterior previously, so there were no additional concerns about the resilience of the sack in testing.

Through our thorough testing in the diving pool at Holy Cross, we were able to validate our design in test conditions, and prove that our ideas had significant merit towards a true redesign of the MACS sack. While the ripcord air purging system represents a significant redesign of a sufficiently effective proven system, we truly believe that our system will allow for quicker and more effective neutralization of buoyancy in the pack in combat situations. From the virtual models that we made, to the prototyping of the pack based on closely related materials, we were able to accurately replicate our design from concept to completion of the prototype with minimal difficulty to acquire ample data for proof-of-concept analysis. We were able to prove our idea has potential to be developed for military applications in the field, and could potentially help our troops in combat situations should the need for these packs ever become more necessary.

3.11 - Testing Facilities

Marines are deployed all over the world in many different scenarios. Sometimes they have to dive into water from a helicopter or a cliff, other times they have to enter the water from underwater vessels. While these are more extreme cases, in order to test the MACS sack successfully we needed to find the best way to simulate the environment in which the sack was used.

The chance a Marine enters the same exact environment more than once is very slim. The density of the water will change with each new body the Marine enters; the main cause of the discrepancy would be the salt content of the water, also known as salinity. Salinity is measured in grams per 1000 ml. The average salinity for open sea water is about 3.5% which is gives a density of 1027kg/m^3, while pure water has a density of 1000 kg/m^3 ("Sea Water Density & Salinity" [37]).The addition of salts and minerals dissolved into water increases the density as the mass is raised per unit volume. When you take readings around coastal regions the salinity is lowered from water sources such as rivers dumping fresh water into the ocean.

The second main factor in the density of the water is the temperature. As water becomes colder its density rises as the molecules move closer together (note this does not apply to ice, as the process is reversed once it starts freezing). This correlates to depth the Marines dive. Since the sun can only warm the top layer of water, as you go deeper into the water the temperature drops ("Density of Ocean Water" [10]). See Appendix for temperature vs. density chart.

The most common sources of water that Marines would have to operate in would be lakes, rivers and oceans. The density of water we would have to worry about would be anywhere from pure to average ocean density, 1000 kg/m^3-1027 kg/m^3.

Taking into account the limitations due to the weather and equipment, the best facility to test a MACS sack would be at a pool. The closest Olympic sized pool, which provided the deepest available depth, was located at holy cross. The College of the Holy Cross was founded in 1843 as an undergraduate Roman Catholic liberal arts college located in Worcester, Massachusetts, USA. Holy Cross is the oldest Roman Catholic college in New England and one of the oldest in the United States. Holy Cross has a six-lane pool at the Hart Recreation Center, which was created in 1982. The pool contains dual wave turbulent lane lines which are the standard 25-yard collegiate length. A separate diving well contains two one-meter boards and one three-meter board (Holy Cross.edu [18]). With the pool having a depth of 13.5 feet we were able to test normal swimming conditions with the sack and with the use of the diving boards we could simulate jumping from different height cliffs or a low flying helicopter.

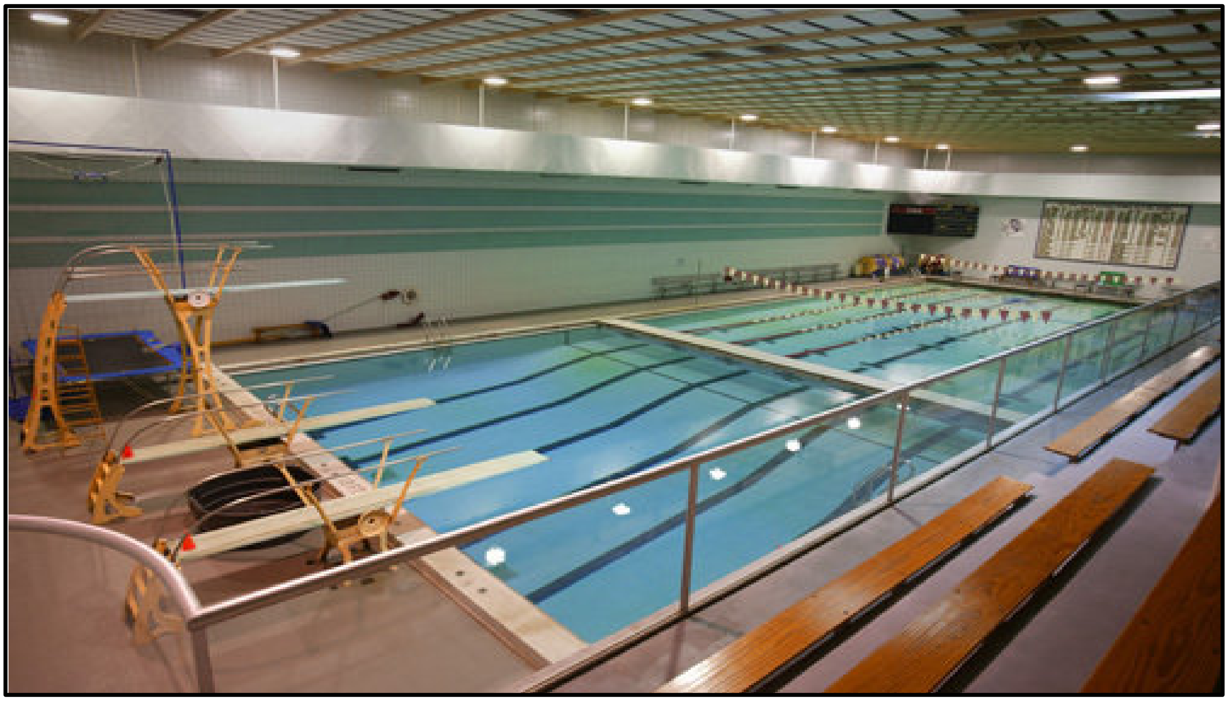


Figure 32: Athletic Pool, located at the Hart Center at the College of the Holy Cross

Using the pool facility as a testing ground had many positives. Since we were the only ones in the pool at the time, it provide a good control factor as the water was relatively settled with no obstructions to disrupt the test results. Also the human error for measuring the depth that was taken was minimized by bringing the bag to the bottom of the pool every time. While taking results from jumps, the height was controlled from the diving boards, and the only influence affecting the results was the deflection of the diving board while we ran off of it. Lastly the density of the water was the same throughout the testing phase as it never changed and temperature interference could be neglected due to the low depth.

While the pool provided a good environment to test the MACS sack in, it lacked a few key elements we would have otherwise wanted to test, but due to the circumstances of our equipment and time of year we were unable to. While the density remained the same throughout the testing, unfortunately not many Marine operations take place in a pool. The average density of water in a pool is 1030 kg/m^3 while the average for sea water is 1027 kg/m^3 ("Technical Methodology for Swimming Pool" [41]**)**. It is not that large of a discrepancy but would have been nice to have tested in the ocean to produce more accurate results. Another drawback from testing at the pool was the depth. As noted before, Marines often go on dives exceeding 20 feet depths, and since buoyancy force we measured was only at 13.5 feet we can only make assumptions on how our prototype would perform at greater depths. Also at greater depths the temperature could come into effect altering the density of the water.

While it does not affect buoyancy directly, the current in the ocean or a river could be taken into account when taking results. Ocean currents near the surface can get up to 2.5 m/s, while this can be neglected to get controlled results, a sample of data with this taken into account to see the total effects would have been nice (Statnikov, "Speed of Ocean Currents" [40]).

3.12 - Testing Tools

In order to test the forces on the MACS sack we used a mechanical spring scale attached to the bottom of the bag and dragged it to the bottom of the pool. Spring scales provide direct readings for both force and measurements. The scale had readings for Newton's and for pound feet; each scale can be fully zeroed (Nasco Science [32]).

As a note into the history of this mechanism, the first spring scale was made in 1770by Richard Salter of West Bromwich. They are often used in high schools for educational purposes and in industries where accuracy can be substituted for simplicity and cheapness (Hewison [16]).

Spring scales work simply by Hooke's Law, which states that the force required extending the spring is proportional to the distance it moves from rest. By marking the spring with equal spacing you can make a simple and accurate scale to measure forces. The reason we chose the spring scale to measure our results was its simplicity. There is very little that can go wrong with it and it is easy to replace with a similar scale if it does break saving us from having to reproduce all our results.

One limitation from using the spring scale was pulling it while swimming down the bottom. Since the measurement is done from a simple slider in front of the spring, if you tug harder that the force that is measured at the bottom of the pool the result will not be recorded and the test would have to be run again. The last limitation was the precision of the scale, the scale only measured to the tenths place, and with human error it is possible to be off more than preferred. To increase our precision we could use an electronic spring scale, but we would have to find a water proof one first.

The model spring scale we used was the Rapala Pro Guide Mechanical Scale. It is made of an Anodized Aluminum Handle, Stainless Steel Hook, Stainless Steel Soft Grip Handle, and a marker slide that marks weight ("His Tackle Box" [17]).

Figure 33: Rapala Spring Gage utilized during testing

In order to make sure our spring scale was functional, preliminary functionality tests were taken to ensure the scale used was accurate. To achieve this end, commercial excercise weights from a gym were taken and measured. For these preliminary tests we took four samples from a 2.5 pound weight and four samples from a 5 pound weight, results can be seen below.

Table 5: Tool Performance Testing Results

Known Weight	Tested Results (lb.)			
	Test 1	Test 2	Test 3	Test 4
2.5 Pound weight	2.5	2.6	2.5	2.5
5 Pound weight	5.1	5.0	5.1	5.0

From the results one can see that the accuracy of the scale is within an acceptable range but the precision could vary a total of .39 lb. As mentioned earlier, in order to increase the precision a better water proof scale would have to be used.

In order to get the pool density for our testing we used a graduated cylinder in conjunction with a scale to get the mass per unit volume. Flasks and beakers could also be used to get the volume to measure the density of the water, but to be as precise as possible we used a graduated cylinder. Graduated cylinders are often used for precise measurements as they usually measure to the precision of a milliliter. To test the accuracy of the graduated cylinder we used multiple cylinders and compared results with the same amount of liquid.

With regard to tools for compression, for our base testing we used manual compression on the sack. By definition, the compressive strength is that value of uni-axial compressive stress (Groover [14]). Stress is defined as

$$\boxed{\sigma = \frac{F}{A}}$$

Where, F = Load applied, A = Area

The average hand length for a male is (measured from wrist to end of middle finger) is 7.49 inches and the average breath is 3.52 inches (Andrea). For simplicity assume that the area is a simple rectangle, yielding an area of 26.36 inches^2 = 0.1831 feet^2.

The average force applied could be determined to be equivalent to the amount one can pressaway from then body with the only fixture of the body being the feet on the ground, which after taking the average would be 116 lbs (Jeeverajan, “Human Performance” [22]).

By dividing 116 by .1831 we get that the average compressive stress on the bag is 633.53 lb/ft^2. The issue with these results is that it is assuming we are compressing a box with flat surfaces. With the MACS sack we often ran into the issue of compressing it at bad angles which yielded poor results. Another issue was accidentally covering the valve that purged the air.

In order to increase the compression forces on the MACS sack we needed another approach, one that could also be controlled to prevent failure in the purge of air. Analyzing the stress equation, in order to increase the compression you need to increase the force on the MACS sack. The strongest position a human can present itself is in one which it has its back against a surface and presses with its legs or hands against another surface. Since the Marines have to be able to seal the bag in a short amount of time and at any position we assumed that the most practical position was to assume that the Marine was standing or sitting. Then strongest force that a human can perform while standing and only using his or her arms is pulling an object apart with both hands. The average strength for pulling with the left arm is 60 lb. while for the right arm it is 66 lb (Jeeverajan, “Human Performance” [22]). While one arm pulling is weaker, both working together would yield an 8% increase in force applied to the compression. To apply the force to the sack a pulling mechanism needed to b e created.

To test our theory out we used a water sports rope to constrict the MACS sack. Water sports rope is generally made of nylon. Nylon fiber was invented at the E.I. du Pont de Nemours Company in Delaware (Moore, “The History of Nylon” [38]). Nylon rope is made from continuous filament polyamide - nylon 6 or nylon 6.6. At a diameter of ½ and inch it would require a minimum of 5670 lb. force to tear the rope, and it would only weigh .063lb per foot (“Engineering toolbox” [13]). See appendix for more results.

There are many positives and negatives to using nylon rope for a concept rope. Out of all the fiber ropes, nylon is the strongest. The only stronger rope would be a wire. While we are worried about the strength of the rope, wire would be overdoing it; also wire rope is not as flexible as nylon rope, and we need to be able to surround and constrict the bag with it. Nylon rope also has many appealing qualities to our experiment such as weather resistant. While some metals will rust in ocean water, nylon does not. Also various temperatures would affect the performance of metal while nylon would keep its qualities. Nylon also has a very long plastic range; it is able to stretch up to 46% extra of its original length and still perform its task before breaking. This would be very helpful for the Marines as they would be able to know when the rope should be replaced, and if they started to stretch it they would have ample time before anything needed to be done. The last redeeming quality of the nylon rope is its density, which is slightly larger than that of water (1150kg/m^3), this would allow the rope to sink (Dosh, "Nylon Rope" [11]). This is a positive quality which endeared it toward our selection of chord for if it floated would be counterproductive for our project. See different size nylon ropes below.

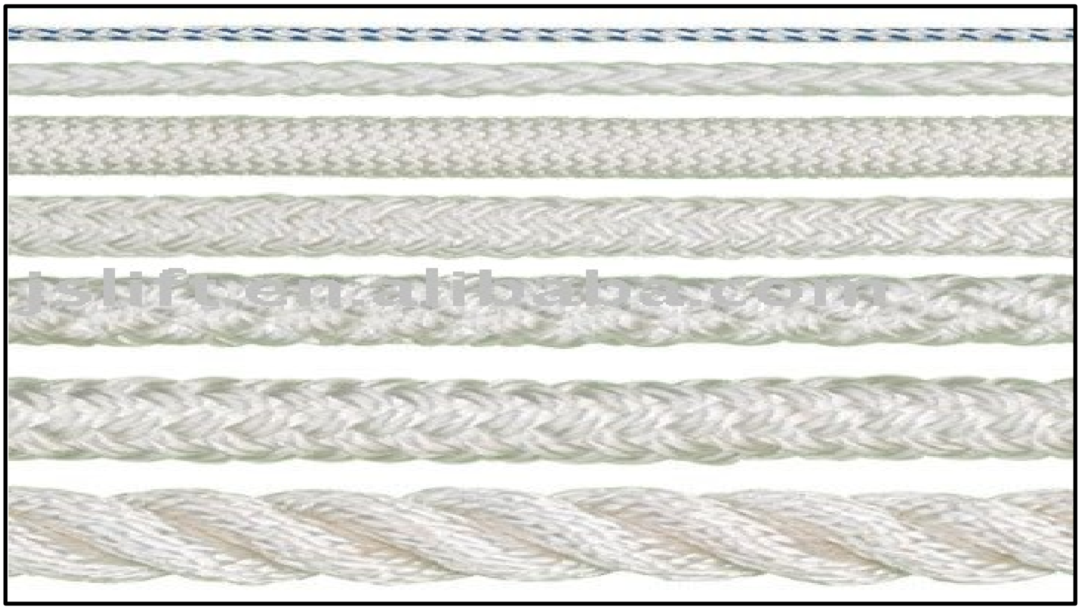


Figure 34: Variations of nylon rope gage, and consequently varying densities

In order to attach our rope we needed a tool to simulate the high density plastic loops our group had in mind for the ideal design. Given the resources at hand, the team went to home depot to look for a simple substitute. Our team considered the use of PVC, which is widely used by many rugged military plastics. PVC was invented twice by accident, once in 1835 by Henri Victor Regnault, and once in 1872 by Eugen Baumann. The material appeared as a white solid inside flasks of vinyl chloride that had been left exposed to sunlight (Wilkes, et al [46]). Today PVC is used in a wide variety of products such as piping, signs and insulation for wiring. As previously discussed in this chapter, the use of commonly produced pen casings proved most opportunistic. These casings are in fact made of polyvinyl chloride and so we consider the measurements found from reliable sources. With a density of 1450 kg/m^3 and high weather resistance PVC made for a good test material as we would not have to worry about corrosion or adding buoyancy to the platform.

There are many ways in which the loops could be attached to the MACS sack, but we needed a solution that would not damage it, while keeping the loops in place. With this in mind, any puncture solution was immediately discarded. In addition any type of melding by heat was frowned upon since you could burn holes by accident. This left us with the option of finding some sort of epoxy to attach them.

For our initial tests we attempted to attach the loops using hot glue. Hot glue is a type of thermo plastic adhesive; it usually comes in sticks and is used in conjunction with a glue gun. As the glue is passed through a heating tip it is melted down and forms a bond between two surfaces as it cools down. Hot glue is cheap and forms an effective bond, but at high temperatures the epoxy could melt down removing the bond between the two objects. While this worked for the first couple of tests, they soon fell apart. In addition the hot glue did not make for a strong attachment. If a small amount of torque was applied to it, the loops came off. After looking at these results we started to look for a better epoxy and for other solutions.

Both of the solutions for the concept testing had ups and downs. The manual compression had a significant less mass and took up much less room then the pump. The manual system also allowed more time for damages to be corrected and was still able to perform if damaged, lastly the manual system took less time to decompress the pump and required less down time (just pull the cord on the bag for the manual system, while you have to affix the pump to the bag before you even start to remove the air). Problems arose when testing the manual system when we were unable to find a good epoxy to hold the loops onto the bag.

3.13 – Test and Results

Merriam-Webster defines a test as a procedure, reaction, or reagent used to identify or characterize a substance or constituent. Testing of the original MACS Sack and redesign of the sack were of the utmost importance to determine if the new design was a valid solution to the problem. Values presented in the testing data chart (reference Appendix) reflect the results of all experiments including the control. As can be seen, a variety of materials were used. Each material varied in size and weight to simulate the objects carried by Marines during their operations. These materials were placed inside the sack to examine how the material would conform around them when compressed. The elastic makeup of the original sack versus the new sack has a nominal difference which did not need to be considered. The redesigned MACS Sack included household materials which could simulate the ripcord compression system. All things considered, the testing occurred to once again determine if a new design needed to be implemented by the Marines for their dive operations. Our group traveled to the pool of the college of Holy Cross in order to execute our experiment and analyze the design concept of the modified MACS sack. The objective of this trip was to record compression tests at depths of around 13.5 ft and acquire underwater force readings for each test condition.

The testing included three different methods of compression. Each method was conducted to determine the fastest and most efficient method of removing air from the interior of the sack. The faster the air could be removed from the sack; the faster and farther the Marine would be allowed to dive. Compression styles included a manual horizontal compression, manual vertical compression, and redesigned ripcord compression. The redesigned sack could not include the manual pump because of a lack of means to attaching it to the sack itself. For intensive purposes, the sack was left without the pump. However, based on the results, the pump most likely would have been able to speed up the process upon speculation. The manual vertical and horizontal compressions were done by placing both hands around the sack and squeezing with the greatest force possible.

During testing, we took into account all situations the marine can experience. As a result, one test method we used was horizontal compression on the MACS sack. This compression force required someone to take both ends of the sack and orient it horizontally. Then, the person holding it would squeeze the sack while always maintaining the position. Given that the marine would not have much time to compress the sack, we limited each compression period to five seconds. After compressing it, the spring gauge is attached and taken underwater to the full depth of the pool. The readings were taken and recorded from the spring gauge in lb per force units. The reason we used this unit is that it makes it easier to define force and mass, which are two important variables when considering our objective. Essentially, a lb per force unit consists of a pound in mass multiplied by gravity and all divided by the proportionality constant.

Figure 35: Horizontal Compression

The whole experimentation process was repeated with the redesigned MACS sack. In this segment, we were very careful and cautious with the delicate prototype. With a series of cords meeting at one point, that point was tightened to contract the MACS sack and compress it. As a result, we tried to keep all other variables similar for the sake of accurate results. With these results, comparisons with the original sack would decide the more beneficial design.

After taking the recordings from each test, an organized chart was constructed as seen in the appendices. There are many patterns and trends that can be brought up from the chart. One important one would be how the average lb per force for most horizontal compression recordings was smaller than the vertical compression values. The significance of this observation is that it states how horizontal compression is more effective than the vertical one. The advantage of having horizontal compression is that in one squeeze the marine would be able to squeeze more air out thus less lb per force. With less lb per force, the marine would be able to sink his MACS sack quicker and easier than using the vertical approach.

The first test done was the controlled experiment. A controlled experiment includes an unchanged specimen which is compared to the results obtained from testing on the revised specimen. This helps to build a better basis on the validity of the experiment. If the results obtained from the revised specimen exceed the results from the controlled specimen one can conclude that the revised specimen governs the experiment. Further testing is always encouraged especially when attempting to redesign something. Being that the sack was empty, it made it significantly easier for the individual to compress the sack without any obstruction. This, of course, would not be a logical example of the sack used when Marines dive since they would have multiple objects lining the inside. Based on the trends in our charted experimental results, the horizontal compression gave us an average force of eight pound-force. This eight pound-force is the upward force exerted on the individuals back when they enter the water. This upward force portrays the sack's tendency to become buoyant due to all the air pockets still remaining in the sack. As was noted earlier, the Marines may use up to four of these sacks at once, along with all their other equipment when diving. If a maximum of four sacks were used by the Marine, then an eight pound-force would yield a total force of around thirty-two extra pounds acting buoyantly. This extra upward weight forces the Marine to use more strength to dive deeper. If more strength is used fatigue will then set in causing the Marine to act tired and irrationally. With a redesigned sack the Marines would be able to dive deeper and for longer periods of time without the worry of fatigue.

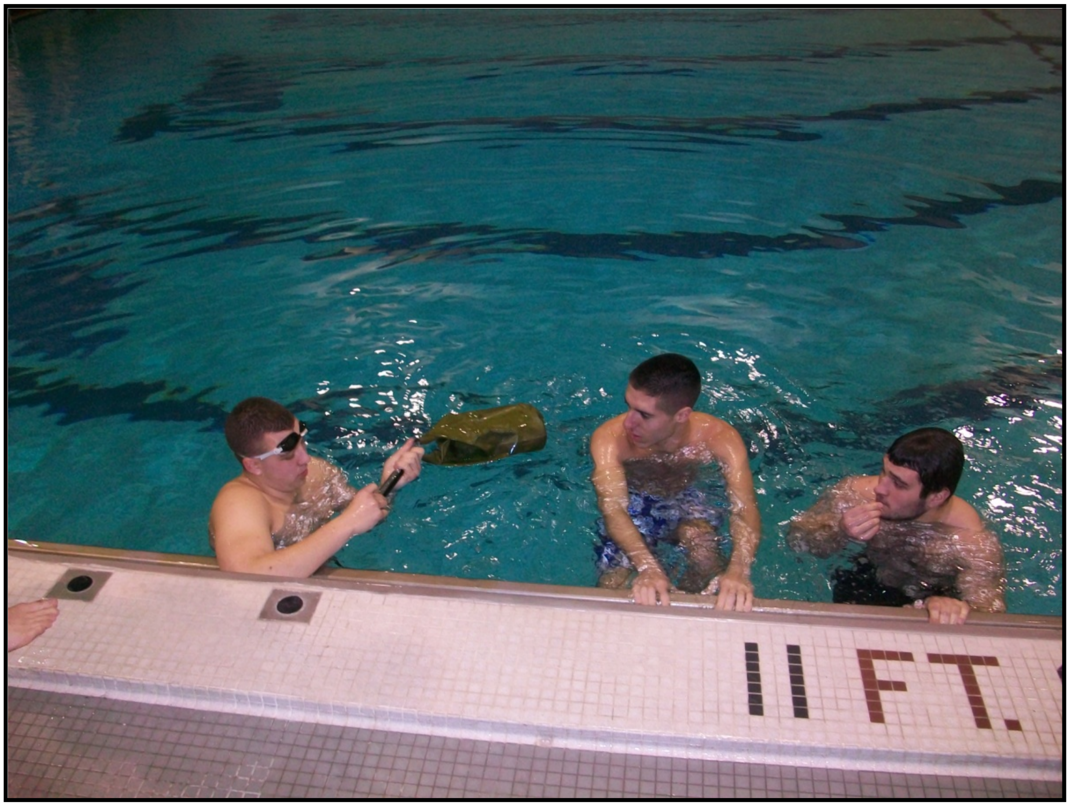


Figure 36: Teammates Preparing To Dive

The other controlled test dealt with the vertical compression of the sack. The empty vertical sack was squeezed for another five seconds to release as much air as possible. It was thought that the vertical compression of the sack would allow the air to be better displaced through the original valve attached to the bottom of the sack. The original valve purges the air out of the sack either when compressed or submerged underwater. Just by visual observations, the vertical compression of the sack did not seem to let out as much air as did the horizontal compression test. The average force resulting from the vertical compression was taken to be 13.82 lbf. This value is significantly larger than the value obtained from the horizontal compression. If this empty sack was compressed vertically and given to the Marines they could experience an upward force of up to fifty-five pounds. As was mentioned, this extra weight can be very detrimental to the soldier.

One of the first tests we did was the horizontal test with the sweatshirt on the original design of the sack. On the first trial, a reading of 10.5 lbf was recorded and so was the second trial. The third trial was 11 lbf while the fourth was back down to 10.75 lbf. The final trial consisted of a measurement of 11.15 lbf and the final average was taken at 10.78 lbf. The set of recordings seem to be consistent with a standard deviation of 0.2928. For the second test, we used T-shirts with the same horizontal orientation. The first trial came out to be 7.75 lbf and the second was 6.75 lbf. Third trial resulted in 8 lbf while the fourth was 7 lbf. The final trial recorded a 7.75 lbf reading and the final average was 7.45 lbf. These readings weren’t as consistent as our first test, but still acceptable with a standard deviation of 0.5420. Now we move on to the third test which we used a shoe to experiment on. The first reading was 5.25 lbf and the second recorded a value of 5.5 lbf. The third and fourth trial was both 7 lbf which proved to be beneficial to due to the consistency factor. The final tryout read 6.25lbf and the calculated average was 6.2 lbf. This test trial was interesting because we had our low, high, and median values. The range of numbers was broad which would explain the standard deviation of 0.8178. The fourth examination consisted of inserting a piece of cardboard into the MACS sack. The first trial of came out to 9.25 lbf while the second increased to a value of 10.5 lbf. The third and fourth tryout consisted of a recording of 9 lbf which is quite favorable when calculating the standard deviation. The final trial was 10.75 lbf whereas the average read 9.7 lbf. These set of readings were also a bit broad and resulted in a standard deviation of 0.8551.

This section will be dealing with the vertical compression of the sack filled with the sweatshirt. After five seconds of compression, the sack was ready to be submerged to the greatest depths of the pool. According to the results table (reference Appendix), the average force applied by the sack was around 11.13 pound-force. This number is a little larger than the value produced from the horizontal test. It is possible that the sweatshirt could have conformed to the bottom f the bag. This conformity to the bottom of the bag could have made it easier to squeeze the air out of the bag horizontally. During a vertical compression, the individual does not have as much of an opportunity to use the object inside as leverage to remove air since it has settled at the bottom.

An issue presented by the results obtained was the standard deviation. A valid standard deviation is one that approaches zero rather than one that approaches a value of one or higher. The standard deviation for the controlled vertical compression test was calculated to be around 0.951. This shows that there was a lot of variance between the results and average obtained. This anomaly could be the result of a few different testing aspects. When the diving to the bottom took place, there could have possibly been a different downward force applied. As the diving took place there was a thrusting motion put into action that could have varied from dive to dive.

This thrusting action could have activated the spring gage resulting in an additional force that was added to the true results of the sack.

The standard deviations for both the standard designed bag and redesigned bag tests are .389 and .478 respectively. These values are respectable values when considered the nature and physics behind the tests. With all anomalies considered these values lie around the average standard deviation for all the projects. The standard deviation for the redesigned pack does seem to be steadily increasing and as mentioned before could be a product of the materials used to build this prototype degrading after each dive. This information shows that an actually prototype should be built with better materials that are both cost effective and durable. The possibilities on improving the quality of this MACS Sack are endless. The progress of the standard deviation over time for the redesigned vertical compression tests can be seen in the figure below.

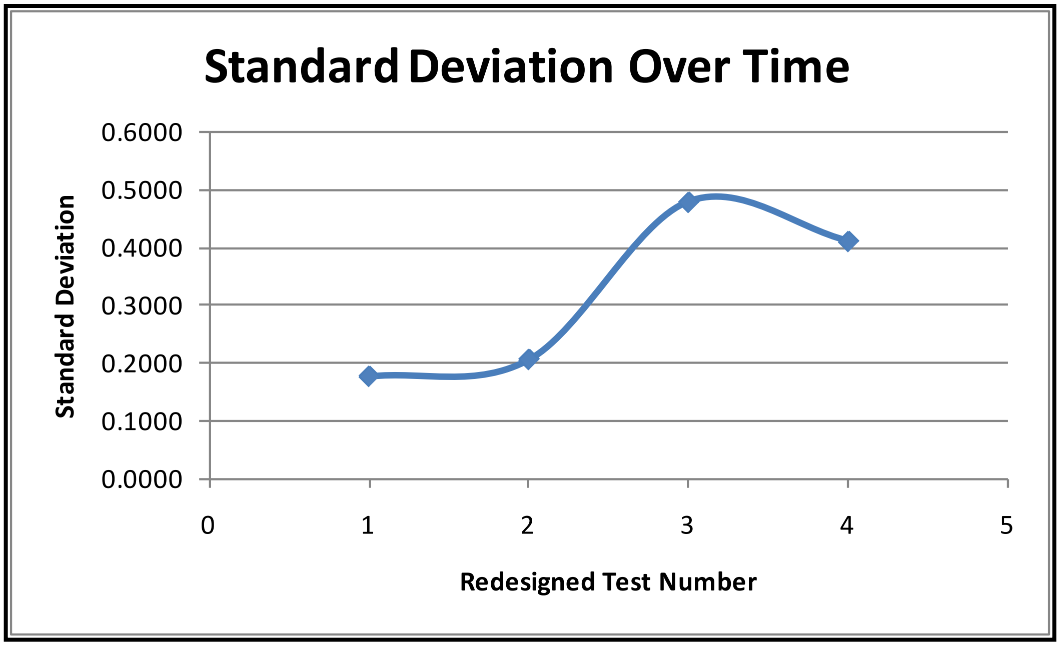


Figure 37: Standard Deviation Progression

As can be seen in the graph, the standard deviation does increase over the first three tests which have already been mentioned. Once the fourth test has been done, the deviation drops off a little possibly showing a failure point in the materials used. This said failure point could suggest that after the third test of constant submerging, the so called household materials may have finally failed. Interestingly enough, the loops used to hold the cord on the bag did start to pull themselves away from the glue finally. All tests can still be considered because the majority of them were done before the bag fell apart.

Figure 38: Spring Gauge Attached to Sack

The next test that was done both vertically and horizontally and with the standard and redesigned sack was done with two t-shirts. Once again, the vertical compression will be focused on for this test. The t-shirts will weight a lot less than the sweatshirt and possibly take up less area too. However, the t-shirts were chosen because they are able to move around more than one sweatshirt. Since there are two separate sweatshirts, they have the ability to stray from each other and occupy different spaces of the sack. There is more air space in the sack since the t-shirts do not take up as much space as the sweatshirt which could lead to a greater air reduction when it is compressed.

The next tests were experimented on the redesigned MACS sack. The first test that was conducted on it was inserting a sweatshirt and compressing it horizontally. Once the sack was closed and tightened within the given time period, it was taken to the full depths of the pool with the attached spring gauge and resulted in force readings. The first trial of the test was 8 lbf and the second tryout recorded 8.75 lbf. The next evaluation resulted in 9 lbf and afterwards a reading of 8.4 lbf. The final trial was a high 9.2 lbf and the final average calculated was 8.67 lbf. These readings consisted of a wider range of values when compared to the other tests on the redesigned MACS sack, thus resulting in a standard deviation of 0.4791. The second experimentation on the sack consisted of using T-shirts. Once they were placed in the sack and taken down below, a first reading of 6.4 lbf was taken and the second was 6 lbf. The third tryout came out to be an increased 6.9 lbf and the fourth was 7 lbf. The final reading came out to be 6.35 lbf and the average was 6.53 lbf. The set of recordings for this test was not as a wide of a spectrum as other readings and that is the reason why the standard deviation was calculated to 0.4147. The third test executed used a Nike shoe and resulted in the value of 4 lbf for the first trial. The second trial brought us a 4.65 lbf reading and the next one came out with a 5 lbf value.

The fourth tryout resulted in 4.25 lbf while the final one was 5 lbf. The average of the set of recordings was 4.58 lbf. These set were fairly precise thus a standard deviation of 0.4481 was calculated. The final test conducted on the MACS sack was the piece of cardboard. The first try out resulted in 8.65 lbf while the second was 8.25 lbf. We received readings of 9 lbf and 8.15 lbf for the third and fourth trials respectively. The final trial brought us with a recording of 8 lbf and an average of 8.41 lbf. These values for this particular test were more precise than the other experimentations. As a result, the standard deviation came out to a lower 0.40835.

Another value to pay attention to when observing these results is the standard deviation. The standard deviation for the standard design test was about .450 while the standard deviation for the redesigned sack was around .178. This shows that the quality of tests for the redesigned sack were much better than those for the standard MACS Sack. Obviously this may have been a result of the anomalies presented earlier, but could this be a result of the testing being a little bit easier to accomplish with the ripcord design? These are all plausible, but the anomalies are usually natural occurrences and would happen either way. Interestingly, however, the redesigned sack could have additional variances in its data because it is a more complex system. The loop and pulley system involves multiple materials which all have different masses and react differently in water. For example, the hot glue used as an epoxy for the loops could have degraded after each dive to the bottom of the pool. This may be one reason why there is almost no variance between the values presented in this first test. If the difference between values begins to get larger as the tests go by, one can make the assumption that the materials used for the prototype degraded somewhat over time. This can be the case for any material or object. Over time the material that the object is made out of will degrade at an exponential rate if used perpetually over time.

The standard deviation determined how much variance or deviance there was between the results obtained and their averages. Anomalies and askew data are a normal occurrence when doing multiple tests. This data may have been a result of longer or shorter compression periods and the depth which was swam to. This could not be an exact science without the use of any expensive technical machinery. Testing was done to the best abilities of the testers.

Another important concept to look at from the data is the smaller values for the redesign portion of the experiment. As one can see, the spring gauge recorded less average lb per force data for the redesigned MACS sack which means more air was compressed out of the sack than when we were compressing it with our bare hands. Due to the cord covering more surface area throughout the sack than our hands, our data proves that the redesigned sack produces a higher compression force.

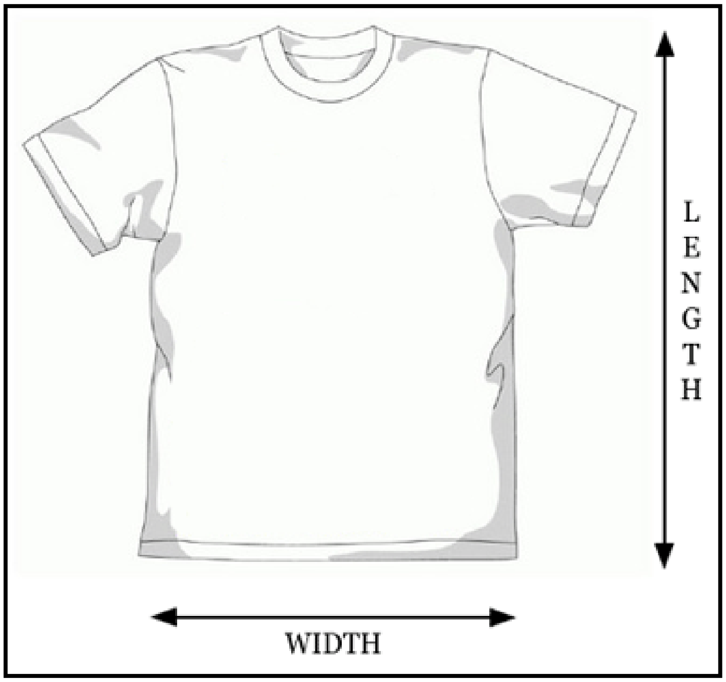


Figure 39: T-Shirt Test

The t-shirts used were standard adult large t-shirts as seen below. According to various shopping websites like sneakerfreaker.com, the official dimensions of an adult large t-shirt are 30.7 inches by 21.3 inches (“Eastern Mountain Sports” [12]). Also, the standard t-shirt is made out of cotton which does not weigh much at all (Figure 39).

Cotton is a material used in the design of most t-shirts. It has the ability to absorb water decently and fold and stretch as well. When being placed in the sack, the cotton t-shirt may affect the buoyancy because of its weight times two, but other than that the cotton will not take up a lot of space. Depending on how many times these t-shirts were worn and how many times they have been dried, these shirts could have shrunken significantly. When exposed to heat a cotton fiber product will tend to shorten and shrink. This process is irreversible and can ruin a lot of clothing. Whether these t-shirts were shrunk or not does not matter because they would not have taken up a lot of space.

According to the table, the average force applied by the sack with the shirts in it was around 8.58 pound-force. This was significantly lower than the value obtained from the tests done on the sack with the sweatshirt in it. This was caused by there being a very large space of empty sack which could be compressed fully. The compressor concentrated on the empty portion of the sack and used all his strength to thoroughly release all the air he could. Within those five seconds of compression, a good portion of the air was removed. Once again, however, the horizontal compression test showed that the gage took on one less pound of force. The horizontal compression method seems to be the better of the two methods through three tests. It is just an easier method of removing the air.

The worst result obtained from this test was the standard deviation. Based on the results, the standard deviation for the vertical standard test was around 1.14. This is an extremely large number that shows an enormous variance in the data. While looking through the data, it can be seen that Trial 1 had the askew data point. It read 10.4 pound-force for one dive down to the pool. On the other hand, the other four trials read values between 7.75 and 8.75 which is not a huge difference. Because the first trial showed such a large difference in force this test can be deemed insufficient. The trial abnormalities must be reconsidered and possibly redone to get a reading that can actually be used for analysis. Even with this insufficient test, there are plenty of other values to show that there is a need for the redesign of the MACS Sack.

Following the standard t-shirt test, the redesigned sack was testing using the same t-shirts. As was done before, the t-shirts were randomly placed in the sack so that they may take up whatever space they wonder to. Also, with the redesigned sack, it was compressed vertically to remain consistent when analyzing this section of results. The redesigned sack used the ripcord design again to release the air from the sack with the t-shirts in it. Since the t-shirts weigh a lot less than the sweatshirt and are also thinner, it was assumed that the ripcords would compress a lot more air out of the system than they did when the sweatshirt was placed inside. The cords could pull the shirts along with, creating the smallest internal area possible.

Based on the results obtained, the redesigned vertical test with the t-shirts yielded a value of around 7.03 pound-force. Once again, this value is lower than the value obtained from the standard design test. It is starting to look like the simply redesigned method of releasing air from this sack is a very effective method. I am sure that the Marines would enjoy being able to pull on these ripcords and release the air rather than squeezing the air out and possibly damaging any contents inside the sack or the exterior of the sack. Easily one of the most importing things to consider when compressing the air out of this sack is the safety of both the Marin and the contents of his sack. If his medical supplies and ammunition were to be crushed when compressed there would be no way for the soldier to protect himself when in a battle or mission. This ripcord design easily limits the compressive force and maximizes the release of air.

The standard deviation of this set of data was quite reliable. For the entire set the value for the standard deviation was .208. That is an exponentially greater value than the value obtained from the standard deviation of the standard t-shirt test. This shows us that the tests were done in a similar manner. The data becomes a lot more reliable once the standard deviation approaches zero. As was the case with the first redesign test (sweatshirt test), the deviation was very low. However, the deviation has increased from the last redesign test. As was mentioned this could be a direct result of the materials beginning to degrade each time they hit and enter the water. The values for the redesigned sack are beginning to be a lot more reliable than the ones displayed for the standard MACS Sack.

This test was a little deceiving in a way. When multiple materials are placed in the sack it should be harder for someone to compress it. This was not the case when talking about the t-shirts. Normally a marine will be carrying more than one item like a sweatshirt. If we were to carry around three small things in this sack, it would be a lot harder to compress than it was for the one sweatshirt. In this case, the t-shirts had the ability to conform to the sack and use less weight than the sweatshirt which allowed for more air to be displaced even though there were more materials inside the sack. In most other cases, more objects inside the sack would make it a lot harder for compression.

The next test involved the first actual rigid body. The specimen that was used for the test was a Nike shoe. The shoe was a male size twelve that is several years old. This object will take up a certain volume of the bag and maintain its shape without being able to conform to the bag when compressed. According to the measurements taken of the shoe, the length was around 11.25 inches and the width was around 4.3 inches. This object obviously is not the easiest thing to carry around on your back because of its awkward shape and size. The material of the shoe is a white leather that is quite durable and resistant toward many liquids and abrasions. This leather does come with a price though. The leather and other highly durable materials leave the shoes kind of heavy. Each Nike can way around two pounds, and with that additional four pounds in the sack the compression and testing will take on some different results. As can be seen in the figure below, the shoes are wide and very stiff. This object is very similar to the gun magazines that the soldiers may be carrying. Assault rifles, which they may carry, have a magazine known as the banana mag. This magazine has a slight bend in it which gives it a very intriguing shape. The shape of this magazine can be a very awkward thing to carry around in your pack when you are trying to fit other necessities inside as well. If the soldier attempted to compress his pack that had a few banana magazines in it, then the bag would possibly compress fine if the magazines were standing, but if they were lying length wise with other materials the compression would be difficult. As seen below the Nike Air Force 1 delivers a shoe that is long and wide at the same time.

Figure 40: Shoes on hand used as Rigid Body Testing

This test easily helped to gain a better understanding of how the sack would respond when rigid bodies were used instead of objects that could conform like the shirts and sweatshirt. If the redesigned sack could pass the rigid body test than it could definitely pass other rigid body tests that might include the other packing materials of Marine divers.

These shoes were also tested horizontally and vertically. This section of the results will deal with the vertical compression of the sack when the shoes were inside. As was the same for the other vertical compression tests, the sack was sealed and clipped with the shoe inside and then compressed for approximately five seconds. This compression was done to the best abilities of the individual squeezing the bag. Since this body was very rigid, the individual squeezing the bag held on to the shoe as if it were actually in their hand. This was almost cheating in a way because this allowed them to keep the shoe stationary. By keeping the object stationary the number of air pockets was minimized. With their being a minimal number of air pockets, the air was able to flow easier through a single path instead of trying to make its way through various or balled up objects. These flows of air lead to a maximum release through the reverse valve of the bag, and also lead to the best results obtained during testing.

The first test using the shoe was the standard design test. While observing the results in Table 1 it was discovered that the average force applied by the bag with the shoe in it was around 6.62 pound-force. This is the lowest average force obtained from the standard tests other than the horizontal compression test. As was mentioned, the rigid body allowed the individual to keep the shoe stationary and release air better. This compressive style shoed that it was a worthy method of displacing air from the bag and should be considered by Marines today who do not have this newly redesigned sack. If the Marine were to be carrying four of these sacks, he would only have to deal with another twenty-four pounds of force instead of the additional fifty pounds of force he would be carrying if nothing was in the sack. Clearly, the presence of objects in the MACS Sack limits the amount of air in the sack and makes it easier to compress.

The presence or absence of an object in the sack brings up an interesting argument. With no objects in the bag the sack becomes a lot tougher to compress, but does not have the additional weight of the objects inside to consider when wearing it. However, when there are objects present in the bag the compression because increasingly easier and immediately decreases the buoyancy properties of the sack drastically. Upon observation of both of these cases, it came to our attention that the additional weight added by the objects inside the sack would be a much better solution than keeping the sack empty and allowing the air inside to act as a flotation device. No matter what, additional weight will act as a downward gravitational force which will push the diver deeper instead of keeping him afloat because of a large upward buoyancy force. This is why the air must be compressed greatly to limit the buoyant forces of the sack.

Following the standard vertical compression shoe test was the redesigned vertical compression test for the same item. As has been done for all the other tests before, the ripcord system was pulled for five seconds to attempt to get the majority of the air out of the sack with the shoe in it. In comparison to how well the shoe performed in the standard test; it performed even better when compressed through the ripcord system. It was able to yield the second lowest value obtained throughout all the tests. The sack only gave off around 5.46 pound-forces when submerged to the bottom. The only other value that bettered this result was obtained during the redesigned horizontal compression test. It is known that the horizontal compression tests far outdo the vertical compression tests, but these results are showing that the performance of the redesigned sack is a possible solution to the problem.

Vertically the sack could improve if there was a means of attaching the manual pump. By holding the bag vertically and pumping it a few times and then pulling the ripcords horizontally could maximize the air reduction to a whole new level. The integration of the pump could lead to a greater variety of tests, but at this point is not a plausible means of testing the performance of the bag.

One of the items placed into the MACS sack used for testing was a Navy midshipmen sweatshirt. The purpose of using this object was to test something which occupied a large volume of the sack but was flexible enough to compress without much difficulty. We heavily took into consideration the material and mechanical properties of the sweatshirt. These properties would affect the lb per force exerted on the sack, thus the providing us with more data on how the sack would react to any given situation.

Figure 41: Navy Midshipmen Sweatshirt

The Navy sweatshirt was made out of a polyester cotton blend, which combines the best properties from both materials. The dimensions for this particular sweatshirt are 24 to 25.5 inches wide and 24 to 26 inches long (“Eastern Mountain Sports” [12]). This material is very versatile and light, yet durable. The versatile characteristics provide a more favorable compression factor for the marine. Also, it’ll allow itself to compress and decrease its size to accommodate the sack. The sweater only weighed eight ounces, due to the properties of cotton, so it would make the compression process easier as well.

The material properties of the sweater definitely influenced the data taken from the spring gauge. As one can see from the first experiment conducted on the original MACS sack with the sweater, the set of recordings were very consistent. Due to the material properties of the cotton polyester blend, the sweater was able to take shape of the sack when stuffed inside. While each compression took place, the conditions inside the sack remained close to the same because of the wrinkle-resistance and additional strength provided by the polyester properties. The standard deviation calculated for this test was actually the second lowest out of all the experiments executed.

A confliction was met with the data for the redesigned MACS sack. Given similar test conditions and same item for the redesigned sack, our recorded data showed an inconsistency in precision with a higher standard deviation of 0.4791 when compared with the other values for the redesigned sack. This could mean that our design is not meant to be used when a high volume and low rigidity item is in the sack. Another possible variable could be the water that traveled through the folds of the sack. Some water from the pool could've have gotten the sweater wet from the first tests of the original sack, as a result, affecting the weight and lbf produced during the later experimentations.

Another object tested in the MACS sack was a piece of cardboard. The cardboard was light and possessed a rigid structure. The density of cardboard is about 0.0173 to 0.0311 lb/in^3 and its yield strength is about 2.18 to 4.93 ksi. By taking the density of cardboard, we can just multiply the volume of a given piece and calculate the mass of it. With a given density, we can calculate the mass of any piece of cardboard that goes into the MACS sack. The mass that would be calculated can be used to give us an idea of how much lb per force would be recorded from the spring gauge. Also, the yield strength would give us an idea of how compression forces would affect it. With this information, an in-depth analysis of how the cardboard would subject to our tests is quite possible. Since this was a vertical compression tests that means that the bag was stood up vertically, and the cardboard would be folded. By folding the cardboard, the area and space taken up by the specimen would be lessened. It does, however, take some effort to fold over a solid piece of cardboard which could be seen in the first five seconds of compression. When observing the results, you can see that the values are not nearly as good as the values obtained from the rigid shoe test. The average force applied by the bag when filled with cardboard was around 8.24 pounds of force. As was mentioned, this could be a direct result of compressing the stiff cardboard.

Following the standard testing, as before, was the redesigned MACS Sack vertical test. The ripcord system had a little trouble compressing the sack around the cardboard. That could have been directly related to the length and orientation of the object. Cardboard is a very interesting object to compress with your hands or mechanically. As a result of the test, the force applied by the sack was around 8.61 pound-force. This value was actually just a little larger than the value obtained from the standard test. This is the only value on the entire table that is higher than its standard design counterpart. This could be a mixture of the tests being done incorrectly, the materials falling off the bag, and the vertical compression method not working as well as the compression method. Whether any of these things actually caused this can only be seen from further testing, and that would have to be done with a new prototype.

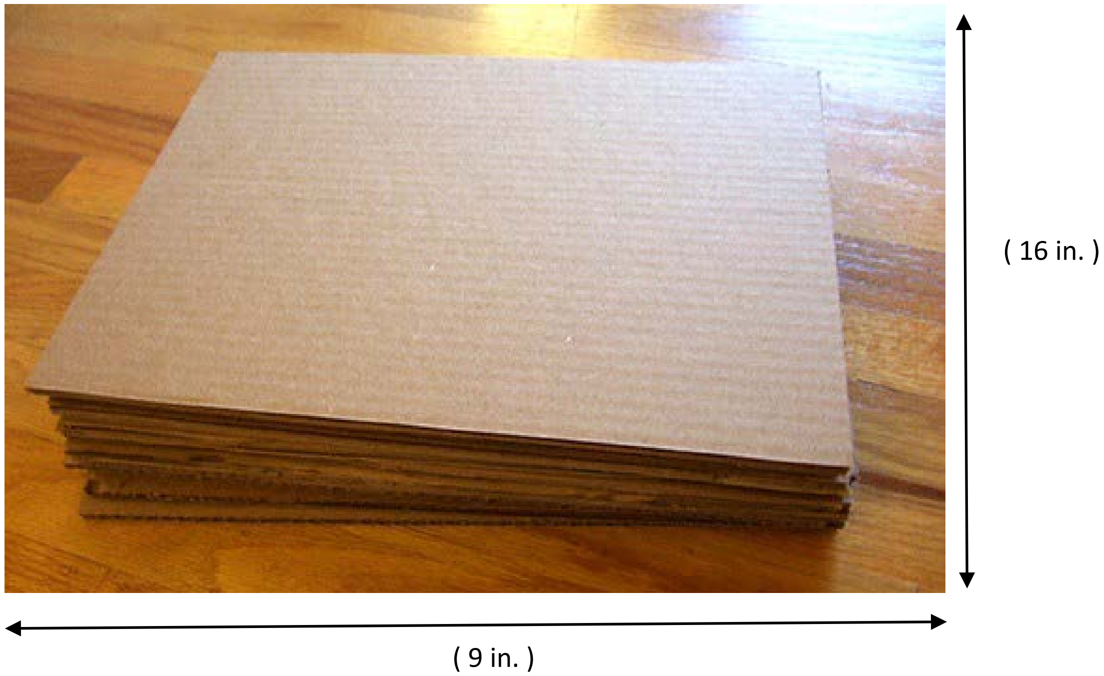


Figure 42: Cardboard used as secondary Rigid Body Test

The cardboard possesses a rigid body, but not a very supportive one which affected the experiment. As one can see from the test results, located in the appendix, there was a broad range of recordings with the original MACS sack and a consistency of values when tested with the redesigned sack. Due to the structural properties of cardboard and its yield strength, cardboard is easy to deform when forces are exerted upon such as compression. During testing, the cardboard must’ve deformed when we were compressing the sack. With its shape changed, it would affect the amount of lbf recorded after its venture to the full depth of the pool. It would make it easier for us to compress the sack after the cardboard’s size has been reduced. This means there would be less volume and resistance in the sack to compress, thus providing more room for error while compressing it. This would explain inconsistency of values for that segment of the experiment. It would make sense that redesigned sack would have more precise values due to the mechanical compression.

A person compressing the sack consists of many variables which would affect the amount of compression forces acting upon it. The volume and rigidity of the item inside would affect the process but also if the same person would do it repeatedly, then he or she would exhaust themselves and not create the same compression they did for the first sack. Marines are issued four MACS sack with each ILBE. Based on our data, it would be more effective to use our redesigned MACS sack to compress the excess air from it. It would eliminate human error and even maybe improve the compression forces acting on the sack.

Throughout this experiment, there were many unconsidered factors that could have affected our data and variables that we could have applied to our process. A factor that could have affected the data was the location of the compression forces. Throughout these experiments, one must always assume human error. When the person with the MACS sack is squeezing the second, third, or fourth time around, their hands would be located in different positions each time. The direction of the compression forces acting on the item in the sack would affect the readings from the spring gauge. Also, if the item in the sack would be compressed from different angles at different times, then the size of the item would be different during the experimentation. Therefore, the tests done later to the redesigned sack with the same items would give a bit of inaccuracy towards our data.

One variable that could have affected our data was the different people swimming the full depth of the pool with the MACS sack. As seen from the pictures, we had three experienced and good-looking swimmers conduct our tests. We chose three swimmers because the tests would exhaust one swimmer and throw off our recordings for the later trials. The benefit of having three swimmers is that we receive an additional three firsthand viewpoints when reading the spring gauge. More swimmers were most importantly a safety precaution. At a scientific viewpoint, three swimmers is not the correct method of going about this experiment. Consistency was a crucial aspect that must have been executed.

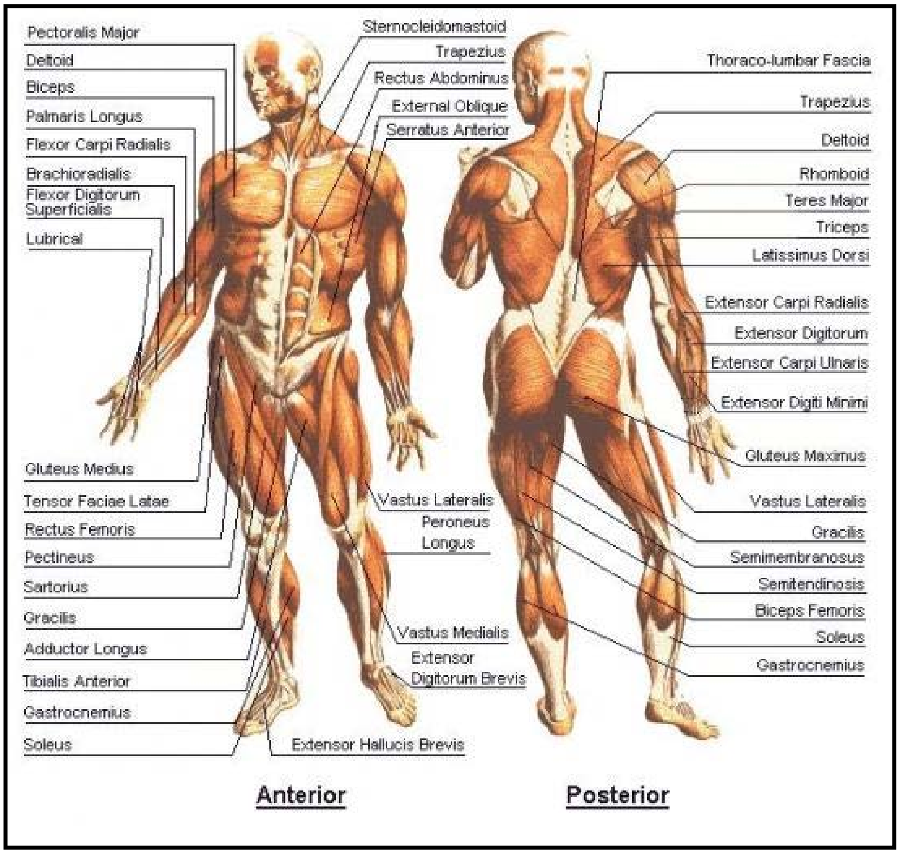


Figure 43: Human Muscle Diagram

Different swimmers have different weight and muscle mass. The heavier swimmer would sink to the depths of the pool faster, therefore changing the lbf exerted on the MACS sack. The swimmer with more muscle mass would have a tendency of sinking more and that extra lbf would have to be taken account for. The human body itself has numerous variables that could have affected the readings taken from the spring gauge.

The next variable that should be identified is the different swimming styles each swimmer performed while going down under with the sack. The more erratic movements the swimmer does, the broader the ranges of lbf the spring gauge would record. A way the group could have improved upon this was tying some type rope to the sack and having all the swimmers gently float down to the bottom of the pool. This would minimize movements and any unnecessary forces acting on the sack. This would provide accurate results from the spring gauge and legitimate data for our compiled recordings.

Figure 44: Lung Capacity

Another major issue would be the amount of oxygen each swimmer can hold while being underwater. When the swimmer with the sack reaches the full depth of the pool, they must stay at that location for some time for the spring gauge to record an accurate reading. People have different lung capacities so the time spent at the bottom of the pool was different. This means that the spring gauge might have not had enough time to receive an accurate reading. An approach that could have been taken was setting a given time period to stay at the bottom of the pool in order for the spring gauge to process the force acting on the sack.

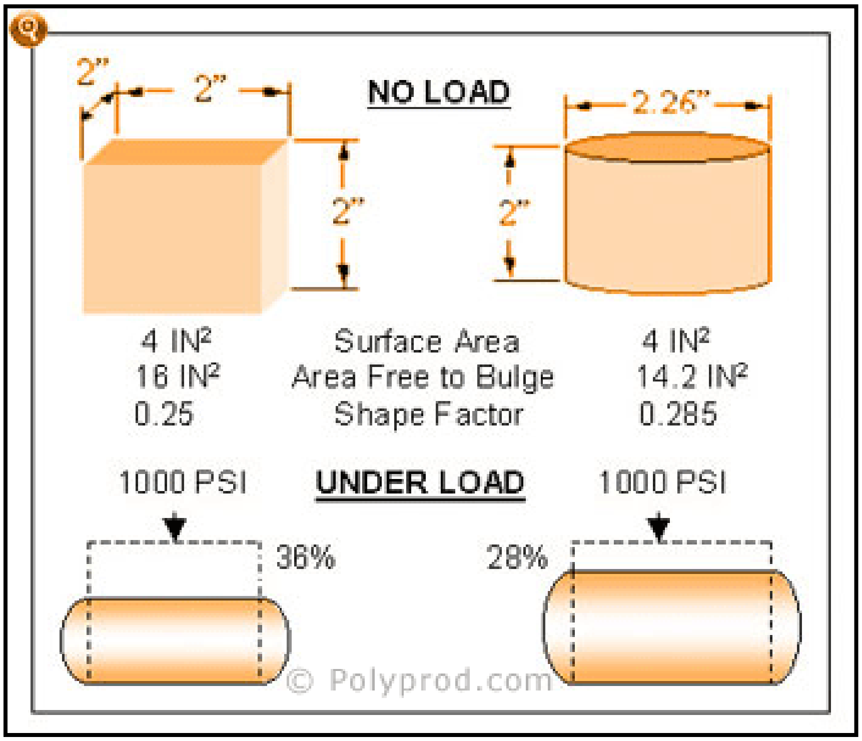


Figure 45: Shape Factor Example

An additional factor that must be considered is the folding of the MACS sack. If there is improper folding and closing of the sack, then water will travel in it and soak the item. It would also add weight to the sack and alter the readings significantly. The physical properties of some items used, such as the t-shirt, sweatshirt, and the cardboard, would change. The t-shirt and sweater would deform from the water due to their flexible characteristics. The cardboard possesses a very low shape factor of 4.5. Shape factor demonstrates the function of the shape in determining how a part with parallel load faces will behave under compressive forces. The chart above shows to two common shapes, one is a cylinder with the proportions of an ice-hockey puck and the other is a block of the same height and cross-sectional area. If the same weights are positioned on the blocks, acting the same compressive forces on them, the rectangular block will deflect more than the cylinder. The blocks will not change in volume, so the reduction in height is caused by the freedom of the sides to bulge. As a result, the rectangular block deflects more than the cylindrical one because the sides of the rectangular block provide a greater area free to bulge. The data and results for this experiment provided us with conclusions and trends to include in the project, but also made the group aware of all the minuscule variables that can prove to be substantial.

The spring gage also posed an issue. The combination of the initial thrust created by the diver, the pressure and buoyancy of the water, and the air inside the pack displayed different force values on the gage. It almost seemed as if the spring gage locked up at a certain point and stopped reading forces. Upon observation, the first five or so feet were the given range for the spring gage. The thrusting motion done by the individual and the buoyancy of the bag, together, seemed to be the initial forces which reacted on the bag. Also, the times the spring gage may or may not have come unattached from the sack during the dive could have thrown off the values slightly. These forces are still worthy for these experiments since Marine divers will be experiencing similar forces when they dive underwater. This is one reason why there could be a disparity between the results obtained from test to test.

Another reason for variance between the test trials could have dealt with the placement of the materials inside the sack. If certain objects were placed at a different orientation than they had been originally placed another issue could be presented. The placement of the materials could allow for more or less air pockets to form. If there was a different amount of air pockets the readings would also change. The manual compression was done to release the air pockets, but if the first time the amount of air was different than the second trial the resulting buoyancy force from the sack could vary. The only way to control this would be to place the objects exactly the same way they were placed in the bag the first place. However, placing objects exactly the same way each time is not practical. This also goes for the Marines and the objects that they place in each one of their MACS Sacks. Whether they place medical supplies, electronics, or ammunition in their sack, it is almost impossible to reenact where they placed those once the sack is sealed. Therefore the resulting forces may fluctuate from dive to dive.

Whether any anomalies or disparities did occur when testing, the results were the best approximation of forces that could be obtained. With no special equipment or measuring devices these tests were the best approaches to determining the validity of this project. Further testing should occur with better machinery when an actually prototype is constructed to determine the correctness of these results.

In conclusion, it can be seen that the redesign of the MACS Sack using a ripcord system is a plausible means of releasing excess air from the inside of the sack. A prototype should be constructed using durable materials and should be implemented to allow the Marines to dive to greater depths without worry of any floatation. Also, the orientation of compression should always be horizontal. Based on all the results obtained, a horizontal compression always trumped the values obtained from vertical compression tests. This new bag design should be considered by all military branches and could also be used for commercial diving purposes.

CHAPTER 4. CONCLUSIONS

4.1 – Our Project Origin in Review

It is said that hindsight is 20/20, and this certainly proves true with respect to the engineering and design process. In concluding this project our group has witnessed and observed a number of successes, a number of failures, and to review those has only given us further ideas. What could have been done better? Which approaches proved to be great ideas? What is our team dynamic like and where could this project continue? All of these short and simple questions yield lengthy and complicated questions. However, in review, this project has taught us all considerably about the engineering process and the skills necessary to achieve a group objective.

Our project's initial objectives stand as evidence that our project was an overall success in the eyes of the engineering process. Our underlying intention from day one had always been to take the existing pack system of the United States Marine Corps and positively improve upon it in a way that contributed to the combat effectiveness and safety of Marines. This bold and difficult objective was a source of pride. It acted as a source of confidence for us that our project, our first in-depth undergraduate research subject, was based off of a purposeful idea. To aid in the operation and mission success of United States Marines seemed to us to be of the highest calling. The Marines have historically been known to act at the forefront of our nation's defense and military strength, upholding the highest order of personal discipline and accountability. They were the ones who fought valiantly across the Pacific in WWII at the shores of Tarawa, fell in great numbers during the TET offensive in Vietnam, and are the ones still today leading the global war on terror and the search for the likes of Osama Bin Laden and the Taliban. To remember their ranks and consider the immense sacrifice made by all marines, it was our group's great honor to work for their sake through our interactive qualifying project.

Figure 46: USMC Drill Instructors at Camp Pendleton

Figure 47: USMC landings at Da Nang during the Vietnam War

Figure 48: Osama Bin Laden

With our objective in mind, our initial research led us to investigate the USMC Improved Load Bearing Equipment system. With significant success and hands on deliberation, our group produced a practical and very possible addition to the ILBE. This sub assembly took the form of an inflatable, waterproof, airtight, liner which we intended to act as a working inflatable device. Our motivation and enthusiasm led us to research all fractions of the design we had collectively imagined, and steps were even made to acquire the ILBE platform and continue towards the path of prototyping our design. During this progress we were able to contact a Marine Corps Research and Development representative named Mr. Trevor Scott. A project engineer stationed at the US Department of Defense Materials Laboratory in Natick Massachusetts, Mr. Scott guided us towards a webpage outlining contract proposals the Marines are currently asking of civilian and corporate groups in the manufacturing industry. From this webpage and our correspondence with Mr. Scott, our group was able to discern that our ideas and work regarding the ILBE could potentially be nullified, as the Marine Corp is considering replacing the current system completely in the near future. A group decision was made to reassess our project direction and change course towards a different proposal.

This transition in direction more than anything has expressed to us the principles of the engineering process. In the field of engineering, the process of refining and revising a plan to produce the best end result possible is the foundation of all successful designs. This concept is well known to all of our group members, and has been truly demonstrated to all of us during this project. With that being said, we were very relieved and happy to redouble our efforts when a new direction for our project presented itself to us: to modify a pack sub assembly, a waterproof rucksack, which would continue to be utilized even if the ILBE platform were someday replaced.

The MACS Sack is the standard issued waterproof collapsible dry bag for the Untied States Marine Corps. This item proves an especially prevalent problem to Recon Marine Divers, and the opportunity to aid these, the most skilled and elite, marines certainly fitted the bill of our initial goal. We moved forward with a set of new design goals in mind: construct a system that would decrease the time necessary to deflate the sack, while at the same time did so more effectively. We chased this goal and worked to analyze and address the problem in as many respects as possible. Our hard work resulted in a final and well laid out design with supportive prototype evidence that showed the positive impact our design proposal could potentially mean for the Marines. In this way our resulting project pursued the original objective to the fullest extent, and our group holds great satisfaction that our intent never varied.

4.2 – Approach Taken to Achieve Objectives

Given a new start and new design parameters, our group set to work with our underlying intention in mind. We started with conversation and sketch designing as a group, which soon yielded some constructive ideas. Before we could pursue these ideas, however, we realized that our scope of understanding the problem needed to be improved to include greater detail. Who were the Recon Marines and what were their missions like? What material properties and design flaws of the current MACK Sac have led to the current problem? What job is this platform expected to perform and under what conditions? These were all valid questions that we had to ask of ourselves before continuing forward intelligently. We spent considerable time looking into literary works and reliable sources, even some first-hand accounts, to glean the background we sought.

In hindsight, this literature review contributed largely to our designs. It showed us considerations we had to take stock in, which really speaks positively for the effort our group put forth. We studied the product reviews of the MAC Sack by all the types of combat marines who utilize it. We considered the materials and tools we would ideally include in our design to great specification. We explored the typical mission set of a Recon Dive Unit and the training that they endure personally to become such. Assembling an general information background really aided in expanding our general knowledge surrounding the project's subject. More to the point, this research was incredibly important when we began organizing our methods of design.

From the answers we found regarding our design background, our design began to really take shape and become more convincing in its appeal over the current MACS Sack design. Our group arrived at two possible methods of solving the problem at hand: a compression assist system, and a manually powered vacuum system. We convinced each other that both ideas were valuable despite their individual flaws, and so we researched both accordingly. Considerations such as profile, weight, material, collapsibility, durability, reliability and even cost were all made about both of our redesigned assembly components. These characteristics were all desired to a certain extent, and so we endeavored to correct out design to the best of our ability. During the research into these traits, it became more and more obvious that a compression rip cord system seemed the most likely and most possible advancement over the current designed MACS Sack. All of our imagined designs were assembled into a Solidworks computer model, which went miles towards providing us with further thoughts about minor details. These details included chord pattern, the addition of elastic bindings, the chord gage, etc… The design and redesign of these aspects were each a process in and amongst themselves, but it ultimately added up to a proposed assembly that we were happy with.

Before long our group saw that the need for hands-on testing was a must if our fundamental ideas were to be supported quantitatively. We sought the means to simulate the intended functions of our design and show through trails of underwater tests that, given a constant time of compression, our design did more to dispel air contained within various packing lists. Our group constructed rudimentary guides for a compression chord system and made multiple trips to an Olympic swimming pool to conduct testing. The tests were designed to compare the function of the standard MACS Sack to our redesigned model, and they worked brilliantly. The results of the tests reflected our design objectives with a reproducible effect.

The advancement of our project (from background research, initial designs, the progression and refining of our design, the constructing a comprehensive proposal, the building of a prototype and then the testing of our redesigned model conclusively) resulted in a positive end result, and can therefore be seen as an effective scheme of fulfilling our project objectives. Reference the figure below for a clear summarization of this advancement starting with the initial and ending with final stages of project.

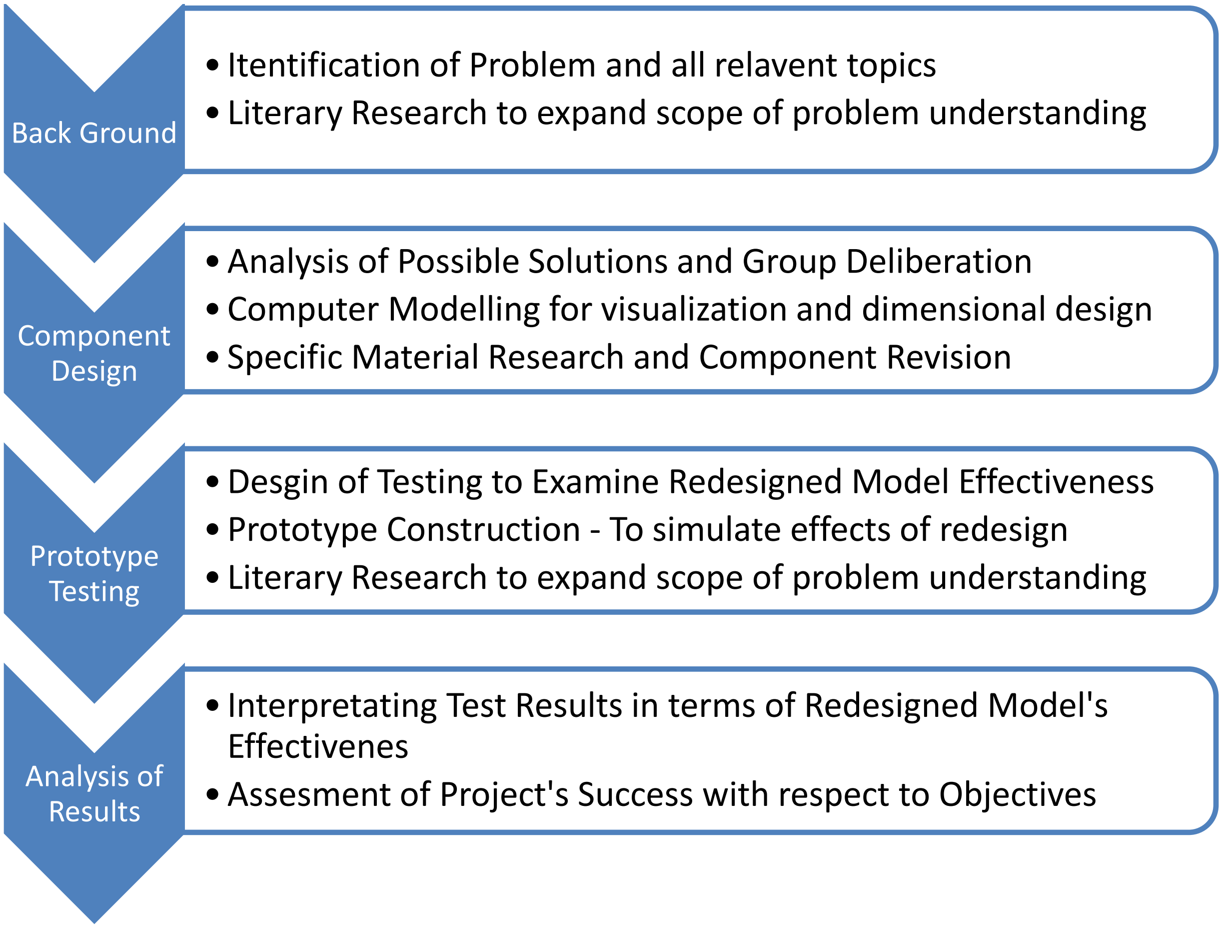


Figure 49: Project Approach to Achieving Objectives

4.3 – Significant Work Accomplished

In review of all the work accomplished within this project, there are several areas of work worthy of more significant mention then the rest. These moments were the ones that made a larger impact on the overall success of our project than others. Moreover, they are the accomplishments whose contributions towards our group's forward progress are most notable.

The first of these strides was our contacting of and correspondence with Natick Laboratories. Our contact provided us with invaluable guidance in the early stages of our design process. It was through his advice that we found a particular cause, the MACS Sack, which was both worthy of our project’s focus and relevant to today’s and tomorrow’s Marine Corps. By contacting the labs we learned firsthand what a setback can mean during the engineering project, but we were able to overcome it and realign our efforts to move forward. What’s more, given the available expertise in this line of engineering design, the laboratory personnel’s commendation for picking a worthy project objective added credibility to our plan to proceed.

The second most notable stride made over the course of this project was the acquisition of an actual MACS Sack. Being able to have a tangible model from which we could form a computer model and develop our design was critical to the steady progress of our work. This physical MACS Sack also proved essential when it came to base performance testing and prototype construction. Without this significant step in the process, any proposal our project would have otherwise yielded would be without concrete evidence supporting its benefits.

This train of thought leads into the topic of our last significant milestone: qualitative testing. Our team’s visit to the pool facilities at the College of the Holy Cross proved very productive. From this we were able to attain and organize data regarding the mission effectiveness of the standard issue MACS Sack compared to one modified in the fashion described by our redesign. This data spoke volumes regarding the efficiency and impact our added compression system could potentially offer if pursued to the full extent of professional manufacturing.

4.4 – Project Limitations

It might have benefited us take note of other waterproof platforms more. In retrospect, that is a step that – if taken to a further extent – might have improved our knowledge even more. To learn from other designs with similar working parameters as ours, we could have potentially saved time and effort during research. This would have provided us with more time to build a prototype that accurately reflects our design and ultimately help the overall conclusiveness of our project. That being said, our consideration of the MACS Sack's current characteristics and their shortcomings was extensive.

Another area of concern in which our project may have been better performed was our testing. There were a great many of variable, and we made our best efforts to mitigate any inconsistency or risk. However, our testing could have certainly been expanded to include greater depths, saltwater environments, greater number of trials, or even the addition of stressors to the participant compressing the bag to simulate the rush of real time combat. The testing was conclusive in the end, but nonetheless, a greater degree of complexity would have only added to the validity of end result.

4.5 – End Result of Our Project

As expressed by those of Natick Laboratories, there is a need for a bag liner that will submerge under water when the Marines partake in their dive ops. The MACS Sack, the waterproof liner currently issued to Marines, has a reverse valve which releases air when compressed but not at a very good rate. Our designs will improve upon the current design drastically. Whether it is the ripcord compression assist or the further assist of a possible vacuum pump, our redesigned model should remove more air than what the reverse valve does when it hits and submerges under water, even under strenuous conditions and a lack of time. The vacuum may be an unlikely means of removing air because of its awkward shape and possible failure to reach airspace, but our project also showed the need for efforts beyond simple and even assisted physical compression. From this, a small profile vacuum pump could potentially prove the most effective way of removing the air. However, it would also face the breaking and failing to operate. The ripcord design was obviously the fastest way of removing the most air, but there is always the risk of the cords snapping and or tangling. As can be seen, these designs all have their pros and cons. The results of our testing omitted the addition of a vacuum, but proved the positive impact our ripcord compression assist design could prove – even in the rudimentary prototype scale of performance. Our testing did not indicate as to whether a final reproduction of the MAC Sack should include both of these alterations, but it did support the concept that more can be done than simply compressing the dry bag by hand. Our extensive iteration of design and our interpretations of test data have convinced us that our platform would help to develop a better bag which will keep the Marines safer when they dive. Whether it helps them to enter the water faster or sink at a better rate, our designed improvements would improve all aspects of the original.

4.6 – Potential To Market Design Elsewhere and Continue Project

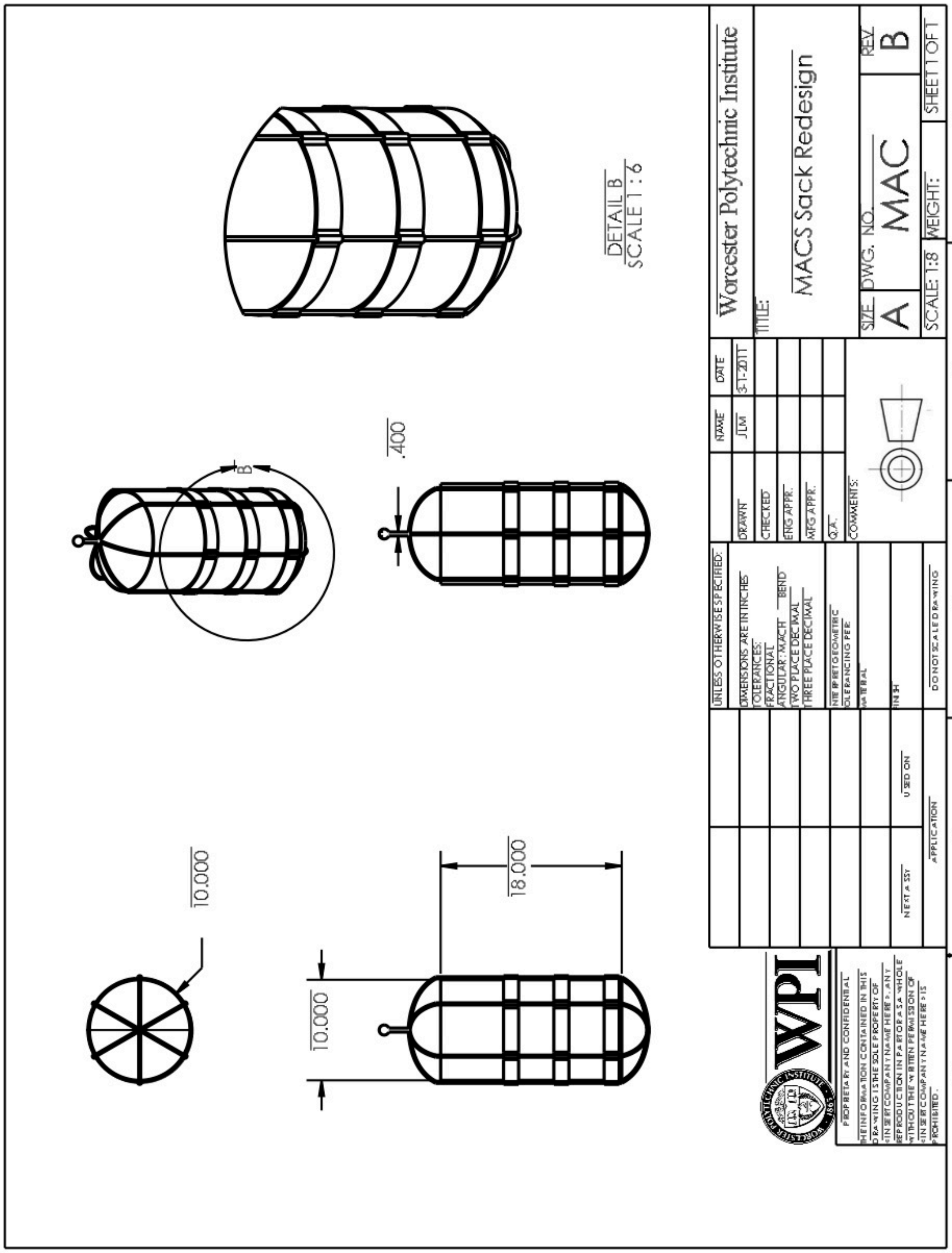
The design for a more efficient air release system to this pack may or may not be accepted by the Marines. Any sort of government branch is very difficult to sell something to especially when what they have was put into circulation just a few years ago. The MACS Sack had been redesigned and altered earlier this year with more efficient and durable materials. As there are many marines enlisted it would cost the military a whole lot more money to purchase newly designed bags. This purchase may not be in their interests now but may be in the future. Once they have realized the potential of this design they may then consider purchasing the new design.

On the other hand, this bag could be put on the retail market where it will most likely receive a better welcoming from individuals who partake in water sports, tactical-diving, and even camping. If we were to join forces with Cascade Design Inc. (the designers of the MACS Sack) we could then propose our ideas for the alterations to the bag. With these propositions, Cascade may take our ideas into consideration and place our design on the market for sale. Anyone in need of a waterproof liner that can both keep things dry and have no problem compressing itself to release air would absolutely be looked at by individuals who like to partake in outdoor excursions. As of today a standard MACS Sack retails for around twenty-two dollars on various websites. With this in mind, a standard waterproof liner is a decently cheap investment which we could build upon and sell it at a reasonably similar price which would be appealing to investors.

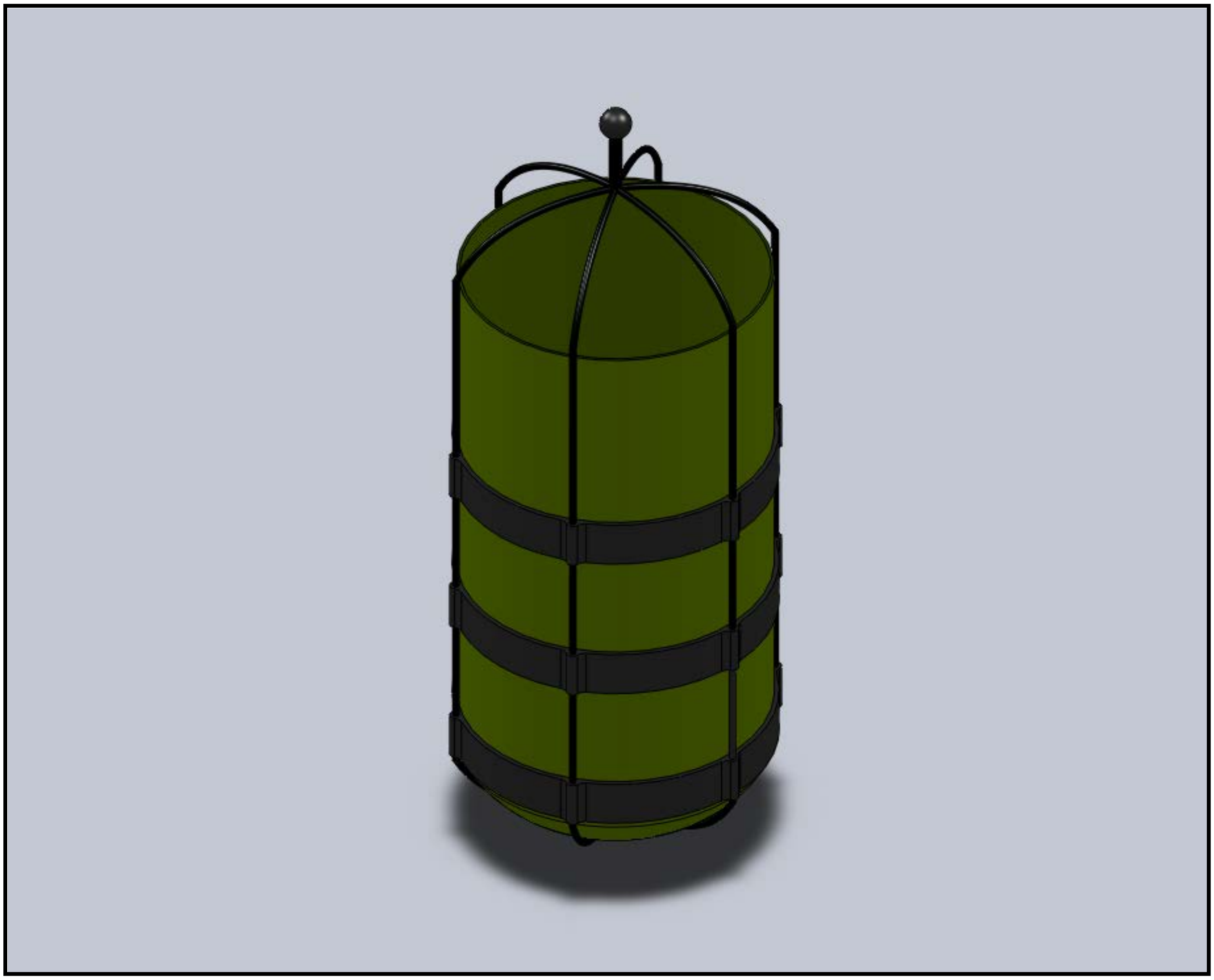
Taking the above considerations in mind, the final question we have asked ourselves is this: If we had more time, where would we go from here? To answer that is not very difficult. The next step would most certainly to try and manufacture a legitimate prototype from scratch using the ideal materials. The testing we have performed thus far proves the effectiveness of our ideas, but to take that to the next level would involve contacting a company with the means to professionally manufacture our design. This project has a very honorable mission objective: to help protect and aid Marines who serve in the protection of our country. It would undoubtedly be a worthy endeavor if this project were to be continued even further than what has been accomplished here.

APPENDIX: DATA CHARTS AND PLOTS

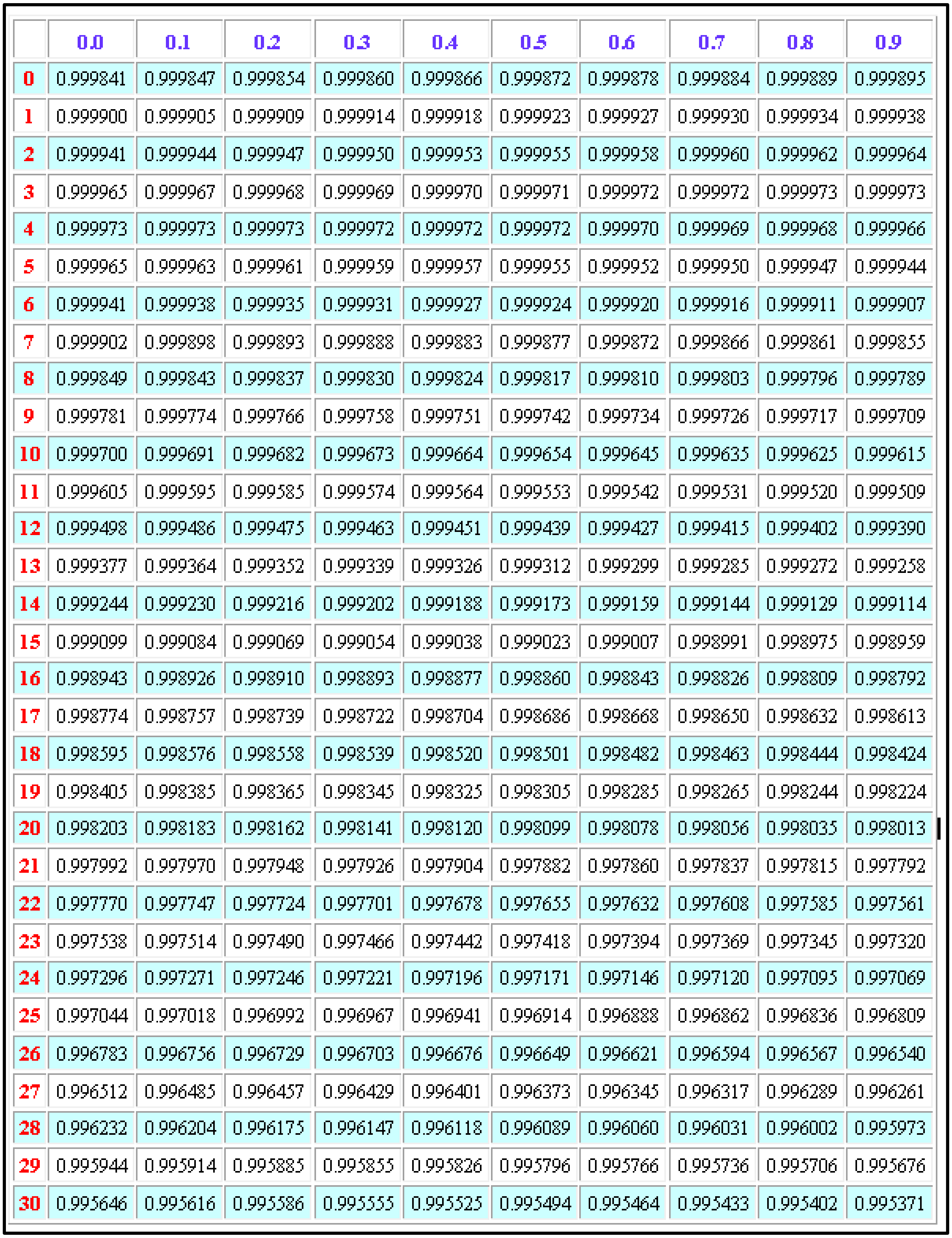
SolidWorks Drawing File, Revision B *(generated by Jim MacDonald)*



SolidWorks Part File, Revision B *(generated by Jim MacDonald)*

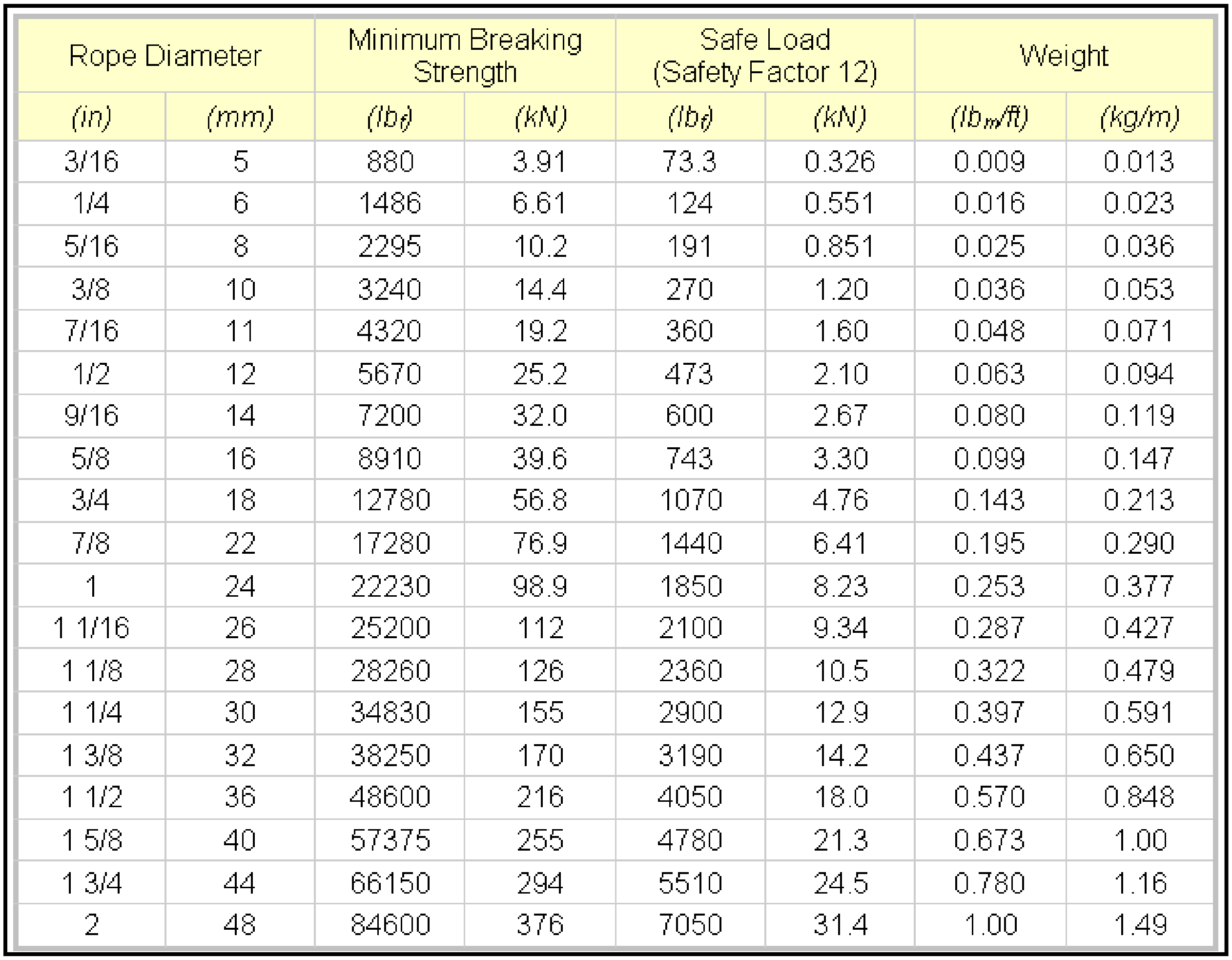


Density of Water (g/mL) vs. Temperature (°C). (“Sea Water Density & Salinity” [37])



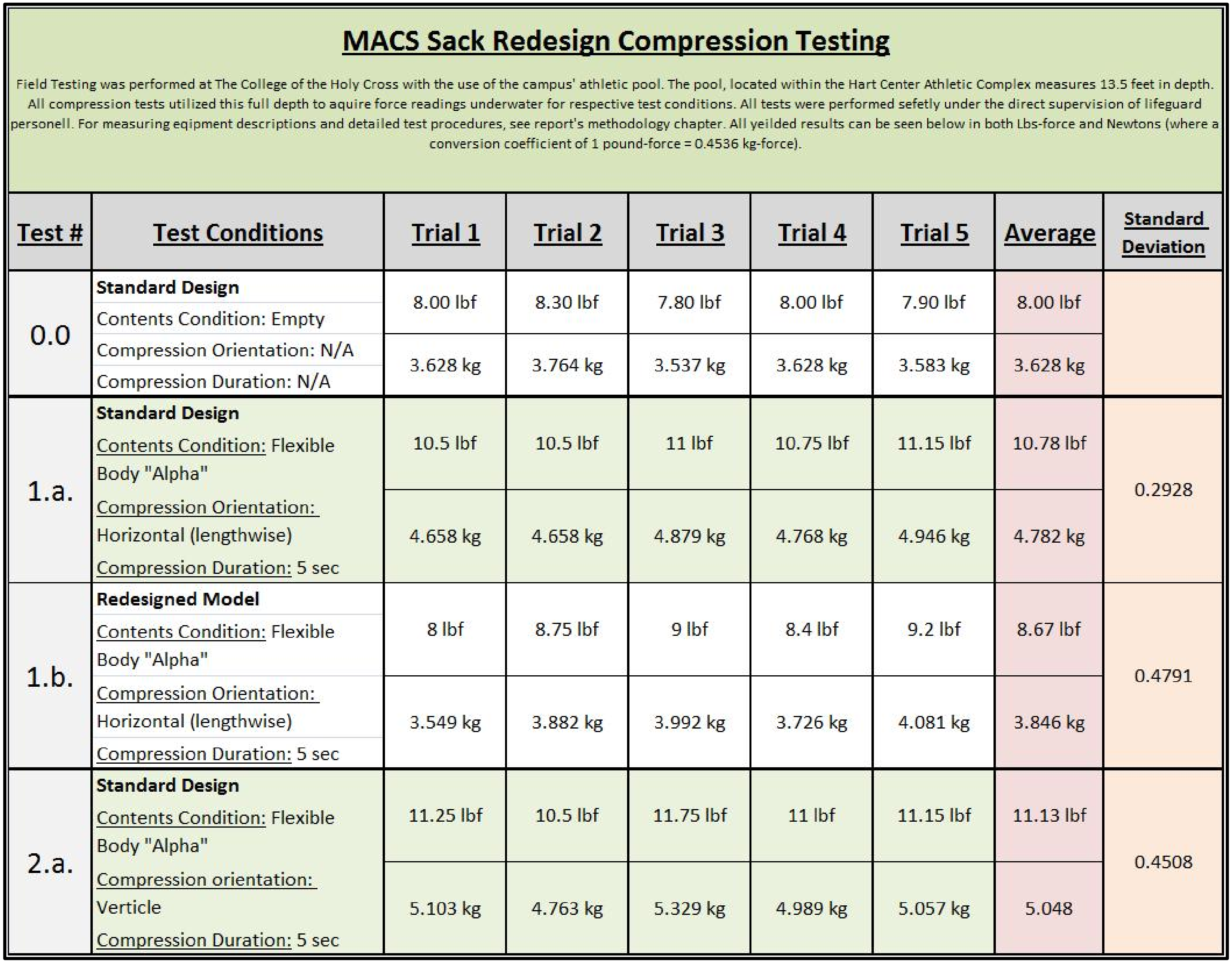
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.999841	0.999847	0.999854	0.999860	0.999866	0.999872	0.999878	0.999884	0.999889	0.999895
1	0.999900	0.999905	0.999909	0.999914	0.999918	0.999923	0.999927	0.999930	0.999934	0.999938
2	0.999941	0.999944	0.999947	0.999950	0.999953	0.999955	0.999958	0.999960	0.999962	0.999964
3	0.999965	0.999967	0.999968	0.999969	0.999970	0.999971	0.999972	0.999972	0.999973	0.999973
4	0.999973	0.999973	0.999973	0.999972	0.999972	0.999972	0.999970	0.999969	0.999968	0.999966
5	0.999965	0.999963	0.999961	0.999959	0.999957	0.999955	0.999952	0.999950	0.999947	0.999944
6	0.999941	0.999938	0.999935	0.999931	0.999927	0.999924	0.999920	0.999916	0.999911	0.999907
7	0.999902	0.999898	0.999893	0.999888	0.999883	0.999877	0.999872	0.999866	0.999861	0.999855
8	0.999849	0.999843	0.999837	0.999830	0.999824	0.999817	0.999810	0.999803	0.999796	0.999789
9	0.999781	0.999774	0.999766	0.999758	0.999751	0.999742	0.999734	0.999726	0.999717	0.999709
10	0.999700	0.999691	0.999682	0.999673	0.999664	0.999654	0.999645	0.999635	0.999625	0.999615
11	0.999605	0.999595	0.999585	0.999574	0.999564	0.999553	0.999542	0.999531	0.999520	0.999509
12	0.999498	0.999486	0.999475	0.999463	0.999451	0.999439	0.999427	0.999415	0.999402	0.999390
13	0.999377	0.999364	0.999352	0.999339	0.999326	0.999312	0.999299	0.999285	0.999272	0.999258
14	0.999244	0.999230	0.999216	0.999202	0.999188	0.999173	0.999159	0.999144	0.999129	0.999114
15	0.999099	0.999084	0.999069	0.999054	0.999038	0.999023	0.999007	0.998991	0.998975	0.998959
16	0.998943	0.998926	0.998910	0.998893	0.998877	0.998860	0.998843	0.998826	0.998809	0.998792
17	0.998774	0.998757	0.998739	0.998722	0.998704	0.998686	0.998668	0.998650	0.998632	0.998613
18	0.998595	0.998576	0.998558	0.998539	0.998520	0.998501	0.998482	0.998463	0.998444	0.998424
19	0.998405	0.998385	0.998365	0.998345	0.998325	0.998305	0.998285	0.998265	0.998244	0.998224
20	0.998203	0.998183	0.998162	0.998141	0.998120	0.998099	0.998078	0.998056	0.998035	0.998013
21	0.997992	0.997970	0.997948	0.997926	0.997904	0.997882	0.997860	0.997837	0.997815	0.997792
22	0.997770	0.997747	0.997724	0.997701	0.997678	0.997655	0.997632	0.997608	0.997585	0.997561
23	0.997538	0.997514	0.997490	0.997466	0.997442	0.997418	0.997394	0.997369	0.997345	0.997320
24	0.997296	0.997271	0.997246	0.997221	0.997196	0.997171	0.997146	0.997120	0.997095	0.997069
25	0.997044	0.997018	0.996992	0.996967	0.996941	0.996914	0.996888	0.996862	0.996836	0.996809
26	0.996783	0.996756	0.996729	0.996703	0.996676	0.996649	0.996621	0.996594	0.996567	0.996540
27	0.996512	0.996485	0.996457	0.996429	0.996401	0.996373	0.996345	0.996317	0.996289	0.996261
28	0.996232	0.996204	0.996175	0.996147	0.996118	0.996089	0.996060	0.996031	0.996002	0.995973
29	0.995944	0.995914	0.995885	0.995855	0.995826	0.995796	0.995766	0.995736	0.995706	0.995676
30	0.995646	0.995616	0.995586	0.995555	0.995525	0.995494	0.995464	0.995433	0.995402	0.995371

Minimum breaking strength and safe load of a nylon rope. (Dosh, “Nylon Rope” [11])



Rope Diameter		Minimum Breaking Strength		Safe Load (Safety Factor 12)		Weight	
(in)	*(mm)*	*(lb$_f$)*	*(kN)*	*(lb$_f$)*	*(kN)*	*(lb$_m$/ft)*	*(kg/m)*
3/16	5	880	3.91	73.3	0.326	0.009	0.013
1/4	6	1486	6.61	124	0.551	0.016	0.023
5/16	8	2295	10.2	191	0.851	0.025	0.036
3/8	10	3240	14.4	270	1.20	0.036	0.053
7/16	11	4320	19.2	360	1.60	0.048	0.071
1/2	12	5670	25.2	473	2.10	0.063	0.094
9/16	14	7200	32.0	600	2.67	0.080	0.119
5/8	16	8910	39.6	743	3.30	0.099	0.147
3/4	18	12780	56.8	1070	4.76	0.143	0.213
7/8	22	17280	76.9	1440	6.41	0.195	0.290
1	24	22230	98.9	1850	8.23	0.253	0.377
1 1/16	26	25200	112	2100	9.34	0.287	0.427
1 1/8	28	28260	126	2360	10.5	0.322	0.479
1 1/4	30	34830	155	2900	12.9	0.397	0.591
1 3/8	32	38250	170	3190	14.2	0.437	0.650
1 1/2	36	48600	216	4050	18.0	0.570	0.848
1 5/8	40	57375	255	4780	21.3	0.673	1.00
1 3/4	44	66150	294	5510	24.5	0.780	1.16
2	48	84600	376	7050	31.4	1.00	1.49

Prototype vs. Standard Design Testing Data Acquired. (Team Generated)



MACS Sack Redesign Compression Testing

Field Testing was performed at The College of the Holy Cross with the use of the campus' athletic pool. The pool, located within the Hart Center Athletic Complex measures 13.5 feet in depth. All compression tests utilized this full depth to aquire force readings underwater for respective test conditions. All tests were performed sefetly under the direct supervision of lifeguard personell. For measuring eqipment descriptions and detailed test procedures, see report's methodology chapter. All yeilded results can be seen below in both Lbs-force and Newtons (where a conversion coefficient of 1 pound-force = 0.4536 kg-force).

Test #	Test Conditions	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Standard Deviation
0.0	**Standard Design** Contents Condition: Empty Compression Orientation: N/A Compression Duration: N/A	8.00 lbf	8.30 lbf	7.80 lbf	8.00 lbf	7.90 lbf	8.00 lbf	
		3.628 kg	3.764 kg	3.537 kg	3.628 kg	3.583 kg	3.628 kg	
1.a.	**Standard Design** Contents Condition: Flexible Body "Alpha" Compression Orientation: Horizontal (lengthwise) Compression Duration: 5 sec	10.5 lbf	10.5 lbf	11 lbf	10.75 lbf	11.15 lbf	10.78 lbf	0.2928
		4.658 kg	4.658 kg	4.879 kg	4.768 kg	4.946 kg	4.782 kg	
1.b.	**Redesigned Model** Contents Condition: Flexible Body "Alpha" Compression Orientation: Horizontal (lengthwise) Compression Duration: 5 sec	8 lbf	8.75 lbf	9 lbf	8.4 lbf	9.2 lbf	8.67 lbf	0.4791
		3.549 kg	3.882 kg	3.992 kg	3.726 kg	4.081 kg	3.846 kg	
2.a.	**Standard Design** Contents Condition: Flexible Body "Alpha" Compression orientation: Verticle Compression Duration: 5 sec	11.25 lbf	10.5 lbf	11.75 lbf	11 lbf	11.15 lbf	11.13 lbf	0.4508
		5.103 kg	4.763 kg	5.329 kg	4.989 kg	5.057 kg	5.048	

Prototype vs. Standard Design Testing Data Acquired (Team Generated)

2.b.	**Redesigned Model** Contents Condition: Flexible Body "Alpha" Compression Orientation: Verticle Compression Duration: 5 sec	9.8 lbf	10 lbf	10 lbf	10.3 lbf	10 lbf	10.02 lbf	0.1789
		4.446 kg	4.536 kg	4.536 kg	4.672 kg	4.536 kg	4.545 kg	
3.a.	**Standard Design** Contents Condition: Flexible Body "Bravo" Compression Orientation: Horizontal (lengthwise) Compression Duration: 5 sec	7.75 lbf	6.75 lbf	8 lbf	7 lbf	7.75 lbf	7.45 lbf	0.542
		3.515 kg	3.062 kg	3.629 kg	3.175 kg	3.515 kg	3.379 kg	
3.b.	**Redesigned Model** Contents Condition: Flexible Body "Bravo" Compression Orientation: Horizontal (lengthwise) Compression Duration: 5 sec	6.4 lbf	6 lbf	6.9 lbf	7 lbf	6.35 lbf	6.53 lbf	0.4147
		2.903 kg	2.722 kg	3.130 kg	3.175 kg	2.880 kg	2.962 kg	
4.a.	**Standard Design** Contents Condition: Flexible Body "Bravo" Compression Orientation: Verticle Compression Duration: 5 sec	10.4 lbf	7.75 lbf	7.5 lbf	8.5 lbf	8.75 lbf	8.58 lbf	1.1405
		4.717 kg	3.515 kg	3.402 kg	3.855 kg	3.969 kg	3.892 kg	
4.b.	**Redesigned Model** Contents Condition: Flexible Body "Bravo" Compression Orientation: Verticle Compression Duration: 5 sec	7 lbf	7.15 lbf	6.75 lbf	7.3 lbf	6.95 lbf	7.03 lbf	0.208
		3.175 kg	3.243 kg	3.062 kg	3.311 kg	3.153 kg	3.189 kg	

Prototype vs. Standard Design Testing Data Acquired (Team Generated)

5.a.	**Standard Design** Contents Condition: Rigid Body "Nike" Compression Orientation: Horizontal (lengthwise) Compression Duration: 5 sec	5.25 lbf	5.5 lbf	7 lbf	7 lbf	6.25 lbf	6.2 lbf	0.8178
		2.381 kg	2.495 kg	3.175 kg	3.175 kg	2.835 kg	3.812 kg	
5.b.	**Redesigned Model** Contents Condition: Rigid Body "Nike" Compression Orientation: Horizontal (lengthwise) Compression Duration: 5 sec	4 lbf	4.65 lbf	5 lbf	4.25 lbf	5 lbf	4.58 lbf	0.4481
		1.814 kg	2.109 kg	2.268 kg	1.928 kg	2. 268 kg	2. 077 kg	
6.a.	**Standard Design** Contents Condition: Rigid Body "Nike" Compression Orientation: Verticle Compression Duration: 5 sec	6.4 lbf	6.1 lbf	7 lbf	6.6 lbf	7 lbf	6.62 lbf	0.3899
		2.903 kg	2.767 kg	3.175 kg	2.994 kg	3.175 kg	3.003 kg	
6.b.	**Redesigned Model** Contents Condition: Rigid Body "Nike" Compression Orientation: Verticle Compression Duration: 5 sec	5.5 lbf	4.95 lbf	5.85 lbf	6 lbf	5 lbf	5.46 lbf	0.4788
		2.495 kg	2.245 kg	2.654 kg	2.722 kg	2.268 kg	2.477 kg	
7.a.	**Standard Design** Contents Condition: Rigid Body "Sierra" Compression Orientation: Horizontal (lengthwise) Compression Duration: 5 sec	9.25 lbf	10.5 lbf	9 lbf	9 lbf	10.75 lbf	9.7 lbf	0.8551
		4.196 kg	4.763 kg	4.083 kg	4.083 kg	4.876 kg	4.400 kg	

Prototype vs. Standard Design Testing Data Acquired (Team Generated)

7.b.	**Redesigned Model** Contents Condition: Rigid Body "Sierra" Compression Orientation: Horizontal (lengthwise) Compression Duration: 5 sec	8.65 lbf	8.25 lbf	9 lbf	8.15 lbf	8 lbf	8.41 lbf	0.4084
		3.924 kg	3.742 kg	4.082 kg	3.697 kg	3.629 kg	3.629 kg	
8.a.	**Standard Design** Contents Condition: Rigid Body "Sierra" Compression Orientation: Verticle Compression Duration: 5 sec	9 lbf	7.8 lbf	7.8 lbf	8 lbf	8.6 lbf	8.24 lbf	0.5367
		4.082 kg	3.538 kg	3.538 kg	3.629 kg	3.901 kg	3.737 kg	
8.b.	**Redesigned Model** Contents Condition: Rigid Body "Sierra" Compression Orientation: Verticle Compression Duration: 5 sec	8.9 lbf	9 lbf	8.65 lbf	7.95 lbf	8.55 lbf	8.61 lbf	0.4114
		4.037 kg	4.082 kg	3.924 kg	3.606 kg	3.878 kg	3.905 kg	

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