RIGGING LAB ACADEMY

THE MAINLINE OPERATIONS EBOOK

With an introduction by Lance Piatt

BY RIGGING LAB ACADEMY

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INTRODUCTION

Thanks for downloading The Foundations of Mainline Systems eBook from Rigging Lab Academy.

We’re pleased to offer this exclusive material to you as this is the full Chapter 7 excerpt of the Rope Rescue Course Text Manual, the official course manual for all of Pat Rhodes' courses inside Rigging Lab Academy.

The complete version of this amazing manual, which is available inside many of the courses we have over at Rigging Lab Academy, covers NFPA Levels, Awareness, Operations, and Technician and is solely intended for the exclusive use of Rigging Lab Academy and Rescue Response Gear members only.

Thanks for hanging out with us,

LANCE PIATT
Founder of Rigging Lab Academy
& Rescue Response Gear

DISCLAIMER

This book is solely intended for the exclusive use of Rigging Lab Academy and Rescue Response Gear members only.

Rope rescue is inherently dangerous, even if the techniques, procedures, and illustrations in this book are diligently followed, serious injury and/or death may result. This book makes no claim to be all-inclusive on the subject of rope rescue. There is no substitute for quality training under the guidance of a qualified instructor.

Insofar as the author of this book has no control over the level of expertise of the reader of this material, or the manner this information is used, the author assumes no responsibility for the reader's use of this book.

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MAINLINE OPERATIONS

When building a Mainline system, consider the possibility of the need to convert from a lowering system to a raising system. There are numerous hidden factors that have caught many teams by surprise. By predicting these factors and pre-planning the Mainline, life becomes much easier and safer when the time comes to convert to the raising system.

Typically, lowering systems are safer than raising systems because we're cooperating with gravity. As soon as we go to a raising system, gravity becomes our prime enemy, and gravity’s most powerful accomplice is friction. What we are talking about mostly is the friction coefficient or Mainline contact with the surface between the Mainline anchor and the rescue package. Yes, friction is working in our favor during the lowering process, and if we are going down only, then ground friction isn’t that big of a deal (although we still keep a sharp eye out for rope abrasion, and damage), but when it's known that a raising system is going to be employed, we must mitigate rope contact with the surface before the lowering system is put into action. This is best accomplished by the use of a high directional.

The **Ideal Load Weight (ILW)** is the weight of the load during a static state; the **Practical Load Weight (PLW)** is the actual weight of the load plus the effects of the friction coefficient. Unfortunately, this fact is many times overlooked by many teams. During a lowering with approximately 20 feet of rope contact with the surface, the PLW of a 450 pound two person load may be only 150 pounds. During a raising with the same 20 feet of rope drag, the PLW will skyrocket to about 1100 pounds!

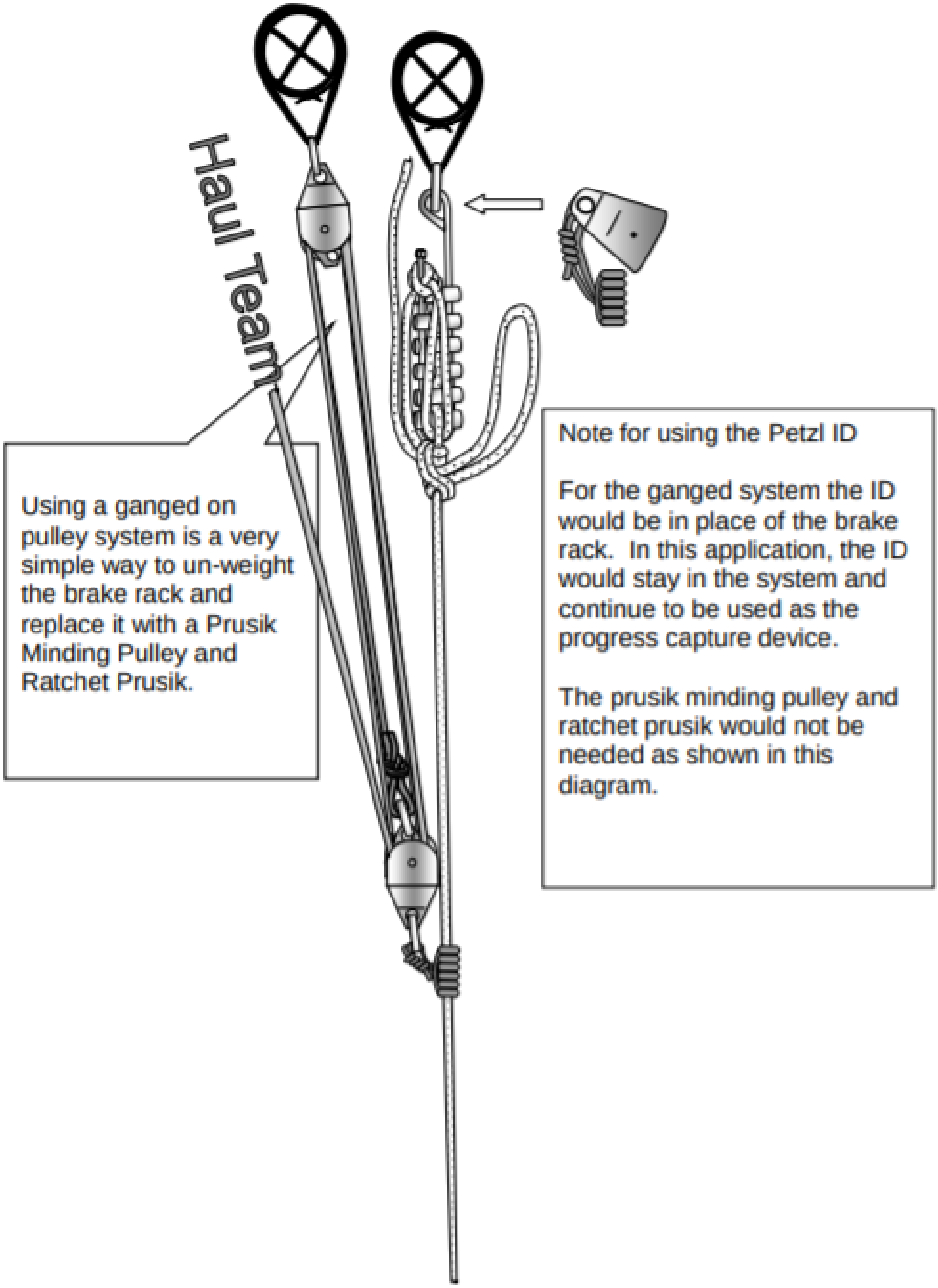
What does this mean to our anchor selection? With the use of a high directional the unwanted friction is all but eliminated. Without the use of a high directional, our anchor system is very susceptible to this hidden weight and possibly prone to failure. Control of all the many aspects of friction during a rope rescue operation is a must.

EQUIPMENT FOR LOWERING SYSTEMS

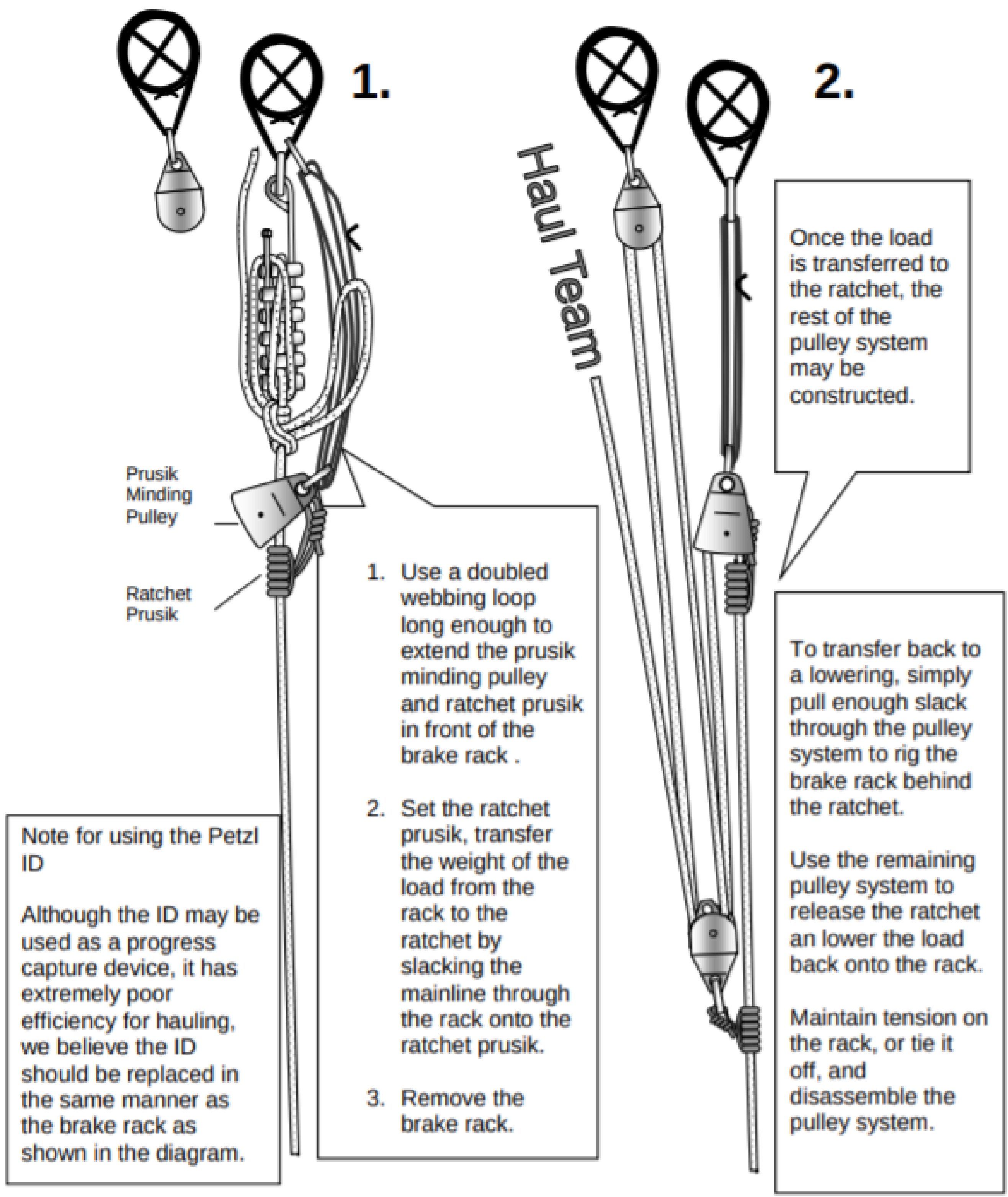
For the most part, the “6” bar Brake Rack has been the standard for a friction lowering device. The Brake Rack offers maximum control, and with a little practice, it can become very easy to operate. There are, however, new products on the horizon that are much more user-friendly. One that is on the market now is the **BMS (Bassett Metal Studios) Micro-rack**. I have used the BMS Micro-rack extensively, and have found it to perform exceedingly well.

Many teams automatically include a rigging plate in the construction of their Mainline system. All though at times, a rigging plate is useful in making other adjunct attachments to the system, we don't consider it a mandatory part of the mainline construction. When a rigging plate is needed, choose the smallest one available.

Converting From a Lowering to a Raise with a Ganged Pulley System



Converting From a Lowering to a Raise with an Intrical Pulley System
(Belay Line has been omitted for clarity)



PRE-PLAN THE WORKING LINE

All too often, teams rig their haul system with the progress capture device (the ratchet) at a directional anchor located in front of the mechanical advantage system. This ratchet position is most often due to the lack of pre-planning the layout of the working/haul line system.

Usually, the rigger will build the braking system for lowering at the anchor most inline with the fall line. Typically, this anchor is too close to the edge and offers a very small throw for the soon to become haul system. To overcome this problem the team will then look for another anchor that will provide a longer throw and hauling field beyond, or to the side of the first anchor.

One problem leads to another. The working line, now in need of a hot change-over, (going from a lowering to a raise under tension) has only one place the brake system (lowering) can be replaced with a ratchet (raising). This is at the original anchor, the one closest to the edge, the one that is now a forward directional for the haul system.

There are some inherent problems with a ratchet that is in front of the MA. During the reset phase of the haul, the rope behind the haul rope grab device is always slack, making for sloppy re-sets, but even more problematic, is the ebb and flow, back and forth movement of the directional anchor that occurs between re-sets and even at every tug of the rope. At best, this type of inefficient system mandates a back-tie that opposes the haul team.

As a result of this ebb and flow movement, the continual change in the force vector of the directional anchor gives us great concern for the integrity of the anchor. Keep in mind when looking at the drawings below, the static weight of the load at the directional anchor (non-moving, with equal tension on both sides of the directional pulley) is approximately 141% greater after the conversion to a raising system than it was during the lowering. The anchor stress will always be substantially greater during a haul than during a lowering. When choosing an anchor for a lowering system, we must build it strong enough to withstand the forces generated by the raising system that we will be going to later.

What is the friction profile of the edge? Are we making a 90-degree turn over sandstone or granite, or are we utilizing a high directional? During a raise, a 90- degree turn over a rock surface will ad over 3x the weight of the load at the edge. Using the force vector formula on page 114, one can quickly see the potential for a catastrophic failure of an underestimated directional anchor. The problem is magnified when the ratchet is put at the forward position, this constant change of low tension to high tension and back again is what has been the downfall of many anchors.

The solution to this problem is very simple: pre-plan the best location for the future haul system and ratchet and put the braking device for the lowering at that position from the start.

Fig. 1 ***YES***

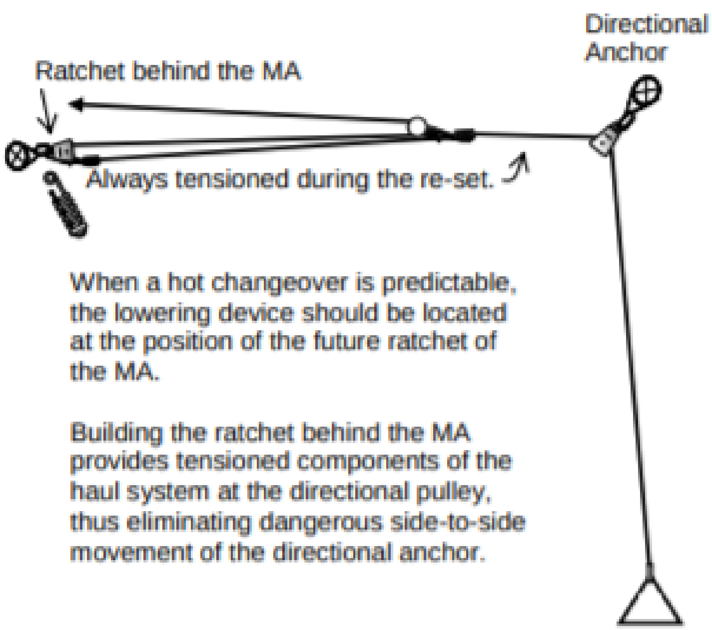
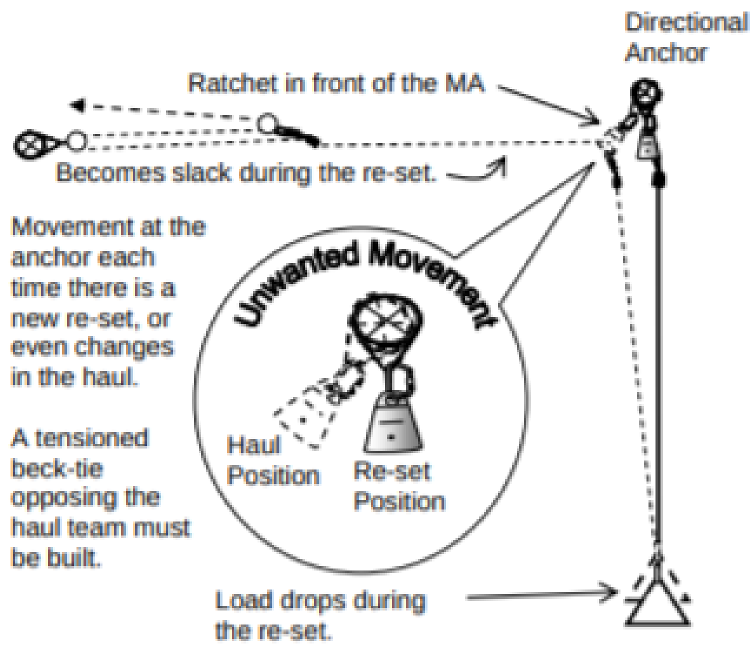


Fig. 2 ***NO***



MECHANICAL ADVANTAGE WITH PULLEY SYSTEMS

There are three categories of mechanical advantages using pulleys; **Simple**, **Compound**, and **Complex**. A **Simple MA** consists of a pulley system that has a single haul connection between the load and the haul team. A **Compound MA** is a simple mechanical advantage system pulling on the haul line of another simple mechanical advantage. Multiplying the two systems will give the total advantage.

HERE ARE FIVE RULES THAT CAN BE USED TO DETERMINE SIMPLE AND COMPOUND MECHANICAL ADVANTAGE SYSTEMS:

#1 If the pulley closest to the haulers is on the anchor, the pulley is only considered a **change of direction (cd)**. The same rule applies to ANY pulley system.

#2 If the rope used in the pulley system is tied to the anchor, the **ideal mechanical advantage (IMA)** will be EVEN (i.e., 2:1, 4:1. 6:1, etc.)

#3 If the rope used in the pulley system is tied to the load, the **ideal mechanical advantage (IMA)** will be ODD (i.e., 1:1, 3:1. 5:1, etc.

#4 To determine the IMA of a simple pulley system, count the ropes between the anchor and the load. Do not count the ropes between two anchors.

#5 A simple MA pulling on the haul line of another simple MA is called a compound MA system.

A **Complex MA** system is neither simple or compound, and the above rules will not work in determining the system. The only way in determining the mechanical advantage of a complex MA system is by calculating the "tension units". See “Critical Thinking On Mechanical Advantage Systems” on page 17.

The combinations of pulleys that can be incorporated in an MA system are infinite. With this in mind, how many pulleys are needed, and what are the characteristics of a quality haul system?

In general, the **ideal mechanical advantage (IMA)** is the ratio between the distance the load moves and distances the haul team moves. In a 2:1 system the load will move 1' to every 2' of haul. However, this does not mean that lifting the load is twice as easy. The **practical mechanical advantage (PMA)**, or simply put, the efficiency of the system, is the actual physical advantage the haul team ends up with. In short, based on the size of the haul team, try to build the MA system as small as possible. More pulleys create more friction, resulting in efficiency loss.

Consider the hauling field; that is to say, configure the MA system in a way that maximizes that amount of ground area the haul team can operate. This will also minimize the number of re-sets of the haul system. Build the MA system clean. Avoid crossed or twisted lines as this will add unwanted friction in the system.

When the haul prusik slips, this is an indication that something is not right. Do not add an additional prusik, correct the problem. A slipping haul prusik as like having a pressure relief device in the system, the haul prusik typically slips between 800 and 1200 pounds. With the exception of tandem haul prusiks on a tensioning system for a "highline" operation, putting tandem haul prusiks in the MA is like replacing a 15-amp fuse with a 30-amp fuse, something could very well fail.

A **"ganged on" MA system** is separate from the main line. An **"integral" MA system** is built with the same rope as the main line and runs continuously from the load to the haul team. Each way offers advantages; the "integral" system is less equipment intensive. "Ganged on" systems can be pre-rigged, and moved into place speeding the change over from a lowering system to a raising system. A **”piggyback” MA** is a compound system that consists of two or more identical simple mechanical advantages, i.e., a 2:1 pulling on a 2:1 equals a compound “piggyback” 4:1.

PULLEY SYSTEMS FOR HAULING, LOWERING, AND HOLDING

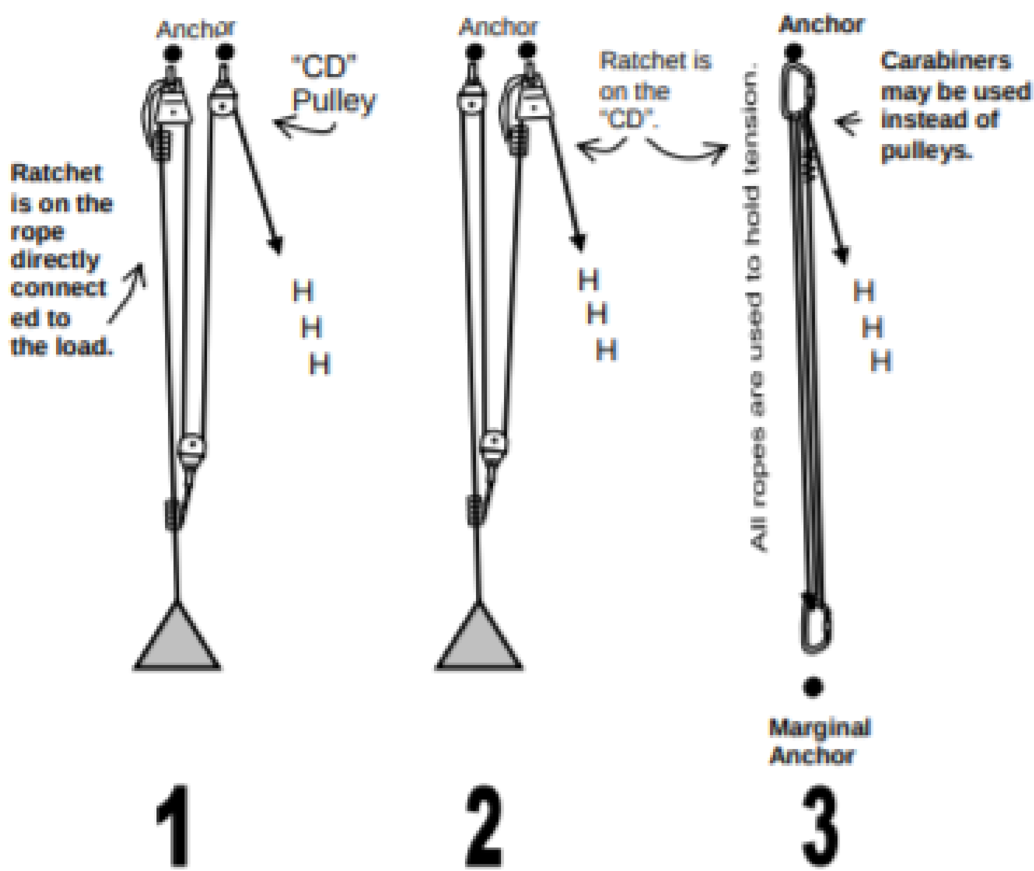
Rope rescue requires rigging skills to either move things or hold things in place. As simple as this sounds, a complete working knowledge of pulley systems and mechanical advantage is a must. Pulley systems used for lifting a load horizontally are somewhat different than a pulley system or mechanical advantage used to backtie a tree or guy a high directional.

In addition to hauling and holding, a third type of pulley system is used for rapid changes from a hauling system to a lowering system. The difference of all these examples is the position of the ratchet (progress capture device).

Hauling pulley systems are designed to hold the load during resets of a hauling operation. The ratchet is on the leg of rope directly connected to the load.

Hauling, Lowering, and Rapid Response pulley systems may be used up or down very quickly. The ratchet is on the change of direction.

Back-tie pulley systems are designed to maintain tension between two anchor points (may use only carabiners as pulleys). The ratchet is on the change of direction.



OTHER CONSIDERATIONS

Rope and Equipment: How much rope, pulleys, carabiners and other needed equipment is available?

Size of the Load (output): What and how much weight is required to lift? Is it a single person, or a rescue or extreme rescue load?

Number of Haulers (input): What are the manpower resources available for hauling?

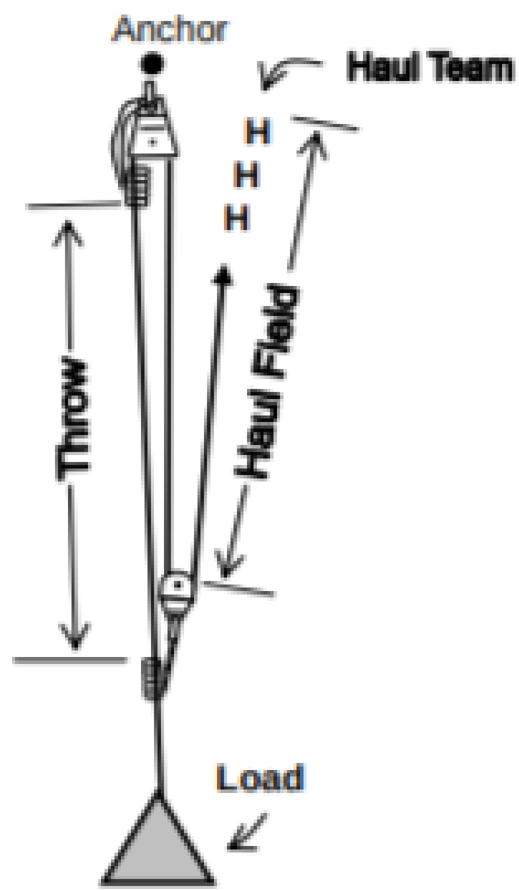
Work Area: What is the size of the work area for the team to safely operate?

Throw: What is the distance the MA system can operate before a reset?

The Incline of the Hauling Field: Is the hauling field level? Downhill hauls are much easier than uphill.

Adaptability: Can you easily change to a larger or smaller mechanical advantage?

Lowering: Can the pulley system be employed as a lowering system?



CLARIFICATION OF MA TERMS

Integral Versus Ganged On:
Plain and simple, if its built with the one rope that is connected to the load it is an integral system, this may be a simple, compound, or a complex system. A ganged system is an MA which is built with a separate rope that is attached to the working rope.

Ganged On Versus Piggyback:
A piggyback system is a compound MA that is made up of two or more identical simple MA's. i.e. a compound 4:1 (2:1)(2:1). A Ganged MA system is attached by a haul grab to a second main rope for the purpose of lifting or lowering a load.

Change of Direction Versus Directional:
A change of direction is a pulley on the anchor closest to the haulers, notated (cd). A cd adds no mechanical advantage to the system. A directional is a pulley or pulleys between the pulley system and the load to be raised, notated (d) or (1:1).

Throw Versus the Haul Field:
The throw is the available distance between maximum pulley system extension and two-block. **Note:** Simple pulley systems have only one throw. Compound pulley systems have a minimum of two throws. The haul field is the available distance a hauler or haulers can run out or the space that they have to stand and pull.

SIMPLE PULLEY SYSTEMS

Simple pulley systems must be considered one of the primary tools of rope rescue work. Some of the advantages are; they are easy to remember and perform. They have long throws and are easily modified if more advantage is needed. The disadvantages are, they typically have more friction, use more rope, and require more equipment in larger MAs.

Pulley systems are the backbone of most technical rescues.

CRITICAL THINKING ON MECHANICAL ADVANTAGES

Understanding how to calculate the **ideal mechanical advantage (IMA)**, and the **practical mechanical advantage (PMA)** can be extremely useful in developing skills that will assist the technician in building mechanical advantages that are the most efficient for the job at hand. This is done by determining the amount of tension on each pulley in the system.

All operational pulleys have two legs of rope, one leg going in, and one leg coming out. The tension or force these two legs apply to the pulley will always be equal. This is most readily seen in the simplest of mechanical advantages, the 2:1. One leg is attached to the anchor, it runs in a pulley connected to the load, and the second leg comes out the pulley to the haul team.

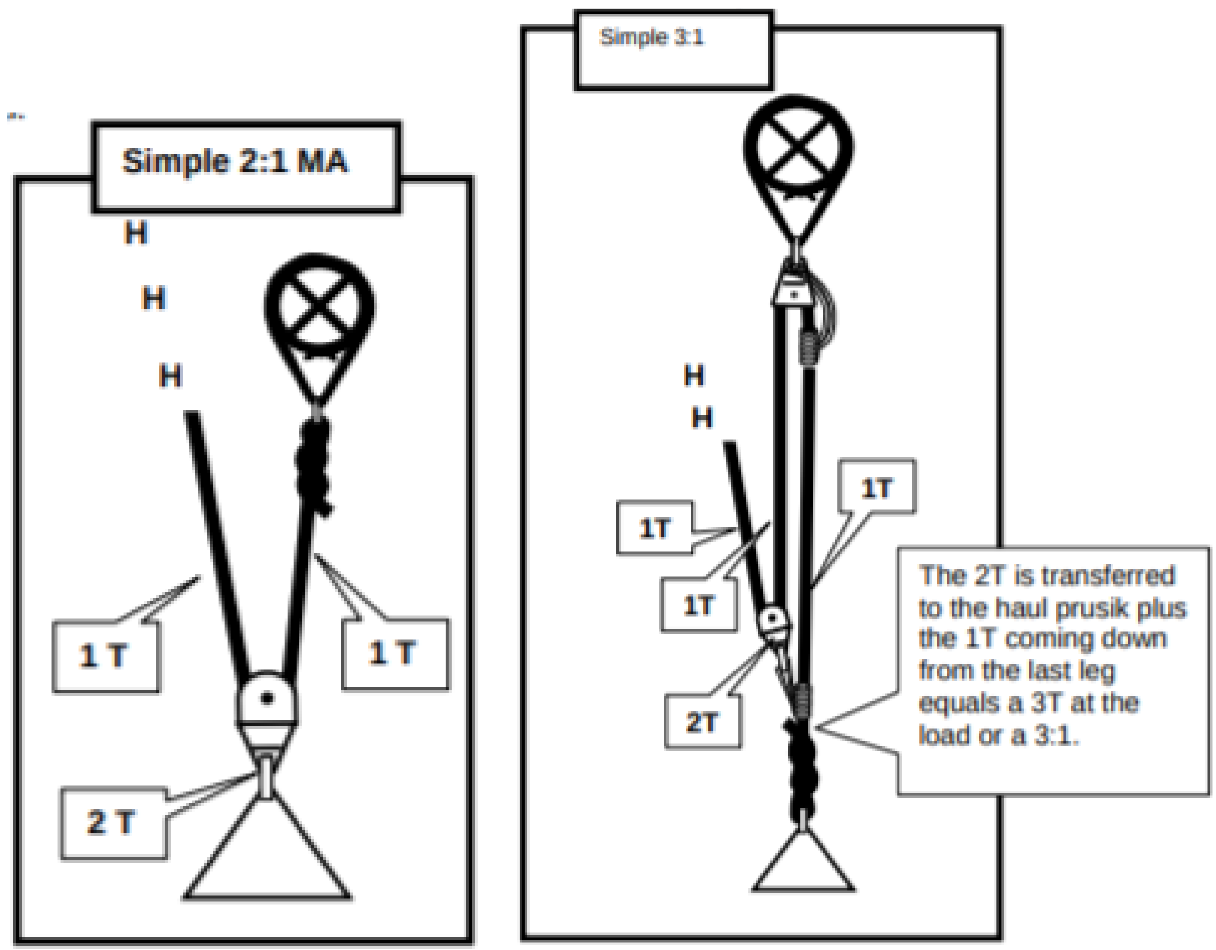
These two legs add up to equal 2 tension units at the pulley. Therefore when the haul team applies 1 tension unit of pull, they benefit from 2 tension units of lift on the load. This is the “DNA” of mechanical advantages.

HERE ARE A FEW SIMPLE TIPS TO REMEMBER WHEN CALCULATING THE TENSION UNITS OF AN MA:

- Start adding the tension units with the leg closest to the haul team.

- Pulleys that are connected directly to the anchor do not contribute to the MA.

- When the tension units of a pulley that is pulling on the haul leg of another MA system (compound and complex systems) those tension units are transferred to that haul leg.

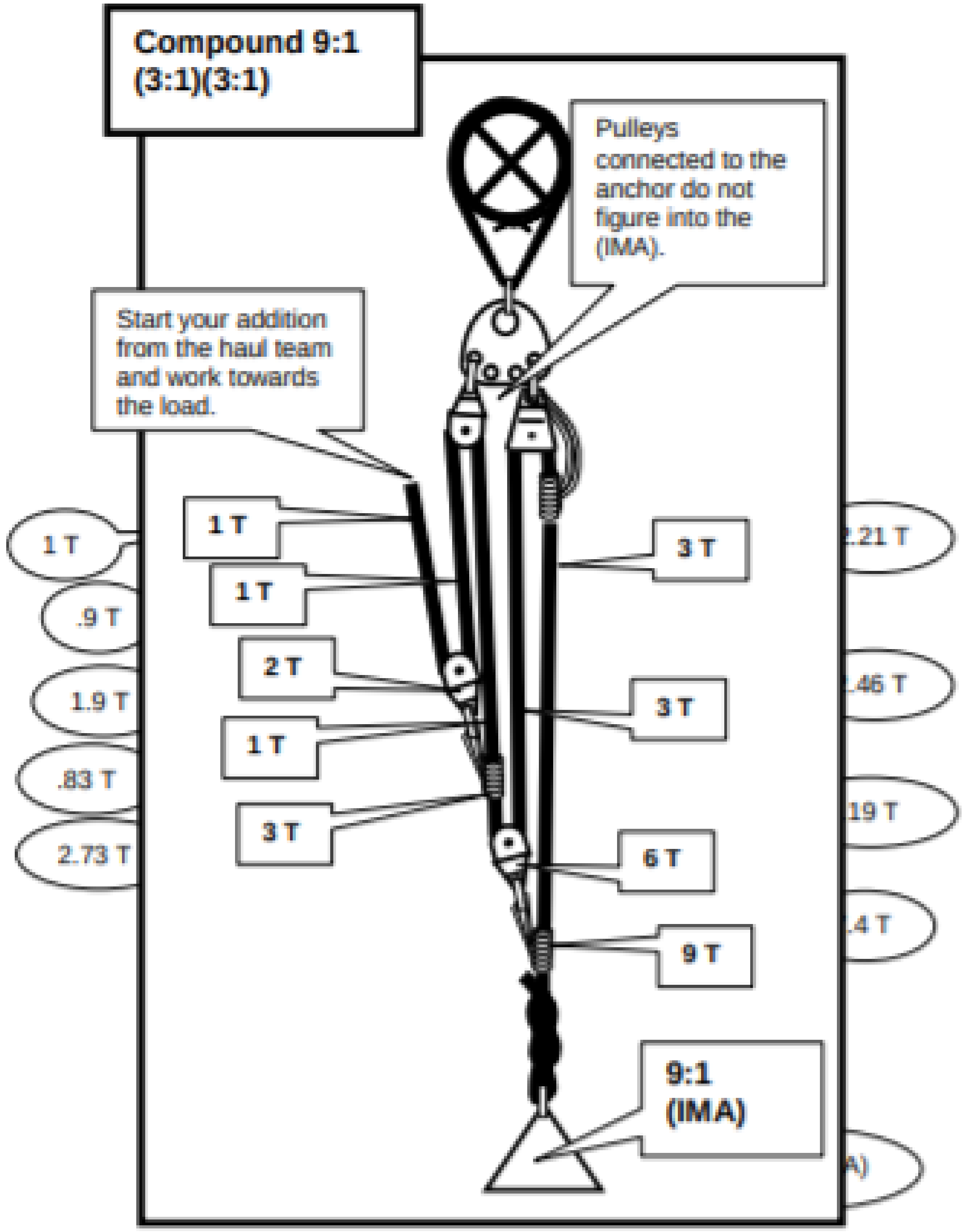


PRACTICAL MECHANICAL ADVANTAGES (PMA)

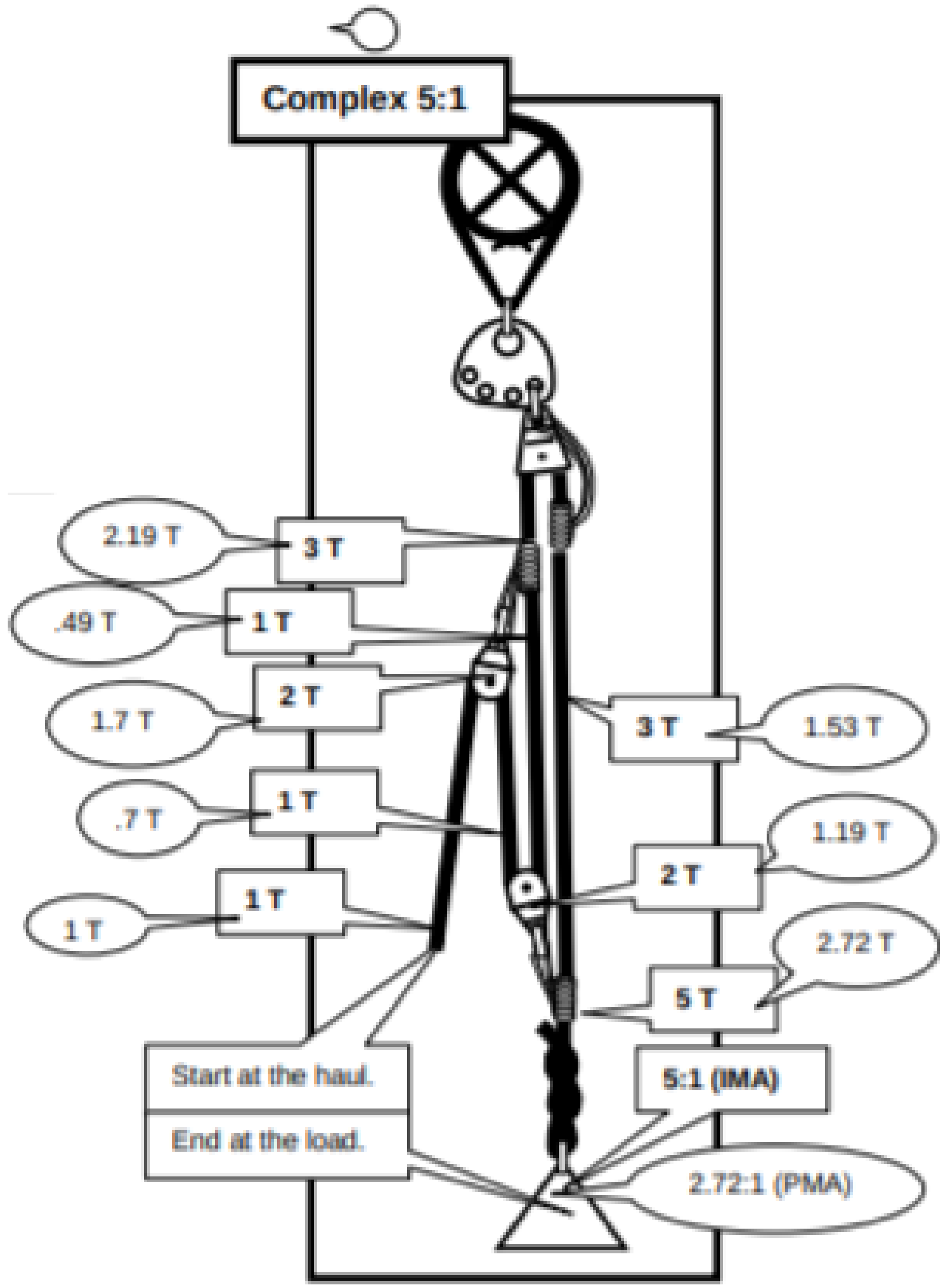
The **Ideal Mechanical Advantage (IMA)** is based on 100% efficiency, but because of friction and inefficiency of the pulleys (most ball bearing pulleys are about 90% efficient, and bushing pulleys are about 70% efficient), it's important to understand the **Practical Mechanical Advantage (PMA)** of the system.

Generally speaking, the more pulleys in the system the less efficient it will be.

Take ball bearing pulleys; 90% efficient, each time the rope passes through the pulley, it loses 10% of its efficiency. This efficiency loss is multiplied each time the rope passes through another pulley. Note the 9:1 MA figure on the next page; the round callouts denote the PMA figures.



Compound 9:1
(3:1)(3:1)
Pulleys connected to the anchor do not figure into the (IMA).
Start your addition from the haul team and work towards the load.
1 T
1 T
2 T
1 T
3 T
3 T
3 T
6 T
9 T
9:1
(IMA)
1 T
.9 T
1.9 T
.83 T
2.73 T



Note the complex 5:1 above; In this case, we'll calculate the efficiency loss of bushing pulleys (70% efficient). The **Ideal Mechanical Advantage (IMA)** is denoted by the square callouts, and the **Practical Mechanical Advantage (PMA)** by the round callouts.

WRAP UP

Thank you for joining us for the Mainline Operations eBook.

Mainline systems are the workforce contingents for all rescue and rigging operations. There is a lot going on and much to keep track off. As you noticed, a mainline is not always a “simple 3:1” raise change to lower or the other way around. Mainline systems can be very much a 360° option at times. We hope you found the material inside this eBook to be helpful, insightful, and encouraging.

Rigging Lab Academy offers new opportunities to increase your rope handling knowledge. Experience a broader spectrum and cross-pollination of rope access disciplines by viewing our growing list of courses, all designed by top rigging thought leaders from across the globe to help you bridge the gap between effectiveness and efficiency. Start increasing your knowledge of several different rigging styles.

DEFINITIONS

Accessory Cord: Any low-stretch cordage [rope] made from nylon, Spectra, or Kevlar fibers and used for any number of purposes. Generally, any cord smaller than 9mm is considered an accessory cord.

Active Protection: Rock climbing protection (camming devices) which have moving parts as part of the camming mechanism. Spring-loaded camming devices are considered “active”.

Air Monitoring: Those actions needed to ensure atmospheric safety during a confined space emergency through the use of specialized monitoring equipment. Air monitoring is the single most important diagnostic tool used in making a confined space emergency atmospherically safe. Ventilation is the prescribed treatment. Air monitoring must continue during the full extent of the rescue and must work in harmony with the ventilation sector. The areas of primary concern are:

- The opening of the space.
- The source of air being supplied to the space.
- The air being drafted from the space.
- The interior of the space (personal monitors on the entry team).

Anchor: Any means of attaching the rope to an object. It may be a natural anchor such as a tree or rock formation, or an artificial anchor provided by the rescuer, such as a bolt or rock protection.

Anchor Types:

- Single Point Anchors: Anchors that originate from one location, such as a pole, tree, bolt, etc. A single point anchor may be bombproof or may be a marginal component of an anchor system.

- Tensioned Anchors: Anchors working in harmony by virtue of a back-tie system.

Hard Ascender: Hardware camming devices which grip the rope in one direction.

Belay System: Protection against a fall by handling a secondary unloaded rope (belay rope) in such a manner that is may be taken in or let out yet can be secured to hold this load in case of failure of the working line or rappel line.

Bolt: Artificial, reliable means of anchoring in rock requiring the drilling of holes and the placement of bolts.

Brake Rack: A friction device used for rappelling or the safe control of lowering systems. Typically, the brake rack employs multiple friction bars held in place by a steel frame. The friction bars are capable of collapsing or loosening around the rope, therefore providing the needed friction for the safe control of the descent.

Carabiners: Hardware used for the purpose of connecting any two points of a given rope system. Carabiners typically employ a self-closing, gate as opposed to other connecting hardware that employs manually operated screws that close the opening, see screw-links and tri-links.

Change of Direction Pulley: A change of direction is a pulley on the anchor that directs the last leg of rope to the haul team, notated (cd).

Compound Mechanical Advantage Pulley System: Any pulley system that is made up of two or more simple pulley systems. Example; a compound 6:1 could be a 3:1 pulling on the end of a 2:1, or a 2:1 pulling on a 3:1. The simple components are multiplied to give the compound mechanical advantage.

Cordelettes: Typically, a small rope, typically 8 mm or 9 mm, and approximately 10 meters long, used for rigging. Example; small pulley systems, whipping, and frapping, etc.

Critical Point Test: A test rescue teams use to determine the inherent safety within a rope rescue system. In order to pass the Critical Point Test, a system must have no point or single piece of equipment which, were it to fail, would cause catastrophic failure of the entire system.

Directional Pulley: A directional is a pulley or pulleys between the pulley system and the load to be raised, notated (d) or (1:1)

Dynamic System Safety Factors (DSSF): In a dynamic state, (movement and maximum system stress, with a suspended load) the ratio between the load and the weakest link in a system using the rated breaking strength of each piece of equipment in the system and a theoretical prediction of those factors that will add maximum stress to the system. For instance, any part of a given system will only hold 6000 lbs. and the work being placed on the system is 1000 lbs, including approximately 20' of rope drag at or over the edge, will in effect double the weight of the load on a raising system. The Safety Factor would then be approximately only a 3:1. A 7: 1 Dynamic System Safety Factor is a realistic goal when a belay rope is present.

Ganged Mechanical Advantage Pulley System: When a separate rope used for an MA system is attached by a haul grab to a second main rope for the purpose of lifting or lowering a load.

Hardware: Those components of a rope system that are made of metal.

Haul Field: The haul field is the available distance a hauler or haulers can run out or the space that they have to stand and pull.

High Directional: A means of suspending a loaded rope at least 2 meters above the edge so that edge trauma is reduced. There are structural, natural and artificial high directionals.

Horizontal Systems: Any adjunct rope system that is employed for the purpose of changing the original direction of the mainline and belay line systems.

Loaded Changeover: Those actions needed to convert the mainline from a lowering system to a raising system while the load is suspended and under tension.

Litter: A device used to contain a patient and maintain stability during the extrication process.

Lockout/Tagout: Those actions needed to bring all potential hazards, typically electrical, mechanical, and engulfment, to a neutral state prior to the beginning of any rescue.

Mainline: Also known as the Working Line, it is the main rope system used to do the lowering and raising of the rescue package.

Mechanical Advantage: The increase of the input of power for the purpose of moving objects, typically during rope rescues, this would most often include the use of pulley systems.

Multipoint Anchor System: Any combination of point anchors that are employed to make one reliable anchor. The following are the two major divisions of multipoint anchor systems:

- **Self Distributing:** (Also known as "Self-Equalizing") A multipoint system rigged to where the force of the load is distributed between all the point anchors. Due to friction and many other unseen factors, this distribution is not as equal as most would assume.

- **Fixed Multi-point:** (Also known as “Load Sharing”) A multipoint anchor system which is distributing during the construction of this anchor and is then fixed into place, typically by virtue of an overhand loop.

Passive Protection: Rock climbing protection which has no moving parts (as opposed to active protection, which does). Examples are stoppers, hexcentrics, and tri-cams.

Patient Packaging: Patient packaging is the act of getting the patient ready to be evacuated.

Personal Loads: Any load equal to a single person.

Piggyback: A piggyback system is a compound MA that is made up of two or more identical simple MA’s. i.e. a compound 4:1 (2:1)(2:1).

Pulleys: A small grooved wheel used with a rescue rope to change the direction and point of application of a pulling force. They may be used in combinations to employ mechanical advantage especially for the purpose of a raising operation.

Rappelling: The act of descending a fixed rope system in a controlled manner for the purpose of vertical transportation.

Ratchet: A progress capture device employed for the sole purpose of holding the load in place during the reset phase of a raising operation.

Reset: Action taken to re-extend the pulley system for another haul after it has fully collapsed during a raising operation.

Rescue Load: As determined at the Fourth Annual Technical Rescue Symposium, 1987, a rescue load is considered to be 200 Kg, 448 lbs. It is the weight of one victim/patient, one rescuer, and associated gear.

Risk/Benefit Analysis: A command decision that determines the type of action needed based on the hazards present and the risk they pose to the team and the victim.

Rope: Typically, kernmantle rope is the most common rope used for rescue operations. Because of its floating properties polypropylene is sometimes used in swiftwater rescue. Kernmantle rope is constructed of a load-bearing core, or "kern", of nylon fibers surrounded by a braided, protective outer sheath, or "mantle". The core is completely protected by the mantle and holds most of the load. It has a high strength to weight ratio and maintains most of its strength when wet (approximately 85%). The kernmantle rope comes in two types; **Dynamic** and **Static**.

Dynamic rope consists of twisted or bundles that make up the core. This twisted core provides a high stretch quality. This allows as much as 40% stretch in the rope, depending on the manufacturer. Dynamic rope is very important in rescue work solely for the purpose of belaying a lead climber.

In contrast, **static kernmantle rope** stretches very little, from 2-4% under load. This type of rope is made from an outer braided sheath (mantle) which is woven over straight nylon fiber core (kern). The core supports 85% of the rope's strength. "Static" rope is used for rigging rescue system because of its high strength, low stretch and handling characteristics.

Rope Grabs: Any device attached to a rope for the purpose of holding or grabbing, may be software or hardware.

Screw-links: Hardware connectors that employ a manually operated screw to close and open the gate.

Size-up: The initial evaluation of the emergency scene by the first responder.

Soft Ascenders: Any number of rope hitches which grab the rope in one or both directions.

Software: Any rope system component that is either rope, webbing, or is constructed of rope or webbing.

Static System Safety Factor (SSSF): In a static state, (no movement, with a suspended load) the ratio between the load and the weakest link in a system using the rated breaking strength of each piece of equipment in the system. For instance, any part of a given system will only hold 5000 lbs. and the work being placed on the system is 1000 lbs.. The Safety Factor is then 5: 1. A 10: 1 Static System Safety Factor is a realistic goal when a belay rope is present.

System Loads: See "Rescue Loads".

Throw: The throw is the available distance between maximum pulley system extension and the need for a reset.

Tri-links: Triangle shaped, hardware connectors that employ a manually operated screw to close and open the gate. Tri-links are particularly suited for multiple loading in multiple directions.

Webbing: Widely used by rock climbers and rope rescuers, webbing is a flat nylon software that is relatively inexpensive and extremely strong. Although webbing has multiple uses, it is particularly suited for anchor rigging.

Working Line: Also known as “the mainline”, the working line is the main support rope for the rescue operation.

Working Load Limit (WLL): A rating that is sometimes used in conjunction with hardware, typically screw-links and tri-links.