Technical Rescuer-Trench Rescue; Mechanical Advantages

NORTH CAROLINA RESCUE TECHNICIAN

Some Principles To Consider

- "Every Object Resting On Earth Is "At Rest" Or A State Of Equilibrium.
- "The Greater The Weight Of An Object, The Greater The Friction Force."
- "The Smoother The Contact Surfaces, The Less Friction Between Those Surfaces"
- "Materials With Rounded Surfaces That Break Contact Between Objects Will Generally Reduce Friction."
- Energy: "The Property That Gives Something The Ability To Do Work."

Some Principles To Consider

- Types Of Energy:
  - Kinetic- Energy Possessed By A Body Or Object In Motion.
  - Potential: Stored Energy

Some Principles To Consider

- Work:
  - The Rate At Which Something Produces Energy.
- Need Power To Do Work And Overcome Friction, Gravity, Inertia, And Air Resistance.

Considerations For Rescue Hauling Systems

- When speed is needed, a simple system may be the best choice .
- Lack of personnel is an issue, a higher and more complex (MAS) may be needed.
- Small amount of gear is available, a simple MAS is recommended.
- Keep hauling area clear.
- Light load, use a low MAS system.
- Heavy load, use a high MAS system.

Ways Of Reducing Friction

- Directional systems.
- Reposition the haul system.
- Portable anchors
- A-Frames
- Tripods
- Edge rollers

Purpose Of A Mechanical Advantage

- It makes lifting a rescue load easier.
- It makes the lifting operation much safer.

Theory Of A Mechanical Advantage System (MAS)

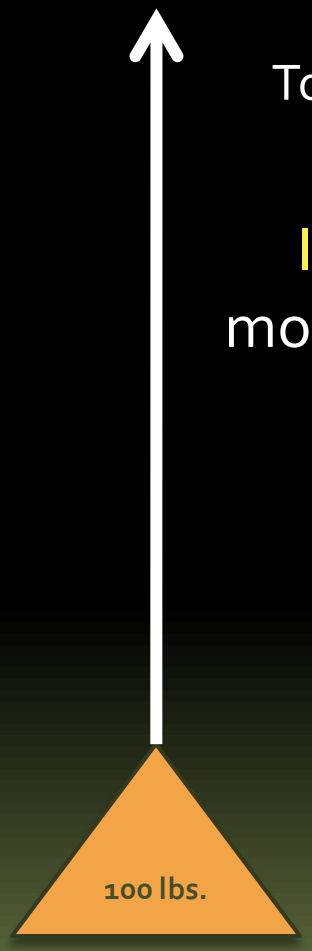
- The simplest hauling system is a direct pull.
- A direct pull system is:
  - The pulling force = to the load. (1:1 MAS).
- Load (output force) is 100 pounds
- Pulling force (input force) is 100 pounds
- No mechanical advantage for the pulling force is provided.
- To move: 100 lbs.; 10 feet (Direct Pull)
- Input Force of more than 100 pounds using 10' of rope.

Direct Pull; 1:1 MAS

Pulling force (input force) is 100+ pounds

To move: 100 lbs.; 10 feet

Input Force (Pulling) of more than 100 pounds using 10' of rope.



Load (output force) is 100 pounds

A Mechanical Advantage System Occurs…

- When the input force (pulling) exerted by the rescuers is less than the output force on the load.
  - 2:1 system
    - Load is 100 pounds (Output Force)
    - Pulling force (Input Force) needed to move the load is approximately 50 pounds or half the weight of the load.

TMA & AMA

- Theoretical Mechanical Advantage (TMA)
- When calculation does not include:
  - Size of pulleys
  - Friction
  - Contact with objects
  - Bends in rope
  - Therefore it is considered a 2:1
- Actual Mechanical Advantage (AMA):
  - When we factor in the friction of rope, rope stretch, and rope rubbing on edges… so actual mechanical advantage is approximately 1 7/8:1.

TMA & AMA

- The difference between theoretical and actual mechanical advantage is friction.

Mechanical Advantage:

- Is the ratio between the output force to the input force that is furnished for a machine to do work.
- The ratio refers to how efficient and effective a machine is.
- M/A less than 1 means:
  - The output force (load) delivered to the machine is less than the input force (pulling) supplied to the machine.
- M/A greater than 1 means:
  - The output force (load) delivered to the machine exceeds the input force (energy).

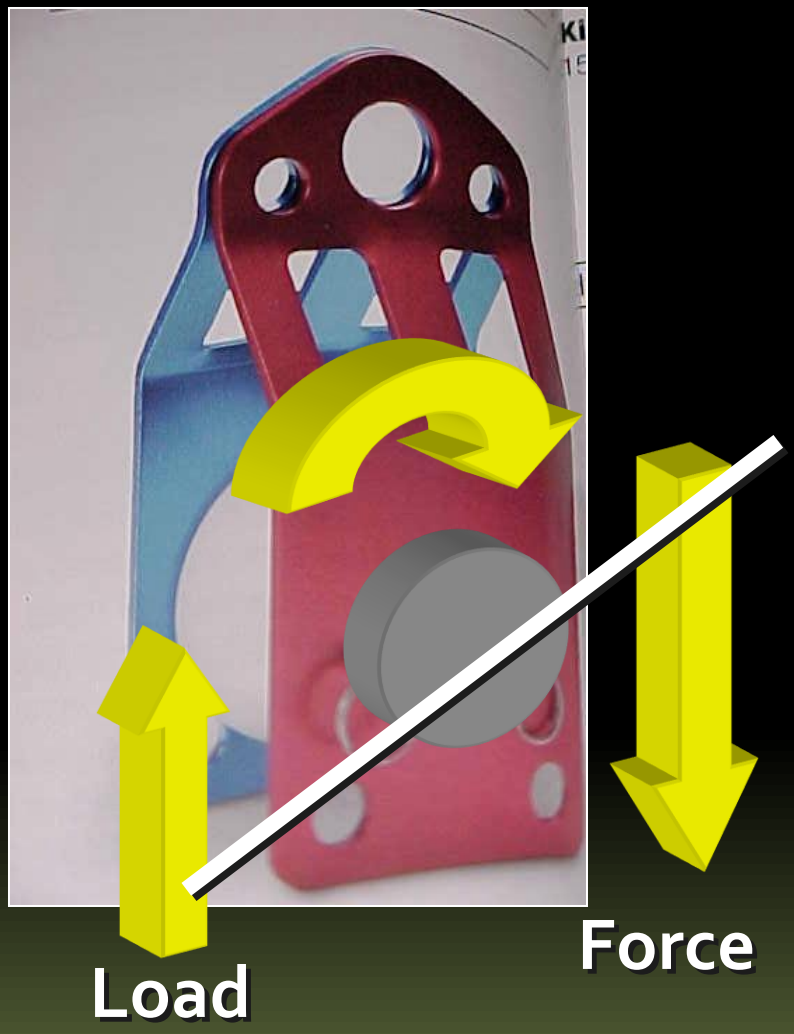
Mechanical Advantage

- Applied to the relationship between the weight of a load being lifted and the power of force required to lift, push, or hold a load.

Mechanical Advantage

- Examples of ways to reduce friction include:
  - Pulleys
  - Cams
  - Incline Planes
  - Screws…

Is A Pulley a Lever?



Why would we use M/A?

- Excessive Loads
- Minimal Manpower To Move Load
- Unanticipated Loads During The Lift.
- For Rigging Support Systems Such As Gantries, Derricks, Tripods, A-frames…
- Stabilization Systems

But which M/A do we use?

- Consider:
- Exceeding the 15:1 Safety Ratio when building M/A's.
- Manpower to move victim.
  - Less manpower means more M/A.
- KISS
  - (20 mules: 1 victim)
- Rule of 12's *(# of rescuers x M/A= less than 12)*
  - No more than 4 people pulling on a 3:1
  - No more than 3 people pulling on a 4:1
  - No more than 1 person pulling on a 9:1

- ***Rule #1 :***

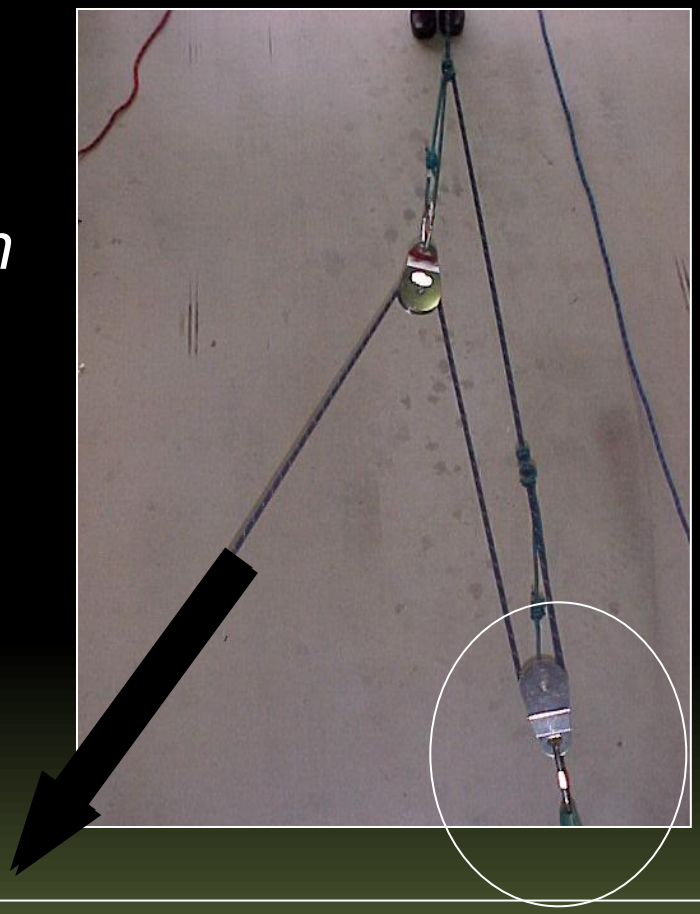
  "If The Rope You Are Pulling <u>Begins At The Load</u>, The Mechanical Advantage Will Always Be Odd."

  i.e. 1:1

CHANGE OF DIRECTION

Rule #2:

If a turn in the rope or pulley doesn't move, then it is nothing more than a "change of direction", with no mechanical advantage.



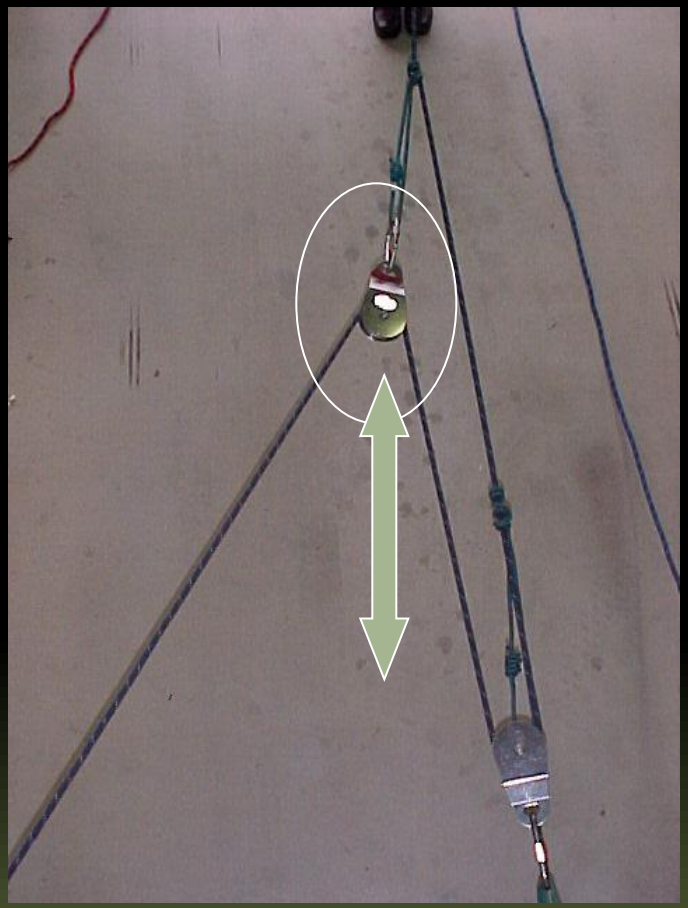
RESCUE NORTH CAROLINA
rescuenc.com

Rule #3:

"If the rope you are pulling begins at the anchor, the mechanical advantage will always be even." i.e. 2:1

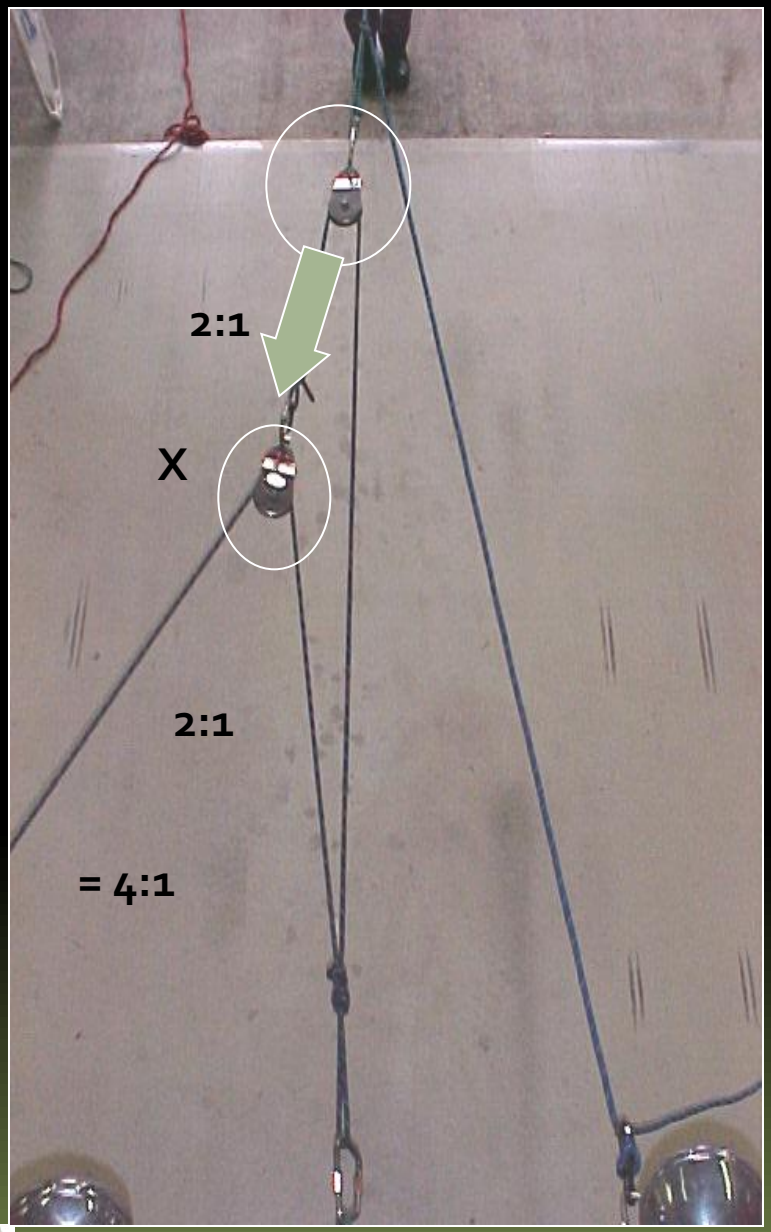
Rule #4:

"If the pulley (or a turn in the rope) moves or travels within the system, it will create a mechanical advantage."



Rule #5:

"When stacking pulleys into a system, a traveling pulley, placed on top of another traveling pulley MULTIPLIES the mechanical advantage."This is known as Compounding the Mech. Advantage. So, if we have one system pulling on another M.A., we multiply.

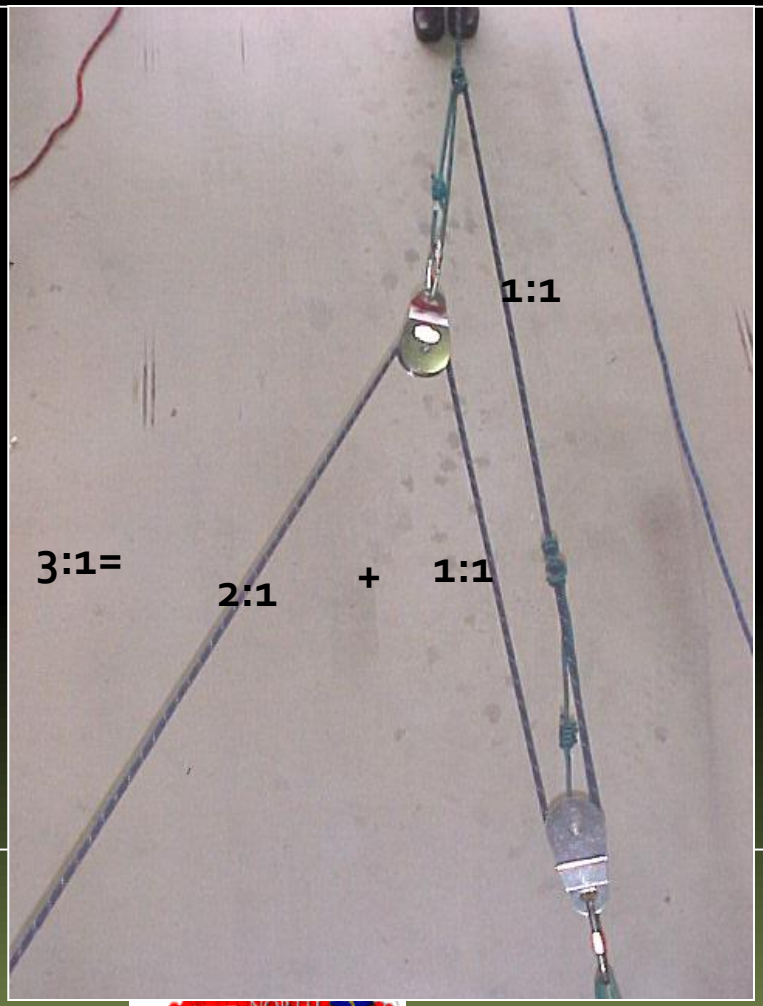


- ***COMPOUND M/A***
- ***2:1 X 2:1= 4:1***

Rule #6:

"If we stack a pulley on a non-traveling pulley, we ADD the mechanical advantage."

2:1 + 1:1= 3:1



- Move a 100 lb. load 10 feet with a 2:1 MAS. What is the input force? And how much rope would we need?
- Move a 100 lb. load 10 feet using a 4:1 MAS. What is the input force? And how much rope would we need?

Precautions with MAS

- All hardware/software should be rated for the load being moved.
- Pulling the haul line.
- Do not stand or work under the load.
- Try to make the pull downhill allowing gravity to assist the operation.

The "Rule Of 12's"

- Used whenever a haul system is used as a tensioning tool for systems like a static highline system that uses 7/16" rope.
- Purpose:
  - reduce and eliminate over tensioning
  - reduce shock load that may cause failure of the system.
- Calculate:
  - Divide the MAS into 12
  - Answer is the maximum number of rescuers that should be pulling on the hauling system.
  - 12 ÷ MAS= # of rescuers pulling
    - Calculate 2:1, 3:1. 4:1, 5:1

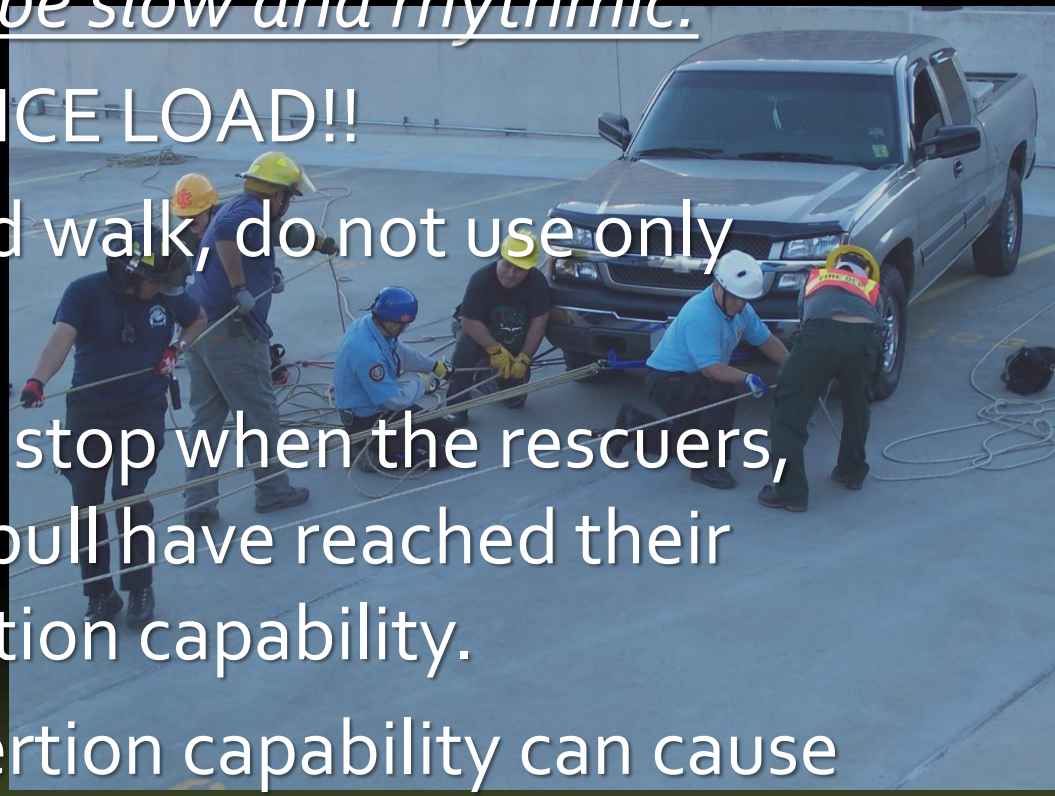
The "Rule of 18"

- Used whenever a haul system is used as a tensioning tool for systems like a static highline system that uses 1/2" rope.

- Purpose:
  - reduce and eliminate over tensioning
  - reduce shock load that may cause failure of the system.
- Calculate:
  - Divide the MAS into 18
  - Answer is the maximum number of rescuers that should be pulling on the hauling system.
  - 18 ÷ MAS= # of rescuers pulling
    - Calculate 2:1, 3:1. 4:1, 5:1
- 18 ÷ MAS= # of rescuers pulling
  - Calculate 2:1, 3:1. 4:1, 5:1
- Pulling should stop when rescuers have reached their maximum exertion capability without having to jerk and pull sporadically to continue the haul.

Pulling the load with MAS

- *The pull should be slow and rhythmic.*
- DO NOT BOUNCE LOAD!!
- Rescuers should walk, do not use only arms.
- The pull should stop when the rescuers, using a steady pull have reached their maximum exertion capability.
- Beyond the exertion capability can cause catastrophic failure of the system.



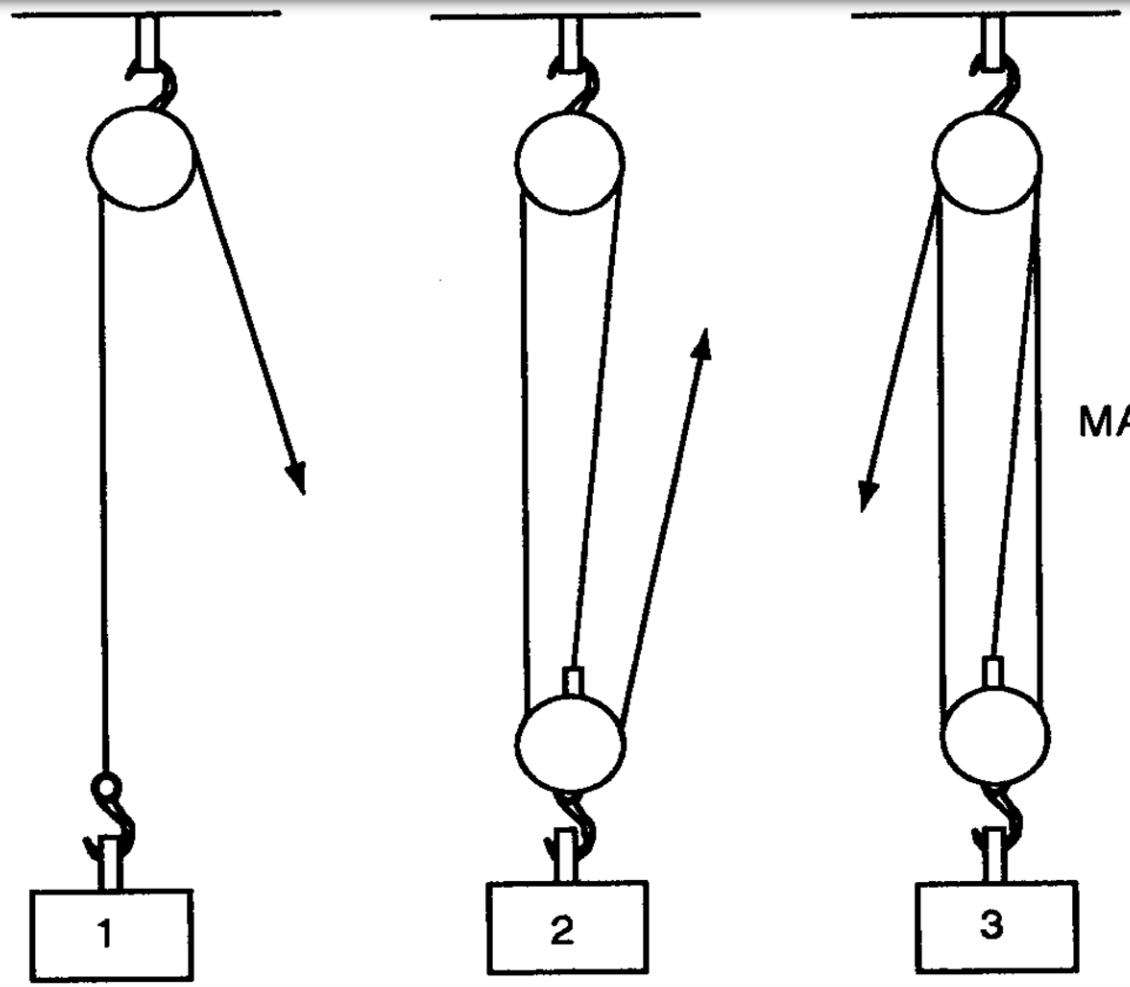
Simple Mechanical Advantage System

- Consist of one rope and one or more pulleys.
- By adding pulleys and/or reeving more sheaves, you can increase efficiency.
- *Calculate the MAS of a simple system is to count the number of ropes that are supporting the load*

Simple Mechanical Advantage System

- All moving pulleys move toward the anchor, each one moves at the same rate as the next.
- *If the end of the rope in a simple system is attached at the load, the mechanical advantage (MA) will be an odd number.*
- *If the end of the rope in a simple system is attached at the anchor, the mechanical advantage (MA) will be an even number.*

Simple Mechanical Advantages



MA of simple system number:

1. 1:1
2. 3:1
3. 3:1

Compound MAS

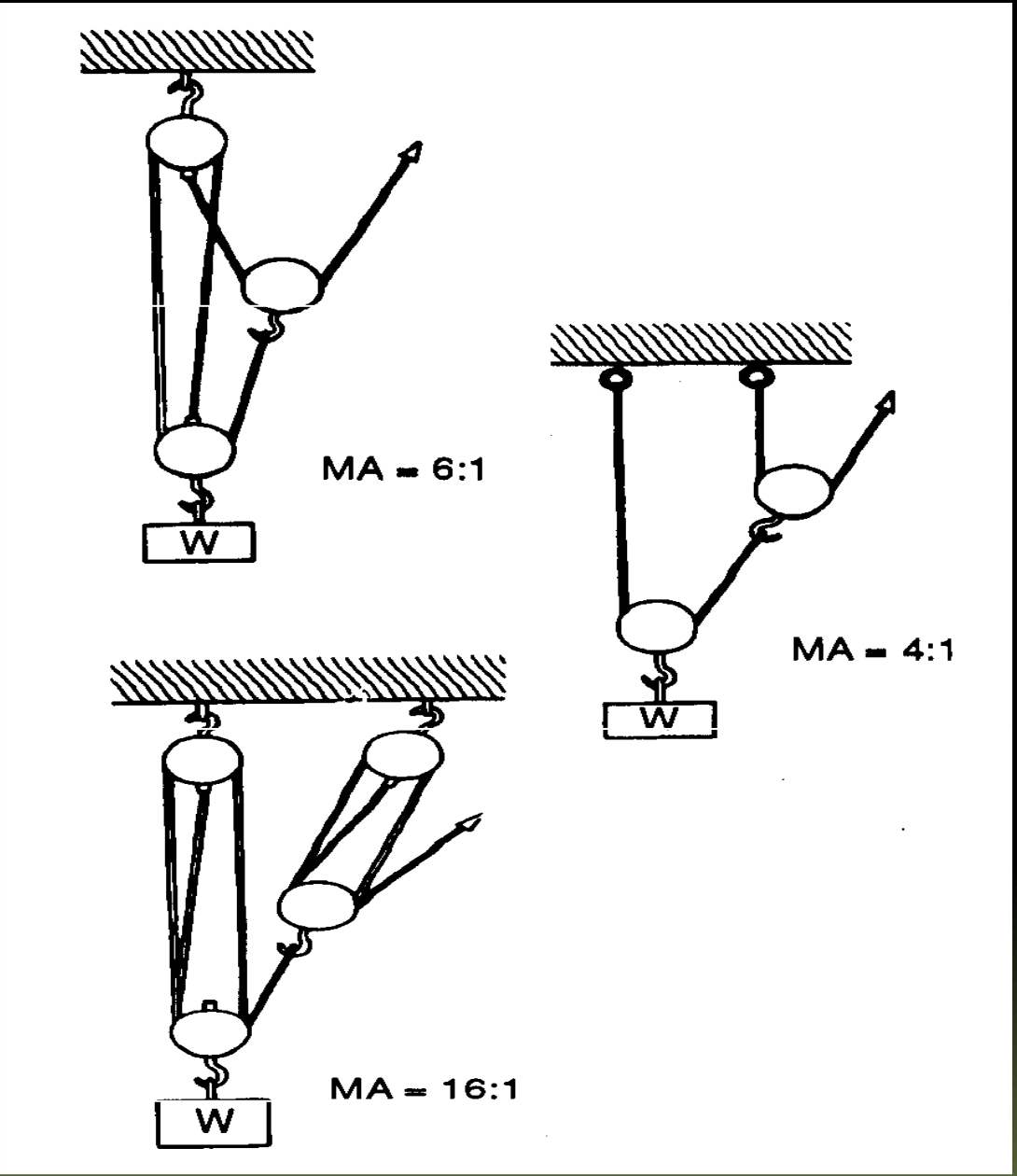
- *The combination of two or more simple mechanical advantage systems where <u>one system applies force (or pull) to another system to multiply the total lifting capability</u> .*

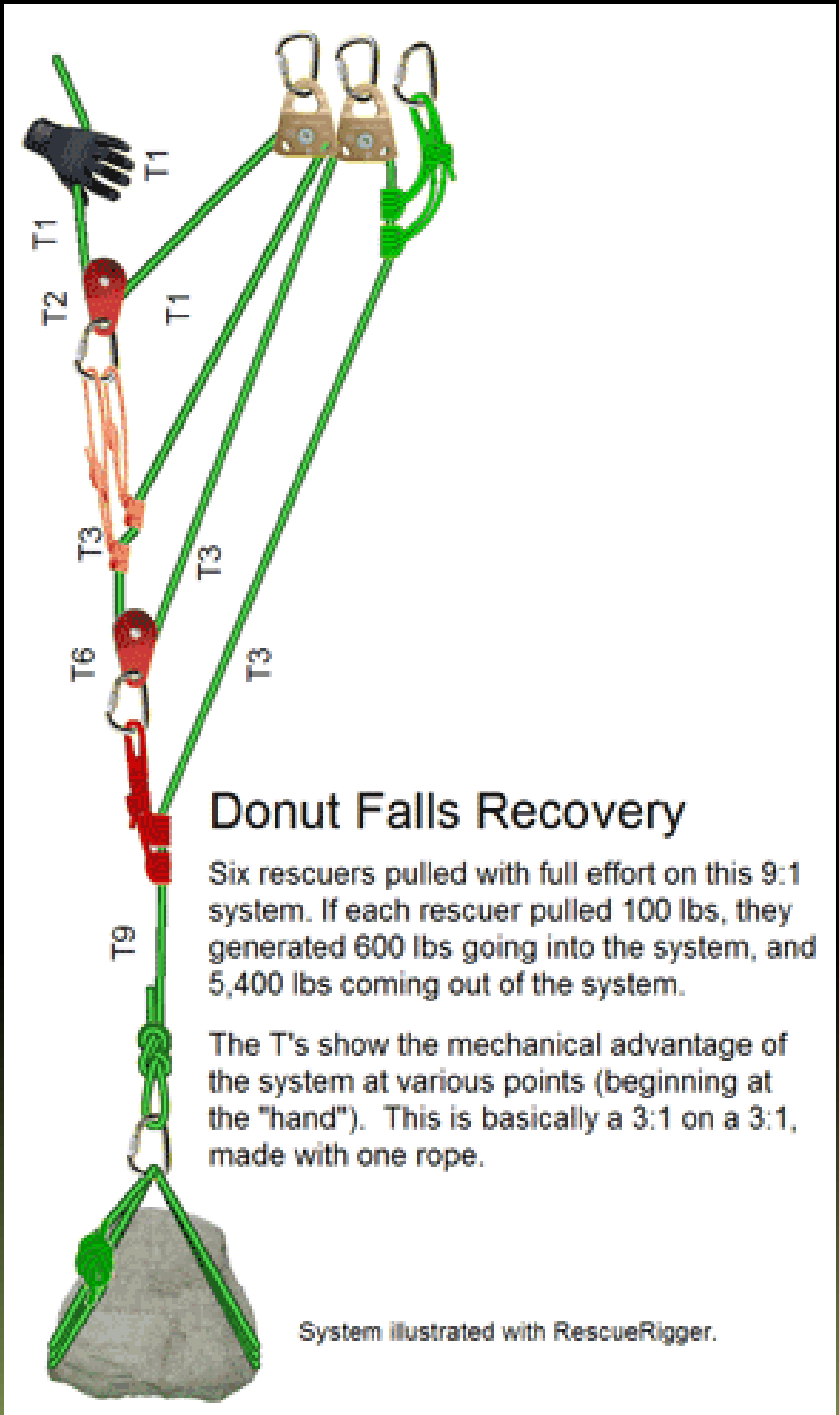
- This (TMA) system allows for an increase in the in the MA equal to the original system's TMA multiplied by the original system's TMA.

- When two haul systems are joined at the input(pulling) point, the resulting MA is achieved by <u>multiplying the two TMA's.</u>

- *There are three common compound systems:*
  - *The 4:1 (easiest to construct)*
  - *The 6:1 more complex*
  - *The 9:1 the most complex system.*

Compounds MAS

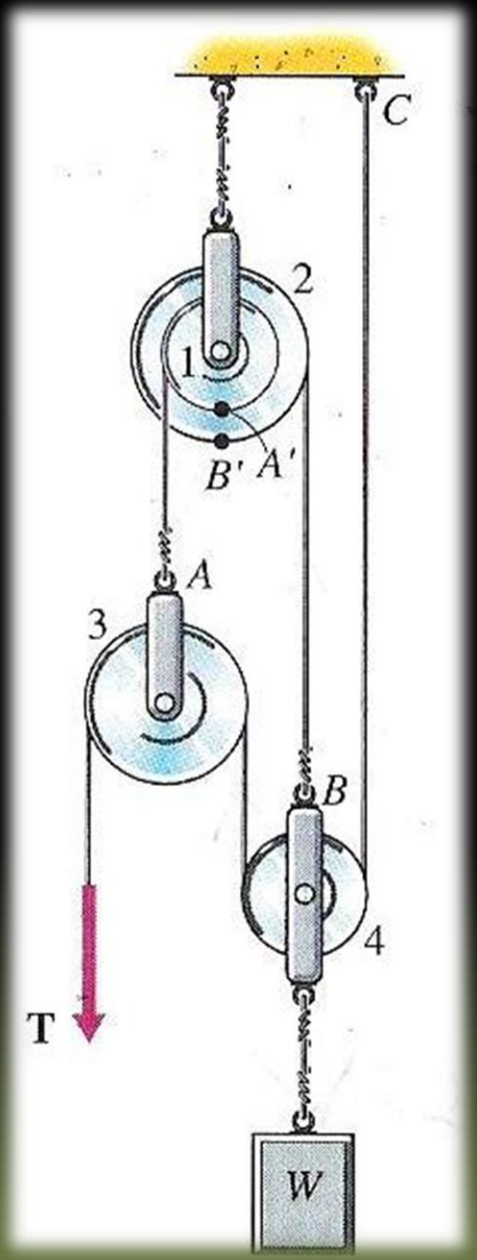




9:1 Compound MAS

Complex MAS

- *They have limited practical use in most rescue applications.*
- Complex systems can have pulleys moving toward the load and the anchor at the same time



Manufactured Rope Grab Appliances

- They are devices rated for gripping a rope.
- Rope grab devices with teeth should not be used in hauling systems involving humans.
- The rope grab device should be rated for the load, light duty, or general duty.

Manufactured Rope Grab Appliances

Petzel Rescuecender

Gibbs Ascender

Rock Exotica

DO NOT USE!!!!

Prusik Hitches & MAS

- *Prusik slings for MAS are constructed with pre-tied lengths of 65" and 53" inches.*
- *The prusik sling should be a tandem-triple wrapped prussik hitch.*
- ***For rescue operations MAS prusik hitches, are used in tandem.***

Prusik Hitches & MAS

- Use 6-7mm on light duty lifeline for one person loads up to 300 pounds (7/16")
- Use 8- 9mm on general duty rope for rescue load over 300 pounds (1/2"-5/8").

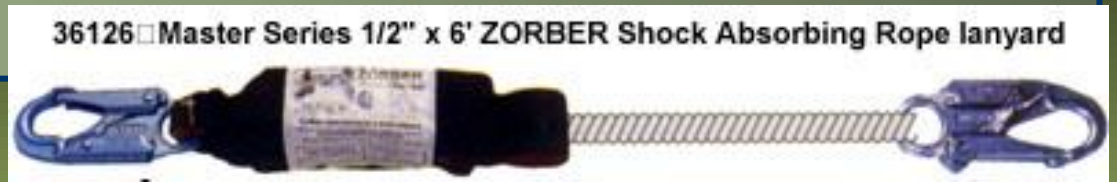
- NOTE: A pulling prusik hitch seizes the rope and pulls it into motion. The prusik hitch can begin to slip at approximately 10 kilo-newtons.

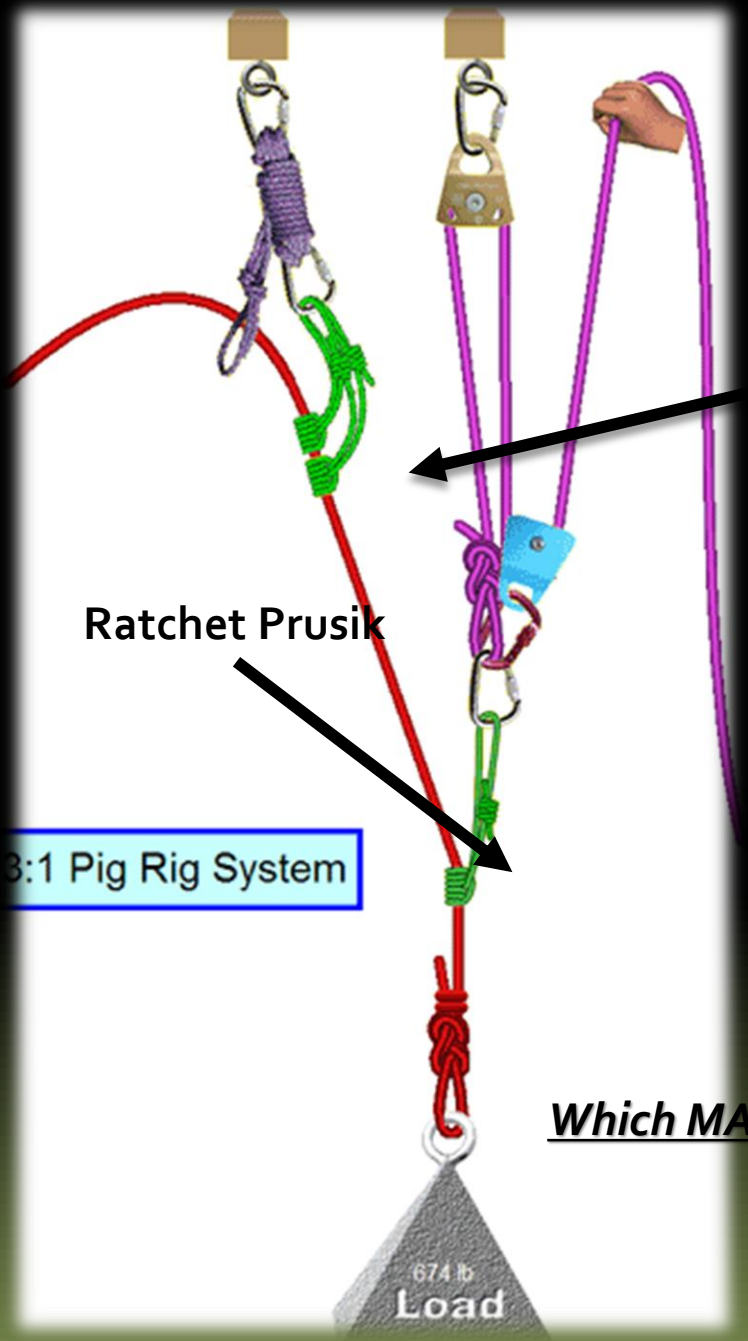
Rope Grabbing Devices Can Fail

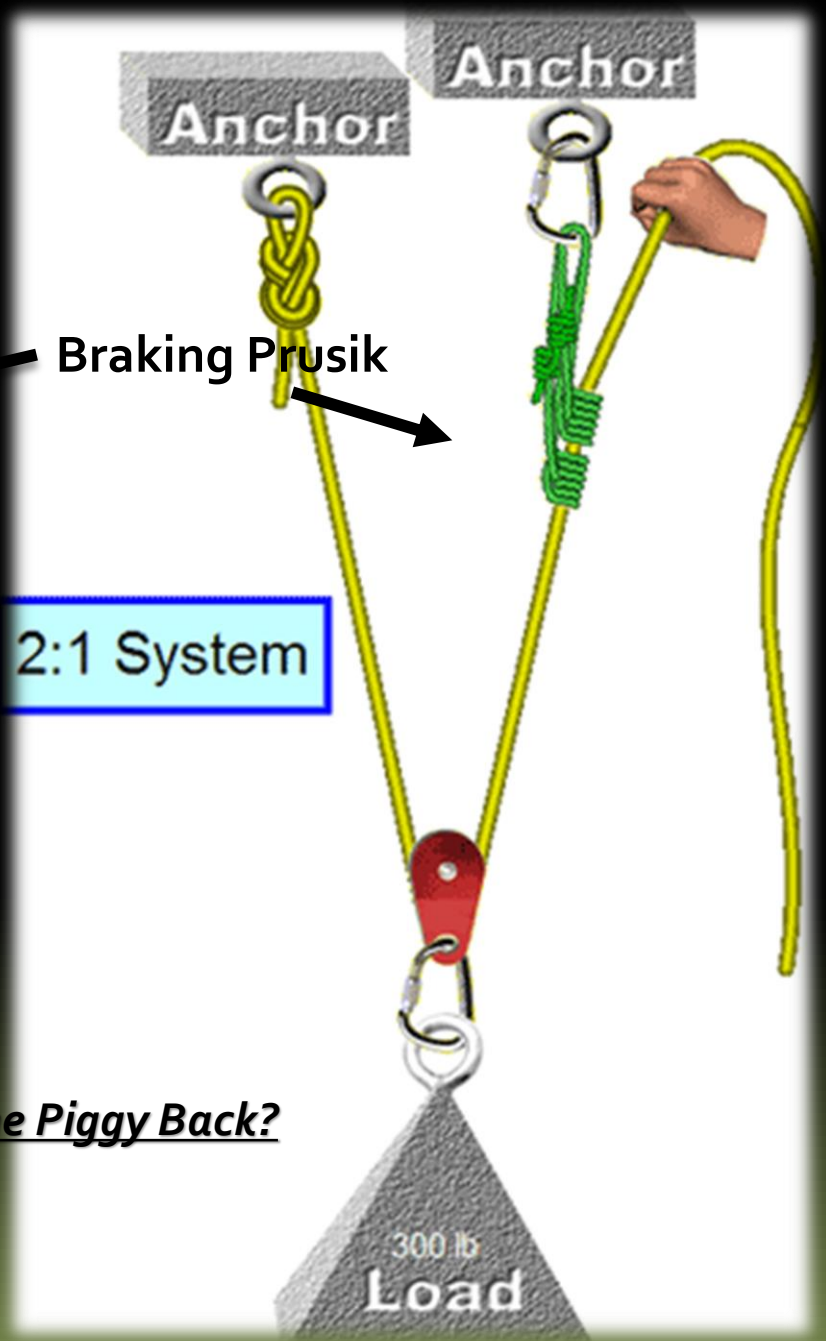
RESCUE NORTH CAROLINA
rescuenc.com

- A braking prusik hitch seizes the rope and prevents it from moving.
- This is known as a *Progress Capturing Device (PCD).*
  - A PCD can be tandem prusik hitches or rope grab devices rated for the load.
  - A PCD can be rigged to an anchor near the edge or near the primary anchor.
  - When possible, the PCD anchor should include a Load Release Hitch.

- A ratchet prusik hitch allows mechanical advantage pulley systems to be reset repeatedly for multiple pulls.
- When a shock load potential exists; attach a shock absorbing system to the load.
- A belay system should always be used for systems supporting a human load.







Which MAS is the Piggy Back?

Load Releasing Hitches

- The load release hitch has some shock absorbing capability.
- It can be used to:
  - Switching over from a raising system to a lowering system and visa versa.
  - Pass a knot through the system

Load Releasing Hitches

- Radium Hitch:
  - A type of hitch constructed using 8mm nylon low stretch kernmantle cord, two locking carabiners, and a Munter Hitch.
- Mariner's Hitch:
  - Uses 1' webbing, 3 Carabiners
- *It has two purposes. It sustains major loads, and with tension is applied, it is used to release tension in the system into which it was incorporated.*

The component parts of a block and tackle system

- The Block is the wooden or metal shell encasing the sheaves.
- The Sheaves are the metal roller inside the shell.
- The Tackle, is the system incorporating 2 blocks and the rope.

The precautions to be considered when using a block and tackle system

- All components of a block and tackle system should be rated for the load.
- The haul line should be pulled in a steady rhythmic fashion.
- No one should stand or work under the load.
- Whenever possible the pull should be downhill allowing gravity to assist the operation.

- *Describe and demonstrate the correct method to reeve a 4:1 mechanical advantage system using a block and tackle system using two, double sheave pulleys.*
- *When the hauling line (fall) comes out of the stationary block, the mechanical advantage is said to be 4:1, when the hauling line comes out of the moving block, the mechanical advantage is said to be 5:1.*

- *To calculate the amount of rope needed to lift a load 20 feet, using double-sheave pulleys, multiply the distance to be raised times the number of returns (reeves) through the tackle and 1 haul line, for a total of five, plus add an additional 4 feet for room for the chock-a-block.*

- *Example: 20 ft. distance to be raised or lowered x 5 returns. 100 + 4 ft. chock-a-block = 104 ft. of rope needed.*
- *Distance to be raised x # of returns*

- *To calculate the load capacity of a block and tackle system, safe working load of the rope x the number of returns x 2/3.*
  - *Example: 600 pound load x 5 returns x 2/3 (.66) = 1,980 pound load capacity.*

- *Chock-a-block is the term used to describe the minimum distance between the anchor and the tackle at which the mechanical advantage is no longer efficient.*
- Some texts use 4 feet and some texts use 3 feet when referencing chock-a-block.

- The rule that when using laid rope, the correct way to reeve the standing block or anchor pulley should be to place it in the vertical position and the running block or moving pulley should be placed in the horizontal position to prevent twisting and entanglement of the laid rope as it goes under load.
  - This rule need not be applied when using kernmantle rope, and both pulleys may be laid in the horizontal position when reeving a block and tackle system.

The concept of a compound MA system

- A compound system is created by adding or stacking additional MAS onto the original system.
- *A compound system is based on the engineering principle where a simple m/a acting/pulling on a simple m/a creates a compound machine.*
- As an accepted rule of thumb, when joining two hauling systems together at the input point of the first hauling system, the end result is the TMA obtained by multiplying the two systems together. Example of the above includes: 2:1 x 2:1 = 4:1, 2:1 x 3:1 = 6:1.

Constructing a 4:1 compound system using two ropes

- Tie a figure 8 on a bight into one end of the haul line and secure it to the primary anchor.
- Attach a locking carabiner and a pulley at the load point.
- Reeve the haul line through the pulley, then tie a figure of 8 on a bight at the end of the haul line
- Using a second rope, tie a figure 8 on a bight and secure it to the primary anchor or a secondary anchor next to the primary anchor.
- Attach a locking carabiner and pulley into the figure 8 on a bight of the first rope, just behind the first pulley.
- Feed the second rope through the second pulley, the haul line should point toward the primary anchor.
- Secure a PCD to the system.

Using A Piggy-back MAS

- Can be pre-rigged with a short section of life line rope and pre-packaged for quick deployment.
- *Piggy Back systems are separate MAS that can be added to an existing lowering system.*
- The piggy-back system can be switched from one haul or lift line to another line quickly.

- Demonstrate rigging a piggy-back 3:1 and 4:1 mechanical advantage system using a commercial rescue rated rope grab device.

- Demonstrate rigging a piggy-back 4:1 mechanical advantage system using tandem triple wrap prusik hitches.

THE END