Technical Rescuer Lesson Two Mechanical Advantage Systems

DOMAIN: COGNITIVE / PSYCHOMOTOR

LEVEL OF LEARNING: COMPREHENSION

MATERIALS

IFSTA 7th Edition Fire Service Search and Rescue; High Angle Rescue Techniques, 3rd Edition, by Tom Vines and Steve Hudson, CMC Rope Rescue Manual 4th Edition revised; Delmar Engineering Practical Rope Rescue Systems; laptop computer, multimedia projector, whiteboard or flipchart, and marking pens. A suitable number of flat or tubular web slings in suggested pre-tied lengths of 5' and 12'; carabiners and body cords; various sizes of single and double sheave pulleys including a Prusik minding pulley; various lengths of 6mm - 8mm Prusik cords with recommended pre-tied lengths of 53" and 65"; commercial rope grab devices weighted objects to be lifted; and a suitable number of training lifelines and 25’ to 50’ body cords to practice rigging mechanical advantage systems.

NFPA 1006, 2013 Edition JPRs

5.5.4 Construct a simple MAS
5.5.5 Use a simple MAS in a raising operation
5.5.6 Function as a litter tender in a low-angle lowering or hauling operation.
5.5.7 Construct a lowering system.
5.5.8 Direct a lowering operation in a low-angle environment.
5.5.9 Construct a belay system.
5.5.10 Operate a belay system.
5.5.11 Belay a falling load
5.5.12 Conduct a system safety check
6.1.3 Construct a multiple-point anchor system

6.1.4 Construct a compound rope mechanical advantage system.
6.1.5 Construct a fixed rope system.
6.1.6 Direct the operation of a compound rope mechanical advantage system

Junior Member Statement:

Junior Member training activities should be supervised by qualified instructors to assure that the cognitive and psychomotor skills are completed in a safe and non-evasive manner. While it is critical that instructors be constantly aware of the capabilities of all students both mentally and physically to complete certain tasks safely and successfully, the instructor should take every opportunity to discuss with departmental leaders and students the maturity and job awareness each participant has for the hazards associated with fire and rescue training.

TERMINAL OBJECTIVE

The Technical Rescuer shall correctly identify, describe and demonstrate the setup, operation and function of compound mechanical advantage systems used during rope rescue incidents.

ENABLING OBJECTIVES

1. The Technical Rescuer shall correctly describe in writing the design and purpose of the various types of mechanical advantage systems.

2. The Technical Rescuer shall correctly identify and describe in writing the function of various types of rope grab systems when incorporated into a mechanical advantage system.

3. The Technical Rescuer (given the appropriate equipment) shall correctly describe and demonstrate rigging various simple mechanical advantage systems used by the AHJ.

4. The Technical Rescuer (given the appropriate equipment) shall correctly describe and demonstrate rigging various compound mechanical advantage systems used by the AHJ.

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MOTIVATION

In almost any high or low angle rescue operation, manpower will usually be at a premium. Seldom will there be enough personnel to simply raise or lower patients and rescuers by the hand over hand method. An easier method must be incorporated into these operations to ease the strain on personnel and speed up overall operations. Mechanical Advantage systems can provide a solution to this problem by significantly reducing the number of personnel required to raise, lower, or tension a system. Since tremendous forces can be generated with mechanical advantage systems, it is imperative that the Technical Rescuer be proficient not only in constructing these systems, but also in understanding the load capabilities and limitations of the components of these systems.

PRESENTATION

ENABLING OBJECTIVE #1

The Technical Rescuer shall correctly describe in writing the design and purpose of the various types of mechanical advantage systems.

1. Discuss the general considerations for rescue hauling systems.
    a) When speed is needed, a simple system may be the best choice for performing a quick and safe operation.
    b) If lack of personnel is an issue, a higher mechanical advantage may be needed to move the load.
    c) If only a small amount of gear is available, a simple mechanical advantage system is recommended.

d) If the hauling area is cluttered, the potential is high for the system to become snagged.
e) If the load is light, use a low ratio mechanical advantage system.
f) If the load is heavy, use a high ratio mechanical advantage system.

2. Discuss ways of reducing friction in the hauling system.
   a) Edge rollers.
   b) Directional systems.
   c) Reposition the haul system.
   d) Portable anchors, A-frames, and tripods (known as artificial high directionals).
   e) Pulley size and placement.
   f) Ball bearing versus bushing.

3. Discuss the purpose of a mechanical advantage hauling system.
   a) It makes lifting a rescue load easier.
   b) It makes the lifting operation much safer.

4. Discuss how to calculate mechanical advantages.
   a) The simplest hauling system is a direct pull. A direct pull system is one in which the required pulling force exerted by the rescuers is equal to the load. An example would be a 1:1 system. (E.g. the load (output force) is 100 pounds and the pulling force (input force) is 100 pounds of force (lbf).) To move a 100 pound object 10' with a direct pull system, rescuers would have to exert a little more than 100 pounds of force (lbf) (due to friction and other factors) and would use ten feet of rope in the process.
   b) A mechanical advantage system is a system where the pulling (input) force exerted by the rescuers is less than the (output) force on the load. An example would be a 2:1 system. (E.g. the load is 100 pounds and the pulling force needed to move the load is approximately 50 pounds of force (lbf) or half the weight of the load).
   c) This calculation does not address the size of pulleys, ropes, and friction created by rope making contact with various objects or the number of bends in the rope; it is a theoretical mechanical advantage (TMA).

d) The actual mechanical advantage (AMA) does factor the friction through the rope, rope stretch, and rope rubbing on edges. In a 2:1 system, the AMA is approximately 1 7/8:1.
e) The major difference between theoretical and actual mechanical advantage is friction.
f) In any change of direction effort the pulley is stationary. This does not change the theoretical mechanical advantage.
g) A gain in mechanical advantage occurs when a pulley is moving. This changes the mechanical advantage depending upon the use.
h) If the bitter (terminating) end of a mechanical advantage system is attached at the load, then the simple system is odd.
i) If the bitter (terminating) end of a mechanical advantage system is attached at the anchor, the simple system is even.

Reference: IFSTA Fire Service Search and Rescue manual, 7th Edition, pages 137 through 139.
Reference: High Angle Rescue Techniques, 3rd Edition, pages 278 through 280.
Reference: Delmar Engineering Practical Rope Rescue Systems, pages 242 and 243 and 265 through 267.

5. Discuss the precautions to be considered when using a mechanical advantage system.
   a) Rope and auxiliary equipment should be rated for the load being moved.
   b) The haul line should be pulled in a steady rhythmic fashion.
   c) No one should stand or work under the load.
   d) Whenever possible the pull should be downhill allowing gravity to assist the operation.

6. Discuss the Rule of 12 and Rule of 18 for preventing overloading a hauling system.
   a) For 7/16" diameter rope, the Rule of 12 applies. Example: for a 3:1 MA, a maximum of 4 rescuers may tension the line; 3 x 4 = 12.
   b) For 1/2" diameter rope, the rule of 18 applies. Example: for a 3:1 MA, a maximum of 6 rescuers may tension the line. 3 x 6 = 18.
   c) This concept originates from the maximum tension (using the rule of 12 or 18) that should

only be applied when the rescue load is at center span of a high line.

7. Discuss the proper use of Prusiks in a mechanical advantage system.
   A. The progress capture device or "braking system" should be a proper capturing device or matched pairs of appropriate diameter triple wrap Prusiks; and should be located near the anchor, attached by a load releasing hitch. This provides the highest degree of safety and gripping strength; and fall protection for the line being hauled.
   B. The pulley system or individual pulleys should be attached with single triple wrap Prusik hitches. This will allow for the mechanical advantage system to slip at a much lower weight if the rescue package become snagged or entangled.
   C. This does not subtract from system safety in any form since the progress capture is being performed with a rated device or a matched set of triple wrap Prusiks.
   D. Some teams refer to this as the "one to haul two to fall principle for mechanical advantages.

8. Point out that the pull should be slow and rhythmic. The pull should stop when the rescuers (using a steady pull) have reached their maximum exertion capability without having to jerk and pull sporadically to continue the haul.

9. Discuss the definition of a simple mechanical advantage system.
   a) Consists of one rope and one or more pulleys.
   b) By adding pulleys and/or reeving more sheaves, you can increase the mechanical advantage.
   c) An easy way to calculate the mechanical advantage of a simple system is to count the number of ropes that are supporting the load.

10. Discuss the definition of a compound mechanical advantage system.
   a) A compound mechanical advantage system is the combination of two or more simple mechanical advantage systems working together to multiply the overall capability.

b) Creating this type of MA system allows for an increase in the TMA equal to the first system's TMA multiplied by the second system's TMA.
c) As a general rule of thumb, when two rescue hauling systems are joined in series, the resulting MA is achieved by multiplying the two mechanical advantage systems.
d) There are three common compound systems used in rescue operations: the 4:1, the 6:1, and the 9:1.

Reference: Delmar Engineering Practical Rope Rescue Systems pages 260 through 265.
Reference: CMC Rope Rescue Manual 4th Edition revised, pages 141-156.

PRESENTATION

ENABLING OBJECTIVE #2

The Technical Rescuer shall correctly identify and describe in writing the function of various types of rope grab systems when incorporated into a mechanical advantage system.

1. Discuss the use of rope grab appliances in the construction of mechanical advantage systems.
   a) Rope grab appliances are devices rated for gripping a rope.
   b) There are many commercial designs available, such as those made by Gibbs, Rock Exotica, Petzl, and others.
   c) Rope grab devices with teeth should not be used in hauling systems involving humans due to their tendency to damage the rope.
   d) Rope grab devices should be rated for the load encountered (e.g. light duty or general duty).

2. Discuss the use of Prusik hitches in the construction of a mechanical advantage system.
   a) Prusik slings for mechanical advantage systems are usually constructed with pre-tied lengths and secured using a double fisherman knot. Assure that there is a 12" difference in rope length.
   b) The Prusik sling can be used to create a triple-wrap Prusik hitch on a lifeline creating a manmade rope grab system.

c) For rescue operations Prusik hitches (also referred to as friction hitches) are usually used in tandem in fall protection, and singles for mechanical advantage system connections.
d) The selection of diameter should be based on the load to be moved and be based on proven testing. Ultimately it is the choice of the AHJ.

3. Explain that a pulling Prusik hitch seizes the rope and pulls it into motion.

4. Explain that a braking Prusik hitch seizes the rope and prevents it from moving (also known as a progress capture device).
   a) This device can consist of tandem Prusik hitches or rope grab devices rated for the load.
   b) This device can be rigged to an anchor near the edge or near the primary anchor.
   c) When possible, the progress capture device should include a load release hitch.

5. Explain that a ratchet Prusik hitch allows mechanical advantage pulley systems to be reset repeatedly for multiple pulls.

6. Point out that a belay system should be used for systems supporting a human load.

7. Describe the function of the load release hitch.
   a) A load release hitch is a type of hitch constructed using webbing or accessory cord.
   b) It has three purposes. It sustains major loads, it is used to release tension in the system into which it was incorporated, and it can be used to pass a knot.
   c) The load release hitch has some shock absorbing capability.
   d) It can be used in switching over from a raising system to a lowering system and vice versa.

8. Point out that one line of thought used by some instructors is to use half to two-thirds the diameter of the rope being used.

References: High Angle Rescue Techniques, 3rd Edition, pages 193 through 195, and 284 through 287.

Reference: CMC Rope Rescue Manual 4th Edition revised, pages 157-168.

PRESENTATION

ENABLING OBJECTIVE #3

The Technical Rescuer given the appropriate equipment shall correctly describe and demonstrate rigging various simple mechanical advantage systems (incorporating rope grab systems used by the AHJ).

1. Describe and demonstrate rigging a static 3:1 Z-Drag mechanical advantage system.
    a) A static system is used when there is sufficient room to set up the system so the haul can be completed in one pull.
    b) Secure a figure-eight-on-a-bight knot or other appropriate knot suited for the load into one end of the haul line and secure it to the load.
    c) Select an anchor point a sufficient distance away from the load to ensure the haul can be completed with one pull.
    d) Secure the sling pulley and carabiner to the anchor.
    e) Tie a directional figure-of-eight knot (bight should face the anchor) or a butterfly knot just behind the figure-eight-on-a-bight that is attached to the load.
    f) Clip a carabiner and pulley into the knot.
    g) From the load, feed the running end of the rope through the anchor pulley.
    h) Then the rope should be fed through the load pulley so the shape of the hauling system resembles a “Z” pattern.
    i) Secure a progress capture device to the main line at the most appropriate location between the figure-eight-on-a-bight knot and the anchor.

2. Describe and demonstrate rigging a dynamic 3:1 Z-Drag mechanical advantage system.
    a) A dynamic system is used when there is not sufficient room to set up the system and perform a haul in one pull.
    b) Secure a figure-eight-on-a-bight knot or other appropriate knot suited for the load into one end of the haul line and secure it to the load.

c) Select an anchor point a sufficient distance away from the load.
d) Secure the anchor sling, pulley, and carabiner to the anchor.
e) Secure a tandem triple-wrap Prusik (for rescue load) near the edge and hook a carabiner and pulley to it.
f) From the load, feed the running end of the rope through the anchor pulley.
g) Then the rope should be fed through the load pulley so the shape of the hauling system resembles a “Z” pattern.
h) Secure a progress capture device to the main line at the most appropriate location between the figure-eight-on-a-bight knot and the anchor.

References: IFSTA Fire Service Search and Rescue manual, 7th Edition, page 138.
Reference: High Angle Rescue Techniques, 3rd Edition, pages 291 through 292.
Reference: CMC Rope Rescue Manual 4th Edition revised, pages 141-156.

3. Describe and demonstrate rigging a simple 4:1 mechanical advantage system.
   a) Secure a figure-eight-on-a-bight knot or other appropriate knot suited for the load into one end of the haul line and secure it to the anchor.
   b) Select an anchor point a sufficient distance away from the load. Secure an anchor sling, locking carabiner, and a pulley to the anchor.
   c) Secure a second locking carabiner and pulley on the load line.
   d) Secure a second anchor sling, locking carabiner, and pulley next to the first anchor.
   e) From the load, feed the running end of the rope through the first anchor pulley, down to the pulley on the load, back up to the second anchor pulley, and through it forming an "M” with the haul line pointing towards the load.
   f) Secure a progress-capturing device to the main line at the most appropriate location between the figure-eight-on-a-bight knot and the first anchor.

4. Discuss the component parts of a block and tackle system.

a) The block is the wooden or metal shell encasing the sheaves.
b) The sheaves are the metal roller(s) inside the shell.
c) The tackle is the system incorporating 2 blocks and the rope.

5. Discuss the precautions to be considered when using a block and tackle system.
   a) All components of a block and tackle system should be rated for the load.
   b) The haul line should be pulled in a steady rhythmic fashion.
   c) No one should stand or work under the load.
   d) Whenever possible the pull should be downhill, allowing gravity to assist the operation.

6. 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.

7. To calculate the amount of rope needed to lift a load 20' with a 4:1 block and tackle system, 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' for room for the chock-a-block.
   a) Point out that 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' and some texts use 3' when referencing chock-a-block.
   b) Example: 20' distance to be raised or lowered x 5 returns. 100' + 4' (chock-a-block) = 104' of rope needed.

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

9. Discuss 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.
    a) 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.

Reference: IFSTA Fire Service Search and Rescue manual, 7th Edition, pages 92 and 93.
Reference: High Angle Rescue Technician, 3rd Edition, page 281.
Reference: CMC Rope Rescue Manual 4th Edition revised, pages 141-156.

PRESENTATION

ENABLING OBJECTIVE #4

The Technical Rescuer given the appropriate equipment shall correctly describe and demonstrate rigging various compound mechanical advantage systems (with rope grab systems used by the AHJ).

1. Discuss the concept of a compound MA system.
    a) A compound system is created by adding or stacking additional mechanical advantage systems onto the original system.
    b) A compound system is based on the engineering principle that a simple machine acting on a simple machine creates a compound machine.
    c) As an accepted rule of thumb, when joining two hauling systems together in series, 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.

Reference: Delmar Engineering Practical Rope Rescue Systems, pages 260 through 265.
Reference: CMC Rope Rescue Manual 4th Edition revised, pages 141-156.

2. Demonstrate constructing a 4:1 compound system using two ropes.
   a) Tie a figure-eight-on-a-bight knot into one end of the haul line and secure it to the primary anchor.
   b) Attach a locking carabiner and a pulley at the load point.
   c) Reeve the haul line through the pulley and then tie a figure-eight-on-a-bight knot at the end of the haul line.
   d) Using a second rope tie a figure-eight-on-a-bight knot and secure it to the primary anchor or a secondary anchor next to the primary anchor.
   e) Attach a locking carabiner and pulley into the figure-eight-on-a-bight knot of the first rope, just behind the first pulley.
   f) Feed the second rope through the second pulley and the haul line should point toward the primary anchor.
   g) Secure a progress capture device to the system.

3. Demonstrate constructing a 4:1 compound system using one rope.
   a) Tie a figure-eight-on-a-bight knot into the middle of a short section of haul line (suggest 50') creating 2 sections of rope and secure it to the primary anchor.
   b) Attach a locking carabiner and a pulley at the load point.
   c) Reeve the haul line through the pulley and then tie a figure-eight-on-a-bight knot at the end of the haul line
   d) Attach a locking carabiner and pulley into the figure-eight-on-a-bight knot of the first rope, just behind the first pulley.
   e) Feed the second section of rope through the second pulley and (the haul line should point toward the primary anchor).
   f) Secure a progress capture device to the system.

4. Demonstrate constructing a 6:1 compound system.
   a) Construct a dynamic 3:1 Z-Drag system as previously described.
   b) Tie a figure-eight-on-a-bight knot at the end of the haul line after it comes out of the traveling pulley.
   c) Secure a second sling around the primary anchor.

d) Tie a figure-eight-on-a-bight knot into the end of a second rope and secure it to the second anchor sling with a locking carabiner.
e) Secure a locking carabiner and pulley into the figure-eight-on-a-bight knot that was created on the first rope after it passed through the first traveling pulley.
f) Pass the standing part of the second rope through the second traveling pulley so the haul is in the direction of the primary anchor.
g) Secure a progress capture device to the system.

5. Discuss the advantages provided by using a piggyback mechanical advantage system.
   a) The piggyback system can be pre-rigged with a short section of lifeline rope and pre-packaged for quick deployment.
   b) The piggyback system can be switched from one haul or lift line to another line quickly.

6. Demonstrate rigging a piggy-back 3:1 or 4:1 mechanical advantage system using tandem triple wrap Prusik hitches.

Reference: High Angle Rescue Techniques, 3rd Edition, page 292.
Reference: CMC Rope Rescue Manual 4th Edition revised, pages 141-156.

APPLICATION

Ideally there will be enough equipment to set up at least four stations where Technical Rescuers can construct the various types of mechanical advantage systems. Have each Technical Rescuer construct a simple 3:1 static and a dynamic Z-drag, a 4:1 block and tackle, a compound 4:1, and a 6:1 mechanical advantage system. Have the Technical Rescuer describe how to calculate the TMA of each system and describe the difference between static and dynamic systems; also have each Technical Rescuer describe or point out the difference between simple, compound mechanical advantage systems. If possible, have these systems rigged where a weight of approximately 100 pounds can be lifted with each completed system. The instructor should make sure all safety precautions are taken,

including a sufficient number of instructors and the use of appropriate PPE.

SUMMARY

This lesson plan addresses simple, compound mechanical advantage systems. Each system is designed to prepare the Technical Rescuer to meet the needs of low and high angle rescue operations. Being able to safely lift the required load with the equipment and personnel on hand is directly related to the Technical Rescuer's understanding of mechanical advantage systems. The Technical Rescuer must understand that mechanical advantage systems are capable of generating tremendous forces that can make the job of raising a load easier. However, it can also make the job far more dangerous if the limitations of a single component are exceeded. Review the advantages and disadvantages of each of the systems discussed. Verify the fact that each of the Technical Rescuers understands the terminology of static and dynamic; as well as simple, compound, and complex systems.