OBJECTIVE PAGE

LESSON TWO
RT: Confined Space - Mechanical Advantage Systems

DOMAIN: COGNITIVE / PSYCHOMOTOR

LEVEL OF LEARNING: COMPREHENSION / APPLICATION

MATERIALS

IFSTA 6th edition Fire Service Rescue; IFSTA 4th edition Essentials of Firefighting; High Angle Rescue Techniques, 3rd edition, by Tom Vines and Steve Hudson, Laptop computer, multimedia projector, and whiteboard or flipchart, and marking pens. A suitable number of 2 inch flat or tubular web slings in suggested pre-tied lengths of 5 and 12 feet; carabiners and body cords; various sizes of single and double sheave pulleys including a prusik minding pulley; various lengths of 6-8 mm prusik cords with recommended pre-tied lengths of 65 inches and 53 inches; commercial rope grab devices such as Gibbs Ascender, Rock Exotica Ascender or equivalent; weighted objects to be lifted; and a suitable number of training lifelines and 25' to 50' body cords to practice rigging mechanical advantage systems, cribbing blocks, shims, high an low pressure bags to include all hoses, gauges and extra air bottles.

NFPA 1006, 2003 edition JPRs

9.1.5 Prepare for entry into a confined space
9.1.6 Enter a confined space
9.1.7 Package the victim for removal from a confined space
9.1.8 Remove all entrants from a confined space

TERMINAL OBJECTIVE

The Rescue Technician shall correctly identify, describe, and demonstrate the setup, operation, and function of compound mechanical advantage systems used during confined space rescue incidents.

ENABLING OBJECTIVES

1. The Rescue Technician shall correctly describe in writing the design and purpose of the various types of mechanical advantage systems (MAS).

2. The Rescue Technician 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 Rescue Technician when given the appropriate equipment shall correctly describe and demonstrate rigging various simple mechanical advantage systems with rope grab systems used by the AHJ.

4. The Rescue Technician when given the appropriate equipment shall correctly describe and demonstrate rigging various compound mechanical advantage systems with rope grab systems used by the AHJ.

LESSON TWO
RT: Confined Space - Mechanical Advantage Systems

MOTIVATION

In almost any confined space 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 Rescue Technician be proficient not only in constructing these systems, but also the Rescue Technician must possess an understanding of the load capabilities and limitations of the components of these systems.

NOTE: When performing confined space rescue application skills at actual sites, all personnel should wear appropriate PPE, and use a training mannequin to simulate a patient. If a student is used as a patient, make sure all safety precautions are adhered to, including the use of a back-up safety line.

NOTE: When tensioning any mechanical advantage system, great care must be used to prevent more force from being applied to the system components than they are rated for.

PRESENTATION

ENABLING OBJECTIVE #1

The Rescue Technician shall correctly describe in writing the design and purpose of the various types of mechanical advantage systems (MAS).

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 and more complex mechanical advantage system (MAS) may be needed.
    c) If only a small amount of gear is available, a simple MAS 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 MAS system.
    f) If the load is heavy, use a high MAS system.

2. Discuss ways of reducing friction in the hauling system.
    a) Directional systems.
    b) Reposition the haul system.
    c) Portable anchors, A-Frames, and Tripods.

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 the theory and advantages of a mechanical advantage system (MAS).
    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. The load (output force) is 100 pounds and the pulling force (input force) is 100 pounds, thus no mechanical advantage for the pulling force is provided. To move a 100 pound object 10 feet with a direct pull system, rescuers would have to exert a little more than 100 pounds of force and using ten feet of rope in the process.

b) A mechanical advantage system is one in which 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. The load is 100 pounds and the pulling force needed to move the load is approximately 50 pounds or half the weight of the load. 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). The actual mechanical advantage (AMA), when factoring the friction through the rope, rope stretch and rope rubbing on edges, for the above calculation is approximately 1 7/8:1.
c) If the pulley is stationary there is no MA. If the pulley moves there is MA.

5. Discuss how to calculate mechanical advantages.
   a) Forces for mechanical advantage are usually expressed using the metric system.
   b) An accurate measure of force is expressed in newtons; one newton equals 0.225 pounds of force (lbf.) It is a unit of force required to accelerate a mass of one kilogram one meter per second.
   c) Impact loads on rope breaking strength and hardware is expressed in kilonewtons; one kilonewton (1,000 newtons) equals approximately 225 pounds of force (lbf). 100 pounds of force would equal 444 newtons (45 kilograms). 50 pounds of force would equal 222 newtons (22.5 kilograms).
   d) To calculate mechanical advantage for a 2:1 ratio; the formula would be 444N:222N equals a Theoretical Mechanical Advantage (TMA) of 2:1 ratio.
   e) In theory to move a 100 pound load 10 feet using a 2:1 mechanical advantage system, the rescuers, exerting 50 pounds of force, would have to pull 20 feet of rope through the system.
   f) Moving a 100 pounds load 10 feet using a 4:1 mechanical advantage system, the rescuers, exerting 25 pounds of force would have to pull 40 feet of rope through the system.

Reference: IFSTA 6th edition Fire Service Rescue manual, pages 112 through 115.
Reference: High Angle Rescue Techniques, 3rd edition, pages 278 through 280.

6. 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.

7. Discuss the Rule of Twelve regarding the number of personnel needed to operate a hauling system.
   a) The Rule of Twelve is used whenever a hauling system is used as a tensioning tool for systems like a static highline system that uses 7/16” rope.
   b) Its purpose is to reduce and eliminate over tensioning by zealous rescuers and reduce shock load that may cause failure of the system.
   c) The formula divides the mechanical system such as a 2:1, 3:1, 6:1 into twelve, and the resulting answer is the maximum number of rescuers that should be pulling on the hauling system; this reduces the risk of overstressing the system. An example for a 3:1 hauling system would be to divide 3 into 12; the resulting answer indicates that no more than 4 rescuers should be pulling on the hauling system.
   d) The Rule of Eighteen is used whenever a hauling system is used as a tensioning tool for systems like a static highline system that uses 1/2“ rope.
   e) An example for a 3:1 hauling system would be to divide 3 into 18; the resulting answer indicates that no more than 6 rescuers should be pulling on the hauling system.

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

10. Discuss the definition of compound mechanical advantage systems.
    a) A compound mechanical advantage system is the combination of two or more simple mechanical advantage systems where one system applies force (or pull) to another system to multiply the total lifting capability of a given resource.
    b) Creating this type of theoretical mechanical advantage (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.
    c) As a general rule of thumb, when two rescue hauling systems are joined at the input point of the first, the resulting MA is achieved by multiplying the two TMAs.
    d) There are three common compound systems used in rescue operations: the 4:1, the easiest to construct; the 6:1 more complex than the 4:1; and the 9:1, the most complex system.

11. Discuss the definition of a complex mechanical advantage system.
    a) A complex pulley system is characterized by being neither simple nor compound. There is no one definition that characterizes all complex systems due to their great diversity.
    b) With only four pulleys, over one-hundred combinations of pulley systems can be made, most of them being complex pulley systems.
    c) With the exception of a few common complex pulley systems such as the Spanish Burton, these systems are not often seen being used in rescue work.

d) Objectives can be meet by using simple and compound systems that are easier for rescuers to recognize and are more flexible for modifications as required.

Reference: IFSTA 6th edition Fire Service Rescue, pages 114 through 115.
Reference: 3rd edition High Angle Rescue Techniques, pages 280 through 282.

12. Discuss the “T” System for calculating MA system efficiencies.
    a) Beginning with the input side of the system, where the haul team begins pulling, the value *T* (tension) should be assigned to the loaded rope and the first pulley in the system.
    b) In theory, the rope tension on one side of the pulley should be equal to the rope tension on the other side.
    c) The output carabiner of the first pulley, the closest to the anchor has a value of 2*T*.
    d) The input and output tension to the second pulley has a value of 2*T.*
    e) The Tension value assigned to the carabiner attached to the second carabiner (closest to the load) and the pulling prusik hitch would be 4*T.* That is the same as the load to be lifted.
    f) If the load weighs 400 pounds, the tension applied to the pulling prusik hitch and the second carabiner would also be 400 pounds. The tension applied to the pulley system connected to the pulling prusik hitch would be 200 pounds. The tension applied to the pulley system closest to the anchor would be 100 pounds. That is the pulling force that is applied by the rescuers, which gives the system a 4:1 theoretical mechanical advantage (TMA).

Reference: 3rd edition High Angle Rescue Techniques, pages 283 through 284.

PRESENTATION

ENABLING OBJECTIVE #2

The Rescue Technician 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) They are devices rated for gripping a rope.
   b) There are many commercial designs available such as Gibbs, Rock Exotica, Petzl and others.
   c) Rope grab devices with teeth should no be used in hauling systems involving humans.
   d) The rope grab device should be rated for the load, 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 of 65 inches and 53 inches and secured using a double fisherman knot.
   b) The prusik sling should be a triple prusik hitch for creating a manmade rope grab system.
   c) For rescue operations prusik hitches, also referred to as friction hitches, are usually used in tandem.
   d) The selection of diameter and number of wraps should be based on the load to be moved and ultimately is the choice of the AHJ.

3. Point out that one line of thought used by some instructors is using 6-7mm on light duty lifeline for one person loads up to 300 pounds (7/16”) and 8- 9mm on general duty rope for rescue load over 300 pounds (1/2”-5/8”).

4. Explain that a pulling prusik hitch seizes the rope and pulls it into motion. The prusik hitch can begin to slip at approximately 10 kilo-newtons.

5. Explain that a braking prusik hitch seizes the rope and prevents it from moving. This is known as a Progress Capturing Device (PCD).

a) A PCD can be tandem prusik hitches or rope grab devices rated for the load.
b) A PCD can be rigged to an anchor near the edge or near the primary anchor.
c) When possible, the PCD anchor should include a Load Release Hitch.

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

7. Point out that when a shock load potential exists; attach a shock absorbing system to the load.

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

9. Describe the function of the load release hitch.
   a) A type of hitch constructed using 8mm nylon low stretch kernmantle cord, two locking carabiners, and a Munter Hitch.
   b) 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.
   c) The load release hitch has some shock absorbing capability.
   d) It can be used in the switching over from a raising system to a lowering system and visa versa.

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

PRESENTATION

ENABLING OBJECTIVE #3

The Rescue Technician when given the appropriate equipment shall correctly describe and demonstrate rigging various simple mechanical advantage systems with 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 8 on a bight 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 pulley and carabiner to the anchor.
e) Tie a directional figure eight (bight should face the anchor) or a butterfly knot just behind the figure 8 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 PCD to the main line at the most appropriate location between the figure 8 on a bight 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 multiple hauls are required.
   b) Secure a figure 8 on a bight, 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 tandem triple wrap prusiks (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 PCD to the main line at the most appropriate location between the figure 8 on a bight and the anchor.

Reference: IFSTA 6th edition Fire Service Rescue manual, page 113.
Reference: 3rd edition High Angle Rescue Techniques, pages 291 through 292.

3. Describe and demonstrate rigging a simple 4:1 mechanical advantage system.
   a) Secure a figure 8 on a bight, or other appropriate knot suited for the load, into one end of the haul line, and secure it to the load.
   b) Select an anchor point a sufficient distance away from the load, and secure an anchor sling, locking carabiner, and a pulley to it.
   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 PCD to the main line at the most appropriate location between the figure 8 on a bight 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 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 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.
    a) Example: 20 ft. distance to be raised or lowered x 5 returns. 100 + 4 ft. chock-a-block = 104 ft. 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. 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 feet and some texts use 3 feet when referencing chock-a-block.

10. 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 6th edition Fire Service Rescue manual, page 71.
Reference: 3rd edition High Angle Rescue Technician, page 281.

PRESENTATION

ENABLING OBJECTIVE #4

The Rescue Technician when 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 MAS onto the original system.
   b) A compound system is based on the engineering principle where 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 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.

2. Demonstrate constructing a 4:1 compound system using two ropes.
   a) Tie a figure 8 on a bight 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, then tie a figure of 8 on a bight at the end of the haul line
   d) 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.
   e) Attach a locking carabiner and pulley into the figure 8 on a bight of the first rope, just behind the first pulley.
   f) Feed the second rope through the second pulley, the haul line should point toward the primary anchor.
   g) Secure a PCD to the system.

3. Demonstrate constructing a 4:1 compound system using one rope.
   a) Tie a figure 8 on a bight into the middle of a short section of haul line (suggest 50 feet) 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, then tie a figure of 8 on a bight at the end of the haul line
   d) Attach a locking carabiner and pulley into the figure 8 on a bight of the first rope, just behind the first pulley.
   e) Feed the second section of rope through the second pulley, the haul line should point toward the primary anchor.
   f) Secure a PCD 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 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 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 8 on a bight 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 in the direction of the primary anchor.
   g) Secure a PCD to the system.

Reference: IFSTA 6th edition Fire Service Rescue, page 114.
Reference: 3rd edition High Angle Rescue techniques, pages 292.

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

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

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

APPLICATION

Ideally there will be enough equipment to set up at least four stations where Rescue Technicians can construct the various types of mechanical advantage systems. Have each Rescue Technician construct a simple 3:1 static and a dynamic Z-drag, a 4:1 block and tackle, a compound 4:1 and 6:1 mechanical advantage system (MAS). Have the Rescue Technician describe how to calculate the ratio of each system and describe the difference between static and dynamic. Also have each Rescue Technician describe or point out the difference between simple, compound and complex 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 adhered to including sufficient number of instructors and the use of appropriate PPE.

SUMMARY

This lesson plan addresses simple, compound, and complex mechanical advantage systems. Each system is designed to prepare the Rescue Technician to meet the needs of confined space rescue operations. Being able to safely lift the required load with the equipment and personnel on hand is directly related to the Rescue Technician's understanding of mechanical advantage systems. The Rescue Technician must understand that the mechanical advantage system is capable of generating tremendous forces that can make the job 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 that each Rescue Technician understands the terminology of static and dynamic, as well as simple, compound, and complex in relation to mechanical advantage systems.