The T-Method for Pulley Systems

Rigging for Rescue®—Notes

A pulley system's Ideal Mechanical Advantage[1] (IMA) is expressed as a ratio of the amount of output force to the amount input force (e.g. 6:1 or "6 to 1"). The input force is the tension you apply to the system, and it is always expressed as one. One method of calculating the IMA of any pulley system in the world is often referred to as the Tension Method, or T-Method.

Some basic physics principles need to be understood and applied to knowing how tension is distributed through a pulley system. Mechanical advantage in pulley systems is gained by increasing the number of times your initial one unit of tension is applied to the load. Recognize that there are many ways that this can be accomplished, or rigged, using simple, compound or complex pulley systems.

By assigning one unit of tension (called "T" in subsequent diagrams) to where you pull on the pulley system, then following the path of the rope through the pulley system to the load itself, the IMA can be determined by keeping track of how that initial unit of tension is distributed throughout the system. Simply compare the amount of tension the load receives to the initial input unit of tension.

The key to understanding the T-method is in recognizing what happens to the tension in the rope as it flows through the pulley system. Whenever there is a 'junction' in the ropes of the pulley system where either more than one rope acts on another rope, or one rope acts on more than one rope, then the tension on one side of the junction must be equal to the tension on the other side of the junction, and for each side of the junction, the tension must be distributed appropriately (not always equally) to each rope. For example, if a rope having one unit of tension makes a 180° change of direction through a pulley (a junction), then whatever that pulley is connected to receives two units of tension (Fig 1). In essence, two ropes each having a tension of one (for a total of two units of tension) are acting on (and being opposed by) what the pulley is connected to. Below are some illustrations of tension distribution in ropes at junctions:

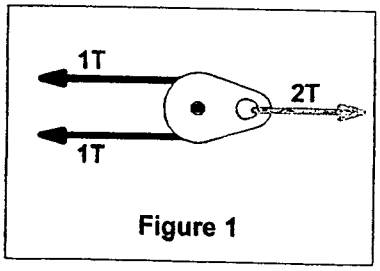

Figure 1

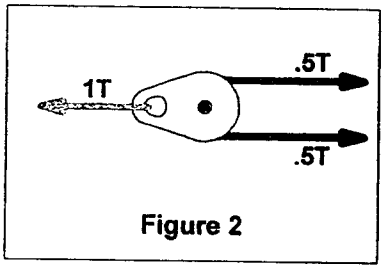

Figure 2

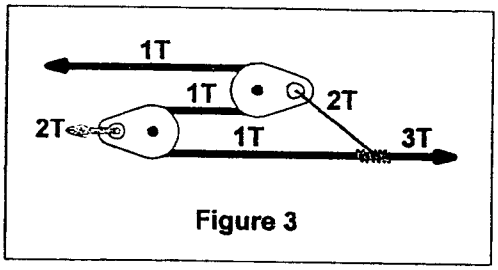

Figure 3

[1] Ideal Mechanical Advantage assumes that there are no losses in pulley system mechanical advantage due to factors such as pulley friction, or ropes rubbing, bending or unbending.
Pulley System Graphics created by Earl Fröm

Summary of how to apply and use the T-Method to Calculate the IMA of any Pulley System:

1. Assign one unit of tension to where you pull on the pulley system.
2. Follow the rope through the pulley system and when you encounter a junction, apply the principles of tension distribution. Keep track of all units of tension through to the load.
3. Total all units of tension that reach the load; the Ideal Mechanical Advantage is the ratio between this total and the initial one unit of tension.

Examples of using the T-Method to Calculate the IMA of pulley systems:

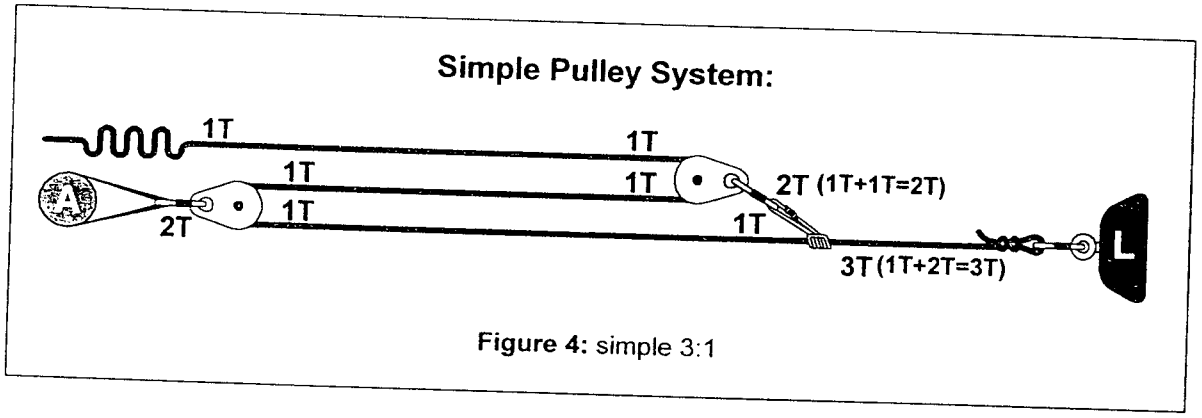

Figure 4: simple 3:1

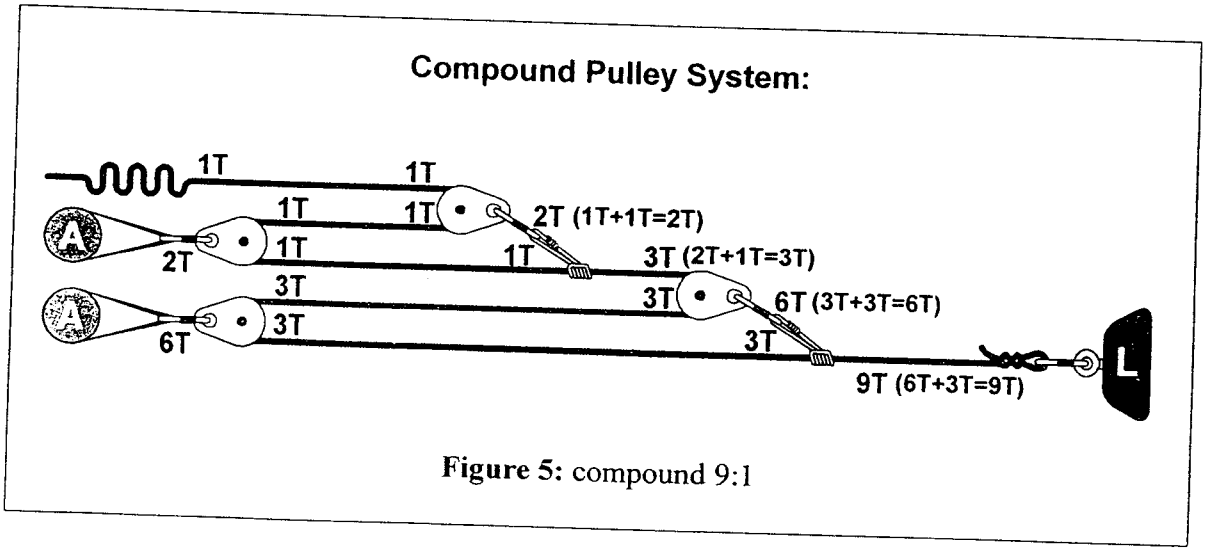

Figure 5: compound 9:1

Pulley System Graphics created by Earl Fröm

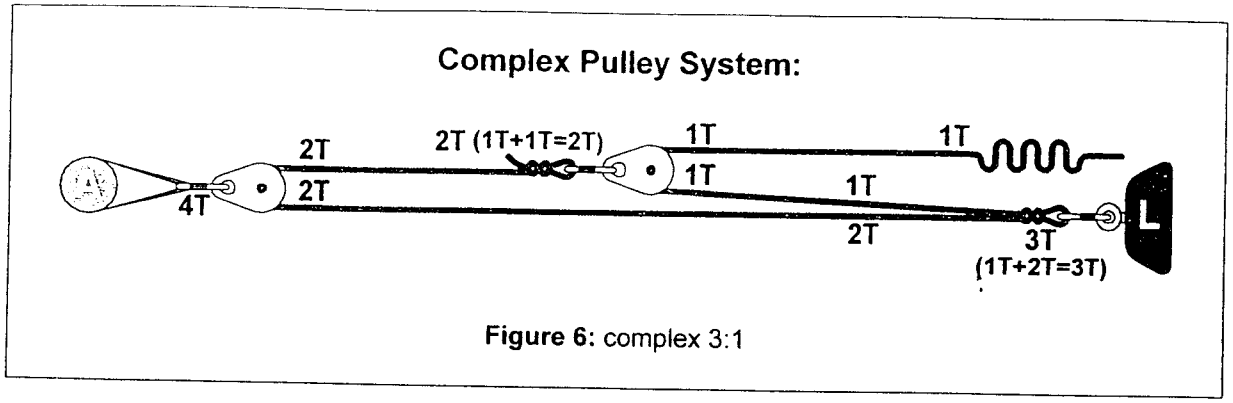

Figure 6: complex 3:1

Calculating the Theoretical Mechanical Advantage (TMA)

The TMA is the estimated Actual Mechanical Advantage (AMA) calculated after taking into account factors that affect IMA; the largest component of which is friction. The greatest friction losses occur as the rope comes into contact with the pulleys. Sometimes carabiners are used in place of pulleys which results in an even greater friction loss.

To calculate the losses due to friction, one must first know the efficiency of the pulleys and/or carabiners being used. Efficiency is the measure of friction loss calculated as the input force over the output force, expressed as a percent. For example if 90 N is required on 1 side of a pulley to hold a 100 N load on the other side, the efficiency of the pulley is said to be 90% or 90/100.

With efficiency information, the friction loss through the system can be calculated. Figure 7 shows the calculations for a pulley system with pulleys that have an efficiency of 0.90.

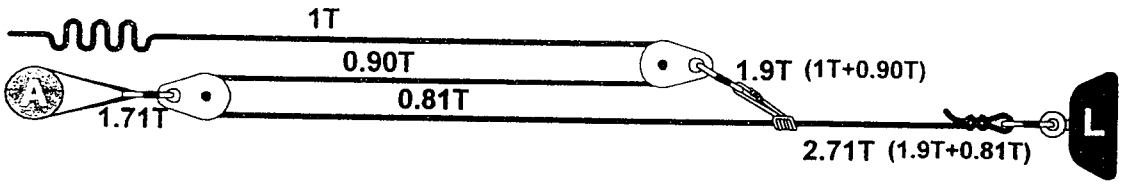

Figure 7: Simple 3:1 TMA

Pulley System Graphics created by Earl Fröm

Assuming that the pullers pull at the end of the pulley system with 1 unit of Tension (1T), only 0.90 T will be transferred past the first pulley. When that 0.9 T reaches the 2nd pulley, only 0.81T will be transferred on (0.9 * 0.9 = 0.81) as the friction loss is now compounded over two pulleys. Follow this process all the way through the pulley system. When you are finished, use the T-method to determine the final TMA, which in this example is 2.71:1.

If higher efficiencies pulleys are used (i.e. 0.95 efficiency), the TMA is increased to 2.85:1, which is closer to the IMA of 3:1. Also important to note, is that if you are using pulleys of different efficiencies, less losses occur if the most efficient pulley is placed closest to the pullers. This is because the loss at the 1st pulley is compounded throughout the system.