Mechanical Advantage
Basic Absolutes

(1) Newton's law of reaction tells us that every action has an equal and opposite reaction. If i pull on a rope attached to an anchor, with a force of 50 #, the anchor pulls back with an equal force. The force runs through the rope in both directions. Both ends of the rope are loaded equally!

(2) A pulley equalizes the tension in both legs running through it.

(3) Pulleys are **always** force multipliers. **Both** fixed and moving traveling pulleys magnify the force running through them.

Fixed pulleys Attach to anchors

Fixed pulleys Change direction only

Fixed pulleys Do NOT contribute mechanical advantage

Fixed pulleys Do not move

Traveling Pulleys Attach to the load or to the interior of the rope system

Traveling pulleys Change direction and DO add mechanical advantage

Traveling pulleys Move

T Method Of Force Calculation

Using the T Method, We can gain a much clearer understanding of the forces at work within mechanical advantage systems and their anchors. It can show us areas within the system that are most likely to fail, it can also show us the actual forces, that each individual component will be exposed to for a given load.

The T Method relies on easy to understand principles, is easy to use in the field, and quite accurate.

First principle, Any force applied to the input of the system is applied through the entire system, and that force runs in both directions within the rope.

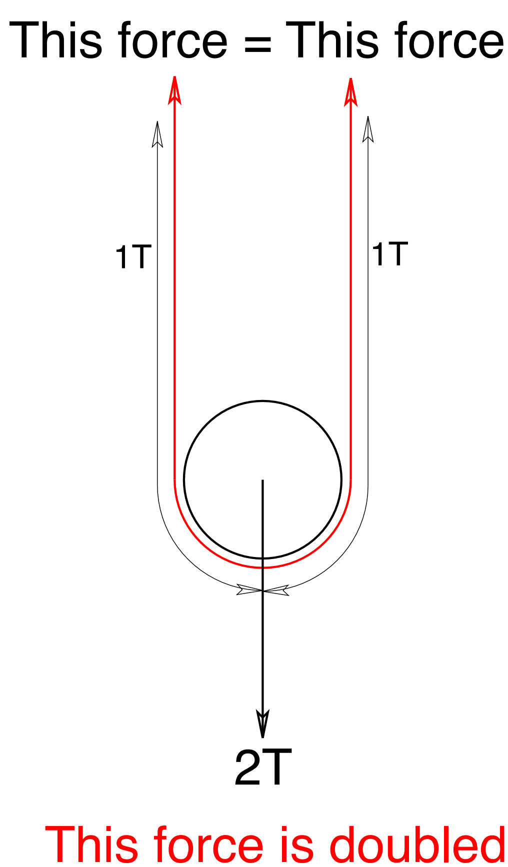
Second Principle The force on a rope going into a pulley, is equal to the force on the rope leaving it on the other side.

Third Principle Pulleys always Magnify the force running through them, and direct that force in the direction of their attachment point.

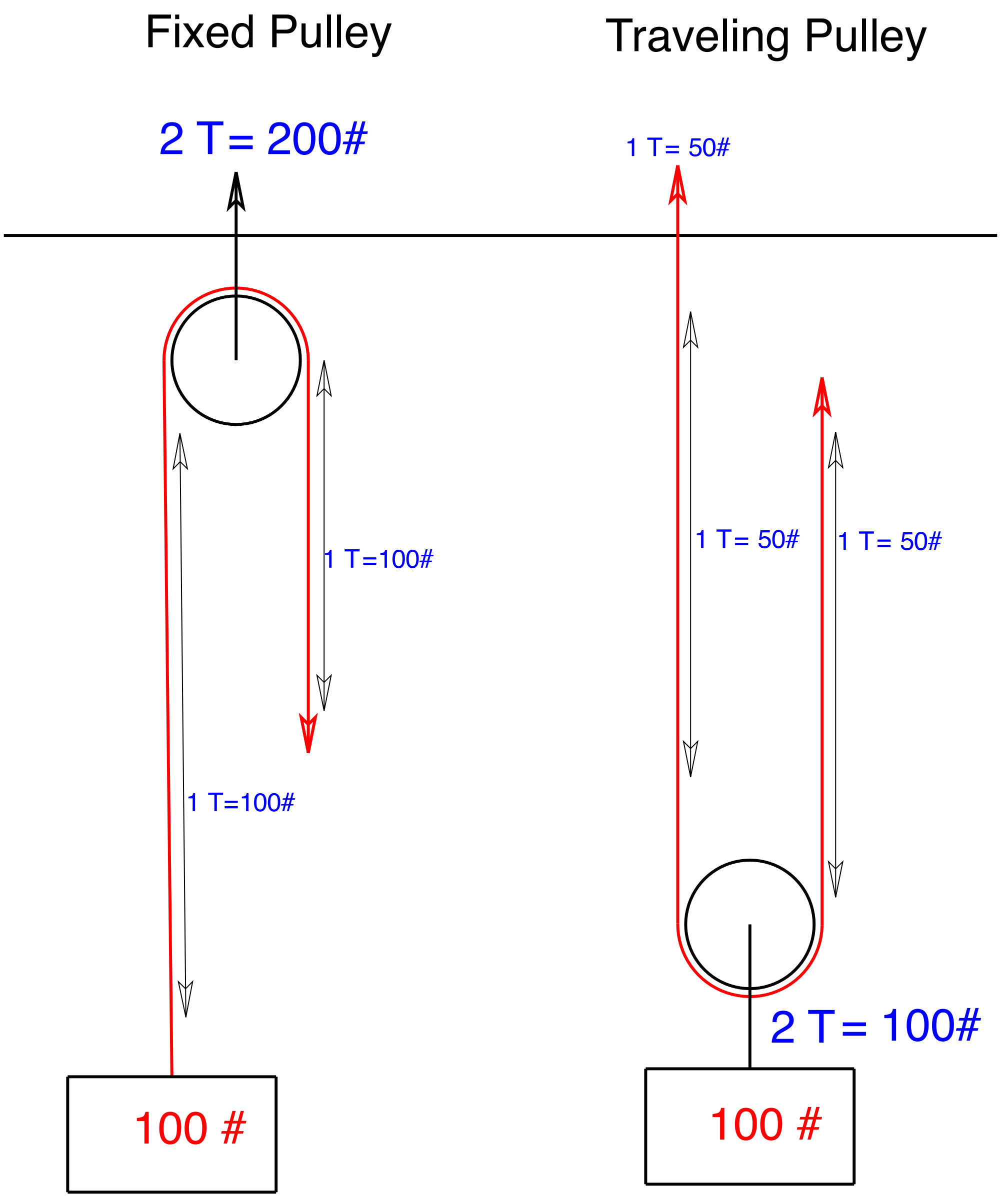
Fourth Principle If the lines running through a pulley are parallel, the force running through a pulley will be doubled. (more about this later)

Fig.1

The tension in a rope runs in both directions.



1T is the force required to balance the system

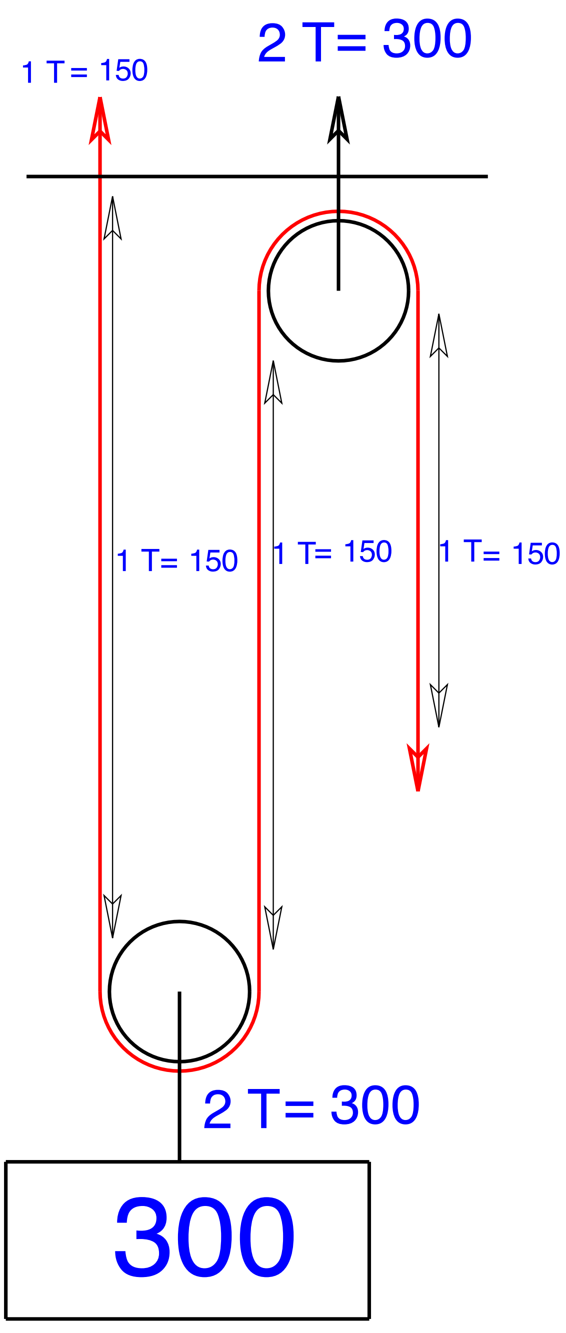


As you can see, both pulleys are multiplying the force running through them. The fixed pulley directs it's force towards the anchor, while the traveling pulley directs it's force towards the load. In the case of the traveling pulley, your input 1T force, supports half of the 100# load, while the anchor supports the other half. In the case of the fixed pulley, your 1T input force must match the entire 100# load to balance the system. This is why the force on this anchor is 200#. Input force must increase to raise the load. A body at rest tends to stay at rest, So it requires more force to start an object moving, then to keep it moving.

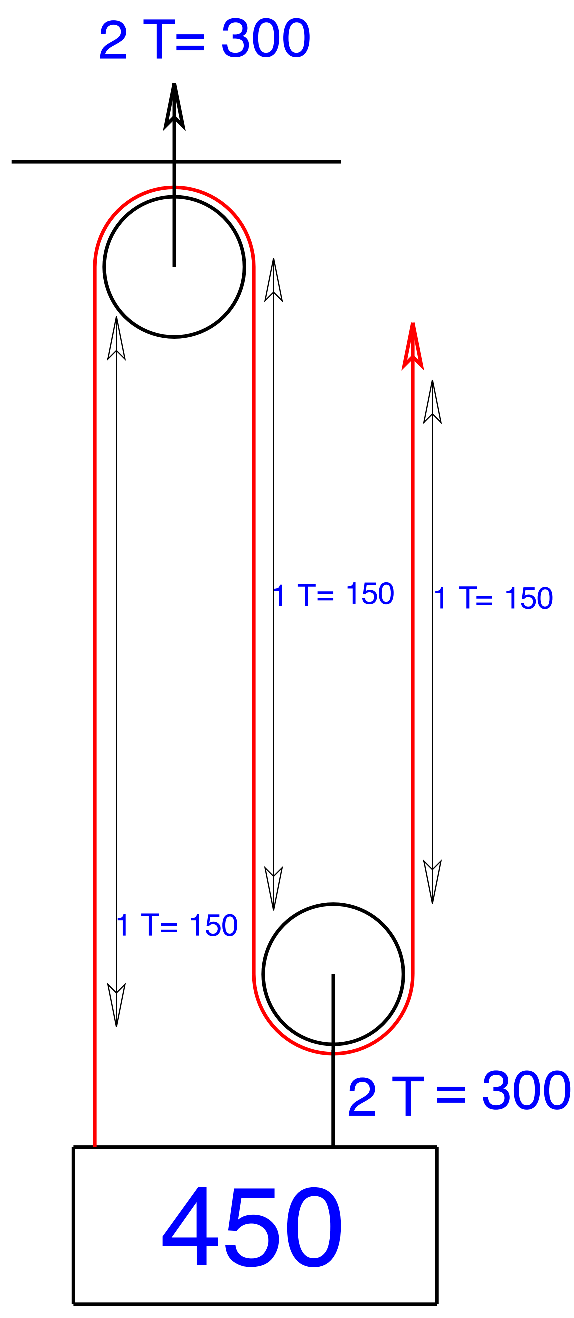
Simple Systems

Again 1T is the force required to balance the systems

2/1 simple with change of direction



3/1 simple with out change of direction

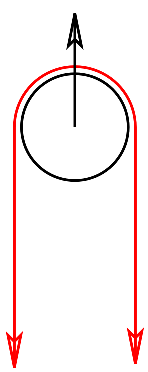


look closely at the anchor forces again, notice the combined anchor forces for the 2/1 (450) are greater then the actual load.

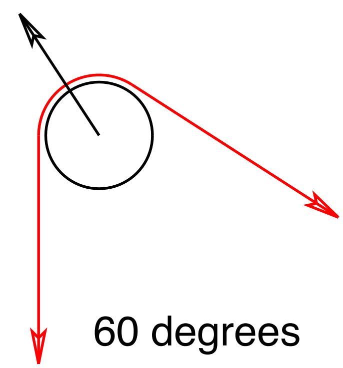
Have you noticed yet, that a 2/1 with a c.o.d. is the same system as a 3/1 with out a c.o.d. If you turn one system 180 degrees it becomes the other system.

Pulleys and angles

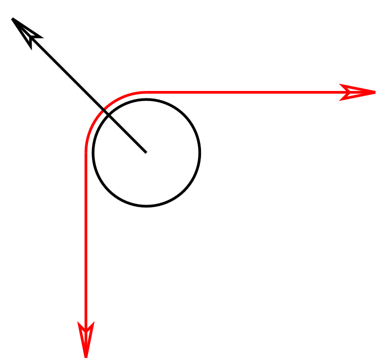
Our fourth Principle tells us that when the angle of the ropes running through a pulley are at 0 degrees the force will be doubled. When the angle of the running lines is not 0 degrees, the effectiveness of the pulleys is diminished.



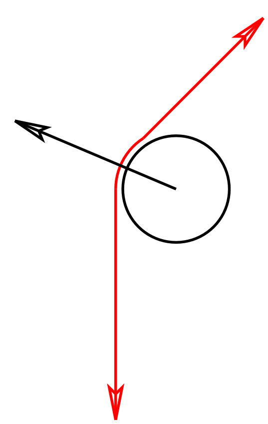
0 degrees
multiply force by 2



60 degrees
multiply force by 1.73



90 degrees
multiply force by 1.41

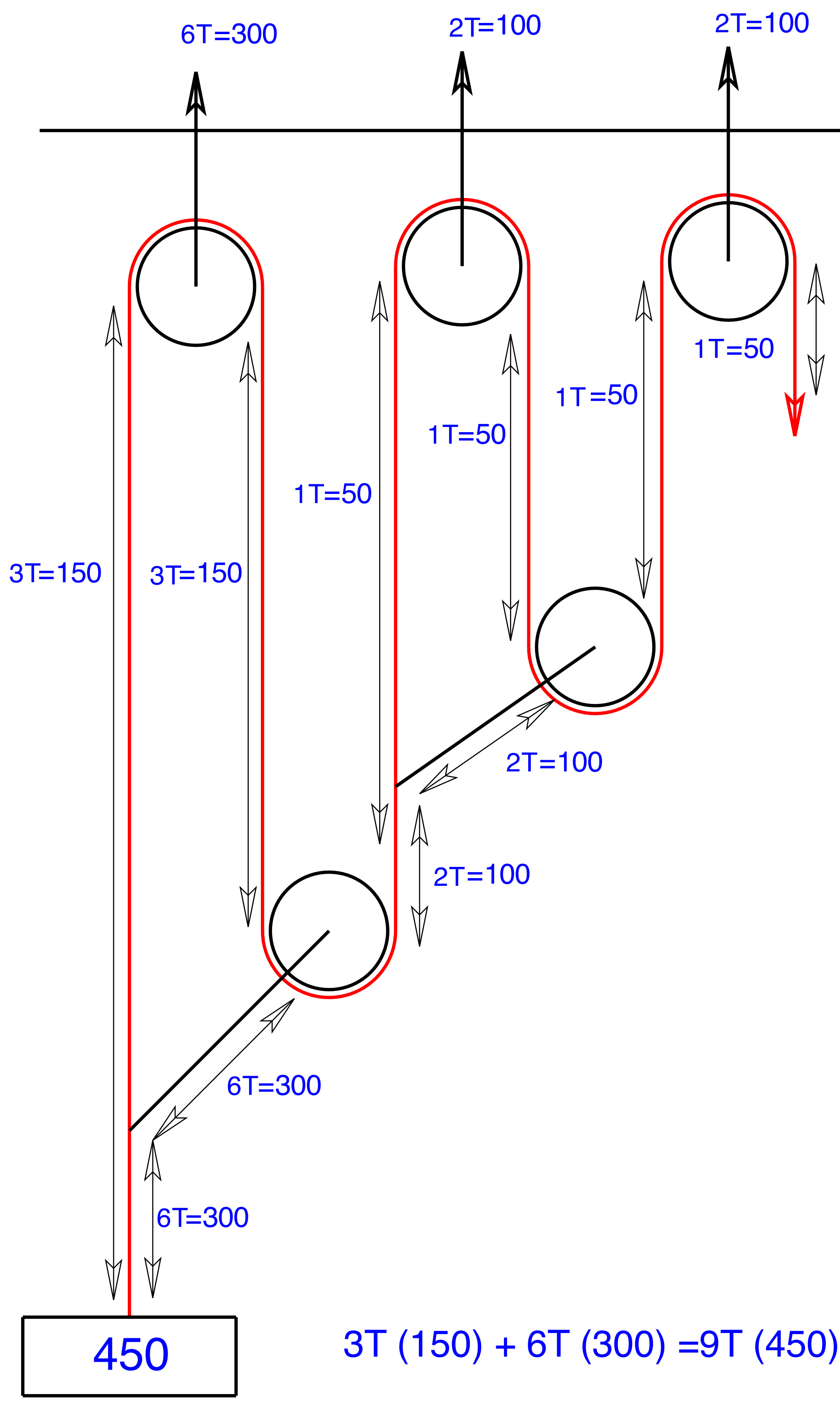


120 degrees
multiply force by 0

We can use this knowledge to our advantage. We often incorporate c.o.d. pulleys into our systems. So we can diminish the c.o.d. anchor forces by increasing the angle the line runs through the pulley.

Compound Systems

9/1 with change of direction



Breaking it down

The above system is a 3/1 system pulling on a 3/1 system to create a compound 9/1 mechanical advantage system.

The 1T input force runs through the entire first 3/1 system.

The first traveling pulley doubles the input force to 2T and adds it to the the 1T force directing that increased force to the second traveling pulley through it's prusik.

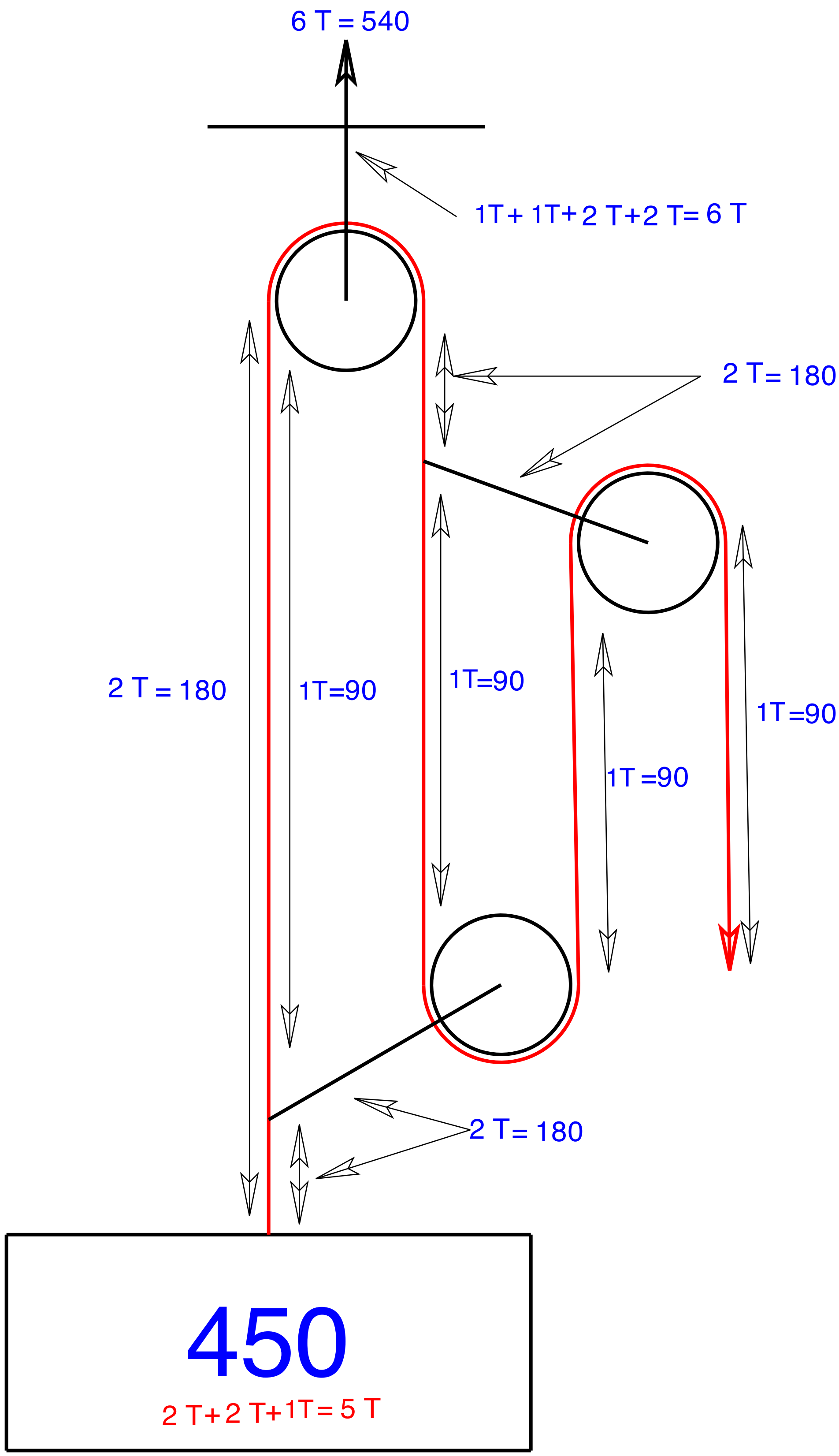
The 3T force enters the second 3/1 system and is equalized through the system.

The second traveling pulley doubles the 3T force to 6T and adds it to the 3T force through it's prusik.

3T + 6T = 9T

Complex Systems and the T method

5/1 without C.O.D.



Breaking it down

In the 5/1 complex above, the 1T input force is equalized by all the pulleys and is transmitted through all the legs of the system.

The upper traveling pulley doubles the input 1T force to 2T which is added to the 1T running force through it’s prusik.

This 1T+ 2T= 3T force runs through the standing pulley, and is equalized in both legs, doubling the 3T force to 6T and directing it to the anchor.

The lower traveling pulley doubles the 1T input force, and transmits it to the mail haul line through it’s prusik.

The final force applied to the load, is a combination of the original input force, plus the 2T force contributed by the upper traveling pulley, plus the 2T force contributed by the lower traveling pulley. 1T 90 + 2T 180 + 2T 180 = 5T 450

If we look closely at the above system, it soon becomes clear that if we turned it 180 degrees, we would have a 6/1 system.

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Final thoughts

Friction

The above diagrams depict theoretical frictionless systems, in the real world, pulleys do add friction. Rescue pulley manufacturers publish friction specifications for the pulleys they make. Most modern rescue pulleys are about 90% efficient. So the actual 1T force for a system must be increased by 10% for each pulley in the system. All the forces within the system will also increase accordingly.

How we think about mechanical advantage

As rescue personnel, we often think about M.A. systems in terms of their output, 3/1 5/1 9/1and so on. The above diagrams, show us that there is more to think about then just the output. The number of pulleys, the anchor forces, number of lines going over an edge, C.O.D. pulley anchor forces etc. All these things affect wether a system will preform effectively. M.A. is only one of many factors that make a well designed rope system. Using the T method, with a little practice, and keeping the basic Absolutes and principles in mind, you will be able to design safe effective rope systems