Pulley System Forces - Angles of Pull
How much advantage do I need to raise this load? Which way will it be pulling on my anchors? How much force will be put on my anchor? How can I get the most pulley advantage with the fewest pulleys? What advantage is this anyway? How many feet of rope to do I need to pull, to raise this litter to the top? Is this a Compound, or Complex, or why can't we keep this thing Simple? The list goes on in regards to pulleys, pulley advantage, and the effects of a pulley system.

Resultant Forces, and Resultant Angle of pull are probably in the very top as to causes of accidents. Of course, that boils down to "Pilot Error," but these errors can be avoided if the rescue professional understands how forces can compound or multiply depending on various configurations, and how angle of pull change, depending on the situation.

In this presentation we will address: How to identify what type of advantage is gained in various pulley configurations. The amount of force put on your anchors. The dangers of not understanding: Resultant Forces and Resultant Angles of Pull. Why we need to use a compound verses a Simple Pulley System, and what is so Complex about a Complex System. Pros and Cons of various pulley systems. And more.

About the Presenter:

In 1969 **Doug Hansen** became actively involved in the vertical environment. Since then his life has essentially been High Angle Work, Engineering, Rescue, Emergency Response, and Equipment sales. Experience and training include: Military 1972, he enlisted in the 19th Special Forces Group (Green Beret). He graduated as an Army Medic (91B20) from the Army Medical Training Center in Fort Sam Houston, TX. Short while later transferred to the 117th Engineers Corps In 1975, he was hired by the National Park Service to work as a Park Ranger. His duties included training park personnel in climbing and rescue procedures, and organizing and directing rescues within the Park. At this same time he established a professional organization that focused on teaching high angle skills, doing work in high places, and selling high angle equipment. In 1976, Hansen was invited to join the Utah County Sheriffs Mountain Rescue Team and eventually became captain and operational leader of the Rescue Unit. Work experience includes for U.S. Steel Corporation, Safety Department, and Professional Fireman/EMT. 1985 he opened a full time High Angle Business: Hansen Mountaineering, Inc., which he sold in 2000. In 1992 he organized and lead an Expedition to the North Face of Everest. In the early 90's he formed a business called High Angle Technologies, Inc. that focused on high angle work, teaching and equipment sales. He has produced several videos that deal with the vertical environment. Including: "Vertical Rope Skills, recipient of the Telley Award. He has served as an instructor for a number of different universities and schools. He currently works full time in his high angle business writing, teaching, doing specialty high angle projects, and teaches rock climbing for Brigham Young University.

Pulley Systems, Resultant Forces and Angles of Force

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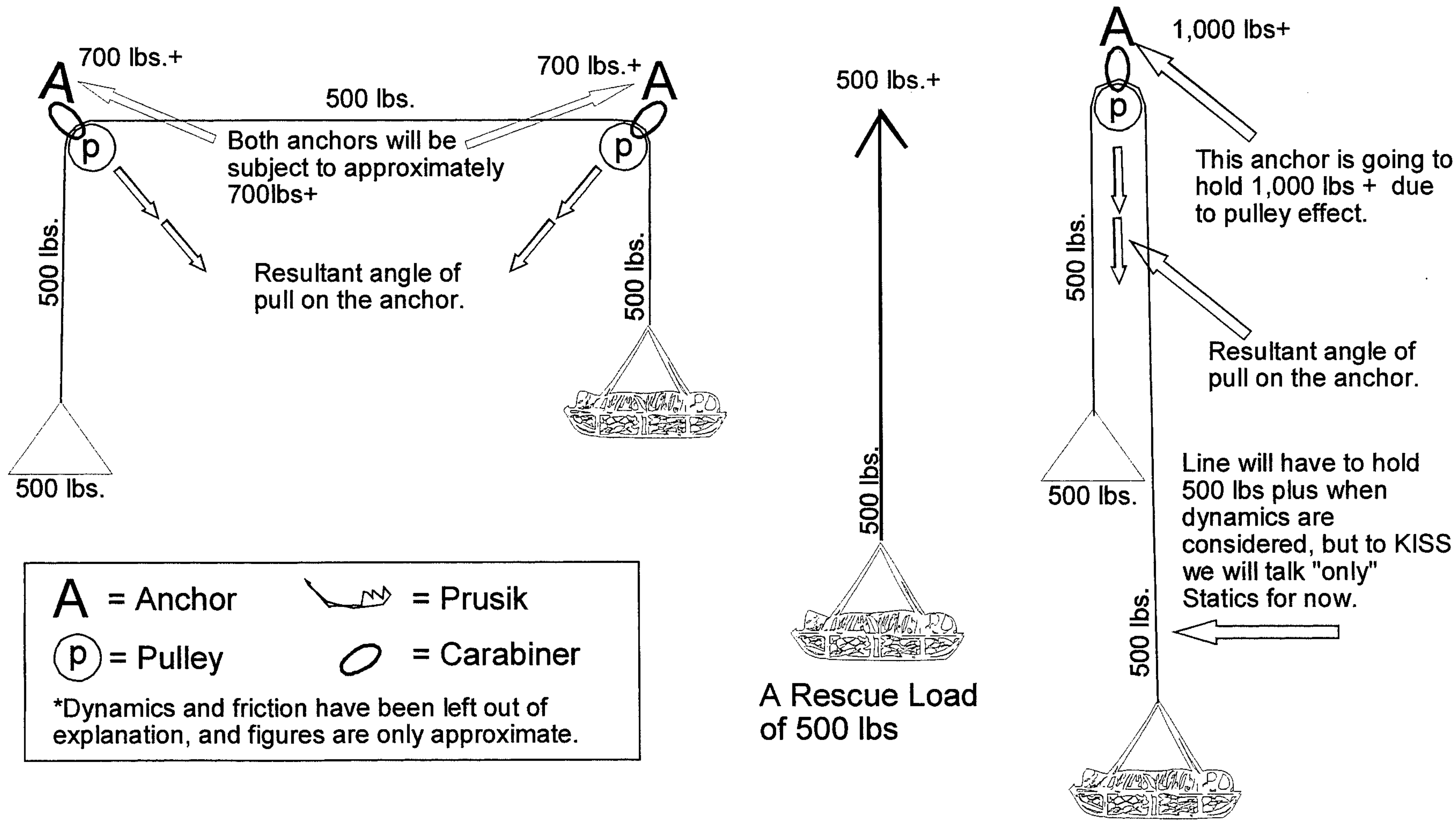
*These are 1:1 systems. Let's take a look at a few of the possible forces and principles that effect their operation. **Note:** There are a number of variables that will change these numbers..



As you can see, when a 1:1 system is a straight pull (center), forces are less. When pulleys are used they can change things, including forces on various parts of the system and angle of pull on anchors.

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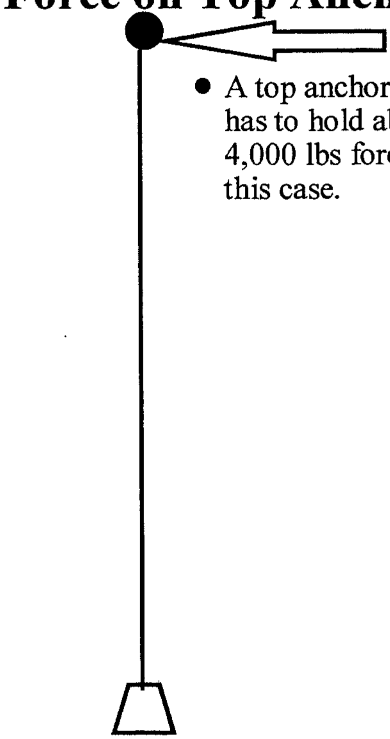
Force Changes on Top Anchors ~ Pulley Effect vs No Pulley Effect

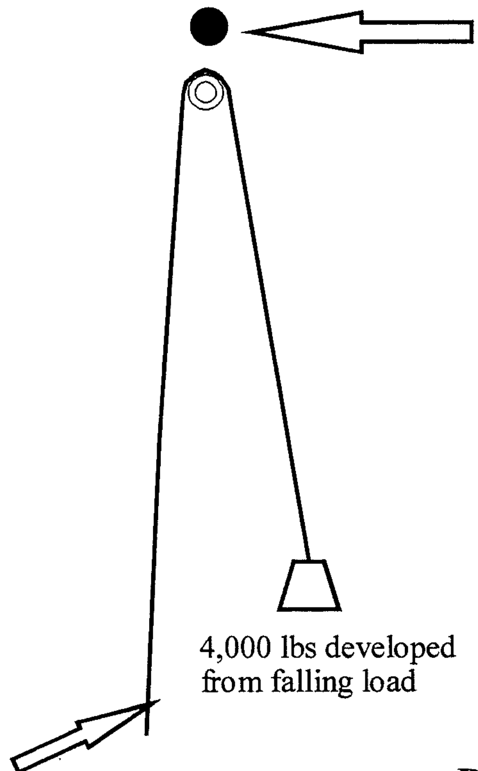
Force on Top Anchor



- A top anchored fall has to hold about 4,000 lbs force in this case.

No Pulley Effect

Force on Top Anchor with pulley effect



- If a pulley or carabiner were totally frictionless, then forces on top anchor would be 8,000 lbs., or 4,000lbs from each side of system. There is essentially a 2:1 disadvantage (disadvantage because it doesn't help us, in this case).
- If a good pulley is used the force would be reduced to 7,600 lbs. A good pulley is approximately 90% efficient, so 4,000 lbs. for falling load less 400 lbs. loss due to friction equals 3,600, for a total of 7,600 lbs. on top anchor.
- If a carabiner is used the force would be reduced to 6,600 lbs. A carabiner is approximately 65% efficient, so 4,000 lbs. for falling load less 1,400 lbs. loss due to friction will = 2,600, for a total of 6,600 lbs. on top anchor.
- If a Munter hitch were tied on the top rope carabiner, the force on the top anchor would be about 4,600 lbs. Depending the variables factors

☺Bottom anchor, or belayer, may have to hold 4,000 lbs. (If frictionless), about 3,600 lbs. (for a high quality pulley), about 2,600 lbs. if a carabiner is used, or about 600 lbs. if a Munter hitch is used.

Understanding principles such as pulley effect, can be used to our advantage, or at the least, be planned for.

<u>Please Note:</u> The numbers are just approximate numbers. There are a number of variables. The concept is to remember: Build-in extra strength when needed, or use these principles to your advantage. Sometimes these situations are <u>NOT</u> obvious.

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Rope System Evaluation and Analysis

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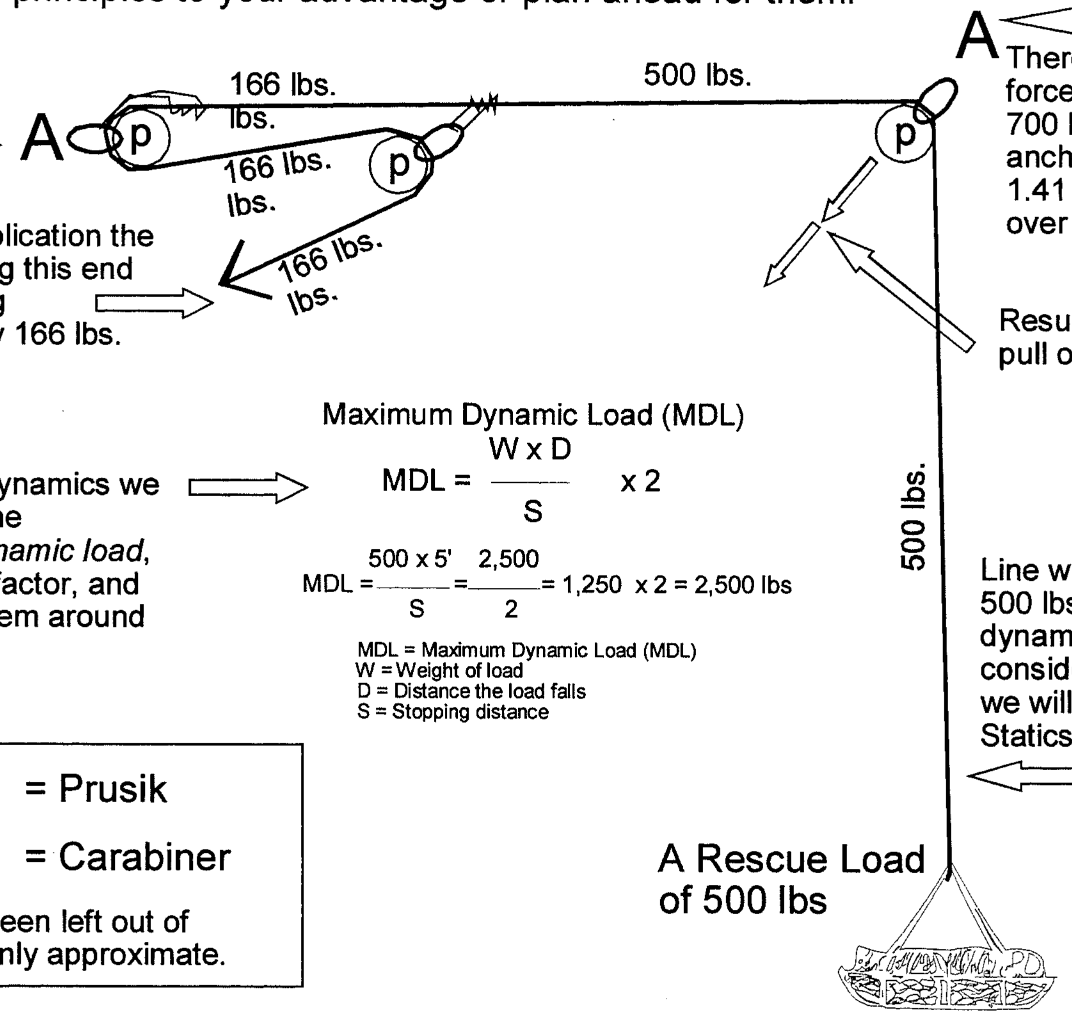
*This is a typical 3:1 (z-rig) pulley system with a direction change. Let's take a look at a few of the possible forces and principles that effect its operation. **Note:** There are other variables that will change the numbers. The idea is to either use these principles to your advantage or plan ahead for them.



In a static application this anchor will be holding approximately 333 lbs.

In a static application the person holding this end will be holding approximately 166 lbs.

There is a resultant force of approximately 700 lbs on this anchor. (multiply by 1.41 due to 90° angle over the pulley).

Resultant angle of pull on the anchor.

Line will have to hold 500 lbs plus when dynamics are considered, but to KISS we will talk "only" Statics for now.

To figure in dynamics we usually use the *maximum dynamic load*, add a safety factor, and build the system around that.

Maximum Dynamic Load (MDL)

$$MDL = \frac{W \times D}{S} \times 2$$

$$MDL = \frac{500 \times 5'}{S} = \frac{2,500}{2} = 1,250 \times 2 = 2,500 \text{ lbs}$$

MDL = Maximum Dynamic Load (MDL)
W = Weight of load
D = Distance the load falls
S = Stopping distance

A = Anchor
(p) = Pulley
= Prusik
= Carabiner

*Dynamics and friction have been left out of explanation, and figures are only approximate.

Pulley Effect, Resultant Angle of Pull, and Resultant Force

In this case, during a pull, the anchor to which the 3:1 pulley system is attached will actually have to hold less because of pulley effect and the fact that a person pulling on the rope will hold approximately 1/3 of the weight.

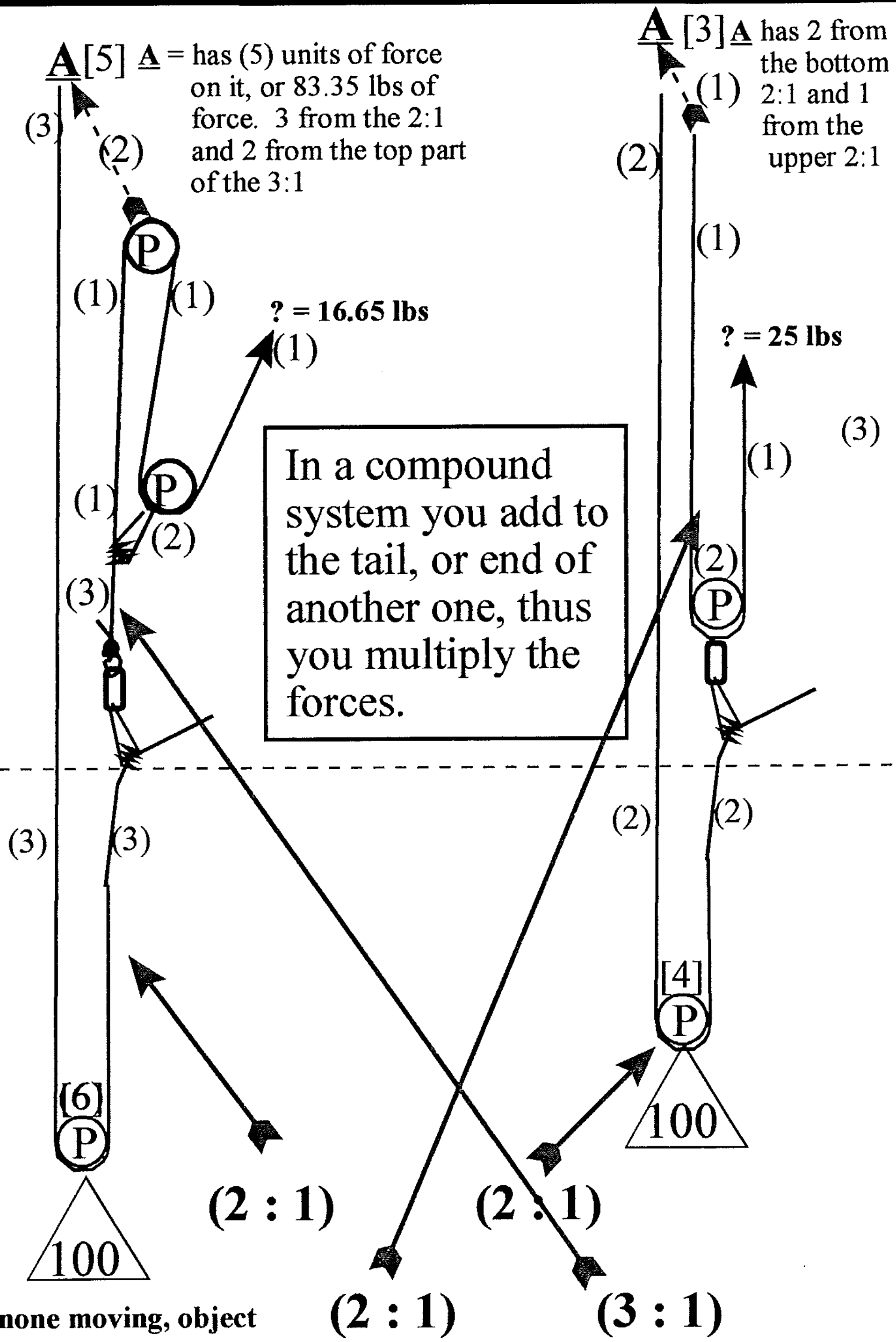
F = 1 = ? Figuring Pulley Effect "Compound Pulley Systems"

A system for determining the pulley advantage of any pulley system: simple, complex, or compound. The object of this system is to count the number of units of force being exerted on the load. Also, by multiplying the (?) by the units of force, one can determine the amount of force that will be required to lift a given load. Pulley friction, edge friction, etc. all will increase the amount of force required to lift the load.

With only 5 units of force : (3 + 2) = 5 x 16.67 = 83.35 on the anchor (A). Where is the other 16.65 pounds?

If you pull on the anchor in your pulley system you add the amount . In this case, we are pulling on the load so we subtract the amount. You will be holding the extra 16.65 lbs. in order to balance it.

6 units of force on top side : 1 you are holding, and the anchor is holding the other 5 units.



Legend:

- **(P) = Pulley**
- **Rope grab symbol = Rope grab**
- **- - - = Balance line**
- **(D) = Double pulley**
- **Triangle "100" = Load of 100 lbs**
- **Arrow = Direction of pull**
- **(1) = Units of tension or force**
- **A = Anchor point, to a solid, none moving, object**
- **? = an amount of force. For this sheet we will say ? = 100 lbs.**
- **F = one or more units of force being applied to the load**
- **? = Pull, or the amount of force being applied to balance the load. This amount, plus 1 pound would cause the load to raise.**

***Note: We are assuming there is NO friction.**

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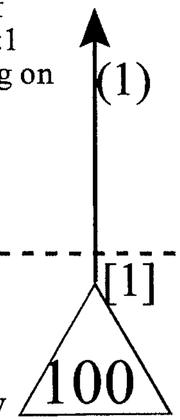
F = 1 = ?

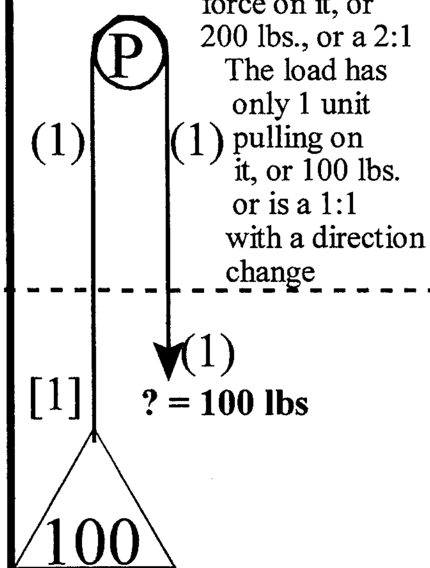
Figuring Pulley Effect, "Simple Pulley Systems"

A system for determining the pulley advantage of any pulley system: simple, complex, or compound. The object of this system is to count the number of units of force being exerted on the load. Also, by multiplying the (?) by the units of force on the load onee can determine the amount of force that will be required to lift a given load. Providing there is no friction. Pulley friction, edge friction etc. will increase the amount of pull required to lift a given load.

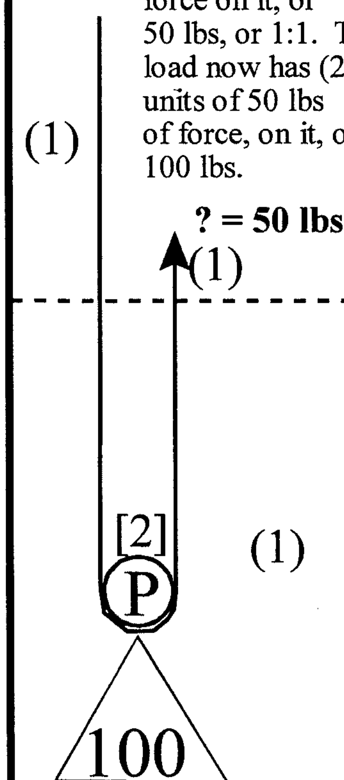
A has (1) unit of force on it, or 100 lbs of force, or a 1:1 1 unit pulling on the load.



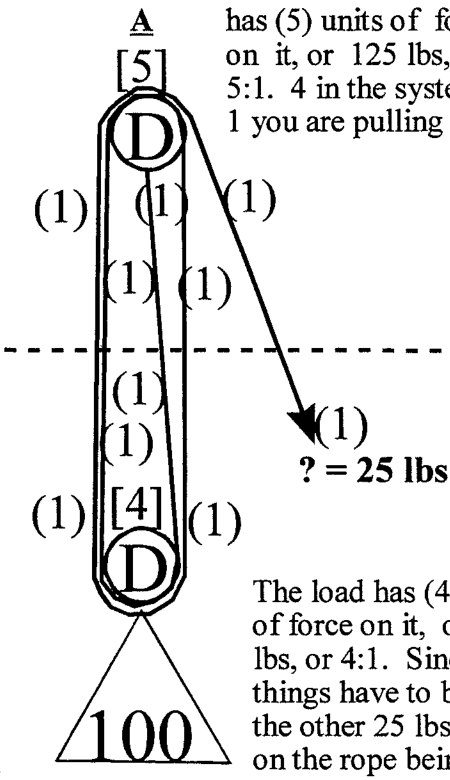
A = has (2) units of force on it, or 200 lbs., or a 2:1 The load has only 1 unit pulling on it, or 100 lbs. or is a 1:1 with a direction change



A = has (1) unit of force on it, or 50 lbs, or 1:1. The load now has (2) units of 50 lbs of force, on it, or 100 lbs.



A has (5) units of force on it, or 125 lbs, or 5:1. 4 in the system and 1 you are pulling



The load has (4) units of force on it, or100 lbs, or 4:1. Since things have to balance, the other 25 lbs. Are on the rope being pulled.

Legend:

Ⓟ **= Pulley**

\- - - **= Balance line**

Ⓓ **= Double pulley**

△ **= Load of 100 lbs**

= Direction of pull

(1) = Units of force

? = an amount of force.

F = one or more units of force

A = Anchor point, a solid, none moving, object

? = Pull, or the amount force being applied to balance the load.

This amount, plus 1 pound would cause the load to raise.

***Note: We are assuming there is NO friction.**

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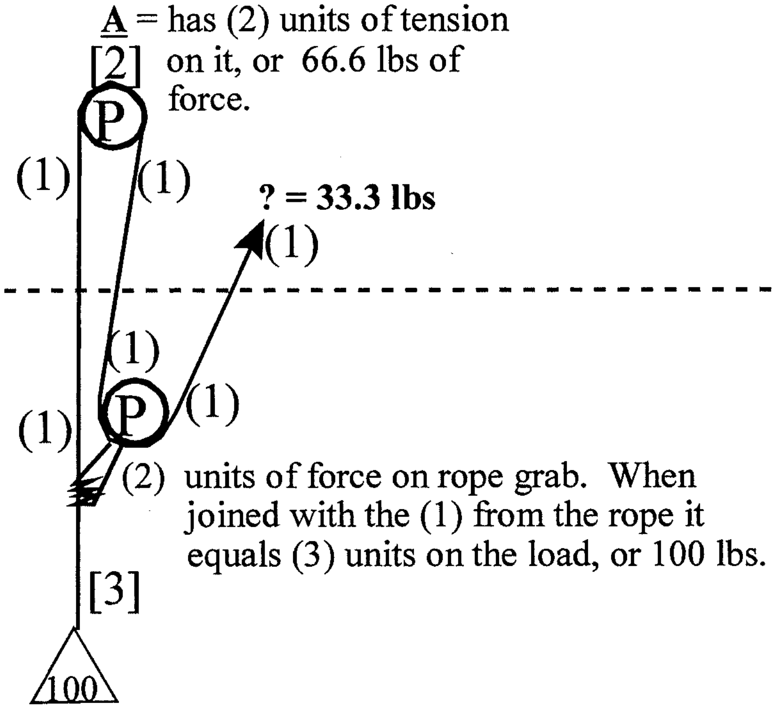
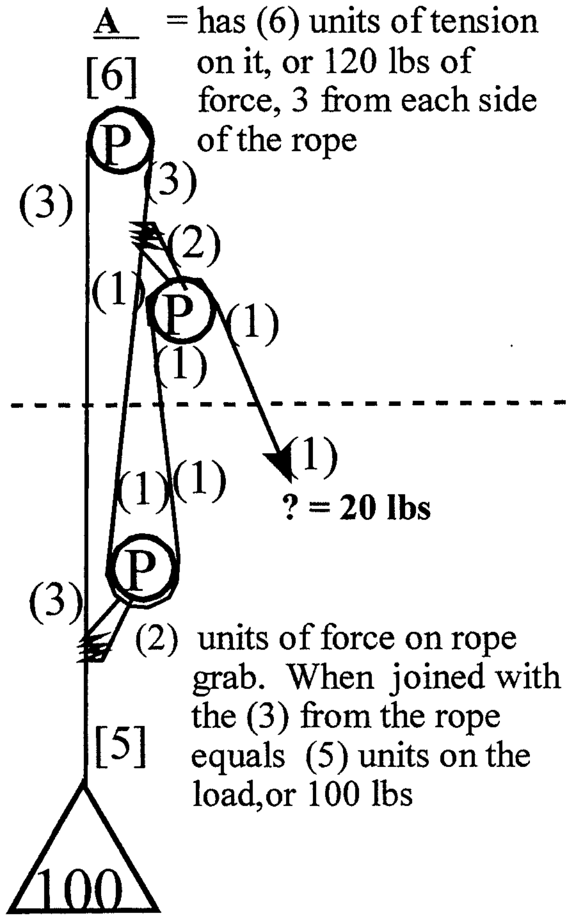
F = 1 = ? Figuring Pulley Effect "Complex Pulley Systems"

A system for determining the pulley advantage of any pulley system: simple, complex, or compound. The object of this system is to count the number of units of force being exerted on the load. Also, by multiplying the (?) by the units of force, one can determine the amount of force that will be required to lift a given load. Pulley friction, edge friction, etc. all will increase the amount of force required to lift the load.





Legend:

(P) = **Pulley**

= **Rope grab**

- - - = **Balance line**

(D) = **Double pulley**

(100) = **Load of 100 lbs**

= **Direction of pull**

(1) = Units of tension or force

A = Anchor point, to a solid, none moving, object

? = an amount of force. For this sheet we will say ? = 100 lbs.

F = one or more units of force being applied to the load

? = Pull, or the amount of force being applied to balance the load.

This amount, plus 1 pound would cause the load to raise.

***Note: We are assuming there is NO friction.**

Guess why they are called "complex" ?

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